APPLICATION HOLY WARS OR A NEW REFORMATION?

A Fugue on the Theory of Knowledge

(Rev. 28/03/2016)

William P Hall

(Kororoit Institute)

APPLICATION HOLY WARS OR A NEW REFORMATION?

A Fugue on the Theory of Knowledge

William P. Hall

Senior Fellow
Engineering Learning Unit
University of Melbourne School of Engineering
Victoria 2010, Australia
william-hall@bigpond.com
http://www.orgs-evolution-knowledge.net

USAGE NOTES

This "book" is a literary fugue in five Episodes with an Interlude and is but one product of revolutions in human cognition fuelled by revolutionary technologies. It is a hypertext offering more than the linear development of a paper book or academic "paper". If printed as a book, it offers a normally sequenced narrative and argument supported by numbered endnotes and bibliography. Alive in the Web, the text connects directly to the world of knowledge. If you read the text while connected to the Web, every issue discussed in the core is electronically linked to additional facts, current debates, and illustrative multimedia. To enter the extended world of knowledge relating to my core arguments, follow and explore the links as you read.

In addition to direct hyperlinks to definitions and the like in the text itself, superscripted numbers link to endnotes with additional commentary, links, and annotations. Author references in the text or endnotes link to source citations in the Bibliography. Where an electronic version of a source is freely available, the bibliography entry links to it directly..

My policy on sources has been to link where possible to a version of the source existing in the Internet Archive. Because many URLs are long, they are compressed to TinyURLs where appropriate. Links to the live Web often break, but I trust that Internet Archive links will be more stable. Where links break because of changes to Web sites, you can often find the linked item in a new location through a Google search on the title (in quotation marks).

In the 10 years since I started this project, virtually all journal references and even some recent scholarly books have become available electronically via subscriptions to major research libraries. For those with such access, Google Scholar offers essentially seamless access to the source via your library subscription (requires setting Scholar's Preferences to your library). Thus, even if I haven't given a link or the link in my text is broken, copy the article title to Scholar's search field, enclose the title in quotes, and if this seems ambiguous add the author name. Chances are that you will be taken directly to the electronic copy of the source document. Also, every year an increasing fraction of the papers are available free to the Web at least in pre-publication versions. Even for paper books, useful fractions of the texts are available electronically via Google Books or Amazon.com.

Abstract

This hypertext explores the nature of knowledge and its evolution in simple organisms, multicellular organisms, people, biological species and socio-technical organizations. A major focus is to understand the role of exponential knowledge growth in the human lineage over the last 5 million years in the evolution of individual and organizational cognition as these are impacted by technological revolutions in mnemonics, books, libraries, computer memories, the World Wide Web, etc. My approach derives from my mixed careers as an evolutionary biologist and as an analyst and designer of organizational knowledge management systems.

My path crosses many disciplinary fields ranging from epistemology, thermal physics, history, and evolutionary biology, to theories of organization and society. This expedition explores revolutions in technologies, cognition and even concepts of what it means to be living. Because I have mapped the terrain, I can highlight and explain pitfalls that would otherwise impede understanding as we travel through historical time and across disciplinary borders.

Pitfalls exist because each discipline along the path has its own worldview and theory-laden language. Thomas Kuhn called these domain-specific thinking patterns paradigms. His (1970) book, Structure of Scientific Revolutions provides some clues as to how to develop a metalanguage allowing us to consider the different worldviews without getting lost in metaphysical or irrational argument. In our exploration, I try to minimize paradigmatic confusions by using a fugal development, starting with simple and relatively mundane themes and then elaborating them through a semi-recursive series of episodes and variations crossing different disciplinary domains to reach what I hope will be a climax of understanding.

My narration of the expedition is at least partially autobiographical. By describing my own path to develop the insights presented here, I hope readers will find it easier to follow in my footsteps than they would when confronted with what might seem to be a chaotic landscape of incommensurable paradigmatic worlds.

The book’s title needs some explanation. Knowledge workers using different text processing tools so often argue irrationally about which tools are best, that bystanders called such discussions "holy wars"1. Such holy wars are symptomatic of historically unprecedented cognitive and technological revolutions that can change what it is to be human. Such revolutions profoundly affect all humans and now extend to our entire biosphere. To explain what is behind these holy wars and their existence, I weave together a number of disparate themes from in my own life and experience, from observing revolutions in text processing technology, and in evolutionary biology and genetics, history and philosophy of science, military affairs, and knowledge management in large organizations. Because collectively these revolutions amount to a new Renaissance, it is appropriate to unfold my ideas using one of the greatest cognitive artifacts of the last Renaissance - the fugue2. An example of a fugue also demonstrates some of the capabilities of hypermedia. Click this link to access a sound file of J. S. Bach's "Little" fugue in G minor, BWV578 (hit Back to return to this page). This example is from John's Midi Files. It illustrates in audible form the fugal properties I am trying to emulate in the construction of this hypertext. My fugue here consists of a Subject, Counter Subject, 5 Episodes with an Interlude, and concludes with a Cadenza and Coda.

My **Subject** explores theoretical foundations of knowledge and its growth based on Karl Popper's evolutionary epistemology as expressed in "Objective Knowledge" (1972) and “Knowledge and the Body-Mind Problem” (1994), and on the nature of scientific revolutions as described by Thomas Kuhn (1970, 1983). These disparate approaches are combined with concepts of evolutionary adaptation to explore when evolutionary change becomes revolution. Twelve critical revolutions in human history are reviewed, where each triggered major grade shifts in humanity’s ecological role in nature. Five revolutions are based on the invention of new classes of technology. The other seven are cognitive – involving fundamental changes in the way information is technologically processed into knowledge.

My **Counter Subject** introduces disparate arenas of evolutionary biology, military affairs and information theory to explore categories of information along independent dimensions of quantity and epistemic quality to show how recursive evolutionary processes cybernetically transform data into power. The late Col. John Boyd's (1996) (**O**)bserve, (**O**)rient, (**D**)ecide and

(**A**)ct adaptive feedback concept (the "OODA loop") is a generic cybernetic process for generating evolutionary and revolutionary change in complex adaptive systems, ranging from individual organisms to competing corporations and warring states. Such adaptive changes are a form of knowledge in their own right.

Episode 1 discusses how the inventions of counting, writing, the printing press, and books enabled and enhanced the major conceptual revolutions of the Renaissance, Reformation, Scientific and Industrial Revolutions.

Episode 2 follows the invention of and revolutionary growth of digital computer technology over my lifetime, to consider the magnitude and hyper-exponential growth of microelectronics and implications for processing, data, information and knowledge.

Episode 3 considers inventions and revolutions in computer-based "productivity" applications for individual use and their roles in on-going cognitive revolutions in the way people generate, capture, and use knowledge. Word processing, spreadsheets, and relational databases quantitatively extend human cognition and represent revolutionary changes in the evolution of human capabilities. Structured authoring, indexing and retrieval systems, the World Wide Web and knowledge management applications revolutionize, automate and add epistemic quality to cognitive processes that were purely human activities until the last few decades. In little more than three decades, the "personal" computing has given people "*post-human*" cognitive abilities - orders of magnitude beyond anything conceivable to previous generations outside science fiction.

Interlude. Before we can fully understand the impacts of the revolutions in cognitive technologies on human society and organizations today, we need to consider the fundamental interactions of life and knowledge. The concept of autopoiesis (from the Greek "self" + "production") formally defines what it means to be living. The idea of autopoiesis was developed by Humberto Maturana and Franscisco Varela in the 1970s (summarized in their 1980 book). I argue that knowledge and autopoiesis are intertwined to the extent that one cannot exist without the other and show that autopoietic organization can emerge at several levels of complexity. These levels minimally include individual living cells, autopoietic organisms comprised of interacting cells, and autopoietic social organizations such as companies and other human enterprises comprised of interacting organisms such as people.

Returning to the recent history of technological change, **Episode 4** explores how social and cloud computing technologies since around 2008 have fueled the emergence of what may be called humano-technical individuals. The spread of these newest technologies and the profound ways in which they extend the cognitive abilities of humans and their organizations again changes the nature of people and their organized social interactions.

Episode 5 looks at the five million year evolutionary history of humanity to understand how co-evolution and revolutions in technology and cognition enabled a lineage of tool-using ape ancestors stranded by climate change on the African savanna came to completely dominate the biosphere of Planet Earth. The episode particularly explores how these revolutions impacted the acquisition and management of cultural and organizational knowledge. Extending concepts of knowledge to organizations uses the deeper theory of knowledge and organization presented in the Interlude. It follows from these discussions that many businesses and organizations are living entities in their own rights and have cognitive capabilities that transcend the sum of their individual human members.

A **Cadenza** is a virtuosic section for the performer, usually near the end of the composition and reflecting and elaborating some key themes of the overall composition. I consider here the corporate management of knowledge from my active involvement over 17½ years with successfully designing, completing, and delivering 10 high-technology warships to the navies of Australia and New Zealand. Paradoxically, this major success was followed immediately by the effective demise of the company because it no longer knew how to complete a much simpler and smaller shipbuilding project.

A brief **Coda** considers the future. Is there a sting in the tale? Are the current revolutions a point of inflection in a logistic growth (sigmoid) curve or are we rising along a true evolutionary singularity (or spike) as some would claim?

TABLE OF CONTENTS

FIGURES

PREFACE

Background

The hypertext you have before you started its long journey in late 2000 when I was a documentation and knowledge management systems analyst and designer for a major defense company. The hypertext began as a contribution to a flame war on the impact of new knowledge management technologies in relationship to technical writing in an engineering environment. My responses were based on my personal experiences with new technologies and cognitive revolutions but were informed by my earlier experiences as an evolutionary biologist:

- I grew up on a boat docked in the estuarine marinas of Southern California, and spent most of my free time peering into the diversity of aquatic and intertidal life on or near the dock or in the pristine ocean waters around Catalina Island.
- I joined academia in 1957 in physics, interested in astrophysics and engineering (3½ years), and then switched to zoology with an interest in systems ecology (another 3½ years).
- As a biologist I was involved for 15 years in graduate and professional research, teaching and publishing (general biology, comparative anatomy, genetics, population biology, ecology, systematics, speciation and evolution).
- I first experienced digital computers as a physics student, and as a biologist I worked with and taught about the wealth of manual and computerized indexing and information retrieval services available through major academic research libraries (20 years);
- While on a postdoctoral fellowship, for two years I explored the history and philosophy of science and its concerns with the growth of scientific knowledge (epistemology and scientific revolutions, where I became familiar with the works of Thomas Kuhn and Karl Popper).
- In my lifetime I have had hands-on experience with the revolutionary changes in all generations computer technology from hand-cranked cog-wheel calculators to personal and super-computers (45+ years).
- Following my career in biology, for 25 years I practiced as a technical writer, document content manager, and knowledge management systems analyst for a software house, commercial bank and defense industrial environments. In the last role, I implemented some of the world's most sophisticated structured authoring and content management applications for what was then the largest Australian defense contractor, Tenix Defence; and learned to use the resources of the World Wide Web as research and communication tools (since around 1998).

In the flame war it became apparent that things I thought were obvious about technological change in knowledge intensive industries are anything but obvious to most people in those industries. I would have to do a lot more work to have any hope to explain why and how the new generation of software tools were so much more (and more powerful) than fancy typewriters and document filing systems. I also thought a good explanation would interest a broad community ranging from students, academic philosophers and historians to hard-nosed scientists and business managers. Thus, I judged the project to be worthy of the effort required; and while still warm from the flames, early in 2001 I stepped off a precipice into uncharted territory to start writing this book.

My concept of the work was to explore the evolution of human cognition and the impacts of technological revolutions on cognition. What I sought to describe is how cognitive processes have expanded and accelerated from those of our early ancestors where cognition was based purely on genetically determined neuroanatomy, to our present use of culturally transmitted cognitive tools and technologies that actually extend cognition beyond our organic capabilities.

From the outset the work was conceived as a hypertext, because:

- I lived on a 5 acre farmlet on the rural fringe of Melbourne, Australia, and while I worked intensively in the defense industry, I did not have practical access to the resources of an academic library. From using it Web at work, I knew the Web provided light-speed access to indexing and retrieval (i.e., via AltaVista then and Google now) for most of the background material I required to support the various ideas I wished to explore. Although only a small fraction of primary academic documentation was then available free to the Web, a large and rapidly growing volume of secondary material already existed that pointed to primary sources. The Web made what would have otherwise been a fantastic dream into a realistic writing project.

- I gambled that hypertext would give me a way to build a cognitive Web to interconnect the reader's personal cognition and the same artifacts of knowledge I used as sources and evidence for my ideas. Most of my queries and resulting links I found as I wrote would equally be available to readers – an impossibility with paper documentation.
- This work itself would form powerfully tangible proof of many of the concepts I wanted to write about.

I established the structure of the book more-or-less as it is still represented in the Table of Contents, and started to expand my first thoughts and the outline over the 2000/2001 holidays. In this first period of work I roughly completed the initial discussion of epistemology and scientific revolutions, the history of microelectronics technology and the origins and spread of the World Wide Web. The intellectual demands of my job as a documentation systems analyst and designer were high, so the work progressed slowly through the rest of the year. During the 2001/2002 holiday period, I took two months accumulated leave to "finish" the work.

I thought the episode on organizational knowledge management would be easy to write because I had some very firm ideas as to how the subject should be approached from my decades of experience collecting and managing knowledge.

What I found when I began to dig into the academic and professional literature on organizational knowledge management was, for me, a nearly incomprehensible chaos of competing and incommensurable paradigms in epistemology (objective vs. personal knowledge), organization theory (resource view vs. environment view), how to analyze knowledge in the organization (individual view vs. social view vs. critical and alternative views), and how organizations create knowledge (cognitivism vs. connectionism vs. autopoiesis) amongst others. I clearly could not complete the work as planned without making enough sense of the differing paradigms so I could compare these views with my own, and I could not do this without full access to a major academic research library and knowledge management research centre.

Thanks to a fortunate meeting with Dr Frada Burstein, Director of the Knowledge Management Lab of Monash University's School of Information Management & Systems, Monash University made me an Honorary Research Fellow and full academic access to their extensive library facilities, including remote Internet access to electronic catalogues of library holdings at Monash and around the world, electronic journal subscriptions, and interlibrary loans for materials they did not hold themselves. Even then, subscriptions to electronic journals provided light-speed access to perhaps half the significant articles I sought. During the 2002/2003 holidays I was able to spend 1½ months in residence in the KM Lab, and 2003, my employer, Tenix Defence, supported my collaborative work with the KM Lab with one day per week release time, which provided physical access to the library on a weekly basis for material that was only available on paper.

In this period it became evident that the disciplines of organization studies and knowledge management lacked sufficient coherence for me to be able to finish the book until I fully developed and defended my own theoretical foundations for these fields. Thus, in 2003 I abandoned further work on this book to do the necessary theoretical and scholarly groundwork as presented in a number of formal and informal papers that are referenced in appropriate contexts throughout this book and on my personal web site.

In 2005 I resigned my Monash University fellowship and was appointed as a National Fellow of the Australian Centre for Science, Innovation and Society by Jim Falk at The University of Melbourne. When this organization finished its term of existence in 2010, Dr Roger Hadgraft, then Director of the Engineering Learning Unit, continued my formal appointment through 2012. Today

I still have a continuing involvement with the University of Melbourne via an association with the eScholarship Research Unit under its Director, Gavan McCarthy and Visitor status in Melbourne School of Engineering. For all of my time with University of Melbourne, I have had access to office facilities and Web services when I need to be on campus, first in the Department of Information Systems in the Faculty of Science – thanks to Liz Sonnenberg, the eScholarship Research Centre – thanks to Russell Thompson and Roger Hadgraft. The resourceful people of the Inter-Library Loans desk of the Melbourne University Library have managed to provide reference material I could get no other way. Thanks to the University of Melbourne's subscriptions to electronic resources, as I complete this work, I now have virtually instant electronic access to probably more than 95% of the world's science and technology journals by content value, if not absolute numbers.

What I have ended up with in this project after weaving my own personal threads together with the many paradigms of epistemology and knowledge management is a unified theory of the evolutionary biology of life, knowledge and organizations that I think offers new and radical insights on the evolution and roles of cognition in individuals and organizations. In this work the application of biological concepts of evolution and cognition to organizational entities is very much more than just a metaphor. As I will explain in the Interlude and Episode 5, and others have already shown elsewhere, organizations clearly have the property of "life" and "cognition" in ways that transcend the lives of their individual members. Thus, the life sciences help to clarify many aspects of organization that should be of interest to those who think they manage or own organizations.

Many of the ideas and concepts of the evolution of cognition and organizational biology are not original with me, and my discoveries of these ideas in my own thinking have certainly been modified and reshaped as I found them in earlier sources. However, I believe that I am the first to present them from a genuine background in evolutionary biology. The intellectual forebears of the biological approach presented here include the following seminal works, more or less in the order I encountered them:

- Harold Morowitz (1968), Energy Flow in Biology
- Leslie Orgel (1973) The Origin of Life: Molecules and Natural Selection
- Karl Popper (especially Epistemology Without a Knowing Subject, and Evolution and the Tree of Knowledge, as found in Popper 1972),
- Thomas Kuhn (1962), The Structure of Scientific Revolutions
- James Martin (1996) Cybercorp (the networked organization as a living organism)
- Michael Polanyi (1958, 1967), (on personal and tacit knowledge)
- Georg von Krogh & Johan Roos (1995) Organizational Epistemology
- Col. John Boyd (1976), Destruction and Creation (introducing the OODA Loop) Richard Nelson and Sidney Winter (1982), Evolutionary Theory of Economic Change
- Humberto Maturana and Francisco Varela (1972), Autopoiesis and Cognition.
- Stanley Kauffman (1993, 1995) Self Organization and Selection in Evolution, and Search for the Laws of Self Organization and Complexity
- Sir Stafford Beer (1981) The Brain of the Firm
- Eric Chaisson (2001) Cosmic Evolution
- Elizabeth Eisenstein (1979) The Printing Press as an Agent of Change
- Tim Berners-Lee's (1999) Weaving the Web - and of course what he and others did to create the World Wide Web
- Steven Gould (20 2) The Structure of Evolutionary Theory
- Howard Pattee (1973, 1977, 1995, 1995a, 2000, 2001)
- Herbert Simon (1962, 1973, 1979)
- Stanley Salthe (1985, 1993)

Following the trail I have charted

To assemble this book I have crossed (and recrossed) many disciplines including biophysics, theory of knowledge, military affairs, evolutionary biology, history of technology, engineering, anthropology, etc. Each has their own paradigmatic language and world view. I've lived within most of them. From the outset, I conceived and built the book as a hypertext. Although it can be printed on paper and read in a linear way as you would read a printed book, it is embedded in the World Wide Web. When displayed on a screen connected to the Web via a browser, you can instantly access other texts and objects by clicking the links in my text. Besides texts, links may open tables, images, audios, or video formats elsewhere in my book or in the Web. The book's top layer is the axial structure of its argument that is logically organized into a set of episodes or parts sequentially divided into segments (≈ chapters with subdivisions). This axis is a fugally structured argument that guides you through a variety of philosophical and disciplinary paradigms that may be crossed several times as the book's central themes are developed in a semi-recursive spiral.

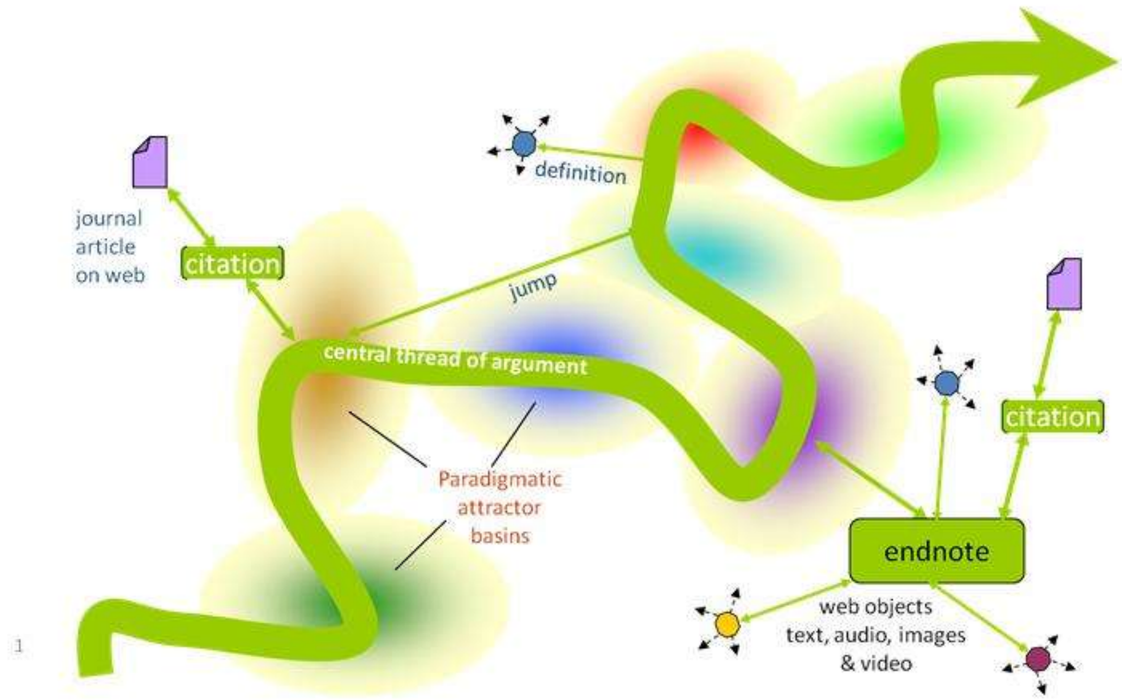


Figure 1. Charting a pathway through a complex landscape of ideas and paradigms.

As shown in Figure 1 and Figure 2, hypertextual links from the main axis of the book are used several different ways. These include:

- Jumps to other locations and contexts in the main text that significantly relate to the current text.
- Links to definitions of terms that are uncommon or have paradigmatically significant meanings in the current contexts that might otherwise be unclear or ambiguous.
- Citations to complete source references in the Bibliography. Where I have found a version of the source on the open Web, a TinyURL is provided in the visible text. Hover the cursor over the TinyURL to see the complete link. To preserve a link as I found it against being broken, it will often go to a dated permanent entry in the Web Archive's WayBackMachine.
- End notes provide additional bibliography references, links, discussions and illustrative and explanatory material that I think are interesting but not essential to the current discussion in the main text.

- Other web objects – web pages, blogs, videos, sound files, etc… illustrations or jumping off points that are relevant to the current discussion that may themselves provide access to an endless tree of further links in some way related to the current.

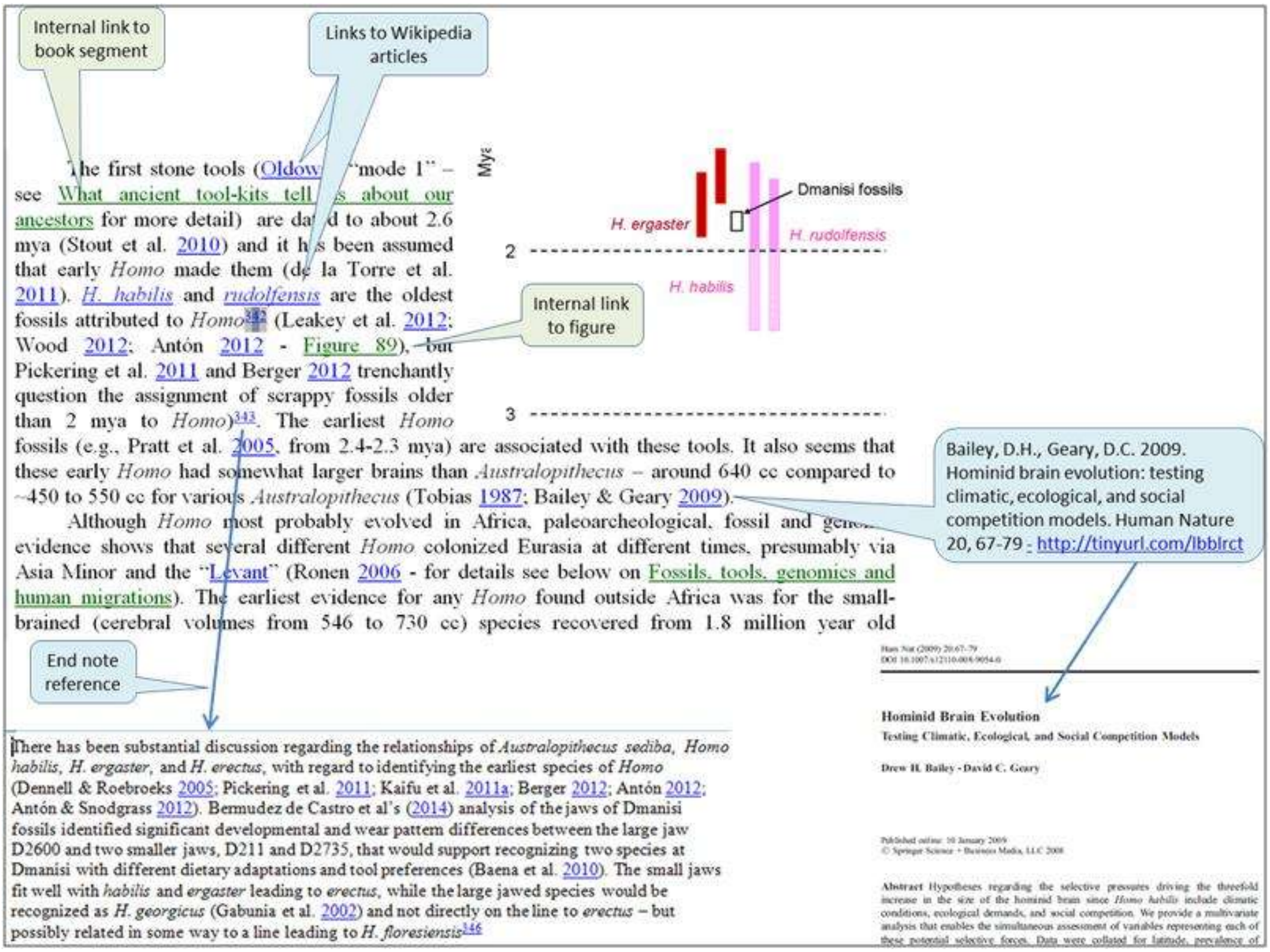


Figure 2. Examples of the main types of links I use: Green underlined – cross reference links to other places in the main document, e.g., sections, paragraphs, figures & tables. ### Blue superscript number – links to endnote, where the endnote may include several more internal or external links. (####) Blue underlined four digit number (year of publication) – hyperlink to complete reference in the bibliography that may link directly to a copy of the complete article on the open web if this is available. Blue underlined text – hyperlink to an external document, e.g., Wikipedia or other definition, web page, or other object (e.g., picture, sound, video, etc.). Still pictures or other graphic objects may also link to original, larger versions or videos from which the still picture was captured. These latter cases should be identified as such in figure captions.

Although I select links because they related directly to the book's arguments, objects at the other end of these links may in turn offer further links to other related documents or objects, such that the book can be seen to be embedded in and supported by the world of human knowledge.

Comments on Links and Referencing

The style and nature of the links and references I have used has changed considerably over the history of my writing of this book. When I bought into the flame war on technical writing, the Internet Web had only existed for about 10 years, with the first graphical browser developed in 1993 and the World Wide Web consortium established only in October 1994. My first access to the Web's exponentially growing resources was around 1998, via my job at Tenix (that installed its first internal computer network only in 1991).

Wikipedia was established only in January 2001, so early parts/drafts of the book did not include Wikipedia as a source for definitions. Of necessity, I had to be more creative to find suitable links. Wikipedia has now grown to more than four million entries in English (Figure 3), with continuing refinement via peer review. It now proves to be a generally reliable source for definitions and for documenting what might be called the "general knowledge". Thus, for more recent topics in the book, the ever growing Wikipedia has been used almost exclusively for background knowledge to provide explanations and additional details on particular subjects - unless I have a problem with its content on a particular subject.

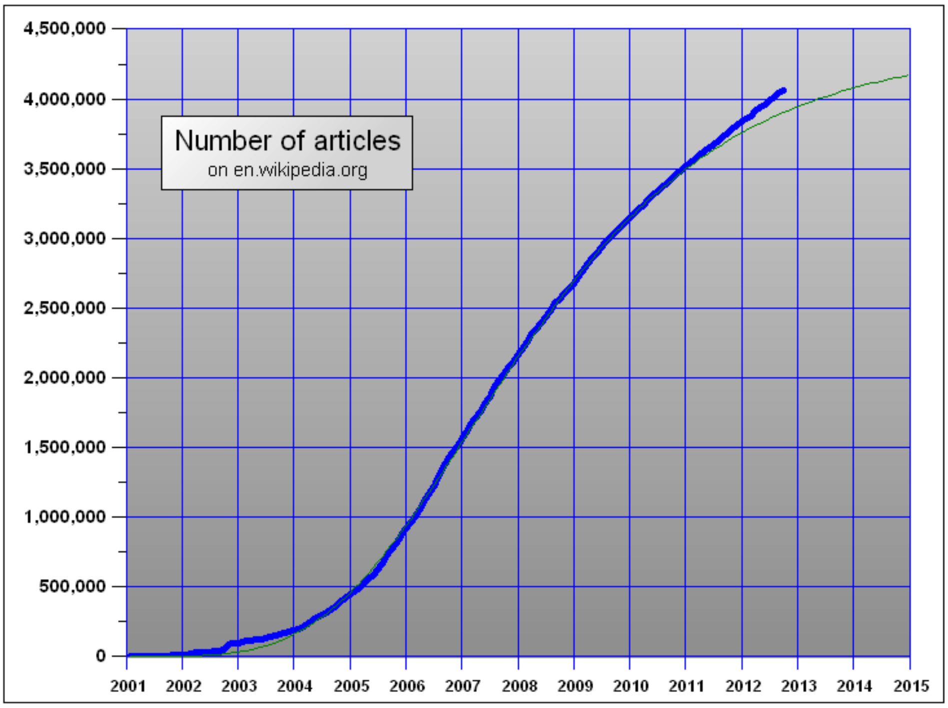


Figure 3. Growth of knowledge in Wikipedia (Click figure for most recent measures).

Similarly, when I started the project, only a small fraction of the knowledge available in peer-reviewed literature was available free-to-the-web – or even available electronically via library subscriptions. Thus, for the early episodes of the book, the majority of references were to individually maintained web pages. However, this actually suits the logical development of the episodic structure of the book. Many of the technologies described are now obsolete and historical (e.g., typesetting, letter-press printing, early generation computers), such that many people today have forgotten contemporary details about how they actually worked and their impacts on the people that used and lived with them. Thus, many references documenting early stages of computing and the internet are contemporary first-person reports on the early web by people involved in the innovations. Although not the majority, a surprising number of these historical sites still survive on the Web today if you know to look for them. (The Web rarely forgets anything – as many people using social media discover to their embarrassment and regret). Beyond this, most sites that no longer exist in the living Web have been preserved in the WayBackMachine's Web Archive. Thus, when links I recorded in the early 2000's fell off the live Web, in most cases I could provide a permanent link to the historical site via the time machine offered by the Web Archive.

As noted above, in 2004 I effectively stopped work on the book after drafting the history and impacts of the Internet when I found that I had to do much more research in the areas of organizational theory and the theory of organizational knowledge before I could finish it. Serious work on the book resumed only in 2011 after I had researched and published several papers on these issues. By then substantial fractions of the peer-reviewed academic literature was available free-to-the-Web, via personal or institutional web sites; and virtually all of the remainder could be accessed electronically via library subscriptions. Also, the Interlude and Episodes 4 and 5 reflect things that have emerged since 2004, so these segments benefit much more from citing the original, peer-reviewed academic and scientific work. In most cases, I have been able to select and reference relevant work that is available free-to-the-web. Thus most source references are as readily available to readers of this book by one or two clicks of the cursor as they were to me when I wrote the passage. I prefer to cite these readily accessible works because I want readers to be able to make their own decisions as to whether I have fairly reported the best available knowledge on a subject. However, on important subjects, I have not hesitated to reference critical works that are still hidden from the general reader behind subscription barriers, believing that all peer-reviewed knowledge will be soon be freely available via the Web (Hall & Nousala 2010a). If you want to find the current status of an article that I have not linked, simply go to Google Scholar and search on the article's title enclosed in quotes. This may give new links that are open, and it will also refer you to subsequent publications that cited the work I referenced. Some of these more recent papers may be even more relevant than those I referred to.

The bottom line is that this book is immersed in a world of links to what I think is the best available knowledge in the world. I hope that you will enjoy following my logic and seeing where it leads.

Application Holy Wars – the Tech Writer List Manager's Nightmare

Virtually everyone writes down things to aid their memory or to communicate across time and space. Few of us pay much attention to our writing tools. By contrast, technical writers professionals employed to capture, distil and transmit practical and essential knowledge for other people to use. They are passionate about the tools they use for writing and managing document content. In the early 2000s, some of the most passionate discussions on Techwr–l forum for technical writers related to the relative merits of different software tools used in their work. The tools most commonly compared by technical writers when I started this project in 2001 were (and probably still are) users of Microsoft's MS Word or Adobe's FrameMaker. These two applications have some interesting fundamental differences in how they work and how they are used. Neutral bystanders called such passionate "discussions" about authoring technology "application holy wars" because they often degenerated into violently irrational and personal attacks known as "flames". The List Manager periodically needed to douse the flames; and in at least once case I recall, the name-calling led to litigation threats between the name-callers. In fact, it was my own participation in one such holy war that stimulated me to start writing the present work.1

These kinds of holy wars are symptoms of extraordinarily fundamental technological changes in the way humans record, manage and retrieve knowledge. These changes are currently redefining the meaning of human cognition and our relationships to the world and each other. My professional experience implementing knowledge management systems shown me how little most people, including managers and leaders of these industries actually know about knowledge: what it is, why it is important, and how ever more rapidly changing technology is changing the way we personally use knowledge as individuals and in our organizations and society. By understanding better what knowledge is and the underlying processes driving changes in the way we create and use it, we may be able to better understand and forecast the implications and impacts these technological changes have on our lives and on the organizations we belong to.

In hopes of assisting this understanding, and because my explorations exposed fundamentally important issues in philosophy of knowledge and the nature of humanity, my book reviews some aspects of revolutions in tools that assist human cognition. My point of view is that of an evolutionary biologist who studied how species are formed, with printer's ink in his blood, who – as a technical writer and organizational knowledge manager – has had hands–on contact with almost all stages in the evolution of computer technology and implementing state of the art knowledge management systems into a large defense contracting organization.

Because I believe the revolutions in our cognitive tools are changing the nature of humanity itself in a new Renaissance, I think it is appropriate to base the development of my ideas on one of the greatest cognitive artifacts evolving out of the ferment initiated by the last Renaissance - the fugue2.

SUBJECT – Epistemology, Technology and Knowledge Growth

"Holy Wars" Highlight Fundamental Changes in the Creation and Use of Knowledge

My jumping off point for this book is that the growing shift (partly associated with the growth of the Internet) from format oriented writing tools3 such as MS Word, to tools such as FrameMaker and ArborText that work with semantic structure, arguably forms part of a fundamental technological and cognitive revolution in the ways individuals and organizations create, manage, retrieve and use knowledge. I will also argue that this current revolution is part of the most fundamental and far–reaching of several cognitive revolutions in human evolution and history. Only by understanding the nature of this current revolution can we fully grasp the implications of what the new Internet technology means to humanity – and, more practically, be able to rationally discuss and choose appropriate tools for capturing knowledge without resorting to “flames” and ad hominem attacks.

My own background and history are relevant.

My maternal grandfather was a printer and my father was an industrial engineer. Following this cultural heredity, practical courses I took in secondary school included commercial typing, and a year each of mechanical drawing and print shop. In the print shop, I learned typography and page design the same way Gutenberg and Benjamin Franklin did. We set and spaced moveable type in composing sticks and then laid out and imposed (formed) the rows of type and furniture into the chase for printing. In the 1950’s my high school still ran a manually fed and inked platen press4. The revolutionary conceptual difference between mechanized typesetting and handwriting or chipping text onto stone slabs with hammers and chisels is that the printing press allowed multiple copies of a document to be produced far faster, more accurately and for much less cost per copy than being chipped on stone or hand copied by scribes.

I began university as a physics major. On rare occasions students in the lab were allowed to use the electrically driven mechanical calculators to help reduce our lab data. Later, as a zoology student, and long before I could afford an early transistor calculator, I was able to use a Monroe electrically driven mechanical calculator. My first hands–on experience with stored program computers was in 1958-59 with an early vacuum tube Burroughs machine using a 32 bit x 1024 word magnetic drum "memory", and IBM's 7095. I eventually completed my PhD in Evolutionary Biology. As a research biologist, I learned the power of computer generated indexing services such as Biological Abstracts (now BIOSIS Previews), Science Citation Index (now Web of Knowledge) and Index Medicus (now PubMed Central), all of which were available as paper documents in research libraries in the 1970’s and could be accessed and searched electronically via early Telnet or other comparable services if one could afford the high cost.

I bought my first personal computer6, using the CP/M operating system on a Z80 chip. To pay for the $7,000 computer, I opened a one–person academically oriented word processing bureau and graduated into technical writing and building user interfaces for a software house that developed multi-user applications for CP/M based machines. From there I went on to implement and manage document authoring and delivery systems for a bank and then a large defense contractor. In the latter role, I was involved in implementing what I believe to be the worldwide state of the art XML–based document and content management system[7] as a corporate knowledge management system.

My history of involvement in knowledge intensive activities eventually led me to focus on the nature of knowledge itself as a topic worthy of deep study in its own right, hence my selection of knowledge as the primary subject of this book. My focus on understanding knowledge began with an unexpected crisis in my academic career.

Thomas Kuhn's Scientific Revolutions and Karl Popper's Epistemology

In writing up my PhD research at Harvard University on chromosome evolution and speciation in lizards in the early 1970s, I found that reviewers and peers had difficulties following my arguments, to the extent that after reading one draft of the thesis, my adviser commented, "*I don't like it – do it over*". I eventually earned the degree (Hall 1973) – but at the time none of my reviewers had articulated in a way I could understand why they had so much difficulty with my efforts to explain the work.

The nature and scope of my writing problem only began to become clear when one of my ex-research assistants (then working on his own doctorate), who helped with my research for more than a year in the field and lab, accused me of being "unscientific". When he undertook to rewrite my draft of a major paper, it was clear the issue between us was not my poor command of English or inadequate research, but something fundamental about how I presented my whole research program. After spending more than a decade learning to do what I thought was scientific research, to have someone I respected suggest what I had been doing was *not* actually science was a huge kick to the solar plexus. The black hole in the pit of my stomach grew even larger when I realized that I did not have a clear enough verbal understanding of what science was to defend my research approach. As was the case with most other people in that era, I had learned to do science tacitly by studying under and working with people who were scientists, but no one in my many years of education had ever clearly defined to me what that kind of science actually was, or exactly what made scientific claims to knowledge any better than any other claims.

My last major research project as an academic was to try to determine whether my research actually qualified as being scientific, and if it was, then why was I having problems communicating that? To do this I studied the epistemological differences and communication difficulties between users of the "comparative" research methodology8, as I had applied it9, and the more commonly understood hypothetico–deductive methodology[10] many biologists had tacitly adopted from the physical sciences. My methodology was in fact rational and appropriate for the kind of research I had done (Hall 1983)[11] (as eventually accepted by my peers – e.g., Sites et. al, 1992; Hall 2009).

In completing the 1983 study, I learned a lot about what knowledge is, and how it is acquired, organized and communicated from two seminal thinkers who helped me understand the specific difficulties I had encountered, and are the source of many of the ideas presented in this book and its fugal structure. Karl Popper's works[12] on the theory of knowledge (epistemology)[13] provided rational criteria for evaluating the scientific basis of my methodology. Thomas Kuhn's (1962, 1970), The Structure of Scientific Revolutions, from a much more historical point of view, helped me achieve a useful understanding of the problems I had communicating my research findings to my peers. Although I did not gain these insights soon enough to salvage my career in evolutionary biology, this career excursion greatly informed my later professional work as a technical writer and as a knowledge management systems analyst and designer, in introducing revolutionary information management technologies into inherently conservative industries (Hall, 1998).

Theory of knowledge

A question that that most people don't ask, that is central to my work both as a scientist and as a knowledge manager (and is also at the foundation of the theory of knowledge) is: *What is this stuff called knowledge*? Defining knowledge is quite contentious - leading to flame wars on knowledge management forums (see discussion in the Counter Subject), and I will return to this question several times in attempts to find still deeper answers, but to give us something to start with I can't do better than Karl Popper's (1972) simple pragmatic formula that states that *knowledge is solutions (or at least claims to have solutions) to problems*[14]. When claimed solutions are actually tested through application in the real world, those that fail can be assumed to be in error, while those that succeed can be assumed to correspond at least somewhat to the actual reality. Another simple, and probably the most common definition, is that knowledge is "justified true belief". However, there are problems with each of the three words (Gettier 1963). "Belief" is a matter of personal faith not bearing any necessary relationship with the external world. Justification has its own problems (Binmore 2007), and "Truth" is a concept that has bothered philosophers for as long as there have been philosophers (David 2009).

Karl Popper argued that nature (the external world) exists and that what we know about it may possibly correspond to this external reality, but no finite number of facts or observations can ever absolutely prove that what one claims to "know" actually is the truth. It makes no difference whether these facts are collected before or after the statement of knowledge. In other words, just because I say I believe it to be true and point to many supporting instances, this doesn't *prove* the truth of the claim for all cases or even one of them. Arguing from metaphysical assumptions, Popper goes even further to assert that repeated substantiations or confirmations do not even provide evidence that a theory is "probably" true. This is the "problem of induction"[15].

Popper's (1959) repudiation of inductive methods in science raised the core issue of how to differentiate between good science and pseudo science, non–science and just plain fantasy: i.e., how to determine rationally which of several competing claims to know something are more likely to be true or resemble the truth. Popper called this the "problem of demarcation", and first tried to resolve it by taking the other end of the stick (Popper 1959).

If we: (1) claim to have true knowledge (i.e., stated as a hypothesis), (2) logically deduce certain consequences which *must follow* from that hypothesis, and (3) then test for the existence of these deduced consequences in nature – and these do not occur; we can at least potentially prove the claimed knowledge to be false.[16]

Popper then argued that one can claim knowledge to be "scientific" only if it is constructed in such a way that one can logically deduce circumstances from that knowledge that are at least potentially falsifiable through testing against the real world. Better (scientific) knowledge is that which is so constructed, and which has survived a variety of robust attempts to falsify it through testing. If a claim to knowledge is formulated in such a way that there is no possible test that might be able to falsify it (i.e., angels exist but they are impossible to see or touch) or otherwise connect it to reality, then such claims are metaphysical and have no more *scientific* value than myth or fantasy. Many scientists (especially those in the physical sciences) assume these usually unstated criteria as the basis for what they would call a "good" scientific hypothesis.

Popper's logic of falsification can be applied with some justification in sciences dealing with phenomena assumed to be deterministic and universal. However, Popper (1972) recognized in his *Objective Knowledge: An Evolutionary Approach*[17], that an absolutist model of falsification is not appropriate for evolutionary and historical processes – or indeed, for most human affairs. Here, the claimed knowledge does not apply universally and at best only makes probabilistic (rather than certain) predictions about consequences. In the non-deterministic world of "fuzzy" science and messy human affairs, Popper argued that one could not even prove something was false to some given statistical degree of confidence.

However, Popper took a similarly critical approach to that used in the deterministic case. He argued that claims to knowledge that are multiply connected to reality through at least potentially falsifiable predictions, even if only statistically – and that have survived robust attempts to falsify these predictions[18] – are qualitatively better than claims to knowledge that haven't been so tested. In other words, claimed knowledge that makes many testable predictions that have survived robust attempts to falsify them are qualitatively better than claims that can't be tested or that are supported only by searching for confirmatory evidence. He also argued that attempts to logically connect many "unexpected" aspects of reality were more valuable than those that made few claims or only claimed what was already "known". To Popper, the best theories are those that claim a lot and whose claims had been robustly criticized (both in terms of formal logic and in terms of their logical connection to observable reality) without substantial failures.

Popper's bottom line is that genuinely useful knowledge – as opposed to uncritically accepted fantasy and myth, is logically connected to reality and experience by multiple links that have survived rational attempts to test and falsify them. Popper argued that human knowledge evolves and grows by proposing increasingly bold hypotheses built on prior knowledge that survive vigorous testing against reality. Hypotheses that fail testing are eventually discarded as demonstrably providing little predictive value (i.e., *the principle of natural selection applies to the evolution of human knowledge as well as a species' genes*). An amalgam of Popper's Objective Knowledge with a more thorough understanding of evolutionary adaptation has led to the development of what is now called "evolutionary epistemology" (Heylighen 1995; Calvin 1996; Plotkin 1994; Bradie and Harms 2008; Vehkaraa 1998). This is elaborated below.

Popper's evolutionary theory of knowledge

How does knowledge emerge and grow? Popper and other evolutionary epistemologists (e.g., Campbell 1960, 1974, 1988) have something important to say about this question. Popper argued that no objective truth could be proved - only that certain claims could be shown to be in error through tests or criticisms of the claims as they impact reality (Popper 1935 [1959], 1963). However, a theory can be articulated and shared. Through iterated testing and intersubjective criticism to eliminate errors, what is asserted can approach correspondence with reality, as Popper (1972) explains in his "tetradic schema" or "general theory of evolution" (Figure 4; see also Hall 2013 presentation).

$\boldsymbol{P_n}$ is a "*problem situation*" the living entity faces in the world, $\boldsymbol{TS_m}$ represent a range of "*tentative solutions*" or "*tentative hypotheses*" the entity may act on or propose. ***TS****s* may even be randomly generated (cf. Campbell's 1960 "blind variation". ***EE*** ("error elimination") represents a process by which ***TS****s* are tested or criticized against the world to selectively remove solutions or claims that don't work in practice (this is the converse to Campbell's "selective retention").

P_{n+1} represents the now changed problem situation remaining after a solution has been incorporated. As the entity iterates and re-iterates the process (the arrow indicating iteration is added), it will construct increasingly accurate representations of and responses to external reality, even where there is no possibility for knowledge to directly "reflect" external reality. Through continuously iterated cycles of problem solving, the entity constructs increasingly accurate knowledge about the world it is living in. These interconnected ideas formed the basis of Popper's (1972) "general theory of evolution" and "growth of knowledge" that takes place in living entities (Figure 4).

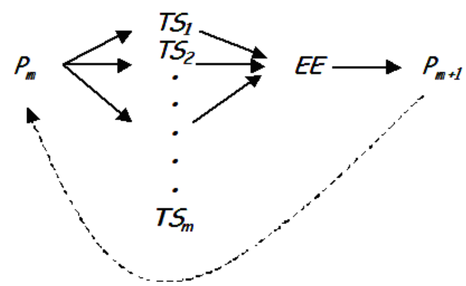


Figure 4. Popper's "general theory of evolution" (From Hall 2005, after Popper 1972: pp. 243).

Karl Popper's three worlds

One of Karl Poppers' major contributions to the theory of knowledge is his discussions of various ontological "worlds" as collected in Objective Knowledge (Popper 1972; see also Popper 1978, 1994). There are basically two sorts of knowledge, "subjective" knowledge possessed by a "knowing" person or "organismic" knowledge held by some living being; and "objective" knowledge that "*consists of the logical content of our theories, conjectures, guesses (and, if we like, of the logical content of our genetic code)*" (Popper 1972:73). To clarify this, Popper posits three "worlds" relating to cognitive activities:

- World 1 – ("W1") the physical universe as it actually exists independently of any perceptions, i.e., reality.
- World 2 – ("W2") the world of our subjective perceptions and experience, i.e., what knowing entities or subjects think about the world.
- World 3 – ("W3") *the world of logical contents of books, libraries, computer memories, and suchlike*" (Popper 1972: p. 74 - my italics) and *genetic code* (p. 73). Based on his discussion on the preceding page, Popper explicitly includes encoded hereditary information in W3.[19]

Popper assumes that the logical content of this W3 *may* connect to W1 by truthfully representing W1 as it exists. He posits some important theses about this W3 (p. 74):

> (1) We can discover new problems in world 3 which were there before they were discovered and before they ever became conscious; that is, before anything corresponding to them appeared in world 2….
>
> (2) Thus there is a sense in which world 3 is *autonomous*: in this world we can make theoretical discoveries in a similar way to that in which we can make geographical discoveries in world 1….

> (3) Main thesis: almost all our subjective knowledge (world 2 knowledge) depends upon world 3, that is to say on (at least virtually) *linguistically formulated* theories. Example: our 'immediate self-consciousness', or our 'knowledge of self', which is very important, depends very largely upon world 3 theories; on our theories about our body and its continued existence when we fall asleep or become unconscious; on our theories of time (its linearity); on our theory that we can pick up our memory of past experiences in various degrees of clarity; and so on. With these theories are connected our expectations of waking up after falling asleep. I propose the thesis that *full consciousness of self* depends upon all these (world 3) theories, and that animals, although capable of feelings, sensations, memory, and thus of consciousness, do not possess the full consciousness of self which is one of the results of human language and the development of the specifically human world 3.[20]
>
> ... The commonsense theory of knowledge [i.e., the subjective knowledge of the knowing subject, which Popper (1972) has discussed at some length] is unaware of world 3, and it thus ignores the existence of knowledge in the objective sense. [Popper's emphasis]

As defined by Popper, this third world is a unique kind of domain (Popper 1972 p:159):

> ... I suggest *that it is possible to accept the reality or (as it may be called) the autonomy of the third world, and at the same time to admit that the third world originates as a product of human activity*. One can even admit that the third world is man-made, and, in a very clear sense superhuman. **It transcends its makers**. [Popper's italics, my emphasis]…
>
> [from the footnote] Although man-made, the third world (as I understand this term) is super-human in that its contents are virtual rather than actual objects of thought, and in the sense that only a finite number of the infinity of virtual objects can ever become actual objects of thought... That the third world is not a fiction but exists in 'reality' will become clear when we consider its tremendous effect on the first world, mediated through the second world. One need only think of the impact of electrical power transmission or atomic theory on our inorganic and organic environment...

As Popper (1972) argues, much of conventional epistemology has completely ignored or at least underestimated the value of the objective artifacts of knowledge in W3. From my own experience I would also argue that this is the case for the knowledge management discipline. A major concern of this book is understand the origins and evolution of W3 and how changing technologies can help us build, evaluate and use W3 knowledge based on our experiences in W1.

By contrast, Kuhn's paradigms as discussed next exist and function almost entirely in W2, and his concept of incommensurable differences between the (subjective) world views of people holding different paradigms indicates that every individual has his/her own private W2, with communication about sensible things depending on the exchange of W3 objects. The utility of such communications to each individual depends; first on how well the W3 artifact represents W1, and second on how well the individual is able to connect his/her personal W2 with the W3 artifact.

For those wishing to delve deeper into the Web on the frontier between Popperian and Kuhnian approaches to evaluating "fuzzy" theories in science, Forster (2000; 2000a) offers interesting reading.

As will be discussed in Episode 4, Popper (1972) offers many other deep and even prescient insights into the evolution of organismic and organizational cognition in his essays on "Epistemology without a knowing subject" and "Evolution and the Tree of Knowledge". It took me more than 30 years after I first encountered Popper's thinking to begin to understand its full depth.

Knowledge revolutions

Popper was the quintessential philosopher. Having earned his doctorate in philosophy (Thornton 2009; Watkins (1997), he developed his ideas about the nature and growth of knowledge from first principles, and apparently had comparatively little contact with the actual practice of science. Thomas Kuhn (see Pajares 1998), my other guide to what represents "good science", took a comparative and historical approach in his attempts to elucidate processes in the growth of "scientific" knowledge[21]. Without much concern for what knowledge was, Kuhn's major work, The Structure of Scientific Revolutions (1962, 1970), provided deep insights into sources of communication problems that can turn a Popperian evolutionary growth of knowledge into a scientific revolution.

I tried to understand and apply Kuhn's ideas to my own problem in scientific communication, and they seemed to fit my experiences. Scientists are naturally grouped into content related disciplines or "invisible colleges" (Gmür 2003) that are not consciously apparent to their respective members. Each college tacitly shares (a) a theory laden vocabulary (based on implicit connotations as well as explicit definitions), (b) an unspoken set of examples of what the discipline believes to represent "good science", and (c) a lot of other uncritically held assumptions about their discipline inherited from their education as scientists. Kuhn called this tacitly learned and implicit disciplinary framework a "*paradigm*"[22].

As long as the growth of factual knowledge in a discipline conforms to the subliminally received paradigm, the growth proceeds "normally" – in an incremental or evolutionary fashion. However, when continued tests against reality do not fit the theory as received and cannot be answered by extensions to it within the limits of the implicit paradigm held by the discipline, the situation becomes more complex and potentially chaotic. A new underlying paradigmatic structure may fit the anomalies within a new theoretical structure. The new structure often involves inventing new vocabulary (or by redefining existing words), accepting new examples of what constitutes "good" science, or even finding new ways to think about the discipline. Thus the different paradigms often become "*incommensurable*"[23]. Because the conceptual components forming paradigms are not discussed and debated in the same way "facts" and observations are, communication problems almost inevitably arise between disciplines built on the different paradigms. Kuhn suggested that two disciplines dealing with similar subject matters might often use the same words in their discussions. However, because the words have tacitly come to have different meanings or shades of meaning in the respective paradigms, attempts between members of the different schools to rationally discuss their competing theories often degenerate to emotional arguments and ad hominem attacks — or "flames" in internet parlance.

Paradigms and incommensurability

In Kuhn's most generic usage, "A paradigm is what the members of a 'scientific community' [discipline], and they alone, share. Conversely it is their possession of a common paradigm that constitutes a scientific community [i.e., discipline] of a group of otherwise disparate men" (1977: pp. 460). Kuhn further notes that the discipline will "to a remarkable extent... have absorbed the same literature and drawn similar lessons from it. Because the attention of different [disciplines] is focused on different matters, professional communication across [discipline] lines is likely to be arduous, often gives rise to misunderstanding, and may, if pursued, isolate significant disagreement" (pp. 460-461).

In responding to Mastermann's (1970[22]) and other criticisms of his loose usage, Kuhn stated he was most concerned to use "paradigm" in the meaning of a "disciplinary matrix" of shared exemplars of what the discipline considered to be "good science". His paradigm concept in the sense of a disciplinary matrix includes four major components (Kuhn 1970, 1977; Forster 1998):

- *Symbolic generalizations* — deployed by authors without question or introspection, and immediately understandable by the group,
- *Models* — including those with heuristic and metaphysical presumptions that provide the group with preferred analogies or even with an ontology,
- *Exemplars* — which are unquestioned and accepted concrete examples of how to solve particular kinds of problems or of what constitutes "good" science — i.e., paradigms in the common English usage of the term, and
- *Values* — in the sense of providing a predictive or epistemic value (as discussed below): "values to be used in judging whole theories: they must, first and foremost, permit puzzle-formulation and solution; where possible they should be simple, self-consistent, and plausible, compatible, that is, with other theories currently deployed" (Kuhn 1970: p. 185)

In the sense I use the term paradigm, both in Hall (1983) and here, I follow Kuhn's preferred definition, and emphasize that the Kuhnian paradigm includes the implicit and tacitly accepted a priori beliefs, theory-laden vocabulary and jargon[24] that members of the discipline accept more-or-less uncritically along with their exemplars. Symbolic generalizations, models, and exemplars within a paradigm are all expressed in vocabulary that is often based on unstated assumptions. Like most vocabularies or jargons, theory-laden vocabulary is mostly learned tacitly "by example" as part of the conceptual "world view" or "gestalt" within which the discipline works.

Kuhn's concept of incommensurability derives from the mathematical concept of incommensurability (Kuhn 1983), and arises in science from the tacit nature of a paradigm. Kuhn (1962) developed the concept primarily in the framework of studying scientific "revolutions", where there was a historical progression from an earlier paradigm (disciplinary matrix) to a newer one. According to Kuhn, scientific revolutions may occur when new observations can no longer be adequately explained within an existing paradigm (the observations are anomalous). In some cases the anomalies can only be accommodated in theory based on new exemplars, models and/or symbolic generalizations. These changes often require new vocabulary and often alter the meaning and connotations of existing vocabulary. Even where the same words are used within each of the paradigms, there is often no longer a direct logical correspondence in their meanings. In other words, the world view (created by symbolic generalizations, models, exemplars and their associated theory-laden vocabulary) held by practitioners of one paradigm is logically incommensurable with that held by the alternative paradigm. Even though practitioners of both paradigms are looking at the same data, they see different worlds.

Because paradigmatic changes to vocabularies, models and exemplars are rarely discussed explicitly, Kuhn argues that the adoption of a new paradigm by an individual is a "conversion experience" (1970: p. 151) more than it is a reasoned, logical process. Because practitioners working within the respective tacit paradigms don't know how to deal logically with their different views of the same external phenomena, discussions often become heatedly emotional, and consequently the process individuals undergo to accept a new paradigm may be more akin to religious conversion or cognitive revolution than it is to "normal" science.

Although Kuhn explored the ideas of paradigms and incommensurability primarily in the temporal process of change from one paradigm to another, two paradigms can (and often do) exist side-by-side at the same time, with the same consequences for communication between holders of the different paradigms.

To rationally compare two paradigms one needs the ability to step outside the respective disciplinary frameworks and become a "translator" to explicitly explore their merits in a "meta-language" not fundamentally grounded in either paradigm (Kuhn 1970: p. 202-204).

The next section looks at the impact of other kinds of revolutions[25] on the nature of humanity, where the invention and adoption of new physical and conceptual tools have actually changed the nature of *Homo sapiens* as a biological species.

Technological and Conceptual Revolutions in Human Affairs

Biological evolution vs. revolutions

Evolution in its broadest sense means change through time, where the changes once made tend to persist to provide a platform for further change. Most evolution is gradual. In biology, evolutionary changes are most often associated with hereditary changes (Gould 2002; Jablonka & Lamb 2005, 2007). Most biological species live surrounded by other species making their living in somewhat similar but not identical ways. Individuals belonging to one species in such environments survive competition with individuals of their own and other species by doing one or a few things a little bit better than their competitors. Each species has its own ecological space, or *ecological niche*, defined by aggregate details of the ways its individuals make their livings. Each individual's heritage[26] is tested against the environment including other individuals of its own and other species. Those individuals whose heritage better prepares them to survive and reproduce in the competitive environment are more likely to successfully pass on their heritage and other forms of "knowledge" of what has worked in practice to the next generation. Equally obviously, unsuitable heritages that reduce survival or reproductive success in a generation are less likely to be passed on. Natural selection of this type over many generations may cause a species' average capabilities, and thus the ecological niche it occupies, to evolve through the gradual accumulation of new genes and changes in the frequencies and combinations of existing genes; together with experience-based change in other heritable knowledge.

However, in some cases, small incremental changes over many generations may reach a point of instability or opportunity enabling a significant change in the way a species makes its living; e.g., when the small changes allow the species to cross some kind of geographic or ecological threshold into a new adaptive zone not available to its current competitors. Having crossed the threshold, such a pioneering species may begin to evolve rapidly to exploit the environment in ways not available to competitors that have not crossed the threshold. Once the threshold is crossed, the species' population may grow explosively and (at least on an evolutionary time scale) and/or fragment into a large number of new species specialized in new ways to more effectively exploit the new kinds of niches[27]. The shift into a new adaptive regime is called a "*grade shift*"[28]. This corresponds to Robertson's (2003) concept of a "phase change" that he compares to Kuhn's (1962, 1970) "scientific revolution". Periods of relative stability punctuated by rapid phase changes are typical of complex nonlinear systems (as discussed in "Biological evolution vs. revolutions" in the Subject and "System concepts and dynamics" in the Interlude).

Technological and cognitive revolutions that reinvent the nature of humanity

We humans have reinvented our roles in the ecosphere to the extent of making grade shifts several times since becoming a species separate from our close relatives, the largely herbivorous chimpanzees and bonobos, and have evolved in increasingly revolutionary directions away from their comparative placidity. The first reinventions in our ancestry were almost certainly evolutionary, probably involving genetic changes taking place over many hundreds or thousands generations (i.e., tens or hundreds of thousands of years). However, as humanity evolved, an ever increasing percentage of our tested and accumulated knowledge about the world has been passed on culturally rather than genetically or epigenetically. This has also profoundly affected the cognitive processes by which we interact with the environment and create our ecological niches.

What is often not considered when looking at people and knowledge from purely ecological or sociological points of view is that the increasing use of various tools and production technologies to extend human physical capacities caused many changes in peoples and organizations' strategic power over their environments, such that it is useful to consider "socio-technical" organizations comprised of people plus their machines and technologically mediated processes (Harvey 1968). Over the last 30 years, in addition to the ways humans organize to produce physical products, tools such as personal computers and the internet that act to extend human cognition have even more radically revolutionized the way people interact in organizations (Hall 2006a; Yakhlef 2008). People in today's socio-technical organizations are cognitively knitted together with a wide variety of technologies (e.g., Hall 2006a; Hall et al. 2008; 2010; Hall and Kilpatrick 2011; Nousala et al. 2011) that support distributed decision-making processes extending beyond the mental bounds of human bodies. The result is what Pepperell (1995), Hayles (1999) and Yakhlef (2008) consider to be a "post-human"[29] condition where humans as organisms and their technologies essentially become inseparable. Paradigms from the traditional social sciences do not encompass or adequately illuminate this post-human complexity (Yakhlef 2008). Hall (2006a) and Jeffares (2009, 2010) propose that our use of tools extends our cognitive processes beyond the limits of our physical bodies. Consequently, our evolving ecological relationships to the rest of nature have changed from a slow sequence of incremental changes depending on genetically based natural selection; to increasingly rapid, abrupt and radically revolutionary transformations in our cultural heritage now taking place in less than a generation as we adopt new tools. Changes of incomprehensibly great magnitude in the relationship of the human species to the rest of the physical and biological world now occur in less than a decade by comparison to the tens or hundreds of thousands of years required for genetic evolutionary change.

Karl Popper (1972 p:238-9) recognized the fundamental difference between animal evolution and human evolution that I will elaborate here:

> Animal evolution proceeds largely, though not exclusively, by the modification of organs (or behaviour) or the emergence of new organs (or behaviour). *Human evolution proceeds, largely, by developing new organs outside our bodies or persons: 'exosomatically', as biologists call it, or 'extra-personally'. These new organs are tools, or weapons, or machines, or houses.*
>
> The rudimentary beginnings of this exosomatic development can of course be found among animals. The making of lairs, or dens, or nests, is an early achievement. I may also remind you that beavers build very ingenious dams. But man, instead of growing better eyes and ears, grows spectacles, microscopes, telescopes, telephones and hearing aids....

> *Yet the kind of extra-personal or exosomatic evolution which interests me here is this: instead of growing better memories and brains, we grow paper, pens, pencils, typewriters, dictaphones, the printing press, and libraries.*
>
> These add to our language--and especially to its descriptive and argumentative functions--what may be described as new dimensions. The latest development (used mainly in support of our argumentative abilities) is the growth of computers. [My italics]

This section considers twelve revolutions that have enabled grade shifts that have reinvented the nature of humanity. Five involve the invention/adoption of new kinds of technology, i.e., the development of tools external to the human body itself.[30] Seven relate to less tangible mental cognitive revolutions in the way humans gain and use non–genetic knowledge. The cognitive and technological changes are often synergistic. The impact of these changes on the nature of humans and human organizations[31] will be a major thread in weaving the themes of my Subject. The revolutions identified here are then discussed in much more detail in Episode 4 and Episode 5.

Technological revolutions

Here and throughout this book technology is defined broadly as *the practical application of knowledge especially in a particular area*, where knowledge is defined in Popper's sense as solutions to problems, whether the knowledge is held objectively in genomes or texts or in the brains of living entities. Humanity's first technological revolutions that began to make humans what we are today took place at an evolutionary rather than revolutionary pace long ago in our fossil history and accounted for the first major grade shifts. We have only a few details of where or when these early stages in the development of technology may have been incorporated in our human heredity. However, we know they occurred, because they are key features in differentiating our ancestors from their primate relatives, and because they opened new ways of making a living in the natural world exploited by few other animals.

- *Use of sticks, stones (hammering, cutting and throwing), clubs, levers and fire to extend reach and metabolism beyond anatomical and physiological limits of individual bodies beginning perhaps around 6 million years ago.*

Most non–human animal interactions with their surroundings are limited entirely to the capabilities of their physical anatomy: teeth and claws for defense and feeding, limbs for movement, hair and integument for insulation and protection from the elements, etc. Our primate relatives, and occasional bird species such as some ravens[32] and Galapagos finches use cactus spines and sticks (and may shape and carry to places where they are used) to obtain food they cannot access within the limited capabilities of their own bodies. Our closest relatives in Africa, chimpanzees, have gone beyond this to use and make a variety of simple tools including stone hammers (Whitten et al. 2009; Sanz and Morgan 2007)[33]. Capuchin monkeys in South America, who last shared a common ancestor with humans some 35 million years ago (Visalberghi 2009), seem to have independently reached that stage[35]. It also seems that our close relatives the bonobos (*Pan paniscus*), a sister species to the chimpanzee also have the mental capacity to make and use fairly sophisticated tools (Whitten et al. 2009; Roffman et al. 2012). Kanzi, who was raised with humans and who has learned a production vocabulary of 480 word symbols (using a keyboard) and understanding some 2000 English words (Savage-Rumbaugh 1998), has shown a remarkable ability to learn to make and use reasonably sophisticated tools simply by watching humans making such tools. (It should be noted that such language facility or tool use by bonobos has not been observed in the wild where bonobos live in lush tropical forests.)

However, the paleontological record from East Africa shows that some 2.6 million years ago our hominin ancestors[34] began to make even more sophisticated tools (Roche et al 1999; Davidson and McGrew 2005; Toth and Schick 2009). By this time proto–humans were consistently making complexly shaped cutting tools from stone. There is some evidence that these tools enabled the hominins to successfully exploit food sources considerably beyond the anatomical and physiological capacity of their very close anthropoid relatives.

Figure 5. Kanzi cutting a rope using a flint knife he knapped for the job[36]. Click picture for the Stone Age Institute's video. Kanzi's intelligence and extraordinary life is presented in Kanzi, a 53 minute NHK documentary.

The proto–humans' dietary changes enabled by tool use may have physiologically facilitated the development of larger brains (Laden and Wrangham 2005; Leonard et al. 2007; Dominy et al. 2008). Natural selection to better manage and learn to use tools may have selectively favored the evolution of more brainpower and language (Aunger 2009; see also Hall 2006a; Jeffares (2009, 2010). Although genetically determined aspects of primate biology may facilitate learning about and using tools, it is clear from the cited studies that the *knowledge* of how to make and use these simple tools is transmitted culturally through observation of other tool users in the social group. At this early stage in our evolution, even though the new technology seems to have enabled the spread of our ancestors out of Africa, there is no evidence that the rate of cultural change was rapid on the scale of a single human generation.

- *Ropes and digging implements used to control and manage non–human organic metabolism and water for human benefit (agriculture and transport) 13,000 - 10,000 years ago.*

Archeological evidence suggests that the next major reinvention of humanity enabling a major grade shift took place in the Fertile Crescent towards the end of the last Ice Age or just after it – probably 10,000-13,000 years ago (Horan et al. 2008a), with the development of a settled village life and agriculture, enabled by ever more sophisticated tools (Lewin 1988; Pringle 1998, 1998a). This, in turn, enabled a major demographic change (Gupta 2004; Richerson et al. 2009; Salamini et al. 2002; Ibanez et al., 2007; Mithen 2007). The first agricultural tools were probably of wood, stone, bone, sinew and skin; but the demands of the new agricultural existence eventually led to the development of metallurgy and effective metal tools. Native metals first appear to have been used as jewelry contemporaneously with the development of agriculture, with the first evidence for smelting around 7,000 years ago (Roberts et al. 2009)[37] but metallurgy was not revolutionary in the sense that the development of agriculture was. Metallurgy only enabled better agriculture and building, maintaining and defending larger villages. Possession of tools to control nature's resources for husbandry and agriculture implies ownership and establishes the dynamics for trade to develop. Trade requires mechanisms for accurate counting, reckoning and accounting (Horan et al. 2008).

- *The industrial revolution extends human and animal muscle power with mechanical power (water power, external and internal combustion) 300 years ago*.

In the Agricultural Revolution, tools helped to subdue and control nature. However, except for cooking, smelting involved in making metal tools, and water wheels for grinding grain and raising water (used since around 300 or 200 BC - Reynolds 1983), human ecology was still based almost entirely on the direct application human metabolic energy (e.g., slave labor) and harvesting the flow of external energy via plant and animal metabolism. The Industrial Revolution fundamentally changed that relationship and enabled a grade shift of the greatest magnitude so far. The Agricultural Revolution probably took place over a time scale of centuries or even millennia. The pace of the Industrial Revolution was measured in decades.

Key inventions that started the Industrial avalanche were Thomas Newcomen's steam engine[38], invented in 1712, for pumping out coal mines and James Watt's substantially improved the steam engine (Thurston 1878; Carnegie 1905)[39] around 1765, which used heat released by combustion to create the steam. In 1771 Richard Arkwright opened the first spinning mill driven by inorganic power (water).[40] Steam engines soon powered all kinds of factory operations including printing presses, and eventually transport. By removing constraints from the limited availability of living resources of metabolic energy, the industrial exploitation of the new non–metabolic energy resources fuelled an unprecedented period of exponential population growth that may only now be slowing down.

Change enabled by the grade shift of the Industrial Revolution continues today, with the development of ever more efficient and powerful energy sources to fuel the expansion of human control of global resources: internal combustion engines, turbines, nuclear power, etc. In 200 years (8 – 10 generations) humanity's populations and industrial activities have exploded, doubling and redoubling to the point where we now threaten the very survival of a substantial fraction of organic life on the planet.

- *The Microelectronics Revolution extends human cognitive capabilities ~50 years ago.*

The revolutions considered above respectively enabled grade shifts by extending human anatomical and metabolic capabilities. The development of computers, in the still continuing "Microelectronics Revolution"[41], provides tools to extend mental processes beyond the limits of human neurons.

Computer Hope provides a detailed timeline and history for the evolutionary development of computing technology. In this history, I regard the following events as crucial:

Mechanical data processing began when the Librarian of the US Surgeon General's Office, John Shaw Billings suggested to Herman Hollerith that the processing of the 1890 US Census could be automated using punch cards[42]. AT&T developed the first electromechanical relay-based digital calculator in 1937[43] – two years before I was born. The German, Konrad Zuse, probably has the distinction in 1941 of inventing the first program controlled digital computer (Zuse, ????). ENIAC, the first electronic tube–based computing system started development in 1943, and in 1948 ENIAC was given its final conceptual breakthrough by John von Neumann – the stored program (Weik 1961). Shockley, Bardeen and Brattain invented the transistor in 1947. Transistors were first applied to digital computers in 1956. The first integrated circuits were developed in 1958–59 (Texas Instruments Inc. 2000), with the first computer based on integrated circuits built around 1961 (Texas Instruments Inc. 2000a). As a student and budding scientist, I had the opportunity to use all the generations of this technology (see Episode 2).

Once computers began to be built with integrated circuits, the technology began to evolve continuously as transistors shrank in size at a completely unprecedented rate. The number of transistors per chip began to double every year or two in a phenomenon well documented as "Moore's Law", under the name of the person who first predicted the phenomenon in 1964 (Moore 1997, Intel 2007)[44]. In 1959 a single (1) good transistor could be purchased for around $6.00. In the year 2000, one could buy 64 megabit SDRAMs encompassing more than 64 million transistors in a similar sized package to the 1959 transistor for around $6.00[45]. This is an increase in transistor packing density of more than 7 orders of magnitude in less than 40 years (particularly considering that one bit of memory involves several transistor elements). Today, even microprocessor chips (that generally have fewer elements than bulk memory chips), have more than a billion transistors.

As will be discussed in more detail in later episodes, computer "power" has probably increased even faster than this basic measure, since power is determined by a number of other factors in combination with the cost or packing density of transistors, such as: clock speed, word length, speed of peripheral storage, sophistication of architecture and software and so on (Koh & Magee 2006; Nagy et al. 2011). Whatever the increase in computing power has been, it is incomprehensibly large in terms of any other technological or social change in human history.

The revolutions just reviewed primarily concern apparatus and technologies that exist in the physical reality of Popper's W1. As manufactured objects they embody W3 knowledge. As will be discussed in the next section, there have also been a number of revolutions in cognition in the evolution of humanity that have enabled profound "grade shifts"[28] in what we are as humans. As the remainder of this work will demonstrate, these revolutions have been primarily responsible for creating Popper's W3.

- *Cloud and Social Computing gives humans cyborg powers < 10 years ago*

The powers of microelectronic technologies are currently growing at hyper exponential rates, i.e., even faster than predicted by Moore's Law. This has led to technological convergence. Increasingly powerful storage, processing, and communication technologies available through the World Wide Web, accessed by increasingly powerful personal interface devices, are still radically changing human capabilities. Technology accessed via the Web may exist physically anywhere in the world, which is commonly illustrated as an amorphous cloud because it is of no concern to the end-user where the desired functionality exists, as long as it is accessible. Because the technologies exist in the intersection of interpersonal social behavior and computation it is appropriate to discuss them under the heading of social computing.

As the underlying technologies become less expensive they tend to converge; for example, telephones are evolving into "smartphones" that function as audio recorders, still and TV cameras, portable media players, navigation tools, notepads, navigation tools, personal assistants, etc…, as well as fulfilling the original need for voice communication. The cognitive tools resulting from this convergence are again radically changing the ecological and economic nature of humans using them. In essence, the convergent and rapidly shrinking technologies in the smartphone begin to turn their users into posthuman cyborgs (Pleše 2012) as explored in Episode 4, leading to even more profound grade shifts.

Cognitive revolutions

Cognitive revolutions include a sequence of basically intangible revolutions in the way human minds acquire, create, store and retrieve information and knowledge[46].

- *Evolution of memory and learning - perhaps 500,000,000 years ago.*

The first "revolution" was a purely genetic evolutionary process by which primitive organisms developed nervous systems and cognitions able to hold memories of their surroundings and provide a behavioral capacity to learn from experience. How and when this level of organization might have been achieved is discussed by Hall 2011. However, the fact that our primate ancestors had cognitive facilities comprised of a memory and the ability to add knowledge to that memory by learning was fundamental to all of the other revolutions discussed here. Robertson (1998) guesses an individual ancestral human at this "level 0 civilization" could encompass 10^7 bits of information in its brain.

- *Emergence of speech and teaching effectively transfers knowledge from one human memory to another via the spoken word - perhaps 400,000 - 200,000 years ago.*

A major enabler for the spread of the human-Neanderthal common ancestor across Africa and throughout Eurasia may have involved the development of a faculty for language. This allowed one individual to efficiently transfer complex knowledge to his/her offspring or other individuals in the cultural group. Because language does not fossilize, there is no way to determine for certain either when or under what circumstances the capacity for language evolved. However, as discussed in the early parts of Episode 5, we can reconstruct the social and ecological circumstances under which there would be strong selection pressures for the evolutionary emergence of a capacity for language. Bickerton (2007) suggests that a “protolanguage” may have begun to emerge as long as two to three million years ago, with syntactical language emerging no later than the modern human diaspora out of Africa 90,000 years ago[47]. With the acquisition of non–genetic capabilities for the transmission down the generations of a complex cultural heritage of experience, the rate of evolution in humanity's ecological adaptations shifted into a much higher gear (Szathmary 2010).

Robertson (1998) calculated that the capability to transfer knowledge by language would increase the amount of information that a single human could hold in memory by at least two orders of magnitude by comparison to what could be remembered without language - or to around 10^9 bites. The memorization of sayings, homilies, lore, epics, sagas and learnings, facilitating the passage non-genetic cultural heritage from one generation to the next represents the first tentative origins of Popper's World 3.

- *Cultural development of mnemonic strategies and tools increases memory capacity for technological and other survival knowledge – 70,000 – 40,000 years ago*.

Where and how the demarcation between worlds 2 and 3 emerged is a complex and important issue. Walter Ong’s (1982) work, Orality and Literacy offers crucial insights that will be discussed in several contexts below. A brilliant PhD thesis by Lynne Kelly (2012)[48] takes Ong’s work several large steps forward to describe how Australian Aborigines’ use “songlines” to help memorize, index, and to socially transfer large volumes of essential cultural and survival knowledge. A songline is based on physically following a specific path through the geography of a sequence of sites in memorable landscapes. Using ordered sequences of memorable sites to index memories is known as the "method of loci".

As discussed in Episode 5, there were no clear trends leading to lasting technological development in the hunting-and-gathering lifestyle practiced by our ancestors from around ~ 300,000 to ~ 70,000 years ago through the Middle Paleolithic/Middle Stone Age (Wurz 2013). Even with language, the capacity to retain knowledge for the manufacture and use of complex technology (e.g., bows and arrows) without memory aids was limited. However, around 70,000 to 60,000 years ago there is archeological evidence for the increasingly rapid development ever more complex technologies (e.g., Lombard 2012; Lobmard & Haidle 2012). Possibly not coincidentally, around this time modern humans erupted from Africa around 60,000 years ago and quickly spread to the far corners of Eurasia (colonizing Australia no later than 40,000 years ago) to replace all other humans (e.g., Neanderthals, Denisovans, and archaic *H. sapiens.* As argued in Episode 5, the invention of songlines and other mnemonic tools greatly expanded the amount of knowledge that could be remembered and transferred by individuals.

Kelly (2012) argues that as pre-literate cultures using mnemonics became sedentary and lost access to traditional songlines in the broad landscape, they erected monumental structures such as e.g., Stonehenge, whose detailed features could be sequentially traversed to trigger particular memories indexed against unique architectural features. In time the technology was further reduced to complexly carved portable artifacts that could be traversed visually or by touch along paths to specific trigger points. Use of this mnemonic technology enabled accumulation of the substantially greater volume of knowledge required to enable the Agricultural Revolution.

One may speculate that the mnemonic triggers were eventually reduced to sequences symbolic artifacts specific enough to trigger the memory of specific names or phrases corresponding to spoken language, at which point spoken language could be symbolically codified so it was no longer necessary to memorize long orations to preserve essential survival knowledge.

- *Invention of physical counters, tallies, writing and reading to record and transmit knowledge external to human memory >5,000 years ago.*

As discussed in more detail in Episode 1, the Agricultural Revolution carried with it a need to develop and maintain a complex social hierarchy with systems for remembering and tracking the ownership and exchange of goods and services as well as an ever-increasing volume of cultural knowledge. The earliest archeological evidence of counting systems is from sites in Mesopotamia, dated some 11,000 years ago. These are various clay tokens or tallies that looked like the objects they served to count (Schmandt-Besserat 1977, 1979, 1980, 1996 2010; Mouck 2000, 2004; Malafouris 2010; Beynon-Davies 2009). The first evidence for counting is based on the discovery of what seem to be tally markings on bones dating from 30,000 to 12,000 years ago. By 6,000 years ago, a system was devised to gather the counters together into a clay envelope, where the owner of the items represented by the counters was apparently identified by embossing the envelope with a roll seal. The next step was to emboss the envelope with the shapes of the different kinds of tallies and enumerate them with counting systems[49]. Soon, the tokens were dispensed with, and the accounts and contracts were kept simply by marking the clay tablets (Goetzmann 1996). By around 5,500 years ago, together with the emergence of urban communities and the accounting demands of priestly hierarchies collecting taxes and tributes, pictograms expressing more complex ideas were introduced and cuneiform writing developed, followed by alphabetic scripts – all pressed into clay or chipped onto stone (Schmandt-Besserat 1979)[50].

Robertson (1998) calculates this again increased by two orders of magnitude the amount of information a single person could manage prior to the invention of the printing press, i.e., to 10^{11} bits. World 3 begins to be populated with persistent tangible artifacts as people begin to record their memories in writing.

The invention of papyrus, parchment, paper and ink was certainly an improvement in the cost of labor to chip words onto stone or inscribe them on clay, and undoubtedly helped to increase literacy. The development of libraries to collect, house and classify written knowledge also helped to preserve and make it more accessible. However, until comparatively recently, the duplication of writing remained an expensive manual process and literacy was more–or–less restricted to educated royalty or scribes and clerics belonging to conservative priestly classes. Most ordinary people still depended on oral traditions for their cultural heritage, which undoubtedly limited the volume and complexity of the knowledge that could successfully be transmitted. This, in turn, limited the complexity of the technologies people could develop and communicate to succeeding generations.

Also, as will be expanded in later sections of this book, the history of high technology and literature of ancient Greece as embodied in the Mouseion ("museum" - a major research university) and Bibliotheca ("book depository" - probably the greatest library that existed prior to the Scientific Revolution) of ancient Alexandria shows us that threads of knowledge stored and transmitted via handwriting were all too fragile and easily lost. Only with printing and microelectronics does recorded knowledge become robust enough to begin growing exponentially.

- *Invention of printing and spread of universal literacy transmit knowledge to the masses 560 years ago.*

The invention in Europe of moveable type[51] and the printing press in the decade around 1450 turned the production and replication of text documents into one of the first industrial mass production processes[52]. The first major customers for output from the presses were priests – for the production of holy texts (i.e., Johannes Gutenberg's Bible) and mass–produced indulgences that were very profitably sold to sinners. However, printing presses became more efficient over the next 200–300 years; and as book prices declined, more and more commoners became literate, and individuals who wanted books could afford to buy more of them. Literate commoners began writing books themselves to record and pass on knowledge they had accumulated from practical experience with the real world (as opposed to the often metaphysical speculations of the priestly class). The increasing volume and utility of knowledge held in widely circulated books and libraries undoubtedly played a crucial role in fuelling the Protestant Reformation (Knox 1999)[53], the Scientific Revolution and the Industrial Revolution (Eisenstein 1979, 1983).

Given the means to record, reproduce and disseminate accumulated practical knowledge, people began to gather collections of published information relating to particular subjects. The concept of scholarly and scientific investigation and reporting known as the "Scientific Revolution" followed on from an increasing interest in observing and reporting on natural and realistic phenomena and the awareness of multiple connections between scientific explanations and reality (Fjällbrant 1997; Dewar 1998; Harkness 2007)

Robertson (1998: pp, 17-18) describes the origin of the Scientific Revolution as follows:

> Observation, experimentation, and the discovery of patterns are probably as old as mankind itself. Yet the use of these techniques increased enormously in the sixteenth and seventeenth centuries, so much so that a 'scientific revolution' is widely recognized to have occurred at that time. In other words, following the invention of printing we find, first, a massive increase in the production of information, and then an equally massive development and application of old techniques for refining that information. The scientific revolution of the sixteenth and seventeenth centuries can thus be seen as a necessary and even forced response to the large increase in the production [and distribution]of information that followed the invention of printing. The very quantity of newly produced information forced the development of techniques for dealing with large quantities of information. Those techniques are the processes that lie at the heart of modern scientific methods.

This is, of course, a description of how W3 knowledge began to grow. As will be discussed in more detail in Episode 1, in the 1660's the first scientific journals began to be published. Baten and van Zanden (2008) make a good case that the increasing volume of affordable books (and presumably knowledge contained within them) contributed significantly to the growth of human capital in the period prior to the Industrial Revolution. The rise of scientific, scholarly, and technical publishing and information systems helped disseminate the growing knowledge.

As printing became increasingly industrialized, the relative cost of books continued to decline until the mid–20th Century when the mass production process was fully industrialized, and literacy became almost a universal human birth right. Robertson (1998) calculates that with humans able to access libraries of recorded information that the information accessible to a single human brain increased by more than 6 orders of magnitude (or to 10^{17} bits) compared to the pre-printing era of writing. Also, with universal literacy, an ever–increasing proportion of the human heritage has been transmitted down and across the generations, completely extrinsically to the human genome and the lifetime of individual memories.

In the evolution of humanity's relationship to our environment, the development of science and technology and the systems to record and retrieve this kind of knowledge represents a huge grade shift in the relative importance of genetic heredity versus cultural heritage in terms of defining the niche humans, as a biological species, occupy in the world.

- *Invention of knowledge automation tools to manage knowledge externally to the human brain with the personal computer around 1980 and the World Wide Web around 1994.*

As explored in EPISODE 2 – Automating Cognition, sophisticated automation and calculating technologies were first developed in ancient Greece in the millennium before Christ to create "magical" religious and theatrical spectacles and apparently as high status intellectual toys. Because they had little economic value when most work was performed by slaves using simple tools, and because hand writing on perishable substrates provided a poor means for preserving and replicating technical knowledge – the knowledge of such wondrous devices was almost entirely lost until they began to reemerge as clockwork. However, the advent of printing provided the means to replicate, store and distribute practical knowledge at a relatively low cost that supported replication and resurrection of the surviving fragments of ancient technical knowledge. Automation was re-invented until its exponentially explosive growth and evolution began in the mid 20th century. Computerized word processing, networks and the Internet are enabled by the microelectronic revolution, and represent vastly important tools for capturing, replicating and distributing ever larger volumes of knowledge extraordinarily faster. Here, Robertson (1998) estimates that "computers" now allow individual humans to create and control

10^{25} bits of information - or 8 orders of magnitude more information than even cheap printing gave people access to (and this is still growing exponentially).

Because this technology to automate knowledge has changed so radically within single individuals' lifetimes, many people find it difficult to come to terms with the way this last revolution shifts the storage and exchange of knowledge from tangible paper to the intangible aspects of electronic information storage, management, retrieval, display and distribution. The exponentially growing rapidity of change seems revolutionary to many. However, while World 3 knowledge was still being captured and distributed in the form of "documents", I would argue that these changes were not conceptually revolutionary in the sense that they sparked a grade shift qualitatively different from that of the continuing Printing and Industrial Revolutions. From my point of view, true knowledge automation dates from the establishment of the Standard Generalized Markup Language (SGML) in 1986 (Goldfarb 1996). We are now in the midst of that grade shift where the nature of humanity is changing from one decade to the next. I will elaborate these themes below in Episode 3's Tools to Capture Knowledge and Information Science.

The Microelectronics Revolution in hardware has combined with knowledge automation to become the Internet Revolution (Zakon 2010). The result has given people access to more knowledge than individuals can comprehend using their native cognitive abilities. As described in Episode 3 - Tools to Capture Knowledge, an individual with access to the Web (e.g., Google Scholar) and login access to the electronic subscriptions of a major research library can in less than one second search a majority of humanity's published knowledge and retrieve relevant items from that global repository.

The real revolution, which is changing the nature of humanity more fundamentally than any of the previous revolutions and grade shifts, is the development of technology able to *manage* knowledge extrinsically to the human mind (Episode 3 - Tools to Store, Manage and Retrieve Preserved Knowledge[54]. However, before examining this latest revolution in detail, it will be helpful to consider in the Counter Subject the cognitive dimensions of data, information and knowledge in human affairs.

- *Convergence of human and technological cognition in the last 10 years*.

As cognitive technology becomes wearable to form an essentially permanent extension of the physical human body, as is the case now for many smartphone users, where the smartphone becomes an integral part of human cognition by interfacing the capabilities of the cloud with human sense organs (hearing, vision, touch). As explained in Episode 4, we are already well along the path towards interfacing the cognitive technologies directly with the human nervous system, bypassing biological sense organs with retinal and cochlear implants, and even direct brain implants.

COUNTER SUBJECT – Knowledge and its value

Defining Information and Knowledge is Contentious

Flame or holy wars are fought over more than just information and knowledge management ("KM") applications. At least until very recently[55], a sure fire way to start a holy war on a professional knowledge management forum was for a newbie to ask someone to define what it is that knowledge managers are supposed to manage. These KM flame wars reached their height in 2004 across several different forums, as documented in detail by Joseph Firestone in his blog, "All Life is Problem Solving"[56]. I tried to broker a resolution as explained on my own Web page under "Evolutionary Biology of Species and Organizations"[57]. Basically the war was a conflict between two epistemological paradigms (Hall 2003, 2005); (1) the older majority view in the KM discipline derived from Michael Polanyi's (1958, 1966) concept of knowledge as "justified true belief" and (2) the other more recent view developed by Joe Firestone and myself derived from Karl Popper's (1972) evolutionary definition that knowledge represents "solutions to problems of life" together with the idea that the growth and application of knowledge involved the interactions of three "worlds".

The Polanyian paradigm appears to have been introduced into the knowledge management world via the social sciences (where Polanyi's work is well known) either by direct reference or via two of the discipline's founding gurus, Karl Sveiby (1994, 1997) and Ikujiro Nonaka (1991; Nonaka and Takeuchi 1995). Sveiby (e.g., 2000) stressed the idea that the only knowledge that really mattered was personal. Thus, the majority of KM practitioners in this period categorized the contents of documents and the like as mere "information" that was outside the domain of knowledge management. From the point of view of defining what it is that knowledge managers are supposed to manage, the discipline is still very confused (e.g., Baskerville and Dulipovici 2006 review a number of definitions without even mentioning Popper or Polanyi).

The Popperian paradigm of evolutionary epistemology was introduced into KM by Firestone 2000, 2001; Firestone and McElroy (2003, 2003a), Blackman et al. (2004), Capurro (2001), Gaines (2003), Moss (2002) and myself (Hall 2003, 2003a). This approach accepted that objective knowledge as held in documents and books was also of major importance and that all claims to knowledge were fallible, no matter how thoroughly "validated".

The paradigmatic difference between Polanyi's theory of knowledge and Popper's goes much deeper than just the discipline of knowledge management. This is demonstrated by five separate searches performed across Google's entire repository over the period from 2002 to 2010[58]. These searches demonstrate that few authors seem able to cite both books in the same document. On the open Web, between 2002 and 2004 no more than 1.3% of hits on one of the works also cited the other (6.5% in 2010). In the formal literature (journals and books) covered by Google Scholar, in 2010 only 2.5% of the hits cited both works. Thus, although both Polanyi and Popper covered very similar ground in their epistemologies, one can only conclude that their world-views are so different that that it is very difficult to discuss or even refer to both epistemologies in the context of a single document (as I have found personally).

Although I do not know if differences over defining information have generated as much heat as those over "knowledge", "information" is at least as difficult to define (Floridi 2003, 2009; Capurro and Hjorland 2003). Floridi (2003) distinguishes three perspectives for defining information: "information as reality (e.g., as patterns of physical signals which are neither true nor false)", "information about reality" (qualified in Floridi 2007 as "well-formed, meaningful and veridical", where veridical refers to truth value or correspondence to reality), and "information for reality (instruction, like genetic information)". These do not exhaust the possibilities. Paradigmatic confusions also extend to defining information and the relationships between knowledge and information, as indicated by arguments about the meanings of and relationships between data, information and knowledge (e.g., Stenmark 2002; Wilson 2002; Miller 2002; Bates 2005; Land 2009).

The next section begins to address these issues of definition and relationships of data, information, knowledge and related terms. Here, I will present a particular epistemological framework as a paradigmatic theme for the purposes of this book, without attempting to differentiate this framework from many other paradigms (which would require another book in its own right). Then, after exploring the lay of the land and how individuals relate to and use information and knowledge, in the Interlude and Episode 5, I will take a much deeper look at the evolutionary relationships of information and knowledge in a social context.

Transforming Data, Information, and Knowledge into Power

Measuring the Quantity of Information

Information in the broad generic sense exists as identifiable objects in Popper's world 3 (Brookes 1980; Bawden 2007) or as elements of subjective knowledge in W2, and can be evaluated and qualified against at least two dimensions of cognitive value: *quantity* (i.e., how many elements of information exist in relationship to a particular question), and *epistemic quality* or *value*.

Quantity is easy to grasp, as Robertson (1998) demonstrated, because we can often measure and count the information objects we are dealing with. Lyman and Varian (2000, 2002a) added up the total volume of information recorded by humans each year as measured in bytes and described in some detail the methodologies used for making such measurements. For the record, in the year 1999, "The world's total yearly production of print, film, optical, and magnetic content would require roughly 1.5 exabytes (i.e., *billion gigabyte*s) of storage. This is the equivalent of 250 megabytes per person for each man, woman, and child on earth". In 2002 (Lyman and Varian 2003) the amount of *new* information recorded in the year had increased to around 5 exabytes. Unfortunately, more recent studies of the volume of information are not directly comparable to Lyman and Varian's work. However, Gantz et al. (2008) estimated that there were 281 exabytes of storage (or 45 gigabytes per capita) that would increase to 10 times this amount by 2011. For our purposes here the Bohn and Short (2009) study of information "consumption" is not comparable at all, given that the information content of broadcast media (e.g., radio, television, cable, DVD) is multiplied by the numbers of viewer hours. However, these studies all make the point that the volume of data in storage or use is something that can be measured or at least estimated to some degree of accuracy.

Qualitative Values of Different Kinds of Information

The dimension of epistemic quality presents many difficulties. Following Popper (1972), information that does a better job telling us more about what we want or need to know about the world for solving problems of life has a higher epistemic quality than does information that is relatively irrelevant or useful. For example, Lyman and Varian (2000) noted, "Printed material of all kinds makes up less than .003 percent of the total storage of information. This doesn't imply that print is insignificant. Quite the contrary: it simply means that *the written word is an extremely efficient way to convey information* [my italics]". As will become clear as the content of this book is developed, the closest sources to the approach I take here are from the discipline of information science, and especially Bawden's work (2007) that somewhat parallels mine.

I am not concerned to establish a subjective or monetary value for knowledge, as do most works on valuing knowledge, although the approach developed here should help determine these kinds of value. I value knowledge in terms of its *utility to control possible futures to address specific needs or problems*, where utility is defined as the quality of being of practical use (Hall & Kilpatrick 2011). The "*utility value of knowledge*" to its possessor equals the sum of its beneficial consequences minus the sum of its detrimental consequences from applying that knowledge. The principle of utility says whatever course of action (or potential solution to a problem) has the most utility—the best overall outcome—is the preferred (i.e., the most "valuable") choice. Cornejo (2003) gives two types of utility values for addressing personal needs:

- *Objective utility*: when the utility of a particular bit of knowledge can be directly compared with the utility benefits derived from other personal activities, e.g., when the knowledge objects help to improve the person's economic situation or job performance. Examples include methodologies, precedents, tools for professional growth, etc.
- *Subjective utility*: the knowledge isn't seen to have direct economic benefit, but is valuable because it satisfies personal curiosity or sustains a felt need for belonging or appreciation.

Similarly, Cornejo (2003) recognizes two kinds of utility values for organizations:

- *Direct utility*: leading to perceivable and measurable improvements to processes and operations, usually derived from personal knowledge.
- *Indirect utility*: when it is clear the organization benefits from acquired knowledge, but doesn't understand the mechanism so lacks a reliable measure for valuing it.

Therefore, in the case of the direct or indirect utility value of particular knowledge, value is some function of (a) the claim's applicability to particular circumstances and (b) its accuracy in terms of the degree to which it reflects the true state of existence when applied (i.e., the degree that rational actions based on the knowledge produce predictable results). Howard Pattee, a biophysicist concerned deeply with information in biological systems whose work has profoundly affected my thinking, clearly adopts a utility valuation of knowledge: "*Knowledge is potentially useful information about something*. ... By useful information or knowledge I mean information in the evolutionary sense of information for construction and control, measured or selected information, or *information ultimately necessary for survival*" [my emphasis] (Pattee 1995). See also (Pattee 1995a).

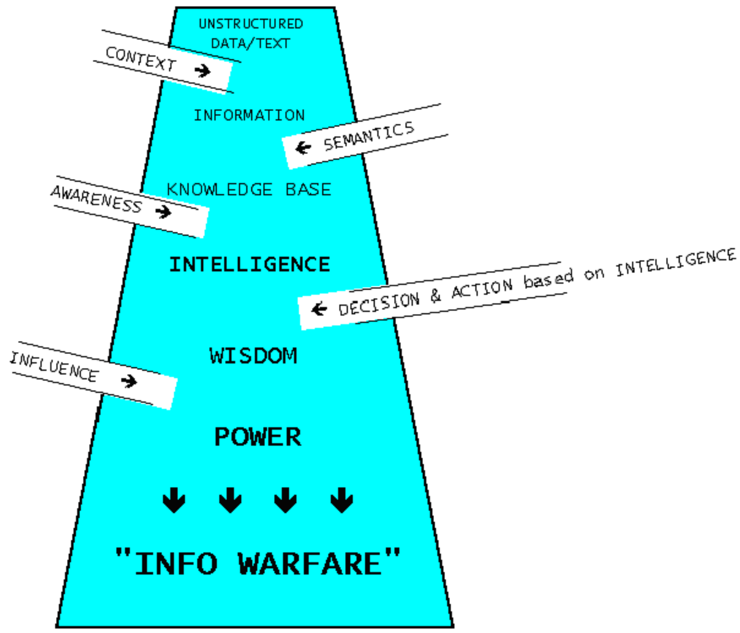


Figure 6. Ian Coombe's Information Definitions and Transformations. (Based on the diagram ©1995 by Ian Coombe, as published in The Australian Army Information Management Manual, Version 2).

Figure 6 ranks data, information, knowledge, intelligence, and wisdom along a qualitative axis. This and following discussion are based on concepts developed by Ian Coombe (1998) that is often known as the DIKW pyramid. My elaboration on Coombe's framework is based on Karl Popper's epistemology (Popper, 1959, 1963, 1972, 1976, 1982, 1994, 1999; Popper and Eccles 1977) as I first explored in Hall (1983), rather than Polanyi's epistemology (Jha 1998; Mullins 1997). I first encountered Coombe's approach to defining these terms in a framework he prepared for the Australian Army's Information Management Manual[59], which may have been sourced originally from Ackoff (1989). A number of people – especially in the information science and organizational knowledge management communities have also discussed the transformations of data to knowledge[60]. There are also some fascinating literary and musical uses of what is initially a commonsense ranking of the words[61]. Rowley (2007 – on the Web) gives a comprehensive review of the various uses of the DIKW relationships. Fricke (2009) reviews and criticizes Ackoff and Rowley's ideas, proposing that the DIKW pyramid should be abandoned because of issues over its representation of "truth", although he offers no replacement. However, given that there is no infallible guide as to what truth is (e.g., Popper 1972), I am happy to use and defend this qualitative value scale for different forms of knowledge.

Coombe's diagram also succinctly illustrates how elements of data are aggregated through a series of *cognitive transformations* into real power to influence events. As will become evident as I develop the argument, I do not imply here that "cognitive" processes are necessarily limited to human (or even organic) brains. *Any sufficiently complex cybernetic control system should be able to carry out the kinds of transformations discussed here*. In a Popperian sense, each level of aggregation and transformation increases the epistemic quality of the information by increasing the coherency, number and robustness of the connections between the information and the world of reality (i.e., as hypotheses are transformed into tested theory and demonstrate their power to influence external events)[62].

Although Michael Polanyi's (1952, 1967) concepts of personal and tacit knowledge are used by many in the organizational knowledge management discipline to establish a framework for judging the epistemic quality of information claimed to be knowledge (discussed in more detail in the Interlude), I personally still follow Popper's concept that personal beliefs must be connected to external reality via some form of testing the beliefs against that reality before they can be called knowledge. Contra Fricke (2009), following Popper's fallibilism, *there is no implication that data, information or knowledge in the strict senses of these words is necessarily true*. Popper (1986) also argues that knowledge and information exist prior to any test of their truth. A degree of correspondence to truth is established only when the information or knowledge is brought to test against external reality. As elaborated in the following text, Coombe's framework provides a useful structure for explaining in terms of epistemic quality how aggregation and testing add value to information to create knowledge, wisdom and power – without implying said knowledge and wisdom are necessarily exactly true.

Below, I have somewhat modified Coombe's expression of the hierarchy to better focus on cognitive issues I wish to treat in more detail in the remainder of this book.

- *Data is the atomic level of information*

The term data is used in a wide variety of contexts. Here, I use data in the sense that it is the atomic level of information, i.e., undifferentiated or disconnected sense data or text. Without structure or connections to other information, data or strings of text are essentially meaningless, either in logic or in a knowing subject. In other words, without structure and an application to parse and process the content according to some set of rules, the sequence of bits contained in a binary file is useless. Data may exist in the external world as records (W3), or in a nervous system as "sense-data" (W2) before being attributed with any meaning.

- Context and *syntax* transform data/text into information

When value (or meaning) is added to data by collecting, classifying and linking elements together into coherent sensory impressions, tables or structured records, the links and surrounding elements of data provide a context that help organisms like humans (in W2) or computers assign meaning to the data. Relational database applications provide technology to help collect, tabulate and link relatively low level kinds of data elements, and can automate cybernetic processes to extract information into useful outputs.

There are many other definitions of information (Jacob 2004), of which Bateson's (1973) "difference that makes a difference" is probably the most useful from a biological or cybernetic point of view.

- *Semantics* guides assimilation and transformation of information into knowledge

Operationally defined, knowledge is appropriate information that is known and available to the user when and where it is needed for a purpose (i.e., to solve a "problem").

Deeper concepts of knowledge and semantics depend crucially on their philosophical and psychological foundations, and consequently are contentious to define. What is considered to be knowledge and how it comes to exist falls within the philosophical domain of epistemology, as well as having objective foundations in biology, ethology and cognitive psychology.

> A piece [i.e., element] of knowledge is an object which we can use to produce (generate) predictions or other pieces of knowledge....

> True knowledge is an instrument of survival [i.e., 'true' knowledge works when applied in nature]. *Knowledge is power*. There is no criterion of truth other than the prediction power it gives. Since powers, like multidimensional vectors, are hard to compare, there is no universal and absolute criterion of truth. (Turchin 1991 – my italics).

New knowledge is built by assimilating and organizing data and information and relating this to experiences with external reality and to prior knowledge. In linguistics, semantics refers to the relatively mechanical processes and rules by which a brain or computer infers meaning from the vocabulary and grammar (syntax) of natural language (whether spoken or written - Akman 1997). In a metaphysical sense, semantics includes the rules and processes by which unevaluated information of any kind is given cognitive meaning (Block 1997). As developed in this work, my concept of knowledge is founded in the framework of *evolutionary epistemology*[63] based on Popper's evolutionary theory of knowledge - first named as such by Donald T. Campbell (1974, 1988 - who gives priority of the idea to Popper 1959). In this epistemology, knowledge is built semantically by making inferences and evaluating them against prior knowledge and external observations. Bad inferences don't mesh well with what is already known and observed, and are quickly discarded, successful inferences count as knowledge until shown to be false through conflicts with observed reality (Popper 1976a; Niiniluoto 2007). Reflecting back to the prior discussion of Kuhnian revolutions: a new inference may not mesh well with the existing body of knowledge, but if some of the existing items of "knowledge" are scrapped, the new inference may help what remains to gel into a larger and more robust network of semantic or logical connections than what is replaced.

People learn semantic processes along with language, professions and disciplines. Authors use the shared semantic processes to select, classify, evaluate and organize information into meaningful communications or documents. In this sense, because documents (W3) include semantic structure, other people can readily use knowledge recorded by one person (an author). Such semantically assimilated knowledge is substantially more valuable to humans than information in a raw database, which must be assimilated, organized and evaluated each time it is encountered anew.

In a sense, culturally transmitted semantic processes are major parts of disciplinary paradigms.

- Awareness and assessment transform knowledge into intelligence

Intelligence is used here in the military sense, where intelligence is the cognitive product resulting from actively collecting, processing, integrating, analyzing, evaluating and interpreting elements of existing knowledge. This is often presented in the form of informed predictions, or in scientific terms, specific hypotheses about the expected state or future of external reality. As such, intelligence represents a valuable extrapolation beyond unassociated elements of knowledge. Intelligence grows as more knowledge (i.e., prior connections with reality) is assimilated into the cognitive product.

- *Decision and action transform intelligence into wisdom*

Coombe says that wisdom represents the "application of intelligence through decisions... Intelligence is of no practical use unless applied by making a decision for action". Merriam–Webster's Collegiate Dictionary qualifies "wisdom" against its synonyms as follows:

> SENSE, COMMON SENSE, JUDGMENT, *WISDOM* mean ability to reach intelligent conclusions. SENSE implies a reliable ability to judge and decide with soundness, prudence, and intelligence <a choice showing good sense>. COMMON SENSE suggests an average degree of such ability without sophistication or special knowledge <common sense tells me it's wrong>. JUDGMENT implies sense tempered and refined by experience, training, and maturity <they relied on her judgment for guidance>. WISDOM implies sense and judgment far above average <a leader of rare wisdom>.

Following Coombe's structure (Figure 6), in a hierarchy of value terms based on epistemic quality, wisdom or strategy would represent intelligence (i.e., hypothetical prediction), which has been further informed through active testing against the world of reality and thus transformed into theory (again using the scientific meaning of the term).

- *Influence* transforms wisdom into power

The term power has many different meanings. In competition, evolution or conflict, power is the ability of an entity (individual or organization) to affect or control unfolding events to its own ends. In the broad sense, this can be defined as "*strategic power*"[64]. Power in such circumstances is purely relative. One entity's abilities to control events are measured against another's abilities to see who wins the day.

Strategic power as defined here has three major sources developed through the epistemic transformation processes discussed above:

- *epistemic power* - the wisdom ("know that") and know how to apply power effectively[65],
- *will power* - the decision or will to apply power,
- *logistic power* - available resources enabling the application of power.

Here, I wish to focus on the importance and sources of epistemic power. Epistemic power can be considered to be the result of knowing how to apply knowledge that has high epistemic value, where epistemic value is considered to be some kind of measure of the truth content of the knowledge (Fallis and Whitcomb 2009), and truth is considered to be correspondence with reality[66].

Adaptation is a cybernetic process (Beer 1981) by which an entity (that may be individual or a collection of entities sharing a common heredity) changes or evolves through time in response to external pressures and to improve or maintain its survival. Where the cybernetic process of adaptation is intrinsic to the entity (adaptation may involve internal changes to the cybernetic process itself), the entity can be termed a "complex adaptive system". As will be discussed in more detail in Episode 4, individual organisms, biological species, social organizations (commercial and military) and even whole nation states are complex adaptive systems relevant to this discussion. If the process of adaptation is successful, the system or entity will achieve and maintain enough power to survive in an environment of change, competition or conflict. Where adaptation fails, the entity diminishes, dies, disintegrates or is consumed by other entities.

In biological species over evolutionary time, the species' "success" is its continued survival in a competitive environment; where evolutionary adaptation is a product of the species' heritage as it changes from one generation to the next. Jablonka and Lamb (2005, 2007) also stress the importance of epigenetic and cultural transmission of adaptive knowledge from one generation to the next. In other words, through successful adaptation an evolving entity gains or maintains epistemic power. Such adaptations represent a form of knowledge about the external environment (Campbell 1960, 1996; Popper 1986, Plotkin 1994). Non-humans adapt during their life-times as individual organisms by learning or physiological change. The human species, in addition to adapting and learning on an individual basis, can also culturally transmit knowledge to other individuals via language and W3 productions to assist their adaptations. Individual humans can also consciously alter their cognitive processes to better adapt to external change, and in turn can also transmit these cognitive adaptations culturally (as I hope I am doing in this book). As will be seen in Episode 5, "Cultural" adaptation also applies to collective human entities that transcend the individual level of organization, such as businesses, military bodies and nations.

Adaptation, Knowledge and Strategic Power in Popper's Three Worlds

Figure 7 illustrates my understanding of the relationships between Popper's three worlds and how adaptation and evolution through natural selection relate to or determine the nature and contents of these domains. Some of the ideas relating to this picture will be introduced here, but they will be substantially elaborated in the Interlude.[67]

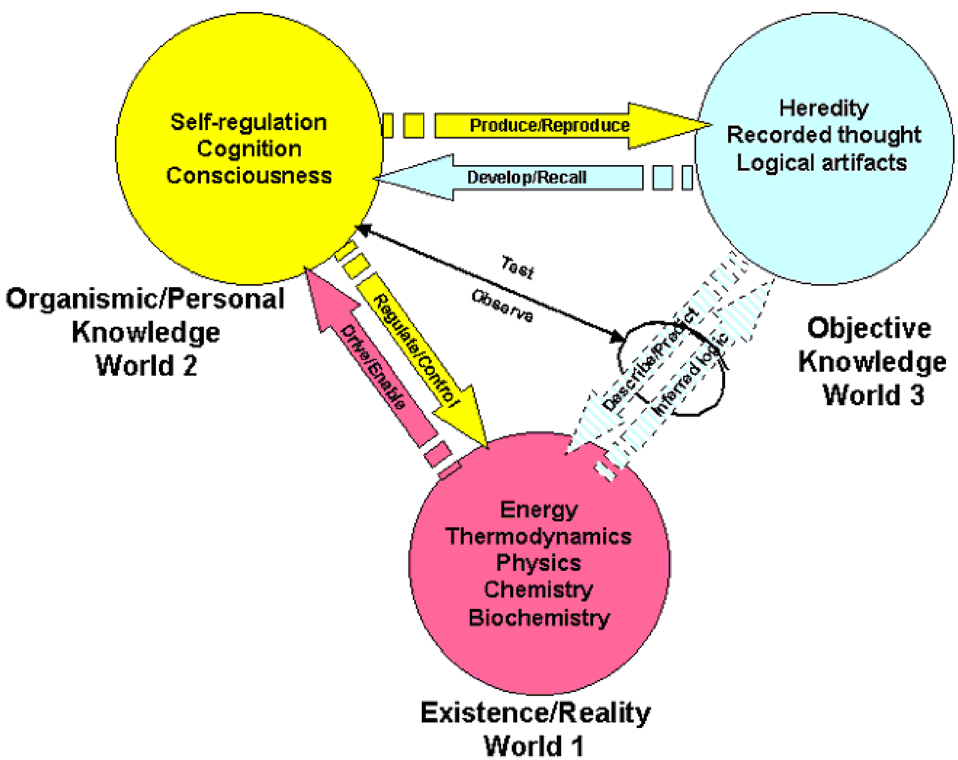


Figure 7. Karl Popper's (1972; 1978, 1994) three worlds of knowledge. World 2 is an emergent property based in World 1. World 3 is an emergent property based in World 2

W1 is physical reality. Our existence as organisms is based W1 and is enabled and constrained by its physical laws. The phenomenon of life is fuelled and maintained by the metabolic flux of energy through our organic systems working in accordance with the laws of physics, chemistry, thermodynamics and cybernetics (Morowitz 1968).

To survive, organisms must self-regulate and control their internal fluxes of metabolic energy. Physiological adaptation within individual organisms is the result of this kind of self-regulation. If the bounds where self-regulation is possible the organism dies. Consciousness is a particularly sophisticated component of the self-regulatory apparatus, and most likely it evolved to facilitate control over the physical world to better protect and regulate internal metabolism through the ability to acquire and control external resources. At the individual level, the ultimate control over external resources is represented by strategic power, which is achieved through epistemic power.

Life as we know it also depends on the existence of system(s) of heredity that controls development and adaptive capacity of the organism - i.e., an individual's physical phenotype and cognitive abilities are at least partially determined by genetic and epigenetic information it inherits from its parent(s). Culturally transmitted memes[68] acquired from its culture help to determine how and to what the phenotypic and cognitive abilities can be applied to. Evolutionary plasticity of living things is determined by how the genetic, epigenetic and cultural heredity is replicated, mutated (to a tiny degree in any one generation), recombined and passed on by at least some individuals of one generation to guide formation of the next generation.

In biological species this hereditary information is shaped and changed over many generations of time through the processes of natural selection resulting from the differential survival and reproduction of individual phenotypes (both genetic and cultural) that are to some degree determined by inherited information. In other words, natural selection leads to heritable adaptations at the population and species level by selectively removing carriers of hereditary information that does not work particularly well in the environment occupied by the species or group. What is left (e.g., as encoded in DNA genomes or cultural memes) is tested experience (i.e., knowledge) about what worked for individuals of the species that survived and passed on their hereditary information. The heritable knowledge passed down the generations has an existence that transcends the lives of any particular individuals carrying that heredity at a particular point in time. It is this transcendent knowledge about what organisms needed to survive and reproduce in World 1 that formed the original basis for W3. In Popper's concept:

The three worlds are so related that the first two can interact and that the last two can interact. Thus the second world, the world of subjective or personal [i.e., biological] *experiences, interacts with each of the other two worlds. The first world and the third world cannot interact, save through the intervention of the second world, the world of subjective or personal experience.... [T]hat is, with the second world as the mediator between the first and third.* (Popper 1972: p 155; see also Popper 1978)

In Figure 7, the solid arrows show the direct interactions, and dotted arrows, those relationships mediated by actions between worlds 1 and 3 that are formulated in and observed from the second world. W1 is the physical world and includes all physical structures and processes, worlds 2 and 3 ultimately are also evolved products of World 1. To further explain what the arrows signify:

- *World 1* ***drives/enables*** *World 2 processes/activities*:

W1 is the source from which W2 emerges. W1 provides the biochemical substrate, sources and sinks for energy fluxes, and the governing laws that determine (i.e., permit and cause) the formation of self-regulatory cybernetic systems built using W1 apparatus. That is, the physical structure and fluxes maintaining the body of the biological organism itself and driving the evolutionary processes are also W1 phenomena (the underlying reasoning behind these assertions will be further developed in Episode 4, but see Morowitz 1968). W2 in the broad sense is the collection of emergent, evolved *dynamic organic/cybernetic processes* that are fed and housed within W1 matrices.

- *World 2 processes/activities* ***regulate/control*** *World 1 energy fluxes/transformations*:

W2 is an emergent domain of W1 comprised of the cybernetic logic (i.e., "control information" – Corning 2001) that is responsible for the self regulation and self maintenance of dynamic organic processes. Initially this logic would have consisted of comparatively simple regulatory feedback loops. However, as organic life evolved greater complexity and regulatory capabilities through genetic natural selection, increasingly powerful functions emerged that were associated with regulation such as memory and consciousness of self – to the extent that humanity is now consciously aware of and regulates or controls (or at least impacts through conscious actions) a substantial fraction of the Earth's organic activities.

- *World 2 processes/activities* ***reproduce/produce*** *World 3 knowledge*
- ***Development*** *of World 2 processes/activities is guided by knowledge* ***recalled*** *from World 3*

The processes involved in the reproduction of complex organisms or cognitive entities are themselves quite complex. The fertilized seed or egg bears no obvious relationship to the parent organism(s) that produce it. However, the seed or egg contains in embodied and encoded form within its W1 structure essentially all of the hereditary knowledge required to control, regulate, develop and grow another self-regulating and self-maintaining adult organism. Even during the lifetime of one organism, the atoms comprising the DNA molecules encoding the heredity are progressively diluted, discarded and replaced many times over as the cells carrying the heredity multiply from a single celled zygote to produce the adult organism, yet the hereditary knowledge remains intact as it is replicated hundreds or thousands of times across many billions of cells forming the adult organism; and furthermore, the heredity is passed on essentially intact (according to the genetic rules of mutation, recombination and assortment) to zygotes that will selectively[69] survive to form subsequent generations.

The hereditary knowledge is real, yet completely intangible in that it can exist independently of the molecular substrate that normally encodes it. Hereditary knowledge is capable of being encoded or expressed in a variety of physical forms, e.g., sequences of nucleotides in DNA or RNA, amino acids in proteins, or even sequences of letters in a printed publication or electrons transmitted over a wire (e.g., see the human genome project). With appropriate tools it is even possible to translate the sequence of printed letters in the publication or coded sequences of electrons back into meaningful DNA (e.g., see Genomes to Life or the current version of this page). As detailed in the Interlude, embodied knowledge in a feedback loop that helped pieces of a proto-organism maintain its self productive and self maintenance capabilities when the parent body was fragmented by external forces, has evolved to become a world of persistent genetic knowledge that can exist independently of the structures that encode it.

In this framework, W1 consists of atoms, molecules, and motion in the fabric of space; W2 consists of self-regulating and self-maintaining dynamic processes in W1; while W3 consists of real, persistently encoded knowledge that self-maintaining organisms require in order to maintain their dynamic structure. W2 organisms require access to this accumulated W3 knowledge in order to maintain their existences in W1.

- *inferred logic*
- *describe/predict*

As defined by Popper, W3 is *virtual* and *transcendent* in sense that the same knowledge content can be transformed and persist in W3 indefinitely as a sequence of nucleotides, electronic bits in a silicon chip, plus and minus voltages along a wire, patterns of carbon patterns on paper, etc. The knowledge contained in the code is something completely different from the electrons, atoms, and molecules that carry the code. However, there are inferred logical connections between the knowledge carried by World 3 artifacts and physical objects and processes in World 1. For example, most of the elements of genetic knowledge carried in the genomes of living species at any point in time have been selected to work together harmoniously to form W1 phenotypes based on knowledge that has worked successfully in the past. Thus, genetic knowledge has a clear (stochastic) causal derivation from W1, and the *inferred logic* represented by the extant genetic knowledge that has survived selection describes developmental processes that past experience *predicts* will again work successfully in the future.

Popper argued that the W3 artifacts produced by conscious individuals to describe World 1 phenomena via their W2 processes thus have an *inferred* connection to W1 because they can *describe* and make logical *predictions* about W1 phenomena. This knowledge may be true, false or incomplete. It is often only tentative. As is the case for genetic information, W3 artifacts created by humans can represent knowledge about W1 that exists independently from any knowing individual. However, knowledge can be recalled and translated from W3 into W2 cognitive systems for conscious use or testing; where the logic of the knowledge can be evaluated and further filtered by predicting and observing W1 phenomena to determine whether the knowledge artifact is pragmatically useful. Conscious processes in W2 can selectively remove artifacts that are false and useless from W3 in much the same way that natural selection works on genetically transmitted knowledge, such that W3 knowledge may be used to facilitate individual, cultural and species adaptation. Thus all of the inferred connections between W3 and W1 can only be *tested* and *observed* via actions mediated by W2 cognitive processes.

The next section continues developing ideas gleaned from the pragmatic world of military affairs, to present a generic adaptive process to show how any complex cybernetic system or "entity" can transform data into epistemic power.

The Cybernetics of Power: Boyd's OODA Loop Concept

Col. John Boyd was a US fighter pilot in the Korean War and became one of the 20th Century's greatest strategic thinkers (Spinney 1997a; Hammond ????; Coram 2000; Osinga 2005; Safranski 2008). Boyd's thoughts on the subject of developing winning military strategies (i.e., strategic power) have strongly influenced the defense community's development of doctrines. Without using this term, Boyd focused on how to achieve epistemic power. Boyd's conception of the cybernetic process of adaptation is summarized under the term "OODA loop"[70], where OODA is the acronym for an iterative feedback loop involving **O**bservation, **O**rientation, **D**ecision, and **A**ction. One cycle produces an action. Iteration and associated feedback from experience, which changes the information content of the orientation process (i.e., learning) result in adaptation. An entity achieves power over an enemy by adapting faster and more effectively than the enemy to control events to its benefit and the opponents' detriments (i.e., the entity "*acts inside the opponent's OODA loop*"). I discuss Boyd's concept and further thinking on the subject in some depth, as this brings together several threads in my argument (see also Hall et al. 2011). Figure 8 summarizes Boyd's concept of the flow and processing of information in an adaptive response.

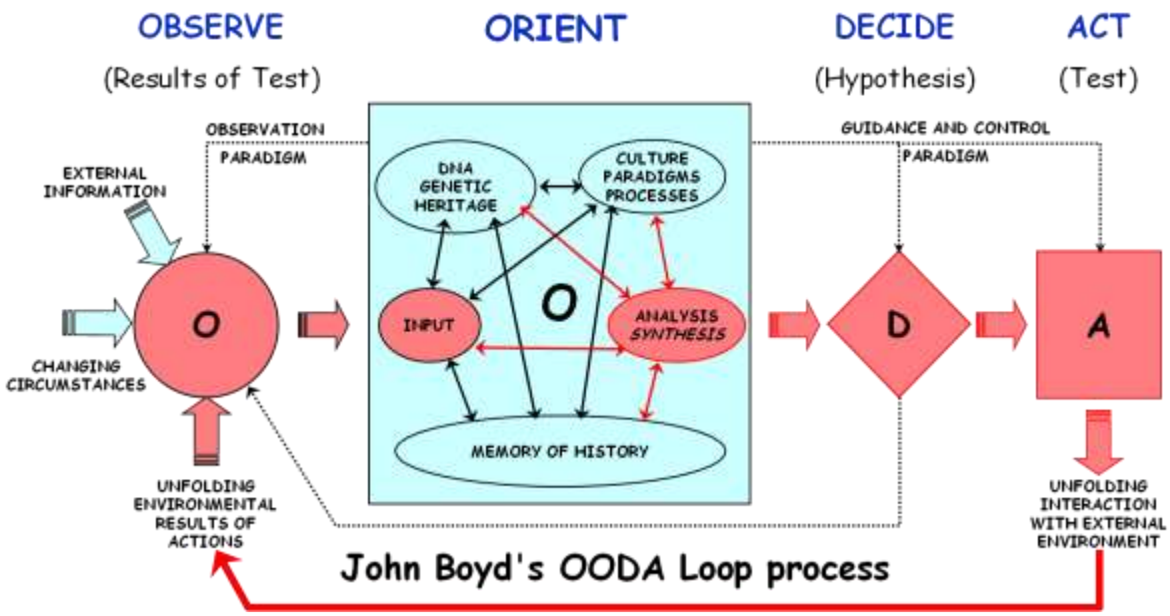


Figure 8. John Boyd's OODA Loop.

The OODA Loop is comprised of the following major elements that any kind of entity could use to seek epistemic power in a competitive environment. For example, the cybernetics of a biological species' adaptation by natural selection is also mapped by the OODA loop, as will be discussed in the Interlude. The discussion here focuses on adaptation by individual entities with cognitive and learning capabilities. Such entities can be individual people or organizations, as will also be elaborated in the Interlude. The OODA Loop cycle bears many similarities to Popper's "general theory of evolution" (Figure 4).

- ***O**bserve (collect data and assemble information)*

Observation covers all aspects of collecting data and assembling information on the current state of the entity's external environment. This includes observing the effects of entity's own prior actions on external circumstances in the unfolding reality, effects of competitor's actions and other changes, as well as taking cognizance of other external sources of information. Quality and quantity of input information contributes significantly to determining the effectiveness of the actions. To achieve epistemic power the entity should both work to improve the quality and quantity of its own inputs, and act where possible to confuse or disrupt its competitors' inputs – thus diminishing the opponents' powers.

- ***O**rient*

In Boyd's OODA schema (Boyd 1996), "orientation" covers the adaptive semantic/cybernetic processes of building and maintaining knowledge (what Popper calls 'knowledge growth') about the continuously changing world. According to Spinney (1997), a close associate of Boyd's, orientation is the adaptive process by which an entity continually breaks down, evolves and shapes its interior mental paradigms (used in the Kuhnian sense), to better enable the entity to respond to and shape external conditions. This is process of taking observations from W1, combining them with knowledge from W3 and individual memory to build and criticize models or representations of reality in W2, and perhaps producing further knowledge artifacts in W3. The criticism that shapes the knowledge is carried out by cognitive processes in W2. Popper describes the process of knowledge growth through criticism or conjecture and refutation as follows:

> ...[T]he growth of our knowledge is the result of a process closely resembling what Darwin called 'natural selection'; that is, the natural selection of hypotheses; our knowledge consists, at every moment, of those hypotheses which have shown their (comparative) fitness by surviving so far in their struggle for existence; a competitive struggle which eliminates those hypotheses which are unfit.
>
> This interpretation may be applied to animal knowledge, pre-scientific knowledge, and to scientific knowledge. What is peculiar to scientific knowledge is this: that the struggle for existence [of hypotheses] is made harder by the conscious and systematic criticism of our theories. Thus, *while animal knowledge and pre-scientific knowledge grow mainly through the elimination of those [individuals] holding the unfit hypotheses, scientific criticism often makes our theories perish in our stead, eliminating our mistaken beliefs*. [My emphasis]
>
> This statement of the situation is meant to describe how knowledge really grows. It is not meant metaphorically, though of course it makes use of metaphors. (Popper 1972: p. 261).

Boyd argues that this adaptive process of knowledge growth is best achieved by iterated sub–processes within the orientation stage. First, *destructively* disassemble existing paradigms into their component elements of information and syntactical connections. This effectively destroys preconceptions. Second, 'inductively' reassemble the components to *create* new and more coherent paradigms. Third, determine by deductive testing how well the newly created paradigms match current observations and prior knowledge of the world. Iterate the destruction/creation process until the paradigms "demonstrate internal consistency and match–up with reality". Boyd noted this orientation process is enabled, shaped and informed by the entity's prior experience and its genetic and cultural heritage. As such, the destruction/creation process itself can be altered through feedback into World 3 via individual and culturally transmitted experience (i.e., training) to better adapt it to changing requirements. Grant (2005) and Grant & Kooter (2004) specifically add concepts of sense-making and planning to the orientation process.

In Coombe's terms, orientation represents the processes by which entities achieve knowledge and intelligence.

- **D**ecide

The process of deciding to take an action is basically one of selecting a hypothesis created within the constraints of the current best–fit paradigm: i.e., if I do A then B is the expected result.

- **A**ct

Act on the best–fit hypothesis. Observing the results of the action tests the epistemic value of the decision hypothesis, and these observations should immediately be fed back into the orientation process for the next cycle to help refine or destroy the current paradigms.

Boyd's development of the OODA Loop concept was apparently informed by Kuhn's Structure of Scientific Revolutions and Popper's earlier works (Osinga 2005), but he appeared to be unaware of Popper's later work as published in Objective Knowledge.[71] However, Boyd's concept, focused on the real world requirements to win battles, is close if not identical to Popper's evolutionary theory of knowledge growth as extended by the evolutionary epistemologists.

Heuer's (1999) book, Psychology of Intelligence Analysis (published by the US CIA), considers in great depth the mental processes that should be involved in this destruction/creation cycle in the framework of defense intelligence analysis. Although Heuer does not cite Popper or Boyd directly, and Kuhn only once, the recommended methodology for developing intelligence estimates is very much that described above:

> Scientific method is based on the principle of rejecting hypotheses, while tentatively accepting only those hypotheses that cannot be refuted. Intuitive analysis, by comparison, generally concentrates on confirming a hypothesis and commonly accords more weight to evidence supporting a hypothesis than to evidence that weakens it. Ideally, the reverse would be true. While analysts usually cannot apply the statistical procedures of scientific methodology to test their hypotheses, they can and should adopt the conceptual strategy of seeking to refute rather than confirm hypotheses. ...
>
> Apart from the psychological pitfalls involved in seeking confirmatory evidence, an important logical point also needs to be considered. The logical reasoning underlying the scientific method of rejecting hypotheses is that "...no confirming instance of a law is a verifying instance, but that any disconfirming instance is a falsifying instance." [Wason 1960] In other words, a hypothesis can never be proved by the enumeration of even a large body of evidence consistent with that hypothesis, because the same body of evidence may also be consistent with other hypotheses. A hypothesis may be disproved, however, by citing a single item of evidence that is incompatible with it. (Heuer 1999: pp. 46-47)
>
> …
>
> Analytical conclusions should always be regarded as tentative. The situation may change, or it may remain unchanged while you receive new information that alters your appraisal. It is always helpful to specify in advance things one should look for or be alert to [what], if observed, would suggest a significant change in the probabilities. This is useful for intelligence consumers who are following the situation on a continuing basis. Specifying in advance what would cause you to change your mind will also make it more difficult for you to rationalize such developments, if they occur, as not really requiring any modification of your judgment. (Heuer 1999: pp. 107-108)

In conflicts and competitions involving humans; knowledge, culture and experience further inform the destructive/creative orientation process. As a fighter pilot in the Korean War, Boyd observed that the only slightly more responsive F86 fighter could achieve an 11/1 kill ratio against the technically better and faster MIG–15 and spent many years of study trying to understand how this could be. He eventually developed the OODA cycle concept and concluded that those entities (i.e., fighter pilots) with the shortest knowledge building cycle times would have the better and more accurate understanding of rapidly changing external circumstances. Because of this they could act first to alter the unfolding environment to their own advantage and disadvantage to their opponents.

Boyd stated that the ultimate objective of using a superior tempo driven system was to break down the enemy. To do this one must "exploit operations and weapons that: generate a rapidly changing environment … and inhibit an adversary's capacity to adapt to such an environment." Utilizing those actions paralyzes the adversary's mechanism for dealing with his foe's increased tempo. The goal of the process can be easily stated: "simultaneously compress own time and stretch–out adversary time to generate a favorable mismatch in time/ability to shape and adapt to change." (Cowan 2000)[72].

Extended into the broader realm of overall military strategy, the best strategy for an entity to achieve power would often be to attack and confuse the opponents' observation and orientation activities.

The Revolution in Military Affairs

Boyd's work leads naturally into my last major excursion into the worlds of knowledge seen from a military point of view – to combine threads on cognitive revolutions and information value. Strategic policies and doctrines around the world are currently in a major state of flux as strategists attempt to incorporate the fruits of the Microelectronics and Knowledge Management Revolutions, together with Boyd's insights about the cybernetics of complex adaptive systems as represented by competing fighter pilots, organizations and states. Staff colleges around the world call this the "Revolution in Military Affairs"[73], or more commonly "RMA". Metz and Kievit (1995) provide excellent background on the concept of a military revolution:

> ...As could be expected with a dramatically new idea, analysts of the RMA have not fully agreed on its meaning. Futurists Alvin and Heidi Toffler, for instance, use a restrictive definition based on macro–level economic structure. They write:
>
> > A military revolution, in the fullest sense, occurs only when a new civilization arises to challenge the old, when an entire society transforms itself, forcing its armed services to change at every level simultaneously–from technology and culture to organization, strategy, tactics, training, doctrine, and logistics. When this happens, the relationship of the military to the economy and society is transformed and the military balance of power on earth is shattered.[74]
>
> From this grand perspective, there have been only two true military revolutions, the first associated with the rise of organized, agricultural society, and the second with the industrial revolution....
>
> Most analysts addressing the RMA, though, have adopted less inclusive and restrictive definitions stressing a "discontinuous increase in military capability and effectiveness."[75]
>
> According to Andrew Krepinevich, a military revolution:
>
> > ...occurs when the application of new technologies into a significant number of military systems combines with innovative operational concepts and organizational adaptation in a way that fundamentally alters the character and conduct of conflict. It does so by producing a dramatic increase–often an order of magnitude or greater–in the combat potential and military effectiveness of armed forces.[76]
>
> Analysts have concluded that a revolution in military affairs dramatically increases combat effectiveness by four types of simultaneous and mutually supportive change: technological change; systems development; operational innovation; and, organizational adaptation.[77]

Personally, I believe the current RMA is clearly going to be of Tofflerian proportions rather than the kind envisaged by Krepinevich. However, I fully agree with Krepinevich's list of drivers for change. All of these are aspects of the Microelectronics Revolution and the associated cognitive revolution in managing information and assembling knowledge. As the OODA concept discussed above demonstrates, information and knowledge, combined with speed of response, are absolutely critical factors in the cybernetics of power.

The following quote from Metz (2000) expresses the concept:

> One of the most important determinants of success for 21st century militaries will be the extent to which they are faster than their opponents. Tactical and operational speed comes from information technology–the "digitized" force–and appropriate doctrine and training [what I have termed epistemic power]. Strategic speed [i.e., logistic power] will be equally important as a determinant of success in future armed conflict. For nations that undertake long–range power projection, strategic speed includes mobility into and within a theater of military operations. Strategic speed also entails faster decision making.
>
> Speed also has an even broader, "meta–strategic" meaning. *The militaries which meet with the greatest success in future armed conflict will be those which can undertake rapid organizational and conceptual adaptation. Successful state militaries must institutionalize procedures for what might be called "strategic entrepreneurship"–the ability to rapidly identify and understand significant changes in the strategic environment and form appropriate organizations and concepts*. [My emphasis]
>
> The "'digitised' force", faster decision making, and "organizational and conceptual adaptation" are all cognitive processes in the cybernetics of developing epistemic power (Metz 2000).

In sum, entities whose OODA decision cycles generate informed actions in less time than their adversaries can increase their strategic and competitive power at the expense of those whose cycles take longer. In an instant of evolutionary time (i.e., in less than a generation), the development of cognitive technologies based on the incredibly shrinking transistor as expressed in Moore's Law have the power to profoundly affect all aspects of organizational decision–making cycles. *Cognitive processes that until now were exclusively limited to human brains are being externalized. People, organizations and nation states that do not take cognizance of the impact of new technologies on the decision–making cycle will be overwhelmed by those who do.*

Evolutionary vs. Revolutionary Adaptation

This section brings the threads of evolution and revolution together with those of the epistemology and cybernetics of strategic power in competition.

Entities in an externally changing environment of competition must continually adapt in order to survive the competition. As is well known to both evolutionary biologists and strategic analysts, adaptation in complex entities like biological species and human organizations is not necessarily a smooth process. Complex systems often behave non–linearly, where a small external change may produce a large and effectively unpredictable response (Beckerman 1999; Czerwinski 1998; Kirschbaum 2002). Complex systems often have unpredictable properties that emerge when a certain level of complexity is reached. An example of the complexity that can emerge even from a non-dynamic World 3 algorithm is illustrated by the Mandelbrot set (Alfeld 1998).

Mathematical analysis and simulation of adaptation in such systems shows that under some regimes of small changes to an external variable, the corresponding adaptive response can be predicted in direct proportion to the external variable. However, as shown in Figure 9, as the rate or extent of change in the external variable increases, a zone is reached where the simulation may predict two possible responses to the external variable. A further small change in the external variable may move the adaptive regime into a zone where there are four possible stable responses; and then eight... to the point where there is chaotic diversity of radically different responses to infinitesimal changes in the external variable. Such non–linear behavior is a well known property of complex adaptive systems and is studied under the heading of chaos theory.

A wide range of reasonably stable adaptive responses may be easily evolved by switching from one region of stability to another closely adjacent one in the region between the second bifurcation and the onset of complete chaos. In the linear (monostable) or bistable region, adaptation is relatively strongly constrained to the path already being followed. In the chaotic region, there can be no consistent relationship between adaptation and the external variable.[78] Issues of complexity and chaos are discussed much more extensively in the Interlude.

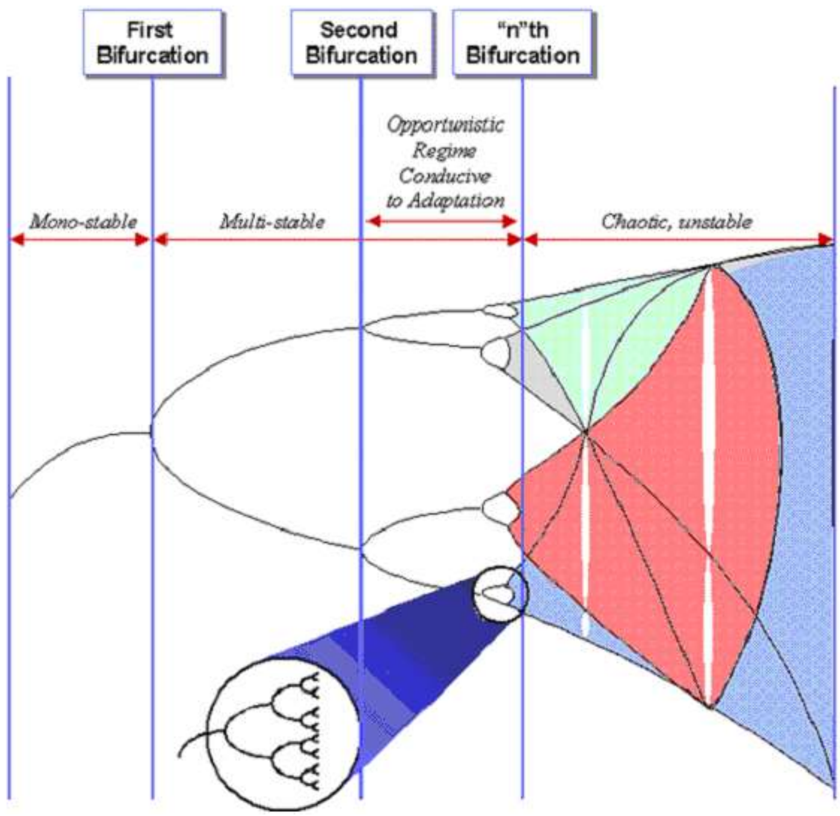


Figure 9. An idealized picture of the development of chaos in a non–linear system (Beckerman, 1999).

The point here is that there are fundamental reasons to expect adaptive processes responding to external change to show periods of reasonable stability punctuated by periods of rapid and chaotic change. In the field of evolutionary biology, the fossil record for many lineages exhibits many examples of stability or gradual change, interspersed with periods of very rapid change known as "punctuated equilibria."[79]. Lineages showing short periods of rapid change may have undergone grade shifts. Where human affairs are concerned, Kuhn (1962) argued that the growth of scientific knowledge in a discipline might exhibit long periods of stability and slow evolutionary growth with occasional chaotic revolutions, where many individual scientists could only accept the changes via irrational mental processes akin to religious reformation. This process could be another manifestation of chaotic change comparable to the punctuated equilibria of evolution.

Boyd (1976), and in his many unpublished presentations) recognized the value of working on the edge of chaos. By minimizing the time required to observe, orient, decide and act; pilots and organizations can maintain their own adaptive responses in a region of control on the edge of chaos, while setting a pace that pushes entities whose OODA feedback processes take longer into an uncontrollable chaos. Fadok (1994) calls this a state of "'strategic paralysis".

> [T]he key to winning in conflict lies in establishing a relative advantage over one's enemy in terms of both OODA loop speed and accuracy. Ultimately, this edge allows one to penetrate the opponent's 'moral–mental–physical being' to negate his capability and will to resist through moral alienation, mental disorientation [cognitive chaos], and physical deprivation [my emphasis].
>
> Boyd's theory of maneuvering inside the enemy's mental process, as depicted by the OODA loop model, is ... philosophical, abstract, nonlinear. He recognizes the uncertainty of war and the subsequent need for mental agility and creativity — in short, genius [or 'wisdom' in Coombe's terms]. He believes genius can be taught and sets out to do just that for his audience by means of the mental process of "destruction and creation." He preaches familiarity with many different theories, doctrines, and models so that, through the genius of "destruction and creation," the military strategist can build from the gems in each of them a plan of attack most appropriate to the situation at hand. Furthermore, through extensive training and practice, the strategist will be able to do so at a faster tempo than his adversary so as to fold [the adversary] back inside himself [i.e., force the adversary into a region of chaos] and ultimately defeat his will to resist. (Fadok 1994)

Tools and Applications that Extend Humanity's Cognitive Abilities

We, who today have virtually free and unfettered access to the entire repository of human knowledge at our fingertips through Web search engines and major research libraries, can only try to comprehend what it was like to be a "knowledge worker" in the primary oral or scribal cultures before printing revolutionized the recording of knowledge. And, before the concepts of counting and writing revolutionized the nature of humanity, we only have a glimmering of ideas how our remote ancestors thought and interacted to manage their survival knowledge (Ong 1982; Kelly 2012).

As noted above, humanity is currently in the midst of major revolutions in knowledge management technology enabled by the microelectronics revolution. In competitive environments in business or war where the management of knowledge by individuals or organizations plays any role at all, the strategic advantage will go to those who generate epistemic power more effectively and faster than their opponents and competitors, as is thoroughly elaborated in the US Air Force's 2025 study[80]. The following section, Episode 1, starts to show how the use of books and printing technology producing persistent knowledge in W3 contributed to evolutionary and revolutionary improvements in cognition that contribute to OODA loop speed and accuracy.

In the remainder of the work, I will describe how the evolution of various information capture, processing, delivery and retrieval tools has extended human cognition, and explore how these technologies are presently causing truly revolutionary changes in human relationships to each other and to our environment. Through history until the last few years, knowledge has only ever been generated in the minds of individual people. Knowledge gained by one person could then be transferred to other people via cultural transmission: first by observation (copycat), then via an increasingly powerful use of W3, with semantically structured language, by writing of pictures, words and mathematics; then print publishing; and most recently by electronic publishing and retrieval (Vines and Hall 2011). Cognitive revolutions have been associated with each major shift in the mode of transmitting knowledge.

Metaphorically, speech is one–dimensional and ephemeral. Writing on paper added a second dimension (i.e., columns, tables, drawings, etc.) and persistence over time. Printing and publishing provided a third dimension enabling the replication of documents across a wide geographic space and through time (Eisenstein 1983). The instantaneous publishing and retrieval of information electronically is now providing additional dimensions of awareness and intelligence - allowing individuals to retrieve knowledge from wherever it exists.

Current advances in tools for authoring, managing, retrieving and distributing documents are sparking a cognitive revolution likely to dwarf all preceding ones. Cognition itself is being moved into tools able to work directly with W3 knowledge. The overall cognitive revolution is being driven by several tool–based revolutions. Referring back to the earlier discussion on the cognitive value of information, some tools add value in quantitative dimensions (i.e., by making it easier to capture information), while others help to increase the epistemic quality of the information through processing and retrieval along the data–power axis.

EPISODE 1 – Memory, Counting, Writing, Books, and Printing

Memory

Before people developed technologies for counting, reckoning and writing, human knowledge existed only in W2 and could only be shared via speech and imitation (Ong 1982; Kelly 2012). Ong observes that speech is ephemeral, instantly disappearing as it is uttered. The only impressions speech leaves on the world are in the variously altered mental states of those who heard it.

As will be discussed in Episode 5, Kelly (2012) explains how primary oral (i.e., pre-literate) cultures could store and share large volumes of essential survival knowledge using mnemonic indexing against ritually constructed mental maps (i.e., following the method of loci). Hunter gatherers (e.g., Australian Aborigines) use prominent landscape features accessed or remembered in sequence (i.e., as "songlines") as memorable locations for indexing their knowledge. She then argues that as cultures adapted to a sedentary life, they constructed sequences of monuments whose primary purpose was to provide sequences of memorable locations (e.g., the various pillars in Stonehenge) where visualizing each location is used to index and mentally trigger for recall a particular unit of memorized knowledge[81].

However, only with the development of writing could knowledge be seen as something external, where speech can be used as something that can convey objective content, and it seems that writing began with counting.

Numeracy, Counting Boards, Chinese Counting Sticks, and the Abacus

Figure 10. Left: Clay tokens from Susa (Iran) c. 3,000 BCE from Musée du Louvre (Schmandt-Besserat 1977). Right: Cuneiform script tablet from the Kirkor Minassian collection in the Library of Congress. From Year 6 in the reign from Amar-Suena/Amar-Sin between 2041 and 2040 BC (Wikimedia Commons).

As discussed below, the archeological record shows that the use of tokens to externalize counting and reckoning (Figure 10, left) emerged to support trading commodities in conjunction with the agricultural revolution taking place after the end of the Eurasian Ice Age, millennia before writing[50] developed in conjunction with the objective record keeping requirements of emerging city-states. Once the concept of keeping written records emerged, it seems to have been a comparatively small revolution to use writing as a generic tool for the durable recording of all kinds of memories. Cuneiform writing apparently was first developed in the last third of the fourth millennium BC in the Late Period of Uruk, the first true city in the Mesopotamian region, as tools to support the kind of extended cognition required for practical administrative record keeping in an increasingly centralized agrarian society (Mouck 2000, 2004; Cooper 2004).

Counting and reckoning probably began with using body parts as a form of "embodied" cognition (Fischer & Brugger 2011; Gers 2011) and then extended to counters. According to (De Cruz 2008):

> This examination of natural number representation shows that external media are a necessary and irreducible part of human numerical cognition. … I argue that external media together with the internal cognitive processes involved in number form a hybrid cognitive process. Next to this, I make a relatively strong claim for the interaction between internal and *external* cognitive resources. *The enduring use of external media results in structural changes in the brain: the cognitive scaffolding we use to accurately represent cardinalities (number words, body parts, tokens, numerical notation systems and gestures) is recruited in numerical cognition alongside the number-sensitive neurons.* For instance, body-part

recognition (finger counting) is recruited for solving numerical tasks involving Arabic digits. [De Cruz 2008: p. 486- my emphasis]

Schmandt-Besserat (1979) sees evidence for the direct evolutionary transformation of counting tokens used for reckoning over thousands of years prior to around 5500 years ago into the kinds written textual records for accounting records[50] as simple agrarian communities transformed into hierarchically organized urban "nations" controlled by priestly classes. To facilitate learning extensive lexical texts were developed to define the symbols that could used). The concept of writing then quickly spread (i.e., within a few generations – Cooper 2004) to Sumer and Egypt or developed independently in those areas in the same time frame (Baines 2004). However, at some point, possibly in less than a human lifetime (Glasner 2003), scribes extended this to a generic representation of language that allowed the recording of narratives and epics. We begin our survey of technologies used to establish world 3 with a more detailed look at counting and reckoning.

Young children (before they learn to count) and animals such as our primate relatives have an innate capability to make quantitative comparisons referred to in the psychological literature as the "mental number line" (Zhang and Norman 1955; De Cruz 2008; De Cruz & Smedt 2013; Fischer & Brugger 2011; Gers 2011), that is something like this, 1, 2, [3], "few", "many", "uncountable". This mental capacity is used for estimating relative values (e.g., for the number of food items). These authors argue that humans learned to count accurately only when they were able to build a concept of numbers based on physical objects, such as an ordered sequence of fingers or body parts, or perhaps pairing individual pebbles from a pile with individual sheep in a herd. We now have the concept of physical line of ordinal numbers extending in an ordered sequence from one to infinity.

Figure 11. Transformation of some ancient clay counting tokens into cuneiform writing (Schmandt-Besserat 1979)

Pebbles then provided the basis for some very effective tools for extending mental arithmetic, invented in antiquity that are still used in "primitive" parts of the world, such as the abacus and related counting boards or frames and counting sticks or rods. These are all "technologies" using inert markers to extend mental arithmetic (De Cruz 2008). They all probably derived from finger counting (Turner 1951; Sugden 1981; Schmandt-Besserat 1981). Counting on fingers was logically followed by placing pebbles in piles, and then manufactured clay tokens representing particular types of commodities. This began an immense revolution in human cognition facilitating the emergence of structured agrarian communities and eventually socially stratified nation-states. Schmandt-Besserat (2007: pp. 165-166 - Figure 11) notes that:

> The true cognitive significance of the token system was to foster the manipulation of data. *Compared to oral information passed on from one individual to the other, tokens were extra-somatic, that is outside the human mind* [i.e., in Popper's world 3]. As a result, the Neolithic accountants were no longer the passive recipients of someone else's knowledge, but they took an active part in encoding and decoding data….

Patterning, the presentation of data in particular configurations, also promoted the abstraction of particular features. For example, the tokens representing the budget for a festival could be ordered in columns abstracting the merchandise according to its types, donors, entries and expenditures, and intended use, i.e. for particular rituals. The relative value of merchandise could be abstracted by lining up units of greater value above those of lesser value. For instance, spheres, standing for large measures of grain could be placed above the cones, representing small measures of grain. It is well possible that the geometric lay out of operations such as adding two tokens to two tokens, and three tokens to three tokens, and so on, helped the conceptualization of abstract numbers….

Finally, because the clay tokens could be manufactured at will and stored indefinitely they abstracted goods from time. Consequently, accountants could manage merchandise independently of their current status. For instance, quantities of grain could be accounted for whether they were still in the fields or harvested, stored in granaries or in transit, delivered or promised.

In sum, the immense value of the token system was in promoting the acquisition of new cognitive skills that capitalized upon the visualization and physical manipulation of data. Computing with tokens in ever greater volume of more complex data paved the way to writing. [my emphasis]

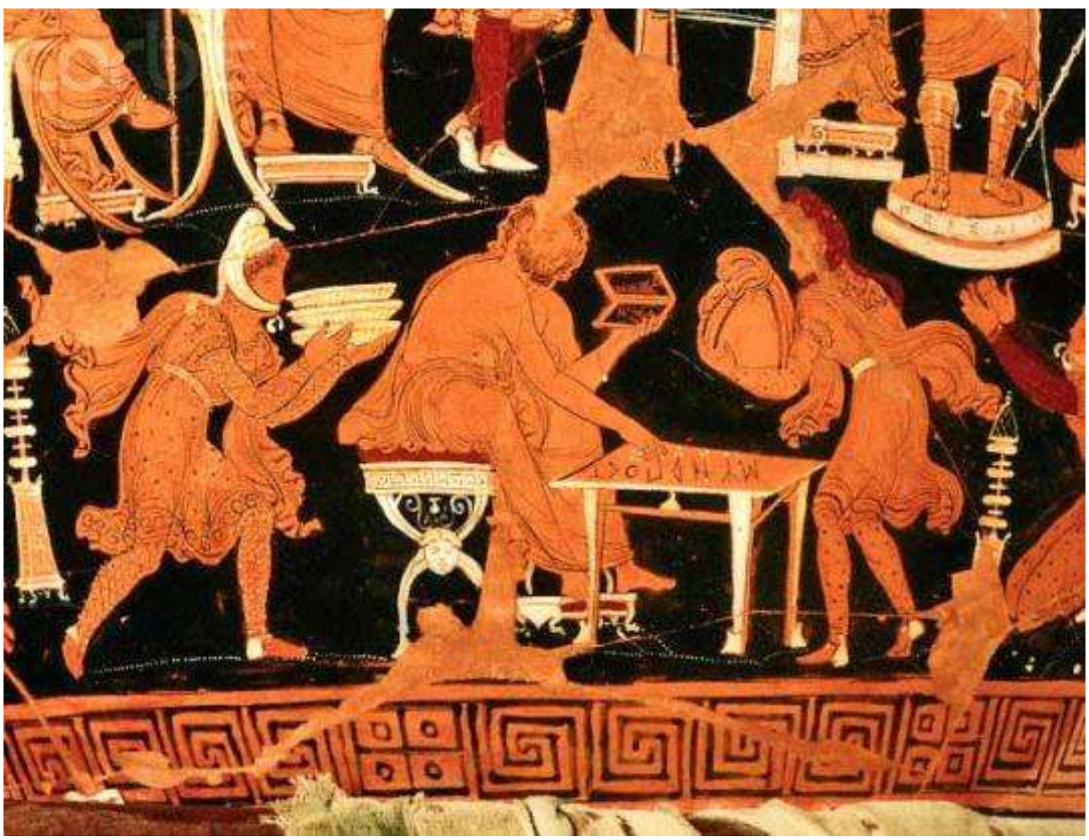


Figure 12. King Darius' treasurer with tablet and counting table. From Darius I (Dârayavauš) in Thracia and Dacia. The Achemenid Empire to the Danube, Skudra/Thracia, and the Getai (Sakâ tyaiy paradraya), 600 BC, in Romanian History and Culture. The vase was painted by "Darius Painter" between 340 and 320 BC.

There is archeological evidence for the further systematization of accounting by using counting boards by around 2000 BCE. Figure 12 from a Greek vase dated from between 340 and

320 BC, shows King Darius, with his accountant counting tribute with an abacus or counting board[82]. According to Sugden (1981), The counting board clearly shows the sum 1231 drachms 4 obols. Although not mentioned by Sugden, the folding tablet[83] in the accountant's left hand is probably filled with either clay or wax where results of the calculations will be inscribed as an aid memoir. The abacus or counting board was not the only early technology developed to assist mental arithmetic. Lam (1986) describes the Chinese counting sticks or rods, known to have been in use in China since at least the Warring States period from 480 BCE to 221 BCE. These were no more than simple rods (tooth picks would do) that when laid down vertically or horizontally on a flat surface provided a simple way to positionally represent numbers (i.e., in columns) in calculations (Figure 13). This notation was readily represented in the Chinese abacus (Figure 14, right) when this was developed, and provided the concept of a decimal place, and a possible basis for the Hindu-Arabic number system when this was developed in the Indian subcontinent.

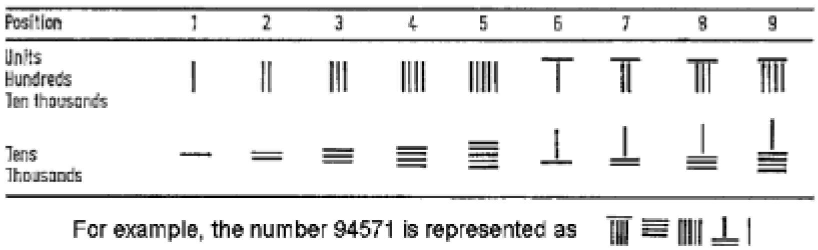


Figure 13. Chinese counting stick notation (from Lam 1986).

As was the case for the use of counting boards and sticks, there are a variety of abacuses that differ in the way they represent numbers (i.e., base 10, base 12, base 20, and base 60 are known!) and the ways in which the beads are manipulated to represent intermediate values in the process of performing calculations (Stephenson 2010, Fernandes 2010). In the Roman world, the base 12 abacus (Figure 14, left) was apparently developed as a portable counting board[84]. Stephenson's (2010) web page, Ancient Computers, reconstructs the use of the early Babylonian, Greek and Roman counting boards and abacus, and concludes:

> The ancients had FAST and POWERFUL computers, with BUILT-IN ERROR CHECKING, to use to power their empires; and
>
> Now we know what those computers looked like and how they were used to perform all four arithmetic operations on decimal, duodecimal, and sexagesimal numbers. Numbers that could be represented in an exponential notation, where both the fractional part and the exponential part could be positive or negative. The decimal numbers could have up to 10 significant digits in their fractional part and 4 significant digits in their exponent part. For duodecimal or sexagesimal numbers the fraction and exponent parts had up to 5 and 2 significant digits.

Compared to digital and analog calculators, where the technology actually performs the calculations, the tools described in this section all function as aids to focus human working memory and cognition, where the human doing the calculation sets the positions and relationships of the markers to represent input and output numbers and intermediate steps in the calculation. Several authors explore the hand-brain coordination involved in these calculating technologies. Turner (1951) describes how four kinds of "tools" were used as aids to mental calculation, (a) memorization of mathematical tables (e.g., the "times table"), (b) written calculation with roman numerals, (c) different kinds of counting and computation using fingers as memory aids where two hands could be used to represent any number up to 9999, and (d) the counting table or abacus. Cuomo (2012 - watch video of her lecture) surveyed Greek and Roman texts to determine how widespread numeracy actually was in the ancient world compared to literacy. Clearly mathematics of a high degree was required for building the complex gear-driven analog computer known as the Antikythera Mechanism described in Episode 2, to say nothing of needs for commerce and state administration. There are many unanswered questions, but Cuomo concludes that numeracy was less widespread even than literacy, where only a small fraction of the population were literate. Reynolds (1993) explores the reluctance of the 13th and 14th centuries to adopt decimal notation and "pen reckoning" in place of using Roman numerals. She argues that Roman numerals show a tangible relation to the way in which counting boards and the abacus is used, and that:

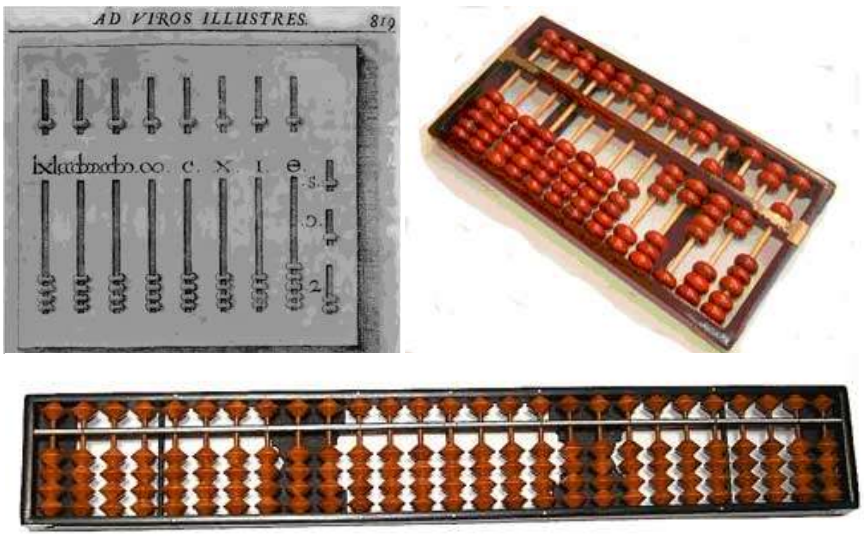


Figure 14. Left: A Roman portable abacus (as illustrated in Welser, 1682), Right: a modern Chinese 2:5 abacus (from Wikipedia Commons), Below: a modern Japanese 1:4 sorobin abacus (from Abacus: Mystery of the Bead).

> The thought processes involved in using the abacus are very closely related to the process of counting, and are surprisingly similar to the arithmetic of making change. For more than two thousand years, the abacus has been used throughout the world to do base-10 arithmetic. Yet the early historic roots of the abacus are older than the common acceptance of decimal notation. Roman numerals, awkward for "pen-reckoning," seem to be a natural notation for recording the results of calculations done on an abacus (Reynolds 1993: p. 223).

Writing

Although reckoning involved the use of tools external to the body to make the processes of counting and arithmetic explicitly tangible (Zhang and Norman 1955; De Cruz & Smedt 2013; Fischer & Brugger 2011), writing (Figure 15) evolved a means to provide an explicit and persistent record of a cognitive product. As such this further revolutionized human cognition (Gers 2011). Writing and keeping records provided the long-term memory of accounts, events and myths as required to enable the growth organized religions and bureaucratic city states. The fact that such records could also be carried to other places for the exchange of information and to encourage uniformity of thought and belief further enabled the development of nation states and empires.

Figure 15. Ancient and modern tablets. (Left) Teacher instructing from a wax tablet (Douris's 'school cup' Berlin, Staatliche Museen - click picture to enlarge). (Right) The modern equivalent (Ehow)

However, when knowledge was preserved and transmitted through documents written and transcribed by hand, the critical difficulty was to maintain the accuracy of the written content or even to preserve the knowledge embodied in the writing at all (Eisenstein 1983). Because the dry or fired clay tablets were essentially indestructible, we have good records of cuneiform writing and the development of the states that depended on it[85]. On the other hand, where perishable substrates (wax or clay notepads, papyrus or velum) were used for writing and because the manual copying process was labor intensive, previously documented (i.e., transcribed) knowledge was always at considerable risk of corruption and extinction. *Because creating the copy was almost as labor intensive as creating the original, much recorded knowledge may have only ever existed in the one record*.

Writing and the development of scholarship

As described by Eisenstein (1983) and Ward (2000), loss of the recorded knowledge only required a failure to manually transcribe the only or last remaining copy before it was lost or disintegrated. Ward's discussions of how little Classical Greek, Roman and early church literature that references and quotations show to have existed has actually survived makes this abundantly clear. The great enemies of preserved knowledge were the vicissitudes of simple wear and tear, decay, disposal, fire, flooding, or loss in the chaos of war – as happened with the priceless knowledge collected in the great library of Alexandria, etc.

The first lengthy documents were written on parchment scrolls. Scrolls were comparatively inexpensive to make, but with scrolls one had to access content by scanning linearly through the document (i.e., the scroll only allowed sequential access). The development and use of the codex early in the Christian era (Bowman 1975; Woudhuysen 2004) was a major improvement over the scroll as a means of recording knowledge because it allowed any part of the content to be randomly accessed by opening the pages at the desired point (Clement 1997; 1997a). Codices were much more complicated and expensive to assemble. Thus, before printing made it economically feasible for single scholars to own books, codices were designed and illuminated as elaborate and unique mnemonic aids to train human memory[86], not to preserve knowledge in their own rights or to help scholars find new knowledge. Codices were so costly and rare that they certainly were not written and designed to be consulted along with hundreds of others to locate particular kinds of information.[87] Some concept of their cost can be inferred from the fact that to produce the velum for a single full bible required the *skins of up to 500 calves*, to say nothing of the human labor to prepare the vellum and to inscribe and illuminate the assembled codex by hand (Ward 2000). As an animal product, vellum making is not for the squeamish or faint-hearted[88].

Scribal scholars may have had access to assorted records written by others, but these would often be held in different repositories separated by days or weeks of travel time (when travel was by foot, ox cart, horse or boat), where the owners of the documents might or might not allow an itinerant scholar to even see, let alone touch them. Once a document was found, the only way a scholar could record the content for later use was to copy it by hand (and to save time only material seen to be relevant at the time would be copied). Beyond that, scribes and scholars lacked uniform chronologies, maps or any of the other kinds of reference material commonly used to classify and organize knowledge. "Each scribal text was uniquely flawed – or, arguably, uniquely correct with regard to subjective understanding" (Griscom 1998).

As discussed in the Subject, writing provided a means for individuals to record transactions and eventually to record significant amounts of knowledge external to memory to begin populating Popper's W3. Printing provided the means to preserve and widely replicate written knowledge to ensure it against easy loss. The mass production of printed materials also enabled the cognitive evolution of universal literacy.

Replicating, Preserving, and Disseminating Knowledge

Replicating Written Knowledge with Printing

Robertson (1998) estimates that people with access to libraries of printed books have available 6 orders of magnitude more W3 knowledge to fuel their cognition than would have been available before books began to be printed and collected into libraries.

Eisenstein (1979, 1983) analyzed the role of printing in the three major European cultural revolutions in the 15th, 16th and 17th Centuries – the Renaissance, the Reformation and the Scientific Revolution - which together laid the groundwork for the Industrial Revolution. The Renaissance – which rediscovered some of the ancient Greek and Roman knowledge, was already underway before the invention of the printing press. However, the combination of moveable type with the wine press enabled development of a handcraft industry able to broadcast the results of these intellectual revolutions (e.g., fuelling the Reformation and Scientific Revolution) as they occurred (Levinson, 1997). Eisenstein makes the point that the ability to print and circulate hundreds or thousands of identical copies of the same documents widely across Europe and beyond had a slow but profound influence on who became literate, the nature of literacy and the kinds of things that literate people could do. In other words, the availability of printed books caused or enabled a major revolution in human cognition within around 10 generations - much too fast for any extensive change in hereditary knowledge encoded in human DNA.

Because the first printing processes were labor intensive and thus still very expensive by comparison to today's mass production processes, large organizations such as the churches and states were the primary customers for printed products. However, to facilitate marketing their books, the early book printers developed a number of cognitive improvements that turned illuminated codices into modern reference books which could be mass produced and marketed (at least by Renaissance standards):

- woodcuts for illustration,
- page numbers,
- title pages and prefaces (Shevlin 1999),
- publication details,
- metal engraving for detailed charts and diagrams,
- folded plates (i.e., oversize pages for high quality illustrations),
- cross referencing,
- indexing, and
- table of contents.


MARCI VELSERI,
MATTHÆI F. ANT. N.
REIP. AUGUSTANÆ
QUONDAM DUUMVIRI.
OPERA
HISTORICA
ET PHILOLOGICA,
SACRA ET PROFANA.
In quibus
Historia Boica, Res Augustanæ, Conversio & Passio SS. Martyrum, Afræ, Hilariæ, Dignæ, Eunomiæ,
P. Optatiani Porphyrii Panegyricus,
exoptimo Codice à PAULLO VELSERO divulgatus,
Præfatio ad Lectorem, de singulis scriptis nunc recusis,
VITA, GENUS, ET MORS
AUCTORIS NOBILISSIMI.
CHRISTOPHORO ARNOLDO.
NORIMBERGÆ,
Typis ac sumtibus WOLFGANGI MAURITII, & Filiorum
JOHANNIS ANDREÆ, ENDTERORUM.

AD VIROS ILLUSTRES. 819

Figure 16. Cover and page 819 of Welser (1682). Read online.

This made the printed book[89] as exemplified by Figure 16, far easier to use by scholars as sources of preserved knowledge. Where the growth of knowledge is concerned, the primary effect of the presses in the first century of printing was to preserve, codify, consolidate, disseminate and enable criticism of the existing classical knowledge. Only when copies of multiple works on the same subjects were readily available to cognoscenti without the immense travel time and labor costs to copy by hand the rare, priceless, and closely guarded ancient authorities, did printing begin to have a major impact on the growth of *new* knowledge (Eisenstein 1983; Hobart and Schiffman 1998; Berner 1987).

As will be seen, the application of inorganic motive power to book production in the Industrial Revolution transformed printed matter into something so inexpensive that it could be read once and then thrown away (as in newspapers), or at least something that could be afforded by almost anyone. The ever decreasing cost of printed matter promoted universal literacy and the use of printing as a primary medium for broadcasting both knowledge and mythology.

Within the framework of evolutionary epistemology and the cybernetics of power, multiplying and disseminating the sources of ancient knowledge through printing was the crucial enabler that allowed scholars to criticize and reevaluate knowledge via an OODA loop process (Figure 8). Kircz's (1997) paper summarizes Eisenstein's assessment of these impacts of printing on the origins of modern scientific endeavor. Following Eisenstein, the spread of knowledge went through several phases:

- preservation of the content ancient manuscripts by printing multiple copies;
- circulation, comparison, criticism, correction and translation to the vernacular of the ancient sources to achieve a consensus understanding of the classical texts;
- comparison and criticism of the classical claims to knowledge against observable reality;
- collection of observations, and the construction and circulation of new knowledge for further criticism.

It took nearly 200 years to reach the critical point where the cycles of interaction between the three worlds involving dissemination (W2 to W2 via W3), criticism (W3 by W2), testing (W3 to W1 via W2) and reformulation (W2 to W3) enabled the beginnings of exponential growth of knowledge. Once begun, the process has been inexorable.

Printing, as the first industrial mass production process, had a huge impact on the evolution of knowledge and initiated huge changes of the roles of humanity in nature. The rapid replication and wide dissemination of knowledge allowed many repetitions and cycles of evaluation, testing and reformulation of aggregated knowledge within the average lifespan of an individual human. Thus, over the five centuries following Gutenberg, printing enabled the huge evolutionary grade shift from *Homo agriculturis* to *Homo industrialis.*

The ability to rapidly assemble, codify and disseminate knowledge to discrete groups of individuals enabled the development of new kinds of state, religious and commercial organizations defined and coordinated by their shared knowledge base or intellectual capital.

Setting words into print –printing and typesetting

In secondary school in the 1950s, one of my ideas about a future career was to become a printer like my maternal grandfather who became wealthy operating the Lord Printing Company in Los Angeles, specialists in printing daily menus for restaurants amongst other lines. To explore this trade I took the junior high school print shop course and learned typesetting and printing. This gave me a strong foundation for my life-long interest in the mechanics of transferring knowledge from W2 to W3. It is in this area where technological change has been most profound.

From around 1550, Gutenberg combined moveable type, wine presses and paper to invent the printing industry that led to the widespread circulation of texts and the development of literacy (see the printing revolution in Subject). Clement (1997a) describes the medieval handcraft technology and process for printing books. In the 1800's this began to be industrialized with the development of mechanized and rotary papermaking machines, presses and industrial typesetting machines. Although the printed products were intended to be read by single individuals, commercial printing became a highly industrial process, involving some of the most complex machinery of the time to mass produce codified knowledge on paper

Industrial printing involves three major technologies (paper making, typesetting, and printing), a number of minor ones (e.g., ink making, type founding, plate making, lithography, metallurgy) and some sophisticated "post-press" engineering to assemble the final product such as a book, magazine or newspaper, that all have to work together to put words on paper into your hands.

- *Papermaking.*

Papermaking involves two major processes, pulping a fibrous material to make a water-based slurry and then collecting fibers from a dilute slurry onto the surface of a boxed screen that allows the water to drain away, leaving a mat of interlocked fibers that is then separated from the screen and left to dry, creating a sheet of paper (Hubbe & Bowden 2009). The industrial process works the same way, but is managed as a continuous flow. In the handcraft, which sufficed for the first 250 years of printing, each sheet of paper was created as an individual product as demonstrated in the following YouTube videos of differing craft traditions: Handmade Paper Making Operation in Kathmandu, Nepal (2.02 m); The traditional handicrafts of making Xuan paper, China (8.52 m); Sekishu-Banshi: papermaking in the Iwami, Shimane Prefecture, Japan (9.01 m).

In the Industrial Revolution various components of the papermaking processes were mechanized (e.g., milling pulp), with the most revolutionary industrial technology being the development of the continuous-flow "Fourdrinier" process in the UK in the early 1800's[90]. In present machines (Figure 17), the paper is formed and output from this almost completely automated industrial process flows out of the machine at speeds up to 100 km/hour, where up to 100 km at a time of unbroken paper is wound on to a reel up to 10 m wide. Full reels weighing as much as 25 tons each are moved to a splitter, where paper is unreeled, split and rewound onto smaller rolls of a ton or less to meet client requirements (e.g., for newsprint or pulp books). The industrial papermaking machines are huge, up to 115 M long (longer than a football field!), and cost many millions of dollars. However, because of automation and the speed and volume of production, the paper produced is very inexpensive. See the Sappi YouTube video - The Paper Making Process that illustrates and explains the full process from trees to shipment to the end-user.

Figure 17. The "wet end" of a modern Fourdrinier paper making machine where a slurry is spread on a fine wire screen to begin draining the water and consolidating the fibers. The far end of the dryer and the take-up reel is lost in the distance.

- *Typesetting*

From Gutenberg until the mid 1800's words to be printed were hand assembled character by character from individual letters taken from type cases into a composing stick (Figure 18) – a technology which is still used today in some letterpress printing[91]. Learning Typesetting from YouTube demonstrates just how labor intensive and slow the handcraft process was. On the other hand, once the type was set and formed into a page, that labor cost to set the type could be amortized into the printing of tens or even hundreds of thousands of identical copies of the page.

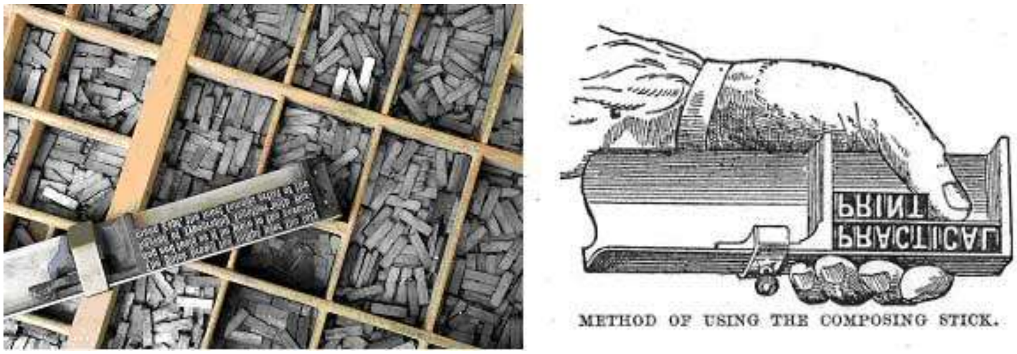


Figure 18. Hand setting type of a particular type font from the type case. The case has two major divisions (or there may be two separate cases used at the same time), where the "upper case" contains capital letters, and the "lower case" (closer to the typesetter) contains the small letters. The arrangement of boxes in the cases is standardized, with the size of the box for each letter based on how commonly used it is.

Typesetting was revolutionized in the 1880's by a fascinatingly complex machine called a Linotype (Figure 19) that cast whole lines of type from molten metal at 10 to 20 times the speed of the fastest hand typesetters[92].

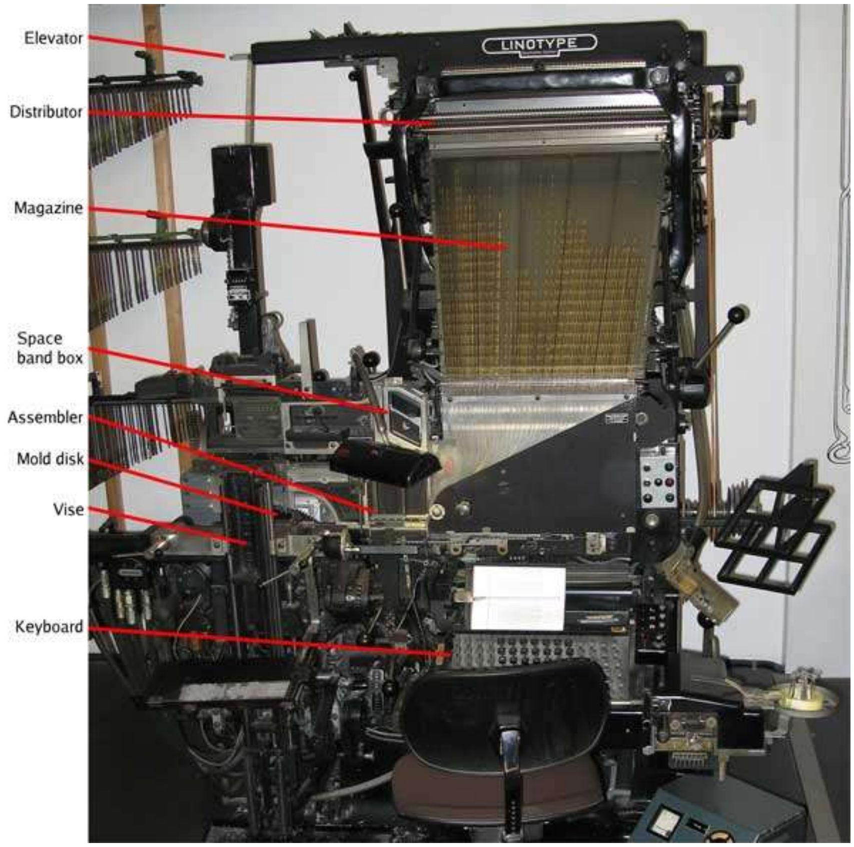


Figure 19. Linotype machines used to cast molten metal into lines of type for printing. Wikipedia explains in some detail how this technology worked. How mechanical typesetting works (Intertype, Linotype, Hot Metal).

Increased productivity more than amortized the high cost of the technology. A 35 min. video, How mechanical typesetting works (Intertype, Linotype, Hot Metal), illustrates the incredible mechanical complexity of this technology. Manually operated Linotype and related technology dominated the printing industry until the 1970's when they began to be replaced by the much lighter, faster and more easily maintained phototypesetting machines that are discussed in Episode 3. In turn, beginning in the 1980s and continuing today, the large phototypesetting machines requiring print-trade skilled operators, have been increasingly replaced by the software of word processing systems on authors' own desktops, where copy is sent electronically directly from the author's word processor to the publisher's editor, and then directly to the printer, with no involvement of print trades in the pre-press workflow, making these skilled crafts completely obsolete.

- *Printing*

Printing is the process of transferring ink from the raised surfaces of the assembled type, graphics blocks (such as woodcuts or engravings) and other furniture such as borders onto paper (or other flat material). Gutenberg's press, built much like a wine press, served to press the paper onto the printing surface with enough pressure to ensure that the ink was transferred onto the paper. Presses changed little from Gutenberg's wooden framed screw presses, which were only replaced by much faster operating iron-framed lever operated Wells presses in 1819 (Figure 20). These were still slow to operate because each piece of paper had to be manually placed on the printer and the type re-inked before an impression could be made. By 1840 platen presses with a reciprocating motion powered by a belt-driven flywheel (e.g., initially driven by foot pedals or steam engines, and later by electric motors) were developed that allowed a much more rhythmic operation. Skilled operators could produce a thousand or more impressions of the same page in an hour. In operation, ink is spread on the rotating ink disk (the quantity suffices for many impressions and the disks' rotation assured uniform distribution of the ink from one impression to the next), the press opens to allow a previously printed sheet to be removed while a new sheet of paper is placed on the flat plate of the platen while rollers transfer ink from the ink disk to the type, and the press closes with substantial force to make the impression when the platen forces the paper against the type. A short documentary on letterpress printing (5.52 min video) demonstrates that letterpress printing survives today for the production of beautiful hand craft products[93].

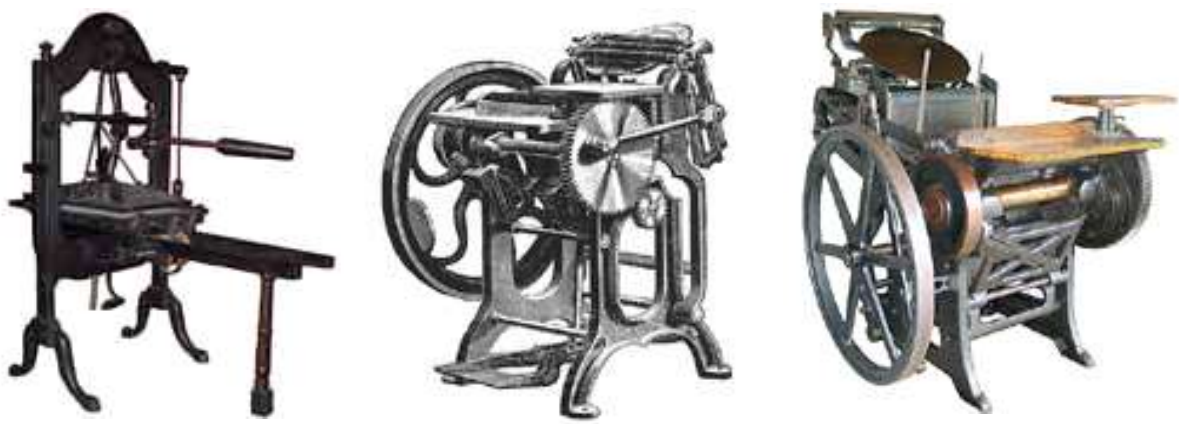


Figure 20. Letter presses. An iron lever press (left), one of the first platen presses(Gordon Franklin - middle), the kind of platen jobber (Chandler & Price New Series - right) I used in my print shop course (pictures from Briar Press's Museum of letter press printers.

As with paper making, the application of engine driven rotary motion to pull a continuous flow of paper (a "web" of paper) through the printing machinery fully industrialized the printing processes for long print runs such as books, journals and newspapers. For newspaper printing, Richard March Hoe introduced the first sheet feed double-cylinder rotary press in 1847, and a rotary web press in 1871[94]. By 1875 he had added in-line folding apparatus to complete the basic structure of the modern newspaper press. Other critical inventions involved processes for casting the content (characters and pictures) to be printed onto curved plates that would fit the circular drum ("web letterpress") and more recently of rotogravure and offset lithography0. Paper can flow continuously through large offset presses up to speeds approaching 50 km per hour and that can splice from one roll to another without stopping. Non-stop print runs for newspapers and books can be up to a million signature impressions or more. The modern, high-volume offset presses are almost totally automated and are nearly as large as the biggest Fourdrinier paper machines and a lot more complex as illustrated in the videos: printing 5 million copies of a book - The Making of Dan Brown's The Lost Symbol (4.1 min); magazine printing - Publishers Press: magazine printer (6.4 min); and printing the Edmonton Journal newspaper: Newspaper printing press at work (1 min)[95].

In the last couple of decades a number of smaller offset or laser toner printing machines have been developed that fully automate the printing and binding of small print runs. – for example, making it economical to print small circulation scholarly works more or less on demand where the print run may be anything from a single copy to a few hundred at a price the single scholar can afford.

The industrialization and then automation of printing reduced in two stages (late mid to late 1800s, and then in the 1980's and 1990's) what had been a skilled labor force in the print trades employing millions of people around the world to a few highly skilled maintenance engineers and print machine tenders.

- *Post press*

Most readers would have some concept of papermaking, typesetting and printing, but few consider the technology required to turn webs or loose sheets of printed paper into handy sized knowledge containers such as books or even broadsheet newspapers (although the latter are hardly handy when one is trying to read the daily news on a train or tram!). As for the other technologies, binding began as a handcraft trade.

In the modern printing industry, a number of now highly automated technologies are used to turn printed sheets or webs into products consumers can use. These include[96]:

- Cutting: that turns the web into individual pages or sheets.
- Folding: that may finish the process for a small brochure, or may be applied to "signatures" or sheets comprising the contents for 16 to 32 pages, whose placement on the sheet depends on the "imposition" or folding plan.
- Assembly: brings all the printed (e.g., signatures and inserts such as plates, fold-outs, etc.) and non-printed elements of the product together prior to binding. See also gathering and gathering machine. Assembly may be followed by additional cutting operations to square up the book or other product.
- Binding: is the process that ties all of the internal components of the product together to form a single unit book or magazine (most newspapers are only folded and assembled). There are a three main binding methods; adhesive (see also adhesive binding machine), side (e.g., see side sewing), and saddle (see saddle stitching and saddle sewing), where a variety of different processes may be used for each type (e.g., see machine sewing).
- Covering: applying a durable protective cover to hold the bound materials together. Again a variety of types and technologies are possible.

Each of these post press processes used to be done by hand by skilled craftspeople in the printshop or specialized job shops. The industrialization of craft processes began in the latter part of the 19th Century with the addition of folding machines to the large news printing machines. Except for book conservation and small special projects such as binding theses, to further reduce costs finishing is now an automated in-line process involving a number of computer-controlled machines connected directly to the web or sheet press.

The Second and Third Printing Revolutions – industrializing and automating the production of words on paper

The first printing revolution launched by Gutenberg in the mid 1500s capped off the Renaissance, fuelled the Reformation and made the Scientific and Industrial Revolutions possible. The Industrial Revolution in the 1800s applied external motive power (replacing human power) to mechanize and industrialize the printing trades. This caused a second printing revolution; increasing the capabilities to print books by one or more orders of magnitude and reducing the cost of printed products to the point that they became consumables – that could be read once for information (e.g., newspapers and magazines) or entertainment (penny dreadfuls or dime novels; see also Stanford University's Dime Novels and Penny Dreadfuls) and then possibly thrown away. The Microelectronics Revolution beginning in the 1970's fuelled a third "printing" revolution (to be discussed in Episode 3) to automate most printing processes. A fourth revolution, allowing authors like me to communicate my words directly with readers like you via the Web is on the way towards replacing the entire printing industry. Social changes caused by these revolutions in printing have been immense, but are beyond the scope of this work to explore in any detail[97]. However it is worth pointing out that except for some of the concepts of composition and page-layout, the printing trades I studied in secondary school are now extinct except for a few hobbyists and a small number of specialists practicing arcane trades in the luxury craft market. The entire industry for putting words on paper may soon follow.

Just how much and how fast news printing has changed in my own lifetime is shown by an historic film produced on the 50th anniversary of the Christian Science Monitor in1958 following the production process from reporters to readers: Part 1 (6.3 min), Part 2 (7.5 min), Part 3 (8.11 min), Part 4 (6 min). An excellent summary of the range of press technologies at the start of the 21st Century can be found in the hypertext, Printing process explained, provided by Dynodan Print Solutions; see also Print Process Descriptions, provided by Printers' National Environmental Assistance Center. A 27 min. video of the Toronto Star press shows the complete process for printing a million copies of a large metropolitan daily paper using a state-of-the-art integrated system [sorry about the tacky narration aimed at 10 year old kids – but the video is excellent].

Except for papermaking, by 2015 most of the printing crafts and industrial processes are becoming obsolete thanks to Web delivery of electronic content directly to readers. Ten year old mechanical and technical wizardry for printing physical books, magazines, and newspapers is beginning to be junked as this eBook is being finalized for publication (Figure 21). Inert paper does not provide a suitable medium for distributing the content I am assembling. News*papers* around the world risk extinction from the revolutionary rise of news deliveries via the World Wide Web. As an example, Fairfax Press, publisher of Australia's two most respected newspapers has stopped its state of the art presses and is junking some of them as I write this paragraph: the 19 year old Sydney Morning Herald press in Chullora and The (Melbourne) Age's 10 year old press at Tullamarine RIP Age print plant at Tullamarine (Elliott 2014, Bendel 2013). Every time I drive into Melbourne at the end of 2014 I drive past the for sale signs on the Age's architecturally spectacular printing plant. The German company Manroland that built the Age's presses, went bankrupt in 2011.

Figure 21. *Stop the presses and last day on the job!* Fairfax's 19 year-old printing press in Chullora rolled out its final Sydney Morning Herald and will be sold for junk (Elliott, 2014)

Accumulating Written and Printed Knowledge for Public and Private Use

As noted earlier, writing allows knowledge to be recorded and preserved as objective knowledge in W3 outside the human brain. The development of libraries or collections of written materials follows on naturally from the development of writing. Printing made the production of books an industrial process, such that single individuals could afford to accumulate thousands of books on multitudes of subjects into their private libraries[98], and major public and institutional libraries could accumulate hundreds of thousands or even millions of books in a single repository. Recorded knowledge is most useful if people other than the original authors can find and retrieve what they need from the records when and where it is needed. To fulfill this function, repositories or libraries need to be much more than random collections of documents.

Originally, most records stored in libraries were religious and literary works of high culture. In the latter half of the 17th Century European philosophers such as Roger Bacon stressed the importance of documenting knowledge of the world (Bell, 2000). The first scholarly and scientific journals were established in the 1660's to provide standard means of communicating scientific discoveries and practical knowledge of the world (Fjällbrant, 1997; MacDonell, 1999). As the volume of knowledge held in books and other publications grew beyond the capacity of an individual remember which document held which knowledge, the need for systems to manage and retrieve specific knowledge objects from the storehouse became paramount. As will be seen in Episode 3, the requirements to manage and retrieve content from books in general versus retrieval of specific kinds of knowledge from the scientific and scholarly literature are actually quite different and have become highly automated using electronic technologies

Books, Journals and Libraries

As noted earlier, writing and books allowed knowledge to be recorded and preserved as objective knowledge in World 3 externally to the human brain. The development of libraries or collections of written materials follows on naturally from the development of writing and printing. Recorded knowledge is most useful if people other than the original authors can find and retrieve what they need from the records when and where it is needed. To fulfill this function, repositories or libraries need to be much more than random collections of documents. Libraries have also evolved as immensely important cognitive tools contributing to the later revolutions in human cognition.

Originally, most records stored in libraries were religious and literary works (i.e., books). In the latter half of the 17th Century European philosophers such as Roger Bacon stressed the importance of documenting knowledge of the world (Bell, 2000). The first scholarly and scientific journals were established in the 1660's to provide standard means of communicating scientific discoveries and knowledge (Fjällbrant 1997); MacDonell, 1999; Harkness 2007). As the volume of knowledge held in books and other publications grew beyond the capacity of an individual to remember which document held which knowledge, the need for organized systems to manage and retrieve specific knowledge objects from the storehouse became paramount. As will be seen, the requirements to manage and retrieve content from books in general versus retrieval of specific kinds of knowledge from the scientific and scholarly literature are actually quite different.

Library structure and catalogs helped individuals find books

To be usefully available, the records (or "books") in the knowledge storehouse (library) need to be systematically organized – both to manage them physically in space, and conceptually to facilitate retrieving the knowledge they contain. Two approaches provide systematic clues to the contents of a library: indexes and catalogs. An *index* is an alphabetically ordered list of contents, e.g., by author name and title – which points to the book's physical location in the library. A *catalog* attempts to provide a systematically organized conceptual structure of knowledge that places each book or object at a particular place within that structure based on the principal subject(s) or content of the book. Until they became completely computerized, most libraries maintained both an author/title index and a subject catalog. In most cases, the catalog organizes subjects according to some kind of hierarchical logic as discussed below. Before computerization, indexes and catalogs were physical files of index cards that had to be manually sorted and maintained.

The earliest Sumerian tablet archives, dating to the Third Dynasty of Ur (c. 2100 BC) apparently already used simple classification systems. Some 30,000 tablets were excavated from the temple complex in Nineveh, Ur (many of which had probably been purged and used as land-fill). The best evidence, based on administrative texts, suggests the number of documents actually maintained in the library (Assurbanipal's) at any one time was closer to 5,000 (Potts 2000). These covered diverse topics, including linguistics, ideogram registers, grammatical exercises, lists of names of mountains and cities, of gods and temples and of minerals and plants, medical prescriptions and incantations, liturgical texts and hymns, etc. Based on physical evidence, the material was shelved to help determine three things: the identity of every tablet, its specific content and its extent[99]. I have found no references on the Web to tablets found in these libraries describing the classification philosophy followed, but even these early repositories may have been conceived as "universal" libraries to catalog all recorded knowledge.

To quote from the introduction to the Second Anglo–German Seminar on Library History[100]:

> The 'universal library' has long been a dream of literate societies. The idea that it might be possible to assemble a collection of texts in which all human knowledge was contained had obvious appeal for tyrants, democrats, and scholars alike.

The Library (ΒΙΒΛΙΟΘΗΚΗΑ = "bibliotheca" = book depository) in what became Alexandria, Egypt, founded between 310 and 275 BC together with the Mouseion (= "museum"), a state-supported research and teaching campus (Al-Abbadi 1992; Bagnall 2002), is the earliest of the universal libraries we know much about (Jameson 1993; Brundige 1998; El-Abbadi 1992, 1998; Delia 1992; MacLeod 2000; Philips 2010)[101]. The Mouseion and Bibliotheka probably represent the pinnacle of pan-Hellenic culture and science. Some of its history may be myth or legend (Bagnall 2002; Hannam 2007, 2009; Yatsuhashi 2010), but there is no doubt that the Bibliotheka demonstrated many of the knowledge management concepts that underpin modern libraries.

Demetrius of Phaleron supposedly founded the Bibliotheka as a part of the Mouseion ("Temple of the Muses" - a research academy or "museum" of the arts and sciences), under the patronage of Alexander the Great's satrap, Ptolemy I Soter. Ptolemy intended the library to hold a copy of every book in the world. At its apogee in the first century BCE, the library may have held substantially more than 500,000 manuscripts, although a few tens of thousands is more probable (Bagnall 2002; Yatsuhashi 2010; Ward 2000). As well as adding to the presige, of the Ptolemy dynasty, the library existed to serve the Mouseon's scholars (Jacob 1997, 2002) To readily access the knowledge in its holdings required the development of cataloguing and indexing systems. According to Jameson (1993), Callimachus of Cyrene (ca.305–240 BC), invented the kind of hierarchically systematic catalog still used by modern libraries:

> In the Pinakes, Kallimachos devised a system by which a large collection of books could be arranged. The "lists" of the Pinakes constitute an author–title catalog and a subject catalog, the first such scientific classifications in the history of western libraries. But the catalog, as it evolved from Kallimachos' work, was much more than an aid for the retrieval of books. By adding specific biographical information about authors and compiling lists of similar or related works, Kallimachos invented the bibliography....
>
> Kallimachos had no known precedent for his work, but what he put together subsequently became a model for all librarians. For his accomplishment, he deserves to be called the 'inventor' of the catalog and the bibliography–the two indispensable tools of the scholar and librarian.

An important lesson from history discussed in more detail in EPISODE 2 – Automating Cognition is that apparently only a tiny fraction of the knowledge that had been collected in the Bibliotheca and Mouseion survived to influence the world that grew out of the Scientific Revolution. To ensure the long-term survival of knowledge requires more than writing, books and libraries. Only when recorded knowledge can be inexpensively replicated many times over for wide distribution can it easily survive disinterest, wear-and-tear, wars and natural calamities.

One of the oldest and certainly most important of the early universal libraries surviving today is the Vatican Library, founded in the 1450's. This is now open to all via a virtual tour of its origins, history, impacts on scholarship and important holdings in the early history of the book. Unfortunately, the Library, founded in the 1450's, only began to be effectively catalogued in the 20th Century. At least through the 16th Century, books were chained to benches more or less organized by subject[102]. A bench list identified the books chained to each bench, but these were sequential records on paper which meant titles were listed in the order added to the bench (Boyle 1994). Although its collections were eclectic, for most of its early history it was more concerned to protect its repository of early knowledge from scholars rather than making it available for their use.

The core technology for locating information in modern libraries is still the (now electronic) catalog. There are several major cataloguing systems in use today and all are based on systematically classifying the contents of the catalogued knowledge containers (i.e., objects)[103]

The Dewey Decimal Classification system (DDC) is first and still most widely used general classification system developed in the modern era. It is designed to cover the whole of general knowledge within an organizational scheme that is continuously revised to keep pace with the growth of knowledge. The system was conceived by Melvil Dewey in 1873 and first published in 1876. It is maintained up to date by a division of OCLC Online Computer Library Center, Inc. currently working out of the US Library of Congress[104].

The second major universal classification system is the US Library of Congress Classification[105] (LCC) system, which some think to be more suitable for the largest collections. The Library of Congress was founded in 1800, but was burned by the British when they attacked Washington in 1814. The Library was rebuilt and Thomas Jefferson sold his extensive personal collection to form the nucleus of the new Library. Jefferson's personal classification system, based on the philosophies of Bacon and d'Alembert, continued in use until it was replaced by the current system, developed in the period from 1887 to 1903[106]. The adoption of the LCC system by other libraries was facilitated when in 1901 the Library of Congress began selling copies of its own catalog cards for use by other libraries. Cole (1992) provides a history of the library.

Other commonly used "universal" cataloguing and classification systems include the Universal Decimal Classification (NISS 1997) and the Colon Classification. A core idea fully developed in Ranganathan's Colon Classification system is to describe in an indexable form, several different "facets" of the item being indexed[107].

All these systems seek to provide pigeonholes for filing (and retrieving) the entire scope of human knowledge. Only if there is a comprehensible and unambiguous scheme defining where knowledge should be stored, is it likely that someone other than the person who filed it can find the knowledge when needed. To do this reliably requires complicated administrative apparatus to accession, catalog, shelve and retrieve the printed knowledge. However, no matter how sophisticated the classification system, there has never been a completely satisfactory method for filing objects as large and complex as books by single codes able to represent their content. The situation is even worse for the contents of scientific and scholarly journals.

This was understood more than 2,200 years ago in the in the ancient library of Alexandria:

> Problems arose for works without author or title, or copies of the same work with different titles, or different work with the same title. [Kallimachos] also had to deal with scrolls that were inscribed on both sides and collective scrolls which contained works by several authors. His famous maxim 'Megabiblion, megakakon' (Big book, big evil) expresses the frustration felt ever since by librarians when they have to catalog a multi–authored work. (Jameson 1993).

Thomas Jefferson, expressed similar frustrations in describing the system he used to catalog his own library, which he sold to the Library of Congress in 1914 and which formed the basis of the Library of Congress's catalog through the 1880's:

> The arrangement according to subject is far preferable, altho' sometimes presenting difficulties also, for it is often doubtful to what particular subject a book should be ascribed. This is remarkably the case with books of travels, which often blend together the geography, natural history, civil history, agriculture, manufacturing, commerce, arts, occupations, manners, etc. of a country, so as to render it difficult to say to which they chiefly relate. Others again are polygraphical in their nature, as encyclopedias, magazines, etc.[108]

Weinberg (1996) discussed problems and limitations of complex classification systems.

> The ultimate representation of the thought content of a document, which was espoused by Ranganathan [Colon Classification], represents optimization in classification and indexing. Human beings may not require this. Pointing the user to a manageable chunk of text or number of documents that can be scanned in a reasonable amount of time for the desired fact or information would constitute satisficing[[109]] in the field of content analysis.... There is considerable evidence that users don't want intermediaries to retrieve only the single most

> specific document on a topic. Users want to select from a group of documents and make their own relevance judgments. (Weinberg, 1996:5).
>
> ...
>
> *Computers are great at counting words, but are not so successful at distinguishing the significant occurrences of words from the insignificant ones. Moreover, computers are terrible at recognizing concepts. (Weinberg,* 1996*:6).*

The conclusion from thousands of years trying to organize knowledge held in libraries, is that even the most sophisticated cataloging systems offer limited capabilities for identifying and retrieving knowledge held in books. Knowledge held in primary professional literature – the scholarly and technical journals where newly developed knowledge is first published and disseminated, is even more difficult to catalog for effective retrieval.

Episode 2 reviews the immense and continuing technological changes of the Microelectronics Revolution that have taken place during my lifetime. Episode 3 explores how these technological changes have and still are changing the ways in which we can access recorded knowledge.

EPISODE 2 – Automating Cognition

Automation Technology and its Replication

Printing was a revolutionary technology that industrially replicated recorded knowledge at a price individuals could afford to own. *We are currently in the midst of a new kind of "printing" revolution resulting from the development of an automated industrial technology able to literally print electronic circuits and chips feeding into the mass-production of personal knowledge processors (personal computers) for an equivalent price of less than what a single book cost 500 years ago.* Figure 22 exemplifies this. The book illustrated, printed in 1477, provides access to the words of a single author. Not only can the commodity laptop provide access to the complete text and image of this incunabulum from anywhere in the world (via the Internet Archive), but to a substantial fraction of the corpus of explicit human knowledge. As will become increasingly evident, these personal knowledge processors externalize many aspects of cognition that could only be carried out in organic brains.

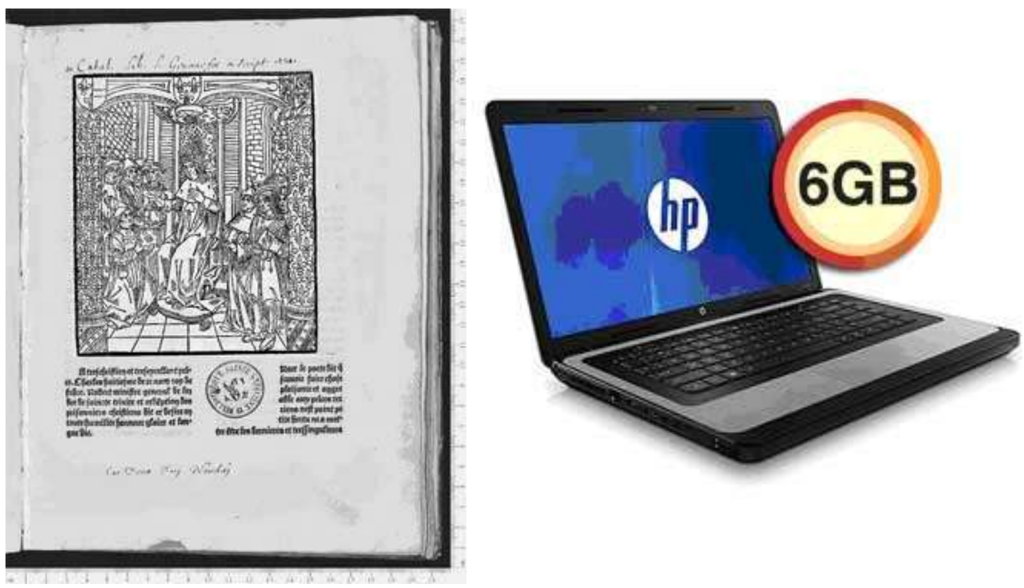


Figure 22. The book vs the world of knowledge. Left – Caesar, Caius Julius (1486), *Les commentaires de iules cesar*: publisher: Antoine Caillaut ? pour Antoine Vérard[110]. Right - HP Compaq 630 Core i3-2310M 6GB 15.6 inch Laptop LV426PA-6GB for just A$499 (RRP $869). Specifications: 15.6" display. Hard drive. Intel core processor i3-2310M. Windows 7 Home Premium 64-bit. Memory 6GB DDR3 SDRAM. HDMI. Bluetooth wireless. Integrated HP VGA Webcam and more..).

Also revolutionary is the fact that the knowledge held in and accessed electronically via the PC can be replicated "virtually" at essentially zero cost to whoever wants it, whenever they want it, and wherever they happen to be in the world. Industrially replicated microprocessors and related mass produced artifacts using *printed* circuits now give *individual people* access to what is approaching *the sum total of recorded human knowledge* for close to free! As will be explored in Episode 3, Since I started this book over a decade ago, the knowledge in significant books and journals in the English language is available on-line to be accessed by me at my desktop has grown from probably less than 10% to what is now more than 70% of the total (Hall & Nousala

2010a; Hall, Nousala & Best 2010; Hall, Nousala & Vines 2010)[111], while the price to access a given volume has probably diminished by an order of magnitude or more.

And still more revolutionary yet, is the fact that the electronic circuitry of the computer is actually able to perform automated logical operations on knowledge it can access entirely within the domain of Popper's world 3 without requiring any subjective involvement from the human World 2. Arguably, the physical processes within the computer are creating its own world 2.

The present Episode describes how computing technology came to be, explores how it has evolved, and demonstrates how truly revolutionary it really is. Episode 3 will describe cognitive impacts of the technological revolution from the viewpoint of individual cognitive revolutions; and Episode 4 and Episode 5 will examine the even more profoundly revolutionary impacts on organizational level cognition that transcends the individual level.

Forgotten and Invisible Generations of Computing and Automation

The history of ancient technologies is often not considered when thinking about today's technologies - for good reason. The technology of the ancient Hellenistic world is only known to us through a relatively few scraps of writing (original works, anecdotes, compendia, etc.) that may or may not have been written by those they are attributed to, and that had to survive many copyings and often translations into other languages (e.g., Arabic, Latin, Egyptian, etc., into modern English, French, German, Italian, etc…) before they were printed. The inventors of this technology are also poorly known, via a few biographical notations. However, enough information survives in these scraps that they reveal the existence of highly sophisticated tools and thinking. For example, today's computer technologies have some genuinely ancient roots. Automation and computing were among the first high technologies to be developed in human history. The "documented" history begins in ancient Greece, possibly contemporaneously with the founding of the Mouseion and Bibliotheka at Alexandria in the third century BCE under the reign of Ptolemy Soter (Bedini 1964; Koetsier 2001; Valavanis et al. 2007). Two threads of technology developed in that time for the apparent amusement of leisured aristocrats those who sought priestly power. These intersecting technological threads produced tools for astronomical measurement and prediction and for the automation of temple "magic". Measurement, calculation and geometry were clearly important in both threads. After nearly being lost in anarchy and the dark ages, the very tenuous threads re-emerged in the Renaissance and Enlightenment as clockwork to be involved in the genesis of mass production and modern computing.

Antikithera Mechanism – 2100 year old gear driven analog computer/simulator

So far as we know, given the sparse and imperfect records that survive, the first innovators in geometry and machinery we know much about were Thales (c. 620 BCE – c. 546 BCE - O'Grady 2004), one of the first to apply scientific thinking; and Archytas (c. 428 – c. 347 BCE - Huffman 2011), who was reputed to have made an automated dove. Although there is little direct information about the people themselves, better known writings about the ancient science and technology of that survive are those attributed to Euclid, associated with the Mouseion in Alexandria around 300 BCE (O'Connor & Robertson 1999d) and Archimedes (c. 287 BCE – c. 212 BCE) of Syracuse (in Sicily – a colony of Rhodes), who may have studied in Alexandria (Rorres 1995; O'Connor & Robertson 1999b). Most of what was known about early geometry was systematized under Euclid's name, and it is clear that a high level of geometrical and mathematical knowledge would have been required to construct the technological devices we know anything about. A number of sophisticated inventions have been attributed to Archimedes, possibly including the Antikythera Mechanism[112]. This thread of ancient Greek automation leads directly to analog computation.

In 1900-1901, the remains of a small and highly complex mechanism of bronze gears was recovered from an ancient shipwreck found off the island of Antikythera, between Greece and Crete (Rice 1995; Bako 2001). Besides a few small and corroded pieces of a bronze artifact, the ship was carrying a heavy load of Greek statuary and other high status goods. Based on reconstructions of what has become known as the Antikythera Mechanism and inferences drawn from the surviving parts, the bronze artifact appears to have been a highly sophisticated gear driven analog calculator (MacLennan 2007) of calendrical and astronomical events, making it by far the most complex of the earliest known calculators (**Error! Reference source not found.**).

Figure 23. Reconstruction of the Antikythera Mechanism. A full scale version by John Gleave, Orrery Maker, based on the Price (1959) reconstruction. Height 12.25 inches. Left: The front dial - showing the annual progress of the sun & moon through the zodiac, against the Egyptian calendar, rendered in Greek on the outer annulus (In the latest reconstructions, the front dial includes at least 10 more gears and five more pointers for the planets known to the Greeks - Freeth et al. 2006, 2008, Freeth & Jones 2012). Right: The back dials. The upper back dial displays a four year period and has five concentric inscribed rings, most probably each with 47 divisions giving the Metonic Cycle of 235 synodic months, which equals 19 solar years. The lower back dial gives the cycle of a single synodic month, and the subsidiary dial the Lunar year of 12 synodic months (Pictures from Grand Illusions).

All or parts of 30 different triangularly toothed gears have been identified in the surviving fragments (Efstathiou et al. 2012). Reconstructions of the physical device based on the extant fragments (Freeth et al 2006, 2008; Evans et al. 2010; Freeth & Jones 2012, Efstathiou et al 2012; Wright 2012) postulate about 40 gears, 18 shafts, a double axel bearing with 2 off centered axes and one axle-shaft. Improved readings of an inscription that was on the Mechanism's back cover that described its external features and displays leave little room for doubt that the front display incorporated revolving pointers bearing little spheres to represent all five planets known in antiquity. The pointers predicted the apparent motions of the planets around the Earth against a zodiacal calendar[114]. In 2008, in association with the Freeth et al. article, Nature published a video presenting a conservative view (i.e., not including the gears and pointers for planetary motions) of the history and complexity of the Mechanism.

Several attempts have been made to understand the Mechanism's functions (Price 1959; Koetsier 2009; Valianatos 2012; Wright 2012; Freeth & Jones 2012). According to Wright and Freeth & Jones the Mechanism provides a 19 year calendar of the Olympiads; a predictor of lunar and solar eclipses, positions of the Sun, Moon, Mercury, Venus, Mars, Jupiter and Saturn in the zodiac based on Babylonian and Archimedean tables; and many other functions (Evans et al. 2010; Gourtsoyannis 2010; Papathanassiou 2010; Pastore 2010; Moussas 2011).

Based on these reconstructions, other recovered contents of the wrecked ship, and relatively detailed descriptions of similar technology in surviving writings by the contemporary Roman orator and statesman Marcus Tullius Cicero; Price (1974), Pinotsis (2007) and Freeth & Jones (2012) suggest that the Mechanism was made by the polymath Posidonius on the island of Rhodes from formulas developed by Archimedes[115]. The island of Antikythera is on the direct sailing route from Rhodes to Rome. Freeth et al. (2008) have deciphered the names of the months used, which suggest that the Mechanism was intended to be used in Corinth or a Corinthian colony. All the dating evidence available including textual labeling on the Mechanism itself (Price 1974, Weinberg et al. 1965, Pinotsis 2007) are consistent with archeological and radio carbon evidence suggesting the ship carrying it was wrecked within a few years after 70 BCE (they suggest "limits 80-50 B.C. for the date of the shipwreck, with an earlier date more likely than a later one").

Price (1974) gives a translation of one of Cicero's writings where he described a mechanism representing all five planets:

> Suppose a traveler to carry into Scythia or Britain *the orrery recently constructed by our friend Posidonius, which at each revolution reproduces the same motions of the sun, the moon and the five planets that take place in the heavens every day and night*, would any single native doubt that this orrery was the work of a rational being? These thinkers however raise doubts about the world itself from which all things arise and have their being, and debate whether it is the product of chance or necessity of some sort, or of divine reason and intelligence; they think more highly of the achievement of Archimedes in making a model of the revolutions of the firmament than of that of nature in creating them, although the perfection of the original shows a craftsmanship many times as great as does the counterfeit. De natura deorum, II, xxxiv-xxxv (87-88), Rackham's translation. [from Price 1974: p 57]

In an earlier passage referring to Cicero's writings, Price (1974: footnote, p. 9) speculates that:

> …there is even a faint but quite unprovable possibility that the ship was carrying the goods of Cicero who had been staying on Rhodes 79 to 77 B.C. and had seen a recently constructed geared planetarium instrument there at the School of Posidonios. I do not know how reasonable it is to think that the statuary from the wreck is such as might have been purchased by a Roman gentleman of taste at this time. Cicero does not mention any loss of his baggage, nor does he write of any relics of this period brought home with him.

Another possibility is that the ship was carrying spoils from the war the Romans were fighting around this time with King Mithridates IV of Pontus in Asia Minor (Marchant 2010).

Papathanassiou (2010) ventures an alternative hypothesis to the apparent consensus of Price, Freeth & Jones, etc., that the Mechanism was made by or for Posidonius, to propose that:

> the astronomical theories of Hipparchus during the years of his activity in Alexandria have been combined with the necessary technical knowledge provided by Archimedes's works (and available to Alexandrian astronomers and mechanicians) in this sophisticate[d] astronomical device very likely constructed in Alexandria. The answer to the question: «Were it possible that this exceptional device has been made for and used by Hipparchus himself?» [who "was active in both Alexandria and Rhodes… between the years 162 BC and 127 BC"] is left to the reader of [his] article.

However, Gourtsoyannis (2010) argues

> the Mechanism modeled the variations in the Moon's angular velocity as seen from the Earth, to better than 1 part in 200. A major implication of this analysis is that the Antikythera Mechanism of the 2nd century BCE modeled the anomalistic motion of the Moon more accurately than [Claudius] Ptolemy's account of Hipparchus's theory of the 2nd century CE.

Edmonds' (2011) estimates of mechanical inaccuracies in the measured and postulated gear trains in the Antikythera Mechanism were large enough that the analog predictions of some events (e.g., eclipses and the zodiacal crossings of planets) would be off by several days, thus suggesting that this kind of gear-driven computer would be too inaccurate for navigation (performed by astrolabes and tables) or digital commercial calculations (performed by the abacus). Thus, this particular technology was more likely for teaching theory and for display purposes. However, one wonders what today's world would have been like if this stream of technological development had flourished rather than disappearing.

Automated theaters, temples, and toys

The most sophisticated products of Hellenistic automation are the temple "miracles" by Heron of Alexandria. Following Koetsier (2001: p. 589-590, from Steinbuch),

> An automaton (Greek, 'self-mover') is a mechanical device which (after releasing a brake) executes a function on its own and in a completely determined way… A programmable machine is an automaton that can execute (significantly) different functions depending on the information stored on one or more material information carriers, that are part of the automaton.

The economy of ancient Hellenic world was based largely on slavery. The building of machines able to act autonomously from the provision of obvious human interference was not developed to save human labor, but rather out of scientific curiosity and for the performance of magic and "miracles" in association with religion and theater. However, this narrow but sophisticated market stimulated the development of technologies that are impressive, even by today's standards.

Archeology and the surviving written history from the Hellenic Mediterranean of the First Millennium BCE tells us the society revolved around its many competing temple-based religions and theaters. Religions and theaters depended economically on the quality and wizardry of the spectacles they could create. There was no need or economic purpose for automation in the context of commerce, as it was far cheaper to employ intelligent and self-reproducing slaves to do work than to design and construct complex apparatus from often rare and expensive materials – leaving slaves with time on their hands to think about the condition of slavery.

However, there was a market for those who could amaze an audience by building miraculous animated contrivances that were lifelike or appeared to be controlled by the unseen hand of a god. Surviving writings describe complexly programmed apparatus driven by gravity and/or water via complex mechanics. Weights and pulleys operated pegged shafts that operated and controlled a variety of processes via hidden cords and pulleys, possibly aided by hydraulics and pneumatics (Bedini 1964; Evans 1999; Koetsier 2001; Valavanis et al. 2007). Many of these ancient "engineering" writings have been attributed to Heron, who may have lived in Alexandria from c. 10 AD to c. 85 AD (O'Connor & Robertson 1999c; Papadopoulos 1997). In the following discussion, the Hellenic knowledge of automation will be attributed to Heron even though it clearly would have been built over centuries by at least a guild of temple and theater technicians, many of whom may have been trained by or associated with the Mouseion.

One of the more "commercial" inventions used to help fund the temples described in these writings was a coin-operated automatic vending machine that miraculously transmuted a coin into holy water (**Error! Reference source not found.**)[116]. Two much more sophisticated examples of automated technology from Heron's writings are particularly well documented and demonstrated in the web pages of Hellenica's Ancient Greece/Science and Technology[117], i.e., the Self-Moving Automatic Theater (Figure 24)[118] and the Staton Automatic Theater[119]. More detailed descriptions of the mechanisms are provided by Xagoraris (1991).

Although Heron's ideas and inventions relating to automation were developed to entertain and amaze, the writings describing his mechanical ideas were good enough to be passed down through the centuries via those cultures that appreciated miraculous spectacles or priceless toys that boggled the mind. According to Boas (1949), Heron's work on pneumatics was referenced via Greek writings in the 12th and 12th Centuries with complete manuscripts appearing in the late 15th and early 16th Centuries, with translations into Latin beginning around 1500, followed by further translations into vernacular languages, with mechanisms actually being applied by the 17th Century.

One path Heron's knowledge of automata followed to reach western Europe seems to have been via Al-Jazari's Book of Knowledge of Ingenious Mechanical Devices written in Arabic (see MuslimHeritage.com and Nadarajan 2007). Al-Jazari was apparently a great technician and inventor in his own right as illustrated in Figure 25, in addition to building on and transmitting the Greek knowledge.

Randell (1994) observes that Heron's use of pegged cylinders and winding patterns of strings represented the first mechanism for storing a program for automating a device, and describes how these ideas were implemented and passed down through time. Koetsier (2001) does not consider these to be a program, although examination of the realizations of the automatons referenced above demonstrates many degrees of freedom for altering the automatons' behaviors.

Figure 24. Part of the mechanism for Heron's Automatic Theater illustrating the programmed controls for drumming and cymbals (metal balls held in perforated wheels on the upper right of the mechanism are dropped one-by-one onto the drumhead as the attached cord is wound onto a shaft, where they then roll through one of the hole in the drum mechanism and fall onto the cymbals). The lengths of the strings and the way they are wound on pegged shafts controls the sequence of events[120]. The mechanics of the operation are shown and explained more clearly on a detailed video of the complete mechanism. (from Hellenica's Ancient Greece/Science and Technology).

Most interestingly, Bowles (1966) also traces the origins of the mechanisms in the first European musical instruments operated by keyboards and weight driven clockwork back to Heron's automata:

> The mechanical principles upon which these latter instruments were based came more or less directly from the Automatic Theater of Heron of Alexandria (first century A.D.), one of two treatises by this author known to the West in the Middle Ages. It is significant that the aim of such sophisticated mechanisms was not only to make things move but to have them sound as well - in other words, complete simulacra, such as singing birds, set in motion by waterpower, wind, or bellows. Greek, Roman, and Alexandrian science, preserved through many centuries in Byzantium, was acquired by the Arabs, who developed the art of astronomical instrument-building to an extraordinary degree. Among the texts translated into Arabic and thus preserved for posterity were the works of Heron.
>
> During the thirteenth century Europe underwent what has been termed a mechanical rebirth…. [I]n 1274 came the transmission westward of the Islamic tradition of model-making which had flourished from the mid-tenth through the twelfth century. Part of *this important body of material included astronomical treatises, instrumentation, linkwork, and gearing. These influences led to a renewed interest in things mechanical and, ultimately, to the weight-driven clock.* During this period in Europe, both speculation and experimentation in the field of mechanical science took place by such scholars as Roger Bacon and Albertus Magnus. [Bowles 1966: p. 157-158; my emphasis]

Still following Bowles, the concept of an escapement as used both in keyboards and the development of church clocks with their automated figures and bells was also received from China around this same time. The keyboard technology developed for controlling the sounding of musical instruments also provided the technological basis for typewriter keyboards to capture text onto paper. Cams also provided a means for programming mechanical actions.

Figure 25. Ibn al-Razzas Al-Jazari's autonomous musical toy (Smithsonian via Wikipedia). A video by MTE Studios based on Al-Jazari's written explanation demonstrates how it worked[121].

18th Century androids and automatons

The pinnacle of mechanical clockwork and cam-driven automation was reached in the last half of the 18th Century Europe[122]. This re-born technology is best illustrated by watches, clocks and mechanical toys constructed for the amazement of aristocrats by the watchmaker Pierre Jaquet-Droz and his associates[123]. The most complex of these were three exquisitely beautiful androids: The Writer (Figure 26) is an android boy who is able to handwrite any message up to 40 characters in length using a quill pen and ink. The ~6000 components of this near life-sized android include a stack of letter cams in the boy's backbone, where the formation of each character is controlled by the coordinated actions of a separate cam for each the three degrees of arm motion (up/down, left/right, and lift/press on the pen). Each letter (and space) to be written is selected by a specifically shaped peg inserted into one the 40 slots around the circumference of the letter sequencing cam in the hip region. A number of detailed photos of the selector and cam mechanisms can be accessed via the Web[124]. Jaquez-Droz's other androids are the Musician (3000 components) and the Draughsman (2500 components). Prof Shaffer[122] argues that mechanisms invented for automatons formed the basis for automated weaving machines of the Industrial Revolution.

Figure 26. The Writer automaton, constructed from around 6000 components between 1768 and 1774 by Pierre Jaquet-Droz, his son Henri-Louis, and Jean-Frédéric Leschot in Switzerland (From Miklós 2013).

Forgotten knowledge is lost knowledge

We can infer from the material cited above and a great deal more information on the ancient Greek/Hellenistic world of the half millennium BCE beyond the scope of this book that there was an active community of scientists, mathematicians and practitioners supported by skilled metallurgists and crafts people who were actively building and sharing knowledge between at least two centers: Ptolomaic Alexandria in Egypt, and Rhodes on the Adriatic together with Rhodes' colonies such as Syracuse (on the island of Sicily). At least in the early part of the first century BCE, most of this theoretical and technological knowledge was probably documented in the Bibliotheka and taught in the Mouseion in Alexandria, and it is likely that there would have been a community of artisans also around the Mouseion. According to Moussas (2011), a factor leading to the development of this scientific community,

> was the Greco-Egyptian bureaucracy that was necessary for running the enormous state Alexander the Great, the King of the World… has created. In the new city of Alexandria in Egypt it was necessary to have many well-educated people keeping record of all transactions, commerce and shipping. This led to a large demand for educated people and education that was previously unknown, so it led to new types of education and this eventually led to advances in science and philosophy. Education was previously limited only to few and in the post Alexander era it becomes a necessity for many.

One cannot help but wonder what would have happened if the science and technology in the Hellenic world relating to automata and the Antikythera Mechanism had continued to develop. Would humanity have been space travelers a thousand or more years ago? This raises two major questions. Why did the science and technology not continue to develop? Why was it forgotten? In other words, why has humanity had to wait some 1500 years before these threads of technological development were picked up again as a stream of innovation?

Some of the knowledge may have been lost when a good part of the Bibliotheka was apparently accidentally burned in the Siege of Alexandria (48-47 BCE) between Julius Caesar and Cleopatra (the last Ptolemaic Pharaoh of Egypt) on one side, and Cleopatra's brother Ptolemy XIII on the other. As described in the Wikipedia article on the Bibliotheka and by Philips (2010), there were probably several more destructive events before the Bibliotheka was completely dissipated, leaving only a few literary scraps of information about the Greek technologies that were finally "rediscovered" in the Late Middle Ages and Renaissance. The only technologies surviving in active use were some of the irrigation and military technologies (e.g., Archimedes screw pump and artillery) and some of the simpler mechanisms of automata and clocks that survived in the Islamic world. Only with the Industrial Revolution did European/"western" technology surpass that of the Hellenistic world. So, why this promising technology was lost for more than a millennium.

First is the fact discussed earlier that handwritten documents are extremely labor intensive to produce and reproduce, where the labor must be provided by literate people. At any one time, it is likely that most documents beyond extremely popular ones ever existed in single or a very few copies at most. Once the last copy of a document is lost or destroyed, the contained knowledge is also lost – so, much knowledge is simply lost through wear and tear. According to the stories, the Bibliotheca tried to collect manuscripts from around the world – and many of them would not have been copied….

More importantly, it seems that only a small number of the rich elites of the Hellenic world were interested in high technology and science, as these offered little of commercial value in the slave-based economy of the day. Warburton (2009: pp. 81-82) writes,

> The reconstruction of the Antikythera mechanism reveals that interlocking gears were used to predict the movements of the sun, moon and planets, demonstrating [the existence of] both scientific knowledge of the universe and the technology which made the mechanism work in the second or third century BC…. The device is viewed as being ahead of its time, and this is a rather uncomfortable fact for those who dismiss science and technology in antiquity….
>
> Obviously, this sophisticated device is an unpalatable truth in the current worship of science and technology, which is usually justified in economic terms. The conundrum would increase if this 'technological anomaly' had been produced in an ancient market economy, meaning that it is extremely important that it did not seem to have any consequences…. *Investment in technology in antiquity was restricted to the palaces and the elites, and these had no reason to use technology for productive purposes. Science and technology could be dedicated to the construction of pyramids and toys such as the Antikythera mechanism, which were the exclusive interest of the elite. However, the low value of labour… meant that improving productivity would have served no purpose.* [my emphasis].

The written knowledge of these wondrous things would have been of interest (or even understandable) to very few people in the world – who may not have even known of they existed, and there was no commercial need/interest to copy the knowledge from where it existed and to circulate it to other locations. Only those very few people who were rich enough to travel and had the insatiable curiosity to know would find out about the technological wonders. For example a few scraps of information were recorded in texts by Cicero. These were preserved and replicated through the Dark Ages to survive into the era of printing because they came to be used in teaching Greek, Latin and Greco-Roman culture (Eisenstein 1979, 1983; Woods 1989, Abel 2011)

A final factor, relating more directly to the specific technologies of automation was the rise of Christianity in the Roman Empire. Christian religious dogma anathematized all aspects of pagan religion, and of course the temple technologies that went along with them. Scherrer (1984; p. 600) detects specific references in Revelations 13 to these technologies as they may have been used in the Imperial Cult. Scherrer argues that John, the supposed author of Revelations,

> to all indications… believes that these were genuine miraculous signs worked through supernatural agency - albeit satanic. In this he shares the belief of many early Christians, who, while not denying miraculous signs in pagan cults, explained them as the work of demons.

In other words, genuine knowledge and understanding of the science and scientifically-based technology of the ancient Greek world was a thin veneer on the top of Hellenic society that could only be held and developed by idle and literate elites who had the time and resources for theoretical speculations. Outside of creating religious spectacles and tools for warfare, which were seen to be unworthy applications of deep scientific understanding, there were few applications for scientifically-based tools in a slave-based economy. The knowledge was worth little to economically pragmatic Romans and was anathematized by the new monotheistic religions of the Christian Era.

Only when the surviving scraps of writing were finally turned into print, multiplied, and disseminated did they begin to stimulate the sequence of transformative knowledge building revolutions: Renaissance ("re-birth" – 14-17th Centuries), Protestant Reformation ("new thinking" – 16th Century), Scientific Revolution (16th and 17th Centuries), Industrial Revolution (18th and 19th Centuries), and the development of the Post-industrial society eventuating in the continuing exponential growth of knowledge and understanding of the world that we see today.

Zeroth Generation: Mechanical Technologies for Calculation

Unlike automata that amused the elite, the abacus and counting sticks (see Numeracy, Counting Boards, Chinese Counting Sticks, and the Abacus) that facilitate mental calculation, and the lost and forgotten Antikythera Mechanism, the different mechanical technologies considered in this segment were practical cognitive tools that actually gave answers. These flourished into the 20th century, where they provided the basis for most scientific and engineering calculations extending into the early years of space exploration.

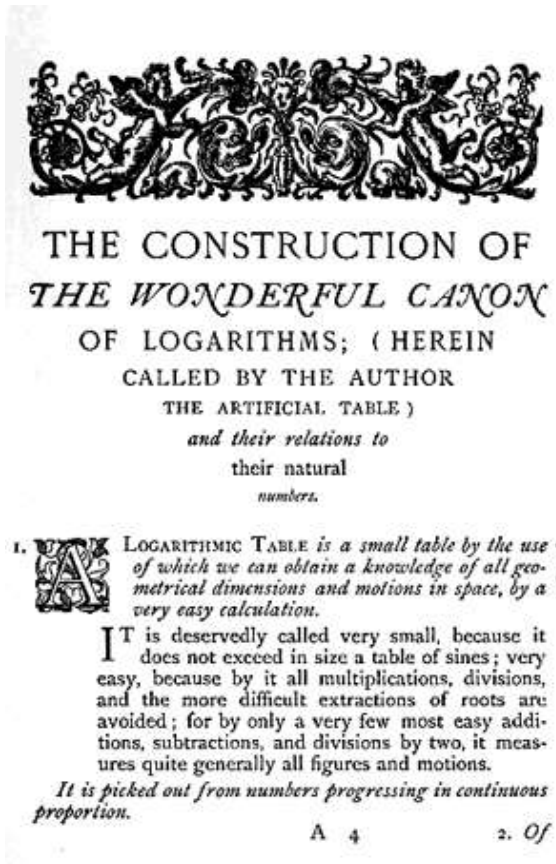
Logarithmic technologies

A major advance in calculating technology began with John Napier of Merchiston's discovery of the properties of numbers in arithmetic vs. geometric progressions that allowed him to invent the use of logarithms[126] (Figure 27) and simple addition and subtraction to replace the multiplication and division of very large numbers as required in astronomical calculations (Smillie 2010; Clark & Montelle 2012). Napier's *Mirifici logarithmorum canonis descriptio*, published in 1614, contains 57 pages of explanatory matter and 90 pages of tables, and has been regarded as the most important publication in the history of British science after Newton's Principia.

The construction of log tables by hand is long and laborious (Wikipedia)[127]. However, once the tables exist, complex numerical calculations involving large numbers, powers, roots and trigonometric function (e.g., in astronomy, engineering, physics, etc.) become much easier where long multiplication and division can be replaced by simple table lookups plus addition and subtraction. Given that reading the tables requires interpolation between the precalculated intervals, the precision (i.e., the number of significant digits that can be relied upon) of calculations is determined by the number digits in the calculated - e.g., 4, 8, etc.)[128].

Achieving higher precision involves a trade-off, as each significant digit used in constructing the table increases the effort to produce the table by a factor of ~10. In fact, one of the earlier uses of automatic computers was in the calculation of log tables. Thus, even when multiplied by printing, log tables with higher precision were quite bulky to use and expensive to procure, given that the number of entries increases by a power of 10 with each additional significant digit.

However, even though human cognition was still required calculate using log tables, the task was greatly simplified by the ability to simply look up relationships rather than having to calculate them out by long-winded algorithmic processes. This greatly aided the labor of engineers in the industrial application of scientific ideas to mechanical engineering in the Industrial Revolution.



THE CONSTRUCTION OF
THE WONDERFUL CANON
OF LOGARITHMS; (HEREIN
CALLED BY THE AUTHOR
THE ARTIFICIAL TABLE)
and their relations to
their natural
numbers.

1. A LOGARITHMIC TABLE *is a small table by the use of which we can obtain a knowledge of all geometrical dimensions and motions in space, by a very easy calculation.*

IT is deservedly called very small, because it does not exceed in size a table of sines; very easy, because by it all multiplications, divisions, and the more difficult extractions of roots are avoided; for by only a very few most easy additions, subtractions, and divisions by two, it measures quite generally all figures and motions.

It is picked out from numbers progressing in continuous proportion.

A 4 2. *Of*

Figure 27. The first page of The construction of the wonderful canon of logarithms. First published in Latin in 1614 and translated from Latin into English with notes and a catalogue of the various editions of Napier's works by William Rae Macdonald (1889) (via Internet Archive)

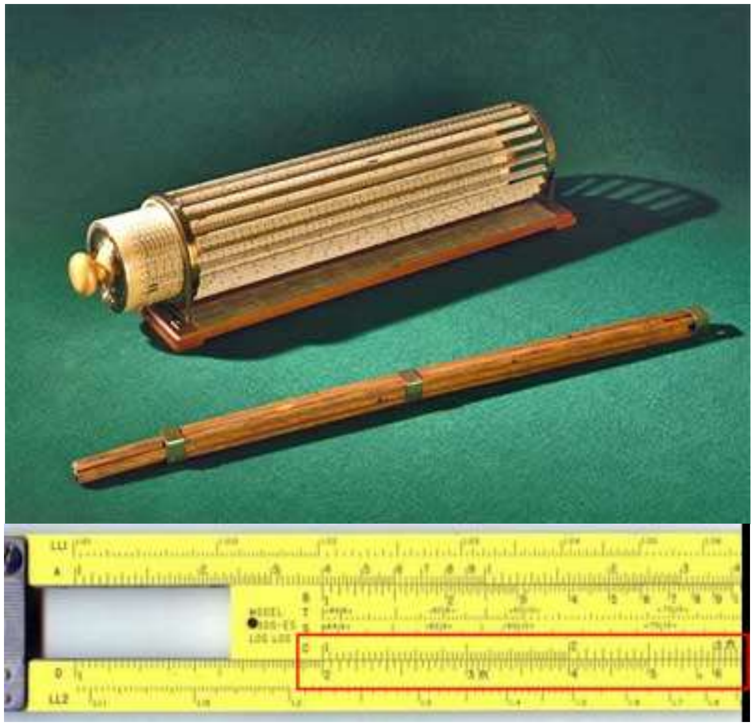


Figure 28. Slide rules. Top - Thacher's slide rule, an important American contribution to slide rules, capable of accurate reading to four decimal places (Science Museum/Science & Society Picture Library). Middle – the first slide rule design after Oughtred, made by Robert Bissaker, 1654. Bottom - A slide rule positioned so as to multiply by 2. Each number on the D (bottom) scale is double the number above it on the C (middle) scale (Wikimedia Commons Benjamin Crowell).

Following the invention of logarithms, it was soon recognized that log values could be easily represented as sliding graphical scales (slide rules), that could be slid in relationship to one another working as an analog computer to simplify calculation without the need to use unwieldy log tables. The first slide rule of this kind was invented by William Oughtred around 1650 (Figure 28, middle). The common 10" rule I learned to use (Figure 28, bottom) was accurate to three significant figures. To give 4 significant figures the scale needs to be 10 times longer. This kind of accuracy could be achieved with spiral scales, either on a cylinder (Figure 28, top) or a disk. (Figure 29).

Figure 29. Dietzgen 1797B (Gilson Binary) 21.1cm dia. Made in USA by Gilson for Dietzgen. Front Scales: C, CI, A, K, Log, LL1, LL2, LL3, LL4, Binary, Fraction, Drill thread, Millimeter; Back Scales: Degrees, S, T, Degrees, S, T, Degrees, S, T, Fractions (Click picture for enlarged view - International Slide Rule Museum)

From the 1700s through to the 1960's every mathematics, science and engineering student was required to learn to use logarithms and slide rules, as these were the tools of choice for performing all but the simplest calculations. The International Slide Rule Museum (2006) offers an Illustrated self-guided course on how to use the slide rule and provides a fully working simulation of the kind of Pickett slide rule most students, including myself, would have used in the 1950's and 1960's. The Museum also provides a fully working simulation of log/log scales. As a university student, I also used a 21 cm circular slide rule very much like that shown in Figure 29.

It is probably true to say that without computational labor saved by logarithms and slide rules, today's science and technology would be much less advanced.

Gear-driven digital *calculators*

Hand-operated gear-driven digital calculators that could add, subtract, multiply and divide were first invented in the 17th Century. Blaise Pascal's Pascaline in the 1640's is the best known. Simple and inexpensive tooth driven adders and subtractors known as Addiators and Addometers were developed in the 1880's and also remained popular up to the 1960's. My father used Addiators for many years to track the performance of his share portfolio. Individually, the machine didn't last long because they were only stamped out of sheet metal, but they also cost so little they would be thrown away if jammed to be replaced immediately by a new one.

In the 1820s Charles Babbage designed highly sophisticated clockwork digital mechanical calculators (the difference engines) able to print mathematical tables (see the analog Antikythera Mechanism), and even a programmable general purpose machine controlled by punched cards called the analytical engine. Although Babbage's designs could have been built with available technology, the cost would have been immense and funding was never provided. A 6.45 min video explains some of the background and demonstrates a working model of the Difference Engine #2, completed in 2008. Thelen (2008) explains how it would have been operated.

By the last quarter of the 19th century much simpler pinwheel calculators were being produced commercially (Tafoya 2002), with the most successful Odhner design (Figure 30) being in commercial production for nearly 100 years, from 1874 through the 1970's (Tout 2008; Odhner ????). The mechanical complexity some of these systems required is illustrated by John Wolff's disassembly of the Original-Odhner 127 calculator (from a version of Wolff 2009 archived in 2005).

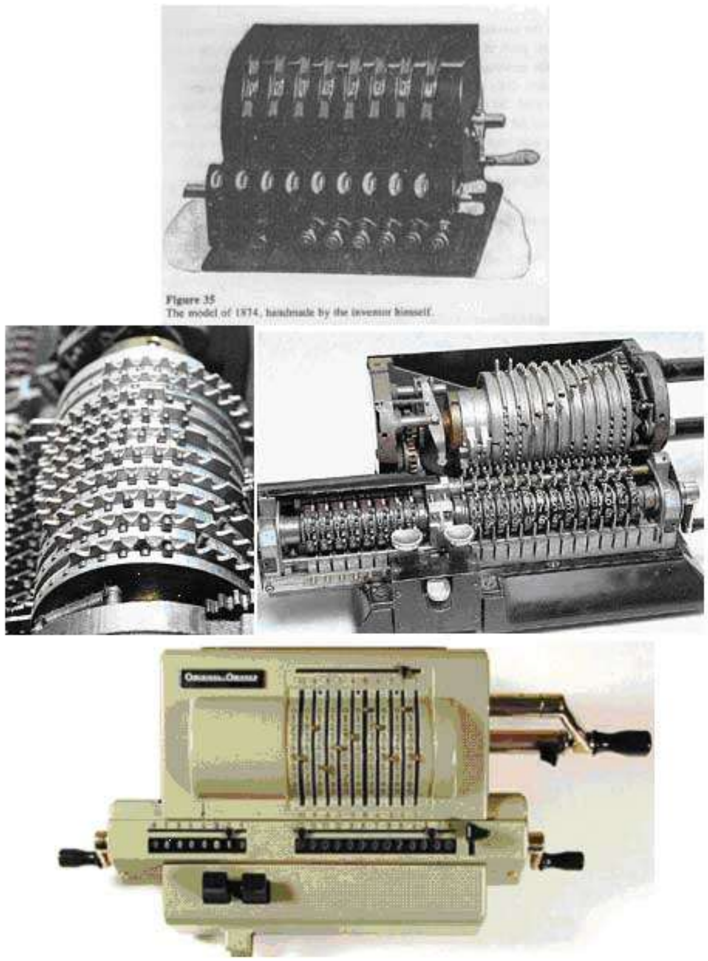


Figure 30. Odhner pinwheel calculators. Middle row from Tout (2008), Top and bottom from Odhner (????). Top shows the original machine built in 1874. The middle row are machines of 1935-45 vintage. The left picture, with the covers removed, shows the mechanism. The right hand picture shows the cog-wheel set for the number (reading from top to bottom) 0087654321. The bottom picture is a 1970's vintage machine. Click video to see and hear the calculation of a square root.

The electrically driven proportional and differentially geared four-function calculators for performing numerical calculations in engineering and science (Figure 31), developed later than the pinwheel versions above, were brought to a high peak of perfection in the middle of the 20th century[129]. How complex these became is illustrated by Wolff's disassembly of the Marchant "Figurematic" Model 10DRX calculator (Wolff 2010). As a science student, I never had an opportunity to use the punch card data processing technology personally, but I did occasionally gain access to some of the marvelous mechanical calculators for carrying out the arithmetical calculations required for physics or biology experiments. Despite the fact that these machines easily fit the desktop, they were not "personal computer" commodities in their day. The top of the line calculators shown here would have cost on the order of $2,500 in the late 1960s. By comparison to the $450 I recently paid for the notebook I am now using for producing this manuscript, in today's inflated dollars these mechanical calculators would have cost in excess of $25,000[130]. Although much more expensive than using logarithms and slide rules, this was true digital computing technology, giving exact results within the range of the numbers they would work with.

All of these calculators required the manual entry of numbers for each calculation, and most also required the results to be manually transcribed to paper – although a few actually printed out their results to paper.

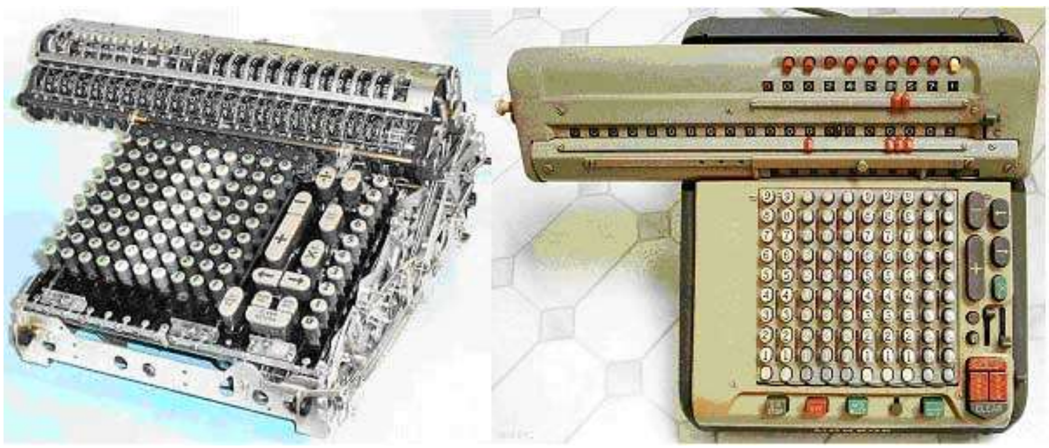


Figure 31. (left) The Marchant Figurematic based on proportional and differential gearing (from Wolff 2009). Wolff shows the complete disassembly of this machine. (right). Monroe electromechanical calculator technology was based on cog wheels and levers (from Museum of HP Calculators: Early Calculators). Both were driven by electric motors. See (and hear!) a Monroematic in operation.

Automating calculations with technology from the weaving industry

Manually writing and administering business records on paper is expensive, slow and fallible. Starting in the 1890's large and wealthy information-based organizations began looking for ways to automate record keeping and administration.

Reducing costs and getting results faster were the major incentives in the last decade of the 19th Century for the US Census Bureau to adopt Herman Hollerith's revolutionary use of punch card technology. Hollerith's technology was adapted from Jacquard systems developed in the first decade of the 19th Century to record fabric patterns and control automated weaving looms[131] (which, in turn was arguably a spin-off from the technology of the 18th Century androids and automatons). With processing of the 1880 census still incomplete, Hollerith won the bid to provide improved technology for tabulating the 1890 Census (Russo ????; O'Connor and Robertson 1999). Census information was collected manually, and the information was later punched onto cards for further processing by Hollerith's punch card tabulating machines (Figure 32). The data from the 1890 census took about three months[132] to process with the punch card tabulators instead of the two years estimated for previous hand counting procedures. Hollerith founded the Tabulating Machine Company to widely commercialize his tabulating machines. Between 1902 and 1905, he automated card feeding, developed a way to read moving cards, and standardized card formats. After new management and mergers with computing weight scale and time recording companies, Hollerith's company became IBM in 1924.[133]

Digital computing – where numbers and letters are encoded in binary bits (i.e., off/on) - began with punch card and tabulating technology, where the presence of presence of a hole in the card allowed a switch to close ("on"), and the presence of paper between the contacts kept the switch open ("off"). Compared to mechanical calculating where numbers are keyed in, tabulating machines used combinations of holes to represent decimal digits. Until the invention of practical electronic computers in the 1950's, punch card tabulating technology (or the related paper tape technology[134]) provided the only way to automate record processing, and the automation was limited to comparatively simple counting and accounting activities[135]. Counting, sorting and other processing tasks were achieved mechanically - doing arithmetic using gears, cams and spring-loaded pins. From 1928, standard punch cards were divided into 80 columns, where the pattern of holes punched in each column encoded a number or alphabetic character[136]. The 80 alphanumeric character contents of each card could be read or processed, and printed out as lines of text and numbers on a paper report for human consumption.

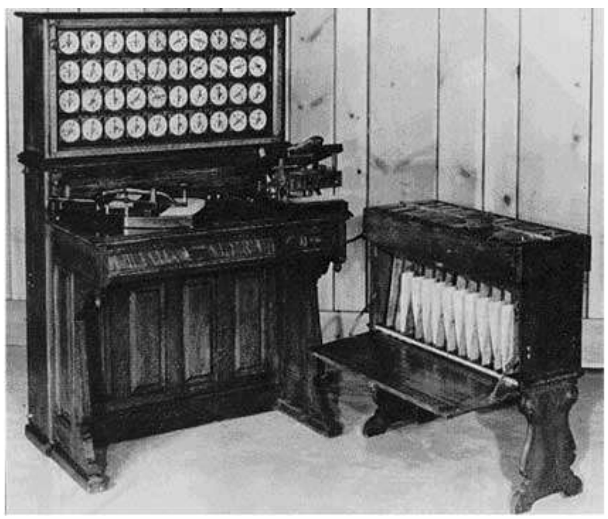


Figure 32. Hollerith's 1890 Tabulating Machine. The results of a tabulation are displayed on the clock-like dials. A sorter is on the right. On the tabletop below the dials are a Pantographic card punch on left and the card reading station ("press") on the right, in which metal pins pass through the holes, making contact with little wells of mercury, completing an electrical circuit. All of these devices are fed manually, one card at a time, but the tabulator and sorter are electrically coupled (From Hollerith 1890 Census Tabulator *in* da Cruz (2008). Click the picture above to see an IBM card sorter from the 1950s in operation.

When tabulating machines incorporated electric relays, what they did with information punched into or read from the cards could be manually "programmed" using plug boards - where jumper wires connected relay circuits for various counting and calculating functions. The latest tabulating machines produced used a punch card wrapped around a drum to specify how each column of punches on a data card should be processed. Here, not only were the numbers represented using weaving technology, but the type and sequence of the tabulations was determined by the holes in the card. Processed outputs could be stored for further processing as punched cards or delivered to users as printouts. In the 1960's and '70's, even though punch cards were no longer used for processing, they continued to provide a data capture interface with the increasingly powerful digital computers, with the cards forming processable transaction and accounting records[137]. The peak consumption of punch cards was in 1967, when the US consumed approximately 200 billion cards - or about 1,000 cards for every living person in the US at that time. At least until end the 1990's, some organizations were still using punch cards for ancient "legacy" systems (Dyson 1999).

First Generation: Electronic Computers (1943-1955)

The development of fully electronic computers to replace mechanical calculators began during World War II[138] with the ENIAC processor developed at University of Pennsylvania, followed later by the EDVAC. Work on the project began in 1943 and went into service in 1946 to build an electronic computer able to do ballistics and atomic energy calculations. By 1948 ENIAC had been modified run from stored programs (Weik 1961). EDVAC was designed from the beginning to use von Neumann's architecture(Figure 33)[139]. Capabilities to process data into information then began to grow by orders of magnitude each decade. Although the first experimental electronic computers were used for military and scientific calculations[140], the technology soon began to be applied to accounting and management requirements of large organizations.

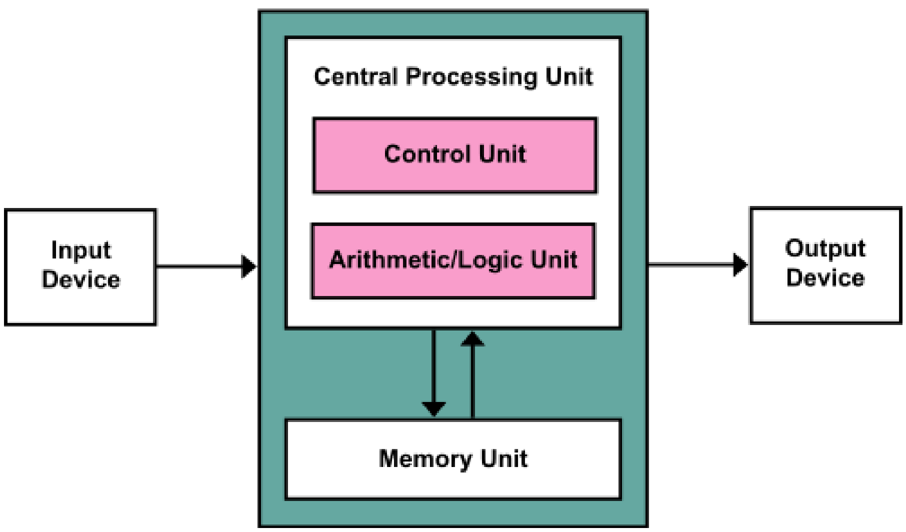


Figure 33. The generic Von Neumann architecture for a digital computer (Wikipedia). The Control Unit is responsible for sequencing operations, where instructions are stored as lines of binary code in the Memory Unit. The Memory Unit is also used to store input data, intermediate results of processing, and output data. The Arithmetic/Logic Unit does binary calculations on data, makes choices according to Boolean logic, and may actively modify some instructions as a result of these choices to enable branching and looping among the sequence of stored instructions.

Remington Rand first began developing commercial electromechanical computers in the US market, with the little known 409, under Gen. Leslie Groves' leadership (during WWII Groves led the Manhattan Project to develop the atom bomb - Fay 1996; Wenning 1997, ????). The first products of this line of development were delivered to their first customers in 1952.

Remington Rand's first business computer, UNIVAC-I (Figure 34), followed on from the ENIAC and EDVAC work begun at University of Pennsylvania by J.W. Mauchly and J.P.

Eckert. They both resigned from the University of Pennsylvania in 1946 as the result of a dispute over who owned patents for the technology, and went on to form formed their own company, which won a contract to build a computer for the US Census bureau. Remington Rand bought the company in 1950 as Mauchly and Eckert were running out of money, and funded completion of the development and production (Weston 1997; Gray, G. 2001). The first UNIVAC was delivered to the US Census Bureau in 1951. Major innovations in the UNIVAC were use of mercury (acoustic) delay lines to provide processor memory and metallic magnetic tapes (solid metal ribbons!) for storage. The more than fifteen UNIVAC I systems implemented by 1955 were installed by defense organizations, two insurance companies, two railroads, and a university[141].

As a general rule, [in the service bureau] individual research, engineering and mathematical projects have numerically exceeded straight data processing jobs while the greater overall volume of machine time is devoted to the latter. In order to keep programming costs at a minimum, extensive use is made of the Library of Univac I Routines whenever possible.... Business applications such as payroll reporting, cost account reporting, sales statistical summarizations and various statistical analyses have been done for a number of firms. Scientific applications include the engineering problem solutions from areas such as helicopter design, nuclear reactor design, bearing design, geodetic surveys and many others... [T]he two systems are operated back-to-back applied to insurance activities.

Figure 34. UNIVAC I at Franklin Life Insurance Company, Springfield, Ill. Franklin operated a second UNIVAC I as a service bureau. Staff for the two systems included 3 supervisors, 32 technical staff (analyst, programmers, operators and service technicians) and 50 clerks (presumably key-punch operators)! The price for a basic UNIVAC-I system was $950,000, including the central computer with power supply, supervisory control desk, and 10 Uniservos tape drives - where a 1,500 foot magnetic tape could store up to 1.4 MB of data. UNIVACs had a clock speed of 2.2 MHz and a memory (mercury acoustic delay lines) of 1000 x 12 digit words (i.e., ~12 KB). It could complete 8,333 additions of approximately 100 bit words (11 decimal digits plus sign) in 1 second (8,300 Hz or 8.3 KHz). The smaller but newer Burroughs machine I learned to program on in 1958-59 had about the same power. Today (August 2010), I am writing this document on a $1000 notebook computer that has around 7.4x10^{13} times more raw processing power than was available from a million dollar room full of electronics to one of the nation's largest life insurance companies 50 years ago[142]! And yet, it was apparently cost-effective for the insurance company to make that investment. [Picture and quote from Weik (1961a).]

Manchester University and Ferranti in the UK also credibly claim to have produced the first commercial computer in 1951[143]. Some of the key people who were involved in the German code breaking efforts at Bletchley Park in WWII joined the work at Manchester University. The Manchester/Ferranti Mark I design was based on the use of cathode ray tubes (CRT) for "core" memory and magnetic drum storage for working files. Alan Turing, one of the greatest mathematicians of the 20th Century, also heavily involved in the German code breaking effort at Bletchley Park, helped develop the coding system for the Mark I and wrote the first programmers manual for it[144].

In the early days, Australia was also a world leader in computing technology with the CSIRAC computer, the fourth computer in the world to be controlled by a stored program and today is the only completely preserved and operable survivor of the time[145]. Beginning in 1947, CSIRAC was developed by Commonwealth Scientific and Industrial Research (now known as CSIRO). It ran its first program in 1949 and was fully operational at CSIRO from 1951 to 1955 when it was disassembled and shipped to University of Melbourne, where it operated from 1956 through 1964. Its technology was based on vacuum tubes, mercury (acoustic) delay lines, and paper punch tape. From 1952 experimentation and work began to fit the computer with magnetic drum or disk storage. By 1956, a horizontal-axis disk-type device was permanently installed with one segment of 1024 words in use.

The concept of computer (hardware) generations is a useful way of summarizing the multiple revolutions in technology that followed[146].

The pace of technological innovation in creating the first generation of computers of the 1950's was rapid (Lee et al. 1995). IBM introduced its first electronic computer, the 701, in 1952[147]. Like the Manchester/Ferranti Mark 1, the IBM 701 used electrostatic CRT's, magnetic drums and/or magnetic cores for memory; and pioneered magnetic tape drives for bulk storage[148]. The drives used vacuum columns to draw the plastic-backed tape out in a long loop between the reels to minimize tape breakage from the frequent back and forth stop and start operation of the tapes. Although processing power was limited, the tape drives allowed the computers to efficiently process and manage large volumes of records by comparison to the mechanical sorting and tabulating of punch cards. However, punch cards still provided the primary tool for entering information into the computing environment.

My first experience with electronic computers5 was in 1958-59 on a first-generation machine in the Burroughs 204-205 series, first marketed in 1954. Programs and working data were all held within a 1000 word x 32 bit magnetic drum memory (fully configured 204-205 machines had 4000 word by 40 bit drums). However, the machines were also equipped with vacuum column magnetic tape drives. The human input was via an electric typewriter keyboard to paper tape punch, which was then written to magnetic or memory via a paper tape reader. All of the first generation computers were programmed directly using machine code or assembly language where machine codes are represented 1:1 by alphanumeric codes.

Second Generation: Magnetic Core Computers (1955 - 1964)

To get around the problems of having to sequentially access information on hundreds or thousands of feet of tape, rotating magnetic drums or disks were used. Here, the information was written onto many shorter tracks where the tracks could then be accessed as required in just one rotation of the drum. With the invention and use of ferrite core memories[149] (Figure 35) replacing the use of magnetic drums and tapes for working memory, and transistors replacing vacuum tubes in processors and registers, the second generation of computers became smaller and faster. IBM introduced its first magnetic core memory (Figure 9) in 1954, in the 704[150]. In 1955 it introduced its first transistorized calculating machine and committed to use solid state circuitry in all new machine developments[151]. In 1956 introduced one of its last vacuum tube-based designs, the RAMAC 305 computer (Figure 36)[152]. The first RAMACs were able to store ~5 MB of data on the 50 disks in its magnetic disk memory (in 2014, my current desktop stores 2 TB on a single disk drives), where the magnetic core served as a fast input/output buffer. More than 1000 RAMACs were produced before they were phased out in 1961. IBM introduced its fully transistorized 7090 in 1959[153]. By the time of Weik's (1961a) Third Survey of Domestic Electronic Digital Computing Systems, there were more than 9000 computers in the US.

First and second generation hardware helped corporations reduce their cost to keep and process records, but the systems were very expensive to manufacture and purchase (or lease), arcane to program and labor intensive to operate (at least by today's standards)[154] Given such costs, only the data processing departments of major government organizations and corporations could afford to implement them. The early computers were technologically revolutionary. However, because they were hand assembled, they remained so expensive that only large organizations could afford them. Also, as long as the clerical high-priesthood of the organizations' data processing departments owned the understanding of how to use the technology, computers had minimal impact on individual's access to knowledge or the nature of organizations (Tanner 1999; Treloar 1996).

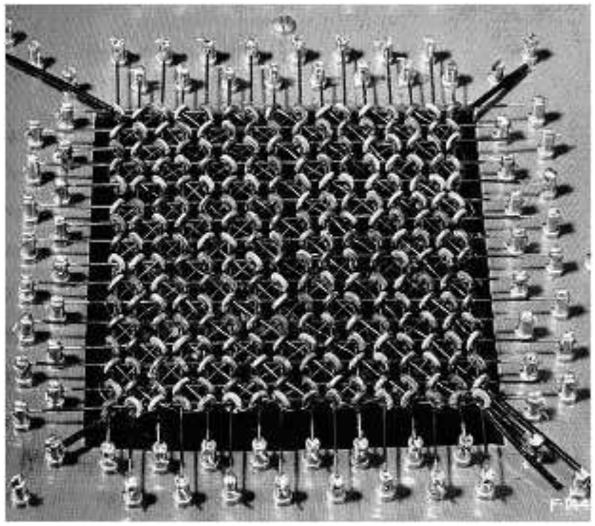


Figure 35. A 256 bit (32 byte) ferrite core random access memory. The donut shaped objects at the intersections of the wire are the ferrite rings (from Lee et. al, 1995).

Figure 36. IBM's 350 magnetic storage unit that was the heart of the 305 RAMAC (Random Access Memory Accounting) system (Wikimedia Commons). 50 disks with 100 recording surfaces provided 3.75 MB storage at a lease cost of 3,200/month. See IBM's advert showing the system in action.

Third Generation Integrated Circuit Computers (1964 - 1971)

Microprocessors

The third generation of computer hardware technology began to be implemented in the mid 1960's[155], with many improvements being driven by IBM research. As the technology developed, record processing and record storage came to depend on two physically quite different technologies.

Processing and short-term memory used by the computer for "work in progress" came to be purely electronic. Because electronic circuits used no mechanical components, data could be moved at light speed and very rapidly manipulated. The downside was that information vanished as soon as the power was lost.

Magnetic media rather than electronics came to be used for long term storage, because once the media was appropriately magnetized to store the data, the pattern persisted, and could be stored off-line and read back into the computer years later. The downside was that reading and writing required the magnetic media to be physically transported past the read/write heads and/or the heads to be physically positioned. By comparison to moving electrons in an electronic circuit the magnetic storage process was slow and ponderous, and could only record and access information in linear sequences - meaning that reading or writing would often require major mechanical movements of the magnetic media and or reading apparatus to locate a particular item of data required. As will be seen, beginning with the third generation computers, both electronic and magnetic technologies began incredible shrinking acts, allowing increasingly more data to be read, written and processed faster, and to be packed into ever smaller and less expensive physical devices

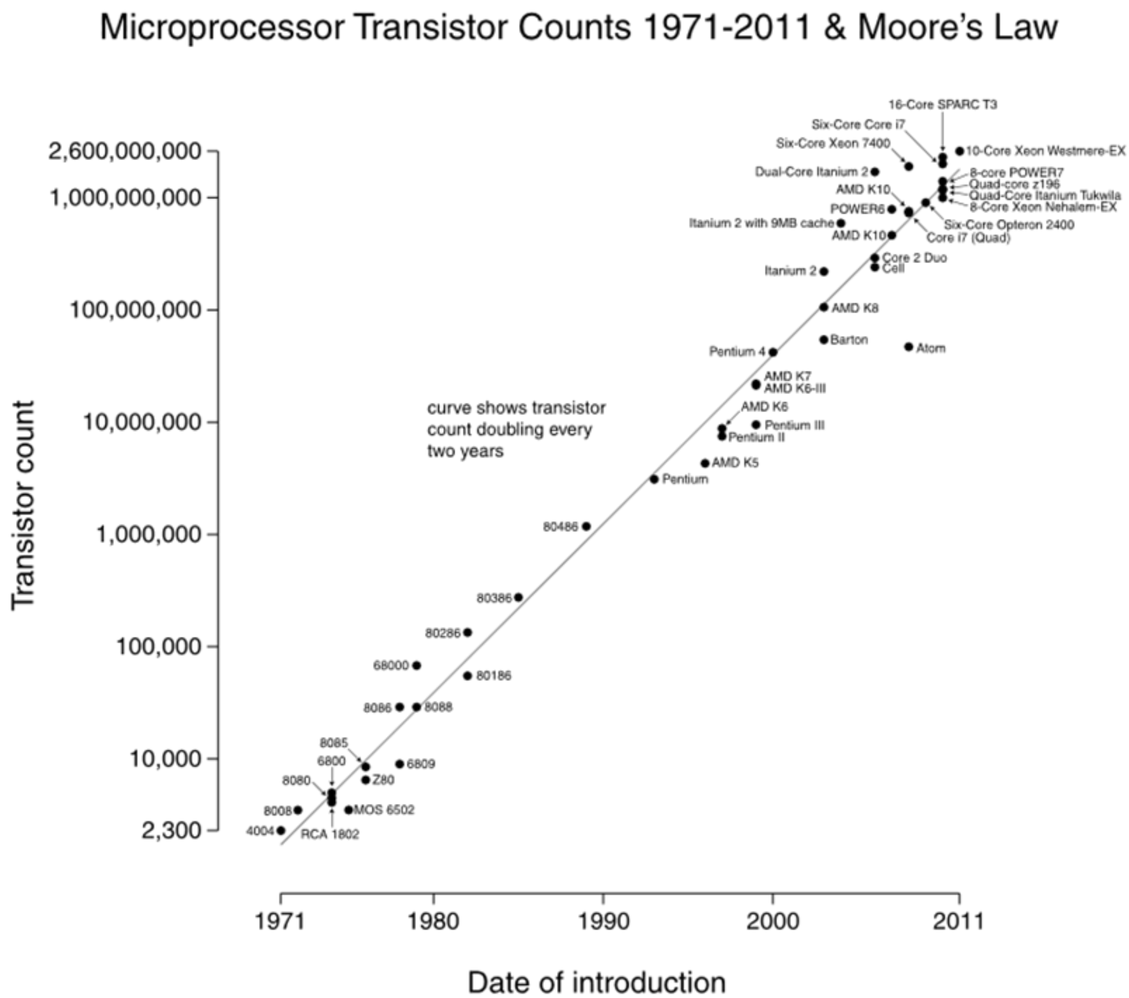
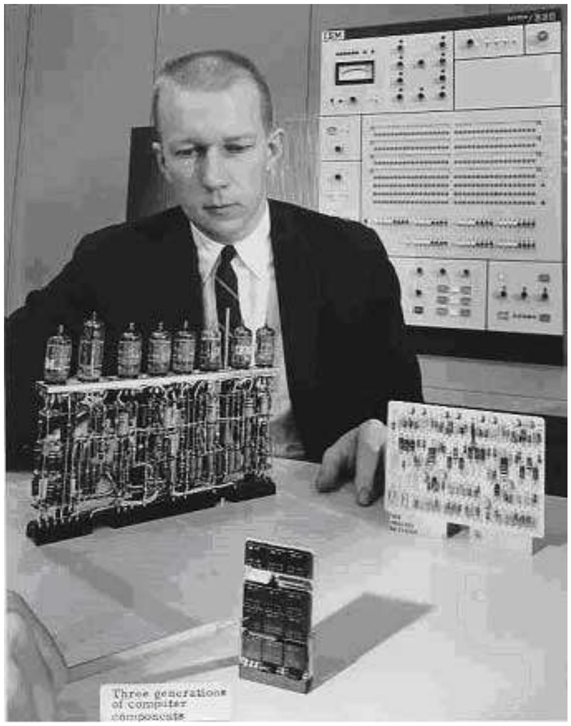


Figure 37. Moore's Law as applied to the evolution of microprocessors (wgsimon, Wikimedia Commons). Click picture to enlarge.

In 1964 IBM introduced its System/360 model computers with transistorized "Solid Logic Technology"[156] processors, but still using ferrite core memory.

In 1971 Intel launched its first "large-scale" integrated circuit processor, the 4004 with 2300 transistors. This was followed in 1972 by the 8 bit 8008 processor with 3500 transistor provided Paul Allen and Bill Gates (of Microsoft fame) with their first experience programming microprocessors (Delany 1997). By 2007 Intel was producing integrated circuits with more than 1.3 billion transistors. With the 4004 chip, silicon chip transistor technology began its incredible shrinking act, memorialized in Moore's Law that claims transistor counts double every two years [157] (Figure 37). Large scale integration also applied to the processor's random access memory, with single chips able to store prodigious amounts of data (up to 8 gigabytes! on the latest Intel/Micron flash memory chip[158]). Assuming Moore's law stays on track, the silicon shrinking act will probably reach the thermodynamic limits heat dissipation in the switching process around 2020 (Zhirnov et al. 2003; Loesch 2009; ITRS 2009; Hassan 2010; Chang & Baek 2010), but it is possible that other technologies may provide for further doublings along the Moore's Law trend line until the quantum limit of Heisenberg uncertainty in determining the location of a single electron is reached around 2036 (Powell 2008). However, as will be seen, Moore's law greatly underestimates the exponentially increasing processing power of microcomputer technologies, in that the microprocessor is only one component in an array of increasingly powerful technologies.



The late 1960s and early 70s, there was much talk about "generations" of computer technology. This photo illustrates what were commonly known as the three generations:

1. First generation: Vacuum tubes (left). Mid 1940s. IBM pioneered the arrangement of vacuum tubes in pluggable modules such as the one shown here on the left. The IBM 650 was a first-generation computer.

2. Second generation: Transistors (right). 1956. The era of miniaturization begins. Transistors are much smaller than vacuum tubes, draw less power, and generate less heat. Discrete transistors are soldered to circuit boards like the one shown, with interconnections accomplished by stencil-screened conductive patterns on the reverse side. The IBM 7090 was a second-generation computer.

3. Third generation: Integrated circuits (foreground), silicon chips contain multiple transistors. 1964. A pioneering example is the ACPX module used in the IBM 360/91, which, by stacking layers of silicon over a ceramic substrate, accommodated over 20 transistors per chip; the chips could be packed together onto a circuit board to achieve unheard-of logic densities. The IBM 360/91 was a hybrid second- and third-generation computer.

Omitted from this taxonomy is the "zeroth" generation computer based on metal gears (such as the IBM 407) or mechanical relays (such as the Mark I), and the post-3rd generation computers based on Very Large Scale Integrated (VLSI) circuits.

Figure 38. Individual logic modules from the first three generations of electronic computers (picture and quote from Computer Generations in da Cruz 2008; click picture for maximum resolution).

The physical manifestations of these words are illustrated in Figure 38, Figure 39 and Figure 41. Electronic computers are assemblies of switches or gates able to decide and output a "yes" or "no" to other switches or to output devices depending on inputs they receive from other switches or input devices. The first generation of computers involved assemblies of thousands of vacuum tubes, where each hand-made tube had two or more stable states (representing the yes or no). The upper left hand module on the table in Figure 38, left is a single module from such a computer. These were connected by hand-soldered wires to other vacuum tubes as illustrated in the figure. The module of 8 tubes shown in the figure may have been the register for a single 7 or

8 bit alphanumeric character or decimal digit (i.e., one byte). A single vacuum tube is shown in Figure 39[159]. In generation 2, vacuum tubes were replaced by very much smaller, more reliable and less energy intensive transistors soldered onto a printed circuit board (PCB) as shown on the right in Figure 38. Assuming the PCB module is equivalent to the tube module, a row of 8 transistor cases equivalent to the top one in the middle picture of Figure 39 can be seen along the top edge of the board. Generation three began with the development of small scale integrated circuits (Figure 39 – Right). The circuit module shown on the bottom of Figure 38 appears to have 9 or 12 IC packages, where each package would have managed a byte (or perhaps even several).

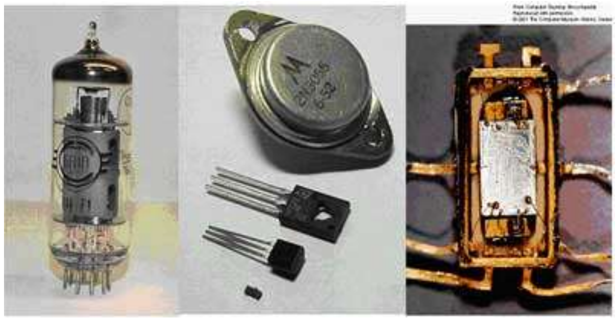


Figure 39. Early electronic logic devices. (Left) Vacuum tube diode. (Middle) Transistor diodes. (Right) Small scale integrated circuit (note, the printed circuit can just be made out). Each picture is linked to its source.

Large scale integration truly began with the automated construction of all the circuitry for a complete computer on a single chip, as illustrated in Figure 40 by Intel's 4004 chip, released in 1971 and the 8008, released in 1972. On these chips one can still see individual conductors and circuit elements. As individual circuit elements shrunk to sizes close to or smaller than the wavelength of light, all one can see are interference colors. Because different modules have different organizations, these show up as different colors in the photographs (e.g., the Core i7 processor - Figure 41).

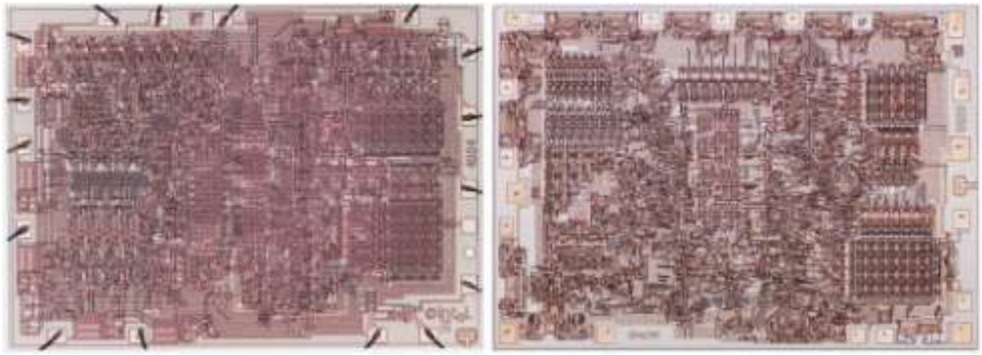


Figure 40. Intel 4004 and 8008 microprocessors. (Left) the 4004 157 from 1971 - the first commercial large-scale-integrated microprocessor on a single chip containing 2,300 transistors, 4-bit logic and able to address 640 bytes of memory. The 4004's word length was 4 bits with a clock speed of approximately 100,000 Hz. It contains no internal RAM. It is possible to discern Individual circuits and transistor elements in this photomicrograph of the whole chip. (Right) This was followed in 1972 with the 8008 microprocessor[161] with 3,500 transistors and 8 bit logic and able to address 16 KB of memory.

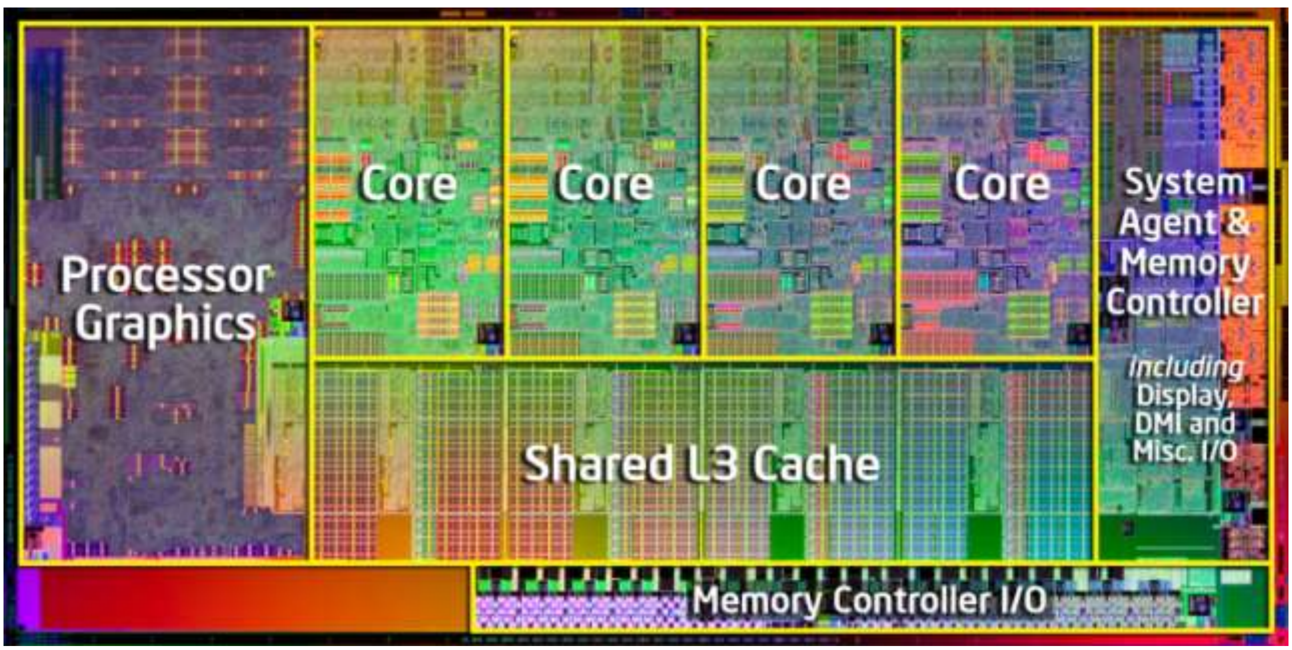
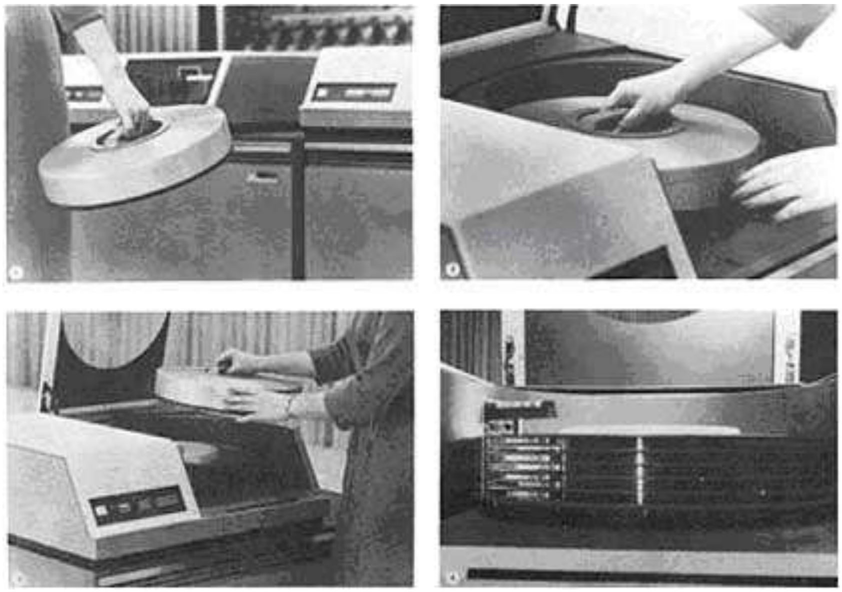


Figure 41. The Intel 2nd Generation Core i7 (3.4GHz, 32nm process) using ~1.4 bn transistors released in 2011. The individual circuit elements are too small to be clearly resolved by ordinary visible light. The colors are interference patterns generated by regular features of the chip structure. Myslewski (2011) - Happy 40th birthday, Intel 4004! illustrates a nearly complete sequence of Intel microprocessors. Compare these with the three generations of component parts (Figure 38) that came before the microprocessor: a vacuum tube module from around 1950, single transistors on a printed circuit board from 1956, and small-scale-integrated circuits from 1964.

Magnetic storage media

Magnetic storage technologies also show an exponential increase in storage capacity that is relatively independent of that shown for processors. In 1971, IBM introduced its Magnetic Tape Selectric Typewriter, a product that pioneered the application of magnetic recording devices and transistorized electronics to typewriting, and gave rise to the concept known today as word processing. Referred to as "power typing," the feature of revising stored text improved office efficiency by allowing typists to type at "rough draft" speed without the pressure of worrying about mistakes." This was based on an earlier generation of electromechanical typewriters (often used as input/output devices for early generation computers) using paper tape as a recording mechanism (Eisenberg 1992)[163]. As will be seen in Episode 3, interesting things started to happen when electric typewriters connected to the computers started to be used for authoring human readable texts.

Where magnetic storage is concerned, IBM introduced its first fixed disk system - the RAMAC - in 1957 (Figure 36). Based on IBM's rental practices at the time and price adjusted to 1998 dollars, it would then cost $100,000,000 (one hundred *million* dollars) to purchase RAMAC storage for a gigabyte of data. In 1998, disk storage cost around $50 per gigabyte (Gilheany 1998). On 31 August 2010, I bought a 1 TB 3.5" USB 2.0 external hard drive for around $100 on sale from my local retailer. *This storage cost $0.10/GB* (not considering inflation and currency fluctuations. IBM introduced removable magnetic disk storage in 1962, with the IBM 1311 (Figure 42). This "hastened the end of the punched card era". *A single disk pack could hold as much information as 25,000 punched cards* (2 MB)[164]. A Disk/Trend table shows the increasing storage capacity and reduced size of the media from 1950 through 2000[165]. What it does not show is that these units also became less and less expensive. Gilheany (1998) also tabulates the annual decline in cost of storage for each year since 1992 and estimates that the annual decline in price per unit of storage is around 37.5 percent.



The photos show the operator loading an IBM 1311 memory disk pack on the IBM 1440 computer. In the picture sequence, the operator carries a disk pack containing six 14-inch memory disks to the IBM 1440. She places the disks on the disk storage drive spindle, removes the pack cover, and the unit is ready to operate. The time required is less than one minute. Disk packs can be removed in the same manner and stored like books on a library shelf until they are needed again. This data storage technology makes it possible for a user to maintain a separate disk pack for each of his major data processing jobs. The disk packs, which weigh less than 10 pounds, have a storage capacity of nearly 3,000,000 alphanumeric characters. [Photos and text from Weik (1964.]

Figure 42. IBM 1311 disk drive with removable storage. A unit cost $90,000 upwards to purchase in 1964[166].

The Fourth Generation Personal Computers and Beyond

Moore's Law soon led to a fourth generation of computers that could be made cheaply enough to be owned and used by individual people (Mazor 1995; Polad et al. ????). Altair, introduced in 1975 (Delany 1997; Sanderson 1998)[167] and Apple in 1976 (Weyhrich 2001) were the first affordable and commercially successful microprocessor-based microcomputers for personal use. Before the end of the 1980s the basic architecture of microprocessor and silicon chip random access memory (RAM), backed up by magnetic disk storage media was well established. Technological improvements enabled by Moore's Law more than doubled raw processing power (processor speed x word length x RAM memory) every year in an unbroken trend up to the present. Patterson (1996?) summarizes some of the benchmarks in the development of personal computing.

Revolutions in fabrication: hand assembly to industrial printing and self-organization

Since the first hand made UNIVAC computer was delivered in 1951 (when I was 12 years old), there has been an ongoing revolution in manufacturing methods for electronic processors that is unprecedented in human history. Over six decades we have moved from “one off” devices built by hand from hand-made vacuum tubes interconnected by looms of color coded wires to solid-state crystalline integrated circuit (IC) devices whose elements are smaller than wavelengths of visible light. ICs can only be made by automated “fabricators” (or “fabs”) comparable to the large web presses in the printing industry. For example, Intel invested $7 BN to build four fabs to make 32 nm chips (Bohr 2009). Some hints of the incredible complexity of the "printing" process are illustrated as follows Intel Factory Tour - 32nm Manufacturing Technique (6:20); Intel: The Making of a Chip with 22nm/3D Transistors (2:41); and "Making of a Chip", explaining the previous video. However, like printing presses can do with paper documents, once the design for a chip has been established, costs of building the factories can be amortized by printing tens of thousands to millions of copies of the same chip at a very low per unit cost that can be afforded by the billions of humans who use the technologies assembled from them.

Basically Moore's Law encapsulates the progress of the microelectronics revolution over a single human life-time from making and assembling electronic components (e.g., Figure 38) that can be grasped in the hand and assembled using simple hand tools like soldering irons and tweezers down to those involving the automated manipulation of a few thousand molecules in multibillion dollar fabs (now), and by the mid 2030s, possibly even down to managing the placements of single atoms in logic switches sensitive to the spin orientation of single electrons.

As will be seen, this technological revolution also completely revolutionizes the cognitive capabilities of human minds to the extent that that they become something more than human, i.e., trans- or post-human.

Revolutions in the application of control: from flipping switches to casting spells

Revolutions in software were also essential to make the rapidly shrinking computer technology easier to use. The concept of "generations" of programming languages is useful here.

- The first generation language is the object code (or machine code) directly understandable by the computer's processor in the form of binary numbers or other code. Many of the first generation computers could only be programmed by object code. Humans had to be able to understand and write this code based on combinations of ones and zeros.
- Second generation languages are processor specific assembly languages, where there is a 1:1 relationship between mnemonics (i.e., an abbreviation for the name of the command) which make some sense to a human and the binary codes used by the computer. The first generation language is the binary object code directly understandable by the computer's processor. A second generation language is the assembler language for a particular processor, where there is a 1:1 relationship between mnemonics (i.e., an abbreviation for the name of the command) which make some sense to a human and the binary codes used by the computer.
- Third generation languages are generic symbolic programming languages such as FORTRAN, COBOL or BASIC, where the commands can be written in words and symbols without knowing the assembler language for a particular computer. Third generation languages are converted into computer-specific assembler language or object code by compiler programs written for each type of computer or assembler language. FORTRAN (FORmula TRANslation) was developed primarily for scientific and engineering applications and included the ability to convert mathematical formulas into computer code. IBM began introducing FORTRAN for its computers in 1957[168], along with what may have been the first second generation assembler language. The original

specifications for COBOL (COmmon Business Oriented Language) were developed in 1959, with the first commercial compilers completed by the end of 1960 (Gürer 2000; Reimann 2001; Burger 2002). BASIC was initially developed in 1964 as a simple language to be learned by students and beginners (Stranahan and Stranahan 1999). Microsoft's history began when Paul Allen and Bill Gates developed a version of BASIC for the 8080 chip for Altair, the first commercial personal computer, in 1975 (Bergmann Tiest ????; Sanderson 1998)[169].

- The concept of fourth generation languages (or high level languages) is used for macros and similar types of computer languages with application oriented syntaxes close to human language normally associated with word processing and database systems. Visual Basic, which MicroSoft standardized across its later Windows applications, is actually a third generation language. In the case of the Excel product, Visual Basic replaced a more powerful macro language used in earlier Excel releases.
- Another very powerful approach to programming was the development of "object oriented" languages such as C^{++} and Java. Rather than a language in its own right, object oriented programming combines functions and procedures relating to real-world objects of interest into modules of code performing specified actions on generic variables, such that different modules can exchange information with each other via standardized interfaces. This allows functional systems to be assembled from predefined, pre-coded and pre-tested modules without having to do any further coding within the modules themselves, greatly reducing the labor to build large and sophisticated systems. Java is an object oriented language designed to work on a wide variety of personal computing platforms, such that program developers can focus on developing systems that satisfy user needs rather than concerning themselves with the idiosyncrasies of the particular processors the systems will be running on.[170]

This new microcomputer technology has been fed into industrial processes to automate its own production. Since mid 1970's the complexity and sophistication of computer-based processes have grown exponentially in trends basically tied to Moore's law. We have reached the point where automated factories producing microprocessors and associated peripherals are now equivalent to highly automated printing presses. For a tiny fraction of the unit costs in labor and materials to print an early book, computer chip-making industrial processes and largely automated assembly lines are now "printing" knowledge processors able to automate the production and retrieval of knowledge itself.

For less than what a single book would cost a scholar 500 years ago, today's scholars have magic tablets (Figure 15) able to find and retrieve specific content from within what is now a majority of the entire corpus of humanity's knowledge recorded in world 3's World Wide Web.

Looking at computing technology in another way, in some 60 years, Moore's Law has taken us from a world where computer engineers and programmers concerned themselves with hand constructing and managing the behavior of single electric switches in room-sized arrays only able to carry out a few simple arithmetical calculations, to today's new and previously unimagined world of solid state machines inhabited by intelligent agents like Siri can understand spoken incantations in human speech to carry out in seconds incredibly complex tasks such as querying the world's knowledge base to find out that in 1925 Ty Cobb said ""Baseball is a red-blooded sport for red-blooded men. It's no pink tea, and mollycoddles had better stay out. It's a struggle for supremacy, a survival of the fittest.""[171]

As will be discussed in more detail in the concluding sections of this work, there is probably at least another 10 years of exponential growth left in silicon-based microprocessor and memory technologies before the limit to what one can do with electrons on doped silicon surfaces is reached. Beyond this, there are several new technologies that promise further orders of magnitude increases in processing power and memory capacity (e.g., photonic and/or quantum computing). As today's technology would be unimaginable to yesterday's scholars, the continuing exponential growth of processing power will take technology beyond what we can imagine today.

I now wish to explore the impact of the technological revolutions on the changing ways individuals and organizations have been able to create and use knowledge.

EPISODE 3 - Cognitive Tools for Individuals

In this episode I will explore how the development of technologies for transferring and transforming knowledge between our personal World 2s and "objective" knowledge in World 3 have enhanced individual cognition. Where print media are concerned, the technologies work primarily to extend our capacity to observe and remember. When the knowledge can exist virtually in electronic or other intangible media, some very interesting things have begun to happen that may radically change what it means to be human.

Tools to Make Knowledge Explicit

From the invention of writing up until 1980s, documents were tangible objects, consisting of text, drawings or formulas inscribed or applied onto a surface: clay tablets, stone slabs, papyrus, vellum or parchment, and finally paper. How the document was formed by an author was irrelevant to the reader, as it could only be read only after the thoughts were codified and imprinted onto tangible objects.

Computer technology radically changed the means of preparing and distributing documents, but to many older readers the electronically stored version is still considered to be irrelevant by comparison to the paper document – while younger readers don't even think about the issue. The concept that "the only real document is paper", is what I call the *paper paradigm*. For people who grew up before the 1990s, a major paradigm shift in Kuhnian terms is required for them to understand that knowledge is now primarily maintained, retrieved and delivered in electronic (electromagnetic) formats. Today, most World 3 knowledge is being created from the outset as electronic virtual documents, and older paper documentation that is considered useful is rapidly being converted into such electronic formats. Today, many people only read documents on electronic displays. Now, paper documents are at best snapshots of the contents of what may be continually evolving electronic virtual containers for knowledge. Compared to ponderous paper, the virtual containers can be endlessly duplicated, distributed and retrieved at nearly the speed of light for essentially no cost[172].

Based on my personal background in scientific and technical writing, most of my discussion in this work focuses on human literacy in the form of creating, retrieving and using textual documents. However, literacy in geometry, algebra and mathematics evolved in parallel with textual literacy, and these forms of expressed knowledge have been equally profoundly affected by the development of printing and computer processing (Hobart and Schiffman 1998). The impact of printing on literacy was discussed in Episode 1. In this episode I will focus on how the microelectronics technology described in Episode 2 has radically altered what is signified by universal personal literacy.

Word processing (extending the paradigm of paper)

Working in a paper paradigm, all of the author's cognition was done in the personal World 2. Once the knowledge was distilled it was transformed to words and committed to paper, perhaps with a pen or pencil or typewriter, or via dictation to another human who would transcribe the words to paper with pen, pencil or typewriter. The ponderousness of the process limited the number of drafts and required a prolonged cycle time from one edit to the next, and an even longer cycle time if work was sent to be printed (Hall & Nousala 2010a; Vines et al., 2010).

Electronic word processing and desk top publishing (DTP) systems extended typewriter and typesetting technology, initially by providing a way to store and correct the content of documents before committing them to paper. From the typists' or printers' points of view, the new technologies enabled "letter perfect" paper documents or plates for printing to be produced without needing to rework the product after its contents were made tangible. Only when document files began to be distributed electronically via a network or floppy discs did something completely new began to replace the paper paradigm.

Xerox's Palo Alto Research Centre (PARC) played a major role in developing the architecture of a networked word processing environment[173]. Cringely (1996) and Hiltzik (1999) provide highly readable accounts of the personalities and business issues involved in introducing the new electronic technology. Although neither author writes from a specifically Kuhnian point of view, it is obvious from both histories that Xerox's executives were unable to grasp the paradigmatic differences between paper and electronic documents in order to understand the revolutionary potential of the disruptive technology their own people developed. Had Xerox effectively exploited PARC's inventions, they could easily have been a giant that might have exceeded the size of Microsoft and IBM combined.

The development of merge printing or "mail merge" in the mid to late '70s linked early word processors to databases of customer details in order to produce personalized form letters. This added an element of automation to the process of typing documents. However, until the beginning of the 80's, word processing was limited to the environment of large corporations who could afford the mainframes and networks supporting the word processing environment (Eisenberg 1992). Affordable *personal* computers changed the equation radically.

WordStar[174], launched in June 1979 (Polsson 2001), was the first mass selling word processing system, and was one of three "killer applications" that led to an explosive growth in the number of personal computers being used as productivity tools by knowledge workers (Byte Magazine 1995). I purchased my first personal computer (a CP/M system) in 1981 for use as a word processor because it ran WordStar.

As printing enabled the same paper document to be distributed physically to many readers, the electronic storage of word processed files in a network allows the instant retrieval/copying of "electronic paper" on demand for reading anywhere in the world at the speed of light. Access to personal computers for reading electronic paper is still not as "universal" as literacy is for reading paper documents. Nevertheless, the explosive spread of personal computer–based authoring and retrieval systems certainly qualifies as a quantitative revolution in the nature of documents by comparison to the paper paradigm. However, as explained in the following paragraphs, word processing on its own has not caused any major qualitative revolution in cognitive processes.

Calculators and spreadsheets (extending the paradigm of a paper spreadsheet)

The second of three killer applications providing a quantitative extension of human cognitive capabilities was the electronic spreadsheet, able to accurately calculate rows and columns of a table in seconds that would take hours to do by hand. Some mainframe spreadsheets had been developed by the early '60s, but these were only available to large corporations and government bodies (Mattessich, ????).

VisiCalc, introduced in October 1979 (Polsson, 2001), soon after Wordstar, also helped turn the personal computer into a real productivity tool. Lotus 1–2–3, introduced in 1983, provided graphing functions in addition to column and row calculations, to enhance productivity still more.[175]

Spreadsheets extend human cognition by greatly improving speed and accuracy in analyzing columnar data and doing mathematical calculations. Assisted by computerized spreadsheets, humans can complete calculations that would otherwise be completely impractical because of the number of individual mathematical manipulations required and the inherent fallibility of human brains for mathematical processing. However, as for word processing systems that functioned initially as better typewriters, the applications did not fundamentally change the basic paradigm of columns and rows of data on one or several large sheets of paper.

Databases (extending the tabular paradigm to more than two dimensions)

During the 1960's and 70's, the need to improve data management drove large businesses and government organizations to install mainframe computers. In this environment, data was still controlled by Management Information Systems (MIS) departments, often tied to computer systems leased from IBM. Early database systems were basically little more than collections of two–dimensional tables, whereby the contents of specific rows of information in each table could be rapidly accessed by indexes to one or more columns of the table. This effectively turned data into information by providing contextual connections. For example details of a customer's account might be indexed by customer name.

The development of relational database (RDB) concepts in the 1970s[176], allowing row contents of two or more tables to be indexed via relationships established via "join" tables, enabled much more efficient data structures to be developed through the process of "normalization". An RDB has no need to repeat information (such as a customer name and address) across different kinds of tables containing information relating to a particular customer. Customer contact details would be maintained in one table, transaction details in a second table, product pricing details in another, and payment details in a fourth table. A unique CustomerID identifies each customer, each order by an OrderID, each product by a ProductID, and each payment by a PaymentID. A single order of several products would be described by several entries in a "join" table indexed by the OrderID, relating the CustomerID to the Order ID on one side, and to each of the products included in the order on the other side. The join table would probably include details on the quantity delivered against each product line item because this information would be unique to particular order by the particular customer. Another join table would contain entries for payments received, linking customer details via the CustomerID, order details via the OrderID, and payment details via the PaymentID. Report generators would then have access to all details required to print invoices without the requirement to maintain the complete set of customer and product details for each individual order. High level programming and query languages made it comparatively easy to develop processes to manipulate the data contained in the RDB.

Database Management Systems (DBMS), which allowed end users to develop their own database applications, were the third kind of killer application driving the spread of personal computing. The Vulcan database program for microcomputers was launched in August 1979. Ashton–Tate later marketed an upgraded version of the product as dBase II in 1981 (Polsson, 2001). This combined relational table structures with a high level programming language that

that simplified the building of applications to help collect and process the tabulated data. Oracle Corp, founded in 1977 is now a dominant supplier of RDB technologies.

Relational DBMS applications with their associated high level (i.e., 4th generation) programming languages greatly extended the clerical paradigm of keeping and processing records. Even small businesses could implement applications that enabled them to compete successfully with the very large commercial and government organizations that could afford large clerical staffs.

As will be discussed further below, DBMS tools also began to provide qualitatively new ways for managing data and simple kinds of information. In parallel with the development of the three killer applications discussed above, comparable computerized tools were developed for geometrical applications like engineering design/drawing and for working with algebraic formulas – first in mainframe environments (Hobart and Schiffman 1998) and then made available to the individual user. However, before beginning my discussion of qualitative revolutions, some additional comments on paper paradigms are warranted.

Paper Paradigms and Microsoft's Waning Dominance of Personal Computing

Moving data aggregation and document authoring and their associated delivery processes into the electronic environment is promoting a major shift in the document paradigm. In the paper paradigm; documents, spreadsheets and data tables or card files are tangible objects (requiring slow and costly physical production, filing, sorting, indexing and distribution processes). In an electronic paradigm, the information and knowledge content of the document or other information lives virtually in a computer memory or other electronic/magnetic storage. Content can be instantaneously retrieved and displayed for viewing whenever and wherever required. Although revolutionary, the initial shift in technology from physical paper to electronic container is primarily quantitative. In this shift, the essential idea that the document or other information object is a discrete container for knowledge has not changed in the minds of many who manage the objects.

However, the paradigm shift from paper to electronic documents is far from complete, and has probably been impeded by Microsoft's dominance of the personal computing market. As will be seen below, as electronic media becomes dominant, Microsoft's dominance will probably wane, and even the concept of a document may become obsolete.

Today, the paradigm of electronic paper is supported by increasingly complex applications providing the ability to represent on–screen the appearance typeset to paper outputs (WYSIWYG – what you see is what you get). The only reason these applications are commercially viable is that Moore's Law ensured tht computer processing power and speed increased faster than the demands made by these hugely complex applications. Microsoft and Apple competed for many years to provide graphical user interfaces (GUIs) to replicate the appearance of paper, to the point that Microsoft's Windows operating environments are amongst the largest software applications ever created[177]. The contest has also been particularly fierce in the office software arena between Microsoft Office and WordPerfect Office, who competed for many years to be all things for all possible users. The story of this competition is well documented because of the long–running anti–trust suite against Microsoft[178].

I am no friend of Microsoft; because Microsoft's popular DOS and Word products supplanted technically superior products I used as productivity tools in my own cognitive toolkit, such as CP/M and WordPerfect. However, as Cringely (1996) and friends of Microsoft[179] note, Microsoft did not create the circumstances that enabled its dominance of the market for operating systems and productivity tools. These authorities argue that Microsoft achieved dominance through being well poised to exploit the opportunity created by the popularity of IBM's PC hardware and by creating products that catered to customers' desires to work in a paper paradigm even though the underlying environment was electronic.

From my own experience, I would argue that Microsoft's success depended heavily on the power of the paper paradigm to influence corporate purchasing decisions. No matter how efficiently information is organized and managed, or how much epistemic quality has been added, a human person cannot use information stored in an electromagnetic environment until it is transformed into a format the human can perceive – whether on screen or on paper. Because early personal computer memory and processing resources were slow and expensive, the pioneering software applications (e.g., WordStar) managed data very efficiently with a few lines of code to produce character-based displays. However, many humans, whose perceptions were based on experiences with paper documents, did not like the esthetics of character–based displays. Application developers targeting large markets wanted to make their products seem to be more "*user friendly*".

Xerox PARC's Alto and Star systems[180] and Apple's Lisa and Macintosh systems established that operating environments and word processing systems providing WYSIWYG tools with bit–mapped graphical user interfaces (GUI) were much "friendlier" to user perceptions (Evans, et. al. 1999; Myers 1998). Microsoft introduced early versions of the Windows GUI to the PC market in 1985, which achieved a comparatively small market share compared to DOS because there were few applications using Windows[181]. The release of Windows was followed by the Windows GUI version of Word in 1989 and then by Excel and PowerPoint. Led by MS Word, the now synergistic Windows packages achieved dominance in their respective application areas around 1992. Because Microsoft's "killer" applications all used a similar paper paradigm, they achieved market dominance over products that were arguably still technically superior (and had been dominant in the past) but lagged in providing the paper–based GUI. (And, of course, Microsoft did not make it easy for its competitors to use the Window's operating environment.)

The other factor which helped Microsoft achieve and maintain its almost total market monopoly over other WYSIWYG/Windows–based desk top publishing and word processing applications is what Liebowitz and Margolis (1999), Evans and Leder (1999) and Evans et al. (1999) call the "network effect" or "network externality"[182]. Liebowitz and Margolis (1998) define the concept as follows:

> Network externality has been defined as a change in the benefit, or surplus, that an agent derives from a good when the number of other agents consuming the same kind of good changes. As fax machines increase in popularity, for example, your fax machine becomes increasingly valuable since you will have greater use for it. This allows, in principle, the value received by consumers to be separated into two distinct parts. One component, which in our writings we have labeled the autarky value, is the value generated by the product even if there are no other users. The second component, which we have called synchronization value, is the additional value derived from being able to interact with other users of the product, and it is this latter value that is the essence of network effects.

The works cited above claim that despite the network effect, a "better" technology can readily displace an entrenched product. From my understanding of paradigms and personal experience with the power paradigms have to influence software purchases in organizations I have worked for, I would argue the opposite. Network externality is a major issue for businesses - especially given that compatibility of systems to interface W3 knowledge with the human communicators across the virtual network of trading partners is paramount.

Word processing applications are tools people and organizations use for communicating with other people and organizations. Spreadsheets and database applications also have important communication functions, but they are primarily personal productivity tools used for individual purposes within organizations. While the majority of organizations were still using paper as their primary medium for exchanging information, it made little difference which word processor was used to produce the paper – everyone could still read the paper copy. A number of competing word processor suppliers could survive in such a market. However, once a proprietary electronic format itself became the primary medium for communication, the network effect virtually assured a monopoly for the leading proprietary product providing the medium for that communication.

Although today's word processors and spreadsheets still firmly use a paper document paradigm for their tangible output, most organizations and many individuals now distribute and access documents produced by these applications electronically for on–screen viewing rather than by physical paper. In this regard it is important that to achieve the formatting result required by the paper paradigm, complex proprietary formatting codes are included within the electronic documents to ensure that the recipient's screen displays the document in as close to a paper format as possible. Despite efforts(?) of software developers to develop software able to convert content between one proprietary formatting code and another, the effective transfer/translation of electronic documents between different applications is fraught with difficulty. Assuming that it is even possible to translate the document at all[183], it is practically impossible to edit documents produced in one brand of word processor in another brand of word processor.

Especially in large corporate or organizational networks where draft documents are frequently exchanged for review and editing, both parties in the exchange must either use compatible software from the same vendor, or revert to the slow and costly physical editing and transport of paper documents[184]. At least in the corporate environment, there is also a continuing requirement to refer to older (i.e., "legacy") documents[185] – and it is far easier to do this electronically from a central repository than it is to maintain and locate the physical document. Thus once any word processing product is taken up by dominant users in an electronic communications network, the simple requirements of smaller users to communicate effectively with dominant organizations ensures that the majority product will drive out the competitors[186], irrespective of any quality issues. Also, the requirement to retain access to "legacy documents" ensures that it would be a very costly for any large organization to switch to an incompatible application.

Only if the fundamental communication paradigm changes, is there likely to be any economically justifiable reason to change the dominant information development and management applications. Such a fundamental change is now taking place and may in time break Microsoft's hegemony over the word processing environment.

Structured Authoring Adds Computer Readable Syntax and Semantics to Text

"Structured authoring" is a technology for capturing text that no longer depends on proprietary word processing codes. Structured authoring applications combined with database management systems enable information to be recorded and managed in revolutionarily new ways. As will be discussed in the following sections, these technologies fundamentally change the ways in which knowledge is captured, stored, discovered and retrieved. In time the concept of a document as a container for storing knowledge will become obsolete.

Recalling that one definition of knowledge is "appropriate information that is available when and where it is needed", all texts written for reading by humans are structurally organized with semantic cues to help the reader comprehend as knowledge, the information contained in the text. These cues include

- grammatical syntax,
- recording of individual thoughts as sentences, in juxtaposition with other sentences,
- use of white space to organize sentences into paragraphs and paragraphs into larger semantic structures such as chapters and sections,

plus additional apparatus such as:

- paragraph numbering,
- abstracts
- introductions,
- cross references,
- notes,
- bibliographies,
- tables,
- lists,
- definitions,
- indexes,
- emphases, and so on.

As discussed above, computerized word processing and typesetting systems offer users a rich array of formatting functions to provide the visual cues needed by humans. However, the proprietary procedural code placed in the text to control output formatting is too inconsistent to identify content for easy semantic recognition by computers.[187]

Although structured authoring systems' user interfaces often resemble those of word processing and desktop publishing systems, the structured authoring system tags syntactical and semantic content for parsing by computers[188] rather than tagging formats for layout on paper. A document type definition (DTD) or schema for a class of documents defines the kinds of elements (which may be defined semantically - Berners-Lee et al. 2001; W3C 2010; Swartz 2002, see also Wikipedia) allowed to occur in a conforming document, and establishes syntactical rules determining where each kind of element may be used in the sequential and hierarchical structure of a document of that type. In authoring structured text, blocks of text are wrapped by tags conforming to the rules of the DTD or schema to identify structural elements in the document's logical flow. When the document is output for printing or viewing, formats are applied to structural elements based on each element's type and location in the logical structure of the document. Text formatting is completely separated from the authoring activity – and in fact may be performed by completely separate applications sourced from independent vendors. By contrast, word processor codes are entered as *ad hoc* formatting decisions relating to particular documents.

Historically, the concept of structured text is a direct development from proprietary "markup" codes used by word processing and typesetting systems. However, as will be shown, a seemingly straightforward evolutionary change in the way electronic text is marked up and processed enables a major grade shift in the epistemic quality of what computer systems can do with the information. The key to this revolution was the Standard Generalized Markup Language (SGML), established as an international standard in 1986 (ISO8879).

"Markup" originally referred to handwritten editorial notes and codes on a manuscript or typescript telling a typesetter how to set text for the printed page. As typesetting was automated with molten metal (e.g., Linotype - Figure 19)[189] and then electronic typesetting systems, editorial markup was turned into special codes[190] setting off particular blocks of character data that the typesetting system would recognize as formatting instructions rather than as text to be set. Most word processors place formatting instructions into the text in the same way[191].

Typesetting Markup

Two strands of development led from format markup to SGML and XML. On the typesetting side, in the 1960's a peak typesetting industry body, the Graphic Communications Association (now known as the International Digital Enterprise Alliance (IDEAlliance), created a non–proprietary standard typesetting language called GenCode able to be understood by a wide range of typesetting systems. GenCode allowed publishers to maintain an integrated set of archives that could be reprinted by a wide range of typesetting systems and printers (Connolly, et. al. 1997).

Beginning in 1970, IBM provided the other strand, with the development of General Markup Language (GML – Goldfarb 1996, 1997). GML formed the basis for IBM's 1978 Document Composition Facility[192] that pioneered the core concepts of a formal Document Type Definition (DTD) and the semantic tagging of functional elements of text (i.e., "content markup").

In the early 1980s, the GenCode and GML communities joined to form the American National Standards Institute (ANSI) Committee on Computer Languages for the Processing of Text, who drafted the ISO specification 8879 (1986). Standard Generalized Markup Language (SGML) incorporated GML's concepts of descriptive/functional markup, document type definitions, and the complete separation of standardized non–proprietary text markup from format processing instructions. Format processing was performed by proprietary output systems that applied formats based on element tags and their location in the overall structure of the document (Sperberg–McQueen and Burnard, 1994).

Structural and Semantic Markup (Enabling the Structural Paradigm)

Specifically, SGML is a general purpose *language* for defining logical structures of different kinds of documents and for defining markup tags allowed to be used in those structures. Documents marked up in the SGML language have three main parts:

- A declaration, defining to the computer (a) what characters may be used as tag delimiters, as characters of normal text, and (b) various parameters determining other syntactical details of the SGML language itself.
- A DTD, defining to the computer what element tags are allowed in the document and

structural rules determining where the defined tags may be used in the logical structure of the document.

- An instance of the textual content (i.e., the output document), which contains elements of text marked up in conformance with the DTD.

Documents may be delivered as completely self–defining containers of information, with their declaration and DTD attached. However, in most cases, declarations and DTDs are held in central repositories and are only referred to as required to control authoring or formatting applications. Many DTDs may be defined using the same declaration, and many documents may be structured in conformance to the same DTD. In most applications, DTD are published as open standards. Many parties exchanging the same types of documents may use these standards, irrespective of the software applications used. Major uses of SGML are in the production of technical documentation and automated assembly of journals and business advisory services. CALS (Computer aided Acquisition and Lifecycle Support) initiatives promoted in the 1990s by defense logistics and acquisition organizations in many countries greatly encouraged the spread of SGML[193].

SGML was designed to be processed on mainframes where the ASCII characters of the tags were manually typed. Consequently, SGML has a number of optional provisions to minimize typing tags in locations where a powerful computer system could infer they must occur. Tag minimization helped those who only had simple line editors create SGML texts. However, the complexity of the processing needed to infer the missing tags made parsing, editing and print formatting programs substantially more complicated than needed and was counterproductive for developing personal computer applications. Nevertheless, authoring software was developed to read SGML DTDs and understand the syntactical rules they described[194]. Much of my work in the Australian defense industry in the period from 1995 to 2000 was devoted to the implementation of SGML authoring systems. To help the author think structurally, most such systems provide a palette or logical tree view (GUI) of the types of elements allowed at any specified point in the document. To ensure conformance to the associated DTD, authoring applications also parse the document structure as the text is typed and marked up, or at least identify and flag illegal structures when the document is saved.

Aside from SGML and GML there are two flavors of semantic markup language in common use today:

- HTML is a tagging standard based on a single SGML DTD, first released to the world in 1993 (Sears, 1998). The DTD defines a standard *format–oriented* markup able to be understood by compliant Web browsers. However, HTML may be hand coded (i.e., using extensive tag minimization) and many browsers do not enforce strict compliance to any version of the HTML DTD. Also the dominant browser developer (e.g., Microsoft) has introduced its own proprietary tagging options on top of the established standard. Consequently, much of the HTML formatted text on the Web today does not strictly comply with any DTD (Sears, 1998)[195]. Because of these factors, although HTML is one of the key factors that enabled the amazing growth of the World Wide Web as a universal information exchange medium between people[196], HTML does not facilitate the computer aided processing or retrieval of semantic content.
- XML is a full featured version of SGML developed and optimized for use by personal computer applications and Web browsers. Compared to HTML, which serves primarily as a standard for formatting markup; XML is intended to tag content with semantic

information for use on the Web and exchanges between different information systems. Like HTML, XML texts can be authored and delivered as "well–formed"[197] documents to the Web without an associated DTD, along with separately constructed style sheets of various kinds to control the formatting. However, as with SGML, texts can be authored and distributed under full DTD control to ensure standardization between communication partners[198].

All of these markup languages have been established as *non–proprietary international standards* for marking up content. The intent of all is to allow content to be readily exchanged between the whole range of applications (editors, viewers, output formatters, indexing systems, etc.) and between different applications of each type conforming to the standard. How HTML has added value to knowledge is explored in a later section, where the growth of the Web is considered.

Tools to Store, Manage and Retrieve Preserved Knowledge

Word processors, spreadsheets and relational databases have quantitatively extended human cognitive capabilities. Most kinds of documents can now be filed, replicated and delivered at light speed to those who need the knowledge they contain. Large–scale arithmetic and mathematical calculations that would be completely beyond the capacity of an individual human to achieve can be carried out in an instant. However, these applications by themselves have not fundamentally changed the cognitive activities of people assembling knowledge into documents or managing them. Current business processes using word processing systems, spreadsheets and databases often still closely resemble those followed when scribes and clerks were pressing cuneiform script onto clay tablets – they just work faster with fewer people.

In the last decades computer-based information management and delivery technologies have begun to replace the paper paradigm. These newer technologies assist human cognitive abilities in new ways, and will lead to more radical changes in the way humans produce and work with knowledge than have occurred in conjunction with past technological revolutions. However, before considering the electronic tools, it is worth considering the evolution of older information and knowledge management technologies practices associated with printed literature.

Information Science: Disseminating, Indexing and Retrieving Scholarly, Scientific and Technical Knowledge

The need to organise existing knowedge for retrieval is a fundamental requirement for scholarship and the growth of scientific knowledge. This was evident as far back as the rise of the Library and Museum in ancient Alexandria (Jacob 1997; 2002), where the attempt was made to build a “universal library” containing all the major texts available in the known world. No one person could comprehend the whole content, so methodologies and systems had to be developed to find and extract relevant information. As discussed previously, this involved abstracting, ordering and indexing content from each document, and storing the documents in the library so they could be found later from the tabulated catalogue or “pinakes”. <<<more work here>>>

The discipline that built up around identifying and retrieving scholarly and technical knowledge became known as information science[199].

The invention and spread of printing greatly facilitated the dissemination of scholarly information. However, as argued above, the needs of technical, academic and scientific research and publishing are not well met by books and library catalogs that are respectively, often too far removed from the original research that generates knowledge, and too coarse–grained to retrieve the kind of detailed knowledge researchers need. This was already recognized with the beginnings of the Scientific Revolution in the latter half of the Seventeenth Century, with the development of the first learned societies, such as the Royal Society (of London) – founded in 1660 and the Académie des Sciences (in Paris) – founded in 1666. The first scientific journal, Journal des Sçavans, was published in 1665[200], followed within the year by Transactions of the Royal Society and Académie des Sciences, respectively (Fjällbrant 1997).

Once the idea of publishing journals on specialized topics took hold, "Scientific" knowledge based on direct observation and experiment began to grow rapidly, and soon differentiated into "primary" and "secondary" literature[201]. *Primary literature* consists of the reports of original research. However, the primary literature quickly grew to the extent that for many disciplines it was (and is) beyond the capacity of any one person to read more than a tiny fraction of what is published in his/her own discipline – let alone science as a whole. Even the early scientific journals included the concept of articles reviewing and summarizing literature published elsewhere. This *secondary literature* evolved to include subject related indexes, abstracts, review articles, textbooks, and bibliographies that attempt to summaries and point to original work in particular disciplines of knowledge. In a sense, the secondary literature fills a comparable role for science and scholarly journal articles that indexing and cataloging does for a library of single topic books. The next, and major, difficulty is to index this complex literature for retrieval.

An early attempt to provide a global index of all articles published by scholarly societies (i.e., comparable to a universal catalog) was the Reuss Repertorium, published from 1801–1821[202]. This was followed by the Royal Society of London's Catalogue of Scientific Papers, published from 1867 to 1925[203]. As scientific and scholarly publishing grew to overwhelming volumes, this kind of global indexing became increasingly difficult to achieve with purely manual means.

Given the difficulties inherent in indexing everything in the one place, more specialized bibliographic services evolved to catalog, index and abstract the literature of particular disciplines. The disciplines involved in developing such indexing services and related technologies became known as *information science*. A comprehensive chronology of the development of information science, along with a list of source references is provided by Williams (2002). Following are highlights some of the earlier services (with their establishment dates) that I have used in my own academic research:

- Apparently the oldest of the specialized services (and one of the first I used academically) is the Zoological Record, first published in 1865, and merged with Biological Abstracts in 1980[204].

  These were followed by

- Index Medicus, established by the polymath John Shaw Billings[205] in 1879 (Zipser 1998; Schulman 2000), was the direct ancestor of the US National Library of Medicine's free to the Web search service, PubMed;
- Science Abstracts (Physics and electrics, from 1889 – now published as Physics Abstracts,

Electrical & Electronics Abstracts and Computer & Control Abstracts) – available electronically as INSPEC[206];
- Chemical Abstracts (from 1907)[207];
- Biological Abstracts (from 1926)[208], where I first learned the incredible retrieval power of computerized indexes and Boolean search and retrieval. BIOSIS publishing assets (including Zoological Record) were purchased in 2004 by Thomson[209] and are now subsumed and submerged in ISI Web of Knowledge (including Science Citation Index).
- Science Citation Index (SCI - from 1961) now part of Web of Knowledge[210]. SCI's importance will be discussed in more detail under Citation Indexing, below.

Legal citation indexing (Liebert 1999; Shapiro 1998; Taylor 2000) was another specialized service that developed early, with the oldest and most familiar being Shepard's, which traces back to 1873.

Before computerization, these indexes were extremely labor intensive and costly to produce. People had to read articles, then abstract, classify, and prepare index entries, and then compile the result into a publishable format. As will be discussed in more detail below, computerization facilitated classification, indexing and compilation – with most services computerizing their indexing activities to some degree and providing computer searchable products (via magnetic tape or online) in the 1960s and 1970s. Now, the increasing use of semantic markup languages such as SGML and XML in the Scientific, scholarly and professional journals are enabling these kinds of indexing services to be produced automatically from the original articles with little or no human intervention.

Computerizing and Moving the Indexes On–Line

Scientific, scholarly and professional publishing grew exponentially after the end of the Second World War along with growing populations of academics and academically trained professionals who needed access to the specialized literature (Walker, 1998; Cox 1998). This involved the publication of more journals and more papers in each journal that would benefit from indexing to aid their retrieval. Beginning in the mid 1950's and with the development of the digital computer being fuelled by Moore's Law, more and more aspects of the indexing, query and retrieval processes could moved into a computerized environment with the development of databases for particular bodies of knowledge. The first on–line systems providing access to single databases were established in the late 1960's (Williams 2001).

The basic idea of a computerized bibliographic database is the same as that of a library catalog. Indexes are created for each separate kind of information about articles held in the database. Terms in each index are arrayed in alphabetic or numeric order so the query process "knows" where to start looking. A hit on a search term in the index then links to a complete bibliographic record detailing the article – or now in most cases, to the whole article itself. For example, the title index will list all words (exclusive of "stop" words) used in the titles of all articles included in the database.

The computerization of single bibliographic databases was followed in the early 1970's by on–line services that provided single access points to aggregated collections of bibliographic indexes. Of the commercial services surviving at least into the beginning of the present century, the first two, both open to the public in 1972 were Lockheed's Dialog[211] and Systems Development Corporation's ORBIT[211]. Librarians used both of these services on my behalf in the mid 1970s as I was collecting literature for postdoctoral work.

Indexing and Semantic Retrieval

Even with bibliographic indexing limited to narrow disciplines, the indexing services are epistemically valuable only if end users can locate source documents containing the desired knowledge with a reasonable effort. Basically, the power of an index and its search engines is determined by how well the contained data can be queried, discriminated and retrieved in ways that will be semantically meaningful to its human users. Hahn (1998) lists a number of functions bibliographic index systems provide for finding sources of knowledge. Most were first introduced in the mid 1960's. Here, I list the most important ones and indicate how the function works to provide the semantic connection.

- *Boolean logic* (AND, OR, NOT)

  Boolean searching is one of the most useful functions provided by modern bibliographic databases, in that it allows users to describe the knowledge sought in a way that is also semantically meaningful to a computer system. Boolean logic allows users to construct reasonably sophisticated search expressions using combinations of keywords joined by the AND, OR, and NOT operators

  Most bibliographic database systems allow Boolean operators to be combined or nested using parentheses to make sophisticated search expressions. Even without other tools, these simple retrieval tools allow a user to substantially filter the likely responses to a reasonable practical number of hits that would be worth exploring further.

- Citation indexing

  Citation indexing is potentially much more powerful semantically than Boolean searching, and is based on a completely different logic inherent in the way that knowledge grows and is aggregated from observations, prior knowledge, and testing. Used originally in manually created legal indexes, computers were first applied to bibliographic databases of scientific and academic literature by Eugene Garfield's ISI[213]. The power of the retrieval methodology depends on the original authors' scholarly work to form semantic links between the articles they publish and articles they reference in assembling the knowledge recorded in their publication[214].

  An author adds a citation to a bibliography or footnote because he/she referred to some relevant information in the cited article. The citation index database is built by extracting citations from a list of papers, and then indexing the original articles against the articles they cite. Thus, a user who is familiar with the literature of the discipline being searched can select one or more relevant papers representing the kind of knowledge being sought, and then go to the index to retrieve details of any more recent articles citing that kind of knowledge. The inference is that at least some of the content of the citing paper will derive semantically from the cited papers. The reference to a cited paper may be trivial, but there will at least be some valid semantic connection between the later citing paper as retrieved and the older cited paper used as a search term. The bibliography of the more recent citing paper may then be used to select citations to possibly more directly relevant older papers that may be used as additional search terms to generate new lists of more recent citing papers. This contrasts with Boolean and other related keyword or topic search methods that depend only on the occurrence of particular words in a single document – which often retrieve a high frequency of irrelevant material.

Citation indexing thus establishes both ends of two-way semantic links between source documents and their derivatives, to build a contextual web of assimilated information and knowledge that exists in World 3, completely independent from any knowing person.

- *stemming* or truncation by wildcards (?, *, ...)

  These are different methods allowing a part of a word to be used for a search term (e.g., search on the root "enter" for enter, enters, entering, entry, entered, etc.). The "?" operator normally accepts any single character at the point of the question mark. The "*" operator normally accepts any combination of characters up to or following the characters actually specified in the search term, depending on whether the asterisk begins or ends the search term. The ELIPSIS operator ("...") may be used in some systems to match all characters occurring between particular beginning and ending characters. Simple wildcard systems will pick up unrelated concepts where the sequence of characters in the root is the same. These operator concepts were first developed in the mid 1950's with the development of "regular expressions", which could be used to identify Boolean matches on a character–by–character basis. Some of the more sophisticated stemming processes will search on all of the parts of speech for a specified term even where the root is spelled differently for some of them. This kind of methodology allows a broader search on a concept not confused by spelling differences introduced by grammar.

- Proximity operators (NEAR)

  First used in 1969, and with details depending on the particular search application, NEAR operators allow Boolean operators to be applied within a sentence, a paragraph; or within a certain number of words, sentences or paragraphs of one another. The concept here is that the search terms are likely to be semantically connected to one another if they occur close together.

- Ranking and relevance

  Listing hits in assumed order of importance relevant to the query.

- Contexts or zoning

  Highlights search terms in displayed text snippets to help users determine whether the article is likely to be worth retrieving.

- Results set iterations

  Users can refine searches by searching on additional terms within a larger set of records returned by a prior search.

- Full document retrieval

  For many of the early systems it was economically impossible to store full documents online. However, an increasing number of bibliographic services did offer some provision for delivering hard copy of selected references at great cost, e.g., via "tear sheets" where pages might be physically torn out of the journals in question or via manual photocopying.

- World–wide access

  The ability to access servers in one country from another country half way around the world was first demonstrated in 1967.

Each of these indexing technologies gave sophisticated users additional powers to retrieve bibliographic entries likely to be relevant to their needs. However, many of the features depended critically on up–front activities to have human indexers actually read the articles to extract meaningful index items to create the bibliographic records. Because of this labor requirement, such systems were expensive to deploy commercially and could not be economically provided to the public for free. Also, even when all of the features could be used together, the computer systems were unable to understand enough of the document structure to provide any real help. For many users, the only way to achieve a practical benefit from these capabilities was to work through expensively trained librarians and information scientists, which increased retrieval costs still further. As will be seen below, Web technologies and new ways of structuring documents have radically changed this equation.

The increasing cost of publishing paper and the limitations of libraries

Even with electronic indexing tools to help people locate the knowledge sought, the growth of the literature and the introduction of revolutionary technology are putting research libraries under ever increasing stress. More journals are published every year, and by the end of the last century individual journals were becoming increasingly expensive (Walker 1997; Odlyzko 1994).

It is becoming prohibitively expensive for even the largest research libraries to maintain complete collections of the literature (Solomon 1999). In the 25 years from 1970 to 1995 the cost of journal subscriptions increased by some 18 times compared to an increase of approximately 4 times for books and monographs (Walker 1998). The Association of Research Libraries' Annual Statistics Reports also make this painfully clear (e.g., Kryllidou 1999, 2000; Case 2001; Kryllidou and Bland 2009), as illustrated in Figure 43.

The current system of scholarly publishing has become too costly for the academic community to sustain. The increasing volume and costs of scholarly publications, particularly in science, technology, and medicine (STM), are making it impossible for libraries and their institutions to support the collection needs of their current and future faculty and students (Case, 2000).

Paper journals are also very costly to publish and distribute. Around year 2000, Odlyzko (1999) estimated that the average journal article costs $4,000[215] to produce (in terms of publisher's revenue per journal divided by the number of articles published in the journal), plus another $8,000 in libraries' administrative and running costs amortized per article, plus $4,000 in editorial and referee costs (in many cases borne by the individuals doing the work) and another $20,000 author's costs to prepare the article. Thus, with paper technology, a single article, on average, costed something on the order of $36,000 to produce[216]). This does not include the indexing services' costs to reference the article in their indexes.

Thus, the cost to record and access knowledge via journals and libraries has become a significant fraction of the cost of doing research. For some libraries – especially those in less well developed countries – comprehensive journal holdings have become an expensive luxury they simply cannot afford. Every year over the last couple of decades (at least), most libraries have faced the question – not what new things they should add to their collections but rather what acquisitions and journal subscriptions *they must cancel* so they can still stay within budget (Krillidou 1999; Russo 2001; Day 1997). In 2010 the crisis is reaching a breaking point, where costs are financially untenable even for the largest and most powerful research universities, as exemplified by the recent standoff between Nature Publishing Group (NPG) and the University of California. The University threatened to cancel many of its subscriptions and to advise its scientists to boycott NPG publications (Scudellari 2010; NPG 2010; Farley et al. 2010; Hall and Nousala 2010a) And for those like myself, who until recently have lacked ready access to high quality research libraries, reasonable access to physical copies of specialist journals is close to impossible without this access.

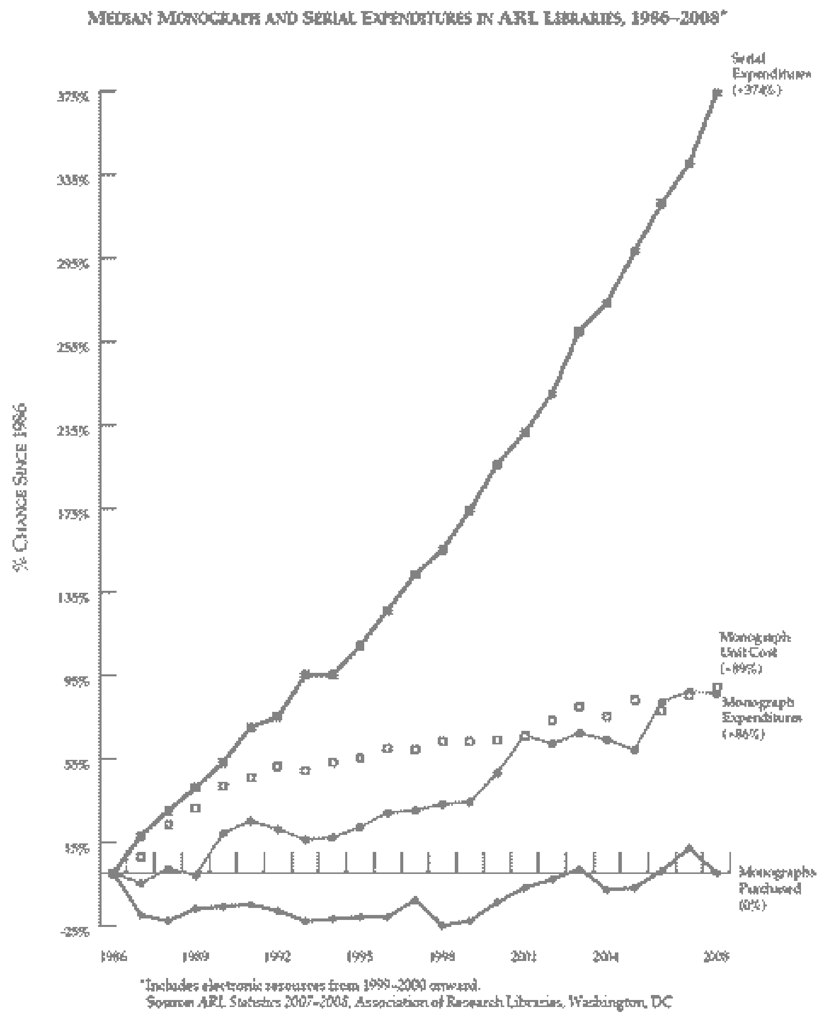


Figure 43. Escalating library costs (from Krillidou and Bland 2009)[217].

However, with an increasing number of journals being distributed electronically to libraries, and the libraries offering electronic access to these journals to their communities via portals (Wetzel 2002) and increasing signs of revolt by libraries and their users (Suber 2002), the economics of journal publishing and distribution are changing in ways that may eventually benefit scholars (see also Hall & Nousala 2010a; Vines et al. 2011).

The other major issue relating to dissemination of knowledge via journal publication has been the long lag between the author's completion of a paper and its availability in a journal to those who need the information. This often costs one to two years or more where paper journals are concerned, and has led to a proliferation of informal means of publication via conferences and pre–prints. These add additional costs to the dissemination and use of knowledge over and above the costs of formal publication summarized above.

The Research Library is Dead – Long Live the World Library

The bottom line is that the cost of publishing scientific and technical information to paper journals has escalated to the extent that there is a major demand for better and less costly mechanisms to record, store and retrieve core knowledge from users, libraries and the increasingly non–competitive publishers themselves (Walker 1997; Day 1997; Varmus 1999; Butler and Wadman 1999; Marshall 1999; Russo 2001)[218]. How these issues are being resolved will be discussed in my Cadenza.

Compared to the library–related bibliographic cataloging and indexing technologies for paper documents discussed above, which have been developed over more than a century, cognitive retrieval and linking tools for personal desk–top use have evolved from essentially nothing in less than 15 years, with the most pervasive one being the World Wide Web. Beginning with the launch of Mosaic in 1994, the Web exploded in less than a decade from an idea into a system used by a significant fraction of humanity in the world's developed countries to access a reasonable sample of humanity's total knowledge. This explosion of cognitive tools is explored in the next section.

The World Wide Web

Web Origins and History

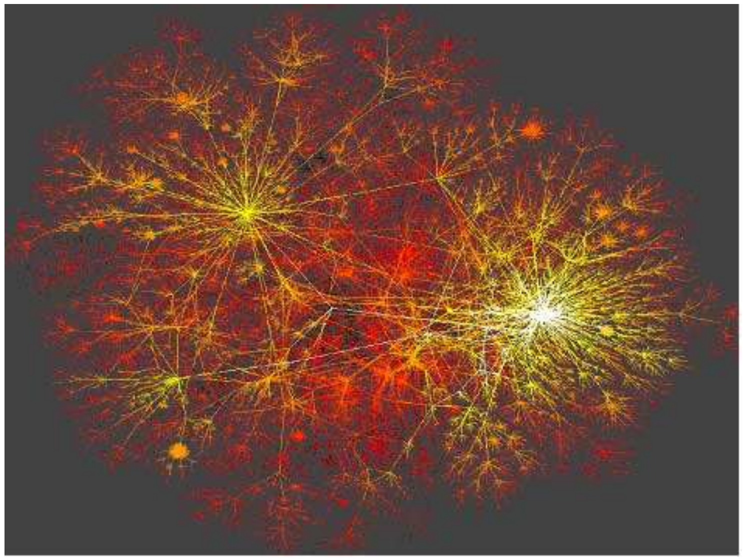


Figure 44. Internet interconnectivity between servers, hubs and trunks. Color represents the time delay from source location (white) – http://www.caida.org/ (from Krioukov 2010 – Navigability of complex networks.

The Internet (or Net) is the logical network capable of interconnecting anyone with a computer and telephone via the TCP/IP communications protocols. Transmission Control Protocol (TCP) controls how packets of information are assembled and disassembled for transmission over the network. The Internet Protocol (IP) controls the address portions of the packets. The Internet is evolving into a global W3 memory for the whole of humanity, with a level of complexity approaching that of biological nervous systems (Figure 44). The Internet supports several different kinds of communication and information interchange standards within TCP/IP: E–mail, gopher (obsolete – supplanted by HTTP), File Transfer Protocol (FTP), Internet telephony, and the HyperText Transfer Protocol (HTTP). HTTP – first conceived of by Tim Berners-Lee in 1989 and released to the public in 1991 (see below) – forms the basis for the World Wide Web (or Web).

All of these Internet features extend human capabilities to transfer and communicate knowledge artifacts, and are revolutionary by comparison to any previous technologies for communication or knowledge exchange. The Web is the most revolutionary of all of these. The origins and evolution of the Internet and Web are well documented, and will not be reviewed except to highlight the origins of particularly significant features[219]. Here, I wish to focus on those capabilities of the Web that generate epistemic power: linking and hypertext; indexing, search and retrieval; and semantic and cognitive processes that are built into some of the more advanced "search" engines.

Vannevar Bush's Memex

The original idea leading eventually to the development of the Web was proposed in 1945 by Vannevar Bush, Science Advisor to Franklin Roosevelt during World War II. In a discussion of the [even then] problems keeping track of proliferating scientific knowledge, Bush (1945) raised the idea of a desk–top associative memory aid based on microfilm technology to record logical connections or links between documents in the building of knowledge. He called this tool the "Memex". The basic idea of the Memex is "*...associative indexing... which is a provision whereby any item may be caused at will to select immediately and automatically another. This is the essential feature of the memex. The process of tying two items together is the important thing.*"[220] In this definition I would emphasize that selecting a linked object automatically retrieves it for viewing. For the scientific, technical and academic literature, reference citations and citation indexing provide this kind of linkage. The Memex was intended to provide this linkage in real time.

The terms hypertext (see also Wikipedia) and hypermedia (text plus graphics, video, sound, etc.) were introduced by Ted Nelson[221] (1965) at the 20^{th} National Conference of the Association for Computing Machinery, with the first Hypertext Editing system developed by IBM for its 360 computers. The ideas continued to develop through the '70s and '80s[222]. One of the first implementations of hypertext on personal computers was Apple Computer's HyperCard, which was introduced in 1987 (Feizabadi 1998).

Tim Berners–Lee Invents the World Wide Web

The World Wide Web concept, including a hypertext/hypermedia capability, began at CERN (European Organization for Nuclear Research) in 1989. Tim Berners–Lee proposed implementing hypertext linking technology specifically as an organizational knowledge management tool to keep track and record contextual connections among of the growing and evolving body of information assembled by the many scientists passing through the institution – which otherwise would be lost on their departure:

> In providing a system for manipulating this sort of information, the hope would be to allow a pool of information to develop which could grow and evolve with the organisation and the projects it describes. For this to be possible, the method of storage must not place its own restraints on the information. ***This is why a "web" of notes with links (like references) between them is far more useful than a fixed hierarchical system.*** [my emphasis]
>
> *... We should work toward a universal linked information system, in which generality and portability are more important than fancy graphics techniques and complex extra facilities.*
>
> *The aim would be . The result should be sufficiently attractive to use that it the information contained would grow past a critical threshold, so that the usefulness the scheme would in turn encourage its increased use.*
>
> *The passing of this threshold [would be] accelerated by allowing large existing databases to be linked together and with new ones. (*Berners–Lee 1989*)*

Ideas for how the World Wide Web would work were first implemented late in 1990 on a NeXT environment using object-oriented technology when I was already 50 years old. The software was ported to other platforms. Berners–Lee released his WWW concept to the world in 1991 via the WWW–talk mailing list (Berners-Lee, Fischetti 1999; Raggett, 1998) The concept included HTTP, HTML, Web servers and clients, and the idea of the Uniform Resource Locator (URL).

The URL is the named location of a file (resource) available for delivery over the Internet. With HTTP, the file can be an HTML page or any other type of file supported by HTTP (e.g., graphics, Java programs, etc.).

> Once the WWW concepts and the protocols were placed in the public domain, programmers and software developers around the world began introducing their own modifications and improvements. Marc Andreesen was one such programmer. Andreesen, a graduate student at the University of Illinois' NCSA (National Center for Supercomputing Applications), led a team of graduate students (including Eric Bina) who, in February of 1993, released the first alpha version of his "Mosaic for X" point–and–click graphical browser for the Web implemented for UNIX. In August of 1993, Andreesen and his fellow programmers released free versions of their Mosaic for Macintosh and Windows operating systems. ***This was a significant event in the evolution of the world wide web in that, for the first time, a world wide web client, with a relatively consistent and easy to use point–and–click GUI (Graphical User Interface), was implemented on the three of the most popular operating systems available at the time*** *[my emphasis]. By September of 1993, world wide web traffic constituted 1% of all traffic on the NSF [Internet] backbone.* (Feizabadi, 1998: 1.3.1).

In 1994, the Mosaic team set up their own company and began developing the Netscape Navigator browser product. With Tim Berners-Lee's encouragement, the World Wide Web Consortium (W3C) was also formed in 1994 as an international body to provide a central steering and standards organization for the Web. This was followed by the release of Netscape's and Microsoft's browsers, which made information on the Web universally available to anyone with a personal computer and an internet connection via telephone, cable or satellite and a desire to access it. Thus, although today (in 2013) the Web as we know it is a pervasive and ubiquitous part of most peoples' cognitive lives, we need to remember that it is still *less than 20 years old*!

Basic Web Tools

Since then, enabled by the development of cognitive tools that establish an environment for accumulating and sharing knowledge, the Web has become a massive repository of all kinds of human knowledge. Tools for building, indexing and retrieving this knowledge include standards and several major groups of applications: structured authoring tools (SGML, HTML and XML), servers, browsers, indexing and search engines.

- Standards

  The development and use of standards for encoding, representing and transmitting content has been particularly important in the development of the Web, because it has made the creation and access of information independent of any particular proprietary software.

  Until recently, the primary standards enabling the Web have been HTTP and HTML. HTTP enables the exchange of requests, Web pages, and the processing of hyperlinks in those Web pages. HTML provides a standard markup understood by Web browsers able to convey enough formatting information for a reader to apprehend document structure. Although the HTML language is defined by an SGML DTD, because HTML (like word processing markup) is almost exclusively concerned with encoding the *visual* formatting of the information retrieved, it conveys limited semantic information beyond the raw text. As will be explained below, XML is replacing HTML as the preferred tool for Web authoring, because XML allows content to be tagged semantically.

- Authoring tools

  HTML was initially designed to provide a limited range of formatting and hyperlinking capabilities, and for its tags to be comparatively simple to type using nothing more than a text editor. However, as demand grew for including a wide range of graphic and formatting objects such as lists, tables, frames, dialog boxes, etc., HTML tagging became increasingly complex, and a number of authoring tools offering similar formatting capabilities to word processing were brought to market. Structured authoring/editing tools are applications specifically designed to help authors tag text and other content in SGML, HTML or XML. Word processors (e.g., MS Word) are also now equipped with capabilities to save text with HTML or even XML markup. In January 2003, Yahoo listed more than 60 HTML editors; in 2010 this had dropped to 48[223]. XML's coding requirement are much more stringent than they are for HTML, and authors wishing to use XML markup for their texts will find that XML editors are essential. In January 2003, more than 50 XML editing tools were listed; by 2008 this had risen to more than 140. Several of these are directly based on the SGML editors; and some of the SGML/XML editors also have the capacity to save formatted text as HTML.

- *Web Servers*

  Web servers store, generate and retrieve content for delivery to the Web in response to HTTP requests. Depending on the volume of material delivered to the Web, the number of requests for information and requirements to generate information from databases, servers can range in size from a single PC in a home office to supercomputers, or server farms (Figure 45) containing hundreds, thousands or even tens of thousands of PCs[224]. Servers may provide search engine and/or directory services.

Figure 45. A small part of one of Google's data centers[224]. Each rack holds 15 server boards (Google Data Centers, photo gallery).

- *Browsers*

Browsers are the primarily tools for viewing (but not editing) documents[225]. Web browsers are internet clients on end users' systems that communicate with Web servers via HTTP to retrieve content and display it for the human operator. Microsoft rapidly dominated the market with its Internet Explorer (IE), anti-competitively bundled with its Windows products, such that anyone purchasing a PC including a Microsoft operating system automatically received IE. This led to the demise of Netscape as a commercially viable product and the successful prosecution of Microsoft in a major antitrust trial.

In the last few years all of the main browsers have also come to understand XML. XML and its associated formatting standards allow the semantic structure of documents to be marked up for both semantic processing and for display in an easily comprehensible format for the human reader[226]. Browsers offer capabilities for rendering or downloading documents in other file formats such as .PDF (either directly or via "plug-ins"), but these do not add significant epistemic quality to content in isolation from the other two classes of Web tools.

An unexpected outcome of Netscape's 'failure' against IE was the release in 1998 of Netscape Navigator's source code into the public domain, and the establishment of the Mozilla Project and related organizations that pioneered idea of open-source software development[227]. The Mozilla team eventually developed the successful FireFox browser. A third major player, Google, released their Chrome Browser in 2008. Today, these three browsers account for approximately 85 percent of the browser market (see Wikipedia on usage share). As a consequence of this kind of competition, essentially all browsers are freely available to install.

As will be seen, these free browsers are open portals to the bulk of human knowledge – something that could not be foreseen just 15 years ago!

- Retrieval tools

  Given that tools exist to author Web content, link content to other content on the Web and to display content retrieved via Web links, the critical tools for recovering Web content of high relevancy are the Web catalogs (directories) and various kinds of Web search engines. These attempt to index the full content of the Web for easy human retrieval, and many are available as free services to Web users (at the cost of being subjected to various kinds of targeted advertising).

All of these classes of tools, and especially a browser are required to make the Web work as a practical repository for knowledge. This is illustrated in Figure 46.

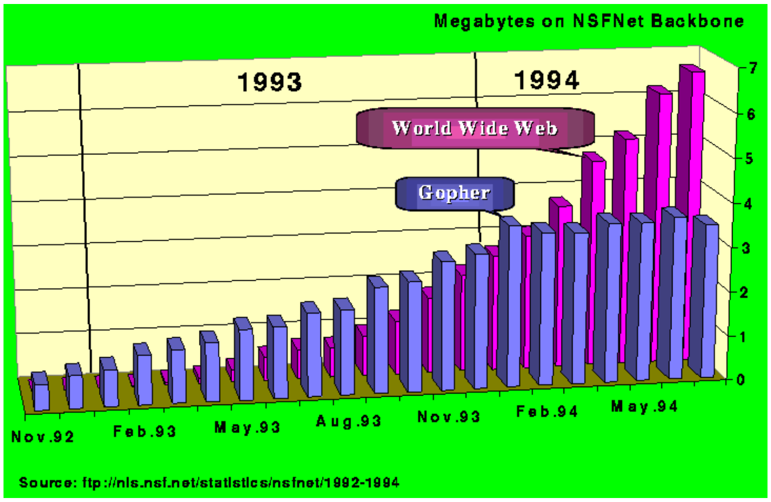


Figure 46. Browser-based document retrieval from the Web surpasses direct retrieval from the Internet (using Gopher) in March 1994.

However, the activities that provide the greatest value to facilitate the aggregation and retrieval of recorded knowledge are those of creating, describing and identifying links between documents. Even the average individual's home page, by providing links to other pages, provides additional semantic information based on the objective structure of the Web's World 3 to identify and qualify knowledge that can be retrieved by following these links – as foreseen by Vannevar Bush's Memex concept, citation indexing and demonstrated by this hypertext book. Web links represent assimilated information. Russ Haynal (????) explains how the pieces fit together into a complete architecture.

The Web Explodes

Because the Web (and the Internet which contains it) originated in the academic world and was highly subsidized by the US government[228], major fractions of the knowledge being placed in the Web and the crucial storage and communications infrastructure for accessing this knowledge were freely available to end users[229]. Undoubtedly fuelled by the growing epistemic value of the content that can be retrieved essentially for free, the Internet's rate of growth was unprecedented in human history, and it soon grew beyond anything that was economically capable of being supported by university or Defence Department hosts. Commercial organizations known as Internet Service Providers (ISPs) evolved to provide the host computers and telecommunications interconnectivity to tie the information resources and users together. Similarly to telephone exchanges, the highly automated ISP's are funded by people seeking hosts for knowledge they wish to place on the Web and by end–user subscriber charges. Many of those seeking services to host their content have something to sell, where hosting costs can be funded from profits. As will be seen, the result is a system that provides end users with access to a cognitively significant fraction of the world's textual knowledge for costs comparable to ordinary telephone services[230].

Since 1994 the system has grown at a rate that is unprecedented for any new technology, as illustrated in the following table and figures.

Table 1. The First 30 Years of Internet Growth (Net Statistics from Gromov 2011)

Date	Hosts [1]	Domains [2]	WebSites	WHR(%) [3]
1969	4			
Jul 81	210			
Jul 89	130,000	3,900	–	
Jul 92 [4]	992,000	16,300	50	0.005
Jul 93	1,776,000	26,000	150	0.01
Jul 94 [5]	3,212,000	46,000	3,000	0.1
Jul 95	6,642,000	120,000	25,000	0.4
Jul 96	12,881,000	488,000	300,000	2.3
Jul 97	19,540,000	1,301,000	1,200,000	6.2
Jan 98	29,670,000	2,500,000	2,450.000	8.3
Jul 98	36,739,000	4,300,000	4,270,000	12.o
Jul 01	126,000,000	30,000,000	28,200,000	22.0

1. A host is a domain name having an IP address (A) record associated with it. This would be any computer system connected to the Internet (via full or part–time, direct or dialup connections). One computer may run several virtual hosts.
2. A domain is a domain name (e.g., .com, .org, .net, .au, etc) that has name server (NS) records associated with it. There may be subdomains or hosts within the global domain (e.g., google.com). Domains are addressable by various Internet protocols. WebSites are specifically HTTP servers.
3. WHR - Web sites to Hosts Ratio – very approximately (!) estimates the percent of content active part of Net community. In other words, WHR reflects the percent of Web surfing people that are trying to become the Web authors by creating their own Web sites.
4. 1992 = first year of experiments with HTML and WWW architecture.
5. 1994 = first year of the public Web.

It is comparatively easy to determine the number of internet sites by automated means, whereby a "search engine spider" or "bot" program simply queries the Web to reach hosts. Growth in the number of domains is shown by Table 1 and Figure 47).

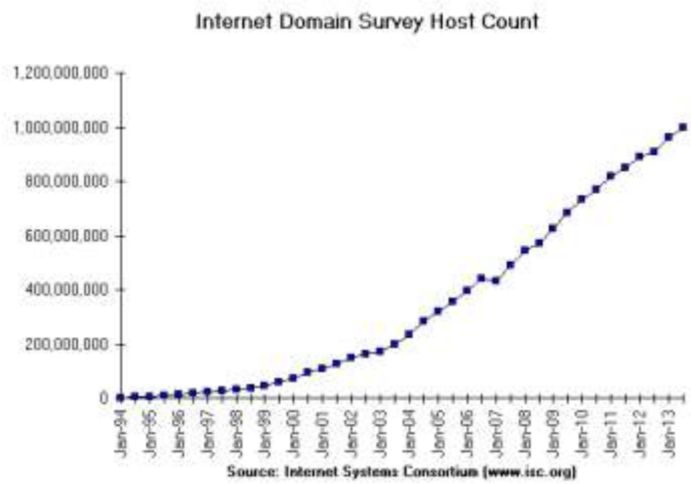


Figure 47. Growth in the number of internet hosts. ICS's Domain Survey attempts to discover every host on the Internet by doing a complete search of the allocated address space and following links to domain names. The survey has been performed since 1981, and twice yearly since 1987 as described by Lottor (1992) and How the survey works. More than 996 million hosts reported in July 2013.

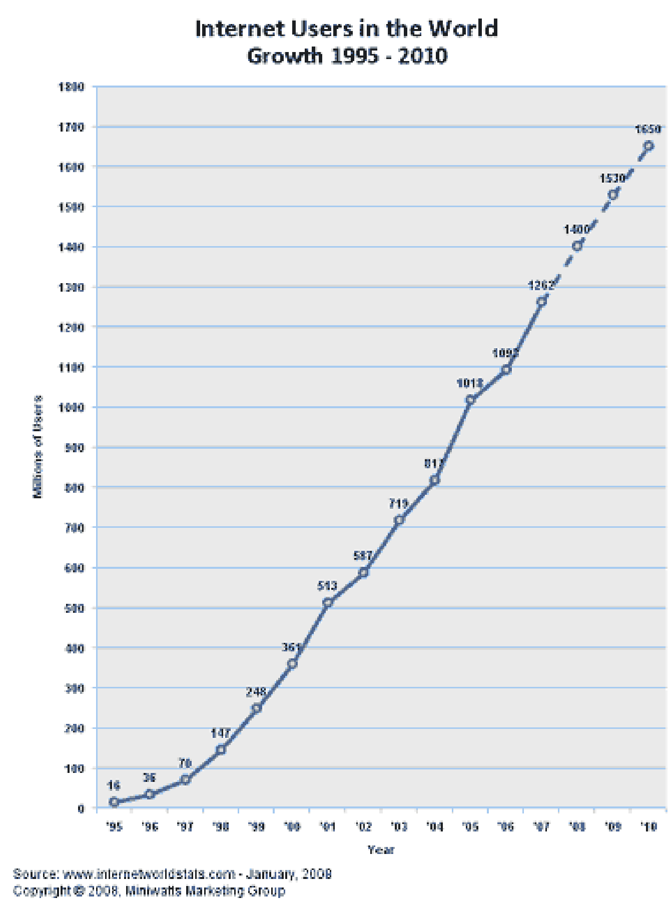


Figure 48. Growth in the number of Internet users from 1995 through 2010. (From Internet Growth Statistics, Internet World Stats (Copyright © 2000 - 2010, Miniwatts Marketing Group), (as at 17 Sept 2010).

How many people actually use the Internet is more difficult to determine, but Internet World Stats attempts to do so, as shown in Figure 48. These estimates are based on proprietary data "published by Nielsen Online, by the International Telecommunications Union, by GfK, local Regulators and other reliable sources." As at June 30, 2010 they estimated the number of users as 1,966,514,816, representing 28.7% of the *world* population and a growth in the number of users of 440% since 2000. By comparison, in *North America* 77.4 percent of the population use the Internet, growing by 146% since 2000.

The US Census Bureau's E-Stats estimates the value of goods and services sold online in the US, whether over open networks such as the Internet, or over proprietary networks running systems such as Electronic Data Interchange (EDI). Two sets of measures are given here to demonstrate rate of change, retail e-commerce sales as a proportion of total retail sales (Figure 49) and sales across four sectors of the economy (Figure 50). From the beginning of 2001 the e-commerce proportion amounted to about 1% retail sales, and by the beginning of 2013 it had risen to 5.5%. As shown in Figure 50, wholesale sales (e.g., automated order fulfillment) accounts for around 20% of the total sales rising to 24.3% in 2011; while the percentage of e-commerce sales transactions in the manufacturing sector rose from about 20% to nearly 50% in 2011. Wholesale and manufacturing sales are often based on semantically based systems using XML-based data exchanges.

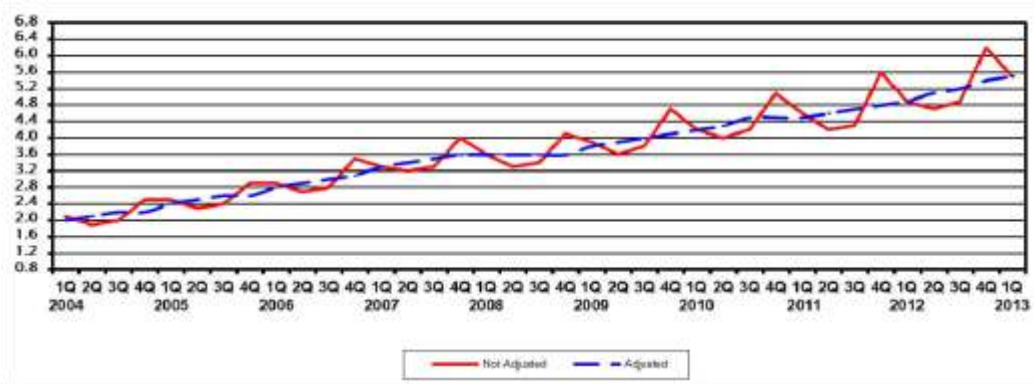


Figure 49. Estimated Quarterly U.S. Retail E-commerce Sales as a Percent of Total Quarterly Retail Sales: 1st Quarter 2004 – 2nd Quarter 2013 ([US Census Bureau News](), 15 Aug. 2013)

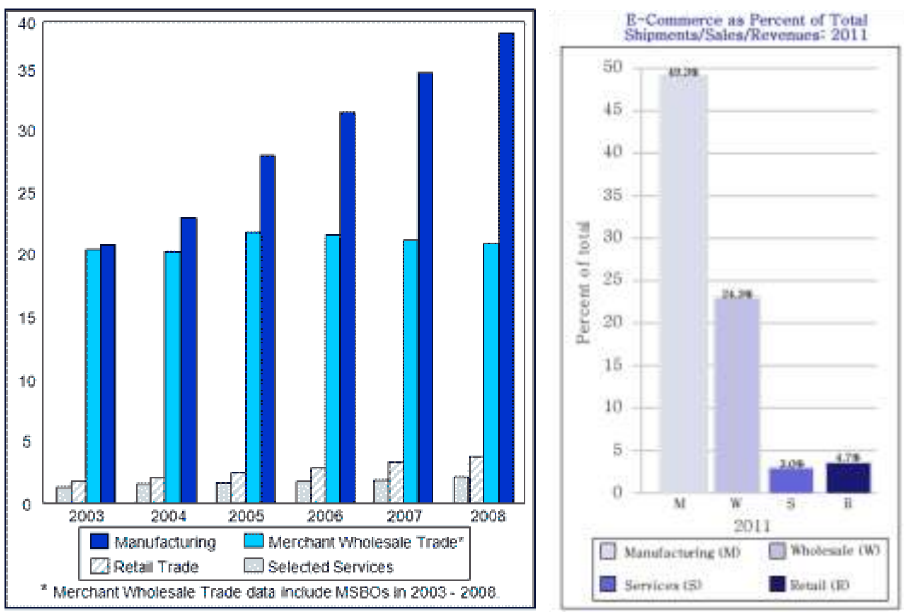


Figure 50. (Left) Growth in eCommerce as a proportion of overall trade in several sectors of the US economy that amounted to $22.4 trillion across the four sectors in 2008 ([US Census Bureau eStats](), in Measuring the Electronic Economy, May 27, 2010). (Right) eCommerce as percent of revenues in 2011 ([2011 eStats Final Report]()).

Prof. W. Tim G. Richardson's [Witiger.Com]() - from a Canadian perspective - tries to provide some perspective on these phenomenal indications of the rapid growth and spread of internet technology:

The number of internet devices in 1984 was 1,000	- one thousand
The number of internet devices in 1992 was 1,000,000	- one million
The number of internet devices in 2008 was 1,000,000,000	- one billion

To reach 50 million users it took the

Telephone	38 years
Television	13 years

Internet	4 years
iPod	3 years
facebook	2 years

However, the mind-boggling numbers only indicate how essential the Web has become for a significant fraction of the people on the planet. This topic will be explored in Episode 4. Of more immediate importance to the purposes of this book is to explore some of the Web's content.

How Much Knowledge Does the Internet Access?

This book is about the roles of technological revolutions in the growth and accessibility of human knowledge and the cognitive revolutions these revolutions have enabled. Of the technologies reviewed, the Internet and particularly the World Wide Web as implemented via the Internet have had and are having the most profound impacts on cognition. The remainder of this episode explores some quantitative and qualitative measures of changes in the magnitude and accessibility of knowledge via the Web.

I first explored this question in 2001 and repeated it in 2010 and 2013 to highlight the changes that have occurred over these relatively short times. By most measures access to knowledge has exploded by several orders of magnitude over the last two decades since the Web was established. Although it is comparatively easy to estimate the number and storage capacities of computers hosting information for the Web (e.g., see Hilbert 2013; Hilbert & López 2011, 2012; López & Hilbert 2012; Short et al. 2011; CISCO 2013), it is more difficult to work out how much of this space is occupied by information that would qualify as usable knowledge (Lesk 2012; Dienes 2012). The capacity of on-line storage is a reasonable proxy for "information" as measured in binary bits. However, as the above works clearly show, the bulk of "information" is uninterpreted data in the form of images and video that are very inefficient carriers of actionable information and knowledge. Also, much information may be stored redundantly many times over (e.g., downloaded movies). Lesk (2012) notes that the end purpose of information it to serve people, i.e., as some form of knowledge. Probably the most useful forms of information and knowledge are represented in the form of words and documents, presented with comparatively high efficiency via web pages or other human readable documents.

Starting from essentially nothing in 1994, by January 2000, Inktomi, estimated that the Web contained more than one billion separate Web pages[232]. In July 2000, Cyberveillance counted two billion Web pages, averaging about 10 KB per page, where the *number of Web pages appeared to double in 6 months* (Murphy and Moore 2000). On June 26, 2000, Google announced that their search engine had identified over one billion Web pages[233]. By December 2001 Google claims direct access to more than two billion (HTML) Web pages and more than three billion documents overall. In November 2002, Google claims more than three billion Web pages and four billion documents (Notess 2002b)[234]. Although these are simple quantitative measures, given the size of the numbers it is difficult to know exactly what has been counted (Notess 2002a; Sullivan 2000). According to Lyman and Varian's (2000) survey of surveys, in mid 2000, the Web contained some 10–20 terabytes of readily measurable information (i.e., text)[235]. In their 2003 survey (Lyman and Varian 2003) this had risen to 170 terabytes.

For some time after these surveys, it was difficult to find authoritative measures of the size of the Web. However, since August 2010, the number of *indexed* web pages has been estimated on a daily basis by de Kunder's WorldWideSize.com: (archived 24 Aug. 2013, live) that showed the number plateauing around 50 billion pages from mid 2011 and down to around 40 billion pages in mid 2013.

There is a very much larger volume of documentary information available via restricted portals to various kinds of static or dynamically generated pages and databases not available to the normal Web indexing services. Many of these are particularly knowledge-rich artifacts including digitally represented books and journal articles. For example, the arXiv.org e–Print archive server provides free access to preprints in physics and related disciplines. As at January 2003 the server held more than 220,000 articles that has risen to 868,000 in August 2013, but has site policies that exclude Web crawlers[237]. In another example, as at January 2003, Elsevier's ScienceDirect provided subscription only access to the full content of more than 3,000,000 articles in more than 1,700 journals plus 59,000,000 abstracts from all fields of science. In August 2013 ScienceDirect offers access to around 11,900,000 articles from 2,500 peer reviewed journals and 11,000 books. Today most journals offer direct electronic access via subscriptions. Beyond journals, there is a large variety of restricted content ranging from market reports to detailed weather data. This larger volume of content not available to the normal Web indexing systems has been variously termed "deep content" or the "invisible Web" (Bergman 2000; Sullivan 2000a). Bergman estimated that the invisible Web contains at least 500 times the content covered by the normal indexing systems. Taking Bergman's and other's estimates of the size of invisible Web, Lyman and Varian (2000) estimated the invisible Web contains around 4,200 terabytes of high quality information[238], three years later the estimate was 91,850 terabytes (Lyman and Varian 2003). Some of this invisible content is available for free. The majority, including the content of most academic, technical and professional journals, is only available via costly institutional or individual subscriptions[239].

As an aside, it is also interesting that the How Much Information study estimates that there were 500 to 600 billion e–mail messages generated in 2000, taking up approximately 900 terabytes of storage at any one time (much e–mail is not saved)[240], while three years later it had risen to between 333,000 and 440,000 terabytes[241].

Google is probably the best source for the latest details in the explosion of Web content. In 1998 their first index had 26 million Web pages. After a few months in beta testing, it formally launched its Web search engine on September 21, 1999[242]. By 2000 Google had indexed 1 billion Web pages, and by July 25, 2008 they claim to have "registered" over 1 trillion (1 x 10^9) web pages (and that is after removing duplicate URLs)[243]! Google's indexes now include major fractions of the deep web. Google Scholar (Figure 51) indexes and provides access to a major fraction of the world's current patents, legal opinions and legal, academic, scientific and technical journals[244]; Google News, indexes and provides customizable access to approximately 4500 of the daily and periodical news sources[245], Google Videos, which finds and indexes videos from a variety of sources, especially including YouTube that Google owns[246], and Google Books, which indexes the millions of books they have scanned).

Where books are concerned, Google has also set out to scan and convert to text *all* the world's books, and by 2010 they have done this for an appreciable fraction in the world's top research libraries such as Harvard University and the University of Chicago. In their count a book is a "tome" that can consist of only one or two copies (e.g., a thesis or dissertation) to millions of copies, and each separate edition is counted as a tome. This excludes bound serials. Their best estimate, as at Aug. 5, 2010, is that there were around 130 million published books (Taycher 2010), and has managed to do so for collections in some of the world's great academic libraries. As of Nov. 19, 2009 Google had scanned more than 12 million books of some 42 million held in US libraries[247]. By 2013, Darnton reports that 30 million books have been scanned by Google. Somewhat independently I also observe that in January 1915, the Internet Archive provides keyword indexed access to more than 7.33 million "texts" that are available free to the Web.

Retrieving Value from the Web Semantically

Fredrick Hayek in "The Use of Knowledge in Society" and Vannevar Bush in "The Way We Think", both as early as 1945, pointed out that the world's knowledge was far outstripping our ability to cope with or use it.

> [But] the "data" from which the economic calculus starts are never for the whole society "given" to a single mind. …. [data] which we must make use never exists in concentrated or integrated form but solely as the dispersed bits of incomplete and frequently contradictory. Or, to put it briefly, it is a problem of the utilization of knowledge which is not given to anyone in its totality." [Hayek 1945: p. 519]

> There is a growing mountain of research. But there is increased evidence that we are being bogged down today as specialization extends. The investigator is staggered by the findings and conclusions of thousands of other workers—conclusions which he cannot find time to grasp, much less to remember, as they appear. [Bush, 1945]

This raises the question, is this huge and ongoing explosion of indexed content worth anything?

Cataloging Approaches

Today's browsers do an excellent job of finding information *if you know what to ask for*. But keyword searches do not understand language and the possible meanings of the texts in which they occur. There is a new profession, the generalist-specialist - not an oxymoron - who can see patterns in areas that appear to have no intersection and then be able to reduce higher-order information into a one-page lay summery. To help with this issues, computer systems need to understand and work with the semantics of human language.

Considering the Web as a W3 library of human knowledge, one methodology facilitating semantic retrieval of information from it is to produce Web-based "subject directories" or catalogs that users can query using browsers. These directory services are human generated Web equivalents of library card catalogs, and list Web pages in hierarchical subject categories, generally according to some "taxonomic" scheme[248]. The directory subject pages also generally include comments written by the editors describing each of the links provided. Directory users can then navigate the directory hierarchy to find subject pages likely to list relevant URLs, and then read the editor's summary description associated with each link to determine its likely relevance[249].

There were three general directories early in the century[250]: the volunteer produced Open Directory Project (still existing and claiming 4.7 million entries in 2010 and 5,2 million in 2013); LookSmart that claimed >3,000,000 entries (as at 3/6/2002[251] that became little more than an advertising directory by 2006[252]); and Yahoo[253] (that may have grown to 3,000,000 entries by 2003[254], but again became little more than an advertising directory by 2007[255]). These all attempted to catalog the full range of Web content. Many other directories focus on single issues (e.g., Robin Cover's XML Page, that through mid 2002 provided an organized directory to a range of XML subjects[256]). Most directories claim that their links have a high chance of being relevant to the human user because they have been hand picked by the human catalogers. However, given that catalogers reject sites they see as unimportant, try to list each site only once (i.e., only under one of several possible subjects), and cannot foresee the users' specific needs for information, it may be difficult for users to locate specific knowledge via a directory[257]. This may account for their waning popularity by comparison to the increasingly powerful indexing search engines.

Indexing Approaches

All of the indexing search engines have three main parts.

- An automated spider or search bot[258] that visits each Web site, and working from the home page, follows hyperlinks to compile information on the contents of each linked Web page. Some crawlers list every word against the URL of the page being indexed. Other crawlers may only list terms found in titles and metadata or close to the beginning of the page. Some, such as Google's, also record details associated with each link out of the page to other URLs[259].
- An index (some kind of table) that minimally associates keywords (i.e., words found in a Web page by the crawler) with the URL of the page containing the words. Depending on the search engine, the index may associate other kinds of information with the page's URL: e.g., links out of the page to other URLs, number of times a particular word occurs in the page, distance of the word from the top of the page, or even the number of other pages known to reference the target page's URL. All of the information in the index can then be processed to determine the best response to a user's query.
- A "query server" that receives user requests for links containing one or more search terms and issues a response page in return, including a list of URLs to pages containing the requested terms. Google's query server farm is probably the largest in the world[224]. The details of how queries are processed and URLs are ranked in the response back to the user depend on the particular service. The processing rules are now normally treated as trade secrets.

The primary limitation all search engines face with HTML tags is that HTML provides only the most limited semantic information about the particular search terms that occur within them. Many of the engines attempt to compensate for this by offering some form of Boolean and "proximity" searching. Proximity searches may be limited to searching for a phrase (as indicated by quote marks) or may include some kind of "near" function. Most engines also attempt to increase the epistemic quality of the hits they return by applying some kind of ranking algorithm to what may often be tens or even hundreds of thousand hits on the search term(s) entered. The engines will then show only the most relevant hits as determined by the algorithm (e.g., occurrence of search terms in metadata tags, within 100 words of the top of the page, number of times the word is used on the page, etc.). For example, combined with other information, Google uses the number of links into the indexed page *from* other indexed pages to help rank relevance[259]. Note that these cybernetic processes are carried out by logical algorithms running on servers - ***without the intervention of a knowing subject***.

Which engine will provide the best results for a particular user request depends on how much information is indexed by the engine, what information the user is seeking and how the engine ranks the relevance of results relating to the user's search terms. Because search engines are so central to extracting information on the Web, many reviews have been published[260]. At least for personal use, the technology leader is now Google, which through network externality is well on the way to hegemonic control over easy access to all the world's codified knowledge as Microsoft has achieved in the content capture realm.

Using Portals

Given that people searching for information in the Web will usually want to use one of the search or directory tools, a number of organizations have aggregated search engines, general and specialized directories, along with a range of commercial content and advertising, into what have been termed portals. A portal may be one of the popular retrieval sites (e.g., Excite, Yahoo, About, AOL) that people access from other areas of the Web, or it may be the home page provided by users' internet service providers (ISP – e.g., Australia's BigPond). Some portals require paid subscriptions, but the increasing majority provide their services free to the users and seek financial return by presenting paid advertising. However, as users become more sophisticated they may choose to use the very simple search engines such as Google that only do what they ask them to do[261] as their default access to Web resources.

Multimedia

An aspect of the Web is its ability to transmit live or from storage many other kinds of media besides simple text and pictures. For, example, as I am writing this paragraph at home in a small country town out of Melbourne, Australia, I am currently listening live to Classic FM, broadcasting on FM from London, England. This station is also transmitting streaming audio over the Web, through the world communication net, to my computer where it is being realized via the computer's media center system while I write. Given that I have a broadband connection, and query the Web for information on how streaming media works. I could just as easily be watching the news or a documentary on a local or overseas TV station[262].

Currently there is a variety of often incompatible formats and software applications for capturing, storing, delivering and receiving media over the Web. These have been developed by three main players: Apple, launched its first QuickTime video system in January 1992. The first systems were designed to author and deliver video from laser discs. "Streaming video" was only released with Quicktime 3.0[263]. RealNetworks, which began marketing its Real products in 1995. Microsoft apparently introduced its Windows Media Player in 1998 or 1999 after working for a time with RealNetworks[264].

Wrapping Up the Web

Within two decades from its emergence he World Wide Web has vastly extended the memory and cognitive capabilities of individuals with access to personal computers and ISPs. As documented above, the first electronic computers were invented in my lifetime. Today, from my notebook computer, in seconds I can deploy sophisticated semantic tools to search substantially more than half of humanity's recorded knowledge that is in any way relevant to my work. With a few more seconds to further assess what is hopefully only a small list of candidate documents meeting my search criteria, I can then download a small number of documents that are directly relevant to my question. This overwhelming wealth of knowledge is made useful as well as accessible by virtual and autonomous cognitive capabilities that exist in the layered architecture of the Web.

- Layer 1, at the bottom, consists of
  - W3 artifacts recorded as persistent objects of knowledge by individuals; web pages, articles, scanned documents, music, videos, downloadable computer programs, etc; and
  - "dynamic" artifacts of knowledge autonomously generated on demand in real time by databases and other processes; catalogues, price lists, product detail, weather reports, etc.
- Layer 2, "static" semantics built into Web objects representing their authors' cognitive understanding of the relationships of their knowledge relative to the rest of World 3, including
  - persistent links and reference citations built into knowledge artifacts by their authors and
  - human generated Web and portal directories
- Layer 3, semantics generated by processes running autonomously in World 3 independently from knowing subjects, e.g.,
  - 'bot' produced indexes,
  - dynamic page ranking processes,
  - autonomously generated classifications,
  - "intelligent agents",
  - etc.

Aside from the physical technology provided by microelectronics and the communications networks, the crucial factor that has allowed this incomprehensibly rapid growth of capabilities and knowledge in the Web has been the establishment of cognitively significant non-proprietary standards for the construction, communication and expression of the knowledge artifacts it stores and generates.

For example, when I am stuck in a windowless office where I can't see the weather, I regularly consult Melbourne's weather radar via Weatherzone, or the satellite images via the Australian Bureau of Meterology to see what weather the wind is blowing in. Similarly, before I made a recent trip to Finland, I occasionally checked in there to see the weather on the other side of the globe – Finnish Bureau of Meterology. To see the weather in your own region, there is a good chance that Google can help you find it: search Google for ["your major regional city name" weather radar]. In other words, the Web extends the scope of my sensory input in near real-time to the entire planet! Some of the tools will even automatically warn me of extreme weather events[265].

Demonstrating Semantic Retrieval

Because I was familiar with the topics to be covered up to this point in the project, the writing has been comparatively easy. However, the situation is different for many of the subjects relating to organizations covered in Episode 5. Given the limited time I have had available for work on this project and very real practical difficulties in physically accessing major research libraries, further progress would have been impossible without the tools the Web provides for extending cognition. Google, PubMed, and a number of Web-based "full-text" retrieval services available through libraries such as ISI's Web of Knowledge and Elsevier's Science Direct have enabled me to rapidly find knowledge in World 3 relating to these interests.

Most readers will have used Google or equivalent indexing services, and many of those in academic environments will also be familiar with Web of Knowledge. However, in my teaching experience it seems that only a few people other than research librarians have learned to make full use of the semantic power these tools provide. To close off this episode on personal productivity tools I will describe the procedure I use to quickly build a World 3 web of knowledge relating to a subject of interest.

In abstract form, the following steps are used to build a web of World 3 knowledge:

1. Select one or more reasonably well known older articles that introduce core concepts relating to the subject of interest. If you are not already familiar with some appropriate papers, search the Web or one of the academic literature databases using appropriate keywords. Select a small number of full-text articles or that at least provide the associated bibliography. Identify a small number of older papers that seem to define the concept(s) you are seeking knowledge about.
2. To find recent work available free-to-the-Web, use the titles of key articles as search terms in Google; i.e., block copy the article title into Google Scholar's search term field and put quotation marks around the title. As illustrated in Figure 51, clicking Search will retrieve Web pages containing exact matches for the title (e.g., as found in in the title of the article, or in bibliographic citations of other articles that refer to the sought article). For very short titles that may also correspond to ordinary strings of text, add the author's surname outside the quotation marks. This will return free-to-the-Web articles and other pages referencing the key article - *presumably because each "hit" includes text that has a specific semantic relationship* (e.g., because the author thought the referencing work derived from or needed to be compared to the referenced work. Note that the hits will normally include articles from the formal literature. Even though the journals in which they are published are not themselves available free to the Web, many articles are now available to the Web via individual authors' home pages or in repositories where they have been deposited by the author[267]. Note: given that Google's Web links may not be current, as long as you can retrieve the URL for an article that once existed free to the Web, chances are good that the article can still be retrieved via the WayBack Machine (http://www.archive.org). If you are a subscriber and logged in to a major university or research library, Google is able to provide a direct link to electronic copies of articles available via your library’s journal subscriptions.
3. I then skim search returns (whether from Google or Web of Knowledge) to determine whether they accurately represent the kind of subject matter I am looking for. If so, I then look through the bibliographies of the electronically retrieved articles for additional references relating to the desired subject matter. In some cases bibliography references will link directly to the cited articles - some in full text. Note: bibliographic references may include works not indexed directly by Google or Web of Science, including books and other materials still available only in paper formats. However, the fact that they have been referenced by papers you regard to be important and information in their titles will probably help you to determine whether it is worth the effort to track down a hard copy of the referenced document.

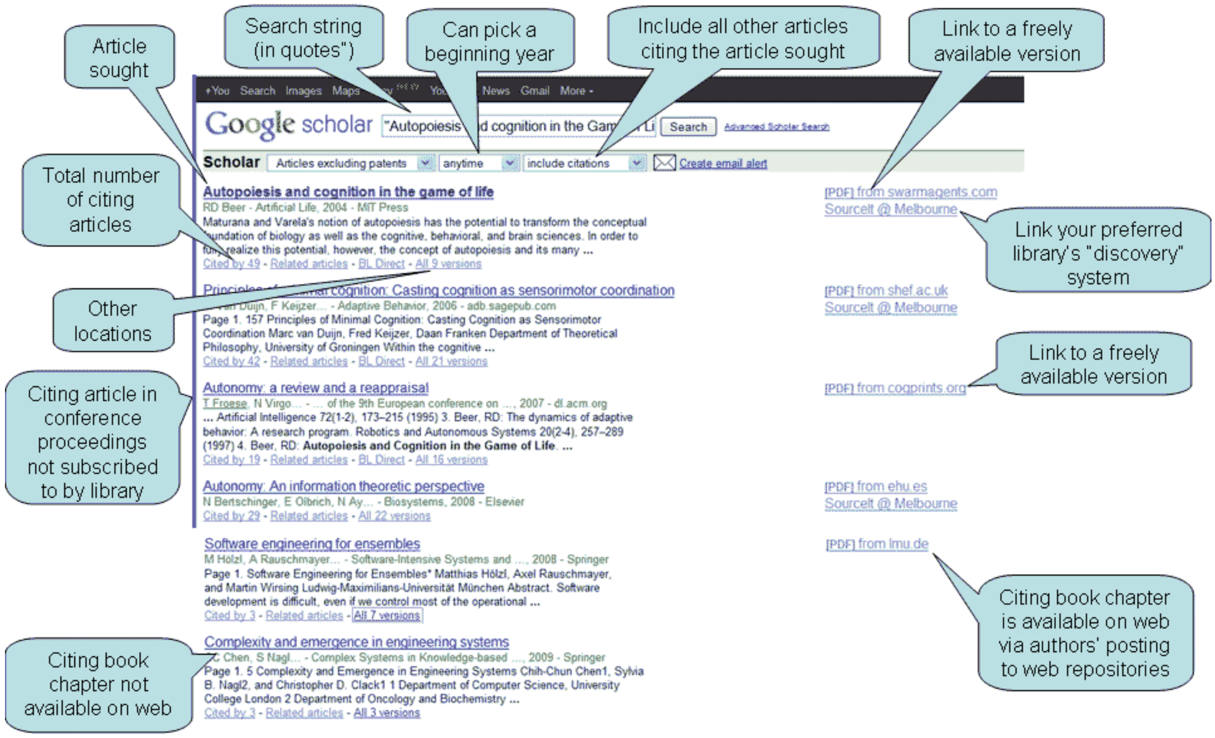


Figure 51. Finding an article with Google Scholar provides a great deal of information about connections and relationships with related knowledge.

4. Older articles referenced by the hits collected in Step 3 can be used as additional search terms to find other more recent articles until diminishing returns are achieved, at which point you can be reasonably confident that your bibliography on the subject in question is reasonably complete. Note that non-electronic references from the returns of your first search can still be used as additional search terms in Google or the Web of Science, in that you are searching for articles that *reference* the search term article, not the search article itself.
5. Once a reasonably complete bibliography has been assembled, you can begin to assemble full texts of the desired articles. Some journals are available free to the Web, either independently or via services like the US National Institute of Health's PubMed Central. In some cases where journals are not available in toto, individual articles may still be found free to the Web via authors' or institutional Web sites. In my experience perhaps 40-50% of the articles I seek can be found on the public Web[268] - which may be all that is required to explain or connect to the literature relating to a key idea. Where access to subscription journal databases can be achieved by logging into a major research library that subscribes to most journal databases, probably more than 90% of the important papers can be retrieved in full text format. Full text databases I now access regularly include Elsevier's Science Direct, Proquest, Emerald, Highwire, ACS Publications, ACM Digital Library, Journals@Ovid Fulltext, JSTOR, etc. as well as several publishers individual sites, e.g., Kluwer Online.

Assuming that you have a broadband connection to the indexing service(s), comprehensive bibliographies can be built in a few hours. Even working from home over a 56 K modem connection via a research library I could do vastly more at home with Web of Science that I was ever able to do working in a library with physical indexing services[269].

Now, with a broadband connection and login access to the subscriptions of a major university/research library, one can access at least 70 to 80 percent of all scientific, scholarly and technical journals that are published. For example, on 31 March 2012[270] I was able to electronically access from Google Scholar via my university library *95472 different catalogued e-journals*. Additionally, I can search among 732 databases containing published material from specialized areas such as engineering, education, medicine, economics, government bodies, the press, etc. that may not be included in the linked library catalog that Google knows about. So, when I find an article that does not have a direct link to my University's catalog, as is with some frequency the case for engineering conference proceedings, I can search for it in these other databases.

What I can do now with a broadband connection and Google Scholar was inconceivable even when I started this book. *In my lifetime as a researcher, I have gone from only being able to use the paper resources of one library at a time, to being able to search and access what I want to know from a reasonable approximation of the totality of humanity's recorded knowledge.*

INTERLUDE

Recap and a Look Ahead

Episode 3 basically completed the review of the revolutionary development of cognitive technologies we humans have used to differentiate ourselves from our animal relatives. In my Subject, Counter Subject and the first three Episodes, I focused primarily on the nature and value of knowledge and the immense technological changes involved in three technologies (writing, printing and computing) used for capturing, preserving, and transmitting knowledge. I have also shown how these new tools have readically extended and changed the cognitive capabilities of individual people to manage ever-increasing quantities of that knowledge.

In my own life I progressed from a dyslexic student fascinated by science who could barely write an intelligible sentence, who then managed to write a few papers with the aid of a correcting typewriter, who now has the capacity to filter the world's knowledge into a work like the present one. My brain is still dyslexic and is now getting old and decrepit as well, but aided by cognitive technologies I now have the capacity to recall virtually anything humanity has recorded and exernalize, see, parse, and edit sentences on the screen as fast as I can type. The technologies have radically changed who I am and my capabilities to think and communicate.

The first three episodes flowed logically from exploring concepts of knowledge and technology as they involve individual people. However, as will become apparent there is no simple transition from looking at how technological revolutions have changed the cognition of individual humans to looking at how technologies have affected the nature of human socioeconomic organizations.

As mentioned in my Preface, I started writing 'Application Holy Wars…' in late 2000, following the flame war amongst technical writers on the Techwr-l site. The first three episodes based primarily on evolutionary epistemology and revolutions in technology were easy to complete. However, I could not then finish what is now Episode 5[271] because I did not know how to build a coherent narrative that adequately explained the coevolution of technology and human social organization. I thought I understood the nature of knowledge reasonably well from my background with Popperian epistemology and more than a decade of professional experience as an organizational knowledge manager, but when I started examining the literature in researching this book, what I thought I knew was very much at odds with what organization theorists and the organizational knowledge management discipline said about organizational knowledge. I could not progress until I understood why my thinking and conclusions were so different from the recognized "authorities". Thus, I set the book project aside to engage in theoretical and practical research to see if a coherent understanding of the social and organizational impacts of cognitive technologies could be developed. Ideas from apparently unconnected disciplines and paradigms in the physical and biological sciences proved crucial in providing the missing insights. My development of this understanding is documented in a number of published papers beginning in 2003[272].

Because they have not been explored to this point in the peresent narrative; and because initially there are few apparent connections with narrative so far, these ideas will be presented outside the fugal development of this book in the form of an Interlude of three major sections:

- Physics of Systems. In the realm of the physical mechanics and thermodynamics of physical systems (the study of motion, energy flows and transformations of energy in physical processes) we need to understand something about physical systems, complexity, the Second Law of Thermodynamics, entropy, dissipation, equilibrium and the thermodynamics of systems far from equilibrium. This section is based on ideas relating to non-equilibrium thermodynamics and complexity introduced between the 1940s and 1960s (Prigogine 1945; Simon 1962) and the natural tendency for complex systems to organize themselves (Morowitz 1968; Kauffman 1993, 1995).

- What is Life? Building on the "laws" of thermal physics, I introduce the theory of autopoiesis (literally "self" + "production") developed in the 1970s (Maturana and Varela 1980), combined with ideas of evolutionary epistemology (Popper 1972) as extended by myself (Hall 2003, 2005, 2006, 2011). This defines what it is about living systems that makes them cohere as autonomous entities in ways that are quite different from other physical systems. My own studies have shown that autopoiesis and knowledge are inextricably intertwined, such that neither can exist without the other (Hall 2006, 2011).
- Theory of Hierarchically Complex Dynamic Systems and Higher Orders of Autopoiesis. To provide a platform for understanding the production and management of human social and economic organizations, I will then explore the theory of hierarchically complex systems that, when combined with the theory of autopoietic knowledge, explains that organized systems at different hierarchically nested levels of complexity can be living entities in their own rights. The result is a theory of knowledge growth in living systems based on the physics and thermodynamics of dynamic systems and derived from Popper's (1972) evolutionary epistemology and Maturana and Varela's (1980) autopoiesis (Hall 2006, 2011; Hall et al. 2005, 2007, 2010; Hall & Nousala 2010, 2010a; Nousala & Hall 2008; Vines et al 2007; Vines & Hall 2011). For example humans are living complex systems formed of interacting cells and noncellular materials, where each cell is a living complex system formed of interacting macromolecules and other substances. Similarly humans interact together and (in recent history) with technologies to form complex organizational systems that can be considered to be living in their own rights. There are also even higher levels of complexity that may be considered to be living entities, e.g., nation states.

The theory to be presented in this last section is likely to be controversial, but it robustly explains the emergence and evolution of complex adaptive systems (such as human organizations) at many different hierarchical levels of structural organization. With this understanding of human organizations in hand, the emergence and evolution of human sociotechnical organizations finally made a lot of sense to me that can be presented in a sensible narrative in Episodes 4 and 5.

Episode 4 will explore how the social uses of the cascading technological revolutions involving cognitive tools have further changed humanity in the short period since I started writing this book. What we are as a biological species today is radically different from all other species we share the planet with – even our genetically close relatives, the anthropoid apes. These differences are closely associated with humans' social capacity for acting together to meet common desires or needs, and especially with the capacity to "organize" for such purposes. These capacities have been radically changed by the social technologies. Episode 5 considers the emergence and evolution of cognition and knowledge in socio-technical organizations in the era of posthuman cognition. The book then concludes with a Cadenza and Coda, considering some aspects of the management of academic and public knowledge.

Physics of Systems

System concepts and dynamics

At a fundamental level, this book is about complex dynamic systems and how they change and evolve over time. For the material that follows it is important to clearly understand the terms "system" and "dynamics" and what they mean when put together

- *System*. The many different dictionary definitions for system, fall into two broad groups: (I) a way of doing things according to a conceptual structure or plan (i.e., in W2, such as defining a classification system for living organisms) and (II) a defined or demarcated collection or assembly of elements or components that actually or potentially interact physically (i.e., the components exist in W1 and interact dynamically, such as the various interacting components that make up a machine of some kind). Here we are concerned purely with type II, i.e., physical systems, which may be simple mechanical machines of interacting gears, shafts and levers (e.g., mechanical calculators); complex electronic systems controlling the flows of electrons through conductors, capacitors, resistors and transistors (e.g., microprocessors); complex organic systems of interacting atoms and molecules; living systems comprised of interacting cells (e.g., living organisms); and even human socio-technical organizations comprised of interacting humans and their machines.
- *Dynamics*. Dynamics is a concept that originally derives from the field of physical mechanics, where it seeks to explain how particles and systems move through time under the influence of causal effects and forces.
- *Dynamic system*. A dynamic system is a causally interconnected set of particles or components that changes through time as the result of causal forces that propagate through the components as one particle influences others, and so on. Urrestarazu (2004[273], 2011a, 2012) very precisely defines what this means in terms of autopoietic systems. In a causal interaction within a dynamic system:

  > We distinguish a cause-effect coupling (interaction) between two dynamic objects *A* and *B* if a state transition in object *A* (triggering or causing transition in *A*) is the condition sine qua non of a state transition in object *B* (a triggered transition in *B*). The latter means that:
  >
  > (a) in the absence of any other cause-effect coupling between B and any other object different from *A*, the caused transition in *B* never occurs before the occurrence of the triggering transition in *A*; and
  >
  > (b) whenever objects *A* and *B* are in a specified state and a specified triggering transition in *A* occurs, the same caused transition always occurs in *B*, within a finite time interval.
  >
  > The mechanism responsible for cause-effect coupling between dynamic objects is not specified, but it is assumed to exist [Urrestarazu 2012: p. 193].

  Considering causation within the range of quantum mechanical effects, with regard to point (b) at the quantum level, I would replace "…the same caused transition *always* occurs in B, …" with "…the same caused transition occurs in B *with a high probability*, …"
- *Causation structure*. Following Urrestarazu (2012: p. 193) at any point in time a dynamic system can be described in terms of its "causation structure":

> The network of oriented relations represented by the graph associated to the interaction configuration constitutes the instantaneous dynamic structure of the system. It is a causation structure, i.e., the path of propagation for all the possible causal effects triggered by a transition occurring in any dynamical object whose equivalent node is “connected” to the graph. The remaining topics in this interlude and Episode 4 will make heavy use of the vocabulary of dynamic systems developed below.

In theory, dynamic systems[274] are those that change through time where changes in the causation structure can be represented by a mathematical formalization that describes the time dependence of each component's position in an n-dimensional state space where each dimension corresponds to a degree of freedom. Examples include models that describe the swinging of a pendulum, voltages in an electronic circuit, and the numbers of predators and prey in a simple ecosystem of two species. At each increment along the time axis the causation structure of the dynamic system can be described by a vector at a point in an appropriate state space that represents the direction and speed of change. In most circumstances small changes in the state of the system correspond to small changes in the vectors. The evolution of a given dynamic system in the absence of perturbations (external disturbances) follows a fixed rule that describes a trajectory that future states will follow from the current state that can be described by a “system state equation”. For a given time interval the possible future state(s) are strictly determined by solutions of the state equation[275].

Basically, when parameters of a dynamic system are set to a point in the system’s state space, the vector associated with that place in space points in the direction of the place in phase space that will be occupied by the system in the next instant. A set of differential equations describing the dynamics of the system allows a vector to be calculated for each point in state space. As the system evolves from a particular point in state space through time, its changes of state follow the vector field. The concept is illustrated in Figure 52. The small arrows are the vectors, and the curves with dark arrows illustrate the evolution of the system through time (or as a controlling variable is incremented) away from its initial starting point. In A the vector field will draw the system to the point of stable equilibrium at 0.0. In B, 0.0 is a node of unstable equilibrium. Any other system state is repelled from the node along a spiral trajectory.

Chaos

In the macroscopic world the dynamic behavior of simple mechanical systems may be quite orderly. Movement of a certain part will deterministically cause other connected parts in the system to move in certain ways. However, even very simple deterministic mechanical systems may exibit chaotic dynamics if the interactions among the components are nonlinear (i.e., where changes in the system are described by two or more variables, and are thus not directly proportional to incremental changes in a controlling variable or time). Calresco’s Complex Systems Glossary[276] defines a *chaotic system* as, “A system whose long term behaviour is unpredictable, tiny changes in the accuracy of the starting value rapidly diverge to anywhere in its possible state space.” The state space of a system with *n* degrees of freedom is the volume in an *n*-dimensional space mapped out by all possible configurations of the system[277].

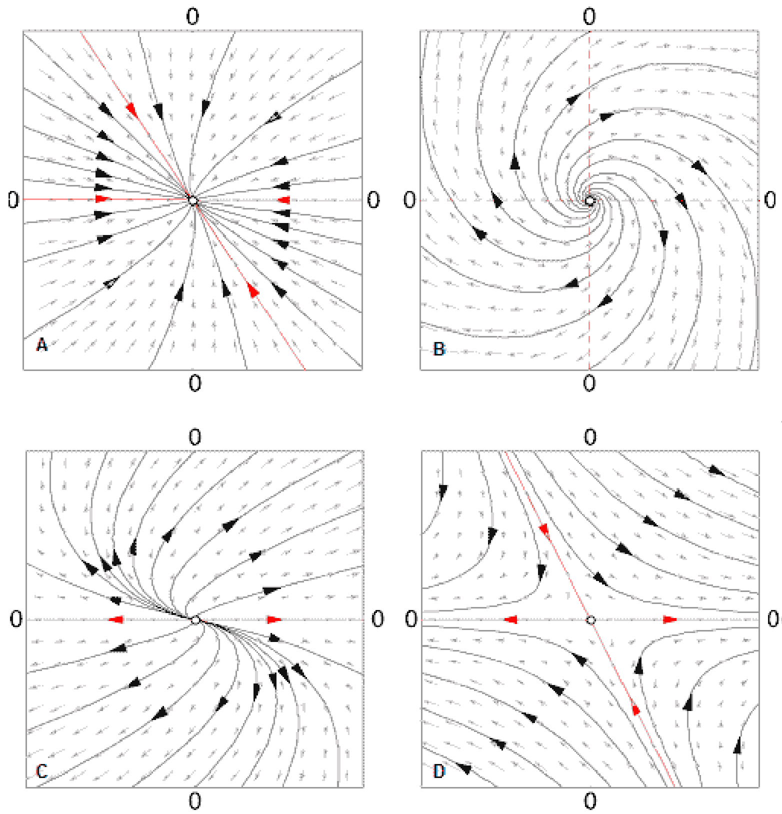


Figure 52. Vector fields and trajectories in a planar state space from Wikipedia. Systems in the real world are all dissipative, i.e., subject to "dissipation" (e.g., due to friction or the gradual conversion of energy available to to do work into heat) corresponding to the laws of thermodynamics.

Although many behaviors of chaotic systems may appear to be random, they are not, and may well be constrained to stay within certain limits. In some areas of state space the output varies smoothly with a controlling variable; however, as variables are changed by very small increments a point may be reached where the system dynamics allows two possible behaviors (i.e., "bifurcation", or "doubling" with the system state rapidly and seemingly unpredictably flipping between the two)[278]. As the input variable increments further, two solutions may bifurcate further into four, and may quickly reach a point where there are large and seemingly indeterminate solutions (i.e., the system behaves chaotically at that point[279]). In other words, chaotic systems display great sensitivity to initial conditions. Given two arbitrarily close (but not identical) values for a control variable, through time the system states will diverge in ways that lose all correlation with their close starting conditions[280].

Attractors

In addition to chaos, many non-linear dynamic systems demonstrate various kinds of attractors. Basically an "attractor set" for a dynamic system is a closed subset of points in the system's phase space from which the system will evolve towards a particular point "A", line, or set of points known as the "attractor". Besides single points, attractors may be "periodic orbits" (also called "limit cycles"), or some other subset of points filling the volume of a torus or "strange attractor" within the attractor set that the system will evolve towards[281]. Many dynamic systems have more than one attractor. For each such attractor, its basin of attraction is the set of initial conditions leading to long-time behavior that approaches that attractor.

Dynamic system concepts in the real world

To this point the discussion of dynamic systems has been concerned with the behavior of mathematical models. In real world systems additional factors have to be considered, dissipation; perturbation, quantum uncertaintly, and the concept of thermodynamic equilibrium.

Dissipation[282] refers to the gradual conversion of available energy in the dynamic system to entropy (i.e., unusable heat) through friction, turbulence or other processes according to the second law of thermodynamics. Systems subject to dissipation are called dissipative systems. All real-world systems are dissipative to some degree (see more below). Unless energy is added from outside, through dissipation of available energy into entropy (e.g., via friction), natural systems will in time evolve from their initial states towards the state of lowest energy available within the local attractor basin.

Perturbation (as used here) refers to a change imposed from outside the defined structure of a physical system, or more broadly any definable system (such as a biological or economic system). In general the perturbation will arbitrarily change the location of the system in its state space, such that it is quite possible that system parameters will be moved to another attractor basin, or even to a trajectory that that directs the system's evolution towards zero or infinity (i.e., stasis or disintegration).

Quantum uncertainty refers to the fact that at small scales (i.e., where we are looking at the behavior of fundamental particles (e.g., electrons, photons) we can never measure exactly both the momentum (i.e., kinetic energy content) and the location of a particle at an instant of time. Thus, there is a certain level of fuzziness or uncertainty in the dynamic behavior of any real world system.

Equilibrium is a local point of minimum energy in the state space of a dynamic system where the system will remain at rest unless it is perturbed through the addition of energy in some form. Thermodynamic equilibrium is a more general concept for a system in a state "where there are no unbalanced potentials (or driving forces) with the system. A system that is in equilibrium experiences no changes when it is isolated from its surroundings" and can do no work on its surroundings.

Two views of how time, change and causation lead to evolution

In some cases where dynamic systems can be isolated from their environments for laboratory study, how they change through time can be described mathematically to a high degree of accuracy (i.e., by equations in W3). However, such mathematical models are only theoretical discriptions of what may be happening in the real world (W1) and do not explain what *causes* the changing relationships of the system properties over time that they describe.

A major question underlying my whole approach to the evolution of cognition and growth of knowledge is "what causes evolution or change through time?", or phrased somewhat differently, "Why do things evolve?" This boils down to understanding change in terms of causation and time. Time is central to all aspects of change, but even physicists and philosophers cannot agree among themselves on what time is (e.g., Maturana 1995; Deutsch 1997; Smolin

2004, 2013; Elitzur & Dolev 2005; Dieks 2006; Hájíček 2006, 2008; Christian 2007; Bertolami 2008; Lobo 2008).

In the following segment, I present two related understandings of how change (and evolution) happen. The first, and more fundamental, derives from a quantum theoretical view of the universe. The second, historically earlier, macroscopic view derives from a theorietical understanding of how heat engines work. From a reductionist view of the microscopic world, changes in the macroscopic world are causally driven from the "bottom-up" by quantum mechanical dynamics. From a holistic or emergentistic view, the higher-level whole, by providing a context of boundaries and constraints, causally controls which possibilities available at the quantum level can actually be realized. Both forms of causation need to be understood in order to comprehend how the self-regulation and autonomy of living things emerges from the mindless chaos of the molecular world (Auletta et al. 2008; Ellis 2008, 2012, 2012b; Ellis et al. 2012; Butterfield 2012; Jaeger & Calkins 2012; Love 2012; Loewer 2012; Okasha 2012; Scerri 2012).

Causation, change and time at the quantum level

The theory of relativity treats time as one of the four dimensions of space-time forming a "block universe", such that the past, present and future represent different locations along the time axis within the four dimensional block, such that our impression of the flow of time and our belief in our abilities to change things as acts of will are simply embedded in the spacetime block that includes now and all past and future time. What system parameters you see at any point in time is simply determined by where you are situated along the time axis of the block. In other words, although it makes sense to mathematicians, there is no provision for free will, freedom of action or the operation of natural selection in evolution.

By contrast, views of time emerging from quantum theory offer the possibility for free will, where some authors suggest that the future is undetermined and that the present state of the world progresses via a sequence of moments of becoming (e.g., Elitzur & Dolev 2005; Ellis 2006b - Figure 53). There are several variants of this view (e.g., Deutsch's 1997 concept of multiverses;; Smolin's 2004, 2008, 2013a, 2013b loop quantum gravity; etc.). The view I follow here has been called the growing, emerging or "*evolving block universe*" (Ellis 2006b, 2008, 2011; see also Elitzur & Dolev 2005; Earman 2008) or, when quantum theory is taken into consideration, the "*crystallizing block universe*" (Ellis & Rothman 2010; Ellis 2012, 2012a, 2013). In these views, the "past" is unchangeably fixed as a spacetime block (if it exists at all), and the future exists only as possibilities until a particular possibility emerges and is realized in the present instant. The "*present*" or "*now*" is an instant of quantum mechanical interaction when one of many possible future worlds becomes real and establishes the possibilities for the next instant. Thus, the real world evolves and unfolds through an inexorable iteration of instants of becoming, where the becoming of each instance quantum mechanically determines the present and defines possibilities for the next instant only. To Ellis, Smolin (and me), this emerging universe view is the only model that genuinely allows for the evolution of new possibilities and potentialities.

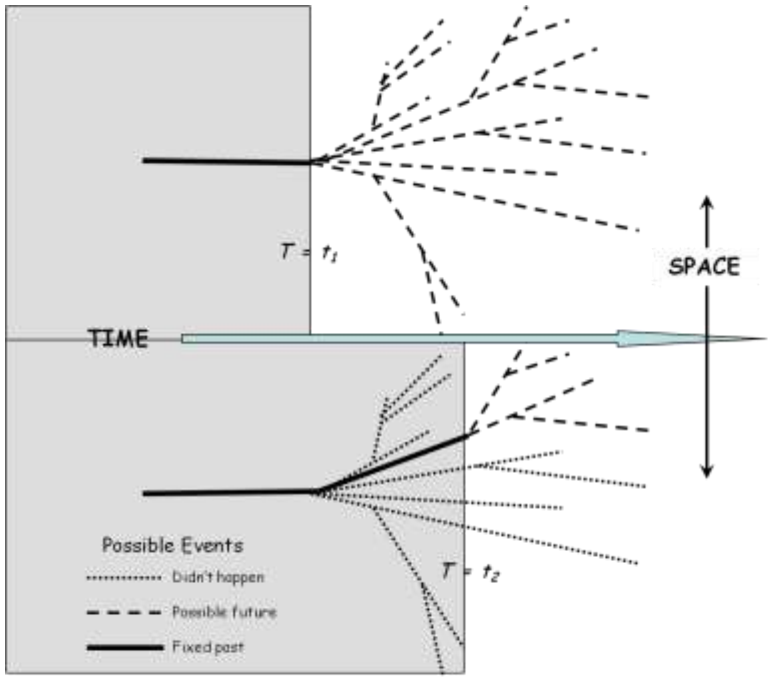


Figure 53. Motion of a particle through space and time where the motion is randomly perturbed. (After Ellis 2006b). t_1 and t_2 represent different instances of becoming or "nows". The trajectory in the past either no longer exists or cannot be changed, and the possible future trajectories don't exist until they are realized in the continually iterating now.

Figure 53 illustrates possible trajectories in the state space of a physical system at two points in time, t_1 and t_2 with time progressing from left to right. The grey areas represent the block universe of time past, with the white area representing the as yet undetermined future. The line dividing the past and future is "now", the instant of becoming as dynamically produced from the prior instant. Historical events in the fixed past are shown by the solid line. States that are possible to reach in the next instant when now = t_1 are indicated by dashed lines. Kauffman (1996, 2003; Kauffman et al 2008) calls the ensemble of such states the "*adjacent possible*" (see also Kauffman & Smolin 1997; Smolin 2001; Longo et al. 2012). In our perceived universe, in any instant, only one of the adjacent possible states available to that instant is realized; in a multiverse as described in the "many worlds" theory of quantum mechanics, every possible state is realized on different world lines branching away from now (Deutsch 1997; 2002; Wallace 2010) – where each state contains a consciousness that is unaffected by any of the other diverging world lines. Note that when a later instant, t_2 is reached, the once possible states along world lines that didn't happen are no longer possible in the universe of any particular worldline.

As will be seen below in the sub-section "The spontaneous emergence of autopoiesis and knowledge", the effect of advancing time's pruning of the adjacent possibles has profound implications for understanding self-determination in autopoietic systems. Organismic and human perception, decision and action through time also present quandaries. The quantum mechanical instant of realization of a possible world is something that would seem to happen over a time span somewhere on the order of a Planck time unit (the smallest physically conceivable unit of time ~5 x 10^{-44} sec.); yet the neural processes involved in the physiology of human perceptions and decisions are measured in milliseconds (10^{-3} sec - Atmanspacher 2004; Glimcher 2005; Christian 2007; Hájíček 2006, 2009; Lobo 2008; Bertolami 2008). Perception and decision making processes in organizations will normally take hours or even days. How can such slow processes serve to "manage" or "cause" physical changes that seemingly must involve the realization of particular possibilities at the quantum level?

The concept of physical causation has been problematic for philosophers and physicists since the time of Plato (Dowe 2009; Schaffer 2009; Bodnar 2010; Falcon 2009; Klein 2007; Castagnino & Lombardi 2009; Urrestarazu 2011, 2011a, 2012)[283]. A rough-and-ready definition is that a cause is that which makes a change (i.e., a difference) in the world that would not have taken place in its absence[284]. Cause implies the existence of time, in that one can identify antecedent and consequent conditions, such that change can be described. The mathematical equations of system dynamics are in principle reversible along a time axis. In other words cause and effect are reversed depending on the point of view. In an Einsteinian or Newtonian block universe system dynamics and trajectories are fixed, with the only variable being time when they are viewed (Ellis 2006, 2006b, 2009)[285]. In such a universe the concept of a cause is essentially meaningless. However, in an emerging universe, a cause in relation to a defined system is a perturbation that can only be directed forward (establishing an "arrow of time") to affect the realization of the next instant.

I don't presume to understand what is going on at the quantum level – along with the nature of time, this is one of the most fundamental questions of physics. However, there are some interesting ideas on "downward causation" that usefully frame the discussions of time and the emergence of knowledge (Emmeche et al. 2000; Pattee 2000; Hulswit 2005; Ellis 2006, 2006a, 2008, 2009, 2009a; Ellis & Rothman 2010; Auletta et al. 2008; Lobo 2008). Basically, (1) the *possible* changes independent from history or circumstances inherent in each specific particle existing in a moment are determined by the quantum mechanical laws governing properties and behaviors of fundamental particles (*upward causation*); while (2) the specific spatial disposition and organization of the particles in that moment, given historical positions and interactions in the previous instant, *determine* (or at least stochastically[286] *affect*) which possibilities are realized (*downward causation* - Ellis 2009; 2012b).

Following Ellis, the experimentally observable existence of quantum entanglement of particles over space and time raises a number of interesting questions about determination of the next instant that were not answered in Ellis's emerging block universe model (Ellis 2006b). Ellis and Rothman (2010) and Ellis (2011, 2012, 2012a, 2012b, 2013) address these questions in the "crystallizing block universe" (CBU) that to me fully provides a dynamic physical context for the progressive growth of knowledge in a naturally evolving universe.

> The key point is that the arrow of time arises simply because *the future does not yet exist* [their empasis]. One can be influenced at the present time from many causes lying in our past, as they have already taken place and their influence can thereafter be felt. One cannot be influenced by causes coming from the future, for they have not yet come into being. The history of the universe has brought the past into being, which is steadily extending to the future, and the future is just a set of unresolved potentialities at present. One cannot integrate over future events to determine their influence on the present not only because they do not yet exist, but because they are not even determined at present….
>
> The direction of the arrow of time is thus determined in a contingent way in the CBU context. Collapse of the quantum wave function is a prime candidate for a location of a physical solution to the arrow-of-time problem, and manifests itself as a form of time-asymmetric top-down action from the universe as a whole to local systems…. **This takes place within the generic context of commonly occurring top-down action in the hierarchy of causality** [my emphasis] (Ellis & Rothman 2010: 1001-1002).

Upward and downward causation in relation to time will be explored in more detail below, and I will argue that slow (in relation to Planck time) processes of downward causation mediated via "cognitive" processes at several levels of organization can shape the becoming of the world even at the quantum level.

Thermodynamics is the driving force of evolution at the macroscopic level

At a macroscopic scale, motion, change, and 'evolution' in the Universe, including processes in dynamic systems such as the metabolism and development of living things, appear to be driven by fluxes of energy and energy-rich matter flowing from sources of high potential to sinks of lower potential. These fluxes are the sums of the spontaneous conversions of other forms of energy into entropy as particle events interact (the "arrow of time" - see Chaisson 2001[287]) and transfer energy (e.g., one particle "works" on the other, diminishing its own energy and adding to the other's energy + entropy of the world in accordance with the laws of thermodynamics). The laws of thermodynamics (i.e., 'laws' are understandings expressed in World 3 of how World 1 works) describe the most fundamental rules governing all change in the Universe (Nave 2005; Farabee 2007; de Rosnay 1998). They are called the laws of thermodynamics because they were first worked out in the flowering of the industrial revolution by scientists attempting to understand the limitations of steam and other external combustion or 'heat' engines in converting heat energy into work to lift water out of mines or to provide motive power for other industrial processes.

Although the macroscopic laws of thermodynamics were worked out in advance of the development of quantum theory, they are now related to quantum theory via the ideas of statistical mechanics.

Some understanding of the absolute physicality of the roles of "thermodynamics" and other fundamental laws in the physical chemical existence is fundamental to understanding the origins of complexity and the evolution of cognition.

The first law of thermodynamics basically states that quantity of energy (matter is a form of energy) is conserved, but that it may change its forms (see also Russell 1995).

The second law of thermodynamics basically states that energy (and energy-rich matter) will *spontaneously* flow (or be converted) only from high potential forms to lower potential forms. The change in potential resulting from a particular conversion process is measured in terms of entropy (representing degraded energy in the form of heat that cannot be used in thermally isolated systems to drive reactions), whose mathematical sign is the reverse to what you would think it should be.

The second law is also often expressed in terms of entropy (or disorder), the entropy/disorder of the universe as a whole or in a closed/isolated macroscopic system system (i.e., not able to exchange any form of energy with its surroundings) will spontaneously only increase with time (Russell 1995a; Klyce 2010). In other words, high potential forms of energy (with low entropy) may spontaneously transform to lower potential forms (i.e., energy conversions will only ever occur spontaneously if they increase entropy) plus entropy, so it is quite reasonable to say that there is a universal tendency for ordered, organized systems to decay. Entropy has also been used to measure disorder in information theory (Shannon 1948; Gray 2001; Hillman. & Gunesch 2001), but we are concerned here with pure thermal physics not information (Klyce 2010).

The concept of 'exergy' has been introduced to measure the availability or quality of a form of energy to be converted into into another form. Following Wikipedia, “the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with" its surroundings; where there are two related definitions for “work”: (1) “Mechanical work**”** is the amount of energy transferred by a force acting through a distance. (2) “Thermodynamic work” performed by a system is the energy transferred by the system to another that is accounted for by changes in the external generalized mechanical constraints on the system. Thermodynamic work generalizes the concept of mechanical work. In open and dissipative dynamic systems work is required to force the state of the system farther away from its equilibrium state. Some exergy is lost in all energy conversions due to the production or consumption of entropy. “*As energy is used to do work in a dynamic system, it loses quality, its exergy decreases.*”[288]

A major quandary for many who do not understand the dynamics of systems far from equilibrium or biological processes is to account for the evolution of increasingly complex and exergy rich living organisms. This seems to run counter to the universal tendency for decay governed by the Second Law. Attempting to preserve a literal interpretation of Genesis 2 (i.e., the story of Adam and Eve), many Christian fundamentalists claim that the evolution of complex exergy-rich entities would be impossible under the laws of thermodynamics, and therefore the only way complex living things could come to exist is through the special actions of a creator god. For example see Christian Answers Net, Morris (????), Wallace (2007) . These and the links within their pages give a flavor of how "creation science" uses misunderstandings and misapplications of these laws in its attempt to discredit evolutionary argument. Several counter arguments to the creationist claims relating thermodynamics are linked via the Talk.Origins Archive (????).

The sciences are developing a coherent understanding for how the laws of thermodynamics result in physical processes that account for the origin of life and biological evolution. I will show later that many of the properties of today's organizations closely parallel (at a higher level of organization) properties believed to have existed for the early protocellular organisms as they achieved self-perpetuating autocatalytic closure more than three billion years ago.

Based on research beginning with his PhD thesis in (1945), Ilya Prigogine won the Nobel Prize in chemistry (Prigogine 1977) for developing an understanding of how fluxes of energy through systems far from equilibrium lead to the formation of complex and ordered dissipative structures (see also Prigogine 1955; Prigogine et al. 1972). Although I knew the principles of thermodynamics close to equilibrium from my physics and chemistry courses, Harold Morowitz's (1968) book, Energy Flow in Biology, was my first guide to provide key ideas for understanding how the fundamental processes of physics lead to the formation and evolution of increasingly complex dynamic systems such as living organisms can grow and evolve more complexity through time - apparently against the trend towards increasing entropy as stated in the second law of thermodynamics. Morowitz describes the thermodynamic framework within which complex dynamic systems evolve:

> *The resolution of* [the] *apparent divergence between a biological and a physical theory is the realization that the second law of thermodynamics applies* [most obviously] *to systems that are approaching equilibrium, whereas the surface of the earth, the matrix of biological evolution, belongs to a different class of physical systems. Equilibrium systems require either isolation (adiabatic systems) or contact with a single fixed reservoir (isothermal systems). Most real physical systems are of another sort; they are in contact with more than one*

> *reservoir, some of which may be regarded as sources and some of which may be regarded as sinks. The description of these systems requires the consideration of the flow of either matter and/or energy from the sources through the systems of interest to the sinks*. (Morowitz 1968: p 3. – my italics)

Morowitz summarises the general argument of his book as follows:

> 1. *The surface of the earth belongs to that class of physical systems which receives energy from a source and gives up energy to a sink. There is a constant and (on the appropriate time scale) almost steady flow of energy through the system.*
> 2. *This flow of energy is a necessary and, we believe, sufficient condition to lead to molecular organization of the system experiencing the energy flow.*
> 3. *This flow of energy led to the formation of living systems, and ecological process is the continued maintenance of order by the energy flow. Thus, the problem of the origin of life and the development of the global ecosystem merge into one and the same problem.*
> 4. *The flow of energy causes cyclic flow of matter. This cyclic flow is part of the organized behavior of systems undergoing energy flux. The converse is also true; the cyclic flow of matter such as is encountered in biology requires an energy flow in order to take place. The existence of cycles implies that feedback must be operative in the system. Therefore, the general notions of control theory* [*cybernetics*] *and the general properties of servo networks must be characteristic of biological systems at the most fundamental level of operations.* (Morowitz 1968: p 120.)

The concept that the origin and continuing evolution of complex living things is a consequence of the actions of the laws of thermodynamics as exergy is "dissipated" in fluxes of energy as matter is cycled between high potential sources to low potential sinks (Prigogine et al. 1972). Following Prigogine and Morowitz, the role of dissipation as a driver of life and evolutionary processes has been substantially extended by a number of workers; Kay 1984; Schneider & Kay 1994, 1995; Patten et al. 1997; Straskraba et al. 1999; Jorgensen et al. 1999; Jorgensen et al. 2000; Kay 2000; Corning 2002; Salthe 2002). Kay (2000) describes the driving force of life and evolution as follows:

> When moved away from their local (spatially) equilibrium state systems shift their states in a way which opposes the applied gradients and moves the system back towards its local equilibrium attractor[289]. The stronger the applied gradient, the greater the effect of the equilibrium attractor on the system. In simple terms, systems have the propensity to resist being moved from equilibrium and a propensity to return to the equilibrium state when moved from it….
>
> [Exergy] *...measure[s] ...the maximum capacity of the energy content of a system to perform useful work as it proceeds to equilibrium with its surroundings and reflects all free energy associated with the system. ... Exergy is a measure of the quality of energy….*
>
> The … second law can be formulated in terms of exergy: A system exposed to a flow of exergy from outside will be displaced from equilibrium. The response of the system will be to organize itself so as to degrade the exergy as thoroughly as circumstances permit, thus limiting the degree to which the system is moved [away] from thermodynamic equilibrium. Furthermore, the further the system is moved from equilibrium, the larger the number of organizational (i.e., dissipative) opportunities which will become accessible to it and consequently, the more effective it will become at exergy degradation.
>
> [This has the consequence that]

> ...new structures and processes can spontaneously emerge which better resist the application of an external gradient, in the sense that it gets harder and harder to move the system [away] from equilibrium because the system gets better and better at degrading the external input of exergy. ... This behavior is not sensible from a classical second law perspective, but is what is expected given the exergy degradation principle. No longer is the emergence of coherent self-organising structures a surprise, but rather it is an expected response of a system as it attempts to resist and dissipate externally applied gradients which would move the system away from equilibrium. The term dissipative structure takes on new meaning. No longer does it mean just increasing dissipation of matter and energy, but dissipation of gradients as well.[290]
>
> *...Autocatalytic reaction systems are a form of positive feedback where the activity of the system or reaction augments itself in the form of self-reinforcing reactions. In autocatalysis, the activity of any element in the cycle engenders greater activity in all the other elements, thus stimulating the aggregate activity of the whole cycle. Such self-reinforcing catalytic activity is in itself self-organizing, is an important way of increasing the dissipative capacity of the system and can act as an active selection process between competing elements in the cycle. Cycling and or autocatalysis are fundamental aspects of dissipative systems and represent not only the building blocks of structure but is the source of complexity in nonequilibrium systems.* [Kay 2000: pp. 5-9 in eprint – my emphasis]

Kay (2000: box, p. 9) summarises the properties of such non-equilibrium systems as driven by a continuing flux of energy from a high exergy source (e.g., sunlight) to a sink of low exergy (e.g., heat lost to the night sky). To paraphrase, such systems are:

- Open to material and energy flows.
- Out of equilibrium.
- Maintained by exergy gradients between sources and sinks.
- *Cyclical transport of matter or energy*: "Cycling and especially autocatalytic cycling is intrinsic to the nature of dissipative systems. The very process of cycling leads to organization. Autocatalysis (positive feedback) is a powerful organizational and selective process."
- Exhibits unpredictable and discontinuous changes (chaos & catastrophe).
- Systems become more organized as forced away from equilibrium
- Dissipate more exergy
- Become more structured
- Organization develops discontinuously as new attractors become available.

A number of workers have argued that that thermodynamically driven processes far from thermodynamic equilibrium will evolve to dissipate energy and produce entropy at the maximum possible rate that drives systems to become more complexly structured in order to provide opportunities for dissipation (Swenson 2000; Martyushev & Seleznev 2006; Salthe 2004; Salthe & Furhman 2005; Kleidon et al. 2010)[291].

Williams and Faústro da Silva (2002, 2003) take a systems approach to argue that the flow of energy from the sun through the physical/chemical system of the Earth's atmosphere, hydrosphere and geosphere have constrained the environment in which organic systems evolved to favor the development of the kinds of complex dissipative organic systems we see today. Russell & Kanik (2010) describe how life may have arisen on Earth under such circumstances.

The laws of thermodynamics have the capacity to drive dissipative systems providing a pathway for the degradation of exergy to become more complex and dynamic at the expense of the exergy they have destroyed. Given suitable media and exergy gradients that persist long enough in the face of local dissipation, it seems that systems will become complex enough to be considered alive.

This raises the question, what does it mean to be alive? The partial definition that follows from the above discussion is that living organisms are complex dynamic systems driven by dissipating energy fluxes flowing from high potential sources to sinks.

What is Life?

As for defining concepts of knowledge and time, there is no generally accepted scientific definition for life (e.g., Cleland & Chyba 2002; Oliver & Perry 2006; Lazcano 2008; Tsokolov 2009). The lack of such clear definitions impair otherwise excellent works relating to the possible origins of life, e.g., Koch (2010). However, a robust definition emerges from extending the ideas of non-equilibrium thermodynamics.

Morowitz (1968), Prigogine, Kay and their followers cited above explain how material (e.g., molecular) systems forced to dissipate extropy in the transport of energy from high potential sources to low potential sinks divert some of the transported energy to become more complex and cyclic. Some of this complexity serves as feedback to resist being disrupted by the flux. Stuart Kauffman in his book, "The Origins of Order" (1993) argues and demonstrates experimentally that if a dynamic system on the border between order and chaos is sufficiently complex (e.g., contains a collection of molecules capable of catalyzing other molecules in the collection) there is a capacity for them to work together as an "autocatalytic set" (1986).

A more complete definition of life will come from considering what it means to be alive. This is a question I first considered seriously in the mid 1960's when I began teaching biology courses as a graduate student[292]. The obvious place to start was to identify the differences between living and non-living things to see if these differences provided any heuristic power to explain some of the things living systems do for a living. In my thinking, the core property living systems had was the capacity for metabolism. I extended this to the definition that the minimal properties of life were dynamic self-maintenance, self-regulation and self-reproduction. Two Chilean neurobiologists, Humberto Maturana[293] and Francisco Varela[294] developed a similar but more complete theory of life, defined as "autopoiesis" (auto = self + poiesis = production) in the 1970s.

Autopoiesis

Maturana and Varela (Varela et al. 1974; Maturana and Varela 1980, 1987) coined the term 'autopoiesis' to cover the list of properties they thought were necessary and minimally sufficient to define the property of life. Maturana and Varela's starting point and their term autopoiesis has been adopted by many systems and organization theorists in their discussions of the life-like properties of autonomous systems and organizations. Whitaker's (1995) hypertext discussion of autopoiesis provides necessary subsidiary definitions and explains autopoiesis in comprehensibly layered detail. The following definition, as quoted by Whitaker from Varela (1979: p 13) is the one I will follow in this work:

> 'An autopoietic system is organized (defined as a unity [i.e., an entity]) as a network of processes of production (transformation and destruction) of components that produces the components that:

(1) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and

(2) constitute it (the machine [i.e., the entity]) as a concrete [i.e., definable] unity in the space in which they [the components] exist by specifying the topological domain of its realization as such a network.'... [Whitaker (1995)]

Even more comprehensive definitions of all the necessary terms within the paradigmatic language are to be found on Whitaker's (2001...) web site, including his Encyclopaedia Autopoietica (Whitaker 2001a)[295]. Crucial terms in the following discussion will be hot-linked to the appropriate entry in this resource (e.g., autopoiesis). In the definition above, the term "unity" (I prefer to use the synonymous "entity"), refers to any simple or compound object that can be distinguished or discriminated from the background by an observer.

Varela et al. (1974) listed six criteria they considered to be necessary and sufficient conditions for recognizing a system to be autopoietic:

- *Bounded* ("the unity [entity] has identifiable boundaries"). In this Varela et al. were primarily concerned that the entity could be discriminated by an external observer. To me this criterion should read, "the entity has *self*-identifiable boundaries". Note: in living cells the boundary is a semi-permeable membrane, perhaps protected by a cell wall.
- *Complex* ("there are constitutive elements of the unity, that is, components").
- *Mechanistic* ("the component properties are capable of satisfying certain relations that determine in the unity the interactions and transformations of these components"). In other words, the complex entity is dynamic, such that components show causal interactions *driven by energy dissipation.*
- *Self-referential or self-differentiated* ("the components that constitute the boundaries of the unity constitute these boundaries through preferential neighborhood relations and interactions between themselves, as determined by their properties in the space of their interactions"). That is, the boundaries of the system are determined by the structural relationships the entity's components.
- *Self-producing* ("the boundaries of the unity are produced by the interactions of the components of the unity, either by transformations of previously produced components, or by transformations and/or coupling of non-component elements that enter the unity through its boundaries"). Note that there is no implication here that the entity is physically closed against exchanges of matter and energy.
- *Autonomous* ("all the other components of the unity are also produced by interactions of its components as in [the statement above], and … those which are not produced by the interactions of other components participate as necessary permanent constitutive components in the production of other components").

The properties of autopoiesis are "embodied"[296] *in the persistent "*organization*"*[297] *of the network of dynamic interactions among the components of a system that perpetuates autopoiesis while its instantaneous structure changes continually as matter and energy pass through it. In this it must be understood that the autopoietic system is a dynamic system open to fluxes of matter and energy, maintaining something approaching a "steady state" that is far from thermodynamic equilibrium by continually dissipating extropy in the flow of energy through it to drive linked processes in the organized system that maintain autopoiesis against the entropic tendency (*Figure 54*). In this picture, "energy" may be in the form of energy rich compounds (i.e., "food"), "materials" may be raw material for synthetic processes, "components" may be* *already complex materials that only need slight modification, "observations" represent perturbations impacting the entity, "actions" represent compensatory activities triggered by the observations that serve to perpetuate the autopoietic state.*

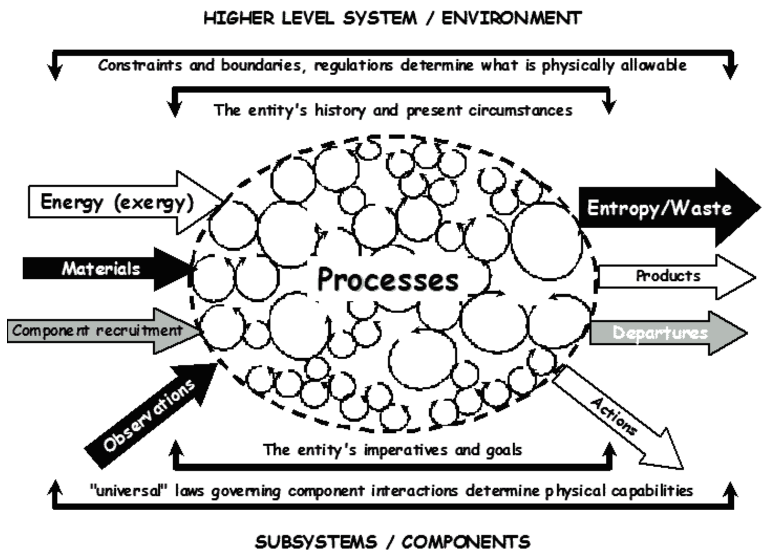


Figure 54. Coupled subsystems in an autopoietic entity. An autopoietic entity as a complex self-producing system of interconnected processes driven by the transport of fluxes from higher potential sources to lower potential sinks in its immediate environment. Intersecting circles represent coupled processes (Hall et al. 2005).

As Maturana (2002) expressed it in a way similar to Varela (1979). A living (i.e., autopoietic) entity is defined by the physical interactions of its (molecular) components and not the components themselves, where the autopoietic entity is recognized,

> [as a] dynamic molecular entity, [that is] realized as a unity as a closed network of molecular productions in which the molecules produced through their interactions:
>
> a) recursively constituted the same network of molecular productions that produced them; and,
>
> b) specified the extension of the network and constituted operational boundaries that separate it as a discrete unity in a molecular space.
>
> [The autopoietic system is] …a molecular system open to the flow of molecules through it as molecules could enter it and become participants of its closed dynamics of molecular productions, and molecules could stop participating in such molecular dynamics leaving it to become part of the molecular medium in which it existed…. [Maturana 2002: p. 7]
>
> Living systems are not the molecules that compose and realize them moment by moment, they are closed networks of molecular productions that exist as singularities in a continuous flow of molecules through them. Indeed, the condition of being closed molecular dynamics is what constitutes them as separable entities that float in the molecular domain in which they exist…. [Maturana 2002: p. 10].
>
> …autopoietic systems in the physical space must satisfy the thermodynamic legality of physical processes that demands of them that they should operate as materially and energetically open systems in continuous material and energetic interchange with their medium… [where] ...the physical boundaries of a living system... are realized by its

> components through their preferential interactions within the autopoietic network... as surfaces of thermodynamic cleavage [Maturana 2002: p. 30].

Maturana infers from this,

> the law of conservation of organization (autopoiesis in the case of living systems) and the law of conservation of adaptation, that is operational congruence, with the medium in which a system (a living system in our case) exists. These two laws of conservation are both relational conditions of the realization of living systems that must be satisfied for living to occur at all. [Maturana 2002: p. 10].

In their writings on autopoiesis, Maturana and Varela emphasized the importance of "circular organization" or "operational closure" whereby negative feedback from self-observation maintained the autopoietic nature of the organization.

In developing these ideas it is apparent that Maturana and Varela encountered difficulties in clearly explaining the recursive "circularity" of autopoietic systems. This was exacerbated by their concerns to clearly understand and differentiate the second-order cybernetics of the apparently circular relationships between autopoietic systems acting as "observers" and what the systems observed; with the further complication that those who describe an autopoietic system are also observers. The situation seemed to be particularly difficult in the "self-observation" required for "self-regulation" by autopoietic systems.[293]

Some authors apparently misunderstood Maturana and Varela's concerns relating to self-observation. For example, Nicklas Luhmann used a concept of "autopoiesis" as a basis for his comparatively well known Social Systems Theory (1995). In his works available in English (1986, 1989, 1990, 1992, 1994, 1995a), he considered that the operation of feedback from self-observation formed a paradoxically and viciously closed causal chain, where A causes B and B causes A – an issue also pursued by others concerned with second order cybernetics (Wolfe 1995; Brier 2005; Leydesdorff 2006; Schwaninger & Groesser 2012). Luhmann went to esoteric extremes in an attempt to work with the assumed paradoxes of self-reflection in autopoiesis, and his view influenced a whole school of predominantly European political, legal and organizational theorists. Although never expressed succinctly by Maturana or Varela, self-observation in a dynamic system propagating itself through time simply is not paradoxical (Hall et al. 2007; Hall & Nousala 2010; Hall 2011)[298] *as explained in the follwing discussion.*

*A*utopoiesis is intrinsic to self-defined physical systems, and it emerges and exists or does not in the physical world independently from any external observer. Maturana went to great lengths linguistically to include structurally coupled observers in his discussions.

The key to understanding autopoiesis is 'organizational closure':

> … characterized by processes such that (1) the processes [within/forming the entity] are related as a network, so that they recursively depend on each other in the generation and realization of the processes themselves, and (2) they constitute the system as a unity [entity] recognizable in the space (domain) in which the processes exist.' [Varela 1979: p. 55]

In other words, I interpret this to mean that in any instant of time, to remain autopoietic a dynamic system exhibiting the properties of autopoiesis needs to be physically organized (i.e., structured) in state space in such a way that the ongoing processes producing autopoiesis are dynamically interconnected in such a way that they maintain an autopoietic structure in the next instant. Stuart Kauffman uses the terms catalytic closure and autocatalytic sets in senses that correspond closely to organizational closure and autopoiesis (see below). For a set to be closed,

> …it must be the case that every member of the autocatalytic set has at least one of the possible last steps in its formation catalyzed by some member of the set, and that connected sequences of catalyzed reactions lead from the maintained "food set" to all members of the autocatalytic set. [Kauffman 1986: p. 3-4]

It follows from these definitions that the autopoietic entity has the capacity to adapt and change (or 'evolve' in the simple sense of change through time) in order to maintain its autopoietic capacity in response to stimuli (perturbations) that affect it.

According to Whitaker 2001a, Maturana and Varela use the term cognition for the collective cybernetic processes involved in achieving homeostasis and adaptation.

> [C]ognition is a consequence of (structurally-realized and structurally-determined) interactions. "A cognitive system is a system whose organization defines a domain of interactions in which it can act with relevance to the maintenance of itself, and the process of cognition is the actual (inductive) acting or behaving in this domain." (Maturana 1970: reprinted in Maturana & Varela, 1980, p. 13)

More specifically:

> "... for every living system the process of cognition consists in the creation of a field of behavior through its actual conduct in its closed domain of interactions, and not in the apprehension or the description of an independent universe. Our cognitive process (the cognitive process of the observer) differs from the cognitive processes of other organisms only in the kinds of interactions into which we can enter, ... and not in the nature of the cognitive process itself." (Maturana 1970: reprinted in Maturana & Varela, 1980, p. 49)

In other words, to Maturana, cognition is a circular, cyclic process of self-regulation within the autopoietic entity able to maintain coherence of the autopoietic system in the face of internal and environmental perturbations, as discussed in earlier episodes. A graphical illustration of a causally dynamic circular process shows why dynamic systems acting through time are not viciously closed (Figure 55).

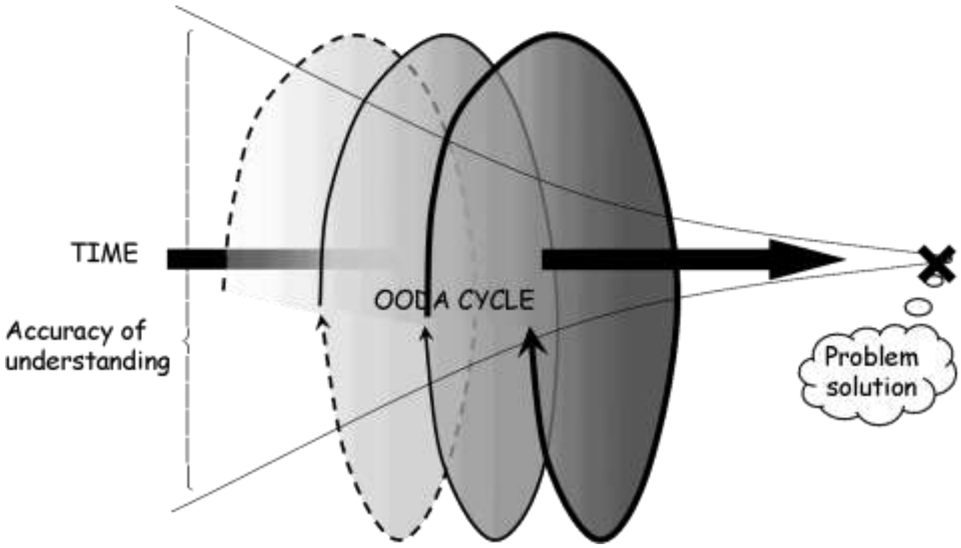


Figure 55. The OODA cycle is a virtuous knowledge building process for finding better solutions to problems of life (Hall et al. 2011).

When stated abstractly, the "circularity" of autopoiesis is difficult to understand. However, Conway's Game of Life (GOL)[299] as explained in Figure 56, demonstrates in a completely deterministic "*toy universe*"[300] a very simple concrete case of how a circularly closed dynamic system such as a "glider" can maintain itself through a sequence of instants. Beer (2004: 311) notes that a glider is "a coherent localized pattern of spatiotemporal activity in the [L]ife universe that continuously reconstitutes itself" through a sequence of cycles. Given the rules of the game, the structural organization of the glider in one instant, say at time 1-1, causes it to change to the state in the instant at interval 1-2 as illustrated in Figure 56. The organization at 1-2, in turn causes that shown at 1-3, causing 1-4, and then repeating endlessly. At any point in time – without considering rules of the game, the instantaneous structure of the grid is a meaningless fact. However, when the rules are applied (i.e., the laws of the toy universe), as the automaton steps from one instant to the next, the "knowledge" the entity requires for its continued survival (i.e., ability to maintain its organized existence) is embodied in its structure at each instant.

Although this process is cyclical, where each change is based on the reflexive interactions of cell states in the previous instant, it is not closed. Each cycle moves the glider forward another step, such that at some future time it may come into interaction range of other dynamic or stationary objects in the automaton. In this sense, at each step the glider opens adjacent possibilities for other kinds of interactions that may involve "mutation", disintegration, or the generation of new areas of chaos.

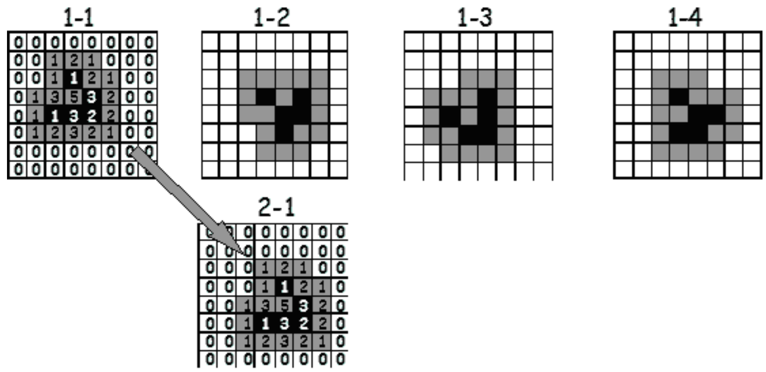


Figure 56. A simple "glider" in Conway's Game of Life (GoL). The GoL universe is a two dimensional grid that iterates along a time axis of discrete intervals according to a set of rules that is applied to the states of all cells in each interval to determine their states in the next interval. No information other than the state of each cell is exchanged between intervals as per Ellis's (2006b) evolutionary block universe. In the GOL universe the next state of each lattice cell in the becoming instant depends only on its own state and the sum of the states of the cells it touches in the present instant (now). The GOL's governing 2/23 rule states that: (1) An inactive cell with exactly three active neighbors becomes active; (2) an active cell with two or three active neighbors remains active. (3) Cells with other than two or three active neighbors become or remain inactive. The figure illustrates a self-generating dynamic entity called a glider that often emerges from areas of chaotic activity. The arrow indicates that every four steps in a repeating cycle the glider moves on the grid diagonally downward by one row and to the right by one column. "Active" cells are black, "inactive" cells playing no role in determining the glider's structure in the next instant are empty, and inactive cells involved in determining the glider's structure in the next step are gray. The cycle and step number are shown above each grid. A number in a cell indicates the number of *active cells* touching the numbered cell. (After Beer 2004)

Given GoL's rules, even though it may be impossible to model the long term evolution of some seeds with a compact algorithm, the temporal evolution of any seeded pattern is completely deterministic. Most seeds evolve to empty, static or or a limit cycle of stably repeating states. A few seeds evolve to generate dynamically self-producing, coherent and mobile simple entities such as the "glider" presented in Figure 56, its relatives, and sometimes much more complex extended "ships", and "engines" that emerge and progress away from the dynamic area generated by the initial seed Gotts (2009). Note that *the "knowledge" for self-producing cellular automatons is always embodied purely in the instantaneous structure of the automaton as driven by the stepping process moving from one instant to the next as governed by the rules of the game* (i.e., laws of the toy universe). Because at T1 the automaton has the structure shown in 1-1, at T2 the rules reflecting on the structure at 1-1 produce the structure at 1-2, and so on until the cycle begins to repeat at T5. Gotts documented the emergence of complex entities in GoL cycling over some 90 steps or more, such as "puffer trains" and "switch engines" that can perturb one another via gliders and debris they generate. In many cases when a dynamic entity is perturbed by interaction with another glider or debris, it follows dynamic pathways that disintegrate and die away to nothing or turn into incoherent stationary debris. However, Gotts has observed the emergence of particular dynamic structures that can compensate for or mutate and survive as slightly different dynamic structures, and has established that scenarios exist with the capacity for the open-ended evolution by natural selection of increasingly robust entities[301].

Thus, in toy universes that the knowledge required for the perpetuation of self-producing entities exists purely in their spatial organization is easily demonstrable.

However "circular" autopoiesis may appear at first glance, when the factors of time and causation in dynamic systems are considered, autopoietic "cognition" must be a virtuously open spiral process as detailed by Hall et al. 2007, 2011). Cognition in this sense leads to the emergence of Popper's World 2 of "subjective" knowledge.

The spontaneous emergence of autopoiesis and knowledge

The point of the previous long argument is that phenomenon of "life" as defined by autopoiesis is a purely a phenomenon of physical dynamics, requiring no metaphysical processes or interference to account for its origin(s), continued existence, or evolution. I have discussed this at length in Hall (2011) and will summarize the argument here.

Earlier in this Interlude, I introduced some of the basic concepts of thermal physics that drive dynamic processes in World 1, and have reviewed what it means to be a living cognitive entity. Now it is time to consider pathways by which the complex cybernetics of World 2 has been able to emerge from the thermodynamically driven physical and chemical processes of World 1. As quoted and referenced earlier, Prigogine, Morowitz, Kay, Patten, Corning and others have shown that the transport and dissipation of fluxes of energy from a high exergy source to a lower exergy source through an intervening aqueous chemical system of carbon, hydrogen, oxygen and nitrogen under a reducing atmosphere will establish transport systems involving chemical cycles that tend to become more complex through time.

Stuart Kauffman (1993, 1995, 1996) argues that as such dissipative biochemical cycles become more complex, systems will organize themselves to become autocatalytic, essentially "for free". For some 30 years Stuart Kauffman explored the mathematical properties of chaos and organization in cyclic and cybernetic systems, seeking to understand how ordered autocatalytic and homeostatic regulatory systems can emerge naturally from initially random and chaotic assemblies of on/off switches and wires or chemical mixtures. Kauffman's (1993) 709 page summary of lifetimes of his own and others' work, explores every step along the road from easily computable networks of on/off (i.e., Boolean) switches connected by wires, through increasingly complex and life-like (i.e., autocatalytic) cybernetic models, to explore the parameters leading to order vs. chaos as the systems grew larger and more complex. In some cases his models are supported by biochemical experiments. His final chapters apply the logic and conclusions tested in his models and experiments to demonstrate that developmental and evolutionary genetics of multicellular organisms are compatible with the principles demonstrated by his models. Kauffman 1996) provides an on-line summary of the logic of this progression, but no summary or abstract can do justice to immense detail of the book.

Brockman (1995) assembled Kauffman's summary along with responses from a number of other people working on the questions reviewed in the present section of my work.

> What kinds of complex systems can evolve by accumulation of successive useful variations? Does selection by itself achieve complex systems able to adapt? Are there lawful properties characterizing such complex systems? The overall answer may be that complex systems constructed so that they're on the boundary between order and chaos are those best able to adapt by mutation and selection.
>
> Chaos is a subset of complexity. It's an analysis of the behavior of continuous dynamic systems — like hydrodynamic systems, or the weather — or discrete systems that show recurrences of features and high sensitivity to initial conditions, such that very small changes in the initial conditions can lead a system to behave in very different ways. … *An*

> *infinitesimal change in initial conditions leads to divergent pathways in the evolution of the system. Those pathways are called trajectories. The enormous puzzle is the following: in order for life to have evolved, it can't possibly be the case that trajectories are always diverging. Biological systems can't work if divergence is all that's going on….*
>
> *We've discovered the fact that in the evolution of life very complex systems can have convergent flow and not divergent flow.* Divergent flow is sensitivity to initial conditions. *Convergent flow means that even different starting places that are far apart come closer together* [i.e., are constrained by their organization in state space to evolve towards an attractor]. That's the fundamental principle of homeostasis, or stability to perturbation, and it's a natural feature of many complex systems…." [my emphasis - Kauffman in Brockman 1995]

Kauffman's argument that physics alone is sufficient to explain the emergence of complex living systems is important, However, as I elaborate below in an argument based on the nature of time in the evolving block universe, I think Kauffman substantially undervalues the role of "*natural selection*" in the process of emergence. My argument begins with the picture of evolutionary time (Figure 57[302]) developed by Hall and his colleagues (Dalmaris et al 2006; Hall et al 2007, 2011a, Martin et al. 2009, Philp & Martin 2009; Hall et al. 2011), lately influenced by ideas from Ellis (2006b, 2008) and Kauffman (1993, 1995, 1996; Kauffman et al. 2008). An essential part of this view is that the past behind the present instant is inert (if it exists at all) and cannot directly influence the becoming of the next instant.

In an instant of time, each particle in the universe has a number of adjacent possible states that can be reached in the next instant, "*now*". Each of these states potentially begins a different trajectory or time-line of change progressing from one instant to the next (Figure 53), and on through a progression of instants leading to "*divergent futures*". Ignoring multiverse concepts, Hall et al. (2007, 2011) called this set of possible time-lines from an instantaneous state the "*stochastic future*"[303]. Two factors affect the adjacent possible states available to a particular individual particle in a particular instant: (1) universal possibilities intrinsic to the type of particle or local state, representing upward causation, and (2) causal influences from other particles or local states that may block, trigger or otherwise influence the probability of particular intrinsic possibilities. In some circumstances these causal influences apply downward causation. *In any instant, the stochastic future available to a system of particles as an ensemble will be a constrained subset of the futures that might be available to the same particles in the absence of any causal influences among the particles.*

As stated by Kauffman above, chaotic systems produce divergent flows leading to disintegration, while living (i.e., autopoietic) systems must maintain convergent flows to stabilize them against environmental perturbations, i.e., to provide "solutions to problems" caused by the perturbations (Figure 57). The major quandary is to understand how self-defined autopoietic systems able to maintain convergent flows emerge historically from blind chaos normally leading to temporal divergence.

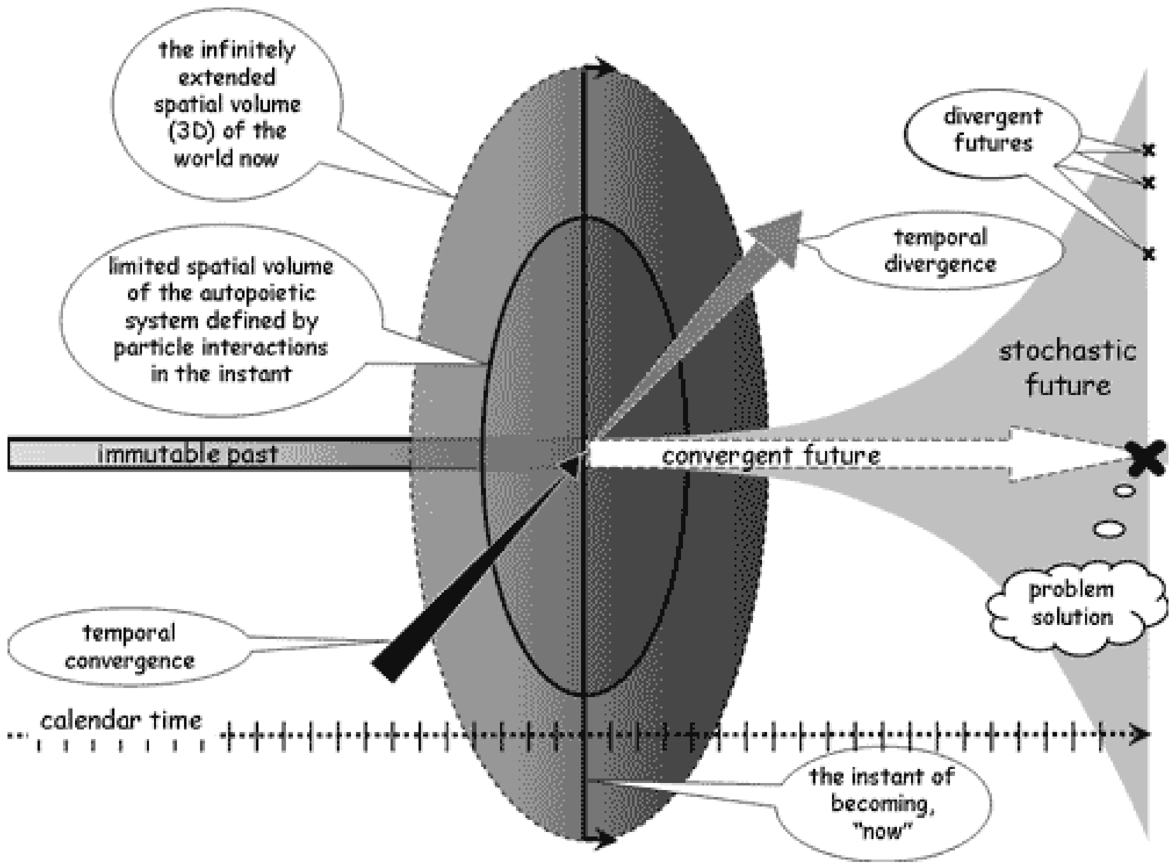


Figure 57. Divergent and convergent futures (derived from Hall et al 2007 – see also endnote 302).

Given the laws of physical dynamics as these affect the interactions of system components in the real world, substantial knowledge can be assumed to be embodied in the instantaneous structure of a living cell, or in the instantaneous structure and connections of a multicellular organism's nervous system. In both of these cases, the continued capacity of the cellular or multicellular entity to maintain itself from one instant to the next depends on its dynamic structure in that instant. This kind of knowledge is embodied in the dynamic structure of a self-maintaining entity, and if that structure dissipates, the entity loses the capacity to maintain itself and dies. Thus, the knowledge embodied in dynamic structure may also be called "*living knowledge*". In Maturana and Varela's words,

> …[T]here may be many different kinds of autopoietic machines in the physical space (physical autopoietic machines); all of them, however, will be organized in such a manner that any physical interference with their operation outside their domain of compensations [i.e., the perterbation exceeds the system's, capacity for self-regulatin and self-repair] will result in their disintegration: that is, in the loss of autopoiesis. It also follows that the actual way in which the autopoietic organization is realized in one of these machines (its structure) determines the particular perturbations it can suffer without disintegration…. (Maturana & Varela 1973: 81)

How might such structural knowledge come into existence in our universe? As discussed above, Kauffman in his (1993) Origins of Order book described the physical circumstances under which some types of autocatalytic sets might be found. However, in these kinds of circumstances, the origin of structural knowledge and its shaping by natural selection probably plays a much more important role than Kauffman acknowledged. Figure 58 places an autopoietic system into the context of Popper's three worlds that provides a context for this discussion.

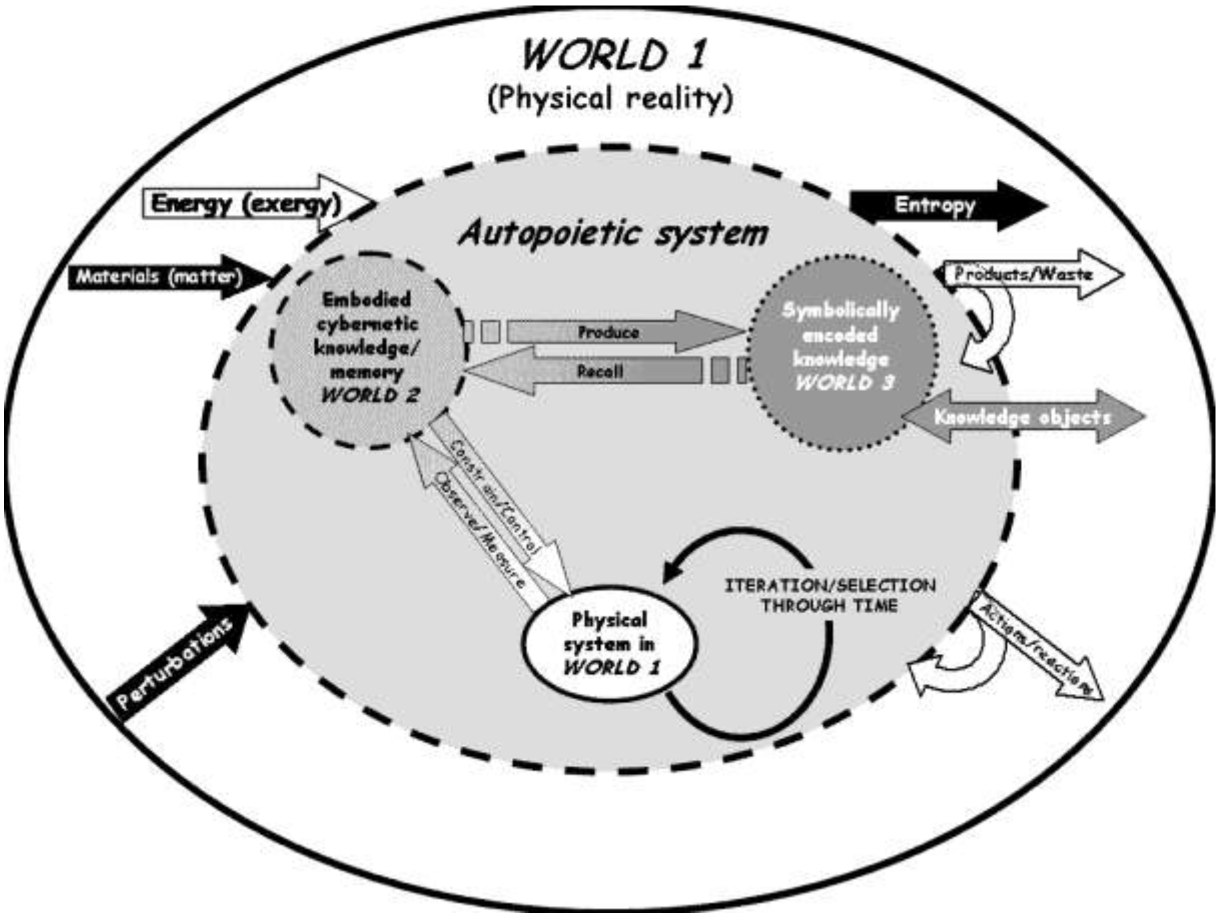


Figure 58. Three worlds in an autopoietic system (Hall 2011 after Hall 2005). The autopoietic system is a living entity separated from its immediate environment by a permeable boundary indicated by the dashed line. The white zone on the outside of the boundary is the immediately adjacent environment the entity must interact with in order to maintain its autopoietic entity. World 1 encompasses physical structure and processes of the autopoietic system and the environment.

In the physical world of stochastic perturbation, a self-defining system cannot maintain its existence as an organized structure without applying compensatory cybernetic knowledge embodied in structured dynamic processes working to maintain its functional integrity. Otherwise perturbations would lead to its structural dis-integration. Corning (2001, 2002, 2007) calls the knowledge embodied in cybernetic control, "control information"; which he defines as: "The capacity (know how) to control the acquisition, disposition and utilization of matter/energy in purposive (cybernetic) processes." Without referencing autopoiesis or evolutionary epistemology, Corning (2002) provides a lucid account for how this structural knowledge or control information can emerge and be shaped by natural selection to produce more complex self-producing entities. As discussed below, autopoietic structural knowledge exists only as long as the system in which it is embodied continues to produce itself.

The largest oval in Figure 58 encompasses the physical world and everything in it (W1). An autopoietic system within W1 is enclosed within the heavy dashed line that indicates its physical boundary with the external world. The smaller solidly bounded clear oval indicates the physical aspects of the autopoietic system. The system's boundary is permeable to energy and semi-permeable to matter.

As fluxes pass through the systerm, exergy is dissipated into entropy, driving production processes that convert at least some of the matter flowing through the system into components (products) required for the maintenance of the system's autopoietic structure and exporting some products and waste to the external world. Physical perturbations create "problems" that might potentially lead to system disintegration. For autopoiesis to continue, cybernetic feedback control processes (W2) within the autopoietic system (indicated by the dashed circle within the autopoietic system) must compensate for these problems by acting internally or on the external world to minimize system disturbances propagating from perturbations, perhaps through the production of particular products (e.g., Tsokolov 2010). Autopoietic systems unable to compensate dis-integrate, and thus are selectively eliminated from the population (i.e, they no longer exist as centers from which other autopoietic systems may emerge). Assuming that living knowledge (W2) is inherited from one instant to the next, it gradually improves through processes of the generation and selective survival of successful solutions compared to the dis-integration and elimination of failed solutions. Evolution may proceed to the point where systems emerge that are able to encode knowledge into inert forms that can persist independently of living autopoietic systems, for sharing and decoding at other times and places.

Hall et al. (2005) and Hall (2006, 2011) describe conditions under which a lifeless physical world bifurcates to form an autopoietically emerging W2 that may eventually enable the emergence of W3 (indicated by the dotted circle within the autopoietic system of Figure 58). The sequential emergence of autopoietic systems can be broken into several stages based on physical processes (Figure 59, Figure 60), and as follows:

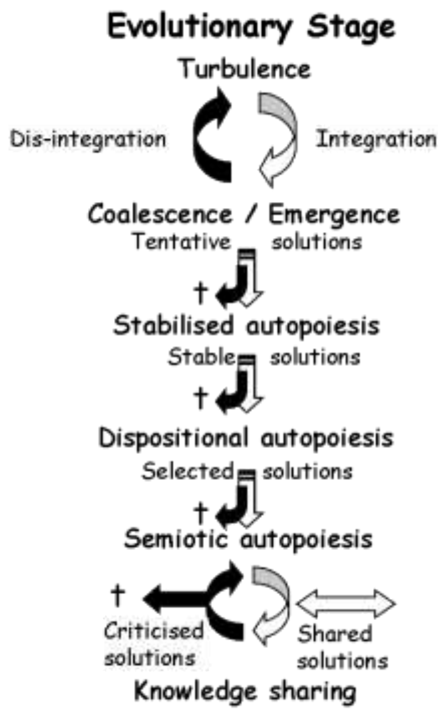


Figure 59. Stages in the emergence and evolution of autopoietic knowledge.

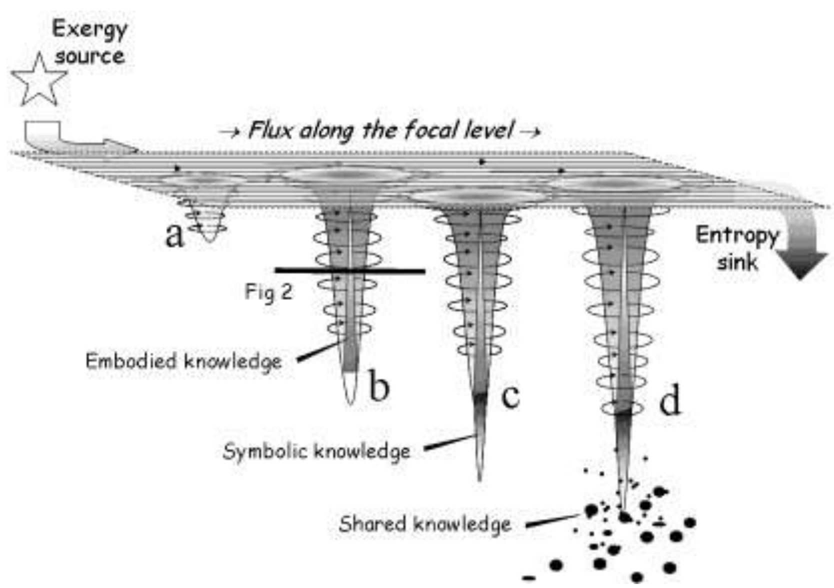


Figure 60. A different view of the emergence and evolution of autopoietic knowledge (after Hall et al. 2005; Hall 2005a provides an animated version of this graphic): a. self-stabilized eddy in a turbulent flux from source to sink. b. surviving autopoietic system - i.e., one where the structure of the system retains the dispositional capacity to maintain and reproduce itself. (Figure 54 shows a cross-section through this eddy). c. evolving autopoietic system where the solutions to problems of survival have been codified in persistent form able to be recalled in appropriate circumstances. d. In individual in a "biological species" able to exchange and share codified knowledge susceptible to intersubjective criticism or selection by the environment. Note: click figure to see related animation.

- *Dissipative fluxes in aqueous molecular systems drive the emergence of complex chemical dynamics.*

Substantial evidence from experiments and modeling shows that when reducing media comprised of small molecules containing carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur (CHNOPS) such as are found in interstellar dust, meteorites and comets are exposed to activation energies from heat, electrochemical gradients and/or radiation larger, and biologically significant molecules are assembled (Morowitz 1968, 1999; Morowitz & Smith 2007; Copley et al 2007, 2010; Ohtsuki & Nowak 2009; van der Gulik et al. 2009; Nitschke & Russell 2009, 2010; Mast et al. 2010; Lane 2010; Simoncini et al. 2010; Fondi et al. 2010)

- *Autopoietic evolution begins with turbulence in dissipative fluxes from sources to sinks*.

Complex recursive eddies or "circularly closed" vortexes in the fluxes of energy and materials from sources to sinks repeatedly form, dissipate and reform (Figure 60a). Initially, such self-regulatory/self-productive (autocatalytic) activities must take place close to chemical equilibrium. Newly coalescent autocatalytic systems have no past, but if an emergent eddy has any autocatalytic/autopoietic capacity for self-producing essential components, while it survives it will produce more of these components that have the tested capacity to participate in the formation of such systems. Each marginally autopoietic system that emerges represents a tentative structural solution to one or more problems of life. Those that dis-integrate lose their their organized structures and thus any histories (heredity/knowledge) embodied in those structures. However, it can be assumed that loose components that were multiplied and tested in such temporarily autocatalytic/autopoietic systems will survive in the environment for a time after the disintegration of the system that produced them, to become more common in the environment. This will shift chemical equilibria to increase the probability that more autopoietic eddies will form based on these tested components. In other words, at least in this very early stage, incipient autopoietic events increase the fitness of the non-living environment to support more autopoiesis of the same kind.

- *Stabilized autopoietic systems persist indefinitely in the face of at least some perturbations*

Stabilized autopoietic systems are those complex entities whose tentative solutions embodied in self-regulatory feedback and self-production enable them to persist indefinitely in the face of at least some common system disturbances, thereby establishing lineages through time (Figure 60b). At this stage survival knowledge in the self-maintaining entity is embodied in the fitness of the component subsystems and their networking organization to participate in self-regulation and self-production of processes. Those entities that fail to solve new problems dis-integrate and lose the historical success of the knowledge embodied in their organizational structure.

Where such stabilized systems are robust, they may grow to the point where physical perturbations such as turbulent shearing causes fragmentation rather than disintegration. If the network of processes producing autopoiesis contains sufficient redundancy, fragments of autopoietic systems may retain enough components of the necessary processes to continue autopoiesis – thus multiplying the number of autopoietic entities sharing a common history.

These share "inherited" control information or "know how" that survived fragmentation (Maturana and Varela 1973; Varela et al. 1974).

- *Dispositional autopoiesis where lineages multiply historically successful solutions as compositional inheritance*

Dispositional/situational autopoiesis (also Figure 60.b) refers to the state where autopoietic lineages multiply historically successful solutions for survival as tested compositional inheritance (i.e., structural or dispositional knowledge - W2). This multiplication may involve nothing more complex than passive fragmentation where at least some of the fragments retain the necessary structures to support autopoiesis. Morowitz (1999), Morowitz & Smith (2007). Rasmussen et al. (2003), Pross (2005, 2009), and Pross and Khodorkovsky (2004) all explain what this phenomenon may look like at the chemical level. This type of knowledge transmission is called "*compositional inheritance*" (Segré & Lancet 2000; Segré et al. 2000, 2001a; Wu & Higgs 2008).

Where self reproduction becomes common, limited environmental resources of exergy and required material components for self-production, growth and replication will be used up, forcing lineages of autopoietic entities to complete dwindling resources. Individuals inheriting comparatively inefficient/ineffective processes will be starved for energy or suitable resources and disintegrate, losing their heritage. The consequence of such Darwinian/Popperian "error elimination" is that survival knowledge will grow in those lineages that best survive their problems of life.

- Semiotic[304] *autopoiesis*

Semiotic autopoiesis (Figure 60c) emerges when lineages evolve capabilities to preserve tested survival solutions in relatively inert persistent forms able to be retrieved, decoded and embodied when relevant to particular problems of life (i.e., codified knowledge - W3). This will be discussed in more detail below. There is an "*epistemic cut*"[305] (Pattee 1995a, 2001, 2001a, 2005, 2007, 2008, 2013; Hall 2011) between system dynamics (W2) and "*energetically degenerate*"[306] media for storage and replication (W3). DNA-based genetic and developmental systems involving replication, transcription and translation are one kind of coding solution. Linguistically encoded and symbolically expressed memory (e.g., a writing) is another such solution. Where knowledge objects can be expressed linguistically, they are able to be consciously criticized to eliminate errors without the need to embody the knowledge in entities that are eliminated if their enacted solutions are erroneous.

- *Knowledge sharing across space and time*

Figure 60d illustrates the stage when knowledge codified in "objective" forms in W3 is able to persist independently from knowing entities able to decode the knowledge objects and is thus available to be shared "horizontally" between different lineages (e.g., Joseph 2010). As discussed in more detail by Hall (2006, 2011), bacterial transformation, transduction and conjugation (Hurlbert 1999; Mulligan 1997-2005), and sexual recombination in eukaryotic cells represent such knowledge transfer and sharing. Where linguistically expressed objects are shared by people, they can be intersubjectively criticized (Popper 1972).

To this point I have implied that Popper's three worlds are something more than metaphysical constructs, i.e., that they actually have an empirical meanings in the physical dynamics of reality. This will be explored in more detail in the next section. Autopoiesis and knowledge are also inextricably intertwined. Autopoiesis cannot exist without knowledge, and as will be elaborated further, all knowledge is constructed by autopoietic systems.

Cognition, structural/dispositional knowledge, codified knowledge and systems of heredity

I have considered above the kinds of processes extending through time that lead to the construction of knowledge in autopoietic systems. I will now consider in more detail "cognitive" processes within autopoietic systems involved in the construction, reproduction and improvement of autopoietic knowledge.

Assuming that the structure of the coalescent autopoietic system and its medium provide possibilities, even without mechanisms to objectively codify and store control information, by removing autopoietic entities that fail to solve problems of life, natural selection will build survival 'knowledge' whenever/wherever self-producing systems persist long enough to begin accumulating a connected history of survival as structural inheritance (i.e., the physically constrained adjacent possible determined by the physical structure of the world – including systems in question - in the prior instant). Even if systems that are only partially or temporarily autocatalytic disintegrate to return their assembled components to the environment, those producing more components of kinds involved in their partially autocatalytic structures will facilitate emergence of other autocatalytic systems depending on properties of those kinds of components. This structural heredity determines the dynamic processes maintaining autopoiesis. Cognition is the sum of the processes *within autopoietic systems* by which this survival knowledge is applied to solve problems.

- *Building W2 knowledge into structural organization through autopoietic reproduction and natural selection*

'Re-production' gives autopoietic knowledge historical continuity. In its simplest form (i.e., requiring the least structural "knowledge" beyond the state of "chaos" close to equilibrium), reproduction needs nothing more than system growth from the self-production of additional components in favorable ratios and structural locations within the autopoietic system until the assemblage becomes physically unstable and fragments into two or more pieces. If some fragments retain an autocatalytic capacity, these now separate fragments will preserve and potentially add to their prior history as autopoietic entites. Even this nearly chaotic reproduction would multiply the histories of working solutions. With no "formal" genetic system to retain and reproduce control information in any objective form, the propagation of survival knowledge via constitutional inheritance would be subject to chaotic variation. Many incipient lineages would dis-integrate and lose their accumulated history. Given the uncontrolled way in which surviving progeny are produced, each survivor would, in Popper's terms, represent a new tentative solution to problems of life. As long as some lineages continue to produce viably autopoietic progeny through time, survivors of those lineages will continue to embody more and more survival knowledge in their structural organization. Eventually, competition among the successfully surviving lineages for limited resources of matter and energy will move them further away from equilibrium with the environment. In Figure 59, this represents the stage of "dispositional autopoiesis" – referring to Popper's (1972 – e.g., pp. 66-67) concept of W2 knowledge embodied in the structural "disposition" of organisms (see also "compositional inheritance" - Segre & Lancet 2000; "live memory" - Bentolila 2005).

- *Emergence of codified knowledge at the macromolecular level to form W3*

Continued selection will favor the evolution of encoded knowledge. For example, some nucleic acid polymers have heterocatalytic properties as well as the potential for self-replication. Such macromolecules may have had cybernetic control functions in early autopoietic metabolism. An autopoietic system physically replicating the structure of these molecules, would also be replicating structural or enzymatic functions those molecules performed in the autopoietic system (Hughes et al. 2004; Poole 2006; Yarus 2010; Benner et al. 2012).

In today's organisms, DNA appears to have no enzymatic or structural functions. However, RNAs still serve both as code carriers (in messenger RNA) and structural/catalytic roles (as ribozymes in ribosomes catalyzing protein synthesis or in other cellular functions). When structural knowledge or control information relating to the autopoietic system is represented in the structures of macromolecules catalyzing their own replication, this will further stabilize lineages carrying such macromolecules. This represents the first emergence of Popper's W3 with persistent and potentially shareable survival knowledge (Fry 2010) and sets the stage for evolving the DNA and RNA-based epistemic systems we now know as genetic systems0. In many papers Pattee has discussed stages in the refinement of replication, transcription and translation systems for the semiotic preservation and application of W3 knowledge (without considering the earlier role of ensemble replication in the inheritance of W2 knowledge). As discussed by Kauffman (1993), presently living things' knowledge of their problems of life have been built into their DNA codes solely through the process of blind variation and death of lineages carrying code variants that failed to solve the problems they faced. As Popper argued, what is left after the failures ("errors") are eliminated will in general encode a broader, deeper and overall more effective response to the problems of life in the real world (i.e., a better understanding of the external world. Thus, the nucleic acid codes based on 3-base codons to specify a single amino acid are purely products of natural selection operating over some hundreds or thousands of billions of generations[307] of autopoietic replication, and not one of rational design.

It seems likely that nucleic acid codes first evolved in a "protein interaction world" where randomly assembled RNA polymers may have had structural and catalytic functions (Poole et al. 1998; Andras & Andras 2005; Lawrence & Bartel 2005; Guimaräes et al. 2008; Poole 2006; Benner et al. 2012). Also, unlike proteins, nucleic acid polymers can serve as templates for the assembly of other nucleic acid polymers with complimentary sequences of nucleotides (i.e., over two cycles of assembly, a sequence would serve as a template for forming the complementary sequence, that would in turn serve as the template for forming the original sequence). Under appropriate circumstances RNAs and DNAs are also able to serve as templates for forming complimetary sequences of the other molecules. Thus, nucleic acids inherently have the capacity to catalyze the formation of structurally significant macromolecules that can be shaped by natural selection into increasingly sophisticated information storage and retrieval systems as explained in any modern textbook on molecular genetics. Over a long enough time, natural selection will favor the reliable storage of nucleotide sequences (i.e., codes) in the substantially more stable and inert DNA molecules, where they can be transcribed and translated into functional RNAs and proteins as required.

Initially, there was probably a 1:1 (complimentary) correspondence between a DNA sequence and a metabolically functional ribozyme. In time an abstract code evolved (through natural selection working on variability in the sequence of nucleotides forming DNA molecules. Today, the epistemic cut between the DNA code and the metabolic and synthetic activities of living cells is profound. Aided by various "machines" constructed of proteins and functional RNA molecules:

1) Sequences of three nucleotides ("codons") strung together in a DNA strand serve as a template for the assembly of a complementary strand of RNA in a process called transcription to form what is called messenger RNA.
2) in a process called translation, messenger RNA strands are captured by nucleoprotein machine machine tool called ribosomes that capture codon specific transfer RNAs carrying particular amino acids from the intracellular medium and join the amino acids together in whatever sequence is specified by the sequence of codons forming the particular messenger RNA to form a polypeptide. Polypeptides then fold themselves with or without the assistance of other molecules into the fully functional protein (see Wikipedia on biomolecular structure).

- *Sharing knowledge in W3 at the macromolecular level across time and space*

There are a variety of means by which codified knowledge can be shared across space and time that will be discussed below where relevant. All organic life we know maintains codified (W3) knowledge in nucleic acid polymers called chromosomes. It is likely that component structures, macromolecular assemblies and pieces of such codified knowledge were shared promiscuously among recently emerged autopoietic entities in local environments. Early life would have been fragile compared to the robustly self-maintaining cellular organisms we know today. Dis-integration would have been common, scattering workable components into the environment - *including usefully coded nucleic acid sequences that would then be available for incorporation into other living entities*. Today many bacteria still share and incorporate "raw" exogenous codes into their functional genomes by processes of "transformation". In the early stages of the evolution of life, it is probable that all life shared a common pool of codified fragments of knowledge – representing the last universal common ancestor or LUCA (Hall 2006; Hall et al. 2005 – see semiotic autopoiesis in Figure 59).

Blind introduction of new control information may further stabilize, change or even add new attractor basins to stabilize autopoiesis, but much more often the new information is likely to perturb the organizational dynamics of the system that incorporates it onto a dynamic trajectory that leads to chaos and disintegration (Kauffman 1993). Thus, once functional genomes have emerged, selection will tend to favor mechanisms to block or disassemble exogenous code sequences by comparison to those that have already been tested for compatibility by survival in close relatives. Once barriers evolve to block the promiscuous exchange of codified fragments (i.e., a form of genetic isolation is achieved), different kinds of ecological specialization can also begin to evolve away from the LUCA as distinct clonal species.

The downside to genetic isolation is that genetically isolated individuals no longer easily share a wide range of experientially tested knowledge from other closely or distantly related individuals. That is, this is the point life as a whole – the last universal common ancestor begins to differentiate into separate species. Selection may then favor the evolution of strategies allowing exchange of genetic information between closely related lineages sharing many genes in common due to recent common ancestry, while keeping out unrelated information. One well documented strategy for identifying whether an exogenous piece of naked chromosome taken up from the environment might be useful is to test whether it has a sequence of code close to one in the host cell (i.e., because it came originally from a related individual). In this case, some or all of the exogenous DNA may be spliced into the cell's chromosome, replacing the more or less matching existing segment (note: this DNA splicing still forms the basis for all genetic recombination today, including the swapping of chromosome segments that takes place in eukaryote meiosis). A second, more sophisticated strategy, would be to package or wrap the encoded fragment in the same kind of material that members of the clone use to separate their autopoietic interior from the external environment. Presumably this genetic package would then be recognized as belonging to a self sharing a common ancestry, and thus be safe to assimilate. In some cases packaged codes have evolved to replicate themselves as bacteriophages or viruses at the expense of the cells that absorb them. Where functional host cell genes are transferred as part of viruses genetic payload without killing the recipient cells, this is known as transduction. Conjugation is a still more sophisticated process involving physical contact of cells presumably allowing the recipient to chemically identify the donor as being “conspecific” before gene transfer is consummated. Cohan (2002) and Cavalier-Smith (2002; 2010) review the means by which bacteria exchange genetically encoded knowledge and the evolutionary significance of such exchanges. Given the exponential reproductive potential of prokaryote clones, the additional evolutionary potential offered by horizontal gene transfer (Treangen & Rocha 2011) perhaps compensates for the more probable disruptive potential of untested genes.

- *Mixing W3 knowledge from different parents*

Once barriers evolve to cut off the survivors of a lineage from the promiscuous exchange of codified control information, different kinds of trophic specialization can begin to evolve as distinct clonal species. Hall (1966)[308] discusses some likely circumstances and selection pressures leading to the differentiation of prokaryotic and eukaryotic organisms as distinct types of trophic specialization[309] emerge from the era when life was physically or genetically promiscuous[308]. Several of these circumstances are recognized by Cavalier-Smith (2009) and O’Malley et al. (2013). Exactly how eukaryotic and prokaryotic organisms are related is still unclear (Gribaldo et al. 2010). However, possibly to compensate for the loss of horizontal gene transfer as a potential source of evolutionary variability, the complex and highly controlled process of meiosis that we see in multicellular organisms today evolved. This causes the recombination and random assortment of DNA organized into chromosomes to produce gametes that then fuse to produce zygotes. This is contrasted with mitosis, the normal means of cellular replication whereby a parent cell replicates its DNA and divides in a process that guarantees each daughter cell receives an exact copy of the parent cell’s DNA (excluding rare mutational errors).

Meiosis involves one replication of the chromosomes in a cell, followed by two cell divisions, as illustrated in Figure 61. This may have evolved from the process of transformation in prokaryotic ancestors of the cytoplasmic component of eukaryotic cells involving DNA repair enzymes and processes (Cavalier-Smith 2002; Wilkins & Holliday 2009; Bernstein & Bernstein 2010; 2013). Prokaryote transformation involves the lengthwise pairing and crossing over of complimentary strands of DNA (the host cell chromosome, and a usually short strand absorbed through the cell membrane from the external environment that presumably originated in another cell that was ruptured or disintegrated) mediated by DNA repair enzymes that exchanges stretches of DNA between the two strands. The requirement for lengthwise pairing of nearly identical DNA sequences effectively ensures that crossing over only takes place between homologous parts of similar DNA strands that that are unlikely to contain disruptive genetic information.

In prokaryotes it is comparatively easy for foreign DNA to cross the cell membrane to reach the cell's chromosome where recombination may take place. In eukaryote cells the chromosomes are separated from the rest of the cellular cytoplasm by a separate nuclear membrane within the cell that largely prevents foreign DNA entering the cytoplasm from getting close to the cell's own chromosomes. This double separation of the cell's explicit knowledge as expressed in its own DNA from DNA fragments in the external environment provided the opportunity to evolve much more sophisticated mechanisms of "premating / prezygotic isolation" to avoid exchanging genetic material with unrelated lineages that is likely to be disruptive.

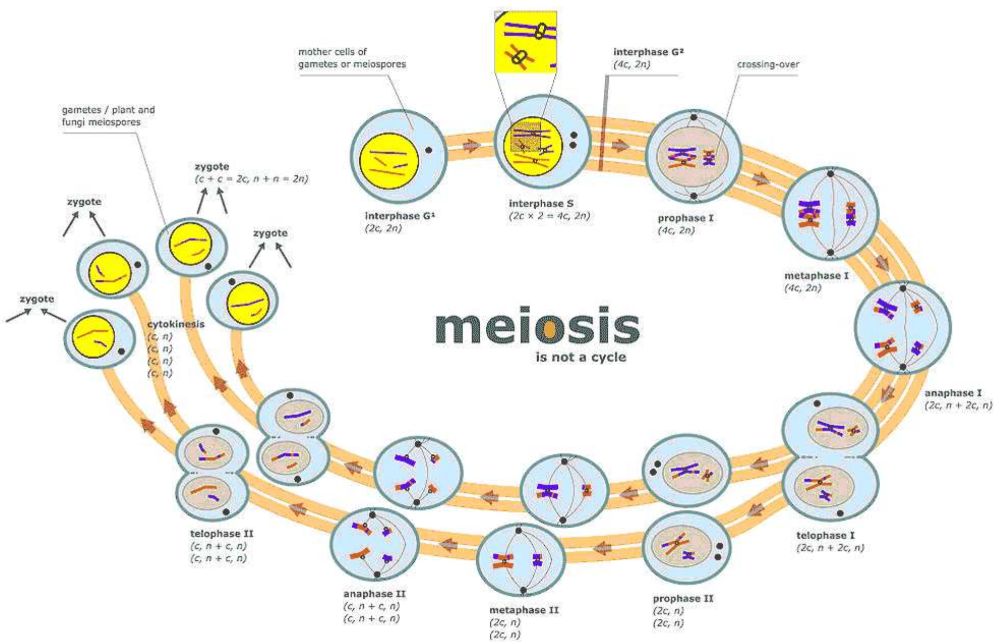


Figure 61. Meiosis in eukaryotic organisms (click to enlarge - Wikipedia/Marek Kultys - licensed under the Creative Commons Attribution-Share Alike 3.0). McGraw-Hill shows an animation of the process of chromosome pairing and segregation (this does not show the actual process of crossing over).

Cellular reproduction by mitosis replicates with great precision existing genotypes that have proven to be successful in an existing environment. In single-celled (protozoan) eukaryotes with high reproductive rates involving the mitotic cell division in benign environments, meiosis is not associated with reproduction per se, but rather is often a response triggered by cellular stress under adverse conditions when genetic innovations may allow representatives of the lineage to survive, where a relatively invariant genotype reproduced by mitosis would not.

Meiosis begins with a single diploid cell, involving one chromosome replication in the preceeding interphase, followed by two cell divisions and no further chromosome replication to produce four haploid cells, each with a single chromatid of each type. These cells are called gametes. In multicellular organisms with two distinct sexes, in the female, one of the haploid cells grows larger to form an egg, while the three remaining cells degenerate; while in the male, all four cells mature to become sperm cells.

The process of genetic mixing concludes with the union of two haploid gametes (e.g., an egg and a sperm in multicellular organisms) to form a single diploid zygote that will develop into an individual with a combination of different parts of chromosomes inherited from both parents. Since crossing over takes place more or less randomly along the lengths of homologous chromosomes, it is highly unlikely that any two of individuals in a sexually reproducing species will have exactly the same genetic composition.

In other words, the process of sexual reproduction insures that there is a constant source of variations in the *recombination* of tested hereditary knowledge encoded in DNA to the development of new individuals in a species. Over several to many generations, sequences of DNA produced by recombination that work well together both in overall development and in solving problems in the lives of individuals carrying those sequences will be favored by comparision to those that fail to help the individuals carring them to answer their problems of life. Thus, the knowledge encoded in DNA behaves as Popperian explicit knowledge.

- *Culture: the social sharing knowledge at a higher level of organization*

Culture can be defined as patterns of behavor and knowledge shared by a population of individuals that depends on capacities for learning and transmitting knowledge between individuals and from individuals of one generation to the next. This is contrasted to the genetic transmission and inheritance of knowledge in the form of instincts and innate behavioral propensities. The development of culture in this sense depends on fairly high degree of cognitive capacity, beyond the development of a genetically programmed behavior, involving individual abilities to observe, orient, decide and act (see Figure 8, Figure 62). Thus, cultural transmission builds a heritable body of adaptive knowledge that is held at a level of organization above that of the molecular and structural oranization of living individuals, i.e., at a level of "social" organization. As discussed earlier in the section, Technological and Conceptual Revolutions in Human Affairs and later in Episode 5, the increasingly technological capacity to socially share and transmit cultural knowledge has enabled exponential growth in human knowledge and our ecological dominance of the world.

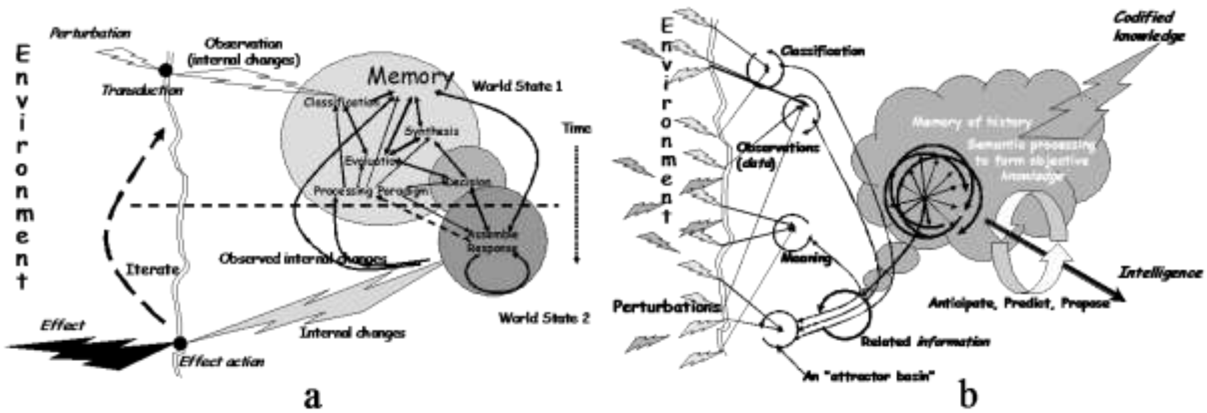


Figure 62. Two depictions of the operation of an OODA cycle within autopoietic systems (after Hall et al. 2005). The double line represents the boundary between the environment on the left and the autopoietic system on the right. Panel a shows the sequence of dynamic effects as a perturbation from the world is transduced into disturbances that propagate through the entity and how sense is made of it in relationship to what the entity already knows, to synthesize one or more possible responses, and to select and apply one of these responses as internal changes that effect an action on the world. Panel b shows a somewhat more detailed depiction of the specifically cognitive aspects of observation and orientation in the OODA cycle involving many simultaneous perturbations (e.g., many photons falling on a retina) and the way these are classified and processed to give meaning. Note: Click figure to see a PowerPoint animation of a and b. Close PowerPoint to return to here.

The cultural transmission and sharing of knowledge provides a multitude of opportunities for consciously mixing threads of knowledge from the widest possible variety of sources and the knowledge can be applied either at the individual level or within familial or socially integrated groups of individuals. Compared to the mechanisms for the mixing of knowledge at the genetic level, the successes of particular mixes of genes are only tested by their after-the-fact survival. The carriers of bad mixes (i.e., errors) are selectively eliminated. At least in humans, it is possible to consciously evaluate different knowledge threads and their compatibilities before they are mixed, and to further evaluate mixes before they are actually applied, thus avoiding the "genetic load" of bad combinations.

As for autopoietic individuals, at the level of groups of individuals, two domains of socially shared knowledge can be distinguished. As will be seen, these domains correspond to Popper's worlds 2 and 3.

- Transferring tacit knowledge (W2) via copying, teaching, learning and apprenticeship

Jablonka and Lamb (2005, 2007) argue that in at least the more "intelligent" organisms (e.g., some primates) knowledge can be passed down through generations via cultural transmission. Where individuals live in social groups, there is the opportunity for some individuals to learn from others by observing what they do. This learning from observing other members of one's social group is particularly evident in some kinds of primates (e.g., rhesus and capuchin monkeys – Ottoni et al. 2005; Mannu & Ottoni 2009[35]), and particularly in our closest relatives, the chimpanzees (including bonobo), gorillas, and orangutans (Whiten 2010). With the sole exception of orangutans, our close relatives in the primates all live in extended social groups; and even young organgutans live for several years with their mothers (Price et al. 2009; Whiten 2000, 2010; Whiten et al. 1999, 2009; Haslam et al. 2009). The social involvement of young members of the group closely observing adult practitioners provides an ideal environment for the social transmission of tacit (i.e., W2) knowledge from one generation to the next (Perry 2006, 2011).

- Storing and sharing explicit knowledge (W3) via writing, printing and communication

As demonstrated in the first four Episodes of this book humans have developed a vast array of tools for the recording, preservation, locating and sharing the body of knowledge developed by human culture. Although collecting and transforming this knowledge from people's heads into explicit forms involves genetically determined capabilities of human cognition, the resulting body of knowledge is now vastly larger than that held in the human genome and is growing exponentially at ever increasing rates as our cognitive technologies become ever more powerful, even to the extent of being able to read the content of single DNA strands to sequence a complete human genome in a few hours (see Oxford Nanopore Technology's "nanopore" systems). Within a very few years we will have the ability to edit and feed back this explicit information into the human genome to use this external heredity consciously control the evolution of the human genome into the future.

Theory of Hierarchically Complex Dynamic Systems and Higher Orders of Autopoiesis

The last element in this Interlude is to show how the concepts of dynamics, autopoiesis and hierarchical complexity apply to higher level organizational entities and to show that they are autopoietic entities in their own rights with their own forms of cognition and knowledge. To this point I have discussed knowledge, cognitive technologies and autopoiesis primarily in the context of "individual" autopoietic entities. These entities have been considered to be "complex", at least in terms of the fact that living individuals are comprised components such as cells that interact in chaotic ways (i.e., where a small stimulus can elicit a large response). However, despite comple/chaotic behavior, the interactions among the components are such that the dynamics of the system normally persists within attractor basins in state space where autopoiesis is maintained. Following Hall (2011), I now want to explore the concept of complexity in more detail.

Hierarchy theory

The modern theory of hierarchically complex systems was established by the Nobel laureate, Herbert Simon (1962, 1973, 2002; Simon & Ando 1961) and has been substantially elaborated from biological points of view by James Grier Miller (1978) and Stanley Salthe (1985, 1993). Following Simon (1962: p. 468): "[A] hierarchic[311] system… [is] composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem".

Even at the macromolecular/cellular level of structural evolution it is likely that early autopoietic systems showed some level of hierarchically modular organization that may have affected the ease with which they subsequently evolved. Complicated/complex systems can be assembled and evolve faster in response to external conditions if they are modular. Simon (1962), demonstrates this using the parable of the watchmakers Hora and Tempus. Both assemble watches containing on the order of 1,000 parts each. Hora assembled his watches piece by piece, that fell apart if the work was interrupted. Tempus assembled his parts into stable low level modules of about 10 parts each, that were in turn assembled into higher level subassemblies that were also stable, each containing about 10 modules from which the watch as a whole was assembled. If this assembly process was interrupted at any point, only a small amount of work would be lost. Simon shows that if the probability of either watchmaker being interrupted while adding a single part is .01, it will take Hora approximately 4,000 times as long to complete a watch as it does Tempus. Hora fails in business, while Tempus is very successful, something that has very clear implications for the evolution of biological systems.

Simon goes on to argue that this process is not teleological, direction is provided purely by natural selection favoring more stable components over less stable ones, and that hierarchically complex systems will be able to evolve much more rapidly than systems with "flatter" structures (Simon 1962, 2002).

Simon's analysis of hierarchically complex systems is based on the concept of "near decomposability" of composite systems, as defined by Simon & Ando (1961) and Simon (1962), near decomposability concentrated mainly on the hierarchical structure of the complex system:

> [C]omposite systems, [are] constructed by the superposition of: (1) terms representing interactions of the variables within each subsystem; and (2) terms representing interactions among the sub- systems. …[O]ver a relatively short period, the first group of terms dominates the behavior of the system, and hence each subsystem can be studied (approximately) independently of other subsystems. Over a relatively long period of time, on the other hand, the second group of terms dominates the behavior of the system, and the whole system moves, keeping the state of equilibrium within each subsystem-i.e., the variables within each subsystem move roughly proportionately. Hence, the variables within each subsystem can be aggregated into indexes representing the subsystem. Thus, the system of variables in the case just described can be represented as a two-level hierarchy, with the aggregative variables at the higher level [and] there is no reason why we need to restrict ourselves to a two-level hierarchy. (Simon & Ando 1961: p. 132)

In other words, even though sub-systems are themselves complex entities, because their internal activities resolve so rapidly by comparison to the higher level system they compose, the details of these internal interactions can be largely ignored by comparison to the interactions of subsystems with one another within the system (i.e., from the higher level view, subsystems interact with one-another in law-like ways as simple entities or 'particles'). Looking at what this means in another way, the system has an identity is essentially independent of the individual identities of the subsystems that compose it.

Simon (1973) focused on the "horizontal" interactions of components at a level of organization and noted that subsystems could be discriminated by the fact that the internal components of a subsystem interact much more frequently/rapidly with one another than they do with components of other subsystems at the same level – i.e., they exhibit "loose horizontal coupling" (Simon 1973: p. 15 et seq.) and where a system may be composed of a comparatively small variety of subsystems, where each variety is represented by many functionally equivalent subsystems (e.g., human bodies are built from only a few hundred different kinds of living cells). Simon suggests that adaptive evolutionary changes may take place independently in any one of these without requiring changes to other subsystems.

Simon's (1962) theory showed how in analyzing organizations and living entities it was easy to distinguish wholes and parts. However, Arthur Koestler (1967, 1978) noted that an entity in such a hierarchy acts as a self-contained whole to its component parts, but at the same time is a dependent component of a higher level entity, such that an entity can never be completely isolated from its network of hierarchical relationships. Koestler introduced the term "***holon***" for a component in a hierarchical system, and described it in terms of the "Janus" effect after the two-faced god, with one face always turned towards the higher level "master" system in which the holon is a component, and the other face always turned towards the lower level "subordinate" systems, i.e., a holon is a system that is at the same time a part in a higher level whole, and a whole for lower level parts. A "*holarchy*" as a hierarchy of holons functioning (a) as semi-autonomous wholes controlling their parts, (b) as dependent parts controlled by a higher level, and (c) in co-ordination with their local environment. As will be seen, qualification (c) confuses the issue.

Stanley Salthe (1985, 1993) further extended Simon and Koestler's ideas from subatomic particles to the Universe, and introduced the particularly useful idea of the "*focal level*" (Figure 63): "That level of a hierarchical system which is being examined or considered by an outside observer" (Salthe 1985: p. 290). Salthe considered that for holonic systems that change through time, most upward or downward causes could mapped from the next higher level system (acting as an environment) or from the next lower level systems that determine what is possible for the holon to do.

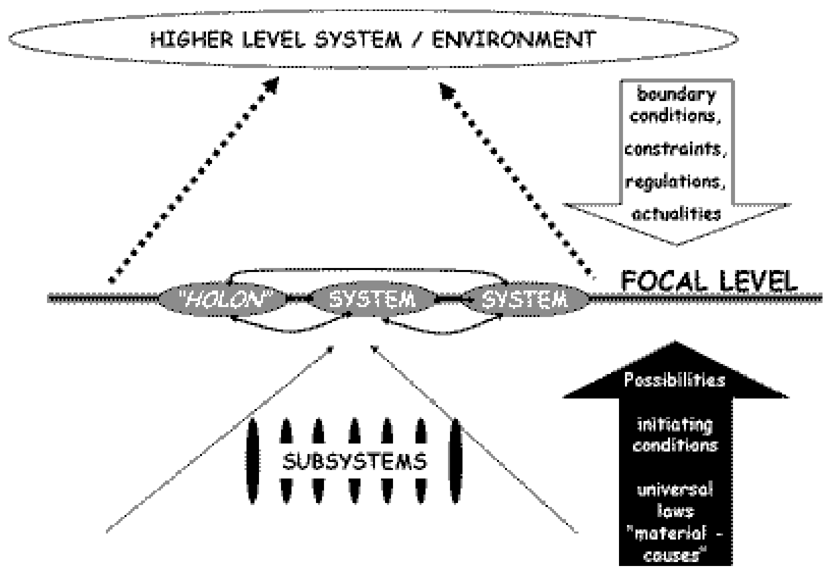


Figure 63. The systems triad in hierarchy of complex dynamic systems (Hall et al. 2005 after Salthe 1985).

A "*holon*" at the "*focal level*" of complexity (i.e., the level of interest in the hierarchy) is the dynamic system on which we focus our analysis. Lower-level components or subsystems forming the holon determine what the holon is and what it can do. Component/subsystem capabilities are described by "universal" laws that are independent of the circumstances of any particular holon they may participate in forming. The higher level supersystem or environment contains the holon as a component. What the holon actually does in this environment is a consequence of the adjacent possibilities resulting from its own past history and being, as shaped by boundary conditions and constraints imposed by the higher level (see The spontaneous emergence of autopoiesis and knowledge, above).

Levels of organization

The next step is to consider the hierarchical structure of the world we live in and our places in it as observers. Working upward from the bottom, quarks are the smallest objects we think we know exists. Quarks interact together primarily via strong nuclear force to compose (i.e., form) subatomic particles such as protons, neutrons, electrons, photons, neutrinos and a zoo of other short-lived particles, etc. that we can detect directly in the debris created by atom smashers. Stable atoms are formed from the dynamic interactions of protons, neutrons and electrons via electromagnetic and weak nuclear forces. Atoms interact electromagnetically to form molecules or crystalline solids such as salt. In many cases the objects at the subatomic, atomic and molecular levels are well defined and readily distinguished using appropriate tools. Atoms and molecules aggregate to form a complex hierarchy solid objects, (i.e., condensed matter) in the universe, where gravitational forces begin to play a dominant role at higher levels of organization.

The planet Earth we live on is condensed matter held together gravitationally that exhibits an extremely complex and dynamic hierarchical structure. From the human point of view a number of levels of complex organization can be recognized. Some levels have been defined for human convenience. Others represent more fundamental discontinuities between objectively bounded subsystems and the higher level systems they comprise.

Molecules aggregate to form chemically bound polymers and macromolecules, that, in turn may aggregate via electrostatic forces to for tertiary and quaternary molecular structures to form functional subunits in living cells.

Combinations of macromolecular functional units providing a pathway and mechanisms for the dissipation of potential energy may form "*first order*" autopoietic cells at the prokaryotic level of organization, where individual cells live autonomously in their own rights. Autonomous eukaryotic cells have more complex structures apparently derived evolutionarily from symbiotic associations of different kinds of prokaryotic cells functioning as membrane bound subsysgtems ("organelles") like chloroplasts and mitochondria in the larger cellular system (see Hall 1966). However, such organelles have been fully subsumed within the larger system such that most of their genetic heritage has been merged with that of the larger eukaryotic cellular system. The organellar level of organization still exists in a structural sense, but the organelles can no longer be considered to be autonomous entities in their own rights.

Multicellular organisms represent a "*second order*" of autonomous autopoietic systems. In most cases single cells may be isolated from the multicellular organism and will continue to grow and multiply if placed in the environment of a comparatively simple culture medium, demonstrating the continuing autopoiesis of the component cells forming the multicellular individual. Biologists define three levels of structural organization between single cells and the autonomous organism: tissues comprised of organized assemblages of cells; organs comprised of organized assemblages of tissues, and organ systems comprised of organs working together to carry out a primary function for the organism. However, none of these are capable of independent functioning outside the overall structure of the living organism. Thus, although we discuss systems at tissue, organ, and organ system levels, none of these human designated systems are living systems in their own rights.

Humans exist at the organismic level of organization, and this represents our natural level of focus. It is relatively easy to see subsystems below our level using analytical tools such as dissection instruments and various kinds of microscopes and where we can clearly see the physical boundaries separating various subsystems at the same level of organization. It is much more difficult to comprehend systems that exist at higher levels of focus – especially when individuals such as ourselves may function as subunits in the larger structure. Entities at a higher level ("*third order autopoiesis*") of biological organization to be discussed below that may be considered to be autopoietic in their own rights (see following) include colonial organisms such as siphonophores (Portuguese man o' war); hard and soft corals formed of networked polyps; biological/evolutionary species comprised of individuals sharing a common gene pool; colonies of "social insects" such as ants, termites and bees that exist as superorganisms; biological or "evolutionary" species; and - most importantly for this discussion - human social/economic organizations.

Still higher levels of organized structure on the planet Earth can be discriminated along two different axes: one of biological organization and the other of human socioeconomic organization. Successively higher levels of organization along the biological axis above evolutionary species are ecological communities of coadapted biological species, complete ecosystems, and Gaia – comprising all living things that interact to form a single, self-regulating complex system that self-maintains the conditions for life on Earth. Successively higher levels on the socioeconomic axis include industry clusters (see Hall 2006b, Hall & Nousala 2007), cities/urban zones, nation states, and the world economy.

Going upwards from our planet, still higher levels of systemic organization driven by the direct dissipation of gravitational (and nuclear) energy include solar systems, galaxies, galaxy clusters, galaxy super-clusters, the universe as a whole, and (possibly) a multiverse of many parallel universes.

Two views of the hierarchical structure of living systems

Two workers have contributed to the theory of hierarchically complex *living systems* – especially with regard to social systems: James Grier Miller, with his "living systems" theory and Stafford Beer, with his "viable systems model". Neither authors' works have been as influential as Maturana and Varela's work on autopoiesis, but they are relevant here because Miller and Beer were both attempting build a generic understanding of life from similar starting points in the cybernetics movement to Maturana and Varelas'. Schwaninger (2006) and Nechansky (2010) review and compare the two models. Schwaninger notes that until his analysis, there had been little cross-referencing between these two authors' schools. Beyond, this, I have found virtually no cross references between them and organsmic biologists, or those concerned with autopoiesis. Nevertheless, Miller and Beer's works demonstrate the kind of hierarchical considerations I will apply to autopoiesis.

- *James Grier Miller's theory of "living systems"*

Miller, trained as a psychologist, began his major writing on hierarchically complex living systems in (1955). This was followed up in (1971) by a major paper in Currents of Modern Biology covering cells, organs and organisms, and beginning in 1971 by a series of papers in the journal Behavioral Science covering groups, organizations, society and supranational systems; a massive book (1978), and again in a brief summary with his wife (1990) under the conceptual title "Living Systems". Miller's intellectual sources at this time were in the cybernetics camp: von Foerster, Bertalanffy, Ashby, von Neumann and

Shannon. In his 1978 book, Miller collected his ideas together and expanded them incorporating Simon's ideas regarding hierarchically complex systems. Miller recognizes 7 levels of "living" organization: *cells, organs, organisms, groups, organizations, societies and supranational systems*; and defines 19 or 20 (Miller & Miller 1990) critical sub-systems necessary for viability that can be identified at each of the 7 levels of organization. These critical subsystems are grouped into systems that process both matter-energy and information (i.e., "reproducer" and "boundary"), those that process matter-energy only (i.e. *ingestor*, *distributor*, *converter*, *producer*, *matter-energy storage*, *extruder*, *motor*, *supporter*), and those that process information only (i.e., *input transducer*, *internal transducer*, *channel and net*, *decoder*, *associator*, *memory*, *decider*, *encoder*, *output transducer*).

Miller 1978: p. 18 defines living systems at each of the seven levels or organization as those that have the following properties, either within the system itself or that the system has parasitized or "borrowed" from a host or symbiotic system:

- Open to matter and energy,
- Maintain a relative state of negentropy by taking in high energy foods and fuels and excreting lower energy waste,
- More than a certain minimum degree of complexity
- Largely composed of an aqueous suspension of macromolecules
- They have a "decider" (i.e., a system controlling the way subsystems and components interact
- They have certain critical subsystems as listed above or have a parasitic or symbiotic relationship with other entities that provide the functions of these subsystems
- Their subsystems are integrated together to form actively self-regulating, developing, unitary systems with purposes and goals (cf. definition of autopoiesis)
- They can exist only in a suitable environment that satisfies their needs.

In several senses, Miller's definition of life paralleled that developed by Maturana and Varela, but without the concept that the living system must be autonomous, and with the added understanding that entities at several hierarchical levels of organizations could be considered living. However, Miller's ideas were too complex and his 19 subsystems did not readily describe many real-world situations, and thus, his ideas have rarely been cited in the biological literature.

- *Stafford Beer's theory of "viable systems"*

By contrast to Miller's background in psychiatry, Stafford Beer was from the beginning primarily a cybernetician. As a founder of the Operations Research Society, he was primarily interested in management control systems. When he was designing control systems for the Chilean national government under Salvador Allende he knew Humberto Maturana, and wrote the Preface to Maturana & Varela (1973) – Beer (1973). Beer (1981) and Medina (2006) detail the history of his Chilean involvement, which might be called a grand failure of Beer's attempt to implement his ideas at a national level.

According to Beer (1979, 1981, 1984, 1985), there are five necessary and sufficient interactive subsystems that must be involved in a person or asocial system at any level of organization involving people for it to be considered to be viable:

- System 1 – the operating units or elements required to "produce" the organization ("i.e., the

system's autopoietic generators, to use Maturana's terminology".
- System 2 – the self-regulatory apparatus amplifying lower level regulation, attenuating dynamic oscillations, and coordinating activities of operating units via information and communication.
- System 3 – the guidance apparatus providing synergies, allocating resources and optimizing performance of the operating elements. Also includes an audit function to investigate and validate information flows between the operating units and systems 2 and 3.
- System 4 – the planning and innovation function.
- System 5 – the goals and values setting function.

Similarly to Miller, Beer also claimed that viable systems are "recursive", such "that every viable system contains and is contained in a viable system" (Beer 1984: p. 8) to form hierarchical organizations of several layers down to the individual humans comprising them. However, despite Beer's connections with Maturana, his system seems to me to be excessively theoretical and lacks connections with the real world.

Where Beer was given more-or-less free rein to design and build a national economic management system in Chile, he was defeated by central planners' limits to rationality (Simon 1947, 1955, 1979; Else 2004; Hall et al., 2007, 2009, 2011) and people's natural tendencies to resist central planning. Between chaotic non-linearities in the command and control system due to substantial time lags between observation, decision and action, and outright economic stabotage from internal and external sources, the whole governmental system failed catastrophically, ending with Salvador Allende's death in the 1973 coup d'etat.

Simon, Salthe and Miller all assume that the living system is perceived and discriminated by an observer. Maturana and Varela and Miller recognize the importance of boundaries in system self-maintenance. Some levels of organization, e.g., macromolecules, organs, organ systems, are distinguished by an observer for his/her own convenience. Others, e.g., living cells, and as I will argue below, multicellular organisms, human organizations, etc., are self-distinguished by the autopoiesis and interactions of living entities on that level of organization.

Emergence of new levels of living organization in the complex hierarchy of living things.

Dissipative dynamic processes involved in transporting fluxes of energy selectively favor the emergence of increasingly ordered cyclical structures or systems such that it is likely that chemical systems involved in the transport will be driven to states of increasing complexity resembling metabolism (Prigogine 1955, 1977; Morowitz 1968; Kay 1984, 2000; Schneider & Kay 1994, 1995; Kauffman 1993, 1996; Chaisson 2001; Corning 2002, 2002a; Salthe 2004; Sharma & Annila 2007; Annila 2010, 2010a; Annila & Annila 2008; Annila & Salthe 2010). Selection will favor dissipative systems that are stabilized by feedback regulation. Morowitz (1968: p. 120) said, "The existence of cycles implies that feedback must be operative in the system. Therefore, the general notions of control theory [cybernetics] and the general properties of servo networks must be characteristic of biological systems at the most fundamental level of operation".

Salthe (2004), Annila & Kuismanen (2009), Annila & Salthe (2009) argue that new dissipative systems can emerge within an existing complex hierarchy where a system at an intermediate level between a system and its component subsystems can increase the overall dissipation of energy flowing from source to sink in the space between existing levels to form a new focal level. In other words, in competitions entities that are able to dissipate more energy than others will have a greater capacity to achieve strategic power over limiting resources.

The main types of autopoietic entities we have considered to this point are single-celled organisms (prokaryotes and eukaryotes) forming the "first order". A "higher order" autopoietic system is one that meets all six criteria to be considered autopoietic at its own level of focus, that is comprised of subsystems at a lower level of organization, that also individually meet all of the criteria to be considered autopoietic. Following Salthe, Annila & Kusimanen, and Annila and Salthe (cited above), selection will favor the evolutionary emergence of such higher level systems (1) where the more complex system achieves greater strategic power over limiting resources due to a greater dissipative capacity to maximize its entropy production and (2) where there is an easy pathway (i.e., one where a series of mutations can provide incremental improvements able to be selected) from a lower-order structure to a higher one able to develop its own system of heredity at the higher level.

Second Order Autopoiesis: Multicellular Organisms

Multicellular organisms are certainly living, but are they autopoietic and do they represent a higher order of autopoiesis than single cells?

Following Hall (2006), to briefly summarize an argument that will be developed in more detail elsewhere, multicellular organisms represent a second order of autopoiesis.

1. Many, if not all of the cells comprising a multicellular organism are themselves autopoietic, as can readily be proven by isolating single cells into appropriate culture media that provides them with the necessary inputs for their metabolisms, where they will continue living, and in many cases even continue growing and dividing.
2. When the focus of analysis is set at the level of the multicellular organism, individual cells are the component subsystems and the environment external to the organism's integument is the external environment or supersystem. The following complex system dynamics can be observed at the multicellular level, fulfilling the requirements for the system to be considered to be autopoietic:

Bounded ("the unity [entity] has identifiable boundaries"): demarcated from the environment by membranes, or the entity's components are identifiably tagged. In most cases there is a visible epidermis, cuticle, or other self-produced boundary composed of or manufactured by cells working together under the embodiment of a common developmental program.

Complex ("there are constitutive elements of the unity, that is, components"): Composed of individually discrete cells. Even for some of the minor phyla where all or part of the adult is formed of a multinucleate cytoplasmic syncytium, the embryonic development of the organism is based on the multiplication and differentiation of cells before the internal cell membranes are absorbed.

Mechanistic ("the component properties are capable of satisfying certain relations that determine in the unity the interactions and transformations of these components") i.e., a system driven by cybernetically regulated exergy fluxes or metabolic processes: Activities of the multicellular entity are driven by molecular metabolism as controlled by the dissipatively dynamic activities of a cellular neuro-endocrine system coordinating cells in the operation of musculoskeletal system, and the distribution of metabolically essential molecules.

Self-referential or self-differentiated ("the components that constitute the boundaries of the unity constitute these boundaries through preferential neighborhood relations and interactions between themselves, as determined by their properties in the space of their interactions"): See part a. above. The system boundaries are developmentally organized under direction of embryonic developmental processes regulated by the entity's hereditary knowledge.

Self-producing ("the boundaries of the unity are produced by the interactions of the components of the unity, either by transformations of previously produced components, or by transformations and/or coupling of non-component elements that enter the unity through its boundaries"): See previous answer.

Autonomous ("all the other components of the unity are also produced by interactions of its components as in [the statement above], and … those which are not produced by the interactions of other components participate as necessary permanent constitutive components in the production of other components"): All cells in the organism come from the division, growth and differentiation of preexisting cells formed within the developmental framework of the organism. The only counter argument is that most multicellular organisms trace their existence to a single fertilized egg cell, although in some cases there are asexual means of reproduction that involve various kinds of fissioning or budding of multicellular offspring from the multicellular parent.

3. 'Lower' multicellular organisms carry W3 knowledge in their DNA chromosomes that is devoted to regulating the intercellular dynamic interactions of cells with other cells in the organism - and is thus an evolved product of the organismic level of complexity. The fact that each cell has its own set of chromosomal DNA is mitigated by fact that in the normal situation all cells in the organism trace their ancestry to the fertilized egg and thus are all so to speak working from the same codebook. The W2 knowledge embodied in the fertilized egg or other propagule provides the necessary structural framework and know-how to transcribe and translate the DNA code into embodied structure.
4. 'Higher' multicellular organisms have well developed cognitive capacities for selective learning, which in a very few cases is supplemented by a capacity for extrasomatic transmission of 'cultural' knowledge from parent to offspring that exists as further evidence for a level of coordinating knowledge that is only relevant to the organizational level. Such transmission is mediated by pheromones, imitation, and eventually language and the products of language.

Higher order autopoietic systems appear to emerge and evolve as new levels in the hierarchy between single-celled organismic systems and the higher level supersystem of the environmental ecosystem where there are opportunities to maximize entropy production. Even among today's living organisms there are examples demonstrating that there are "easy" steps from single cells, through colonies of cells to primitive "second order" – multicellular organisms. Examples can be found in both plants and animals, e.g., in the volvocine green algae (e.g., Nishii & Miller 2010, Hallmann 2011) showing lineages ranging from free-living single cells, cells living in colonies, and more complex cellularly differentiated organisms in Volvox, and on the animal side, the choanoflagelates including lineages of free-living single cells, through colonial forms that have been shown shown to be genetically related to multicellular sponges (e.g., Philippe et al. 2009).

Third Order Autopoiesis: Colonies and Societies

- *"Colonial" organisms*

Several groups of animals have evolved colonial forms of structural organization. These include lineages that alternate sexual and asexual reproduction or that have facultative or obligatory modes of asexual reproduction. These colonial organisms are found in lineages where the ancestral body plan is that of a sessile polyp or zooid that reproduces by budding, where the new polyps remain connected to form some kind of super-organism. Where all the polyps or zooids are of the same type these are really no more than a collection of genetically identical entities that happen to remain connected for the exchange of nutrients and perhaps warning signals via a nerve net or chemicals circulating through the intercellular medium. However, there are also a number of cases, such as Portuguese Man o` War, sea pansies, various kinds of bryozoa (ectprocts) and colonial tunicates (sea squirts) where polyps become developmentally specialized to perform quite different tasks for the overall colonial structure, e.g., defense, food capture, digestion, and reproduction. As noted by Wilson (1975), the polyps develop sequentially from a single larva. In one sense, this might be a similar situation to what led to segmental development in a variety of different animal groups. Again, all share in the common genome due to asexual reproduction, but boundaries between the individual polyps may become quite indeterminate as far as the overall colonial organism is concerned. Here, I am inclined to treat this as a developmental process of a single organism, and thus not representing a significantly higher level of complexity.

Wilson (1975) lists the following advantages deriving from the colonial type of organization in marine organisms:

- Resistance to physical stress for shallow water forms where organisms are subject to wave action and sedimentation. The colonial form raises individuals away from the bottom and enables them to create more effective feeding currents overall.
- Liberation of otherwise sessile forms for a free-swimming, pelagic existence. This has been achieved by some kinds of polypoid coelenterates and urochordates (sea squirts).
- Superior colonizing and competitive abilities.
- Defense against predators.

However, setting the level of analysis to that of the colony does not yield a clear result. Although the colony as a whole is clearly living and thus autopoietic, and in the complex cases polyps or zooids clearly have modes of life that differ from the founding individual, given the lack of identifiable physical or genetic individuality of the constituent polyps (i.e., distinct boundaries), it is arguable as to whether such colonial organisms should be considered to be a higher order of autopoiesis different from that of a common multicellular organism.

The plant world offers similar situations to the colonial animals that simply form many polyps or zooids of the same type. Where plant examples become more problematic is with the formation of alliances and complex symbioses, such as the fungal rhyzosphere forming in conjunction with some trees that allow the collective organism to survive and compete in areas where species involved in the association could not persist on their own. However, the interesting interactions occur in the soil where they are essentially invisible to science. Consequently, we know too little about the dynamics of such associations to analyze them in any detail.

- Social organisms - the evolution of 'social homeostasis'

The autopoiesis of social organisms such hymenoptera (ants, bees, and wasps), termites, and possibly even naked mole-rats, is more easily analyzed. In this case the colony in the hive, anthill or termite mound establishes the level of focus. In the eusocial hymenoptera (ants and bees) a fertilized diploid queen carrying a lifetime supply of sperm founds a colony, and begins laying eggs. Fertilized eggs are diploid and develop into females; unfertilized eggs develop into haploid males. Depending on how the diploid female larvae are fed, their sexual development is suppressed and they develop into sterile workers who help to maintain and feed the growing population of the colony, or they develop into future queens. In most social bees and wasps there is only one kind of worker that carries out a range of specialized tasks as they age, whereas in some ant and termite species, larvae differentiate into a variety of morphologically different kind of workers that perform specialized jobs for the colony.

Colonial honeybees reproduces in three ways (Wilson 1971). When the colony grows to a critical size, workers begin building special enlarged cells where the larvae will be fed in ways that cause them to differentiate into new queens. A larger number of cells are set aside in which the queen lays haploid eggs that develop into male drones. Before the first of these new queens eclose from the pupal stage, the original queen is expelled from the hive by workers, and will depart with a significant fraction of the existing workers to found a new hive. The first of the new virgin queens will attempt to kill or drive other new queens from the hive. These departing queens will also take swarms of workers with them. Once a single virgin queen has the hive and remaining workers to herself she will fly out, mate with a drone, and begin adding new members to the colony. Those virgin queens that left the hive with swarms of workers also find drones to mate with and return to their swarms. However they were formed, the swarms along with a fertile queen will send scouts far and wide in attempt to find a suitable hollow in which to build a new hive.

With some variations due to their pedestrian lifestyle after mating, ants have a similar genetic system to bees (i.e., diploid females, haploid males), where the presence of an existing queen inhibits the development of fertility in other females. Fertile females (future queens) and males emerge from their pupae with wings, followed by mass departures and mating flights of the males and females. Once fertilized, the female searches for a suitable site to begin burrowing, sheds her wings and founds a new colony. As the first generation of workers take over food gathering and maintenance of the burrow system different worker castes may begin to differentiate.

In the hymenoptera, all progeny of the one fertilization event will carry genetically identical male chromosomes (because the male is haploid, all sperm carry exactly the same genes) and have 50% of the genes inherited from their mother in common. With this degree of genetic similarity there is no strong selection for individuality that would tend to prevent the evolution of cooperative behavior.

Termites are complex organisms that have formed an obligatory symbiotic relationship with a variety of flagellated protozoa that provide the enzymatic machinery necessary to digest wood. They also have a different genetic system compared to bees, where both males and females are diploid, but they have evolved similar kinds of social organization where most reproduction is carried out by a single fertile queen (accompanied by a single male consort who will periodically fertilize her), there may be several castes of workers (who may be of either sex). Other differences between termites and the social hymenoptera are that fertilization occurs only after a male and female together find an appropriate site and together begin preparing a burrow. Hymenoptera are holometabolous, which means that the larvae are helpless. Late instar termite larvae are able to help out in the nest.

When examined from a level of the colony, the more developed societies of insects summarised above certainly meet all of the criteria for an autopoietic system.

Bounded. All of the colony-building insects use pheromones to tag and identify members of their own colony, and will often fight with and attempt to kill individuals carrying the wrong tags.

Complex. All of the members of the colony are clearly autopoietic individuals in their own rights. However, individual members interact with one another to maintain the integrity of the colony against various kinds of invaders including conspecifics from other colonies.

Mechanistic. Most of the activities of the hive or society are organized and coordinated by various forms of communication between colony members such as pheromones, tactile exchanges, vibration or possibly even visual cues. These serve to recruit help for defense, repair, food gathering, escape from flooding, etc.

Self-referential or self-differentiated. The establishment and maintenance of a recognizable hive odor for the purpose of member vs. non-member is certainly a form of self-reference for the colony.

Self-producing. Special breeding females are responsible for producing all of the individuals forming a single colony.

Autonomous. Yes. Because all of the individuals forming a colony are normally the progeny of a single individual they share many genes in common as a resource of the necessary control information for maintaining the colony dynamics.

Wilson (1971) notes:

> Social insects display marked homeostasis in the regulation of their own numbers and of their nest environment. This class of steady-state regulation has been aptly termed social homeostasis... [p. 360]
>
> ...
>
> The idea of social homeostasis leads easily to the visualization of the entire insect colony as a kind of super-organism.... Wheeler [1911] saw several important qualities of the ant colony that qualified it as an organism:
>
> 1. It behaves as a unit.
> 2. It shows some idiosyncrasies in behavior, size and structure that are peculiar to the species and other idiosyncrasies that distinguish it from other colonies belonging to the same species.
> 3. It undergoes a cycle of growth and reproduction that is clearly adaptive.
> 4. It is differentiated into 'germ plasm' (queens and males) and 'soma' (workers).

Interestingly, in both the termites and hymenoptera, different species represent all stages from those that make their living as solitary individuals (i.e., with no social organization), through dominance hierarchies to fully eusocial colonies that I do not hesitate to qualify as autopoietic. In terms of their total biomass, the extraordinarily successful autopoietic insect superorganisms (ants and termites) are the terrestrially dominant life forms on Earth.

It should be noted that all of the cases of 2nd-order autopoiesis in the eusocial insects and mammals (naked mole-rats) occur in taxonomic groups showing all stages in the evolution of eusociality from the single free-living individuals, through colonies of similar individuals to the truly eusocial stage where there is substantial developmental differentiation of morphologically and behaviorally specialized castes that fully warrant treating the eusocial colony as a single super-organism.

Human economic and social organizations

Hall (2003; 2005; Hall et al. 2005) presented the argument that at least some human economic organizations are third order autopoietic entities in their own rights. The human economy is an abstraction of real energy fluxes. Individuals as components of organizations use money to purchase the food and fuel they need in order to maintain their lives, and thus measurements and observations of cash flow are a reasonable abstraction of these energy flows from source to sink as high value resources are used in the production of product and dissipated in the form of labor and distribution. Thus, complex dynamics may evolve at a level of complexity involving the economic interactions of humans.

Large economic organizations certainly meet requirements to be considered autopoietic:

Bounded. People know what organizations they belong to. For the benefit of other individuals and organizations, members are variously tagged with ID badges, bear membership cards, wear uniforms displaying the company logo, etc. Machines and equipment are registered in property registers and often also have corporate ID tags. Many organizations are physically bounded by "semi-permeable" walls with windows and gates, etc. providing pathways for exchange with the surrounding world.

Complex. Organization members are individually unique, recognize one another as members, and are identified as such within the organization; also machines, property, bank accounts, etc. are identified with tags, catalogued in property registers, etc.

Mechanistic. Individuals receive rewards and benefits to belong, and are involved in processes, routines, procedures etc. that the organization conducts to ensure its survival.

Self-referential or self-differentiated. Rules of association, voluntary allegiance to organizational goals, etc. determined within the organization itself determine what people and property, etc. belong to the organization.

Self-producing. Members are recruited from the environment, inducted, trained, monitored, and managed, etc. Other property and assets are procured and variously integrated into the overall functioning of the organization.

Autonomous. Most organizations outlive the association of particular individuals, and are readily able to hire, induct and train new individuals to replace other people as they retire or leave the organization; and buy or build new plant and equipment as older components wear out and are discarded.

As in the social insects, human economic human economic organizations show all stages in the emergence of an autopoietic level of complexity ranging from single entrepreneurs, through family groups, despotically controlled groups, through to the full panoply of large organizations. Greiner (1998) reviews some of the structural changes organizations pass through, as they become fully autopoietic.

Evolutionary knowledge generated by organizations is tacitly embodied in the physical and procedural structure of the organization (Nelson & Winter 1982; Dalmaris 2006; Dalmaris et al. 2007), and explicitly in organizational documentation (Hall 2003a). Some knowledge specifically relating to the organization is held in human memories, but the "*bounded rationality*" (Simon 1955, 1957) of organizational members means that no one person can know everything the organization needs to know in order to maintain itself and respond adequately to meet organizational imperatives in a changing and competitive environment (see also Else 2004; Nousala et al. 2005; Nousala 2006; Dalmaris et al. 2006; Martin et al. 2009; Philp & Martin 2009; Hall et al. 2011), thus knowledge required for maintenance of the organization must be distributed beyond the limits of any one individual in the organization.

It should be noted that Niklas Luhmann (1986, 1990, 1995) has described what he calls a form of social autopoiesis in his studies of human social systems. This deviates substantially from the Maturana and Varela (1980) canon in that Luhmann's 'autopoiesis' no longer focuses on the physical interactions of material entities. Basically, Luhmann's autopoiesis is defined on the basis of an idiosyncratic and highly paradigmatic view of informational relationships rather than energy dynamics between physically definable entities. Luhmann developed a major European following in his own right (e.g., see Bakken & Hernes 2003; Seidel & Becker 2005; Brier et al. 2007). However as discussed briefly above in the section What is Life/Autopoiesis and more extensively in Hall & Nousala 2010 and Hall 2011), Luhmann (and on the other hand, many of those who rejected the idea that autopoiesis was a valid definition of life) badly misunderstood the various kinds of self-observational feedback required in the maintenance of autopoiesis, considering autopoiesis to involve paradoxical self-reflection. This is related to what some of these authors thought was a paradoxical use of cognitive processes to study cognition, which is resolved without paradix when it is understood that this understanding is achieved via a spiral learning process of observation, hypothesis, and testing (i.e., after Popper 1972 - Figure 4, Boyd, 1996 - Figure 8), where the self-observation and the acting on the self-observation are always separated in time (Hall 2011, Hall et al. 2011, Hall & Nousala 2010). Thus, I regard Luhmann's discussions "autopoiesis" at the level of social systems to be largely irrelevant to the discussion here, which depends wholly on autopoiesis as defined by Maturana and Varela as extended herein and by my earlier works on the subject.

Many economic organizations (i.e., firms) satisfy the criteria to be considered autopoietic. They also qualify as dynamic entities in a thermodynamic sense, dissipating potential as they conduct energy between sources and sinks. Energy processed directly by the metabolism of the organization's human members and its physical machinery plus the large amounts of potential energy abstracted in an organization's book of accounts all qualify in terms of establishing an energy budget (Bailey 2008).

The place of simple third-order social/economic organizations in in the overall framework of levels of organization is show in Figure 64. The organization of interest – a holon, establishing a focal level, is comprised of people as component subsystems interacting to form the holon, and interacts via exchanges of cash, informaton and products with other organizations at the focal level to form a higher level organization, such as an industry cluster (Hall 2006b, Hall & Nousala 2007) or economy.

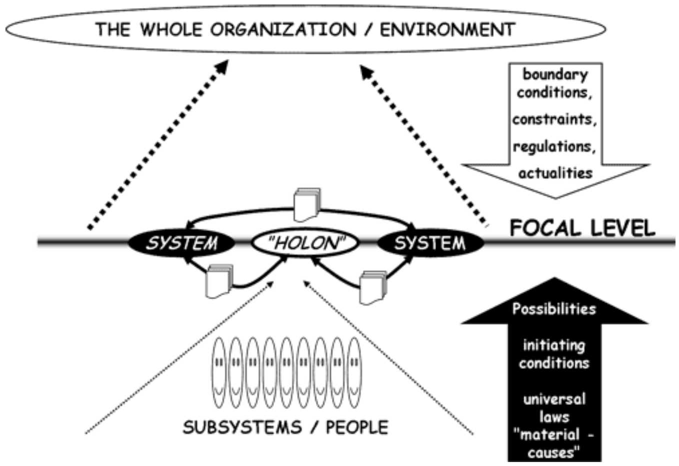


Figure 64. The focal level in the structure of a holonic or triadic organizational system (see Figure 63) – in this case within a social system (after Hall et al. 2005). The arrows labeled by the "documents" icon represent exchanges of knowledge via W3.

The structure of an autopoietic human organizational entity (Figure 65) can be readily mapped onto the structure of a generic autopoietic system as illustrated in Figure 54, where interacting people (who are second-order autopoietic entities, formed of cells – first order autopoietic entities) are involved in the subsystems such as "procure", "market/export", "induct", etc. As in the generic autopoietic system, various forms of knowledge constrain the structures and operations of these subsystems.

Where humans are able to shift their focal level to observe higher orders of organization, we have the opportunity to observe the emergence of higher order autopoiesis in real time. Looking upward, people exist, interact and carry out various roles in an environment composed of a broad ecology and economy of higher level systems. To see these higher level systems we need to focus on the semi-permeable boundaries of social and economic organizations, to see how the people associated with an organization from time to time, working with its plant, equipment, vehicles, premises etc. to establish an organizational entity that has as real an existence in nature as people do looked at from the point of view of a single brain or blood cell.

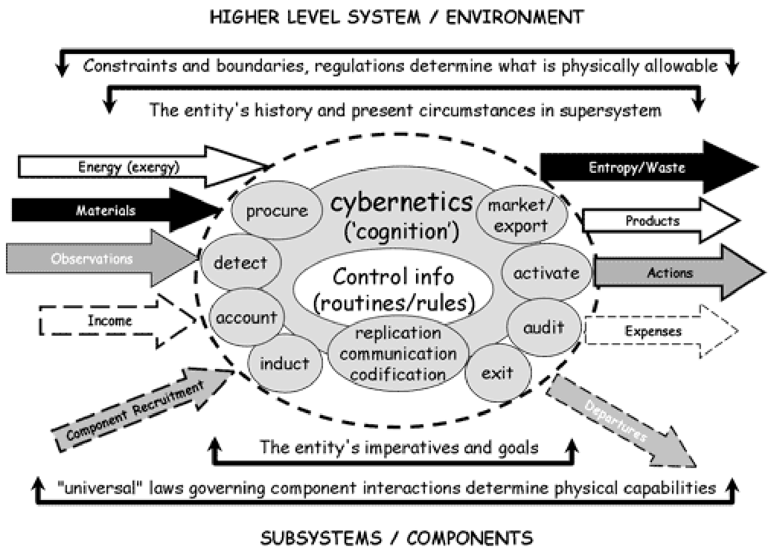


Figure 65. Major subsystems in an autopoietic organization (after Figure 54). Except for the accounting and audit functions that depend on some form of self-conscious cognition, analogs to the other kinds of subsystems can be found in autopoietic at any scalar level of organization (Nousala and Hall 2008).

Nousala and Hall (2008) described how new levels autopoietic organization emerege within existing levels of hierarchical complexity. Basically these have involved the formation of third order autopoietic organizations such as new companies involving second order people working within the higher level supersystem of the economy (Nousala et al 2005, 2009, Hall et al. 2009) the emergence of knowledge-based communities within existing third order companies or other social structures (Nousala 2006; Nousala et al. 2005, 2010a, Hall et al. 2010) and the emergence of 4th order industry clusters between component companies and the higher level supersystem of the economy (Hall 2006b; Hall & Nousala 2007). Three figures from Nousala and Hall (2008) illustrate how a new level of autopoietic organization may emerge.

Figure 66 **Left**: A social network created by a "human attractor" (Nousala et al. 2005) within the organization. "Faces" in these figures correspond to people/actors belonging to the organization at the level of subsystems/components (see Figure 64). **a**. A "human attractor" seeking knowledge to address a high-level organizational imperative or need. **b**. Other seekers socially transferring knowledge relating to what the "human attractor" seeks to know for the benefit of the organization. **c**. Other actors in the organization who are not connected to the seeker's current interest. **d**. A knowledge transfer between individual actors. Line weights indicate strength of the connection. The open vertical arrows indicate the possibility that the community may assemble and generate knowledge that will be valuable in addressing organizational needs. **Right**: The coalescence of a community of interest ("*CoI*") around a "*human attractor*". The human attractor seeks knowledge to solve organizational needs addressing high level imperatives and goals. Bright smiley faces represent people/actors receiving organizational/social rewards for their involvement in addressing the organizational need. Such rewards reinforce the individuals' involvement in addressing the corporate need. Open vertical arrows indicate the value/importance of the assembled, ordered and directed knowledge in addressing higher level organizational requirements. The light dotted line surrounding the attractor's network indicates that participants and others begin to see the network as a community with common interests.

Figure 67 **Left**: Stabilization around a human attractor. Emergence of processes within a stabilized community of interest. Dashed arrows represent control processes. Solid arrows represent knowledge production processes. Knowledge about how to form and sustain the community is still emerging. **a**. Community facilitator. **b**. Emerging boundary between the system by those who identify themselves as participants in the community (for the purposes of the community only) and others in the community. **c**. Faces crossing the boundary are people in the process of being recruited and inducted into the community. **Right**: Achievement of dispositional autopoiesis. Stage where discrete, self-supporting practices have evolved to produce particular (knowledge) products. **a**. grey faces - internal and external monitoring processes providing overall feedback control to maintain and sustain the community. **b**. white faces - a production process delivering a product to the broader organizational environment. **c**. product quality control cycle provides corrective feedback to the production process. **d**. induction process recruiting new individuals into the community to satisfy new needs and to replace attrition. **e**. environmental monitoring to feed observations into monitoring and control process. Note, this evolutionary stage still depends on tacit routines and tacit knowledge/acceptance by individual participants of their learned roles in the routines.

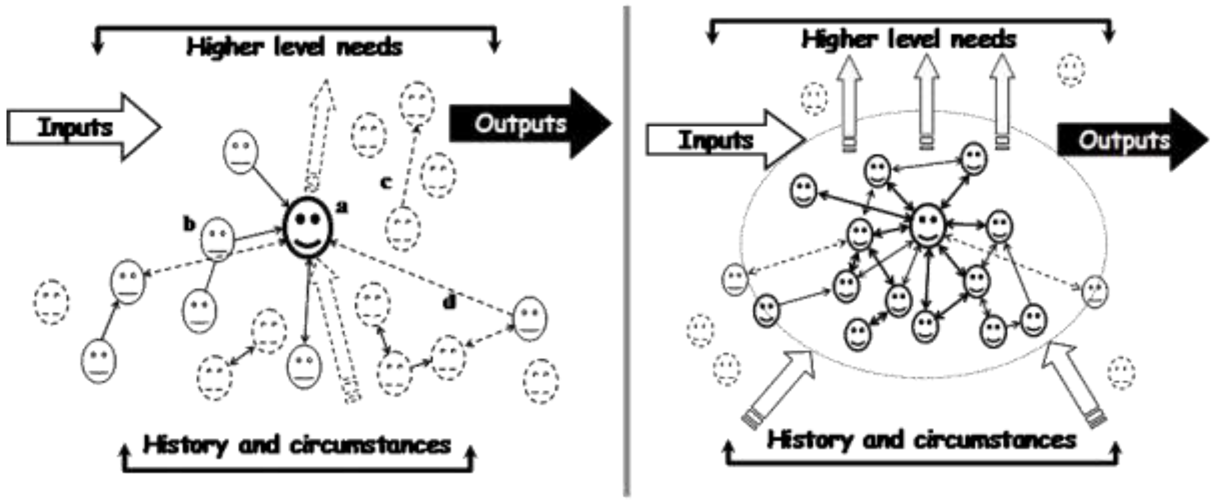


Figure 66. Early stages leading towards the emergence of a knowledge-based autopoietic group (from Nousala & Hall 2008).

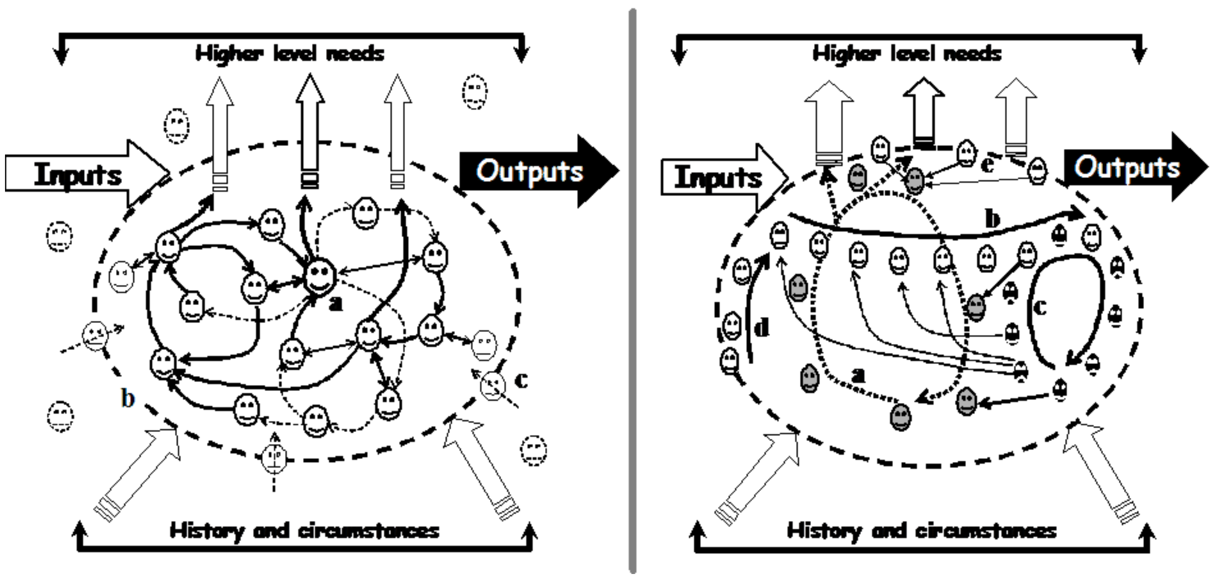


Figure 67. Intermediate stages in the emergence of an autopoietic knowledge-based group (after Nousala & Hall 2008).

Figure 68 shows the state where the practices to form and maintain the community have been objectified and documented (as indicated by the records icons). Grey faces – those following codified knowledge (**a**.) about how to manage internal and external monitoring processes providing overall feedback control. White faces – those following codified knowledge (**b**.) about the production process. Black faces – those following codified knowledge (**c**.) about the product quality control cycle. **d**. codified knowledge about induction process recruiting new individuals into the community to satisfy new needs and to replace attrition. **e**. codified knowledge about environmental monitoring processes. **f**. codified knowledge about how to establish and sustain the community itself.

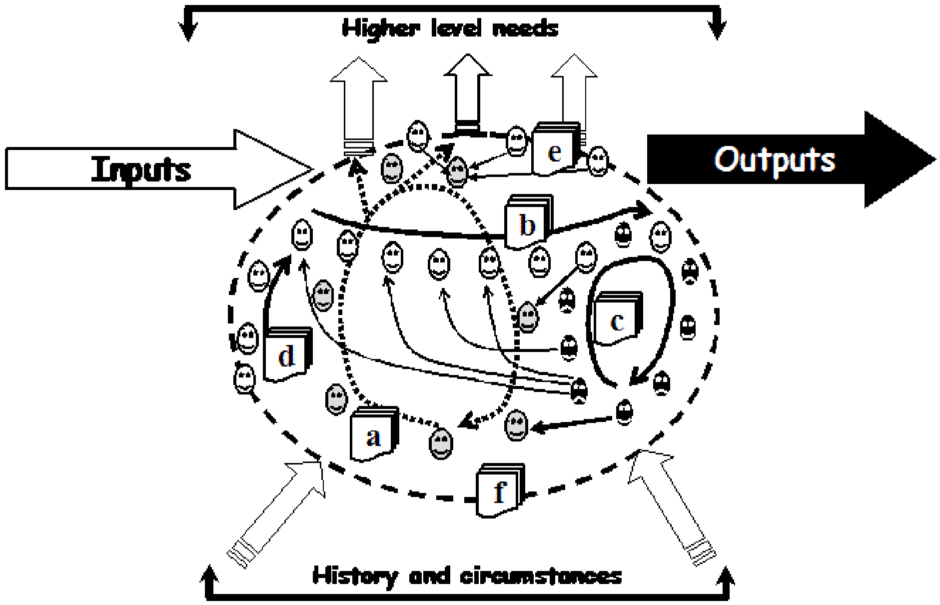


Figure 68. Semiotic autopoiesis (after Nousala & Hall 2008).

EPISODE 4 – Extending Human Cognition and Emergence of Humano-Technical Cyborgs

To this point, my survey of cognitive technologies has focused almost exclusively on how manufacturing, computing and web technologies have extended *individual* capabilities far beyond the bounds of unaided brains. Cognitive technologies have changed our capabilities so much that the human species is making major grade shifts[28] in less than a single human generation towards rapidly becoming "post-human"[312], where we and our technologies now form symbiotic entities with vast powers that were not comprehended even in science fiction when I was going through university 50 years ago (Licklider 1960; Pepperell 1995; Hayles 1999; Hall 2006a; Yakhlef 2008). *We are now interacting with machines, knowledge and with other people via personal connections into computer mediated virtual worlds in ways that were unimaginable even a couple of decades ago*. We are thus becoming what I will call "*humano-technical*"[313] entities rather than purely organic beings. In this episode I will explore continuing trends in cognitive technologies over the last decade and how these may transform the capabilities of humans to be completely new kinds of entities. In a similar way, as will be discussed in Episode 5, human organizations have transcended from being simple collectives of people to become higher order "socio-technical" entities, i.e., comprised of groups of people plus their tools, machines and technologically mediated processes (Harvey 1968).

Moore's Law still at work – clouds, pipes, devices, and apps.

Moore's Law (Figure 37) summarizes the supposedly exponential increases of computing power, data storage, and connectivity that continues to radically change human cognition and what it means to be human in a biological world. As I write this section, the effects of Moore's Law continue unabated. In fact, following Koh & Magee (2006) and Nagy et al's (2011) analyses based on information storage (per unit volume), bandwidth, and calculations per second, as well as their costs; the evidence suggests the increases are *superexponential*, i.e., where the rate of increase becomes even faster than exponential with time. For example, as I write this I have 20 GB paid storage in Google Docs for the several thousand journal articles and eBooks that I share with a number of collagues that we can access from anywhere in the world via our web browsers. This costs me $US 5.00 a year, and even adding dozens of items a week I have only managed to use about ¼ of the paid space. When I started using computers in the early 1980's, a single 8" floppy disk storing around 100 KB cost about that![314] Today bulk storage is so inexpensive that it is beyond estimating just how much capacity is on-line. What this means in real terms is that every year things that were commercially unfeasible to do with computers or the Internet the year before, become possible; and in three or four more years the resource costs become so insignificant that these can be "given away" as an "extras" in the latest services or gadgets being marketed.

Moore's Law has enabled what is known as technological convergence. Until recently, different kinds of products, e.g., TV, camera, telephone, video players, monitor, navigation tools, notepads and drawing tablets, sound recorder, airconditioning equipment, etc., all had their separate evolutionary lineages and were purchased separately. However, as the underlying technologies became less expensive, TV's become connected to the internet and video players, airconditioners become smart enough to know what their owners are doing and adjust temperatures accordingly, and telephones become still and TV cameras, portable media players, navigation tools, and notepads, etc….

The cognitive tools resulting from this convergence are even more radically changing the nature of humans using them in ways that only a very few of the most prescient science fiction writers have imagined[315]. In essence, we are also seeing convergence of the technologies and the users to become in essence, posthuman cyborgs (Pleše 2012). As a consequence of the superexponentially increasing power of computer technology, the human ecology of personal computing described in Episode 3 is rapidly transforming into an ecology where the technology becomes an integral part of the individual autopoietic person's cognitive interactions with other people and the world. There are four areas of increasingly synergistic technologies that are particularly relevant: the cloud, pipes, devices, and apps.

The cloud

In the domain of information technology, the "cloud" initially referred to communications networks that provides connections (potentially between any specified points in the world) while hiding functional details from its users of how the connections are established and messages transported across them. The user simply tosses a message into the cloud, and trusts it to come out of the cloud at its destination and/or come back with an answer – all within fractions of seconds. The Internet is just such a cloud. In other words, the various processes and connections involved in moving information from point A to point B are hidden in the mist as far as the end users are concerned.

In this last decade or so, this concept has been extended under the term "cloud computing" to cover processing applications and storage services where data and files are stored and computing applications do their processing on severs hidden in the fog from end users. This reduces the load on personal computing facilities to input/output and updating screen displays. In most cases the data exchanges are managed by no more than a web browser (perhaps extended with downloadable plug-ins or add-ons) on the end-user's computer.

However, most of the relevant technologies are growing cheaper and more capable at super-exponential rates as documented in Santafe Institute studies, e.g., since 1985 bandwidth (for cable length cost for marine transmission cables has increased by nearly 5 orders of magnitude), computer memory chip cost (DRAM cost per 1000 bits memory has decreased by some 5 orders of magnitude), hard drive storage (number of megabits stored per unit cost has increased by more than 5 orders of magnitude) and aggregate processing power (calculations per second per computer has increased by 5-6 orders of magnitude). For example, *via Google I can query billions of web pages, hundreds*[?] *of millions of journal articles, and millions of books to display on my screen within a second or less in time a specific list of those content objects that contain a particular combination of words together with live links to the objects and short extracts relating to the document or words*.

Another enabler for cloud computing on an increasingly massive scale is the super-exponential increase in hard drive storage capacity (number of megabits stored per unit cost has increased by more than 5 orders of magnitude - Koh & Magee 2006) and aggregate processing power (calculations per second per computer has increased by 5-6 orders of magnitude - Koh & Magee 2006).

The cost of storage is now so low that, as discussed in Episode 3, a commercial company like Google can afford to index, store and serve *at no charge to the consumer* essentially all of the knowledge humanity has published since Guttenberg began printing it around 1450.[224] Google also offers individuals the ability to store personal data/documents for directory access from anywhere in the world via desktop and mobile devices via its Google Drive product. The first 5 GB storage is free and then 25 GB can be purchased for $2.49/month = $29.88/year; storage of a terabyte costs $49.99/month = $599.88/year.[316]

Amazon (the on-line bookseller and retailer) is another commercial company that has built its business on low-cost storage, and is now a major supplier of storage through the cloud via its Simple Storage Service (Amazon S3). Some indication of what storage costs Amazon in bulk is indicated by their rate table as at 1 July 2012 (Figure 69).

Thus, Amazon's *most expensive* storage price works out to $1,500 per year per terabyte (compare this with Google's $599.88)[317]. My current 20 GB allocation on Google costs me $5.00 per year, while the same storage on Amazon would cost around $30 per year. S3 storage can be used by anyone anywhere in the world that has an email address and legal existence. Because storage is so inexpensive, Amazon can even afford to give it away for free via their AWS Free Usage Tier:

> As part of the AWS Free Usage Tier, you can get started with Amazon S3 for free. Upon sign-up, new AWS customers receive 5 GB of Amazon S3 storage, 20,000 Get Requests, 2,000 Put Requests, and 15GB of data transfer out each month for one year.... AWS's free usage tier can be used for anything you want to run in the cloud: launch new applications, test existing applications in the cloud, or simply gain hands-on experience with AWS (http://aws.amazon.com/s3/pricing/).

Region: US Standard

	Standard Storage	Reduced Redundancy Storage
First 1 TB / month	$0.125 per GB	$0.093 per GB
Next 49 TB / month	$0.110 per GB	$0.083 per GB
Next 450 TB / month	$0.095 per GB	$0.073 per GB
Next 500 TB / month	$0.090 per GB	$0.063 per GB
Next 4000 TB / month	$0.080 per GB	$0.053 per GB
Over 5000 TB / month	$0.055 per GB	$0.037 per GB

Figure 69. Amazon S3 storage prices as at 1 July 2012 (http://aws.amazon.com/s3/pricing/).

Pipes

Bandwidth refers to the rate (generally measured in bits per second) that information can flow through communication "pipes", especially in this context – between users and the cloud and between various points in the cloud. From the user point of view, two kinds of bandwidth are particularly important – via land-lines physically connecting desk-top computers to the cloud, and "wireless" to potentially mobile devices that are not physically connected to the internet.

Even though the data exchange requirements for cloud computing are comparatively small, cloud processing was initially fairly slow due to the narrow bandwidths available to most potential end-users. Much more than the bandwidth of trunk cables, the actual bandwidth available to both landline and wireless customers depended primarily on the bandwidth of particular choke points in the communications network discussed under the concept of the "last mile”. Technologically, this last mile has the most complex issues to address, but Moore’s law means that every year the relevant technologies’ are providing increased bandwidth for lower costs, until bandwidth constraints are becoming less and less apparent to the increasing numbers of users of the communication services. Most of the relevant technologies have grown cheaper and more capable at super-exponential rates as documented in Santafe Institute studies, e.g., since 1985 bandwidth (the bandwidth available per unit cost for a standard length of marine transmission cable has increased by nearly 5 orders of magnitude - Koh & Magee 2006).

Devices

It is in the area of personal mobile devices where technological convergence enabled by Moore’s Law has had its greatest impact. A proxy for this is the cost of computer dynamic random access memory chips, where the cost (DRAM cost per 1000 bits memory) has decreased by some 3½ orders of magnitude between 1990 and 2008. Another proxy is the number of instructions that can be processed in a second (MIPS) per dollar cost, which between 1990 and 2004 has increased from something on the order of 3×10^{-3} to more than $1.0 \times 10^{+2}$ or approximately 4½ orders of magnitude (Koh & Mcgee 2006).

This means that what was only a pocket-sized mobile phone able to remember a few phone numbers some 22 years ago in 1989 (e.g., Motorola’s state of the art MicroTAC 9800x - Figure 70 left)[318] weighing 12.3 oz, selling for US$2,495 and US $3,495 has become a “smartphone”, which is in effect multipurpose cognitive prosthesis for connecting its user’s mind to the full resources of the Web from anywhere in the world. An example is Apple’s $399 64 GB iPhone 4S (Figure 70 right)[319], whose functions are listed below. The length of this list may seem to be overkill, but I need to make it clear that this is what results when the doubling time of technological performance is now less than a year (Nagy et al. 2011). It should also be noted that the smartphone market is highly competitive, with a number of other suppliers than Apple also offering comparable technology, using Google’s open Android technology such as Motorola Atrix 4G and Samsung Galaxy S III; and Nokia Lumia 900 using Microsoft’s Windows technology. These devices are unlikely to represent the end of technological convergence.

Figure 70. Smartphones. (Left) Motorola MicroTAC 9800x, launched April 1989. (Right) Apple iPhone 4S released in October 2011. (both from Wikimedia Commons).

Other than the ability to communicate with the Web and people from anywhere on the planet to anywhere on the planet via several cellular and wireless modes, the iPhone 4S is:

- able to determine its location (and orient its user) on the earth via **Assisted GPS** (and GLONASS, the Russian equivalent), a **digital compass**, and in **relationship to Wi-Fi and**

Cellular repeaters

- **show content** on its 3.5” touch-screen at 960 × 640 pixel resolution that supports many languages, simultaneously. Graphical nterface control elements consist of sliders, switches, and buttons
- **tactile interface** responds to gestures and movements such as swipe, tap, pinch, and reverse pinch, shaking and rotating in each of three dimension.
- includes **two still/video cameras** (front and rear): 8-megapixel iSight camera, Autofocus, Tap to focus, Face detection in still images, **LED flash**, Video recording, HD (1080p) up to 30 frames per second with audio, Video stabilization, Front camera with VGA-quality photos and video at up to 30 frames per second, **Photo and video geotagging**.
- **Audio playback** 20 to 20,000 Hz of at least 9 different sound recording formats.
- **TV and video playback** also in a large variety of formats.
- Sensors include: Three-axis gyro, Accelerometer, Proximity sensor, Ambient light sensor (as well as sound via the microphone and touch via the screen).
- **Default applications** include Safari, Mail, Photos, Video, YouTube, Music, iTunes, App Store, Maps, Notes, Calendar, Game Center, Photo Booth, and Contacts.
- **Media access and play** includes access & play music, movies, television shows, ebooks, audiobooks, and podcasts; and it can sort its media library by songs, artists, albums, videos, playlists, genres, composers, podcasts, audiobooks, and compilations
- **Speech recognition and control system** called Siri that understands a wide range of spoken commands and questions and converts speech into text for texting for the languages it understands: English (U.S., UK, and Australian), French, and German.
- **Languages supported for touch graphical control** include: English (U.S.), English (UK), Chinese (Simplified), Chinese (Traditional), French, German, Italian, Japanese, Korean, Spanish, Arabic, Catalan, Croatian, Czech, Danish, Dutch, Finnish, Greek, Hebrew, Hungarian, Indonesian, Malay, Norwegian, Polish, Portuguese, Portuguese (Brazil), Romanian, Russian, Slovak, Swedish, Thai, Turkish, Ukrainian, and Vietnamese.
- **Languages supported for keyboarding text** include: English (U.S.), English (UK), Chinese - Simplified (Handwriting, Pinyin, Stroke), Chinese - Traditional (Handwriting, Pinyin, Zhuyin, Cangjie, Stroke), French, French (Canadian), French (Switzerland), German (Germany), German (Switzerland), Italian, Japanese (Romaji, Kana), Korean, Spanish, Arabic, Bulgarian, Catalan, Cherokee, Croatian, Czech, Danish, Dutch, Emoji, Estonian, Finnish, Flemish, Greek, Hawaiian, Hebrew, Hindi, Hungarian, Icelandic, Indonesian, Latvian, Lithuanian, Macedonian, Malay, Norwegian, Polish, Portuguese, Portuguese (Brazil), Romanian, Russian, Serbian (Cyrillic/Latin), Slovak, Swedish, Thai, Tibetan, Turkish, Ukrainian, and Vietnamese.
- **Dictionary Support (enables predictive text and autocorrect**): includes: English (U.S.), English (UK), Chinese (Simplified), Chinese (Traditional), French, French (Canadian), French (Switzerland), German, Italian, Japanese (Romaji, Kana), Korean, Spanish, Arabic, Catalan, Cherokee, Croatian, Czech, Danish, Dutch, Estonian, Finnish, Flemish, Greek, Hawaiian, Hebrew, Hindi, Hungarian, Indonesian, Latvian, Lithuanian, Malay, Norwegian, Polish, Portuguese, Portuguese (Brazil), Romanian, Russian, Slovak, Swedish, Thai, Turkish, Ukrainian, and Vietnamese.

The other convergent device of major interest is the mobile tablet computer that fills the gap between laptop/notebook style compters and the smartphones, such as the Android based

Samsung Galaxy Tab 10.1 or Apple's New iPad. These substantially more portable than notebooks or laptops but less portable than smartphones and less convenient for photography. However, because of their larger size are better for extensive reading or data input.

Apps (applications)

Wireless and landline pipes into the cloud allow personal devices to connect to and communicate with people, data, knowledge, and computational resources via the Web. Browser functions or separate applications on the end-users' device(s) provide the capabilities to interface human brains with functions of the cloud. *The brain asks and receives, but increasingly, cognitive processing may take place on a server somewhere in the cloud or in the end-user's device*. Also, more and more of the information being processed (observation and memory) lives in the cloud.

Although many of these interfacing applications are also accessible as tools via desktop computers and some are still best accessed via the desktop, it is especially the mobile device (i.e., the smartphone) that becomes an integral part of the person. I saw this beginning some time around 2004 at a work-related party engineering staff and their families including children (mostly around 8 years old). Instead of running around jabbering and screaming in typical primate/human play, the children retired to a room to socialize *in complete silence*. When we looked in on them, they were all sitting in a circle, texting one another rather than interacting physically or verbally (Figure 71).

Figure 71. A group of children texting each other instead of talking (From Humanity+).

In 2004, the mobile phone was mainly useful for talking to and texting other people. Since then, the computational power of the phone has continued to grow superexponentially. There is now a vast and rapidly growing array of smartphone/tablet apps (applications) that serve to directly interface the user's brain with essentially the knowledge of the world. I list some of the pioneering killer apps and their characteristics here that are daily increasing the potential powers of smartphones and tablets. In addition to those listed there are many other applications offering these and more capabilities:

- Text communication
  - email: ARPANET (1971); SMTP early 1980's; email via TCP/IP from 1982.
  - SMS text messaging (2002) – standard for mobile phones (free)

- Gmail (Apr 2005 / Feb 2007 - free). Convergent features include search, five gigabytes of cloud storage – more if paid, instant messaging (voice & text), closely linked calendar functions

- *Voice communications* (i.e., the original telephone function)
  - wireless: mobile telephony (1946), cell phone (1956), first hand-held mobile (1973).
  - internet telephony: development of Voice over IP (1973) – first app (1994).
  - Skype (2003 - free): Includes peer-to-peer voice/video and connects voice to landlines as well as internet. Convergent features include texting, file transfer and multiuser videoconferencing.
  - Google Talk (2005 - free): voice/text associated with Gmail.
  - Google Voice (2005/2007 - free): Convergent features include voicemail, call forwarding, texting, call history, conference calling, screening, voice transcription to text, etc.
  - Etc…

- Portable media players/media libraries/sales of media, software, etc…
  - Windows Media Player (1991 - free)
  - iTunes (1999/2001). Convergent features include playing, downloading, saving, and organizing digital music and video files, connecting to iTunes Store to purchase/download media & app software for iPads and iPhones (over 500,000 free & paid apps are available for the iPhone)
  - Amazon Kindle (2007): Tablet sized book reader using E Ink electronic paper, evolving convergence
  - Google Play (2008 - free): Media store for smartphones using the Android operating system. There are more than 1000 free media players downloadable via Google Play, ditto paid, etc….

- Photography & video-related applications
  - Picassa (2002 - free) Convergent features include viewing, storing & organizing, editing, and sharing pictures.
  - iPhoto (2002 - free): Released for iPhone 2012, ditto Picassa
  - Flikr (2004/2005 - free): Photo and video sharing
  - Panoramio (2005 - free). Geolocated photos converging with Google Earth and Google Maps
  - YouTube (2005 - free): Video sharing and upload (also manages sound only files)
  - Thousands of photo and video apps for Android smartphones are downloadable from Google Play, ditto from iTunes for iPads and iPhones

- Cloud storage and file sharing
  - Napster (1999): originally peer-to-peer sharing of music, dogged by controversy and put out of business because lack of copyright controls
  - BitTorrent protocols (2001): Protocol for the distributed peer-to-peer storage and sharing of digital content of any kind
  - Amazon S3 (2006): Cloud-based bulk storage and sharing not especially friendly to end users
  - DropBox (2008 - free): File storage and synchronization shareable across many users and devices. Local storage ensures file availability when offline, cloud storage ensures total backup.

- Business and office tools via cloud for smartphones
  - Google Docs/Google Drive (2007 - free): Cloud-based text, presentation and spreadsheet authoring apps working via browser, plus cloud storage, full text searching, and file sharing.
  - Android smartphone: downloadable apps include Documents to Go (2008) that provides read/create access to Microsoft Office, Google Docs, and Adobe PDF formats.
  - iPhone: built in apps include Pages (documents from 2011), Numbers (spreadsheets from 2010) and Keynote (presentations from 2010). Documents to Go is also available for iPhone.

- Geospatial

- Google Earth (2001/2005 - free): Virtual globe, stellar sphere & imagery, map, geographical information system (on smartphones from 2008). Convergent with Panoramio and Wikipedia
- Google Maps (2005 - free): web mapping service application and technology behind many map-based services, including the Google Maps website (satellite, topographic and conventional street maps and street views), Google Ride Finder, and Google Transit, offers street maps, a route planner for traveling by foot, car, bike, or public transport and an urban business locator for numerous countries around the world.
- Microsoft Bing Maps (2005/2006): similar functions to Google Maps

- Social
  - Chat rooms (~1980): Synchronous online talk/conferencing.
  - Email groups/listservers (Majordomo 1992; Yahoo! Groups 1998): Electonic mailing lists and Web forums, usually including subject indexing, search and archiving functions
  - Meetup (2001): social networking portal that facilitates offline group meetings, converges with listservers and document sharing
  - LinkedIn (2003): professional networking and job hunting portal, converges with meeting organizer, discussion groups
  - MySpace (2003) / Facebook (2004): Networking space where friends can converse and exchange photos and details of their activities, converging with email, voice calling, etc.
  - Twitter (2006): Limited broadcast tagged text messages with attached files and pictures, search, and notification

- Knowledge construction, sharing and broadcasting
  - Wikis (1994) (MediaWiki/Wikipedia 2002): Controlled tool for collaboratively building knowledge bases on the Web, generally offering versioning, access controls, and other content management capabilities.
  - Blogs (personal blogs late 1990s; WordPress 2003); Some of the earliest cloud applications provided individuals with web-log or diary facilities to present their thoughts, graphical observations, and knowledge to the world. Facilities for outside commentaries and group authoring were soon added. Main entries often limited to a single author or small group, but accepting open commentaries.
  - Google Sites combines blogging and wiki functions (see also Hall and Best 2010) with file sharing

Even today, in mid 2012, downloadable apps give smartphones so many different functions that they are beyond my capacity to summarize in any comprehensible way. Each app turns the smartphone into a different kind of tool or interface and the available possibilities are increasing on a daily basis. The download sites for the major vendors demonstrate this protean diversity:

- iPhone
  - Built in apps (at least 24)
  - From the App Store (claims to be over 500,000! Free and paid)

- Android smartphones
  - Built in apps depend on the smartphone brand and supplier, but in many cases are competitive with the iPhone's, e.g., see Galaxy
  - There are 26 main categories of free and paid apps (not counting games) downloadable via the Google Store.

The economic models for most apps are interesting. For downloadable apps, there is no packaging, and it costs authors nothing to distribute them other than the time to upload onto a sever where they can be fetched by those who want to use them. Many of the free apps are GNU General Public Licensed and/or Open-source products that have been socially developed following open source software development models. Open-source developers are normally not paid, but can gain kudos that improve their employability and rates they can charge for contract work. Many commercially developed apps are distributed for free to gain markets for paid add-ons, or because the providers have other profit models such as Google and Facebook's, where freely provided user content is mined to provide paid advertisers with more accurately targeted ads. Finally, if an app is capable of attracting hundreds of thousands of users, even if they are sold for a few dollars, that can profitably fund a substantial development effort.

So, in a sense Moore's Law even applies to the apps market. More people on-line means more users, a larger and more competitive market for more apps, and thus, more powerful apps for less cost.

Human Computer Interfaces (HCI)

Up to now, humans have used computers and computer-based technologies as external tools to extend cognition, where the tools are perceptually differentiated from the human body[320]. However, in time, people equipped with the next generations of technologies are likely to begin functioning as though the technologies and powers they provide are an integral part of their native cognition, leading to a genuine convergence between technological and the biological processes of cognition. At least to me, I think this convergence of biology and technology represents the beginning of a greater grade shift or revolution in human cognitive powers than has taken place between the invention of writing and the adoption of smartphone technology.

The smartphone is a hand-held tool that remains separate from the body and that provides a consciously controlled portal to the cognitive functions it provides, as does a book or a desktop computer. As discussed below, the next grade shift is represented most immediately by Google's Project Glass (first announced in June 2012 - providing the user with a head-mounted interface with Android-based smart-phone technologies). This will likely be followed by implanted prosthetics such as bionic eyes and ears (already used by visually and hearing impaired people). In these systems, the technology becomes a functional part of the body, allowing wearers to interact with local and cloud functions via visual or auditory overlays on their normal sensory systems. However, before exploring the new technologies themselves, it will be useful to consider just what is happening in the interface between humans and computers in order to understand the likely path to be followed by the convergence of human and computer/machine cognition.

Sensing and perceiving the external world

As discussed in The Cybernetics of Power: Boyd's OODA Loop Concept, the loop process (Figure 8) describes the spirally iterated process (Figure 62 and Figure 55) by which living entities construct knowledge of the world. Francis et al. (2009), in their discussion of the challenges in interfacing humans and machines depict the process as shown in Figure 72.

For our purposes here "Observation" in the basic OODA cycle is initiated with a physical stimulus from something happening in the environment (the "environmental stimulus") that impinges with a causal effect (i.e., an "attended stimulus"[321]) affecting receptors on an organismic boundary. In all cases, perceiving and making sense of the world involves complex processes converting physical impacts of the world on the organism into some kind of cognitive picture and understanding of this external world (Figure 73). Physical stimuli from the environment are physically processed and preconditioned by sense organs, then transduced by neural "receptors" (see also transduction - physiology) into internally propagated neural disturbances (usually action potentials). In this physical to neural transduction, energy that corresponds to the attended stimulus reaches specialized cells sensitive to this energy. The physical disturbance causes the cell to energize an electro-chemical action potential able to propagate along a nerve fiber. Note, the action potential is not a result of converting the physical stimulus into the action potential. Rather, intrinsic processes within the nerve cell or "neuron" triggered by the external disturbance create the propagating action potential. Nerve cells communicate with one-another via synapses, where the axon of the "excited" cell releases a neurotransmitter or electrical disturbance that triggers a new action potential in a dendrite of the receiving cell that then propagates through that cell. In the brain or spinal cord these propagating action potentials stimulate a variety of other nerves in various levels of neural processing leading to some kind of "perception" and "recognition" within the brain of the external circumstances that created the physical stimuli from the environment.

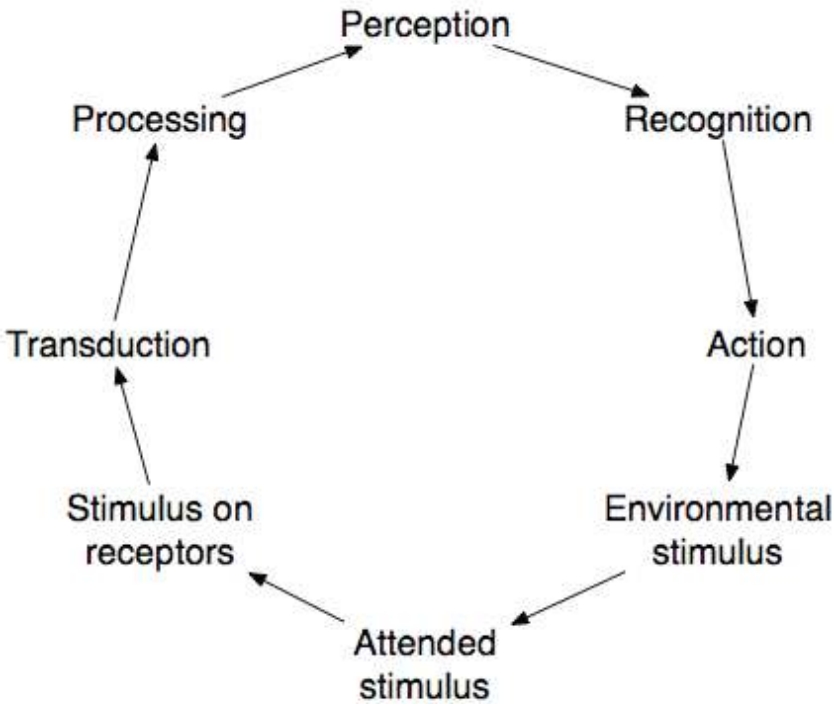


Figure 72. Interactions involved in processing perceptual information into action (corresponding to a single OODA loop). After Francis et al. (2009)

Process type	Subject area	Vision	Hearing	Touch
stimulus	physics	photons	molecular motion / vibration	molecular motion / pressure
physical processing	physics / biology	optics of eye / refraction	outer & middle ear	skin
transduction	biophysics / neurophysiology	rods & cones in retina	hair cells in cochlea	mechanoreceptors
sensory processing	neuroscience	retinal nerve networks	auditory pathway	somatosensory pathway
cognitive processing	neuroscience / cognitive science	multiple brain areas	multiple brain areas	multiple brain areas

Figure 73. Converting sensations to a sense of the world (after Loomis 2003).

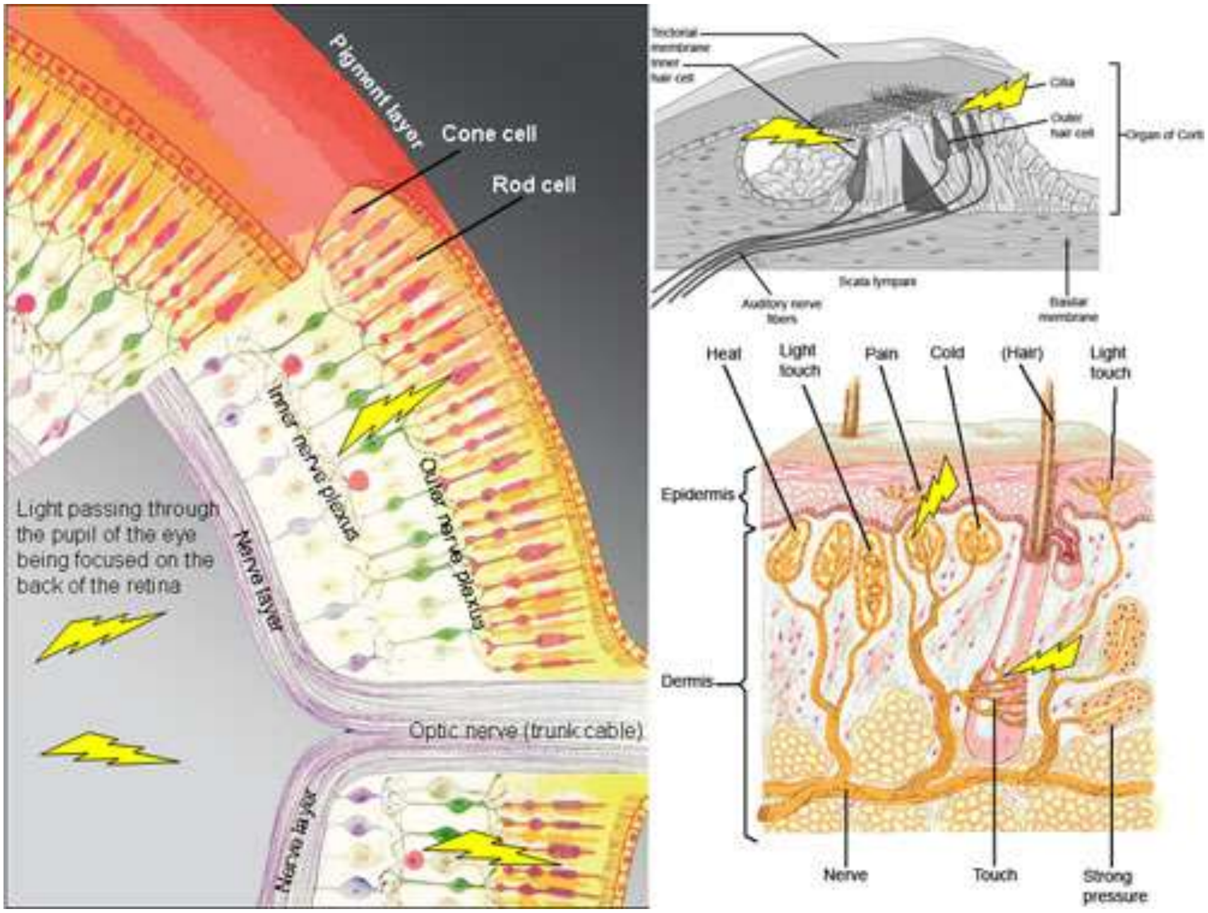


Figure 74. Human sensory transducers. Left: the retina of the eye, Top right: cochlear transducers. Bottom right: transducers in the skin. Yellow arrows: physical stimuli. (based on Francis et al. 2009)

In vision, the eyeball processes light as a camera, where the cornea and lens focus photons to form an image of the external world on the retina at the back of the eye, where the specialized rod and cone cells transduce photon stimuli (the yellow flashes in Figure 74 - left) into action potentials. Based on many years study of vertebrate eyes (beginning with frogs – Lettvin et al., 1959)[322] there is a reasonable understanding of how visual signals are neurally processed in the retina before they reach the optic nerve. The rod and cone cells network with a variety of "bipolar" and "horizontal" cells, that in turn network with "amacrine" and "ganglion" cells connecting to branches of the optic nerve. Thus the action potentials output to the different afferent fibers (i.e., those conducting information to the brain) are nothing like the raster scan or pixel image a camera might transmit. Signals in the optic nerve encode things like edges and their orientation, contrast, motion, etc. (Tessier-Lavigne 2000; Wässle 2004). Further processing takes place in the brain to understand, and possibly to act on, what is seen (Bullier 2001; DiCarlo et al. 2012). This further processing is much less well understood.

In hearing (Evans 1992; Moore 2003; King & Nelken 2009 - Figure 74 upper right), physical processing the outer and middle ear (1) work to focus and concentrate the air pressure waves onto the eardrum causing it to physically vibrate. (2) The hammer (malleus), anvil (incus) and stirrup (stapes) bones of the middle ear physically transmit vibrations of the ear drum to the oval window of the cochlea, causing the perilymphatic fluid in the cochlea to slosh back and forth in tune with the vibrations of the eardrum. The physical vibrations in the fluid (yellow flashes) are then transduced into action potentials by "hair cells" on the organ of Corti in the cochlea that generate action potentials when movements of the fluid cause the hair cells' cilia to bend. Unlike the eye, action potentials in afferent fibers in the auditory nerve from different areas of the cochlea to the brain correspond reasonably directly with those generated by hair cells in different areas of the cochlea. At low frequencies of sound, the frequency of action potentials corresponds roughly to the sound frequency. As the frequency rises beyond what the nerves can conduct, frequency is detected by the resonance of particular areas of the cochlea (basal or proximal end of the cochlear canal resonates at a higher frequency than the distal end). Processing in the brain then decode the input from the auditory nerve as understandable sounds.

For touch, pressure, heat and pain in the somatosensory system, the transducing sensory receptors are located in the dermis of the skin (Figure 74 – lower right), where sensory nerves have specialized endings that respond to various kinds of physical stimuli (pressure, heat, stretching, etc.) and connect back to specialized ganglion cells in or near the spinal cord for intermediate processing and that connect their action potentials back into the brain where they are cognitively interpreted. In some cases, strong stimuli that generate many action potentials simultaneously fire off quick reflex actions via cross connections in the spinal cord ganglia to appropriate muscles (e.g., reflex actions triggered by touching a hot stove with a finger will cause the arm to start retracting even before the brain becomes aware of the pain).

Cognitive processing to understand the world

Boyd's "Orientation" is the collection of neural processes by which the world is perceived and understood (Figure 75). After many millions of years of natural selection and evolution (review Popper's "general theory of evolution" and Autopoiesis) the basic structural connections in the brain are organized to build a an impression of the external world from neural inputs received from the body's sense organs. This involves building and referring to a memory of events and conscious knowledge (McBride 2012). Babies learn to make sense of this information and how to interact with the external world through their active actions to produce new stimuli, and thereby build knowledge of what they can change and what can't be changed.

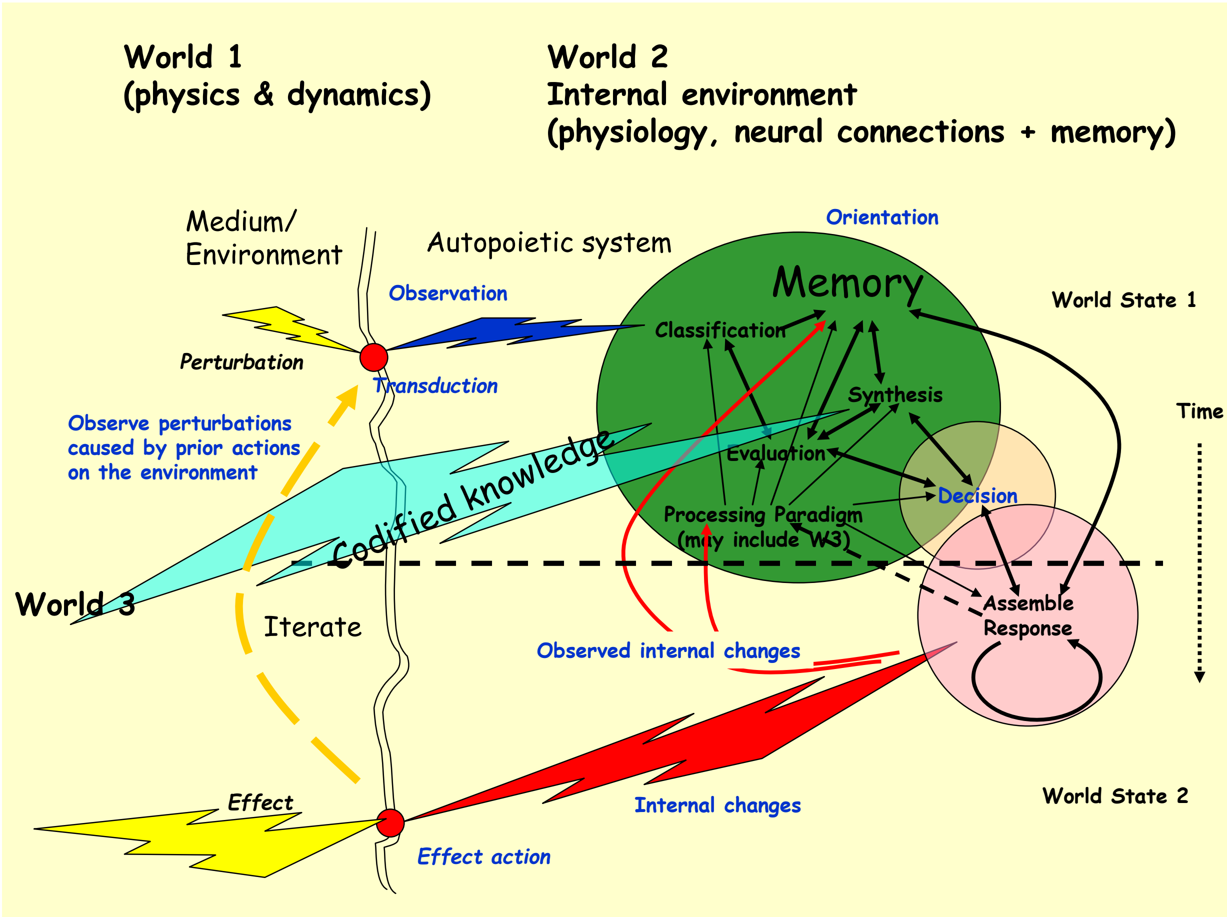


Figure 75. Complete OODA cycle in autopoietic cognition. Click on graphic to display automation.

The cognitive processes involved in making sense of and orienting to a particular set of stimuli involve classifying the sensory impressions of the world at a given time (world state 1) against memory. This allows the impressions to be evaluated against a knowledge of past events and changes, that may lead to recognition of a need or desire for some kind of action to protect from or take advantage of external circumstances (as they were sensed). The need or desire for action may stimulate the synthesis of a range of possible actions. Decision is the process by which a specific action is chosen from among alternative possible actions. Decision then leads to the assembly of output responses from effector and motor systems to apply action(s) to the external environment at some later time (world state 2). Cognitive processes also record and link observations of these internal processes to the external problems that stimulated them.

Given that all of these neural processes take time (Two views of how time, change and causation, Figure 57), actions are always delayed in time from the events that stimulate them, so cognitive processes that can extrapolate and anticipate progressive change in the environment are valuable to the organism.

Augmenting cognition via technological interfaces

To here this book has explored the history of how humans have used a variety of increasingly powerful technologies as external tools to augment personal cognition. There has remained a clear distinction between what the tool existing in the external environment does and the person who interacts with the tool by inputting questions and instructions and then observing outputs via text printouts or on a graphical user interface (GUI) to support his/her personal cognition. However, as the technology has shrunk, it has also gotten closer to the living body – from a standalone console, to the personal desktop, to a portable laptop, to a hand-held smartphone. We are now on the threshold of merging physically with the technology, where the technology interface essentially becomes a part of the person's own body and mind.

The prototype for this wearable or implanted interface is the helmet or head-mounted display that has long been used in the military and in gaming to "augment" or "mediate" reality by overlaying technologically generated information on the native sensory input, or in some cases by completely replacing reality with computer mediated input to make a virtual reality. The basic technology of the head- (or helmet) mounted display (HMD) is not new (Rolland & Hua 2005) and has been used in the military since the 1960s (Bayer et al 2009; Francis & Rash, 2009), where systems are implemented to provide the wearer with some new or extended capability, whether this is provided via see-through designs for aircraft pilots and other war-fighters personally involved in the environment, or via immersive interfaces such as might be used by remotely operated drones. Such enhancements always involve tradeoffs.

Developers often assume that the human visual and auditory systems can accept added sensory and cognitive demands without cost to normal sensation and vigilance. Where increased information load on normal perceptual processes degrades situational awareness or leads to misunderstanding of real circumstances, the possibility of catastrophic errors rise. This is a problem that must considered and resolved in the development of tighter and more active human/computer interfaces if such interfaces are not to be more dangerous than helpful.

Where the military use of such human-computer interfacing systems for augmenting cognition is concerned, the applications and specific designs are normally subjected to detailed and extensive ergonomic studies. It is also understood that the users will be *specifically trained* and *practiced* in working with(in) the perceptual environments created by the interfaces, and that such systems are used only in the specific circumstances for which they were designed. It is unlikely that gaming systems will be as carefully constructed, but given that they are developed to create temporary *artificial* realities when users specifically intend to "play", the concern to not degrade or misrepresent situational awareness does not apply. However, as will be seen, the future human-computer interfaces for people in general are likely to be used much more continuously and as a normal extension to the users' cognitive interactions with their external realities. In these circumstances, I think people will *learn* to use their extended sensory and cognitive capabilities in much the way that babies and children learn to make sense of their built-in senses of sight and sound (e.g., as today's children seem to become one with their increasingly smart personal phones).

The next steps in merging human and computer cognition

Intimately wearable interfaces

Based on what I see on public transport, around town and on campus, many people already seem to live much of their lives with iPod or smartphone buds plugged into one or both of their ears. Many of the earbud cables are also equipped with microphones to provide 2-way voice communication via the wearable device. However, hearing is a comparatively low bandwidth mode for information input to cognition.

What is likely to be the next major step in the convergence and shrinkage of personal cognitive technologies is Google's Project Glass (see video of announcement). Announced April 4, 2012 (Newman 2012), is what Google calls "augmented reality" eye "Glasses" (Figure 76) able to access many smartphone type apps. An "Explorer Edition" prototype was offered to developers attending Google's June 27-29 I/O conference in San Francisco at a price of $1500 for delivery early in 2013, with lower priced consumer versions to be released early in 2014. The eyeglass frame includes a "head-up display" (input to the human eye), camera suitable for lifelogging, microphones and speakers (input to the human ear), powerful processor, lots of memory, a touch pad on the earpiece, multiple wireless (radio) modes, sensors such as gyroscopes, accelerometers and a compass, and instantaneous access to data. One designer said that eventually data should be accessible "so fast that you feel you know it" without having to search for it. (Albanesius 2012; Liedtke 2012). It is clear that Glasses are intended to be worn continuously as many people wear their corrective glasses (according to Medical Eye Services' collection of statistics, 64% of the adult population of the US wear corrective lenses). It is also worth noting that Google already has competitors such as Olympus, Sony almost as far along the prototyping path.

Figure 76. Google's Project Glass for a head-mounted augmented reality system (Google).

Although few commentators seem to have recognized this (as I write in July 2012), I see this further convergence in personal technology enabled by the continued action of Moore's Law, as another grade shift in human evolution where the device and its cognitive apps becomes a more or less permanent part of the person's body, as do normal eyeglasses for people with some vision impairment – not something that is treated as a separate hand-held device.

The lifelogging capabilities raise major questions relating to issues of individual privacy, in that everything within sensory range of the Glasses is potentially recorded and publically available (and then potentially accessible by surveillance organizations). Answering these questions is beyond the scope of this book, but Weber's (2012) essay considers them perceptively.

An even more intimate interface may be provided via contact lenses (Parviz 2009 - Figure 77 bottom). Technology already exists for putting small numbers of active elements into contact lenses and providing them with power. What remains to be developed are methods to bring information displays into focus on the retina, perhaps with microscopic solid-state lasers or with pixel sized lenses built into the contact lens. However, should sufficient money be invested along this path, Moore's law may lead to sufficiently compact technology to make this option practical.

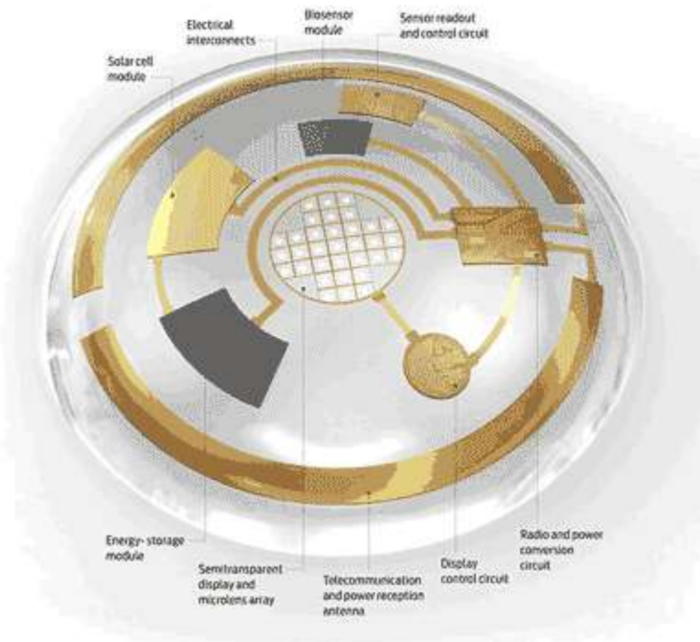


Figure 77. Schematic of a proposed reality augmenting contact lens (Parviz 2009).

Implanted/embodied human-machine interfaces

Even with Google's Glass, the convergent merging of human cognition and cognitive technologies is far from having reached its end-point. We are already transitioning from carrying and wearing cognitive prostheses to implanting their interfaces internally as permanent body parts. Sight and sound are our most critical input channels for cognition, and bionic interfaces of varying degrees of functionality already exist. The "bionic ear" (see also) or cochlear implant (Figure 78) was the first effective system to be developed, while the bionic eye or retinal implant technology (Figure 79) is currently in clinical demonstration and testing (Wallace & Moulton et al. 2012).

- Bionic Ears

Following on from earlier work, House (1976) demonstrated that single electrodes planted in the cochlea were able to stimulate the auditory nerve to cause the perceived sensation of sound. The Australian Graeme Clark and his colleagues (Clark et al. 1977; Clark 1978) developed multi-electrode technology that could be inserted deep into the cochlear spiral (Figure 78 left) to stimulate both high frequency and low frequency areas of the auditory nerve. When coupled with computerized processing of audible speech, even profoundly deaf children could learn to recognize speech and develop normal language skills if implanted early enough (e.g., Geers & Sedey 2011). Mechanically, the electrodes wired into the cochlea (Figure 78 right) interface with an external microphone and computer system via external and internal induction coils (Figure 78 left).

Unfortunately, present multi-electrode implants are not greatly improved on early ones from the 1980s. The difficulty with improving fidelity of hearing is not one of a failure of miniaturization, but in the lack of a deep enough understanding of how the healthy ear encodes sonic pressure waves vibrating nerve cells in the cochlea into patterns of impulses in specific nerve fibers in the auditory nerve that are constructed by the brain into sensations of sound. In many people, the brain eventually learns to "understand" the patterns of stimuli generated by the implant as meaningful "sound", but no one with normally functioning hearing would want to trade in an "earbud" headphone for the current bionic state of the art. In other words, the existing bionic technology seems to work as well is it can with our present understanding of how the human nervous system transduces sound into sensation.

Figure 78. Bionic Ear. *Left*: External device includes a behind the ear microphone and processor sending a signal to the circular induction coil. This energizes a matching induction coil and electrode system implanted under the skin. *Right*: The electrode array is threaded into the cochlea where individual electrodes stimulate nerves sensitive to different sound frequencies along the cochlear canal. The result for users gives a clear enough sensation of sound to understand speech and recognize music. (Graeme Clark Foundation, How the cochlear implant (bionic ear) functions.). Bottom: Clip from a UNSW video showing the insertion of an electrode impregnated with DNA that stimulates the regeneration of auditory nerve cells.

However, as I write this, a new generation prosthesis illustrated in a Universityy of New South Wales video – (Figure 78, bottom), combining a deep understanding of the genetic control of development, hints at the development of technology that may stimulate the formation of direct connections (synapses?) between electrodes and (specific?) neurons (Pinyon et al. 2014). As we learn more about the neurophysiology of human hearing, e.g., via the Human Connectome

Project, and Moore's Law as applied to the technology, I have no doubt that it will not be too many years before the human brain can be directly "wired" for sound.

- Bionic Eyes

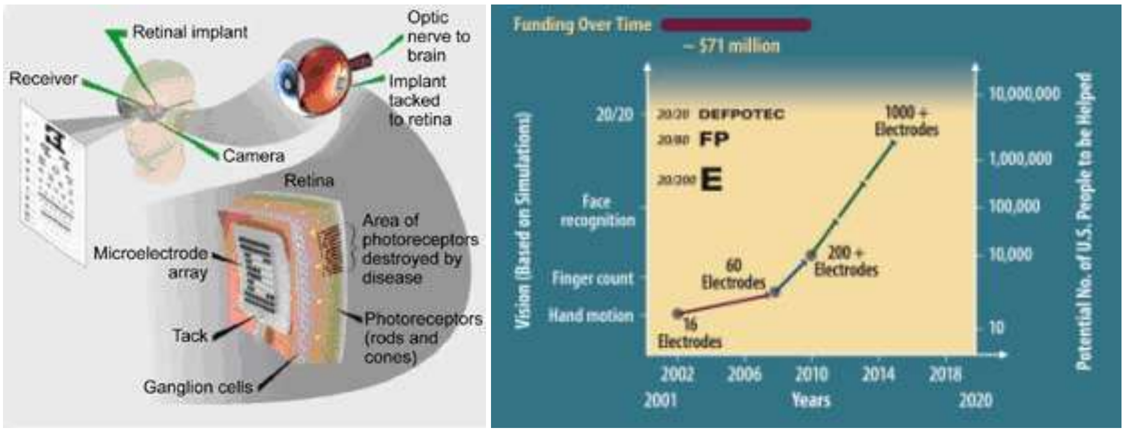


Figure 79. Bionic Eye. Left (DOE Artificial Retina Project). A microelectrode array inserted on the surface of the retina of the eye directly stimulates ganglion cells to generate action potentials in the optic nerve. Although, pre-processing in the plexus layer does not take place, the retinal nerves still convey spatial information to the brain. Right (DOE Artificial Retina Project). The effective resolution of the implants is expected to improve with time in accordance with Moore's Law as manufacturing improvements reduce the size and effectiveness of electrodes as transducers and their density.

Work has been done on a variety of approaches using electrodes to stimulate the retina directly, or to input visual information more deeply into the brain (Ong & da Cruz 2012), These include

- epiretinal (within the central cavity of the eye, resting on the retinal surface);
- subretinal (inserted between the pigmented epithelial capsule of the eyeball and the retina – e.g., just below where the rod and cone cells are located (Figure 74 Left);
- optic nerve or nerve tracts in the lateral geniculate nucleus; and
- direct stimulation of the auditory cortex of the brain.

Deep stimulation approaches (optic nerve/cortex) have been tested with minor success in patients with no retinal functionality, but face the difficulties of understanding how vision is coded in the optic nerve or cortex, and interacting with relevant nerve axons to accurately convey spatial information. In time, as the nervous system is understood in more detail and Moore's Law continues to work at the level of electrode arrays, it is conceivable that deep stimulation approaches may offer better integration and more bandwidth than peripheral stimulation at the level of the retina. However, direct retinal stimulation has been the most effective interfacing technology to date.

Similar to the way a bionic ear converts sound received by a microphone to electronically stimulate the auditory nervous system in ways that give the sensation of hearing, the bionic eye or artificial retina (see also) transduces light impinging on a camera receptor to electronically stimulate the visual system in ways to give the sensation of seeing. Work to build the bionic eye started later than that for the bionic ear (Ong & da Cruz 2012), but is conceptually more straight-forward since the retina works optically in the same way as the photosensitive back of a camera, so there can be something approaching a 1:1 transduction of the two dimensional image the camera "sees" and a two dimensional pattern of stimuli on the retina of the eye (Figure 79 left). . Klauke et al. (2011) provide some details on how the technology works. Further progress is being made towards this goal is being achieved by stimulating ganglion cells directly with encoded signals (Nirenberg and Pandarinath 2012) This is a paradigm where Moore's Law can apply directly, as suggested in Figure 79 right.

- Output transducers for bionic effectors

The converse to the development implantable bionic sense organs is the development of technology for the direct nervous control of prosthetic or other assisted action (Ganguly & Carmena 2009; McFarland & Wolpaw 2011; Onunka & Bright 2011; Fazel-Rezai et al. 2012), e.g., to control artificial arms and hands (Agnew & Dumanlan 2011), drones (Doud et al. 2011), etc… I expect output interfaces to develop along similar lines to those for input.

Moore's Law and its implications for embodied interfaces

Wearable and implanted human-computer interfaces are still relatively clumsy because we do not yet know how to interface electronically with specific receptor or output neurons in ways that correspond to natural interactions with the environment. We are only stimulating many thousands or possibly even millions of neurons simultaneously. We are only beginning to develop a deep understanding of how to best merge the technology and the biology to produce the most fully adaptive bionic whole.

Fallon et al. (2009) discuss this brain computer interfacing challenge in terms of "hardware" (the material components of the technology), "software" (computerized signal processing involved in the interfacing function – i.e., the "machine cognition"), and "wetware" (the biological side of the interface comprising physiological responses to attached/implanted hardware and cognitive responses to the signals). Software processes applying feedback to the technology such as manual tuning by an audiologist or the user, or perhaps by some automated analysis of electrical properties of the interface, adjust the signals crossing the interface to maximize benefit to the user. Similarly, adaptation and learning processes in the user's biological cognition similarly work to get the most out of the interface. Fallon et al. (2009) note that at least with bionic ears, user cognitive adaptation is most extensive and successful if implants are made in the first year or two of life, when the babies' brains are still learning how to process sound and recognize speech. However, the ideal is to integrate with the nervous systems receptors and transmitters in the same ways natural stimuli would excite them.

The continued application of Moore's Law to interfacing technology is likely to lead to much closer and physiologically less damaging connections between technology's hardware and wetware physiology, and between the software and the neural substrate of biological cognition. The most critical aspect for such interfaces is the transduction of signals between the hardware (most likely direct conduction of electrons) and the wetware (most likely electrochemical action potentials, or possibly in the more distant future neurotransmitters at the level of chemical synapses in the nervous system).

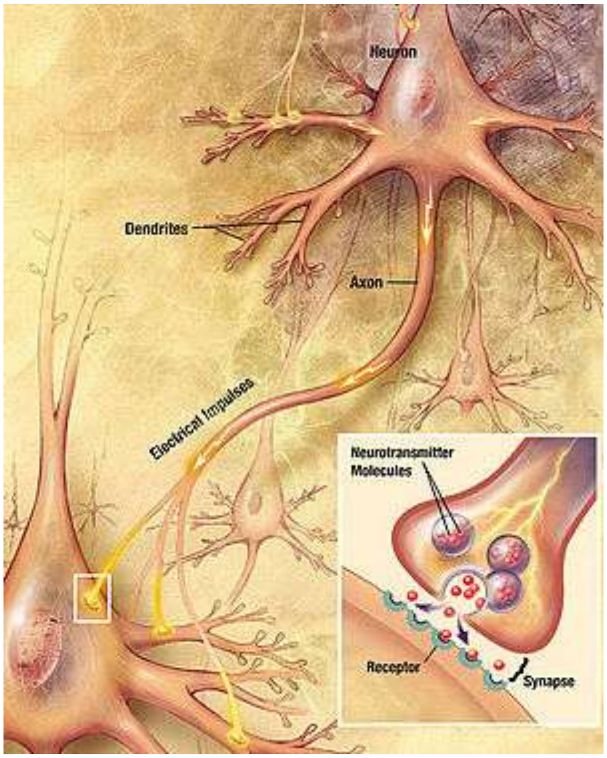


Figure 80. Action of neurotransmitters in a synapse between two neurons (NIH via Wikipedia).

Interface hardware

Although they have not yet been significantly integrated with other hardware and software into brain-computer interfaces, substantial progress has been made in developing nanowires of various metals, semiconductors, carbon nanotubes and graphene that can be made small enough to interface single nerve cells to either receive or transmit impulses (Grill et al. 2009; Cohen-Karni et al. 2011; Wang et al. 2011; Noy 2011; Voge & Stegemann 2011; Wallace & Higgins et al. 2012; etc.). The chemical possibilities for binding particular biomolecules to the electrodes suggest that in time it might be possible to design electrodes able to identify and possibly target particular cell types relevant to the desired interface. Moulton et al. (2012, p. 2012) summarize the requirements that must be met if devices using such technology are to be successful:

> It is critical that the chemical properties, including hydrophobicity and hydrophilicity, of the conductor should be biocompatible, non-cytotoxic, and sufficiently stable to undergo sterilization without deterioration of the above properties. Long-term material stability (e.g., years) in vivo may also be a requirement. … Finally and critically, the electrode materials to be used should be processable in such a way that they lend themselves to fabrication into practically useful devices.

These are hard asks that will probably be addressed via Moore's Law, and literature reviewed for this section suggests that at least some of the materials are biocompatible (e.g., Li et al. 2011 demonstrated the neurocompatibility of graphenes with mouse nerve cells in culture).

Once the physical interface between the technology and the biology is made, there are the possibly much more difficult problem of interfacing the cognitive software and the cognitive wetware. This will involve developing much better understandings of how sensory/situational information is encoded and decoded in the brain. Progress is being made towards this on a variety of fronts.

Wetware structure: brain imaging and mapping

Interfacing at the cellular level will require a deep understanding of how sensory signals are formed and processed in the nervous system, either in or near the sense organs or more deeply within the brain itself. This must be built on an understanding of the brain itself. Some very interesting progress is being made along these lines, where the goal is to map the physical structure of the nervous system in terms of the connections of nerve fibers at multiple scales of organization to produce what is called the connectome. This is progressing at several levels in parallel.

At the "microscale" (sub-millimeter range) people are working to build a picture of neural systems, neuron by neuron, using both various types of microscopy and by testing neural connections in vivo using microelectrode stimuli and recording, building dynamic models of supposed connections, and then testing model results with live recordings (Izihevich & Edelman 2008 Figure 81). It will be a long time before this can be done for a whole human brain, containing 10^{10} neurons and 10^{14} synapses compared to $3x10^{9}$ base-pairs in the human genome. Given that the human genome has already been completely mapped, though large, these numbers are not impossible to achieve[323]. Microscale maps are already being developed for cortical columns (e.g., Maçarico da Costa & Martin 2010; Boucsein et al. 2011; Shepherd 2011).

At the macro scale (greater than a cubic millimeter) a number of different technologies are being applied to understand its overall architecture both in terms of structure and in terms of connectivity. From a structural point of view, a number of techniques allow the macroscopic to near microscopic ("meso" scale) architecture to be worked out: such as histology (especially with Golgi staining) that allows mapping the axons and dendrites of single cells through large areas of the brain (e.g., as Modha & Singh 2010 have done for the rhesus macaque), various whole brain imaging techniques including magnetic resonance imaging (MRI), brain positron emission tomography, diffusion spectrum MRI, etc, and various stimulus-response mapping techniques. Example stimulus-response mapping studies include Murphey et al. (2009); Hill et al. (2012); Kombos & Süss (2009); Koch et al. (2010).

One of the more interesting imaging technologies to be developed recently for mapping connectivity at the meso-scale is diffusion spectrum MRI (Wedeen et al. 2005)[324], that traces the ease and distances water molecules can diffuse along nerve fibers versus across them. The imaging technique is particularly sensitive to the directional vectors of the fibers as shown in Wedeen et al's (2012) more recent work in the Human Connectome Project (see also and Figure 82). This is expected to throw substantial light on long-distance neural connections between different functional areas of grey-matter (where the computing is done) in different functional areas of the brain (Wig et al. 2011; Behrens & Sporns 2012; Van Essen & Ugurbil 2012) and "parcels" or modules that appear to be associated with particular functions (Yeo et al. 2011). The long term aim of the project is to merge the maps at the macro level with those at the micro level to understand the complete architectural structure of the brain. As connectomics is developed it is probably inevitable that the effectiveness and bandwidth of brain-computer interfaces will be greatly enhanced.

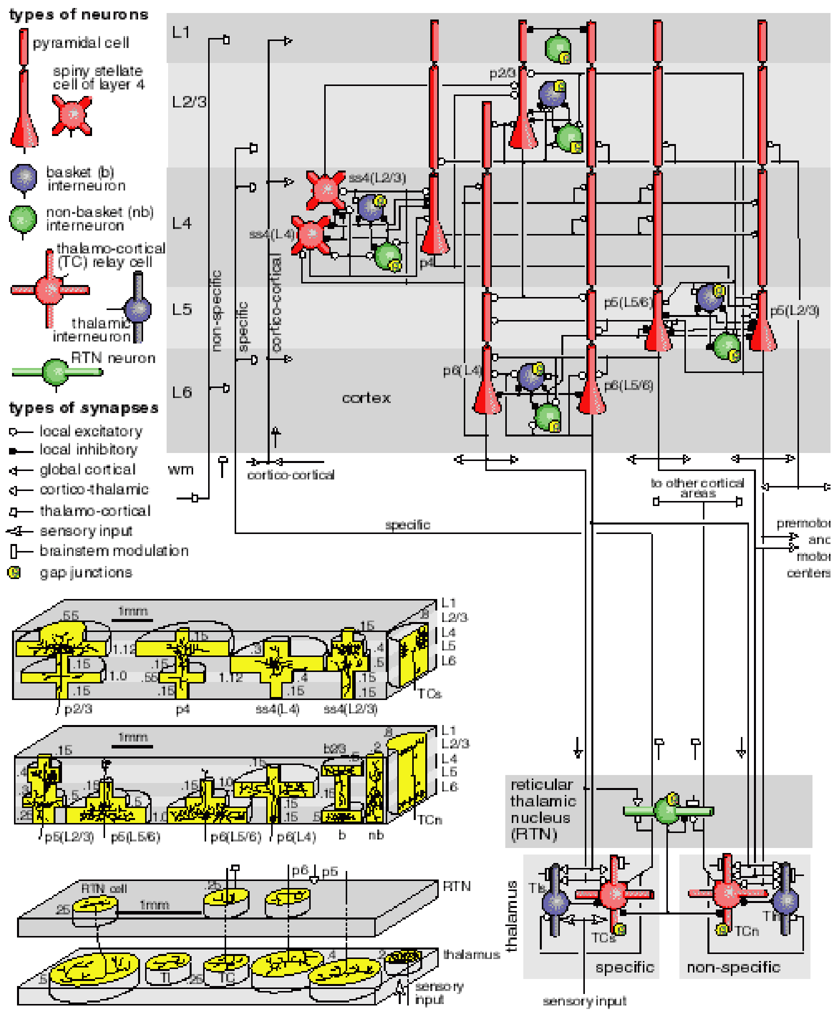


Figure 81. Izhikevich & Edelman's (2008 Appendix) model of the neural connections in a cortical column (upper) and major pathways connecting with the thalamic nuclei (lower).

Figure 82. (Click graphic to launch video). The tangled web of nerve fibers in the human brain turns out to be folding of 2D sheets of parallel neuronal fibers in a 3D grid structure that cross paths at right angles. This video came from the new Connectome scanner. Source: Van Wedeen (NIH News, 29 March 2012; Massachusetts General Hospital News Release, 29 March 2012)

Wetware processing: mapping, simulating and understanding cognition

The test of connectomics will be to simulate systems defined by the connections actually plotted. The long term goal is a complete simulation of the human brain "that replicates the functions of the emulated system by using the computational hardware of another system, and it strives to do this so well that the emulated system behavior is indistinguishable from its behavior on original hardware… *Whole brain emulation means that the functions of mind are implemented*…" (Koene 2012, p. 5). Cattell & Parker (2012) list five major challenges that must be resolved for effective brain emulation:

- *Neural complexity*. There are a variety of different kinds of neurons, with a variable variety of synapses generating various kinds of action potentials and other electrochemical pheonmena.
- *Scale*. A huge system will be required. Present computers have thousands of processors, the human cortex has tens of billions of neurons and a quadrillion or so synapses.
- *Interconnectivity*. A neuron may share synapses with 10,000 up to 100,000 other neurons. Similarly, axons may fan out to an average of 10,000 different destinations.
- *Plasticity*. Memory and learning imply substantial plasticity in the behavior of particular neurons and their connections.
- *Power consumption*. What will be the power consumption and heat dissipations requirements for a computer-based emulation of 50 billion neurons and 500 trillion connections? The human brain is estimated to dissipate around 25 watts!

Given the ongoing convergence of technology and biology empowered by the continued operation of Moore's law on many aspects of the technology, a substantial community of researchers believe that these challenges can/will be met. A number of studies using different simulation approaches are underway (de Garis et al. 2010) . Cattell & Parker's (2012 – see also their Project comparisons) summary describes 6. Two examples highlight different approaches:

- C2S2 SyNAPSE. A team at IBM's Alamaden Research Lab led by Dharmendra Modha used a massively parallel cortical simulator running on IBM's Dawn Blue Gene/P supercomputer, with 147,456 more-or-less conventional CPUs and 144TB of main memory. Following connectome models this was used generically simulate a rat cortex and then a cat cortex (Ananthanarayanan et al. 2009; Merolla et al. 2011; Seo et al. 2011; Arthur et al. 2012). The Spanish language blog, "Francis th(E) mule Science's news" summarises the work (as translated by Google Translate).
- SpiNNaker: A group at Manchester University fabricated custom chips containing 18 very low-power CPUs, each with about 100KB of local RAM for programming and data; 128MB of RAM shared by all 18 CPUs to store synaptic weights and other information; and an on-chip network and packet router that connects the 18 CPUs and 6 adjacent SpiNNaker chips, to reach other CPUs. The maximum number of SpiNNaker chips supported by the address structure is 65,000. this could simulate ~ one billion neurons (Galluppi et al. 2012; Painkras & Furber, S. 2012).

A third project, massively funded (€643 million) by the European Union, is the Blue Brain Project (see also) that seeks to understand what it means to be human, to develop new treatments for brain disorders, and to build revolutionary information and communication technologies

(Markram 2006; Walker et al. 2012). This is also based on IBM technology and may lead to the fabrication of specific hardware.

EU Human Brain Project: €1 BN neuromorphic supercomputing platforms etc. (video playlist).

BRAIN Initiative (US) $3 BN

Ananthanarayanan et al. (2009) apply Moore's law to their progress and supercomputing technology to estimate when systems will have a sufficient scale to emulate 100% of the human brain in real time. Poon and Zhou (2011) argue that complementary metal-oxide-semiconductor (CMOS) transistors working between their threshold current behave very similarly to ion channels in neurons and consume very little power. This enables the development of "neuromorphic" silicon neurons allow neuronal spiking dynamics to be directly emulated on analog VLSI chips without the need for digital computation (or details on the technology see Indiveri et al. 2011). The potentially low power requirements, very simple circuitry, and minimal needs for active programming control may provide solutions to the five major challenges laid out by Cattell and Parker (2012). If these problems do not block steady progress, Ananthanarayanan et al. suggest that the human brain emulation may be achieved as soon as ~2019 (Figure 83)! Of course, it is a long way from there to learning how to teach the emulated brain and to build its sensory interfaces.

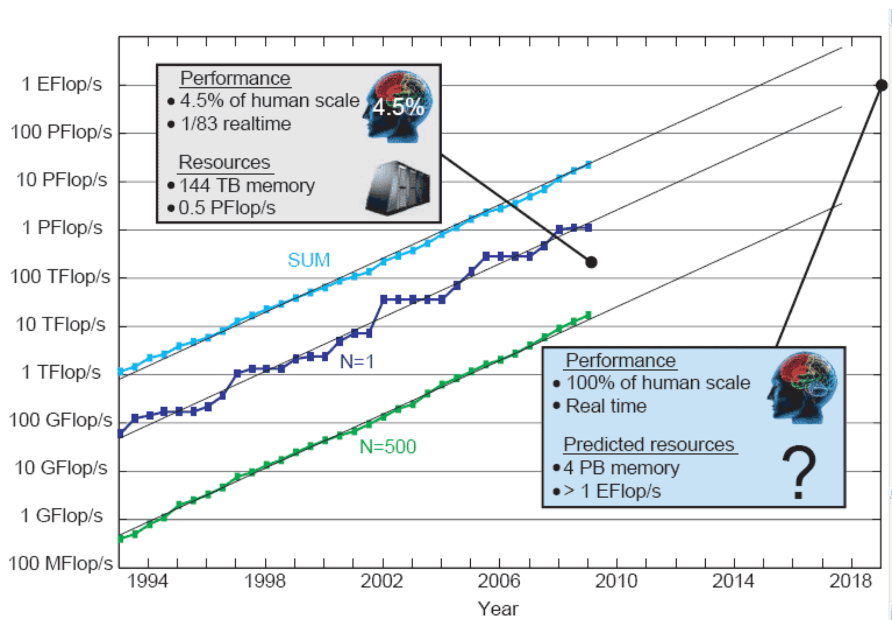


Figure 83. Progress towards computer emulation of neural processing in the human brain (Ananthanarayanan et al. 2009).

Cognitive convergence between wetware and hardware/software

What is likely to happen when the brain-computer interfacing (BCI) capabilities discussed above begin to be implemented in healthy people with no sensory or motor impairments (Nijholt 2011)? From the material surveyed above it seems inevitable that the boundaries between human cognition and cognitive technologies are becoming increasingly blurred and could well disappear within the next decade or so as human wetware and technological hardware/software continue to converge from two directions.

First will be the development of ever closer, more intimate interfaces between people and cloud-based technologies that give the web-extended mind powers beyond anything we can readily conceive from the points of views of un-augmented people (Smart & 2012; Verbeek 2009). An instance of how such mergers might work is given by Pohlmeyer et al. (2011), where an electro-encephalographic "interest detector" helps users identify and select particular types of images from a large database. As such functions become better and more permanently integrated with neurobiologically-based cognitive processes the actual boundary between human and technology will become increasingly difficult to define.

Paralleling the first development, will be the development of increasingly humanoid cognition in the technology itself (Shi 2011). In whatever ways this convergence plays out, a number of moral questions will be raised by the augmentation of human powers and the blurring of borders between people and their technological capabilities (Koops & Leenes 2011; Schermer 2009). These questions are beyond the scope of this particular book to consider in detail.

What does it mean to be human?

A central concern of this book is to understand the evolving nature of humans and how evolving technology has and will change the nature of human evolution. This will be a major consideration in effectively studing the moral questions. Reviewing some of the ideas relating to autopoiesis, consciousness and learning will help us to understand the changing nature of the boundary between the person and the technology.

Autopoietic boundaries and cognition

As discussed in the Interlude section on Autopoiesis, an autopoietic system is an organized network of processes contained within a definable spatial boundary that through their interactions and transformations continuously regenerate and realize this network (relations) as a definably bounded entity. Following Varela et al's (1974) criteria, autopoietic entities are identified by six necessary and sufficient conditions. They are *bounded, complex, mechanistic, self-referential, self-producing,* and *autonomous*. In other words, autopoietic systems are bodies formed by self-referentially cyclic processes that work to maintain their existences through time in a constantly changing world, using feedback from observations of their selves in earlier instants of time (because the process of turning observations into actions always takes time) to maintain the capacity for autopoiesis.

In Popperian terms, dynamic changes in the physical W1 external to the body impact on sensory transducers on or near the body surface where the changes trigger propagating disturbances within the structure of the autopoietic system that may thereby be processed cybernetically in order to act and respond in ways to mitigate threats to or that enhance the continuing autopoiesis of the system (Figure 75). Similarly, changes in the physical WI within the body impact on a variety of internal sensory transducers (receptors) that trigger cybernetic processes leading to actions that regulate bodily homeostasis, such as muscular responses triggered by nerve action potentials or the release of neurotransmitters or hormones that chemically trigger actions elsewhere in the body[325].

In humans, external states of the world are transduced on or near this surface boundary by the well known outward looking sensory systems such as vision, hearing, smell, taste and touch. Processed inputs from these systems are registered or "mapped" on 2-dimensional surfaces of the cerebral cortex (Damasio 2010), where changes can be consciously monitored in case some kind of complex action is needed to help protect/maintain the autopoietic state in face of a threat or attraction. Internal physical, chemical and thermal states are transduced by a variety of nerve endings for such things as proprioception, baroreceptors (sensing blood pressure), and other internal aspects of the somatosensory system, plus a wide range of sensory modalities of the autonomic nervous system and other specialized sensory/response systems such as the carotid body. In many cases the stimuli are monitored and acted on (where action is required) by local ganglia in the peripheral nervous system or unconsciously in lower areas of the brain such as the brainstem. Only in the case where something is seriously wrong with our internal states do we become consciously aware of the sensations and consciously act to remedy external circumstances, self-medicate or call in a doctor to help restore the state of healthy autopoiesis.

Maturana and Varela (1973, 1980) considered the cybernetic processes of these self-regulatory and self-maintenance activities to constitute cognition. All of the processes of autopoiesis are physical/chemical changes taking place in W1. What constitutes autopoiesis (i.e., "life") in the organism are the *cybernetic aspects of the recursive spatial and temporal dynamics* of the processes (i.e., "cognition" in W2) that serve to maintain the continuing structural framework where these processes can continue to iterate as physical changes impact the system. In humans cognition can be divided into the unconscious processes of sensation and self-maintenance, and those that we are at least in part consciously aware of.

Consciousness gives humans the capacity to become aware of, learn about, anticipate, and respond thoughtfully to developing external threats or opportunities in an efficient and timely way before they have major impacts on the body. The survival and success of the autopoietic entity depends on its scopes of perception and possible actions in the face of all of its actual and potential interactions with the external world. In humans, these are greatly extended by our self-conscious cognitive capabilities in comparison to all other animals, including our closest primate relatives. Because we can have highly plastic abilities to sense, learn, anticipate, plan and act; including especially the capability to make and use an infinite variety of tools to extend these capabilities, humans have totally dominated the Earth's ecosystems. In autopoietic terms, where are we going as we and our cognitive tools continue to evolve and change in grade-shifting ways?

Conventially, as autopoietic entities, individual animals and humans are considered to be bounded by their skin. However, as has been demonstrated in this book, our autopoietic consciousness is being extended and augmented by a variety of increasingly intimate technologies.

Neural basis for self-consciousness

I include the following material mainly to show that neuroscience is already well along the path to understanding the neural processes underlying self-conscious cognition. In other words, our understanding of cognition is growing exponentially towards the point where emulation and the implementation of close technological interfaces will become realistically feasible.

Neuroscience is not one of my specialties, so some of what I write here is very dependent on the literature. Also, I cite mainly literature that is available free-to-the web so it may be easily accessed by those interested in researching the experimental basis for the claims. The conclusion I draw is that there is increasing evidence that human self-consciousness is an emergent phenomenon (in W2) of cyclical neurophysiological processes (in W1) going on in the brain. The issue relates to the fundamental issues of the "body", "mind", and their relationships (Popper 1972, 1994; Popper & Eccles 1977), especially at the neurophysiological level (for which little could be said when Popper was writing). However, studies like those cited above in the previous sections, and of people who are psychopathic or have damaged brains or other neuropsychological defects (e.g., Damasio 2010), are revealing increasing details of the cybernetic workings of the brain. From such studies, we are beginning to develop a reasonable understanding of how the brain generates a conscious mind that senses the self, "owns" a body, and has some degree of free will to decide and act on the world (Synofzik et al. 2008a).

Damasio (2010 p. 158) defines consciousness as "a state of mind in which there is knowledge of one's own existence and the existence of surroundings". Damasio (1999), Synofzik et al. (2008a, 2008b), Morsella et al. (2011), in seeking to understand self-consciousness, argue that one of the core aspects of self-consciousness is *a sense of* "*agency*" or of its capacity for voluntary action (Haggard 2008). In other words, this is the cognitive process that results in the "I" of "I did that" (Engbert et al. 2008). Morsella et al. (2011 and other sources Morsella et al. cite) define agency as the individual's sense that he/she is acting autonomously (i.e., has the free will) to cause a physical or mental action. Figure 84 illustrates the cyclic nature of the comparator model (Nahab et al. 2011) in the framework of the OODA cycle. Haggard (2008 - Figure 85)[326]

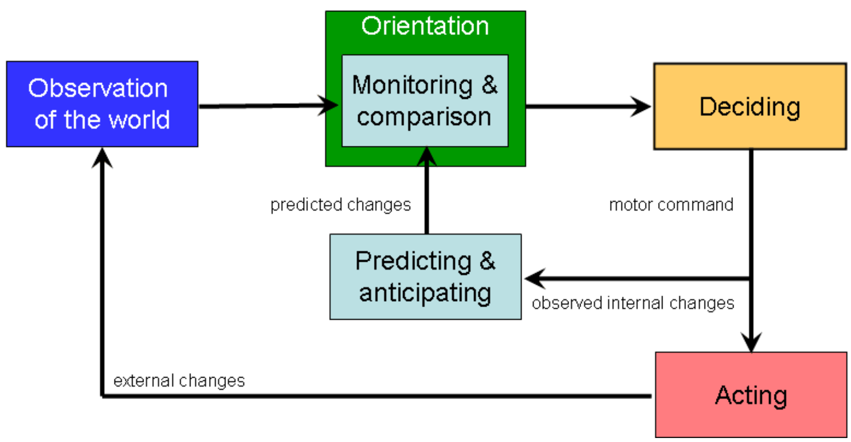


Figure 84. Primary components of a "comparator model" of agency (after Morsella et al. 2010 – ref Figure 75).

Explorations the neurophysiological correlates to this sense of agency seem to be leading towards an understanding of the neurological basis for consciousness, but are at the same time entangled in physical, psychological and philosophical questions as to whether the sense of conscious will is a mental illusion (e.g., Wegner's 2002 "*apparent mental causation*"), or the result of the direct causal effects of conscious intentions (what Schlosser 2012 calls "*real mental causation*"). To address this issue fully is beyond the scope of the present work[327], but I think that Schlosser's review (loc. cit.) and Shurger et al. (2012) provide explanations consistent with real mental causation for the observations used to support apparent mental causation. In any event, whichever is the case, the overall effect of the top-down hierarchy of causal processes in autopoietic consciousness (Hall 2011: pp. 46-48; Hall et al. 2011), Autopoiesis, downward causation and free will) is that the individual has the capacity to decide and act in the environment in ways that protect and enhance the autopoietic state.

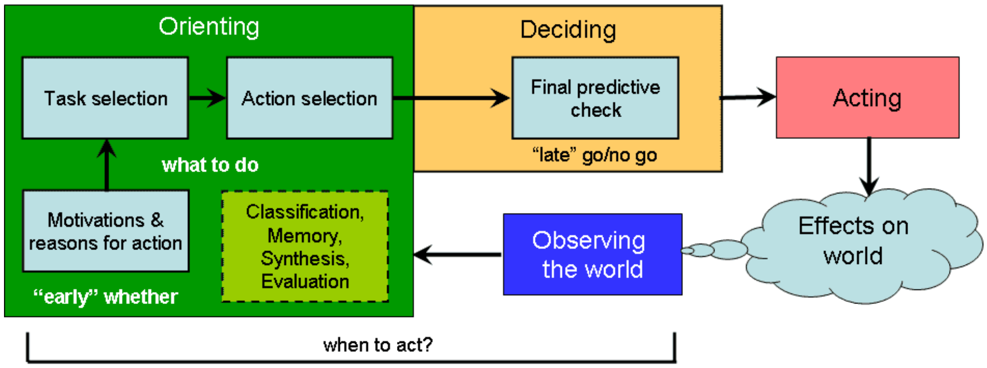


Figure 85. Human volition cycle (after Haggard et al. 2008).

Self-consciousness involving the awareness of self and the self's agency is probably based on iterated volition cycles (Figure 85) where the cycles of sequentially coordinated firings of single neurons in several areas of the brain associated with decision and action can be observed (Haggard 2008; Madl et al. 2011; Fried et al. 2011; Klemm 2011; Haynes 2011; Gluth et al. 2012; van Gaal et al. 2012. At the level of sets of neurons, Klemm (2011) calls these cycles of action potntials circuit impulse patterns (CIP). To me, each cycle would represent a tick of the primary clock underlying the OODA cycle. Comparable to the way that the sense of personal agency is generated when the sensed results of cognitively triggered actions a the level of individual neurons correspond to the predicted results of the actions (e.g., Morsella et al. 2010 Figure 84), it is plausible that, by detecting unanticipated changes in sensory inputs from one CIP cycle to the next, the brain is alerted to a potential change in the world that may require orientation and some form of adaptive response to manage the change. Through the continual iteration of such cycles, the autopoietic individual works to sense and control the world. In humans, through our sense of agency and self, we are consciously aware of the world, its changes, and our abilities to respond to and control those changes with decisive actions.

Human evolution in several dimensions

Even though cognitive tools extend our powers, as long as we keep them at arm's length (i.e., in the hand), it is still relatively easy to accept the skin as the real boundary of our autopoietic existence. It is physically easy to turn off a smartphone and walk away from it. And to now it has been easy to think of humans and the technologies we use as evolving more-or-less independently. However, the situation changes very radically when interfaces with the technology are worn more-or-less permanently on the skin as a part of the body (e.g., head-mounted devices - except possibly when we are asleep) or permanently implanted under the skin where they can bypass the normal input transducers (e.g., eyes & ears) and output effectors (e.g., arms & legs) to interface directly with the nervous system (e.g., as with bionic eyes and ears). In these situations, the boundary of the autopoietic entity extends to include the capabilities of the interfaced devices – which we have seen in the case of the smartphone can extend from to include almost any imaginable networked function we may wish to control through the interface.

I will conclude this episode with some thoughts about what these changes in the autopoietic boundary mean for human evolution.

One of the themes of this book is that revolutionary technologies have caused major grade shifts in the evolution of the human species as we eolved the capacity to use tools, speech, writing, computing, etc., where, arguably, each grade shift in the sequence took less time (millions of years, hundreds of thousands, centuries, and now decades or less), and each shift expanded the scope of human control over the environment to a substantially greater extent than did each previous shift. Natural selection in the Popperian sense drives these changes to occur. Basically, entities whose adaptations give them more strategic power to control any limiting environmental resources they need or can benefit from will thrive and flourish at the expense of those with less strategic power. What suffices today may not suffice tomorrow. Advantage goes to those able to adapt to the changing world – random change, changes resulting from own actions, changes from actions of others (see Qualitative Values of Different Kinds of Information, Adaptation, Knowledge and Strategic Power in Popper's Three Worlds, and The Cybernetics of Power: Boyd's OODA Loop Concept).

Different dimensions of heredity are involved as the grade shifts evolve over ever shorter time spans. Acquiring the capabilities for speech and to make and use tools required thousands or more generations of natural selection working on the genetic basis for cognition. The development of counting and writing primarily involved the cultural development, intragenerational sharing, and transmission from one human generation to the next through time of the knowledge of how to do these things. Once substantial knowledge was encoded in books, the knowledge base could evolve as fast as people could generate and test theknowledge. Learning to use printed books is something that virtually every child learns to do in the first decade of life. Similarly, we see most children now learning to use their smart phones and other computer-based devices almost as fast as they learn to talk. Similarly, the knowledge accessed via the devices is evolving in the electronic environment with increasing rapidity compared to the comparatively slow publishing cycle for paper books. Today, most of our adaptations to the environment are technologically mediated – by technologies we may soon be able to control via neural interfaces by thought alone.

Needless to say, this will change the nature of autopoietic humans in ways we cannot conceive by looking at human history up to this point in time, such that we are rapidly approaching a complete discontinuity in the evolution of humanity. Also, as will be seen in the next episode, social and organizational implications of the changes may represent an even greater break with the past than we see from looking at the impacts on single individuals.

EPISODE 5 – Extending Social Cognition and Emergence of Socio-Technical Organizations

Introduction

Previous episodes have explored the historical evolution of different grades of cognitive technologies and their impacts on individual people through time and as extrapolated a bit into the future. In this last and long episode, a fugue within the fugue that forms the book, I reconstruct the evolutionary emergence of modern humans together with our technologies and our knowledge-based socio-technical cognitive systems. Based mostly on evidence published since 2010 or so, I try to answer the question of how the unique biological and behavioral solutions evolved that enabled humans to dominate the planet. As a result of this success, the biomass of living humans is now probably more than eight times the biomass of all other terrestrial wild vertebrates combined (Hill et al. 2009, Smil 2002) and there are now more economic specializations in the US than there are mammalian species on Earth[328]. I then explore how higher level socio-cognitive systems formed by humans became autopoietic and emerged as evolutionary entities in their own rights.

This reconstruction traces the evolutionary history of humans from our common ancestor with chimpanzees and bonobos, forest apes with a capacity for enough cultural knowledge to make and use a few very simple tools, through to today's humano-technical cyborgs and self-perpetuating autopoietic organizations. This will be developed in the following main sections:

- *Material Evidence: What We Think We Know About Hominin Evolution*: Examines some critical ideas and recent papers setting out the fossil, genomic, and paleoarcheological evidence used to constrain development of the evolutionary hypothesis and reconstructs the deep pedigree and family history of our species that has been revealed over the last decade through the application of automated gene sequencing technologies and computer analysis.
-

- *An Evolutionary Hypothesis: - Our First Five Million Years or "How Did We Get Here*?": Presents a detailed hypothesis explaining how selection shaped forest dwelling apes into the planet dominating post humans we are today. This is fleshed out by what paleontology (i.e. fossil bones), paleoarchaeology (the remains of ancient tools and living sites) and comparative behavioural studies of our close primate relatives tell us about how our ancestors made their livings as they progressed from being cowering savanna apes to become apex carnivores across Africa and Eurasia able to consume whole ecosystems.
- *Cooperation is innate – human social organizations as higher order living systems*: explains the evolution of knowledge-based autopoietic organizations from cooperative groups of people.
- *Moores Law and the rise and rise of socio-technical organizations*: explores the roles of exponentially more powerful cognitive technologies in the emergence and proliferation of modern socio-technical organizations such as states and large corporations.

This episode presents my reconstruction of the evolutionary dance between humans and human technologies from a strongly biological point of view, and assumes some understanding of evolutionary biology. For those who may have difficulties following this approach or its jargon, the Appendix 1 explains key ideas about biological species and evolutionary processes underlying this presentation.

Material Evidence: What We Think We Know About Hominin Evolution

This section reviews the latest available material evidence to reconstruct the last five million years or so of human history. It describes our differentiation from the anthropoid apes and explains how we have reconstructed this process.

Modern humans (*Homo sapiens*) belong to a taxonomic group or clade called Hominina (informally known as hominins)[329]. This group includes several extinct primate species along with modern humans that diverged some five to seven million years ago (abbreviated mya) from the Panina (panins) including the surviving chimpanzees and bonobos. These two species probably resemble our last common ancestor (LCA) more closely than we do. The present episode explores how we humans came to be so different from these close living relatives. The detail of this section will help inform thinking about and to constrain and develop a detailed evolutionary hypothesis in the following sections that explains how we humans came to dominate the world.

What fossils tell us about our pedigree and relationships

A fossil is the surviving indicator that a particular organism died. Depending on how complete they are, fossils tell us something about the morphology of the individuals they represent. A given fossil also tells us that the individual whose remains formed the fossil died at or near the particular geographic location *where* it was found. There are also a number of ways we can determine with more or less accuracy *when* the remains came to be interred, such as stratigraphy combined with geochronology and radiometric dating. Given that a species' morphology is part of its adaptation to a niche, even a scrappy fossil (e.g., an isolated tooth) may tell us something about the kind of food the species was adapted to eat. In exceptionally rare and important cases fossils less than approximately 400,000 years old may even carry DNA that is good enough for genome sequencing[330].

The fossil record and the ecological and geographical distributions of our living relatives provide some constraints on where, when, and how various grade shifts occurred in the evolutionary emergence of modern humans' ecological dominance of Earth's resources. It should be noted that names, definitions and relationships of the fossil species discussed here are all subject to significant differences of interpretation and controversy among the range of authors cited herein, as reviewed by Schwartz & Tattersal (2010). However, fossil teeth, jaws, skull shape and connection to the backbone, pelvis, limb proportions, wrist and ankle joints, and finger proportions – when available – allow us to infer a lot about the biology of the organisms leaving the fossilized remains.

In the early Miocene several fruit eating, arboreal, ape-like primate species lived in tropical forests around the margins of the ancestral Mediterranean (Andrews & Kelley 2007; Begun 2007, 2009, 2010). Tectonic activities offered occasional connections between Africa and Eurasia allowed migrations between the two continents (Begun et al. 2012; Senut 2011). Gibbons and possibly orangutans may be direct survivors of the early Eurasian primates (Jablonski & Chaplin 2009) or they may have come out of Africa (Chaimanee et al. 2003), while the ancestral hominines (ancestors to all of the great apes, including ourselves) either migrated from Eurasia to Africa or emerged from stocks native to Africa (Begun *loc. cit.*).

As the Miocene progressed there were a number of major climatic fluctuations resulting from tectonic changes to the proto-Mediterranean Sea and surrounding lands. Large areas of the continental margins were variously submerged or raised, providing sporadic land bridges between northern Africa, Europe and Asia. Resulting impacts on climate variously moved the boundary between ape friendly tropical forests that provided suitable habitats for tree-dwellers, and drier savannas and grasslands where they could not survive, back and forth between the Eurasian and African sides of the proto-Mediterranean Sea (Senut 2011; Crowley 2012). For some 300,000 years at the end of the Miocene, during the Messinian Salinity Crisis around five million years ago, the Mediterranean basin became landlocked and evaporated to desert (Popov et al. 2006; Garcia-Castellanos et al. 2009).

By the Late Miocene apes in Europe and Asia Minor (Anatolia) were extinct due to the loss of suitable tropical forest habitats as these were replaced by drier, more open, and more uniform grassy habitats favored by grazing ruminants (Merceron et al. 2010). This left ancestors of today's gibbons and orangutans in the surviving forests of SE Asia, and the ancestral hominines in the surviving humid forests of central and southern Africa where they were subjected to further upheavals associated with the opening of the Great Rift Valley, mountain building and associated fluctuations in climates and vegetation (Christensen & Maslin 2008, Bonnefille 2010)[331].

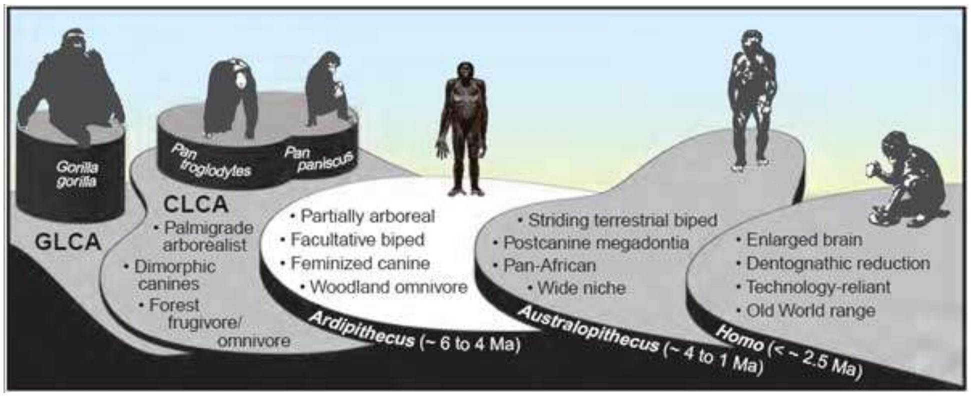


Figure 86. Adaptive plateaus achieved by different hominin grades in the Pliocene as our ancestors became more adapted to more open and arid environments that required terrestrial locomotion favoring bipedalism White et al's (2009).

The fossil record of early hominines (includes gorillas, chimpanzees, bonobos and human) is sparse, but does provide some clues. The story seems to be one of a sequence of grade shifts followed by adaptive radiations on what White et al. (2009) call "adaptive plateaus" (Figure 86)[332]. The hominin stock (the lineage giving rise to modern humans) diverged from the chimpanzee/bonobo (panin) stock during the late Miocene or early Pliocene. Wood & Harrison (2011) suggest that this divergence occurred between 4 and 8 (more likely 6) million years ago (mya), and that the skeleton of the last common ancestor of panins and hominins probably more closely resembled today's panins than today's modern humans. Wood (2010), Wood & Baker (2011) and Wood & Harrison (2011) also review the known fossil species with regard to the different grades (Figure 87). MacLatchy et al. (2010) present a formal taxonomy for all hominin fossils. Given the scattered nature of references to the various fossil species, de Sousa & Cunha (2012 - Table 2) list approximate date ranges for the more important named species. However, even their "splitters'" taxonomy does not cover all the fossil names encountered in the literature.

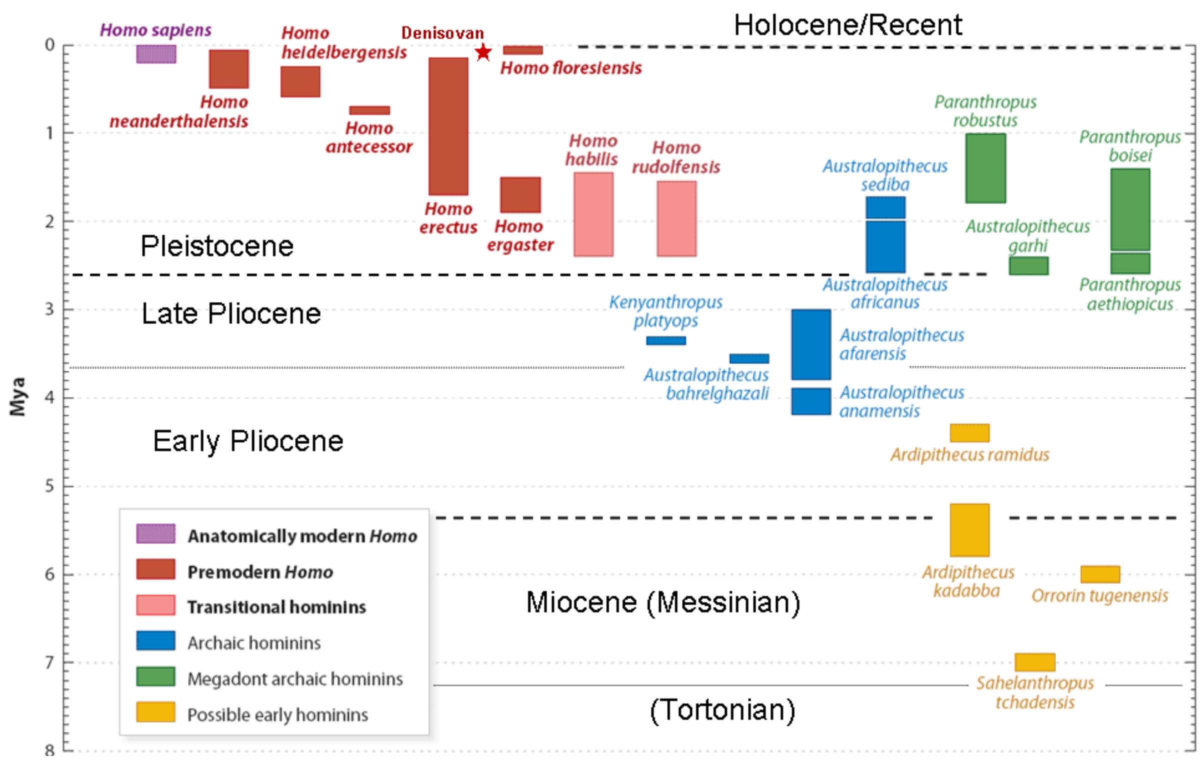


Figure 87. Grades and temporal distribution of hominin fossils. Bar colors indicate morphological grade - Wood & Baker 2011; see also Fig. 5 in White et al. 2009). Bar heights indicate the time periods represented by the available fossil evidence (in terms of dates of first and last occurrence – or uncertainty). The earliest fossils of anatomically modern humans date from 190 thousand years ago (kya) and 160-154 kya (both from Ethiopia – in the Rift area). In Eurasia Neanderthals are dated from ~200 kya to ~30 kya (Vandermeersch & Garralda 2011). The genomically characterized Denisovan individual is known from one finger joint and two teeth dating from about 40 ± 10 kya[334]. *H. floresiensis* fossils and associated tools are dated to 74 -17 kya. The Smithsonian National Museum of Natural History explores the hominin family tree in considerable detail.

Based on life-styles and biology of our living relatives, the most recent (i.e., last) common ancestor of humans and chimps (White et al. 2009, Figure 86; see also Duda & Zrzavý 2013) was probably a forest dweller feeding on fruit and other soft foods that clambered in trees hand-over-hand and walked quadrupedally along branches on the palms of its hands (i.e., like a monkey). The first probable hominins showing evidence of bipedalism included *Sahelanthropus*, *Orrorin*, and *Ardipithecus*[331]. Stanford (2012) argues that *Ardipithecus* fossils strongly support a chimpanzee model for the behavioral ecology of early hominins. The first grade shift from the forest dwelling last common ancestor with chimpanzees probably involved the evolution of a more omnivorous diet and improved bipedalism, facilitating exploitation of more open woodlands.

Table 2 (de Sousa & Cunha 2012)

Approximate date ranges for fossil hominin species, which are defined according to both speciose and short taxonomies (after de Sousa & Cunha 2012**)**

	Splitters taxonomy	Lumpers taxonomy	Approximate date range
Possible hominins	*Sahelanthropus tchlldensis*	*Ardipithecus ramidus* s.l.	7Ma
	Orrorin tugenensis	*Ardipithecus ramidus* s.l.	6Ma
	Ardipithecus kadabba	*Ardipithecus ramidus* s.l.	5.8-5.2Ma
	Ardipithecus ramidus	*Ardipithecus ramidus* s.l.	4.5-4.3Ma
Archaic hominins	*Australopithecus anamensis*	*Australopithecus afarensis* s.l.	4.2-3.9Ma
	Australopithecus afarensis	*Australopithecus afarensis* s.l.	3.7-3Ma
	Australopithecus bahrelghazali	*Australopithecus afarensis* s.l.	3.5-3.0Ma
	Kenyanthropus platyops	*Kenyanthropus platyops*	3.5-3.3Ma
	Australopithecus africanus	*Australopithecus africanus*	3-2.4Ma
	Australopithecus sediba	*Australopithecus sediba*	1.95Ma
Megadont archaic hominins	*Australopithecus garhi*	*Australopithecus garhi*	2.5Ma
	Paranthropus aethiopicus	*Paranthropus boisei* s.l.	2.5-2.3Ma
	Paranthropus boisei s.s.	*Paranthropus boisei* s.l.	2.3-1.4Ma
	Paranthropus robustus	*Paranthropus robustus*	2.0-1.5Ma
Transitional hominins	*Homo habilis* s.s.	*Homo habilis* s.l.	2A-1AMa
	Homo rudolfensis	*Homo habilis* s.l.	2.4-1.6Ma
Premodern Homo	*Homo erectus* s.s.	*Homo erectus* s.l.	1.9-1.5Ma
	Homo ergaster	*Homo erectus* s.l.	1.8Ma-30ka
	Homo antecessor	*Homo antecessor*	780-500ka
	Homo heidelbergensis	*Homo heidelbergensis*	600-100ka
	Homo neanderthalensis	*Homo neanderthalensis*	200-28ka
	Homo floresiensis	*Homo floresiensis*	74-17ka
Anatomically modern Homo	*Homo sapiens* s.s.	*Homo sapiens s.l.*	195ka-present

Note 1: s.s., sensu stricto; s.l., sensu lata.

Note 2. Genomic data argues that *H. neanderthalensis* , Denisovan Man, and *H. heidelbergensis* are not *H. sapiens* .

The second major grade shift was probably to full bipedalism. White et al. (2009), suggest that *Ardipithecus ramidus*[332] may be ancestral (or at least closely related) to the later radiation of *Australopithecus*. The more recent *Australopithecus* were apparently fully bipedal (i.e., the skeleton supported a striding and possibly running gait, although they still retained adaptations for tree climbing – DeSilva et al. 2013) and thus able to readily exploit drier savanna and grassland habitats over much of Africa away from forests. *Australopithecus* were ancestral to robust terrestrial herbivores on one hand (*Paranthropus)*, and more gracile tool-users able to exploit a wider range of dietary niches (*Kenyanthropus* and probably also *Homo*). Berger et al. (2010) suggest that the still small-brained early Pleistocene *Australopithecus sediba*[335] may be transitional to early *Homo* species. *Au. sediba* is securely dated to 1.977 mya by the uranium-lead method and geomagnetic reversals. Pickering et al. (2011) and Berger (2012) claim the *Au. sediba* date precedes the first clearly documented/dated *Homo* fossils and thus might be ancestral to *Homo*. Berger et al. (2015) described *Homo naledi*, based a remarkably complete collection of as yet undated hominin fossils from the Rising Star cave system in South Africa with a mosaic of primitive 'arborial' and 'modern' features (Stringer 2015) suggesting that it might represent a basal *Homo*[333]. Until these fossils are dated, their evolutionary significance remains highly uncertain.

- *Homo emerges and crosses the continents*

The grade shifts in Africa initiated an evolution of increasingly large brains in "early *Homo*" → "*erectus*" → *heidelbergensis* → [*neanderthalensis* + Denisovans + *sapiens*], that successively dispersaled out of Africa. In the next segment, genomic data shows that contemporaneous Neanderthals, Denisovans, a probable 'ghost' species known only from its imprint on the other species, and *sapiens* are sufficiently distinct genetically, but cohabited long enough for minor hybridization and introgression between these four species of *Homo* that met and paired with one another in their migrations[336].

Until recently the well known Oldowan "mode 1" tools (see What ancient tool-kits tell us about our ancestors for more detail) from about 2.6 mya (Stout et al. 2010) were the oldest known stone tools, and it has been assumed that early *Homo* made them (de la Torre et al. 2011). *H. habilis* and *rudolfensis* are the oldest fossils attributed to *Homo*[337] (Leakey et al. 2012; Wood 2012; Antón & Snodgrass 2012 - Figure 88), but Pickering et al. 2011 and Berger 2012 trenchantly question the assignment of scrappy fossils older than 2 mya to *Homo*)[338]. The earliest *Homo* fossils (e.g., Pratt et al. 2005, from 2.4-2.3 mya) are associated with these tools. It also seems that these early *Homo* had somewhat larger brains than *Australopithecus* – around 640 cc compared to ~450 to 550 cc for various *Australopithecus* (Tobias 1987; Bailey & Geary 2009). The recent discovery of stone tools from around 3.3 mya at Lomekwi 3, West Turkana, Kenya, predates the oldest Oldowan tools and recognized *Homo* by some 700 kya, suggesting that other hominins were also able to knap cutting tools (Harmand et al. 2015). Similarly, the dating of pebble tools and cut marked bones from NW India to 2.6 mya (Malassé et al. 2016) suggests than an older tool-making hominin colonized Eurasia before *Homo* did.

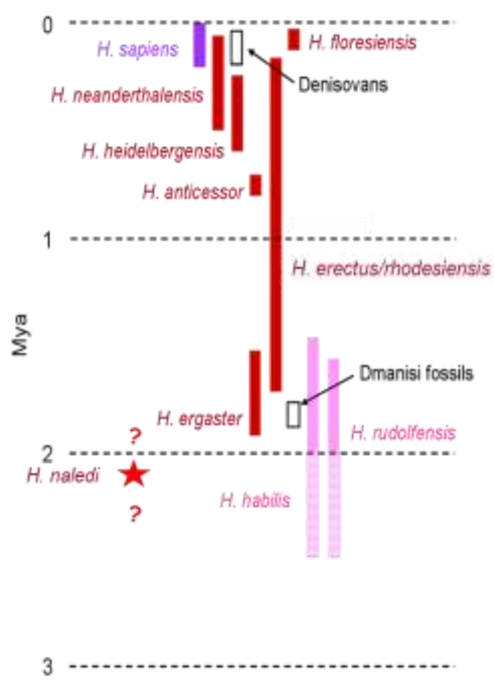


Figure 88. Temporal distributions of generally recognized fossils assigned to the genus *Homo* (after Wood 2012). Colors indicate grades as defined in Figure 87. Fossils older than 2 mya are very fragmentary and their assignment to species is tentative. Although Denisovans have been characterized genetically as related to but specifically distinct from both *H. sapiens* and *H. neanderthalensis*, except for two teeth and part of a little finger bone, the Denisovan's morphology is still completely unknown.

Although *Homo* most probably evolved in Africa, paleoarcheological, fossil and genomic evidence shows that different *Homo* colonized Eurasia at different times, presumably via Asia Minor and the "Levant" (Ronen 2006 - for details see below on Fossils, tools, genomics and human migrations). The earliest fossil evidence for any *Homo* found outside Africa was for the small-brained (cerebral volumes from 546 to 730 cc) species recovered from 1.8 million year old sediments in the Georgian town of Dmanisi, Georgia (Gabunia & Vekua 1995; Lordkipanidze et al. 2013)[339]. Except for brain size, the Dmanisi fossils are close to if not the same as the generally larger-sized and larger-brained (725 to more than 1100 cc) *Homo erectus*[340] (Rightmire 2004, Rightmire et al.

2006) that crossed Asia to Indonesia and China earlier than 1.5 mya, and possibly as early as 1.8 mya (Swisher et al. 1994; Larick et al. 2001; Zhu et al. 2008; Ao et al. 2013).

Several different species names have been applied to these comparatively small-brained Dmanisi hominins. Gabunia et al. (2001), Lordkipanidze et al. (2005, 2007) and van Arsdale and Lordkipanidze (2012) all place the fossils in or close to the root of the wide-spread and variable *Homo erectus*. Lordkipanidze et al. (2013) have argued that the Dmanisi population should be seen as an early *H. erectus* combined with *H. ergaster* specimens in a single chronospecies. Gabunia et al. (2002) argue that the earliest dated mandible (D2600) is so different from the other specimens that it may represent a different species from *H. ergaster/H. erectus*, *Homo georgicus*. Skinner et al. (2006) and Bermúdez de Castro et al. (2014) agree, and observe that *H. georgicus* shares primitive characters with and may be related to *H. habilis* (see also Rightmire et al. 2006). The authors cited above all accept the idea that some or all of these Dmanisi *Homo* were at least close to the ancestry of *H. erectus* that spread from Africa to China and Java in the Indonesian Archipelago of SE Asia. Van Arsdale & Wolpoff (2013) argue that *habilis*, early African *erectus*, and the Dmanisi fossils known to them (not including the new cranium described by Lordkipanidze et al. 2013) probably belong to a single chronospecies. Lordkipanidze et al. (2013) also agree that the range of variation among the five *Homo* skulls encompasses early *erectus*, *habilis* and possibly *ergaster*, and supports the idea that these form a single chronospecies. White (2013), Hublin (2014), and Antón et al. (2014) review issues with the taxonomic classification and nomenclature. Here I will refer to this population as the Dmanisi *Homo*.

Whether the Dmanisi *Homo* are directly ancestral to *Homo sapiens* or a side shoot cannot be determined at this stage, but they do provide a lot of information about capabilities of early members of our genus.

The Dmanisi site is remarkable for a number of reasons beyond the hominin fossils. Carnivore bones including sabre-toothed cats and a giant cheetah accounted for 18% of the site's animal bones (Gibbons 2013), with the *Homo* fossils recovered from what may have been carnivore dens. Nevertheless, these small-brained *Homo* maintained their existence against such predation. Agusti and Lordkipanidze (2011) argue that the evidence suggests that these small brained Oldowan tool-using *Homo* migrated out of Africa on their own – ahead of any other African fauna.

To me the most remarkable skull of them all is described by Lordkipanidze et al. (2005) - that of an elderly individual who had clearly survived for several years with only the partial remains of one tooth. Sockets for the other teeth had been completely resorbed (Figure 89).

> Applying clinical comparative standards, the advanced alveolar bone atrophy indicates substantial tooth loss several years before death as a result of ageing and/or pathology…. [This] individual apparently survived for a lengthy period without consuming foods that required heavy chewing, possibly by eating soft plant and animal foods and/or by virtue of help from other individuals, which must have exceeded that capable of being offered by non-human primates. [Lordkipanidze et al. 2005: p. 718].

Could this small-brained individual have survived to a great age without substantial assistance from his/her group? Does this indicate that he/she may have held valuable survival knowledge to be worthy of such help? Gilmore & Weaver (2016) discuss this question for Neanderthals showing fossil evidence of surviving for long periods of tooth loss.

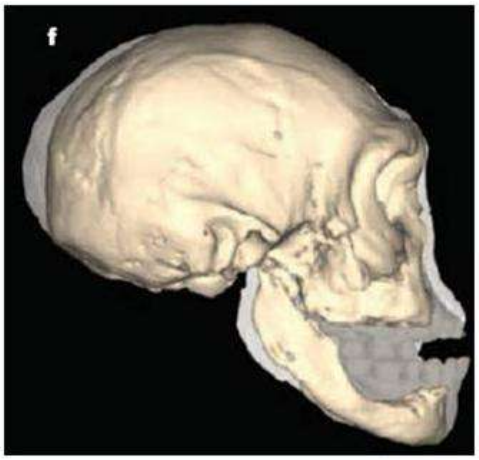


Figure 89. Homo fossils from Dmanisi. Toothless skull (shaded) superimposed on a juvenile skull with most of its teeth. Note the large amount of bone resorbtion and remodelling compared with the juvenile skull with most of its teeth still intact. (from Lordkipanidze et al. 2005)

H. erectus broadly defined presumably evolved from the early *Homo* sometime around or prior to 1.8 mya. The African *H. ergaster*, found in NE Africa from ~1.8 – 1.3 mya may be ancestral to early *H. erectus*; or possibly the early Dmanisi species may be ancestral to both *ergaster* and *erectus*[336, 338, 339]. Whatever its ancestry, *Homo* managed to disperse to and colonize East and South Asia (Agusti & Lordkipanidze 2011; Wood 2011; Antón et al. 2014). *H. erectus* had a long history in East Asia (Kaifu et al. 2010), where its possible derivative, the apparently dwarfed and small-brained (~400 cc) *H. floresiensis* (the "Hobbit"), managed to survive on the Indonesian island of Flores at least until 17,000 years ago (Morwood & van Oosterzee 2007; Aiello 2010; Kaifu et al. 2011)[341].

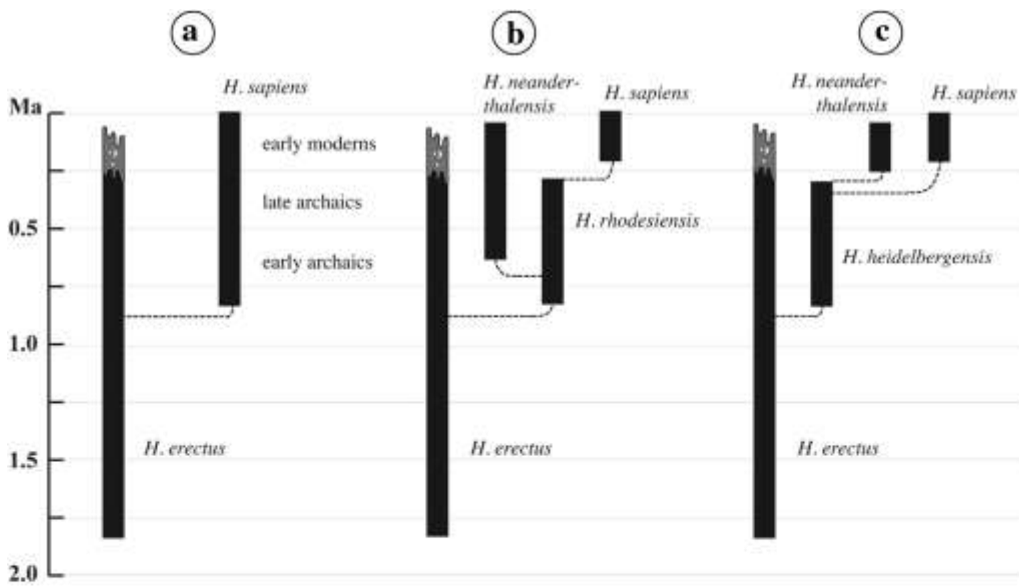


Figure 90. Alternative evolutionary trees showing possible relationships of *H. erectus* to Middle Pleistocene hominins, Neanderthals, and modern humans (Rightmire 2013). Solid bars depict the duration (first appearance date and last appearance date) estimated for each species. Broken lines indicate show proposed ancestries. (a), mid-Pleistocene and later populations are grouped into a series of more archaic and more modern grades within a broad *sapiens* chronospecies. In (b), there are (at least) two lineages in addition to *erectus* and recent humans. Here a Neanderthal chronospecies in Europe can be traced far back into the Middle Pleistocene. Those holding this view claim that even the oldest European hominins have Neanderthal-like features and can be distinguished from a lineage in Africa that can be called *rhodesiensis*. (c) holds that the differences between the earliest European and African specimens are minor and due to geography and intragroup variation. In this scenario, the appropriate name for this species is *heidelbergensis*.

H. erectus seems to have vanished from the arid Levant around 400 kya coincident with extinction of the elephants they hunted in that region. Ben-Dor et al. (2011) argue that the

Levantine *erectus* were near obligatory carnivores and depended on large amounts of fat to help them metabolize their highly proteinaceous diet. Enough fat could not be supplied by more difficult to hunt smaller game. When the elephants disappeared, perhaps as a result of overkill, this "created a need to hunt an increased number of smaller and faster animals while maintaining an adequate fat content in the diet, [which] was the evolutionary drive behind the emergence of the lighter, more agile, and cognitively capable hominins" (Ben-Dor et al. 2011: p. 1). Based on dental remains and the replacement of Oldowan tools with the more sophisticated Acheulean ("mode 2" tools), Ben-Dor et al. state this newer hominin resembled the lineage of *heidelbergensis* (some, such as Bräuer (2008, 2012) consider *heidelbergensis* to be an ancient form of *sapiens*) and the later Neanderthals.

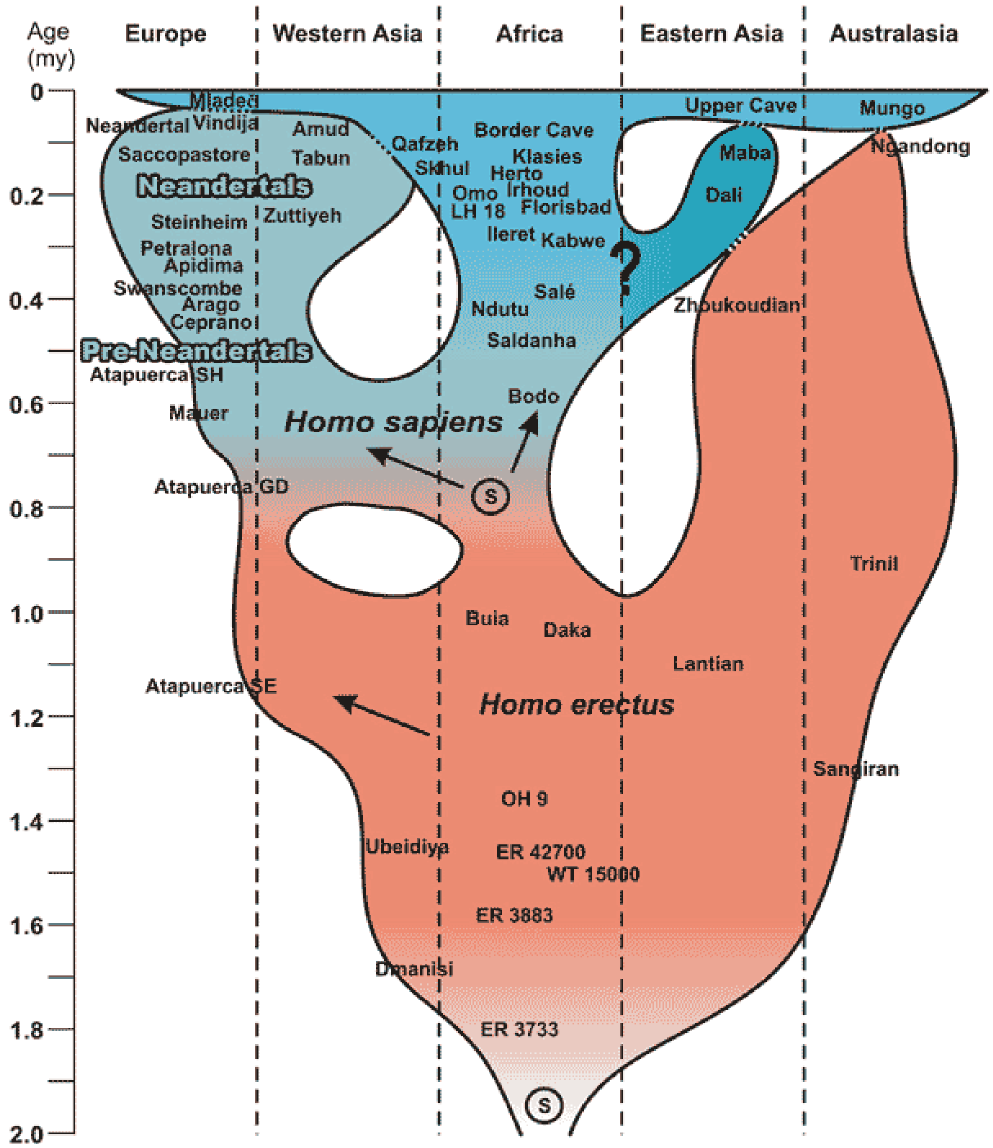


Figure 91. The fossil record for late *Homo* as reconstructed by Bräuer (2008, 2012). The various names relate to time and geographic location of particular fossils used in the reconstruction. Ⓢ indicates speciation events recognized by Bräuer. The dotted contacts represent possible hybridization events when populations were geographically separated come into secondary contact.

Figure 88 shows the supposed temporal ranges of the species involved in the ancestry of modern humans. *H. heidelbergensis* (*rhodesiensis* may represent the same evolutionary species) is presumed to be the common ancestor of modern humans, Neanderthals, and the Denisovans, i.e., Figure 90.c (Hublin 2009; Manzi 2011; Stringer 2012a; Rightmire 2013)[342]. Rightmire (2013 - Figure 90) presents three possible evolutionary trees. Based on studies of variation in skull characteristics Rightmire concludes that Bräuer's proposal is contradicted by the evidence and that the Middle Pleistocene hominin skull characteristics did not fit into anatomical trends shown by *H. erectus*, Neanderthals, or *sapiens*. This supports the idea that several Middle Pleistocene fossils belonged to a separately identifiable species that could be called *heidelbergensis*. In all of these analyses, it should not be forgotten that fossil skulls (or any other anatomical parts) that are suffiently complete to be useful for such comparisons are few and far between.

Bräuer (Figure 91) argues that there are two main chronospecies involved in our lineage, *H. erectus* and *sapiens* (both broadly defined). In this scenario *erectus* gave rise through a speciation event to archaic *sapiens* in Africa, which spread into western Asia and Europe[343]. The western Asia and European branch evolved into Neanderthals. Archaic *sapiens* remaining in Africa evolved into anatomically modern humans that then crossed into Eurasia through western Asia (i.e., the Levant) to dominate the planet.

What comparative genomics tells us about our genealogy<start>

The flood of genomic evidence published in the last few years (Table 3) combined with paleontology and paleoarcheological clues show in remarkable detail when and how different species belonging to the primate family Hominidae (i.e., anthropoid and bipedal apes) diverged from a common ancestral stock. The common ancestor of *H. sapiens*, Neanderthals and Denisovans probably emerged in Africa probably between 1,200 and 800 kya – although it is possible that the derivation took place in Eurasia and migrated back into Africa as primitive *sapiens*. Genomic data (Meyer et al. 2012 and Prüfer et al. 2014 - referenced in (Table 3)[344] show clearly that around 800 kya this stem species split (1) into a lineage leading to anatomically modern humans (*sapiens*) that dominated Africa before emerging into Eurasia some 70 kya and (2) to a lineage that spread in Eurasia and then split into the Neanderthals in Europe and Denisovans in Asia.

Table 3. Complete Genomes from Related Primate Lineages[345]

Lineage	Publications
genus *Homo*	
humans - *Homo sapiens*	IHGSC 2001; Levy et al. 2007; Rasmussen et al. 2011; Pugach et al. 2013; Lachance et al. 2012; Raghaven et al. 2014; Lazaridis et al. 2014 [346]
Denisovans	Krause et al. 2010; Reich et al. 2010, 2011; Harmon 2012; Meyer et al. 2012; Gibbons 2012
Neanderthals[347]	Green et al. 2010; Prüfer et al. 2014
400 kya Sima de los Huesos[348]	Meyer et al. 2014; Meyer et al. 2016
genus *Pan* (chimpanzees in the broad sense)	
common chimpanzees	CSAC 2005
bonobos	Prüfer et al. 2012
gorillas	Scally et al. 2012; Gordon et al. 2016
orangutans	Locke et al. 2011
gibbons	Kim et al. 2011
rhesus macaques	RMGSAC 2007

- *Denisovans*

There is no fossil record for Denisovans except for the finger tip and two teeth possibly dated to a period 50 to 30 kya (Reich et al. 2010) that provided ancient DNA for genome sequencing. Genomic analysis shows that modern *H. sapiens* exiting Africa into Asia briefly hybridized with Denisovans. Based on the absence of Denisovan genes in otherwise archaic SE Asian populations, Reich et al. (211) suggest that Denisovans' hybridization with *sapiens* occurred in south*east* Asia – implying that Denisovans were widely distributed in Asia. Based on genomics, the early *sapiens* populations on the Asian mainland that carried Denisovan genes were subsequently replaced by more recent migrants not including any Denisovan hybrids in their ancestries.

- *Neanderthals*

Reasonably typical Neanderthal fossils are known from between ~180 kya and 30 kya, distributed over much of Europe and substantial areas of Asia not covered by ice, at least as far east as Denisova and Okladnkov in the Altai Mountains of south Central Asia and as far south as the Levant (Hublin 2009; Vandermeersch & Garralda 2011; Tattersall 2011; White et al. 2014). Prüfer et al. (2014), applying similar techniques to those used to establish the Denisovan genome, mapped to a very high quality the genome of a Neanderthal from a toe bone found in an earlier stratum of Denisova Cave below that where the Denisovan bone was found. Sanchez-Quineto & Lalueza-Fox (2015) review Neanderthal genomics.

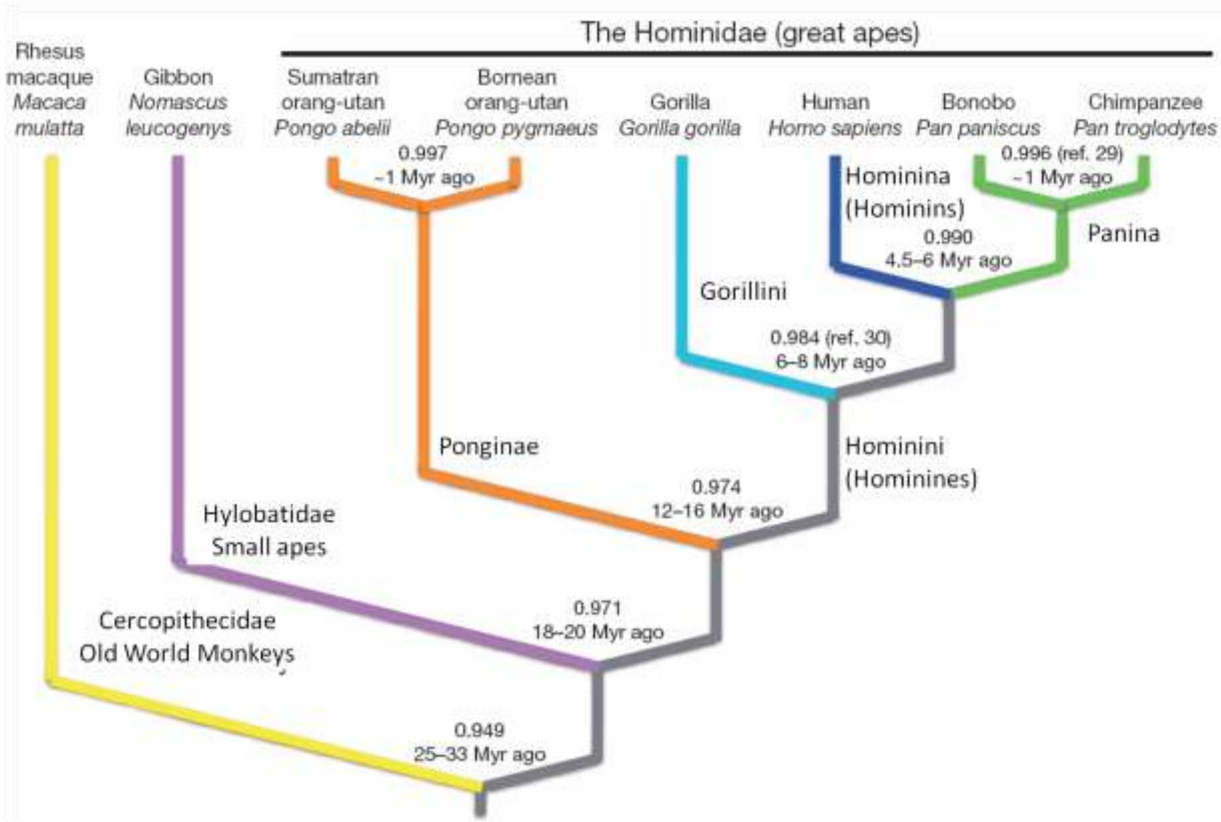


Figure 92. Divergence times of human's closest relatives based on complete genome sequencing (Locke et al. 2011). Decimal numbers above each split indicate proportion of the other species' genome(s) that are identical to the human genome. Neanderthal and Denisovan lineages should be added to the human branch, where the Denisovan-Neanderthal common ancestor and humans diverged ~ 700 kya years ago (Meyer et al. 2012). Taxonomic classification follows Wood & Harrison (2011).

Figure 92 summarises the genomic relationships of humans and our relatives among the anthropoid primates. Based on this concrete evidence, we now have a very clear idea of how we humans are related to other primates and can then infer from the various kinds of comparative evidence to be discussed how changes in cognitive processes may have been involved in grade-shifting revolutions[349] in our own direct ancestors' ecological capabilities. Geographic variation in extant populations, combined with genomic data from fossils is also beginning to give us a detailed view of spatial and temporal variation in human populations (Hawks 2013, Pickrell & Reich 2014).

Moore's Law and the microelectronics revolution have enabled the complete sequencing of the ~ three billion nucleotides in the genomes of individual humans and our hominid relatives. From this, we now know down to the level of single nucleotide differences (SNPs) where our genes differ from those of our relatives. And we are also beginning to understand the developmental consequences of these genetic differences. The rapidly growing technological ability to map complete genomes from tiny amounts of ancient DNA has even provided us with similar details for two now extinct relatives in the genus *Homo*, the Neanderthals and Denisovans334. In most cases we do not yet know the phenotypic effects of these genic differences. However, phylogenies can now be constructed on the basis of tens of to hundreds of thousands of heritable differences, that also give reasonable estimates based on mutation rates for when they diverged from a last common ancestral stock.

Given uncertainties about mutation rates in different lineages, the timings of the splits shown in Figure 92 are approximate. However, the detail of complete genomes establishes the *sequences* of derivation beyond doubt. Meyer et al. (2012), assuming the split between proto-humans and chimps took place 6.5 mya, place the human-Denisovan divergence at ~800 kya years ago. Prüfer et al. (2012), working from the estimated bonobo-chimpanzee split one million years ago, date the hominin and panin split to be 4.5 mya (proportionately reducing the time of the human-Denisovan split). Scally et al. (2012), using an average mutation rate based on the human-macaque sequence divergence, estimates this split to have taken place around 6 mya, and the human-chimpanzee lineage's divergence from the gorilla divergence around 10 mya based on observed mutation rates in humans. The latter estimate corresponds better with known fossils believed to be hominins. Based on fossil evidence, the orangutan split is believed to be more recent than the estimated 12-16 mya based on genetic differences. This suggests mutation rates have varied as the lineages evolved.

The comparative analysis of the genomes of the high quality Neanderthal, Denisovan and modern human genomes (e.g., Prüfer et al 2014 - Figure 93) provides additional evidence for the existence and timing of hybridization events between the various species of *Homo*[350].

Based on their Sima de los Huesos ("SH") mitochondrial and autosomal genomes and other samples of ancient and modern mitochondrial DNA, Meyer et al. (2014) provide a phylogenetic tree for populations of modern humans, chimpanzees, and bonobos (Figure 94). The SH DNA, estimated to be approximately 400 kya, is most closely related to the Denisovan samples, with the divergence between their common ancestor estimated to have diverged about 700 kya. The divergence between the SH/Denisovan lineage and Neanderthal/Human lineage is even older. In itself, mitochondrial DNA gives no evidence about the nature of the species from which it derives, but when tied to fossil evidence gives strong clues about how the species leaving the fossils are related and how much time they have had to evolve along different paths (Orlando 2014).

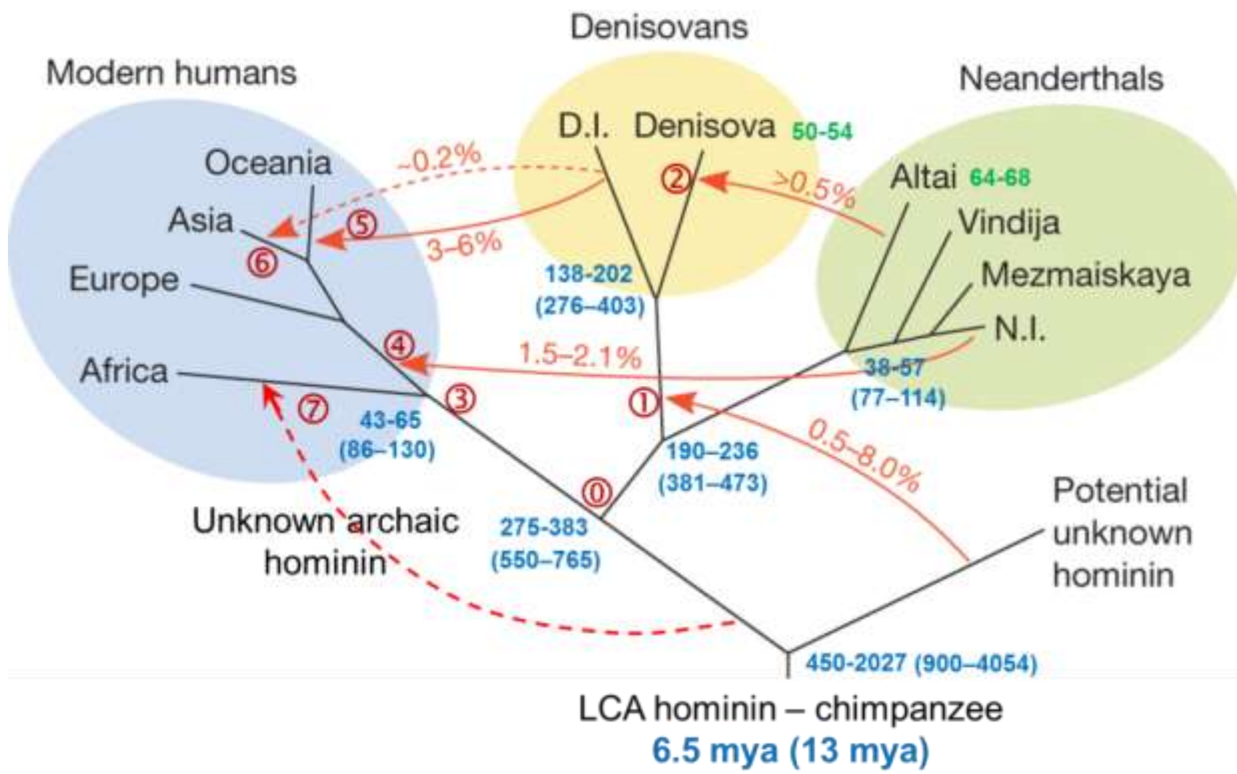


Figure 93. Genomic relationships of the *Homo heidelbergensis* complex species (Prüfer et al. 2014). Altai is the high quality Neanderthal genome recovered from Denisova Cave in the Altai Mountains of central Siberia. Vindija and Mezmaiskaya are respectively Neanderthal sites in Georgia and western Siberia where lower quality genomes were recovered. N.I. is the genome introgressed into Eurasian *Homo sapiens*. Denisova is the high quality Denisovan genome that was recovered from Denisova Cave. D.I. is the genome introgressed into Oceanian and E. Asian *sapiens*. Red arrows show gene introgression between species. Red numbers show percentages of the total genome in the recipient species deriving from source species. Blue numbers are estimated ages in thousands of years (kya) of divergences based on a constant rate of mutation from the last common ancestor between hominins and chimpanzees some 6.5 mya; the ages in parentheses are based on direct measurement of per generation mutation rates or 13 mya for human–chimpanzee divergence (Scally & Durbin 2012). Green numbers are estimated ages of the Denisovan and Neanderthal fossil DNA based on the length of their respective branches (i.e.., number of mutations from the hominin-chimpanzee LCA) compared to modern humans living today. Circled numbers refer to hybridization events discussed in Proliferation and genomics of the heidelbergensis species complex.

Mitochondrial DNA can be used to trace matrilineal genealogies and similarly, non-recombining Y chromosomal DNA tracks patrilineal genealogies. As discussed in more detail in Fossils, tools, genomics and human migrations, when combined with evidence from tools and fossils, mitochondrial and Y chromosomal DNA provide important and accurate evidence for the phylogeny and migrations of modern humans and their exit from Africa (Figure 108).

Figure 94. Reconstruction of mitochondrial gene sequence evolution comparing the Sima de los Huesos mitochondrial DNA to DNA from 54 present day humans, 9 ancient humans, 7 Neanderthals, 2 Denosivans, 22 bonobos and 24 chimpanzees. The horizontal axis is a measure of the amount of differences between the different DNA samples (Meyer et al. 2014 – supplement Fig. 6).

What ancient tool-kits can tell us about our ancestors

Based on the tool-making abilities demonstrated by chimpanzees and bonobos, it is reasonable to assume that our common ancestors made and used wooden tools that may have been important to their survival. However, wooden artifacts do not survive for long in the archeological record, and we have no evidence about early *Homo*'s use of wooden or orther organic tools. Stone is much more durable, and there is good evidence that some *Australopithecus* and all *Homo* probably made stone tools. Stone tools survive even better in the geological record than do fossils of the tool makers. The presence of an identifiable tool in the record tells us that a tool-maker was also present, and also – even more than fossil bones – something about the tool-maker's cognitive abilities to make tools. Where no fossils are associated with the tools, we can't say what species made the tools. In the paleoarcheological record up until say < 100 kya, only a small variety of stone tools were made, and these seemed to be made in traditionally standardized ways. Thus, it is reasonable to talk of wide-spread and long-lasting stone tool or "lithic" industries. The different industries each seem to have been maintained as a cultural inheritance over relatively long periods of time. Grahame Clark (1969 -) recognized five modes from the earliest to appear archeological record and the simplest to make, to increasingly later industries with more elaborate and difficult manufacturing methods (see also Foley & Lahr 1997, 2003).

Shea (2013) argues that use of these mode names carries an implicit assumption that they represent a unidirectional evolutionary trend to increased complexity. He writes that a purely descriptive typology is better because this carries no assumptions about who made the tools or evolutionary relations among the different types. However, in this book, discussions of tool kits follow Clark's scheme because most authors up to now have used it to identify the tools they wrote about, as summarized below[351]. Applicable European cultures and approximate ages of first appearance in the archeological record are given in parentheses. It should be noted that newer technologies do not necessarily replace older ones that often continue in use.

It is likely that our earliest ancestors used stone anvils and hammer stones to crack nuts and break open marrow bones from scavenged meat - very much like the tools chimpanzees use today. These are essentially unrecognizeable in the archeological record. Recognizable tools are classified in the following modes:

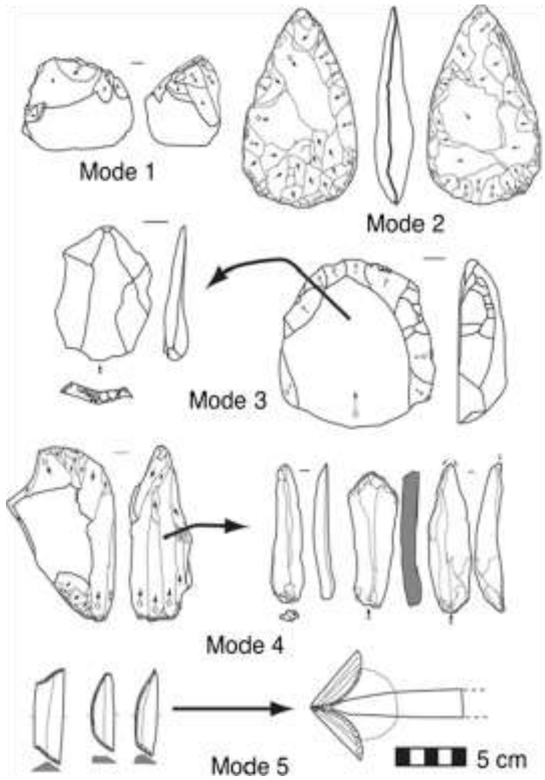


Figure 95. Grahame Clark's five modes of stone tool making (after Shea 2013).I

- *Mode 1* (Oldowan ~ 2.6 mya): Clearly worked stones began to appear in the archeological record in the Olduvai Gorge of the East African Rift System. These are simple flakes struck off pebbles, where the sharp edges of the core could be used as a chopper, and the even sharper flakes served as knifes.
- *Mode 2* (Acheulean ~ 1.7 mya): Large flakes or cores that are carefully shaped on both sides to produce a sharp cutting edge edge (i.e., they are known as "bifacial"). These are the result of a planned process to produce relatively large "hand-axes" for effective slicing and butchering.
- *Mode 3* (Mousterian & Levallosian ~ 300 kya): Prepared cores, retouched flake forms, flake tools. These included spear points & some experimentation with compound tools.
- *Mode 4* (Aurignacian, Gravettian, & Solutrean 36 kya): Long thin flakes removed from cores and shaped into a large variety of tool types.
- *Mode 5* (Magdalenian, Azilian, Maglemosian, Sauveterrian, & Tardenoisian ~ 17 kya): Very small flakes are made, retouched and used in a variety of composite tools ranging from arrows to sickles. Rapid evolution of the variety and complexity of tools.

Foley & Lahr 1997 - Figure 96) plot the temporal and geographic distributions of the different types of tools together with the hominin species that seem to be associated with them. Although dated in several respects, this figure gives a reasonable picture of when and where tools belonging to the various modes appear in time and space. Two areas where more recent data and interpretations differ relate to when Modes 4 and 5 first appeared in association with *H. sapiens* lineages and the times when when each of the modes last appeared – especially in Africa and Eurasia. There were sporadic appearances of Mode 4 tools associated with *sapiens*, going back to the earliest Archaic *sapiens* in South Africa (Wilkins & Chazan 2012; Wilkins et al. 2012; Wurz 2013), and apparently depending on circumstances, earlier tool modes continued in sporadic use long after later ones appeared (McBrearty 2007; McBrearty & Brooks 2000; Shea 2011, 2011a).

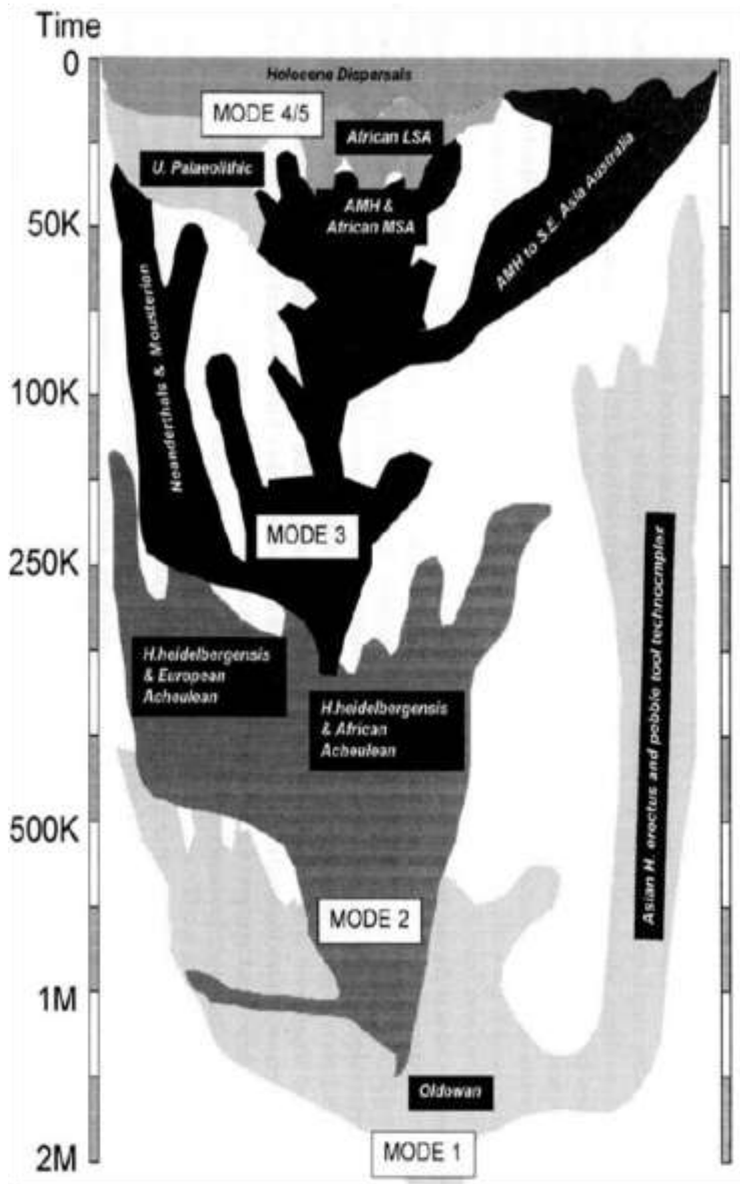


Figure 96. Distribution of stone tool industries in time and geography (Foley & Lahr 1997). Europe is on the left, Africa in the middle, and Asia on the right.

Fossils, tools, genomics and human migrations

Hominin fossils and tools made and used by hominins provide potentially dateable evidence that people occupied particular places on the physical landscape This helps us infer what kind of people existed through time in those locations. Stone tools are particularly useful, as these are direct products of hominin activities and cultures, and are imperishable compared to organic remains of people that are only rarely preserved in any identifiable form (i.e., as fossils).

Genomic evidence does not give us physical evidence of time and place. However, detailed differences among genomes can provide very clear and powerful indicators of genealogical relationships and approximate times of genetic divergence (see “molecular clock”) about the origins and migrations of *Homo sapiens*. However, because DNA degrades over time, genomics offers little help unravelling the pedigrees and migrations of early *Homo* species.

- *Oldowan origins in the crucible of the Rift valley*

Based on genetic, fossil, and archeological evidence it has long been believed that our hominin ancestors originated in Africa. As shown by genomic relationships (Table 3 and Figure 92), our closest living relatives, chimpanzees and bonobos are African, and all the fossils of early hominins are found there (Figure 87). Our domination of the world can be said to begin when the first hominins reached Eurasia around 1.8 mya (Dennell 2010; Ferring et al. 2011; Lordkipanidze et al. 2013) to start our ancestors' dominance of other continents (see discussions in notes 336, 338, 339, and 341 regarding the first exit from Africa).

Susman (1994) argued that tool use was probably widespread in early hominin species, as would be expected given that the chimpanzee human last common ancestory probably also used tools for extractive foraging (Dudy & Zrzavý 2013). Many of these species may have even used simple stone tools such as hammers and anvils. (Figure 97). The ealiest dated clearly worked stone tools have been found near West Turkana, Kenya, in the African Great Rift Valley system around 3.3 mya (Harmand et al. 2015). McPherron et al. (2010) attribute scratch marks on 3.39 myo bones from Dikika in the Ethiopian Rift with butchery by stone tools (no tools were recovered). The tools and tool marks cannot be confidently associated with any particular hominin species as both *Australopithecus* and possible early *Homo* were likely present in the environment, although it is assumed by most that knapped tools from 2.6 my were made by early *Homo*.

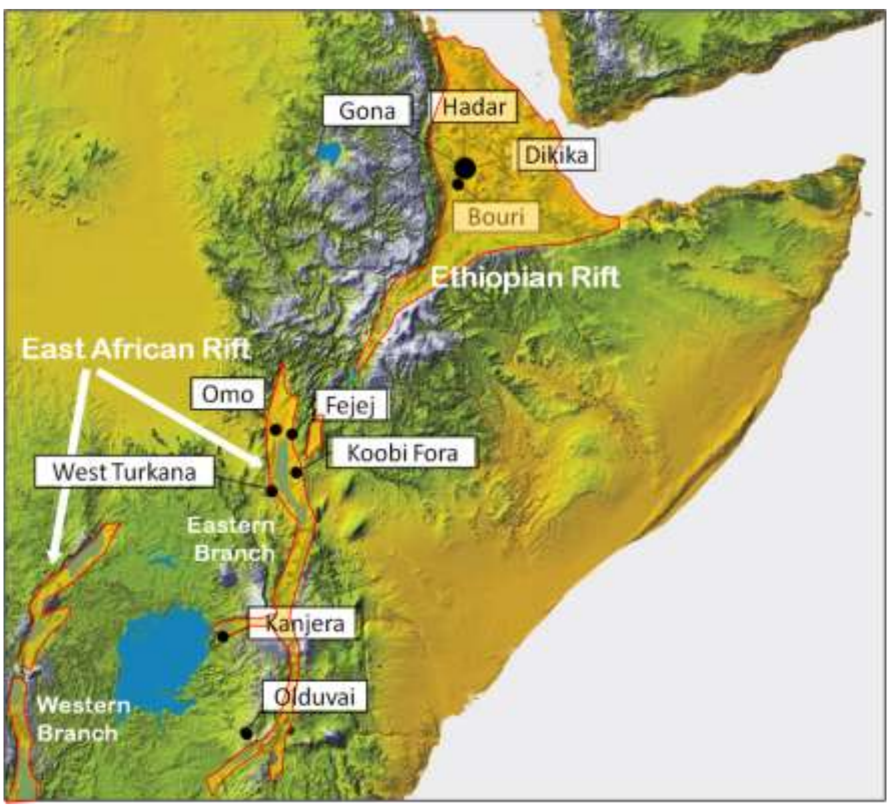


Figure 97. Key hominin fossil and tool sites in the African Rift System. Gona has the oldest dated tools. Other old sites with Oldowan tools are also shown. Rifts are outlined in red (after de la Torre 2012; Wood & Guth 2013).

A Late Pliocene assemblage of broken stone tools similar to those described by Harmand et al. (2015) and cut bones (McFerron et al. 2010) have been found in the Himilayan foothills in the Upper Indus Basin of Punjab in NW India and recently dated to 2.6 mya (Gaillard et al. 2016, Dambricourt Malassé et al. 2016a, 2016b). As will be discussed below, these raise some interesting questions relating to the geographic origins of *Homo*.

Table 4. Date ranges for early Oldowan tool sites

Region	Site	Age (mya)	Hominins[a]
East Africa	Gona Sites, Ethiopia	2.7–2.6	A
	Lower Omo Valley	2.4–2.3	P, H
	Hadar, Ethiopia	2.3	H
	Middle Awash Ethiopia	2.3	A
	Kanjera, Kenya	2.0	-
	East Turkana KBS	1.9–1.7	P, H
	Olduvai Bed I	1.8–1.6	P, H
	East Turkana, Okote, Kenya	1.7–1.3	P, H
	Peninj, Tanzania	1.7–1.3	P, H
	Olduvai Lower-Middle Bed 2	1.6–1.4	P, H
	West Turkana, Lower Natoo, Kenya	1.5	H
	Olduvai Upper Bed 2	1.4–1.2	H
	Konso Gardual, Ethiopia	1.4–1.3	H
	Gadeb, Ethiopia	1.4	-
	Olorgesailie, Kenya	1.0–0.9	H
Southwestern Asia	Yiron, Israel[b]	2.4	-
	Erq el-Ahmar,Israel[b]	1.8–2.2	-
	‘Ubeidiya[c]	1.6–1.2	H
South Africa	Sterkfontein, Member 5	2.0-1.5	P, H
Northwest Africa	El Kherba, Algeria		-
South Asia	Riwat, Pakistan	2.0-1.9	-
South China	Renzidong	>2	
Indonesia	Perning/Modjokerto	1.8	H
Western Asia	Dmanisi, Georgia	1.77	H
Northeast China	Majuanguo	1.6-1.54	H
Southern Europe	Pirro Nord, Italy	1.6-1.53	

a. Hominin fossils A = Australopitheus, P = Paranthropus, H = Homo
b. The dating of these sites are not substantiated (Bar-Yosef & Belmaker 2011).
c. Data from Bar-Yosef & Belmaker 2011)
Source: unless otherwise noted, extracted from Shea (2010), Table 4.2.

The oldest reported occurrences of *Oldowan* tools in the world are from 2.6-2.5 myo strata at Gona, Afar in the Ethiopian Rift have yielded (Domínguez-Rodrigo et al. 2005; Shea 2010; Stout et al. 2010; de la Torre 2011; Shea 2010: Table 4.2 - Figure 97). Stout et al. (2010) state that “years of intensive survey in older (c. 2.7-2.6) deposits at Gona immediately overlying a region-wide unconformity... have failed to yield evidence of flaked stone or modified bone prior to the sudden appearance of high density sites...” at the 2.6 myo level. They suggest that the conchoidal fracture technique was a “breakthrough discovery” made by hominins in the Afar area “that already possessed the sensorimotor and cognitive capacities for the full range of Oldowan technological performance”, and diffused from there to the rest of Africa and the Old

World as a as a set of "generalized craft practices". Even in this oldest level, analysis of the tools and tool-making debris showed that the tool-makers were proficient knappers able to use a full range of Oldown reduction strategies, consistent with the idea that there was essentially no change in this technology for a million years – from 2.6 to 1.6 mya. The comparative sophistication of the Oldowan knapping suggests that this may have been based on an already long tradition of using simpler stone tools.

Domínguez-Rodrigo et al. (2005), report the close association of Oldowan tools and faunal remains in the Omo area, where several of the long bones show clear cutmarks corresponding to those left in modern experiments when knapped stones are used to butcher carcasses. The evidence suggests these 2.6 myo tools were used to eviscerate bovid carcasses and deflesh long bones, implying that the hominins using them gained early or even first access to these prey in competition with large predators. Similar observations were made from a well dated 1.95 mya site at Koobi Fora (Braun et al. 2010).

The first appearance dates of Oldowan tools at other sites in Africa and Eurasia (Table 4 - extracted from Shea 2010) shows the spread of Oldowan culture through Africa and Eurasia. It must be noted that suitable circumstances of deposition and erosion for finding and dating stone tools in the archeological record are rare, and never sample the entire history of a location. The geology of the Rift System has offered many good fossil sites, so we need to be mindful that the fact that tools and fossils found in the Rift System may be more a function of suitable geology for preservation and exposure rather than representing actual points of origin. However, the evidence for geological activity and fluctuating climates within the rift system (Shultz & Maslin 2013) suggests that hominins in this region would be under continuing selection pressure to broaden their niches, and culturally mediated tool-use can be considered to enhance tool-users' versatility.

- *"Out of Africa 1 (and 2?)" – what tools and fossils from India, Dmanisi and Flores tell us*

Prior to the emergence of our recent direct ancestors, "anatomically modern" *Homo sapiens*, from Africa sometime around 70 kya, there were several dispersals from Africa into Eurasia of hominins that made stone tools.

Outside of Africa, possibly the oldest stone tools have been dated at 2.6 mya in the Indus Basin in NW India (Sao et al. 2016; Gaillard et al. 2016; Dambricourt Malassé et al. 2016a, 2016b – claims not yet subject to independent scrutiny) and 2.4 mya from the Yiron Plateau in Israel (Ronen 1991, 2006 - doubted by Rolland 2013 on the basis of artefact identification and taphonomy).

The oldest accurately dated hominin fossils and associated tools are those from Dmanisi, Georgia in the Caucasus region of western Asia, where there is evidence for repeated use of the site from 1.85 to 1.78 mya (Ferring et al. 2011). Garcia et al. 2010 independently date the oldest Dmanisi hominin fossil – the D2700 skull to 1.81 mya. Agustí & Lordkipanidze (2011) suggest that in the Late Pliocene – Early Pleistocene the African fauna giving rise to early Homo spread along East African Rift Valleys including the northern extension into the Jordan Valley of now Israel, providing easy access to the Dmanisi region and routes to the Far East. In any event, within at most a few hundred thousand years, early erectine hominins (Kaifu et al. 2010) spread across Asia to Indonesia and eastern China.

Whichever the case may be, fossil remains show that the Dmanisi hominids were effective hunters. Clear cutmarks on de-fleshed bones (Lordkipanidze et al., 2007; Baena et al. 2010) show that they sometimes were able to gain first access to reasonably large prey. Also, the fauna being hunted at Dmanisi was predominantly European – not African. Lordkipanidze et al. (2007) and Bar-Yosef & Belmaker (2011) suggest that this early migration out of Africa took place independently of any spreading of a predominantly African fauna. In other words, these early *Homo* already had the adaptive versatility and dispersal capacity to cross and survive in a variety of environmental domains that differed from what they originally evolved in.

A suspicion that the story of *Homo*'s early exit from Africa may may be more complex than previously believed is based on the first appearance dates ("FADs") of early *Homo* in Africa and Asia (Rightmire and Lordkipanidze 2009, 2010). Aside from the still untested date of 2.6 mya from the Indus Basin and the contested date of 2.4 mya from the Yiron Plateau of Israel, the earliest evidence for hominin tools outside of Africa is in the Armenian Highland, possibly as early as 1.9 mya (Presnyakov et al. 2012) and Dmanisi, Georgia by 1.8 mya (Gabunia et al. 2001)[352] and on the island of Java in Indonesia, possibly as early as 1.8 mya and almost certainly by 1.6 mya (Zaim 2010; Huffman et al. 2006).

There is some question as to whether the first exodus from Africa involved a single chronospecies, e.g., *H. erectus* (*ergaster* is considered by many to be a synonym for early *erectus)*[337]; or more than one species of hominin (an early *Homo*, cf. *habilis* or *rudolfensis*, plus *erectus*); or even whether the first hominin species to exit differentiated into *erectus* in Asia and then migrated back into Africa (Asfaw et al. 2002; Rightmire & Lordkipanidze 2009, 2010; Wood 2011) [338, 339]. Figure 98 summarizes the alternatives.

The discovery in 2004 of recent fossils of the primitive hominin, *Homo floresiensis*, on the Indonesian island of Flores (Bown et al. 2004; Morwood et al. 2004, 2005)[341] lends a bit of support to the idea that at least two species of hominins exited Africa in the period around or before 1.8 mya. Remains from Flores, dated from < 38 to 18 kya, included a nearly complete cranium with some post-cranial bones, stone tools and animal remains. The first individual described was estimated to stand approximately 1 m tall, with an endocranial capacity around 380 cm^2. Because of its small stature and small brain, *floresiensis* has been colloquially known as the "Hobbit". Both Brown et al. and Morwood et al. noted that *floresiensis* most resembled the Dmanisi hominins, and suggested that the hobbits had been isolated on Flores for a long enough period to have evolved insular dwarfism. Falk et al. (2005), measured the endocraninal capacity to be 417 cm^2 and noted that the shape of the endocast most closely resembled those of early *Homo erectus* from China and Java but that the brain/body size ratio scales like that of an australopithecine, suggesting that *floresiensis* might be an insularly dwarfed *erectus*. Others (e.g., Weber et al. 2004; Jacob et al. 2006) proposed that the remains represented a pathological case of microcephaly in a population of small *Homo sapiens* similar to the Rampasasa pigmies living close to Liang Bua today. This is refuted by a number of articles in an open access edition of the Journal of Human Evolution, "Paleoanthropological Research at Liang Bua, Flores, Indonesia" (vol 57, no 9, 2009 – see especially Argue et al. 2009; Morwood et al. 2009; Morwood & Jungers 2009) plus subsequent papers by Kaifu et al. (2011), Brown (2012), Kubo et al (2013), and Baab et al. (2013).

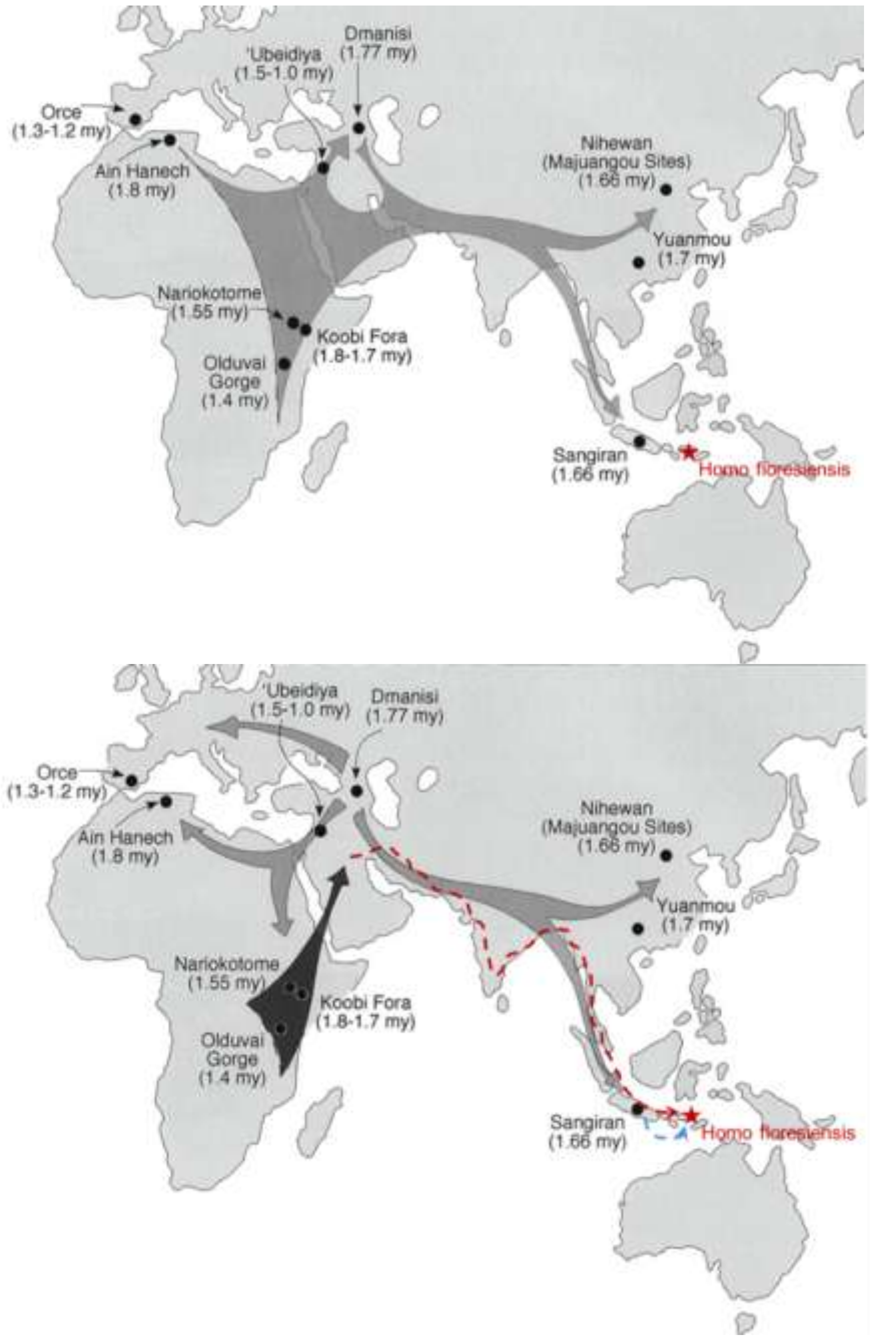


Figure 98. Alternative hypotheses for early exits from Africa (after Rightmire & Lordkipanidze 2010). Top: one species (*H. erectus*) evolved in Africa and spread through Eurasia. Bottom: an early African *Homo* spread to Eurasia, giving rise to *erectus* in Asia, that then returned to Africa.

The consensus among most of those authors who accept that *Homo floresiensis* are not pathological or dwarfed *H. sapiens* is that *floresiensis* traces its origin from an early *Homo* stock that possibly diverged even prior to the Dmanisi hominins (Figure 87, Figure 88). Argue et al. (2009) tested relationships using a cladistic approach based on a number of cranial and post-cranial characters that could be measured on the available *floresiensis* material and hominin fossils including *H. erectus* and *sapiens.* They found two equally likely evolutionary derivations:

(1) *floresiensis* is an early member of *Homo* that branched off after *H. rudolfensis* and before *H. habilis*, or (2) that it is an early member of *Homo* that diverged after *habilis*[338, 339]. Furthermore, *floresisensis* is not a sister species to any other species, e.g., *erectus*, included in the analysis. In other words, *floresiensis* appears to derive from a small hominin species that originated in Africa or SW Asia, either in the Late Pliocene or Early Pleistocene, that then dispersed east across Asia to the Indonesian archipelago where it colonized Flores before it was replaced by the somewhat more modern *H. erectus* everywhere except Fores – where *floresiensis* survived in isolation until relatively recent times. Brumm et al. (2010; see also Amos 2010) provide well dated evidence of hominin (probably *floresiensis*) tool-making on Flores dating back to 1.02 ± .02 mya.

Morwood & Jungers (2009) and Dennell et al. (2014) consider the various modes and pathways by which an early hominin could have reached Flores, and conclude that if they existed in Borneo (Kalimantan) or Sulawesi to the north[353] (Figure 99), they could have reached Flores by passive rafting following a cyclone or tsunami as did Stegodon elephants (that appear to have been good swimmers). The region is in the tropical cyclone belt and experiences several tsunamis per century. Because strong currents flow to the south through the deep water Lombok strait[354] between Bali and Lombok (the closest continental shelf to the Lombok-Flores shelf) and trend to the west when the Indian Ocean is reached, Dennell et al. consider passive rafting from Sumatra and Java to Lombok and Flores is much less likely than rafting from Borneo or Sulawesi to the north (areas known to be inhabited by *Stegodon*).

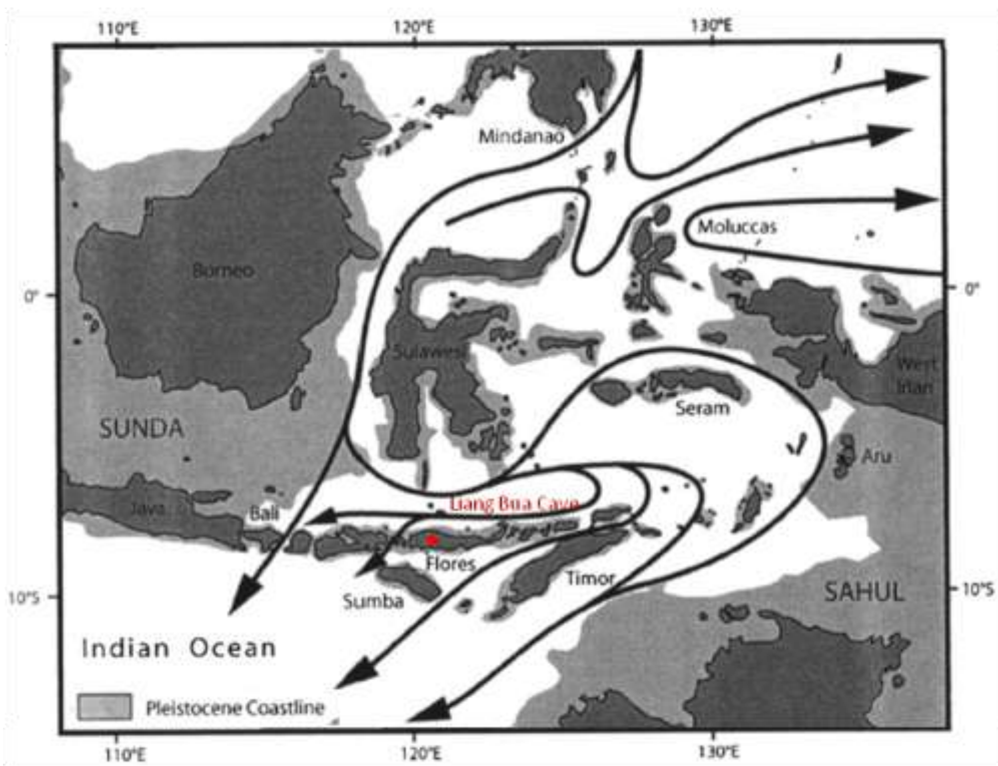


Figure 99. Geography and ocean currents affecting migration of *Homo floresiensis* (from Morwood & Jungers 2009 - after Kuhnt et al., 2004; see also Zaim 2010). The location of Liang Bua Cave where *H. floresiensis* fossils have been found is shown in red. Sunda is the southeasternmost extension of the Asian continental shelf as exposed above water at times of maximum glaciations. Sahul is the Australia-New Guinea continental shelf. Strong currents flow southward through the deep water Lombok Strait between the islands of Bali and Lombok (see also Wallace's Line).

Considering the possible relationships of the hominins from Dmanisi and Flores with *Australopithecus* and early Homo, Wood (2011) following e.g., Argue et al. (2009) and Morwood & Jungers (2009) accepts that *floresiensis* was an endemically dwarfed version of a more primitive *habilis*-grade hominin (Figure 98 bottom). Wood further argues that the "adaptive coherence" of the genus *Homo* would be compromised if *habilis* (and by extension, *floresiensis* and the Dmanisi hominins) are included in *Homo*. In other words, Wood implies that *habilis* and *floresiensis* fit better in *Australopithecus* than with *erectus* and the post-*erectus Homo*. Given the dating of Asian vs. African fossils, he also considers that it is possible that *erectus* emerged first in SW Asia from habiline *Australopithecus* and secondarily spread back into Africa rather than the more conventional idea that *H. erectus* emerged from Africa (Figure 98 top). If *floresiensis* is considered to be a late australopithecine, the red line indicates the path followed by its ancestors before its replacement by the more modern *H. erectus*, leaving no fossil trace between Dmanisi and Flores. Alternatively, if *floresiensis* is considered to be a insularly dwarfed *erectus*, its ancestor only needed to get from mainland Indonesia to Flores as indicated by the blue line.

If Wood's argument that *habilis* and the dmanisi hominins should be considered to be late australopithicines, it follows that *Homo* (as *erectus*), may have originated in Eurasia and migrated back into Africa. However, it should not be forgotten that these various arguments all remain speculations without more informative African and Asian fossils from 2.5 to 1.5 mya.

It should be noted that all of these early *Homo*, including those from Dmanisi and *H. floresiensis*, and early sites in Java and the Asian mainland have been associated with Oldowan grade tools made by what Bar-Yosef & Belfer-Cohen 2013 call the "core and flake" industry Dennell et al. 2013; Norton et al. 2010; Ao et al. 2013) (or even more primitive knapped tools). Oldowan tool are also typical of earliest European sites (Carbonell et al. 2010; Garcia et al. 2013; Bermúdez de Castro et al. 2013; Ollé et al. 2013). Irrespective of the details of *Homo*'s origins, the conclusion is that even the Oldowan flaked stone tools were adequate to support the spread of meat-eating late *Australopithecus* and/or *Homo* across the clement width of Eurasia between Spain and Indonesia and Eastern China (Figure 96; Figure 98). The more sophisticated and complex Acheulean hand axes are conventionally believed to have been invented by *Homo erectus*, although as noted previously there are often no telltale fossils associated with tool finds to indicate who made the tools.

- *Origin and spread of the Acheulean toolkit through Africa and Asia*

Aside from the Dmanisi hominins and the still undated *Homo naledi*[333], the first *Homo* we know much about is *H. erectus*, whatever that is considered to be[355]. If we follow Lordkipanidze et al. (2013), most early *Homo* would be considered to be *H. erectus*. However, the very oldest fossils attributed to *H. erectus* (although *h. rudolfensis* cannot be excluded) are a femur (KNM-ER 1481) dating to slightly older than 1.945 mya, and a pelvis (KNM-ER 3228) from 1.92 mya from Koobi Fora (Joordens et al. 2013). The oldest uncontested *erectus* are from the Turkana Basin (Kenya), with the earliest definitive cranium from 1.78 mya (Antón 2003 - Figure 97 shows localities). Spoor, et al. (2007) have identified both *Homo habilis* and *erectus* from east of Lake Turkana (i.e., near Koobi Fora), suggesting that the two species lived in the same area of East Africa for nearly half a million years.

As discussed above, whether one or two *hominin* species exited Africa prior to or around 1.8 mya is unclear, however it seems from the fossil evidence that typical *erectus* was able cross the spread of two continents (from South Africa to Indonesia and eastern China by no later than 1.6 mya (Antón 2003; Carbonell et al., 2008, 2010; Dennell 2010; Zeitoun et al. 2010; Bar-Yosef & Belfer-Cohen 2001, 2013 - Figure 100). An apparently typical *erectus* is also known from Turkey prior to 1.1 mya (Lebatard et al. 2014).

Stone tools survive better in the record of the past than do bones as evidence for hominin occupation. Acheulean tools differ from Oldowan grade tools in that the former involved more complex and planned knapping strategies to produce large cutting tools (). The first Acheulean tools (bifacial handaxes = “large cutting tools”, etc.) appeared in East Africa around 1.75 mya (Lepre et al. 2011; de la Torre et al. 2012; Beyene et al. 2013; Gallotti 2013), in South Africa around 1.7-1.6 mya (Beaumont 2011; Gibbon et al. 2009 - questioned by Herries 2011), and in India by 1.5 mya (Pappu et al. 2011; Dennell 2011). Petraglia (2010) states that Acheulean technology was well established in India after 700 mya but there is little chronometrically controlled evidence for Acheulean using hominins before that time.

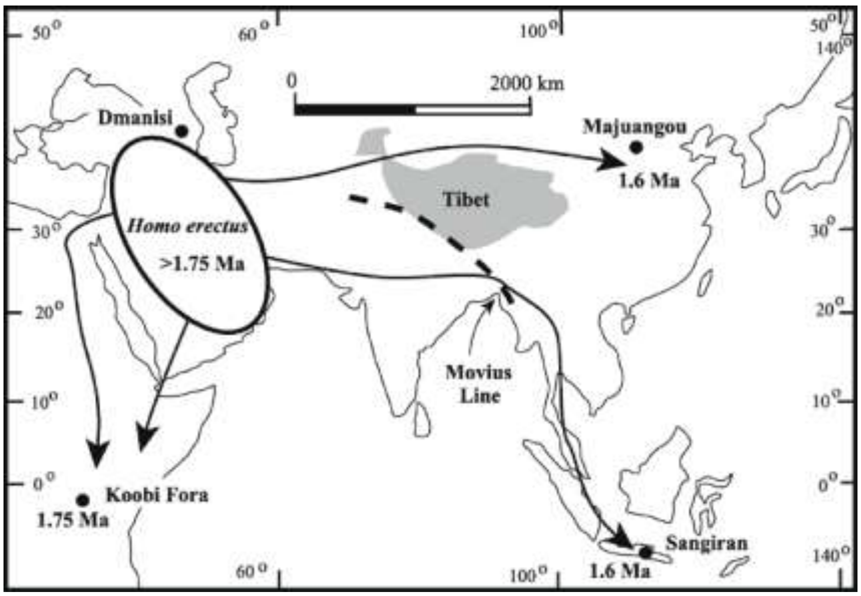


Figure 100. Early spread of *Homo erectus* assuming a West Asian emergence, i.e., that the Dmanisi hominins are the earliest representatives of or ancestral to *erectus* (Dennell 2010)

Homo erectus were also found in East and Southeast Asia by around 1.5 mya (possibly as early as 1.7 mya – Norton et al. 2010), but their stone tools were less complex than those from Western Asia and Africa. Some authors believe that Acheulean grade tools arrived late or not at all in East and Southeast Asia beyond what is called the Movius line (Movius 1944, 1948 - Figure 100). Since then, some East/Southeast Asian sites have been found, e.g., handaxes securely dated to 803 kya (Wang et al. 2012a; Wang et al. 2014) and Dennell (2016) argues that the Movius Line concept is no longer useful. In any event, in the Paleolithic of East and South Asia bifaced tools are rare compared to the Oldowan grade core and flake tools (Lycett & Bae 2010; Lycett & Norton 2010 – but see Brumm & Moore 2012). It also appears that the bifaced tools found were developed independently from African sourced technology (Bar-Yosef & Wang 2012; Wang et al. 2012a; Wang et al. 2014). The penetration of African technology may have been limited because of difficulties crossing the Ganges-Brahamaputra drainage, demographic factors (Lycett & Norton 2010) and/or wooden/bamboo tools that could be made with simpler stone tools that filled similar functions to the Acheulean tools (Bar-Yosef et al. 2012).

- *Fossil hominins in Europe prior to Homo sapiens*

Despite its proximity to Africa and Western Asia, Europe was apparently the last part of Eurasia colonized by hominins (Carbonell et al. 2010; Parés et al. 2013; Rolland 2013). The earliest archeological evidence in Western Europe is from Italy and Spain dating from perhaps 1.6-1.2 mya (Carrión et al. 2011; Garcia et al. 2013; Bermúdez de Castro et al. 2013; Toro-Moyano et al. 2013; Ollé et al. 2013), although Muttoni et al. (2013) and Rolland (2013, p. 61) discount dates much earlier than 1 mya. As discussed above (Figure 87, Table 2, Figure 90, Figure 91), the record of Early and Middle Pleistocene hominins fossils is still too incomplete and scrappy to provide an unambiguous history of the early occupation of Europe or the ancestry of the more recent Neanderthals and anatomically modern *Homo sapiens*. It is also likely that the history of European occupation during this period will prove to be even more complex than it seems now, with the extinction of lineages during periods of extreme glaciations followed by recolonizations from core areas of dispersals from Western Asia or the Balkans (Sirakov et al. 2010, Bermúdez de Castro & Martinón-Torres 2013 - Figure 100; Figure 101).

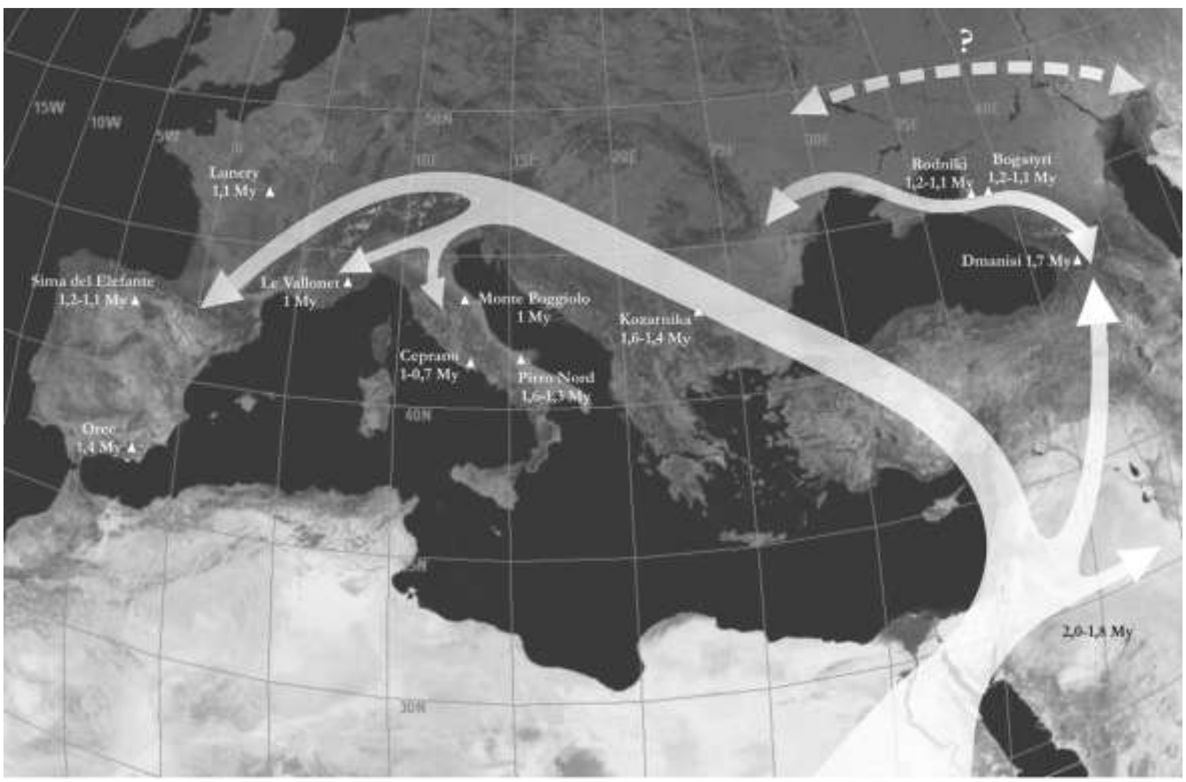


Figure 101. Possible paths for the first hominins to reach Europe in Early and Mid Pleistocene (Sirakov et al. 2010).

Possibly the earliest tools found in Western Europe are those from Pirro Nord, tentatively dated biostratigraphically to 1.6-1.3 mya (Arzarello & Peretto 2010; Pavia et al. 2012) and Lezignan-la-Cebe, France, radiometrically dated to 1.57 mya (Crochet et al. 2009). No hominin fossils have been found with these tools. The earliest fossils are those from Spain, *H. antecessor* (Bermudez de Castro et al. 1997, 2013), dated from 1.22 mya and around 800 kya (Carbonell et al. 2008; Manzi 2011, 2012; MacDonald et al. 2012). All of these finds have been Mode 1 (Oldowan). Few fossils are available between ~ 800 kya and ~ 700 kya, and most earlier and later specimens are fragmentary, making it difficult to define clear boundaries and infer genealogical relationships among the varous species based solely on morphological traits preserved by the fragments.

Prior to the spread of Neanderthals and *H. sapiens*, evidence suggests there were at least two separate occupations of Europe during the Early to Mid Pleistocene by different hominin lineages, separated from one another by an absence of hominin remains during an extreme glacial period (Mallegni 2011; MacDonald et al. 2012; Bermudez de Castro et al. 2013; Bermúdez de Castro & Martinón-Torres 2013; Mosquera et al. 2013). Vandermeersch & Garralda (2011), suggest the Bilzingsleben hominins (around 350 kya) represented an erectine lineage separate from the *heidelbergensis*-Neanderthal lineage. The earliest fossil evidence for the first occupation is from the Iberian Peninsula in the period around 1.2 mya, tentatively allocated to *H. antecessor* or perhaps to an earlier species (Bermúdez de Castro & Martinón-Torres 2013). Fossils from the period 1.0 to 0.8 mya are attributed to typical *H. antecessor*, which is not known more recently than that time. The earliest definitive Neanderthal specimen dates from around 175 kya (Tattersall 2011; Vandermeersch & Garralda 2011) and modern *sapiens* out of Africa, replaced Neanderthals some 46-35 kya – Benazzi 2011; Higham et al. 2011; Mellars 2011; Hiscock 2013; Villa & Roebroeks 2014).

In the middle Pleistocene, after the latest *antecessor* fossils, the next hominin remains are those from Mauer, (Germany) dated to ~ 600 kya (Wagner et al. 2010); Sima de Huesos (northern Spain) dated to around 500-400 kya (Bermúdez de Castro & Martinón-Torres 2013); those from Ceprano, Italy (Mounier et al. 2011) around 400 kya; Tattersal 2011. Most authors have related these Middle Pleistocene fossils to *Homo heidelbergensis*, based on the type specimen from Mauer, although several different interpretations of their ancestry and derivation have been offered without offering enough evidence to clearly decide which is correct. For example:

- Rightmire (2013 - Figure 90) offers three possible derivations: (a) *Homo erectus* gives rise to *H. sapiens* chronospecies around 800 kya, (b) *erectus* gives rise to *rhodesiensis* around 800 kya, that splits off *neanderthalensis* around 600 kya and splits off or becomes *sapiens* 200kya; and (c) *erectus* gives rise to *heidelbergensis* around 800 kya that splits into *neanderthalensis* around 250 kya and *sapiens* around 200 kya;
- Endicott et al. (2010), attempting to reconcile paleontology with early DNA chronologies for *sapiens* and Neanderthals proposed four possible derivations: (a) *heidelbergensis* becomes *helmei* (in Africa 300-150 kya) that splits off *neanderthalensis* and *sapiens* around 250 mya, (b) *heidelbergensis* (Europe and Africa) splits off *neanderthalensis* chronospecies (in Europe) around 400 kya and splits off or becomes *sapiens* (in Africa) around 250 mya before going extinct, (c) *rhodesiensis* (in Africa) splits off (in Europe) *heidelbergensis-neanderthalensis* chronospecies around 600 kya and splits off or becomes *sapiens* chronospecies (in Africa) around 250 kya; and (d) *antecessor* (in Europe) gives rise to *heidelbergensis-neanderthalensis* chronospecies by 600 kya and splits off or becomes *rhodesiensis* (African) soon after 800 kya that splits off or becomes *sapiens* chronospecies around 250 kya.

- Árnason (2016) concludes that fossil evidence of early Homo in the Caucasus, Denisovans in the Altai Mountains and Neanderthals in localities from the Altai Mountains, the Caucasus, the Levant, Asia Minor, southern and central Europe and the Iberian Peninsula will change our ideas about the geographic origins of modern humans. The Eurasian location of these finds lends no support to the out of Africa hypothesis. A conclusion that can also be drawn from genomic findings, that (a) show the presence of Denisovan and Neanderthal nuclear DNA in genomes of recent Eurasians and (b) similar admixture from early modern humans into Neanderthals in the Altai Mountains. Archaeological finds in Sulawesi and the discovery of ~100,000 years old human teeth in southern China also challenge the out of Africa hypothesis.

> The genomic and palaeogenomic results and the new palaeontological and archaeological discoveries suggest (a) that the ancestors of modern humans had their origin in a Eurasian (largely Asian) biogeographic region which may also have extended into NE Africa, and (b) that the founders of basal African lineages became separated, geographically and genetically, in the westernmost part of this region and spread from there to different parts of the African continent (Arnason 2016).

There are so many options because surviving fossils are so rare and fragmentary that there are few clearly definable morphological characters that can be surveyed across all the taxonomic names applied to particular specimens (Vandermeersch & Garralda 2011). Mounier and Lahr's (2016) efforts to virtually reconstruct the skull of the last common ancestor of *sapiens* and Neanderthals demonstrates just how sparse the morphological evidence still is. Presumably as more fossils are discovered through time, the quality of the available data will improve enough to falsify some of the alternatives discussed above.

Stone tools give a somewhat clearer picture. Prior to ~ 650 kya tool discoveries associated with *antecessor* have been classified as belonging to Mode 1 (Oldowan). After an apparent hiatus in hominin activity between ~ 800 kya and around 700-600 kya (Martínez et al. 2013; Garcia-Medrano et al. 2014). The earliest Mode 2 (Acheulean) tools appeared in Europe around 700-600 kya (Carbonell et al. 2010; Barsky & de Lumley 2010; Moncel et al. 2013), sometimes associated with fossils attributed to *heidelbergensis*). This supports the idea that *antecessor* and its culture died out, to be replaced after several millennia by a Mode 2 culture, carried by one or more waves of ancestral *heidelbergensis* migrating west from a source area (refugium) in southeastern Europe, the eastern Mediterranian or southwestern Asia, where Mode 2 (Acheulean) technologies existed much earlier. The earliest African sites for Acheulean technology are 1.7 mya in Eastern Branch of the East African Rift on the west side of Lake Turkana (Beyene et al. 2013 - Figure 97). This technology reached Ubeidiya in the Eastern Mediterranean by around 1.4 mya, and more distant Eurasian sites by 800 kya (Carbonell et al. 2010), presumably carried by migrants from the Mideastern source area(s).

- *Proliferation and genomics of the heidelbergensis species complex*

For many years there has been a debate over the geographic origins of the populations of modern *Homo sapiens* around the world. Two models have been proposed (Frayer et al. 1993; Lahr & Foley 1994; Stringer 2014): the"recent African origin", which assumes that anatomically modern humans evolved first in Africa and then recently spread to the rest of the planet, replacing older hominin species and leading to their extinction; versus a "multiregional origin", arguing that the major human races evolved in parallel, more-or-less in situ from older hominin species such as Neanderthals and *Homo erectus* (Coon 1962) that had previously colonized Europe and Asia. In this book I have assumed the former, but I mention the multiregional hypothesis here because evidence for the parallel emergence of *Homo sapiens* morphology would serve to falsify the recent African origins of modern humans. Evidence presented in this segment provides clear evidence for refuting the multiregional hypothesis.

Ignoring the dotted lines, Figure 102 gives the temporal distribution of fossil hominins over the last million years. According to the multiregional hypothesis, Europeans evolved in Europe via *heidelbergensis*[342] and Neanderthals, while Asians evolved in Europe from an erectine ancestry. As discussed by Frayer et al. (1993), this may have also involved a greater or lesser degree of admixture with migrants from other geographic regions. The recent African origin hypothesis posits that *Homo sapiens* evolved in Africa and only recently emerged to entirely replace the older species such as Neanderthals and *erectus*. Over the last few years genomics have given us a clear view of the genealogical relationships and genetic exchanges between our ancestors and our closely related hominin species, Denisovans (a species that was unknown in the fossil record) and Neanderthals (Hawks 2013; Prüfer et al. 2014 - Figure 93; Meyer et al. 2014 - Figure 94).

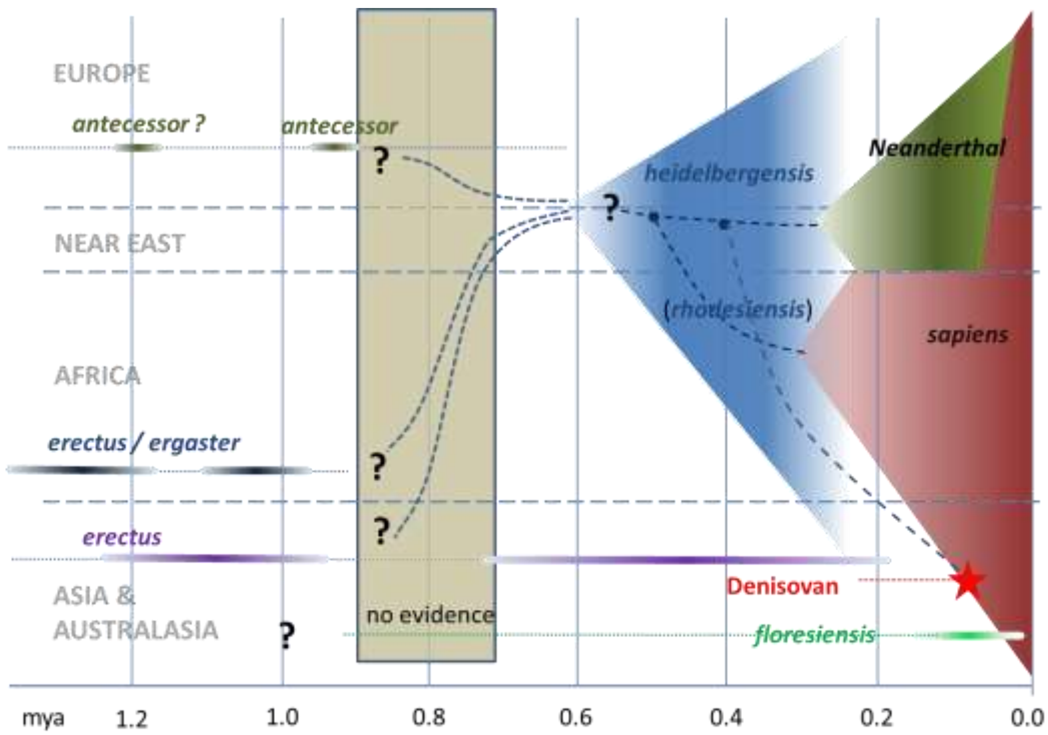


Figure 102. Temporal and continental distribution of fossil species of *Homo* recognized over the last million years (after Manzi 2012). Notes: *H. ergaster* is a synonym for African *erectus*. Based on the presence of tools, *H. floresiensis* is assumed to have colonized the island of Flores around 1 mya. Genomic evidence shows the phylogenetic relationships of Denisovans, Neanderthals and modern humans (after Prüfer et al. 2014) Estimated ages and divergence times follow Scally and Durbin (2012).

Scally & Durbin (2012) estimate divergence times of the three species based on their new measurements of actual mutation rates in living humans (Figure 93 includes Scally & Durbin's revised divergence times in parentheses). The bottom panel in Figure 103 compares divergence times recalculated from published genomic data referenced in the top panel with the inferred and actual existence of particular species in the fossil record (middle panel).

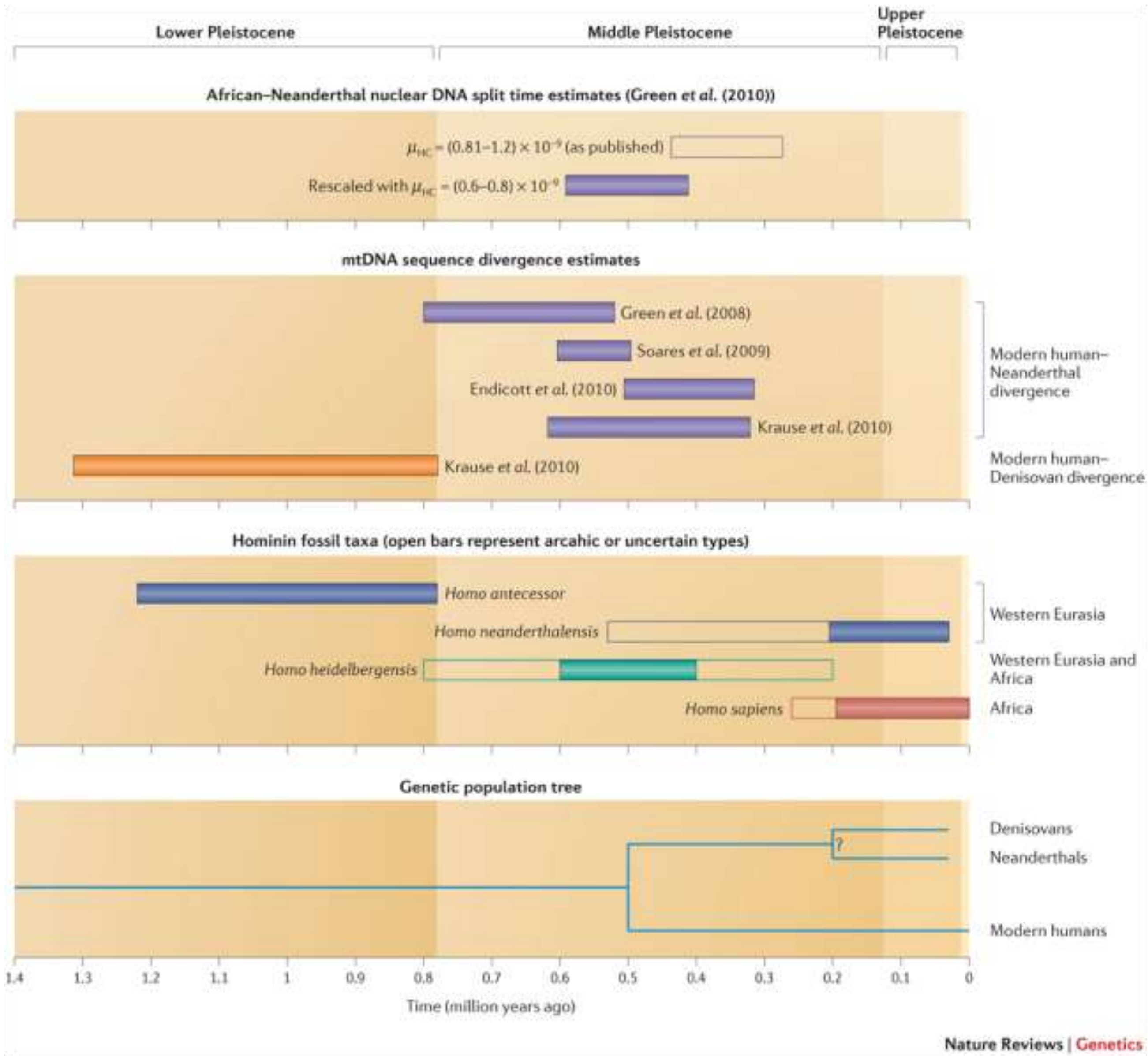


Figure 103. Genomic divergence times for *Homo sapiens*, Neanderthals and Denisovans (Scally and Durbin 2012) - estimated and adjusted. In the upper two panels, the length of the bar represents both the range of mutation rates assumed and additional spread from the estimation procedure. In the third panel from the top, hominin fossil taxa are represented by bars spanning the dates of fossils classified within them. Open bars represent putatively archaic forms or uncertain classifications. Note that this graphic does not include more recent data from Prüfer et al. (2014) and Meyer et al. 2014.

The adjusted genomic divergence times suggest that the last common ancestor of *sapiens* and the Neanderthal/Denisovan lineages lived around 500 kya. Fossil evidence suggests that Eurasian *heidelbergensis* may have evolved directly into Neanderthals in Europe (Arsuaga et al. 2014; White et al. 2014), while African *heidelbergensis* (*rhodesiensis* – Hublin 2009; Manzi

2011) gave rise to *sapiens*. Denisovans may have evolved directly from *heidelbergensis* somewhere in Asia (Martinón-Torres et al. 2011).

Figure 102 represents my attempt to depict what can be inferred about the relationships of *heidelbergensis* and its descendents (humans and our closest relatives). Thus, *heidelbergensis* gave rise to an African branch (*rhodesiensis*) that in turn gave rise to the ancestral *sapiens* within Africa, and a pan-Eurasian *heidelbergensis* that split geographically into European Neanderthals and Asian Denisovans. As detailed in the next section, there can be no practical doubt that modern *sapiens* emerged from Africa into Eurasia 70 – 50 kya as a genetically well defined species. Although *sapiens* out of Africa clearly hybridized with resident Neanderthals and Denisovans leading to small amounts of admixture, *sapiens* actively or passively exterminated all other surviving hominin lineages. The still unanswered (and probably unanswerable) question is where within the archaic *Homo* already spread across three continents did *rhodesniensis*/*heidelbergensis* arise? Did this lineage emerge from within Eurasian erectines, or from the more diverse mix of species in Africa?

There seem to be no clear boundaries in the cultural tool kits used by *heidelbergensis* and Neanderthals, in that regional and temporal variation do not seem to align with morphological boundaries, nor are there species-wide differences between technologies used by Neanderthals and *sapiens*, although for particular localities, there are often local cultural changes presumably associated with the replacement of Neanderthals by *sapiens* (Goren-Inbar 2011; Ahern et al. 2013; Richter et al. 2012; Hovers & Belfer-Cohen 2006).

The overall picture is that *heidelbergensis* and their derivatives were mobile and adaptable hunter-gatherers. Genomic evidence from a number of hybridization events supports the following reconstruction of the origins and geographic spreading of the *heidelbergensis* complex and its derivatives based on Veeramah & Hammer (2014 - Figure 104).

Whether the ancestral *heidelbergensis* originated in Africa or Eurasia, it colonized both Africa and Eurasia (⓪ in Figure 93 and Figure 104) during glacial minima and presumably survived in refugia on both continents during times of glacial maxima (evidence regarding their biology will be reviewed in

An Evolutionary Hypothesis: - Our First Five Million Years or "How Did We Get Here?"). Restriction of populations to refugia during periods of glacial maxima would have provided ample opportunity for genetic differentiation to support incipient geographic speciation (Mayr 1972) within the *heidelbergensis* species complex.

Ancient DNAs tell a surprising amount about the ancestries of the different members of the complex (Hawks 2013). Following Prüfer et al. (2014 - Figure 93) and Veeramah & Hammer (2014 - Figure 104), the last common ancestor of Denisovans and Neanderthals lived somewhere in Eurasia around 200-400 kya. By the Middle to Late Pleistocene, the Eurasian *heidelbergensis* had split into two species: Neanderthals (in Europe, western Asia and the Levant) and Denisovans (presumably in central and easern Asia). Fossils show that both species occupied Denisova Cave in the Altai Mountains of Siberia (located at ② in Figure 104) at different times (Prüfer et al. 2014).

An ancestor of the Denisovans hybridized with survivors of a much more distantly related *Homo* (① in Figure 93, Figure 104). Genes from this hybridization have not been found in Neanderthals, suggesting the hybrid Denisovans were separated by distance or reproductive isolation from genetically sampled Neanderthals. Denisovans' last common ancestor with the survivors of this older lineage probably lived more than 1 mya – suggesting that an Asian *erectus* lineage might have been the other species in the hybridization (Krause et al. 2010; Reich et al., 2010; Veeramah & Hammer 2014). In any event, Prüfer et al. traced 0.5 to 8.0% of Denisovan DNA from this older "erectine" lineage, indicating that Denisovans and the older species must have met geographically, such that some of the foreign DNA was able to introgress into the continuing Denisovan population before the erectines were entirely replaced by the Denisovans carrying some erectine genes and/or both were later replaced by *sapiens* expanding out of Africa.

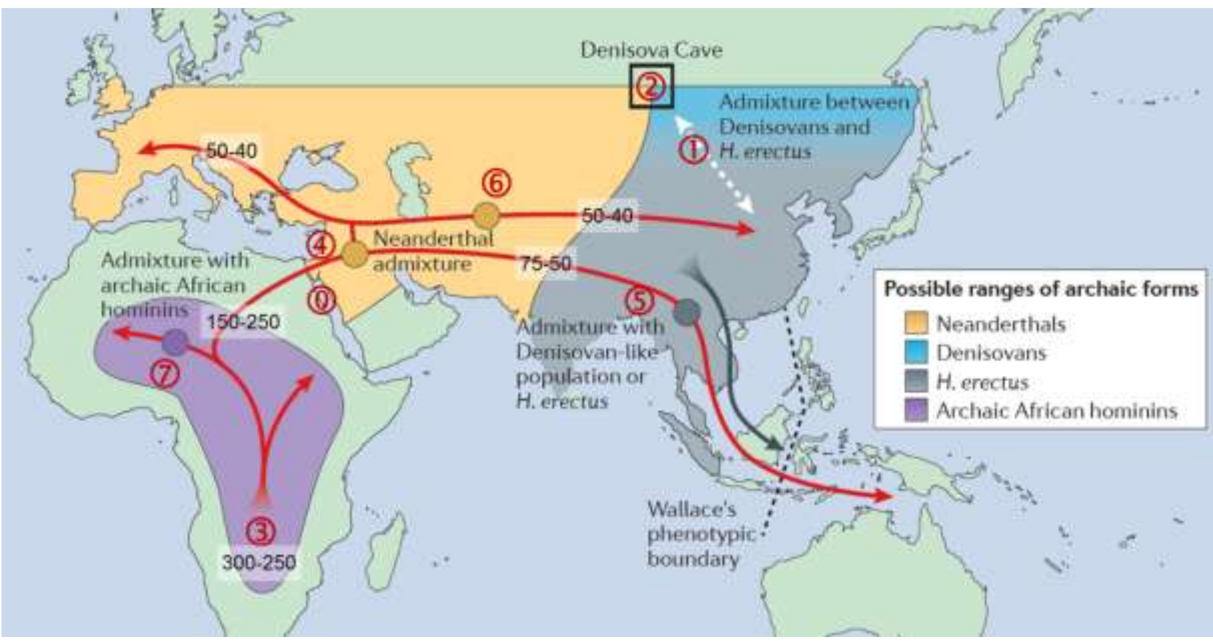


Figure 104. Possible geographic distributions of extinct species of *Homo* (Veeramah & Hammer 2014). Solid colors show the supposed ranges of species before the expansion of *Homo sapiens*. The red lines trace the migrations and hybridizations of *sapiens* as they expanded out of Africa, hybridizing first with Neanderthals where they encountered them in Asia Minor and with a Denisovan derivative in South East Asia as the first *sapiens* x Neanderthal wave migrated towards the Sahel (the Australian continental shelf). Members of this first *sapiens* wave carrying Denisovan DNA were apparently totally replaced by

later *sapiens* carrying essentially no Denisovan DNA. Circled red numbers refer to speciation and hybridization events discussed in the text and depicted in Figure 93. Dates in Africa (from Scally & Durbin 2012) refer to the north-south separation of populations ancestral to Khoe-San (South African) and other Africans. Those in north Africa represent the separation between the West African Yoruba and Eurasians. Other dates represent estimated timings of dispersals out of Africa.

At some point after they diverged, Denisovans also hybridized with Neanderthals, such that a small percentage of Neanderthal genes also introgressed into the Denisovan lineage that left its DNA in Denisova Cave (Prüfer et al. and Veeramah & Hammer loc. cit. ② in Figure 93 and Figure 104). This proves (1) that the two species met geographically, and (2) that by the time they met again, they had evolved enough genetic differences that the Neanderthals maintained their genetic identity nearly intact as biological species (Vivelo 2013; Stringer 2014; White et al. 2014) even though they were in contact with Denisovans to the east. There is also a chance that Neanderthals hybridized with an erectine survivor in Europe (Vandermeersch & Garralda 2011).

Analysis of genomes from three separate Neanderthal lineages from southern Siberia, Spain and Croatia, showed that Neanderthals had a remarkably low genetic diversity compared to modern humans from Africa, Europe and Asia (Castellano et al. 2014; Sanchez-Quinto & Lalueza-Fox 2015 - coding variation in different Neanderthals showed small effective population sizes). Tracing from the last common ancestor, genes involved in skeletal structure evolved more in the lineage leading Neanderthals than in the lineage leading to modern humans. Conversely, genes involved in behavior and pigmentation show more evolution in the modern human lineage than in the Neandarthal lineage.

Because we are the only hominin species surviving today, there are thousands of complete genomes available for *Homo sapiens* compared to the small handful of Neanderthal and Denisovan fossils yielding useful amounts of DNA. Presumably, *sapiens* is the survivor of the African branch of the *heidelbergensis* species complex (Veeramah and Hammer 2014). Given that modern humans only expanded into Eurasia some 60-45 kya (Gronau et al. 2011, Henn et al. 2012), it is evident that the immediate ancestors of Eurasian and American humans arose in Africa – possibly in southern Africa rather than East Africa (Henn et al. 2011 - ③ in Figure 93 and Figure 104). This is evidenced by three kinds of genomic information, the accumulated number of differences from the genome of the last common ancestor (a method discussed above), and by mapping genetic diversity and linkage disequilibrium.

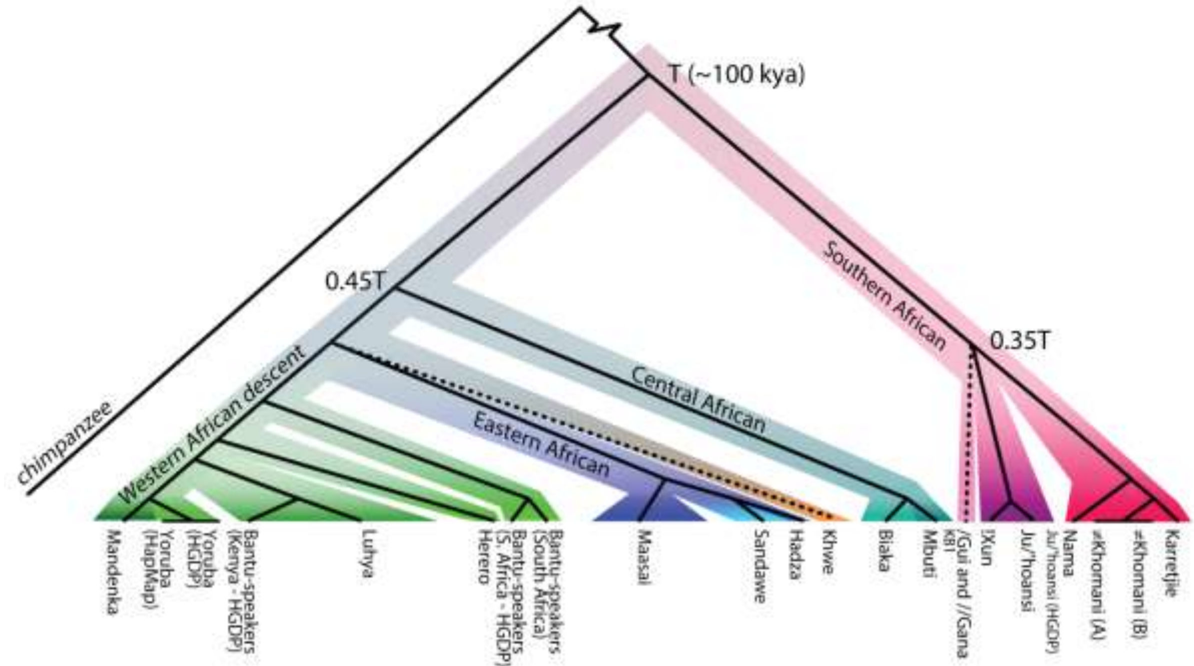


Figure 105. Genetic derivations of some sub-Saharan African populations based on a study of some 2.3 million single-nucleotide polymorphisms across the whole genome sampled from a group of 220 individuals from 11 southern African populations (Lombard et al. 2013). The Southern African branch dates from at lest 100 kya, while the Central Africans are about 45 kya. Note, these dates are based on older estimates of human mutation rates and do not incorporate Scally & Durbin's (2012) revised dating scheme.

Where genic diversity is concerned, the greatest genetic diversities of nuclear genomes, mitochondria, and Y-chromosomes in living humans are found in southern Africa, with progressively less diversity the farther away from southern Africa it is sampled. This is believed to be a consequence of a series of founder events, where a small number of individuals colonizing new territories carry only a sample of the genetic variability in the ancestral population, e.g., moving from southern Africa to NE Africa, then to Asia Minor, Australasia; and Siberia to North America, then to South America (Ramachandran et al. 2005; Manica 2007; Henn et al. 2012 - Figure 105). Some variability is lost in each founder event and it takes many thousands of generations of mutation and/or the later admixture of genes from other populations to restore diversity.

Linkage disequilibrium is where frequencies of alleles at different genic loci on the same chromosomal DNA strand differ from those expected from random assortment in a population. Because alleles that occur close together on a chromosome (i.e., closely linked) are only rarely separated by crossing over, founder populations tend to perpetuate the linkage arrangements of their founder members as the population grows. Again, it takes many generations before allelic frequencies along the length of the chromosomes approach randomness. The lowest levels of linkage disequilibrium are found in southern and western Africa, with the level of disequilibrium increasing with distance (Henn et al. 2011, 2012 - Figure 105; Petersen et al. 2013 - Figure 106).

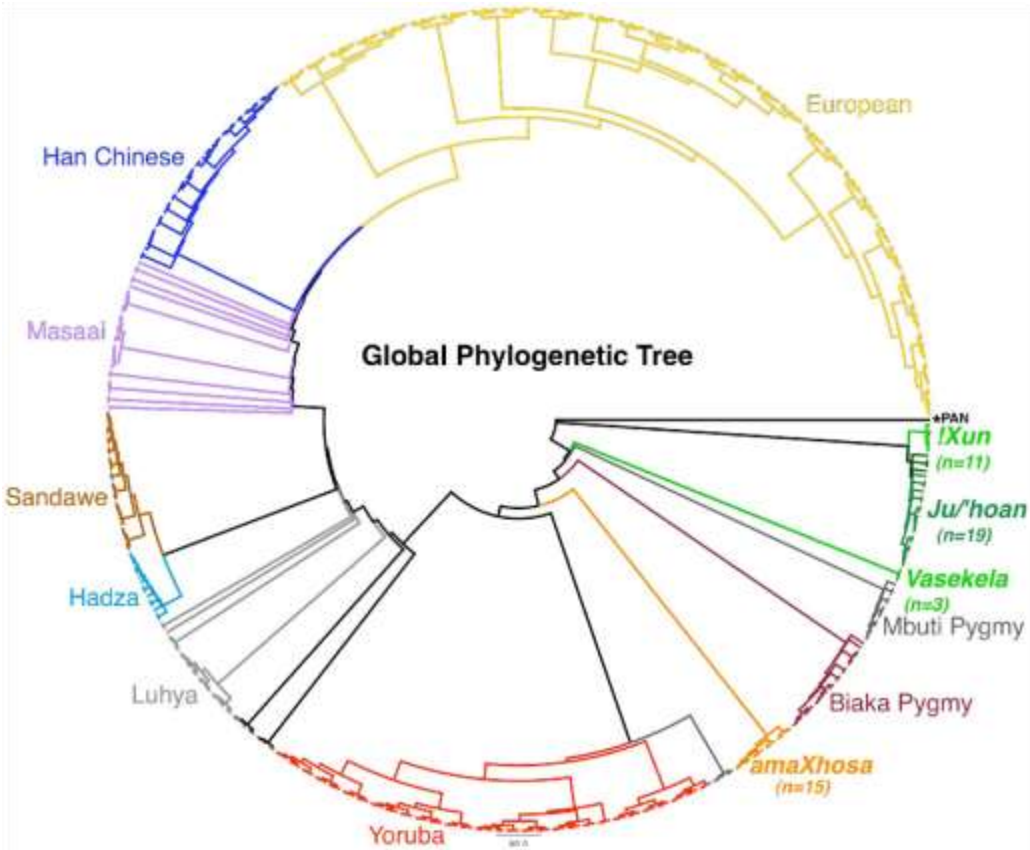


Figure 106. Phylogenetic tree for 24,402 linkage disequilibrium pruned autosomal markers based on 521 samples from 14 African populations compared to non-African genomes, with chimpanzees as the outgroup. The oldest groups, the !Xun and Jo/hoan are from Namibia and Botswana in southwestern Africa, while the amaXhosa are from SE South Africa (after Petersen et al. 2013).

As noted previously, the sequence in which specific genetic changes are accumulated in lineages provides a very clear trace of the genealogical relationships. Whether these are autosomal single nucleotide mutations (Schlebusch et al. 2012; Veeramah et al. 2012; Labuda et al. 2013; Petersen et al. 2013; Lombard et al. 2013), or genealogies constructed from uniparentially inherited mutations in mitochondrial DNA (Schlebusch et al. 2013; Barbieri et al. 2014, 2014a) or non-recombining Y-chromosomal DNA (Scozzari et al. 2012; 2014; Mendez et al. 2013b[356]; Elhaik et al. 2014), they all show similar patterns. The bottom line is that southern or western African hunter-gatherers include alleles tracing from the oldest surviving branches of the *Homo sapiens* lineage and that sapiens expanded outward from there to fill Africa and then the rest of the world[357].

Near modern *sapiens* reached the Levant for the first time around 130-80 kya or possibly as early as 220-200 kya (Bar-Yosef & Belfer-Cohen 2013). In the Levant these early migrants did not survive the next glacial epoch, when the region was occupied by Neanderthals in the period around 75-57 kya[336]. *H. sapiens*' residence in the Levant is tagged genetically by limited hybridization with Neanderthals (Henn et al. 2012; Veeramah & Hammer 2014 - ④ in Figure 104; Figure 105). All non-African *sapiens* from the British Isles and Scandanavia to Australia and South America carry 1.5% to 2.1% Neanderthal genes. (Prüfer et al. 2014 - ④ in Figure 93). Consequently, I am confident that this hybridization event occurred on the threshold of *sapiens*' expansion into Eurasia (perhaps as early as 70 kya) as our ancestors were poised to begin their expansion. Despite the hybridization, *sapiens* retained its integrity as an evolutionary species based on evidence for a significant degree of male hybrid sterility, and that many initially introgressed Neanderthal genes were selected against in the *sapiens* genome (Sankararaman et al. 2014). A few introgresed genes were selectively favored, e.g., those associated with skin structure and pigmentation, and immunology. Interestingly, there is no evidence that stable hybrid zones (Hall 2010) were established (Varki2016). Varki suggests that some unique cognitive features of *H. sapiens* greatly outcompeted Neanderthals where the two species met. I think it more likely that *sapiens* actively exterminated competitors.

However, some of these early immigrants may have survived in the southern Arabian Peninsula. In any event there is evidence that two waves of *sapiens* spread out from the area of the Levant and Arabia. The first wave leaving Arabia around 70 kya may have followed a coastal route into southeast Asia that was was almost entirely replaced by a second wave of *sapiens* that spread into Eurasia around 60-50 kya (Reyes-Centeno et al. 2014; Weaver 2014). Rare early Y chromosome variants found in southwestern Asia may represent surviving traces of this early dispersal (Fernandes et al. 2012; Scally & Durbin 2012; Scozzari e al. 2014; Schiffels & Durbin 2014). These early migrants to southeast Asia hybridized with a Denisovan-like population somewhere along their route (Veeramah & Hammer 2014 - ⑤ in Figure 104). Cooper and Stringer (2013) argue that the interbreeding between Denisovans and *sapiens* actually took place east of Wallace's Line when migrating *sapiens* hybridized with a preexisting indigenous Denisovan population already established on the Australia-New Guinea continental shelf. Any surviving Denisovans or *sapiens* carrying Denisovan genes on the mainland were then essentially completely replaced by later *sapiens* migrants carrying only Neanderthal genes (Fu, Q. et al. 2013). We know the *sapiens* x Denisovan hybridization occurred because Denisovan genes are found in native populations in Sahul (the Australia/New Guiea continental mass) and Oceania. There, 4% to 6% of the genes sampled from New Guinea and Australia are derived from Denisovans, while natives of eastern Indonesian, Philippines, and western Pacific islands have lower but still significant frequencies (Reich et al. 2010 2011; Skoglund & Jakobsson 2011; Meyer et al. 2012; Pugach et al. 2013; Prüfer et al. 2014; Sankararaman et al. 2016 - ⑤ in Figure 93)[358]. There is some evidence that the island populations from eastern Indonesia and Oceania also carry genes surrounding the OAS1 locus from a lineage that is even older than the Denisovans. This "ghost" species possibly dates from a separation 330 kya that is too early even for the divergence time of ~300 kya proposed for the split between *sapiens* and Denisovans. Mendez et al. (2012) speculate that this deeply divergent region may have introgressed into the Melanesians via hybridization with Denisovans that had earlier hybridized with an an earlier hominin branch, such as *Homo erectus* (see also Birney & Pritchard 2014).

Further introgressive hybridization between the second wave of *sapiens* and Neanderthals in Asia after the separation of the ancestors of Europeans and East Asians is evidenced by a higher frequency of Neanderthal genes in East Asian Han Chinese and Japanese than in European populations (Wall et al. 2013; Vernot & Akey 2014; Veeramah & Hammer 2014 - ⑥ in Figure 104). Hu et al. (2014) in a genome-wide scan for Archaic hominin introgressions in Eurasians sampled by the 1000 Genomes Project (2012) clearly detected Neanderthal specific genes in Eurasian (but not African) *sapiens*. They also found evidence for two other introgressions from more ancient (i.e., pre *heidelbergensis*) hominin derivatives from an ancient population that branched ~3,500 kya and a later population that branched ~860 kya. The ~3,500 kya branch may have represented an *H. erectus* or earlier lineage out of Africa. Some of these ancient genes introgressed via chromosomal segments inherited via the Neanderthal hybridization, while others already existed in the Eurasian *sapiens* lineage, perhaps due to direct hybridization between *sapiens* and an erectine in Eurasia. The admixture of more recent ~860 kya genes may have come from a hybridization with *H. antecessor*.

Finally, there is evidence for the comparatively recent introgression of ancient hominin genes into sub-Saharan African *sapiens* populations subsequent to the divergence to the north of migrants into Eurasia (Hammer et al. 2011; Lachance et al. 2012; Veeramah and Hammer 2014 - ⑦ in Figure 93 and Figure 104). This involved a study of 61 noncoding autosomal regions sampled from three sub-Saharan populations – two primitive hunter-gathers (Biaka and San) and one practicing agriculture (Mandenka). Three regions were identified, representing about ~2% of the sampled genes, that included chromosome segments assessed to have introgressed ~35 kya from an archaic population that split from the ancestors of anatomically modern humans ~700 kya. In other words another *Homo* species survived in Africa (possibly isolated in West Africa) alongside the *heidelbergensis* lineage at least until the two lineages met and hybridized ~35 kya.

Thus, the genomic evidence reviewed above shows us that although modern humans carry the genetic traces of small amounts of introgression from hybridization with closely related species we met on our migrations; we are still around 95% African in our recent ancestry. In short, African genomes did not mix with the locally resident species but replaced them. The uniparental genomics of mitochondria (passed only from mothers to their daughters) and Y chromosomes (passed from fathers to sons provide significant details regarding the modern human exodus from Africa and their dispersals around the planet.

Eriksson et al. (2012 - Figure 107) studied patterns of genetic variation across modern human populations and climate reconstructions over the past 120 kya to model the demographics of the dispersal of anatomically modern humans out of Africa. Colors indicate median arrival times (kya) for anatomically modern humans predicted from their model, beginning from a sub-Saharan distribution 80-70 kya, escape through a temporarily habitable southern Arabian Peninsula to colonize Eurasia around 70-65 kya, to arrival in SE Asia and Australia 65-40 kya, and spread through the Americas 15-10 kya. Red arrows indicate archaeological evidence. Although archeological and anthropological data were not used to inform their reconstruction, the arrival times of modern humans in the different continents derived from the model are broadly consistent with archeological and anthropological evidence. This scenario is also supported by analysis of the genome of a pure-blood Australian Aborigine based on a 100 year old hair sample (Rasmussen et al 2011), showing that the Aboriginal genome diverged from the general Eurasian population 75-62 kya, that the East Asian genome and general European genomes diverged 38-25 kya, and that native American genomes and East Asian ones diverged 30-15 kya.

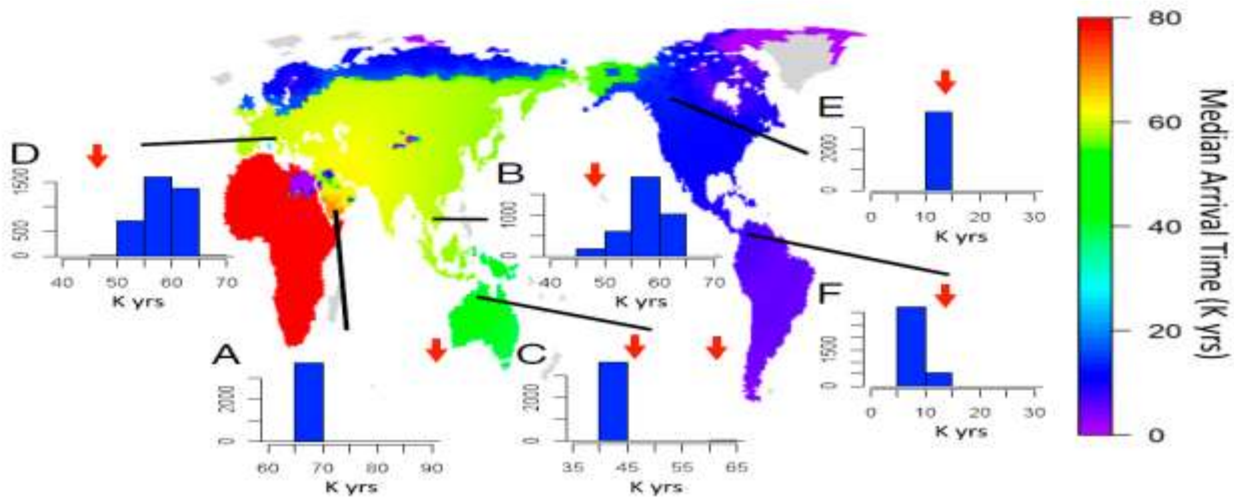


Figure 107. Median arrival times for anatomically modern humans dispersing out of Africa (Eriksson et al. 2012).

- *Triumph of anatomically modern Homo sapiens out of Africa to the world*

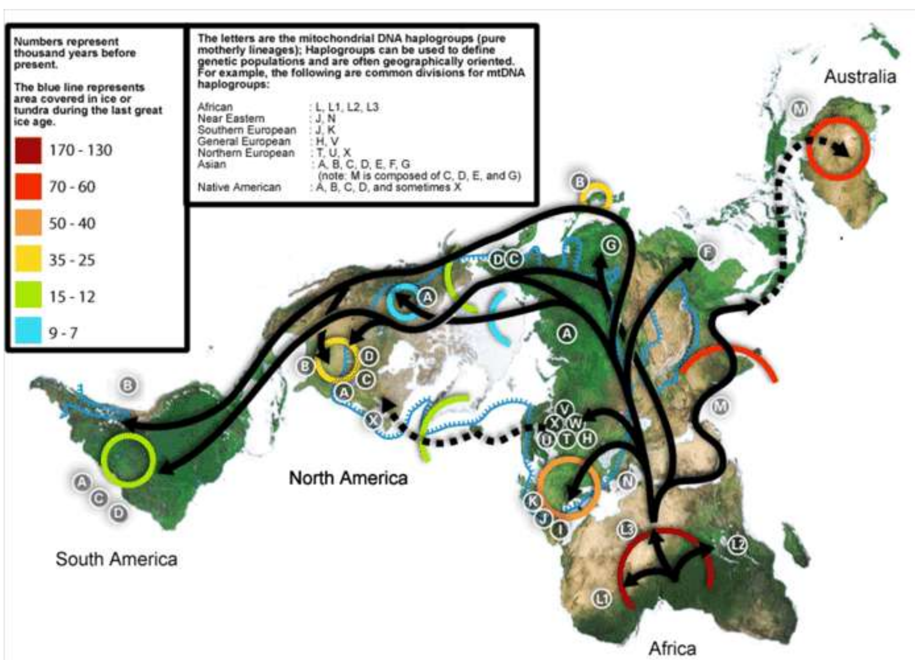


Figure 108. Human dispersal from Africa based in mitochondrial DNA. Click graphic for a larger version. A second click gives a still larger version (Wikipedia - Dudy001)[359].

As discussed above, uniparentally inherited mitochondrial (mtDNA) and Y chromosome DNAs together with autosomal genomics offer valuable markers for reconstructing genealogies down through the ages back into the times before *H. sapiens* first migrated out of Africa. More recent mutations in these DNAs trace the differentiation and migration of subpopulations across Eurasia and into Australia and the Americas (Behar et al. 2008; Cruciani et al. 2011; Soares et al.

2011; Appenzeller 2012; Oppenheimer 2012; Scozzari et al. 2012, 2014). Figure 108 summarizes the sequence of derivations of the various mitochondrial DNAs around the world.

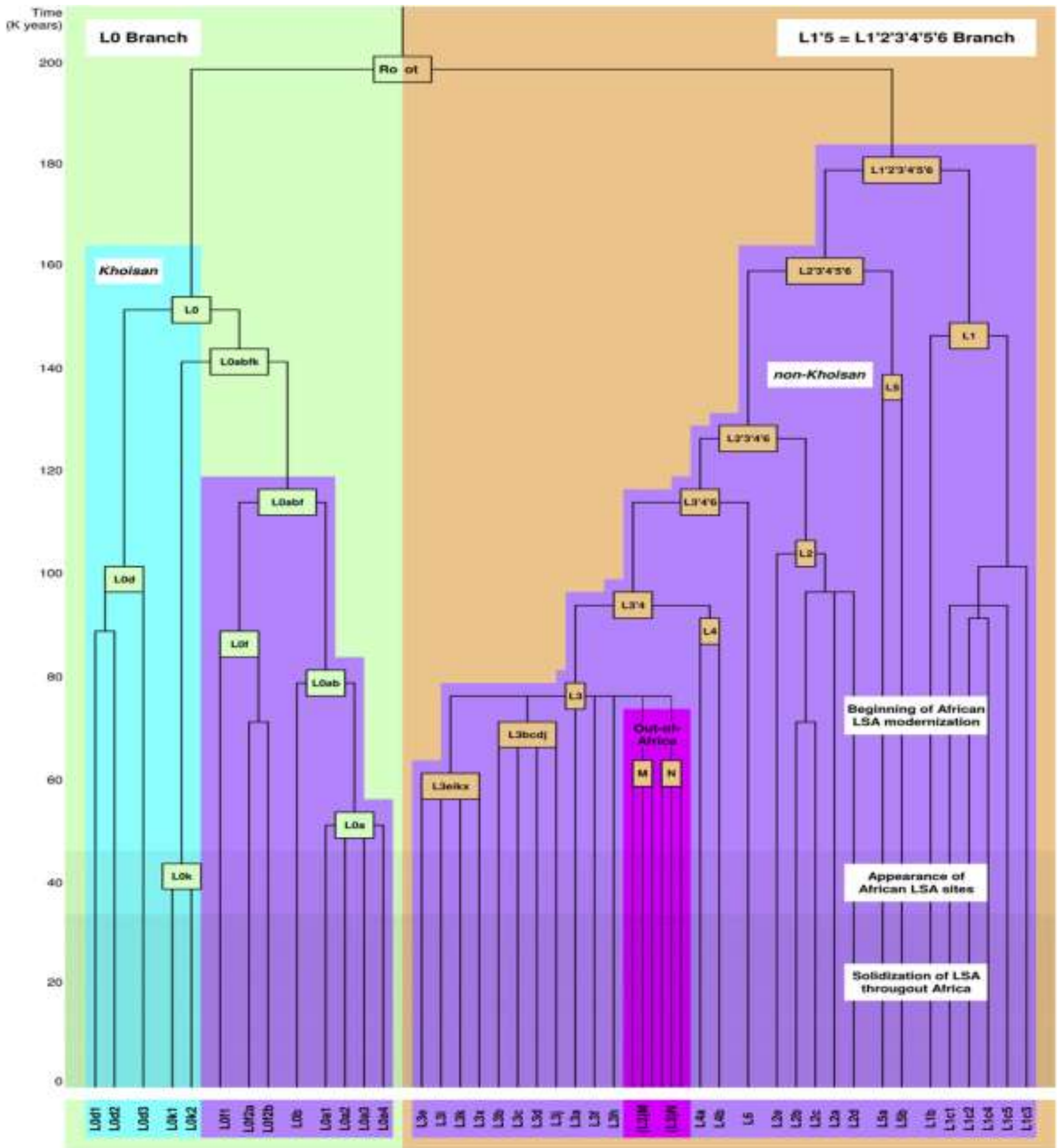


Figure 109. Simplified phylogeny of human mitochondrial DNA variants (Behar et al. 2008). The L0 and L105 branches are highlighted in light green and tan, respectively. The branches are made up of haplogroups L0–L6 which, in their turn, are divided into clades. Blue highlights Khoisan speaking clades while purple indicates non-Khoisan clades. Clades involved in the exodus from Africa are shown in pink. Years before present are shown on the left. Approximate time periods for different Late Stone Age epochs are shown by increasing color densities. To download the detailed phylogeny in Microsoft Excel format click here.

In Figure 109, Behar et al reconstructs the derivation of the different mtDNAs that traces the sequence of mutations back to a single woman who lived around 200 kya. One of her children founded the L0 lineage and a mutation in another child gave rise to L1’5. Each of these lineages gave rise to many derivative branches in Africa. The ancestral L forms are limited to Africa where there is a broad tree with two major branches and many sub branches from those two early sequences. The most divergent mitochondrial and male specific Y chromosomal genomes (i.e., those that differ by the most mutations) are found in hunter-gathers speaking Khoisan languages of south and southwestern Africa that represent the earliest surviving branch of anatomically modern humans. *All human populations outside of Africa derive from a single branch found at least six steps down from that first divergence.* This sixth order branch (pink in Figure 109) gave rise to M (migrating along the coastal routes to E Asia and Australia) and N haplogroups (proliferating to the rest of the world outside Africa.

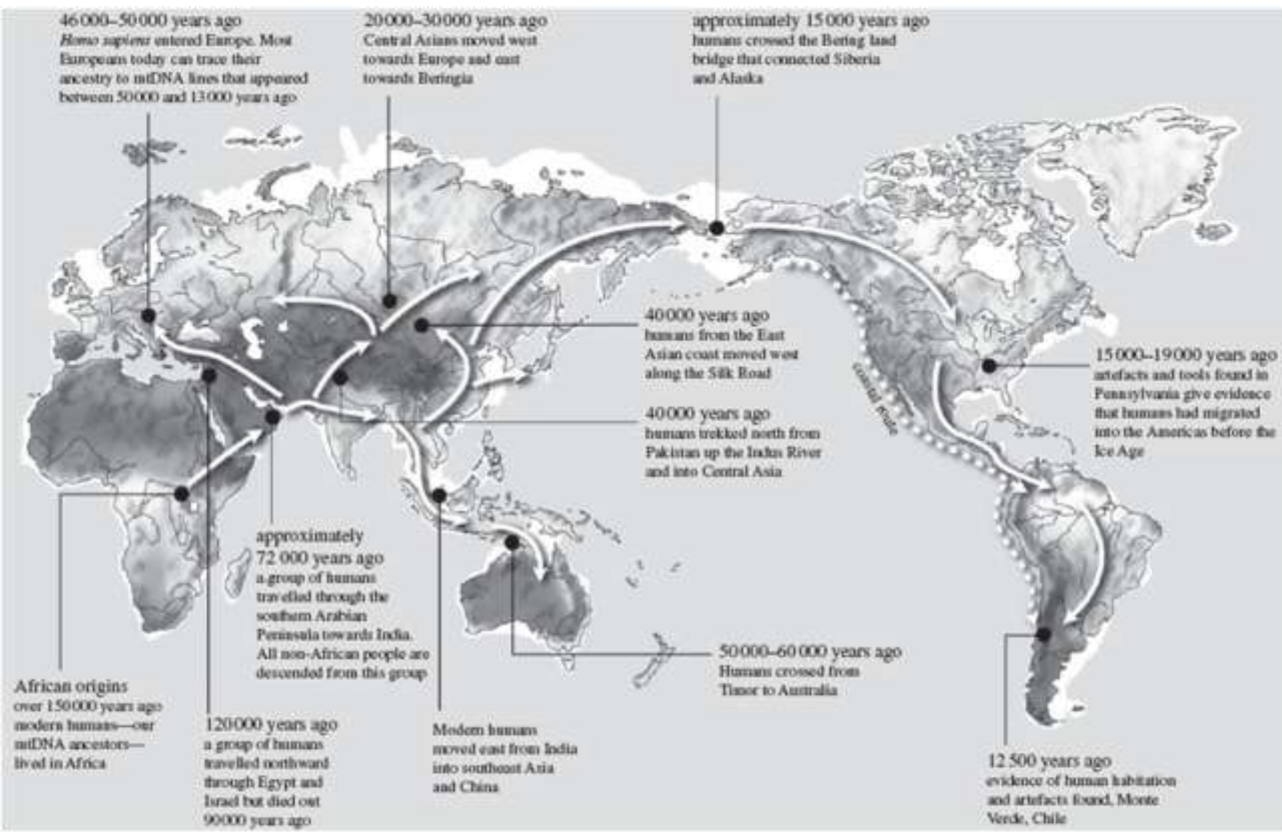


Figure 110. Dispersals of modern humans as reconstructed from uniparental gene trees (Oppenheimer 2012).

Stephen Oppenheimer’s interactive Journey of Mankind: The Peopling of the World[359] (Figure 110) traces the early migrations out of Africa based on evidence from mtDNA, Y chromosome sequences, archaeology, climatology and fossils. Recent studies map in more detail the migrations and admixtures of sub-populations as streams of migrants split and rejoined (e.g., Hellenthal et al. 2014; Gebremeskel & Ibrahim 2014; Ko et al. 2014; Lipson et al. 2014; Rasmussen et al. 2014; Sikora et al. 2014; Fernández & Pérez-Pérez 2014; Sarkissian et al 2014; Skoglund et al. 2014). Most interestingly, these studies chart the movements, spreading and replacements as different populations of hunter-gatherers developed pastoralism and then agriculture as humans invented the means to completely dominate the entire surface of the Earth. And today, as transport can take people anywhere on the planet within 24 hours to find a mate, these genomic differences are rapidly being mixed and remixed in so many ways the genetic traces of our ancestors migrations will be completely swamped within only a few more generations.

To this point I have presented some of the factual evidence showing the incremental steps by which modrn humans became different from our common ancestry with our still surviving cousins, the tropical forest-dwelling anthropoid apes. It now remains to explain how simple tool-using apes evolved into modern humans with the capacity to destroy the entire planetary ecosphere that nurtured our development.

An Evolutionary Hypothesis: - Our First Five Million Years or "How Did We Get Here?"

The evidence reviewed in the previous section tells us that our ancestors living in tropical forests some five million years ago were apes not greatly different from today's tenuously surviving great apes: orangutans, gorillas, chimpanzees and bonobos. Yet some combination of circumstances caused our hominid ancestors to evolve in different directions and very much more rapidly than our close cousins, or for that matter more rapidly than almost any other species on the planet.

The success (i.e., the continued survival) of a lineage or species depends on its ability to occupy and maintain an ecological niche where it can out-compete other contenders for the resources available in that ecological space. Evolution of populations is driven by the constant arms-race with other populations contending for those resources ("Red Queen Hypothesis"; Van Valen 1973; Dawkins & Krebs 1979). At the individual level this boils down to accessing enough resources to survive and reproduce well enough for subsequent generations of the population to maintain access to adequate resources. Genetically determined anatomical, physiological, and behavioral adaptations are all involved in maintaining access to the necessary ecological space for population survival. In this segment I will be looking at two aspects of hominid biology that are less tangible, but appear to be particularly important to maintaining the successful continuity of an evolutionary lineage – life history and system of heredity.

An organism's life history is the sequence of events related to its survival and reproduction that occur from birth to death. From a thermodynamic point of view, the life history "strategy" of a population or species involves the settings of complex series of trade-offs in the allocation of individuals' limited energy budgets towards growth, maintenance, reproduction, raising offspring to independence, and avoiding death (Schwartz 2012; Robson & Wood 2008). Thus, natural selection should favor the allocation of energy in ways that minimize mortality and maximize the number of surviving offspring. Life history theory seeks to understand the scheduling and magnitudes of key events in individual lifecycles, such as timing of maturation, age at first reproduction, frequency of reproduction, gestation length, number at birth (i.e., single or multiple), age at weaning, frequency of birth, interbirth interval, overall fecundity, and lifespan. The sequence and scheduling of these kinds of events is a "life history profile" and is the result of how developmental variables (growth rates, skeletal maturation, sexual maturation, etc.) interact with environmentally determined demographic variables (survival, reproduction, population growth, etc.) to influence the survival and transmission of individuals' heredity. In turn, the life history profile of a lineage is subject to natural selection.

Similar to the way life history profiles can be ascertained for species and evolutionary lineages, systems of heredity (or more commonly "genetic systems" control how species and lineages can evolve in response to natural selection. Surprisingly to me, although the evolution of genetic systems was a central topic for my PhD thesis (Hall 1973), the concept of a genetic system is not well documented in the literature or the Web.

The concept was introduced by C.D. Darlington in (1939). Rieger et al. (1976) defined the concept I use as follows:

> [A]ny of the species-specific ways of organization and transmission of the genetic material… which determine the balance between coherence and recombination of genes and control the amount ant type of gene combinations. Evolution of genetic systems means the evolution of those mechanisms effecting and affecting genetic variability. Factors which characterize a [genetic system] include the mode of reproduction, the type of population

> dynamics (breeding size, sex ratio, degree of panmixia), the mode of chromosome organization (genetic information all in one linkage group or distributed to several such groups), the chromosome cycle…, the recombination index, and the presence or absence of genetic and chromosomal polymorphism.
>
> *The genetic system and its components determine the capability of a population to undergo evolutionary changes. Any genetic system is under genetic control* [my emphasis – and thus the genetic system itself is subject to evolutionary change by natural selection].

In the present work I use the term, "*system of heredity*", to extend the idea of the genetic system. Where humans are concerned much of our survival knowledge is transmitted non-genetically between generations as cultural heredity. The combination of genetic and non-genetic heritage still determines the capacity of human populations and groups to evolve and adapt, this capacity is itself controlled by heredity, where the system of heredity itself is also subject to adaptive evolutionary change.

In stable environments where species' life history profiles and systems of heredity have similar capacities to evolve, selection is usually normalizing (See Appendix 1: Figure 161) to ensure survival in that ecological space. However, changes in the environment inhabited by our hominin ancestors established a pattern of directional selection that caused the hominin system of heredity and life history strategy to evolve in ways that allowed hominin species to change and expand their niches far beyond the adaptive and evolutionary capacities of other competing species in the environment. This directional selection is what has turned forest apes into what we humans are today.

Life in the primeval forest

Figure 111. Detail from Garden of Eden (c. 1615) by Jan Brueghel the Elder and Pieter Paul Rubens (Wikimedia). Click illustration to see the complete picture at full resolution.

Fossils and the biologies of our closest living relatives suggest that our last common ancestor with today's anthropoid apes very probably lived in Edenesque (Figure 111), well watered forest habitats in eastern or southern Africa, similar to those occupied by most of today's chimpanzees and bonobos). In most seasons our ancestors could forage either in trees or on the ground with little effort to feed on readily available fruits, herbs, nuts, insects and the occasional small mammal prey. They probably slept in trees, and if on the ground during the day they were threatened by one of the few large carnivores hunting in the forest, e.g., leopards (Boesch 1991), they could usually escape up a tree.

Fossils and comparative studies tell us a lot about these ancestral apes (e.g., White et al. 2009[332]; McGrew 2010; Whiten 2011; Sponheimer et al. 2013; Haslalm 2014); Duda & Zrzavy 2013); Su 2013). Based on a comparative and phylogenetic analysis of the biology of living primates, Duda & Zrzavy list a variety of biological traits confidently or likely to be found in the last common ancestor of chimpanzee and humans (CHLCA). The following would seem to be biologically significant from an environmental adaptation or life-history point of view (Duda & Zrzavy 2013: pp 433-434).

- *Life History*: Gestation length >8 months; medium-size neonates (3-10% of maternal weight); infant (preweaning) mortality <40%; weaning at approx. 4-7 years; onset of puberty at 6-10 years; first female reproduction at 11-15 years (postponed); interbirth interval <5 years; year-round breeding; maximum lifespan 40 - 50 years; female post-reproductive lifespan absent (i.e., no menopause).
- *Behavior contributing to system of heredity*: female-biased dispersal (male philopatry), both sexes dispersal; single male - multifemale mating system; possessive male mating strategy; exerted female mate choice; male dominance; paternal care and paternal protection present; conjugal families within semi-cohesive communities; opportunistic male mating strategy; forced copulations absent; positive correlation of male rank and copulation rate, high top-sire male mating success (100-81%).
- *Other behaviors*: group foraging; fission-fusion social groups, cultural diversity (behavioral traditions) present, simple tools; nest building present; sexual adornments of adult males present; medium-size testes; medium copulatory frequency; exchange of favors for sexual access present; moderately hostile intergroup encounters (limited amount of lethal intergroup violence); multimale groups present.
- *Anatomical*: moderate sexual dimorphism in body weight and canine size.

As long as our progenitors remained in moist forests they would have faced comparatively few large predators other than leopards (Boesch 1991) and food resources would have been readily available on a year-round basis. Selection would remain normalizing, with little pressure for adaptation to different or broader niches. Unfortunately for our ancestors and fortunately for what we have become, it seems that they lived in an area of East Africa that began to be impacted by the effects of continental rifting and mountain building between 10 and 5 million years ago. At least for apes isolated in the area affected by the rifting, the lush forests began to dry out.

The end of Eden and adapting to a hard life in a drier world with fewer trees

Global cooling and the mountain building associated with the opening of rifts East African Rift Valley System and periodic changes to the Earth's orbit caused climatic deterioriation and fluctuations (Prömmel et al. 2013; Magill et al. 2013, 2013a). The growing mountains on either side of the widening rift reduced precipitation in the rift valleys by removing humidity as rain on windward sides of the ranges. In turn this led to replacement of moist forests by today's more seasonal grassy woodlands, savannas, and grasslands as shown in the satellite view (Figure 112, Figure 113).

Figure 112. Rift Valley fault scarp and floor at Lake Baringo, Kenya, showing grassy woodland/savanna and the great productivity for large herbivores offered by the floors of rift valleys – see Wood & Guth (2013).

The extent of "marginal" dryland habitats also fluctuated over time with climatic and rainfall cycles affecting the size and location of permanent streams, lakes and springs. Potts (2012, 2013 - Figure 114) argues that single climatic events are probably not responsible for major adaptive shifts, but rather that it is the impact of the entire range of environmental variability that shapes evolutionary change. This encourages the evolution of versatility and niche broadening rather than niche shifting (Figure 162). The emergence of key adaptations and capacities in the hominin lineage seems to coincide with intervals of high climatic variability including aridity as indicated by the reduction and even drying out of lakes (Figure 115 – Maslin et al. 2014). Under these drier conditions hominins would have to travel farther and go to the ground to move from one tree to the next and to find sources of permanent water, increasing risks of predation while on the ground. As will be seen, the climatic expulsion of our ancestors from stable, moist forests into new climatically variable and directionally selective environments caused a sequence of grade shifts into new adaptive zones leading inevitably to human domination of almost all habitats on planet Earth.

Figure 113. Satellite view of the African Rift Valleys showing the great lakes and arid zones. The large lake in the upper center is Victoria (shared among Uganda, Kenya, and Tanzania). The four large lakes to the left (west) are Tanganyika, Kivu, Edward, and Albert, aligned along from the bottom off the Western Branch of the Great Ruft. The red arrow indicates Lake Baringo (Figure 112) The mountains forming the west side of the Western Rift block moisture from the Atlantic Ocean that is precipitated in the moist forests to the west of the mountains (note intense green). Mountains along the east side of the Eastern Branch of the Great Rift block clouds bringing moisture from the Indian Ocean to the east, forming an arid zone of seasonal/dry forest, savanna and grassland. Picture taken October 6, 2008 by camera MERIS (Medium Resolution Imaging Spectrometer) Envisat high resolution - credit ESA (see Envisat).

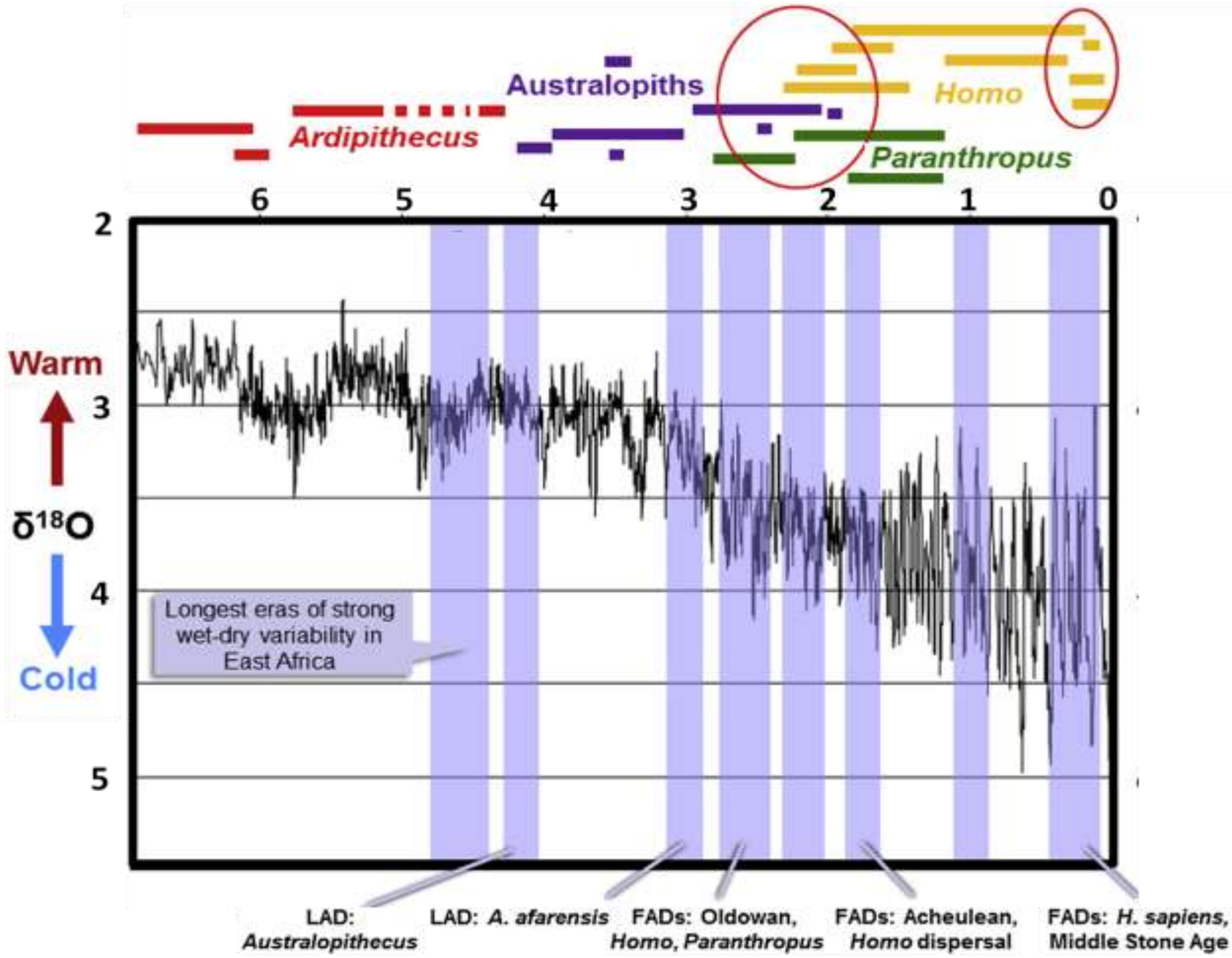


Figure 114. Hominin evolution and environmental variability over the past 7 million years (Potts 2013). The black line shows variation in oxygen isotope ratios in ocean sediments that is a proxy for average temperatures, showing overall decreasing temperatures and increasing variability over the last 3 million years. Occurrence data for hominin species are summarized at the top, with areas of major change circled in red. These are associated with closely spaced intervals of high climatic variability as indicated by the blue bars. FAD (first appearance date), LAD (last appearance date). The Smithsonian Institution National Museum of Natural History's Human Evolution Timeline Interactive adds important milestones.

Dry woodlands and savannas would have offered early hominins less of the resources habitually used by their forest-dwelling relatives and ancestors. To find enough food, they would have to find new and scarce resources over a much wider home ranges comprising possibly up to several thousand km^2, or might even have had to migrate over hundreds of km to follow seasonal rainfalls to find reliable water and suitable forage.

When the forests our ancient ancestors lived in dried up, early hominins would have to find and subsist on different menus of often seasonal plant foods scattered across an extensive landscape. New foods may have included nuts and fruit from widely separated trees and shrubs with short seasons, buried roots and tubers, and dry grass seeds, and may well have established selective environments favoring the use of tools for cracking nuts and seeds and mashing fibrous roots (Humle 2011; Matsuzawa 2011).

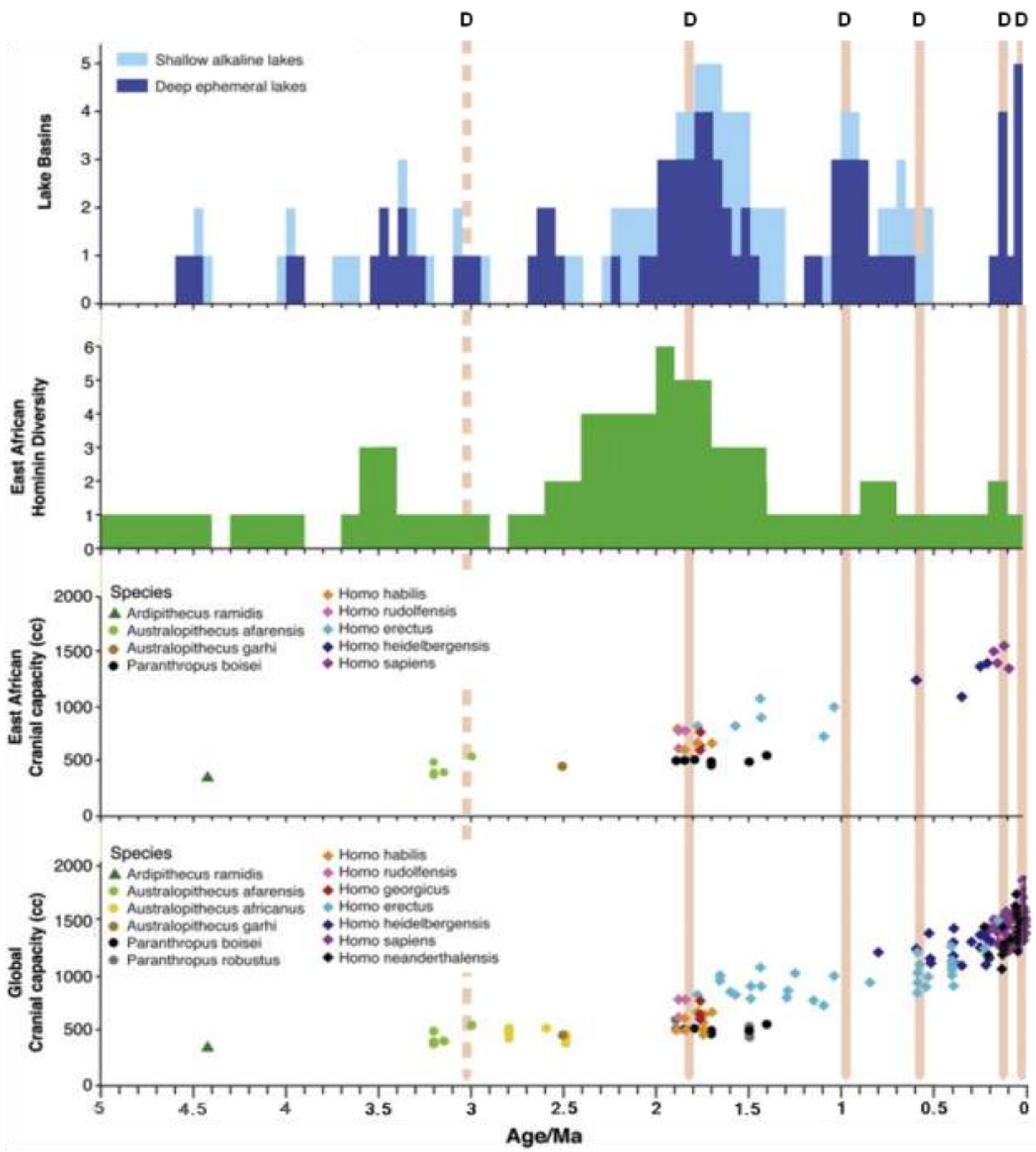


Figure 115. Climate variability and hominin evolution (after Maslin et al. 2014). Top panel shows lake basin extents calculated by collating the published geological evidence for the appearance of either deep ephemeral or shallow alkaline lakes in seven major basins in East Africa. Middle panel shows East African hominin species diversity over time, which was calculated every 100 kyrs interval using first and last appearance dates from the literature (Shultz et al., 2012). Bottom panels show hominin brain capacity estimates for Africa and for Africa and Eurasia combined. Hominin specimen dates and brain size estimates were taken from Shultz et al. (2012). *Homo erectus* and *H. ergaster* were treated as a 'super-species' referred to in the figure as '*Homo erectus* (sensu lato)'. Hominin dispersal dates were estimated by first appearance dates of hominin specimens of particular species outside of the East African Rift System and are shown by the pink bars labled 'D'

Although visible and easily digestible plant foods would be hard to find, grassy woodlands and savannas also offer a wide range of potential animal prey feeding on grass and other herbaceous vegetation the early savanna apes/hominins could not digest. However, most of the herbivores were large and very able to out-run or defend themselves against apes. Ape grade tools such as hammers and anvils (i.e., grinding stones) and digging sticks would have helped process things like seeds, roots, and possibly marrow bones scavenged from carnivore kills, but survival in the dry forests and savannas must have been difficult without grade shifting innovations.

In grassy woodlands, and especially out on the savanna away from large trees they could escape into, relatively slow and defenseless hominins would also risk predation by an extensive ecological guild[362] of large carnivores including lions, leopards (Figure 116), three species of sabertooth cats, a large bear, a wolverine the size of a small bear, several species of large hyenids, wild dogs, etc. (Treves & Palmqvist 2007; Werdelin & Lewis 2013). Today, leopards are a danger wherever chimpanzees live, but those coping with the savanna are also at risk from being taken by lions (Boesch 1991; Klailova et al. 2012; Muller & Wrangham 2014).

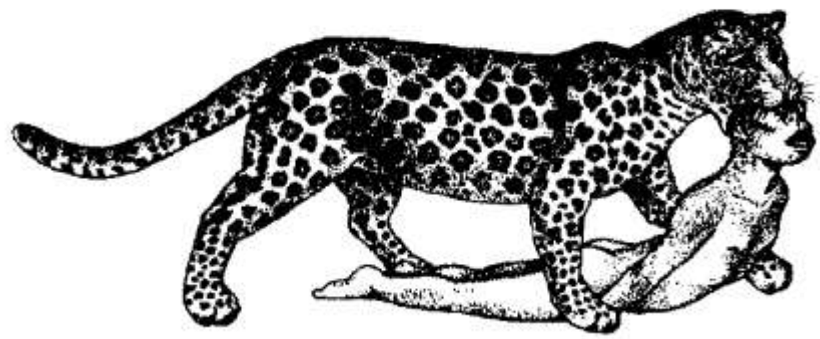


Figure 116. Early hominins must have been at great risk of predation. Major predators included leopards, lions, sabre-toothed cats, several species of hyenas, etc. (Picture from Tattersall 2012)

The replacement of moist forests by dry thorn forests, savanna and grasslands changed the selective environment by reducing the availability of forest resources and by providing the opportunity/necessity for niche expansion to exploit potentially nutritious roots & tubers belonging to seasonal plants (Laden & Wrangham 2005) and for carnivory (Guthrie 2007). Compared to forests, savannas offered new resources in terms of buried roots and tubers and comparatively large game animals (in some cases large enough to be dangerous in their own rights) for food – but little that was as easily harvested as forest resources. However, hominins lacked anatomical defenses against the large carnivores and needed a powerful edge – both to avoid becoming their prey and to compete successfully with them for meat. Arboreal primates who have to carry young while climbing through the trees also have low reproductive rates compared to the large cats, hyenas, etc., and would be unable to survive even comparatively moderate levels of predation without having some means to avoid or deter predators. In forests, primates avoid predators by living and sleeping in trees. Early hominins on the savanna would be at much greater risk of being taken by large carnivores.

To understand how early hominins adated to these circumstances we need to understand the capabilities of our remote ancestors and plausible pathways by which these could incrementally evolve to result in modern humans able to dominate the biotic resources of an entire planet. The discovery of *Ardipithecus ramidus* (White et al. 2009)[332] dating from around 4.4 mya provides a picture of the likely anatomical capabilities of an early hominin in the process of adapting to drier woodlands. The most complete skeleton, a female, probably weighed about 50 kg and stood about 120 cm tall, while other specimens suggest there was little difference between males and females in body size. *Ardipithecus*'s brain capacity was comparable to that of living chimpanzees. Small canines and face compared to chimpanzees and gorillas suggested that there compared to chimpanzees, there was little social aggression. Comparatively small molar teeth were not well adapted to chewing dry and fibrous foods. Hands, arms, feet, pelvis, and legs were still adapted to arboreality, using the palms of hands and feet and showing no characteristics typical of the suspension, vertical climbing, or knuckle-walking of modern gorillas and chimps. However, they already showed better adaptations for bipedality than today's forest apes (Lovejoy et al 2009b). This suggests that Ardi's first adaptation to more open and drier habitats was an improved ability to carry things while covering more distance on the ground between suitable food could be found and areas where there were trees they could climb for safety and sleeping. *Australopithecus* (Berger 2013)[335] was even better adapted for savanna life.

The primary imperative for the survival of any species is to maximize the reproductive success over its lifetime – at least to ensure that the death rate does not exceed the birth rate. This imperative can be resolved into several subsidiary requisites that can be met by various kinds of adaptations. Given that the productivity of a population is limited by its access to resources in competition with other populations, investment to improve one kind of adaptation may involve trade-offs with other adaptations.

One requisite is that the rate of reproduction must maintain the population against losses due to predation and other causes. For a given energy cost, this can be met by adaptations for producing more progeny in a lifetime (e.g., cooperative parenting to reduce the cost to the mother of care per individual young), or by providing greater protection for a smaller number of young (e.g., increasing parental investment via monogamy - De Waal & Gavrilets 2013), or by evolving effective means to deter predation (Kortlandt 1980; Boesch 1991; Klailova et al. 2012).

Another need is for a diet to support to support the requisite rate of reproduction. Females may evolve reproductive strategies (e.g., hidden or cryptic ovulation) to encourage males to provide food in return for sex ("vested provisioning" or "monogamy with a purpose"). Depending on relative energy costs and benefits the population can adapt by increasing mobility to look in more places for existing varieties of food, or acquire and maintain knowledge to use new tools and use them in new ways to extend the variety of food that can be eatern.

Lovejoy (2009 - Figure 117) reconstructs the web of likely interactions and adaptations working to shape the life history profile of our forest ape ancestors into early hominins. Assuming that early hominids were primarily herbivores and frugivores, as they grew larger in size and climates deteriorated in the Pliocene, one way selection could work to maintain adequate dietary input is through the development of increased cognitive and manipulative capabilities to find food that is not visible or is otherwise inaccessible. Extending the diet beyond things that can be simply be grazed or picked and eaten as individuals wander through the environment involves development of "extractive foraging" (see foraging) to find and extract food items such as encapsulated and/or defended nuts and seeds, ants, termites, honey, burrowing grubs, edible roots and tubers. Thus, the extractive forager can extend its feeding niche to resources that are not found or cannot be used by species that merely graze or pick.

Finding enough food to make a living as conditions deteriorate would involve a progressive development of associated cognitive and manipulative abilities including the use of tools to assist foraging. Here, I recognize four evolutionary grades, each involving increased cognitive and manipulative skills:

- Random picking (if it looks and smells good, pick it and taste; if it tastes good, eat it)

- Targeted picking (know what is in season and where to find it; go there, pick and eat)
- Extractive foraging (as above, and know where edibles hide and how to extract them)
- Tool assisted extraction + processing (as above, and know how to use tools to make what is otherwise inedible edible).

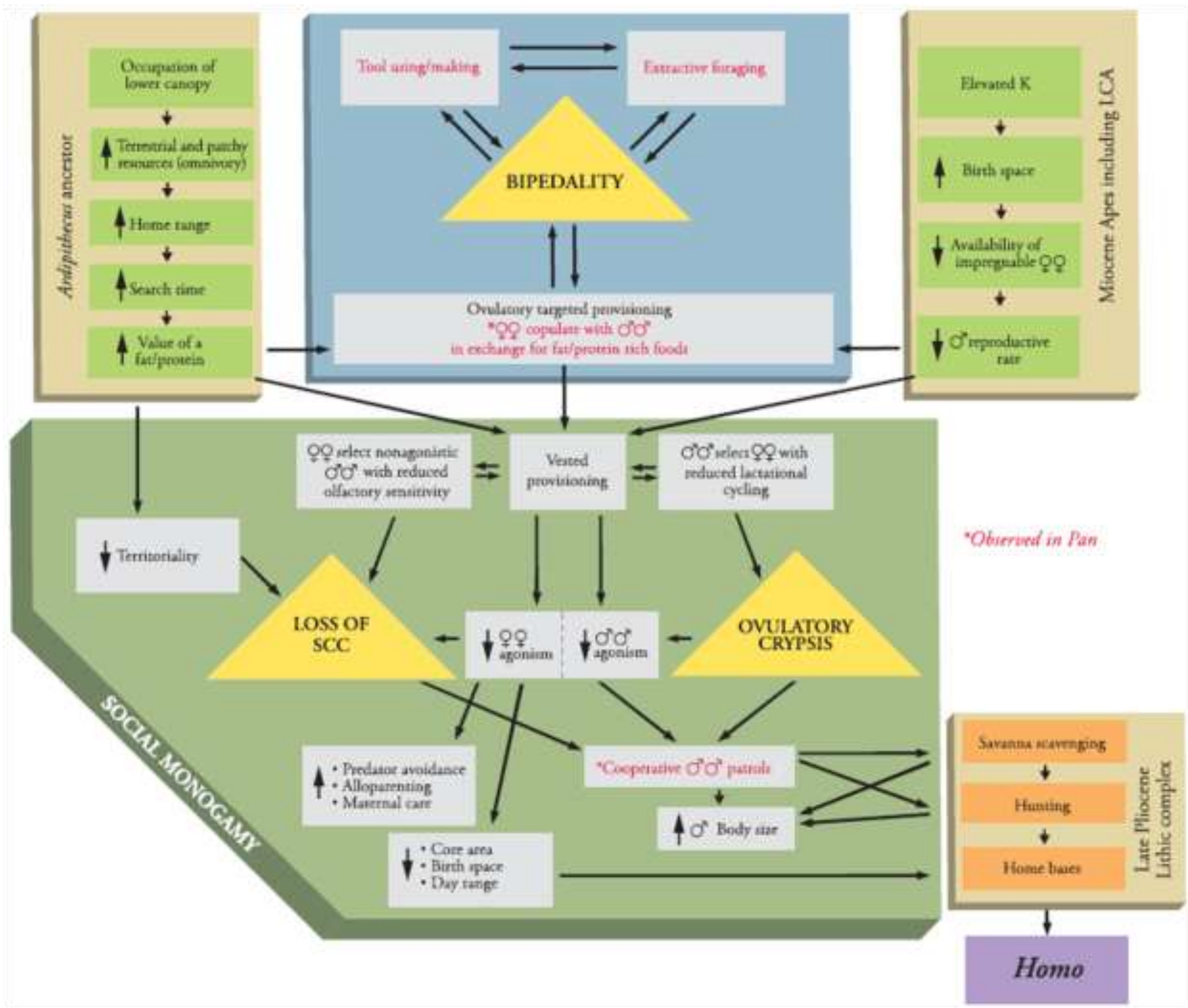


Figure 117. Changes as basal hominins adapt to drier, less forested habitats (Lovejoy 2009). The drying environment favored two sets of evolutionary responses. The box on the left highlights changes encouraged by the need to seek food more widely and on the ground leading to reduced individual territoriallity. The box on the right highlights factors relating to the need for more investment in a fewer number of offspring (K-selection) to ensure their survival in harsher environments. Yellow triangles indicate three new adaptations: bipedal locomotion, loss of SCC - self-honing canines (both evidenced in fossils), and hidden ovulation (as in modern humans). Selective factors are hypothesized as follows: (a) needs to forage over larger areas and carry objects (esp. tools & food) leads to habitual bipedality, (b) female choice of mates based on factors other than fighting eliminates selection for large canines, and (c) hidden ovulation favors monogamy. "Vested provisioning" by males of females caring for the males' children is a response to both shifts. Lovejoy speculates this culminated in scavenging on the savanna, use of primitive stone tools for butchering meat and extracting marrow, and cooperative hunting, establishing feedback encouraging further evolution along these trajectories.

Compared to picking, extractive foraging makes more demands on cognition to mentally map the territory where resources may be found, to imagine where food and other resources might be hidden from the senses or protected, the strategies by which they may be harvested. Similarly, substantial manipulation may be required to access the resources, demanding increasingly complex and precise neuro-muscular coordination. In this scenario, there will be major benefits if knowledge of the hidden food and processes for extracting it can be remembered and transferred as cultural heritage rather than having to be learned by every individual through trial and error. In turn this places a premium on adapting to live and forage in large and stable groups to retain and share this important survival knowledge from one generation to the next. Together, these factors would select for the evolution of increased cognitive capabilities and larger brain sizes to support the cognitive requirements.

What Can We Learn About Early Hominins from Chimpanzees and Capuchin Monkeys

Comparative studies of our closest cousins from around 5 mya, chimpanzees; and much more distant relations from 34-40 mya, the New World capuchin monkeys both provide significant information about the likely lifestyles and problems early hominins faced, and how tools helped them make the transition from life in an arboreal Eden to more terrestrial life in harsh habitats.

- *Planet of the Apes – Technologically adept chimpanzees could become the next humans*

As discussed in Technological revolutions, the first of several major technological revolutions setting our direct ancestors leading to modern humans' domination of the planet was the use of physical tools to mechanially extend the body and assist extractive foraging. As summarized in Appendix 2 and demonstrated in several videos (Figure 5 and Figure 118)[360], some chimpanzees use simple tools to extend their bodily capabilities such as probes, clubs, hammers and anvils, etc. for "remote" sensing, in defense, communications, and especially to help extract otherwise difficult to access edible materials. Compared to other anthropoid apes still living in moist forests, chimpanzees living today in dry seasonal forests and savanna habitats show how early primarily arboreal hominins may have survived in these kinds of habitats. Field studies show that as easily picked food becomes scarce and seasonal, chimpanzees in the drylands forage over much larger areas and use a wider range of tools to extract hidden and protected food (Figure 117; **Error! Reference source not found.**).

In moist forests, typical home ranges observed for chimpanzee groups are between 10 km^2 or less to as much as 38 km^2 for the largest groups (Nakamura et al. 2013: Table 1; Wilson et al. 2001; Mitani et al. 2010). However, in sparse dry forest or even more arid savanna habitats, the home ranges of groups have been measured to spread from 122 to as much as 560 km^2 (Nakamura et al. 2013: Table 1 in Izawa 1970; Baldwin et al. 1982; Ogawa et al. 2007). Dryland chimpanzees also have to spend much more time looking for a meal (Pruetz & Bertolani 2009). Clearly, it seems that the chimpanzees living outside of the humid forests have to cover much more ground and work harder to make a living, where there is likely to be a selective advantage for improved gaits. Tourkakis (2009) reports a higher degree of bipedalism in savanna chimpanzees than in forest populations.

All living great apes use some tools (van Schaik et al. 1999; Schumaker et al. 2011; Haslam 2013), so it is likely that the first hominins also had some capacity to do so. Since the

1960s (Goodall 1962, 1964, 1968; Kortlandt & Kooij 1963) it has been known that some chimpanzee populations in the wild make and use tools for attack and defence and to assist their comfort and foraging. **Error! Reference source not found.** lists the considerable variety of tools used by various populations in particular circumstances. Chimpanzees in the driest habitats (e.g., Fongoli) use tools in the widest variety of circumstances (Pruetz & Bertolani 2009; Bogart & Pruetz 2011).

Figure 118. Videos demonstrate chimpanzee tool use. (Top left) Chimpanzees using probes to collect ants. Two different tools are used in sequence by the one in the foreground. (Top right) Chimpanzee children watching mothers in a group using hammers and anvils to crack otherwise inedible nuts. (Bottom left) Video clip presumably extracted from Kortlandt et al. (1981) of wild group of male chimpanzees attacking a stuffed leopard with clubs. (Bottom right) Chimpanzee pounding with a sharp stick to break into a bee hive (Sanz & Morgan 2009). Click pictures to watch videos[361].

Chimpanzee's tool using behaviors seem to help them adapt to terrestrial habitats in the dry lands. Chimpanzees spending time on the ground face increased risks of predation from leopards and lions. Interestingly, whenever chimpanzees see a leopard, males will cooperate to mob it, throw things, and in some cases will attack with broken branches or sticks used as clubs, or possibly even spears (Kortlandt 1980 - Figure 118 (bottom left); Boesch 1991). Because of its high energy value, honey is a highly desired commodity for most primates (McGrew 2014), especially including chimpanzees who use a variety of tools in harvesting it. In fact, some dryland chimpanzees show advanced planning to collect and manufacture a variety of tools to breach a bee hive, including pounding clubs, levers, and dip-sticks (Sanz & Morgan 2009; Boesch et al. 2009; Byrne et al. 2013; Wilfried & Yamagiwa 2014 – see video Figure 118 bottom right). Most chimpanzees include animal protein in their diets, where some populations habitually use tools to help (Hicks 2010; Tennie et al. 2014). High protein food ranges from ants and termites (harvested with probes and wands - e.g., Bogart & Pruetz 2011), to small primates (some male chimpanzees cooperatively hunt monkeys - e.g., Fahy et al. 2013), prosimian galagos (speared by single hunters in tree-holes – e.g., Pruetz & Bertolani 2007), and occasional other terrestrial vertebrates such as turtles and pangolins (probably bashed to death - Hicks 2010). Harvested nutmeat also contributes significantly to diets (Yamakoshi 1998). Finally, in one of the most marginal savanna habitats inhabited by chimpanzees (McGrew, 2007), Hernandez-Aguilar et al. (2007) identified 11 sites where chimpanzees had used sticks to dig up roots. Two sites showed 62 and 96 holes, respectively.

As discussed above, forest dwellers such as orangutans, bonobos and chimpanzees have been observed to make and use simple tools of biodegradable materials that would leave no archeological record (Pruetz & Bertolani 2007; Boesch et al. 2009; van Schaik et al. 2003). The only tool use likelty to leave any archeological record are nutcracking sites. The assumption is that the last common ancestor of humans and chimpanzees (Figure 86) probably also lived in forests and made and used similar tools (McGrew 2010). Following White et al. (2009) and Su (2013), we can also surmise that the apes who became hominins had opposable thumbs to aid climbing and manipulation of food, but walked on the palms of their fore and hind feet (palmigrade locomotion), and, like chimpanzees and bonobos, were able to sit or stand more-or-less upright to manipulate tools to assist foraging and defense as can be seen in the videos.

Forest apes find most of their dietary requirements close to hand, and populations vary in their uses of in foraging - presumably because the tools are of relatively minor importance in improving their diets. Those in savanna forests use greatest variety of tools. Different chimpanzee populations use different sets of tools, demonstrating that tool-using knowledge is culturally transmitted. Bonobos and some chimpanzee populations in moist tropical forests are rarely or never seen to use tools, although it is evident from lab studies that both species are amongst the most capable to use tools of all non-human primates (Gruber et al. 2010). However, when faced with a declining availability of forest resources, more extensive use of these kinds of tools could mean the difference between survival and extinction – placing significant selection pressure to enhance cognitive and anatomical capabilities to use tools (Pruetz & Bertolani 2007).

As will be seen below, when tree-dwelling forest primates are forced to survive in harsher environments on the ground, an inevitable adaptive pathway leads to the evolution of socio-technical intelligence and knowledge.

- *Repeating the end of Eden experiment in a new world*

There is an interesting test of the hypothesis that climatic deterioration and a hard life established a selective environment that started our primate ancestors down the track to the cultural evolution of technology and world dominance. This is provided by the evolutionary radiation of New World monkeys in the family Cebidae. Some species in the genus *Sapajus* (long-lived, "robust" capuchins referenced in the older literature as *Cebus apella*- **Error! Reference source not found.**)[364] have independently evolved an intelligence and proficiency for tool-use closely comparable to that of the savanna chimpanzees. Except for their small size (2½ - 4 kg vs. 50-70 kg for a chimpanzee), *Sapajus* also parallel chimpanzees and bonobos in many other ways, including hunting (Rose 1997; Spagnoletti et al. 2013), life history strategy (e.g., persistent group structure with multiple males in persistent dominance hierarchy, life span 40-55 yrs, long childhood, 2 years between pregnancy, social tolerance – Ross 1991; Fragaszy & Bard 1997; Visalberghi & McGrew 1997).

Figure 119. Capuchins were clearly known to Brueghel and Rubens (see Figure 111), who placed them in the Garden of Eden (c. 1615) along with Adam and Eve. Their manipulative abilities are pictured.

For some 500 years it has been known that captive capuchins were highly intelligent (Klüver 1937; Carpenter & Locke 1937; Ottoni & Izar 2008; Visalberghi & Addessi 2013). Their intelligence made them useful to humans buskers on urban streets and carnivals, who enslaved and trained the monkeys to panhandle beg coins (Figure 120). However, as will be seen, in harsh thornscrub habitats in Brazil (southern hemisphere equivalent to the Sahara), some of these small monkeys are hard working and technologically capable extractive foragers who are at least as far along the the path to technological development as chimpanzees are (Figure 121)[365].

Figure 120. The organ grinder and his monkey (© Rice University Archives). Click picture for related video.

Figure 121. *Sapjaus* capuchin working for itself uses a very heavy stone hammer and a log as an anvil. This still photo captures its success in cracking a very hard palm nut after many tries (click to see video showing just how hard it was to break this nut – other nut crackers can be heard in the background) – see also Jenifer Martin's video of these industrious tool-users at work. A 28 minute BBC video, Capuchins – the Monkey Puzzle, places this complex *industrial* behavior in contex.

Arguably, given their technological capabilities, some populations of *Sapajus* living in seasonally arid savanna habitats are only 3-4 million years behind us in their evolution towards a human grade intelligence. Supporting this statement, despite their tiny stature (adult males weigh around 4.5 kg, compared to ~70 kg), these monkeys have an encephalization quotent intermediate between australopithicines and early *Homo*, and exceeding chimpanzees (Aiello & Wheeler 1995 - Figure 122). How did they become so brainy?

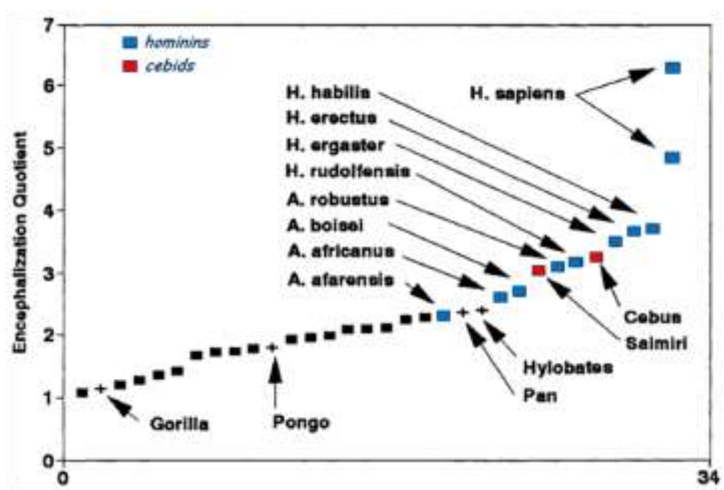


Figure 122. Encephalization quotients (EQ) of 34 species of higher primates, including extinct hominins (Aiello & Wheeler 1995).
Blue squares = hominins,
red squares = New World cebids,
black squares = other monkeys,
Pongo = orangutan,
Pan = chimpanzee,
Hylobates = gibbon,
Saimiri = squirrel monkey,
Cebus = capuchin monkey – probably *Cebus apella* = *Sapajus* "*apella*" EQ confirmed by Hartwig et al. (2011)[366].

Fossils and molecular dating show that the lineage giving rise to the New World monkeys (Platyrrhini) diverged from our own lineage of Old World monkeys and apes (Catarrhini) probably between 45 and 40 mya (Pecon-Slattery 2014; Schneider & Sampaio 2014, Schrago et al. 2013). The evidence suggests that the common ancestor of the New World platyrrhine monkeys was a small, forest-dwelling frugivore, with grasping hands adapted to climbing around in trees and walking on the tops of tree branches. Even 45 mya the Americas were separated from Africa by a slowly widening Atlantic Ocean. The oldest monkey fossil from South America is *Branisella boliviana* from 26 mya (Kay 2015), so it is likely that the ancestor of all New World monkeys crossed the ocean sometime between ~40 and ~26 mya by passive rafting in floating vegetation (e.g., in a tangle of trees washed out into the ocean by a major flood or tsunami – Houle 1999; Jameson Kiesling et al. 2014). It is also likely that this New World colonist would have been smaller than many of its African contemporaries known from the fossil record, as large animals would have had difficulties surviving an Atlantic crossing on the limited resources of food and drinkable water provided by a raft of vegetation. Given similar winds and currents to those that exist today, Houle suggests that the crossing could have been made in one to two weeks, which would not be beyond small migrants' physiological capacity if they were already adapted to surviving dry seasons and finding rain water captured in tree holes.

Based on genomics and anatomy, the surviving families of living platyrrhine monkeys differentiated 20-25 mya (Schrago et al. 2013; Schneider & Sampaio 2014; Pecon-Slattery 2014); with the last common ancestor of all cebids only a few million years younger. Based on the best estimates, the split between *Cebus* and *Sapajus* dates to the late Miocene, about 6 mya (Lynch Alfaro et al. 2012, 2012a) – around the same time as the split between panins and hominins. The the ancestral *Cebus* occupied the forests of the Amazon/Rio Negro-Orinoco Basin and perhaps Central America, and *Sapajus*, the more seasonal and temperate Atlantic forests. It is likely that the ancestors of the two genera were geographically separated by the belt of harsh and seasonally very dry thorn forests of the Caatinga, Cerrado and Central Grasslands (Lynch Alfaro et al. 2012; Jameson Kiesling et al. 2014 - Figure 123). Based on genomics, the *Sapajus* and *Cebus* lineages began to split into distinct species around 2.5 to 2 mya, with major proliferations giving rise to the presently recognized species beginning around 500 kya. *Sapajus* species like *apella* and *libidinosus* differentiated within the last 200 kya and subsequently spread into the Amazon Basin where they became sympatric with species of *Cebus*. Interestingly, these timings are comparable to speciation separating the chimpanzees and bonobos, and speciation within *Homo*

Cebids, including the squirrel monkeys *Saimiri*, *Cebus* and most *Sapajus* are arboreal frugivores and foragers, using intelligence, cultural knowledge, nimble fingers, and strong canine teeth to extract and process edible items that are effectively hidden or protected from other arboreal foragers. Although captive *Cebus*/*Sapajus* are proficient tool makers and users, until recently it was believed that they did not use tools in their foraging activities (McGrew & Marchant 1997; Visalberghi 1997; Ottoni & Izar 2008). However, recently it has been found that *Sapajus* living in the thorn scrub habitats of Brazil, where they spend most of their time on the ground or canyon walls, are habitual tool makers and users (Moura & Lee 2004; Ottoni & Izar 2008; Mannu & Ottoni 2009; Canale et al. 2009; Visalberghi & Addessi 2013). Lynch Alfaro et al. (2012) suggest *Sapajus*'s capabilities to use tools to support their survival in the Caatinga and Cerrado may have allowed *Sapajus* cross the thornscrub and reach the Amazon Basin, where they rapidly proliferated in sympatry with *Cebus*.

Figure 123. Forest zones inhabited by capuchin monkeys in South America. Left – Operational geographic units recognized by Jameson Kiesling et al (2014) in their discussion of the evolutionary radiation of *Cebus* and *Sapajus*. Thorn Scrub comprises the Caatinga and Cerrado - OGU 6 and the Central Grasslands - OGU 9. Right (NASA satallite image of Brazil, showing the arid thorn scrub comprising the Caatinga (as outlined in yellow), Cerrado and Central Grasslands).

Although Amazonian *Sapajus* don't need tools to survive in the lush tropical forests (return to Eden?), their intelligence may have been boosted enough for them to outcompete the closely related *Cebus* as extractive foragers in the same habitat (Lynch Alfaro et al. 2012; Boubli et al. 2012). In any event, the evolution of technological capability and intelligence seems to have been important in adaptation to the hard existence of life on the savanna. Although Amazonian *S. apella* show little evidence for tool use in the wild – in the lab individuals assumed to belong to this species have proven to be highly effective tool makers and users (Figure 124), suggesting they may have had to use tools in the history of their migrations to reach Amazonia.

Figure 124. Vulcan (*S. apella*?) making a stone knife to access honey from a closed tube. Click for BBC video. (see also videos 1 and 2 in End Note 366).

Very similar selection and adaptation to that proposed to have happened with forest apes (= early homininis) finding themselves on the savanna some 4 mya can be seen today in capuchin monkey groups living in the dry forest of Brazil (Mitchell & Moura 2003 video about Moura's work). Selection in this case is likely to involve both genes – to improve anatomical and cognitive capabilities; and culture – to socially transmit more and better knowledge. As was presumably the case with the ancestors of apes and capuchins, selection to improve abilities for clambering trees and walking along the tops of branches preadapts the arms and hands for manipulation and close hand-eye coordination, and the body for bipedal locomotion on the ground (Figure 125).

Genetically, to achieve better adaptations to terrestrial locomotion in the thorn forests, individuals would benefit from energetically more efficient bipedal locomotion, especially to assist the long-distance transport of tools and food resources (D'Août et al. 2004; Crompton et al. 2008; Tourkakis 2009; Duarte et al. 2012). In some areas capuchins have carried suitable hammer stones several hundred meters to anvil sites. Bipedal locomotion frees hands to carry food items to tools or vice-versa. In this regard it is worth watching again how the panin bonobos (Figure 5) and chimpanzees walk and carry things on their foraging expeditions. Panins can walk bipedally if they have to – but at substantial metabolic cost compared to the ease with which we modern humans walk. Given *Sapajus*'s abilities to transport hammer stones weighing a substantial proportion of their own body weight for substantial distances, looking at the videos, they may be further along the path to bipedalism than any of the panins are – at least in terms of carrying heavy loads (Visalberghi et al. 2009a; Lui et al. 2009; Duarte et al. 2012).

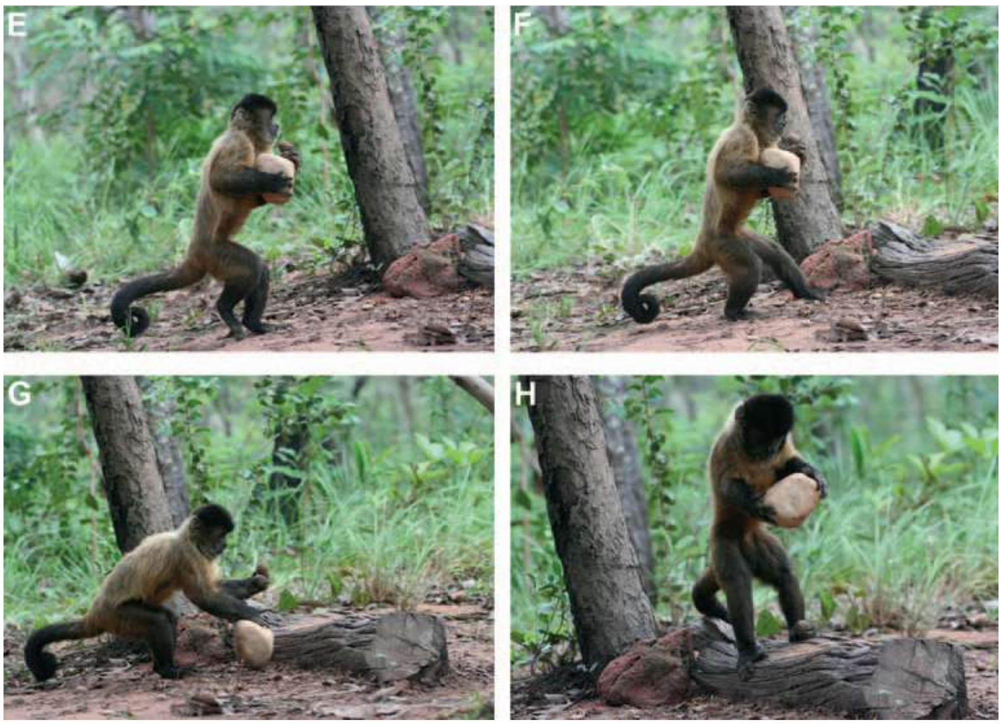


Figure 125. A 4.4 kg capuchin carries a 1.8 kg hammer stone and two palm nuts to an anvil. How easy would it be for you to carry a boulder weighing 40% of your body weight? (Duarte et al. 2012; Visalberghi & Addessi 2013 – photographs by Noemi Spagnoletti).

In the wild, capuchins show a similar range of foraging strategies that chimpanzees do as they adapt to increasingly harsh environments. Types of tool-assisted extraction capuchins (mostly *Sapajus*) are observed to use in the wild include:

- modifying and using sticks as probes to sense what might be in a hole, and to extract honey, wax, insects, and arthropods for eating, and water for drinking (Mannu & Ottoni 2009);
- using sticks as a clubs or spears in defense against snakes (that may also be eaten) or to hunt small vertebrates (Mannu & Ottoni 2009; Moura & Lee 2004, 2010);
- using stone hammers with stone or wood anvils (e.g. tree roots, logs, etc.) to crack nuts (Mannu & Ottoni 2009; Spagnoletti et al. 2012; Visalberghi et al. 2013; Borgo et al. 2013). Spagnoletti et al. photographed a 2.2 kg female using a 3.5 kg hammer stone! and, according to them, "Capuchins use anvil sites repeatedly, they bring stones to anvils, they discriminate among nuts, anvil sites and stones, selecting specific combinations that suit current needs, and they position nuts systematically". Stone outcrops or logs providing

suitable anvils are readily available in areas where nut-cracking has been observed, but suitably hard hammer stones are rare and often have to be transported to anvils from considerable distances (Visalberghi et al. 2013).

- using stone hammers in a variety of other circumstances from digging and mining (to extract more suitable rock tools), to stripping bark or smashing open dead cactus (one female was observed to use the same stone for five different tasks over a 4 minute period, carrying the stone 4, 8, 1, and 2 meters between uses - Mannu & Ottoni 2009)
- using stones and sticks together as shovels, hoes and mashers to assist digging for and processing edible roots and tubers and to access insects and lizards hiding in rock crevices (Mannu & Ottoni 2009; Moura & Lee 2004, 2010).
- stones and large rocks are banged and/or pushed or thrown down cliff faces to deter terrestrial predators (humans, jaguars & other cats – Moura, A.C. de 2007).
- In at least one population females in estrus will toss stones towards dominant males to communicate their interest in courtship (Falótico & Ottoni 2013).

Figure 126. The capuchin nut cracking industry (click picture for BBC Earth's 4 minute video "Nutters - the monkey production line - Clever Monkeys"). Another video clip shows a similar nut-cracking culture developed and learned by a group of our closer relatives, the chimpanzees[386].

Some capuchin groups in the Fazenda Boa Vista (Paiuí, Brazil), operate a complex processing "industry" to access the contents of some palm nuts edible (Visalberghi et al. 2007; Visalberghi et al. 2008; Visalberghi et al. 2009, 2009a; Spagnoletti et al. 2011 - Figure 126). This industry that seems to be far more complex than any subsistence strategy carried out by any other primate except humans. This industry carried out by mature adults involves a sequence that may involve at least 10 separate activities, carried out in three stages over several days to weeks, before the nutmeat can be eaten. Temporal discontinuities are indicated by dotted lines:

1. Find a suitable palm bearing a cluster of suitable nuts.
2. Select suitably ripe nut by appearance, tapping with a finger tip, and perhaps smelling.
3. Twist, pull and perhaps bite selected nut to separate it from the cluster.
4. Peel and remove outer husk and mesocarp with teeth and fingers until the woody endocarp is exposed (the mesocarp of some species of nuts can be eaten). At this point the nut (probably depending on species and ripeness) may be carried directly to an anvil site for further processing (this seems to be assessed by the feel and sound of the nut when it is tapped with a fingernail or another nut).
5. If the nut is insufficiently ripe/dry for immediate cracking, throw it to the ground to dry for a further period of days, weeks or even months. Note that the collection of drying nuts establishes a group resource or larder.

……

6. Periodically inspect and assess the suitability of nuts drying on the ground for further processing. This involves tapping with fingernails and/or banging them together to feel/hear how they sound.
7. Carry selected nut or nuts to a known anvil site that may be located many tens of meters from the harvested palm. Anvils may be suitably dry and hard logs or outcrops of harder sandstone. In either case an anvil must (a) have a level top so nuts won't easily roll off and be large enough (b1) to support the hammer stone so that does not roll off and (b2) to provide space for the capuchin to stand while operating the hammer stone. Through frequent usage, most anvils will have one to several pits that have been eroded by previous cracking activities that help to stabilize and restrain the nut when it is being pounded. Experimental evidence suggests that capuchins at Fazenda Boa Vista have a good mental map of anvil locations and can go directly one to one even when when they cannot see it when they start.

……

8. If a suitably hard and heavy hammer stone is not already located at the anvil site, find one and transport it to the anvil. The predominant type of rock in the region is sandstone that is substantially more friable than the nuts, so capuchins must find substantially hard river cobbles from other anvil sites or, originally, from stream beds where they have been washed in from some distance away. Stones selected and used by capuchins to crack nuts generally weigh from 1 to more than 3 kg (30% to more than 100% of the monkey's body weight!). Stones found at anvil sites must have been lifted and carried by an individual from where they were found (transport distances of more than 50 meters are not unusual) to the location of the anvil.

……

9. Place and orient nut to be cracked in a suitable pit on the surface of the anvil.
10. Lift hammer as high as possible and bring it down onto the nut with as much force as possible. This usually involves lifting the stone from the substrate to over the head and then slamming it down onto the nut with maximum force. This lift and smash cycle may have to be repeated from 7-8 times to more than 100 before the nut is cracked and the meat can be extracted and eaten. Broken nuts may have to be hit several more times to get all of the meat.

Chimpanzees process similarly hard nuts with similarly sized hammers (Boesch & Boesch 1982, 1990; Carvalho et al. 2008), but, of course, chimps are more than ten times the size of these little monkeys and the chimps can easily apply the necessary force with one hand while sitting. There is no indication that the chimpanzee industry involves the kind of temporally separated and complex husking and drying process involved in the capuchin industry.

Summarizing the evolutionary hypothesis to this point: the existence of capacities for arboreal clambering, upright sitting & climbing with grasping hands, active foraging to feed on a variety of plant and animal materials, and use of hands to grasp and pick food (review foraging strategies) provides an initial platform for the development of technological capabilities. Interspecific competition for, or increasing scarcity of, easily picked forage selects for cognitive and manipulative capabilities to identify and harvest a wider variety hidden or protected food items from larger home ranges. Selection for improved manipulative abilities and the need to travel between more widely separated trees to find food favors bipedalism – both to free the hands for improved manipulation and for more efficient movement on the ground. Assuming sufficient dexterity and cognitive capacity exists initially for these to be amplified by selective processes, it becomes likely that species/populations will evolve the capacity to manipulate and make simple tools to extend their manipulative and sensory abilities. Presumably selection for using tools to exploit an increasing variety of resources will also favor the evolution of increased cognitive capacity for innovation and the transfer of knowledge at the family and group level.

<<<start>>>Cultural versus hereditary transmission of technological knowledge

Comparative studies of tool use in our primate relatives suggest that the knowledge for making and using simple tools in early hominins was discovered through individual experimentation and learning, and then *culturally transmitted* through the close observation of successful tool users by their offspring (as can be seen in some of the videos). Such transmitted knowledge can then be further refined and possibly improved by each individual through trial and error in practice. This all depends on the cognitive capacities of individuals to achieve each of these steps.

As discussed in the Wikipedia article Dual Inheritance Theory, individuals potentially acquire the knowledge they need to survive in the world in three ways:

1. *experimentation and learning* within the capabilities of the individuals' cognitive capacities of things the individuals benefit from knowing;
2. knowledge in the form of *genetic heredity* from their parents that provides instructions for the development of
   a. anatomical and physiological structure,
   b. behavioral *propensities* including "instincts" built by natural selection responding to common problems faced by a population over many generations, and
   c. cognitive capabilities (e.g., see Popper 1972) that have also emerged and evolved through the slow process of natural selection because they have helped (or at least not hindered) their ancestors' survival; and
3. *cultural heritage* consisting of living knowledge transferred to individuals by any means from their parents and other members of the species they can observe and interact with.

We are beginning to understand how anatomical and physiological complexity is translated from DNA codes into living dynamic structure. We do not yet understand how behavioral propensities and instincts are developmentally programmed into the physical connections of the developing nervous system, but we have no evidence that this does not involve processes guided and regulated by genomic information or that there is anything mystical about the process. At least when examining related species, it is evident that cognitive capability seems to be associated with the volume of brain tissue and the surface area of the cerebrum - where humans have by far the largest brains with the most complexly folded cerebrum. If factors like cognitive capabilities and instincts are under genetic control, then natural selection over many generations can alter these factors to track slow change in the environment.

For most individuals, many aspects in their local environment, e.g., location and availability of resources essential for survival, vary substantially during their lifetimes. Such aspects change far too fast to be tracked by natural selection at the genomic level; but with suitable cognitive capabilities, indvidual learning (i.e., the construction of new knowledge) may modify behavior to track environmental changes. Where the capacity to construct new knowledge improves survival, natural selection will work to improve the cognitive capabilities for building such knowledge. However, if each individual has to learn anew everything it needs to know, and the acquired knowledge is then lost with the individual's death, individual learning is an inefficient way of adapting to a changing world.

However, if individuals in a group or species have the social and cognitive capacity to exchange useful knowledge they have acquired about the world with other individuals, this establishes the necessary conditions for cultural adaptation and evolution. As noted in passing in the previous section, anthropoid apes and capuchins all demonstrate their capacity for the cultural transmission of knowledge. This section elaborates on this evidence to focus on how the capacity to share knowledge has affected human evolution.

Probably associated with their relative large brains, detailed observations and controlled experiments in laboratory environments show that chimpanzees and capuchins have a significant memory capacity and cognitive capabilities to make and use tools, and in at least some cases transmit tool using knowledge to naive members of the group.

- *How does technology become part of a population's suite of adaptations to construct a niche?*

As discussed in Technological and Conceptual Revolutions in Human Affairs, individuals apply knowledge to control, modify (perhaps), use components of the external environment as "tools" to extend the capabilities of their bodies. The use of tools by a population to exploit additional food and other resources, to create/provide shelter, or to defend against predation and other dangers changes the parameters of the niche space where the population can survive and thrive.

The tools used by some chimpanzees and capuchins to access terrestrial food resources not as easily available to unaided individuals help them to maintain adequate diets for survival in savanna and thornscrub habitats. Examples discussed in the previous sections include the use of probes and wands to efficiently harvest honey, ants and termites; hammers and anvils for cracking otherwise inedible nuts, and sticks and stones for harvesting edible roots and tubers. Savanna chimpanzees (Kortlandt 1980; Boesch & Boesch 1990) and capuchins (Boinksi 1988) are also known to use large sticks as clubs to deter predators that otherwise might kill members of the populations forced to spend time feeding or moving around on the ground.

- *Culture as a reservoir for heritable knowledge*
- *Evidence for cultural inheritance in apes and capuchins*

Although capuchins learn to break stones to make knives in the lab (Westergaard & Soumi 1994, BBC video 1 and video 2), Cummins-Sebree & Fragaszy (2005) argue that because they are so small that they are at a disadvantage compared to larger-bodied primates where flaking stones by manual action alone is concerned. Also, compared to humans, they

> predict that capuchins could master the basic elements of knapping through carefully-scaffolded learning experiences, although most likely they would require far more practice for improvement at each aspect than do adult humans. But they are unlikely, unless perhaps

> they devote a lifetime to knapping under expert tutelage, to match a moderately-skilled human knapper in any aspect of skill. Capuchins generate the same kinds of information for learning through action that humans do, but they seem to learn from their actions or recognize the significance of various information less slowly and less richly than humans, and they modulate their actions through a smaller range than do humans. The human advantage is cumulative and synthetic: we do not possess any single proclivity or action capability relevant to stone knapping that capuchins do not possess, but we are better at every single step, and / or acquire skill in each domain more quickly, so that we can master additional levels of integration, cope with variations more quickly, modulate our movements more precisely, etc. [Cummins-Sebree & Fragaszy 2005: pp 179-180)

Bonobos and chimpanzees share an impressive cognitive capacity (but still limited when compared to humans), as demonstrated by their abilities to learn and use symbolic language (Sevic & Savage-Rumbaugh 1994; Lyn et al. 2010). In the lab when bonobo productive vocabulary of 105 word, chimpanzee 70

- *Technologies provide selective advantages*
- *What kind of knowledge is there to be transmitted*

In humans, this would be deemed as tacit knowledge transfer. In a captive environment, the bonobo Kanzi exhibited an inherent capacity to learn to make and use a variety of tools despite evidence that bonobos in nature use only the simplest tools. For example, Kanzi learned to knap simple stone choppers comparable to Oldowan tools from cobbles by watching experienced humans make such tools (Schick et al. 1999; Toth & Schick 2009; Savage-Rumbaugh et al. 2001; Roffman et al. 2012 - Figure 5). Although such tool use has never been observed in wild bonobos, Kanzi successfully used a flint blade within a day of his first observation, and successfully made his first tool within the first month of the study. His half-sister, Panbanisha learned the technology from Kanzi. Whiten (2005) observes that this tacit cultural transmission of knowledge is a second mode of inheritance (after genetic inheritance) that plays an important role in the evolution of primate species.

Where brain capacity is concerned – natural history knowledge, tool use and making, resource mapping, transfer of cultural knowledge.

- *Positive feedback and coevolution of culture and technology*

Boesch, C. 2012. From material to symbolic cultures: culture in primates. (in) The Oxford Handbook of Culture and Psychology, (ed.) Valsiner, J. Oxford University Press. DOI: 10.1093/oxfordhb/9780195396430.013.0032, 16 pp. - http://tinyurl.com/nes3oty.

*Chudek, M., Henrich, J. 2011. Culture–gene coevolution, normpsychology and the emergence of human prosociality. Trends in Cognitive Science15, 218-226 - http://tinyurl.com/ozoenjw

*Dindo, M. Whien, A., de Waal, F.B.M. 2009. In-group conformity sustains different foraging traditions in capuchin monkeys (*Cebus apella*). PLoS ONE 4(11): e7858. doi:10.1371/journal.pone.0007858.

Fragaszy, D.M. 2012. Community resources for learning: How capuchin monkeys construct technical traditions. Biological Theory 6, 231-240 - http://tinyurl.com/qfro5sd.

Fragaszy, D.M., Biro, D., Eschar, Y., Humle, T., Izar, P., Resende, B., Vislaberghi, E. 2013. The fourth dimension of tool use: temporally enduring artefacts aid primates learning to use tools. Philosophical Transactions of the Royal Society B 368, no 1630, 10 pp. - http://tinyurl.com/kmhct3j.

*Henrich, J., McElreath, R. 2003. The evolution of cultural evolution. Evolutionary Anthropology 12, 123 – 135 - http://tinyurl.com/l3jgm27.

*Meulman, E.J.M., Seed, A.M., Mann, J. 2014. If at first you don't succeed... Studies of ontogeny shed light on the cognitive demands of habitual tool use. Philosophical Transactions of the Royal Society B 368: 20130050, 12 pp. - http://tinyurl.com/ljr3ber.

Panger, M.A., Perry, S., Rose, L., Gros-Louis, J., Vogel, E., Mackinnon, K.C., Baker, M. 2002a. Cross-site differences in foraging behavior of white-faced capuchins (Cebus capucinus). American Journal of Physical Anthropology 119, 52-66 – http://tinyurl.com/kdjqcxg.

Perry, S. 2011. Social traditions and social learning in capuchin monkeys (*Cebus*). Philosophical Transactions of the Royal Society B. 366, 988-996 - http://tinyurl.com/q8a6jsn.

*Pradhan, G.R., Tennie, C., van Schaik, C.P. 2012. Social organization and the evolution of cumulative technology in apes and hominins. Journal of Human Evolution 63-180-190 - http://tinyurl.com/q6xo85l.

Price, E.E., Lambeth, S.P., Schapiro, S.J., Whiten, A. 2009. A potent effect of observational learning on chimpanzee tool construction. Proceedings of the Royal Society B 276, 3377-3383 - http://tinyurl.com/6wy9vgb.

Richerson, P.J., Boyd, R., Henrich, J. 2009. Cultural innovations and demographic change. Human Biology 81(2-3), 211-235 - http://tinyurl.com/2vdvy5t.

Richerson, P.J., Boyd, R., Henrich, J. 2010. Gene-culture coevolution in the age of genomics. Proceedings of the National Academy of Sciences USA, 107, Suppl. 2, 8985-8992 - http://tinyurl.com/966xjsl

Tennie, C., Call, J., Tomasello, M. 2009. Ratcheting up the ratchet: on the evollution of cumulative culture. Philosophical Transactions of the Royal Society B. 364, 2405-2415 - http://tinyurl.com/9a2z8o6.

van Schaik, C.P., Burkart, J.M. 2011. Social learning and evolution: the cultural intelligence hypothesis. Philosophical Tansactions of the Royal Society B 388, 1008-1016 - http://tinyurl.com/9uwpeud

van Schaik, C.P., Pradhan, G.R. 2003. A model for tool-use traditions in primates: implications for the coevolution of culture and cognition. Journal of Human Evolution 44, 645-664 - http://tinyurl.com/lr5pjwj.

Whiten, A. 2000. Primate culture and social learning. Cognitive Science 24(3), 477-508 - http://tinyurl.com/oxxvgju.

Whiten, A. 2005. The second inheritance system of chimpanzees and humans. Nature 437, 52-55 - http://tinyurl.com/lw27ptg

Whiten. A. 2011. The scope of culture in chimpanzees, humans and ancestral apes. Philosophical Transactions of the Royal Society B 366, 997-1007 - http://tinyurl.com/8epgvp2.

Whiten, A., van Schaik, C.P. 2007. The evolution of animal 'cultures' and social intelligence. Philosophical Transactions of the Royal Society B 362,603-620 - http://tinyurl.com/me9qnj3.

*Yamamoto, S., Humle, T., Tanaka, M. 2013. Basis for cumulative cultural evolution in chimpanzees: social learning of a more efficient tool-use technique. PLoS ONE 8(1): e55768. doi:10.1371/journal.pone.0055768 - http://tinyurl.com/lhsk5dz.

In humans, this would be deemed as tacit knowledge transfer. In a captive environment, the bonobo Kanzi exhibited an inherent capacity to learn to make and use a variety of tools despite evidence that bonobos in nature use only the simplest tools. For example, Kanzi learned to knap simple stone choppers comparable to Oldowan tools from cobbles by watching experienced humans make such tools (Schick et al. 1999; Toth & Schick 2009; Savage-Rumbaugh et al. 2001; Roffman et al. 2012 - Figure 5). Although such tool use has never been observed in wild bonobos, Kanzi successfully used a flint blade within a day of his first observation, and successfully made his first tool within the first month of the study. His half-sister, Panbanisha learned the technology from Kanzi. Whiten (2005) observes that this tacit cultural transmission of knowledge is a second mode of inheritance (after genetic inheritance) that plays an important role in the evolution of primate species.

Where brain capacity is concerned – natural history knowledge, tool use and making, resource mapping, transfer of cultural knowledge.

see http://www.veoh.com/watch/v1409539kcDBdYCz?h1=Capuchins+-+The+Monkey+Puzzle

Videos:

Two Monkeys: Teamwork can Beat the System - From the BBC documentary "Capuchins: The Monkey Puzzle", narrated by the ever brilliant Sir David Attenborough. Read more at http://www.liveleak.com/view?i=e82_1345278829#v5rB1qoQlFjkgAib.99 - http://www.liveleak.com/view?i=e82_1345278829.

Nut Cracking Monkeys from near Gilbues, Piaui an area of human induced desertification (Crepani 2009) – Jennifer Martin - https://www.youtube.com/watch?v=63L8PnxZ2uo

Capuchin monkey fights for equal rights - Inside the Animal Mind: Episode 3 - BBC Two (Franz de Waal?) - https://www.youtube.com/watch?v=xot4z1CKFMo.

Capuchins – the monkey puzzle - http://www.veoh.com/watch/v1409539kcDBdYCz?h1=Capuchins+-+The+Monkey+Puzzle (28 min) BBC/Attenborough

Evidence for adaptations in early hominins:

-bipedalism

Ardipithicus's skeleton was better adapted to bipedalism (Lovejoy et al 2009b).

-weapon use for defense and hunting

Dentition - Suwa et al. (2009a) Stable isotope Lee-Thorp et al. 2010; Sponheimer et a. 2013

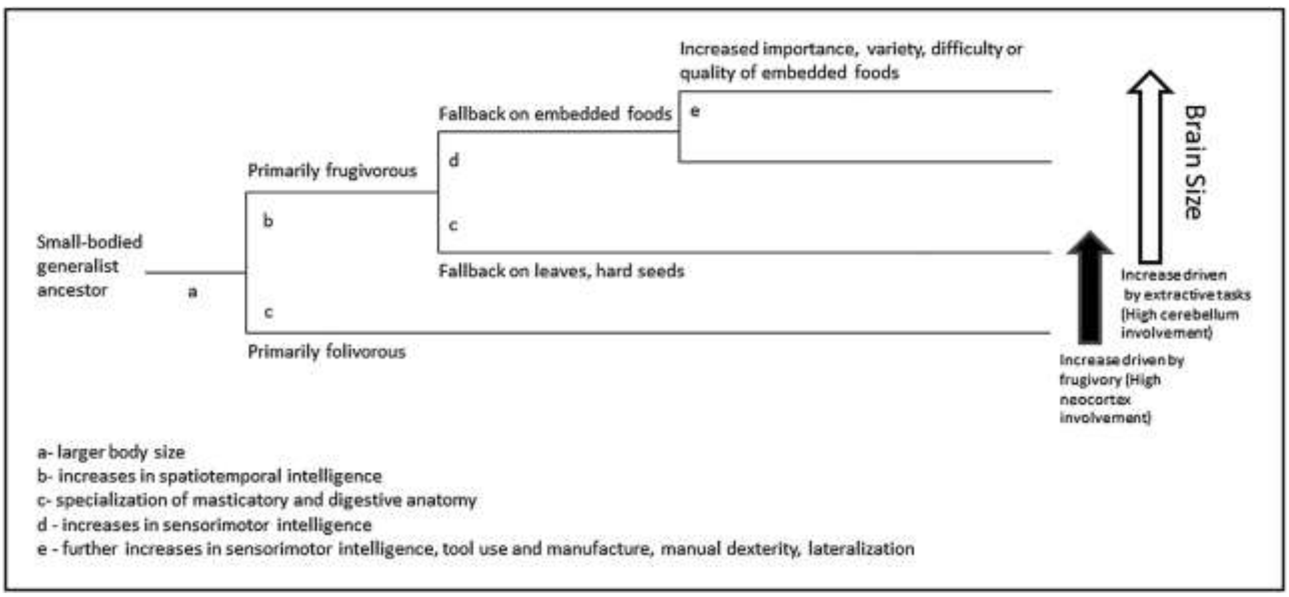
Nevertheless there is some evidence that bipedal (and presumably) tool-using hominins were surviving on the savanna 2-3 million years before worked stone tools appeared in the archeological record as made objects.

New dangers from full exposure to carnivoran guild

Hart & Sussman (2011); Pievani (2011)

- Big cats
- Hyenas
- Wild dogs
- Bears

- Adaptive responses
  - Cultural change and transmission
    - Mapping a larger home range: shelter, water, other resources (some only seasonal)
    - New diets, food identification and selection
      - Wynn et al. 2013
    - New tools & uses
      - Access & process new foods
      - Anti-predator defense
  - Socially mediated (Fragaszy et al. 2013)
    - Gamble et al. 2011
  - Genetically mediated (i.e., slow)
    - Increase ***capacity*** for social learning, memory & transfer cultural knowledge
    - Increase fine motor skills (i.e., dexterity and sequencing) for making tools
    - Increase propensity for cohesive & cooperative group dynamics.
    - Brain evolution, e.g., Zollikofer & Ponce de Leon 2013
  - Energetic changes. Pontzer 2012
- Lovejoy (2009)



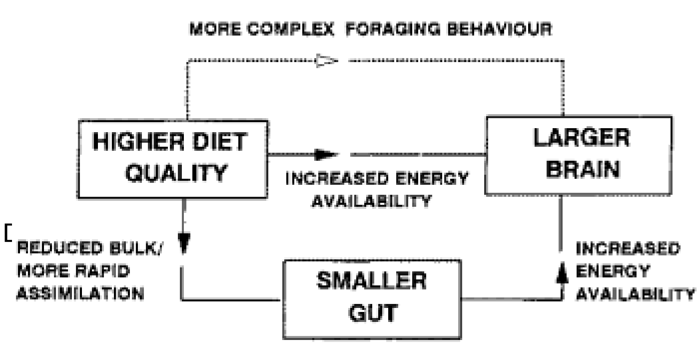


Figure 127. Trade-off between brain size and digestive apparatus (Aiello & Wheeler 1995; Kaplan et al. 2007 offer a more detailed analysis of the evolutionary tradeoffs)

Ardipithecus, Australopithecus and bipedalism – Jeffares 2013
Behavior & cognition
Social foraging
Environmental objects used directly or made into simple tools
Fission-fusion social structure, some transfer of cultural knowledge
High selfishness, limited cooperation in defense and hunting
Limited cognitive capacity
Cognitive evolution: Goddard et al. (2014)

Based on the biologies of our closest living relatives, it is likely that the first hominins made and used simple tools. As discussed early in this book under Technological revolutions, primates such as capuchin monkeys, chimpanzees, and bonobos already have the cognitive and manipulative capacity to make and use relatively simple tools. This is demonstrated in some videos: in Figure 5, the bonobo, Kanzi shows how he knaps a stone to make a sharp blade and uses it to cut a rope to unlock a box so he can retrieve a banana; in Figure 163 capuchins demonstrate their multi-stage nut processing and cracking industry; other videos linked via Note 35 show more tool making/using activities by capuchins. Such tools are linked to food gathering and (especially in chimpanzees) hunting small mammals as prey. Forest dwellers such as orangutans, bonobos and chimpanzees have all been observed to make and use simple tools of biodegradable materials that would leave no archeological record (Pruetz & Bertolani 2007; Boesch et al. 2009; van Schaik et al. 2003 - Figure 118). The assumption is that the last common ancestor of humans and chimpanzees (Figure 86) probably also lived in forests and made and used similar tools (McGrew 2010).

Where hominins have gone beyond chimpanzees and capuchins.

- *Scavanging meat on the savanna*

The largest resource of food that is potentially edible by hominins on the savanna is provided by a large guild of grass-eating herbivores
Savanna apes can't access this resource except by scavenging carnivoran kills
Must be able to deter other very dangerous scavenging carnivores to access kills
Savanna apes lack strength & dentition to tear skin and dismember large herbivores
One resource potentially accessible to a tree-climbing savanna ape
Tree caches, e.g., as left today by leopards (Hemmer et al 2011)
Left unguarded for hours at a time
Returning "owner" can be deterred by stick waving apes in the tree
Simple requisites for grade shift to *aggressive scavenging* on the ground
More coordinated & cooperative defense and offense (cognitive evolution)
More effective deterrence tools (changed tool)
Driving predators from their kills using *haak en steek* (Guthrie 2007)
Oldowan butchering tools for cutting skin & ligaments (repurposed tool)
Repurposing broken hammer stones used for cracking bones passively scavenged from the ground to access marrow
Break stones deliberately to create cutting edge (e.g., Kanzi)
Ferraro et al. 2013

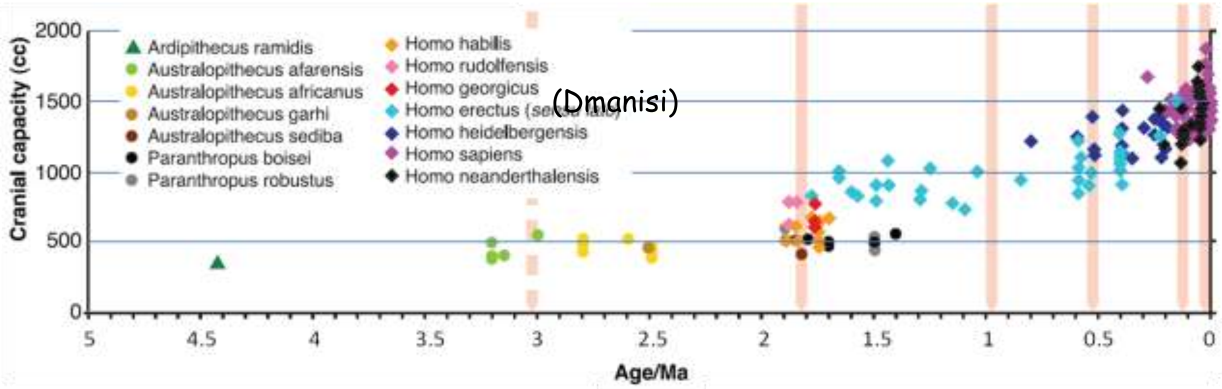
Domínguez-Rodrigo et al. (2005) – Oldowan technology gave hominins first or early access in order to butcher prey for prime steak.

Lieberman et al. 2009. Brains, brawn, and the evolution of human endurance running capabities

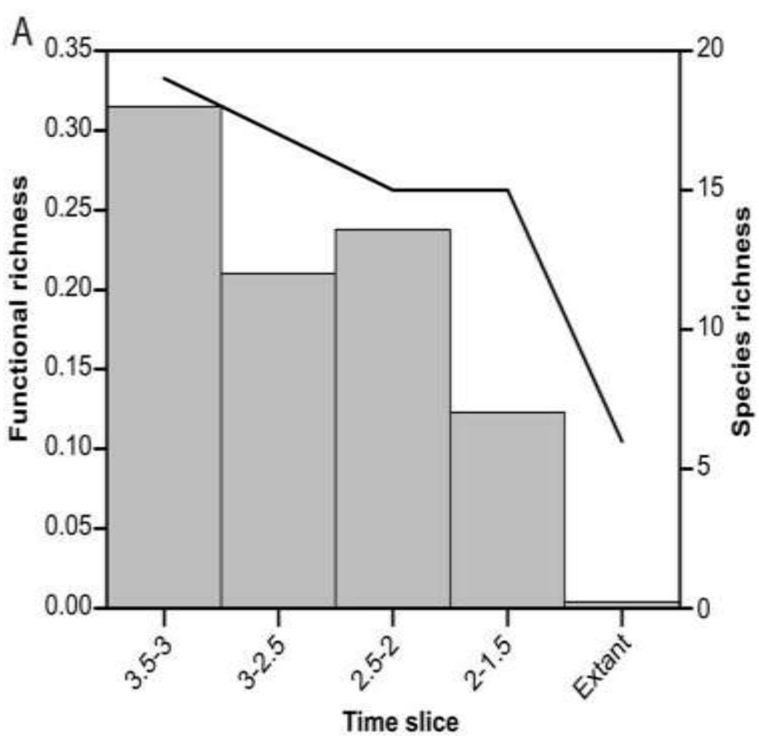
Ungar & Scott 2009. Dental evidence for diets of early Homo

- *Becoming top carnivores on the savanna*

Egeland (2014)



Shultz, S., Maslin, M. 2013. Early human speciation, brain expansion and dispersal influenced by African climate pulses. PLoS ONE 8(10): e76750. doi:10.1371/journal.pone.0076750 - http://tinyurl.com/m38zfke



Inferences from the paleontological record (Werdelin & Lewis 2013)

Large carnivores included lions, leopards, three sabertooth cats, large bear, bear-sized wolverine, several large hyenids, wild dogs, etc.

3 mya aggressive scavenging of kills reducing food supply for some carnivores causing local extinctions.

2 mya active hunting of large mammal prey using spears + Oldowan butchering tools further reduces carnivore resources.

1.8 mya hominins in Olduvai Gorge were top carnivores selectively hunting prime quality bovid prey (Bunn & Pickering 2010; Bunn & Gurtov 2013).

By 1.8 mya carnivorous hominins extended to Dmanisi, Georgia (Hemmer et al. 2011; Carrion et al. 2011), and from there quickly spread across Asia and into Europe (as H. erectus)

Rolland (2010)

The Acheulean tool-kit gives H. erectus the fangs and claws it needs to be top carnivore

Cultural accumulation of knowledge begins to replace genetic change as most important adaptive mechanism

Knowledge accumulation still limited

Virtually no change in erectus tool-kit

Capacity to remember

Slow genetic evolution of more memory capacity

Technological innovations may be lost & reinvented several times & may take hundreds of thousands of years to be consolidated

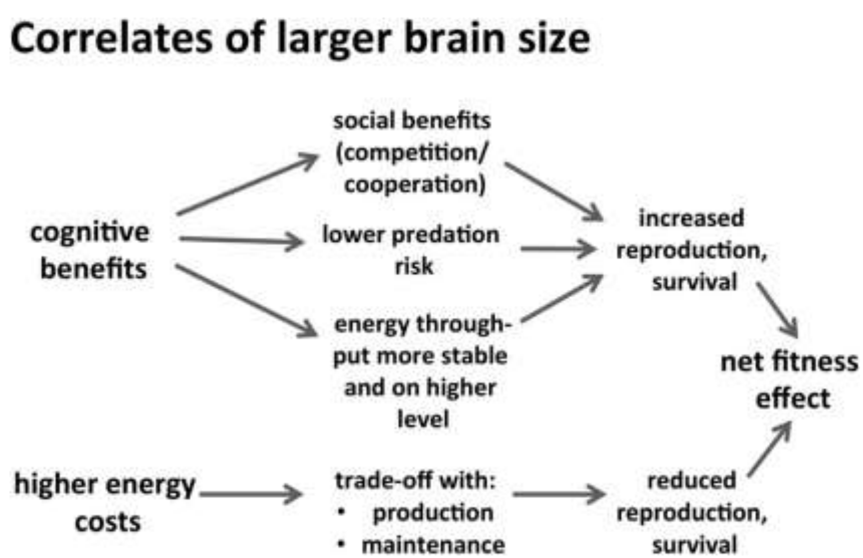


Figure 128 - Simple cost-benefit analysis of increasing brain size (Isler & van Schaik 2014).

Positive feedback into the selective environment promoting further genetic adaptation

Genetic enhancements to meet increasing cognitive needs

Capacity for geographical (mental map) and natural history knowledge

Understand & communicate time & process to plan & coordinate hunting

Anatomical and cognitive apacity to make and use tools

Neuromuscular control

Planning and sequencing of actions for tool-making
knowledge of best resources
Increased capacity for teaching & learning
Facilitate master-apprentice and other social relationships
Share and direct attention to critical aspects of process & technique
Use gesture, mime and acting-out (dance)

- *Becoming a good colonizer and evolving extraordinary intelligence*

Hill et al. 2009

Huguet et al. 2013 [Successful subsistence strategies of the first humans in south-western Europe];

Bar-Yosef & Belfer-Cohen 2001, 2013; Wells & Stock (2007); Palombo 2013; importance of carnivory: Martínez-Navarro 2010; Pontzer et al. 2010

Selection for dispersal, etc. Antón et al. 2002.

Positive feedback and selection for intelligence Flinn et al. 2005

Discuss "Out of Africa scenarios"

"There are essentially three competing hypotheses: (1) the "savanna hypothesis", in which a relative shift toward cooler and drier conditions caused a change from more forested to more open vegetation; (2) the "turnover pulse hypothesis", which relates broad-based faunal turnovers to climatic events; and (3) the "variability selection hypothesis", which focuses on the repetitive nature of environmental oscillations through time" – Parés et al. 2013

Dennell 2010a; Lahr 2010; Shea 2010; Potts & Teague 2010; Hou & Zhao 2010

Acheulean stability – Hopinnson et al. 2013

Becoming human

- *Using, Keeping & Making Fire*

Opportunistic users > 3 mya ?
Savanna burns naturally every 2-5 years
Knowing that just burnt savanna is a good source of high cuisine
Roast meat much more digestible than raw
Roasting makes inedible/indigestible nuts, roots & tubers edible
Fire keepers > 1 mya (Rolland 2004; Twomey 2011; Gowlett & Wrangham 2013)

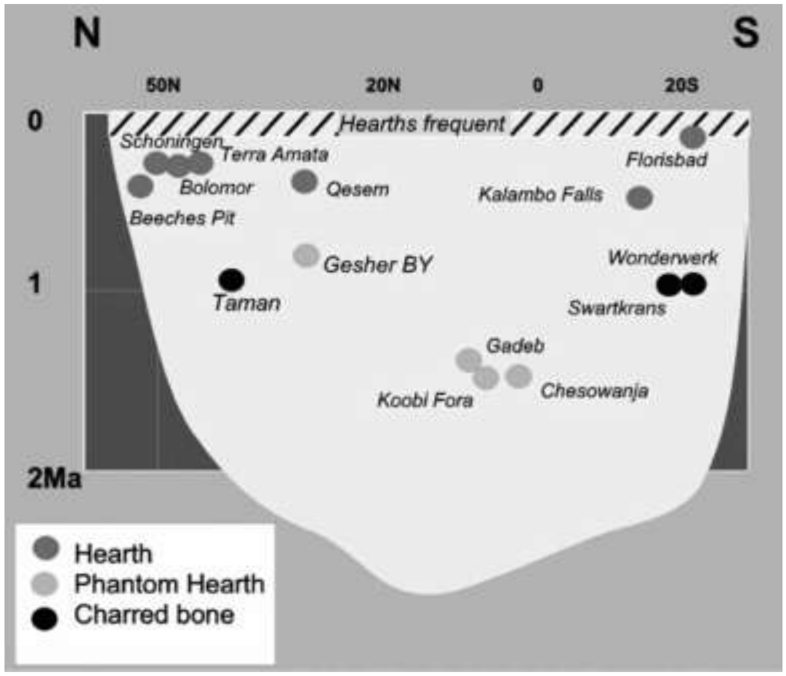


Figure 129. Early archeological evidence for controlled use of fire. Gowlett & Wrangham (2013)

Keepers much better off (cooking, warmth, deter predators)
Loss of fire potentially catastrophic to group
Maintaining fire requires social coordination
Know how to feed and keep a fire (process knowledge)
Know how to move fire to a new place (anticipation, planning, techniques)
Fire makers ~ 0.5 – 0.4 mya
Knowing how to start a fire without a natural source
Striking a spark (what rocks, what tinder?)
Using a fire stick to create friction embers
Keeping fires facilitates increase in cognitive capacity
Cooking reduces caloric requirements for mastication, digestion, & assimilation
More energy available to support development of larger brains & better cognition
Better cognition
More capacity for fire-related knowledge
Facilitates niche expansion
Increased variety of food resources made edible
Better anti-predator defences – protection of campsites
Able to survive greater (cold) climate extremes
Cognitive skills needed to accumulate knowledge for niche expansion
Hand-eye coordination - fine motor control needs more neurons
Causal reasoning - time-binding; understand goals, actions, and consequences
Function representation - associate particular tools with particular jobs
Natural history intelligence - conscious attention to understanding the behaviors of predators, prey, fire, other changing aspects of environment
Executive control – anticipating, deciding & planning; not just reacting

Social intelligence - extended childhood, social learning (imitation not emulation), understanding of intentions of others (mirror neurons?), focused teaching & learning, apprenticeship
Intragroup coordination
Intergroup collaboration
Language
Cooperation and the emergence of higher level autopoiesis – MacKinnon & Fuentes (2011)

- *Language revolution and the emergence of "archaic" humans*

Complex cognition (Wadley 2013)
Selective drivers for the evolution of language
(Huget et al. 2013 - Successful subsistence strategies of the first humans in south-western Europe)
Kuhn & Hovers (2013 – Wenner-Gren Symposium Intro)
Burdukiewicz (2014)
Beaumont (2013)
When and where we learned to talk
Indications that speech was common to common ancestor Neanderthals and sapiens
Johannson 2013; Dediu & Levinson 2013; Krubitzer & Stolzenberg 2014
"All modern human populations have language, and there is no difference in language capacity between living human populations. Parsimony implies that the most recent common ancestor of all modern humans had language, and had all the biological prerequisites for language" (Johansson 2013).
The common distribution of language proxies across human and neanderthals in genomic, paleoanthropological, and paleoarcheological contexts show that human, Denisovan and Neanderthal common ancestor had a capacity for modern language, speech and culture (Dediu & Levinson 2013, etc.)
Hovers & Belfer-Cohen 2006
Extraordinary snapshots imply that linguistic capabilities already existed 400 kya
Schöningen II (single-use hunting camp 380 kya – Thieme 2005)
Captured, butchered and processed at least 20 horses
Tools made elsewhere include 9 wood lances left (ritually?) with herd remains
4 hearths, associated tools & evidence for spit-roasting, smoking and drying
Earliest evidence for compound tools
Bilzingsleben (base camp 370 kya - Mania & Mainia 2005)
3 x 3-4 m dia. huts with hearths all oriented against wind
Prey included fish, amphibians, reptiles, birds, elephants, rhinoceros, horses, bison, deer, pigs, lions, bears, wolves, hyenas, foxes, badgers, and martens
Spit roasting & smoking for preservation
Evidence for making & use of wide variety of stone and bone tools
Paved area with artifacts suggestive of ritual activities.
Implications
Long-range planning (harvesting and preserving; anticipating the need)

Planning and coordinating cooperative hunting of large, dangerous animals
Wide range of natural history, tool-making and food-processing knowledge
Ritual activities/thinking
Diversity and complexity of cultural knowledge for inferred activities beyond the capacity to communicate without language.
Genetic adaptations (anatomical, neurological)
Triadic niche construction: neural/cognitive/ecological (Iriki & Taoka 2012)
Brocas' Area
Expanded area of brain involved in speech and fine motor control
Identifiable in hominin endocasts – H. habilis like modern humans compared to apes.
Mirror System Hypothesis (MSH) proposes primitive action-matching system evolved to support imitation, pantomime, manual 'protosign' and ultimately vocal language
FOXP2 and other speech related genetic changes affected Broca's area in our common
ancestors with Neanderthals and Denisovans
Food processing technologies make food more digestible enabling natural selection to divert metabolic resources from the digestive system to development of larger brains
Larger brains support increased cognitive capacity: memory, mental maps, greater social complexity, better neuromuscular coordination

- *Language and the emergence of groups as higher order autopoietic systems*

Hoffecker et al. 2013. The information animal and the super-brain
Sterelny 2014.
Language - phenomenon of groups not individuals (one hand clapping)
Drivers for the evolution of a faculty of language
Coordinates individuals' involvement in group activities and society
Transmits essential cultural knowledge (heritage)
Common language, cultural norms & xenophobia determine group boundaries
Cultural knowledge propagated among individuals between generations by language determines group success on the adaptive landscape
An entity is autopoietic if it exhibits all the criteria (Varela et al. 1974)
Autopoietic entities represent units of selection
Pre-linguistic groups probably qualified as autopoietic – but group identity and adaptive variation greatly strengthened by language-assisted cultural accumulation

- *Homo sapiens' dispersal out of Africa*

Nomadic foragers: Fry 2011
Richter et al. 2012
Migrations: Davidson 2013; Balme 2013.
d'Errico & Stringer 2011
Extinction of Neanderthals (Hortolà & Martínez-Navarro 2013)

- *Considering the pace of technological change*

Speech and the emergence of the Middle Stone Age / Middle Paleolithic
More complex tool kit
Niche expansion from top carnivore to generalist hunters and gatherers
exploitation of a wider variety of foods
expansion of heidelbergensis into Eurasia (note difficulties with sparse fossils)
still a recognizable niche in the planetary ecosystem
Evidence for an MSA/MP technological plateau
Primary references: Current Anthropology, Vol. 54, No. S8, Wenner-Gren Symposium: Alternative Pathways to Complexity: Evolutionary Trajectories in the Middle Paleolithic and Middle Stone Age
Acheulian tools continued to be used by *H. erectus*
Technology variable through MSA / MP but no clear temporal trends to continuously increase complexity
Sporadic development and loss of complex technologies
Operational chains of limited length
Despite major ecological shifts between glacial and inter-glacial there is no evidence for permanent settlements or cultural shifts from nomadic hunting and gathering.
Little technological difference between Neanderthal/Denisovan/archaic H. sapiens in Europe, anatomically modern sapiens in South Africa, and AM sapiens in the Levant (eastern Med.) early colonization ~ 100 kya, and permanent colonization and spread to Eurasia ~ 70 kya
Populations limited in size to small bands, with evidence that Neanderthals & Denisovans passed through more severe genetic bottlenecks than sapiens
Even with language, the capacity for cultural memory and transmission was limited
Use of fire in making fine blades and points, or use of ochre and beads may have been developed & lost several times before being fixed in culture
Even where ideas can be xpressed in words, an individual's ability to remember detail is limited.
Where population is divided into small groups any knowledge not securely acquired by the next generation in the group is lost
Speech alone is not enough to enable limitless cultural accumulation of knowledge

When human organizations began to dominate the world

- *Mnemonics started modern humans on the road to planetary dominance*

Something changed 70-50 kya that enabled H. sapiens to substantially increase its cultural capacity to store & transmit knowledge
Mnemonics – increasing capacity for accumulating knowledge in primary oral culture differs from typographically based culture
Primary sources for understanding mental techniques used in primary oral cultures to accurately memorize and recall large and complex bodies of information:
Ong, W.J. 1982.
Kelly, L. 2012.

Techniques - think memorably: express knowledge in rhythm and rhyme with common formulas and phrases, link breathing and gesture, act out, associate with song and dance, organize by intrinsic logic, etc.

Master technique: the method of loci

May increase individual memory capacity by 10 to 100-fold or more

Use at group level to preserve and transmit cultural knowledge

Cultural capacity depends on group size – larger groups allow formation of subgroups (i.e., "guilds") to manage specialized bodies of knowledge

Method of Loci builds on the natural rhythms and progression of life

Memorable events happen in time and space (specific locus in 3D space)

Christophe Boesch demonstrates and discusses nut cracking and describes evidence for chimpanzee's mental map of its resources (video - http://www.exploratorium.edu/tv/index.php?program=00000766&project=22

Innate way to organize memory probably common to all "intelligent" animals (Corballis 2013); Shaw-Williams 2013

Focus on the space-time locus to retrieve memories of circumstances and events that happened at that locus

Songlines:

hunter gatherers learned to consciously index geographic, resource & natural history knowledge against tracks in the existing landscape where it is relevant.

Other knowledge may be indexed against loci on other shared lines (e.g., stars in the night sky) or with stories associated with landscape features, etc

Method of loci uses an ordered sequence of memorable loci as indexing points along existing or imagined space-time lines

Associates memorably expressed snippets of knowledge with particular loci in the line

Other mnemonic techniques make snippets memorable (e.g., imagery, rhythm, rhyme, oration, song, dance)

Group rehearsal and repetition strengthens memory traces

Group sharing adds redundancy and corrects errors in individual memory

In larger populations subgroups can maintain specialized knowledge

Anatomically modern H. sapiens irrupt from S/E Africa and replace all other hominins in Africa and Eurasia

Review genomic history

We exponentially build knowledge of the world to become super-competitors

We replace an increasing number of natural species in their ecological niches with human economic species to give humans hegemonic control over the world environment

- *Becoming settled – surmounting the knowledge capacity of nomadic life*

Nomads limited to technology they can carry or fabricate on demand

Accumulating technological knowledge enables more effective use of smaller geographic areas – larger populations accumulate more knowledge

Becomes practical to establish core living areas with permanent goods & structures (e.g., specialized tools, houses, and structures for cultural activities and processing and storage of food and other property)
Reduced contact with tracks in the broad landscape combined with need to manage more and more specialized knowledge of technology drives development of new and archeologically significant mnemonic systems
Solution: When songlines no longer suffice, build compact monumental landscapes that can be traversed sequentially (Kelly 2012 - e.g., Stonehenge, Poverty Point, Chaco Canyon Kivas, etc.)
Early site: Göbekli Tepe ~ 12-11 kya southern Turkey - https://www.youtube.com/watch?v=7ceXk_VLQAE
Grillo & Hildebrand 2013
3 ky before the agricultural revolution
Many other sites from primary oral cultures moving from nomadic hunting and gathering to settled life have similar monumental structures
Schmidt 2010
Mnemonics, settlement, the agricultural revolution and increasing cultural complexity
Current Anthropology 52(S4), Wenner-Gren Symposium: "The Origins of Agriculture: New Data, New Ideas" (October 2011) reviews in detail the archeological record of cultural & demographic transitions from nomadic hunting & gathering to formation of agricultural towns
With settlement, nomadic groups become territorial villages
The autopoietic entity becomes a socio-technical construct comprised of people, their linguistically mediated communication networks, their knowledge, their technologies and their built environment
Positive feedback drives ever-increasing growth rate of cultural knowledge accumulation for ever-increasing ecological hegemony over environmental resources
Accumulating cultural knowledge enables more efficient/effective control of local resources
Surplus resources enables population growth in turn providing more capacity for cultural memory
Development of ever more sophisticated mnemonic devices
Population growth enables more specialization of crafts, trades and guilds able to accumulate still more varied and detailed knowledge of the world
Ecological grade shifts enable demographic transitions increasing socio-cultural/economic complexity
Mobile hunter-gatherers (~15 – 20 adults in group – say 2-4 families)
Part-time tool-makers & apprentices (specific resource and processes knowledge)
Organized hunting parties
Leader/organizers + possibly specialized team members
Geographic & natural history knowledge target prey and dangers
Skinning, butchering, processing
Gatherers use specialized geographic & natural history knowledge to find resources
Temporary shelter construction, child-care, fire tending, food processing

Extended networks for additional mating opportunities, knowledge exchange & barter

Settled foragers (~ 40 adults in community – say 8 families)

Specialized tools that can be kept on hand, perhaps leading to full-time specialization

Wide ranging hunting parties transport butchered products back to home-base

Locally intensive gathering and harvesting with processing and storage

Construction & maintenance of permanent shelters & specialized structures

Need to protect valuable "capital" (community / personal "property")

"Tribal" networks & mnemonic systems for preserving & exchanging knowledge

Production of specialized goods and surplus resources encourages formal barter economy

Social norms and knowledge specialties common to interrelated communities ("tribe")

Development of specialized "cultic" sites on neutral territory for rehearsal, standardization, and sharing of various bodies of knowledge

- *Agricultural Revolution - humans control animal and plant metabolism*

Major techno-ecological transitions

Hunting → herding & corralling → husbandry, dairying, cheese-making, tanning, animal power & transport

Harvesting, storage, milling, baking & brewing → planting → tilling & irrigating → hydraulic engineering

Stone & mud construction → brick making & firing → ceramics, pottery & metallurgy → structural engineering

Demographic revolution – egalitarian communities become hierarchically organized tribal regions and towns (encompassing dozens to hundreds of families)

Population growth and technological innovation leads to proliferating specialization & restriction of life roles: farmers, pastoralists, despots, leaders, warriors, administrators, traders, priests & healers, educators, masons, artisans (e.g., tool-makers, potters, tanners, bakers, candlestick-makers, smiths, armorers), etc.

Specializations dependent on knowledge passed down via family specialization, confraternities, and guilds

Management of surpluses, specialized production, and trading leads to development of formal economies and despotic/priestly states

Revolutionary emergence of new mnemonic and knowledge management technologies to release cognitive demands for memorization for thinking and doing

Indexing living memory vs representing and preserving knowledge with objective symbols

Reduction of the monumental landscape onto distinctive paths and loci sculpted/fabricated into hand-held objects

Representing reality with symbolic tokens:

Counting and recording, the clerical accountant, taxing and contracting

Logographic writing (cuneiform), scribes

Phonetic alphabets

Tablets, scrolls, libraries, & offices

Increasing socio-economic complexity, economic speciation, and emergence of knowledge-based autopoietic entities at intermediate levels

Religious orders, trades, guilds, factories, chartered companies, societies

The Emergence of Sociotechnical Organization and their Interactions with Humano-Technical Individuals

The Industrial Revolution: replacing metabolic power and externalizing memory

The Microelectronics Revolution: externalizing individual and social cognition

Interconnecting minds and cognition via the cloud: technological convergence

---------------*Beyond here be chaos to be mined*----------------

Hominins using and making tools

- *Dating the cultural evolution of hominins by their tool kits*

Most of the work cited in this segment is based on chronological dating of different kinds of tools found in the paleoarcheological record of Africa and Eurasia. The Paleolithic Era in Europe (comparable to the Stone Age in works relating to Africa) covers virtually the entire prehistory of hominin/human technological development prior to the end of the last ice age around 12 kya (i.e., 99% of the time-line for hominin technology. I cannot do better than refer readers to Wikipedia for reasonably detailed summaries of the various time periods referred to by paleoarcheologists: The Lower Paleolithic (Early Stone Age in Africa) spans the time from ~2.6 mya up to 300 kya, and is identified first by the production of the very simple Oldowan (mode 1 - Figure 130 Left) tools from ~2.6 to ~1.8 mya and then by the slightly more complex and more highly finished Acheulean (mode 2 - - Figure 130 Right) tools from ~1.8 mya to 100 kya. The Middle Paleolithic (~ Middle Stone Age in Africa) ranges from ~ 300 to 30 kya, and is characterized in Europe by the Mousterian tool kit associated with the Neanderthals and in Africa with the emergence of a wider variety of tools, compound projectile weapons (such as bows & arrows), and artifacts with possible symbolic significance assumed to be associated with early *Homo sapiens.* The exponential growth of technology begins with the development of compound tools. The Upper Paleolithic (Late Stone Age in Africa, corresponding to Upper Paleolithic plus Mesolithic and Neolithic times) extends from ~50 kya to ~12 kya and represents the flowering of modern *Homo sapiens* prior to the development of agriculture. The Neolithic extends from the beginnings of agriculture in the Fertile Crescent until the development the smelting of copper and tin to make bronze about 5.6 kya.

Figure 130. (Left) Oldowan chopper, ~ 1.7 mya from Melka Kunture, Ethiopia (Wikipedia). (right) Acheulean tools from Kent (UK) – clockwise: handaxe, drill, discoid (Wikipedia).

The significant message from these epochs is that Oldowan grade tools were used *without significant changes* for at least 800,000 years to be followed by only slightly more complex Acheulean grade tools that were used again with only small changes for some 1.7 million years. Only in the last 100 kya does the variety and complexity of hominin tool kits begin to increase with ever more rapidity. It took a substantial time for the coevolutionary relationships between tools, cognition, and culture to reach an evolutionary grade that supported the rapid building and accumulation of new knowledge.

The first clearly worked stone tools (e.g., Oldowan choppers and scrapers - Figure 130 - left) appeared in the archeological record possibly as early as 3.4 mya (McPherron et al. 2010, 2011; Dominguez-Rodrigo et al. 2010, 2011, 2012) and definitely around 2.6 mya (de la Torre 2011; Wynn et al. 2011)[371]. These were sometimes associated with fossils of apparently bipedal hominins such as *Australopithecus* whose brain size was comparable to that of living apes. The main apparent difference between the *Australopithecus* or early *Homo* and their close ape relatives is the bipedalism apparently associated with their occupation of grassy woodland and savannah habitats rather than forests. Energy-efficient bipedalism allowed early hominins to range over larger distances to find scarcer food resources, to avoid or drive off large predators, or even to run down prey (assuming they had a tool for killing it – see Figure 148 - right). In any event, it seems that an increasingly large proportion of their diet came from carnivory and plant underground storage organs that could be harvested on the savanna (Kaplan et al. 2007; de Heinzelin et al. 1999; Braun et al. 2010; Pobiner et al. 2008; Plummer 2004[372]). Many sites with Oldowan tools are associated with the butchering of sometimes quite large prey (pigs, antelopes, zebras, bovids – from 72-320 kg in size). By comparison, when forest-living apes hunt, they capture prey in the 1-5 kg range (Plummer 2004). Interestingly, orangutans, chimpanzees and bonobos all demonstrate the mental capacity to learn from watching humans how to make and use stone tools for cutting things (Schick et al. 1999; Whiten et al. 2009; Toth & Schick 2009;

Roffman et al. 2012). However, none of our ape relatives living in nature have developed these skills as cultural traditions, probably because they do not live in habitats where suitable stones could easily be found or where use of stone choppers and scrapers would provide them with a selective advantage[371]. On the other hand, hominins scavenging or hunting large prey in a savannah habitat would gain major advantages from the ability to rapidly butcher kills before they are discovered by dangerous competitors such as lions, leopards, saber-toothed cats or hyenas that could steal their kills (Plummer 2004).

Based on studies of chimpanzee and African hunters and gathers hunting in the wild (Kaplan et al. 2007; Pickering & Domínguez-Rodrigo 2010), scavenging and hunting might well have provided early hominins a way to maintain caloric input during times of the year when fruit and nuts were scarce. Hunting success in chimpanzees also depends on at least some cooperation among larger groups of males. As discussed above, the first *Homo* associated with Oldowan stone tools had only slightly larger brains than other anthropoid apes (Tobias 1987; Bailey & Geary 2009; Plummer 2004).

The use of butchering tools enabled the ape men to exploit large prey on the savannah in direct competition with big cats and other large carnivores, in addition to food resources such as roots and tubers that could be gathered. They may have even used tools to assist with the digging. In any event, success in this savannah/grassland niche must have depended on social cooperation and the cultural transmission of several kinds of knowledge regarding the making of tools, understanding the behavior of prey species and dangerous/competitive carnivores, and knowing where edible roots and tubers might be found.

At this early stage in human evolution there is no evidence that these small-brained *Homo* had a facility for language or for the making of complex tool sets. Plasticity of cultural adaptation would be limited to the cognitive capacity to transfer knowledge by observation and imitation. However, early hominins such as *Australopithecus* and *H. habilis* were clearly living in environments where they could gain strategic power by developing capabilities afforded by increasing cranial capacity (Figure 131, Figure 132, Figure 133). Comparative, paleoanthropological and archeological evidence show clear associations between increasingly sophisticated tool use with the enlargement of brains and reduction of teeth and gut. This suggests that tool use enabled more and higher quality food to be harvested to support the evolution of metabolically more expensive brains required for making and using the increasingly sophisticated tools (Aiello & Wheeler 1995, Leonard et al. 2007; Babbitt et al. 2011). As discussed further below, the management of fire and cooking also contributed to the development of the socio-cultural growth of knowledge.

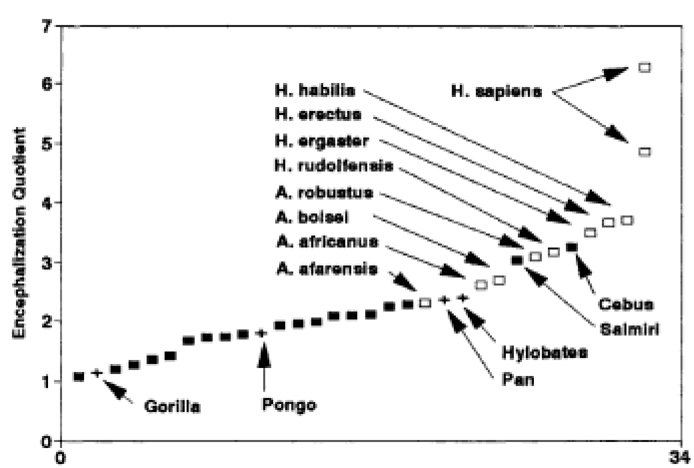


Figure 131. Encephalization quotients of 34 species of higher primates, including extinct hominins (Aiello & Wheeler 1995). Open squares = hominids/apes, closed squares = monkeys, Pongo = orangutan, Pan = chimpanzee, Hylobates = gibbon, Cebus = capuchin monkey[366].

Stone tools with an Oldowan level of complexity were made from > 2.6 mya through about 1.4 mya, associated with the emergence of early *Homo*. The next technological advancement discernible in the archaeological record is the development of the more varied and complexly finished Acheulean tool set associated with *Homo ~erectus* (Figure 130), dated from > 1.6 mya through as recently as 250 kya (Stout 2011). Stout notes that over the more than a million years these tools were made, the products gradually became more sophisticated and required increasingly sequenced, complex and precisely controlled actions to form them. This is associated with and may have been facilitated by increasing brain capacity (Figure 133). Also, the knowledge underlying the actions had to be socio-culturally transmitted, enabling the cumulative improvement that represents cultural evolution. However, McNabb et al. (2004), based on their analysis of large Acheulean cutting tools dated ~ 400-500 kya from the Cave of Hearths argue that this cultural knowledge did not extend to holding and transferring detailed mental templates for the tools capable of transmitting artistic or symbolic details of the end product.

> *H. ergaster* and *H. heidelbergensis* may have had a capacity for creating and manipulating chains of sequentially related routine actions that was drawn from their primate heritage and represented a significant advance beyond earlier *Homo* or *Australopithecus*.... The data … make a strong case for no direct social imposition of standardized values and no strong lines of social learning…. Rather, knappers attempted to reproduce what they had seen around them all their lives…. The idea of a large cutting tool and how to go about realizing it was held in the memory; the specificity of the end product was not. (McNabb et al. 2004: p. 667)

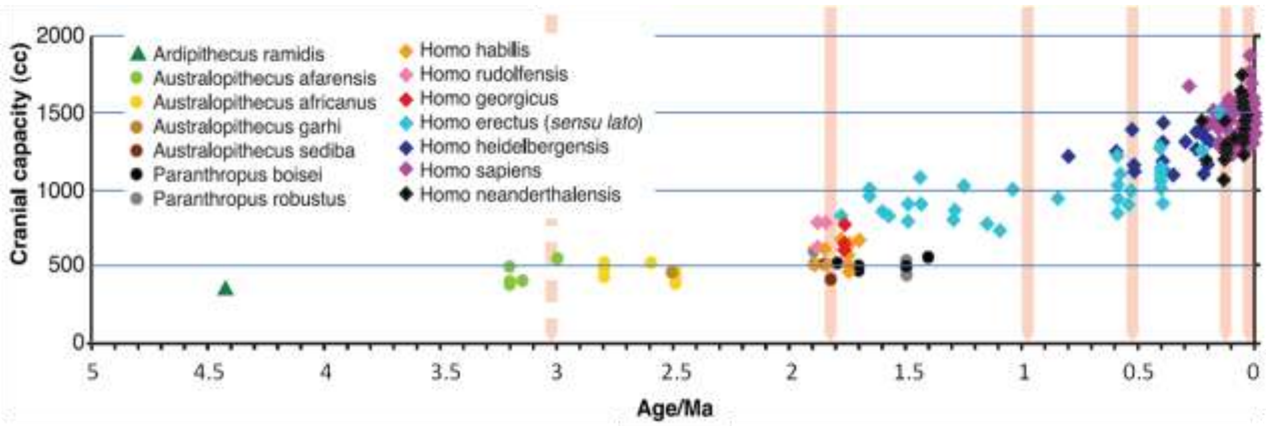


Figure 132. Estimated brain capacities for different hominin individuals recovered from the fossil record (from Shultz & Maslin 2013). Pink bars indicate hominin migration dates as estimated from first appearance dates in the fossil record outside of the East African Rift System. Specimen dates and brain size estimates were taken from Shultz et al. (2011).

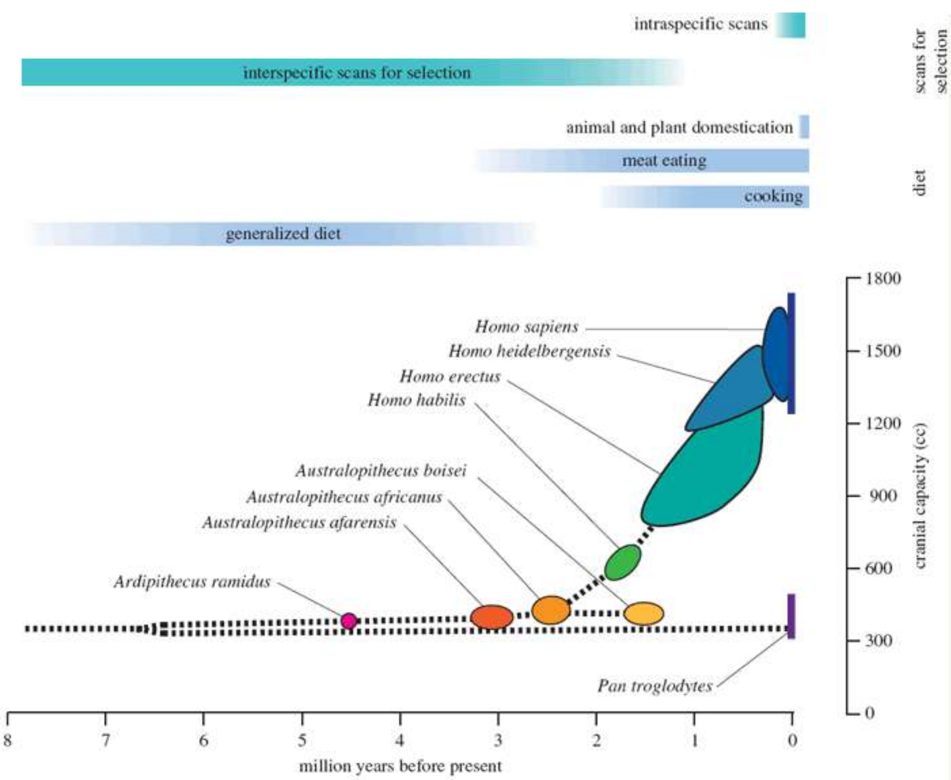
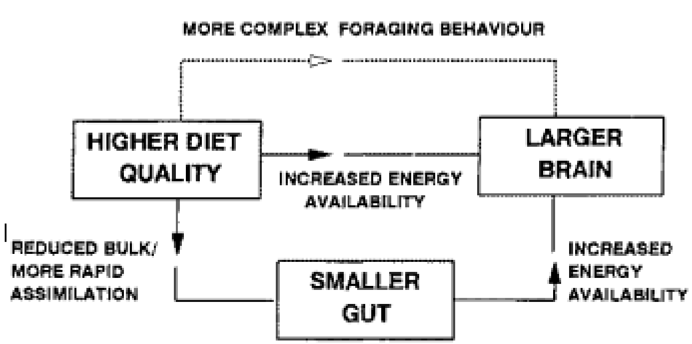


Figure 133. Hominin diets vs cranial capacities (Babbitt et al. 2011). Note: *H. heidelbergensis* here includes Neanderthals.

- *The rise of Homo 'incendius' – fire tamers*



After the development of butchering tools, a second major innovation increasing the size of human niche that may at the same time have selectively favored the evolution of increasingly large and energy demanding brains is that of using fire to cook food (Roberts & Bird 2012). Cooking processes food that would otherwise be difficult and energetically costly to digest or inedible, such as meat and the large variety of plant roots and tubers to make it easily digestible.

Figure 134. Trade-off between brain size and digestive apparatus (Aiello & Wheeler 1995; Kaplan et al. 2007 offer a more detailed analysis of the evolutionary tradeoffs)

Aiello & Wheeler (1995 - Figure 134) introduced the idea that hominids are energetically limited, and that there are direct trade-offs between the amount of metabolic energy on one side that can be extracted from digesting food minus the energy costs of the 'digestive processes' – including the energetic demands of chewing, gathering and hunting; versus the particularly high energetic demands of the brain. Given that that populations of large primates such as tool-equipped savanna hominins and forest apes were probably limited by the availability of food in their niches rather than predation, brain size could increase significantly only at the expense of reducing the consumption of available energy by other organs – e.g., in the digestive and muscular systems.[373]

Wrangham & Conklin-Brittain (2003) and Carmody & Wrangham (2009) suggest that cooking may have accounted for the success of early *Homo erectus*. Wrangham & Conklin-Brittain show that today's humans are not equipped to live on raw food alone. They summarize German studies that showed that even where "raw-foodists" had access to shops with a wide range of foods from around the world, they were vulnerable to energy shortages. Of those following a raw food only diet, 31% suffered from Chronic Energy Deficiency. Also women's reproductive performances deteriorated progressively as the percentage of cooked food decreased. Approximately 50% of women on 100% raw food diets became completely amenorrheic, with others suffering menstrual disturbance. By contrast, weight-stable vegetarian women have fewer menstrual disturbances than non-vegetarians, supporting the conclusion that energy shortage rather than food type caused the difficulties, and that a purely raw food diet could not guarantee an adequate energy supply. Given that the observations of "raw-foodists" concerned sedentary urban dwellers with access to high quality foods over the entire year, Wrangham and colleagues concluded that a pure raw-food diet would not have supported the energy-demanding life styles of early human hunter-gatherers. Cooking improves food in five ways: by breaking physical barriers such as skins or husks, bursting cells to make contents more easily available for digestion, physically modifying molecules into more digestible forms, breaking large molecules down into smaller more easily digestible fragments, and denaturing toxins and compounds that impede digestion or absorption.

The use of Oldowan processing tools facilitated niche expansion into savannah habitats, presumably supported by increased caloric intake from somewhat more readily digestible meat. However, in diets with an adequate balance of essential amino acids (and only a small amount of meat is needed to provide this), not all of the potential caloric value can be recovered from digesting raw animal flesh (Aiello & Wheeler 1995; Wrangham & colleagues, loc. cit.). Also the digestion of excess amounts of protein entails a number of metabolic costs reducing the caloric value of the increase (Ben-Dor et al 2011). Thus it is supposed that, as long as hominins were limited to energy they could extract from raw food, their niche could not supply enough calories to support the evolution of larger brains required for a cognitive capacity to developmen and maintain more complex tools and social systems for food gathering. Wrangham & colleagues argue that the domestication of fire for the external processing and cooking of food substantially changed the equation (1) by substantially increasing the number of calories absorbed from the same amount of food, and (2) substantially reducing the metabolic costs of digesting the food – i.e., allowing selection to reduce the size and energy demands of the gut, chewing apparatus, and the musculature required to support digestion (carnivores have small guts by comparison to herbivores). By contrast, Leonard et al. (2007) argue that tool assisted foraging and meat eating alone would have provided sufficient resources of essential long-chain polyunsaturated fatty acids and essential amino acids, combined with available calories from roots and tubers to fuel the growth of larger brains in *H. erectus*.

This raises the questions – when and where in the archeological record do we find early evidence for the domestication of fire and what else do we learn from these sites?

- *First evidence of controlled fire ... > 1.5 mya? Wonderwerk Cave 1 mya.* As discussed by Berna et al. (2012), several claims have been made that hominins used fire as far as 1.5 mya or even earlier (Beaumont 2011; Roberts & Bird 2012) – when early *H. erectus* appear in the fossil record. Traces of fire in the archeological record are easily erased, and it is difficult to discriminate between the archeological effects of wild vs controlled fires (e.g., Karkanas et al. 2007) without close and meticulous examination microstratigraphy. In their own studies of one million year old strata in Wonderwerk Cave in South Africa, Berna et al. (loc. cit.) meticulously document the controlled and habitual use of fire in conjunction with Acheulean tools assumed to be made by *Homo erectus* (Roberts & Bird 2012; Pickering 2012). Berna et al were unable to confirm Beaumont's (2011) claim that the supposed ash layer dating to near 1.7 mya was in fact ash, but securely document that African *H. ~erectus* at Wonderwerk Cave were consistent fire users as early as 1 mya – with older strata still to be studied in the same detail (Figure 133).

- *Gesher Benot Ya'aqov – beginning 780 kya (sporadic for 100 ky span).* In their excavations of the Gesher Benot Ya'aqov on the banks of the Jordan River in Israel, Goren-Inbar et al. (2004), Alperson-Afil (2008), Alperson-Afil & Goren-Inbar (2010) clearly document that fire was habitually used at this site, then a lake margin, for approximately 100,000 years encompassing the well-dated Matuyama-Brunhes geomagnetic reversal 0.79 mya (Goren-Inbar et al. 2000) during the time when *Homo erectus*, *ergaster* and/or early *sapiens* may have lived in the region (Goren-Inbar et al. 2004). This site is on a plausible migration corridor between East Africa and Eurasia. The archaeological evidence for the making of Acheulean-type tools shows that hominins camped on the lake margin, but does not identify the species that made the tools. Based on bones showing signs of butchering with stone tools, meat from large animals (elephant, large bovids, rhinoceros and gazelle) plus fish and crabs was processed (Goren-Inbar 2011). A wide range of leafy and fruiting plant food was gathered (preserved and identifiable in the archeological record due to anaerobic waterlogging), including grapes, water chestnut, water lily, cattail, oak, pistachio, olive, plum and jujube (Goren-Inbar et al. 2000). Hammer stones and pitted anvils at the site point to nut processing. The association of seeds and fruits with the hearth and anvil stones shows an association with the firing and heating process. Although no intact hearths (e.g., stone circles) were found, the distributions of archeological finds around "virtual" hearth locations suggested that fires were central locations around which tools were made and used for butchering that would have served as points for social congregation.

- *Regular use of fire after ~400 kya*. Roebroeks & Villa (2011) review the archeological evidence for the use of fire in Europe and Africa. There is solid evidence based on a large number of sites for the regular use of fire after ~400 to 300 kya. However, despite the presence of hominins using Acheulean grade technologies associated with *H. erectus* in southern Europe since ~ one mya and in more challenging subarctic or boreal climatic zone some 800 kya, they found virtually no evidence for use of fire in otherwise comparably preserved sites before the 400-300 kya period. Post 300 kya there is strong evidence at several sites for the habitual use of fire in both cave and open-air settings – corresponding to *H. heidelbergensis/neanderthalensis/sapiens* evolutionary grades (**Error! Reference ource not found.**).

- *Schöningen ~ 400 - 380 kya - a seasonal hunting camp.* The Schöningen II sites provide the oldest examples of *wooden* tools for hunting and other purposes (Thieme 1997, 2005; Lang et al. 2012). These sites, where the earliest is dated between 400 - 380 kya, were discovered within an open-cut brown coal mine in Saxony, Germany. Excavations in the mine revealed two particularly significant archeological horizons alongside what was then a boggy lake shore (Thieme 2005). Schöningen II, Level 1 (the older) yielded flint artifacts, more than a thousand bones of ten mammalian taxa, and four worked silver fir branches with diagonal grooves cut into one end – probably for holding sharp flakes (that would make them the oldest compound tools discovered!).

Figure 135. ~380 kya spear from Schöningen II, Level 4 (Thieme 2005: p. 124)

The second site, Schöningen II, Level 4 - perhaps 100-200 ky younger than Level 1 (Thieme 2005: Fig. 8.1), yielded an anaerobically preserved single season's hunting camp containing more than 25,000 well preserved bones, with substantially more than 90% belonging to horses and many those showing signs of butchery. Four separate hearths were also identified, each about a meter in diameter and separated from each other by several meters. All stone artifacts were flint – which had been brought the site ready made. The only flint debris is from retouching, and bone retouching tools were also found. Wooden tools included a double pointed throwing stick (all branchlets removed and both ends sharpened) similar in size and shape to throwing sticks used by Australian Aborigines to bring down flying birds (there is evidence for slaughtering of geese at the site). Also found were nine wooden spears (Figure 135) ranging in length between 1.8 and 2.5 m, with maximum diameters between ~30 and 50 mm. Most of the spears were made from spruce trunks with closely packed growth rings, selected to be particularly hard and dense. As constructed, the spear tips were shaped from the base of the trunk (the hardest wood). Points are symmetrical and cut to avoid the pith. Tails are long and taper towards the end. The carefully worked surfaces of the spears were intentionally polished and cleaned, with the maximum thickness and weight concentrated towards the tip – shaped much like modern Olympic javelins. Among many other worked wooden objects and fragments, is what seems to be a well finished, well-used, partly charred roasting spit (identified as such by a 7 mm lateral branch apparently used to keep roasting items from slipping off as they cooked). But see Stahlschmidt et al. 2015 for evidence and argument that there there was no controlled use of fire at Schoningen.

The structure of the site suggests that it was an autumn hunting camp largely based on the successful cornering and killing of a single group of at least twenty horses (based on complete skulls), including adults of both sexes plus juveniles, that had been moving along the lakeshore. This would have required sophisticated hunting strategy and cooperation, and implies that the hominins had the capacity to process large amounts of meat and hide. Thieme considers that the number of animals slaughtered and the layout of the hearths and tools recovered suggests the hominins may have had the capability to preserve meat by smoking and drying over the fires. The site also contains a number of flat-topped bison radius bones covered with series of deep cut marks suggesting that strips of meat were cut up into handy sized pieces for smoking or storage.

The location of the site within a zone of dry peat and mud at the edge of the lake suggests that it was occupied when the water level was at a seasonal low (i.e., late summer - autumn); and preservation of the bones and wooden implements indicate that soon after the butchering they were covered with wet vegetation from the reed bed, such as would have happened in late autumn snows. The lack of scavenger or carnivore damage to the bones suggests that hominins controlled the site until the bones were either fully covered by decaying plant matter and/or flooded by rising water level in the next spring.

Thieme concludes his summary of the site by pondering why at least eight perfectly good spears – which may have been the majority used in the hunt - were left behind at the site?

> [O]ne needs to ask why these weapons, which have been produced according to individual needs and abilities and with a considerable amount of effort, were not reworked and used for other purposes, e.g. digging or throwing sticks. Is the act of leaving behind these important tools maybe a reflection of differentiated hunting rituals, which we have to assume for the time [these hominins existed] and which prohibited further use of the tools used for killing? Was a taboo placed on them, to secure the success of future hunting activities? And does this stand in connection with the skulls of the killed horses that were not smashed or used in any form so that one gets the impression that they were treated with respect, to ask the animals for forgiveness after the act of violence? (Thieme 2005: p. 131).

- *Bilzingsleben 370 kya (single occupation period).* The extraordinarily well preserved Bilzingsleben site (Figure 136)[374] in Thuringia in the east of Germany has also provided substantial evidence for the use of fire in association with a complex culture (Mania & Mania 2005) around 370 kya, during an interglacial climatic optimum during the Pleistocene when temperatures were somewhat higher than they are today. Thieme (2005) describes evidence about the relative dating of horse fossils from both sites that suggests the Bilzingsleben site is somewhat more recent than Schöningen.

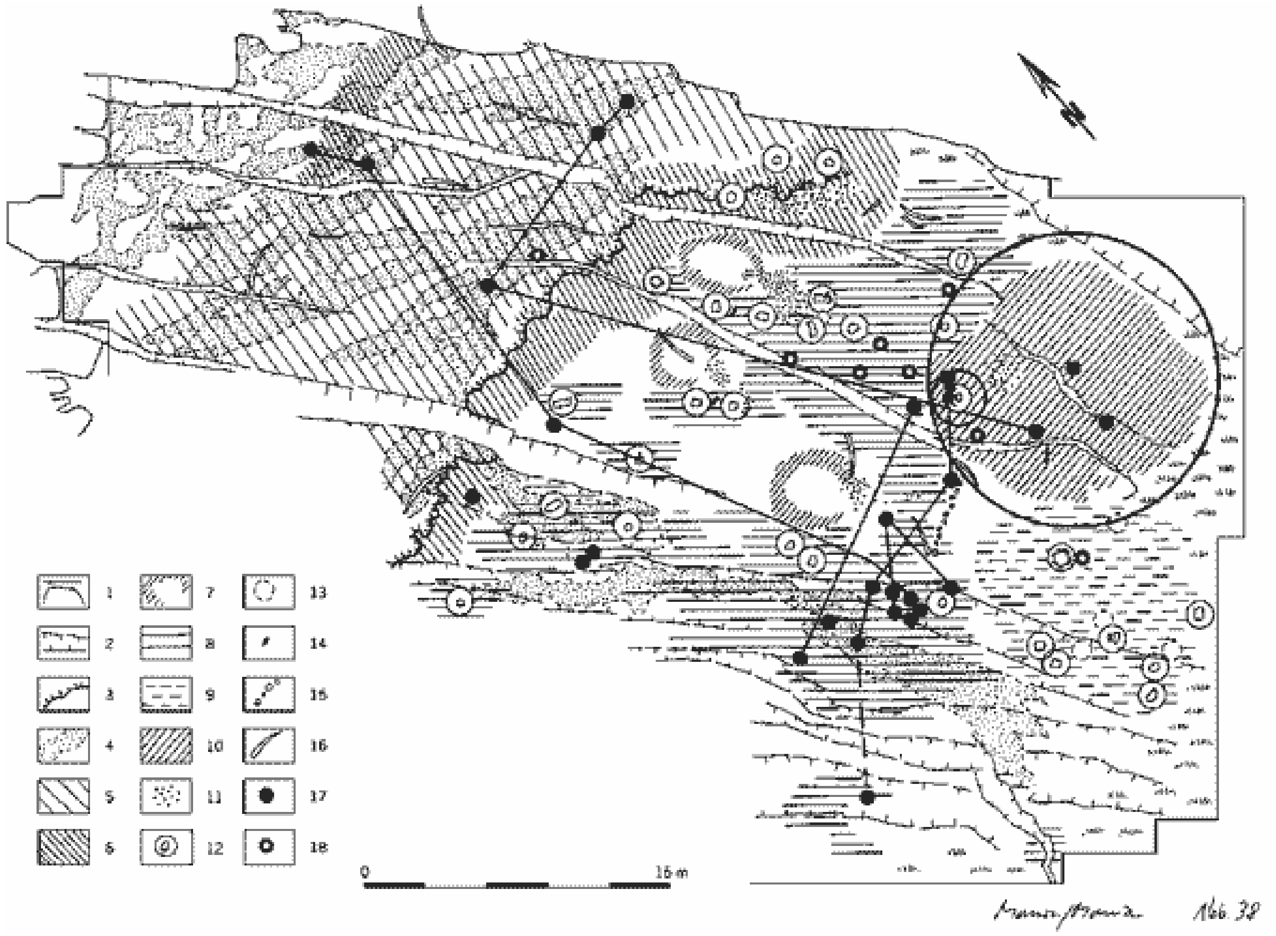


Figure 136. The Bilzingsleben Site, ~370 kya. Key: 1. Limits of excavated area; 2. Geological fault lines; 3. Shore line; 4. Sandy travertine sediment; 5. Alluvial fan; 6. Activity area at the lake shore; 7. Outlines of living structures; 8. Workshop areas; 9. Special workshop area with traces of fire use; 10. Circular paved area; 11. Charcoal; 12. Bone anvils; 13. Stone with traces of heat; 14. Bones with intentional markings; 15. Linear arrangement of stones; 16. Elephant tusk. 17. Human skull fragments; 18. Human tooth. (Mania & Mania 2005: p. 101).

Mania & Mania's (2005) summary shows that Bilzingsleben was an open-air camp site on the shore of a small lake located in a region of karst at the outlet of a travertine spring. The site was preserved with extraordinary fidelity in calcareous sediments from the stream and by later flooding when it was further covered and protected under a layer of chalk. Excavations revealed three "settlement structures" (i.e., huts of some kind) around 3-4 meters in diameter containing hearths (Figure 136 - key 7), as evidenced by burned rocks and charcoal near the entrances (key 11). These would have provided winter warmth and possibly cooking. Large tools made from stone, bone and antler and some preserved wooden objects were placed around the outside of the huts. Four other areas of activity close at hand were evidenced by stone anvils, debris, flint tools and choppers and other evidence of hominin activities. These included:

- A central activity area approximately (key 8) 6 x 30 m, located 3-5 m in front of the huts was characterized by large amounts of stone, antler, bone and ivory debris, choppers, many small flint tools, large bone and antler tools and anvils. Based on the kinds of debris it was evident that different kinds of work were concentrated in different parts of the activity area.

- A second activity area (also key 8) was "paved" with travertine pebbles that had to be carried to the site from over 250 m distance. This area contained several large travertine blocks weighing around 75 kg that also had to be transported from elsewhere that were apparently used as supports of some kind that were also associated with large travertine stones showing traces of intense heating. Tools found in the area were hammer stones and large bone scrapers. Was this a barbeque area for spit roasting?
- A third activity area (key 6) stretched along the lake shore included hoe-like tools made from red deer antlers and very large scrapers made from elephant leg bones. To me, this suggests an area for processing animal skins (e.g., for clothing, hut covers). A large quartzite anvil contained small particles of bone in its fissures indicating that bones were processed, as confirmed by articulated animal skeletal remains in the vicinity.
- An approximately circular activity zone or special workshop area (key 9) about 9 m in diameter was paved with a single layer of transported travertine, shell-bearing limestone, and small bones and teeth that had been pressed into the surface of soft sediment. Essentially no tools were found in the area, but remains and outlines of long wood objects were common. A temporary hearth was located in the center and there was a large travertine boulder (80 x 60 x 40) that had been exposed to intense heat was located on the eastern margin of the activity area. A large quartzite anvil near the western margin was "embraced by the horns of the skull of a large aurochs" (bison). Fragments of two hominin skulls were also found close to this anvil.

As for Gesher Benot Ya‧aqov, the residue of bones shows that the fire-makers hunted fish, amphibians, reptiles, birds and mammals – the latter including elephants, rhinoceros, horses, bison, red deer, fallow deer, roe deer, and wild pigs. Based on the presence of bones and teeth in the occupied area, they may have also hunted carnivores up to the largest, including cave lions, cave bears, grey wolves, spotted hyenas, red foxes, badgers, and martens. It is less clear what plant material was included in the diet, but it is evident that their control of fire and their hunting and food processing tools placed these fire-makers were at the very top of the carnivory food-chain and kept them sufficiently safe from predation themselves that they were able to live semi-permanently in the open air.

Based on hominin skull fragments found on the site, Vlcek and colleagues (Vlcek 1978; Schwarcz 1988; Mania et al. 1994; Vlcek et al. 2000) classified the fire-makers as *Homo erectus*. Cook et al. (1988) suggested they might have been archaic *H. sapiens*; Street et al. (2006) suggest that they were late *H. heidelbergensis* or pre *neanderthalensis*. Stringer (2012a) tentatively classifies the Bilzingsleben fossils as late *heidelbergensis* and notes later in the paper that mitochondrial DNA sequencing places the divergence of Neanderthals and modern humans between 407 and 345 mya.

It is likely that the capabilities represented by Schöningen and Bilzingsleben populations were close to those of a very early *H. sapiens*. The hints of ritual from both sites suggests these hominins probably had some linguistic capabilities. However, given that all of today's Eurasian and New World people derived from an out-of-Africa exodus 100 and 50 kya (Dennell & Petraglia 2012; Sankararaman et al. 2012), it should be understood that these fire-makers probably were *not* on the direct line to currently living humans.

- *Qesem Cave 380-200 kya*. Karkanas et al. (2007) describe micromorphological and other evidence in Qesem Cave near Tel Aviv in Israel that clearly indicate extensive, repeated use of fire by hominins between roughly 380 and 200 kya. This is associated with medium-sized ungulate remains that show clear signs of butchering and marrow extraction. Many of the bones show evidence of burning (cooking?).

As shown in the cases above, the control of fire enabled food to be cooked, presumably significantly increasing nutritional and caloric intake for a given amount of foraging (minus the energetic cost of gathering firewood and tending the fire). Thus, fire helped provide the metabolic resources for brain growth and presumably the growth of the brain's cognitive facilities. However, the maintenance of fire as another type of tool also added new demands on cognitive capacity. Clark & Harris (1985) and James (1989) reviewed the limited evidence that very early hominins may have used as much as 1.5 mya, and considered how the relationship between hominins and fire may have developed (Figure 137).

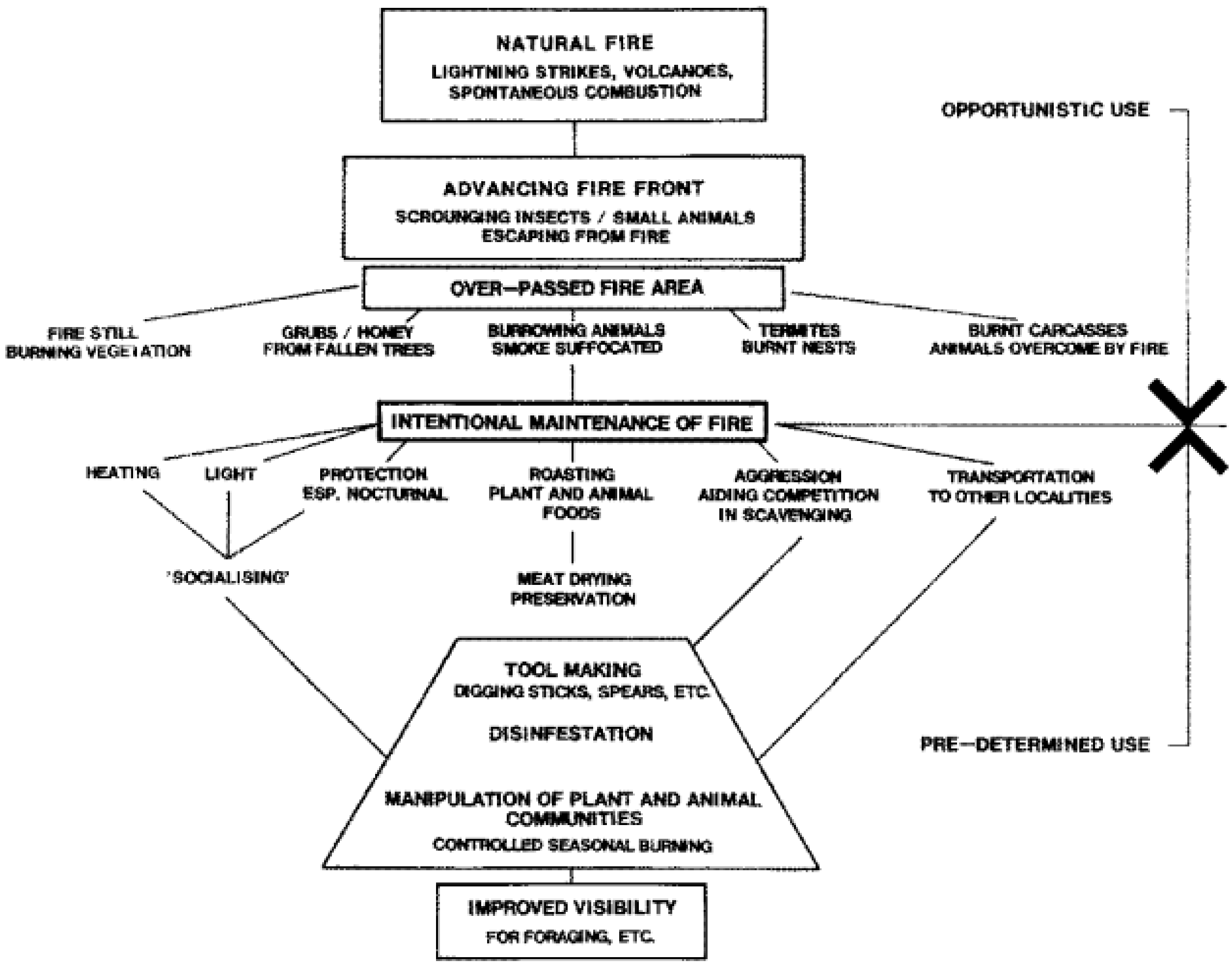


Figure 137. Possible use and maintenance of natural fire by early hominins (Clark & Harris 1985).

Like many birds and some small carnivores that follow wildfires, our early ancestors may have discovered that fires left behind cooked and edible casualties. They may have also learned that wildfires also cooked and made it easier to harvest root vegetables, other plant foods and nuts. This seems to be the case for chimpanzees that do not fear fire and have a preference for cooked food (Clark & Harris 1985; James 1989; Wobber et al. 2008). From following wildfires, it is a small step to carrying a slow-burning or smoldering branch to start a fire somewhere else, or to use it to start and maintain a campfire. A source of fire could also be conserved for several days by setting a tree stump on fire. Clark in Clark & Harris (1985) observed that such fires can burn for weeks and even months, something also known to our local country fire brigades here in Australia.

Sue Savage-Rumbaugh demonstrates that Kanzi, the bonobo, has mastered the essentials of making and tending a fire (assuming he has a tool to start it - Figure 138). It is not beyond belief that our last common ancestor with chimps and bonobos 5-6 mya had the mental capacity to maintain a fire for long periods once they discovered a source of ignition. Given that African savanna woodlands regularly burn on a 2-6 year schedule (Frost 1998), the ancestral hominins seeking to use the savanna would have several opportunities during individual lifetimes to see fires and obtain potential ignition sources.

Figure 138. Kanzi the bonobo uses a lighter to start a fire that he also helps to feed in order to cook dinner and roast a marshmallow (click picture for Sue Savage-Rumbaugh video).

Thus, even though clear evidence for early hominins' use of fire is lacking, it is plausible that fire could have played a role in hominin biology well before the time documented by the established cases described above. A number of authors cited here observe that very few of the locations where paleontological or paleoarcheological evidence suggest hominins lived provided suitable conditions that would have preserved evidence for the controlled use of fire. In other words, lack of evidence is not evidence of lack.

Rolland (2004) and Twomey (2011) amongst others propose the establishment of centrally located hearths led to a major shift in the behavioral biology of habitat use. Our living ape relatives establish core areas or home ranges over which they wander, often camping in a different area of that range every night. Kill and butchering sites on the savanna would attract dangerous predators – especially overnight. Once a hearth is established and kept burning, while it remains lit, the hearth provides a secure home base to which hominins could return every night and where young, ill and expectant mothers might safely be left during the day – somewhat guarded against predation by the fire. Thus, the fireplace provides a center for socialization and the possibility to continue activities such as tool-making and food processing after dark. Following Rolland (2004: p. 259) "The role of fire-making in understanding the shift from a core area system to a home base system may be sought as part of a multivariate network of developmental feedback loops bringing into play long-term factors such as hominin-carnivore coevolutionary relationships." He then lists seven major transformations, the first five of which probably all began more or less synchronously with the separation of the ancestral hominin from the closely related ape lineages:

- Bipedalism providing for increased mobility and larger home ranges
- A dietary shift including a larger component of carnivory (and probably also increased reliance on starchy roots and tubers
- Development of a "natural history" type of intelligence (i.e., giving more conscious attention to understanding the behaviors potential predators and prey and wild-fires, and for the location of

hidden tubers and roots) besides retaining the "Machiavellian intelligence" typical of our primate relatives

- The cumulative development of skills for making tools to facilitate butchery and the exploitation of other natural resources (e.g., probes and digging tools – as made and used by Capuchin monkeys[35] for harvesting honey and root vegetables)
- Learning to change the nature of their environments in a "time-binding" manner – i.e., knowing when to set fires to aid hunting.

These then established conditions favoring:

- evolutionary development of increasingly structured forms of social organization, speech, and symbolic behavior; and
- changes in reproductive biology and behaviour providing for longer childhoods and opportunities for social learning.

As argued by Twomey in his PhD Thesis (2011 and as supported by additional references therein) in the period before our ancestors learned how to make fire from scratch, the value of having fires in marginal habitats and the problems associated with maintaining the fires would have provided strong selective pressures for increased cognition. Hominins regularly using fire to cook, for warmth or for extending the day (e.g., for tool making activities) and to deter nocturnal predators would gain immediate positive benefits to enhance their survival chances in marginal habitats. Once cooking came into regular use, selection would favor the evolution of smaller guts, reduced chewing apparatus and larger brains. However, such adaptations would make hominins dependant on maintaining fire. Hominins who lost their fires may have survived without it for long periods in good climates, but would be at considerable disadvantage if they came into contact with those who had fire.

Several problems face fire users, beginning with limited availability of high quality fuel and the increasing effort to gather fuel from ever larger distances the longer they stayed at one location. Natural shelters able to protect fire from rain are few and far between, and moving a burning stick or log to start a fire in a new area would be risky. Hominins living in fire prone regions with seasonal fire regimes could probably re-acquire it within a few years at most. However, groups living in temperate or humid forested regions could go decades or generations without encountering a natural source, and could thus could easily lose any socially transmitted learning about fire management, or even become extinct if their ecological adaptations were based on fire use.

The need for early fire users to protect their fires from being doused by rain may have been the initial impetus for the building of artificial shelters, e.g., broad leaves, bushes, or even tented sticks covered with skins from their butchered animals (e.g., see the evidence for "settlement structures" with hearths summarized above from Bilzingsleben – Mania & Mania 2005). The movement of fire from one place to another would have taken considerable planning and preparation to ensure that the burning wood used to transport the fire didn't go out. To successfully maintain fires, hominins would have faced considerable cognitive demands (Table 5). However, there would always be major advantages to be gained from learning how to start fires at will.

Still following Twomey, fire-making is a culturally transmitted skill at least as complex as making compound tools, involving understanding how to use several components, where none have any obvious relations to the results. In the absence of matches or a lighter, it would take a stroke of genius even for a modern human to work out how to start a fire without instruction or demonstration. Both striking a spark by hitting stones together or wood-on-wood friction require substantial knowledge and understanding as to the types of stones and woods and how to turn the spark or glowing ember into a useful fire. Twomey notes that one of these skills involves controlled breathing to blow on the glowing tinder just enough for it to generate a flame, and ties this with the controlled breathing required for vocalization in the evolution of language.

Twomey concludes his thesis with a summary of the cognitive capabilities hominins must have achieved just to achieve the reliable maintenance of fire (Figure 139), such as was clearly achieved by the hominins occupying the Bilzingsleben site 370 mya. The value of fire may have been rediscovered and lost many times before hominins discovered ways to reliably start fires. However, there is little archeological evidence that fire had a significant and continuing impact on hominin biology prior to 400 – 300 kya.

Table 5
Cognitive demands associated with the maintenance of fire
(Twomey 2011: p. 132)

Fire Related Behaviors	Possible Problems	Cognitive demands
Access to Fire from Others - force or stealth - free access - exchange	- Risk of injury and death - Open to free-riding - Lack of Intragroup cooperation - Agreeing on suitable barter items	- Intergroup level collaboration - Monitoring information about free-riders - Understanding and communicating intentions
Maintaining Fire Gathering fuel - group gathering - proximate or remote Individual Gathering - stockpiling	- Group coordination - Divided labor - Adopting complimentary roles - Reciprocity - Acting remotely from each other	- Group level cooperation - Deciding who does what - Monitoring reciprocal exchanges - Knowing what remote others were doing - Group contingency planning
Transporting Fire - burning logs - fire carriers	- Fire Must be kept oxygenated - Must decide who carries the fire - Needs to be fed and attended to	- Attention to the task - Being ready in advance - Division of labour
Protecting Fire - cave use - finding new shelters - shelter construction	- Increased travel costs - Group level cooperation - Novel problem solving situations	- Stockpiling - Division of labour required - Novel action planning
Using Fire - Cooking - Warmth - Light - Protection	- Food stealing - Need a large fire to be effective.	- Monitoring and dealing with free riders - Social coordination required to bring in fuel

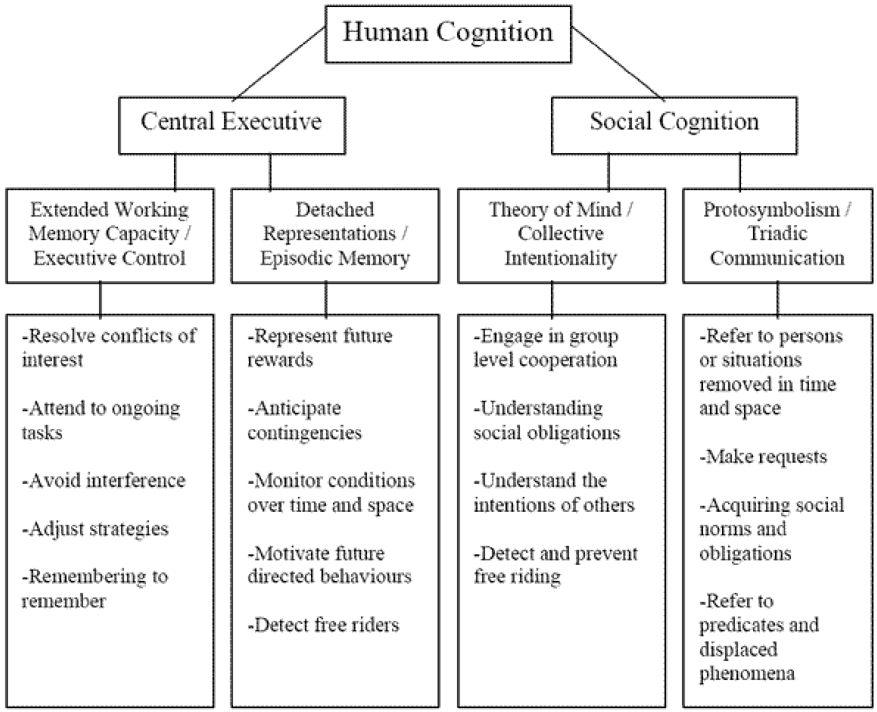


Figure 139. Cognitive requirements for maintaining fire (Twomey 2011: p. 216)

Hominin fire-makers, including Neanderthals, achieved a high level of technical competence by comparison to their ape relatives and ape-man ancestors, and learned to make a wider variety of more complex tools that helped them become apex predators in a number of habitats in Africa and Eurasia. However, by comparison to today's humans, while technological capabilities accompanying the mastery of fire grew over time, that growth was glacially slow, sometimes involving periods of apparent stasis lasting several hundreds of thousands of years (as in the Acheulean technology). Importantly, the slowly increasing technological capacity was accompanied by an approximately doubling of brain size (Figure 133). In this period of slow technological change and rapid brain growth there is no hint that hominins had evolved any kind of symbolic communication that would facilitate the transfer of abstract information.

I think we have to assume that the transfer of technical knowledge from one individual and generation to the next had to take place tacitly, depending on innate propensities and capabilities of the nervous system (i.e., as illustrated in Figure 139 – see also the "monkey business" demonstration - Figure 163). Without the benefit of language, the tacit transfer of technical knowledge from a practitioner to a learner would involve the following steps:

- Understand the end purpose/goal of performing the technology
  - It helps if the practitioner can communicate key ides using gestures and pantomime
- Observe the practitioner carry out a component task within the technology.
  - try to remember the practitioner's actions
  - try understand end result and purpose (e.g., to prepare something for the next task)
  - focus attention on steps that appear to be related to the end purpose
  - try to understand how and why the observed step(s) contribute to the end purpose

- Try to imitate what the practitioner did
  - for each step, did your action produce the same result the practitioner achieved?
  - if not, try to understand why not? (watch the practitioner perform the same steps again, and again, and again…)
  - try again, and again, and again… until you get the correct result
  - how do the steps go together to complete the task
- Put the steps together
  - have you achieved the end purpose/goal?
  - If not, try to understand why not?
  - etc.

Think back to the discussion of Kanzi lighting a fire with a lighter. If you had seen a fire, needed one, and found a pile of wood, but you had never seen anyone start a fire and had no writing or pictures showing you how, how would you do it? I think this explains the need for major brain growth in the early species of *Homo*. Each generation of hominins had to learn tacitly from the previous generation's practitioners how to do everything necessary to maintain their niche as apex predators – an increasing large volume of pictorial and action memory without a verbal structure to organize it. Something that we, who get most of our knowledge pre-digested from books and classrooms, can hardly conceive of. Also, *all the culture and knowledge that groups depended on could be held only in living memory*. If the only individual holding a particular item of knowledge died or left the group before it was fully transferred to another member of the group by slow and fallible tacit processes that knowledge would be lost until it could again be reinvented. This is a very difficult situation for small groups trying to survive in difficult and hostile environments. However, we know from the fossil and paleontological records that our hominin ancestors managed to construct ever-increasingly more capable technologies that have allowed us as their inheritors to completely dominate the entire biosphere of our planet.

I will conclude this section on hominin tool use by considering how accumulating knowledge and increasingly capable tools provided our ancestors and closest relatives with the strategic power required for constructing increasingly broad ecological niches to flourish in physical environments and ecosystems that are generally hostile and filled with fiercely competing species.

- *The virtuous evolutionary spiral of niche construction and the rise of Homo spiens*

The development of an effective and efficient cultural capacity for the cumulative construction of technologies and knowledge was unprecedented in in more than three billion years of evolutionary history before the emergence of hominins. Exploring the emergence of this capacity will be central to the remainder of the book.

Tomasello and colleagues (Tomasello et al. 1993; Tomasello 1999; Tennie et al. 2009) have called the role of culture in the cumulative growth of knowledge the "ratchet effect", and note that it depends on the faithful transmission across generations of cultural developments that can be added to by subsequent generations[375]. In other words, humans have the capacity to *accumulate* knowledge. Selection at individual and group levels works to shape the elements of cultural and genetic heredity in directions that improve adaptation. This may involve clustering and consolidation of several of those elements to achieve the adaptive response. As new cultural additions accrete together with already existing knowledge and capacities, the original elements cannot be deleted without collapsing the entire cultural structure built on top of it. Riegler (2001) independently reaches a similar "ratchet" construction.

Tomasello and colleagues observe that our ape relatives do transmit some knowledge and skills culturally, mainly via social facilitation. Ape learners see that something is possible by watching a skilled practitioner at work, and then basically work out for themselves by trial and error how to do it. This "*emulation*" to produce a similar result is a low fidelity means of cultural transmission, providing an unstable basis for the accumulation of additional modules. Apes do not have the cognitive or cultural capacity to accumulate knowledge beyond what is a very low level. On the other hand, humans learn the skill by closely "*imitating*" the expert, such that the skill is transferred more or less as a unitary module, that may be added to at a later date as it is tested and refined.

However, this is only a partial account of what is a remarkable process of cultural accumulation, and it does not explain how it started and what accounts for its continued acceleration in humans. What is missing is a clear understanding of the synergistic interactions of ecological changes, neural anatomy and physiology, cognition, and cultural artifacts over evolutionary time.

The survival of species' populations depends on how well they are adapted to the circumstances of the biological and physical environment they find themselves in. An organism or population's responses to resources, hazards and competitors and its impacts on those same environmental factors defines its ecological niche. Genetic heritage (and to some degree in various lineages, cultural heritage) determine individuals' capabilities to interact with their environments. Thus, as discussed in the Interlude, the capacity to establish and occupy a niche where the population can survive depends on the various forms of inherited "knowledge" and cognitive capabilities to solve problems of life as consolidated by selective processes in the evolutionary history of the population. Thus, species can be said to "construct" their niches in competition with all other species able to access resources in that environmental space.

Niche construction and expansion (Laland et al. 2001, Laland & O'Brien 2012) involves dynamic feedback cycles between species' populations, their environments, resources, and competing species in those environments. At any time the niche occupied/made by a species represents the current dynamic state of Malthusian niche-expansion pressures resulting from the capacity for excess reproduction, versus niche-narrowing or shifting pressures from the abiotic environment and from all other species' activities to widen their own niches[378]. As a consequence of the species' trophic and competitive interactions and alterations of physical resources in its natural environment, the species unavoidably alters that environment both for itself and other species. Those environmental alterations based on accumulated knowledge establish the selective environment that in turn biases the inheritance of genetic and cultural knowledge and cognitive capabilities to guide further evolution.

Niche construction activities can have two different kinds of outcomes, leading either to niche "shifts" across the adaptive or fitness landscape on the one hand, or to an "expansion" of the area occupied on the fitness landscape on the other (Figure 140). In general, genetic selection takes hundreds to thousands of generations to make significant changes in a species' biology. Most genetically determined traits are affected by multiple loci working through different regulatory paths. Also, most natural selection is effectively normalizing (whereby extreme phenotypes on both sides of a median are selectively disadvantageous) or directional (where only one extreme is particularly disadvantaged relative to the other extreme - Figure 140 – left).

Genetically determined developmental systems offer few opportunities to accumulate a *wider* variety of traits (Figure 140 – right), as this ordinarily requires some duplication of the genetic code so duplicated sections of the code can begin to evolve different capabilities – a kind of mutation event that is considerably rarer than simple mutations to an existing gene.

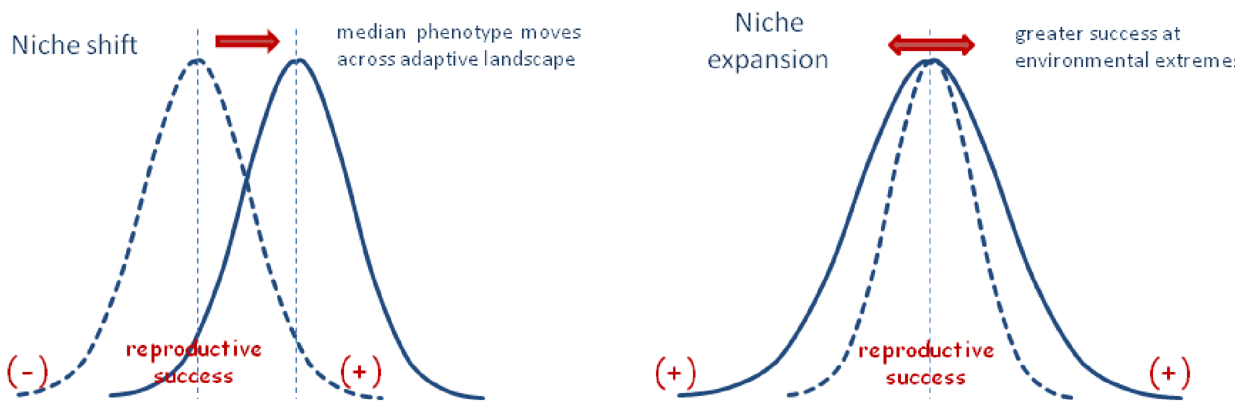


Figure 140. Niche shifts (left) vs niche expansions (right). Vertical axis represents survival probability of particular phenotypes.

By contrast, cultural knowledge may be developed and shared in less than one generation. Where knowledge can be transmitted between individuals with some fidelity, the acquisition of knowledge to use the environment in a new way does not necessarily require existing knowledge to be changed or replaced. In this situation the accumulation of diverse solutions to using the environment can easily lead to niche expansion, where new solutions facilitate survival at both extremes of the fitness landscape – leading to survival over larger areas of the fitness landscape.

As a species expands or moves its niche across the adaptive landscape it may cross a threshold to a previously inaccessible area on the landscape where it is able to expand (e.g., due to an absence of competitors). For example, when ape men evolved genetic or cultural adaptations that allowed them to survive beyond the forest, not only did they reduce competition with other species of apes left behind in the forests, but they were faced with a wide range of new selective pressures (e.g., increased bipedalism, increased use of new tools for defense and hunting, changed diets, physiological adaptations to get the most out of the new diet, etc.) that led to a grade shifting expansion into grassy woodland and savanna habitats. Using new types of tools and using existing tools in new ways provided access to new types of resources for niche expansion, and at the same time would selectively favor the cognitive ability to use an increasing *variety* of tools.

A *species*' knowledge is embodied in the slowly shifting contents of the species' gene pool *and* potentially rapidly shifting cultural heritage. Learning in a genetic sense takes place only through the incremental action of natural selection on the reproduction of whole genomes over generations of time. An *individual's* knowledge is embodied in the shifting contents of his/her cognitive processes and living memory. Individuals learn problem solutions through iterated knowledge building cycles of observation, orientation, decision and action; but this knowledge vanishes with the individual's death. The group's cultural knowledge is that which can be successfully transferred from the cognition and memories of one individual to other individuals during the first individual's lifetime.

As will be discussed in more detail in the next section – Society, culture and language, pre-linguistic hominins could only share knowledge via shared attention, observation, emulation/imitation, practice, and self-criticism of the results – processes that are slow and limited in their capacity to impart detailed process knowledge. Cultural accumulation critically depends on fidelity of transmission and survival of transferred knowledge (Tomasello 1999). Transmission of cultural knowledge is facilitated by structured social systems and genetically determined behavioral predispositions.

Malone et al. (2012 - Figure 141) argue that the early- to mid-Miocene primate stock ancestral to the hominids exhibited a limited social plasticity compared to modern hominins. In common with most anthropoid primates, these pre-hominins lived in groups with social bonding between related individuals (e.g., parent-child, sibling-sibling) and had the capacity to create wider social networks. They suggest the resulting variability in ecological and social selection pressures favored individuals showing greater behavioral and demographic plasticity to cope with changing habitats and opportunities for successful reproduction – first by niche shifts and eventually by niche expansion. As discussed earlier in this Episode, *genetic changes favoring expanded cognitive capabilities would offer immediate selective advantages*, because learning and cultural changes can respond much faster to changing circumstances than can genetic changes affecting instincts, physiology, or morphology that would otherwise take many generations to be established.

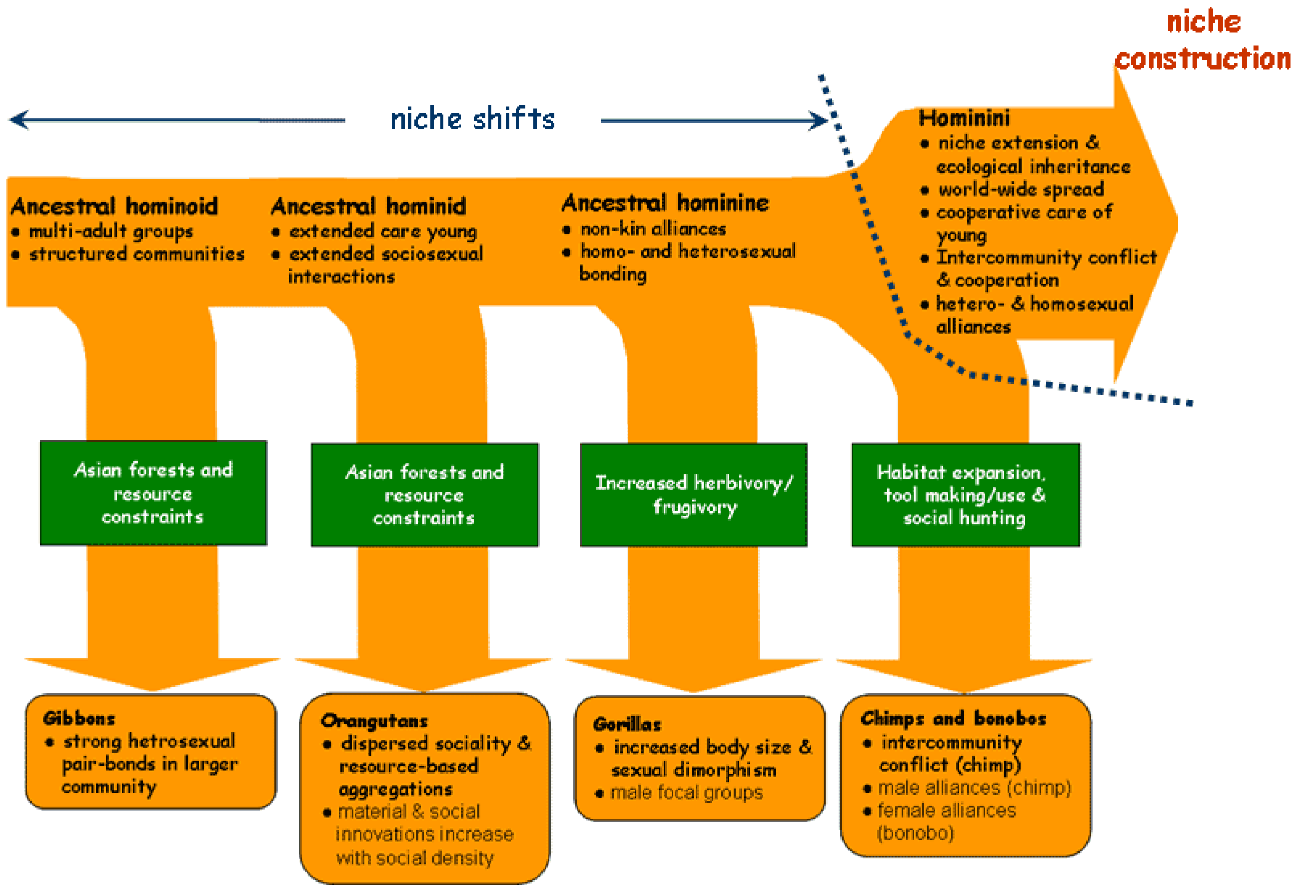


Figure 141. Evolutionary diversification of social structures in hominoid primates from the Miocene to the present (after Malone et al. 2012).

Malone et al. (2012), Iriki & Taoka (2012) and others present niche construction models for the evolution of a social system in early hominids that set the stage for the substantial expansion of social complexity and behavioral plasticity in the hominin line (Figure 142).

This emphasizes a central role for the evolution/emergence of capabilities to expand both ecological and social niches. The comparative method (Hall 19838) can be applied to hominins and their primate relatives, where looking for differences among closely related species and similarities among more distant relatives helps to disentangle responses to environmental influences on a background of similar inheritance. The cultural accumulation of knowledge via evolutionary learning cycles to broaden niches begins a positive feedback process leading to an exponential growth of cultural heritage and accelerating grade shifts increasing the rates of evolutionary adaptation and niche expansion.

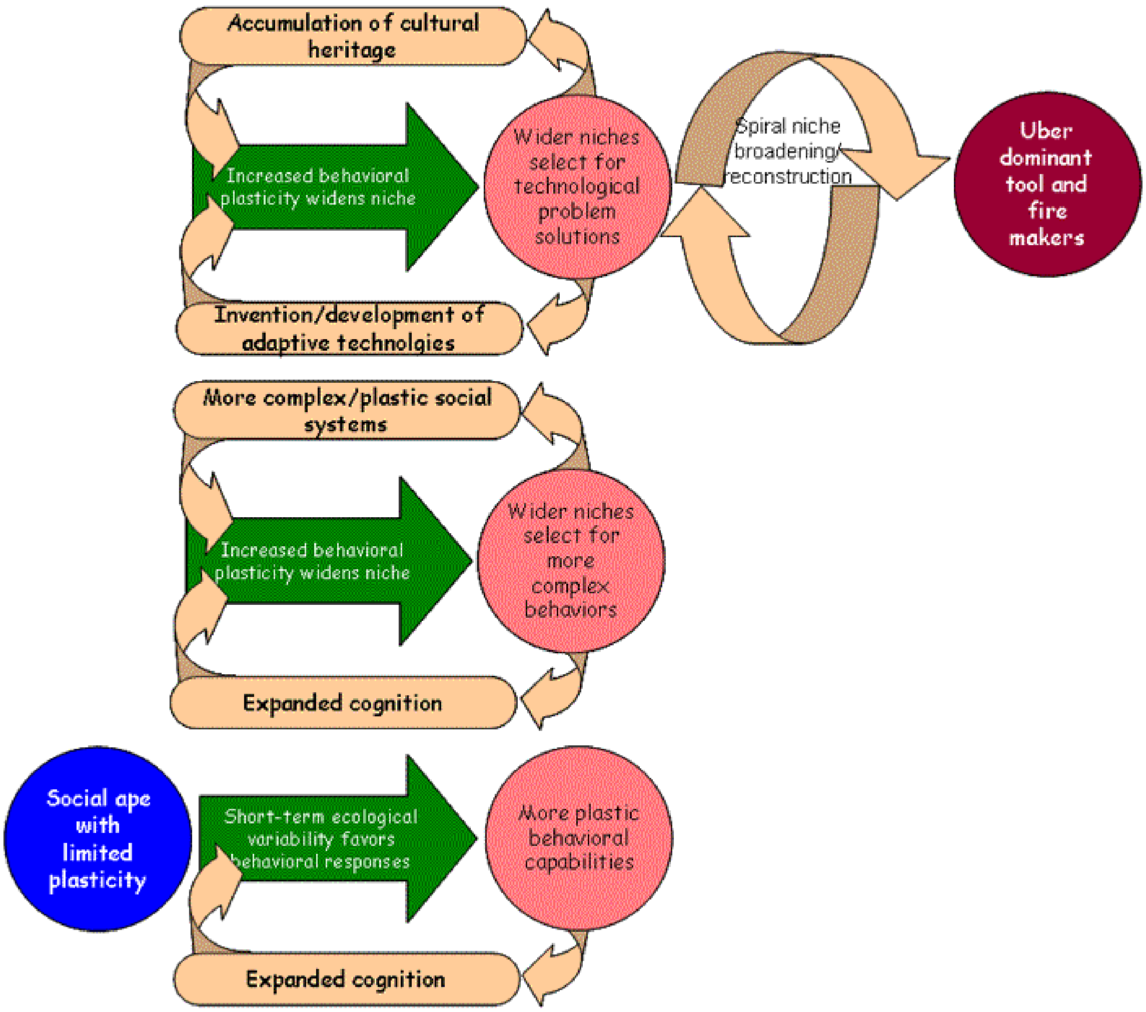


Figure 142. Selective factors including positive feedback loops leading to expanding social plasticity and niche expansion (after Malone et al. 2012).

Paleoarcheological evidence shows that hominins maintained fires for cooking a million years ago (see Wonderwerk Cave and Gesher Benot Ya'aqov), and that by around 400 kya some hominins were making sophisticated wooden and stone weapons and maintaining well organized hunting and butchering camps with hearths (see Schöningen, Bilzingsleben. However, the cultural accumulation of knowledge seems to have been a gradual process until the last 150-50 kya (Figure 155) when it seemed to accelerate with the development by Neanderthals and modern humans of much more complex toolkits, to begin an exponential growth in tool complexity and sophistication that is still continuing today (Figure 37) in humans. The increasingly rapid change is seen to be evidence for symbolic behavior and the emergence of what is called "behavioral modernity".

The archeological signals for modern behavior include (McBrearty & Brooks 2000: p. 492 - Figure 143):

- Ecology
  - Range extension to previously unoccupied regions
  - (tropical lowland forest, islands, the far north in Europe and Asia)

  - Increased diet breadth
- Technology
  - New lithic technologies: blades, microblades, backing
  - Standardization within formal tool categories
  - Hafted and composite tools
  - Tools made of novel materials, e.g., bone, antler
  - Special purpose tools, e.g., projectiles, geometrics
  - Increased numbers of tool categories
  - Geographic variation in formal categories
  - Temporal variation in formal categories
  - Greater control of fire

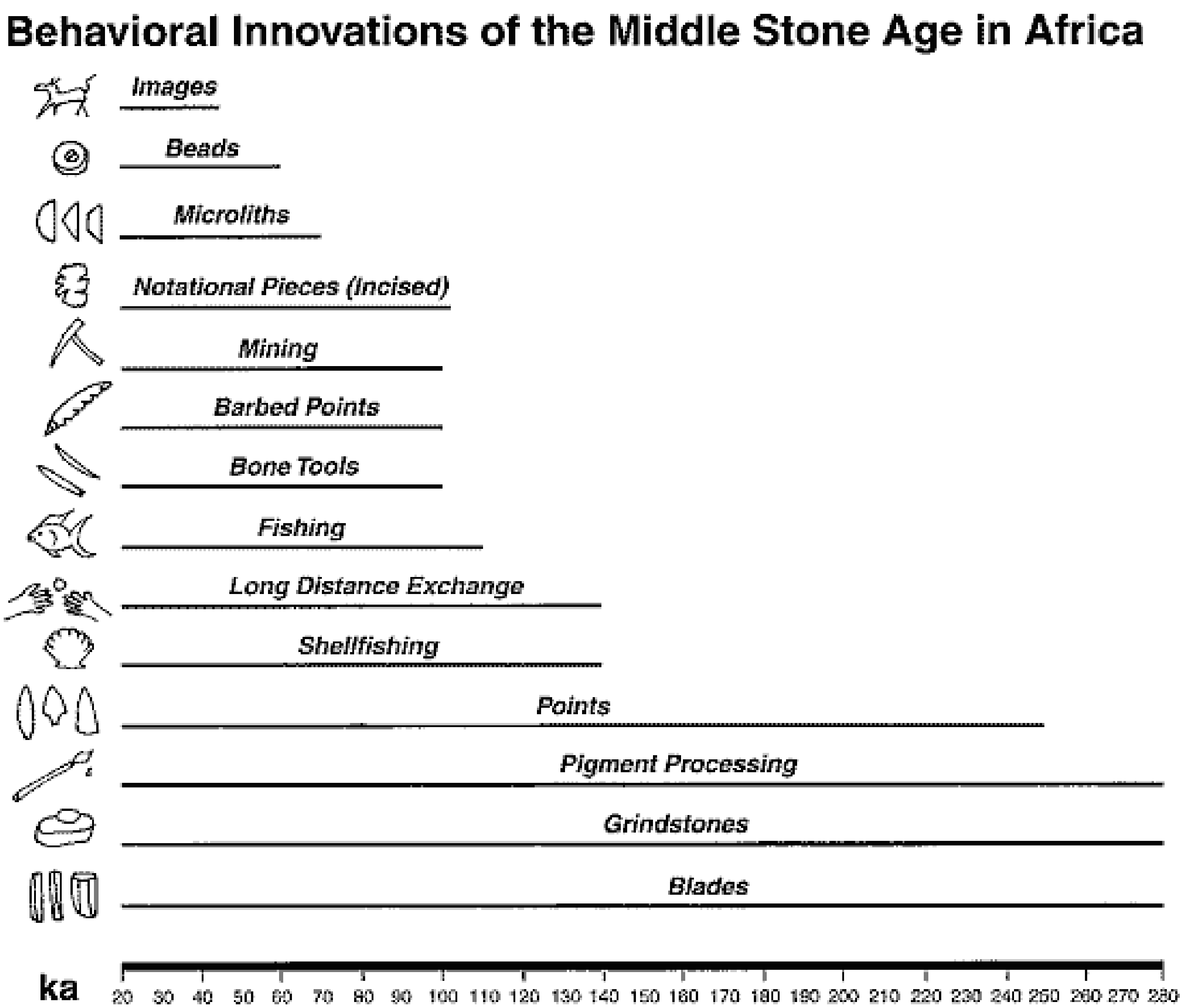


Figure 143. Earliest African evidence for cognitively significant technologies (McBrearty & Brooks 2000).

- Economy and social organization
  - Long-distance procurement and exchange of raw materials

  - Curation of exotic raw materials
  - Specialized hunting of large, dangerous animals
  - Scheduling and seasonality in resource exploitation
  - Site reoccupation
  - Intensification of resource extraction, especially aquatic and vegetable resources
  - Long-distance exchange networks
  - Group and individual self-identification through artefact style
  - Structured use of domestic space

- Symbolic behavior

  - Regional artefact styles
  - Self adornment, e.g., beads and ornaments
  - Use of pigment
  - Notched and incised objects (bone, egg shell, ocher, stone)
  - Image and representation
  - Burials with grave goods, ocher, ritual objects

McBrearty & Brooks (2000, Figure 143) argue that the behaviors leaving these archeological traces involve four major abilities: (1) to think and act in reference to abstract concepts not limited in time or space; (2) to formulate and act on group plans and strategies; (3) to innovate behaviorally, economically and technologically; (4) to represent objects, people, and abstract concepts with arbitrary vocal or visual symbols, and to use these symbols in cultural practice.

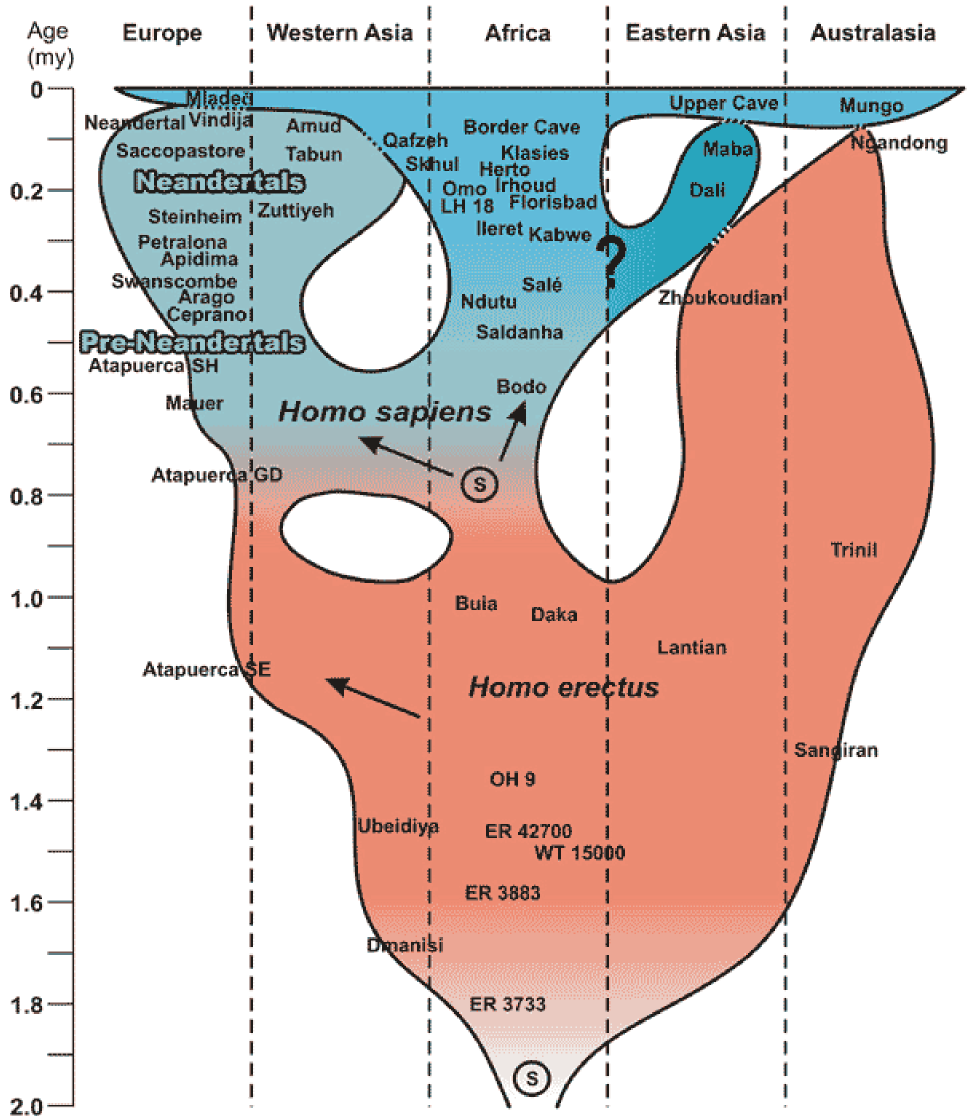


Figure 144. The fossil record for late *Homo* as reconstructed Bräuer (2008, 2012). The various names relate to time and geographic location of particular fossils used in the reconstruction. Ⓢ indicates speciation events recognized by Bräuer. The dotted contacts represent possible hybridization events when populations were geographically separated come into secondary contact.

Until recently, reflecting their largely European experience, most paleoanthropologists believed that behavioral modernity represented a major cognitive revolution coinciding with the emergence of *Homo sapiens* that occurred around 50-40 kya, and that this revolution was related to the emergence of modern linguistic capabilities around that time. Recent discoveries and the development of increasingly accurate chronologies for hominin fossils and technologies (Figure 143, Figure 144) over the last 300 ky in Africa show that the evolutionary species that became *Homo sapiens* evolved its modern morphology and behavior through the sporadic emergence and convergence of a mosaic of anatomical, behavioral and cognitive capacities.

Understanding the evolutionary origins of *Homo sapiens* is made difficult by the variety of taxonomic names applied to fossil representatives of different populations over time. Bräuer (2008, 2012) reviews the various species names applied to extant fossils relating to anatomically modern humans and their ancestors and concludes the various fossils attributed to *Homo sapiens*, *H. helmei* and *H. heidelbergensis* represent members of a single gradually evolving biological species that differentiated from *H. erectus* something on the order of 800 kya (Figure 144). By 600-600 kya this split into geographically separated African lineages leading to modern *H. sapiens* and a Eurasian lineage leading to Neanderthals. According to this view, the oldest anatomically modern *H. sapiens* are from around 196 kya (McDougall et al. 2008). By the time *H. sapiens* and *H. neanderthalensis* met in the Levant sometime in the last 100 kya they were sufficiently different that only limited hybridization occurred, leaving them as genetically distinct species. It was migrants out of this *H. sapiens* population in the Levant that went on to replace all preexisting hominin populations throughout Eurasia and the Indonesian Archipelago, and to colonize Australia and the New World.

The various indicators of niche expanding behavioral modernity first appear at different times and places in the paleoarcheological record – often not associated with identifiable hominin remains (McBrearty & Brooks 2000 - Figure 143; McBrearty & Tryon 2006; Kuhn & Hovers 2006; Shea 2011, 2011a; d'Errico & Stringer 2011). Fire was domesticated perhaps 1 mya; stone blades, pigments, and grindstones first appear > 280 kya; apparently hafted spear points by ~250 kya; and so on.

Based on this kind of evidence, there is no longer clear that all the aspects of behavioral modernity and speech emerged simultaneously in some kind of major revolution that made *H. sapiens* immediately different from other *Homo*. Rather, there is increasingly strong evidence for accelerated cultural accumulation of technology probably associated in some way with the refinement of a facility for language. All of this is involved with the evolution of an increased capacity for "social intelligence" (Sterelny 2007; 2012) as will be discussed at length over the next section(s).

Society, culture and language - how savanna apes learned to make complex tools and speak

Based on observations from lab and field studies, by comparison to modern humans, our forest-dwelling ape relatives are limited in their neural capacity (e.g., constructive memory – Ambrose 2010 and working memory – Wynn & Coolidge 2011) to deal with complexity in terms of assemblages of objects, processes, or thought. The thinking processes of bonobos and chimpanzees can be inferred from their amazing but still limited abilities to learn to make and use tools (Figure 5, **Error! Reference source not found.**, Figure 147) and to understand human speech and to express their thoughts in lexigrams (as studied in Kanzi the bonobo and his friends - Savage-Rumbaugh et al. 2001). All our ape relatives (and presumably our early ape-man ancestors) exhibit some mental abilities to make and use simple tools, but lack the mental capacity learn to use more than a few tools at any one time or to express ideas involving more than 2 or 3 words/lexigrams, or to use either in complex ways. To do more with tools or language requires the slow genetic evolution of increased brain capacity to manage the necessary volume and complexity of knowledge.

So far I have discussed the importance of culture, but have written little about the role that the emergence of language may have played in accelerating the co-evolutionary spiral of hominins' technological development and niche expansion. Material technologies leave paleoarcheological traces. By contrast, speech vanishes in the instant of its expression. To understand how our ancestors evolved a facility for language and how it may have interacted with material technologies that enabled humans to dominate the resources of an entire planet, we need to understand the nature of speech and language in pre-literate societies that have no concept of words as symbolic objects in their own rights. The concept of pre-literate speech is very difficult to grasp for those of us living in cultures or societies where words are controlled by written language (e.g., via dictionaries, encyclopedias, Wikipedia, etc.).

It is even more difficult for us to imagine how our remote ancestors thought about and coped with a hostile world *before* they evolved a capacity to speak and express thoughts in words. In this section I survey recent thinking and contribute my own ideas on how our ancestors coped with the changing climatic conditions that forced them out of their forest Eden onto the savanna, and how learning to survive there led more-or-less inevitably to the expansion of material tool-based culture and the emergence of speech as one of the most significant cognitive revolutions in hominin history.

The expulsion from Eden

Our last common ancestor with today's anthropoid apes very probably lived in well watered forest habitats in East Africa, similar to habitats occupied by today's chimpanzees and bonobos. In most seasons they could feed without much work on readily available herbs, fruits, nuts, insects and the occasional small mammal prey. They slept in trees and during the day could easily escape up a tree if they faced one of the few large carnivores hunting in the forest. Unfortunately, global cooling and the mountain building associated with the opening of the East African Rift Valley caused climatic fluctuations and deterioration, leading to replacement of the forest Eden by grassy woodlands and savannas (**Error! Reference source not found.**; Shultz & aslin 2013).

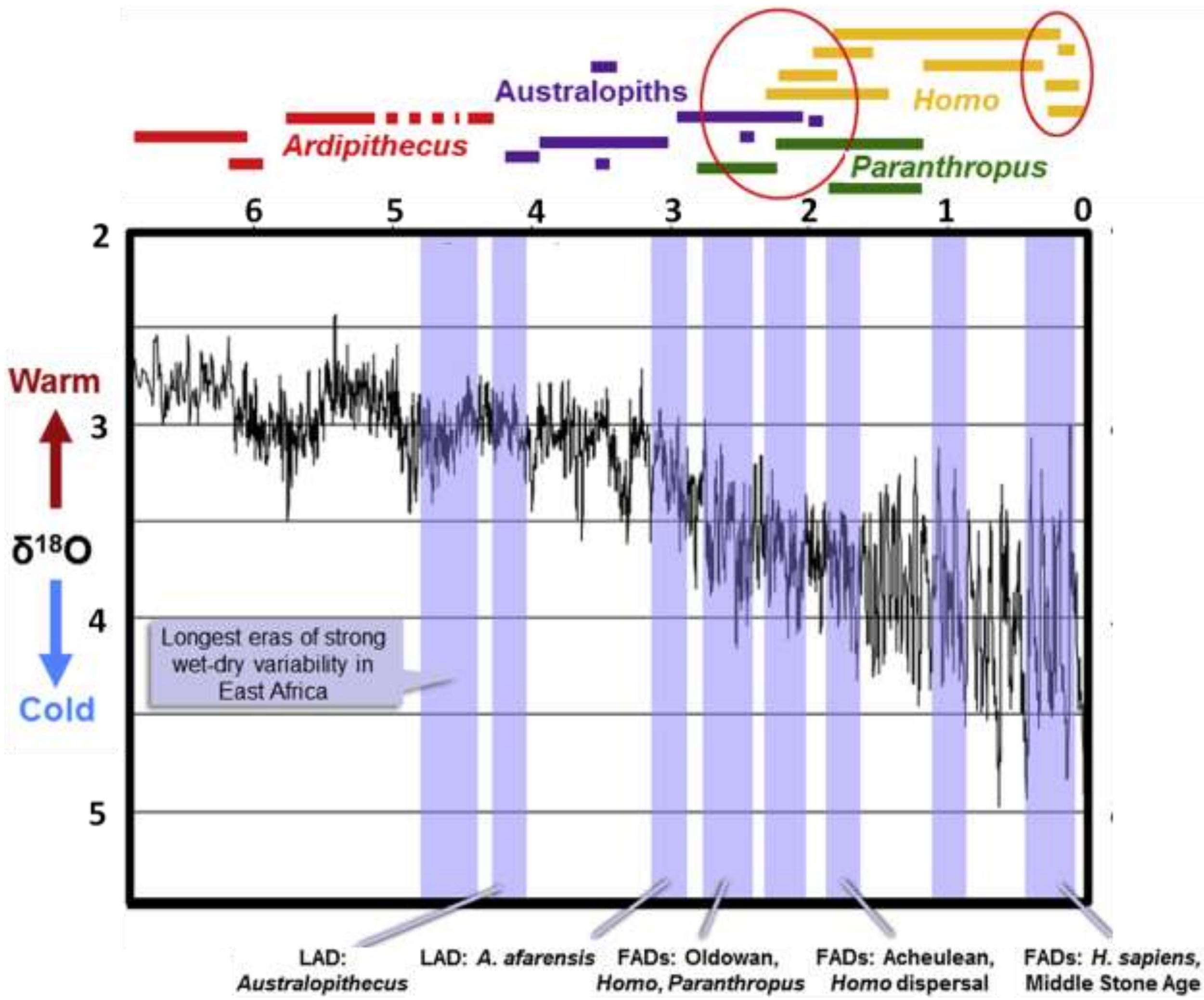


Figure 145. Hominin evolution and environmental variability over the past 7 million years (Potts 2013). The black line shows variation in oxygen isotope ratios in ocean sediments that is a proxy for average temperatures, showing overall decreasing temperatures and increasing variability over the last 3 million years. Occurrence data for hominin species are summarized at the top, with areas of major change circled in red. These are associated with closely spaced intervals of high climatic variability as indicated by the blue bars. FAD (first appearance date), LAD (last appearance date).

The savanna would have offered few, if any, of the resources habitually used by their forest-dwelling relatives and ancestors. To find enough food, apes forced onto the savanna would have to learn about and find scarce resources over a much wider home range comprising possibly several thousand km^2 (Whallon 2006), or might even have had to migrate over hundreds of km to follow seasonal rainfalls to find suitable forage. Such “marginal” dryland habitats also fluctuated over time with climatic and rainfall cycles affecting the size and location of permanent streams, lakes and springs. Potts (2013) argues that single climatic events are probably not responsible for major adaptive shifts, but rather that it is the impact of the entire range of environmental variability that shapes evolutionary change. The emergence of key adaptations and capacities in the hominin lineage seems to coincide with and are associated with long intervals of high climatic variability.

Apes forced onto the savanna had to make use of a very different menu of often highly seasonal plant food items that were scattered across an extensive landscape: including buried roots and tubers, dry grass seeds, different species of widely separated trees with short fruiting seasons. Out on the savanna – away from large trees they could escape into, the relatively slow and defenceless hominins would have also been at risk of predation by an extensive ecological guild[362] of large carnivores including lions, leopards, three species of sabertooth cats, a large bear, a wolverine the size of a small bear, several species of large hyenids, wild dogs, etc. (Werdelin & Lewis 2013) (Figure 146).

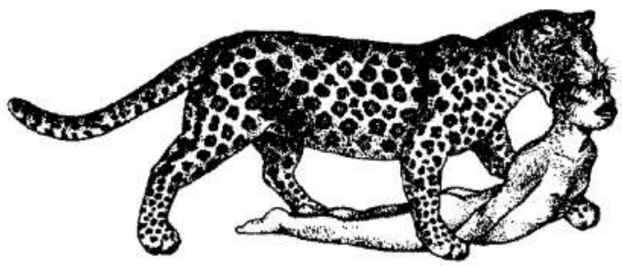


Figure 146. Based on predator damage to fossil remains, early hominins must have been at great risk of predation from big cats (leopards, lions, sabre-toothed cats, several species of hyenas, etc. (Picture from Tattersall 2012)

Although digestable plant foods would be hard to find, grassy savannas offered a wide range of animal prey feeding on grass and other herbaceous vegetation the early savanna apes could not digest, but most of these herbivores were large and very able to out-run or defend themselves against apes. Ape grade tools such as hammers and anvils (i.e., grinding stones) and digging sticks would have helped process things like seeds, roots, and possible marrow bones scavenged from carnivore kills, but survival must have been difficult without a grade shifting cognitive innovation – which may have been a change in the the savanna apes' style of foraging.

A crucial innovation sets our ancestors on the path to world dominance

Most primates are social, in that they forage in groups in a way that offers learning opportunities and many eyes to see when someone recognizes danger or finds good forage. The benefit is considerable and the cost is negligible. However, individuals remain selfish – satisfying themselves with no thought for sharing. The next step involves a combination of extractive foraging involving dexterous manipulation, intelligence (including capacities for insight and imitation) and social toleration (van Schaik et al. 1999; van Schaik & Pradhan 2003). Although the forest apes forage in close-knit groups, where young are tolerated to closely observe everyones' extractive activities including tool use and share food with their mothers, they show little or no inclination for active cooperation when a resource is found. In extensive laboratory experiments with captive apes and field observations (e.g., Tomasello 1999, 2008; Tomasello et al. 2005; Tomasello et al. 2012; Hare 2011; Whiten & Erdal 2012) they rarely show any kind of cooperation, except in chimpanzees for defense against predation or in the social hunting of small monkeys. In the latter case, food will be shared with sufficiently insistent group members.

Where human hunter-gatherers are studied, close cooperation is the norm. Resources are brought back to the camp and shared among the group. How cooperative foraging developed is a key step in the transition to humanity. As mentoned above, large grass-eating herbivores offer a large resource of high value food edible by apes if only they can be captured. At least in the beginning, for meat, the savanna apes would have been largely dependent on scavenging kills made by large carnivores. Also, with few trees available to allow escape by climbing, relatively defenseless apes on the savanna would have been at grave risk of predation while foraging or sleeping. What kind(s) of simple tool able to be used by a bipedal ape would help them avoid becoming cat food or even to be able to drive cats off their prey? Obviously, such a tool would have to be readily available and easily used by an ape man (and leave no archeological evidence of its use). Kortlandt (1980) reviews the ecological requirements primates face for defence and describes the defensive and offensive use of weapons by various primates, including chimpanzees. The latter have been observed to attack leopards with sticks used as clubs (Figure 147). But in a very uncoordinated way.

Figure 147. Chimpanzees attacking a stuffed leopard with clubs. (Click picture for video – see Kortlandt 1980 that may be the source for this video, as it describes an experimental situation he and his colleagues carried out).

Guthrie (2007) rules out essentially all of the potential weapons that have been proposed as either being as too difficult for a chimpanzee grade hominin to conceive or make, or else being relatively ineffective against a determined predator. However, there is one readily available weapon on the savanna that meets all criteria – thorny acacia branches that only need to be picked up off the ground or broken off nearby scrub (Kortlandt 1980). These only need to be held facing or poked at potential predators (Figure 148 - left). Kortlandt's experiments showed that big cats were quite fearful of moving thorn branches. Also, any kind of defense is much more effective when it is conducted by a group of several cooperating individuals rather than only one, or even an uncoordinated mob.

Figure 148. Hominins using thorn branches as tools (Guthrie 2007): (Left) for driving big cats away from their prey. (Right) for hunting - given the simple conversion of a thorn branch into a "megathorn" lance.

Some common acacia species have *haak en steek* thorns, combining on the same branch short cat-claw grabbing and slashing hooks with long sharp prongs up to 17 cm long. Any large carnivore running into such a collection of thorns faces a substantial risk of its eyes being pierced and torn, and thus being blinded - to die a lingering death. The threat of blindness is clear enough to be understood by carnivores that fear running head-on into thorn bushes. Rings of piled thorn branches called bomas are used by African herdsmen today to effectively protect their cattle and camps at night[370].

Cognitively, it is a very short step for foragers seeking meat to go from defending themselves with thorn branches to waving them at carnivores to drive them away from fresh, partially dismembered kills, or to drive herbivore parents away from their weak newborn. As hominins became more proficient wielding thorny branches, the next steps to using sharpened branches as spears in the killing role would also be relatively easy (Figure 148 - right). However, even if hominins equipped with *haak en steek* were able to kill large adult prey such as a zebra or antelope with a wooden lance, surviving fossils suggest that they lacked the sharp and powerful teeth able to tear its leathery skin or the strength to dismember it. On the other hand, broken hammer stones may have sharp enough edges to cut skin and tendons, and scrape flesh off bones. Something that is so simple that an ape with Kanzi's intelligence could figure it out.

Sterelny (2007, 2011, 2012) and Tomasello et al. (2012) present a model based on an initially slight cognitive change from selfishly *social* to *cooperative foraging* that crossed a divide on the fitness landscape that left the selfish panins eating lotus in Eden, but put actively cooperating hominins on a direct pathway to dominate the planetary ecosystem.

Solving these problems requires more knowledge than it seems today's forest apes have the genetic capacity to store and transmit.

For relatively defenseless and slow-moving forest apes to survive and reproduce in rapidly fluctuating savanna environments and make the adaptive transition from herbivory to become mobile apex carnivores they had to manage a wider range of knowledge and new skills. To eat, they would need to know the natural histories of prey species, appropriate hunting techniques and tools for them, how to deter predators, about finding water and preparing other food resources that may be cryptic or seasonal, the locations of scarce or seasonally available resources, and tool-making resources and manufacturing processes. In other words, individuals needed much more knowledge than an individual could hope to acquire through simple trial and error learning. The social environment was critical to the accumulation and sharing of cultural knowledge (Whiten & van Schaik 2007; van Schaik & Burkart 2012).

The evidence suggests that our evolving socio-cultural and cognitive capabilities for managing knowledge crossed the following set of grade-shifting thresholds between our savanna ape ancestry and modern human linguistic capabilities:

- Tacit learning supported by attention directing gestures and vocalizations (Tomasello 2008; Arbib et al. 2008).
- Increasing verbalization of knowledge as vocalization transformed from attention getting and directing, through situational communication, to increasingly abstract knowledge separated temporally and spatially from immediate situational contexts. This eventually culminated in the development of a full linguistic capability described by Tylén et al. (2010) as summarized above. The evolution of the cognitive capacity to make complexly flaked tools such as Acheulean hand-axes may have preceeded and facilitated the emergence of language (Stout et al. 2008; Ambrose 2010).
- What is probably the least understood or appreciated evolutionary grade in this evolution: the development of individual and cultural mnemonic tools for standardizing, indexing preserving, and communicating critical survival knowledge between generations (extending ideas of Ong 1982 and Kelly 2012).
- The development of material technologies for the symbolic capture, storage and transmission of knowledge – i.e., writing, which takes us back to Episode 1 of this book.

- *Cooperative social foraging*

I have already explored the some aspects of the roles of diet and tool-making in creating a selective environment favoring the expansion of neural capacity of carnivorous savanna apes by comparison to largely frugiverous forest apes. Here, I will specifically consider interactions between life-histories of carnivorous savanna apes and their requirements to learn, share and transmitting the quantity and quality of knowledge required to survive and flourish in what Whiten and Erdal (2012) call the "socio-cognitive niche".

Today's forest apes are well adapted to a relatively stable type of habitat that has survived somewhere in Africa for many millions of years. What changed was the extent of that habitat. The demands on apes remaining in forest habitats to cope with the dimunition and loss of important resources of food and shelter from the environment, or to make use of new resources not previously encountered are relatively minor. Although the availability is seasonally variable, food items such as fruit, leaves and nuts are normally stationary and aside from thorns and poisons, they don't actively fight back. The small volumes of insect and vertebrate prey consumed are readily available and normally don't require much skill to capture. Forest apes are also at little risk from predation. Few big cats or other large predators exploit closed forest, and apes can easily avoid them by escaping to or sleeping in trees or climbing higher if threatened. In this environment there is little need to learn about complex technologies or to acquire a large repertoire of natural history knowledge about the world they live in. What culturally transmitted knowledge they need is easily acquired by following mother and seeing what other members of the troop are doing – and even that seems to take years to get right.

Today's forest apes seem to have a real, but limited capacity to transmit knowledge culturally. Basically a young ape will observe its mother and other chimps using stones to crack nuts (Matsuzawa 2011; Whiten et al. 2009; Gergely & Csibra 2006). The child observes that nuts can be cracked with stones and over *years* of trial and error learning (**Error! Reference source ot found.**) it eventually learns how to hold the stone, level the anvil, place the nut, and the correct force with which the nut should be struck with the stone. Anthropologists call this cultural learning "*emulation*". Price et al. (2009) make the interesting observation that individuals who do not learn this behavior by the age of 3-5 years, they never become proficient, but the most complex behaviors, such as using a prop to level the anvil, have only been observed in individuals over 6½. They imply that it is possible that by the time they reach an age when they are physically and cognitively able to carry out these higher level techniques, they are too old to be tolerated by proficient practitioners.

By comparison to forest apes, apes having to establish new ways to survive on the savanna would be under strong selection to increase their cognitive capacities (i.e., intelligence) for observational learning and memory to acquire the substantially larger amount of natural history knowledge they would need to harvest resources and avoid predation. Today, young humans, by accurately copying the skilled practitioner, can learn basic components of the procedure in just a few tries via what the anthropologists call "*imitation*" (Tomasello 2008; Tennie et al. 2009) or "*complex imitation*" (Arbib 2011).

Following van Schaik et al. (2012), a genetically-based platform for the evolution of a material culture of tool use is provided by four criteria possessed by the forest apes:

- extractive foraging requiring detailed manipulation of the environment;
- manual dexterity involving fine motor control and hand-eye coordination for tool making and use (Whiten & van Schaik 2007; van Schaik & Burkart 2012; Jeffares 2010);
- intelligence – e.g., increased brain capacity (Figure 150) to learn through insight and

emulation or imitation to understand and remember tool-making procedures, the types and locations of edible food items, the locations of dispersed resources (e.g., suitable stones for knapping, good campsites, permanent or seasonal water) and dangers (e.g., ambush sites used by big cats), etc.

- and (4) social toleration of the curiosity driven learning activities children.

As will be seen, when some apes crossed a threshold between social foraging to actively cooperative foraging, this may have been the crucial grade shift that opened the gate to hominin dominance of the savanna and then the world.

Some forest apes use their simple tools to add variety to their diets, but could probably survive as species without the tools (there are many ape groups such as bonobos, some chimps, and gorillas that don't normally use tools) and seem to have little incentive to improve them. On the other hand without digging sticks for harvesting roots and tubers, clubs and thorn branches for keeping big carnivores at bay (Figure 147, Figure 148) and bringing down prey, and sharp stone flakes (Figure 5, Figure 130) for quick butchering, apes probably could not survive for long on resources offered by the savanna. However, as demonstrated by the maintenance of various cultural traditions in chimpanzees and orangutans, at least some traditions of making and using the simple types of tools required for survival on the savanna could be culturally transmitted from one generation to the next via tacit learning.

A starting point for the development of carnivory as a crucial part of the hominin diet – at least in seasons where edible plant resources were scarce – would be through scavenging kills made by large predators. Lewis (1997) agrees with Cavallo & Blumenschine (1989) that a comparatively low-risk resource for scavenged meat would be leopard kills cached in trees. According to Cavallo & Blumenschine's own and other published field observations, cached kills are not closely defended and last much longer (sometimes more than a day) than do kills left in the open on the ground (largely consumed within an hour or two by hyenas and lions). Tree caches would represent a resource easily accessed by tree-climbing savanna apes and would also provide good opportunities to learn to use new tools to facilitate butchering. Harvesting such resources would provide an incrementally staged pathway where there would always be selective advantages to be gained from a capacity for tool use and working cooperatively towards a capability to drive large carnivores and other scavangers from kills on the ground while the prey is rapidly and effectively butchered for transport back to a defensible campsite.

The greatest climatic changes in East Africa towards drying and unreliability seem to have taken place 2-3 mya (Potts 2013 - Figure 145), around the time when Oldowan choppers/scrapers appeared in the archaeological record. The appearance of these manufactured tools suggests that the savanna dwelling hominins made a technological and sociocultural grade shift from using broken stones to butcher large carcasses – whether they gained access to these carcasses by scavenging, driving large carnivores away from their kills or via their own hunting successes.

Over the long run, it seems that hominin carnivores wielding Oldowan tools became so successful that they outcompeted what were originally many and diverse species of large carnivores, leading eventually to loss or extinction of many of these species from the East African fauna (Werdelin 2013; Werdelin and Lewis 2013 - Figure 156; see also Haak en steek).

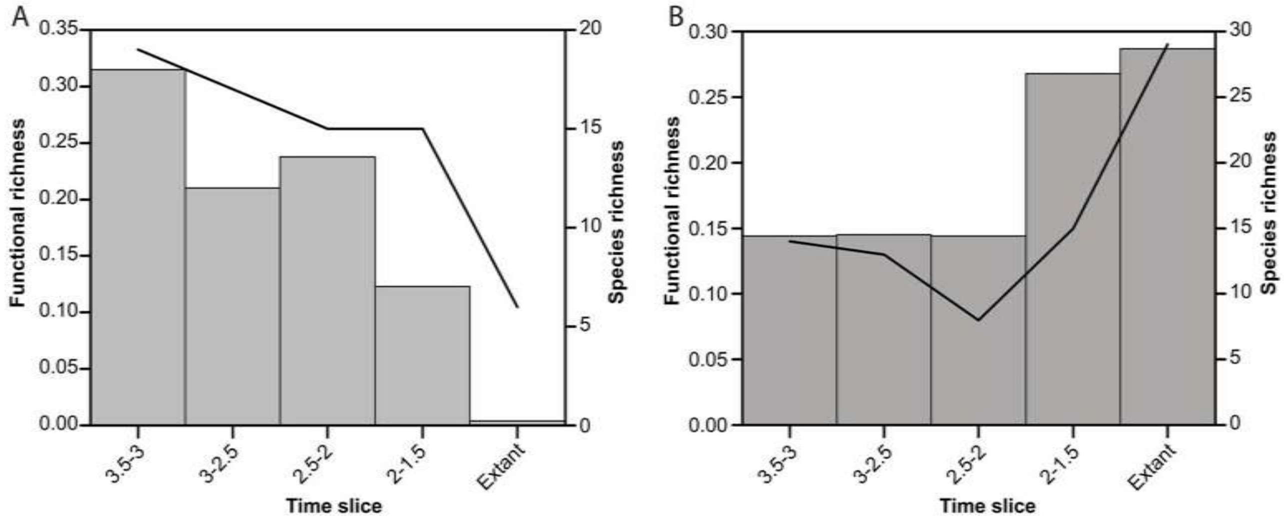


Figure 149. Functional and species richness of carnivores in East Africa through time. A. The richness of large carnivores (> 21.5 kg). B. The richness of small carnivores (<21.5 kg). (Werdelin & Lewis 2013). The bars show the functional richness of the carnivoran fauna against the left hand scale, while the line shows the species richness against the right hand (number of species) scale.

Functional richness and species richness are more or less equivalent measures in the overall diversity of an ecological guild[362] (Mason et al. 2005). What Werdelin & Lewis (2013) infer and Figure 156 shows is that as tool-making hominins in East Africa took up carnivory, the diversity of other large carnivores declines sharply, leaving only a small number of specialized species with the genetic capabilities to exploit a tiny fraction of the initial resource space. If anything, small carnivores, who are unlikely to compete directly with hominins appear to have benefited from the reduced diversity of large carnivores. It seems that the presence of hominin hunters on the savanna made survival impossible for many species of large carnivores (see discussion of strategic power and adaptation in Counter Subject). Whether this was because the Oldowan hominins drove the cats and their ilk away from their kills, whether they attacked and killed the cats directly to eliminate them as dangers and competitors[443], or both is impossible to know – but it is clear that hominins with the cultural knowledge to use tools and hunt cooperatively gained strategic control over the carnivoran landscape.

Surviving as carnivorus apes on the savanna placed the early hominins in an ecological arms-race with the large carnivores, where the hominin's preadaptations to evolve transmit cultural knowledge eventually trumped the genetic adaptive capacities of the large carnivores as genetic selection continued to improve hominin's cognitive capacities for constructing cultural knowledge. It is clear from the paleoarcheological record that the building of cultural knowledge started very slowly, as it took something on the order of a million years for hominins to replace their Oldowan toolkit with the significantly improved Acheulean tools.

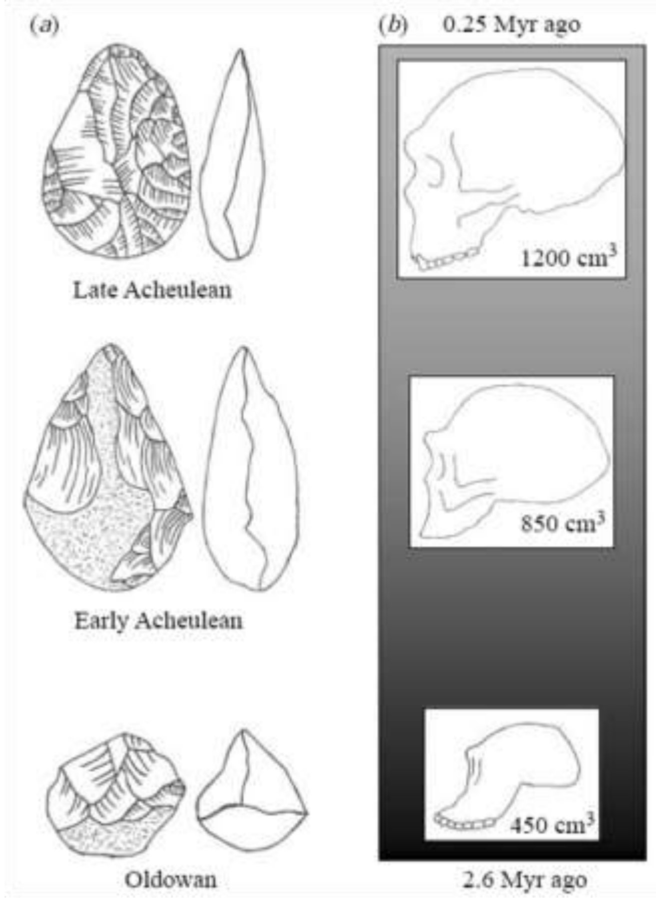


Figure 150. Growth in brain size (assumed to be a proxy for cognitive capacity) associated with the manufacture of increasingly complex tools (Stout et al. 2008).

A framework allowing the cultural transmission of survival knowledge provides a platform selection can work on towards developing increasingly complex and comprehensive bodies of knowledge to secure and expand the niche(s) maintained by savanna apes. Also, over many generations, selection working at the genetic level would favor neurological adaptations increases in mental capacity for individual knowledge building and its cultural transmission together with increased neuromuscular control for making complex tools. As diets improved through the application of more knowledge, more energy could be diverted from the physiological activities of chewing and digestion to growing bigger and more effective brains (Kaplan et al. 2007).

On the whole, the ecology of the savanna would constantly favor anything that increased an ape's capabilities to store and act on culturally transmitted knowledge or that increased the bandwidth for transferring it between individuals and down the generations.

Kaplan et al. note that *chimpanzee foragers subsisting mainly on easily harvested fruits and green plant material don't achieve a caloric break-even in their foraging activities until they are at least 5 years old, and don't begin to produce a surplus before they are around 10 or ll. Similarly, today's human hunter-gatherers on the savanna don't achieve a break-even before they are 20 – with peak productivity being achieved around the age of 45!* It takes that long to become fully skilled. The cooperative nature of early hominin hunting and gathering is indicated by the archeological evidence for the transport of prey, tools, and materials for tool-making over distances up to a kilometer or more to central processing sites (Plummer 2004).

Learning the tasks and actions required for a complex process by imitation without verbal direction is slow and inexact, as learners must work out through trial and error to understand and remember the necessary detailed actions to do the process for themselves (Tomasello et al. 2005; Arbib et al. 2008). If accompanied by a lot of practice and trial and error learning, ape intelligence may suffice to culturally transmit enough knowledge to make and use an Oldowan-level tool (Arbib 2011), to understand that by breaking a hard stone in just the right way, a sharp enough edge may be created that can be used to skin and butcher a large prey animal. But with this level of cognition, may still be impossible to learn complex, multi-step processes requiring a specific sequence of actions, where each action has to be performed successfully to reach the ultimate goal such as is required for making an Acheulean tool (Arbib 2011; Goren-Inbar 2011).

By contrast, where sufficient cognitive capacity exists to emulate or copy a sequence of actions reasonably exactly, it is much more likely that the goal of the sequence of processes will be reached. Clearly, this is a transition that can be made incrementally by natural selection, with the result that the increasingly fine details of more complex tasks can be learned by demonstration, observation, trial and improvement. Oldowan tools were made by hominins from ~2.6-1.4 mya, being replaced by Acheulean tools from ~1.6-0.25 mya. The very long time (a million years or more!) to make seemingly minor improvements seemingly required significant genetic change to increase brain capacity can be inferred from Figure 150 and Figure 155.

- *Managing and transmitting knowledge without speech*

Even with brain enlargement and the development of a theory of mind, it is extremely difficult to impart build and transmit technical knowledge without words and a language to understand and describe why/how a particular sequence of actions produces the desired results. Stout (2011) considers what a would-be stone knapper has to learn in order to make effective tools. I will review this here in some detail to demonstrate the formidable difficulties hominins faced in communicating technical knowedge without words and speech. These difficulties can be inferred from the geologically slow progression of technological improvement that took hominins 2-3 million years to progress from our last common ancestors with the forest apes using hammers and anvils to the Oldowan cutter by around 2.6 mya, and another million years or so to the slightly more sophisticated Early Acheulean handaxe that began to appear around 1.6 mya – and something like another one and a half million years for the Late Acheulean tools to be superseded by genuinely complex technologies.

What needs to be learned for making a useful tool is a precise sequence of operations (called a chaîne opératoire by anthropologists) where each step in the sequence has to be completed successfully to achieve the desired end result.

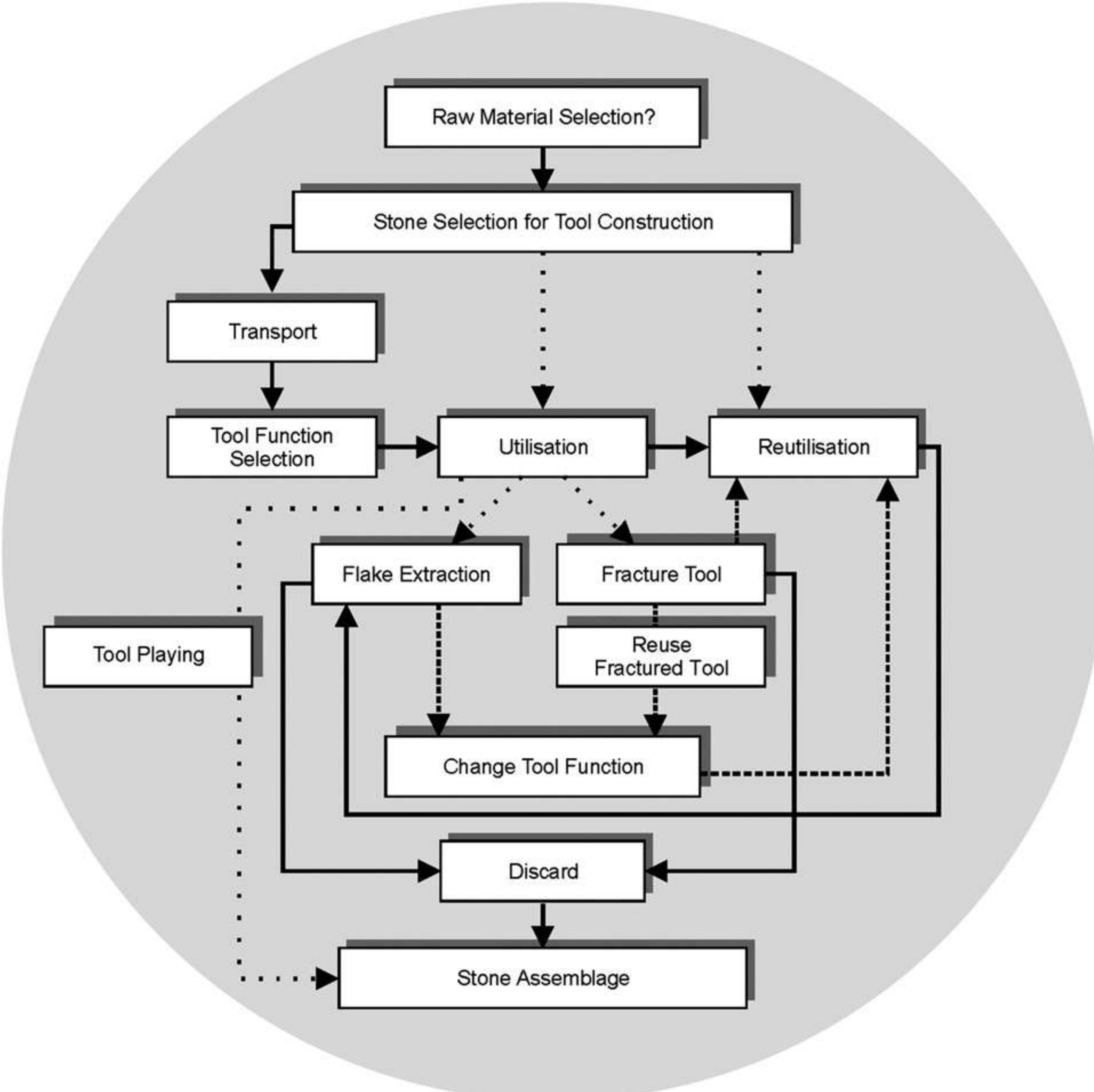


Figure 151. Operational sequence for using a hammer and anvil for cracking a nut (Carvalho et al. 2008)..

Sucessful stone knapping involves a combination of mental decisions and neuromuscularly effected actions. Making an Oldowan grade cutter is comparatively simple (but is a lot more complex than placing a nut or stone on an anvil and banging it with another rock - Figure 152).

To make a cutter/chopper one begins with an immediate or anticipated requirement, to cut skin, tendons, and joints in order to harvest flesh from a carcass so it can be taken to a place of relative safety for consumption. Once the requirement make the tool is established, the following steps are required:

1. *Find an appropriate core.* Most stones are inappropriate for knapping.
    1.1. *Select a likely candidate.* The process begins with background knowledge of where suitable core and hammer stones might be found, going there, and visually selecting a possible candidates.
    1.2. *Examine the selected stone to see/feel if it has the right properties*. Factors that affect knappability include density, grain size, orientation, existing cracks & flaws, etc. These must be known in advance and sensorally examined for acceptance/rejection of the stone.
        1.2.1. *Pick up the selected stone*.
        1.2.2. *Rotate the stone for close examination.*
        1.2.3. *Based on examination decide whether the stone is suitable for knapping.*
        1.2.4. *Discard unsuitable stones*
2. *Select an appropriate hammer stone.*
3. *Detach a handy sized sharp flake*. The knapper must have a reasonable knowledge of what end properties a flake must have to be suitable for the task.
    3.1. *Detach a flake from the core*. Based on the properties of the core, the knapper must decide where, how hard, and with what kind of a hammer stone to hit the core to break off a suitable flake.
        3.1.1. *Pick up a suitable core*
        3.1.2.. *Examine the core to decide where it should be struck to detach a suitable flake.*
            3.1.2.1. *Grasp.*
            3.1.2.2. *Rotate*
        3.1.3. *Detach a flake*
            3.1.3.1. *Position core to be struck*
                3.1.3.1.1. *Grasp*
                3.1.3.1.2. *Rotate*
            3.1.3.2. *Grip and orient hammer stone*
                3.1.3.2.1. *Grasp*
                3.1.3.2.2. *Rotate*
            3.1.3.3. *Strike*

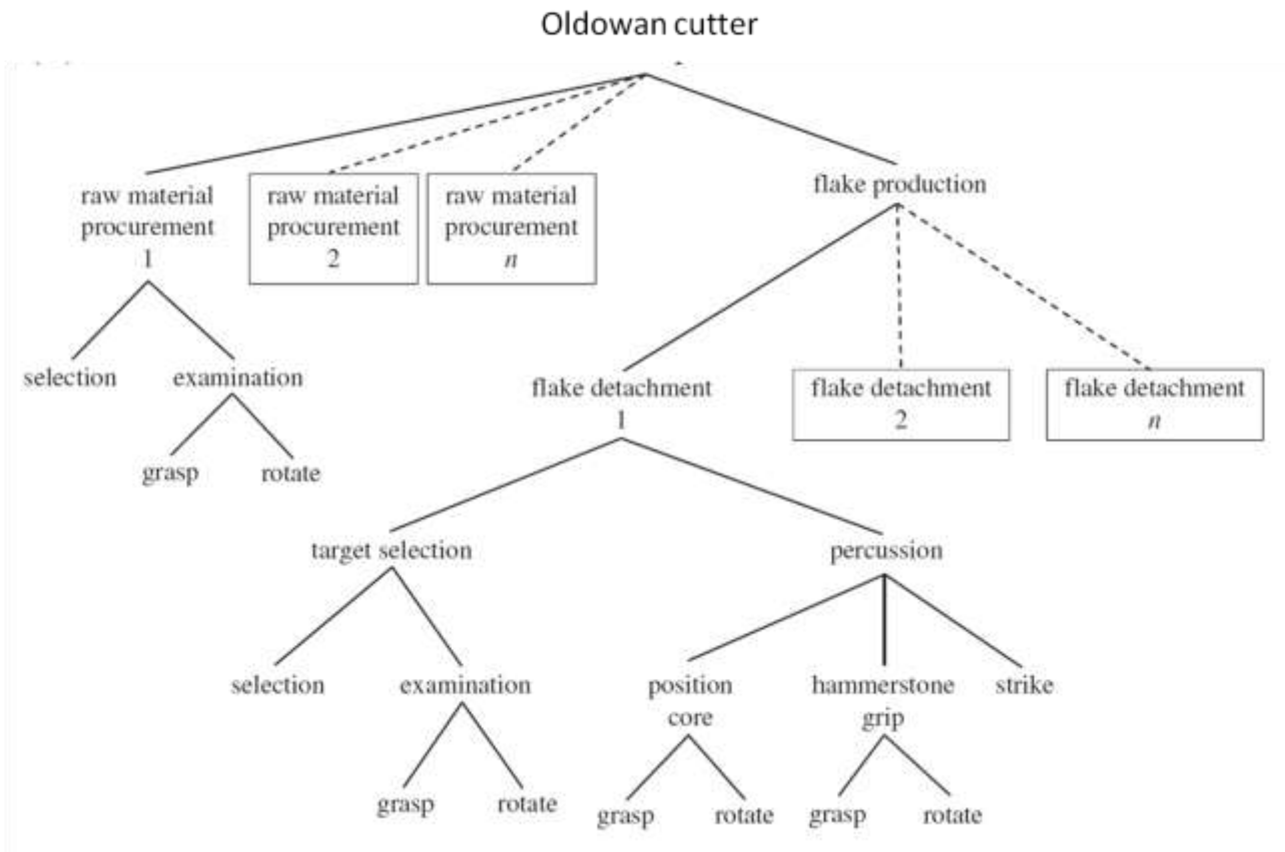


Figure 152. Hierarchical analysis of the sequence of actions required to produce an Oldowan grade cutter or chopper. Sequential steps are show horizontally. Steps (that may be iterated) on the first line can be decomposed into sub steps on the second line, which in turn may be decomposed into still smaller steps. Solid lines connect tasks with their required subordinate elements. Dotted lines connect optional subordinate elements. Boxes enclose tasks where their subordinate elements have been collapsed.

Kanzi the bonobo demonstrated that he has the mental and physical capacity to learn by watching and to work out how to knap effective cutters (Toth & Schick 2009 – and see other references in this work). The earlier Acheulean cutting tools represented a significant improvement on oldown choppers as they were more precisely shaped for sharpness, but required the cognitive capacity to build and transmit a much more detailed understanding of the shape and function of end product and of the purpose and sequence of movements required to achieve that end (Figure 154). <<<

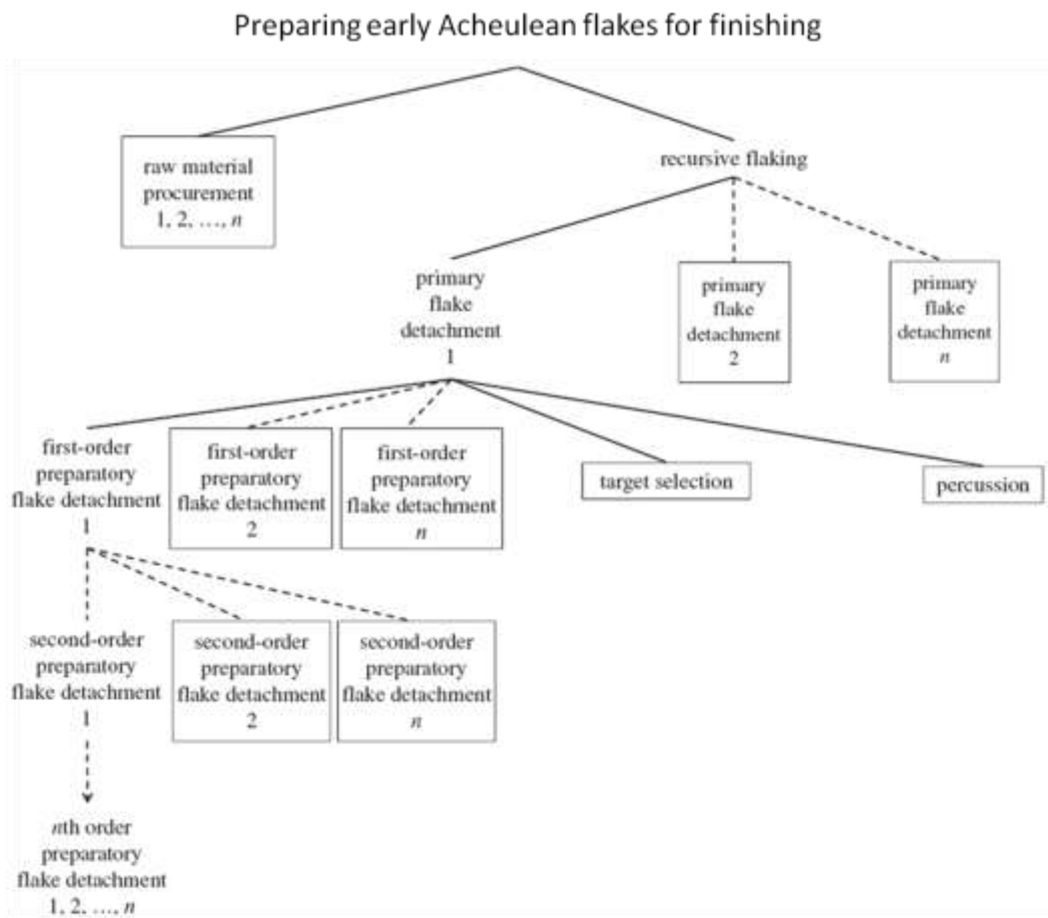


Figure 153. Early Acheulean preparation of "blank" flakes for further processing to produce the finished toos (Stout 2011). See Figure 152 for line definitions.

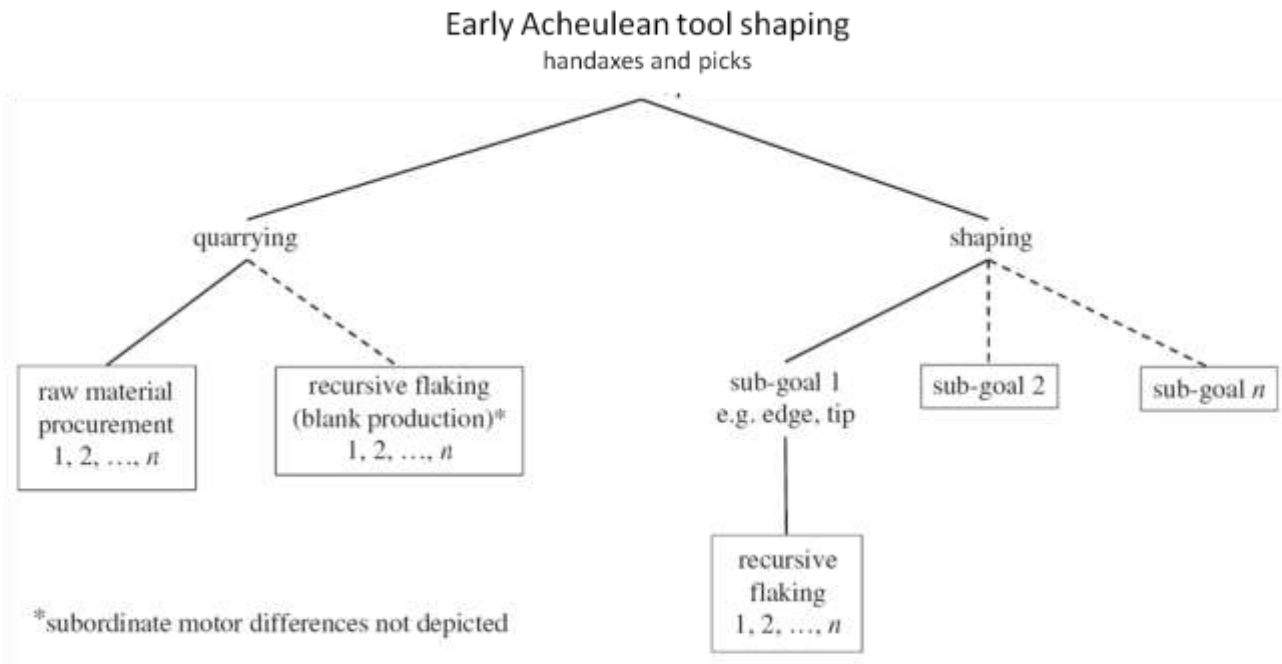


Figure 154. Sequence of actions required to produce an early Echeulean pick from prepared flakes.

Stout, D. 2010. The evolution of cognitive control. Topics in Cognitive Science 2, 614-630 - http://tinyurl.com/m8w37wc

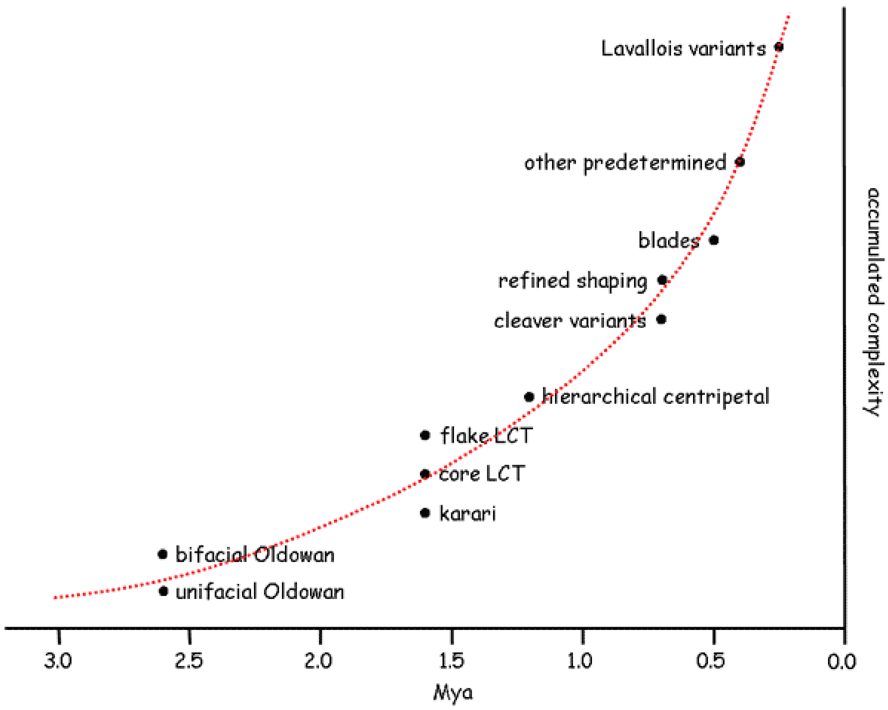


Figure 155. Development of increasingly complex stone tools (after Stout 2011). LTC's are early Acheulean large cutting tools. The curve is fitted by eye.

Vaesen (2012 – paraphrased here) considers the cognitive abilities that would be required to make tools of an Acheulean level of complexity and compares them with what is required for the kinds of tools made by chimpanzees (including bonobos), and lists ten, the last four of which are cognitive functions enabling evolution on the socio-cultural level of organization:

- *Hand-eye coordination*: Of several components, fine motor control is probably the most important. In the smaller chimpanzee brain, single nerve cells control many muscle fibers that must therefore contract in concert. In humans more cells control the same number of muscle fibers, such that more precisely graded muscle responses are possible. Throwing accuracy depends substantially on fine motor control.
- *Body schema plasticity*: This refers to the ability to sense and control the tool as an extension of the living body. In this area humans and chimpanzees are probably equivalent.
- *Causal reasoning*: The ability to learn cause and effect relationships by inference, analogy, and through recognizing anomalous events and learning from them by test and trial (e.g., observing and correcting for the fracture properties of a particular stone). Humans do this much better than chimpanzees.
- *Function representation*: The development of a long-term understanding that particular tool shapes/types fit them to particular functions. Humans see a hammer and ascribe the function of hammering to it. Chimpanzees, given their quadrupedalism and generally arboreal life, do not make tools for multiple use (excepting hammerstones and anvils left at nutcracking sites). Rather they modify what is at hand for the purpose in front of them.
- *Executive control*: According to Vaesen this involves four components (1) inhibition; (2) autocuing – i.e., the initiating a learned sequence without an immediate stimulus; (3) foresight and (4) monitoring hierarchically structured action. Chimps haven't been studied for autocuing and perform well on hierarchically structured action, but exhibit limited capabilities for inhibition and foresight.

- *Social learning* (including imitation, emulation, and establishing social goals): Human social learning in these areas is advanced. By default humans are precise imitators becoming more selective over the years as to who they copy. Humans develop a wide variety of goals via social learning, and are also good emulators.
- *Teaching*: Here, humans actively work to help learners develop skills/knowledge via direct guidance. Language is helpful, but much guidance can be provided nonverbally.
- *Social intelligence*: Vaesen lists four areas he considers to be important in the environment for learning to make and use tools: (1) heuristics for selecting models for social learning; (2) theory of mind abilities; (3) contingent reciprocity; and (4) goal sharing. To learn from the most skilled, the learner needs to have some heuristic for deciding whom it is best to learn from. Theory of mind is important, (a) it helps the learner to understand the teacher's intentions, i.e., why some possible actions are executed and other omitted; and (b), to separate making the tool from a later need to make use of such a tool. Contingent reciprocity supports the division of labor, where one proficient tool maker may provide tools for several hunters. Goal sharing helps distribute the costs of making complex tools among the group as a whole. Chimps show some tendencies in these areas but don't score well by comparison to humans.
- *Language*: It is obvious that language facilitates the making and use of complex tools, but it is likely that language is the result of the evolution of complex tool-making facilities than the other way around. As will be discussed below, it is likely that the facility for language evolved in concert with tool use, as selection pressures favoring advancements in both areas led to larger brains with increasing cognitive capacity.

Improved individual survival enabled by effective tool use would favor the action of natural selection on the genetic basis for cognitive capabilities as enabled in/reflected by increasing brain capacity. Our living hominid relatives already use simple tools suitable in their comparatively unchanging ecological niches. By using more complex and sophisticated tools to improve nutrition, reproduction and survival, our direct hominin ancestors could expand their ranges into savannah habitats. Natural selection in the new and more demanding environment would favor changes in the machinery of cognition that would support such tool making and use. In the early Paleolithic (Babbitt et al. 2011), brain capacity tripled along with the evolutionary development of tools (Figure 133). Stout (2011) suggests that the slowly accelerating increase in the complexity of the hominin toolkits (Figure 155) is a consequence of the accumulation of culturally transmitted knowledge (enabled by increasing brain capacity to support cultural transmission).

This initially slow acceleration over a million years may be continuous with the still increasing acceleration rate of technological change we face today. In other words, *the continuing acceleration of technological change we see today in Moore's Law may have its origin in the Early Paleolithic*. This accelerating technological change shows in the development of ever more complex hunting tools following the period of Acheulean tool production, e.g., the discovery of 400 kya old wooden throwing spears at Schöningen (Thieme 1997) associated with *Homo erectus*, and projectile weapons (spear throwers, bows & arrows) associated with *Homo sapiens* (Churchill & Rhodes 2009; Lombard & Haidle 2012).

- *Emergence of speech*

Arbib 2011
Ambrose 2010

Uomini, N.T., Meyer, G.F. 2013. Shared brain lateralization patterns in language and Acheulean stone tool production: a functional transcranial Doppler ultrasound study. PLoS ONE 8(8): e72693. doi:10.1371/journal.pone.0072693 - http://tinyurl.com/n73pxvr

- *Limitations of living memory*

Walter Ong explores this in his 1982 book, "Orality and Literacy – The Technologizing of the Word". Before the invention of technologies for counting and writing, human knowledge existed only in living memories and material technologies[380], and could only be shared by speech and apprenticeship. Speech is ephemeral, consisting of sound waves in the air that dissipate instantly as it is uttered. The technologies do not explain themselves. The only effect of speech on the world is in the altered mental states of those hearing it – and only to the extent that it is heard and registered and understood in the minds of the listeners. Speech can be used to coordinate immediate social responses of those within earshot or to communicate knowledge of processes, situations and cultural norms. However, without a hearer, speech is meaningless.

What is language?

The faculty of language may have evolved from something like the gestures, simple shrieks and hoots of our ape relatives. Observations suggest that apes can modulate their comparatively stereotyped calls and/or gestures to convey significant context dependent information about food resources and threats from different kinds of predators (Pollick & de Waal 2007; Arbib et al. 2008). Zuberbühler et al. (2009) describe experiments (such as playing recorded calls in different contexts) and comparative observations of different species of monkeys and anthropoid apes that demonstrate that different calls and different sequences of calls repeatably convey specific information that is meaningful to those in particular contexts who hear them.

Even these rudimentary abilities to communicate can help groups to survive in an otherwise hostile world. Our close relatives, the great apes, give us some indications of what capabilities the early hominids may have started with towards the development of a faculty of language. In the wild, chimpanzees and bonobos have very limited vocal repertoires, where vocalizations appear to be instinctive and tied to particular emotional states. However, in laboratory and joint cultural environments (e.g., human-bonobo-chimpanzee), chimpanzees and bonobos show a real but limited capacity to learn and meaningfully use a variety of arbitrary lexigrams (Rumbaugh 1977; Savage-Rumbaugh et al. 1986; Greenfield et al. 2008). By comparison, modern humans have used their fully developed faculty of language to scientifically understand the universe and maintain strategic power over the entire planet, such that every other species on it survives only because we have not exterminated them directly or destroyed their critical resources.

Genetically, physiologically, and anatomically, except for its enlarged brain, adaptations for an efficient bipedal gait and a diet of cooked food, *Homo sapiens* is a tool-using anthropoid ape. As we will see, a fully developed faculty of language and the associated social coordination and cultural inheritance probably enabled the exponential proliferation of increasingly complex tools that accounts for *Homo sapiens*' overwhelming dominance of the Earth's ecosphere. Because language is so fundamental to what we are, it is difficult to define. A good place to start is with Wikipedia's definition of language (see also Philosophy of Language), and explore how we can reach this definition from what we know about an ape's linguistic capabilities.

To start with, as Ong (1982) observes, today we can hardly conceive what language was to pre-literate humans, who had no concept of formal grammars or written words as discrete objects of thought or discussion. Such pre-literate languages are not what we speak today, nor is it likely that we process what we hear in the same ways our pre-literate ancestors did. Standard English has a recorded vocabulary of at least 1.5 million words. A purely oral dialect will commonly have only a few thousand words, and its speakers will have no understanding of their semantic histories. Written languages are very different tools from purely oral dialects (as will be considered when I return again to writing as a cognitive tool).

> All thought, including that in primary oral cultures, is to some degree analytic: it breaks its materials into various components. But abstractly sequential, classificatory, explanatory examination of phenomena or of stated truths is impossible without writing and reading. Human beings in primary oral cultures, those untouched by writing in any form, learn a great deal and possess and practice great wisdom, but they do not 'study'.
>
> They learn by apprenticeship—hunting with experienced hunters, for example—by discipleship, which is a kind of apprenticeship, by listening, by repeating what they hear, by mastering proverbs and ways of combining and recombining them, by assimilating other formulary materials, by participation in a kind of corporate retrospection—not by study in the strict sense. (Ong 1982, p. 8)

In addition to enhancing our natural potentials to act on the material world, some tools allow us to act on the material world in entirely new ways (i.e., to construct new niches – Stotz 2010 – enabling a revolutionary grade shift). In a similar way, verbal language is a tool for solving particular kinds of cognitive problems such as mediating *between* minds to facilitate human interaction. According to Tylén et al. (2010: pp. 4-5) language does this in four interrelated ways:

1. Language extends the 'interaction space' in space and time: While non-linguistic, social interaction between individuals is bound to the here-and-now of multisensory coordination, language (especially when written) liberates social interaction from these immediate contexts.
2. Language provides a way to precisely structure, profile and navigate joint attentional spaces and scenes (present, past, or fictional).
3. Language allows people to create, align and share higher-order situation models and action plans to predict what they and others are going to do to facilitate engagement in joint activities and actions.
4. Language guides our cultural attunement to norms of visual, auditory and spatial perception to influence and shape non-linguistic cognition in our cultural space.

A shared common language provides its users with a multidimensional conceptual space for coordinating social interactions and exchanging of ideas and information about aspects of the world that are out of sight or hearing, in the past, or about future possibilities that do not even exist in the present. This capacity does not exist for any other organism we know of.

How did language and speech emerge?

Caveat: In the following discussions, recall that I am writing as an evolutionary biologist and knowledge management systems analyst with some pretensions in epistemology, not as a cognitive scientist, cultural anthropologist or linguist. The apparently relevant literature is growing exponentially and I have virtually[381] no personal contact with the disciplines. However, to understand the emergence of modern cognitive tools – language being the foremost of these tools – I think it is important to try to bridge the gap between the physical evidence (genomics, fossils, paleoarchaeology, and comparative biology of extant primates) and the threads of modern human history gleaned from archaeology and history. Assuming that I have not biased my conclusions by seeing what I want to see, I think there is now enough readily accessible literature to understand how natural selection working on heritable aspects of the genetics and cultures of forest apes stranded led inevitably to today's hyperexponentially growing cognitive technologies. The emergence of language was the most important of the early technological revolutions as it provided the bandwidth and storage capacity to share and build on all of the other technologies.

Ape vocalizations are genetically determined and stereotypical, thus not flexibly related to anything but the basic stimulus situations that trigger them (Tomasello (1999, 2008). In apes, gestures are more pliable, and offer an initial plasticity that can be operated on by natural selection. At least where chimpanzees are concerned, gestures are developed ontogenetically and subject to cultural modification. Although apes are moderately social, they are not cooperative and most utterances are self-directed imperatives. An ape apparently cannot conceive that another ape would actually want to help. Human language, on the other hand is based around cooperative endeavour within shared attention spaces.

- *Thinking about making tools drives brain evolution*

Directing attention to boost the transmission of survival knowledge

There is a plausible incremental pathway towards the next major steps in increasing capacity for the socio-cultural transmission of knowledge. This begins with an existing capacity for directing and sharing attention as demonstrated in our closest relatives – the forest apes, and is accompanied or closely followed by the development of a capacity to imagine, plan and order a sequence of tasks that might be required for the successful completion of a complex process. Cooperative scavenging/hunting and toolmaking provide the selective framework for building cognitive capacities to do these things well.

- *Focusing on the selective environment*

Savanna apes had two requirements they would have to have to meet for long-term survival on the savanna in direct competition with large carnivores for protein resources and to avoid being prey themselves – an ability to work in groups for offense and defense, and the ability to make and use simple tools such as Oldovan scrapers for butchering, hammers and anvils for breaking bones, and clubs or thorn branches for keeping large carnivores at bay.

Chimpanzees and bonobos exhihbit abilities to be expected in our last common ancestor with them (Begun 2010; Stanford 2012). I have shown that it is demonstrably within the capacity of these forest apes to use intact stones as hammers and anvils (**Error! Reference source not ound.**) and broken ones for cutting (Figure 5), and to gang together to deter leopards (Figure 147) or to hunt monkeys (YouTube). It is reasonable to assume that apes forced onto the savanna would also have had these rudimentary capabilities to jump start their adaptations as social foragers to a more complex, variable and risky environment where groups would have benefited from an increased cognitive capacity for the socio-cultural construction and sharing of knowledge (Laland and O'Brien 2012). According to Sterelny (2012: p. 2142), these social foragers

> …increasingly combined a reliance on extractive foraging (targeting very valuable but heavily defended resources) with the capacity to cooperate and coordinate… This cooperation included informational cooperation across generations. *Ecological expertise of the kind needed to kill dangerous game with short-range weapons, or to find and detoxify tubers, is not acquired from scratch each generation*. But informational cooperation was also needed for coordination, and eventually for planning. So selection for cooperation included selection for enhanced communication. [my emphasis]

- Haak en steek – *the grade shifting tool that opened the savanna to ape men*

<<<A starting point for the development of carnivory as a crucial part of the hominin diet – at least in seasons where edible plant resources were scarce – would be through scavenging kills made by large predators. Lewis (1997) agrees with Cavallo & Blumenschine (1989) that a comparatively low-risk resource for scavenged meat would be leopard kills cached in trees. According to Cavallo & Blumenschine's own and other published field observations, cached kills are not closely defended and last much longer (sometimes more than a day) than do kills left in the open on the ground that are largely consumed within an hour or two by hyenas and lions. Tree caches would represent a resource easily accessed by tree-climbing savanna apes and would also provide good opportunities to learn to use new tools to facilitate butchering. Harvesting such resources would provide an incrementally staged pathway where there would always be selective advantages to be gained from a capacity for tool use and working cooperatively towards a capability to drive large carnivores and other scavangers from kills on the ground while the prey is rapidly and effectively butchered for transport back to a defensible campsite.

The greatest climatic changes in East Africa towards drying and unreliability seem to have taken place 2-3 mya (Potts 2013 - **Error! Reference source not found.**), around the time when ldowan choppers/scrapers appeared in the archaeological record. The appearance of these manufactured tools suggests that the savanna dwelling hominins made a technological and sociocultural grade shift from using stones as hammers and anvils to crack the odd marrow-bones scavenged from primary carnivores, to achieve a capability to butcher large carcasses – whether they gained access to these carcasses by scavenging, driving large carnivores away from their kills or via their own hunting successes. It seems that hominin carnivores wielding Oldowan tools became so successful that they outcompeted what were originally many and diverse species of large carnivores, leading to loss or extinction of many of these species from the East African fauna (Werdelin 2013; Werdelin and Lewis 2013 - Figure 156; see also Haak en steek).

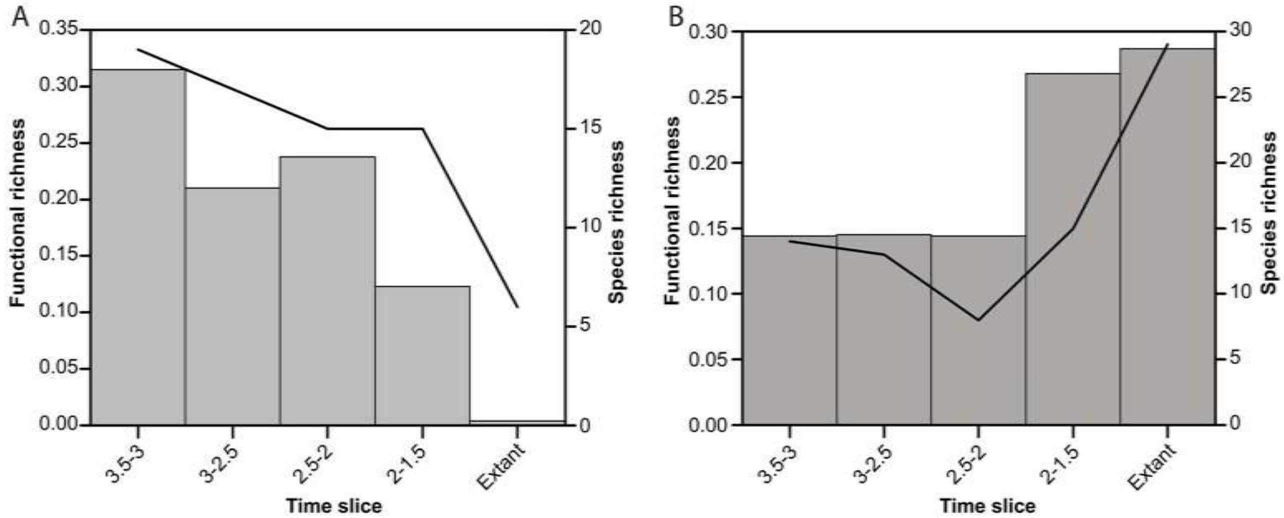


Figure 156. Functional and species richness of carnivores in East Africa through time. A. The richness of large carnivores (> 21.5 kg). B. The richness of small carnivores (<21.5 kg). (Werdelin & Lewis 2013). The bars show the functional richness of the carnivoran fauna against the left hand scale, while the line shows the species richness against the right hand (number of species) scale.

Functional richness and species richness are more or less equivalent measures in the overall diversity of an ecological guild[362] (Mason et al. 2005). What Werdelin & Lewis (2013) and Figure 156 show is that as tool-making hominins in East Africa take up carnivory, that the diversity of other large carnivores declines sharply, leaving only a small number of species with the genetic capabilities to exploit a tiny fraction of the initial resource space. If anything, small carnivores, who are unlikely to compete directly with hominins appear to have benefited from the reduced diversity of large carnivores. The bottom line is that the presence of hominin hunters on the savanna made survival impossible for many species of large carnivores (see discussion of strategic power and adaptation in Counter Subject). Whether this was because the Oldowan hominins drove the cats and their ilk away from their kills, or whether they attacked the cats directly to eliminate them as dangers and competitors is impossible to know – but it is clear that hominins gained strategic control over the carnivoran landscape.

Surviving on the savanna placed the early hominins in an ecological arms-race with the large carnivores, where the hominin's preadaptations to transmit cultural knowledge eventually trumped the genetic adaptive capacities of the large carnivores as genetic selection continued to improve hominid's cognitive capacities for constructing cultural knowledge. It is clear that the building of cultural knowledge started very slowly, as it took something on the order of a million years for hominins to replace their Oldowan toolkit with the significantly improved Acheulean tools. We will now focus on the specific features of this scenario that can account for the emergence of linguistic abilities.

- *Directing attention with voice and gesture*<<<

Mirror neurons, theory of mind, sequencing actions Joint attention – Tomasello et al 2005; Tomasello 2008; Sherwood et al. 2008

Stout 2011

Non-verbal mind reading – Whiten, A. 1999. The evolution of deep social mind in humans. (in) Corballis, M.C., Lea, S.E.G.

* Pradhan, G.R., Tennie, C., van Schaik, C.P. 2012. Social organization and the evolution of cumulative technology in apes and hominins. Journal of Human Evolution 63, 180-190 - http://tinyurl.com/8afh4js

- *Planning the hunt with voice, gesture and mime*

Sterelny, K. 2012. Language, gesture, skill: the co-evolutionary foundations of language. Philosophical Transactions of the Royal Society B 367, 2141–2151 - http://tinyurl.com/95w4mmr

(1) the gestural and vocal capacity to direct attention to critical aspects of a process needed to be performed successfully for the successful completion of that process, e.g., to make a compound tool, and (2) the capacity to plan and order a sequence of tasks, e.g., as in the group planning of a hunt (Abib et al. 2008; Számadó 2010).

Számadó, S., Szathmáry, E. 2006. Selective scenarios for the emergence of natural language. Trends in Ecology and Evolution 21(10), 555-561

(eds), The Descent of Mind: Psychological Perspectives on Hominid Evolution. Oxford University Press, Oxford, pp. 173-193

- *Speech, teaching and the transmission of complex projectile technologies*

> If language (or protolanguage) evolved as a system of gesture, the evolution of elaborated manual skill and the evolution of gestural communication would support one another. They would depend on the same fundamental cognitive, perceptual and motor capacities…. Both select for the capacity to learn, memorize and fluently execute increasingly complex sequences. In both cases, we would expect selection for some capacity to represent one's own capacities. For as gesture and skill both elaborated, both involve sequences with structure, and with elements reusable in other contexts. This is an evolutionary two-for-one deal. The costs of the evolutionary innovation are supported by two benefits: the evolution of the capacity to represent and use behavioural programmes upgrades both skill and gestural communication. Gestures are .sometimes described as social tools. (Sterelny 2012: p. 2144)

Krause, J., Lalueza-Fox, C., Orlando, L., Enard, W., Green, R.E., Burbano, H.A., Hublin, J.-J., Hänni, C., Fortea, J., de la Rasilla, M., Bertanpetit, J., Rosas, A., Pääbo, S. 2007. The derived FOXP2 variant of modern humans was shared with Neandertals. Current Biology 17, 1-5 - http://tinyurl.com/kymv7tm.

Coop, G., Bullaughey, K., Luca, F. Przeworski, M. 2008. The timing of selection at the human FOXP2 gene. Molecular Biology and Evolution 25(7), 1257-1259 - http://tinyurl.com/lbfkxhg.

Fisher, S.E., Scharff, C. 2009. FOXP2 as a molecular window into speech and language. Trends in Genetics 25(4), 166-177 - http://tinyurl.com/n67lwqh

Pinel, P., Fauchereau, F., Moreno, A., Barbot, A., Lathrop, M., Zelenika, D., Le Behan, D., Poline, J.-B., Bourgeron, T., Dehaene, S. 2012. Genetic variants of FOXP2 and IAA0319/TTRAP/THEM2 locus are associated with altered brain activation in distinct

language-related regions. Journal of Neuroscience 32(3), 817– 825 - http://tinyurl.com/lofzwly
Knopka, G., Bomar, J.M., Winden, K., Coppola, G., Jonsson, Z.O., Gao, F., Peng, S., Preuss, T.M., Wohlschlegel, J.A., Geschwind, D.H. 2009 Human-specific transcriptional regulation of CNS development genes by FOXP2. Nature 462(12), 213-218 - http://Human-specific transcriptional regulation of CNS development genes by FOXP2

- *Song and ritual dancing for the social transmission of culture*

may have been

Riel-Salvatore, J. 2010. A niche construction perspective on the Middle-Upper Paleolithic Transition in Italy. Journal of Archaeological Method and Theory 17, 323-355.

Burkart et al (2009) cooperative breeding

Grueter et al. (2012) multilevel social systems

Castro et al. (2010) approval and disapproval;

Whiten (2011) - culture is broken down into three major aspects: the large scale, population-level patterning of traditions; social learning mechanisms; and the behavioural and cognitive contents of culture.

Durand (2010), Gintis (2012),

van Schaik, C. P., Preuschoft, S., & Watts, D. P. (2004). Great ape social systems. In A. E. Russon & D. R. Begun (Eds.), The evolution of thought: Evolutionary origins of great ape intelligence (pp. 335–345). Cambridge: Cambridge University Press, pp. 190-209 (requested ILS)

Stiner, M.C., Kuhn, S.L. 2009. Paleolithic diet and division of labor in Mediterranean Eurasia. (in) Hublin, J.J., Richards, M.P. (eds), The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence. Springer Science + Business Media B.V., pp. 157-169

Stotz, K. 2010. Human nature and cognitive-developmental niche construction. Phenomenological and the Cognitive Sciences 9: 483-501.

Jeffares, B. 2010. The co-evolution of tools and minds: cognition and material culture in the hominin lineage. Phenomenology and the Cognitive Sciences 9, 503-520 - http://tinyurl.com/9ghajx6

Shea, J.J. 2009. The impact of projectile weaponry on Late Pleistocene hominin evolution. (in) Hublin, J.J., Richards, M.P. (eds), The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence. Springer Science + Business Media B.V., pp. 189-199.

Sisk, M.L., Shea, J.J. 2011. The African origin of complex projectile technology: an analysis using tip cross-sectional area and perimeter. International Journal of Evolutionary Biology 2011, ID 968012, 8 pp. - http://tinyurl.com/9su8n8b

Villa, P., Lenoir, M. 2009. Hunting and hunting weapons of the Lower and Middle Paleolithic of Europe. (in) Hublin, J.J., Richards, M.P. (eds), The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence. Springer Science + Business Media B.V., pp. 59-85.

Wadley, L. 2010. Compound-adhesive manufacture as a behavioral proxy for complex cognition in the Middle Stone Age. Current Anthropology 51, Suppl. 1, S111-S119.

Ambrose, S.H. 2010. Coevolution of composite-tool technology, constructive memory, and language: implications for the evolution of modern human behavior. Current Anthropology 51(Suppl 1), S135-S147.

Churchill, S.E., Rhodes, J.A. 2009. The evolution of the human capacity for "killing at a distance": the human fossil evidence for the evolution of projectile weaponry. (in) J.-J. Hublin and M.P. Richards (eds.), The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence, 201–210. © Springer Science + Business Media B.V. 2009

Lazuén, T. 2012. European Neanderthal stone hunting weapons reveal complex behaviour long before the appearance of modern humans. Journal of Archaeological Science 39(7), 2304-2311.

Straus, L.G. 2012. The emergence of modern-like forager capacities & behaviors in Africa and Europe: abrupt or gradual, biological or demographic. Quaternary International 247, 350-357.

Carbonell, E., Ramos, R.S., Rodriguez, X.P. Mosquera, M., Olle, A., Verges, J.M. Martinez-Navarro, B., de Castro, J.M.B. 2010. Early hominid dispersals: a technological hypothesis for "out of Africa". Quaternary International 36-44.

Steele, T.E., Klein, R.G. 2009 Late Pleistocene subsistence strategies and resource intensification in Africa. (in) Hublin, J.J., Richards, M.P. (eds), The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence. Springer Science + Business Media B.V., pp. 113-126.

Tattersall, I., Schwartz, J.H. 2009. Evolution of the genus Homo. Annual Reviews of Earth and Planetary Science 37, 67-92.<<<

Language doesn't fossilize until it is written
Paleoarcheological proxies for symbolic behavior
"masterpieces" (specially worked complex tools)
body and artifact painting (ochres & other pigments)
shell beads jewelry
ritual burials and "grave goods"
representational painting
musical instruments (i.e., bone flutes)
Emergence of dateable genetic & fossilizable morphological/neurological prerequisites
FOXP2 etc (common to H. sapiens & neanderthalensis)

Mnemonic Technologies

Couch 1989; Ong 1982, Kelly 2012

Recent (3 years) integration of genomics & fossil record

African genesis – a competitive pressure cooker

Ape cultures making and using tools

Homo, the carnivorous savannah ape was a collaborative big game hunter

Success limited by brain capacity for complex thinking/expression/action

Several Pleistocene colonizations of Eurasia

Primitive H. erectus entered Eurasia (Dmanisi) 1.8 mya or earlier & spread to Flores Island, Indonesia, survived in E. Asia/Indonesia until ~30 kya

Acheulean toolkit (simple flaked stones, probably included wooden spears & clubs)

H. heidelbergensis (Denisovan ancestor?)/neanderthalensis entered Eurasia ~400 kya, replacing H. erectus in Europe & western Asia, Neanderthals survived until ~14 kya

Complex tools (multistep fabrication), symbolic language ~200-100 kya?

H. sapiens entered Levant where they met & ~60 kya hybridized with Neanderthals (all non-African H. sapiens populations carry ~3% Neanderthal genes) first wave of migrants to east meet & hybridize with Denisovans in central Asia (Australian & New Guinea natives carry ~ 6% Denisovan genes)

Mechanically projected weapons, i.e., bows & arrows (Churchill & Rhodes 2009; Lombard & Haidle 2012)

When did hominins learn to speak?

~~Goodman, M., Sterner, K.N. 2010. Phylogenomic evidence of adaptive evolution in the ancestry of humans. Proceedings of the National Academy of Sciences 107 (Suppl. 2), 8918–8923 - http://tinyurl.com/lwyhh75.~~

Larynx & hyoid bone (ditto)

Neuromuscular control of breathing (lack in ergaster & erectus

Broca's & Wernicke's areas of the cerebral cortex

Last 200,000 years

Social coordination of cooperative hunthing

Last common ancestor H. neanderthalensis & sapiens was on the way (H. heidelbergensis)

Co-evolved with the development of complex technologies & social systems

Only fully developed with the emergence of domestication

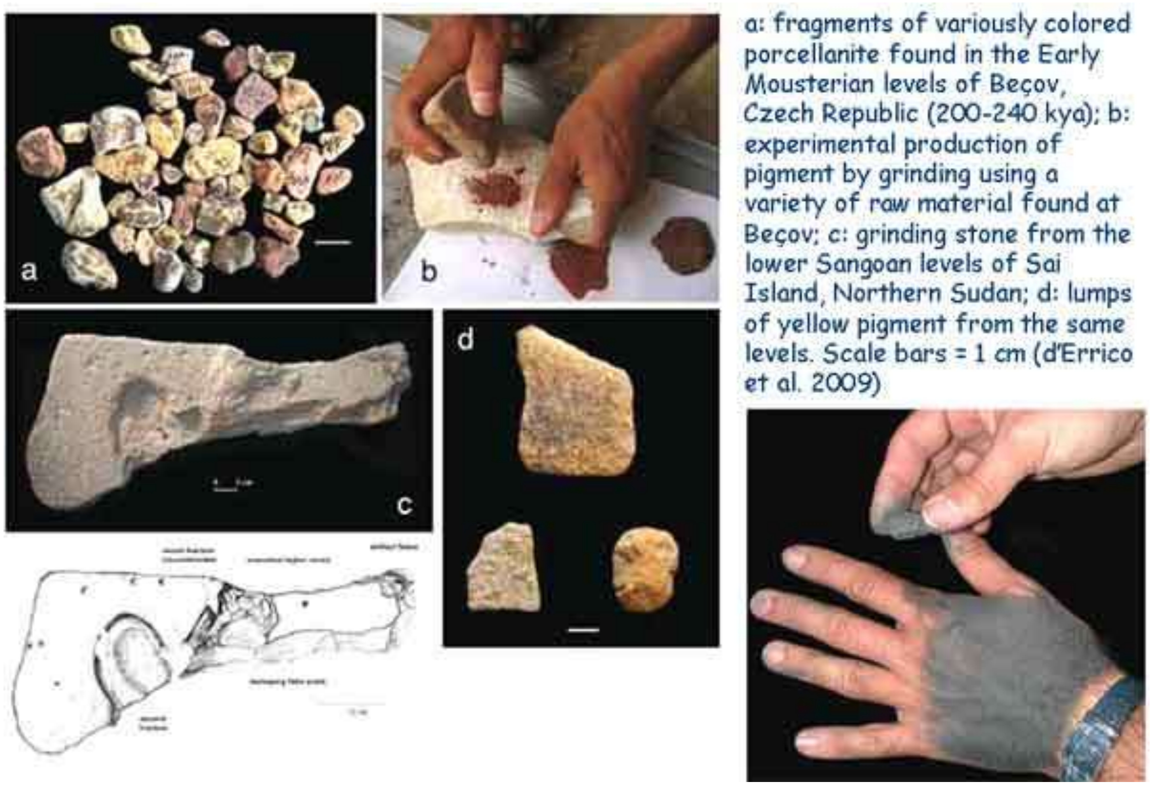


Figure 157. Working with pigments (after d'Errico et al. 2009).

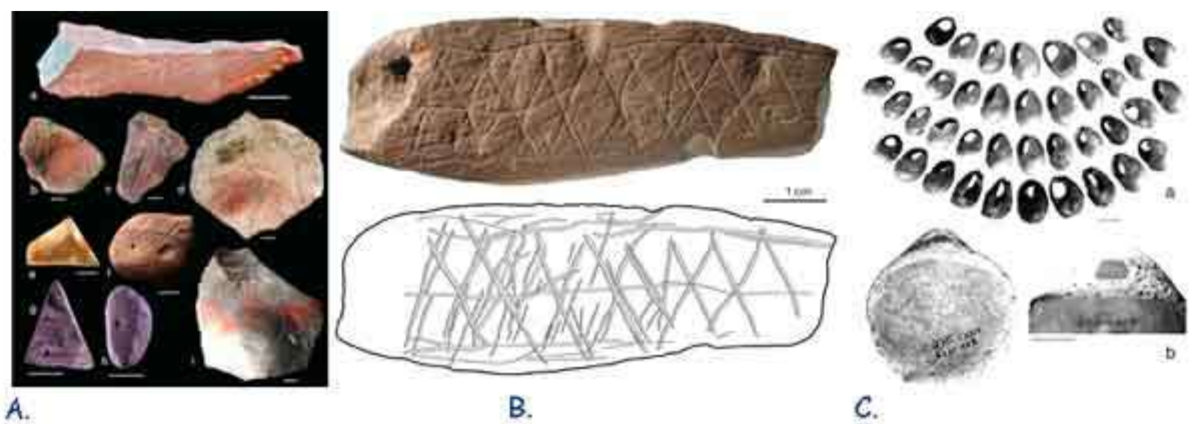


Figure 158. Symbolic artifacts? A. Different pigments & ochred artifacts from various times and locations. B. Engraved ochre slab, C. shell beads, both from Still Bay layers of Blombos Cave, S.A. ~75 kya (d'Errico et al. 2009)

Figure 159. Fire-processed microlithic blades from Pinnacle Point on the south coast of South Africa dating from 71 kya (Brown et al. 2012). Characteristically, the blades are "backed", i.e., retouched to leave a broad back for hafting into a compound spear or projectile point – as shown by the top and side view of the blade in the lower right hand corner. Other blades are shown from side-view only.

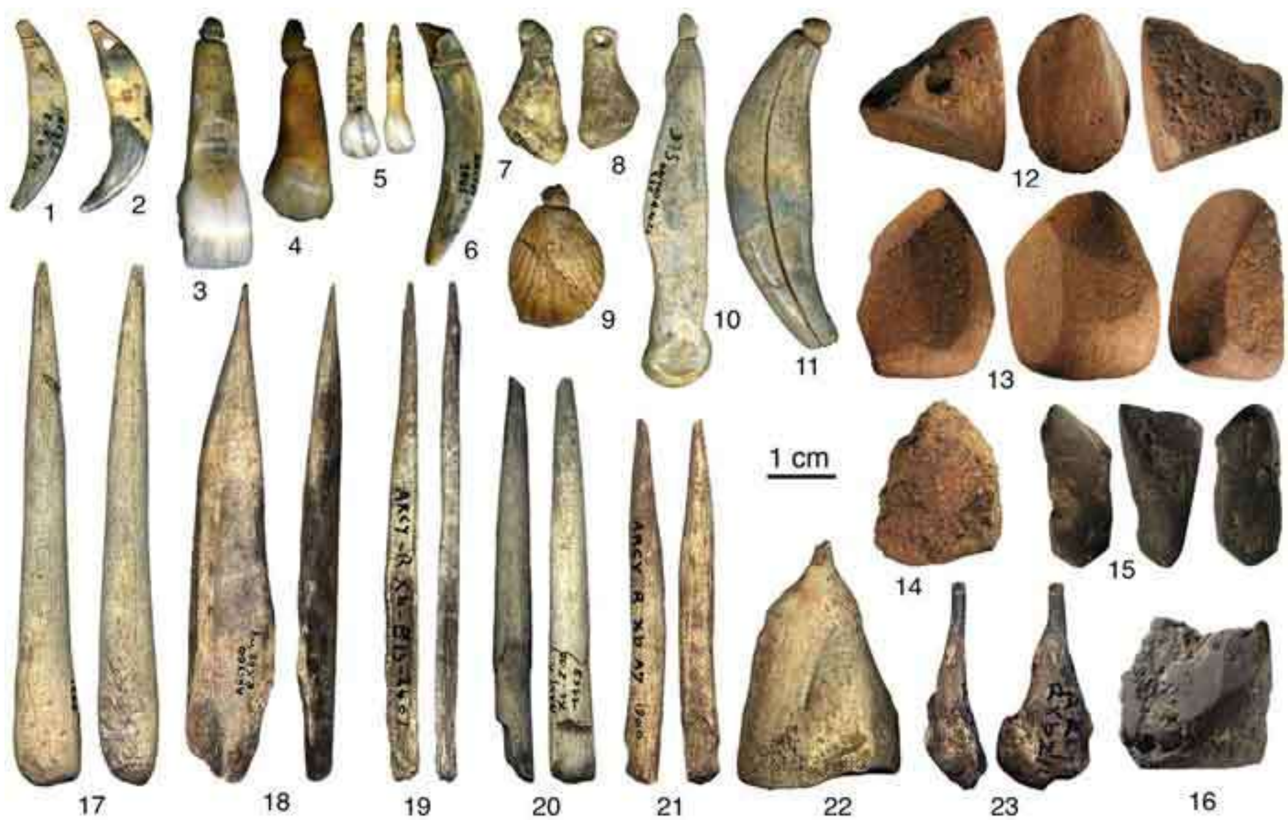


Figure 160. Neanderthals also had well-developed symbolic culture ~ 48-40 kya from Grotte du Renne (France), Chatelperronian symbolic artifacts. Personal ornaments made of perforated and grooved teeth

(1–6, 11), bones (7–8, 10) and a fossil (9); red (12–14) and black (15–16) pigment stones with facets produced by grinding; bone awls (17–23). (Caron et al. 2011)

What knowledge can be recalled, how can it be transmitted, how can it be committed? (more Ong)

In a purely oral culture, restriction of thoughts to sound determines not only what you can say, but what you think & remember

You only know what you can recall

We don’t record what we hear, we only remember what we think

How do you remember the solution to a complex problem that takes several hundred words to describe? (no notes, no jottings....!)

How would you know what you recalled was even correct?

“Think memorable thoughts”!

Think in mnemonic patterns, shaped for ready oral expression

Think heavily rhythmic, balanced patterns, in repetitions or antitheses, in alliterations and assonances, in formulary expressions

Set your thinking in standardized scenes, themes & stories

Use common expressions and clichés, known to all

How to communicate orally (Ong)

Additive rather than subordinative (ensure a progressive flow)

Aggregative rather than analytic (reliance on mnemonic formulas and traditional expressions)

Redundant or ‘copious’ (speech vanishes in the instant of its creation, need repeated cues to stay on track for it to sink in)

Conservative or traditionalist

conceptualized knowledge that is not repeated aloud soon vanishes

oral societies must invest great energy to say over and over again what has been learned

Close to the human lifeworld (knowledge is preserved in the doing)

Situate knowledge in a context of struggle (When verbal communication can only be by direct word of mouth, interpersonal relations are kept high—both attractions and, even more, antagonisms.)

Empathetic and participatory rather than objectively distanced (fit the speech into the hearer’s life)

Homeostatic (The meaning of each word is controlled by the real-life situations in which the word is used here and now – no dictionaries = no past)

Situational rather than abstract (objective rather than conceptual)

Language puts cultural evolution into overdrive

Transmission of industrial knowledge for the making of compound/complex tools

tacit apprenticeships

memorable rules of thumb

Mythical tales as repositories of knowledge

Tribal cultures

Trading

Herding

Farming & settled villages

Power elites

Only with writing does knowledge become objective

Revolutionary technologies lead to grade shifts in organizational cognition

Tallies for taxation and trading in the Neolithic agrarian world enable temples, city states and theocracies

Counting, recording and accounting: computation, archives & filing systems enable bureaucratic empires

Documents as organizational memory systems makes process knowledge explicit enables process and production industries (Industrial Revolution)

Automated cognition extends organizational cognition facilitating the police state and transnational organizations

I assume here that the faculty of language emerged to facilitate coordination and transfer knowledge within and between hominin social groups.

Davidson, I. 2010. The colonization of Australia and its adjacent islands and the evolultion of modern cognition. Current Anthropology 51(S1), S177-S189.

Protolanguages and learning to talk about objects, concepts, and processes

Nowell (2010) Defining Behavioral Modernity in the Context of Neandertal and Anatomically Modern Human Populations

Hauser et al. (*2002*) comparative studies – what is uniquely human is recursion and the ability to generate an infinite variety of utterances.

Coolidge, F.L., Overmann, K.A., Wynn, T. 2011. Recursion, what is it, who has it, and how did it evolve. Wiley Interdisciplinary Reviews: Cognitive Science 2(5), 547-554.

***Sterelny, K. 2012. Language, gesture, skill: the co-evolutionary foundations of language. Philosophical Transactions of the Royal Society B 367, 2141–2151 - http://tinyurl.com/95w4mmr.

Savage-Rumbaugh, S., Sevcik, R.A., Hopkins, W.D. 1988. Symbolic cross-modal transfer in two species of chimpanzees. Child Development 59(3) – 617-625.

Savage-Rumbaugh, E.S., Lyn, H. 2000. Observational word learning in two bonobos (Pan paniscus): ostensive and non-ostensive contexts. Language and Communication 20(3), 255-273.

Savage-Rumbaugh, S., Fields, W.M., Taglialatela, J.P. 2001. Language, speech, tools and writing: a cultural imperative. Journal of Consciousness Studies 8(5-7), 273-292 - http://tinyurl.com/9elmqn6f

Gillespie-Lynch, K., Greenfield, P.M., Lyn, H., Savage-Rumbaugh, S. 2011. The role of dialogue in the ontology and phylogeny of early symbol combinations: a cross-species comparison of bonobo, chimpanzee, and human learners. First Language 31, 442-460.

Lyn, H., Greenfield, P.M., Savage-Rumbaugh, E.S. 2011. Semiotic combinations in Pan: a comparison of communication in a chimpanzee and two bonobos. First Language 31(3), 300–325 -

Lyn, H., Greenfield, P.M., Savage-Rumbaugh, S., Gillespie-Lynch, K., Hopkins, W.D. 2011. Nonhuman primates do declare! A comparison of declarative symbol and gesture use in two children, two bonobos, and a chimpanzee. Language and Communication 31, 63-74 - http://tinyurl.com/9oygznu

Lyn, H., Greenfield, P.M., Savage-Rumbaugh, E.S. 2011. Semiotic combinations in *Pan*: a comparison of communication in a chimpanzee and two bonobos. First Language 31(3), 300-325.

Fitch, W.T. 2011. The evolution of syntax: an exaptationist perspective. Frontiers in Evolutionary Neuroscience 3, no. 9, 12 pp. - http://tinyurl.com/8fbt2eq

Baggio, G., Van Lambalgen, M., Hagoort, P. 2012. Language, linguistics and cognition. (in) Philosophy of Linguistics, Kempson, R., Fernando, T., Asher, N. (eds). Elsevier, pp. 325-356 - http://tinyurl.com/9fphsfs

Malone, N., Fuentes, A., White, F.J. 2012. Variation in the social systems of extant hominoids: comparative insight into the social behavior of early hominins. International Journal of Primatology. DOI 10.1007/s10764-012-9617-0, 27 pp. - http://tinyurl.com/93akcro

***Pinker, S., Jackendoff, R. 2005. The faculty of language: what's special about it? Cognition 95, 201-236 - http://tinyurl.com/8amcywk

Nathalie Gontier (2012): Selectionist approaches in evolutionary linguistics: an epistemological analysis. International Studies in the Philosophy of Science 26(1), 67-95 - http://www.tandfonline.com.ezp.lib.unimelb.edu.au/doi/pdf/10.1080/02698595.2012.653114

Rossano, M.J. 2010. Making friends, making tools, and making symbols. Current Anthropology 51(S1), S89-S98 - http://tinyurl.com/8wd7qq9

Reuland, E. 2010. Imagination, planning, and working memory: the emergence of language. Current Anthropology 51(S1), S99-S110 - http://tinyurl.com/8wmjx7y

Welshon, R. 2010. Working memory, neuroanatomy, and archaeology. Current Anthropology 51(S1), S191-S199 - http://tinyurl.com/9lk72xu

Barceló-Coblijn, L. 2011. A biolinguistic approach to the vocalizations of *H. neanderthalensis* and the genus *Homo*. Biolinguistics 5(4), 286–334 - http://tinyurl.com/8an8txr

it is conceptually useful to distinguish between the language faculty in its broad and narrow sense, to dissect the broad language faculty into sensorimotor, conceptual, and grammatical components, and to differentiate among the issues of shared versus unique abilities, gradual versus saltational evolution, and continuity versus change of evolutionary function.

Conceptual

Sensorimotor

Linguistic

In this, I would like to emphasize that vocalization and gesture are only meaningful in group social contexts, where receivers "understand" in some adaptive sense what the communication means.

Steele, J. Ferrari, P.F., Fogassi, L. 2012. From action to language: comparative perspectives on primate tool use, gesture and the evolution of human language. Philosophical Transactions of the Royal Society B 367, 4-9 - http://tinyurl.com/9gcuxy5.

Coolidge, F.L., Overmann, K.A., Wynn, T. 2011. Recursion, what is it, who has it, and how did it evolve. Wiley Interdisciplinary Reviews: Cognitive Science 2(5), 547-554.

* Read, D.W. 2008. Working memory: a cognitive limit to non-human primate recursive thinking prior to hominid evolution. Evolutionary Psychology 6(4), 676-714 - http://tinyurl.com/8bxd4x5.

Language use does not fossilize

Based on fossils, primary areas in the hominin brain began a period of rapid expansion some 2 million years ago.

Neurological, anatomical, and genomic correlates of language and social grouping

Rilling et al (2012), Richerson et al. (2010)
DeSilva (2011);
McBride (2012) importance of observing, mapping and change detection
van Schaik et al. (2012) – social vs cultural brains;
Bailey & Geary (2009) social competition

Iriki, A., Taoka, M. 2012. Triadic (ecological, neural, cognitive) niche construction: a scenario of human brain evolution extrapolating tool use and language from the control of reaching actions. Philosophical Transactions of the Royal Society B 367, 10-23 - http://tinyurl.com/8w6dfkr

Kyriacou, A., Bruner, E. 2011. Brain evolution, innovation and endocranial variations in fossil hominids. PaleoAnthropology 2011, 130−143 - http://tinyurl.com/9vkjh5k

Wynn, T., Coolidge, F.L. 2011. The implications of the working memory model for the evolution of modern cognition. International Journal of Evolutionary Biology 2011, article 741357, 12 pp. doi:10.4061/2011/741357 - http://tinyurl.com/8pplsug

Gignoux, C.R., Henn, B.M., Mountain. J.L. 2011. Rapid, global demographic expansions after the origins of agriculture. Proceedings of the National Academy of Sciences USA 108(115), 6044-6049 - http://tinyurl.com/93ah58h

This includes the mirror neuron system for visuomotor control of hand movements for grasping that also recognizes when another individual is performing the same manual actions. Arbib and colleagues (2005) propose evolutionary changes based on this function facilitates speakers (and gesturers) to coordinate their understanding of language. In monkeys. Aboitiz (2012) reviews a large body of evidence suggesting the close involvement of these systems in working memory, and suggests that

> The ability to rehearse and keep newly learned phonological sequences in short-term memory became an inflection point [i.e., grade shift] that changed human sociality forever, being a fundamental factor in the evolution of complex language and culture. This "inner speech" capacity also allowed the elaboration of new and more complex messages by manipulating the phonemes being learned (Aboitiz 2012: p.4).
>
> [Also,] from the mirror neuron perspective, gestures have been proposed to be crucial for the acquisition of a primitive semantics…. In this process, grasping ability and voluntary hand control may have been important elements to facilitate shared attention, and possibly led to the appearance of pointing behavior, which is critical for making reference to the world…. From pointing, other meaningful hand gestures may have evolved, especially in the context of a primitive tool-making and tool-using technology in which the emulation of tool use may have conveyed a ritualized semantics (Aboitiz 2012: p.9).

Wood, B., Baker, J. 2011. Evolution in the genus *Homo*. Annual Review Ecology, Evolution and Systematics 42, 47-69.

Wood, B. 2010. Reconstructing human evolution: achievements, challenges, and opportunities. Proceedings of the National Academy of Sciences USA 107 (suppl. 2), 8902-8908 - http://tinyurl.com/8rsq5kn.

Sherwood, C.C., Subiaul, F., Zawidzki, T.W. 2008. A natural history of the human mind: tracing evolutionary changes in brain and cognition. Journal of Anatomy 212, 526-454 - http://tinyurl.com/8d98667

Pastra, K., Aloimonos, Y. 2012. The minimalist grammar of action. Philosophical Transactions of the Royal Society B 367, 103-117 - . - *Language and action have been found to share a common neural basis and in particular a common 'syntax', an analogous hierarchical and compositional organization*

Alves I., Šrámková Hanulová, A., Foll, M., Excoffier, L. 2012. Genomic data reveal a complex making of humans. PLoS Genet 8(7): e1002837. doi:10.1371/journal.pgen.1002837, 7 pp. - http://tinyurl.com/c8p6fcr

By 300,000 years ago, our ancestors were anatomically almost "modern" with the larynx located at the top of the trachea that enabled an increased variety of sounds to be made (also increasing the vulnerabity to choking). Deacon 1997 argues there must have been a sufficient evolutionary advantage (i.e., the capacity for speech) to be gained by this change to override the negative selection from choking.

Other hints come from genetics. Specific mutations to the FOXP2 gene between 100,000 and 200,000 years ago seem to have had major effects on both cognitive processes involved in language and in the ability to articulate. Holden (2004) identifies possible genetic milestones in the evolution of speech. Chater et al. (2009) s *Other possible milestones come from genetic studies. For example, researchers at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, reported last year that the FOXP2 "speech gene," which affects both language and the ability to articulate (Science, 16 August 2002, p. 1105), was apparently a target of natural selection. This gene may have undergone its final mutation fewer than 100,000 years ago—and no more than 200,000 years ago—perhaps laying the groundwork for a new level of linguistic fluency.*

Most researchers are inclined to the view that language gradually emerged over perhaps a couple of hundred thousand years (Science, 20 November 1998, p. 1455). But all we know for certain, says Pinker, is that fully developed language was in place by at least 50,000 years ago, when humans in Europe were creating art and burying their dead, symbolic behaviors that point unequivocally to fluent language.

Fitch, W.T. 2011. Genes, language, cognition, and culture: towards productive inquiry. Human Biology 83(2), 323-329 - http://tinyurl.com/9bek8ay

As discussed by Donald 1991 and Logan 2004

As a starting point it was assumed that before the advent of speech hominin thought processes as inherited from our earliest ancestors were percept-based. Donald (1991: 226) makes a similar assumption about the perceptual basis of mimetic culture, the culture of hominins that existed just before the emergence of verbal language. "The principle of similarity that links mimetic actions and their referents is perceptual, and the basic communicative device is best described as implementable action metaphor." (Donald, 1998: 61)

Our earliest human-like ancestors, which we will refer to as hominins, emerged in the savannas ofAfrica, where they were an easy target for various predators. To defend themselves from this threat as well as to increase their food supply they acquired the new skills of tool making, the control of fire, group foraging, and coordinated hunting. These activities resulted in a more complex form of social organization, which also increased the complexity of their lives. At first, this complexity could be handled through more sophisticated percept-based responses, but at some point the complexity became too great. Percept-based thought alone did not provide sufficient abstraction to deal with the increased complexity of hominin existence. The hominin *mind could no longer cope with the richness ofits life based solely on its perceptual sensorium. It is conjectured that in the information overload and chaos that ensued a new abstract level of order emerged in the form of verbal language and conceptual thinking.*

This idea can be expressed in a slightly different way by making use of Ashby's Law of Requisite Variety (LRV) which has been formulated in a number of different ways. The following two formulations best describe our use oflanguage as a system that we use to represent the environment in which we live. One formulation of Ashby's LRV is "a model system or controller can only model or control something to the extent that it has sufficient internal variety to represent it." (Heylighen and Joslyn, 200 I) Another formulation of Ashby's LRV is "for appropriate regulation the variety in the regulator must be equal to or greater than the variety in the system being regulated." (Ibid) By making use of these formulations of Ashby's LRV we are assuming that language is used by humans to regulate or control their social and physical environment.

When the complexity of hominin life became so great that perception and learned reactions to perceptions alone could not provide enough requisite variety to model or regulate the challenges of day to day life a new level of order emerged based on concepts. Percepts arise from our impressions of the external world that we apprehend with our senses and are mediated by neural networks in our brains. Concepts, on the other hand, are abstract ideas that result from the generalization of particular examples. Concepts allow one to deal with things that are remote in both the space and time dimension. If our first words were concepts then language allowed us to represent things that are remote is both space and time and, hence, provide language with what Hockett (1960) defines as displacement.

Concepts also increase the variety with which the brain can model the external world. Percepts are specialized, concrete and tied to a single concrete event but concepts are abstract and generative. They can be applied to many different situations or events. They can be combined with other concepts and percepts to increase variety in ways that percepts cannot. It is for this reason that only humans are able to use their symbols generatively to create new ideas and to make plans for the future. Some animals that have been enculturated are able to comprehend symbols but they do not use these symbols generatively or to express ideas about themselves. They use the symbols indexically in the sense of the way in which Pierce divided signs into icons, indices and symbols.

What, we may ask, was the mechanism that allowed this transition to take place? Assuming that language is both a form of communication and an information processing system it is conjectured that the emergence of speech represented the actual transition from percept-based thought to concept-based thought. The spoken word, as we shall see, is the actual medium or mechanism by which concepts are expressed or represented. We must be very careful at this juncture to make sure that we do not formulate the relationship of spoken language and conceptual thought as a linear causal one. Language did not give rise to concepts nor did concepts give rise to language, rather human speech and conceptualization emerged at exactly the same point in time creating the conditions for their mutual emergence. Language and conceptual thought are autocatalytic and the dynamically linked parts ofa dynamic cognitive system, namely, the human mind.

Synergistic co-emergence of language, cultures and material technologies

Hare (2011), Gamble et al. (2011). Freeberg et al. (2012), Gintis (2012a)

Languages and the tacit and explicit transfer of group and cultural knowledge

- *Limitations of individual learning, vs learning via cultural transmission*
- Hauser et al. (2002) comparative studies – what is uniquely human is recursion and the ability to generate an infinite variety of utterances.

Mesoudi, A., McElligott, A.G., Adger, D. 2011. Introduction: integrating genetic and cultural evolutionary approaches to language. Human Biology 83(2) 141–151 - http://tinyurl.com/9uywh88

-
    - *Imitation of parents and peers*
    - *Social cueing: gestures & non-verbal vocalization*
    - *Separation of content from form*
- *Signs, signals and language*

Walter Ong (1982)
Vocalization for coordination
Ong: speech vs print as a medium for transferring knowledge.

- *The emergence of groups and group knowledge*

Historical dynamic structure of interpersonal relationships
Organizational OODA cycles
Language for trade

Pagel, M. 2012. Adapted to culture. Nature 482, 297-299 - http://211.144.68.84:9998/91keshi/Public/File/34/482-7385/pdf/482297a.pdf
http://departments.columbian.gwu.edu/anthropology/sites/default/files/u12/2012.Human_.Brain_.Evol_.Writ_.Large_.pdf

Donald, M. 2000. The central role of culture in cognitive evolution: a reflection on the myth of the "isolated mind".
Bickerton 2007 - https://docs.google.com/file/d/0B2Z6nYMfgdWVZjQ3NzBjOGItZTc4YS00OGE4LTk5MDktNzNiYjc4NjkxODQ0/edit
Logan 2006. The Extended Mind Model of the Origin of Language and Culture - http://w.media-ecology.org/publications/MEA_proceedings/v5/Logan05.pdf (also Gontier book)
Logan 2007. The Origin and Evolution of Language and the Propagation of Organization - http://triple-c.at/index.php/tripleC/article/viewArticle/60
Logan, R.K. 2010. The emergence of language as an autocatalytic set of the elements or mechanisms that make speech possible: an enquiry. Explorations in Media Ecology

Kauffman, S., Logan, R.K., Este, R., Goebel, R., Hobill, D., Shmulevich, I. 2008 Propagating organization: an enquiry. Biological Philosophy 23:27-45 - http://tinyurl.com/2f6cbrp

Holden 2004 Constance Holden, The Origin of Speech - ftp://ftp.soest.hawaii.edu/engels/Stanley/Textbook_update/Science_303/Holden-04b.pdf

Magnani, L 2012. Mimetic minds as semiotic minds. How hybrid humans make up distributed cognitive systems. Journal of Mind Theory Vol. 0 No. 2 – 217-248 - http://preview.tinyurl.com/97uh6me

Moore, 2007 Spoken Language Processing: Piecing Together the Puzzle - http://peer.ccsd.cnrs.fr/docs/00/49/91/74/PDF/PEER_stage2_10.1016%252Fj.specom.2007.01.011.pdf

Horan et al. 2008. Coevolution of human speech and trade - http://adres.ens.fr/IMG/pdf/02102006.pdf

Agricultural revolution

Munro, N. 2009. Epipaleolithic subsistence intensification in the Southern Levant: the faunal evidence. (in) Hublin, J.J., Richards, M.P. (eds), The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence. Springer Science + Business Media B.V., pp. 141-155

Social and economic organizations are transcendent entities

- *What does it mean to be organized*
- *The autopoietic organization*
- *Addressing organizational imperatives*

Social construction and management of knowledge to increase self regulation and control

- *Personal knowledge*
- *Group knowledge*
- *Formal knowledge*
- *General knowledge*

Knowledge based groups

- *Kin group*
- *Collective*
- *Formal organization*
- *Higher order organizations of organizations*

OODA system of systems in organizational cogniton

Emergence of the socio-technical organization

Early office machines – see 1876 exhibition catalog http://www.officemuseum.com/exhibits.htm

Revolutionary technologies lead to grade shifts in organizational cognition

Moore's Law — yet again, and technologies underlying the emergence of the transhuman organization

- *The scribal state*

  Taxes, accounts and obligations
  Lore and laws
  Clerical duties

- *Printing and the industrial organization*

- *Information processing and the controlled state*

  Double entry bookkeeping & filing systems
  Census & citizenship

Punch card systems and automated data processing
Databases and electronic data processing
Information systems
Content and knowledge management systems
Artificial intelligence

- *Knowledge processing in today's state-of-the-art organizations*
    - *Engineering project management organizations*
    - *TeraText for global surveillance*

Distributed, extended and virtual organizations

Convergence of posthumans and sociotechnical organizations – social constitution of the Global Brain Clark, A. 2012. Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behavioral and Brain Sciences (in press) - http://tinyurl.com/99lwdru

CADENZA

Liberating Knowledge

Vinjamuri, D. 2012. Publishing is broken, we're drowning in indie books - and that's a good thing. Forbes, CMO Network, 8/15/2012 @ 9:38AM - http://tinyurl.com/8rlv3wf

http://www.intel.com/research/silicon/ieee/circa2000.pdf

Koehler, W. (1999). Digital libraries and World Wide Web sites and page persistence. Information Research, 4:4 – http://informationr.net/ir/4–4/paper60.html

Morrison A, 'Hijack on the road to Xanadu: The Infingement of Copyright in HTML Documents via Networked Computers and the Legitimacy of Browsing Hypermedia Documents', 1999 (1) The Journal of Information, Law and Technology (JILT). <http://elj.warwick.ac.uk/jilt/99–1/morrison.html>

Harnad, S. & Hemus, M. (1997) All Or None: No Stable Hybrid or Half–Way Solutions for Launching the Learned Periodical Literature into the PostGutenberg Galaxy. In Butterworth, I. (Ed.) The Impact of Electronic Publishing on the Academic Community. London: Portland Press. 18–27. (Copyright 1997 Portland Press) – http://cogsci.soton.ac.uk/~harnad/Papers/Harnad/harnad97.hybrid.pub.html

Nunberg, G. (1998). Will Libraries Survive?, The American Prospect vol. 9 no. 41, November 1, 1998 - http://www.prospect.org/print/V9/41/nunberg-g.html

Economics of scholarly publishing is stifling the growth of knowledge

The Move to Electronic Publishing and Retrieval

Keep, C., McLaughlin, T. and Parmar, R. (1995). The Electronic Labyrinth – http://www.iath.virginia.edu/elab/elab.html. See also Hyperizons – http://www.duke.edu/~mshumate/hyperfic.html

Kirschenbaum, M.G., Lines For A Virtual T[y/o]pography: Electronic Essays on Artifice and Information. A dissertation presented to the Graduate Faculty of the University of Virginia in Candidacy for the Degree of Doctor of Philosophy. – http://jefferson.village.virginia.edu/~mgk3k/dissertation/main.html

Difficulty in determining actual costs: Luther, J (2001) White Paper on Electronic Journal Usage Statistics. The Journal of Electronic Publishing 6(3) http://www.press.umich.edu/jep/06–03/luther.html

Costs of tangible distribution: Digital Alternatives: Day, C. (1997), Solving the Problem or Shifting the Costs? Journal of Electronic Publishing. 4(10). http://www.press.umich.edu/jep/04–01/day.html "I hope I have succeeded in puncturing the panaceas. I am sure that none of the alternatives to the traditional system can offer the kind of major cost savings that would make the fundamental problem of the monograph go away. The most prevalent error that has led people to believe in those panaceas is to ignore the value of scholars' time and forget that it should be directed not to mundane publishing chores but to the teaching and research for which faculty are uniquely qualified, expensively trained and rigorously selected"

Competition and cooperation: Libraries and publishers in the transition to electronic scholarly journals, A. M. Odlyzko. Journal of Electronic Publishing 4(4) (June 1999), http://www.press.umich.edu/jep/ and in J. Scholarly Publishing 30(4) (July 1999), pp. 163–185 http://www.research.att.com/~amo/doc/competition.cooperation.pdf

How Scientists Retrieve Publications: An Empirical Study of How the Internet Is Overtaking Paper Media by BO–CHRISTER BJÖRK and ZIGA TURK The Journal of Electronic Publishing December, 2000 Volume 6, Issue 2 http://www.press.umich.edu/jep/06–02/bjork.html

DIGITAL LIBRARY WORK: MEETING USER NEEDS by Mats G. Lindquist, Paper presented at: "The impact of electronic publishing on the academic community", an Academia Europaea workshop, Stockholm, Sweden, 16–20 April, 1997. – http://www.lub.lu.se/UB2proj/LIS_collection/lindquist.html

A Science Publishing Revolution: Grassroots initiative demands free, searchable content from publishers. By Eugene Russo –

WAITING FOR THOMAS KUHN, First Monday and the Evolution of Electronic Journals by EDWARD J. VALAUSKAS – http://www.press.umich.edu/jep/03–01/FirstMonday.html

Harter, S.P. and H.J. Kim (1996). Electronic Journals and Scholarly Communication: A Citation and Reference Study. Proceedings of the Midyear Meeting of the American Society for Information Science, San Diego, CA, May 20–22, 1996, pp. 299–315 – http://informationr.net/ir/2–1/paper9a.html.

Electronic Journals: A Selected Resource Guide – Harrassowitz Booksellers and Subscription Agents. 2000. http://www.harrassowitz.de/services/ejresguide.html Comprehensive survey of scholarly publishing

Lisse, May 3 2000 SwetsNet content expands significantly with additional publisher signings http://www.swets.nl/press/content.html – more than 3,100 electronic journals

NewHoo: Yahoo Built By The Masses – http://www.searchenginewatch.com/sereport/98/07–newhoo.html

NewHoo origins: http://slashdot.org/articles/older/980613118210_F.shtml

Scholarly Publishing, Peer Review and the Internet. Peter Roberts. 1999. http://www.firstmonday.dk/issues/issue4_4/proberts/

Scholarly Electronic Publishing Bibliography. Bailey, C.W. 2000. http://info.lib.uh.edu/sepb/sepb.html

- Further growth
    - limitations of HTML
    - W3C initiatives to develop XML
- Importance of semantic markup for the future
    - The world–wide brain

http://dmoz.org/ann.html Netscape and newhoo; http://home.netscape.com/newsref/pr/newsrelease702.html

An Introduction to the Resource Description Framework by Eric Miller – http://www.asis.org/Bulletin/Oct–98/ericmill.html

The Document Management Alliance – by Chuck Fay – http://www.asis.org/Bulletin/Oct–98/chuckfay.html

Collaborative Authoring on the Web: Introducing WebDAV. by E. James Whitehead, Jr. – http://www.asis.org/Bulletin/Oct–98/webdav.html

1994 – Web traffic overtakes Gopher traffic. NetScape "buys up" all manpower from NCSA and releases Netscape 1.0. Tim Berners–Lee leaves CERN for MIT. The W3C is founded.

Burk D L, 'Proprietary Rights in Hypertext Linkages', 1998 (2) The Journal of Information, Law and Technology (JILT). <http://elj.warwick.ac.uk/jilt/intprop/98_2burk/>

http://homepage.seas.upenn.edu/%7Egaj1/shiftgg.html

XML

XHTML http://www.w3.org/MarkUp/Activity

Delbridge, A. and Butler S. (1999). The Macquarie Dictionary, its History and its Editorial Practices. Lexicos 9. – http://www.sun.ac.za/wat/lex9/macqua3.html

D–Lib Magazine, July/August 1998, Archiving Digital Cultural Artifacts: Organizing an Agenda for Action. Peter Lyman and Brewster Kahle. – http://www.dlib.org/dlib/july98/07lyman.html

Christos, J.P., et. al. (1999). History of the Internet.: a Chronology 1843 to the Present. ABC CLIO, 320 pp. – extracts: http://www.historyoftheinternet.com/index.html

Khare, R and Rifkin, A. (1998). The Origin of (Document) Species. Presented at the WWW7 Conference in Brisbane, Australia, April 14–18, 1998, published in Computer Networks and ISDN Systems, Volume 30, Pages 389–397 – http://www.cs.caltech.edu/~adam/papers/www/origin–of–species.html

Alexa – http://www.alexa.com/

E–zine list – http://www.meer.net/~johnl/e–zine–list/

http://www.isinet.com/isi/isilinks

http://www.searchenginewatch.com/sereport/98/12–newhoo.html how newhoo works

Sparc policy http://www.dlib.org/dlib/may00/johnson/05johnson.html

The crisis in scholarly publishing http://www.lib.uwaterloo.ca/society/crisis.html http://www.shef.ac.uk/~is/publications/infres/paper9a.html

http://www.arl.org/scomm/tempe.html

Linking Everything to Everything: Journal Publishing Myth or Reality? S. Hitchcock, F. Quek*, L. Carr, W. Hall, A. Witbrock* and I. Tarr (1997) http://journals.ecs.soton.ac.uk/IFIP–ICCC97.html

Indexing services http://www.public.iastate.edu/~CYBERSTACKS/Morning.htm

Cost issues : The future of scientific journals: lessons from the past – http://csssrvr.entnem.ufl.edu/~walker/fewww/aedraft.htm

The slow evolution of electronic publishing. Andrew Odlyzko (1997) – http://www.research.att.com/~amo/doc/slow.evolution.txt

Electronic librarians, intelligent network agents, and information catalogues. Draft paper by Edward A. Fox http://www.uky.edu/~kiernan/DL/fox.html

Hermans, Bjorn. Intelligent Software Agents on the Internet: An Inventory of Currently Offered Functionality in the Information Society and a Prediction of (Near) Future Developments. First Monday 1997; 2(3). – http://www.firstmonday.dk/issues/issue2_3/ch_123/

InfoGuide – Artificial Intelligence Applications in Libraries for Information Professionals Date: July 1997 Compiled by: Deborah Jones RMIT – http://www.bf.rmit.edu.au/Dimals/rguides/ai–library.htm

Specialty skills

Rising cost of journals

Research Libraries as Knowledge Publishers not Purchasers

The Free Literature Movement

http://www.biomedcentral.com/info/conference.asp
http://xxx.lanl.gov/blurb/pg00bmc.html

Technological Requirements and Standards for Structured Documents

http://www.raycomm.com/techwhirl/xmlandtechwriters.html

A number of alternatives have been proposed to change the way scholarly knowledge is published and distributed to those who need to access it.

In the "early days" before personal computers when I was a student and an academic, individual users minimised their requirements for personal subscriptions to costly journals by photocopying articles they needed from library copies of journals. Publishers, of course, regarded this as an infrigement of their copyrights but found it difficult to impossible to police at the individual level.

However, today, the means of accessing journal papers for personal use are changing rapidly from retrieving paper documents from the library to accessing them electronically via library networks, where the library serves as an authentication hub for subscription management

content capture tools

Bollen, J. _ Adaptive Hypertext Networks That Learn the Common Semantics of their Users. http://pespmc1.vub.ac.be/papers/namurart.html; http://pespmc1.vub.ac.be/papers/BollenNRHM/Default.html; Heylighen F. (1999): "Collective Intelligence and its Implementation on the Web: algorithms to develop a collective mental map", Computational and Mathematical Organization Theory 5(3), p. 253–280 – http://pespmc1.vub.ac.be/Papers/CollectiveWebIntelligence.pdf

Dahlström, M. and Gunnarsson, M (2000). Document architecture draws a circle: on document architecture and its relation to library and information science education and research. Information Research, 5:2 – http://informationr.net/ir/5–2/paper70.html

Miller, E. (1998). An Introduction to the Resource Description Framework. http://www.dl.ulis.ac.jp/DLjournal/No_13/1–emiller/1–emiller.html; Ceri, S., et. al. (1999). XML–GL: a Graphical Language for Querying and Restructuring XML Documents – http://www8.org/w8–papers/1c–xml/xml–gl/xml–gl.html; W3C Resource Description Framework (RDF) – http://www.w3.org/RDF/; Martin P. and Elkund P. (1999), Embedding Knowledge in Web Documents *in* the Eighth International World Wide Web Conference, Toronto, May 11–14, 1999 – http://www8.org/w8–papers/3b–web–doc/embedding/embedding.html; Berners–Lee, T. (1998). Semantic Web Road map. http://www.w3.org/DesignIssues/Semantic.html

A Science Publishing Revolution: Grassroots initiative demands free, searchable content from publishers. By Eugene Russo –

BUBL LINK / 5:15 Catalogue of Internet Resources –Electronic journal costs – http://bubl.ac.uk/link/e/electronicjournalcosts.htm

025.0 Pricing in digital libraries – http://link.bubl.ac.uk/ISC1548

025.0 Searching and use of digital libraries – http://link.bubl.ac.uk/ISC1549

eBooks The Battle to Define the Future of the Book in the Digital World by Clifford Lynch http://firstmonday.org/issues/issue6_6/lynch/index.html (issue 6_6)

Smart and stupid networks: Why the Internet is like Microsoft, A. M. Odlyzko, ACM netWorker, Dec. 1998, pp. 38–46. http://www.acm.org/networker/issue/9805/ssnet.html

The Knowledge Explosion

Mason, J.S. (2000). From Gutenberg's Galaxy to Cyberspace: The Transforming Power of Electronic Hypertext. Doctoral Dissertation at McGill University, Montréal, Canada

Where is meaning when form is gone? Knowledge representation on the Web. Terrence A. Brooks – http://informationr.net/ir/6–2/paper93.html

A billion Web pages encompasses a very large volume of knowledge, but this is still only a small fraction of the total knowledge compiled by humanity. To date, only a tiny fraction of the knowlege recorded in scientific, technical and academic publications is freely available or indexable by the Web services. Perhaps between 10 and 50% of current content in science journals is available electronically to subscribers[1], but

http://web.archive.org/web/20000510064014/http://www.raycomm.com/techwhirl/xmlandtechwriters.html

A number of alternatives have been proposed to change the way scholarly knowledge is published and distributed to those who need to access it.

In the "early days" before personal computers when I was a student and an academic, individual users minimised their requirements for personal subscriptions to costly journals by photocopying articles they needed from library copies of journals. Publishers, of course, regarded this as an infrigement of their copyrights but found it difficult to impossible to police at the individual level.

However, today, the means of accessing journal papers for personal use are changing rapidly from retrieving paper documents from the library to accessing them electronically via library networks, where the library serves as an authentication hub for subscription management

THE NEW INFORMATION PARADIGM: Threat or Opportunity (or Both)? By Dr. Roger Summit – http://www.pa.utulsa.edu/nfais/miles.d/1996.html

At the Speed of Thought: Pursuing Non–Commercial Alternatives to Scholarly Communication by Mike Sosteric http://www.arl.org/newsltr/200/sosteric.html

A Comparative Analysis of the Role of Multi–Media Electronic Journals in Scholarly Disciplines BY Ken Eason, Chris Carter, Susan Harker, Sue Pomfrett, Kathy Phillips and John Richardson – http://www.ukoln.ac.uk/services/elib/papers/tavistock/eason/eason.html

BUBL LINK Catalogue of selected Internet resources – 070.5 Electronic journals: research http://link.bubl.ac.uk/ISC2093

The Evolution of Journals – The Future of Electronic Journals BY Hal R. Varian http://www.arl.org/scomm/scat/varian.html

The slow evolution of electronic publishing, A. M. Odlyzko, in Electronic Publishing '97: New Models and Opportunities, A. J. Meadows and F. Rowland, eds., ICCC Press, 1997, pp. 4–18 http://www.research.att.com/~amo/doc/slow.evolution.txt

The Public Library of Science and the ongoing revolution in scholarly communication, A. M. Odlyzko. [preprint, text] http://www.research.att.com/~amo/doc/nature.pls.txt

The future of scientific communication, A. M. Odlyzko. Access to Publicly Financed Research: The Global Research Village III, Amsterdam 2000, P. Wouters and P. Schroeder, eds., NIWI, 2000, pp. 273–278. http://www.research.att.com/~amo/doc/future.scientific.comm.pdf

Stevan Harnad. (2001) For Whom the Gate Tolls? How and Why to Free the Refereed Research Literature: Online Through Author/Institution Self–Archiving, Now http://www.cogsci.soton.ac.uk/~harnad/Tp/resolution.htm – Harnad/Oppenheim

Richard J. Roberts,* Harold E. Varmus, Michael Ashburner, Patrick O. Brown, Michael B. Eisen, Chaitan Khosla, Marc Kirschner, Roel Nusse, Matthew Scott, Barbara Wold (2001). Building A "GenBank" of the Published Literature. Science 291: 2318–2319. http://www.sciencemag.org/cgi/content/full/291/5512/2318a

As noted above, my first experience was with using Biological Abstracts' BIOSIS service via Lockheed Dialog's on–line service around 1977.

****What do they do for the user: Text Retrieval Online: Historical Perspective on Web Search Engines by Trudi Bellardo Hahn http://www.asis.org/Bulletin/Apr–98/hahn.html

Bits of power : issues in global access to scientific data / Committee on Issues in the Transborder Flow of Scientific Data, U.S. National Committee for CODATA, Commission on Physical Sciences, Mathematics, and Applications, National Research Council.
http://www.nap.edu/readingroom/books/BitsOfPower/index.html

Online Retrieval of Bibliographic Information, Timeshared – Began late 60's commercially available in 1972

Cost of indexing
the beginnings of computerisation
Database history – role of Dialog, Orbit, etc.:
Charles P. Bourne

Pioneers of Information Science In North America – A Project of SIG/HFIS (History and Foundations of Information Science) American Society of Information Scientists (ASIS) – http://www.asis.org/Features/Pioneers/isp.htm

Dialog – http://www.asis.org/Features/Pioneers/dialog.htm

Introduction to Online Searching and Electronic Research. Lecture 1. *from* Online Searching and Electronic Research, UC Berkeley Extension – http://www.exo.net/ref/uce/uce1_introduction.html. (Full course: http://www.exo.net/ref/uce/online.html)

Lynn Flanagan, Sharon Campbell Parente. Constructing Effective Search Strategies for Electronic Searching.
Middle Tennessee State University, Murfreesboro, Tennessee. – http://www.mtsu.edu/~itconf/papers96/Construct.html – History;

Legal Citation inexing http://www.store.westgroup.com/products/newprods/keycite.htm
http://www.libsci.sc.edu/bob/confprog/confprog.htm; http://www.chemheritage.org/
http://www.slais.ubc.ca/courses/arstlibr512/00–01–wt2/database1.htm

Legal citation analysis: 1873 http://www.store.westgroup.com/products/newprods/keycite.htm

Cameron, R.D. (1998). A Universal Citation Database as a Catalyst for Reform in Scholarly Communication. First Monday 2(4). – http://www.firstmonday.dk/issues/issue2_4/cameron/

Garfield (1955) – http://garfield.library.upenn.edu/essays/v6p468y1983.pdf – citation indexing

Garfield (1955) – http://garfield.library.upenn.edu/essays/v6p459y1983.pdf – use of punch cards

Garfield (1958) – http://garfield.library.upenn.edu/essays/v2p674y1974–76.pdf

Institute for Scientific Information (1958) – http://www.asis.org/Features/Pioneers/isi.htm

The ISI® Web of Science® – Links and Electronic Journals: How links work today in the Web of Science, and the challenges posed by electronic journals http://www.dlib.org/dlib/september99/atkins/09atkins.html

(O'Neill, 1998) History of Citation Indexing http://www.isinet.com/isi/hot/essays/21.html;

(Testa, 1997) The ISI Database: The Journal Selection Process http://www.isinet.com/isi/hot/essays/199701.html

web of science http://www.dlib.org/dlib/september99/atkins/09atkins.html

http://www.garfield.library.upenn.edu/ci/chapter1.PDF

Cited Title Unification or Making a Molehill Out of a Mountain (Robertson, 1998) – http://www.isinet.com/isi/hot/essays/22.html 25X 10^6 citations per year indexed. 14 million refer to indexed journals, remainder refer to 1.5 million cited journals, books, patents, etc.

The growth of knowledge

Primary and secondary literature

University Libraries and Scholarly Communication: A Study Prepared for The Andrew W. Mellon Foundation. by Anthony M. Cummings, Marcia L. Witte, William G. Bowen, Laura O. Lazarus, and Richard H. Ekman. Published by The Association of Research Libraries for The Andrew W. Mellon Foundation. November 1992. http://www.lib.virginia.edu/mellon/

Automating the Growth of Knowledge, Intelligence and Wisdom

The Knowledge Growth Cycle

> Three striking facts emerge from these estimates. The first is the "paucity of print." Printed material of all kinds makes up less than .003 percent of the total storage of information. This doesn't imply that print is insignificant. Quite the contrary: it simply means that the written word is an extremely efficient way to convey information.
>
> The second striking fact is the "democratization of data." A vast amount of unique information is created and stored by individuals. Original documents created by office workers are more than 80% of all original paper documents, while photographs and X–rays together are 99% of all original film documents. Camcorder tapes are also a significant fraction of total magnetic tape storage of unique content, with digital tapes being used primarily for backup copies of material on magnetic drives.
>
> As for hard drives, roughly 55% of the total are installed in single–user desktop computers. Of course, much of the content on individual user's hard drives is not unique, which accounts for the large difference between the upper and lower bounds for magnetic storage. However, as more and more image data moves onto hard drives, we expect to see

the amount of digital content produced by individuals stored on hard drives increase dramatically.

This democratization of data is quite remarkable. A century ago the average person could create and access only a small amount of information. Now, ordinary people not only have access to huge amounts of data, but are also able to create gigabytes of data themselves and, potentially, publish it to the world via the Internet, if they choose to do so.

The third striking fact is the "dominance of digital" content. Not only is digital information production the largest in total, it is also the most rapidly growing. While unique content on print and film are hardly growing at all, optical and digital magnetic storage shipments are doubling each year. Even today, most textual information is "born digital," and within a few years this will be true for images as well. Digital information is inexpensive to copy and distribute, is searchable, and is malleable. Thus the trend towards democratization of data – especially in digital form – is likely to continue.

Comments on the fact that text is a highly EFFICIENT medium compared to sound or vision. How Much Information? by PETER LYMAN and HAL R. VARIAN The Journal of Electronic Publishing December, 2000 Volume 6, Issue 2 http://www.press.umich.edu/jep/06–02/lyman.html

http://www.martinhilbert.8m.net/HilbertLopez%20InfoCapacityMethod.pdf

http://www.soundofruins.net/wp-content/uploads/2011/02/Cubitt-et-al-Does-Cloud-Computing-Have-A-Silver-Lining.pdf

http://141.213.232.243/bitstream/2027.42/85223/1/J15%20Conway%20Preservation%20Age%20of%20Google%202010.pdf

Observation, Orientation, Decision, Action Loop
The Internet Power Crisis

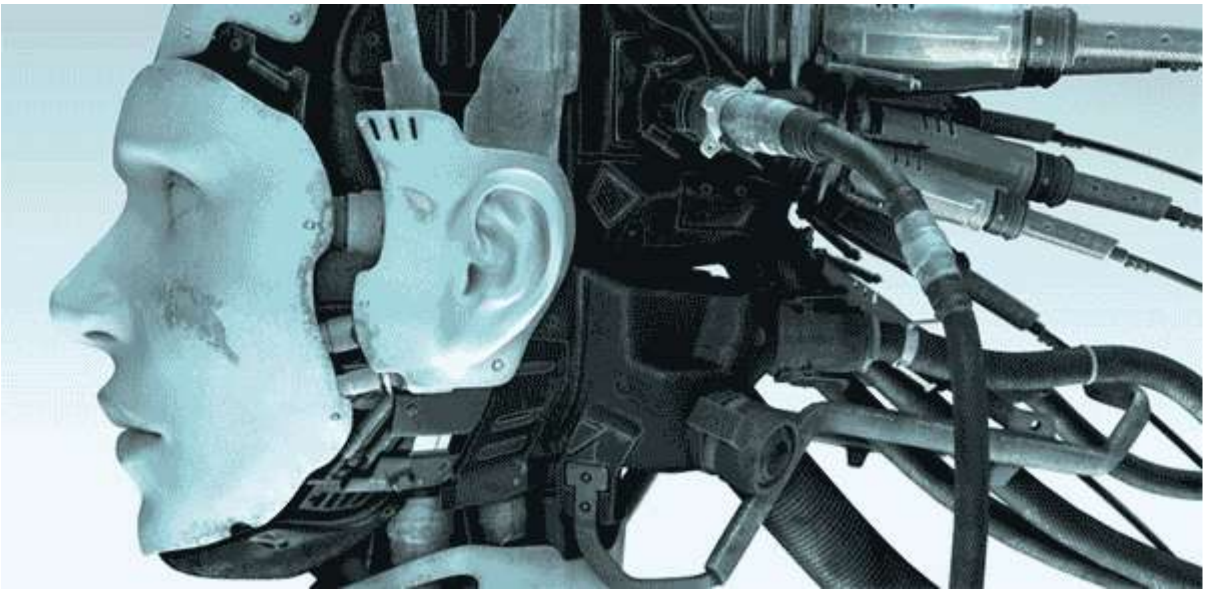
http://www.usatoday.com/life/cyber/tech/2001–01–22–power.htm
http://www.eetimes.com/story/OEG20010125S0036
http://www.abcnews.go.com/sections/wnt/WorldNewsTonight/wnt010112_serverfarms_feature.html
http://www.abcnews.go.com/sections/wnt/WorldNewsTonight/wnt010112_serverfarms_feature.html
http://www.latimes.com/business/reports/power/earlier/lat_elec001212.htm

Artificial Intelligence

Bayesian Philosophy/Networks
http://www.cs.berkeley.edu/~murphyk/Bayes/bayes.html]http://www.cs.unr.edu/~qiangji/bayes.html http://www–users.cs.york.ac.uk/~sara/reference/bayesnets/bnunsorted.html; http://bayes.cs.ucla.edu/jp_home.html

CODA

Another Look at the Knowledge Management Revolution



Saniotis, A., Henneberg, Maciej. 2011. Future evolution of the human brain 16(1), 1 – 18 - http://tinyurl.com/7axyrxv

Application areas:
linking and creating knowledge (authoring)
Butler, D. 2000. Souped Up Search Engines. Nature 405:112–115 – http://www.nature.com/cgi–taf/DynaPage.taf?file=/nature/journal/v405/n6783/full/405112a0_fs.html
Internet encyclopedia's – ARTFL thesaurus and dictionary (plus encyclpedia)
http://humanities.uchicago.edu/homes/MICRA/
management (edit, review and release)
archiving and indexing
discovery, retrieval and use

The next stage shifts the focus from what we can do in the computers to what we can accomplish with them as elements in the larger infrastructure. The computers themselves will "disappear into the woodwork". Our challenge is to learn how to master this new arena – one in which we are not writing programs but adding intelligence to everything around us. The limit is in our ability to manage complexity. It is a world in which resiliency is more important than perfection. A resilient system is one that can continue to function in the midst of the chaos and failure which is the norm. Frankston, B. (1997). Beyond Limits: Innovation and the new Infrastructure. *In* Beyond Calculation: The Next 50 Years of Computing. Denning P.J. and Metcalf, R.M. (*eds*), The Next Fifty Years of Computing. Copernicus Book. – http://www.frankston.com/public/Writings/ACM Beyond Computing Innovation Chapter.asp

Do citation systems represent theories of truth? Betsy Van der Veer Martens http://informationr.net/ir/6–2/paper92.html
Rydberg–Cox, Jeffrey A., Robert F. Chavez, Anne Mahoney, David A. Smith, and Gregory R. Crane. 2000. "Knowledge Management in the Perseus Digital Library." Ariadne 25: – http://www.ariadne.ac.uk/issue25/rydberg–cox/

The Management of XML Documents in an Integrated Digital Library. David A. Smith, Anne Mahoney, Jeffrey A. Rydberg–Cox.
Paper presented at Extreme Markup Languages 2000: The Expanding XML/SGML Universe, Montréal, 15–18 August 2000 – http://perseus.csad.ox.ac.uk/Articles/hopper.pdf
Essay prepared for the ACADEMIA EUROPAEA workshop on
The impact of electronic publishing on the academic community
Stockholm, April 16–20, 1997
Riding the knowledge waves of the centuries to come
Heinz–Dieter Böcker
GMD–IPSI, Dolivostr. 15, 64293 Darmstadt – http://academia.darmstadt.gmd.de/sweden/boecker.html

Miguel A. Quintanilla, (1998) TECHNICAL SYSTEMS AND TECHNICAL PROGRESS: A CONCEPTUAL FRAMEWORK. *from* Advances in the Philosophy of Technology: Proceedings of a Meeting of the International Academy of the Philosophy of Science, Karlsruhe, Germany, May 1997–III. Technology and Society. Techné: Journal of the Society for Philosophy and Technology 4.1 – http://scholar.lib.vt.edu/ejournals/SPT/v4n1/QUINT.html
Klaus Mainzer. (1998) ,COMPUTER TECHNOLOGY AND EVOLUTION: FROM ARTIFICIAL INTELLIGENCE TO ARTIFICIAL LIFE. *from* Advances in the Philosophy of Technology: Proceedings of a Meeting of the International Academy of the Philosophy of Science, Karlsruhe, Germany, May 1997–III. Technology and Society. Techné: Journal of the Society for Philosophy and Technology 4.1 – http://scholar.lib.vt.edu/ejournals/SPT/v4n1/MAINZER.html
Dudley Shapere (1998). BUILDING ON WHAT WE HAVE LEARNED: THE RELATIONS BETWEEN SCIENCE AND TECHNOLOGY. *from* Advances in the Philosophy of Technology: Proceedings of a Meeting of the International Academy of the Philosophy of Science, Karlsruhe, Germany, May 1997–III. Technology and Society. Techné: Journal of the Society for Philosophy and Technology 4.1 – http://scholar.lib.vt.edu/ejournals/SPT/v4n2/SHAPERE.html
Karl Leidlmair (1999). From the Philosophy of Technology to a Theory of Media. *from* Advances in the Philosophy of Technology: Proceedings of a Meeting of the International Academy of the Philosophy of Science, Karlsruhe, Germany, May 1997–III. Technology and Society. Techné: Journal of the Society for Philosophy and Technology 4.3 – http://scholar.lib.vt.edu/ejournals/SPT/v4_n3html/LEIDLMAI.html
Werner Rammert (1999). RELATIONS THAT CONSTITUTE TECHNOLOGY AND MEDIA THAT MAKE A DIFFERENCE: TOWARD A SOCIAL PRAGMATIC THEORY OF TECHNICIZATION *from* Advances in the Philosophy of Technology: Proceedings of a Meeting of the International Academy of the Philosophy of Science, Karlsruhe, Germany, May 1997–III. Technology and Society. Techné: Journal of the Society for Philosophy and Technology 4.3 – http://scholar.lib.vt.edu/ejournals/SPT/v4_n3html/RAMMERT.html
Friedrich Rapp (1999). THE MATERIAL AND CULTURAL ASPECTS OF TECHNOLOGY *from* Advances in the Philosophy of Technology: Proceedings of a Meeting of the International Academy of the Philosophy of Science, Karlsruhe, Germany, May 1997–III. Technology and Society. Techné: Journal of the Society for Philosophy and Technology 4.3 – http://scholar.lib.vt.edu/ejournals/SPT/v4_n3html/RAPP.html

Günter Ropohl, (1999) PHILOSOPHY OF SOCIO–TECHNICAL SYSTEMS – http://scholar.lib.vt.edu/ejournals/SPT/v4_n3html/ROPOHL.html
Ladislav Tondl, (1999). INFORMATION AND SYSTEMS DIMENSIONS OF TECHNOLOGICAL ARTIFACTS – http://scholar.lib.vt.edu/ejournals/SPT/v4_n3html/TONDL.html
J. van Brakel. (1999). TELEMATIC LIFE FORMS http://scholar.lib.vt.edu/ejournals/SPT/v4_n3html/VANBRAKE.html

The Evolving Global Brain

use of Google + The Wayback Machine to study the growth and development of cognitive processes through time.

Hypertext Publishing and the Evolution of Knowledge Drexler, K.E. (1996). Hypertext Publishing and the Evolution of Knowledge. *from* Social Intelligence 1.2: 87–120 – http://www.foresight.org/WebEnhance/HPEK1.html; About the Open Directory Project – http://dmoz.org/about.html; Weise, E. (2000). Search sites brush up on people skills. USA Today Tech Reviews – http://www.usatoday.com/life/cyber/tech/review/crg841.htm
Goertzel Ben. (1997–1999). Wild Computing: Steps Toward a Philosophy of Internet Intelligence – http://www.goertzel.org/ben/wild/Contents.html
CritLink: Better Hyperlinks for the WWW
Yee K–P(1998). CritLink: Better Hyperlinks for the WWW. Hypertext 98 – http://crit.org/http://crit.org/~ping/ht98.html
Heylighen F. & Bollen J. Development and Publication of Systems Knowledge on the Internet: the Principia Cybernetica Web, Cybernetics and Systems: an International Journal [submitted] – ftp://ftp.vub.ac.be/pub/projects/Principia_Cybernetica/Texts_General/PCP_Web.txt; Heylighen F. & Bollen J. (1996) The World–Wide Web as a Super–Brain: from metaphor to model, in: Cybernetics and Systems '96 R. Trappl (ed.), (Austrian Society for Cybernetics).p. 917–922. – http://pespmc1.vub.ac.be/papers/WWWSuperBRAIN.html
Hansen, J. (). Dieoff.com. http://dieoff.com/page1.htm
John P. Sullins III. GÖDEL'S INCOMPLETENESS THEOREMS AND ARTIFICIAL LIFE. *from* Advances in the Philosophy of Technology: Techné: Journal of the Society for Philosophy and Technology 2.3–4 – http://scholar.lib.vt.edu/ejournals/SPT/v2n3n4/sullins.html

CODA

For nearly five billion years of Earth's history, the only knowledge has been chemical. Where life is concerned, knowledge of what has survival value in a competitive world has been generated through the processes of natural selection and passed on down through the generations of species almost exclusively in DNA molecules through the genetic heritage passed from parents to offspring.

Some time in the last 50 million years of Earth's histories the anthropoid apes evolved a prolonged childhood that provided the circumstances for the transmission of a limited heritage of learned knowledge from tribes, troops and parents to the younger generations through observation and imitation.

Around 500,000 years ago, early Homo sapiens evolved speech, which allowed the coherent transmission of cultural learning from one individual to another and from one generation to the next. The slow stochastic processes of natural selection and genetic inheritance no longer limited the evolution of knowledge.

Around 5,000 years ago humans learned to write down knowledge in a way that allowed one individual's knowledge to survive independently of that individual's own physical survival, and to make that recorded knowledge available to many individuals over many generations.

The printing revolution around 550 years ago broadcast recorded knowledge to thousands or even millions of individuals, exposing knowledge to many repetitions and cycles of experience, testing, refinement and elaboration within the normal lifespans of its human authors. Knowledge of the world began to evolve a great deal faster than the biological species that created it.

The computer and microelectronics revolution beginning 50 years ago (within my own lifetime) has provided the technology to double the total store of knowledge (and the ability to process and extend it) every two years or less.

What will nanotechnology and quantum computing mean for the evolution of knowledge?

The Spike or a Point of Inflection?

Tyler, T. (). The Origin of Life - http://originoflife.net/takeover_types/; http://originoflife.net/takeover/index.html

Vaneechoutte, M. 1999. The scientific origin of lif: Considerations on the evolution of information, leading to an alternative proposal for explaining the origin of the cell, a semantically closed system. Presented at the Closure Symposium, Gent, Belgium, May 3-5th 1999. Revised version is published in the Annals of the New York Academy of Sciences 901. March 2000. - http://www.geneticengineering.org/belgium/default.htm

Ronfeldt, D. (1992). Cyberocracy is Coming. The Information Society 8:4 - http://www.totse.com/en/technology/cyberspace_the_new_frontier/cybocrac.html

see also http://www.totse.com/en/technology/cyberspace_the_new_frontier/

Re Accelerando: http://www.nytimes.com/2012/09/23/technology/data-centers-waste-vast-amounts-of-energy-belying-industry-image.html

Appendix 1

This explains some of the basic features of evolution as background to Episode 5.

Life, species and their evolution and speciation

Background to most of this Episode is some understanding of evolutionary biology and what species are as evolving entities. This segment summarizes key concepts and provides links to deeper discussions of what they mean. If my brief summaries here do not sufficiently answer your questions, please explore the links.

Living entities maintain their lives through interactions with (1) the non-living environment in which they are immersed and (2) other living entities also existing in that environment. As discussed in the INTERLUDE, each individual continues living only so long as it can sustain its self-maintaining dynamics through its interactions with its immediate environment (Figure 54, Figure 58). In other words, continued survival depends on the individual's capacity to respond adaptively to the ever changing nature of its immediate environment. "Adaptation" has two meanings that are important to us here. As a noun, an adaptation is a characteristic of an individual's or species' biology that helps it survive in its present environment. As a verb, adaptation refers to physiological changes and individual makes or the evolutionary a species makes to better survive in its environment. This adaptive capacity is determined by the knowledge embodied in its dynamic structure through genetic heritage and living cognition. An individual's accumulated knowledge is lost with its death. Life continues with reproduction, where an individual's progeny inherets some of the survival "knowledge"[382] accumulated by its parent(s).

In sexually reproducing animals, progeny inherit genetic knowledge from both parents (see Mixing W3 knowledge from different parents), and e.g., in mammals, may also have the opportunity to culturally acquire additional survival knowledge (i.e., inherit cultural knowledge) from parents and other related individuals (see Culture: the social sharing knowledge at a higher level of organization). As a result of this kind of inheritance a malleable "*heritage pool*"[383] of shareable survival knowledge comprised of genes and cultural heritage is established in the population or group of interbreeding and possibly knowledge sharing individuals. Such pools of heritable knowledge are able to persist through times much longer than the lifespan of any single individual. The total population of individuals existing at any time that carry parts of that shareable knowledge form an "evolutionary species" (see White et al. 2014 for discussion of different species concepts)[384]. The evolutionary species persists through time as long as individuals sharing heritage from that heritage pool continue to survive and reproduce. The heritage pool changes through time as individuals carrying parts of it succeed or fail to transmit the genetic and cultural knowledge they carry to their progeny or (in the case of cultural knowledge) other members of the population. It should also be noted that the heritage an individual passes to the subsequent generation is not always an accurate copy of the knowledge received from its parents. Further, if at any time no individuals of the species survive to reproduce the heritage they carry, its pool of survival knowledge is forever lost and the species becomes extinct.

The best we can do to reconstruct the evolutionary history of a species through time is to build an "*evolutionary hypothesis*" based on our understanding of evolutionary processes and such physical evidence that survives into the present from past events that can be used to constrain our reconstruction. If we are lucky, physical evidence may include fossil remains, geological traces of paleoclimates and ecologies, and the comparative biologies of species of interest and their assumed close relatives. Based on our reconstructions we can talk in terms of "paleospecies" and "chronospecies". A paleospecies refers to the population assumed to exist at a particular time that left the remains resulting in the formation of a morphologically distinctive fossil (or, if we are very lucky, a group of more or less contemporaneous fossils). A chronospecies is what we infer left a sequence of morphologically related fossils over a long enough period of time to exhibit significant changes in morphology (i.e., the differences between early and late fossils might be large enough that they have been named as different paleospecies).

A chronospecies' survival and evolution through time depends on knowledge inherited by each generation from the species' heritage pool of the previous generation that determines the capabilities of individuals to adapt to the vagaries of their immediate environments (see Adaptation, Knowledge and Strategic Power in Popper's Three Worlds). The part of the environment where individuals carring knowledge sampled from the species' pool can successfully reproduce in competition with other species and that is accessible for their use is called the species' "ecological niche" (see also Biological evolution vs. revolutions). The niche can be described as a multidimensional space where the species can survive described by an array of variables relating to geography, such as trophic position (place in the food chain), gradients of temperature and humidity, access to cover and other limiting resources (e.g., water to drink). The species' niche can evolve through time as the physical, biological or competitive environment changes and the species' individuals are more or less successful passing their heredity to subsequent generations. According to the competitive exclusion principle, two different species cannot occupy the same niche in the same environment for a long time. One or both species must adapt (i.e., shift their respective niches) in such a way that each is better able to pass on their species specific knowledge in some part of the environment than the other. Species' hereditary pools of knowledge will change through time (i.e., evolve) as they continue to improve their adaptations in response to changes in their physical and biotic environments.

We need to clearly distinguish between the different units of inheritance. "Genes" determine individual anatomical, physiological and neurological capacities. A mutation to a gene is a physical change affecting one or more DNA nucleotides at specific places on a chromosome. Change in the genetic composition of a heritage pool is a slow multi-generational process depending on natural selection from the environment results in slow changes to the species adaptive responses. In other words, genetic evolution generally results in movement of the species' ecological niche rather than increases in its overall versatility. "Memes" are units of culture (ideas or values or patterns of behavior or items knowledge) that may be passed between individuals or from one generation to another by non-genetic means (Dawkins 1989). Memetic changes are often *intra*-generational depending on innovation, interpersonal relationships and social processes. Transmission of memetic knowledge is limited by genetically and culturally determined capacity to communicate detailed information. Given the subjective nature of memes, essential information easily lost or corrupted over generations. Finally, the overall the rate and extent of cultural accumulation of memetic knowledge depends on genetic capacity, group size, and (culturally transmitted) cultural practices.

A population adapts to changes in its environment in two ways. Natural selection on genes works at the level of individual genetic variation depending on successes of carriers of particular genes in the population. Where a particular gene or combination of genes improves the ability of its carrier(s) to pass the genes on to its progeny, it will increase in frequency in the population. The converse is also true. Selection on cultural knowledge works at the level of culturally variant groups within the broader species, depending on successes of the different groups. A group whose shared cultural knowledge allows it to solve problems other groups can't solve grows at the expense of those other groups. It should be noted that items of cultural knowledge may be carried by individuals between groups to speed the evolutionary arms race. And, finally, the rate of cultural evolution depends fundamentally on individual's genetically determined capacities to understand, remember, and transmit cultural knowledge.

When we consider a population's or species' evolving adaptation, we think in terms of the niche it occupies on the adaptive landscape. In most cases the population's adaptive landscape is determined by how well its heredity adapts its members to the states of variables relating to particular locations in the physical geographical landscape. Individuals/groups close to the optimum match between their hereditarily determined capabilities and the states of important environmental variables have best chances to pass on their hereditary knowledge of the environment (i.e., the greatest fitness in the particular landscape). The population's niche is that area of the environment where individuals can survive and reproduce. Individuals/groups whose heredity poorly equips them to survive in the landscape are less successful in transmitting their heredity.

Different successes among individuals in the group or population in transmitting the heritable knowledge (genetic or cultural) they carry results in natural selection to change the shape/distribution of the population's niche on the landscape. In the absence of environmental change, selection is normalizing. If changes in the physical environment reduce fitness on one extreme of the adaptive landscape, and improves fitness on another, natural selection on the heredity determining the population's adaptation will cause the niche to shift in a direction that optimizes the overall population fitness (Figure 161 left). Alternatively, under some circumstances selection may also work to make the population more versatile, with the result that the population becomes fitter across several environmental extremes (Figure 161 right).

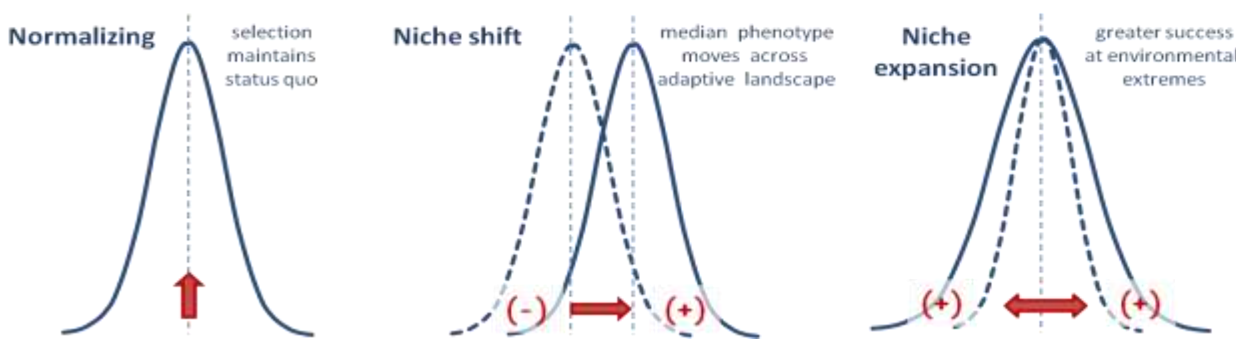


Figure 161. Niche shift vs niche expansion. The vertical axis represents reproductive success in passing heritage from one generation to the next. The horizontal axis represents environmental variables. Pluses and minuses represent positive and negative changes in fitness. The red arrows indicate changes in the shape and location of the occupied niche on the adaptive landscape.

Genetic adaptation is passive and slow in the sense that gene pools are slow to respond to natural selection. Selection can only operate on genetic variation existing in a population at any time. Mutation is blind, and most new mutations are quickly eliminated because they are lethal or detrimental to the individuals carrying them. Even where an individual mutation is significantly beneficial, frequencies change only from one generation to the next, such that it takes several to many generations to make a significant genetic change. By contrast, where a population's genetic constitution provides the necessary cognitive capacity for this to be possible, cultural adaptation can be quite rapid, where a meme can be shared with all members of a population within a single generation.

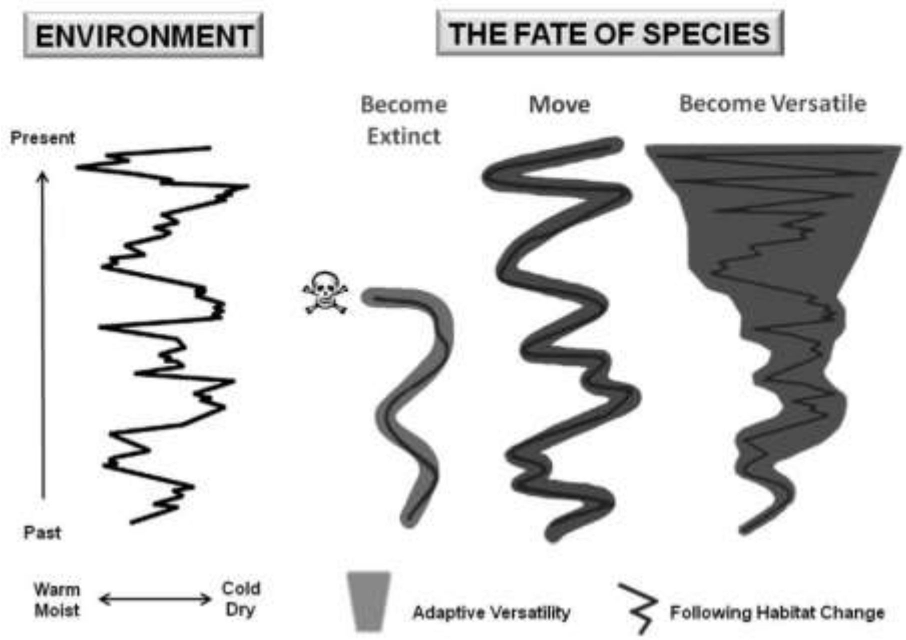


Figure 162. Possible adaptive responses to environmental variability (after Potts 2013a).

Populations facing stresses from environmental variability have three possible adaptive responses (Figure 162). If the environment changes more rapidly than the population can track adaptively, it becomes *extinct*. Where the population can adapt fast enough to cope with environmental changes, it can survive by tracking changes to *move* its niche accordingly. A third possibility is that the species may adapt to become more versatile, in that it adapts to fit current requirements without losing its previous adaptations to conditions that may return at some time in the future. Excepting rare instances of gene duplication that may allow the independent adaptation of genetically determined physiological process determined by the products of single genes, genic selection rarely leads to diversification. On the other hand, where a population has the necessary cognitive capacity to store and transmit cultural knowledge, a population may add new adaptive memes to its heritage pool without losing or altering existing ones, thereby leading to the *cultural accumulation* of survival knowledge. Finally, adaptive changes to a varying environment may lead the population across some kind of environmental threshold where it gains access to broader adaptive landscape (i.e., leading to a grade shift).

Species' populations and associated gene pools can fragment, e.g., where an environmental change creates a "geographic barrier" to separate populations by regions of the environment where they cannot survive, or where chromosomal or other mutational differences between subpopulations reduce the fertility of hybrids enough to significantly impede gene flow between the subpopulations (Hall 2009). In such circumstances, the separated populations can then respond independently to adapt their niches to the environmental circumstances they find themselves in. Over time, the separated populations may become so different that they no longer attempt to interbreed if their ecological/geographical ranges subsequently come into contact. This is called "speciation".

How and under what circumstances different species are recognized taxonomically by formally naming them is very subjective and dependent on the circumstances and the taxonomist(s) studying them. For extant species it is generally assumed that they are sufficiently different to be named when they can be clearly differentiated by morphological characters and no longer exchange genes with one-another. In the past, before the development of the "biological" and evolutionary species concepts, species were recognized by morphological (i.e., phenetic) differences. It is also the case that intermediate situations exist in nature where populations are in some borderline realm between clearly belonging to what is a single biological species and existing as clearly different biological species.

For virtually all fossils (i.e., excepting only the exceedingly rare cases where ancient DNA has been successfully extracted and sequenced) species identifications are based purely on morphological evidence. Two concepts are applicable: "paleospecies" for fossils from a particular time period, and "chronospecies" which applies to what is assumed to be a single evolutionary species over a longer time period, where there appear to be gradual morphological changes in the lineage through time in response to changing adaptive requirements. Assigning a species name to a fossil is always difficult (White 2014). As for living species, morphological differences are assumed to relate to adaptive differences relating to the ecological niches occupied by the species.

Individuals and societies

All living entities have three major imperatives that must be met if they are to survive: sustenance, shelter, and defense. From a species' point of view, enough individuals must also reproduce in order to maintain a viable population beyond the lifespans of single individuals. What this means is that individuals must "know" enough about the environments in which they live to maintain *strategic power*[385] over sufficient "resources" in that environment to maintain a enough energy flow through their bodies to support maintenance, growth and reproduction; and to be safe from extreme environmental conditions, predation, and aggression by other living things in the environment. This "survival knowledge" or epistemic power may be built into the genomes of biological species by natural selection or the development of knowledge that can be transmitted culturally, where it must be understood that culture and society mean different things.

Most mammals are social to some degree. Males and females must find each other and come together to mate, often leading to social interaction and competition within the sexes for mates. Males may also help females raise young. On the other hand, because members of the same species generally have the same or at least very similar ecological requirements for resources, there is always some conflict between the social and individual exploitation of resources. Herding, communal nesting, and living together in social groups are selectively advantageous only where there are more survival and reproductive advantages to be gained from associating in a group than from maintaining independent territories or home-ranges. Aside from the advantages gained by herding animals from cooperative defense and confusing predators, and that of associating with a member of the opposite sex that might otherwise be hard to find in the breeding season, *a major evolutionary advantage social behavior offers can be the cultural transfer of useful survival information/knowledge from parents to progeny or amongst other* *members of the group*. Such information may be transferred by calls or gestures to alert or warn others in the group of dangers (e.g., predators), or of good things to eat; and by leading or finding the way to scarce or seasonally limited resources such as water, salt licks, green fodder, and fruiting trees.

In our close and primate relatives (and presumably in our ancestors), the cultural transmission of survival knowledge has become an important component of their knowledge-based ecology. For example, older members of the troop have learned where seasonably abundant food sources are located, or where water can be found during droughts (e.g., in tree hollows, by digging in dry stream beds), etc. For survival of the species this knowledge needs to be passed on from one generation to the next and is too specific or ephemeral for it to become encoded at the genetic level. This knowledge transfer presumably takes place as younger members of the group follow older, more experienced parents and other troop members and learn from watching and imitating what they do.

Most significantly, some primates have learned to make and use tools to harvest otherwise inaccessible foods (as discussed earlier in the topic on Technological revolutions). Without speech, young members of the troop (group) acquire this knowledge through many OODA cycles (Figure 8) where they watch skilled individuals, try to understand what the skilled individual is doing, try to replicate what was done, and observe and improve the results of their own actions. These activities can be seen in one of my favorite BBC video clips (Figure 163a). As cognitive capacity continues to evolve to facilitate group living (see Cognitive revolutions), learning may extend to understanding what other individuals in the group may be thinking and using vocalizations to influence this as illustrated by another short clip (Figure 163b). Observations of group structure, socialization, vocalization, culture, and tool use in the various groups constrain speculations about how human language, tool-using and social organization emerged and evolved to give us effective dominion over the earth.

Figure 163. Monkey business. Years one and two learning the capuchin nut-cracking industry (click picture for BBC video). Another video clip shows a similar nut-cracking culture developed and learned by a group of our closer relatives, the chimpanzees[386].

Over 5 to 7 million years ago our hominin lineage split from our last common ancestor with chimpanzees and bonobos, became bipedal, made simple tools, and risked being eaten by big cats. By 2 to 1½ million years ago hominins had become the apex carnivores over most of Africa and Eurasia. In the last ~70,000 years, supported by an emerging capacity to transfer knowledge via speech and remember it using mnemonics, our ancestors entered an exponential evolutionary spiral of recursive positive feedback between the social accumulation of cultural knowledge about the world and the making of increasingly complex and powerful tools to interact with that world. This positive feedback cycle (1) enabled progressively more extensive ecological niches to be controlled by groups of people and (2) provided ever-more opportunities for accumulating knowledge. Cultural knowledge represents a new kind of heredity that is preserved and transmitted by group processes that can be shaped by evolutionary processes. How this happens is based on the following premises:

- Humans are fundamentally social organisms

- Sustenance, information, knowledge, and status are all shared and exchanged via social interactions
- All social interactions depend on communication
- Evolving social systems increase human control over "nature"
- Technological revolutions enabled grade-shifting cognitive and ecological changes in the nature of humans

Humans have evolved through the following scenarios of increasing (self-)regulation and control over the world:

- Cooperative scavengers & hunters tacitly build/maintain tribal knowledge
- Hunter-gatherers add capacity for language to coordinate hunts and accurately transfer knowledge
- Add mnemonics to greatly increase memory capacity to support the Agricultural Revolution
- Add counting and recording capabilities to enable the development of the clerical city state
- Add literacy to enable the development of commercial trading companies
- Add printing and universal literacy to enable science and industry.
- Add computing to enable national and global enterprises.
- Add social technology to re-enable smaller groups and organizations to compete with the national and global enterprises.

Societies and cultures

Humans are fundamentally social. Social interactions make the fabric of our lives, first between babies and their mothers, then babies and their extended families, then children with their neighbors and peers, and adults with friends, colleagues, and people they interact with in the economic ecologies of their communities. Sustenance, information, knowledge and status are all shared and exchanged via the social interactions we all engage in. All social interactions depend on communication of some kind. The networks of interaction and communication that are important to daily work and survival form social systems that are defined here as "organized groups of individuals joined together because of work, interests, etc. in common". The heritable result their shared interests, interactions and communications is culture: "the ideas, customs, skills, arts, etc. of a people or group, that are transferred, communicated, or passed along, as in or to succeeding generations" (definition 6 from Webster's New World).

Before writing allowed long-distance interactions via asynchronous correspondence, other than leaving visible environmental changes people could *only* communicate visibly or audibly face-to-face. Before electricity was domesticated for communications, the number of other people a person could interact with over (say) the period of a day was substantially limited. Similarly, until the last few decades, essentially all our interactions with tools and technology were mediated via direct physical contact between the person and the technology. By comparison to what we can do today, this requirement for physical proximity within reach, sight or earshot, or communication via the comparatively slow physical transport of paper correspondence, made the sharing of knowledge and the development of group decisions or actions a reasonably deliberate process that maintained clear physical and cognitive boundaries between one individual and the next. *The social capabilities and culture we inherit today did not evolve to* *cope with instantaneous communication over long distances.* The new world of instantaneous communication creates a variety of new demands.

With telephones and radio, it became possible for people anywhere in the world to interact in real time and with increasingly powerful technologies than possible for face-to-face or face-to-interface contacts. However, telephones, radio, TV and even email (because it is asynchronous) caused relatively minor changes in human cognitive activities, compared to radical and revolutionary changes mediated beginning around the year 2000 by newly developed "social networking" and "cloud computing" technologies as discussed in the last two Episodes.

This episode looks at the coevolution of human cognition and cognitive technologies as these impact interactions of people forming organized social entities that depend on and construct cultural knowledge. It explains how certain apes, whose ancestors from the early Miocene era 10 million years ago remained forest dwellers and became today's orangutans, gorillas, chimpanzees, and bonobos (see below); while our hominin ancestors gradually developed new tools allowing them to thrive on the African savanna three to four million years ago. From this beginning, hominin tools became more complex with the development of compound weapons less than 70,000 years ago to begin a period of rapid technological evolution to dominate local ecologies with domesticated animals and agriculture around 9,000 years ago; to the point of having such a powerful impact on our natural environments over the last 100 years or so that to long sustain our societies on planet Earth, we need the resources of two more planets like Earth.

This story begins with our ancestors' evolutionary developments of tools and language, and follows the coevolution of tools, cognition and social systems through the various revolutions discussed in the previous episodes of this book to explain how we humans have achieved our presently unsustainable hegemony over our planet. As will be seen, the impacts of evolving technologies on organizational cognition is even more pervasive than their impacts on individuals.

APPENDIX 2

Chimpanzee Technologies

Purpose	Name	Tool	Usage	Ext.[a]	Freq.	Manufacture	Refs
			Defense /aggression				
Attack/ defend	Aimed throw	Rock, Stick	Threat/attack against predator, human or other threat	7	+/C	Pick up	Goodall 1968; Boesch & Boesch 1990; Watts 2008
Attack	Club	Large stick	Bash predator	4	+/H	Gather/ (remove side branches?)	Kortlandt 1980; Boesch & Boesch 1990; Figure 118 bottom left
			Display /signal				
Attract attention	Branch shake	Tree branch	Shake/wave large branch to attract attention (courtship/threat)	9	C	Nil	Goodall 1968; Watts 2008; Whiten et al. 2001
Attract attention	Buttress-beat	Tree trunk/buttress	Beating/drumming with hands or feet to advertise presence	9	C	Nil	Watts 2008; Whiten et al. 2001
Attract attention	Kunckle-knock	Hard surface	Knuckle banged on hard surface to attract attention	5	C	Nil	Whiten et al. 2001
Attract attention	Leaf-clip	Leaf	Tear/rip leaf with fingers or mouth, making a noise to gain attention	4	+/H/C	Gather	Whiten et al. 2001; Watts 2008
Indicate mood	Play start	Plant stems	Hold several plant stems with mouth to invite play	9	H/C	Gather	Whiten et al. 2001
Threaten	Drag branch	Large branch	Drag large branch while running to display aggression	8	H/C	Break off from tree/shrub	Boesch & Boesch 1990; Whiten et al. 2001
Threaten	Unaimed throwing	Stick / rock	Throw accessible rocks/sticks			Grab	Goodall 1968

Foraging and Feeding

Access Nutmeat	Crack Nut	Hammer + anvil + optional leveler (1 H)	Stabilize nut on level anvil (log or stone), strike with hammer (branch or stone) hard enough to crack nut without mashing contents	6+	C	Select suitable anvil (stone or hard log), select hammer (hardness & weight), level anvil with other stone if needed	Kortlandt 1986; Sugiyama 1997; Matsuzawa 2011; Ohashi 2006; Carvalho 2011; Figure 118 top right
Branch haul	Stick hook	Strong stick with protruding side branch	Used to pull a branch of an otherwise unclimbable fruit bearing tree close enough to grab, and climb into the tree	1	+	Break off stick/branch of suitable length and side branch, strip off thorny bark leaving side branch to serve as the hook	Sugiyama & Koman 1979
Capture animal prey from hole	Probe for / spear prey	Sharp stick	Poke into hole	3	'+/H	Break off branch, trim off leaves/side branches, trim ends/strip bark, sharpen end with teeth	Ohashi 2006; Puretz & Bertolani 2007; video
Dig roots / tubers	Stick dig	Stick / branch / thick bark	Use as pick / shovel / hoe to access roots / tubers	1+	H	Select suitable tool	Hernandez-Aguilar et al. 2007
Drink	Sponge	Wad of leaves, moss, other fiber (use of a stick to extend sponge into a deep hole seen once)	Sop up water or other fluid / squeeze in mouth to drink	U	C	Chew in mouth / gather	Sugiyama 1997 (palm juice); Ohashi 2006; Sugiyama 1995 (drinking water stick+sponge); Lanjouw 2002; Hobaiter et al. 2014 (moss sponge)
Drink	Well (+ sponge)	Hole dug in river bed	Dig well in river sand, allow water to collect, use sponge if required for deep hole	1	H	Dig hole by hand	McGrew et al. 2013

Extract flesh	Pick	Probe	Extract contents of cracked nut, bone, skull to eat	1	C	Strip	Boesch & Boesch 1990; Sanz & Morgan 2007
Extract fluid	Fluid-dip	Stem, stick or wand	Use probe to extract water/honey	7	H/C	Strip leaves/twigs	Goodall 1968; Boesch & Boesch 1990; Ohashi 2006; Sanz & Morgan 2007; Watts 2008
Harvest ants on ground	ant-dip	Wand (grass stem or leaf), small stick	Collect insects swarming up wand manually or with lips. Longer probes used with biting ants than for termites. Used for nests in/on trees and underground	3	+/H/C	Strip leaves/twigs	Goodall 1968; McGrew 1974; Nishida & Hiraiwa 1982; Sugiyama 1997; Boesch & Boesch 1990; Hicks et al. 2005; Ohashi 2006; Fowler & Sommer 2007
Harvest ants/termites from nest	Perforate / fish	Woody sapling, (often followed by) straight wand (often with frayed tip)	(Optionally) break hole into ant nest prior to dipping, insert wand through hole (often made by perforator) into ant or termite nest to collect insects that bite the wand	13	C	Select woody sapling & remove lower branches	Sanz et al. 2009, 2010; Sanz & Morgan 2007; Sugiyama 1997; Hicks et al. 2005; Fowler & Sommer 2007; Watts 2008; Figure 118 top left
Harvest honey	Pound, probe, brush Dip, kill, probe, dig, pry/ram, pound, swab, whisk	Twig, stem, stick, club, bark strip, leaves	Maximise honey harvest, minimize stings	21	C	Whatever it takes! Often involving a tool set: pounder/ enlarger to open hive followed by probe or brush dipper to collect honey [See Sanz & Morgan 2009]	Sanz & Morgan 2009 [review of methods/tools]; Sanz & Morgan 2007; Ohashi 2006; Wilfried & Yamagiwa 2014; Hicks et al. 2005; Figure 118 bottom right
Harvest insect larvae	Probe hole	Small stick	Probe into hole to remove larvae	1	+	Break off suitable length from tree/shrub	Ohashi 2006

Harvest insects	Expel/stir	Strong stick	Agitate in a hole/hollow to force out insects	4	H/C	Strip leaves/twigs ?	Whiten et al. 2001
Harvest insects from tree nest	Nest club / pound	Heavy stick	Pound nest, kill bees, smash surrounding substrate	3	+/H	Strip leaves / branchlets	Whiten et al. 2001
Masticate	Food pound	Hard substrate	Pound food on substrate to tenderize it	3	H/C	Nil	Whiten et al. 2001
Masticate	Pestle-pound	Base of palm frond	Mash palm crown apex	1	C	Strip leaves from axil	Ohashi 2006; Yamakoshi 2011;
Pry	Lever-open	Strong stick	Pry open/enlarge entrance hole in tree/branch/log	3	H/C	Remove side branches	Goodall 1968; Watts 2008
Scoop algea	Harvest spirogyra algea	Wand	Swirl stiff grass stem in algea patch to collect on stem, then strip algea with mouth	1	C	Strip leaves from stem	Ohashi 2006.
			Personal care				
Chase insects	Bee whisk	Leafy branch	Swat bees away from hive	1	+	Break off tree	Watts 2008
Clean	Sponge	Leaves	Wipe body	1	+	Gatjer	Boesch & Boesch 1990
Comfort	Seat vegetation	Large leaves	Make comfortable seat	3	+/H	Gather	Whiten et al. 2001
Groom	Comb	Leaf stem	Comb body hair	1	+	Nil?	Whiten et al. 2001
Groom	Nasal probe	Small stem or stick	Probe own nose to clear nasal passage	1	+	Strip leaves/twigs	Whiten et al. 2001
Security / sleep	Nest-build	Leafy branches in living tree	Make comfortable nest for sleeping	U	C	Tree: bend, break off, weave, line	Stewart 2011
Stimulate	Self-tickle	Stone or other object	Probe, push or rub ticklish areas on self	1	H	Gather	Whiten et al. 2001
Wipe	Leaf-napkin	Leaf(vs)	Clean body	6	+/C	Gather	Goodall 1968; Watts 2008
			Sensory				
Distance sense	Investigatory probe	Stem or stick	Insert into hole or recess to feel / withdrawn to sniff end	6	+/H/C	Strip leaves/twigs	Goodall 1968;; Ohashi 2006; Sanz & Morgan 2007

Notes: [a] Extent/number of sites where observed (Whiten et al. 2001)

Notes

1. The application holy war suggesting my title started on 7 November 2000 on a Web forum for technical writers with a relatively innocuous question about implementing the new technology of content management, and can be followed forward in time using the [Thread Next] links before spawning several more threads. It then jumps to a new thread. Further threads can be followed sequentially in a search of the thread index for "real value". The war heated up further when I joined the argument link. The issue of the *value* of the new technology was where most heat was generated. The list owner eventually banned some of the participants when the debate became too personal and vitriolic. This book began with my attempts to explain this phenomenon to its participants.

2. Obviously, given that this is a textual work rather than musical, fugal theory (see Wikipedia) serves more as an ideal for organizing the work rather than a literal structure for my work.

3. Word processors, most desk top publishing applications, HTML editors, etc.

4. My thanks to Briar Press's Web pages and the Melbourne Museum of Printing's Glossary of Printing and Typography for help in recovering an arcane vocabulary I had almost totally forgotten related to an essentially extinct technology. See link for a movie clip of the type of press I learned on. Some of the elements of typesetting are discussed on Graphion's Type Museum pages; see especially link for a discussion of the impact of technological change on 20th Century typesetting.

5. For an extraordinary extracurricular project, Occidental College's calculus instructor (I have lost his name in the mists of time) made arrangements for a group of his students (including myself) to use an early Burroughs (it may have been the 201 model) computer to develop a program able to symbolically differentiate mathematical equations. This seems to be a low-end version of the Burroughs 204-205 range - a first generation commercial computer, implemented in 1954 - see timeline, only three years after the very first commercial computers were produced in 1951. Programming was in machine language, but the project introduced the ideas of analysis, flow-charting and design. The Burroughs 204-205 family is documented *in* Weik, M.H. (1961a) and University of Virginia Department of Computer Science Museum - link. Programming in this environment is described by Joel Rose – link. Having succeeded with differentiation, our next step was to see if we could develop programs to help infer integral equations. This was well beyond the capacity of the Burroughs machine, so arrangements were made for us to submit jobs using decks of punch cards to UCLA's new IBM 709 computer - one of the earlier commercial machines to use magnetic core memory. This latter exercise also introduced us to the FORTRAN compiled language, developed from 1954-58 – link. See Paul Pierce's Computer Collection page for some background on the 709 - link; see also link.

6. In 1981, this was a prototype based on the Z80 chip, mounted on a trolley for portability, having 64 K memory and two 80 K 8" floppy diskettes for programs and storage, running the CP/M operating system with WordStar. Byte Magazine (Sept. 1995) listed both in the top three of their choices as the most influential software products for personal computing - http://tinyurl.com/kp6o5ww. Robert Sawyer (1996) explains why the pre-Windows WordStar is still a better authoring environment than any of today's page layout oriented word processing systems such as MS Word. See also Les Bell's CP/M and Derivatives for a more complete history – link.

7. The SIM system, developed in Melbourne, Australia, by RMIT University, and currently marketed world-wide under the name TeraText by SAIC International (Hall 2001, 2003a, 2007; Hall and Brouwers 2004; Hall et al. 2002, 2008.

8. An indication of how poorly the comparative methodology is understood even at the end of 2014 is indicated by the lack of any definition for "comparative approach" in Wikipedia, despite many uses of the term in other Wikipedia entries; and the great brevity of the entry for "Comparative biology". Although paradigm of the comparative approach is frequently mentioned (with nearly 500,000 hits via Google Search, and 200,000 on Google Scholar), it is learned so tacitly that very few workers have thought to define what it is or how they use it. I had implicitly absorbed the methodology from my coursework in comparative vertebrate anatomy and comparative animal psychology (ethology). Harvey and Pagel (1991) and Miles and Dunham (1993) are amongst the very few to provide conventional descriptions of the methodology. See link for a summary of the Harvey and Pagel book.

9. Notwithstanding the fact that my research was performed at Harvard University's Museum of Comparative Zoology. (I prepared many of the 20,000 lizard chromosome slides referred to on the Web site for my thesis research.).

10. See Lawson 2000.

11. When researching the 1983 paper, I was unable to find any sources actually analyzing the comparative methodology or its epistemic value.

12. Karl Popper's works on epistemology (1959, 1963, 1972, 1994); See also: Routledge's Karl Popper pages - link for works by Popper and works about Popper; R.S. Percival's The Karl Popper Web - link; for a general review of Popper's importance in developing the theory of knowledge see Rafe Champion's The Rathouse - link.

13. See Heylighen, F. (1993). *in* Principia Cybernetica Web for a brief discussion of what epistemology is.

14. A difficulty here is that Popper avoided making definitions due to his stance against Witgensteinian "word games" (Edmonds and Eidinow 2001). Although the definition given here is not an exact quite, it is what I infer from many discussions in his 1972 book.

15. Popper's "The Problem of Induction" (published in "Popper Selections" ed. Miller, D.W. Princeton Univ. Press (1985), pp. 101-117. can be found at - link; the introduction to Diettrich (2000), provides an update review of the problem of induction, and many references to the primary literature. See also Wikipedia – link.

16. As will be discussed below, this is an oversimplified view, which Popper substantially modified and elaborated in later works (e.g., Objective Knowledge - Popper 1972). See also Thornton (2009); Hansson (2008); Stove (1982) and Champion's (2003) critique of Stove's position. Popper's books and philosophy are effectively summarized and explained in a series of Kindle books published in 2013 by Rafe Champion:

- A Guide to The Logic of Scientific Discovery (The Popular Popper)
- A Guide to Conjectures and Refutations (The Popular Popper)
- A Guide to Objective Knowledge (The Popular Popper)
- A Guide to The Open Society and its Enemies (The Popular Popper)
- A Guide to The Poverty of Historicism (The Popular Popper)
- Popper and the Austrian School of Economics

17. At least from my point of view as an evolutionary biologist, Popper's (1972, 1994) epistemology is appropriately applied to establishing evolutionary biology as a science (Hall 1983), but his expositions are weakened by his lack of a deep understanding of biological evolution or evolutionary sciences. The Interlude shows how Popper's evolutionary theory of knowledge combined with an understanding of Maturana and Varela's autopoiesis actually applies fundamentally to evolutionary phenomena. I was startled by the conclusions I reached in

this analysis when after many years familiarity with Objective Knowledge when I came to understand fully what Popper was saying. However, discussion of Popper's evolutionary theory of knowledge requires development of a vocabulary and worldview that is out of context for this early stage in exploring the theory of knowledge. The deepest discussion of this topic will be found in the Interlude section.

18. Basically, a “test” is an attempt to apply a claim or hypothesis to the real world and observing whether the result achieved corresponds to what has been claimed would happen. If something else is observed, the claim has been falsified (at least tentatively).

19. It must be noted here that at least one competent authority on Popper, Joseph M. Firestone (in correspondence) disagrees with my suggestion that Popper was actually thinking of knowledge encoded in DNA as being equivalent to objective knowledge produced by human consciousness. Nevertheless, it was the passages quoted here that started me thinking along the lines that led to this book. The importance of this similarity between evolutionary knowledge encoded in DNA, the encoded contents of computer memories resulting from computations, and human learning encoded in writing will become apparent as the fugue is developed.

20. I don’t disagree with Popper’s thrust in this paragraph. However, as my book develops, it will become clear that my version of world 3 deviates from Popper’s in its placement of speech. To me, speech – unless codified in a persistent medium – is a world 2 phenomenon. Following Walter Ong (1982), speech serves to coordinate immediate social responses in living societies. My reasons for this distinction will become clear in Episode 5.

21. Popper and Kuhn published their seminal works early in the second half of the 20th Century. These provided substantial fodder for many subsequent authors. However, from my point of view as a once practising scientist who had a real-world need to understand the core issues, I have yet to find sources who significantly improve on Popper's and Kuhn's original ideas. Many writers who discuss both Popper and Kuhn in the same work don’t appear to understand that the two followed what I believe were incommensurably different paradigms. One was an epistemologist, the other one was working primarily as an historian. Kuhn's last words on the subjects are to be found in the posthumously published book, The Road Since Structure (Kuhn 2000), which also includes his philosophical autobiography (Baltas et al. 2000).

22. According to at least one critic (Masterman 1970, with whom I agree in this case), Kuhn is an unreliable witness even regarding his own ideas. Even in Structure, Kuhn used the term "paradigm" with more 20 identifiably different meanings. Nevertheless, the term is a useful label for the concept described here. In later works (Kuhn 1970, 1977, 1983), he emphasised that he intended to use the term in its meaning as a "disciplinary matrix".

23. It has also often been debated what Kuhn means by “incommensurability” Chen 1997 clarifies the issue.

24. This is essentially what Nelson & Winter (1982) call organization specific “jargon” that provides part of an organization’s tacit knowledge that serves as a kind of heredity distinguishing one organization from another.

25. The kinds of technological and conceptual "revolutions" discussed in this document do not necessarily involve the replacement of one paradigm by another. As used here, the basic concept of a revolutionary change or revolutionary difference is that distinct groups of people hold onto *incommensurable* paradigms, and thus deal with their subject matters in substantially different ways that may (and often do) lead to communication problems between the groups holding different paradigms.

26. "Heritage" is a concept I will explore in more depth in the INTERLUDE. Here it is only necessary to say that the knowledge an individual inherits from its parents and community includes: (a) genetic information codified in the nucleotide sequences of DNA molecules, (b) epigenetic information passed on in the form of structures in the parent cells including proteins regulating access to particular regions of the DNA molecules, (c) behaviourally transmitted (i.e., "cultural") knowledge, and (d) exosomatically codified knowledge that may be passed on culturally or by parents. Jablonka and Lamb's (2005; 2007), Evolution in Four Dimensions explains how all of this works in an evolutionary sense.

27. Chaotic evolutionary changes associated with threshold crossings may often be an underlying factor contributing to the evolutionary phenomenon that Eldridge and Gould (1972) referred to as "punctuated equilibrium". Prothero (1992) reviews the concept and gives some examples. Gould (2002) is definitive. However, having personally spent more than 10 years studying the population cytogenetics of a lizard radiation encompassing more than 150 species (Hall 1973, 2009), where some lineages appear to exhibit what many would term punctuated equilibria, I do not uncritically accept much that has been written about the sources of the phenomenon. I also note that because well preserved fossils are so rare, changes in the fossil record of a lineage may appear to be "punctuated", that in reality may actually have taken place gradually over hundreds or thousands of generations from one benchmark fossil to the next. Although this is an instant of geological time, it may still a gradual process in evolutionary time, as Gould (2002) reminds the critics of punctuated equilibria and Darwinian evolutionary theory.

28. Rieger, et. al., (1976) defines grade as "a unit of biological improvement from an evolutionary point of view comprising a group of individuals similar in their level of organization" after Huxley (1958). A "grade shift" or "grade change" corresponds to a significant change in the structure or organization of the group or species not directly related to simple changes like body size. In the context I use the term, a grade shift represents changes sufficient to allow the species to exploit a revolutionarily new way of making a living. For example, evidence of grade shifts in brain size in monkeys, apes and humans correlates strongly with major changes in ways the different groups relate to the world (Kaplan & Robson 2002: Dunbar 2003, 2010; MacLeod et al. 2003; Rilling & Insel, 1998).

29. My usage of the term "post-human" does not intend any deep philosophical implications, but only the literal fact that aspects of human cognition are extended, distributed, and may even be shared beyond the physical limits of human bodies. Transhuman would also be an appropriate term but I wish to avoid confusion with de Chardin's "transhumanism".

30. Some time-lines situate the later technological revolutions in history (Barger 1996; Nunberg & Brownstein ????; Lee et al. 1996). These time-lines are old references from my first (2001) draft of the present book, but were constructed from perspectives that are in danger of being lost in the increasingly rapid frenzy of technological change, so I retain them.

31. I tried to introduce the following "picture" of revolutionary changes in 1991 as part of a computer literacy training package I was developing for corporate executives and managers, in hopes that it would help them to comprehend why they needed to understand the new capabilities and rates of changes involved in managing computer technology in the organizational workplace. Development of the training package was cancelled when management decided that they already knew everything they needed to know about computers. In part, the present book grew out of the frustration generated by this kind of attitude. The consequence of the management disinterest cited in this note is that despite having been Australia's largest and arguably most successful defense contractor, the company eventually failed because of its inability to understand how to manage knowledge in their organization (Hall et al. 2009).

32. Corvids (ravens, crows and their allies) are particularly impressive, as shown in this New Scientist video and another reported in Science 9 August 2002.

33. Search YouTube for [animal "tool use"] – notable sequences showing tool use by http://www.veoh.com/watch/v1409539kcDBdYCz?h1=Capuchins+-+The+Monkey+Puzzle monkeys and chimps have been filmed by BBC Wildlife. Hall and Best (2010) have collected links to some of these videos on a single web-page.

34. This book looks at human cognition in an evolutionary context from several points of view relating to the broad question of how did humans come to be different from our ape relatives. We need some common terms we can use to refer to groups of species in our direct ancestory and closely related lineages of anthropoid species we can compare ourselves with. Our understanding of the biology and genealogies of these species has grown immensely over the last couple of decades. This has led to changes in higher level classification that has caused several potentially confusing changes in the meaning of common terms used for various groupings. Most specifically, this relates to collective terms like hominid and hominin that I will use frequently and that must be understood correctly. In this book *hominid* refers to all modern and extinct great apes (that is, modern humans, chimpanzees, gorillas and orangutans plus all their immediate ancestors); *hominin* refers to the group consisting of modern humans, extinct human species and all our immediate ancestors (including members of the genus *Homo* and the extinct genera *Australopithecus*, *Paranthropus* and *Ardipithecus*). For more background see Wikipedia on hominid and hominin and The Australian Museum on hominid and hominin

35. The capuchin monkeys have developed a socially transmitted industry for processing otherwise completely inedible palm nuts that is probably as sophisticated as anything our own anthropoid ancestors were capable of up to 2 million years ago. Field work (Mannu and Ottoni 2009; Visalberghi et al. 2009 – the latter article supported by video clips) and laboratory work (Evans and Westergaard 2004; 2006) suggests capuchins have a very good understanding of tools, and are even capable of flint knapping to make their own. Manu and Ottoni have observed capuchins to use sticks and stones to dig up edible tubers (2009) See also Ottoni et al. (2005) on teaching and learning in wild capuchins.

36. According to Sue Savage-Rumbaugh et al. (2001), Kanzi mastered knapping in four distinctive stages over many years of practice: (1) Kanzi got the idea of knapping stones to produce a cutting tool by watching a human knapper. However, rather than using the bimanual method demonstrated by the human (where a target "core" stone is held in one hand and a precision blow is aimed against its edge by a "percussion" stone held in the other hand to form a sharp flake), Kanzi began by symmetrically banging two stones together until one broke. Pieces formed this way were generally only marginally useful. (2) Kanzi soon improved the process by throwing broke the stone against a concrete pad using either hand. (3) The next improvement in his technique occurred when the knapping site was moved to an area where only soft soil was available. For a short while he went back to banging the stones together as in (1), but then improved his technique by putting one stone on the ground and using precision to throw the second stone against it – which yielded more useful flakes. (4) It took several more years before Kanzi acquired the proper bimanual technique shown in the video. To learn this, he was only allowed to do his knapping in a wading pool filled with a foot or so of water. On hot days Kanzi was quite happy with this arrangement! Given that none of his old techniques worked in this environment, he eventually combined precision muscular control learned from throwing one stone at another with the need to hold the core stone stationary while striking with the percussion stone. With practice he further learned to strike the edge of the core and to tell by sound alone whether he had struck an appropriate flake. (On a personal note, while completing my undergraduate degree at San Diego State College in the early 1960's, I helped Sue and her

husband Duane maintain the colony of primates they used in their studies of monkey intelligence).

37. E.g., see Cramb (????) for other references to the origins of metallurgy.

38. E.g., see The Newcomen Steam Engine. Arguably the hand-operated European printing press, invented around 1450, was the first industrial technology. However, the huge cognitive impact of this particular industrial invention is the theme of another major subtheme in my Subject, to be elaborated below.

39. See other fascinating source documents on the history of steam technology from the University of Rochester's "Steam Engine Library".

40. E.g., see: Textile manufacture during the Industrial Revolution - Wikipedia.

41. I make no claim to have invented the term, "microelectronics revolution", but I am intrigued by the fact that as at 9 May 2010, Google returned only about 25,000 hits on this term compared to more than 4,670,000 hits on the term "industrial revolution". More common names for the microelectronics phenomenon are "information revolution", which yielded more than 444,000 results hits, "internet revolution", yielding about 322,000 hits, and "computer revolution", with 300,000 hits. (Note: click the "hits" links to see today's count.) However, the latter terms mingle and confuse issues relating to the revolution in technology measured by Moore's Law (see below), together with the cognitive revolution in how humans manage knowledge enabled by the technology. I am further intrigued by the fact that the industrial revolution is still more recognised as a phenomenon deserving a distinctive name than is the currently pervasive phenomenon named by the microelectronics revolution and its near synonyms. (*Note added in December, 2014* – in reviewing the numbers of hits today, it seems that pages referring to the microelectronics revolution are falling off the Web, with about half the number of hists recorded in 2010; while the number of references to the industrial revolution have doubled and other references are about the same. However, to me, the fundamental driver of the revolution is the continued shrinkage in the size of the logic elements.)

42. History of Medical Informatics - link; ASIS Pioneers of Information Science in North America: John Shaw Billings - link; O'Connor and Robertson (1999). An abacus helps a human compute. The calculating machine does the computation for the human.

43. See link for an English view of the early history of the development of computing (Note: the rectangular boxes along the left margin of the Web page take you to illustrated articles).

44. It must be recognized that Moore's Law, even with added doublings enabled by using the 3rd dimension and quantum computing the exponential increase will be stopped at the sizes of individual electrons, atoms and molecules that may potentially be used as logic switches. However, quantum computing, by completely changing the nature of computation may offer further doublings of processing speed when the phsical limits of substrate are reached.

45. [http://www.ebnonline.com/digest/story/OEG20000505S0063] This reference, used in my 2001 draft of this work is not recoverable.

46. These are obvious cognitive revolutions in human history (e.g., Harnad 1991). Harnad and I both agree that the "Fourth Revolution" is a knowledge-based revolution being enabled by microelectronics, but - probably given our different time horizons in the revolution - we differ on what its key features are/will be from the cognitive point of view. Robertson (1998) identifies the same revolutions as being crucial "categories of civilization", and measures their cognitive impact in terms of the increased number of bits of information that could be controlled by a single human.

47. There is no evidence that anthropoid apes, our tool-using and making close relatives have anything approaching a symbolic language (see notes [33] and [35]). However, there is increasing evidence that our common ancestor with Neanderthals probably did have this capacity (Dediu & Levinson 2013; Johansson 2013).

48. Cambridge University Press, who will be publishing Lynne Kelly's research as a book sometime in 2015 has required Lynne to have Latrobe University embargo her 2012 PhD thesis, "When Knowledge Was Power" until August 2016. Some of Lynne's ideas have been published on her blog, Memory Spaces.

49. Nissen (1993); Eby (????); Lo (2000) see Cuneiform - http://tinyurl.com/y8aab55, Timeline - http://tinyurl.com/6xd46e; Heise (1996?) Chapter 4 - Cuneiform Writing Systems - http://tinyurl.com/27nhsob.

50. Writing is defined by Trigger (2004) strictly as a system to "represent an utterance in such a way that it can be recovered more or less exactly without the intervention of the utterer" (after Daniels) or more broadly, that it is a "system of intercommunication by means of conventional visible marks" (after Gelb). Some argue that Schmandt-Besserat's (1980, 1996, 2010) supposed evolutionary development of writing lacks solid evidence. Rather, following Glasner (2003), at least in Sumer, it is possible writing was "invented" within the lifetime of a single person (Damerow 1999; Houston 2004; Postgate 2005; Sprochi 2004).

51. Orientals used moveable ideographic type at least 300 years earlier, but there is little evidence that this greatly influenced the evolution of their cultures, e.g., see Chartier, R. (1996). For information and links on early typesetting in the European context see Graphion's Typesetting Museum - http://tinyurl.com/24rtx4e.

52. Clement (1997a); Rubenstein (1994-1999). See Gutenberg Digital, a hypertext prepared by the Goettingen State and University Library in 2000 to celebrate the 600th anniversary of Johannes Gutenberg's birth. This includes a digitized copy of the complete Göttingen edition of the Bible. See also, Guild Hall: Gutenberg Notes, a lovely hypertext rendition of what it meant to be a printer in Gutenberg's times put together by students(?) of Twin Groves Junior High School, Buffalo Grove, Illinois.

53. A major reason I have chosen to refer to a new "Reformation" in the title of this hypertext is that we are undergoing a revolution in cognition comparable (though greater in scope) to that introduced by the invention of the printing press and the transition it enabled from the limited access to knowledge in priceless manuscripts to personally affordable books. Interestingly, protests against veniality of the commercial sale of the cheaply produced indulgences was one of the immediate causes of the Protestant Reformation. Knox and Eisenstein both note the importance the availability of affordable printed bibles made individual bible study possible. Although printing assisted its spread, the Renaissance began before the invention of printing with the rediscovery in Europe of ancient Greek knowledge that had been preserved in the Muslim world.

54. Douglas Robertson (1998), in his book, The New Renaissance: Computers and the Next Level of Civilization, argues that the major impacts of the four revolutions were due to the orders of magnitude increases in the number of bits of information that individuals and society could manage as summarized above. As I will show in the Counter Subject and elaborate more below, *qualitative* changes in the *kinds* of information that can be managed cognitively are probably much more important than the very real quantitative changes Robertson highlights.

55. The main reason the wars are no longer fought is that the main protagonists have tired of the battle or have agreed to disagree, not that they have agreed on a consistent definition.

56. Firestone, J. 2004. "All life is Problem Solving":
On Definition
Ad Hominems, etc.
Poverty of Communitarianism
Poverty -- Act-KM Incident One Pt. One
Poverty -- Act-KM Incident One Pt. Two
Poverty -- Act-KM Troubled Pt. One
Poverty -- Act-KM Troubled Pt. Two
Poverty -- Act-KM Road Pt. One
Poverty -- Act-KM Road Pt. Two
Poverty -- Act-KM Road Pt. Three
Poverty -- Act-KM Incident Two

57. Hall, W.P. 2004. Groupthink, the CIA, and KM: to solve the problem we need to know what it is. (in) "Evolutionary Biology of Species and Organizations".

58. Google is actually a very powerful tool for exploring the spread of ideas. In reviewing some slides for a new KM presentation I came across and updated an old snippet prepared for a KM forum on the fundamental issues differing paradigms create for discourse. The search strings I used are also in brackets – quoted titles in the search strings restrict hits to references to their primary book titles. The numbers speak for themselves:

Search dates: 11/02/2002, (15/08/2002), [14/07/2004], {20/10/2004}, ((11/05/2010)). Click the links to see current hits.

- [Michael Polanyi "Personal Knowledge"] - Google hits = 1,760 (1,450) [4,040] {4270} ((26,300))
- [Karl Popper "Objective Knowledge"] - Google hits = 1,850 (1,570) [3,730] {4310} ((19,700))
- Both of the above together - Google hits = 64 (55) [88] {106 - 7 of the 106 are to my own contributions} ((2,810))

Through 2004, only between 1 and 1.3% of authors citing either book cited both! In 2010 this has increased to 6.5%. Similar results are found doing a similar search on 11/05/2010 of books and journals using Google's recently introduced Scholar search tool:

- [Michael Polanyi "Personal Knowledge"] – Scholar hits = 6,230
- [Karl Popper "Objective Knowledge"] – Scholar hits = 5,760
- both of the above together – Scholar hits = 291, of which 8 are my papers.

Thus, in 2010 only 2.5% of all academic and professional writers citing one of the authors' works on knowledge actually cite both.

59. Until changes in the Computer Sciences course outlines made around 2001 took effect, The Australian Army Information Management Manual, Version 2, was publicly available via the Australian Defence Forces Academy Web server. It would appear that Coombe sourced his hierarchy from Ackoff's (1989) DIKW hierarchy, as elucidated on the Web by Sharma (2008) and Bellinger et al. (2004).

60. Fjällbrant (1994) in Data, Information and Knowledge. Chapter2. - link, presents similar rankings of data, information and knowledge. When I searched Google in March 2001 while working on an early draft of this work for "data, information, knowledge" and "data, information and knowledge", nearly 300 hits were recorded (e.g. sample hits: link, link, link, so the idea of ranking these three terms - and sometimes the fourth and/or fifth terms - intelligence and wisdom (sometimes listed in reverse order under the acronym WIKID) – was already reasonably widespread. When the same search was performed on 7/03/2003, 6480 hits were

recorded, and on 15/05/2010, there were 368,000 hits! However, Coombe extended the ranking further. In 2003 I found one hit (Sheridan 2003) considering these terms (except that he replaces information with "indicators") along a value dimension, that also considers their relationships to power. In 2010 there were 43 hits.

61. The following passage from T. S. Eliot's (1934) play, “The Rock” appears to have been the original source for the DIKW hierarchy (Sharma 2008; Kaminski 2001):

The Eagle soars in the summit of Heaven,
...
The Hunter with his dogs pursues his circuit.
O perpetual revolution of configured stars,
O perpetual recurrence of determined seasons,
O world of spring and autumn, birth and dying!
The endless cycle of idea and action,
Endless invention, endless experiment,
Brings knowledge of motion, but not of stillness;
Knowledge of speech, but not of silence;
Knowledge of words, and ignorance of the Word.
All our knowledge brings us nearer to death,
But nearness to death no nearer to God.
Where is the Life we have lost in living?
Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?
The cycles of heaven in twenty centuries
Brings us farther from God and nearer to the Dust.

Even more interesting to me is that Eliot worked for a PhD in philosophy at Harvard (without taking the degree) before turning to poetry and drama. (Vericat 2000).

Following another lead in Kaminski (2001), I found the philosophical quote from Frank Zappa's (1979) largely obscene song, “Packard Goose”:

Information is not knowledge
Knowledge is not wisdom
Wisdom is not truth
Truth is not beauty
Beauty is not love
Love is not music
Music is the BEST...

...Which, of course relates to my belief that some of the fugues composed as the Renaissance was becoming the Baroque represent a pinnacle of human cognition.

62. Note that the knowledge generated by these processes is not necessarily “true”. Following Popper (1972), all claims to know must be considered fallible.

63. Dempsey (1996); Heylighen (1995); Christianini (1997); Spinney (1997); Christensen & Hooker (1998); Bradie & Harms (2008); Vehkavaara (1998). For further readings in evolutionary epistemology see Konrad Lorenz Theory Lab - Evolutionary Epistemology: link. For definitions of knowledge not specifically grounded in evolutionary epistemology see also Fumerton (2008); Dykes (1996).

64. This meaning may bear some resemblance to Michel Foucault's concept of power; e.g., see Patton (1994), Al-Amoudi (????). See also other references to "strategic power" in this text: [1], [2].

65. My definition here follows that of Peter Morriss (1987: p. 53) based on relative ability, where "epistemic abilities include all your basic actions, and all your actions, and the consequences of them, that you know how to do or bring about." (without distinguishing between an action and its consequences.

66. See also David (2009).

67. I first studied Popper's Objective Knowledge (1972) more than 25 years ago as reported in Hall (1983). Then, in my intellectual arrogance, because his understanding of the practice of the science of biology seemed so poor, I completely failed to understand the significance of his three worlds to the biological sciences. Now, after I have studied Maturana and Varela's (1980) concept of autopoiesis, and have begun applying biological principles to organizational knowledge management (Hall 2003, 2003a, 2005, 2006; Hall et al. 2007; Hall and Nousala, 2010, 2010a; Nousala and Hall 2008; Vines et al 2007; Vines et al. 2010 – as detailed in Episode 4), I now understand that Popper was explaining in clear and simple prose that biology in its own right is epistemology or that epistemology is biology. In this area, the scope and depth of Popper's insights about the evolutionary origins of knowledge have barely been realized.

68. I note here that Lynne Kelly (2012), as will be discussed in depth elsewhere, provides an entirely convincing theoretical argument for the reality of memes as discrete items of inheritance.

69. Under the topic "hierarchical theory of selection" Gould (2002) in his Structure of Evolutionary Theory explains in great detail that natural selection filters hereditary knowledge at many different levels of biological organization and presents a number of arguments as to how this understanding modifies some of the peripheral understandings of the Darwinian theory of natural selection and descent with modification. I accept Gould's arguments, but prefer my own formulation as to what these levels are and how they are defined. From my own point of view as an evolutionary biologist I see organismic natural selection operating on "individuals" at any of the levels of organization corresponding to

- single genes (i.e., some single gene mutations are "lethal" in that they absolutely prevent survival of their carriers to reproduction in any combination of other genes),
- physical chromosomes as they are assorted in the divisions of cells in mitosis and meiosis,
- genic interactions involved in coherent developmental pathways (i.e., some combinations of genes may be detrimental to survival and reproduction even though the individual genes perform adequately in other combinations),
- gametes as they compete to form zygotes (i.e., the expression of genes prior to the formation of a fertile egg or seed is lethal to the gamete or impairs its ability to fertilize or be fertilized),
- zygotes/individual organisms as they compete to begin an independent existence from their parents or as they compete as independent individuals to survive and pass their heredity to the subsequent generation
- demes or local populations of interbreeding individuals as they exist for many or fewer generations of limited genetic exchange with other populations,
- species - the entire population of individuals sharing a common heredity and still potentially capable of interbreeding to form subsequent generations in competition with other species to survive through time, and
- clades - (groups of species sharing a common heredity) in competition with other clades to survive through time.

Note that selective failures to transmit hereditary knowledge can occur at any of these levels of organization. For natural selection to produce adaptive changes in the heredity,

1. the specific item of genetic knowledge must control the development of some form of phenotypic trait (i.e., something that is exposed as a real World 1 product) and
2. that the survival value of that trait in World 1 depends to some degree on the genetic knowledge.

It follows that the failure of any physical (World 1) of the genetically determined individual to survive or pass on its hereditary knowledge leads to a loss of that specific knowledge (as well as all of the other knowledge carried by that individual).

In other words the heritable knowledge passed to subsequent generations is filtered (to the extent that there is some degree of causal relationship between specific knowledge and the expressed phenotype) at many levels, such that knowledge that does not have survival value is not propagated. In each generation a low frequency of random mutation adds variation to the knowledge available to the population of individuals (at whatever level of organization), which is then subject to selection. Knowledge that doesn't work well or at all is selectively removed, such that that which survives is a produc product selectively shaped by its World 1 values.

70. Boyd's concept of the OODA loop has been adopted in a number of disciplines. An indication of the richness of the concept is given by the number of references found via Google - http://www.google.com/search?q=%22ooda+loop%22&btnG=Google+Search (111,000 in July 2013).

71. Boyd's personal library and files included three copies of Kuhn's Structure of Scientific Revolutions (one of them annotated), as well as Popper's The Logic of Scientific Discovery and Conjectures and Refutations. Boyd also specifically used the term paradigm in several of his presentations.

72. Boyd's (1992) Conceptual Spiral talk developing the OODA concept in detail is available via YouTube: Introducing John Boyd, Part 1, Part 2, Part 3, Part 4, Part 5, Part 6, Part 7, Part 8, Q&A session 1, Q&A session 2, Q&A session 3, Q&A Session 4 (Q&A unbroken in QuickTime); The unbroken audio only presentation for the talk is available on Apple's QuickTime, and the presentation slides accompanying the talk are available on http://tinyurl.com/kkmp6zn

73. See especially US Marine Corps Doctrine Publication 6. Chapter 2, Command and Control Theory in, Command and Control:

> This doctrinal publication describes a theory and philosophy of command and control for the U.S. Marine Corps. Put very simply, the intent is to describe how we can reach effective military decisions and implement effective military actions faster than an adversary in any conflict setting on any scale. In so doing, this publication provides a framework for all Marines for the development and exercise of effective command and control in peace, in crisis, or in war. This publication represents a firm commitment by the Marine Corps to a bold, even fundamental shift in the way we will view and deal with the dynamic challenges of command and control in the information age. ... C. C. KRULAK, General, U.S. Marine Corps, Commandant of the Marine Corps [Forward]

For other citations, see Joshi (1999); Berry (2000); Sloan (2000); Black (2007); Nuneck & Alwardt (2008) with thousands more available via Google:

http://www.google.com/search?q=%22Revolution+in+Military+Affairs%22&btnG=Google+Search.

74. Toffler, A., and Toffler, H. (1993), War and Anti-War: Survival at the Dawn of the 21st Century, Boston: Little, Brown, p. 32. [*citation from the original*].

75. Cooper (1994), p. 21. [*citation from the original*].

76. Krepinevich (1994) [*citation from the original*]. Galdi's (1995) Section 3 summarises Krepinevich's lists of revolutions.

77. Krepinevich (1994) p. 30; Cooper (1994), p. 1; in addition, each of the Department of Defense-sponsored service roundtables on the RMA were organized around these four elements. (See The U.S. Army Roundtable on the Revolution in Military Affairs, McLean, VA: Science Applications International Corporation, October 1993; The U.S. Air Force Roundtable on the Revolution in Military Affairs; The U.S. Navy Roundtable on the Revolution in Military Affairs; The Summary Roundtable on the Revolution in Military Affairs.) [*citation from the original*]

78. See http://www.cut-the-knot.com/blue/chaos.html for a simple mathematical explanation and some live demonstrations of the emergence of chaos.

79. Eldridge and Gould (1972) defined the concept of punctuated equilibria. Prothero (1992) provides many examples and reviews how well the idea has stood the test of time. Gould (2002) provides a comprehensive explanation of the non-linear aspects of evolution.

80. 2025 Final Report, Air University - http://tinyurl.com/274gdd3.

81. This is somewhat of an oversimplification. Ong (1982) explains how primary oral (i.e., pre-literate) cultures used a variety of mnemonic 'technologies' to hold large volumes of narrative material in memory. In groundbreaking research Kelly (2012) builds on ethnographic and archeological evidence to argue that the use of group rehersal and ritual combined with the method of loci enabled the storage, sharing and transmission of very large volumes of community knowledge relating to complex technologies, the natural environment, agriculture, etc. necessary for survival. In Episode 5 I will argue that the use of mnemonic technologies to manage community knowledge represents a major cognitive revolution in its own right standing between speech and writing.

82. The etymology of abacus is interesting: The word derives from Latin, from Greek *abak-, abax,* literally, slab, such as the flat tablature at the top of a Greek column. Dusted with sand or inscribed with columns and rows it provides a flat surface for reckoning using pebbles or finger marks as tokens. Today's abacuses represent this surface in an easily portable frame.

83. There is archeological and literary evidence for tablets that are apparently identical to the one depicted on the Darius Vase (Figure 12, see also Figure 15) are known from antiquity up into at least the 16th century (Bowman 1975; Havlock 1977; Woudhuysen 2004).

84. Luis Fernandes' (2010) web site, Abacus: The Art of Calculating with Beads summarizes the historical development and different varieties of this tool, explains how modern abacuses are used to aid calculating, and provides links to a variety of other web-based resources. Heffelfinger & Flom (2010) provide a detailed manual for using the modern Japanese 1:4 bead soroban abacus (Figure 14, bottom). By studying the kinds of mistakes in numerical calculations recorded in Herodotus' writings (ca. 484-425 BC), Lang (1957) also attempts to understand how the Roman abacus was used. In a footnote Lang (1957: 271), quotes specific references to the abacus in Herodotos work:

> Herodotos himself (II, 36, 4) speaks of the Greek method of counting with pebbles in what must be vertical columns and so presumably a form of abacus…. Aischylos' phrase (Agamemnon, line 570) seems also to refer to an abacus. Two calculating references in Aristophanes, Vespae, suggest the physical form and use of the abacus: lines 332-3 … [and] lines 656-7…. The stone slab used to count the votes in the courts is mentioned in Aristotle's Constitution of the Athenians, 69. The use of pebble-counting for calculations too difficult to be done in the head (on the fingers) is also suggested by the fourth-century comedy-writer Alexis (Athenaios, 117 c-e) and by Demosthenes (XVIII, 229). The abacus is mentioned by Lysias (fr. 50 Thalheim)…. As early as the sixth century Solon is supposed to have compared tyrants' men to the pebbles of an abacus: Diogenes Laertios, I, 59 …. Much the same analogy occurs in Polybios, V, 26.

85. Apparently once the contents of clay tablets bearing records became obsolete, they were purged from the archives and literally used for land-fill.

86. Griscom (1998): see Scribal Culture.

87. Hobart and Schiffman (1998) make the point that the illumination and rich visual design of manuscripts and codices were provided primarily as aids to memory for people whose primary mode of transmitting knowledge was by speech from memory (as discussed in Episode 5 - Kelly 2012). *Richly illuminated documents (see link above) were not designed to help a new reader to discover its contents, but rather to retain in memory what was read from the document*. By today's standards of mass produced paperbacks, manuscripts and codexes were incomprehensibly expensive. Far better to help the reader mentally file and retain the contents in memory than to rely on having the priceless artifact at hand when the recorded knowledge was needed.

88. di Curci, M. 2003. The history and technology of parchment making *in* The Royal College and Confraternity of Scribes and Illuminators of the Kingdom of Lochac - http://tinyurl.com/25bm93q. How to make vellum? eHow - http://tinyurl.com/28lclht; Wikipedia: Parchment

89. A chronology of highlights in the historical development of book technology is provided by Knops, C. (2000). Time-table (Chronological). *in* Book Information Website – Time-Table (Chronological). See also Knops Boekrestauratie - Conservation and Restoration of Books and Paper for information on the construction and restoration of early books (note: click on the picture of each kind of book to follow the appropriate link. Sean Gabb The Joys of Bookbinding provides a personal account on the joys of bookbinding.

90. Papermaking in the United Kingdom in The Paper Trail. Rojas & Hubbe 2004.

91. Interestingly, although Orientals invented moveable type and printing some 300 years before Gutenberg (see Note 51), it was in the West where printing fuelled the development of modern science and technology. Apparently, in the East printing was mainly used for the replication and circulation of religious bureaucratic texts rather than providing the basis for Popperian OODA cycles of knowledge testing and growth.

92. How the linotype worked is described by The big scheme of simple operation in Mergenthaler (1940). To me, the linotype is one of the most wonderful inventions of all time – a magical machine that turned molten metal into words.

93. A vocational training film from 1947 demonstrates the entire process of letter press printing when this was the main form of commercial printing - Letterpress Printing Vocational Film (1947 – 10.4 min).

94. Hoe presses dominated the web printing industry for many years: National Inventors Hall of Fame (2002) – Richard March Hoe.

95. I still remember our school print shop's excursions in the early 1950's to the local newspaper to see how the press was set up and run to produce a print run of 100,000 copies of the daily paper. We may well have also watched the same vocational films I have hyperlinked here.

96. See Postpress from Print Process Descriptions: in Printing Industry Overview - http://tinyurl.com/23co634.

97. It is beyond the scope of this hypertext to explore the social upheavals caused by this kind of technological change, but a few references may give a hint: Effects on employment - Baker (1933); changes in newspaper printing during the Industrial Revolution - Musson (1958); demise of the typesetting profession – Pilot (1999), see pp. 12; loss of skills in printing industry 1931-1978 – Wallace & Kalleberg (1982); profound changes in Europe - Bjurstedt (2005).

98. As I write this and despite culls resulting from several overseas moves and losses due to flooding, my private library has 3,500 cataloged books (746 fiction – the rest covering science, politics, history, world affairs, comparative religion, cooking, misc.).

99. Mesopotamian - , in Staikos, K.S (????) - http://tinyurl.com/25okpax. Potts (2000).

100. Library History Group: The Universal Library: From Alexandria to the Internet - Second Anglo-German Seminar on Library History.

101. History (Hellenic), in Staikos K.S. (????); see also the 9 minute video, Mostapha el-Abbadi and the Ancient Library of Alexandria. The concept of the universal library and history of the Bibliotheca is documented a History Channel Video, Library of Alexandria.

102. A library takes shape: Books, benches and borrowers. in Vatican Exhibit - http://tinyurl.com/2b258k6.

103. Wikipedia provides a review article on libraries covering library history, science, classification systems and administration - http://tinyurl.com/58uz2. See also Wikipedia on Library Classification and links therein

104. Introduction to the Dewey Decimal Classification: History and Current Use. OCLC - http://tinyurl.com/36n57bn.

105. Library of Congress Classification Outline. Cataloging Policy and Support Office. Library of Congress - http://tinyurl.com/2u94bca.

106. MacRae Library Handbook, Arrangement of Materials, Background on the Library of Congress System - http://tinyurl.com/2vybrhl gives a brief summary; American Treasures of the Library of Congress: MEMORY: The Order of Books (Monticello, May 7, [18]15) - *in American Treasures of the Library of Congress - http://tinyurl.com/2c722ps.* The following is quoted from a polygraph copy of Thomas Jefferson's manuscript "...*Yet on the whole I have preferred arrangement according to subject; because of the particular satisfaction, when we wish to consider a particular one, of seeing at a glance the books which have been written on it, and selecting those from which we expect most readily the information we seek.*"

107. Leise, F. 2008. Using faceted classification to assist indexing in Con[text]ualanalysis - http://tinyurl.com/m99kfn6.

108. Quoted from a facsimile copy of Jefferson's original letter to George Watterston (Monticello, May 7, [18]15) - http://tinyurl.com/2d2toau.

109. See discussion of satisficing and time in knowledge management in Hall et al. 2011.)

110. As at 18 June 2012, Abe Books has on sale a copy of the Commentarii Edited by Petrus Justinus, Publisher: Milan: Philippus de Lavagnia, Publication Date: 1478, 1st Edition for US$ 20234.99, with 152 leaves.

The text comprises the seven books of the Gallic War with the continuation by Caesar's friend Aulus Hirtius, together with the six books on the Civil Wars attributed to various authors. Added in this edition is the geographical index by the Milanese scholar Raymondo Marliano which had first appeared the previous year in the first edition printed at Milan, by Antonio Zaroto. The editio princeps was printed by Sweynheym and Pannartz at Rome in 1469. The inscription in Latin written on the last leaf verso in a fine lettre bâtarde reads in translation, "This book was bought by Lord Henry Keddekij[?] the twenty-seventh abbot of the church of the Blessed Mary for [?] All Saints Chapel in the year 1480 AD. This book belongs to the church of the Blessed Mary in [?] All Saints Chapel of the Cistercian Order in the Diocese of Tournai in Flanders". This contemporary provenance places this copy close to the University of Louvain, where the compiler of the geographical index Marliano taught classics from 1461 to 1475, one of an unbroken sequence of notable Italian lecturers there. From the library of William Horatio Crawford (1815–1888), the notable Irish collector of books, works of art and rare plants. Crawford, a reserved and dignified man of "ascetic temperament", inherited from his father Lakelands, an old house overlooking Cork Harbour "richly stored with rare books, paintings and engravings" and with a fine arboretum. He funded the building of the magnificent 1884 extension to the Cork customs house which now houses the Crawford Municipal Art Gallery, and part-funded the astronomical observatory at University College Cork which also bears his name. De Ricci (p. 165) refers to his "great library of manuscripts, incunabula and other rare volumes". His estate sale, sold by Sotheby's over 12 days beginning in March 1891, realised £21,255.

111. Justifying these values is difficult, highly subjective and dependent on qualitative as well as quantitative assessments, but as this book develops my reasoning behind these guesses will become evident. It is also worth noting that it would have been impossible to write such a book without near universal access to most knowledge of the world.

112. With the striking exception of the Antikythera Mechanism, an utterly unique archeological treasure, the technology of the ancient Hellinistic world is only known to us through a relatively few scraps of writing (original works, anecdotes, compendia, etc.) that may or may not have been written by those they are attributed to, and that also had to survive many copyings and often translations into other languages (e.g., Arabic, Latin, Egyptian, etc.) before they were printed into modern English, French, German, Italian, etc.

113. A 50 min video from the History Channel, "The Antikythera Mechanism: World's oldest computer" gives a great deal of information about the context and antecedents of the Mechanism.

114. The ten gears that would have been required to produce the planetary motions have not been recovered, although the casing provided adequate space for them.

115. For Archimedes, see also Chris Rorres' web page on Archimedes.

116. See entry on Heron's COIN automat in Michael Lahanas' Heron of Alexandria, Part 2 in Hellenica's Ancient Greece/Science and Technology.

117. A History Channel video on YouTube demonstrates some of the inventions attributed to Heron.

118. See a detailed video and explanation of the operation of the Self-Moving Automatic Theater. Koetsier 2001 does not consider the Automatic Theater to be programmable. However, as noted by Valavanis et al. (2007) and Nadarajan (2007), the mechanism of threads/ropes wound in various ways around the pegs of rotating shafts in these automata was fully programmable by varying the locations of the pegs and the ways in which the ropes were wound. As is also the case for using the pegged shafts to operate sequences of levers or push-rods.

119. See a detailed video and explanation of the operation of the Staton Automatic Theater.

120. As shown, the device is not fully set to its starting position as the cords controlling the ball dropping wheels have not yet been wound around the wheels' shafts.

121. MuslimHeritage's 7 min. video reviews more of Al-Jazari's works.

122. An hour long documentary film on Vimeo by Professor Michael Shaffer, Wonders of the Clockwork World illustrates and documents the ultimate peak of such technology. This is one of the most beautifully produced documentaries I have seen.

123. Details of the three android automatons are summarized by Georgi Dalakov in his History of Computers. The current Pierre Jaquez-Droz company corporate video details the three automatons and other horological treasures they produced in the last half of the 18th Century. Beginning at 5.00 min shows mechanical details of the operation of the Writer. The presentation of the Draftsman and its mechanical details begin at 5.48. The Musician begins at 6.34. The video concludes with a review of their current products, which in my opinion are paltry compared to the 18th Century pinnacle.

124. Still photography gives some idea of the meticulous three dimensional detail of the Writer (Watchonista): (1) high resolution view showing the cover plate for the letter sequencer – note that this is inscribed with the list of 40 different characters the android is able to write; (2) complete letter sequencing mechanism; (3) top of the letter sequencing cam (Watchonista) showing part of the letter selector mechanism; (4) shoulder region (Watchonista); letter cams forming the android's backbone; (5) high resolution diagonal view showing some detail of the actuating mechanism for the writing arm as well as most of the backbone mechanism.

125. See also, Yatsuhashi (2010).

126. Although I learned to use logarithms as a physics student in the late 1950's and early 1960s before I could afford a calculator, there is now virtually no trace left in my brain of this technology, and today it is as arcane to research as is the technology of hand-setting of type for letter-press printing. Thus, I apologize to readers, if my explanations of what was once a hingly important component of scientific and technical learning contains errors or lacks clarity. Note that the time was right for the development of logarithms. Napier's work was paralleled by Joost Bürgi (1552-1632).

127. Clark & Montelle (2012) note that Napier had to make some 10 million individual calculations to formulate his log tables.

128. k12math.com demonstrates the use of log tables with a provision of three significant figures.

129. See The Museum of HP Calculators: How Calculating Machines Work. The model illustrated on this Web page with its cover removed was cranked by hand, but I presume the ones driven by an electrical motor worked the same way. The electrically driven machines were fun to use, making a whirring clatter as they summed a column, a thunk with each shift, and a very satisfying kerwhunkity clatter clatter as they completed a multiplication or long division. In many ways these were the culmination of Babbidges invention. The University of Amsterdam Computer Museum has a manual for the kind of calculator I used - http://tinyurl.com/27w2cb4.

130. Pricing this technology has proved to be difficult. I have been helped by John Wolff (see Wolff 2009). It is even difficult to determine an appropriate inflation index to apply. The way in which the standard US Government consumer price index is calculated was changed in 1980 from a fixed basket of goods to a basket of cheaper alternatives (Williams 2006), which does not correspond to my experience, that today's equivalent to a top of the line 4WD 5 door half-ton van purchased around 1965 for ~$7,000 would now cost ten times this much. Using Williams' Shadow Stats based on the CPI formulas used in 1980 in Tom's Inflation Calculator, for comparative purposes, the equivalent price for a $2,500 calculator purchased in 1970 would be $41,000 in 1990 – definitely out of the personal use category for a financially challenged student.

131. The Jacquard Loom. *in* da Cruz, F. (2008); Punch Card Loom; Connections Episode 4 Supplement: Punched Cards and Computers - http://tinyurl.com/2ebaa8f; http://tinyurl.com/2b9ltn7.

132. Several values have been given, but most seem to agree that the introduction of the tabulating machines reduced the overall labour requirement approximately by an order of magnitude by comparison to the previous census.

133. IBM's corporate history begins with, "IBM Through the Years: Pre 1890" - http://tinyurl.com/29mq4gn.

134. See Wikipedia on punched tape technology. In the early 1960's my wife was one of Australia's first "word processor" operators, where she used a Friden JustoWriter (which stored correctable texts on paper tape – see note under Commercial Printing for Just-O-Writer specific detail) to produce justified camera ready copy for some of the Commonwealth Scientific and Industrial Organisation's journals. See also Eisenberg (1992).

135. IBM Tabulators and Accounting Machines, The IBM 285, The IBM 407 Accounting Machine and Interconnected Punched Card Equipment, all *in* da Cruz, F. (2008) trace the evolution of punch card tabulating and calculating technology as used by Columbia University up through 1950 (and to 2008 for computing in general).

136. Herman Hollerith; Hollerith 1980 Census Tabulator. - *in* da Cruz, F. (2008); Hollerith's Punched Cards *in* Maxfield and Montrose (1998); Punched Card History *in* Jones (2006)

137. Lubar (1992); The IBM 407 Accounting Machine *in* da Cruz, F. (2008)

138. Weik, M.H. (1961); Winegrad and Akera (1996); The Proceedings of the International Conference on the History of Computing, 14-16 August 1998 at Paderborn, Germany published a number of papers on the people and technologies involved in the first electronic computers. See also Copeland 2000 for a history of early computing.

139. The EDVAC Design - http://tinyurl.com/239ppfn. *in* Goldschmidt and Akera (2000); 1944 AD to 1952 AD: The First Stored Program Computer -- EDVAC *in* Maxfield and Montrose (1998); Riley (1987); Zaft (1997).

140. Muuss (????) provides a cornucopia of old documents on the US Army's involvement in developing the first generations of computer technology. See especially Kempf (1961).

141. UNIVAC *in* Weik (1955); UNIVAC I *in* Weik (1961a)

142. UNIVAC *in* Weik (1955). In 2010, by comparison to the UNIVAC, the $1000 laptop I am writing this document on in January 2002 (uses an Intel Core 2 Solo) has a clock speed of 1,400 MHz compared to an add cycle time of 120 milliseconds (168,000 times faster); 2 GB memory compared to ~12 KB (167,000,000 times greater capacity), 32 bit word compared to ~ 12 (and 286 GB disk storage. While I am writing this text on my computer, I have open a number of

Web pages, and I am also listening to Scarlatti's harpsichord sonatas via Windows Media Player on my computer.

The "raw power" of a computer can be measured by the amount of memory × the clock speed × the word length. Given that the UNIAC's words are processed as decimal digits, the Pentium is actually able to add larger numbers in a single cycle. However, in this calculation I assume both machines process the same length of word. By this measure, my notebook computer is ~$7.4x10^{13}$ times more powerful than UNIVAC I, the first fully commercial electronic computer. My laptop cost around $1000 (0.001 × the cost of the UNIVAC - which is probably closer to 0.0001 when inflation is taken into consideration). The raw power per dollar ((speed× memory)/cost) on my desktop is approximately 7.4×10^{16} times that of the UNIVAC I. These numbers do not take into consideration the much higher sophistication of today's processors and software by comparison to the first ones, which would probably equate to another order of magnitude in power.

143. The Ferranti Mark 1 *in* Napper (1998). Napper's pages on Manchester University's celebration of 50 years of computer technology are a cornucopia of information on the origins and early developments of digital computer technology. More details on the early British computer industry can be found in Lavington (1980).

144. Alan M. Turing (1912 - 1954) *in* Napper (1998). For more information on Turing's impact on mathematics and philosophy see: Hodges (2001); O'Connor and Robertson (1999a); Copeland (1997).

145. CISRAC is preserved and exhibited by Museum Victoria. Follow the Related Resources links to a plethora of information about the historical development and operation of this system, e.g., Resources. Melbourne University, where I am an honorary Fellow, also owned operated the computer from June 1956 through June 1964 in its new Computation Laboratory, and offers a CSIRAC page providing substantial information on the system. The Melbourne University page also provides some performance comparisons with more recent "high end" computer technology:

	CSIRAC - 1949	Desktop PC - 1996	Laptop PC - 2000
Speed	.001MHz	> 100MHz	> 500MHz
Word size	20 bit	32 bit	64 bit
RAM	768 words	>8,388,608 bytes	536,870,912 bytes
Disk capacity	2048 words	>1,048,576,000 bytes	19,327,352,832 bytes
Power consumption	30,000 watts	250 watts	10 watts
Weight	7,000 Kg	25 Kg	2.6 Kg

146. Computer Generations *in* da Cruz. (2001); Polad et. al (????). Both works have excellent photographs and summary explanations of the early technologies to give some idea of their massive physical scales by comparison to today's desk-top and lap-top machines.

147. IBM Archives: Our History of Progress, 1952; IBM 701: a notable first – the IBM 701 - http://tinyurl.com/2adlt3o.

148. The IBM 701 - The IBM 701-7094 II sequence, a family by evolution *in* Bell (1971); IBM-701 Electronic Data Processing System *in* Weik (1955); Wikipedia on IBM 701.

149. Core Memory in Computer Museum, Universiteit van Amsterdam / The Netherlands - http://tinyurl.com/mzo4mxe. Core Memory *in* da Cruz (2008); Redin (2000); Beebe. (1994).

150. 1954 in IBM Archives: Our History of Progress

151. 1955 in IBM Archives: Our History of Progress

152. IBM 350 disk storage unit in IBM Archives: Storage product profiles.

153. 1950s in IBM Archives: Our History of Progress.

154. Section III - Analysis and Trends in Weik (1955) summarises user experience including facilities, maintenance and operating labour resource requirements for all of the first generation computers used in the US.

155. Third Generation *in* Polad et al (????)

156. IBM Archives: Our History of Progress, 1964.

157. Moore's Law; Moore (1965); Gilheany (2008); Koh & Magee (2006); Chang & Baek 2010; Moore's Law timeline - http://tinyurl.com/ycr2bfu

158. Darling (2010); Bohr (2009); Ghani (2009).

159. See also Computer vacuum tubes in Wikipedia.

160. Utley, B. 2006. Intel 4004 – 35th Anniversary. Technology Evangelist - http://tinyurl.com/262azvy.

161. Myslewski (2011) - Happy 40th birthday, Intel 4004! Note: this site shows a range of Intel processors from the 4004 through the 2nd Generation Core i7 with ~ 1.27 billion transistors (my current desktop system as at 20 August 2013 uses this chip).

162. Intel® Itanium® Processor 9000 Sequence, Intel - http://tinyurl.com/2ay4qha.

163. Typewriters using paper tape as a storage medium had already been in use for more than a decade.[134]

164. Rostky, (1998); Magnetic Disk Heritage Center - http://tinyurl.com/2ed837n; A history of firsts from the leader in data storage - http://tinyurl.com/28dxnl3; Storage Devices - http://tinyurl.com/leb83kr; Disktrend: of special interest - for links relating to the historical development of (initially) magnetic storage technologies. "Computer Peripherals" course at Nanyang Technological Unitersity, Singapore. Chapter 7 Hard Disk Drives.

165. Disk/Trend - Five decades of disk drive industry firsts - http://tinyurl.com/molc54g.

166. IBM 1440 Data Processing System. *in* Weik (1964).

167. See also: 1998 email from Doug Yowza to the Altair Collectors Association for evidence that Altair really wasn't the first.

168. A brief history of FORTRAN/Fortran *in* Anon (1998); HPCWire (2001); The Fortran programming language.

169. See also Microsoft History (1996) – 1975: http://tinyurl.com/2dweg5k.

170. See Wikibook's Object Oriented Programming for background history and theory, as well as some practical examples of how it works.

171. This took a single incantation: "Who said 'baseball is a red-blooded sport for red-blooded men'"

172. Google Books has set out to scan all the books in the world, where a book is a "tome" that can consist of only one or two copies (e.g., a thesis or dissertation) to millions of copies, and each separate edition is counted as a tome. This excludes bound serials. Their best estimate, as at Aug. 5, 2010, is around 130 million (Taycher 2010), and has managed to do so for collections in some of the world's great academic libraries such as Harvard University and the University of Chicago. As of Nov. 19, 2009 Google had scanned more than 12 million books of some 42 million held in US libraries (von Lohmann 2009).

173. Innovation Milestones in "About Parc", from 2007, provides Xerox's corporate view on what PARC invented beginning from 1970. See here for their current view.

174. Despite the fact that WordStar is commercially extinct, as at 20/08/2013 there are still active user groups prepared to fight holy wars over their preferences for the product, e.g., Wordstar Resource Site. The History page on this site offers interesting insights (Petrie 2004). The science fiction writer, R.J. Sawyer (1990) explains in near epistemological terms why he believes that the early WordStar was the best word processing tool ever developed for capturing thoughts as text.

175. Power, D.J. (2004); Tanner, D. (1999); see also J. Walk and Associate's Spreadsheet History links - http://tinyurl.com/2b46pv7.

176. Hutchings (1996); Committee on Innovations in Computing and Communications (1999) - Chapter 6 - The rise of relational databases - Funding a Revolution: Government Support for Computing Research http://tinyurl.com/n72gtj8; Silberschartz (1991); CERN (2000).

177. All of humanity working from the beginning of time would probably not be able to test all permutations and combinations of these features. Windows 95 was reputed to have 15 million lines of code, XP 35 million lines, and Vista, Microsoft's main operating environment from 2007 through 2009, is reputed to contain more than 50,000,000 lines of code (Cusumano 2006 – note: In several hours searching I have been unable to verify these numbers from original sources). It is inevitable that users will try sequences and combinations of functions that have never been tested together. It is also inevitable that some of these combinations will cause the system to fail. Coffee (2000) notes that at least 63,000! bugs in Windows 2000 have actually been documented. See also (Hyde 1999). In Windows Vista, more than 100,000 bugs were identified before its general release, and another 5,000 identified "in the wild" after release (Glerum et al. 2009). The situation with MS Word is no better. Working with a nearly blank document in MS Word 97, in a four hour effort in 2002 I counted approximately 1,200 user selectable or modifiable options through menu options, dialog box inputs, etc. The actual number of features is incalculable, since the menu options available at any given point in an editing procedure are sensitive both to the location of the cursor in the document being edited and to contexts created by other options previously selected. Based on statistics provided to me by professional technical writers measuring their productivity using MS Word 95/97, 20-30% of their keyboard effort was nugatory due to loss and corruption of files or other software-based problems. Additional effort is lost trying to make Word's formatting functions work as they are advertised. "Master documents" and the paragraph numbering functions provided in Word have never worked properly). The answers provided by John McGhie explain why on - Why master documents corrupt, and How to recover master documents. To simplify its user interface, Word 2000 and later versions hide infrequently used options by removing them from menu bars, which makes them even harder to find when they are needed! As if that isn't enough, in reach new release of its office products, Microsoft seems compelled to redesign its user interface – meaning that experienced users have to learn all over again to use the applications efficiently.

178. Microsoft Antitrust links: CPT's Microsoft Antitrust Page; FindLaw Microsoft Case; n/e/r/a Microsoft Antitrust Litigation.

179. Extract on word processors from Chapter 8, Liebowitz and Margolis. (1999); and Evans, D.S., et. al. (1999) present comprehensive histories on the rise and fall of various personal computer applications. Note: NERA was a consultant to Microsoft on antitrust matters.

180. n some regards the PARC's Alto still represents the best implementation of the paper metaphore ever developed - the Alto recognised that paper documents are almost always presented in the 'portrait' mode, and used monitors in the portrait mode (long axis vertical!) Hiltzik (1999) – see

Alto Photograph. For whatever reason, today's monitors are still virtually all landscape mode, making A4 or letter sized formats difficult to read if the whole page is displayed at one time. See also Johnson et. al (1998) for information on Xerox's 1981 Star system.

181. Hart, S. (1999) summarises the competion between the various word processing systems.

182. Economides (2000) and in several other papers accessed on the same site, provides a more neutral discussion of the network effects in relationship to the US vs Microsoft case.

183. Through the 1990s Microsoft Word was infamous for its lack of backward compatibility between new versions of Word and its own older versions. Content received from an older version into a new version is easily converted. The new version may also have an optional capability to save a file in an older format. However users of older versions of Word who are unfortunate to be exchanging files with those who do not deliberately save files in the old format had no choice but to pay Microsoft for an upgrade to their system. Thus, once a few members of a business community upgraded their standards, other members of the community have been forced to update to be able to communicate with the early adopters. And, once businesses have been forced to upgrade, individual customers using word processors to communicate with the businesses have no choice but to upgrade also. In the 2000s this has not proved to be such a difficulty – perhaps as a consequence of the Microsoft antitrust actions?

184. This comment made around 2002 was based on 15 years up to then of personal experience in various documentation system management roles in a multi-branch bank and a defence prime contractor.

185. "Legacy documents" are electronic documents in an organization that can no longer be read using current corporate technology. In other words, when an organization replaces its word processing technology with a new system, the risk is that all of the documentation produced using the older system will no longer be readable with the new system – a problem that doesn't exist when the human eye and brain are the primary reading technology.

186. In my own experience, around 1993/4 when the major government client of the company I worked for switched to MS Word and required tender documents to be delivered electronically in MS Word format, the company had no choice but to comply. To communicate internally the company had no choice but to standardise on MS Word and force our subcontractors to do the same. Now that the company, the government, and the cloud of subcontractors all have substantial legacies of MS Word documents, all face major costs trying to convert to any other communication standard.

187. Most word processing systems offer authors many different ways to code format structures that look the same on screen or on paper. For example, by my own count, MS Word 97's menu tree provided access to over 1200 different functions – without considering the fact that many functions at the ends of the branches themselves have numerous parameters that can be set to further alter the way they behave. This situation has not changed for the better in the later Microsoft Office products. Consequently, the semantic significance of formatting instructions cannot be reliably recognised by computer systems that do not actually comprehend the textual content of the document.

188. In fact, in some cases, depending on author preferences, the exact same application can either work with documents in the paper paradigm or in a semantic structure paradigm. Examples of such systems are Adobe FrameMaker and Corel WordPerfect. However, because of the fundamental differences between procedural and semantic markup, individual document files are never easily or reliably converted between a paper paradigm and a structural paradigm, even if the same application is used for both. Similarly, even where semantic structure paradigms are

used, conversion of content between different paradigms is highly problematic (Vines & Firestone 2009),

189. Hot metal typesetters were probably some of the more complex machines ever created for use by a single person. See Woodside Press's The Linotype: What it is - http://tinyurl.com/mzm3jd7; Melbourne Museum of Printing's Thematic Glossary of Typesetting (Hot Metal and Later) http://tinyurl.com/kp9yyks.

190. In advanced hot metal mechanical typesetting systems, the markup was encoded by particular combinations of holes in a paper tape. As the mechanical systems were replaced by electronic systems beginning in the 1970s, binary electronic codes were used.

191. Microsoft took a somewhat different approach with its MS Word product, by placing most formatting instructions at the end of the document or after Section Breaks. These instructions then point to the areas of text they affect. It is this totally different formatting logic which has made conversion between MS Word and other word processing environments so difficult. The answers provided by John McGhie explain why - http://tinyurl.com/lhs38m5; http://tinyurl.com/mcjm8ky. Microsoft has partially rectified this problem by developing its openly defined but still proprietary Rich Text Format (RTF) and DOCX markup language. RTF markup directly tags the blocks of text affected by most formatting instructions, but it still doesn't solve the generic word processing problem that there are many different ways for the computer to code formats that look the same to human readers.

192. I first encountered GML in 1988 as a documentation manager in the information systems area of an IBM-based banking environment.

193. Defense requirements in the 1990s to standardise technical documentation (as expressed in CALS - Computer aided Acquisition and Lifecycle Support) policies and standards assisted the spread of SGML. The US Navy Digital Logistics Technical Data (CALS) page as at May 24 2002 links to various standards on the Technical Information Systems Branch) The NATO CALS site (June 12 2002) explains many of the benefits.

194. Currently available SGML authoring applications in 2011 include FrameMaker, Arbortext Editor, and XMetaL (although this is more specialized for editing XML).

195. Graham (2000) discusses the different versions of HTML and how different browsers interpret particular HTML elements. Darkside of the HTML is an essay dating from 1995 or 1996 on some of the difficulties resulting from the early looseness in the HTML definition. The situation has not improved markedly up to the present time.

196. Some statistics, discussed in more depth in a later section make clear the magnitude of this revolution: The HTML DTD was finalised in 1993 (Sears, 1998). By 2000 more than 1 Bn HTML Web pages have been published – Inktomi WebMap; Web surpasses one billion documents; spread across more than 93 million hosts (growing from around 370,000 in 1991) – (Internet Software Consortium's Internet Domain Survey July 2000, through 2008, through 2013). By November 2001, Google claimed to have indexed more than 1.6 BN Web pages. By July 25, 2008 they claim to have registered over 1 trillion (1×10^9) web pages (and that is after removing duplicate URLs! – Alpert & Hajaj 2008). By August 2001, an estimated 513 million users worldwide use the Web; 180 million of these were in the USA and Canada – NUA – How many online?

197. Carleton University School of Business On Line Learning (2000) - Well-Formed XML.

198. Carleton University School of Business On Line Learning (2000) - Valid XML

199. The scope and history of the discipline are summarised in the Wikipedia page.

200. The Amsterdam printing of the Journal des sçavans *in* Dibner Library of the History of Science and Technology

201. Chapter 3. Channels for Scientific and Technological Communication *in* Fjällbrant (1994).

202. History of Scholarly Societies: The Reuss Repertorium and Scholarly Societies as Meeting Sponsors and Publishers *in* Scholarly Societies Project, University of Waterloo Library.

203. The Royal Society of London Catalogue of Scientific Papers *in* Scholarly Societies Project, University of Waterloo Library.

204. Zoological Record, *from* Thompson Reuters; see also Zoological Record in The Biological Abstracts Family of Products as at 14/10/2000.

205. John Shaw Billings was a major player in the early development of information systems. In addition to his role in founding the National Library of Medicine and Index Medicus, it was Billings's suggestion that Herman Hollerith should use punch card technology for the US Census beginning in 1890 (Russo ????. This provided the foundation from which the IBM corporation developed (Herman Hollerith *in* IBM Builders Reference Room). For Billings' other influences, see also:
John Shaw Billings Centennial *in* History of Medicine, National Library of Medicine;
John Shaw Billings *in* Agency History, US Census Bureau;
Colonel John Shaw Billings in Office of Medical History, US Army Medical Department.

206. Centenary Website: The History of Science Abstracts.

207. CAS History: Milestones in CAS 100th Anniversary Celebration, CAS A Division of the American Chemical Society; Chemical Abstracts Service (CAS) of the American Chemical Society in Pioneers of Information Science in North America; Williams, R.V., Bowden, M.E. 1999, Chronology of Chemical Information Science.

208. History; Biosis Evolutions 8:1 (2001): 75 years of looking to the future.

209. Thomson acquires BIOSIS publishing assets in BIOSIS News Releases and Announcements as at 22/05/2003.

210. Corporate Timeline in About ISI (2002).

211. http://www.dialog.com/. For its early history see: Bourne (1999); Summit (2002); DIALOG Information Services *in* Pioneers of Information Science in North America (2002). DIALOG is now part of the Thomson organization.

212. http://www.questel.orbit.com/**Error! Hyperlink reference not valid.**: History of Questel-Orbit *in* Corporate Information (Questel-Orbit 2001). Orbit was developed by System Development Corporation (RAND Corp spinoff) – System Development Corporation *in* Pioneers of Information Science in North America (2002).

213. History of Citation Indexing: in The ISI Essays, Thomson ISI; citation indexing - Garfield (1955); use of punch cards - Garfield (1955a); Garfield (1958) – Institute for Scientific Information *in* Pioneers of Information Science in North America (2002).

214. Atkins (1999); Testa, (2001) - See here for current Web of Knowledge policy as derived from this document; Chapter 1 - A conceptual view of citation indexing *in* Garfield (1979).

215. King and Tenopir (1998) also calculated a similar value for the cost to produce a journal article.

216. This is comparable to the the average annual income per person in the USA of $34,870 in 2001! GNI per capita 2001, World Bank Atlas method and PPP; and United States Data Profile both from the World Bank Group Data & Statistics.

217. Graphs for earlier years in the ARL Statistics series included number of serial subscriptions and unit cost for "serial subscriptions". (Statistics and comments regarding earlier reports can be found in the Education Resources Information Center Collection.) However, as libraries increasingly subscribe to electronic services bundling multiple title (where the same title may actually be provided by several different services, these measures no longer adequately represent trends. Since the 2006-2007 report, ARL is measuring number and unit cost for "serial titles", but the two time series are inconsistent, so these values are not included in the graph (Krillidou and Bland 2009).

218. See also: Create Change: A resource for faculty and librarian action to reclaim scholarly communication.- http://tinyurl.com/26rgo3x.

219. There are a number of Web resources documenting the phenomenal growth of the Internet as a communications medium and the World Wide Web as a repository of human knowledge: Cringley provides highly popular histories of computer technology in general and the Web in particular (Cringley 1996, 1996a, 1998). Cringley (1998) is an especially notable example of an advanced hypertext document that could not be represented in any other medium except the Web. Howe (2001) provides a brief and more linear history of the Web. A more detailed history is presented in Abrams (1998). Internet Com Corp's Web Developers Virtual Library provides a History of the Internet and the World Wide Web, with a number of links to related sites. December and Ginsberg (1996) provide an early history of the Web and review basic principles in the introduction to their book. The Internet Society provides links to several other histories.

220. Feizabadi (1998) Chapter 1 gives more details on Bush's ideas, and reviews the origin of hypertext. Zachary (1997) claims Bush as the "godfather" of most modern technology and the cognitive revolutions associated with it. Lesk (1996), originally in a Bush symposium at MIT, reviewed progress as at the latter part of 1995 towards meeting MEMEX's technological requirements. *It is also worth emphasising that my procedure for capturing and using links to develop the present work represents an embodiment of the ideas proposed in Bush's paper and Lesk's progress report - except that only the links are captured. The referenced documents reside in their source repositories and (assuming they are not moved) can be accessed at any time by following the link*. See also Garfield (1955, 1958)

221. Ted Nelson's home page and Home Page of Ted Nelson.

222. See Xanadu Australia.

223. Click query to see the current count.

224. As the Web has grown, so have the number of servers required to support it. For example, Pandia Search Engine News in July 2007, citing a Norwegian article by Peter Hidas of the Gartner Group, estimated that more than ***one million***(!) servers may be required to support Google's various internet services to the world. Royal Pingdom (August 2009) using data from Katz (2009), estimates ***Google may be running more than 2% of all the servers in the world***. Shankland (2009) describes the modular nature of Google's server farm architecture built around Google's self manufactured servers. These are assembled into standard shipping containers, each with 1,160 servers with a power consumption of 250 kilowatts, were each data center may contain many containers. Mellor (2007) estimated that Google had more than 500,000 servers spread over 40 to 60 datacenters world wide, growing from 8,000 servers in 2001 (see also Markoff and Hansell 2006). Levy (2012), reporting on his tour of one of Google's normally top-secret data centers says that it probably impossible to determine how many servers Google runs at any one time, but that it is probably at least a million. He also states that data centers consume up to 1.5 percent of all electricity in the world! James Pearn on

Google+, Jan 26, 2012 estimated that as of January 2012 Google had 1,791,040 servers, based on the standard layout of available floor areas of Google's data centers. See also Prigg (2012).

225. Tim Berners-Lee (Berners-Lee & Fischetti 1999) has argued for years that commercial Web browsers should also provide users with an equivalent ability to create documents for the Web. To date there are no effective products that include both browsing and authoring in the same tool. However, this is now a moot point as many blogging and web development sites provide WYSIWYG editors that integrate seamlessly with the more popular browsers.

226. However, in 2010 the semantic power of XML is still rarely used in general purpose Web applications.

227. In an audio podcast, Mitchell Baker, "Chief Lizard Wrangler" at Mozilla, discusses the organization's unique, community-based culture and how it has contributed to their success. She explains how freedom, openness, and dedication to improving Internet usability fosters extraordinary contributions from Mozilla's employees and volunteers.

228. Subsidies have been provided by Defense Advanced Research Projects Administration (DARPA) and the National Science Foundation (NSF) (Committee on Innovations in Computing and Communications 1999), Chapter 7 Development of the Internet and the World Wide Web.

229. This assumes access to a computer and telephone connection to an ISP (internet service provider) - which are all available to individual end users in developed countries at highly competitive commodity prices (i.e., for a price equivalent to 5-10 university textbooks). And failing this, many public libraries now provide free internet access, as I recently demonstrated to myself on a recent trip to Finland where I used the public library closest to my hotel to access my e-mail via my Australian university's Web portal because my laptop's modem did not understand the European telecom standards.

230. In 1993-1994 AT&T foresaw what the Web could become in a series of TV commercials that are remarkably prescient – see on YouTube.

231. Remarkable vision for a tablet newspaper (1994) - see http://www.youtube.com/watch?v=JBEtPQDQNcI&NR=1&feature=endscreen

232. Inktomi WebMap statistics - Press Release.

233. Google press releases: Google Launches World's Largest Search Engine (June 26, 2000); Google Achieves Significant Business, Growth Milestones in 2000 (February 1, 2001).

234. Google press release: Google Offers Immediate Access to 3 Billion Web Documents.

235. Internet – WWW Details in Lyman and Varian (2000).

236. The methodology as described by de Kunder (2007) depends on the number of pages returned for searches on common words, adjusted for the frequency with which those words occur in a large corpus of web pages.

237. http://arxiv.org/cgi-bin/show_monthly_submissions. Site policy excludes most web crawlers - http://xxx.lanl.gov/RobotsBeware.html.

238. Internet – WWW Details in Lyman and Varian (2000); see also Lesk, M. (1997?).

239. Access is limited by two factors. (1) Virtually all formally published journal content resides on publisher or society websites that are off-limits to web crawlers because access requires user passwords. (2) Beyond this, even where access is free, as in the case of http://www.arxiv.org/, the document server for the physics, astronomy and mathematics community, crawlers are barred (http://www.arxiv.org/RobotsBeware.html). Around 2000, most of the content was held

in paper oriented layout formats (e.g., .PDF, postscript, TEX, LaTEX, MS Word, etc.) that were unreadable by that era's web crawlers. Note, Google had just begun to index PDF, PostScript, Lotus and most Microsoft formats (Frequently asked questions – file types (as at Nov. 10, 2001). Today (2013) most types of files containing text are indexed (What file types can Google index?). Google Scholar has arranged with publishers to index most scholarly work, although much of this is still held behind subscription barriers so the indexed material is not freely available on the open Web.

240. Internet – Email Details in Lyman and Varian (2000).

241. Email and Spam in Lyman and Varian (2003). They also observe that in July 2001, 8% of email was span. In November 2002, 30% was spam. And in May 2003 55% of email was spam.

242. Google's New GoogleScout Feature Expands Scope of Search on the Internet, (Mountain View, Calif. -- September 21, 1999).

243. We knew the Web was big… in The Official Google Blog July 25, 2008. See also The size of the World Wide Web in Pandia Search Engine News, 25 February 2007.

244. Google Scholar is an exceptionally powerful personal tool for searching *and retrieving* the academic literature – where the person's library has entered into an agreement with Google to access the library's electronic journal subscriptions (i.e., stuff that is very definitely in the deep web – see Google Scholar Library Links). Because Google indexes on every word in every document, in effect, Google's simple logic allows everything from Boolean keyword searches to searching on cited documents (simply put quotation marks around the title of the cited paper, and if this proves to be a common phrase, add the author name). This will return more recent papers that have cited the given document. Based on my own personal experience documenting a large number of academic papers and this book, Google Scholar will retrieve on the order of 90% of the relevant literature (as determined by backtracking from the most recent bibliographies. At least with the library link I use (to the University of Melbourne) and even when working from home, once I am logged on to the library, electronic copies of most indexed documents can be retrieved in two keystrokes from Google Scholar's search results.

245. About Google News.

246. Google Video began as a video hosting service that was phased out when Google acquired YouTube. The relatively undocumented service existing in 2013, indexes videos from all sources for retrieval and viewing. Indexing is based on textual information provided in Video metadata and the hosting Web page.

247. von Lohmann 2009. Google books settlement 2.0: evaluating access. Electronic Frontier Foundation, in Deeplinks Blog, Nov. 17, 2009.

248. Internet Subject Directories (current) and (archived Dec. 2, 2003) in Search Engine Showdown by G.R Notess. From 2003 to 2007 (the last update at this writing, there is comparatively little change in the number of directory entries. Tool Kit for Expert Web Searchers - Subject Guides in Library and Information Technology Association's Top Technology Trends; Was Ranganathan a Yahoo!? by Aimee Glassel, Internet Scout Project.

249. Where Do I start? (Web Directories) in The Cyberlibrarians' Rest Stop; Searching the Internet: Recommended Sites and Search Techniques in Internet Tutorials.

250. Internet Subject Directories (Oct. 30, 2003) in Search Engine Showdown.

251. LookSmart Launches Zeal UK Community Additions to LookSmart Directories Worldwide Surpass 100,000 URL Mark

252. LookSmart's directory format in 2005 versus advertising format in 2006.

253. The History of Yahoo! - How It All Started...

254. Review of Yahoo! Directory (Oct. 30, 2003) in Search Engine Showdown.

255. Compare 2006 (where the general directory hangs on near the bottom of the left column) to 2007.

256. The XML Cover Pages (June 3, 2003). By October this had transformed to (from my point of view) a much less useful "story format" (Oct 10, 2003).

257. Open Directory Editing Guidelines.

258. Various kinds of Web bots available through late 2007 are described on BotSpot.

259. Google searches more sites more quickly, delivering the most relevant results (2003). Technology overview (2009).

260. The most useful, complete and continuously updated review of search engines and Web directories I have found are by Notess' Search Engine Showdown. As Notess (2007) documents, the large majority of search engines have left the field.

261. This is a philosophy explained and espoused by Gerry McGovern in his weekly email newsletters that I find filled with uncommonly common sense.

262. I could just as easily be watching live ABC News 24 on Australia's national network.

263. QuickTime is History (30 Nov, 2001); Quicktime 3.0 - The Multi-Platform Non-Streaming Streamer (Feb, 1998).

264. The earliest date I can find for Windows Media Player on the Web is 27 Apr. 1999, which is for Media Player 6.1 for Windows Internet Explorer. The alliance with RealNetworks (then Progressive Networks) began in 1995 - Progressive Networks' RealAudio player has exclusive with Microsoft's Internet Explorer (Aug 17 1995). By early 1998 the relationship was severed - RealNetworks issues statement regarding Microsoft's decision to sell Its minority stake in RealNetworks.

265. Weatherzone offers several types of automated alerts, e.g., free Email Alerts and Alarms, or SMS Weather on subscription.

266. Many (or even most) citations found by both Google and Web of Knowledge can be accessed electronically via Web of Knowledge or Google. It used to be that Web of Science/Web of Knowledge provided the best results for citation searches, but in my experience, because of Google's access agreements with diverse publishers and library associations, combined with their library scanning effort, they now seem to have the widest coverage of journal literature and (of course) books.

267. In the case of Web of Science, automatically generated links will also point to records for other cited articles in the bibliography that have also been indexed. With Google Scholar you will have to manually copy and search for the titles of additional works you want to see.

268. Every year I find that an increasing proportion of references revealed by Google Citations are available free to the web due to the fact that authors are increasingly uploading copies of their articles or book chapters to institutional or general repositories, e.g., arXive, Social Science Research Network, Academia.edu, ResearchGate, citeulike. Several of these general repositories have other functions to facilitate the exchange of academic and research knowledge.

269. I first started working with ISI's Science Citation Index in paper format in the 1960s, long before there was any concept that the index would be accessible electronically from home. Even then the power of its semantic indexing was quite evident.

270. My access is to the University of Melbourne Library that uses EBSCO Discovery Service. This offers an A-Z browsing function for electronic subscriptions. To determine the total number of journals accessed it is necessary to use the Browse function to select each letter of the alphabet in sequence. On selecting the letter the browse function will display the number of items beginning with that letter. The total is then determined by adding together the counts for each letter.

271. The need for what is now Episode 4 on 'social computing' did not even exist when I started this book.

272. Google Citations lists my academic publications.

273. Although Urrestarazu 2004 is not formally published, it is a penetrating analysis of the physical basis for autopoiesis with an excellent lineage. Hugo Urrestarazu was a student of Maturana's at the University of Chile in the 1970's and a friend of Varela. Hugo subsequently undertook postgraduate studies in solid state physics at University College, London and has worked as a software systems engineer. My ideas on the dynamics of autopoietic systems owes a lot to this and two other unpublished works by Urrestarazu.

274. Most definations relating to dynamic systems will point to various pages of Scholarpedia that provides depth and clarity with a good balance of text, illustrations and mathematics to describe important concepts for the remainder of this work that can be very difficult to describe in plain English.

275. See Equation of State in Wikipedia and Control Systems/State-Space Equations in Wikibooks Control Systems for examples.

276. Simulations do not work in Web Archive versions of the Calresco site. To explore Calresco for simulations, use the live link: http://www.calresco.org/glossary.htm. Another excellent glossary is provided by CNA Corp - Nonlinear Dynamics and Complex Systems Theory Glossary of Terms.

277. A simple **nonlinear system** is illustrated by a swinging double pendulum in a gravity field (two lengths of bar, connected by a flexible joint, where one end of the pendulum is fixed to a stationary pivot point, and the other end can swing freely, e.g., see Peter Selinger's Double Pendulum, in The Lagrange Applet). Note: the simulation is of an ideal pendulum, unaffected by friction or entropy. Although the motion can be calculated deterministically, very small differences in the initial parameter values soon lead to very different solutions for the location of the pendulum. This can be seen by restarting the simulation multiple times from the default position. Although the first few cycles of the pendulum trace similar paths, they soon diverge – and I suspect no two simulations will ever draw identical paths. As the system evolves over an infinite period of time, the trace left by the pendulum bob maps out every every position that can be reached by the assembly for constant settings of gravity, segment lengths, and initial energy content (the "**state (or phase space**"). If the initial energy is sufficient to allow the both segments to extend straight up, the phase space will be a circular disk if both pendulum segments are the same length, or a disk with a hole in the middle representing the area where it is mechanically impossible for the trace to reach because of the difference in lengths of the pendulum's segments. Click the Change Parameters button in the simulation and experiment with segment lengths to see why this is so. You can speed up this mapping by setting the time factor to 5.0 (on my computer, processing glitches appear with a setting to 10). Using the default settings (except for speed) there is insufficient energy in the system to fully extend the pendulum at the top of its swing.

278. See also F.-J. Elmer's Pendulum Lab discussion of Stability and Bifurcation; and Clint Sprott's Chaos and Time Series Analysis lecture on Bifurcations.

279. Bogomonly's (2010) webpage Emergence of Chaos demonstrates both period doubling and chaos quite effectively.

280. Sensitivity to initial conditions is illustrated in a video by Timothy Jones of Drexel University.

281. See F. Heylighen's brief essay on Attractors in Principia Cybernetica Web and Strange Attractors in G. Elert's Chaos Hypertextbook. See also Michael Hogg's video illustrates period doubling, attractors and the emergence of chaos using the forumula for calculating the Mandelbrot Set. Note: text associated with the video also explains what you are seeing, and includes several Wikipedia links at the bottom for more information. A second video, attributed to James N. Shears, shows an XY plot on an oscilloscope of the behaviour of a chaotic Chua oscillator circuit as a control variable in incremented. The plot begins with s stable limit cycle (a symmetrical ellipse) that begins to distort and then flip (time 0:12 - period doubling?) to a reasonably stable doubled strange attractor that becomes increasingly chaotic until it flips into into another limit cycle at time 1:08 that flips again into various forms of increasingly chaotic attractors. At time 2.38 the system flips to a completely different attractor structure that continues to morph and flip to other structures. The documentation is sparse, but I would guess that these "flips" represent "crises" or "catastrophes".

282. See also Wikipedia's dissipative systems and the Dissipative Systems Model in Sundarasaradula &Hassan (2004).

283. See also Causality and Causality (physics) in Wikipedia. Following Wikipedia and many other sources, Aristotle recognized four kinds of cause:

- Material cause, the material from whence a thing has come or that which persists while it changes, as for example, one's mother or the bronze of a statue (see also substance theory).
- Formal cause, whereby a thing's dynamic *form* or static *shape* determines the thing's properties and function, as a human differs from a statue of a human or as a statue differs from a lump of bronze.
- Efficient cause, which imparts the first relevant *movement*, as a human lifts a rock or raises a statue.
- Final cause, the criterion of completion, or the end or aim, of an action or instrument of action, as Socrates takes a walk after dinner for the sake of his health.

Ellis (2012b: p. 132) modernizes these causes in the framework of upward and downward causation as follows:

> [C]onsider causation in the hierarchical context considered here, identifying as especially significant to the immediate lower level (Physical) cause, the same-level (Immediate) cause, the immediate higher (Contextual) cause and the topmost level of purpose or Telos, which activates the rest. We cannot identify an ultimate lower level cause because no one knows what the bottom level is (we have no fully successful ultimate theory of particle physics).

In a quantum mechanical sense, the physical structure of one "instant" causes the structure of the next instant. At a given level of analysis, events of one instant are the immediate causes of events in the next instant. The context provided by the structure of the next higher level causally influence which possible events in the lower level actually occur. Telos only becomes causal with the emergence of minds able to establish purpose.

284. Let me be very clear here. I am exploring the concept of causation here in a purely physical realist sense, i.e., that which "causes" change even in the absence of any kind of mind to perceive it. A panoply of causes accounted for the evolution of the Universe from the big bang until now, entirely in the absence of minds to perceive them. Ellis (2012: p. 7) begins his

argument for the reality of temporal causation with the following basic premise (which I happily accept):

> **Basic Premise**: *Individual Events Happen*
> Each word is important:
> **Individual**: Statistics is not enough. An ensemble of events is made up of individual events. There is no ensemble if individual events don't separately happen.
> **Events**: Specific things occur. Universal laws describe multifold possibilities of what might happen, but we experience specific events in our own particular history.
> **Happen**: They occur in time: they are about to occur, they occur, then they have occurred. Uncertainty about what might occur changes to the certainty of what has occurred.
> **What is the evidence for this statement**? Apart from the overwhelming evidence from everyday life, every single physics experiment is proof it is true! - we plan experiments, carry them out, analyse the results, publish them. Each experiment is an individual event that occurs at a particular time and place in the history of the universe. Science would not be possible if this were not the case.

Ellis underlines this premise considering that events happen at both micro and macro levels and emphasizes that these events happen whether we know about them or not.

285. Where theories of spacetime are concerned George Ellis has substantial claims to authority, e.g., coauthor with Stephen Hawking of The Large Scale Structure of Space-Time (1973), President of the International Society on General Relativity and Gravitation (1989-1992), over 500 published papers including 17 in Nature. See Wikipedia; Ellis' web page; author entries for Ellis in inSPIRES High Energy Physics Database.

286. I always use the term stochastic in its second sense, as "involving chance or probability : probabilistic". In other words a stochastic phenomenon is *not* purely random, nor is it purely deterministic. A stochastic rule describes a probability distribution rather than a single, specific outcome.

287. For an on-line Chaisson's treatment of entropy and the second law of thermodynamics (i.e., the "arrow of time", see http://tinyurl.com/2dbyf4j). For other discussions of the arrow of time see also Salthe & Fuhrman 2005; Callender 2009; Maccone 2009; Castagnino & Lombardi 2009).

288. About….. Exergy (James Kay). See also Taftan Data's Exergy or Availability for a precise thermodynamic definition of exergy in equilibrium or steady-state conditions. Kay (2002) explains the relationships between exergy, entropy, information and uncertainty.

289. The concept of an attractor comes from dynamic systems theory – see above. Lucas 2003 provides more detail.

290. Where source and sink reservoirs are vast by comparison to the dissipative channels, the gradients persist despite local dissipation.

291. But see Corning 2002 for a somewhat critical view of this idea.

292. I had a very spotty and confusing undergraduate transcript (3½ years of physics before I started over in zoology), so I had few choices for graduate work. I was accepted by Southern Illinois University, Edwardsville that had just established a new and rapidly growing campus and was in the process of forming its graduate program. I found myself lecturing in both general and invertebrate zoology (the latter heavily based on my first hand experience with most of the marine phyla in the coastal habitats of Southern California, where I grew up). In both courses, I was essentially on my own to organise the content for teaching. To give some structure to my approach, I based it on the foundation question, "what is life" as elaborated by logical evolutionary processes. In order to gain academic credibility in a well established graduate program and access to a well established research library, I enrolled as an external student in

Hampton Carson's Genetics and Evolution course offered by Washington University in St Louis (across the Mississippi from Edwardsville). The topic I chose for the research paper in this course was on the origins and early evolution of life, where I attempted to reconstruct the origins of the various animal phyla - based on my readings and lectures for the invertebrate zoology course I was teaching at SIU,E. Many of the conclusions in this course paper predated many of the pioneering papers cited in this section. Unfortunately, at the time I had neither the writing skills nor the opportunity to attempt to publish the ideas. However, the logic of that paper (Hall 1966) underlies the presentation in this section.

293. *Maturana's concerns about second order cybernetics presumably grew out of his associations with Heins von Foerster.* Considering how his work has influenced thought, Humberto Maturana is poorly documented on the Web. Wikipedia says the most. Born in Santiago, Chile in 1928 Maturana studied at the University of Chile and completed his PhD at Harvard University in 1958 on the ultrastructure and neurophysiology of vision in frogs and birds (Maturana 1958, 1959; Maturana et al. 1959; Maturana & Varela 1982; Letvin et al. 1968) that was key research in proving that what brains observe of the environment via the eye is not simply a camera-like image. Around 1960 Maturana began an association around 1960 with Heinz von Foerster, founder of the Biological Computer Laboratory at University of Illinois (see also Müller 2007) that influenced both workers' understanding of their disciplines. Von Foerster was the architect of cybernetics or control theory and especially of second-order cybernetics, concerned about the recursive interactions of observers and the systems they are studying.

294. Francisco Varela was also born in Santiago, Chile, in 1946 and worked with Maturana on the neurophysiology of avian vision. He completed his PhD at Harvard University in 1970 on "Insect retinas: Information processing in the compound eye", continuing his studies on insect neurobiology in the 1970s and collaborating with Maturana in the 1980s on color vision in birds. The collaboration with Maturana on autopoiesis began in 1970 and continued through 1987. (see Thompson, E. 2001. Francisco J. Varela (1946-2001). Psyche vol. 7, no. 12))

295. For reasons that will be explained shortly, Maturana and Varela's work is difficult to comprehend because of its hermetically paradigmatic nature and highly self-referential vocabulary, but nevertheless rewarding. Whitaker's (1995, 2001, 2001a) Web-based works are invaluable guides to understanding the relationships of concepts within the paradigm of autopoiesis. In the development of the current section I will map these paradigmatic concepts onto the more commonly understood vocabulary of dynamic systems.

296. My usage of the concept of embodiment (see Wikipedia on embodied cognition) may cause some misunderstandings. In my usage, it refers to the physical consequences of or representation in W1 of processes or knowledge defined in W2 without going to the extremes of Cartesian dualism. In other words, living knowledge is embodied in physical structure.

297. "Organization" refers to the persistent coherence through time of the material components forming an autopoietic system. "Structure" refers to the instantaneous state of the components and their causal connections of that organization at a particular point in time.

298. As Hall and Nousala 2010 state:

> …[T]o Maturana self-observation was only "apparently" paradoxical (e.g., [Maturana 1970, 1988], but he lacked the epistemological framework and vocabulary to clear the fog. Because Luhmann and his followers accepted that self-observation of autopoietic self-maintenance and self-production was viciously paradoxical, they performed extraordinary linguistic and logical contortions in an attempt to work within the circle. However, Karl Popper's evolutionary epistemology turns the apparently vicious circle of self-

observation and self-criticism into a virtuous spiral [Nousala 2006; Nousala et al. 2005; Hall et al. 2007], clarifying many aspects of Maturana and Varela's also recursive writing.

299. A freely available tool, "Golly", allows GoL and a wide variety of other cellular automata to be run and experimented with on Microsoft, Apple and UNIX computational platforms. The Golly software is easily downloadable from http://golly.sourceforge.net/. The notation for describing rules in Golly is, ***0..8/1..8/n***. In this, any cell may be considered to be 'live', 'dead', or optionally, 'dying'. The first set of digits specifies the number of 'live' neighbors necessary for a cell to survive to the next instant. The second set of digits specifies the number of live neighbors a cell must have to be born in the next instant. The final, optional number, 'n', specifies the number of instants (up to 256) a 'dying' cell must pass through before it can again become live. The rule for GoL, illustrated in Figure 56, is 3/23.

Golly's processing begins when the universe is seeded with an initial pattern of live cells, that may be as simple as a single live cell to large areas of 'chaos' where cells are randomly live or dead. For most rules, the seed either evolves to a statically organized state of some kind (as well as inertly static cells, the organized state may include stationary dynamic objects such as 'blinkers' where cells endlessly cycle through an unchanging set of patterns) or alternatively the automaton tends towards an ever expanding chaos. A few rules are evenly balanced on the edge between order and chaos.

300. The term "toy universe" is used for a cellular automaton or other computer based model representing laws of existence and interaction whereby the behaviour of the model is strictly and completely determined by these laws.Personally, I think each adjacent possible points to the creation of a new universe. However, whether or not this is the case is beyond our ken, as it is evident that even if they exist we are not aware of our multiple selves in this endlessly proliferating set of universes. From the point of view of any particular autopoietic system or consciousness, in the becoming of any instant, all of the adjacent possibles of the previous instant are pruned to the one that forms that instant. At level of quantum mechanics things are fuzzier, but as detailed by Ellis and Rothman 2010, very similar arguments would apply as the adjacent possibles of the previous instants collapse and crystallize to form the new now.

301. A colleague of mine, Tony Smith (2010), has been experimenting with a number of cellular automata on the Golly platform[299], concentrating on the 345/3/6 rule known as 'Living on the Edge (LOTE) and others that generate long-lived evolving objects. Following 345/3/6 rule, live cells survive into the next instant if 3, 4, or 5 adjacent cells are live; a dead cell becomes live in the next instant if three adjacent cells are live, and dying cells remain inert and cannot be counted by other cells as live or dead for 6 instants before they can again become live. A significant number of relatively simple seeds lead to slowly growing regions of apparent chaos that give birth to a wide variety of dynamic entities, some able to survive and evolve following collisions with other dynamic and stationary objects. Smith has captured many 'movies' of self-maintaining dynamic entities that have emerged from areas of chaos in these toy universes that can be seen by following links on http://www.thewildca.com/.

302. For an on-line animation of this complex figure see slides 14 and 15 in Hall 2007a - http://tinyurl.com/kvgxcqf.

303. In this context "stochastic" refers to the fact that there is a component of randomness in the selection of which adjacent possible time-lines leading into the divergent future become real in the becoming of the next instant. The network of causal influences operating on the system will constrain (either positively or negatively) the probabilities that particular adjacent possible states may be realized.

304. See also Wikipedia on semiotics.

305. Pattee uses "epistemic cut" (1995a, 2001, 2001a, 2005, 2007, 2008, 2013) in reference to the strict ontological separation (in physical and philosophical senses) between:

> ... *knowledge of reality* from *reality itself*, e.g., description from construction, simulation from realization, mind from brain [or *cognition* from *physical dynamics*]. Selective evolution began with a description-construction cut.... The highly evolved cognitive epistemology of physics requires an epistemic cut between reversible dynamic laws and the irreversible process of measuring initial conditions. This is also known as the measurement problem. (Pattee 1995a).

The epistemic cut is also known as the "Heisenberg cut" (Graben & Atmanspacher 2009), that relates to Wolfgang Pauli's (1950, 1952) principle of complementarity. Abel (2008) defined the related concept 'cybernetic cut': "The dynamics of physicality ('chance and necessity') lie on one side. On the other side lies the ability to choose with intent what aspects of ontological being will be preferred, pursued, selected, rearranged, integrated, organized, preserved, and used (cybernetic formalism)."

On the other hand, there is little similarity to the "epistemic gap" separating "phenomenological knowledge" from "physical knowledge" (Alter & Walter 2006; Chalmers 2006). Not only are the paradigms surrounding the "cut" and the "gap" quite different, but epistemic gap relates to forms of human consciousness, not fundamental aspects of living things. Pattee's "cut" relates to the ontological difference between uninterpreted physical reality on one side and information about that reality on the other side, i.e., the cut is between physical reality and knowledge of the physics.

306. Following Pattee, when the energy content (i.e., exergy) of a codified object is essentially independent of the meaning of the code it carries, it is said to be energetically degenerate. For example, beyond a few clues used by regulatory proteins and ribozymes to identify particular bits of code for transcription, there is no energetic difference between a piece of purified DNA from a bacterium and one of the same length from a human; or, there is no energetic difference between a letter sized piece of paper containing part of the instructions for making an atom bomb and the text of an child's ABC reader.

307. Small organisms such as bacteria and yeast may undergo several generations of replication in one day, times the number of days in a year over at least three billion years life has existed on Earth. It is also likely that early in the emergence of autopoiesis that macromolecular "experiments" took place very much faster than does the tightly controlled reproduction of today's bacteria which can double every 20 minutes under optimum conditions, or baker's or brewer's yeast (an eukaryote cell) which can double as rapidly as once every one or two hours.

308. The Hall (1966) manuscript was first submitted in Hampton L. Carson's Genetics and Evolution course at Washington University, St. Louis., May 3, 1966. It was revised Summer, 1966, in hopes of finding a sponsor for its publication. It was shown at the cell biology meetings in Ames, Iowa, with no result, and has not been updated since. The 1966 MS has now been converted to HTML and PDF for publication on the Web. The paper is historically important because one of the first anywhere to present comprehensive evidence in support of the theory that the cellular structure of single-celled algae arose from a symbiotic association between a non-photosynthetic protozoan and blue-green algae - a thesis that is now accepted by most biologists but was highly revolutionary when it was first made famous by Lynn Margulis in her 1968 article in Science (161:1020-2) and her 1970 book, Origin of Eukaryotic Cells. There are important differences between Hall's (1966) and Margulies's (Sagan 1967; Margulies 1968, 1970) approaches to understanding the evolutionary processes giving rise to the endosymbiotic eukaryotic cell.

309. i.e., specializations in the way organisms obtain the energy resources they need to fuel their dissipative metabolic processes, self-production and self-reproduction.

310. In the epoch of promiscuous interchange of hereditary information, for the individual autopoietic entity to survive, all important genes must be able to work together with other genes that may at any time be picked up from the environment. This requirement for broad coadaptation would greatly impede evolutionary differentiation away from some average form of adaptation. From this point of view, the first life on earth would have been a diffuse "last universal common ancestor" or LUCA, possibly spread throughout the world's oceans.

311. Hierarchy in this sense refers to a scalar nesting relationship, where individual subsystems are all contained as components within the boundary of a larger system. Salthe (2012) now defines this as a "compositional" hierarchy.

312. I define the posthuman condition as the state where humans as individual organisms and their technologies essentially become inseparable in their ecological/economic relationships with their environments. In using the term "post-human" I do not imply any deep philosophical or metaphysical implications, but only the literal fact that aspects of human cognition are extended, distributed, and may even be shared beyond the physical limits of human bodies and brains in ways I discuss in Hall (2006a).

313. An "Humano-technical" entity is defined as a human individual together with the array of tools and technologies that the person habitually uses in his/her normal life.

314. As advertised by several suppliers in the June 1982 "80 Microcomputing Magazine" (retrieved from the Internet Archive - http://tinyurl.com/7ks65vt) targeting the TRS 80 (CP/M) market boxes of 10 8" floppy disks were advertised for prices from $30 to $50 depending on density and formatting. In Australia we paid a premium for this stuff.

315. Two Sci-Fi writers that I think have come the closest to foreseeing the future were John Brunner in his 1975 The Shockwave Rider and Charles Stross's 2005 novel, Accelerando. Shockwave Rider anticipated many aspects of the Internet and Web that developed over the next 20 years. Accelerando has a much broader scope and traces the step-by-step evolution of the convergent posthuman cyborg that at least until now is closely tracking the emergence of this grade-shifted creature[28]. Unlike the book Shockwave Rider that still lives only in the paper world, Stross made Accelerando available under a Creative Commons license as a free eBook (download from here).

316. The market for storage in the cloud is changing as I write this. I suspect that to now Google has priced its cloud storage below actual cost as its licensing allows it to datamine contents in aid of better targeting advertisements on its Gmail service. As at 24 April 2012, Google replaced its old storage plan associated with Google Docs that I use (Free: 7+ GB in Gmail, 1 GB in Google Docs, and (uploaded files only) 1 GB in Picasa; + 20 GB @ $5.00/year **|** with **|** 10 GB in Gmail, 5 GB in Google Drive, 1 GB in Picasa; + 25 GB @ $2.49/month = $29.88/year). Note that this is now closely comparable to Amazon S3's cost of 20 GB @ $30/year.

317. The storage prices are not as different as they seem. Google's pricing plans are for fixed charges for any storage used under the plan up to the amount of the cap. Amazon prices are prorated on the amount of storage actually used per day within each pricing band over the accounting period.

318. http://en.wikipedia.org/wiki/Motorola_MicroTAC.

319. http://www.apple.com/iphone/specs.html.

320. This line may be blurred with people who are lost figuratively as well as literally without their smartphones.

321. Francis et al. (2009) define the attended stimulus as "the part of the environmental stimulus that is positioned in such a way that sensory systems can acquire information."

322. Humberto Maturana was a coauthor of the Lettvin et al. (1959) paper. Maturana learned from his work on the neural processing of vision in the Lettvin collaboration and later studies with pigeons demonstrated that the brain *constructed* a "view" of the world that was nothing like a photographic image. As Maturana (2002: pp. 5-6) described, this started him thinking of cognition as an autopoietic process.

> In 1965 when I was studying color vision in pigeons I realized that I could no longer pretend that one saw the colors as features of an external world, and that I had to abandon the question, "how do I see that color?" and ask instead, "what happens in me when I say that I see such a color?" To make this change meant abandoning the notion that there was an external independent world to be known by the observer. Instead I had to accept that knowing has to do with the congruent interactions between entities each of which is a structure determined system – that is a system in which all that happens with it and to it is determined at every instant by the way it is made (its structure) at that instant.
>
> To adopt the epistemological grounding entailed in these changes meant that henceforth I would not ask "what is?", but I would ask myself "what criterion do I use to validate my claim that something is what I say that it is?" Furthermore, to do this entailed a fundamental ontological change, namely the fundamental question was no longer "*what is the essence of that which I observe?*" but rather "*how do I do what I do as an observer in observing?*"

323. On his website in 2007, Izihevich follows Moore's Law to forcast that by 2046 it will be possible to simulate the human brain in real time.

324. It is worth noting that the power of the imaging technology is also highly dependent on the ever-increasing power of computation and the rapid shrinking of other electronic technologies enabled by Moore's Law.

325. It is worth exploring these Wikipedia links to gain a more concrete understanding of the physiology of bodily self-regulation as this makes the concept of autopoiesis more concrete (see also chemoreceptor).

326. Good general references for this paragraph are Damasio's book, The Feeling of What Happens (1999) and chapter 3 "Making Maps and Making Images" in his Self Comes to Mind: Constructing the Conscious Brain (2010).

327. Other recent reviews of the area of mental causation are David (2012); Moore & Obhik (2012); Umair (2012); Alsmith (2011); Krieghoff et al. (2011).

328. Updating links from Hill et al. (2009), in the US Bureau of Labor Statistics 2010 Standard Occupational Classification System the Alphabetical Index to the 2010 lists 8442 different job titles; the ICUN Red List of Threatened Species 2013.2 lists the status of 5,488 named mammalian species http://www.iucnredlist.org/mammals/redlist_status.

329. Deciding what constitutes a species – particularly over a span of time – is rather arbitrary. This issue is reviewed in an excellent article by Galway-Witham (2016) in terms of the various species discussed in this section. Biological species, e.g., *Homo sapiens*, are defined on the basis of presumably interbreeding populations. The taxonomic naming of species based on fragmentary fossils, and the allocation of fossils (e.g., of hominins) to particular species names

is much more arbitrary. Fossil "species" are based on few sets of surviving bones that are separated in time and space from one another. These are hardly representative of variation in a population. Also, beyond the range of radiocarbon dating (useful only for the last 60,000 years or so), only rarely do the geological conditions of fossilization allow the specimen to be precisely located in time or relative to the dating of other fossils from other places. Other dating methods include other radiometric dating techniques and geomagnetic reversals, all tied in with stratigraphy. The great difficulty is that many important fossils are not associated with readily dateable strata.

330. More frequent survivors indicating hominin activities are stone tools. These tell us that a tool-maker existed close to where the tools are found, but they are also subject to the same dating difficulties. Carrión et al. (2011) show dates and locations for the earliest records of fossil species and stone tools. Thus, both because of the level of (often vested) interest in the story and because of the unavoidable uncertainties surrounding the scarce and scrappy fossils, the interpretation of the sparse record of fossil hominids will be subject to argument and controversy. (In my opinion, most of the Wikipedia articles linked to generic and species names do a reasonable job of representing the controversies around particular taxonomic names.) Nevertheless, as scrappy as the fossils may be, they are objective markers that a hominid existed in a certain place in the past. In some cases, the preserved remains can tell us a lot about the morphological capabilities of the organism that left the remains.

331. See Su's (2013) "The earliest hominins: *Sahelanthropus*, *Orrorin*, and *Ardipithecus*".

332. White et al's (2009) discovery of a "fairly complete" skeleton of *Ardipithecus ramidus* together with the collection of a variety of other information from the site gives a good understanding of what the first hominins deriving from the human-chimpanzee last common ancestor may have been like. The results of this finding are detailed in a Science video (The analysis of *Ardipithecus ramidus*--one of the earliest known hominids) and a special issue of the journal Science: WoldeGabriel (2009); Louchart et al. (2009); White et al. (2009a); Suwa et al. (2009); Suwa et al. (2009a); Lovejoy et al. (2009); Lovejoy et al. (2009a); Lovejoy et al. (2009b); Lovejoy et al. (2009c).

333. The fossils described as *Homo naledi* were found in 2013 by cavers exploring a particularly inaccessible part of the Rising Star cave system about 40 km N of Johannesburg, South Africa (Dirks et al. 2015). The chamber where the fossils were found could only be accessed by very small skinny people. The structure of the cave system suggests that the fossils could not have been washed in, suggesting that bodies were carried in by conspecifics. In two seasons of exploration funded by National Geographic more than 1500 pieces of at least 15 individuals, many lying on the soil surface, were recovered. Many still remain. Dating will be difficult because the fossils were not embedded in datable rocks and no other fossils were found to allow comparative dating.

334. Denisovans are an extinct species of human sharing a common ancestry with Neanderthals that lived in Siberia contemporaneously with modern humans (Reich et al. 2010, 2011; Meyer et al. 2012). The only fossil record (so far) is part of a single finger bone and two teeth that provided DNA for sequencing. These were found in a layer of Denisova Cave in the Altai Mountains in southern Siberia believed to date from 30,000 to 50,000 years ago. The archaeological record of hominin occupation in Denisova Cave starts some 280,000 years ago, and may have also been occupied at different times by Neanderthals and modern humans (*Homo sapiens*). The two teeth are morphologically clearly different from both modern humans and Neanderthals, sharing more similarities with *H. habilis* and *H. erectus* (Reich et al. 2010). More significantly DNA from the bone (chromosomal and mitochondrial) and mitochondrial DNA from the teeth clearly show that the bone and teeth were from a species of *Homo* that was neither Neanderthal nor modern

human, but one that was closely related to both. Differences in the mitochondrial DNA (mitochondrial DNA is passed down solely through the female line without recombination because sperm carry no mitochondria) suggests that the Denisovan mitochondrion diverged from the common ancestor of Neanderthals and Homo sapiens around one million years ago. Nuclear DNA (inherited from both parents and recombined in each generation) suggests the Denisovans diverged from a common Denisovan-Neanderthal common ancestor around 640,000 years ago, and the common Denisovan-Neanderthal stock from African *Homo sapiens* around 804,000 years ago. Intriguingly, the genetic evidence shows that there was a small amount of hybridization between the Denisovans and migrating *Homo sapiens* stocks that survive today as Australian Aborigines and Melanesians on and near the island of New Guinea (Reich et al. 2011; Meyer et al. 2012). The suggestion is that later waves of human migration from more western areas of Asia that had not encountered Denisovans replaced the earlier stocks on the Asian mainland, Borneo and Java.

335. The discovery and description of the remarkably complete *Australopithecus sediba* fossils adds further understanding to the early evolution of the hominins: Carlson et al. 2011; Kibii et al. 2011; Kivell et al. 2011; Zipfel et al. 2011; Pickering et al. 2011; Henry et al. 2012; Berger 2013; Irish et al. 2013; Churchill et al. 2013; de Ruiter et al. 2013; Schmid et al. 2013; Williams et al. 2013; DeSilva et al. 2013; Gibbons 2011; Spoor 2011; Bower 2013; DeSilva 2013; Science podcast interview with Lee Berger about *Australopithecus sediba*; Balter 2010, 2011.

336. The paleontological and paleoarcheological records suggest that anatomically modern humans occupied Asia Minor between approximately 135 and 80 kya in areas adjacent to those occupied by Neanderthals (Reyes-Centeno 2016). These early Eurasian *sapiens* apparently died out and were totally replaced by Neanderthals during climatic deterioration (Garcea 2012). Based on all the genomic evidence available, there is little evidence that these early sapiens colonists into Eurasia left any genetic imprints on today's humans, although later Neanderthals show hints of introgression from *sapiens* that may date from this time (Árnason 2016). A second dispersal out of Africa via the Horn of Africa and the Arabian Peninsula, beginning around 70-60 kya, hybridized with *both* Neanderthals and Denisovans, and made its way along coastlines to the east as far as Australia (Fernandes et al., 2012). The available genomic evidence suggests that these early southern migrants were then largely replaced by yet another wave of migrants from a core Eurasian area into East Asia some 38-23 kya that had Neanderthal genes but no contact with Denisovans (Reich et al 2011; Pugach et al 2013). Reich et al suggest that this pattern indicates hybridization with Denisovans took place in tropical SE Asia close to the jumping off point for colonization of Sahul and the Pacific Islands.

337. Eberly (2007), Wood & Leakey (2011) and Wood & Bauernfeind (2012) comprehensively review evidence and names applied to early hominin fossils up to the emergence of *Homo erectus* in Africa. More than most others, these papers make it clear just how fragmentary our information is on the emergence and early evolution of *Homo*. See what the Smithsonian National Museum of Natural History has to say about *H. habilis* and *rudolfensis*. All of these issues are clouded in uncertainty as discussed by Cela-Conde & Nadal (2012).

The current majority view is that only a single, variable species of *Homo* existed through the early and middle Pleistocene (Kramer 1993; Antón 2003; Baab 2008; Lordkipanidze et al. 2013;).

van Arsdale & Wolpoff (2012) would lump *habilis* and the Dmanisi hominins with *erectus* as a single chronospecies based on morphometric analysis.

Scott (2013) based on simulation experiments argues that it is premature for vanArsdale and Wolpoff to reject the hypothesis that these represented different lineages.

Kaifu et al. (2010) concludes that the oldest Indonesian (~1.7 myo) and African *erectus* are comparable in terms of cranio-mandibulo-dental morphology.

Jimenez-Arenas et al. (2011) would recognize three taxa for *Homo*, a "habiline" cluster including Dmanisi hominins involved in the first dispersal out of Africa, an "erectine" cluster including Neanderthals, and anatomically modern humans.Hublin (2014), criticize the excessive lumping without offering alternative classifications.

338. There has been substantial discussion regarding the relationships of *Australopithecus sediba*, *Homo habilis*, *H. ergaster*, and *H. erectus*, with regard to identifying the earliest species of *Homo* (Dennell & Roebroeks 2005; Pickering et al. 2011; Kaifu et al. 2011a; Berger 2012; Antón & Snodgrass 2012). Bermudez de Castro et al's (2014) analysis of the jaws of Dmanisi fossils identified significant developmental and wear pattern differences between the large jaw D2600 and two smaller jaws, D211 and D2735, that would support recognizing two species at Dmanisi with different dietary adaptations and tool preferences (Baena et al. 2010). The small jaws fit well with *habilis* and *ergaster* leading to *erectus*, while the large jawed species would be recognized as *H. georgicus* (Gabunia et al. 2002) and not directly on the line to *erectus* – but possibly related in some way to a line leading to *H. floresiensis*[341].

339. As has been the case for *Ardipithecus ramidus*[332] and *Australopithecus sediba*[335] for early hominins, the remarkable collection of fossils found by Lordkipanidze and colleagues at Dmanisi have generated a number of excellent publications by Gabunia, Lordkipanidze, and their colleagues regarding the early speciation and evolution of *Homo*: Gabunia & Vekua (1995); Gabunia et al. (2000) – considered to have affinities with *H. ergaster*; Gabunia et al. (2001); Gabunia et al. (2002) – named a new species, *H. georgicus*; Gabunia et al. (2002a); Vekua et al. (2002) - assigned to *erectus*=*ergaster*; Lordkipanidze et al. (2005); Lordkipanidze et al. (2006); Rightmire et al. (2006) – Close to stem from which *H. erectus* evolved; Lordkipanidze et al. (2007); Rightmire & Lordkipanidze (2009, 2010) – equivocal as to whether *habilis* and *rudolfensis* are *Homo* or *Australopithecus*, Dmanisi specimens may represent early *erectus* evolved in Asia; Baena et al. (2010); Garcia et al. (2010); Messager et al. (2010); Messager et al. (2010a); Pontzer et al. (2010); Vekua & Lordkipanidze 2010; Agusti & Lordkipanidze (2011); Vekua & Lordkipanidze (2011); Ferring et al. (2011) – Mode 1 artifacts dated to ≤ 1.85 my show tool-using hominins in Dmanisi before *erectus* appeared in Africa; Mgladze et al. (2011); Pontzer et al. (2011); Messager et al. (2011); Hemmer et al. (2011); van Arsdale & Lordkipanidze (2012); Lordkipanidze et al. (2013) – degree of variation in Dmanisi hominins compared to overall variation suggests they belong to a single *erectus* chronospecies; Martin-Francés et. al 2013. Skinner et al. (2006) and Bermúdez de Castro et al. (2014) – argues that size, shape, developmental pattern, and wear pattern of the large jaw D2600 is sufficiently different from the other Dmanisi jaws to support the idea that Dmanisi was occupied by two different hominin species[338].

340. Use of the species name "*erectus*" in this book is problematic in several major respects (Antón et al. 2014). (1) What early fossils should be considered as members of *erectus* – especially with regard to the temporal and geographic relationships between specimens from Java (where the name originates), Africa, and Dmanisi? – closely related to the question of how many species existed in the early to mid Pleistocene: a single variable species (i.e., a broadly defined *erectus*) or more than one? (2) How do the early European fossils ancestral to Neanderthals relate to "typical" *erectus*? Is *erectus* directly ancestral to *sapiens* and our close relatives? Some of the most recent evidence and thinking is reviewed by Galway-Whitlam (2016).

341. Brown et al (2004) discovered a fairly complete skeleton of a small-brained and small-bodied hominin (*Homo floresiensis*, the "Hobbit") in sediments dated from 38 to 18 kya (Morwood et al. 2004, 2005) in the Liang Bua cave on the Indonesian island of Flores. Based on the folk tales of mountain tribes, Forth (2005) suggests that Hobbits may have survived on Flores at least up

to the last few hundred years ago. Based on more detailed analyses of dating evidence, Sutkina et al. (2016) find no evidence that *floresiensis* survived beyond 50 kya.

In brain and body size, the Hobbit resembled an australopithicene, with skull structures most similar to early *Homo erectus* (ref the Dmanisi hominins). Brown et al. attributed Hobbit's small brain and body size to insular dwarfism, an adaptation to resource limitations in the limited habitat of a comparatively small island, similar to the dwarfism of the pigmy elephant *Stegodon florensis*, hunted by the hobbit. Morwood et al. (2004) also described a variety of stone tools found in association with the fossils implying that it was a tool-maker. Many people could not accept that an early hominin had survived until recent times, and argued that the fossil was a pathological or pigmoid modern human, e.g., suffering from microcephaly or cretinism (e.g., Weber et al. 2005; Martin et al. 2005; Jacob et al. 2006). Given the importance of these findings, *floresiensis* has been studied in comparable detail to *Ardipithecus ramidus*[332], *Australopithecus sediba*[335,] and the Dmanisi hominins[339]: Falk et al. (2005, 2005a, 2006); Culotta, E. (2006); Gordon et al. (2008); Morwood et al. (2009); Westaway et al. 2009; Westaway et al. 2009a; Roberts et al. 2009; Moore et al. 2009; van den Bergh et al. 2009; Jungers et al. 2009; Larson et al. 2009; Brown & Maeda 2009; Falk et al. 2009; Baab & McNulty 2009; Argue et al. 2009; Morwood & Jungers (2009); Meijer et al. 2010; Montgomery et al. 2010; Kaifu et al. 2011; van Heteren 2012; Montgomery 2013; Orr et al. 2013; Hayes et al. 2013; Zeitoun (2016).

342. Bräuer (2012) argues that fossils assigned to *H. heidelbergensis* are early representatives of the *sapiens* chronospecies that should be considered ancestral to modern humans, Neanderthals and Denisovans. Personally, I think the concept of a chronospecies should only be applied to cases where we lack evidence regarding the biological status of the species concerned. Given the amount of genomic evidence discussed below showing that *H. sapiens*, Neanderthals and Denisovans were genetically distinctive evolutionary species I do not think the chronospecies concept can be used to link *heidelbergensis* and *sapiens*. Stringer (2012a) explains just how vexed the naming of this common ancestor is. Some, especially those still arguing for a multiregional origin for *Homo sapiens,* would prefer to scrap the *heidelbergensis* name entirely (Balter 2014). However, in the context of this book the name remains useful.

343. Others would split early *erectus* at least into African and Asian branches (Skinner et al. 2006; Bermúdez de Castro et al. 2014) The allocation of species names to fossil specimens in the later Pleistocene is also fraught with difficulties (Cela-Conde & Nadal 2012), especially with regard to the relationships of *erectus* and *sapiens*, and whether intermediate and other species are involved in the direct genealogy (Rightmire 2012; 2013; Stringer 2012; Mounier et al. 2011; Wu et al. 2011). Tattersal (2011, 2012), prefers to assign European fossils called *erectus* to *antecessor* and *heidelbergensis,* retaining *erectus* as extending from Africa into Asia. Aside from the clear evidence for their emergence in Africa, Tattersal is unable to clearly trace anatomically modern humans from any one of the earlier hominins. There are few reasonably complete fossils from the time and none at all from many areas of Africa.

344. Rizzi et al. (2012) describe the technologies and their limitations for recovering and reading ancient DNA samples. This is also discussed by Prüfer et al. 2014.

345. There is a large very rapidly growing array of more detailed and comparative genomic studies linking to these seminal publications to further refine genome maps, document genetic variability within populations and clarify differences and relationships among the various lineages. Use Google Scholar to find more recent papers up to the date when you read this that cite the seminal article. Many of these subsequent articles will question, extend, or elaborate the original findings. How to do this is described in the section on Demonstrating Semantic Retrieval.

346. See Nature's Special Issue on "The Human Genome at Ten", several of the articles are open (i.e., free to the Web).

Note: According to Rasmussen et al. (2011), based on analysis of the complete genome sequence taken from a 100 year old hair sample,

> Aboriginal Australians [including New Guinea Highlanders] are descendants of an early human dispersal into eastern Asia, possibly 62,000 to 75,000 years ago. This dispersal is separate from the one that gave rise to modern Asians 25,000 to 38,000 years ago. We also find evidence of gene flow between populations of the two dispersal waves prior to the divergence of Native Americans from modern Asian ancestors. Our findings support the hypothesis that present-day Aboriginal Australians descend from the earliest humans to occupy Australia, likely representing one of the oldest continuous populations outside Africa.

Pugach et al. (2013), working with complete genomes of a number of northern Australia Aboriginals substantially refined this picture. Australian Aborigines, New Guinea Highlanders (but not coastal populations) and the Mamanwa (a Negrito group from the Philippine) are descendents of a "southern route" migration out of Africa towards the East as reported by Reich et al. (2011) and Rasmussen et al (2011). These early emigrants from Africa diverged from other modern humans around 75-62 kya, encountered limited hybridization with Denisovans, and were then completely replaced everywhere except in Australia, the New Guinea Highlands and some of the Pacific Islands (e.g., the Philippine Mamanwas) by a 'northern" migration of more modern humans to Asia that diverged from the core African stocks around 38 to 23 kya carrying no Denisovan genes (see also Genomes link aboriginal Australians to Indians). The Australian, New Guinea Highland, and Mamanwa populations began diverging from one another at least 35 kya. Australian Aborigines, but not the New Guinea or Philippine populations, show evidence for the introduction of genes from India about 4.2 kya (~141 generations). In the paleoarcheological record this corresponds to the introduction of dingos ("native" dogs) and the introduction of new stone tool technologies. There is no evidence for the existent of these comparatively recent Indian genes into the SE Asian, New Guinea, or Pacific Islander genomes, indicating that the colonization was somehow or other directly with India. Pugach et al.'s data indicate serial bottlenecks associated with the southern route migration out of Africa. Assuming that immigrants to Australia had to cross water gaps to reach the continent, it is somewhat surprising that Australian Aborigines show less evidence for bottlenecks than do the New Guinea Highlanders or the Mamanwas. Additional genomic and biogeographic information on early *Homo*'s migrations out of Africa can be found in O'Regan et al. (2011), van der Made (2011), Árnason (2016) and Vernot et al. (2016).

347. The highly accurate sequencing techniques used by Meyer et al. (2012) for the Denisovan sequencing is applied to a Neanderthal toe bone from Denisova Cave.

348. At ~400,000 years old, the mitochondrial and nuclear DNA samples reported by Meyer et al. (2014; 2016) from the Sima de los Huesos cave in northern Spain is the oldest hominin DNA to be sequenced, and is probably approaching the age limit of DNA that can survive without being frozen in permafrost. The skeletal remains show some affinities to Neandertals (Árnason 2016), but predate their accepted time of origin in the fossil record. The bones may be allocated to the poorly defined *Homo heidelbergensis*.

349. Recall that I listed speech as the first major cognitive revolution leading to a major grade shift in human biology and ecology. In this episode it will be seen that even before the emergence of speech. there were several other mutually supportive grade shifts in the evolutionary transformation of tool-using forest apes into technologically based modern humans.

350. As discussed in the various papers cited, the resolution of the genetic evidence is so detailed that it shows several of the speciation events were not "clean" breaks; e.g., humans vs Neandertals – Currat & Excoffier (2011); humans vs Denisovians - Reich et al. (2011); Alves et al. (2012);

Huerta & Sanchez et al. (2014); and splits amongst the gibbons – Kim et al. (2011). In all of these cases there is evidence that speciation events and genetic divergence of the separated populations were subsequently followed by a small amount of hybridization that allowed the introgression of a few genes that had differentiated in the respective lineages (Prüfer et al. 2014). One may speculate that the "potential unknown hominin" shown in Figure 93 may have been Asian *Homo erectus*. See also Vernot et al. (2016); Kuhlwilm et al. (2016).

351. More information, illustrations and definitions about the modes of ancient tools can be found in Nature Education Knowledge Project's A Primer on Paleolithic Technology.

352. Based on the scale printed on Presnyakov et al.'s (2012) site map and Google Earth, the Karakhach, Armenia and Dmanisi, Georgia sites are only about 25-30 km apart.

353. It should be noted that Borneo and Sulawesi have hardly been explored from an archeological point of view. Except for Java, which was colonized by *Homo erectus*, the fossil record for southern and southeast Asia is very poor. In other words, the absence of primitive hominin fossils from these areas is no indication that they were not there for at least a while before being replaced by *erectus*.

354. Lombok Strait is the location of Wallace's Line, separating Asian and Australian faunas.

355. A nice summary of *Homo erectus* is provided on Nature Education's Knowledge Project by van Arsdale (2013).

356. Elhaik et al. (2014) criticize the dating methodology of Mendez et al. (2013b) to show that that their extraordinarily early estimated time of 338 kya to the most recent common ancestor for A00 and A0 lineages of the Y chromosome is based on several inappropriate statistical and analytical methods. Elhaik et al.'s estimate for the time of the divergence is a still early, but more reasonable 208 kya.

357. It should be noted that Klyosov (2014) disputes the entire "Out of Africa" concept for the emergence of modern humans based on dating Y chromosome haplogroups, and argues instead that the data better support a concept that modern humans arose in Eurasia from a pale-skinned, fair-haired Neanderthal ancestry, and only recently migrated back into Africa in several successive waves to explain the existing haplotype diversities. Klyosov's argument is refuted by the absence of evidence for Neanderthal autosomal genes in any sub-Saharan African samples (e.g., Lombard et al. 2013; Prüfer et al. 2014; and earlier works cited in these papers). Also, Vernot & Akey (2014) suggest that modern Eurasian humans may have acquired their genes for skin and hair phenotypes through admixture with the Neanderthals they replaced.

358. Some fascinating evidence for human x Denisovan hybridization has been found in a survey of genetic variation in Tibet. Huerta-Sanchez et al. (2014) discovered that the "hypoxia pathway gene, EPSA1" and a surrounding chromosome segmentthat had been identified as having the most extreme signature of positive selection in Tibetans' adaptation to life at the low oxygen levels found over 4000 m elevation is virtually identical to a Denisovan gene sequence, not found in a large sample of Han Chinese or othern modern human genomes.

359. Oppenheimer's interactive is a hypertext constructed much like this book that provides a great deal of information providing background and describing the methodologies and the ways the evidence is used. See also the the wall-chart graphic of the spread of anatomically modern humans out of Africa in Aldhous (2009). This is based on genetics and summarizes paleontological and archaeological evidence available to that time.

360. KPBS/Nova's The Last Great Ape on Bonobos is a 50 minute long PBS/Nova documentary on the biology of wild bonobos and their disastrous interactions with people (watch it on YouTube).

361. Videos show chimpanzees using a variety of tools for processing food and hunting: goup hunting in the BBC's video of group hunting in Uganda (BBC), and chimps spearing bush-babies in Senegal. Videos from Bossou shows a variety of chimpanzee feeding strategies.

362. The concept of guild is an important component in understanding the ecological selective pressures operating on early hominins. To go beyond the Wikipedia definition, see Simberloff & Dayan (1991).

363. It should be noted that many other kinds of tools may have been used that are unmodified, decay easily (e.g., wood artifacts), or were used in areas that were not studied archeologically. Stones or bones that have been modified for use as tools, may be recognized if they are found in a context that would associate them with hominid activities, but even then, the modifications to the substrates may be difficult to discriminate from those caused by natural processes that break stones or erode bones. In other words, it is entirely possible that stone or bone tools were made and used millions of years prior to the first datable records, and excepting truly extraordinary taphonomic circumstances, many other kinds of tools would leave no archeological traces at all. For example, Tattersall (2012) suggests that naturally broken stones often have sharp enough faces that they could cut skin and muscle that could not be done with unaided human teeth and that they could cause the cut marks described by McPherron et al. (2010, 2011) without being registered from the archeological site as tools. However, tools that survive can provide a lot of information about the cultural and cognitive circumstances of their manufacturing and use (Gowlett 2009).

364. In the Pliocene and Pleistocene there was a major proliferation of species in the family Cebidae that was not recognized and understood until clarified in the work of Lynch Alfaro et al. (2012, 2012a). Prior to this all capuchins were placed in the genus *Cebus*. Although there is a large literature on the biology and behaviour of capuchin monkeys in captivity and in the wild, without knowledge of their geographic origin it is difficult to know which species these older works referred to. Most studies on capuchin tool-using referenced *Cebus apella* – which most probably would now be classified as one of the *Sapajus* species, most likely *S. libidinosus* or one of the other (most closely related) species from the seasonally very dry forests of south central Brazil.

365. Although capuchins have not been studied as intensively in the wild as have chimpanzees there is now an extensive recent literature on capuchin systematics, behavior, cognition, and technology that via the following links:

Systematics - Houle 1999; Kay 2014; Kiesling et al. 2014; Lynch Alfaro et al. 2012, 2012a; Pecon-Slattery 2014; Perelman et al. 2011; Perry et al. 2014; Perez et al. 2013; Pozzi et al. 2014; Schrago et al. 2013; Schrago & Voloch 2014; Schneider & Sampaio 2014; Springer et al. 2012; Steiper & Seiffert 2012; Voloch et al. 2013.

Biology – Beran & Parrish 2012; Beran et al. 2012; Boinski 1988; Borgo et al. 2013; Bräuer & Hanus 2012; Brosnan 2011; Brosnan & de Waal 2003; Canale et al. 2009; Cleveland et al. 2004; Carpenter & Locke 1937; Cummins-Sebree & Fragaszy 2005; de Moraes et al. 2014; de Waal & Davis 2003; de Waal et al. 2005; Drapier et al. 2005; Drayton & Santos 2014; Duarte et al. 2012; Duran et al. 2013; Emido & Ferreira 2012; Evans & Westergaard 2004, 2006; Falotico & Ottoni 2013; Fragaszy 2012; Fragaszy & Bard 1997; Fragaszy & Perry 2003; Fragaszy et al. 2003; 2009; 2010; 2010a, 2010b; 2013; Garber & Brown 2004; Garber et al. 2012; Gunst et al. 2010; Hartwig et al. 2011; Hattori et al. 2012; Honeysett 2006; Hopkins et al. 2012; Isler et al.

2008; Izar et al. 2011; Izawa & Mizuno 1977; Janson 2007; Judge & Bruno 2012; Klüver 1937; LaCour et al. 2014; Leimgruber et al. 2014; Liu et al. 2009, 2011; MacKinnon 2013; McGrew & Marchant 1997; Mannu & Ottoni 2009; Manrique et al. 2011; Manson et al. 1997; Marshall & Wrangham 2007; Massaro et al. 2012; Melin et al. 2014; Meulman & van Schaik 2013; Moura 2004, 2007; Moura & Lee 2004, 2010; Ottoni et al. 2005; Ottoni & Izar 2008; Parker & Gibson 1997; Panger et al. 2002, 2002a; Perry 2011; Potts 2004; Rindler 2014; Rose 1997; Ross 1991; Russon et al. 2014; Sabbatini et al. 2012, 2014; Savage-Rumbaugh et al. 1978, 1978a; Skerry et al. 2011; Souto et al. 2011; Spagnoletti et al. 2011, 2012, 2013; Suchak & de Waal 2012; Verderane et al. 2013; Visalberghi 1997; Visalberghi & Addessi 2013; Visalberghi et al. 2007, 2008, 2009; 2009a, 2011, 2013; Visalberghi & Fragaszy 2011, 2012, 2013; Visalberghi & McGrew 1997; Westergaard 1998, 1999; Westergaard et al. 1995, 1998, 1998a, 2000, 2004, 2007; Wesergaard & Fragaszy 1987; Westergaard & Suomi 1993, 1994, 1994a, 1995, 1995a, 1997, 1997a; Wright et al. 2009; Yamamoto & Takimoto 2012.

366. I find the placement of the capuchin monkey on this graph to be most interesting. As referenced in note 35, capuchins are accomplished tool users and have developed a complex socially transmitted nut cracking industry that appears to show more long-range foresight and planning than any of our living ape relatives have shown. Field studies show that the capuchins also seem to have a genuine understanding of the qualities of the tools they use (Fragaszy et al. 2010a). Lab studies show (1) that they are also able to knap flints (video 1) (2) they will pass the tool to where another monkey needs the tool to access a treasured food item the knapper cannot access, and (3) the monkey who uses the tool will share the treasure thus made accessible with the knapper who cannot reach it directly (video 2). Note: these videos are earlier and slightly longer takes of segments also included in the "Capuchin – the monkey puzzle" video linked via (Figure 121) There is also strong evidence for social learning and the development of cultural traditions (Perry 2011) as seen in chimpanzees.

367. Note the capuchins depicted in the lower left corner of the Detail from the Garden of Eden (Figure 111 and **Error! Reference source not found.**). They too were expelled from Eden. Given the life-like poses and accuracy with which they were depicted in the painting from around 1615, it is clear that Jan Brueghel the Elder who was responsible for the animals in this painting must have had first-hand experience with the monkeys.

368. To assess whether their samples are reasonably considered to belong to one morphological species or are segregated among more than one, many of these authors compare the variation among their fossil samples with the variability observed among modern *Homo sapiens*. To me this is highly suspect. Our current species is comprised of more than 7 billion individuals, many of whom capable of migrating half way around the planet in less than a day, and where local populations consist of tens of thousands or even millions of individuals. (For example, I was born in California and I married a woman in Washington DC who was born in north Queensland, Australia that I met in Melbourne, Australia – both our families are of European ancestry). Two million years ago, *Homo* was represented by probably small hunter-gatherar bands (probably less than 25 individuals) moving around their local landscapes at a walking pace. Many bands would probably die out in bad years. Yet, over tens of thousands of years (a very short span of time compared to a 2-3 million year geological record of *Homo*) hominins could spread from the African Rift system to the Indonesian peninsula, but the structure of the species would be very different from modern humans. With this kind of population structure it would be very difficult to define what constituted a biological species, either geographically or temporally. Where innovation and the spread of technology are concerned, it is probably not particularly useful to worry about which particular species of early *Homo* was using it.

369. John Hawks is a paleoanthropologist involved in establishing many of the hominin genomes. His especially lucid Weblog (paleoanthropology, genetics and evolution) provides a great deal of information genetic relationships amongst the various extinct and living populations of *Homo*. See Neandertals, Denisova, and Malapa in his blog for relevant posts elaborating these observations.

370. Hear Prof. Lordkipanidze's talk on TED[X] describing the importance of the Dmanisi findings.

371. Toth & Schick (2009) observed that the tools made by the bonobos Kanzi and Panbanisha are distinguishable from Oldowan tools, possibly as a consequence that the bonobos are somewhat less dextrous holding the cores than were Oldowan hominins or contemporary humans. This is not surprising, given that there is no evidence that the chimpanzee lineage ever made such tools or even lived in an environment where there would be significant advantage to be gained by making them. Chimpanzees generally hunt small prey in thick forests where their kills can simply be torn apart and are much less likely to be seen and stolen by competitors such as big cats or hyenas. Although hammer stones and anvils may be used for processing nuts as demonstrated in the videos, there is nothing in chimpanzee biology that suggests a major advantage could be made by cutting things with broken stones.

372. Plummer (2004) is a masterwork reviewing all work published till then on the Oldowan industry and those who made and used the tools.

373. The evolutionary tradeoffs between diet, digestion, and brain capacity are explored very lucidly from a number of viewpoints and at length in the book Roebroeks edited 2007 book, Guts and Brains: An Integrative Approach to the Hominin Record. The book can be dowloaded for free, and I highly recommend it.

374. The Bilzingsleben archeological site is detailed by an excellent German language web site. The link here points to Google's translation of this site: Bilsingsleben: Ein altsteinzeitlicher Siedlungsplatz des Homo Erectus in Thüringen.

375. This, of course, is equivalent to a Popperian knowledge improvement cycle (see Popper's Evolutionary Theory of Knowledge).

376. Guthrie (2007) notes that he has helped bush pilots who have flown him to remote savanna locations in Africa to build thorn fences around the aircraft's wheels and tails to prevent hyenas chewing on and damaging them.

377. Even today, some traditional tribal Africans such as the Maasai prove their manhood by hunting down dangerous predators (Ikanda & Packer, 2008; Goldman et al., 2010).

378. For additional explanation see Levins 1968 on effects of changing environments; Dawkins & Krebs 1989 on evolutionary arms races and the red queen hypothesis; and Grove 2011 and 2013 on the impacts of climatic variability as a driver for niche broadening.

379. For additional studies of the protolinguistic nature of primate vocalizations see: Seyfarth et al. (2010), Clay & Zuberbühler (2009); and Slocombe et al (2010).

380. Because of their artificial nature as physical objects, Popper (1972) considered man-made artefacts to belong in his world 3.

381. I use the term "virtually" because I actually have some preparation during my academic career to deal with this material: as a monkey handler for Duane and Sue Rumbaugh in their early 1960s studies on primate cognition; as teaching fellow in Irven DeVore's general studies course at Harvard University on primate evolution around 1970, and as a master's thesis advisor for Dianne Chepko-Sade's 1977 study of the organization and splitting of social groups in free-ranging rhesus macaques on Caya Santiago. In all of these cases learn something about the materials being studied or taught.

382. Following Karl Popper's "knowledge is solutions to problems of life, "knowledge" is used here in the broad sense that I have defined earlier in this book, e.g., see Defining Information and Knowledge is Contentious, The spontaneous emergence of autopoiesis and knowledge.

383. This is the concept of a gene pool as defined in evolutionary biology with the addition of culturally transmitted knowledge.

384. The term "species" has many conceptual flavours indicated by modifiers as discussed in this Wikipedia article, and I will use several of these flavours in the following sections. See also "species problem".

385. See discussion following Influence turns wisdom into power.

386. There are two complete video programs giving detailed stories of what has been learned about chimpanzee and gorilla cultures: (1) BBC's, The Cultured Ape (Part 1 of 6), (Part 2 of 6), (Part 3 of 6), (Part 4 of 6), (Part 5 of 6), (Part 6 of 6); (2) National Geographic's, Ape Genius (includes examples of chimpanzees hunting with spears – begin 6 min, 30 sec - Pruetz & Bertolani 2007 and Pickering & Dominguez-Rodrigo 2010 also document this kind of hunting).

Bibliography[1]

1000 Genomes Project Consortium (2012). An integrated map of genetic variation from 1,092 human genomes. Nature 491, 56-65 - http://tinyurl.com/af8u4mk.

Abel, D.L. (2008) The 'cybernetic cut': progressing from description to prescription in systems theory. The Open Cybernetics and Systems Journal 2, 252-262 - http://tinyurl.com/ls7a4a8.

Abel, R. 2011. The Gutenberg Revolution: A History of Print Culture. Transaction Publishers, New Brunswick, NJ.

Aboitiz, F. 2012. Gestures, vocalizations, and memory in language origins. Frontiers in Evolutionary Neuroscience 4, no. 2, 15 pp. - http://tinyurl.com/9dce3k2

Abrams, M., ed. 1998. World Wide Web - Beyond the Basics, Prentice Hall - http://tinyurl.com/253nujw.

Ackoff, R.L. 1989. From data to wisdom. Journal of Applied Systems Analysis 16, 3–9.

ACAUS (Association of Chartered Accountants in the US) (1999–2001). Accounting: A virtual History. – http://www.acaus.org/history/ [http://Web.archive.org/Web/20020127162659/http://www.acaus.org/history/]

Agnew, S.P., Dumanlan, G.A. 2011. Mind meets machine: targeted rennervation and prosthetic devices in upper limb amputees. Congress Quarterly (Spring 2011), 20-21 - http://tinyurl.com/bo4d3qw.

Agusti, J., Lordkipanidze, D. 2011. How "African" was the early human dispersal out of Africa? Quaternary Science Reviews 30, 1228-1342 – http://tinyurl.com/pdy94ku

Ahern, J.C.M., Janković, I, Voisin, J.-L., Smith, F.H. 2013. Modern human origins in Central Europe. The Origins of Modern Humans: Biology Reconsidered, Second Edition. (eds) Fred H. Smith and James C. M. Ahern. John Wiley & Sons, Inc., pp. 151-222 - http://tinyurl.com/kde2mde

Aiello, L.C. 2010. Five years of *Homo floresiensis*. American Journal of Physical Anthropology 142, 167-179 - http://tinyurl.com/m82bmhk

Aiello, L.C., Wheeler, P. 1995. The expensive-tissue hypothesis: the brain and the digestive system in human and primate evolution. Current Anthropology 36(2), 199-221 - http://tinyurl.com/k2j3eoz.

Akman, V. 1997. John Lyons. Linguistic Semantics: An Introduction. *Book review in:* Natural Language Engineering - http://tinyurl.com/pl52ol4.

Al-Abbadi, M. 1992. Life and fate of the ancient Library of Alexandria. 2nd Ed. Rev. United Nations Educational, Scientific and Cultural Organization. Paris.

Al-Amoudi, I. No Date . The Economy of power, an analytical reading of Michel Foucault – http://tinyurl.com/n95xn64.

Albanesius, C. 2012. Google reveals $1,500 Project Glass Explorer Edition. PCMAG.COM, 27 June 2012 - http://tinyurl.com/cqhg62f.

Aldhous, P. 2009. Huge gene study shines new light on African history. New Scientist 30 April 2009 - http://tinyurl.com/oswabja.

[1] The server resolving DOI links to articles via http://libgen.org may or may not be available. If these links don't work try a Google search for the document title to find possible new links to archived versions of the article.

Aldrich, M.L. (2001). Scientific Association Records Programs: A Beginner's Guide (2nd Edition). AAAS History and Archives - http://archives.aaas.org/guide

Alfeld, P. 1998. The Mandelbrot set. Understanding Mathematics, University of Utah - http://tinyurl.com/l8tace8 [danger - infinite complexity can be dangerously absorbing!].

Allen, R.T. (1996). Polanyi's overcoming of the dichotomy of fact and value. Polanyiana Volume 5:2. - http://www.kfki.hu/~cheminfo/polanyi/9602/polanyi1.html - 8.

Alperson-Afil, N. 2008. Continual fire-making by hominins at Gesher Benot Ya'aqov, Israel. Quaternary Science Reviews 27, 1733-1739 - http://tinyurl.com/9dy55h3.

Alperson-Afil, N., Goren-Inbar, N. 2010. The Acheulian Site of Gesher Benot Ya'aqov - Volume II - Ancient Flames and Controlled Use of Fire. Springer.

Alpert, J., Hajaj, N. 2008). We knew the web was big… The Official Google Blog July 25 2008 - http://tinyurl.com/m4frbfa.

Alsmith, A.J.T. 2011. The structuring body: a critical study in the description & explanation of perceptual experience. Thesis. Universität Mainz http://tinyurl.com/8k6dhct

Alter, T., Walter, S. 2006. Introduction to phenomenal concepts and phenomenal knowledge: new essays on consciousness and physicalism, in Alter, T., Walter, S. (eds) , Phenomenal Concepts and Phenomenal Knowledge: New Essays on Consciousness and Physicalism. Oxford University Press, New York, pp 3-13.

Alves, I., Hanulová, A.S., Foll, M., Excoffier, L. 2012. Genomic data reveal a complex making of humans. PLoS Genetics 8(7), art. e1002837, 7 pp. - http://tinyurl.com/l26d8wz

Ambrose, S.H. 2010. Coevolution of composite-tool technology, constructive memory, and language – implications for the evolution of modern human behavior. Current Anthropology 51 (Suppl. 1), 135-141 - http://tinyurl.com/m2ju9ku

Amos, J. 2010. 'Hobbit' island's deeper history. BBC News, Thursday, 18 March 2010 - http://tinyurl.com/md3mx3t

Ananthanarayanan, R., Esser, S.K., Simon, H.D., Modha, D.S. 2009. The cat is out of the bag: cortical simulations with 109 neurons, 1013 synapses. SC09 November 14-20, 2009, Portland, Oregon, USA - http://tinyurl.com/3wn58h7.

Andras, P., Andras C., 2005. The origins of life – the 'protein interaction world' hypothesis: protein interactions were the first form of self-reproducing life and nucleic acids evolved later as memory molecules. Medical Hypotheses 64, 678-688 - http://tinyurl.com/ktjl22r.

Andrews, P., Kelley, J. 2007. Middle Miocene dispersals of apes. Folia Primatologica 78, 328-343 - [log in researchgate.net, then go to http://www.researchgate.net/profile/Jay_Kelley/publication/5984489_Middle_Miocene_dispersals_of_apes/links/0c96051d570800c77b000000.pdf].

Annila, A. 2010. All in action. Entropy 12, 2333-2358 - http://tinyurl.com/kc79h8f.

Annila, A. 2010a. The 2nd law of thermodynamics delineates dispersal of energy. International Review of Physics 4(1), 29-34 - http://tinyurl.com/34xhxmh.

Annila, A., Annila, E. 2008. Why did life emerge. International Journal of Astrobiology 7(3-4): 293-300 - http://tinyurl.com/4o4zmbd.

Annila, A., Kuismanen, E. 2009. Natural hierarchy emerges from energy dispersal. BioSystems 95, 227-233 - http://tinyurl.com/4hemjvl.

Annila, A., Salthe, S. 2009. Economies evolve by energy dispersal. Entropy 2009(11), 606-633 - http://tinyurl.com/kf6qcjm.

Annila, A., Salthe, S. 2010. Physical foundations of evolutionary theory. Journal of Non-Equilibrium Thermodynamics 35: 301-321 - http://tinyurl.com/7oljpce.

Anon (1998). User notes on FORTRAN Programming: An open cooperative practical guide - http://tinyurl.com/2f5puz7.
Antón, S.C. 2003. Natural history of *Homo erectus*. Yearbook of Physical Anthropology 46, 126-170 - http://tinyurl.com/lxzummb
Antón, S.C., Leonard, W.R., Robertson, M.L. 2002. An ecomorphological model of the initial hominid dispersal from Africa. Journal of Human Evolution 43, 773-785 - http://tinyurl.com/l5xzwlr.
Antón, S.C., Potts, R., Aiello, L.C. 2014. Evolution of early Homo: an integrated biological perspective. Science 345, DOI: 10.1126/science.1236828/ - http://tinyurl.com/mu5bpgp.
Antón, S.C., Snodgrass, J.J. 2012. Origins and evolution of genus Homo – new perspectives. Current Anthropology 53(S6), S479-S496 - http://tinyurl.com/kr5zhmf
Antón, S.C., Swisher, C.C., III. 2004. Early dispersals of Homo from Africa. Annual Review of Anthropology 33: 271-296 –
Ao, H., Dekkers, J.J., Wi, Q., Qiang, X., Xiao, G. 2013. New evidence for early presence of hominids in North China. Scientific Reports 3, 2403 | DOI: 10.1038/srep02403, pp. 1-5 - http://tinyurl.com/l422ogn.
Apostolou, and D. Mentzas, G. (1998). Managing Corporate Knowledge: A Comparative Analysis of Experiences in Consulting Firms, paper from the "Second International Conference on Practical Aspects of Knowledge Management", 29-30 October 1998, Basel, Switzerland. - http://project.know-net.org/documents/pakmcons.pdf
Appenzeller, T. 2012. Eastern Odyssey. Nature 485, 24-26 - http://tinyurl.com/m37x6hd
Arbib, M.A. 2005. From monkey-like action recognition to human language: an evolutionary framework for neurolinguistics. Behavioral and Brain Sciences 28, 105-167 - http://tinyurl.com/95y42yj
Arbib, M.A. 2011. From mirror neurons to complex imitation in the evolution of language and tool use. Annual Review of Anthropology 40, 257-273.
Arbib, M.A., Liebal, K., Pika, S. 2008. Primate vocalization, gesture and the evolution of human language. Current Anthropology 49(6), 1053-1076 - http://tinyurl.com/ldg8x82.
Argue, D., Morwood, M.J., Sutikna, T., Jatmiko, Saptomo, E.W. 2009. Homo floresiensis: a cladistic analysis. Journal of Human Evolution 57, 623-639 - http://tinyurl.com/ls9pkgf.
Árnason, Ú. 2016. The Ouut of Africa hypothesis and the ancestry of recent humans: Cherchez la femme (et l'homme). Gene doi: 10.1016/j.gene.2016.03.018 - http://tinyurl.com/guqucwb.
Arsuaga, J.L., Martínez, I., Arnold, L.J., Aranburu, A., Gracia-Téllez, A., Sharp, W.D., Quam, R.M., Flagueres, C., Pantoja-Pérez, A., Bischoff, J., Poza-Rey, E., Pares, J.M., Carretero, J.M., et al. 2014. Neandertal roots: cranial and chronological evidence from Sima de los Huesos. Science 344, 1358-1363 - http://tinyurl.com/q53vztm.
Arthur, J.V., Merolla, P.A., Akopyan, F., Alvarez, R., Cassidy, A., Chandra, S., Esser, S. Imam, N., Risk, W., Rubin, D., Manohar, R., Modha, D. 2012. Building block of a programmable neuromorphic substrate: a digital neurosynaptic core. 2012 IEEE World Congress on Computational Intelligence, June 10-15, Brisbane, Australia, 8 pp. - http://tinyurl.com/cgjbd46.
Arzarello, M. Peretto, C. 2010. Out of Africa: the first evidence of Italian peninsula occupation. Quaternary International 223-224, 65-70 - http://tinyurl.com/lycgcnd
Asfaw, B., Gilbert, W.H., Beyenne, Y., Hart, W.K., Renne, P.R., WoldeGabriel, G., Vrba, E.S., White, T.D. 2002. Remains of *Homo erectus* from Bouri, Middle Awash, Ethiopia – http://tinyurl.com/mvcoxzr.

Atkins, H. (1999). The ISI® Web of Science® - Links and Electronic Journals: How links work today in the Web of Science, and the challenges posed by electronic journals. D-Lib Magazine 5(9) - http://tinyurl.com/3abulkf.

Atmanspacher, H. 2004. Quantum theory and consciousness: an overview with selected examples. Discrete Dynamics in Nature and Society 2004(01), 51–73 - http://tinyurl.com/oxsupuv

Auletta, G., Ellis, G.F.R., Jaeger, L. 2008. Top-down causation by information control: from a philosopohical problem to a scientific research programme. Journal of the Royal Society Interface 5, 1159–1172 - http://tinyurl.com/me4e6cw.

Aunger, R. 2009. What's special about human technology. Cambridge Journal of Economics. doi:10.1093/cje/bep018 - http://tinyurl.com/32uj3da.

Baab, K.L. 2008. The taxonomic implications of cranial shape variation in *Homo erectus*. Journal of Human Evolution 54, 827-847 - http://tinyurl.com/l88jqhp

Baab, K.L., McNulty, K.P. 2009. Size, shape, and asymmetry in fossil hominins: the status of the LB1 cranium based on 3D morphometric analyses. Journal of Human Evolution 57(5), 608-622 - http://tinyurl.com/myd2s9h

Baab, K.L., McNulty, K.P., Harvati, K. 2013. *Homo floresiensis* contextualized: a geometric morphometric comparative analysis of fossil and pathological human samples. PLoS ONE 8(7): e69119. doi:10.1371/journal.pone.0069119, 11 pp. - http://tinyurl.com/k8nsela.

Babbitt, C.C., Warner, L.R., Fedrigo, O., Wall, C.E., Wray, G.A. 2011. Genomic signatures of diet-related shifts during human origins. Proceedings of the Royal Society B 278, 961-969 - http://tinyurl.com/8s6ap9v

Baena, J., Lordkipanidze, D., Cuartero, F., Ferring, R., Zhvania, D., Martín, D., Shelia, T., Bidzinashuili, G., Roca, M., Rubio, D. 2010. Technical and technological complexity in the beginning, the study of Dmanisi lithic assemblage. Quaternary International 223-224, 45-53 - http://tinyurl.com/kakpmgl.

Bagnall, R.S. 2002. Alexandria: library of dreams. Proceedings of the American Philosophical Society 146(4), 348-362 - http://tinyurl.com/828evqt.

Bailey, D.H., Geary, D.C. 2009. Hominid brain evolution: testing climatic, ecological, and social competition models. Human Nature 20, 67-79 - http://tinyurl.com/lbblrct

Bailey, K.D. 2008. Boundary maintenance in living systems theory and social entropy theory. Systems Research and Behavioral Science 25: 587-597 - http://tinyurl.com/pgow7np.

Baines, J. 2004. The earliest Egyptian writing: development, context, purpose. (in) The First Writing: Script Invention as History and Process. Houston, S.D. (ed.). Cambridge University Press, Cambridge, Pp. 150-189 - http://tinyurl.com/2anyhho.

Baker, E.F. 1933. Displacement of Men by Machines – Effects of Technological Change in Commercial Printing. Columbia University Press - http://tinyurl.com/mk6gxua

Bakken, T., Hernes, T. (eds.) 2003. Autopoietic Organization Theory: Drawing on Niklas Luhmann's Social Systems Perspective. Abstract Forlag, Oslo, Norway.

Bako, H. 2001. The Antikythera Mechanism: A True Mystery of the Ancient World - Rational Inquiry - http://tinyurl.com/lshdc94.

Baldwin, P.J., McGrew, W.C., Tutin, C.E.G. 1982. Wide-ranging chimpanzees at Mt. Assirik, Senegal. International Journal of Primatology 3(4), 367-385 - http://tinyurl.com/h87ojuk

Balme, J. 2013. Of boats and string: the maritime colonization of Australia. Quaternary International 285, 68-75 - http://tinyurl.com/kwjpwee

Baltas, A., Gavroglu, K. and Kindi, V. (2000). A Discussion with Thomas S. Kuhn. pp. 255-323 *in* Kuhn 2000.

Balter, M. 2010. Candidate human ancestor from South Africa sparks praise and debate. Science 328, 154-155 - http://tinyurl.com/l68zok5.

Balter, M. 2011. Paleoanthropologist now rides high on a new fossil tide. Science 333, 1373-1375.

Balter, M. 2014. RIP for a key *Homo* species? Science 345, 129 - http://tinyurl.com/nl5c7t5.

Bandstra, B.L. (1999). Reading the Old Testament: An Introduction to the Hebrew Bible, Wadsworth Publishing Company - http://www.hope.edu/academic/religion/bandstra/RTOT/RTOT.HTM.

Barbieri, C., Güldermann, T., Naumann, C., Gerlach, L., Berthold, F., Nakagawa, H., Mpoloka, S.W., Stoneking, M., Pakendorf, B. 2014. Unravelling the complex maternal history of southern African Khoisan populations. American Journal of Physical Anthropology 153, 435-448 - http://tinyurl.com/o8we2nb.

Barbieri, C., Vicente, M., Oliviera, S., Bostoen, K., Rocha, J., Stoneking, M., Pakendorf, B. 2014a. Migration and interaction in a contact zone: mtDNA variation among Bantu-speakers in southern Africa. PLoS ONE 9(6): e99117. doi:10.1371/journal.pone.0099117 - http://tinyurl.com/hkj67ea.

Barsky, D., de Lumley, H. 2010. Early European Mode 2 and the stone industry from the Caune de l'Arago's archeostratigraphical levels "P". Quaternary International 223-224, 71-86 - http://tinyurl.com/z9y7pwy.

Barsky, D., Sala, R., Menéndez, L., Toro-Moyano, I. 2014. Use and re-use: re-knapped flakes from the Mode 1 site of Fuente Nueva 3 (Orce, Andalucía, Spain). Quaternary International http://dx.doi.org/10.1016/j.quaint.2014.01.048, 13 pp.

Bar-Yosef, O., Belfer-Cohen, A. 2001. From Africa to Eurasia – early dispersals. Quaternary International 75, 19-28 - http://tinyurl.com/n8xwxch

Bar-Yosef, O., Belfer-Cohen, A. 2013. Following Pleistocene road signs of human dispersals across Eurasia. Quaternary International 285, 30-43 - http://tinyurl.com/n79gd8x.

Bar-Yosef, O., Belmaker, M. 2011. Early and Middle Pleistocene faunal and hominins dispersals through Southwestern Asia. Quaternary Science Reviews 30-1318-1337 - http://tinyurl.com/md85dvw.

Bar-Yosef, O., Wang, Y. 2012. Paleolithic archaeology in China. Annual Review of Anthropology 41, 219-335 - http://tinyurl.com/m3kc84y.

Bar-Yosef, O., Eren, M.I., Yuan, J., Cohen, D.J., Li, Y. 2012. Were bamboo tools made in prehistoric Southeast Asia? An experimental view from South China. Quaternary International 269, 9-21 - http://tinyurl.com/kt9yg3k

Barberio, D. (????). Tacit Knowledge. *in* Chris Eliasmith (ed.), Dictionary of Philosophy of Mind. - http://www.artsci.wustl.edu/~philos/MindDict/tacitknowledge.html

Barger, J. 1996. HyperTerrorist's Timeline of Hypertext History *from* The Robot Wisdom Pages - http://tinyurl.com/34uzqhe.

Barnes, J. A., 1954, Class and committees in a Norwegian island parish. Human Relations 7, 39-58 - http://tinyurl.com/7o6g5aq.

Barry, R.E. (????) - Best Practices for Document Management in an Emerging Digital Environment. - http://www.rbarry.com/UKRMS1/UKRMS1.html [obsolete]

Barry, R.E. (1995). The Changing Workplace and the Nature of the Record. Unpublished paper written in preparation for presentation made at ACA Conference, Regina, Canada, June 16, 1995 — http://www.rbarry.com/aca–pv16/ACA–PV16.html [broken link 13/01/2003]

Barry, R.E.. (2002). Technology and the Transformation of the Workplace: Lessons Learned Traveling Down the Garden Path. Dearstyne, B. *ed*. Effective Approaches for Managing Electronic Records and Archives. Scarecrow Press. - http://www.mybestdocs.com/barry3-published ver-dearstyne2002.htm

Baskerville, R., Dulipovici, A. 2006. The theoretical foundations of knowledge management. Knowledge Management Research & Practice 4, 83-105.

Batai, K., Babrowski, K.B., Arroyo, J.P., Kusimba, C.M., Williams, S.R. 2013. Mitochondrial DNA diversity in two ethnic groups in southeastern Kenya: perspectives from the northeastern periphery of the Bantu Expansion. American Journal of Physical Anthropology 150, 482-491.

Baten J., van Zanden, J.L. 2008. Book production and the onset of modern economic growth. Journal of Economic Growth 13, 217-235. http://tinyurl.com/oag2n5m.

Bates, M.J. 2005. Information and knowledge: an evolutionary framework for information science, 10(4) - http://tinyurl.com/2fpnupq.

Bateson, G. 1973. Steps to an Ecology of Mind: Granada Publishing, London – [download book: http://tinyurl.com/n3trt5z].

Bawden, D. 2007. Organised complexity, meaning and understanding: an approach to a unified view of information for information science. Aslib Proceedings: New Information Perspectives 59(4/5), 307-327 - http://tinyurl.com/p356jby.

Bawden, D. 2008. Smoother pebbles and the shoulders of giants: the developing foundations of information science. Journal of Information Science 34(4), 415-426 - http://tinyurl.com/nawyk4c.

Bayer, M.M., Rash, C.E., Brindle, J.H. 2009. Introduction to helmet-mounted displays. (in) Helmet-Mounted Displays: Sensation, Perception and Cognition Issues, Rash, C.E., Russo, M.B ., Letowski, T.R., Schmeisser, E.T. (eds.). US Army Aeromedical Research Laboratory, Fort Rucker, Alabama, USA, pp. 47-107 - http://tinyurl.com/7g6ugle

Beaumont, P.B. 2011. The edge: more on fire-making by about 1.7 million years ago at Wonderwerk Cave in South Africa. Current Anthropology 52(4), 585-595 - http://tinyurl.com/p3jzsqf.

Beaumont, P.B. 2013. Tracing the emergence of palaeoart in Sub-Saharan Africa. Rock Art Research 30(1), 33-54 - http://tinyurl.com/k7pxq95

Beckerman, L.P. (1999). The Non-Linear Dynamics of War. Asset Group, Science Applications International Corporation - http://tinyurl.com/lpz5eql.

Beckett, R.G. (2000). A Characterisation of a Corporate Memory as a Knowledge System. Journal of Knowledge Management, 4(4). - http://dsslab.mis.ccu.edu.tw/jkm/jkmV4N4/p311.pdf.

Bedini, S.A. 1964. The role of automata in the history of technology. Technology and Culture 5(1), 24-42 - http://tinyurl.com/p9vbwdd.

Beebe, N.H.F. (1994). The impact of memory and architecture on computer performance - http://tinyurl.com/nebtm6t.

Beer, R.D. 2004. Autopoiesis and cognition in the Game of Life. Artificial Life 10, 309–326 - http://tinyurl.com/ks7cohc.

Beer, S. (1973). Preface to Maturana, H.R., Varela, F.J. (1983) Autopoiesis: the organization of the living. [Reprinted in Maturana, H.R., Varela, F.J. (1980) Autopoiesis and cognition: the realization of the living, pp. 63-72)] - http://tinyurl.com/466bf5h
Beer, S. (1979). The heart of enterprise. Wiley, Chichester, UK
Beer, S. (1980). Preface [to Autopoiesis: The Organization of the Living], *in* Maturana and Varela (1980), pp 63-72.
Beer, S. 1981. The Brain of the Firm: The Managerial Cybernetics of Organization (2nd ed. - [1st ed.1972]. John Wiley & Sons, Chichester, England - http://tinyurl.com/26obtgg.
Beer S. 1984. The viable system model: its provenance, development, methodology and pathology. Journal of the Operational Research Society 35: 7–25.
Beer S. 1985. Diagnosing the system for organizations. Wiley: Chichester.
Begun, D.R. 2007. Fossil record of Miocene hominoids. (In) Henke, W., Rothe, H., Tattersall, I. (Eds.), Handbook of Palaeoanthropology, Vol. 2: Primate Evolution and Human Origins. Springer, Berlin, pp. 921–977 - http://tinyurl.com/onpv73l.
Begun, D.R. 2009. Dryopithecins, Darwin, de Bonis, and the European origin of the African apes and human clade. Geodiversitas 31(4), 789-816 - http://tinyurl.com/p9nkjkz.
Begun, D.R. 2010. Miocene hominids and origins of the African apes and humans. Annual Review of Anthropology 19, 67-84 - http://tinyurl.com/jlm8csn
Begun, D.R., Nargolwalla, M.C., Kordos, L. 2012. European Miocene hominids and the origin of the African ape and human clade. Evolutionary Anthropology 21, 10-23 http://tinyurl.com/jatc5qx.
Behar, D.M., Villems, R., Soodyall, H., Blue-Smith, J., Periera, L., Metspula, E., Scozzari, R., Makkan, H., Tzur, S., Comas, D., et al., Genographic Consortium. 2008. The dawn of human matrilineal diversity. The American Journal of Human Genetics 82, 1130-1140 - http://tinyurl.com/8offepk
Bell, C. (1997). Organizational Change: What is it, and what does it mean for records professionals? [unpublished draft] Annual Meeting of the National Association of Government Archivists and Records Administrators Sacramento, California July 17, 1997 — http://tinyurl.com/keco9eb
Bell, G. 1971. Computer Structures: Readings and Examples. McGraw-Hill, Inc. - http://tinyurl.com/264byzs
Bell, H. (2000). Scientific publishing, 17th-century style: precepts of Francis Bacon. Learned Publishing 13:2, pp. 124-126.
Belli, M.. (????a). The Invention of the Intel 1103 - The World's First Available DRAM Chip. - http://inventors.about.com/library/weekly/aa100898.htm?once=true&
Bellis, M. (????). History of Computers. About.com - http://tinyurl.com/9sfad.
Bellinger, G., Castro, D., Mills, A. (2004). Data, information, knowledge and wisdom. Systems http://tinyurl.com/2fr3nr7.
Bendel, N. 2013. Fairfax to slash debt with Chullora and Tullamarine sales. ProPrint 13 Feb. 2013 - http://tinyurl.com/qbkquvm.
Ben-Dor, M., Gopher, A., Hershkovitz, I., Barkai, R. 2011. Man the fat hunter: the demise of *Homo erectus* and the emergence of a new hominin lineage in the Middle Pleistocene (ca. 400 kyr) Levant. PLoS ONE 6(12): e28689. doi:10.1371/journal.pone.0028689 - http://tinyurl.com/maj7zxo
Benazzi, S., Douka, K., Fornai, C., Bauer, C.C., Kullmer, O., Svoboda, J., Pap, I., Mallegni, F., Bayle, P., Coquerelle, M., COndemi, S., Ronchitelli, A., Harvati, K., Weber, G.W. 2011.

Early dispersal of modern humans in Europe and implications for Neanderthal behaviour. Nature 479, 525-529 - http://tinyurl.com/k7kt7lq

Benner, S.A., Kim, H.-J., Yang, Z. 2012. Setting the stage: the history, chemistry, and geobiology behind RNA. Cold Spring Harbor Perspectives in Biology 2012;4:a003541, pp. 1-13 - http://tinyurl.com/msu7cvm

Bentolila, S. 2005. "Live memory" of the cell, the other hereditary memory of living systems. BioSystems 80, 251–261.

Beran, M.J., Parrish, A.E. 2012. Sequential responding and planning in capuchin monkeys (*Cebus apella*). Animal Cognition 15(6), 1085-1094 - http://tinyurl.com/m8q7f4o.

Beran, M.J., Perdue, B.M., Parrish, A.E., Evans, T.A. 2012. Do social conditions affect capuchin monkeys' (*Cebus apella*) choices in a quantity judgment task?. Frontiers in Psychology 2, Art 492, 7 pp. - http://tinyurl.com/ngmj2rt.

Berger, L.R. 2012. *Australopithecus sediba* and the earliest origins of the genus *Homo*. Journal of Anthropological Sciences 90, 1-16 - http://tinyurl.com/kra3m7b

Berger, L.R. 2013. The mosaic nature of *Australopithecus sediba*. Science 340, 163 - http://tinyurl.com/nvzfxfm.

Berger, L.R., de Ruiter, D.J., Churchill, S.E., Schmid, P., Carlson, K.J., Dirks, P.H.G.M., Kibii, J.M. 2010. Australopithecus sediba: a new species of Homo-like Australopith from South Africa. Science 329, 195-204 - http://tinyurl.com/lsgzaep.

Berger, L.R., Hawks, J., de Ruiter, D.J., Churchill, S.E., Schmid, P., Delezene, L.K., Kivell, T.L., Garvin, H.M., Williams, S.A., DeSilva, J.M., Skinner, M.M., Musiba, C.M., et al. 2015. Homo naledi, a new species of the genus Homo from the Dinaledi Chamber, South Africa. eLife DOI: 10.7554/eLife.09560, 35 pp. 4 - http://tinyurl.com/hhf2dwd

Berger, P., Luckman, T. (1967). The Social Construction of Reality, Penguin, New York, NY [not seen].

Bergman, M.K. (2000). The Deep Web: Surfacing Hidden Value, The Journal of Electronic Publishing7:1, August, 2001 - http://tinyurl.com/2fjtyee.

Bergmann Tiest, W.M. (????). A brief history of the development of BASIC. in The Basic Archives. - http://tinyurl.com/27fysmr.

Bermúdez de Castro, J.M., Arsuaga, J.L., Carbonell, E., Rosas, A., Martínez, I., Mosquera, M., 1997. A hominid from the Lower Pleistocene of Atapuerca, Spain: possible ancestor to Neandertals and modern humans. Science 276, 1392-1395 - http://tinyurl.com/mege22w.

Bermúdez de Castro, J.M., Martinón-Torres, M. 2013. A new model for the evolution of the human Pleistocene populations of Europe. Quaternary International 295, 102-112 - http://tinyurl.com/hea3twk.

Bermúdez de Castro, J.M., Martinón-Torres, M., Blasco, R., Rosell, J., Carbonell, E. 2013. Continuity or discontinuity in the European Early Pleistocene human settlement: the Atapuerca evidence. Quaternary Science Reviews 76, 53-65 - http://tinyurl.com/ke6lf97.

Bermúdez de Castro, J.M., Martinón-Torres, M., Sier, M.J. Martin-Francés, L. 2014. On the variability of the Dmanisi mandibles. PLOS ONE 9(2): e88212. doi:10.1371/journal.pone.0088212, 15 pp. - http://tinyurl.com/lbyqs5g.

Berna, F., Goldberg, P., Horowitz, L.K., Brink J., Holt, S., Bamford, M., Chazan, M. 2012. Microstratigraphic evidence of in situ fire in the Acheulean strata of Wonderwerk Cave, Northern Cape province, South Africa. Proceedings of the National Academy of Sciences USA 109(20), E1215-E1220 - http://tinyurl.com/9l32owu; Supporting Information - http://tinyurl.com/8cyurng.

Berner, T.R. (1987). The printing press as an agent of preservation. Presented to the first Pennsylvania Symposium of Medieval and Renaissance Studies, September 18-19, 1987. - http://tinyurl.com/25qss67.
Berners-Lee, T. (1989). Information Management: A Proposal - http://tinyurl.com/gpscs.
Berners-Lee, T. & Fischetti, M. (1999). Weaving the Web: The Original Design and Ultimate Destiny of the World Wide Web by its Inventor. HarperCollinsPublishers - http://tinyurl.com/2comu7t.
Berners-Lee, T., Hendler, J. & Lassila, O. (2001). The Semantic Web: A new form of Web content that is meaningful to computers will unleash a revolution of new possibilities. Scientific American, May 2001. - http://tinyurl.com/28rcnvf.
Bernstein, H., Bernstein, C. 2010. Evolutionary origin of recombination during meiosis. BioScience 60(7), 498-505.
Bernstein, H., Bernstein, C. 2013. Evolutionary origin and adaptive function of meiosis. (in) Meiosis, Bernstein, C., Bernstein, H. (eds). InTech, DOI: 10.5772/56557 - http://tinyurl.com/p8rulho.
Berry, N. (2000). The revolution in military affairs (RMA) is not only about high-tech weapons. Center for Defence Information, Asia Forum Archives, August 16, 2000. - http://tinyurl.com/2gyet5n.
Berti, M., Costa, V. 2010. The Ancient Library of Alexandria: a model for classical scholarship in the age of million book libraries. CLIR Proceedings International Symposium on the Scaife Digital Library. (in press) - http://tinyurl.com/28zdyws.
Bertolami, O. 2008. The mystical formula and the mystery of Khronos. Contribution to the volume "Minkowski Spacetime: A Hundred Years Later" to be published by Springer in the series "Fundamental Theories of Physics", V. Petkov, Ed - http://tinyurl.com/plyzypd.
Beyene, Y., Katoh, S., WoldeGabriel, G., Hart, W.K., Uto, K., Sudo, M., Kondo, M., Hyodo, M., Renne, P.R., Suwa, G., Asfaw, B. 2013. The characteristics and chronology of the earliest Acheulean at Konso, Ethiopia. Proceedings of the National Academy of Sciences 110(5), 1584-1591 - http://tinyurl.com/nzovpmd
Beynon-Davies, P. 2009. Neolithic informatics: the nature of information. International Journal of Information Management 29, 3–14.
Bickerton, D. 2007. Language evolution: a brief guide for linguists. Lingua 17, 510-526 - http://tinyurl.com/3x2pk2s.
Biggiero, L. 2001. Are firms autopoietic systems. [in] G. Van Der Zouwen & F. Geyer (Eds.) Sociocybernetics: Complexity, Autopoiesis, and Observation of Social Systems. Pp. 125-140. Westport (Ct): Greenwood. 2001 - http://tinyurl.com/74ch8qx.
Binmore, K. 2007. Can knowledge be justified true belief? ESRC Cenre for Economic Learning and Social Evolution Working Paper, no. 265 - http://tinyurl.com/2enzmyw.
Birney, E., Pritchard, J.K. 2014. Four makes a party. Nature 505, 32-34 - http://tinyurl.com/j9jdmlm.
Bjurstedt, A. 2005. The European publication printing industry: an industry in profound changes. Thesis Licentiate of Technology, Royal Institute of Technology, KTH, Stockholm University - http://tinyurl.com/q8tnyfx.
Black, J. 2007. The revolution in military affairs: the historian's perspective. Journal of Military and Strategic Studies 9(2) - http://tinyurl.com/2ahxrhh
Blackman, D., Connelly, J., Henderson, S. 2004. Does double loop learning create reliable knowledge? Learning Organization 11(1): 11-27 - http://tinyurl.com/nrbr374

Block, N. 1997. Semantics, Conceptual Role *in* The Routledge Encyclopedia of Philosophy - http://tinyurl.com/2a96r4e.
Boas, M. 1949. Hero's Pneumatica: a study of its transmission and influence. Isis 40(1), 38-48.
Bodnar, I. 2010. Aristotle's natural philosophy. In Zalta, E.N. (Ed.). The Stanford Encyclopedia of Philosophy (Spring 2010 Edition) - http://tinyurl.com/29u3c2n.
Boesch, C. 1991. The effects of leopard predation on grouping patterns in forest chimpanzees. Behavior 117(3-4), 220-242 - http://tinyurl.com/mutlkuz.
Boesch, C. 1995. Innovation in wild chimpanzees {*Pan troglodytes*}. International Journal of Primatology 16, 1-16 - http://tinyurl.com/k98mggv.
Boesch, C. 2012. From material to symbolic cultures: culture in primates. (in) The Oxford Handbook of Culture and Psychology, (ed.) Valsiner, J. Oxford University Press. DOI: 10.1093/oxfordhb/9780195396430.013.0032, 16 pp. - http://tinyurl.com/nes3oty.
Boesch, C., Boesch, H. 1982. Optimisation of nut-cracking with natural hammers by wild chimpanzees. Behaviour 83, 265-286 - http://tinyurl.com/peobr6f.
Boesch, C., Boesch, H. 1990. Tool use and tool making in wild chimpanzees. Folia Primatologica 54, 86-99 - http://tinyurl.com/qa9mfnh.
Boesch, C., Head, J., Robbins, M.M. 2009. Complex tool sets for honey extraction among chimpanzees in Loango National Park, Gabon. Journal of Human Evolution 56(6), 560-569 - http://tinyurl.com/mmg6tcp.
Boesch, C., Marchesi, P., Marchesi, N., Fruth, B. Joulian, F. 1994. Is nut cracking in wild chimpanzees a cultural behaviour? Journal of Human Evolution 26, 325-338 - http://tinyurl.com/jwf8745
Bogart, S.L., Pruetz, J.D. 2011. Insectivory of savanna chimpanzees (*Pan troglodytes verus*) at Fongoli, Senegal. American Journal of Physical Anthropology 145-11-20 - http://tinyurl.com/k7lspra
Bogomolny, A. (2010, Oct. 1). Emergence of Chaos from Interactive Mathematics Miscellany and Puzzles - http://tinyurl.com/oubffqf.
Bohn, R.E., Short, J.E. 2009. How much information? 2009 report on American consumers. Global Information Center, University of California, San Diego - http://tinyurl.com/ydd75l6.
Bohr, M. 2009. Silicon technology for 32 nm and beyond system-on-chip products - http://tinyurl.com/l7e3agv.
Boinksi, S. 1988. Use of a club by a wild white-faced capuchin (*Cebus capucinus*) to attack venomous snake (*Bothrops asper*). American Journal of Primatology 14, 177-179 - http://tinyurl.com/j79h7t5.
Bonnefille, R. 2010. Cenozoic vegetation, climate changes and hominid evolution in tropical Africa. Global and Planetary Change 72, 390-411 - http://tinyurl.com/jumv4hz.
Borgo, S, Spagnoletti, N., Vieu, L., Visalberghi, E. 2013. Artifact and artifact categorization: comparing humans and capuchin monkeys. Review of Philosophy and Psychology 4, 375-389 - http://tinyurl.com/k8xfz5o
Bornmann, L., Nast, I., Daniel, H.-D. 2008. Do editors and referees look for signs of scientific misconduct when reviewing manuscripts? . Scientometrics 77(3), 415-432.
Bostock, A. (2002). Avoiding Information Overload: Knowledge Management on the Internet. Technology and Standards Watch Reports TSW 02-02. Technology and Standards Watch, Joint Information Systems Committee. - http://www.jisc.ac.uk/techwatch/reports/tsw_02-02.html.

Boubli, J.P., Rylands, A.B., Farias, I.P., Alfaro, M.E., Lynch Alfaro, J.W. 2012. *Cebus* phylogenetic relationships: a preliminary reassessment of the diversity of the untufted capuchin monkeys. American Journal of Primatology 74:381-393 - http://tinyurl.com/mhso3za

Boucsein, C., Nawrot, M.P., Schnepel, P., Aertsen, A. 2011. Beyond the cortical column: abundance and physiology of horizontal connections imply a strong role for inputs from the surround. Frontiers in Neuroscience 5, no. 32, pp. 1-13 - http://tinyurl.com/d9njtso.

Bourne, C.P. (1999). 40 Years of Database Distribution and Use: An Overview and Observation. 1999 Miles Conrad Memorial Lecture, NFAIS Annual Conference - February 23, 1999, Philadelphia, PA - http://tinyurl.com/283wwwy.

Bower, B. 2013. Notorious bones: South African finds enter fray over origins of the human genus. Science News, August 10, 2013.

Bowles, E.A. 1966. On the origin of the keyboard mechanism in the Late Middle Ages. Technology and Culture 7(2), 152-152.

Bowman, A.K. 1975. The Vindolanda writing tablets and the development of the Roman book form. Zeitschrift fur Papyrologie und Epigraphhik 18, 347-252 [Vindolandia Tablets Online explores the tablets in depth].

Boyd, J.R. 1992. Conceptual Spiral briefing (audio, Air War College, Maxwell Air Force Base, AL) - http://tinyurl.com/6xkbpl.

Boyd, J.R., 1996, Unpublished briefings available via Defence and the National Interest - http://tinyurl.com/6x5z45 [Scroll down for titles listed under heading, "A Discourse on Winning and Losing"].

Boyle, E. (1994). The Vatican Library. Introduction to the Vatican Exhibit - http://tinyurl.com/27k4b5l.

Bradie, M and Harms, W. (2008). Evolutionary Epistemology, The Stanford Encyclopedia of Philosophy (Winter 2008 Edition), Edward N. Zalta (ed.) - http://tinyurl.com/234emhz.

Bräuer, G. 2008. The origin of modern anatomy: by speciation or intraspecific evolution? Evolutionary Anthropology 17, 22-37 - http://tinyurl.com/nxcpeqx.

Bräuer, G. 2012. Middle Pleistocene diversity in Africa and the origin of modern humans. (in) Hublin, J.-J., McPherron, S.P. (eds.), Modern Origins: A North African Perspective, Vertebrate Paleobiology and Paleoanthropology. Springer Science+Business Media, pp. 221-240.

Bräuer, J., Hanus, D. 2012. Fairness in non-human primates? Social Justice Research 25, 256-276 –http://tinyurl.com/qy3xyte.

Braun, D.R., Harris, J.W.K., Levin, N.E., McCoy, J.T., Herries, A.I.R., Bamford, M.K., Bishop, L.C., Richmond, B.G., Kibunjia, M. 2010. Early hominin diet included diverse terrestrial and aquatic animals 1.95 Ma in East Turkan, Kenya. Proceedings of the National Academy of Sciences USA 107(22), 10002-10007 - http://tinyurl.com/8uyaccs

Brezillon, P. and Pomerol, J-C. (2001). Is Context a Kind of Collective Tacit Knowledge? *in* European CSCW 2001 Workshop On Managing Tacit Knowledge, Bonn, Germany September 16, 2001 - http://www.unite-project.org/ecscw01-tkm/papers/Brezillon-ecscw01.pdf.

Brier, S. 2005. The construction of information and communication: A cybersemiotic reentry into Heinz von Foerster's metaphysical construction of second-order cybernetics. Semiotica 154(1/4), 355-399.

Brier, S., Baeker, D., Thyssen, O. (2007) Luhmann applied. Special Issue, Cybernetics & Human Knowing 14(2-3)
Brin, S. and Page, L. (1998) - The Anatomy of a Large-Scale Hypertextual Web Search Engine. WWW7 / Computer Networks 30(1-7): 107-117 - http://www-db.stanford.edu/pub/papers/google.pdf
Brocklesby, J. 2004. Reconnecting biology, social relations and epistemology—a systemic appreciation of autopoietic theory. International Journal of General Systems, 33: 655–671
Brockman, J. (1995). Stuart Kauffman: Order for Free. Chapter 20 in The Third Culture: Beyond the Scientific Revolution [Download book]. New York: Simon & Schuster - http://tinyurl.com/kw5qrkm.
Brookes, B. 1980. The foundations of information science. Part I. Philosophical aspects. Journal of lnformation Science 2, 125-133 - http://tinyurl.com/kyxgzql.
Brosnan, S.F. 2011. A hypothesis of the co-evolution of cooperation and responses to inequality. Frontiers in Neuroscience 5, Art. 43, 12 pp. - http://tinyurl.com/ly8jj9t.
Brosnan, S.F., de Waal, F.B.M. 2003. A concept of value during experimental exchange in brown capuchin monkeys, *Cebus apella*. Folia Primatologica 75, 317-330 - http://tinyurl.com/q73ns3g.
Brown, K.S., Marean, C.W., Jacobs, Z., Schoville, B.J., Oestmo, S., Fisher, E.C., Bernatchez, J., Karkanas, P., Matthews, T. 2012. An early and enduring advanced technology originating 71,000 years ago in South Africa. Nature 491, 590–593 - http://tinyurl.com/l6expxq.
Brown, P. 2012. LB1 and LB6 *Homo floresiensis* are not modern human (*Homo sapiens*) cretins. Journal of Human Evolution 62, 201-224 - http://tinyurl.com/mjc9mbt.
Brown, P., Maeda, T. 2009. Liang Bua *Homo floresiensis* mandibles and mandibular teeth: a contribution to the comparative morphology of a new hominin species. Journal of Human Evolution 57(5), 571-596 - http://tinyurl.com/kz5q2c9.
Brown, P., Sutikna, T., Morwood, M.J., Soejono, R.P., Jatmiko, Saptomo, E.W., Due, R.A. 2004. A new small-bodied hominin from the Late Pleistocene of Flores, Indonesia. Nature 431, 1055-1061 [+ additional related articles] - http://tinyurl.com/kh8ma3c.
Brubach, N. (2000). Development and Traditions of Records Management and Archives in Germany. *in* The Records & Information Management On-line Service - http://www.caldeson.com/RIMOS/brubach.html
Brumm, A., Aziz, F., van den Bergh, Morwood, M.J., Moore, M.W., Kurniawan, I., Hobbs, D.R., Fullagar, R. 2006. Early stone technology on Flores and its implications for Homo floresiensis. Nature 441, 624-628 - http://tinyurl.com/l9q9oe5.
Brumm, A., Jensen, G.M., van den Bergh, G.D., Morwood, M.J., Kurniawan, I., Aziz, F., Storey, M. 2010. Hominins on Flores, Indonesia, by one million years ago. Nature 464, 748-752.
Brumm, A., Moore, M.W. 2012. Biface distributions and the Movius Line: a Southeast Asian perspective. Australian Archaeology 74, 32-46 - http://tinyurl.com/kcz3bao
Brundige, E.N. (1998). The Library of Alexandria - http://tinyurl.com/nu69tw5.
Bullier, J. 2001. Integrated model of visual processing. Brain Research Reviews 36, 96-107 - http://tinyurl.com/cjko9zr.
Burdukiewicz, J.M. 2014. The origin of symbolic behavior of Middle Paleolithic humans: recent controversies. Quaternary International http://dx.doi.org/10.1016/j.quaint.2013.08.042, pp 1-8.
Burger, T.W. (2002). Cobol in an Open Source Future: COBOL and Linux in the 21st Century. - http://tinyurl.com/2ezu4w2.

Burkart, J.M., Hrdy, S.B., Van Schaik, C.P. 2009. Cooperative breeding and human cognitive evolution. Evolutionary Anthropology 18, 175–186 - http://tinyurl.com/9km6wt3

Burrel, G. & Morgan, G. (1979). Sociological Paradigms and Organizational Analysis, Heineman, London.

Bush, V. (1945). As We May Think. Atlantic Monthly, July 1945. - http://tinyurl.com/lvjwphl

Butler, D. (2000). Souped-up Search Engines. Nature 405:112 - 115. - http://www.nature.com/cgi-taf/DynaPage.taf?file=/nature/journal/v405/n6783/full/405112a0_fs.html&filetype=

Butler, D. and Wadman, M. (1999). Mixed response to NIH's web journal plan. Nature 399:8-9.

Butterfield, J. 2012. Laws, causation and dynamics at different levels. Interface Focus 2, 101–114 - http://tinyurl.com/ktljmfq.

Byrne, R.W., Sanz, C.M., Morgan, D.B. 2013. Chimpanzees plan their tool use. (in) Tool Use in Animals: Cognition and Ecology. (eds) Crickette M. Sanz, Josep Call and Christophe Boesch. Cambridge University Press, pp 48-63 - http://tinyurl.com/mnlmmfd

Byte Magazine 1995. Most Important Software Products. Byte (September 1995) - http://tinyurl.com/246m8cw.

Callender, C. 2009. Thermodynamic asymmetry in time. In Zalta, E.N. (Ed.), The Stanford Encyclopedia of Philosophy (Spring 2009 Edition) - http://tinyurl.com/274p2ub.

Calvin, W.H. (1996). The Cerebral Code: Thinking a Thought in the Mosaics of the Mind. MIT Press, 264pp. – [electronic book text] http://tinyurl.com/29gqbks.

Campbell, D.T. 1960. Blind variation and selective retention in creative thought as in other knowledge processes. Psychological Review 67, 380-400.

Campbell, D. T. 1974. Evolutionary epistemology. In: Schlipp, P. A. (Ed.), The philosophy of Karl Popper. LaSalle, IL: Open Court, 413-63 - http://tinyurl.com/kjmcz74.

Campbell, D.T. 1988. Popper and selection theory. Social Epistemology 2(4), 371-377 - http://tinyurl.com/q5xrsvh.

Campbell, D.T. 1996. From evolutionary epistemology via selection theory to a sociology of scientific validity [Heyes, C., Frankel, B. (eds.)]. Evolution and Cognition 3, 5-38 - http://tinyurl.com/m6fx8h2.

Canale, G. R., Guidorizzi, C. E., Kierulff, M. C. M., and Gatto, C. A. F. R. 2009. First record of tool use by wild populations of the yellow-breasted capuchin monkey (*Cebus xanthosternos*) and new records for the bearded capuchin (*Cebus libidinosus*). American Journal of Primatology 71, 366 – 372 - http://tinyurl.com/hoam479

Cannon D. (1999). Polanyi's "Invitation to Dogmatism"? A Response to Andy Sanders' "Polanyian Puzzle" . Polanyiana. 8:1–2. - http://www..kfki.hu/~cheminfo/polanyi/9912/cannon.html.

Capurro, R. (2001). Sceptical Knowledge Management, in: Hans-Christoph Hobohm (Ed), Reader: Knowledge Management and Libraries. IFLA (International Federation of Library Associations and Institutions) Publication series, Munich: Saur (2004) - http://tinyurl.com/28uqp4h.

Capurro, R., Hjorland, B. 2003. The concept of information. Annual Review of Information Science and Technology 37(1), 343 – 411 -http://tinyurl.com/m5wu7lh

Carbonell, E., Mosquera, M., Rodríguez, X.P., Bermudez de Castro, J.M., Burjachs, F., Rosell, J., Sala, R., Vallverdú, J. 2008. Eurasian gates: the earliest human dispersals. Journal of Anthropological Research 64, 195-228 - http://tinyurl.com/l5gz89l.

Carbonell, E., Bermudez de Castro, J.M., Pares, J.M., Perez-Gonzalez, A., Cuenca-Sescos, G., Olle, A., Mosquery M., Huguet, R., van der Made, J., Rosas, A., Sala, R., Vallverdu, J. et al. 2008. The first hominin of Europe. Nature 452, 465-470 - http://tinyurl.com/lp5nvj6.
Carbonell, E., Ramos, R.S., Rodríguez, X.P., Mosquera, M., Ollé, A., Verguès, J.M., Martinez-Navarro, B., Bermudez de Castro, J.M. 2010. Early hominid dispersals: a technological hypothesis for “out of Africa”. Quaternary International 223-224, 36-44 - http://tinyurl.com/mtuot7v.
Carlson, K.J., Stout, D., Jashashvili, T., de Ruiter, D.J., Tafforeau, P., Carlson, K., Berger, L.R. 2011. The endocast of MH1, Australopithecus sediba. Science 333, 1402-1407 - http://tinyurl.com/noa4sr8
Carmody, R.N., Wrangham, R.W. 2009. The energetic significance of cooking. Journal of Human Evolution 57, 379-391 - http://tinyurl.com/8zwdmcc
Carnegie, A. (1905). James Watt. Doubleday, Page & Co., New York - http://tinyurl.com/28xhol8.
Caron, F., d’Errico, F., Del Moral, P., Santos, F., Zilhão, J. 2011. The reality of Neandertal symbolic behavior at the Grotte du Renne, Arcy-sur-Cure, France. PLoS ONE 6(6): e21545. doi:10.1371/journal.pone.0021545 - http://tinyurl.com/ayav3f7.
Carpenter, C.R., Locke, N.M. 1937. Notes on symbolic behavior in a cebus monkey (*Capucinus appella*). The Pedagogical Seminary and Journal of Genetic Psychology 51, 267-278 - http://tinyurl.com/hsofq3c.
Carré, P.A. (1994). The Optical Telegraph: Chappe Innovation and Politics in 1793 and 1794. Proceedings of a Symposium on The Optical Telegraph held in Stockholm June 21-23 1994 at Telemuseum - http://www.telemuseum.se/historia/optel/otsymp/Frankrike.html
Carrión, J.S., Rose, J., Stringer, C. 2011. Early human evolution in the Western Palearctic: ecological scenarios. Quaternary Science Reviews 30, 1281-1295 - http://tinyurl.com/jvuhvv5.
Carvalho, S. 2011. Extensive surveys of chimpanzee stone tools: from the telescope to the magnifying glass. (in) Matsuzawa, T., Humle, T., Sugiyama, Y. (eds), The Chimpanzees of Bossou and Nimba. Springer, pp. 145-155.
Carvalho, S., Cunha, E., Sousa, C., Matsuzawa, T. 2008. Chaînes opératoires and resource-exploitation strategies in chimpanzee (Pan troglodytes) nut cracking. Journal of Human Evolution 55, 148-163 - http://tinyurl.com/llnornf.
Case, M. (2000). Principles for emerging systems of scholarly communication. ARL A Bimonthly Report on Research Library Issues and Actions from ARL, CNI, and SPARC. Issue 210, June 2000.
Case, M.. (2001). The Impact of Serial Costs on Library Collections. ARL Bimonthly Report 218, October 2001 - http://tinyurl.com/3724aso.
Cash, J.M. (1996) - The Papers and Michael Polanyi's Career. *in* Guide to the Papers of Michael Polanyi. Polanyiana 5:2. - http://www.kfki.hu/chemonet/polanyi/9602/trad1.html
Castagnino, M., Lombardi, O. 2009. The global non-entropic arrow of time: from global geometrical asymmetry to local energy flow. Synthese 169, 1-25.
Castellano, S., Parra, G., Sánchez-Quinto, F.A., Racimo, F., Kuhlwilm, M., Kircher, M., Sawyer, S., Fu. Q., Heinze, A., Nickel, B., Dabney, J., Siebauer, M., White, L., Burbano, H., et al., Pääbo, S. 2014. Patterns of coding variation in the complete exomes of three Neandertals. Proceedings of the National Academy of Sciences 111(18), 6666-6671 - http://tinyurl.com/ooqbwhn.

Castro, L., Castro-Noguiera, L., Castro-Noguiera, M.A., Toro, M.A. 2010. Cultural transmission and social control of human behavior. Biology and Philosophy 25(3), 347-360 - http://tinyurl.com/9gmtj6k

Cattell, R., Parker, A. 2012. Challenges for brain emulation: why is building a brain so difficult. Synapticlink.org - http://tinyurl.com/bqspf9v

Cavalier-Smith, T. 2002. Origins of the machinery of recombination and sex. Heredity 88, 124-141 - http://tinyurl.com/nxx9qty.

Cavalier-Smith, T. 2009. Predation and eukaryote cell origins: A coevolutionary perspective. The International Journal of Biochemistry & Cell Biology 41, 307–322 - http://tinyurl.com/mb2pyz9.

Cavalier-Smith, T. 2010. Origin of the cell nucleus, mitosis and sex: roles of intracellular coevolution. Biology Direct 2010, 5(7), pp 1-78 - http://tinyurl.com/n5k4sua

Cavallo, J. & Blumenschine, R. 1989. Tree-stored leopard kills: expanding the hominid scavenging niche. Journal of Human Evolution 18, 393–400.

Cela-Conde, C.J., Nadal, M., 2012. Taxonomical uses of the species concept in the human lineage. Human Origins researach 2(1), 9 pp. - http://tinyurl.com/kw47ays.

CERN DB Group (2000). A Brief History of Databases. - http://tinyurl.com/2fe8726.

Chaimanee, Y., Jolly, D., Benammi, M., Tafforeau, P., Duzer, D., Moussa, I., Jager, J.-J. 2003. A Middle Miocene hominoid from Thailand and orangutan origins. Nature 422, 61-65 - http://tinyurl.com/hdwmpbl

Chaisson, E.J. 2001. Cosmic Evolution: The Rise of Complexity in Nature. Cambridge, Mass: Harvard University Press. – [companion website: http://tinyurl.com/ljuy7es].

Chalmers, D.J. 2006. Phenomenal concepts and the explanatory gap. in Alter, T., Walter, S. (eds) , Phenomenal Concepts and Phenomenal Knowledge: New Essays on Consciousness and Physicalism. Oxford University Press, New York, pp. 167-193. - http://tinyurl.com/lw8l3zh.

Champion, R. 2003. Rafe Champion's critique: Anything Goes: Origins of Scientific Rationalism, by David Stove. The Rathouse - The Philosophy Site of Rafe Champion - http://tinyurl.com/274tzc8.

Champion, R. 2013. A Guide to Objective Knowledge (The Popular Popper). Amazon Kindle Edition - http://tinyurl.com/n5ucdnu.

Chang, Y.S., Baek, S.Y. (2010). Limit to improvement: myth or reality? Empirical analysis of historical improvement on three technologies influential in the evolution of civilization. Technological Forecasting & Social Change 77, 712-729 - http://tinyurl.com/2bksyso .

Chartier, R. 1996. Gutenberg Revisited from the East. *in* Special Issue: Publishing and the Print Culture in Late Imperial China. Late Imperial China 17.1: 1-9.]

Chater, N., Reali, F., Morten H. Christiansen, M.H. 2009. Restrictions on biological adaptation in language evolution. Proceedings of the National Academy of Sciences USA 106(4), 1015-1020 - http://tinyurl.com/ctw655g

Chen, X. 1997. Thomas Kuhn’s latest notion of incommensurability. Journal for the General Philosophy of Science. 28(2), 257-273 - http://tinyurl.com/25s4gh8.

Choo, C. W. (1998). The Knowing Organization: How Organizations Use Information to Construct Meaning, Create Knowledge, and Make Decisions. Oxford University Press, N.Y. - http://128.100.159.139/FIS/KO/default.html [http://library.monash.edu.au/cgi-bin/PWebrecon.cgi?v2=1&ti=1,1&SEQ=20030108110435&Search_Arg=Knowing+Organization&SL=None&Search_Code=TALL&PID=21460&CNT=10&SID=3]

Choo, C. W. (1999). The Structure of Organizational Knowledge. PrimaVera Working Paper 99-27. The University of Amsterdam. - http://primavera.fee.uva.nl/PDFdocs/99-27.pdf

Choo, C. W., Detlor, B. and Turnbull, D. (2000). Working the Web: An Empirical Model of Web Use. Paper presented to HICSS 33 (Hawaii International Conference on Systems Science), Jan 4-7, 2000. - http://128.100.159.139/FIS/ResPub/HICSS/default.html

Christensen, B., Maslin, M. 2008. Rocking the cradle of humanity: new thoughts on climate, tectonics and human evolution. Geotimes: Earth, Energy and Environment News - http://tinyurl.com/k83laoe

Christensen, W.D. and Hooker, C.A. (1998). Organisation, Evolution and Cognition: Beyond Campbell's Evolutionary Epistemology. PSA '98. Sixteenth Biennial Meeting of the Philosophy of Science Association , Thursday, October 22 - Saturday, October 24, 1998, Kansas City, Missouri - http://tinyurl.com/ntbzgy4.

Christian, J. 2007. Absolute being vs relative becoming. In: Relativity and the Dimensionality of the World. Petkov, V. (Ed.), pp. 163-196. Dordrecht: Springer - http://tinyurl.com/o644h98.

Christianini, N. (1997). Evolution, Learning and Popper's Epistemology *submitted at* the European Conference on Artificial Life 1997 - http://tinyurl.com/27osshu.

Churchill, S.E., Rhodes, J.A. 2009. The evolution of the human capacity for "killing at a distance": the human fossil evidence for the evolution of projectile weaponry. (in) The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence, (eds) J.-J. Hublin and M.P. Richards, Springer Science + Business Media, pp. 201–210 - http://tinyurl.com/kb5bxnu.

Churchill, S.E., Holliday, T.W., Carlson, K.J., Jashashvili, T., Macias, M.E., Matthews, S., Sparling, T.L., Schmid, P., de Ruiter, D.J., Berger. L.R. 2013. The upper limb of *Australopithecus sediba*. Science 340, 1233477, pp 1-6 - http://tinyurl.com/lawea87.

CISCO. 2013. The zettabyte era—trends and analysis. CISCO White Paper, pp. 19 - http://tinyurl.com/mr8ljv8.

Ciochon, R.L. 2010. Divorcing hominins from the *Stegodon-Ailuropoda* fauna: new views on the antiquity of hominins in Asia. (in) J.G. Fleagle et al. (eds.), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_8, © Springer Science+Business Media B.V, pp. 111-126.

Clark, J.D., Beyene, Y., WoldeGabriel, G., Hart, W.K., Renne, P.R., Gilbert, H., Defleur, A., Suwa, G., Katoh, S., Ludwig, K.R., Boisserie, J.-R., Asfaw, B., White, T.D. 2003. Stratigraphic, chronological and behavioural contexts of Pleistocene Homo sapiens from Middle Awash, Ethiopia. Nature 423, 747-752 - http://tinyurl.com/nyf9vo5

Clark, K.M., Montelle, C. 2012. Logarithms: the early history of a familiar function. The MAA Mathematical Sciences Digital Library - http://tinyurl.com/nfoldx6.

Clark, G. 1969. World Prehistory: A New Synthesis. Cambridge University Press, Cambridge.

Clark, G.M. 1978. Cochlear implant surgery for profound or total hearing loss. Medical Journal of Australia 2 (13), 587–588.

Clark, G.M., Tong, Y.C., Black, R., Forster, I.C., Patrick, J.F., and Dewhurst, D.J. 1977. A multiple electrode cochlear implant. Journal of Laryngology & Otology 91 (11), 935–945.

Clark, J.D., Harris, J.W. 1985. Fire and its roles in early hominid lifeways. The African Archaeological Review 3(1), 3-27.

Clay, Z., Zuberbühler, K. 2009. Food-associated calling sequences in bonobos. Animal Behavior 77, 1387–1396.

Cleland, C.E. and Chyba, C.F. (2002). Defining 'life'. Origins of Life and Evolution of Biospheres 32(4), 387–393 - http://tinyurl.com/m6khr2q.
Clement, R.W. 1997. Medieval and Renaissance Book Production, I - Manuscript Books. *from* ORB: The Online Reference Book for Medieval Studies. - http://tinyurl.com/2f3v2j8.
Clement, R.W. 1997a. Medieval and Renaissance Book Production, II - Printed Books. *from* ORB: The Online Reference Book for Medieval Studies. - http://tinyurl.com/277jump.
Cleveland, A., Rocca, A.M., Wendt, E.L., Westergaard, G.C. 2004. Transport of tools to food sites in tufted capuchin monkeys (*Cebus apella*). Animal Cognition 7, 193-198 - http://tinyurl.com/hbrv98m.
Cnet News (2006). Images: 35 years of Intel chip design - http://tinyurl.com/2647rea
Coffee, P. (2000). Analysis: Win2K rollout asks 63,000-bug question. Welcome to Bloat City. eWeek. ZDNet. - http://tinyurl.com/2dr3kc9.
Cohan, F.M. 2002. Sexual isolation and speciation in bacteria. Genetica 116, 359-370.
Cohen-Karni, T., Qing, Q., Li, Q., Fang, Y., Lieber, C.M. 2010. Graphene and nanowire transistors for cellular interfaces and electrical recording. Nano Letters 10(3), 1098-1102 - http://tinyurl.com/d8no5lj
Cole, J.Y. (1992). Jefferson's Legacy: A Brief History of the Library of Congress. Library of Congress. - http://tinyurl.com/2479so4.
Committee on Innovations in Computing and Communications: Lessons from History, et al. 1999. Funding a Revolution: Government Support for Computing Research, National Academy Press, Washington, D.C. - http://tinyurl.com/kwq8jjc.
Connolly, D., Khare, R, Rifkin, A. (1997). The Evolution of Web Documents: The Ascent of XML - http://tinyurl.com/2eah8s7.
Cook, J., Stringer, C.B., Currant, A.P., Schwarcz, H.P., Wintle, A.G. 1988. A review of the chronology of the European Middle Pleistocene hominid record. Yearbook of Physical Anthropology 25: 19-65.
Coolidge, F.L., Overmann, K.A., Wynn, T. 2011. Recursion, what is it, who has it, and how did it evolve. Wiley Interdisciplinary Reviews: Cognitive Science 2(5), 547-554.
Coombe, I. 1998. Decisions and power in the Information Age (WIKID Power™) - http://tinyurl.com/edqkg.
Coon, C.S. 1962. The Origin of Races. Alfred A. Knopf, New York.
Cooper, A., Stringer, C.B. 2013. Did the Denisovans cross Wallace's Line. Science 342, 321-323 - http://tinyurl.com/mdu7v7o.
Cooper, J.R. (1994). Another View of the Revolution in Military Affairs. Strategic Studies Institute Publication. 1994 No. 21. - http://tinyurl.com/ph8hu4y.
Cooper, J.S. 2004. Babylonian beginnings: the origin of the cuneiform writing system in comparative perspective. (in) The First Writing: Script Invention as History and Process. Houston, S.D. (ed.). Cambridge University Press, Cambridge, Pp. 71-99 - http://tinyurl.com/2c2fzfu.
Copeland, B.J. (2008). The Church-Turing Hypothesis. *in* Zalta (2008) - http://tinyurl.com/29xap3l.
Copeland, B.J. (2008a). The Modern History of Computing. *in* Zalta (Zalta2008) - http://tinyurl.com/bs67kgu.
Copley SD, Smith E, Morowitz HD. 2007. The origin of the RNA world: co-evolution of genes and metabolism. Bioorganic Chemistry 35: 430-433 - http://tinyurl.com/k6aafwr.

Copley SD, Smith E, Morowitz HD. 2010. How life began: the emergence of sparse metabolic networks. Journal of Cosmology 10: 3345-3361 - http://tinyurl.com/k865zr4.

Coram, R. (2002) Boyd: The Fighter Pilot Who Changed the World. Little, Brown & Company.

Corballis, M.C. 2010. Mirror neurons and the evolution of language. Brain & Language 112, 25-35 - http://tinyurl.com/3ycg7av.

Corballis, M.C. 2013. Wandering tales: evolutionary origins of mental time travel and language. Frontiers in Psychology 4, Article 485, 1-8 - http://tinyurl.com/kq48r8f.

Cornejo, M, 2003, Utility, value, and knowledge communities. Knowledge Board Knowledge Bank, 02 May 2003 - http://tinyurl.com/m64vxq9.

Corning, P.A. 2001. "Control information": The missing element in Norbert Wiener's cybernetic paradigm? Kybernetes 30, 1272-1288. - http://tinyurl.com/jvhc8yx

Corning, P.A. 2002. Thermoeconomics: Beyond the Second Law. Journal of Bioeconomics 4(1): 57-88. - http://tinyurl.com/kkug6df.

Corning, P.A. 2002a.The re-emergence of "emergence": A venerable concept in search of a theory. Complexity 7, 18–30 - http://tinyurl.com/k7hemv9.

Corning, P.A. 2007. Control information theory: the 'missing link' in the science of cybernetics. Systems Research and Behavioral Science 24, 297-311 - http://tinyurl.com/kux5vao.

Corrall, S. (1998). Knowledge Management: Are We in the Knowledge Management Business. Ariadne no 18. - http://www.ariadne.ac.uk/issue18/knowledge-mgt/

Couch, C.J. 1989. Oral technologies? a cornerstone of ancient civilizations? Sociological Quarterly 30(4), 587-602

Cowan, J.L. (2000) From Air Force Fighter Pilot to Marine Corps Warfighting: Colonel John Boyd, His Theories on War, and their Unexpected Legacy. Masters Thesis. Marine Corps University. Marine Corps Combat Development Command, Quantico, Virginia. http://tinyurl.com/n6pgg2e.

Cox, J.E. 1998. The changing economic model of scholarly publishing: uncertainty, complexity, and multimedia serials. Library Acquisitions: Practice & Theory 22(2), 161-166 - http://tinyurl.com/2eumm2z.

Cramb, A.W. [????]. A short history of metals - http://tinyurl.com/kcl4gkj.

Cringely, R.X. (1996). Accidental Empires : How the Boys of Silicon Valley Make Their Millions, Battle Foreign Competition, and Still Can't Get a Date. Reprint Ed., Harperbusiness – [download book: http://tinyurl.com/myrvvyn].

Cringely, R.X. (1996a). Triumph of the Nerds. The Rise of Accidental Empires. PBS OnLine - http://tinyurl.com/34ll92z.

Cringely, R.X. (1998). Nerds 0.2.1: A Brief History of the Internet. PBS OnLine - http://tinyurl.com/34d8wqo.

Croasdell, D.T. (1998). A Study of Best Practices in Designing and Supporting Effective Organizational Memory Systems. Americas Conference on Information Systems 1998. http://www.isworld.org/ais.ac.98/proceedings/track32/croasdell.pdf

Crochet, J-Y, Welcomme, J.-L., Ivorra, J., Ruffet, G., Boulbes, N., Capdevila, R., Claude, J., Firmat, C., Metais, G., Michaux, J., Pickford, M. 2009. Une nouvelle faune de vertebres continentaux, associee a des artefacts dans le Pleistocene inferieur de l'Herault (Sud de la France), vers 1,57 Ma. Comptes Rendus Palevol 8, 725-736 - http://tinyurl.com/oly8fuv.

Crompton, R.H., Vereecke, E.E., Thorpe, S.K.S. 2008. Locomotion and posture from the common hominoid ancestor to fully modern hominins, with special reference to the last

common panin/hominin ancestor. Journal of Anatomy 212, 501-543 - http://tinyurl.com/nbp9nn8
Crowley, C.W. 2012. An atlas of Cenozoic climate zones. Masters Thesis, University of Texas, Arlington - http://tinyurl.com/hrvpz78.
Cruciani, F., Trobetta, B., Massaia, A., Destro-Bisol, G., Sellitto, D., Scozzari, R. 2011. A revised root for the human Y chromosomal phylogenetic tree: the origin of patrilineal diversity in Africa. The American Journal of Human genetics 88, 814-818 - http://tinyurl.com/9eecbds
CSAC - Chimpanzee Sequencing and Analysis Corporation. 2005. Initial sequence of the chimpanzee genome and comparison with the human genome. Nature 437, 69-87 - http://tinyurl.com/8krgdz3
Culotta, E. 2006. Skeptics seek to slay the 'Hobbit,' calling Flores skeleton a modern human. Science 313, 1028-1029 [included with Brown et al. 2004].
Cummins-Sebree, S.E., Fragaszy 2005. Capuchins as stone-knappers?: an evaluation of the evidence. In Knapping Stone: A Uniquely Hominid Behavior, eds. V. Roux and B. Brill, pp. 171-182. Cambridge University Press, Cambridge - http://tinyurl.com/k4ezkvv.
Cuomo, S. 2012. Exploring ancient Greek and Roman numeracy. BSHM Bulletin: Journal of the British Society for the History of Mathematics 27(1), 1-12 - http://tinyurl.com/oemedc3 [video of lecture - http://tinyurl.com/phukr87; transcript - http://tinyurl.com/mnbejb2; presentation slides - http://tinyurl.com/l3jubku].
Currat, M., Excoffier, L. 2011. Strong reproductive isolation between humans and Neanderthals inferred from observed patterns of introgression. Proceedings of the National Academy of Sciences USA 108(37), 15129-15134 - http://tinyurl.com/9zdznlj
Cusumano, M.A. 2006. What road ahead for Microsoft and Windows. Communications of the ACM 49 (7), 21 – 23 - http://tinyurl.com/2549dd8.
Czerwinski, T., (1988). Coping with the Bounds: Speculations on Nonlinearity in Military Affairs. C4ISR Cooperative Research Program (CCRP), Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (ASD(C3I), US Department of Defense - http://tinyurl.com/p64vr72.
D'Août, K., Vereecke, E., Schoonaert, K., De Clercq, D., Van Elsaker, L., Aerts, P. 2004. Locomotion in bonobos (Pan paniscus): differences and similarities between bipedal and quadrupedal terrestrial walking, and a comparison with other locomotor modes. Journal of Anatomy 204, 353-361 - http://tinyurl.com/nrp8o87.
d'Errico, F., Stringer, C.B. 2011. Evolution, revolution or saltation scenario for the emergence of modern cultures? Philosophical Transactions of the Royal Society B 366, 1060-1069 - http://tinyurl.com/cg8r8jj
d'Errico, F., Vanhaeren, M., Henshilwood, C., Lawson, G., Maurelle, B., Galbier, D, Tillier, A.-M., Soressi, M., van Niekerk, K. 2009. From the origin of language to the diversification of languages – what can archaeology and palaeoanthropology say? (in) d'Errico, F., Jombert, J.-M. (eds), Advances in the Emergence of Language, Human Cognition and Modern Cultures. John Benjamins Publishing Co., Amsterdam, pp. 13-68 [download eBook - http://tinyurl.com/d39jc9c
da Cruz, F. (2008+). Computing at Columbia Timeline: A Chronological History of Computing at Columbia University - http://tinyurl.com/m6uouny.

Dalmaris, P. 2006. A framework for the improvement of knowledge-intense business processes. PhD Thesis, Faculty of Information Technology, University of Technology, Sydney - http://tinyurl.com/2fx5gk5.

Dalmaris P, Hall WP, Philp W, 2006. The time-value of knowledge: a temporal qualification of knowledge, its issues, and role in the improvement of knowledge intense business processes. Paper presented at 3rd Asia Pacific International Conference on Knowledge Management (KMAP 2006), 11-13 December 2006, Hong Kong. - http://tinyurl.com/ltol799.

Dalmaris, P., Tsui, E., Hall, W.P., Smith, B. 2007. A framework for the improvement of knowledge-intensive business processes. Business Process Management Journal. 13(2): 279-305 - http://tinyurl.com/o5xro35.

Dalton, D.R. (????). Is Evolution Really "Proven Fact". - http://www.digisys.net/users/ddalton/evolution_vs__creation.htm

Dambricourt Malassé, A., Singh, M., Karir, B., Gaillard, C., Bhardwaj, V., Moigne, A.-M., Abdessodok, S., Sao, C.C., Gargani, J., Tudryn, A., Calligaro, T., Kaur, A., Pal, S., Hazarika, M., et al. 2016. Anthropic activities in the fossiliferous Quranwala Zone, 2.6 Ma, Siwaliks of Northwest India, historical context of the discovery and scientific investigations. Comptes Rendus Palevol 15, 295-316 - http://tinyurl.com/gwkwkmf.

Dambricourt Malassé, A., Moigne, A.-M., Singh, M.,, Calligaro, T., Karir, B., Gaillard, C., Kaur, A., Bhardwaj, V., Pal, S., Abdessodok, S., Sao, C.C., Gargani, J., Tudryn, A.,, Sanz, M.G. 2016. Intenttional cut marks on bovid from the Quranwala zone, 2.6 Ma, Siwalik Frontal Range, northwestern India. Comptes Rendus Palevol 15, 317-339 - http://tinyurl.com/j5ecche.

Damerow, P. 1999. The origins of writing as a problem of historical epistemology. Symposium: The Multiple Origins of Writing: Image, Symbol and Script. University of Pennsylvania, Center for Ancient Studies, March 26-27, 1999 - http://tinyurl.com/lyrgfcc.

Damasio, A. 1999. The Feeling of What Happens: Body and Emotion in the Making of Consciousness. Harcourt, New York.

Damasio, A. 2010. Self Comes to Mind: Constructing the Conscious Brain. Pantheon Books, New York.

Darling, P. 2010. Intel, Micron first to sample 3-bit-per-cell NAND flash memory on industry-leading 25-nanometer silicon process technology. Intel press release Aug 17, 2010 - http://tinyurl.com/n4d95vj

Darlington, C.D. 1939. The Evolution of Genetic Systems. Cambridge University Press, Cambridge, UK.

Darnton, R. 2013. The National Digital Public Library is launched! The New York Review of Books, April 25, 2013 - http://tinyurl.com/kfe75et

Davenport, T. H. (1997). Information Ecology, Oxford University Press, New York, NY. [http://library.monash.edu.au/cgi-bin/PWebrecon.cgi?v2=1&ti=1,1&SEQ=20030108101204&Search_Arg=Information+Ecology&SL=None&Search_Code=TALL&PID=10697&CNT=10&SID=10 Not seen]

Davenport, T. H. (1997) and Prusak, L. (1998). Working Knowledge: How organizations manage what they know, Harvard Business School Press, Boston. [http://library.monash.edu.au/cgi-bin/PWebrecon.cgi?v2=1&ti=1,1&SEQ=20030108101427&Search_Arg=Working+Knowledge&SL=None&Search_Code=TALL&PID=10697&CNT=10&SID=11 Not seen]

David, M. 2009. The Correspondence Theory of Truth, The Stanford Encyclopedia of Philosophy (Fall 2009 Edition), Edward N. Zalta (ed.) - http://tinyurl.com/2d4se5e.

David, N. 2012. New frontiers in the neuroscience of the sense of agency. Frontiers in Human Neuroscience 6, no. 161, pp. 1-5. http://tinyurl.com/9mdj56v.

Davidson, I. 2013. Peopling the last new worlds: the first colonisation of Sahul and the Americas. Quaternary International 285, 1-29 - http://tinyurl.com/l6rsyy8.

Davidson, I, McGrew, W.C. 2005. Stone tools and the uniqueness of human culture. Journal of the Royal Anthropological Institute 11, 793-817 - http://tinyurl.com/3yb3eoo.

Dawkins, R. 1989. The Selfish Gene. Oxford University Press.

Dawkins, R., Krebs, J.R. 1979. Arms races between and within species. Proceedings of the Royal Society of London B 205, 489-511 - http://tinyurl.com/abple8k.

Day, C. (1997), Solving the problem or shifting the costs? Journal of Electronic Publishing. 4(10) - http://tinyurl.com/2fklgzz.

Day, R.E. 2005. Clearing up "implicit knowledge": implications for knowledge management, information science, psychology, and social epistemology. Journal of the American Society for Information Science and technology 56(6), 630-635.

Deacon, T.W. 1997. The symbolic species: The co-evolution ofthe brain and language. W. W. Norton and Co., New York.

De Cruz, H. 2008. An extended mind perspective on natural number representation. Philosophical Psychology 21(4), 457-490 - http://tinyurl.com/k57mnwp.

De Cruz, H., De Smedt, J. 2013. Mathematical symbols as epistemic actions. Synthese no. 190, 3-19 - http://tinyurl.com/l8q8wng

de Garis, H., Shuo, C., Goertzel, B., Ruiting, L. 2010. A world survey of artificial brain projects, part I: large-scale brain simulations. Neurocomputing 74, 3-29 - http://tinyurl.com/cptxqps

de Heinzelin, J., Clark, D.J., White, T., Hart, W., Renne, P., WoldeGabriel, G., Beyene, Y., Vrba, E. 1999. Environment and behavior of 2.5-million-year-old Bouri hominids. Science 284, 625-629 - http://tinyurl.com/ny2s6kk

de Kunder, M. 2007. Geschatte grootte van het geïndexeerde World Wide Web. Masters Thesis, Universiteit van Tilburg, Noord-Brabant, Netherlands, 68 pp. - http://tinyurl.com/8qtfv8s.

de la Torre, I. 2011. The origins of stone tool technology in Africa: a historical perspective. Proceedings of the Royal Society B 366(1567), 1028-1037 - http://tinyurl.com/9ld72mf.

de la Torre, I, McHenry, L, Njau, J and Pante, M 2012. The origins of the Acheulean at Olduvai Gorge (Tanzania): A New Paleoanthropological Project in East Africa. Archaeology International 15:89-98 - http://tinyurl.com/krhb38g.

de Moraes, B.L.C., Souto, A.D.S., Schiel, N. 2014. Adaptability in stone tool use by wild capuchin monkeys (*Sapajus libidinosus*). American Journal of Primatology 76, 967-977 - http://tinyurl.com/jbngh9u.

de Ruiter, D.J., Churchill, S.E., Berger, L.R. 2013. *Australopithecus sediba* from Malapa, South Africa. (in) Reed, K.E., Fleagle, J.G., Leakey, R.E. (eds.), The Paleobiology of Australopithecus. Vertebrate Paleobiology and Paleoanthropology, DOI: 10.1007/978-94-007-5919-0_9, Springer Science+Business Media Dordrecht - http://tinyurl.com/mg8znpc.

de Ruiter, D.J., DeWitt, T.J., Carlson, K.B., Brophy, J.K., Schroeder, L., Akermann, R.R., Churchill, S.E., Berger, L.R. 2013. Mandibular remains support taxonomic validity of *Australopithecus sediba*. Science 340, 1232997, pp. 1-4 - http://tinyurl.com/oy6vofn

de Rosnay, J. (1998). Entropy and the Laws of Thermodynamics - http://tinyurl.com/23ow9gb In Principia Cybernetica Web

de Sousa, A., Cunha, E. 2012. Hominins and the emergence of the modern human brain. (in) Progress in Brain Research, Vol. 195., Hoffman, M.A., Falk, D. (eds), Elsevier, pp. 293-322 - http://tinyurl.com/lhogf25.
de Waal, F.B.M., Gavrilets, S. 2013. Monogamy with a purpose. Proceedings of the National Academy of Sciences 110, 15167-15168 - http://tinyurl.com/os37m7n.
de Waal, F.B.M., Davis, J.M. 2003. Capuchin cognitive ecology: cooperation based on projected returns. Neuropsychologia 41, 221-228 - http://tinyurl.com/ppym9db.
de Waal, F.B.M., Dindo, M., Freeman, C.A., Hall, M.J. 2005. The monkey in the mirror: hardly a stranger. Proceedings of the National Academy of Sciences 102, 11140-11147 - http://tinyurl.com/p89fpny.
December, J. and Ginsberg, M. (1996). The World Wide Web as a Communications System. *from* HTML 3.2 & CGI Unleashed, Professional Reference Edition. [See also About the Book]. Sams.net Publishing - http://tinyurl.com/264unb2.
Dediu, D., Levinson, S.C. 2013. On the antiquity of language: the reinterpretation of Neandertal linguistic capacities and its consequences. Frontiers in Language Science 4, 1-17 - http://tinyurl.com/k9vsqwq.
Delany, F. (1997). History of the Microcomputer Revolution. Transcript of The Radio Series Broadcast on KPBX FM 91.1 Spokane Public Radio, National Public Radio Network (with a Forward from 2007). - http://tinyurl.com/kqgqrmv.
Delia, D. 1992. From Romance to Rhetoric: The Alexandrian Library in Classical and Islamic Traditions. The American Historical Review, 97(5):1449-1467.
Dempsey, G. T. (1996) Hayek's Evolutionary Epistemology, Artificial Intelligence, and the Question of Free Will, Evolution and Cognition, 2:139-150 - http://tinyurl.com/2d2ojby.
Dennell, R.W. 2010. The colonization of "Savannahstan": issues of timing(s) and Patterns of dispersal across Asia in the Late Pliocene and Early Pleistocene. (in) C.J. Norton and D.R. Braun (eds.), Asian Paleoanthropology: From Africa to China and Beyond, Vertebrate Paleobiology and Paleoanthropology. Springer Science+Business Media, Dordrecht, pp. 7-30 - http://tinyurl.com/lm449uz.
Dennell, R.W. 2010a. "Out of Africa I": current problems and future prospects. (in) J.G. Fleagle et al. (eds.), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_15, © Springer Science+Business Media B.V., pp. 247-273 - http://tinyurl.com/pan959l.
Dennell, R.W. 2011. An earlier Acheulian arrival in South Asia. Science 331, 1532-1533 - http://tinyurl.com/m2mqpjz.
Dennell, R.W. 2016. Life without the Movius Line: The structure of the East and Southeast Asian Early Palaeolithic. Quaternary International, http://dx.doi.org/10.1016/j.quaint.2015.09.001 - http://tinyurl.com/jzddrq9.
Dennell, R.W., Louys, J., O'Regan, H.J., Wilkinson, D.M. 2014. The origins and persistence of *Homo floresiensis* on Flores: biogeographical and ecological perspectives. Quaternary Science Reviews 96, 98–107 - http://tinyurl.com/zrlrr8t.
Dennell, R., Petraglia, M.D. 2012. The dispersal of Homo sapiens across southern Asia: how early, how often, how complex? Quaternary Science Reviews 47, 15-22 - http://tinyurl.com/lqcko6n.
Dennell, R., Roebroeks, W. 2005. An Asian perspective on early human dispersal from Africa. Nature 438, 1099-1104 - http://tinyurl.com/kwkkyt2

Derevianko, A.P., Shunkov, M.V. 2011. Proceedings of the International Symposium "Characteristic Features of the Middle to Upper Paleolithic Transition in Eurasia: Development of Culture and Evolution of Homo Genus" (July 4–10, 2011, Denisova Cave, Altai). Rissian Academy of Sciences, Siberian Branch, Institute of AZrchaeology and Ethnography – [download book: http://tinyurl.com/kyuqu4d]
DeSilva, J.M. 2011. A shift toward birthing relatively large infants early in human evolution. Proceedings of the National Academy of Sciences USA, 108(3), 1022-1027 - http://tinyurl.com/8kdckpn.
DeSilva, J.M., Holt, K.G., Churchill, S.M., Carlson, K.J., Walker, C.S., Zipfel, B., Berger, L.R. 2013. The lower limb and mechanics of walking in *Australopithecus sediba*. Science 340, 1232999, pp 1-5 - http://tinyurl.com/qeywqr8
Deutsch, D. 1997. The Fabric of Reality. London: Penguin Books.
Deutsch, D. 2002. The structure of the multiverse. Proceedings of the Royal Society London, A 458:2911-1923 - http://tinyurl.com/oauvlaa.
Dewar, J.A. 1998. The Information Age and the Printing Press: Looking Backward to See Ahead. Rand Corporation Paper, no P-8014, 30 p. - http://tinyurl.com/2b2u8ed.
DiCarlo, J.J., Zoccolan, D., Rust, N.C. 2012. How does the brain solve visual object recognition. Neuron 73, 415-434 - http://tinyurl.com/coq76qs.
Dieks, D.G.B.J. 2006. The Ontology of Spacetime. Elsevier.
Dienes, I. 2012. A Meta Study of 26 "How much information" studies: sine qua nons and solutions. International Journal of Communication 6, 874–906 - http://tinyurl.com/llxlh8g
Diettrich, O. (1995). A constructivist approach to the problem of induction. evolution and cognition: 1(2) - http://tinyurl.com/2ejnquw.
Dirks, P.H.G.M, Berger, L.R., E.M. Roberts, Kramers, J.D., Hawks, J., Randolph-Quinney, P.S., Elliott, M., Musiba, C.M., Churchill, S.E., de Ruiter, D.J., Schmid, P., Backwell, L.R. et al. 2015. Geological and taphonomic context for the new hominin species *Homo naledi* from the Dinaledi Chamber, South Africa. eLife doi: 10.7554/eLife.09561, 37 pp - http://tinyurl.com/harukgl.
Dominey, N.J., Vogel, E.R., Yeakel, J.D., Constantino, P., Lucas, P.W. 2008. Mechanical properties of plant underground storage organs and implications for dietary models of early humans. Evolutionary Biology 35, 159-175 - http://tinyurl.com/34fe4cs.
Domínguez-Rodrigo, M., Pickering, T.R., Semaw, S., Rogers, M.J. 2005. Cutmarked bones from Pliocene archaeological sites at Gona, Afar, Ethiopia: implications for the function of the world's oldest stone tools. Journal of Human Evolution 48, 109-121 http://tinyurl.com/o7ooj8s.
Domínguez-Rodrigo, M., Pickering, T.R., Bunn, H.T. 2010. Configurational approach to identifying the earliest hominin butchers. Proceedings of the National Academy of Sciences USA 107, 20929-20934 – http://tinyurl.com/cssxkzj
Domínguez-Rodrigo, M., Pickering, T.R., Bunn, H.T. 2011. Reply to McPherron et al: doubting Dikika is about data, not paradigms. Proceedings of the National Academy of Sciences USA 108(21), E116 – http://tinyurl.com/d59dqp2
Domínguez-Rodrigo, M., Pickering, T.R., Bunn, H.T. 2012. Experimental study of cut marks made with rocks unmodified by human flaking and its bearing on claims of ~3.4-million-year-old butchery evidence from Dikika, Ethiopia. Journal of Archaeological Science 39(2), 205-214
Donald, M. 1991. The Origin of the Modern Mind. Harvard University Press, Cambridge, MA.

Dooley, K. (1996). Complex Adaptive Systems: A Nominal Definition - http://www.eas.asu..edu/~kdooley/casopdef.html.
Drapier, M., Chauvin, C., Defour, V., Ulrich, P., Thierry, B. 2005. Food-exchange with humans in brown capuchin monkeys. Primates 46, 241-248 - http://tinyurl.com/l8wb4sz.
Drayton, L.A., Santos, L.R. 2014. Capuchins' (*Cebus apella*) sensitivity to others' goal-directed actions in a helping context. Animal Cognition 17, 689-700 - http://tinyurl.com/ldp2w2b.
Doud, A.J., Lucas, J.P., Pisansky, M.T., He, B., 2011. Continuous three-dimensional control of a virtual helicopter using a motor imagery based brain-computer interface. PLoS ONE 6(10): e26322. doi:10.1371/journal.pone.0026322 - http://tinyurl.com/cj7c2uv.
Dowe, P. 2009. Causal Processes. In Zalta, E.N. (Ed.), The Stanford Encyclopedia of Philosophy (Spring 2009 Edition) - http://tinyurl.com/29h8xve.
Duarte, M., Hanna, J., Sanches, E., Liu, Q., Fragaszy, D. 2012. Kinematics of bipedal locomotion while carrying a load in the arms in bearded capuchin monkeys (*Sapajus libidinosus*). Journal of Human Evolution 63, 851-858 - http://tinyurl.com/or5g9l4,
Duda, P., Zrzavý, J. 2013. Evolution of life history and behavior in Hominidae: towards phylogenetic reconstruction of the chimpanzee-human last common ancestor. Journal of Human Evolution 65, 424-446 - http://tinyurl.com/zrcuzz2.
Dunbar, R.I.M. 2003. The social brain: mind, language, and society in evolutionary perspective. Annual Review Anthropology 32, 163-181 - http://tinyurl.com/7xqtaj3.
Dunbar, R.I.M. 2010. Brain and behavior in primate evolution. (in) Mind the gap: tracing the origins of human universals, Kappelar, P.M., Silk, J.B. (eds), pp. 315-330 - http://tinyurl.com/7dp3cw2 [downloads whole 3.5 MB book over slow connection].
Duran, A., Meyer, A.L.S., Pie, M.R. 2013. Climatic niche evolution in New World monkeys (Platyrrhini). PLoS ONE 8(12): e83684. doi:10.1371/journal.pone.0083684, 6 pp. - http://tinyurl.com/oubhtz9.
Durand, F. 2010. The rise of the human predator and the transcendence of consciousness. Proceedings of the 16th Conference of the South African Science and Religion Forum (SASRF) of the Research Institute for Theology and Religion, University of South Africa, Pretoria, 2-3 September 2010 - http://tinyurl.com/8ur7f8q.
Duranti, L., Eastwood, T., and MacNeil, H. (1997?). The Preservation of the Integrity of Electronic Records. InterPARES: (International project on Permanent Authentic Records in Electronic Systems). University of British Columbia, Vancouver, B.C. - http://www.interpares.org/UBCProject/index.htm
Dykes, N. 1996. A Tangled Web of Guesses: A Critical Assessment of the Philosophy of Karl Popper. Philosophical Notes No. 37, The Libertarian Alliance, London - http://tinyurl.com/28y5mr7.
Dyson, G. 1999. The Undead Wired Magazine Mar. 1999 – http://tinyurl.com/mtzdn3s .
Earman, J. 2008. Reassessing the prospects for a growing block model of the universe. International Studies in the Philosophy of Science 22, 135-164.
Eberly, J. 2007. The *Homo habilis* paradox: is *Homo habilis* an Australopithecine moonlighting as the first migrant out of Africa. Totem: The University of Western Ontario Journal of Anthropology, 15(1), Article 3. 22-31 (2007) - http://tinyurl.com/muoqgrb
Eby, A. (????) - The origin and development of writing in Mesopotamia: an economic interpretation - http://tinyurl.com/2burbcj**.**
Economides, N. (2000). Economics of Networks: Analysis and News of US v. Microsoft - http://tinyurl.com/289dcbv.

Edmonds, D. and Eidinow, J. (2001). Wittgenstein's Poker: The Story of a Ten-Minute Argument Between Two Great Philosophers. Ecco Press. [for a review see – link; extract from the Melbourne Age newspaper, see - link]

Edmonds, M. 2011. An initial assessment of the accuracy of the gear trains in the Antikythera Mechanism. Journal for the History of Astronomy vol. 42-3, no. 148, 307-320 - http://tinyurl.com/kkdwb7v.

Efstathiou, K., Basiakoulis, A, Efstathiou, M., Anastasiou, M., Seiradakis, J.H. 2012. Determination of the gears geometrical parameters necessary for the construction of an operational model of the Antikythera Mechanism. Mechanism and Machine Theory 52, 219-231 - http://tinyurl.com/oloohae.

Egeland, C.P. 2014. Taphonomic estimates of competition and the role of carnivore avoidance in hominin site use within the Early Pleistocene Olduvai Basin. Quaternary International 322-323, 95-106.

Eisenberg, D. (1992). Word Processing (History of). *in* Encyclopedia of Library and Information Science, vol. 49 (New York: Dekker, 1992), pp. 268-78 - http://tinyurl.com/loj9bqo.

Eisenstein, E.L. (1979). The Printing Press as an Agent of Change: Communications and Cultural Transformations in Early-Modern Europe. Cambridge: Cambridge University Press - http://tinyurl.com/2aets7w.

Eisenstein, E.L. (1983). The Printing Revolution in Early Modern Europe. Cambridge University Press, Cambridge UK. [See Jensen (2001) for a detailed summary of Eisenstein's arguments].

El-Abbadi (1998). The Ancient Library *in Hellenic Alexandria* - http://tinyurl.com/28c8shr.

Eldridge, N. and and S.J. Gould. 1972. Punctuated equilibria: an alternative to phyletic gradualism, in Models in Paleobiology. T.J.M. Schopf (ed.). San Francisco: Freeman, Cooper. pp. 82-115 -http://tinyurl.com/no2khlr.

Elert, G. (1995-2000). Chaos Hypertextbook: Mathematics in the Age of the Computer - http://tinyurl.com/pgz64fu.

Elhaik, E., Tatarinova, T.V., Klyosov, A.A., Graur, D. 2014. The 'extremely ancient' chromosome that isn't: a forensic bioinformatics investigation of Albert Perry's X-degenerate portion of the Y chromosome. European Journal of Human Genetics, doi:10.1038/ejhg.2013.303, 6 pp. - http://tinyurl.com/mh6enez

Eliot, T.S. (1934). Choruses from the Rock, Faber & Faber, London.

Elliott, T. 2014. Full stop for Chullora print plant after 19 years. The Sydney Morning Herald, 7 June 2014 - http://tinyurl.com/kxfvjmr.

Ellis, G.F.R. 2006. Physics and the real world. Foundations of Physics 36(2), 227-262 - http://tinyurl.com/my9nfcm

Ellis, G.F.R. 2006a. On the nature of emergent reality. In: Clayton, P., Davies, P.C.W. (eds.) The Re-emergence of Emergence. Oxford University Press, New York - http://tinyurl.com/kj4z5lh

Ellis, G.F.R. 2006b. Physics in the real universe: time and spacetime. General Relativity and Gravitation 38(12), 1797-1824 - http://tinyurl.com/q7edcu

Ellis, G.F.R. 2008. On the nature of causation in complex systems. Transactions of the Royal Society of South Africa 62(1), 69-84. [For an extended version see http://tinyurl.com/pedc4oc].

Ellis, G.F.R. 2009. Top-down causation and the human brain. (In) Downward Causation and the Neurobiology of Free Will: Understanding Complex Systems, Murphy, N., Ellis, G.F.R.,

O'Connor, T. (Eds). Springer Verlag, Berlin, pp. 63-81 [download book - http://tinyurl.com/kolj7gt].
Ellis, G.F.R. 2009a. On the flow of time. Essay for the Fqxi essay contest on The Nature of Time - http://tinyurl.com/kflmozg.
Ellis, G.F.R. 2011. The arrow of time, the nature of spacetime, and quantum measurement. http://tinyurl.com/qjkoacp
Ellis, G.F.R. 2012. On the limits of quantum theory: contextuality and the quantum-classical cut. Annals of Physics 327(7), 1890-1932 - http://tinyurl.com/pjj5phq.
Ellis, G.F.R. 2012a. Space time and the passage of time. [for] Springer Handbook of Spacetime. Petkov V. (ed). Springer, Heidelberg - http://tinyurl.com/ljvwqhe
Ellis, G.F.R. 2012b. Top-down causation and emergence: some comments on mechanisms. Interface Focus 2, 126–140 - http://tinyurl.com/qbrjc45
Ellis, G.F.R. 2013. The arrow of time and the nature of spacetime. - http://tinyurl.com/oy48zju
Ellis, G.F.R., Noble, D., O'Connor, T. 2012. Top-down causation: an integrating theme within and across the sciences? Interface Focus 2, 1–3. - http://tinyurl.com/pjj5phq
Ellis, G.F.R., Rothman, T. 2010. Time and spacetime: the crystallizing block universe. International Journal of Theoretical Physics 49, 988–1003 - http://tinyurl.com/oatrbmd.
Elitzur, A., Dolev, S. 2005. Quantum phenomena within a new theory of time. (in) Eliltzur, A., Dolev, S., Kolenda, N. (Eds.) Quo Vadis Quantum Mechanics? Springer, pp. 325-349 - http://tinyurl.com/nsr7b7y.
Elkordy A., (2001). The Cyberlibrarians' Rest Stop - http://www.thelearningsite.net/cyberlibrarian/reststop.html
Else, S. E. (2004). Organization theory and the transformation of large, complex organizations: Donald H. Rumsfeld and the U.S. Department of Defence, 2001-04. PhD Thesis, Faculty of the Graduate School of International Studies, University of Denver - http://tinyurl.com/mz8eved.
Emido, R.A., Ferreira, R.G. 2012. Energetic payoff of tool use for capuchin monkeys in the Caatinga: variation by season and habitat type. American Journal of Primatology 74, 332-343 - http://tinyurl.com/jrrm4h9.
Emmeche, C., Koppe, S., Stjernfelt, F. 2000. Levels, emergence, and three versions of downward causation. In: Andersen, P.B., Emmeche, C., Finnemann, N.O., Christiansen, P.V. (Eds.), Downward Causation. Minds, Bodies and Matter. Århus: Aarhus University Press. - http://tinyurl.com/mut63lp.
Endicott, P., Ho, S.Y.W., Stringer, C. 2010. Using genetic evidence to evaluate four palaeoanthropological hypotheses for the timing of Neanderthal and modern human origins. Journal of Human Evolution 59, 87-95 - http://tinyurl.com/krwvoo4.
Engbert, K., Wohlschläger, A., Haggard, P. 2008. Who is causing what? The sense of agency is relational and efferent-triggered. Cognition 107, 693-704 - http://tinyurl.com/9mye64h
Ensor, P. (2002). Tool Kit for the Expert Web Searcher. Library and Information Technology Association (LITA), a division of the American Library Association. - http://www.lita..org/committe/toptech/toolkit.htm
Eriksson, A., Betti, L., Friend, A.D., Lycett, S.J., Singarayer, J.S., von Cramon-Taubadel, N., Valdes, P.J., Balloux, F., Manica, A. 2012. Late Pleistocene climate change and the global expansion of anatomically modern humans. Proceedings of the National Academy of Sciences USA 109(40), 16089-16094 - http://tinyurl.com/l8jw6dy

EPFL 2011. Evaluation of the Blue Brain Project and Human Brain Project - http://tinyurl.com/d5tmwa2.
Evans, D.S., Nichols, A., Reddy, B. (1999). The Rise and Fall of Leaders in Personal Computer Software. *from* Microsoft Antitrust Litigation. National Economic Research Associates, Inc. (NERA), Consulting Economists. - http://tinyurl.com/2drlalo.
Evans, D.S. and Leder, M.R. (1999). Economics for the Third Industrial Revolution. Viewpoint 1. Marsh & McLennan Companies, Inc. - http://tinyurl.com/2e5sonm.
Evans, E.F. 1992. Auditory processing of complex sounds: an overview. Philosophical Transactions of the Royal Society of London B 336, 295-306 - http://tinyurl.com/cs5y2tk
Evans J. 1999. The material culture of Greek astronomy. Journal for the History of Astronomy 30(3) 237-307 - http://tinyurl.com/l5aprex [download options must be selected].
Evans, J., Carman, C.C., Thorndike, A.S. 2010. Solar anomaly and planetary displays in the antikythera mechanism. Journal for the History of Astronomy 41 (Part 1), 1-39 - http://tinyurl.com/plc2frx
Evans, N., Levinson, S.C. 2009. The myth of language universals: language diversity and its importance for cognitive science. Behavioral and Brain Sciences 32, 429-492 - http://tinyurl.com/2aprxrl.
Evans, T.A., Westergaard, G.C. 2004. Discrimination of functionally appropriate and inappropriate throwing tools by captive tufted capuchins (*Cebus apella*). Animal Cognition 7, 255-262 - http://tinyurl.com/hh6xcmj.
Evans, T.A., Westergaard, G.C. 2006. Self-control and tool use in tufted capuchin monkeys (*Cebus apella*). Journal of Comparative Psychology 120(2), 163-166 - http://tinyurl.com/jzlrk7d.
Evolution-vs-Creation. (2002). Evolution vs. Creation - A Contentious Debate. - http://www.evolution-vs-creation.com/
Fadok, D.S. (1994). John Boyd and John Warden: Air Power's Quest for Strategic Paralysis. Thesis, School of Advanced Airpower Studies, Air University, Maxwell Air Force Base, Alabama -http://tinyurl.com/krdrr6g.
Fahy, G.E., Richards, M., Riedel, J., Hublin, J.-J., Boesch, C. 2013. Stable isotope evidence of meat eating and hunting specialization in adult male chimpanzees. Proceedings of the National Academy of Sciences 110, 5829-5833 - http://tinyurl.com/laogxhz.
Falcon, A. (2009). Aristotle on Causality. In Zalta, E.N. (Ed.). The Stanford Encyclopedia of Philosophy (Spring 2009 Edition), - http://tinyurl.com/2e62u8j.
Falk, D., Hildebolt, C., Smith, K., Morwood, M.J., Sutikna, T., Brown, P., Jatmiko, Saptomo, E.W., Brunsden, B., Prior, F. 2005. The brain of LB1, Homo floresiensis. Science 308, 242-245 – [included with Brown et al. 2004] .
Falk, D., Hildebolt, C., Smith, K., Morwood, M.J., Sutikna, T., Jatmiko, Saptomo, E.W., Brunsden, B., Prior, F. 2005a. Response to comment on "the brain of LB1, Homo floresiensis". Science 310, 236c, pp. 1-2 [included with Brown et al. 2004].
Falk, D., Hildebolt, C., Smith, K., Morwood, M.J., Sutikna, T., Jatmiko, Saptomo, E.W., Brunsden, B., Prior, F. 2006. Response to comment on "the brain of LB1, Homo floresiensis". Science 312, 999c, pp. 1-2 [included with Brown et al. 2004].
Falk, D., Hildebolt, C., Smith, K, Morwood, M.J., Sutikna, T, Jatmiko, Saptomo, E.W., Prior, F. 2009. LB1's virtual endocast, microcephaly, and hominin brain evolution. Journal of Human Evolution 57(5), 597-607 - http://tinyurl.com/lxqedpp.

Fallis, D. 2004. Epistemic value theory and information ethics. Minds and Machines 14, 101-117 - http://tinyurl.com/27fkxry.
Fallis, D. 2006. Epistemic value theory and social epistemology. Episteme, 2(3), 177-188 - http://tinyurl.com/27bq6yj.
Fallis, D., Whitcomb, D. 2009. Epistemic values and information management. The Information Society 25(3), 175-189 - http://tinyurl.com/lrgztmb.
Fallon, J.B., Irvine, D.R.F., Shepherd, R.K. 2009. Neural prostheses and brain plasticity. Journal of Neural Engineering 6(6), no. 065008 - http://tinyurl.com/7buf29n.
Falótico, T., Ottoni, E.B. 2013. Stone throwing as a sexual display in wild female bearded capuchin monkeys, *Sapajus libidinosus*. PLoS ONE 8(11): e79535.doi:10.1371/journal.pone.0079535 - http://tinyurl.com/o6qqjy4
Farabee, M.J. (2007). Laws of Thermodynamics in On Line Biology Book [Archived 15 Sept. 2007] - http://tinyurl.com/29zlzp4.
Farley, L., Schneider, R.A., Schottlaender, B.E.C. 2010. Response from the University of California to the public statement from Nature Publishing Group regarding subscription renewals at the California Digital Library. (In) Reshaping Scholarly Communication, University of California, 10 June 2010 - http://tinyurl.com/kbgqbmu.
Farrell, A. (2002). An Organisational Intelligence Framework for the Agile Corporation. Woodlawn Marketing Services. - http://www.worksys.com/agile.htm
Fay, F.X. (1996). The Engineers Get Together to Look Back at the Future. The Hour, Friday, October 25, 1996. - http://tinyurl.com/252eyjr.
Fazel-Rezai, R., Allison, B.Z., Guger, C., Sellers, E.W., Kleih, S.C., Kübler, A. 2012. P300 brain computer interface: current challenges and emerging trends. Frontiers in neuroengineering 5, no. 14, pp. 1-14 - http://tinyurl.com/ce6739u.
Feizabadi, S. (1988). World Wide Web - Beyond the Basics, Prentice Hall - http://tinyurl.com/253nujw.
Fernandes, L. 2010. Abacus: the art of calculating with beads -http://tinyurl.com/kymfcx2.
Fernándes, V., Alshamali, F., Aleves, M., Costa, M.D., Pereira, J.B ., Silva, N.M. Cherni, L., Harich, N., Cerny, B., Soares, P., et al. 2012. The Arabian cradle: mitochondrial relicts of the first steps along the southern route out of Africa. American Jounal of Human Genetics 90, 347-355 - http://tinyurl.com/lfw7etg.
Fernández, E., Pérez-Pérez, A., Gamba, C., Prats, E., Cuesta, P., Anfruns, J., Molist, M., Arroyo-Pardo, E., Turbón, D. 2014. Ancient DNA analysis of 8000 B.C. Near Eastern farmers supports an Early Neolithic pioneer maritime colonization of mainland Europe through Cyprus and the Aegean Islands. PLoS Genet 10(6): e1004401. doi:10.1371/journal.pgen.1004401 - http://tinyurl.com/nmjyqnx
Ferraro, J.V., Plummer, T.W., Pobiner, B.L., Oliver, J.S., Bishop, L.C., Braun, D.R., Ditchfield, P.W., Seaman, J.W., III, Binetti, K.M., Seaman, J.W., Jr., Hertel, F., Potts, R. 2013. Earliest archaeological evidence of persistent hominin carnivory. PLoS ONE 8(4): e62174. doi:10.1371/journal.pone.0062174, 10 pp. - http://tinyurl.com/ljfamwl
Ferring, R., Oms, O., Agusti, J., Berna, F., Nioradze, M., Shelia, T. Tappen, M., Vekua, A., Zhvania, D., Lordkipanidze, D. 2011. Earliest human occupations at Dmanisi (Georgian Caucasus) dated to 1.85–1.78 Ma. Proceedings of the National Academy of Sciences USA 108, 10432-10436 - http://tinyurl.com/9y476zo
Feyerabend, P. (1975) Against Method. New Left Books, London.

Firestone, J.M. 2000. Knowledge management: a framework for analysis and measurement. White Paper 17. Executive Information Systems, Inc. - http://tinyurl.com/nnp8g25.
Firestone, J.M. 2001. Key Issues In Knowledge Management. Knowledge and Innovation - Journal of the Knowledge Management Consortium International, Inc. 1(3) - http://tinyurl.com/m4sqlq7.
Firestone, J.M., McElroy, M.W. 2003. Key Issues in the New Knowledge Management. Butterworth-Heinemann, Burlington, MA – [download ebook: http://tinyurl.com/ocg6eyt].
Firestone, J.M., McElroy, M.W. 2003a. Corporate epistemology: competing philosophies of truth in business and how they influence knowledge management. Executive Information Systems, Inc. White Paper. - http://tinyurl.com/q8hopoa.
Fischer, M.H., Brugger, P. 2011. When digits help digits: spatial-numerical associations point to finger counting as prime example of embodied cognition. Frontiers in Psychology. Vol 2/Art. 260 - http://tinyurl.com/pglthag.
Fjällbrant, N. 1994. Communication in science and technology - http://tinyurl.com/mqdzjjj.
Fjällbrant, N. (1997). Scholarly communication - historical development and new possibilities. In Scholarly Communication in Focus: Proceedings of the 1997 International Association of Technology University Libraries (IATUL), Trondheim - http://tinyurl.com/k3uacl8.
Flinn, M.V., Geary, D.C., Ward, C.V. 2005. Ecological dominance, social competition, and coalitionary arms races: why humans evolved extraordinary intelligence. Evolution and Human Behavior 26, 10-46 - http://tinyurl.com/n46q6j8
Floridi, L. 2002. On defining library and information science as applied philosophy of information. - Social Epistemology 16(1), 37-49 - http://tinyurl.com/2cpgax7
Floridi, L. 2002a. What is the philosophy of information. Metaphilosophy 33, 123-145 - http://tinyurl.com/p9en5h9.
Floridi, L. 2003. Information. (in) The Blackwell guide to the philosophy of computing and information. Floridi, L. (ed.) pp 40-61 - http://tinyurl.com/2anqdka.
Floridi, L., 2004. LIS as applied philosophy of information: a reappraisal. Library Trends, 52(3), 658-665 - http://tinyurl.com/ldre5rr.
Floridi, L. 2007. In defence of the veridical nature of semantic information. European Journal of Analytic Philosophy 3(1), 31-41 - http://tinyurl.com/omn5ghr.
Floridi, L. 2009. Semantic conceptions of information. (in The Stanford Encyclopedia of Philosophy (Summer 2009 Edition), Zalta, E.N. (ed.) - http://tinyurl.com/22vjdu7.
Foley, R., Lahr, M.M. 1997. Mode 3 technologies and the evolution of modern humans. Cambridge Archaeological Journal 7, 3-36 - http://tinyurl.com/lnhgdb7.
Foley, R., Lahr, M.M. 2003. On stony ground: lithic technology, human evolution, and the emergence of culture. Evolutionary Anthropology 12:109-122 - http://tinyurl.com/mzuvzz3
Fondi M. 2010. How primordial cells assembled biosynthetic pathways. Journal of Cosmology 10: 3388-3397 - http://tinyurl.com/5rg9v7l.
Forth, G. 2005. Hominids, hairy hominoids and the science of humanity. Anthropology Today 21(3), 13-17 - http://tinyurl.com/m5jfyqe.
Forster, M.R. 1998. Guide to Thomas Kuhn's The Structure of Scientific Revolutions. Department of Philosophy, University of Wisconsin Phil 220 Home Page - http://tinyurl.com/263jsbb.
Forster, M.R. 2000. Key Concepts in Model Selection: Performance and Generalizability. Journal of Mathematical Psychology 44, 205-231 - http://tinyurl.com/289ymbr.

Forster, M.R. 2000a. Hard Problems in the Philosophy of Science: Idealization and Commensurability. In R. Nola and H. Sankey (eds.) After Popper, Kuhn & Feyerabend: Issues in Theories of Scientific Method, Australasian Studies in History and Philosophy of Science, Kluwer, (2000) - http://tinyurl.com/26mwqqu.

Fowler, A., Sommer, V. 2007. Subsistence technology of Nigerian chimpanzees. International Journal of Primatology 28, 997-1023 - http://tinyurl.com/mfyz5ys.

Fragaszy, D. 2012. Community resources for learning: How capuchin monkeys construct technical traditions. Biological Theory 6, 231-240 - http://tinyurl.com/qfro5sd.

Fragaszy, D.M., Bard, K. 1997. Comparision of development and life history in *Pan* and *Cebus*. International Journal of Primatology 18(5), 683-701 - http://tinyurl.com/gupdlb9.

Fragaszy, D.M., Biro, D., Eshchar, Y., Humle, T., Izar, P., Resende, B., Visalberghi, E. 2013. The fourth dimension of tool use: temporally enduring artefacts aid primates learning to use tools. Philosophical Transactions of the Royal Society B 368, no 1630, 10 pp. - http://tinyurl.com/kmhct3j.

Fragaszy, D. M., Greenberg, R., Visalberghi, E., Ottoni, E. B., Izar, P., & Liu, Q. 2010. How wild bearded capuchin monkeys select stones and nuts to minimize the number of strikes per nut cracked. Animal Behaviour, 80, 205-214 - http://tinyurl.com/kxrmb6k.

Fragaszy, D.M., Johnson-Pynn, J., Hirsh, E., Brakke, K. 2003. Strategic navigation of two-dimensional alley mazes: comparing capuchin monkeys and chimpanzees. Animal Cognition 6, 149-160 - http://tinyurl.com/jd4u6nu.

Fragaszy, D.M., Kennedy, E., Murname, A., Menzel, C., Brewer, G., Johnson-Pynn, J., Hopkins, W. 2009. Navigating two-dimensional mazes: chimpanzees (*Pan troglodytes*) and capuchins (*Cebus apella* sp.) profit from experience differently. Animal Cognition 12, 491-504 - http://tinyurl.com/olrz565.

Fragaszy, D., & Perry, S. 2003. Towards a biology of traditions. In Traditions in Nonhuman Animals: Models and Evidence, eds. D. Fragaszy & S. Perry, pp. Cambridge University Press, Cambridge - http://tinyurl.com/m5663ma.

Fragaszy, D., Pickering,. T., Liu,. Q., Izar,. P., Ottoni,. E., Visalberghi, E. 2010b. Bearded capuchin monkeys' and a human's efficiency at cracking palm nuts with stone tools: field experiments. Animal Behavior 79:321–332 - http://tinyurl.com/ozrurby.

Francis, G., Rash, C.E. 2009. Cognitive factors. (in) Helmet-Mounted Displays: Sensation, Perception and Cognition Issues, Rash, C.E., Russo, M.B., Letowski, T.R., Schmeisser, E.T. (eds). U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, USA, pp. 619-673. - http://tinyurl.com/7y5d9bj

Francis, G., Rash, C.E., Russo, M.B. 2009. The human-machine interface challenge. (in) Helmet-Mounted Displays: Sensation, Perception and Cognition Issues, Rash, C.E., Russo, M.B., Letowski, T.R., Schmeisser, E.T. (eds). U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, USA, pp. 29-44. - http://tinyurl.com/799h3jy.

Frayer, D.W., Wolpoff, M.H., Thorne, A.G., Smith, F.H., Pope, G.G. 1993. Theories of modern human origins: the paleontological test. American Anthropologist 95(1), 14-50 - http://tinyurl.com/jwkwq4d

Freeberg, T.M. Dunbar, R.I.M., Ord, T.J. 2012. Social complexity as a proximate and ultimate factor in communicative complexity. Philosophical Transactions of the Royal Society B, 367, 1785–1801 - http://tinyurl.com/92w49gh

Freeth, T. (2002). The Antikythera Mechansim: 1. Challenging the Classical Research. Mediterranean Archaeology and Archaeometry 2(1): 21-35. - http://tinyurl.com/2e82ggc.

Freeth, T. (2002a). The Antikythera Mechanism: 2. Is it Posidonius Orrery? Mediterranean Archaeology and Archaeometry 2(2): 45-58. - http://tinyurl.com/85blsjz.
Freeth, T., Bitsakis, Y., Moussas, X., Seiradakis, J.H., Tselikas, A., Mangou, H., Zafeiropoulou, M., Hadland, R., Bate, D., Ramsey, A., Allen, M., Crawley, A., Hockey, P., Malzbender, T., Gelb, D., Ambrisco, W>, Edmunds, M.G. 2006. Decoding the ancient Greek astronomical calculator known as the Antikythera mechanism. Nature 444, 587-591 - http://tinyurl.com/k94xjrp.
Freeth, T., Jones, A.R. 2012. The Cosmos in the Antikythera Mechanism. ISAW Papers, 4 - http://tinyurl.com/n5xvvft.
Freeth, T., Jones, A., Steele, J.M., Bitsakis, Y. 2008. Calendars with Olympiad display and eclipse prediction on the Antikythera Mechanism. Nature 454, 614-617 - http://tinyurl.com/lmqg9xa.
Fricke, M. 2009. The knowledge pyramid: a critique of the DIKW hierarchy. Journal of Information Science 35, 131-142 - http://tinyurl.com/oj2x5tn.
Fried, I., Mukamel, R., Kreiman, G. 2011. Internally generated preactivation of single neurons in human medial frontal cortex predicts volition. Neuron 69, 548-562 - http://tinyurl.com/45a4tjl
Frost, P.G.H., 1998. Fire in southern African woodlands, origins, impacts, effects and control. (in) FAO Meeting on Public Policies Affecting Forest Fires, Rome, 28-30 October 1998, pp. 181-205 - http://tinyurl.com/ke9ej9f
Fry, D.P. 2011. Human nature: the nomadic forager model. (in) R.W. Sussman, C.R. Cloninger (eds.), Origins of Altruism and Cooperation, Developments in Primatology: Progress and Prospects 36, DOI 10.1007/978-1-4419-9520-9_13, Springer Science+Business Media, LLC.
Fry, I. (2010) The role of natural selection in the origin of life. Origins of Life and Evolution of the Biosphere, DOI 10.1007/s11084-010-9214-1.
Fu, Q., Meyer, M., Gao, X., Stenzel, U., Burbano, H.A., Kelso, J., Paabo, S. 2013. DNA analysis of an early modern human from Tianyuan Cave, China. Proceedings of the National Academy of Sciences 110(6), 2223–2227 - http://tinyurl.com/q6kttrp
Fumerton, R., (2008), Foundationalist Theories of Epistemic Justification *in* - Zalta, E.N. *ed.* Stanford Encyclopedia of Philosophy - http://tinyurl.com/235vyvv/.
Gabunia, L., Vekua, A. 1995. A Plio-Pleistocene hominid from Dmanisi, East Georgia, Caucasus. Nature 373, 509-512 - http://tinyurl.com/zfmpone.
Gabunia, L., Vekua, A., Lordkipanidze, D., Swisher, C.C., III, Ferring, R., Justus, A., Nioradze, M., Tvalchrelidze, M., Antón, S.C., Bosinski, G., Jöris, O., de Lumley, M.A.-, Majsuradze, G., Mouskhelishvili. 2000. Earliest Pleistocene hominid cranial remains from Dmanisi, Republic of Georgia: taxonomy, geological setting, and age. Science 288, 1019-1025 - http://tinyurl.com/kcp6vr3
Gabunia, L., Antón, S.C., Lordkipanidze, D., Vekua, A., Justus, A., Swisher, C.C., III. 2001. Dmanisi and dispersal. Evolutionary Anthropology 10, 158–170 - http://tinyurl.com/zwzphxv.
Gabunia, L., de Lumley, M.A., Vekua, A., Lordkipanidze, D., deLumley, H. 2002. Découverte d'un nouvel hominidé à Dmanissi (Transcaucasie, Géorgie). Comptes Rendus Palevol 1, 243-253 - http://tinyurl.com/zsztsz2.

Gabunia, L., Vekua, A., de Lumley, M.A., Lordkipanidze, D. 2002a. A new species of *Homo* represented by a fossil from the bottom part of the Pleistocene layer at Dmanisi, Georgia. Archaeology, Ethnology and Anthropology of Eurasia 4: 145–152.

Gaines, B.R. 1980. Autopoiesis: some questions. in Zeleny, M. (ed), Autopoiesis: A Theory of Living Organization. New York: North Holland, 145-156.

Gaines, B.R. (2003). Organizational knowledge acquisition, in Holsapple, C.W. (Ed.) Handbook on Knowledge Management: 1 - Knowledge Matters. pp. 317-347. Berlin: Springer, 2003 - http://tinyurl.com/2ajz2dg.

Galdi, T.W. (1995). Revolution in Military Affairs? Competing Concepts, Organizational Responses, Outstanding Issues. Congressional Research Service [CRS] Reports: Military and National Security. - http://tinyurl.com/qhza8nx.

Gaillard, C., Singh, M., Dambricourt Malassé, A., Bhardwaj, V., Karir,, B., Kaur, A., Pal, S., Moigne, A.-M., Sao, C.C., Abdessadok, S., Gargani, J., Tudryn, A. 2016. The lithic industries on the fossiliferous outcrops of the Late Pliocene Masol Formation, Siwalik Frontal Range, northwestern India (Punjab). Comptes Rendus Palevol 15, 341-357 - http://tinyurl.com/jnfd4vk

Gallotti, R. 2013. An older origin for the Acheulean at Melka Kunture (Upper Awash, Ethiopia): Techno-economic behaviours at Garba IVD. Journal of human Evolution 65, 594-620 - http://tinyurl.com/ngh7cxh

Galluppi, F., Davies, S., Furber, S., Stewart, T., Eliasmith. 2012. Real time on-chip implementation of dunamical systems with spiking neurons. 2012 IJCNN International Joint Conference on Neural Networks, Brisbane Australia June 10 – June 15 2012, 10 pp. - http://tinyurl.com/d6upyt9

Galway-Witham, J.K.R. 2016. "What's in a name" the taxonomy & phylogeny of early *Homo*. Papers from the Institute of Archaeology. 25(2), p.Art. 12. DOI: http://doi.org/10.5334/pia.499.

Gamble, C., Gowlett, J., Dunbar, R. 2011. The social brain and the shape of the palaeolithic. Cambridge Archaeological Journal 21, 115-136doi:10.1017/S0959774311000072

Gamble, C., Porr. M. 2005. The Hominid Individual in Context: Archaeological investigations of Lower and Middle Palaeolithic landscapes, locales and artifacts. Routledge, Oxford [download ebook].

Ganguly, K., Carmena, J.M. 2009. Emergence of a stable cortical map for neuroprosthetic control. PLoS Biol 7(7): e1000153. doi:10.1371/journal.pbio.1000153 - http://tinyurl.com/kqmjsz

Gantz, J.F., Chute, C., Manfrediz, A., Minton, S., Reinsel, D., Schlichting, W., Toncheva, A. 2008. An updated forecast of worldwide information growth through 2011. IDC White Paper - http://tinyurl.com/q6hqtka.

Garber, P.A., Brown, E. 2004. Wild capuchiins (Cebus capucinus) fail to use tools in an experimental field study. American Journal of Primatology 62, 165-170 - http://tinyurl.com/n8o4meb.

Garber, P.A., Gomes, D.F., Bicca-Marques, J.C. 2012. Experimental field study of problem-solving using tools in free-ranging capuchins (*Sapajus nigritus*, formerly *Cebus nigritus*). American Journal of Primatology 73, 344-358 - http://tinyurl.com/mqe9xzh.

Garcea, E.A.A. 2012. Successes and failures of human dispersals from North Africa. Quaternary International 270, 119-128 - http://tinyurl.com/jz8mepj.

Garcia-Castellanos, D., Estrada, F., Jiménez-Munt, I., Gorini, C., Fernàndez, M., Vergés, J., De Vincente, R. 2009. Catastrophic flood of the Mediterranean after the Messinian salinity crisis. Nature 462, 778-782 - http://tinyurl.com/zl35xo6.

Garcia, J. Martínez, K., Carbonell, E. 2013. The Early Pleistocene tools from Vallparadis (Barcelona, Spain): rethinking the European Mode 1. Quaternary International 316, 94-114 - http://tinyurl.com/l5exbnz.

García-Medrano, P., Ollé, A., Mosquera, M., Cáceres, I., Díez C., Carbonell, E. 2014. The earliest Acheulean technology at Atapuerca (Burgos, Spain): oldest levels of the Galeria site (GII Unit). Quaternary International 353, 170–194 - http://tinyurl.com/obzyl8a.

Garcia Muina, F.E., Martin de Castro, G. & Lopez Saez, P. (2002). The Knowledge Creation Process: A Critical Examination of the SECI Model. Third European Conference on Organizational Knowledge, Learning and Capabilities. 5-6 April 2002, Athens, Greece. - http://www.alba.edu.gr/OKLC2002/Proceedings/pdf_files/ID151.pdf

Garcia, T., Féraud, G., Falguères, C., de Lumley, H., Perrenoud, C., Lordkipanidze, D. 2010. Earliest human remains in Eurasia: new $^{40}Ar/^{39}Ar$ dating of the Dmanisi hominid-bearing levels, Georgia. Quaternary Geochronology 5, 443-451 - http://tinyurl.com/p97lh2l.

Garfield, E. (1955). Citation Indexes for Science: A new dimension in indexing through association of ideas. Science. 123:108-111. [Reprinted in Essays of an Information Scientist, Vol:6, p.468-471, 1983] - http://tinyurl.com/mhce6bm.

Garfield, E. (1955a). The Preparation of Printed Indexes by Automatic Punched-Card Techniques. American Documentation 6(2). [Reprinted in Essays of an Information Scientist, Vol:6, p.459-467, 1983] - http://tinyurl.com/m5lcep5.

Garfield, E. (1958). A Unified Index to Science. Proceedings of the International Conference on Scientific Information, Washington, D. C., November 16-21, 1958, 2 vols. (Washington, D. C.: National Academy of Sciences National Research Council, 1959) vol. 1, pp. 461-74. [Reprinted in Essays of an Information Scientist, Vol:2, p.674-687, 1974-76] - http://tinyurl.com/lf7g2hq

Garfield, E. (1979). Citation Indexing – Its Theory and Application in Science, Technology, and Humanities. John Wiley & Sons, Inc. New York - http://tinyurl.com/larv492.

Gebremeskel, E.I., Ibrahim, M.E. 2014. Y-chromosome E haplogroups: their distribution and implication to the origin of Afro-Asiatic languages and pastoralism – European Journal of Human Genetics, advance online publication, 26 March 2014; doi:10.1038/ejhg.2014.41, pp. 1-6 - http://tinyurl.com/nmfe3zj

Geers, A.E., Sedey, A.L. 2011. Language and verbal reasoning skills in adolescents with 10 or more years of cochlear implant experience. Ear Hear 32(1 Suppl): 39S–48S - http://tinyurl.com/7e7856z.

Gergely, G., Csibra, G. 2006. Sylvia's recipe: the role of imitation and pedagogy in the transmission of cultural knowledge. In: N. J. Enfield & S. C. Levenson (Eds.) Roots of Human Sociality: Culture, Cognition, and Human Interaction, Oxford: Berg Publishers, pp. 229-255 - http://tinyurl.com/l6mwmtx

Gers, M. 2011. As we build our world we build our minds: the causal role of technology in the development and evolution of human psychological traits. PhD Thesis, Doctor of Philosophy, Victoria University of Wellington - http://tinyurl.com/kuo2okg.

Gettier, E. (1963). Is justified true belief knowledge? Analysis 23, 121-123 - http://tinyurl.com/26frofp.

Ghani, T. 2009. Challenges and innovations in nano-CMOS transistor scaling. Intel - http://tinyurl.com/qzk9moff.

Gibbon, R.J., Granger, D.E., Kuman, K., Partridge, T.C. 2009. Early Acheulean technology in the Rietputs Formation, South Africa, dated with cosmogenic nuclides. Journal of Human Evolution 56, 152-160 - http://tinyurl.com/km6ydx8.

Gibbons, A. 2011. Skeletons present an exquisite paleo-puzzle. Science 333, 1730-1732 - http://tinyurl.com/pp9e2ha

Gibbons, A. 2012. A crystal-clear view of an extinct girl's genome. Science 337, 1028-1029 - http://tinyurl.com/lzuwc9c

Gibbons, A. 2013. Stunning skull gives a fresh portrait of early humans. Science 342, 297-298 - http://tinyurl.com/o587376.

Gilheany, S. (1998). The decline of magnetic disk storage cost over the next 25 years or when will the cost of magnetic disk storage be inconsequential for your document management application?. Archive Planning, Volume 2, number 11, 1998 - http://tinyurl.com/24wdcbs.

Gilheany, S. 2008. The evolution of Intel microprocessors – 1971-2007 - http://tinyurl.com/2a3ybya.

Gilmore, C.C., Weaver, T.D. 2016. Comparative perspective on antemortem tooth loss in Neandertals. Journal of Human Evolution 92, 80-90 -

Gintis, H. 2012. Human evolution: a behavioral synthesis. Conference on the Evolution of Religious and Social Norms. Institute for Mathematical Behavioral Sciences, Irvine, CA, January 27 and 28, 2012 - http://tinyurl.com/9qdjoo6

Gintis, H. 2012a. The evolution of human cooperation. Cliodynamics: the Journal of Theoretical and Mathematical History 3(1), 172-190 - http://tinyurl.com/8rj4hsz

Glasersfeld E.v. (1988): The Construction of Knowledge, Contributions to Conceptual Semantics. Intersystems Publications, Salinas California. [not seen]

Glasner, J.-J. 2003. The Invention of Cuneiform: Writing in Sumer. (Tr. from Ecrier à Sumer: L'invention du cunèiforme, Editions du Seuil 2000), Johns Hopkins University Press, Baltimore Md..

Gleave, J. (????). A Reconstruction of the Antikythera Mechanism: Dated to ca 80 BC. in Grand Illusions - http://www.grand-illusions.com/antikyth.htm

Glerum, K., Kinshumann, K., Greenberg, S., Aul, G., Orgovan, V., Nichols, G., Grant, D., Loihle, G., Hunt, G. 2009. Debugging in the (very) large: ten years of implementation and experience. SOSP'09, Oct 11-14, 2009, Big Sky, Montana - http://tinyurl.com/29n9g6l.

Glimcher, P.W. 2005. Indeterminancy in brain and behavior. Annual Review of Psychology 56, 25-56 - http://tinyurl.com/of9dbgg.

Gluth, S., Rieskamp, J., Büchel, C. 2012. Deciding when to decide: time-variant sequential sampling models explain the emergence of value-based decisions in the human brain. Journal of Neuroscience 32(31), 10686-10698

Gmür, M. (2003). Co-citation analysis and the search for invisible colleges: A methodological evaluation. Scientometrics 57, 27-57 - http://tinyurl.com/2a47uo5.

Goddard, C., Wierzbicka, A., Fabréga, H., Jr. 2014. Evolutionary semantics: using NSM to model stages in human cognitive evolution. Language Sciences 42, 60-79.

Goetzmann, W.N. (1996). Financing Civilization - http://tinyurl.com/24zt64h.

Goldfarb, C.F. (1996). The Roots of SGML -- A Personal Recollection. - http://tinyurl.com/25xquju.

Goldfarb, C.F. 1997. SGML: The Reason Why and the First Published Hint. Journal of the American Society for Information Science. Volume 48(7) - http://tinyurl.com/mbljfc4.
Goldman, M.J., Roque De Pinho, J., Perry, J. 2010 Maintaining complex relations with large cats: Maasai and lions in Kenya and Tanzania. Human Dimensions of Wildlife 15(5), 332-346
Goldschmidt, A. and Akera, A. (2000). John W. Mauchly and the Development of the ENIAC Computer: An Exhibition in the Department of Special Collections, Van Pelt Library, University of Pennsylvania - http://tinyurl.com/n49b4c9.
Gómez-Robles, A., Bermúdez de Castro, J.M., Arsuaga, J.-L., Carbonell, E., Polly, P.D. 2013. No known hominin species matches the expected dental morphology of the last common ancestor of Neanderthals and moderh humans. Proceedings of the National Academy of Sciences 110(45), 18196-18291 - http://tinyurl.com/mqvyr2l.
Goodall, J. 1962. Nest building behavior in the free ranging chimpanzee. Annals of the New York Academy of Sciences 162, 455-467 - http://tinyurl.com/zcy4knf.
Goodall, J. 1964. Tool-using and aimed throwing in a community of free-living chimpanzees. Nature 201, 1264-1266 - https://drive.google.com/open?id=0B2Z6nYMfgdWVM3I4Z0gtcjVvcVE.
Goodall, J. van Lawick- 1968. The behaviour of free-living chimpanzees in the Gombe Stream Reserve. Animal Behaviour Monographs 1(3), 161-311 - http://tinyurl.com/joys2h2.
Gordon, A.D., Nevell, L., Wood, B. 2008. The *Homo floresiensis* cranium (LB1): size, scaling, and early *Homo* affinities. Proceedings of the National Academy of Sciences 105, 4650-4655 - http://tinyurl.com/mf2dke6.
Gordon, D., Huddleston, J., Chaisson, M.J.P., Hill, C.M., Kronenberg, Z.N., Munson, K.M., Malig, M., Raja, A., Fiddes, I., Hillier, L.W., Dunn, C., Baker, C., Armstrong, J., et al. 2016. Long-read sequence assembly of the gorilla genome. Science 352, aae0344, 7 pp. - http://tinyurl.com/h9tunpo.
Goren-Inbar, N. 2011. Culture and cognition in the Acheulean industry: a case study from Gesher Benot Yaʾaqov. Philosophical Transactions of the Royal Society B 366, 1028-1949 - http://tinyurl.com/ktjtenx
Goren-Inbar, N., Feibel, C.S., Verosub, K.L., Melamed, Y., Kislev, M.E., Tchernov, E., Saragusti, I. 2000. Pleistocene milestones on the Out-of-Africa Corridor at Gescher Benot Yaʾaqov, Israel. Science 289, 944-947.
Goren-Inbar, N., Alperson, N., Kislev, M.E., Simchoni, O., Melamed, Y., Ben-Nun, A., Werker, E. 2004. Evidence of hominin control of fire at Gesher Benot Yaʾaqov, Israel. Science 304, 725-727 - http://tinyurl.com/n47xx2w
Gotts, N.M. 2009. Ramifying feedback networks, cross-scale interactions, and emergent quasi individuals in Conway's Game of Life. Artificial Life 15(3), 351-375 - http://tinyurl.com/mpksxvq.
Gould, S.J. (2002). The Structure of Evolutionary Theory. Harvard University Press, Cambridge, Mass. 1433 pp - http://tinyurl.com/2d6rokm.
Gourtsoyannis, E. 2010. Hipparchus vs. Ptolemy and the Antikythera Mechanism: pin-slot device models lunar motions. Advances in Space Research 46, 540-544 - http://tinyurl.com/l5fzzwp.
Gowlett, J.A.J. 2009. Artefacts of apes, humans, and others: towards comparative assessment and analysis. Journal of Human Evolution 57, 401-410.

Gowlett, J.A.J., Wrangham, R.W. 2013. Earliest fire in Africa: towards the convergence of archaeological evidence and the cooking hypothesis. Azania: Archaeological Research in Africa, 48(1), 5-30 - http://tinyurl.com/m8l2c74

Graben, P.b., Atmanspacher, H. (2009) Extending the philosophical significance of the idea of complementarity. (in) Atmanspacher, H., Primas, H. (eds.), Recasting Reality: Wolfgang Pauli's Philosophical Ideas and Contemporary Science. Springer, Berlin Heidelberg. pp 99-113 - http://tinyurl.com/m8utnbt.

Graham, Ian, (2000). - Introduction to HTML. from Web/HTML Documentation and Developer's Resource. The Information Commons, University of Toronto. - http://tinyurl.com/kxhghs6.

Grant, T. (2005). Unifying planning and control using an OODA-based architecture. Proceedings of Annual Conference of the South African Institute of Computer Scientists and Information Technologists, 20 to 22 September 2005, White River, South Africa, pp. 111-122 - http://tinyurl.com/padr3bd

Grant, T., Kooter, B. (2004). Comparing OODA & other models as operational view C2 architecture. 10th International Command and Control Research and Technology Symposium, McLean Va., June 13-16, 2005 – http://tinyurl.com/m4os74d

Gray, G. (2001). UNIVAC I: The First Mass-Produced Computer. Unisys History Newsletter 5:1 - http://tinyurl.com/2ea5v53.

Gray, R.M. (1991). Entropy and Information Theory. Springer-Verlag, New York., 306 pp. [download book - http://tinyurl.com/kl79krw].

Greek, C. 2002. Computers, the Internet and Criminal Justice: Literacy and Beyond. FSU School of Criminology and Criminal Justice. - http://tinyurl.com/2dkwjjt.

Green, R.E., Krause, J., Briggs, A.W., Maricic, T., Stenzel, U., Kircher, M., Patterson, N., Li, H., Zhai, W., et al., Pääbo, S. 2010. A draft sequence of the Neandertal genome. Science 328, 710-722 - http://tinyurl.com/n3gwt3q

Greenfield, P.M., Lyn, H., E.S. Savage-Rumbaugh. 2008. Protolanguage in ontogeny and phylogeny – combining deixis and representation. Interaction Studies 9(1), 34-50 - http://tinyurl.com/n8bpvmc.

Grehan, J.R., Schwartz, J.H. 2009. Evolution of the second orangutan: phylogeny and biogeography of hominid origins. Journal of Biogeography 36, 1823-1844 - http://tinyurl.com/bqmg5tc

Greiner, L.E. 1998. Evolution and revolution as organizations grow. Harvard Business Review, May June 1998, 55-67 - http://tinyurl.com/od3otde.

Greiner, C. and Rose, T. (1997) Knowledge Management in Global Health Research Planning in "Knowledge-Based Systems for Knowledge Management in Enterprises" In conjunction with the: 21st Annual German Conference on AI '97 (KI-Jahrestagung '97) September 9th - 12th Freiburg, Baden-Württemberg, Germany http://www.dfki.uni-kl.de/~aabecker/Freiburg/Final/Greiner/greiner.html - Heading3

Gribaldo, S., Poole, A.M., Daubin, V., Forterre, P., Brochier-Armanet, C. 2010. The origin of eukaryotes and their relationship with the archaea: are we at a phylogenomic impasse? Nature Reviews Microbiology 8, 743-752 - http://tinyurl.com/mcpbp3m.

Grill, W.M., Norman, S.E., Bellamkonda, R.V. 2009. Implanted neural interfaces: biochallenges and engineered solutions. Annual Review of Biomedical Engineering 11, 1-24 - http://tinyurl.com/cdcdvr5.

Grillo, K.M., Hildebrand, E.A. 2013. Context early megalithic architecture in eastern Africa: the Turkana Basin, c. 5000-4000 BP. Azania: Archaeological Research in Africa 48, 193-217.

Griscom, A. (1998). Trends of anarchy and hierarchy: comparing the cultural repercussions of print and digital media. in The Cyberspace and Critical Theory Web - http://tinyurl.com/2ep3rgf.

Gromov, G.R. (2011). History of Internet and WWW: The Roads and Crossroads of Internet History - http://tinyurl.com/kcey74e.

Gronau, I., Hubisz, M., Gulko, B., Danko, C.G., Siepel, A. 2011. Bayesian inference of ancient human demography from individual genome sequences. Nature Genetics 43(10), 1031-1034 - http://tinyurl.com/pkdgbc5.

Grove, M. 2011. Change and variability in Plio-Pleistocene climates: modelling the hominin response. Journal of Archaeological Science 38, 3038-3047.

Groves, C. 2013. Hominin migrations before *Homo sapiens*: Out of Africa – how many times? (in) Ness, I. (ed.) The Encyclopedia of Global Human Migration. Blackwell Publishing Ltd., Oxford, 8 pp.

Gruber, T. (????). What is an Ontology. - http://ksl-Web.stanford.edu/kst/what-is-an-ontology.html

Gruber, T., Clay, Z., Zuberbühler, K. 2010. A comparison of bonobo and chimpanzee tool use: evidence for a female bias in the *Pan* lineage. Animal Behaviour, 80, 1023-1033 - http://tinyurl.com/nw663u6.

Grueter, C.C., Chapais, B., Zinner, D. 2012. Evolution of multilevel social systems in nonhuman primates and humans. International Journal of Promatology, DOI 10.1007/s10764-012-9618-z

Guarino, N. & Giaretta, P. (1995). Ontologies and Knowledge Bases: Towards a Terminological Clarification. *In* N. Mars (ed.) Towards Very Large Knowledge Bases: Knowledge Building and Knowledge Sharing. IOS Press, Amsterdam: pp. 25-32. - http://www.ladseb.pd.cnr.it/infor/Ontology/Papers/KBKS95.pdf

Guimaräes RC, Moreira CHC, Farias ST. 2008. Self-referential formation of the genetic system. (In) The Codes of Life – The Rules of Macroevolution. Barbieri M (ed.). Springer, Dordrecht, The Netherlands, pp. 69-110 - http://tinyurl.com/l8absjn.

Gunst, N., Boinski, S., Fragaszy, D.M.. 2010. Development of skilled detection and extraction of embedded prey by wild brown capuchin monkeys (*Cebus apella apella*). Journal of Comparative Psychology 124, 194-104 - http://tinyurl.com/marqbqw

Gupta, A.K. 2004. Origin of agriculture and domestication of plants and animals linked to early Holocene climate amelioration. Current Science 87(1), 54-59 - http://tinyurl.com/28f4das.

Gürer, D. (2000). "Amazing Grace" – Computer Pioneer, Technologist, Teacher, and Visionary - http://tinyurl.com/2fnttnd.

Guthrie, R.D. 2007. Haak en steek – the tool that allowed hominins to colonize the African savanna and to flourish there. (in) Roebroeks, W. (ed). Guts and Brains: An Integrative Approach to the Hominin Record. Leiden Univ. Press, pp 133-164 [download book]

Hackländer, K., Arnold, W., Ruf, T. 2002. Postnatal development and thermoregulation in the precocial European hare (*Lepus europaeus*). Journal of Comparative Physiology B 173, 183-190 - http://tinyurl.com/8ee4e9a

Haggard, P. 2008. Human volition: towards a neuroscience of will. Nature Reviews – Neuroscience 9, 934-948 - http://tinyurl.com/bp59ffy

Hahn, T.B. 1998 Text retrieval online: historical perspective on web search engines. Bulletin of the American Society for Information Science 24(4) -http://tinyurl.com/kxzzunr.
Hájíček, P., 2006. Liberties in nature. on photons, bugs and chess players - http://tinyurl.com/o8dgvpj.
Hájíček, P., 2009. Freedom in nature. General Relativity and Gravitation 41, 2073–2091 - http://tinyurl.com/ng422yo.
Hall, W.P. [1966]. Is the plastid an endosymbiont. Unpublished mss, 26 pp - http://tinyurl.com/k7aofko.
Hall, W.P. 1970. Three probable cases of parthenogenesis in lizards (Agamidae, Chamaeleontidae, Gekkonidae). Experentia 26: 1271-1273 - http://tinyurl.com/ltt6ujz.
Hall, W.P. 1973. Comparative population cytogenetics, speciation and evolution of the iguanid lizard genus *Sceloporus*. PhD Thesis, Harvard University - http://tinyurl.com/makmmh7.
Hall, W.P. 1983. Modes of speciation and evolution in the sceloporine iguanid lizards. I. Epistemology of the comparative approach and introduction to the problem. (in) A.G.J. Rhodin and K. Miyata, eds. Advances in Herpetology and Evolutionary Biology - Essays in Honor of Ernest E Williams. Museum of Comparative Zoology, Cambridge Mass. pp.643-679 - http://tinyurl.com/nynbzln.
Hall, W.P. 1998. When a good business case alone isn't enough to get SGML into your corporate strategy. SGML/XML Asia Pacific '98, Sydney -http://tinyurl.com/lxpp4gt.
Hall, W.P. 2001. Writing and managing maintenance procedures for a class of warships: A case for structured authoring and content management. Technical Communication, 48(2) 235-247 - http://tinyurl.com/ky3uyyw.
Hall, W.P. 2003. Organisational autopoiesis and knowledge management. Presented, ISD '03 Twelfth International Conference on Information Systems Development - Methods & Tools, Theory & Practice, Melbourne, Australia, 25 - 27 August, 2003 - http://tinyurl.com/kccuomw.
Hall, W.P. 2003a. Managing maintenance knowledge in the context of large engineering projects - Theory and case study. Journal of Information and Knowledge Management, Vol. 2, No. 2 [Corrected version reprinted in Vol. 2, No. 3, pp. 1-17] - http://tinyurl.com/lr86k6w.
Hall, W.P. 2005. Biological nature of knowledge in the learning organization. The Learning Organization 12(2), 169-188 - http://tinyurl.com/lmeljrs.
Hall, W.P. 2005a. Towards a science of knowledge. Seminar presentation. University of Technology Sydney, 27 July 2005 - http://tinyurl.com/lnjxcgt.
Hall, W.P. 2006 Emergence and growth of knowledge and diversity in hierarchically complex living systems. Workshop "Selection, Self-Organization and Diversity CSIRO Centre for Complex Systems Science and ARC Complex Open Systems Network, Katoomba, NSW, Australia 17-18 May 2006 - http://tinyurl.com/l8no2nj.
Hall, W.P. 2006a. Tools extending human and organizational cognition: revolutionary tools and cognitive revolutions. Sixth International Conference on Knowledge, Culture and Change in Organisations, Prato, Italy, 11-14 July 2006. [International Journal of Knowledge, Culture and Change Management, 6(6), 1-10] - http://tinyurl.com/mbe7vx3
Hall, W.P. 2006b. Forming new ICT industry clusters in Victoria. Australian Centre for Science, Innovation and Society. Occasional Paper No. 1. 35 pp. - http://tinyurl.com/my4yly6.
Hall, W.P. 2007. Managing lifecycles of complex projects. Government Transformation Journal, July 2007. Center for Public-Private Enterprise - http://tinyurl.com/2dpbg3.

Hall, W.P. 2007a. Time value of knowledge: time-based frameworks for valuing knowledge. 10th Australian Conference for Knowledge Management and Intelligent Decision Support Melbourne, 10 – 11 December 2007 - http://tinyurl.com/mqewazu. Presentation: Time value of knowledge - time-based frameworks for valuing knowledge. OASIS Seminar, Department of Information Systems, University of Melbourne, 27 July 2007 - http://tinyurl.com/kvgxcqf.

Hall, W.P. 2009. Chromosome variation, genomics, speciation and evolution in *Sceloporus* lizards. Cytogenetic and Genome Research. Cytogenetics and Genome Research 2009;127:143-165; DOI:10.1159/000304050 - http://tinyurl.com/kxhgfrp.

Hall, W.P. 2010. Chromosome variation, genomics, speciation and evolution in *Sceloporus* lizards. Cytogenetic and Genome Research 127, 143-165 - http://tinyurl.com/jq9ccfw.

Hall, W.P. 2011. Physical basis for the emergence of autopoiesis, cognition and knowledge. Kororoit Institute Working Papers No. 2: 1-63 - http://tinyurl.com/ot9omzq

Hall, W.P., Beer, J. & McCauley, B. 2002. Improving the quality of fleet/facility support knowledge. Proceedings of the Australian Conference for Knowledge Management & Intelligent Decision Support, ACKMIDS 2002 Melbourne, Australia, 9-10 December 2002. *in* Burstein F and Linger H. (2003). The Role of Quality in Knowledge Management, pp.155-171 - http://tinyurl.com/l3szo2o.

Hall, W.P., Best, R. 2010. Template for knowledge based community organizations - http://tinyurl.com/27rtqj4.

Hall, W.P. and Brouwers, P. 2004. The CMIS solution for Tenix's M113 program. MatrixOne Innovation Summit. Shangri-La's Rasa Sentosa Resort, Singapore, 12 - 14 August, 2004 [presentation] - http://tinyurl.com/lqv55gg.

Hall, W.P., Dalmaris, P., Else, S., Martin, C.P., Philp, W.R. 2007. Time value of knowledge: time-based frameworks for valuing knowledge. 10th Australian Conference for Knowledge Management and Intelligent Decision Support Melbourne, 10 – 11 December 2007 - http://tinyurl.com/ks957yz. (Seminar Presentation, Department of Information Systems, University of Melbourne, 27 July 2007 - http://tinyurl.com/kvgxcqf).

Hall, W.P., Dalmaris, P., Nousala, S. 2005. A biological theory of knowledge and applications to real world organizations. Proceedings, KMAP05 Knowledge Management in Asia Pacific Wellington, N.Z. 28-29 November 2005 - http://tinyurl.com/k6oa5g7.

Hall, W.P., Else, S., Martin, C.P., Philp, W.R. 2011. Time-based frameworks for valuing knowledge: maintaining strategic knowledge. Kororoit Institute Working Papers No. 1: 1-28 - http://tinyurl.com/ntqm4uz.

Hall, W.P., Kilpatrick, B. 2011. Managing community knowledge to build a better world. Australasian Conference on Information Systems (ACIS) 30th November - 2nd December, 2011, Sydney, Australia - http://tinyurl.com/lbcv2xb.

Hall, W.P., Nousala, S. 2007. Facilitating emergence of an ICT industry cluster. ICE 2007 - 13th International Conference on Concurrent Enterprising - "Concurrent (Collaborative) Innovation", Sophia-Antipolis, France, 4-6 June 2007 - http://tinyurl.com/mw9n88z.

Hall, W.P., Nousala, S. 2010. Autopoiesis and knowledge in self-sustaining organizational systems. 4th International Multi-Conference on Society, Cybernetics and Informatics: IMSCI 2010, Orlando, FL, USA, June 29-July 2, 2010 - http://tinyurl.com/n34y2nx.

Hall, W.P., Nousala, S. 2010a. What is the value of peer review – some sociotechnical considerations. ISPR 2010 – Second International Symposium on Peer Reviewing, une 29th - July 2nd, 2010 – Orlando, Florida, USA - http://tinyurl.com/kz93zfl.

Hall, W.P., Nousala, S., Best, R. 2010. Free technology for the support of community action groups: theory, technology and practice. Knowledge Cities World Summit, Melbourne, Australia, October 16-19 - http://tinyurl.com/k9woura.

Hall, W.P., Nousala, S., Kilpatrick B. 2009. One company – two outcomes: knowledge integration vs corporate disintegration in the absence of knowledge management. VINE: The journal of information and knowledge management systems 39(3), 242-258 - http://tinyurl.com/ldw53ht.

Hall, W.P., Nousala, S., Vines, R. 2010. Using Google's apps for the collaborative construction, refinement and formalization of knowledge. ICOMP'10 - The 2010 International Conference on Internet Computing July 12-15, Las Vegas, Nevada, USA - http://tinyurl.com/kyfcal9.

Hall, W.P., Richards, G., Sarelius, C., Kilpatrick, B. 2008. Organisational management of project and technical knowledge over fleet lifecycles. Australian Journal of Mechanical Engineering. 5(2):81-95 - http://tinyurl.com/muzzvej.

Hallmann, A. 2011. Evolution of reproductive development in the volvocine algae. Sexual Plant Reproduction 24(2): 97–112 - http://tinyurl.com/ly2rynd.

Hammer, M.F., Woerner, A.E., Mendez, F.L., Watkins, J.C., Wall, J.D. 2011. Genetic evidence for archaic admixture in Africa. Proceedings of the National Academy of Sciences 108(37), 15123-15128 - http://tinyurl.com/m94jlcb.

Hammond, G.T (????)., The Essential Boyd. - http://tinyurl.com/mhl6oeu.

Hannam, J. 2007. The foundation and loss of the Royal and Serapeum Libraries of Alexandria *in* Bede's Library: Reasonable apologetics.

Hannam, J. 2009. The mysterious fate of the great library of Alexandria. Bede's Library - http://tinyurl.com/k5ak827.

Hansson, S.O. 2008. Science and Pseudo-Science, (in) *The Stanford Encyclopedia of Philosophy (Fall 2008 Edition)*, Zalta, E.N. (ed.) - http://tinyurl.com/29yo8hj.

Hare, B. 2011. From hominoid to hominid mind: what changed and why? Annual Review of Anthropology 30, 293-309 - http://tinyurl.com/8sag8a9.

Hargittai, I. (1997). John C. Polanyi. Polanyiana 6:2. - http://www.kfki.hu/~cheminfo/polanyi/9702/hargitta.html.

Harkness, D.E. (2007). The Jewel House: Elizabethan London and the Scientific Revolution. Yale University Press, New Haven, CT - http://tinyurl.com/28j4cjz.

Harmand, S., Lewis, J.E., Feibel, C.S., Lepre, C.J., Prat, S., Lenoble, A., Boes, X., Quinn, R.L. Brenet, M., Arroyo, A., Taylor, N., Clement, S., Daver, G., Brugal J.-P., Leakey, L., et al. 2015. 3.3-million-year-old stone tools from Lomekwi 3, West Turkana, Kenya. Nature 521, 310-315 - http://tinyurl.com/hgu95r5.

Harmon, K. 2012. New DNA analysis shows ancient humans interbred with Denisovans. Nature/Scientific American doi:10.1038/nature.2012.11331 - http://tinyurl.com/8gez6gb

Harnad, S. 1991.Post-Gutenberg Galaxy: The Fourth Revolution in the Means of Production of Knowledge. The Public-Access Computer Systems Review 2.1: 39-53 - http://tinyurl.com/3978mgf.

Hart, D., Sussman, R.W. 2011. The influence of predation on primate and early human evolution: impetus for cooperation. (in) R.W. Sussman, C.R. Cloninger (eds.), Origins ofAltruism and Cooperation, Developments in Primatology: Progress and Prospects, DOI 10.1007/978-1-4419-9520-9_3, Springer Science+Business Media, LLC 2011

Hart, S. (1999). Looking through the Windows of Pioneers, Penguins, and Changing Fortunes: A Modern History Lesson. MacNow Magazine. - http://tinyurl.com/23nucgx.

Hartwig, W., Rosenberger, A.L., Norconk, M.A., M. Young Owl. 2011. Relative brain size, gut size, and evolution in New World monkeys. Anatomical Record 294, 2207-2221 - http://tinyurl.com/pscp8sc

Harvey, E. 1968. Technology and the structure of organizations. American Sociological Review, 33, 247-259 - http://tinyurl.com/2dnwyzp.

Harvey, P.H. and Pagel, M.D. 1991. The Comparative Method in Evolutionary Biology. Oxford University Press. 235 pp.

Haslam, M. 2013. 'Captivity bias' in animal tool use and its implications for the evolution of hominin technology. Philosophical Transactions of the Royal Society B 368, 20120421, 10 pp. - http://tinyurl.com/oyt9zbu

Haslam, M. 2014. On the tool use behavior of the bonobo-chimpanzee last common ancestor, and the origins of hominine stone tool use. American Journal of Primatology DOI: 10.1002/ajp.22284 - http://tinyurl.com/kcckvlu.

Haslam, M., Hernandez-A, A., Ling, V., Carvalho, S., de la Torre, I., DeStefano, A., Du, A., Hardy, B., Harris, J., Marchant, L., Matsuzawa, T., McGrew, W., Mercador, J., Mora, R.; Petraglia, M., Roche, H., Visalberghi, E., Warren, R. (2009). Primate archaeology, Nature 460, 339-344 - http://tinyurl.com/nplsdmk.

Hassan, S. 2010. Limitation of silicon based computation and future prospects. Proceedings of 2010 Second International Conference on Communication Software and Networks, pp. 559-561 - http://tinyurl.com/lgnaxq8.

Hattori, Y., Leimgruber, K., Fujita, K., de Waal, F.B.M. 2012. Food-related tolerance in capuchin monkeys (*Cebus apella*) varies with knowledge of the partner's previous food-consumption. Behaviour 149, 171-185 - http://tinyurl.com/lg8xpoc

Hauser, M.D., Chomsky, N., Fitch, W.T. 2002. The faculty of language: what is it, who has it, and how did it evolve. Science 298, 1569-1579 - http://tinyurl.com/9jswbu8

Havlock, E.A. 1977. The preliteracy of the Greeks. New Literary History 8(3), 369-391 - http://tinyurl.com/nlaw7kl.

Hawking, S.W.; Ellis, G.F.R. (1973). The Large Scale Structure of Space-Time. Cambridge: Cambridge University Press.

Hawks, J. 2013. Significance of Neandertal and Denisovan genomes in human evolution. Annual Review of Anthropology 42, 433-449 - http://tinyurl.com/ztedddp.

Hayek, F.A. 1945. The use of knowledge in swociety. The American Economic Review 35, 519-530 - http://tinyurl.com/ovjsodr.

Hayes, S., Sutikna, T., Morwood, M. 2013. Faces of *Homo floresiensis* (LB1). Journal of Archeological Science 40, 4400-4410 - http://tinyurl.com/kx82pkh.

Hayles N.K. 1999. How We Became Posthuman; Virtual Bodies in Cybernetics, Literature, and Informatics. Chicago: The University of Chicago Press

Haynal, R. (????). Internet: "The Big Picture". - http://tinyurl.com/2arfnyg.

Haynes, J.-D. 2011. Decoding and predicting intentions. Annals of the New York Academy of Sciences 1224, 9-21

Heaf, D. (2000). A beginner's guide to genetic engineering. International Forum for Genetic Engineering - http://www.anth.org/ifgene/beginner.htm

Heffelfinger, T., Flom, G. 2010. Abacus: the mystery of the bead: The bead unbaffled – an abacus manual. - http://tinyurl.com/k5vpd73

Heise, J. (1996?). The Akkadian Language - http://saturn.sron.nl/~jheise/akkadian/Welcome.html.
Hellenthal, G., Busby, G.B.J., Band, G., Wilson, J.F., Capelli, C., Falush, D., Myers, S. 2014. A genetic atlas of human admixture history. Science 343, 747-751 - http://tinyurl.com/nexdzrj
Hemmer, H., Kahlke, R.-D., Vekua, A.K. 2011. The cheetah *Acinonyx pardinensis* (Croizet et Jobert, 1821) s.l. at the hominin site of Dmanisi (Georgia) – a potential prime meat supplier in Early Pleistocene ecosystems. Quaternary Science Reviews 30, 2703-2714.
Henke, W., Hardt, T. 2011. The genus *Homo*: origin, speciation and dispersal. (in) Condemi, S., Weniger, G.-C. (eds), Continuity and Discontinuity in the Peopling of Europe: One Hundred Fifty Years of Neanderthal Study. Springer, Dordrecht, pp 17-45.
Henn, B.M., Gignoux, C.R., Jobin, M., Granka, J.M., Macpherson, J.M, Kidd, J.M., Rodriguez-Botigué, L.-R., Ramachandran, S., Hon, L., Brisbin, A., et al. 2011. Hunter-gatherer genomic diversity suggests a southern African origin for modern humans. Proceedings of the National Academy of Sciences USA 108, 5154-5 162 - http://tinyurl.com/9r9umuq.
Henn, B.M., Cavalli-Sforza, L.L., Feldman, M.W. 2012. The great human expansion. Proceedings of the National Academy of Sciences 109(44), 17758-17764 - http://tinyurl.com/mxfha7b.
Henry, A.G., Ungar, P.S., Passey, B.H., Sponheimer, M., Rossouw, L., Bamford, M., Sandberg, P., de Ruiter, D.J., Berger, L. 2012. The diet of *Australopithecus sediba*. Nature 2012, 90-93 - http://tinyurl.com/pzptuys.
Hernandez-Aguilar, R.A., Moore, J., Pickering, T.R. 2007. Savanna chimpanzees use tools to harvest the underground storage organis of plants. Proceedings of the National Academy of Sciences 104, 19201-19213 - http://tinyurl.com/nxzmvue
Herries, A.I.R. 2011. A chronological perspective on the Acheulian and its transition to the Middle Stone Age in Southern Africa: the question of Fauresmith. International Journal of Evolutionary Biology 2011, no. 961401, 25 pp. - http://tinyurl.com/l55nuyd.
Hertler, C., Bruch, A., Märker, M. 2013. The earliest stages of hominin dispersal in Africa and Eurasia. (in) The Encyclopedia of Global Human Migration, (ed.) Ness, I. Blackwell Publishing Ltd. - http://tinyurl.com/mx5uggj
Heuer, R.J., Jr. (1999). Psychology of Intelligence Analysis. Center for the Study of Intelligence. [US] Central Intelligence Organization, Washington - http://tinyurl.com/mr35zk7.
Heylighen, F. 1993. Epistemology, Introduction. *in* Principia Cybernetica Web - http://tinyurl.com/2w3khfn.
Heylighen, F. (1995). Evolutionary Epistemology. *in* Principia Cybernetica Web - http://tinyurl.com/2cj5qqm.
Heylighen, F. (1995). *in* Principia Cybernetica Web - http://tinyurl.com/msgjbyf.
Hicks, T.C., Fouts, R.S., Fouts, D.H. 2005. Chimpanzee (*Pan troglodytes troglodytes*) tool use in the Ngotto Forest, Central African Republic. American Journal of Primatology 65, 221-237 - http://tinyurl.com/pzu7gqx
Hicks, T.C. 2010. Exploring behavioral continuity in *Pan troglodytes schweinfurthii* across northern DR Congo. PhD Thesis, Faculty of Science, University of Amsterdam - http://tinyurl.com/pcuxqzr
Higham, T., Crompton, T., Stringer, C., Jacobi, R., Shapiro, B., Trinkaus, E., Chandler, B., Groning, F., Collins, C., Hillson, S., O'Higgins, P., FitzGerald, C., Fagan, M. 2011. The

earliest evidence for anatomically modern humans in northwestern Europe. Nature 479, 521-524 - http://tinyurl.com/mwtwaod
Hilbert, M.. 2013. Big data for development: from information- to knowledge societies. Social Science Research Network, pp. 39 - http://tinyurl.com/mlz9u4x
Hilbert, M., Lopez, P. 2011. The world's technological capacity to store, communicate, and computer information. Science 332, 60-65 - http://tinyurl.com/ljfeuy4.
Hilbert, M., Lopez, P. 2012. How to measure the world's technological capacity to communicate, store, and compute information - Part I: results and scope. International Journal of Communication 6, 956–979 - http://tinyurl.com/ll5lvne.
Hill, K., Barton, M., Hurtado, M. 2009. The emergence of human uniqueness: characters underlying behavioral modernity. Evoutionary Anthropology 18, 187-200 - http://tinyurl.com/hdpd54o.
Hill, N.J., Gupta, D., Brunner, P., Gunduz, A., Adamo, M.A. Ritaccio, A., Schalk, G. 2012. Recording human electrocorticographic (ECoG) signals for neuroscientific research and real-time functional cortical mapping. Journal of Visualized Experiments 64, no. e3993 - http://tinyurl.com/c8u4z45
Hillman, C. & Gunesch, R. (2001). Entropy in Information and Coding Theory *in* Entropy on the World Wide Web - http://tinyurl.com/lt3tfbs.
Hiltzik, M., (1999). Dealers of Lightning : Xerox Parc and the Dawn of the Computer Age. HarperCollins - http://tinyurl.com/2fv8z75.
Hiscock, P. 2013. Early Old World migrations of Homo sapiens: archaeology. (in) The encyclopedia of Global Human Migration, (ed) Ness, I. Blackwell Publishing Ltd. DOI: 10.1002/9781444351071.wbeghm806, 11 pp. - http://tinyurl.com/kltf4re
Ho, M.-W. & Tappeaser, B. (????). Transgenic Transgression of Species integrity and Species Boundaries. International Forum for Genetic Engineering - http://www.anth.org/ifgene/ho.htm - Horiz.
Hobaiter, C., Poisot, T., Zuberbühler, K., Hoppitt, W., Gruber, T. 2014. Social network analysis shows direct evidence for social transmission of tool use in wild chimpanzees. PLoS Biol 12(9): e1001960. doi:10.1371/journal.pbio.1001960 - http://tinyurl.com/noofw4x
Hobart, M.E. and Schiffman, Z.S. (1998). Information Ages: Literacy, Numeracy, and the Computer Revolution. Johns Hopkins University Press, Baltimore - http://tinyurl.com/26u9uct.
Hodges, A. 2001. Turing: Entry for the Routledge Encyclopaedia of The Philosophy of Science (2003). - http://tinyurl.com/277zan3.
Hoffecker, J.F. 2013. The information animal and the super-brain. Journal of Archaeological Method and Theory 20, 18-41 - http://tinyurl.com/oexhpft
Holden, C. (1998). No Last Word on Language Origins. Science 282:1455 - http://tinyurl.com/2aun2no.
Holden, C. 2004. The origin of speech. Science 303, 1316-1319 - http://tinyurl.com/qj8ck87.
Holtshouse, D. (1999). Knowldege Domains: Opportunities in the New Knowledge Management Environment. Xerox Business Report, 2nd Quarter 1999. http://www.xerox.com.ar/aco/xbr/2nd-1999/english/feature.html [http://Web.archive.org/Web/20010223031550/http://www.xerox.com.ar/aco/xbr/2nd-1999/english/feature.html]

Holtshouse, D. (2000). Ten Knowledge Domains — Model of a Knowledge-Driven Company? *In* Defying the Limits: Reaching New Heights in Customer Relationship Management http://www.crmproject.com/documents.asp?d_ID=721

Holzmann, G.J. and B. Pehrson (1994). How it began. *in* Chapter 1, The Early History of Data Networks - http://www.it.kth.se/docs/early_net/ch-2-1.1.html - 2-1.1

Honeysett, J. 2006. Husbandry manual for brown capuchin/black-capped capuchin *Cebus apella* (Cebidae). Sydney Institute of TAFE, Ultimo, NSW, 91 pp. - http://tinyurl.com/m8fmjqq.

Hopkins, W.D., Russell, J.L., Schaeffer, J.A. 2012. The neural and cognitive correlates of aimed throwing in chimpanzees: a magnetic resonance image and behavioural study on a unique form of social tool use. Philosophical Transactions of the Royal Society B 367, 37-47 - http://tinyurl.com/qghq6wf.

Hopkinson, T., Nowell, A., White, M. 2013. Life histories, metapopulation ecology, and innovation in the Acheulian. PaleoAnthropology 2013, 61−76 - http://tinyurl.com/mkgxzwm.

Horan, R.D., Bulte, E.H., Shogren, J.F. 2008. Coevolution of human speech and trade. Journal of Economic Growth 13(4), 293-313 - http://tinyurl.com/kbtwdtx.

Horan, R.D., Shogren, J.F., Bulte, E.H. 2008a. Competitive exclusion, diversification, and the origins of agriculture. American Agricultural Economics Association Annual Meeting, Orlando Florida, July 27-29, 2008 - http://tinyurl.com/24jz8q3.

Hortola, P., Martinez-Navarro, B. 2013. The Quaternary megafaunal extinction and the fate of Neanderthals: an integrative working hypothesis. Quaternary International 295, 69-72

Horwich, P. 2000. Norms of truth and meaning. Royal Institute of Philosophy Supplement 47:19-34.

Hou, Y.-M., Zhao, L.-X. 2010 New archeological evidence for the earliest hominin presence in China. (in) J.G. Fleagle et al. (eds.), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_6, © Springer Science+Business Media B.V.

Houle, A. 1999. The origin of platyrrhines: an evaluation of the Antarctic scenario and the floating island mode. American Journal of Physical Anthropology 109, 541-559 - http://tinyurl.com/jbakfc6.

House, W.F. 1976. Cochlear implants. Annals of otology, rhinology, and laryngology 85 (Suppl. 27), 1–93

Houston, S.D. 2004. The archeology of communication technologies. Annual Review of Anthropology 33, 223-250.

Hovers, E., Belfer-Cohen, A. 2006. “Now you see it, now you don’t” – modern human behavior in the Middle Paleolithic. (in) Transitions Before the Transition: Evolution and Stability in the Middle Paleolithic and Middle Stone Age. (eds) Hovers, E., Kuhn, S.L. Springer, New York - http://tinyurl.com/k88rfhd.

Howe, W. (2001). A Brief History of the Internet. - from Walt's Navigating the Net Forum - http://tinyurl.com/3x7swau.

HPCWire (2001). Pioneers of the "Fortran" Programming Language: Features and Commentary. HPCwire, June 15, 2001 - http://tinyurl.com/2uera5e.

Hu, Y., Wang,Y., Ding, Q., He, Y., Wang, M., Wang, J., Xu, S., Jin, Li. 2014. Genome-wide scan of archaic hominin introgressions in Eurasians reveals complex admixture history. arXiv:1404.7766, pp. 1-42 - http://tinyurl.com/ojneb2l.

Hubbe, M.A., Bowden, C. 2009. Handmade paper: a review of its history, craft, and science. BioResources 4(4), 1736-1792 - http://tinyurl.com/llp29qw
Hublin, J.J. 2009. The origin of Neandertals. Proceedings of the National Academy of Sciences USA 106(38)m 16022-16027 - http://tinyurl.com/99f6kse.
Hublin, J.-J. 2014. Paleoanthropology: Homo erectus and the limits of a paleontological species. Current Biology 24(2), R82-R84 - http://tinyurl.com/l7x9qvu.
Huerta-Sánchez, E., Jin, X., Asan, Bianba, Z., Peter, B.M., Vinckenbosch, N., Liang, Y., Yi, X., He, M., Somel, M., Ni, P., Wang, B., Ou, X., Husasng, Luosang, J., Cuo, Zha, X.P., Li, K., et al. 2014. Altitude adaptation in Tibetans caused by introgression of Denisovan-like DNA. Nature 512, 194–197 – http://tinyurl.com/lgur6ek.
Huffman, C. 2011. Archytas. *The Stanford Encyclopedia of Philosophy (Fall 2011 Edition)*, Zalta, E.N. (ed.) - http://tinyurl.com/6qqpa89.
Huffman, O.F., Zaim, Y., Kappelman, J., Ruez, D.R., Jr., de Vos, J., Rizal, Y., Aziz, F., Hertler, C. 2006. Relocation of the 1936 Mojokerto skull discovery site near Perning, East Java. Journal of Human Evolution 50, 431-451 - http://tinyurl.com/n683758
Hughes, D. (2001). Dave's Linotype Website. - http://www.linotype.20m.com/index.html.
Hughes, R.A., Roberston, M.P., Ellington, A.D., Levy M. (2004). The importance of prebiotic chemistry in the RNA world. Current Opinion in Chemical Biology, 8, 629–633 - http://tinyurl.com/kaacd6h.
Huguet, R., Saladié, P., Cáceres, I, Diez, C., Rosell, J., Bennàsar, M., Blasco, R., Esteban-Nadal, M., Gabucio, M.J., Rodrígues-Hidalgo, A., Carbonell, E. 2013. Successful subsistence strategies of the first humans in south-western Europe. QAuaternary International 295-168-192.
Hulswit, M. 2005. How causal is downward causation. Journal for General Philosophy of Science 36(2), 261-287.
Humle, T. 2011. The tool repertoire of Bossou chimpanzees. (in) T. Matsuzawa et al. (eds.), The Chimpanzees of Bossou and Nimba. Springer, pp. 61-71 - http://tinyurl.com/h3gq25o.
Hunter, A. (2001). Taxonomies. Knowledge Management, May 2001. - http://www.cs.ucl.ac.uk/staff/a.hunter/tradepress/tax.html.
Hurlbert, R.E. (1999) Chapter IX: Microbial exchange of genetic material. Microbiology 101/102 Internet Text. Washington State University - http://tinyurl.com/l4le5rs.
Hurley, C. (1998). The Making and Keeping of Records: (1) What are Finding Aids For? First published in Archives and Manuscripts, 26 (1) 1998. – http://rcrg.dstc.edu.au/publications/makingkeeping1.html
Hurley, C. (2000). The Making and the Keeping of Records : (2) The Tyranny of Listing. Archives and Manuscripts 28:1 — http://rcrg.dstc.edu.au/publications/makingkeeping2.html
Hutchings, T (1996). Chapter 5. Introduction to Data Management and Database Technology. *In* Data Management and Database Technology. Lecture Notes. - http://tinyurl.com/2ga3chq.
Huxley, J.S. 1958. Evolutionary processes and taxonomy with special reference to grades. Uppsala Univ. Arsskrift, 1958, no. 6: 21-39.
Hyde, W. (1999). Welcome to Bloat City. - http://preview.tinyurl.com/27ms2n2.
Ibanez, J.J., Gonzalez Uriqijo, J., Rodriguez Rodriguez, A. 2007. The evolution of technology during the PPN in the Middle Euphrates: A view from use-wear analysis. (in) Technical Systems and Near Eastern PPN Communities, Astruc, L., Binder, D., Briois, F. (eds.) Editions APDCA, Antibes, France, pp. 153-165 - http://preview.tinyurl.com/29vc8ms.

Indiveri, G., Linares-Barranco, B., Hamilton, T.J., van Schaik, A., Etienne-Cummings, R., Delbruk, T., Liu, S.-C.,, Dudek, P., Haffliger, P., Renaud, S., et al. 2011. Neuromorphic silicon neuron circuits. Frontiers in Neuroscience 5, no. 73, 23 pp. - http://tinyurl.com/9u8wfvk

IHGSC - International Human Genome Sequencing Consortium. 2001. Initial sequencing and analysis of the human genome. Nature 409, 860-921 - http://tinyurl.com/2urrdx2.

Ikanda, D., Packer, C. 2008. Ritual vs retaliatory killing of African lions in the Ngorongoro Conservation Area, Tanzania. Endangered Species Research 6, 67-74 - http://tinyurl.com/jvrellf

Intel. (2007). Moore's Law - http://tinyurl.com/265gh4g.

International Standards Organisation (1986). ISO 8879:1986: Information processing; Text and office systems; Standard Generalized Markup Language (SGML).

Internet Software Consortium (2000). Internet Domain Survey - http://www.isc.org/ds/

Iriki, A., Taoka, M. 2012. Triadic (ecological, neural, cognitive) niche construction: a scenario of human brain evolution extrapolating tool use and language from the control of reaching actions. Philosophical Transactions of the Royal Society B 367, 10-23 - http://tinyurl.com/98vvk6c.

Irish, J.D., Guatelli-Steinberg, D., Legge, S.S., de Ruiter, D.J., Berger, L.R. 2013. Dental morphology and the phylogenetic "place" of *Australopithecus sediba*. Science 340, 1233062, pp. 1-4 - http://tinyurl.com/qyxltfw.

Isler, K., Kirk, E.C., Miller, J.M.A., Albrecht, G.A., Gelvin, B.R., Martin, R.D. 2008. Endocranial volumes of primate species: scaling analyses using a comprehensive and reliable data set. Journal of Human Evolution 55, 967-978 - http://tinyurl.com/man72xa

Isler, K., van Schaik, C.P. 2014. How humans evolved large brains: comparative evidence. Evolutionary Anthropology 23:65-75 - http://tinyurl.com/mgsfk5g.

ITRS (2009). International technology roadmap for semiconductors: 2009 edition - executive summary - http://tinyurl.com/o2l89eo.

Izar, P., Verderane, M., Peternelli-dos-Santos, L., Mendonça-Furtado, P., Presotto, A., Tokuda, M., Visalberghi, E., & Fragaszy, D. 2011. Flexible and conservative features of social systems in tufted capuchin moneys: comparing the socioecology of Sapajus libidinosus and Sapajus nigritus. American Journal of Primatology 74, 315-331 - http://tinyurl.com/o8vgb88.

Izawa, K. 1970. Unit groups of chimpanzees and their nomadism in the savanna woodland. Primates 11, 1-46 - http://tinyurl.com/j9422ur.

Izawa, K., Mizuno, A. 1977. Palm-fruit cracking behavior of wild black-capped capuchin (*Cebus apella*). Primates 18, 773-792 - http://tinyurl.com/j3zp6yl.

Izihevich, E.M., Edelman, G.M. 2008. Large-scale model of mammalian thalamocortical systems. Proceedings of the National Academy of Sciences USA, 105(9), 3593–3598 - http://tinyurl.com/csk5bzj

Jacob, C. 1997. The library and the book: forms of Alexandrian encyclopedism. (Questions of Knowledge at the Origins of the Encyclopedic Dream). Diogenes, Summer 1997. no. 178 pp 63-83 - http://www.accessmylibrary.com/article-1G1-20156857/library-and-book-forms.html.

Jacob, C. 2002. From Alexandria to Alexandria: scholarly interfaces of a universal library. In proceedings – Interfacing Knowledge: New Paradigms for Computing in the Humanities,

Arts and Social Sciences, March 8-10 2002, University of California Santa Barbara - http://tinyurl.com/opb9d5n
Jacob, E.K. 2004. Classification and categorization: a difference that makes a difference. Library Trends 52(3), 515-540 – http://tinyurl.com/q83xnlt.
Jacob, T., Indriati, E., Soejono, R.P., Hsu, K., Frayer, D.W., Ekhardt, R.B., Kuperavage, A.J., Thorne, A., Henneberg, M. 2006. Pygmoid Australomelanesian *Homo sapiens* skeletal remains from Liang Bua, Flores: population affinities and pathological abnormalities. Proceedings of the National Academy of Sciences 103(36), 13421-13426 - http://tinyurl.com/lg5jh95 [also included with Brown et al. 2004]
Jablonka, E., Lamb, M.J. 2005. Evolution in Four Dimensions, MIT Press, Cambridge, MA. [see also - Jablonka, E., Lamb.M.J. 2007. Precis of Evolution in Four Dimensions. Behavioral and Brain Sciences 30, 353-392 - http://tinyurl.com/o2ek9yz]
Jablonski, N.G., Chaplin, G. 2009. The fossil record of gibbons. (in) The Gibbons: New Perspectives on Small Ape Socioecology and Population Biology, Lappin, S., Whittaker, D.J. (eds). Springer Science + Business Media, New York, Chapter 7, pp. 111-131.
Jaeger, L., Calkins, E.R. 2012. Downward causation by information control in micro-organisms. Interface Focus 2, 26–41 - http://tinyurl.com/k854rss
James, S.R. 1989. Hominid use of fire in the Lower and Middle Pleistocene: a review of the evidence (and comments and replies). Current Anthropology 30(1), 1-26 - http://tinyurl.com/l2dea26.
Jameson, A.G. 1993. BIBLIOQHKHA ALEXANDREIAS: The Library of Alexandria. Bohemian Club Library Notes. No. 75 (Summer 1993) - http://tinyurl.com/25jk9fx.
Jameson Kiesling, N.M., Yi, S.V., Xu, K. E., Gianluca Sperone, F., Wildman, D.E. 2015. The tempo and mode of New World monkey evolution and biogeography in the context of phylogenomic analysis. Molecular Phylogenetics and Evolution 82B, 386-399 - http://tinyurl.com/zzeryxf.
Janson, C.H. 2007. Experimental evidence for route integration and strategic planning in wild capuchin monkeys. Animal Cognition 10, 341-356 - http://tinyurl.com/zu8hntx
Jeffares, B. 2009. The evolution of technical competence: strategic and economic thinking. ASC09: Proceedings of the 9th Conference of the Australasian Society for Cognitive Science. DOI: 10.5096/ASCS200925, pp. 162-169 - http://tinyurl.com/l3jw9vj.
Jeffares, B. 2010. The co-evolution of tools and minds: cognition and material culture in the hominin lineage. Phenomenology and the Cognitive Sciences 9: 503-520 - http://tinyurl.com/mskoawc.
Jeffares, B. 2013. Back to Australopithecus: utilizing new theories of cognition to understand the Pliocene hominins. Biological Theory, DOI 10.1007/s13752-013-0146-7, 12 pp.
Jensen, C. (2001). The Printing Revolution in Early Modern Europe, by Elizabeth Eisenstein, Cambridge, United Kingdom: Cambridge University Press, 1983. Lore - Rhetoric, Writing, Culture. 1:3 -http://tinyurl.com/kjfdcfa.
Jha, S.R. 1998. The Tacit-Explicit Connection: Polanyian Integrative Philosophy and a Neo-Polanyian Medical Epistemology. Theoretical Medicine and Bioethics 19(6), 547-568 - http://tinyurl.com/p68hyzr.
Jimenez-Arénas, J.M., Palmqvist, P., Pérez-Claros, J.A. 2011. A probabilistic approach to the craniometric variability of the genus *Homo* and inferences on the taxonomic affinities of the first human population dispersing out of Africa. Quaternary International 242, 219-230 - http://tinyurl.com/lvfpy2t

Jimenez-Arénas, J.M., Santonja, M., Botella, M., Palmqvist, P. 2011a. The oldest handaxes in Europe: fact or artifact. Journal of Archaeological Science 38, 3340-3349 - http://tinyurl.com/mf6cp8a

Johansson, S. 2013. The talking neanderthals: what do fossils, genetics, and archeology say? Biolinguistics 7, 35-74 - http://tinyurl.com/m9fr37p.

Johnson, J., Roberts, T.L., Verplank, W., Smith, D.C., Irby, C.H., Beard, M., Kackey, K. (1998). The Xerox "Star": A Retrospective. [Versions appeared in IEEE Computer, September 1989 and also in the book Human Computer Interaction: Toward the Year 2000 by Morgan Kaufman.] - http://tinyurl.com/m9njxcj

Jones, D.W. (2006). Punched Cards. University of Iowa, Department of Computer Science - http://tinyurl.com/2695twj.

Jones, R.V. (1999) Optical Telegraphy – The Chappe Telegraph Systems. - http://www.deas.harvard.edu/~jones/cscie129/images/history/chappe.html

Joordens, J.C.A., Dupont-Nivet, G., Feibel, C.S., Spoor, F., Sier, M., van der Lubbe, J.H.J.L., Nielsen, T.K., Knul, M.V., Davies, G.R., Vonhof, H.B. 2013. Improved age control on early Homo fossils from the upper Burgi Member at Koobi Fora, Kenya. Journal of Human Evolution 66(6), 731-145 - http://tinyurl.com/kasxdto

Jorgensen, S.E., Patten, B.C., & Straskraba, M. (1999). Ecosystems emerging: 3—Openness. Ecol. Model. 117:111–164 - http://tinyurl.com/l8ks92x.

Jorgensen, S.E., Patten, B.C. & Straskraba, M. (2000). Ecosystems emerging: 4—Growth. Ecol. Model. 126: 249–284 - http://tinyurl.com/m2j47ao.

Joseph R. 2010. The origin of eukaryotes: Archae, bacteria, viruses and horizontal gene transfer. Journal of Cosmology, 10: 3418-3445 - http://tinyurl.com/45fande.

Joshi, A. (1999). A Holistic View of the Revolution in Military Affairs (RMA). Strategic Analysis 22.11:1743-1759. Institute for Defence Studies and Analyses, New Delhi, India - http://tinyurl.com/lvuaat5.

Judge, P.G., Bruno, S. 2012. Transport of functionally appropriate tools by capuchin monkeys (*Cebus apella*). American Journal of Primatology 74, 199-209 - http://tinyurl.com/zyt6y8u.

Jungers, W.L., Larson, S.G., Harcourt-Smith, W., Morwood, M.J., Sutikna, T., Rokhus Due Awe, Djubiantono, T. 2009. Descriptions of the lower limb skeleton of *Homo floresiensis*. Journal of Human Evolution 57(5), 438-454 - http://tinyurl.com/l7x4kfp

Kaghan, B. and Phillips, N (1998). Building the Tower of Babel: Communities of Practice and Paradigmatic Pluralism in Organization Studies *in* Organization 5:2 - http://home.talkcity.com/terminus/wkaghan/Research/Babel.html [No longer available]

Kaifu, Y., Indriati, E., Aziz, F., Kurniawan, I., Baba, H. 2010. Chapter 11: Cranial morphology and variation of the earliest Indonesian hominids. (in) C.J. Norton and D.R. Braun (eds.), Asian Paleoanthropology: From Africa to China and Beyond, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9094-2_11, © Springer Science+Business Media B.V., pp. 143-157 – [download book: http://tinyurl.com/qfztobb].

Kaifu, Y., Baba, H., Sutikna, T., Morwood, J.J., Kubo, D., Saptomo, E.W., Jatmiko, Awe, R.D., Djubiantono, T. 2011. Craniofacial morphology of Homo floresiensis: description, taxonomic affinities, and evolutionary implication. Journal of Human Evolution 61, 644-682.

Kaifu, Y., Zaim, Y., Baba, H., Kurniawan, I., Kubo, D., Rizal, Y. Arif, J., Aziz, F. 2011a. New reconstruction and morphological description of a Homo erectus cranium: skull IX (Tjg-

1993.05) from Sangiran, Central Java. Journal of Human Evolution 61, 270-294 - http://tinyurl.com/k6o2tc9.

Kaminsky, P. 2001. The Rock. KaminskyWiki - http://tinyurl.com/268pqrz.

Kaplan, H.S., Gangestad, S.W., Gurven, M., Lancasetr, J., Mueller, T., Robson, A. 2007. The evolution of diet, brain and life history among primates and humans. (in) Roebroeks, W. (ed) Guts and Brains: An Integrative Approach to the Hominin Record. Leiden Univ. Press, pp. 47-90 [download book].

Kaplan, H.S., Robson, A.J. 2002. The emergence of humans: The coevolution of intelligence and longevity with intergenerational transfers. Proceedings of the National Academy of Sciences USA 99(15), 10221-10226 - http://tinyurl.com/855mtn2

Karkanas, P., Shahack-Gross, R., Ayalon, A., Bar-Matthews, M., Barkai, R., Frumkin, A., Gopher, A., Stiner, M.C. 2007. Evidence for habitual use of fire at the end of the Lower Paleolithic: site-formation processes at Qesem Cave, Israel. Journal of Human Evolution 43, 197-212 - http://tinyurl.com/mldz5ps

Karreman, D. (2002). Knowledge Management and "Organizational Memory" - Remembrance and Recollection in a Knowledge-intensive Firm. The Third European Conference on Organizational Knowledge, Learning and Capabilities. OKLC 2002 5-6 April 2002, Athens, Greece. - http://www.alba.edu.gr/OKLC2002/Proceedings/pdf_files/ID312.pdf

Katchalsky, A. & Curran, P.F. (1967). Nonequilibrium Thermodynamics in Biophysics. Harvard University Press, Cambridge, Mass.

Katz, R.H. 2009. Tech Titans Building Boom. IEEE Spectrum, February 2009 - http://tinyurl.com/mewq9fz.

Kauffman, S.A. 1986. Autocatalytic sets of proteins. Journal of Theoretical Biology 119, 1-24.

Kauffman, S.A. 1993. The Origins of Order: Self-Organization and Selection in Evolution. Oxford Univ. Press, New York.

Kauffman, S.A. 1995. At Home in the Universe: The Search for the Laws of Self-Organization and Complexity. Oxford Univ. Press, New York.

Kauffman, S.A. 1996. Investigations: The Nature of Autonomous Agents and the Worlds they Mutually Create. Working Papers of Santa Fe Institute. 96-08-072 - http://tinyurl.com/2b4ky6l. [Published as Investigations. Oxford Univ. Press, New York (2000)].

Kauffman, S.A. 2003. Molecular autonomous agents. Phil. Trans. R. Soc. Lond. A 361:1089-1099 - http://tinyurl.com/279n8sl

Kauffman, S.A., Logan, R.K., Este, R., Goebel, R., Hobill, D., Shmulevich, I. 2008. Propagating organization: an enquiry. Biology and Philosophy 23:27-45 - http://tinyurl.com/m3doe39

Kauffman, S.A., Smolin, L. 1997. A possible solution to the problem of time in quantum cosmology. Santa Fe Institute Working Paper 1997-03-020, 15 pp - http://arxiv.org/pdf/gr-qc/9703026

Kay, J.J. (1984). Self-Organization in Living systems, Ph.D. Thesis, Systems Design Engineering, University of Waterloo, Waterloo, Ontario, Canada, 458p. - http://tinyurl.com/3tyhzx:
Chapter 2 – Self-organization and the thermodynamics of living systems: A paradigm - http://tinyurl.com/kk4s8dr;
Chapter 3 – Information theory measures of structural self-organization - http://tinyurl.com/kks26xc.
Chapter 6 – Towards measures of functional organization - http://tinyurl.com/mqcsjdx;

Appendix 1 – Maximum entropy principle; minimum cross entropy principle; exergy and statistical mechanics - http://tinyurl.com/lndrtcr.
Kay, J.J. (2000). Ecosystems as self-organizing holarchic open systems: Narratives and the second law of thermodynamics. Jorgensen, S.E. & Muller, F. (eds.), Handbook of Ecosystem Theories and Management. CRC Press Lewis Publishers. pp. 134-160. - http://tinyurl.com/lmg6mje.
Kay, J.J. (2002). On uncertainty, information and predictability: The relationship between exergy, entropy and information and uncertainty. in James J. Kay - http://tinyurl.com/m32zgbw.
Kay, R. 2001. Are organizations autopoietic? A call for new debate. Systems Research and Behavioral Science 18(6), 461-477.
Kay, R.F. 2015. Biogeography in deep time – What do phylogenetics, geology, and paleoclimate tell us about early platyrrhine evolution? Molecular Phylogenetics and Evolution 82B, 358-374 - http://tinyurl.com/jxcsvs7.
Kelly, L. 2012. When Knowledge Was Power. PhD Thesis, Faculty of Humanities and Social Sciences, Latrobe University, Bundoora, Vic., Australia - http://tinyurl.com/mgw6kv9
Kempf, K. (1961). Electronic Computers within the Ordnance Corps. Monograph. Aberdeen Proving Ground, MD, November 1961 - http://tinyurl.com/o3qcf5h
Kerr, M. R. (1995). Tacit Knowledge as a Predictor of Managerial Success: A Field Study. Canadian Journal of Behavioural Science. 27 (April). - http://www.cpa.ca/cjbsnew/1995/april/kerr.html.
Kibii, J.M., Churchill, S.E., Schmid, P., Carlson, K.J., Reed, N.D., de Ruiter, D.J., Berger, L.R. 2011. A partial pelvis of *Australopithecus sediba*. Science 333, 1407-1411 - http://tinyurl.com/odwaazr.
Kiesling, N.M.J., Yi, S.V., Sperone, G., Wildman, D.E. 2014. The tempo and mode of New World monkey evolution and biogeography in the context of phylogenomic analysis. Molecular Phylogenetics and Evolution [http://dx.doi.org/10.1016/j.ympev.2014.03.027] - http://tinyurl.com/ok5w9hf
Kim, S.K., Carbone, L., Becquet, C., Mootnick, A.R., Li, D.J., de Jong, P.J., Wall, J.D. 2011. Patterns of genetic variation within and between gibbon species. Molecular Biology and Evolution 28(8), 2211-2218 - http://tinyurl.com/k47kqpw
King, A.J., Nelken, I. 2009. Unraveling the principles of auditory cortical processing: can we learn from the visual system? Nature Neuroscience 12(6), 698-701 - http://tinyurl.com/d4ybnnm
King, D.W. and Tenopir, C. (1998). Economic Cost Models of Scientific Scholarly Journals. ICSU Press Workshop, Keble College, Oxford, UK, 31 March to 2 April - http://tinyurl.com/knu9vda
Kircz, J. (1997). Scientific communication as an object of science. Academia Europea Workshop on the impact of electronic publishing on the academic community, Stockholm, April 17-20, 1997 -http://tinyurl.com/m9ur8jl.
Kirschbaum, D. (2002). Introduction to Complex Systems. in The Complexity & Artificial Life Research Concept for Self-Organizing Systems. - http://tinyurl.com/lapacum.
Kivell, T.J., Kibii, J.M., Churchill, S.E., Schmid, P., Berger, L.R. 2011. Australopithecus sediba hand demonstrates mosaic evolution of locomotor and manipulative abilities. Science 333, 1411-1417 - http://tinyurl.com/psfqxty.

Klailova, M., Casanova, C., Henschel, P., Lee, P., Rovero, F., Todd, A. 2012. Non-human predator interactions with wild great apes in Africa and the use of camera traps to study their dynamics. Folia Primologica 83, 312-328 - http://tinyurl.com/ka72h4e.

Klauke, S., Goertz, M., Rein, S., Hoehl, D., Thomas, U, Eckhorn, R., Bremmer, F., Wachtler, T. 2011. Stimulation with a wireless intraocular epiretinal implant elicits visual percepts in blind humans. Investigative Ophthalmology & Visual Science 52(1), 449-455 - http://tinyurl.com/735w5y9.

Kleidon, A., Malhi, Y., Cox, P.M. (2010). Maximum entropy production in environmental and ecological systems. Philosophical Transactions of the Royal Society B 365, 1297-1302 - http://tinyurl.com/47v393f.

Klein, E., 2007. About the confusion between the course of time and the arrow of time. Foundations of Science 12, 203-221.

Klemm, W.R. 2011. Neural representations of the sense of self. Advances in Cognitive Psychology 7, 16-30 - http://tinyurl.com/c63w6z4

Klüver, H. 1937. Re-examination of implement-using behavior in a cebus monkey after an interval of three years. Acta Psychologica 2, 347-397 - http://tinyurl.com/hh39ssn.

Klyce, B. (2010). The Second Law of Thermodynamics [Archived 7 July 2008]. in Cosmic Ancestry - http://tinyurl.com/28orr27.

Klyosov. A.A. 2014. Reconsideration of the "Out of Africa" concept as not having enough proof. Advances in Anthropology 4(1), 18-37 - http://tinyurl.com/o92fg5b

Knops, C. (2000). Book Information Website - http://www.xs4all.nl/~knops/index3.htm

Knox, E.L. 1999. The Reformation. ORB: The Online Reference Book for Medieval Studies. - http://tinyurl.com/26nmaqn.

Ko, A.M.-S., Chen, C.-Y., Fu, Q., Delfin, F., Li, M., Chiu. H.-L., Stoneking, M., Ko, Y.-C. 2014. Early Austronesians: into and out of Taiwan. American Journal of Human Genetics 94, 426-436 - http://tinyurl.com/o6nysum.

Koch A.L. 2010. Vesicles first and the origin of self-reproductive life: metabolic energy, replication catalysis. Journal of Cosmology 10: 3275-3285 - http://tinyurl.com/4pyomog.

Koch, S.P., Habermehl, C., Mehnert, J., Schmitz, C.H., Holtze, S., Villringer, A., Steinbrink, J., Obrig, H. 2010. High-resolution optical functional mapping of the human somatosensory cortex. Frontiers in Neuroenergetics 2, no. 12 – 8 pp. - http://tinyurl.com/cnzlhmw.

Koene, R.A. 2012. Fundamentals of whole brain emulation: state, transition and update representations. International Journal of Machine Consciousness 4(1), 5-21 - http://tinyurl.com/bqbl4go.

Koestler, A. 1967. The Ghost in the Machine. Macmillan, New York.

Koestler, A. 1978. Janus: A Summing Up. Random House, New York.

Koetsier, T. 2001. On the prehistory of programmable machines: musical automata, looms, calculators. Mechanism and Machine Theory 36, 589-603 - http://tinyurl.com/jwepl6j.

Koetsier, T. 2009. Phases in the unravelling of the secrets of the gear system of the Antikythera Mechanism. International Symposium on the History of Machines and Mechanisms held in Tainan. Taiwan, Nov. 10 – 14, 2008 – (in) Ceccarelli, M., et al. (eds). International Symposium on the History of Machines and Mechanisms. Proceedings HMM 2008. Springer Publishing, New York - http://tinyurl.com/mrzg4b6.

Koh, H., Magee, C.L. (2006). A functional approach for studying technological progress. Technological Forecasting & Social Change, 73, 1061-1083 - http://tinyurl.com/o366xjc.

Koivunen, H. (1997). From tacit knowledge to cultural industry. Nordic-Baltic Library Meeting. May 15-17, 1997 Birstonas Lithuania - http://www..lib.hel.fi/ulkkirja/birstonas/koivunen.htm

Kombos, T., Süss, O. 2009. Neurophysiological basis of direct cortical stimulation and applied neuroanatomy of the motor cortex: a review. Neurosurgical Focus 27(4), E3 - http://tinyurl.com/chqz4oc.

Koops, B.-J., Leenes, R. 2011. Cheating with implant: implications of the hidden information advantage of bionic ears and eyes. (in) Technologies on the Stand: Legal and Ethical Questions in Neuroscience and Robotics, van den Berg, B & Klaming, L. (eds). Wolf Legal Publishers, Nijmegen, Netherlands, pp. 206-225 - http://tinyurl.com/76rgvkj. [downloads entire book]

Kortlandt, A. 1980. How might early hominids have defended themselves against large predators and food competitors? Journal of Human Evolution 9, 79-112 - http://tinyurl.com/ztknzkt.

Kortlandt, A. 1986. The use of stone tools by wild-living chimpanzees and earliest hominids. Journal of Human Evolution 15, 77-132 - http://tinyurl.com/o66q5pu [extremely slow download].

Kortlandt, A., Holzhaus, E. 1987. New data on the use of stone tools by chimpanzees in Guinea and Liberia. Primates 28, 473-496 - http://tinyurl.com/z6lqbkn.

Kortlandt, A., Kooij, M. 1963. Protohominid behaviour in primates. Symposia of the Zoological Society of London 10, 61-88.

Kortlandt, A., van Orshoven, J., Pfeijffers, R., van Zon, J.C.J. 1981. Chimpanzees in the wild, Guinea 1966-1967: Sixth Netherlands chimpanzee expedition. (Transcripts of film/video texts). University of Amsterdam [not seen].

Kramer, A. 1993. Human taxonomic diversity in the Pleistocene: does *Homo erectus* represent multiple hominid species. American Journal of Physical Anthropology 91, 161-171 - http://tinyurl.com/nfekq4w.

Krause, J., Fu, Q., Good, J.M., Viola, B., Shunkov, M.V., Derevianko, M.P., Paabo, S. 2010. The complete mitochondrial DNA genome of an unknown hominin from southern Siberia. Nature 464, 894-897 - http://tinyurl.com/mawvqnm.

Krepinevich, A.F. 1994. Cavalry to computer; the pattern of military revolutions. National Interest 37, Fall, 30–42 - http://tinyurl.com/lbxaxcg.

Krieghoff, V., Waszak, F., Prinz, W. 2011. Neural and behavioral correlates of intentional actions. Neuropsychologia 49, 767-776 - http://tinyurl.com/d2586c3

Krogh, G.v., Ichijo, K. & Nonaka, I. (2000). Knowledge Creation: How to Unlock the Mystery of Tacit Knowedge and Release the Power of Innovation. Oxford University Press, London. [not seen]

Krubitzer, L., Stolzenberg, D.S. 2014. The evolutionary masquerade: genetic and epigenetic contributions to the neocortex. Current Opinion in Neurobiology 24, 157-165.

Kubo, D., Kono, R.T., Kaifu, Y. 2013. Brain size of Homo floresiensis and its evolutionary implications. Proceedings of the Royal Society B. doi: 10.1098/rspb.2013.0338, 8 pp. - http://tinyurl.com/lr5cyoz.

Kuhlwilm, M., Gronau, I., Hubisz, M.J., de Filippo, C., Prado-Martinez, J., Kircher, M., Fu, Q., Burbano, H.A., Lalueza-Fox, C., de la Rasilla, M., Rosas, A., Rudan, P., Dejana, B., et al. 2016. Ancient gene flow from early modern humans into Eastern Neanderthals. Nature doi:10.1038/nature16544, 7 pp + suppl. - http://tinyurl.com/zr589py.

Kuhn, S.L., Hovers, E. 2006. General introduction. (in) Hovers, E., Kuhn, S.L. (eds) Transitions Before the Transition - Evolution and Stability in the Middle Paleolithic and Middle Stone Age. Springer, pp. 1-11.
Kuhn, S.L., Hovers, E. 2013. Alternative pathways to complexity: evolutionary trajectories in the Middle Paleolithic and Middle Stone Age. Current Anthropology 54(S8), S176-S182 - http://tinyurl.com/kje2u9e.
Kuhn, T. S. 1962. The Structure of Scientific Revolutions. University of Chicago Press, 173 pp.
Kuhn, T. S. 1970. Postscript - 1969. *in* The Structure of Scientific Revolutions, 2nd Ed., Enlarged. University of Chicago Press, Chicago, 210 pp - http://tinyurl.com/oydfe52.
Kuhn, T.S. 1977. Second Thoughts on Paradigms. pp 459-482. *in* Suppe (ed) The Structure of Scientific Theories. 2nd Ed. University of Chicago Press (1977)
Kuhn, T.S. 1983. Commensurability, Comparability, Communicability. *In* PSA 1982: Proceedings of the 1982 Biennial Meetinig of the Philosophy of Science Association, Vol 2. *from* Kuhn (2000). The Road Since Structure. University of Chicago Press.
Kuhn, T. S. 2000. The Road Since Structure. University of Chicago Press, 335 pp.
Kuhnt, W., Holbourn, A., Hall, R., Zuvela, M., Käse, R., 2004. Neogene history of the Indonesian throughflow. Amer. Geoph. Union Monograph 149. In: Clift, P., Hayes, D., Kuhnt, W., Wang, P. (Eds.), Continent-Ocean Interactions in the East Asian Marginal Seas, pp. 299–320 - http://tinyurl.com/mudgqf2.
Kyrillidou, M. 1999. Spending More for Less… ARL A Bimonthly Report on Research Library Issues and Actions from ARL, CNI, and SPARC. Issue 204, June 1999 - http://tinyurl.com/2wouk9p.
Kyrillidou, M. 2000. Journal Costs: Current Trends & Future Scenarios for 2020. ARL A Bimonthly Report on Research Library Issues and Actions from ARL, CNI, and SPARC, No. 210, June 2000 - http://tinyurl.com/32kn4vr.
Kyrillidou, M., Bland, L. 2009. ARL Statistics 2007-2008 - http://tinyurl.com/363g9re.
Labuda, D., Yotova, V., Lefebvre, J.-F., Moreau, C., Utermann, G., Williams, S.M. 2013. X-linked MTMR8 diversity and evolutionary history of sub-Saharan populations. PLoS ONE 8(11): e80710. doi:10.1371/journal.pone.0080710 - http://tinyurl.com/ncc92db
Lachance, J., Vernot, B., Elbers, C.C., Ferwerda, B., Froment, A., Bodo, J.-M., Lema, G., Fu, W., Nyambo, T.B., Rebbeck, T.R., Zhang, K., Akey, J.M., Tishkoff, S.A. 2012. Evolutionary history and adaptation from high-coverage whole-genome sequences of diverse African hunter-gatherers. Cell 150, 457-469 - http://tinyurl.com/mundfkh.
LaCour, L., Stone, B., Hopkins, W., Menzel, C., Fragaszy, D. 2014. What limits tool use in nonhuman primates? Insights from tufted capuchin monkeys (*Sapajus* spp.) and chimpanzees (Pan troglodytes) aligning three-dimensional objects to a surface. Animal Cognition17, 113-125 - http://tinyurl.com/pdx5lfb.
Laden, G, Wrangham, R., 2005. The rise of the hominids as an adaptive shift in fallback foods: Plant underground storage organs (USOs) and australopith origins. Journal of Human Evolution 49, 482-498 - http://tinyurl.com/k5acqqy.
Lahr, M.M. 2010. Saharan corridors and their role in the evolutionary geography of 'Out of Africa 1". (in) J.G. Fleagle et al. (eds.), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_3, © Springer Science+Business Media B.V., pp. 27-46 http://tinyurl.com/lt7l9ne.
Lahr, M.M., Foley, R. 1994. Multiple dispersals and modern human origins. Evolutionary Anthropology: Issues, News and Reviews 3(2), 48-60 - http://tinyurl.com/l75kqmd

Lakatos, I. (1978). The Methodology of Scientific Research Programmes, (ed. J. Worrall & G. Currie). Cambridge University Press.

Laland, K.N., Odling-Smee, J., Feldman, M.W. 2001. Cultural niche construction and human evolution. Journal of Evolutionary Biology 14, 22-33 - http://tinyurl.com/l8vj3pp.

Laland, K.N., O'Brien, M.J.O. 2012. Cultural niche construction: an introduction. Biological Theory. DOI 10.1007/s13752-012-0026-6 - http://tinyurl.com/msav4t8

Lam, L.Y. 1986. The conceptual origins of our numeral system and the symbolic form of algebra. Archive for History of Exact Sciences 36(3), 183-195 http://tinyurl.com/mwt497v.

Land, F. 2009. Knowledge management or the management of knowledge? (in) King, W.R.(ed) Knowledge Management and Organizational Learning, Vol. 4, Annals of Information Systems, Springer US. pp. 15-25 – [download book: http://tinyurl.com/lslpl7b

Lane, N. 2010. Chance or necessity? Bioenergetics and the probability of life. Journal of Cosmology 10: 3286-3304 - http://tinyurl.com/4o5kp3n.

Lang, J., Winsemann, J., Steinmetz, D., Polom, U., Pollok, L., Böhner, L., Serangeli, J., Brandes, C., Hampel, A., Winghart, S. 2012. The Pleistocene of Schöningen, Germany: a complex tunnel valley fill revealed from 3D subsurface modeling and shear wave seismics. Quaternary Science Reviews 39 - doi:10.1016/j.quascirev.2012.02.009

Lang, M. 1957. Herodotos and the abacus. Hesperia: The Journal of the American School of Classical Studies at Athens 26(3), 271-288 - http://tinyurl.com/ny4ljqa.

Langemo, M. (2001) Filing Systems - Refinement, Development, and Management. The 2001 ARMA International Conference, Montreal, Quebec, Canada http://www.armavancouver.org/Proceedings/M29 Mark Langemo.PDF [Obsolete]

Langer, J. (2001). Physicists in the new era of electronic publishing. Physics Today Online. 53:8 (August) - http://www.aip.org/pt/vol-53/iss-8/p35.html.

Lanjouw, A. 2002. Behavioural adaptations to water scarcity in Tongo chimpanzees. (in) Behavioural Diversity in Chimpanzees and Bonobos, (ed) Marchant, L.F. Cambridge University Press, West Nyack, NY, pp. 52-60.

Larick, R., Clochon, R.L., Zalm, Y., Sudijono, Suminto, Yan Rizal, Aziz, Y., Aziz, F., Reagan M., Heizler. 2001. Early Pleistocene $^{40}Ar/^{39}Ar$ ages for Bapang Formation hominins, Central Jawa, Indonesia. Proceedings of the National Academy of Sciences 98(9), 4866-4871 - http://tinyurl.com/ml57qlm

Larson, S.G., Jungers, W.L., Tocheri, M.W., Orr, C.M., Morwood M.J., Sutikna T., Rokhus Due Awe, Djubiantono, T. 2009. Descriptions of the upper limb skeleton of *Homo floresiensis* http://tinyurl.com/lxhvy3j

Lavington, S.H. (1980). Early British Computers: The Story of Vintage Computers and the People Who Built Them. Manchester University Press. - http://tinyurl.com/lnchjrh.

Lawrence MS, Bartel DP. 2005. New ligase-derived RNA polymerase ribozymes. RNA 11: 1173-1180 - http://tinyurl.com/l632nv2.

Lawson, A.E. 2000. The generality of hypothetico-deductive reasoning: making scientific thinking explicit, The American Biology Teacher 62(7), 482-495 - http://tinyurl.com/2f9fctu.

Lazaridis, I., Patterson, N., Mittnik, A., Renaud, G., Mallick, S., Kirsanow, K., Sudmant, P.H., Schraiber, J.K., Castellan, S., Lipson, M., Berger, B., et al., Reich, D., Krause, J. 2014. Ancient human genomes suggest three ancestral populations for present-day Europeans. arXiv:1312.6639v2 [q-bio.PE], pp. 1-152 [incl. supplementary information] - http://tinyurl.com/lpkdp8c

Lazcano, A. (2008). Towards a definition of life: The impossible quest? Space Science Reviews, 135(1):5–10.

Leakey, M.G., Spoor, F., Dean, M.C., Feibel, C.G., Anton, S.C., Kiarie, C., Leakey, L.N. 2012. New fossils from Koobi Fora in northern Kenya confirm taxonomic diversity in early Homo. Nature 488, 201-204 - http://tinyurl.com/m4zy7zu

Leander, A. 2005. The power to construct international security: on the significance of private military companies. Millennium - Journal of International Studies 33, 803-826.

Lebatard, A.-E., Alçiçek, M.C., Rochet, P., Khatib, S., Vialet, A., Voulbes, N., Bourlès, D.L. Demory, F., Guipert, G., Mayda, S., TItov, V.V., Vidal, L., de Lumley, H. 2014. Dating the Homo erectus bearing travertine from Kocabas (Denizli, Turkey) at at lest 1.1 Ma. Earth and Planetary Science Letters 390, 8-18 - http://tinyurl.com/k3k6h8z.

Lee, J.A.N., et. al. 1995. Key events in the history of computing. Prepared for the IEEE Computer Society For Distribution in 1996 As Part of the 50th Anniversary Activities. - http://tinyurl.com/2vatvkl.

Lee-Thorp, J.A., Sponheimer, M., Passey, B.H., deRuiter, D.J., Cerling, T.E. 2010. Stable isotopes in fossil hominin tooth enamel suggest a fundamental dietary shift in the Pliocene. Philosophical Transactions of the Royal Society B 365, 3389-3396 - http://tinyurl.com/nvcbwtw

Lehner, F., Maier, R. & Klosa, O. (1998). Organisational Memory Systems: Application of Advanced Database & Network Technologies in Organisations. Forschungsbericht Nr. 19, Schriftenreihe des Lehrstuhls für Wirtschaftsinformatik III, Universität Regensburg, Februar 1998. - http://www-wi.uni-regensburg.de/(en)/forschung/engl_pub/fb19_oms.pdf.

Leimgruber, K.L., Ward, A.F., Widness, J., Norton, M.I., Olson, K.R., Gray, K., Santos. L.R. 2014. Give what you get: capuchin monkeys (*Cebus apella*) and 4-year-old children pay forward positive and negative outcomes to conspecifics. PLoS ONE 9(1): e87035. doi:10.1371/journal.pone.0087035, 8 pp - http://tinyurl.com/phwa8ht.

Leonard, W.R., Snodgrass, J.J., Roberston, M.L. 2007. Effects of brain evolution on human nutrition and metabolism. Annual Review of Nutrition 27:311–327 - http://tinyurl.com/n9xjs3z.

Lepre, C.J. 2014. Early Pleistocene lake formation and hominin origins in the Turkiana-Omo rift. Quaternary Science Reviews 102, 181-191 – http://tinyurl.com/lkpfvnv

Lepre, C.J., Roche, H., Kent, D.V., Harmand, S., Quinn, R.L. Brugal, J.-P., Texier, P.-J., Lenoble, A., Felbel, C.S. 2011. An earlier origin for the Acheulian. Nature 477, 82-85 - http://tinyurl.com/pjyjswx

Lesk, M. (1996). The Seven Ages of Information Retrieval. International Federation of Library Associations and Institutions, Universal Dataflow and Telecommunications Core Programme Occasional Paper 5 - http://tinyurl.com/27olysr.

Lesk, M. 1997. How much information is there in the world? - http://tinyurl.com/23yo8k4.

Lesk, M. 2012. One in a million: information vs attention. International Journal of Communication 6, 907–919 - http://tinyurl.com/lpde5dd

Lettvin, J.Y., Maturana, H.R., McCulloch, W.S., Pitts, W.H. (1968). What the frog's eye tells the frog's brain. In Corning, W.C., Balaban, M. (Eds.) The Mind: Biological Approaches to its Funcions. New York: Wiley. Pp. 233-258. [reprint from Proceedings of the Institute of Radio Engineering 47:1940-1951 (1958)] - http://tinyurl.com/233v6q2.

Levins, R. 1968. Evolution in Changing Environments – Some Thoretical Explorations. Monographs in Population Biology. Princeton University Press, Princeton, N.J.

Levinson, P. (1997). The Soft Edge: A Natural History and Future of the Information Revolution. Routledge, New York.

Levy, S. (1992). Artificial Life: The Quest for a New Creation. Penguin Books, London.

Levy, S. 2012. Google throws open doors to its top-secret data center. Wired 10.17.12 - http://tinyurl.com/m8ogwt5

Levy, S., Sutton, G., Ng, PC., Feuk, L., Halpern, A.L., et al. 2007. The diploid genome sequence of an individual human. PLoS Biology 5(10), 2113-2144. e254. doi:10.1371/journal.pbio.0050254 - http://tinyurl.com/8s8jmqq

Lewin, R. (1988). A Revolution of Ideas in Agricultural Origins. Science 240: 957-1112.

Lewis, M.E. 1997. Carnivoran paleoguilds of Africa: implications for hominid food procurement strategies. Journal of Human Evolution 32, 257-288 - http://tinyurl.com/m24yul4

Leydesdorff, L. 2006. The biological metaphor of a second-order observer and the sociological discourse. Kybernetes 35(3/4), 531-546 - http://tinyurl.com/llxtrou.

Li, N., Zhang, X., Song, Q., Su, R. Zhang, Q., Kong, T., Liu, Li, Jin. G., Tang, M., Cheng, G. 2011. The promotion of neurite sprouting and outgrowth of mouse hippocampal cells in culture by graphene substrates. Biomaterials 32, 9374-9382 - http://tinyurl.com/c3mcz3b.

Licklider, J.C.R. 1960. Man-computer symbiosis. IRE Transactions on human factors in electronics, 1, 4-11 - http://tinyurl.com/2ah4ysx.

Licklider, J.C.R., & Taylor, R.W. 1968. The computer as a communication device. Science and Technology, 76, 21–31 - http://tinyurl.com/2g87txw.

Lieberman, D.E., Bramble, D.M., Raichlen, D.A., Shea, J.J. 2009. Brains, brawn, and the evolution of human endurance running capabilities. (in) F.E. Grine et al. (eds.), The First Humans: Origin and Early Evolution of the Genus Homo, Vertebrate Paleobiology and Paleoanthropology, © Springer Science + Business Media B.V., pp. 77-91 - http://tinyurl.com/ktp9l7d.

Liebert, T. (1999). New Shepard's v. KeyCite: How Do We Compare? - http://tinyurl.com/28gaalb, *in* LLRX.COM, 1 June 1999

Liebowitz, S.J. and Margolis, S.E., (1998). Network Externalities (Effects). *entry in* The New Palgraves Dictionary of Economics and the Law, MacMillan - http://tinyurl.com/28sw3nm.

Liebowitz, S.J. and Margolis, S.E., (1999). Winners, Losers & Microsoft: Competition and Antitrust in High Technology. Independent Inst., 288pp - http://tinyurl.com/keh5bbq.

Liedtke, M. 2012. Google's futuristic glasses move closer to reality. Associated Press 27 June 2012 - http://tinyurl.com/857henn.

Lipson, M., Loh, P.-R., Patterson, N., Moorjani, P., Ko, Y.-C., Stoneking, M., Berger, B., Reich, D. 2014. Reconstructing Austronesian population history in Island Southeast Asia. Nature Communications 5, Article number 4689, 7pp. - http://tinyurl.com/glebfjt.

Litke, R. 1997. Domination and other kinds of power. (in) Kaplan, L.D., and Bove, L.F. (eds.) Philosophical Perspectives on Power and Domination: Theories and Practices. Editions Rodopi, B.V. Amsterdam - http://tinyurl.com/28t692g.

Lui, Q., Simpson, K., Izar, P., Ottoni, E., Visalberghi, E., Fragaszy, D. 2009. Kinematics and energetics of nut-cracking in wild capuchin monkeys (Cebus libidinosus) in Piaui, Brazil. American Journal of Physical Anthropology 138, 210-220 - http://tinyurl.com/mupaf7d.

Liu, Q., Fragaszy, D., Wright, B., Wright, K., Izar, P. & Visalberghi E. 2011. Wild bearded capuchin monkeys (*Cebus libidinosus*) place nuts in anvils selectively. Animal Behaviour 81, 297-305 - http://tinyurl.com/op4ly4r.

Lo, L.K.L. (1996-2010). AncientScripts.com. http://www.ancientscripts.com/

Lobo, F.S.N. 2008. Nature of time and causality in physics. In Grondin S. (Ed.), Psychology of Time (pp. 395-422), Bingley, UK: Emerald Group Publishing - http://tinyurl.com/nrk6zse.
Locke, D.P., Hillier, L.W., Warren, W.C., Worley, K.C., Nazareth, L.V., Muzny, D.M., Yang, S.-P., Wang, Z., Chinwalla, A.T., Minx, P., et al. 2011. Comparative and demographic analysis of orangutan genomes. Nature 469(7331), 529-533 - http://tinyurl.com/9sszcrf; supplementary information - http://tinyurl.com/9kxbu5u.
Loesch, C.W. 2009. Beyond Moore's Law – beyond CMOS – post silicon. Proceedings Interdisciplinary Information and Management Talks - IDIMT-2009, Sept. 9-11, Jindrichuv Hradec, Czech Republic, pp. 413-422 – http://tinyurl.com/llxwuze.
Loewer, B. 2012. The emergence of time's arrows and special science laws from physics. Interface Focus 2, 13–19 - http://tinyurl.com/k8r5zjn
Logan, R.K. 2004. The extended mind model of the origin of language and culture. Proceedings of the Media Ecology Association, Volume 5, 2004 – 18 pp. - http://tinyurl.com/9szzxma
Logan, R.K. 2006. The extended mind model of the origin of language and culture. (in) Gontier, N., van Bendegem, J.P., Aerts, D. (eds.), Evolutionary Epistemology, Language and Culture: A Non-Adaptationist, Systems Theoretical Approach. Springer, Dordrecht, pp. 149-167.
Lombard, M. 2012. Thinking through the Middle Stone Age of sub-Saharan Africa. Quaternary International 270, 140-155.
Lombard, M., Haidle, M.N. 2012. Thinking a bow-and-arrow set: cognitive implications of Middle Stone Age bow and stone-tipped arrow technology. Cambridge Archeological Journal 22(2), 237-264 - http://tinyurl.com/lgy4c68.
Lombard, M., Schlebusch, C., Doodyall, H. 2013. Bridging disciplines to better elucidate the evolution of early *Homo sapiens* in southern Africa. South African Journal of Science 109(11-12), 1-8 - http://tinyurl.com/k7l4ajy.
Loomis, J.M., 2003. Sensory replacement and sensory substitution: overview and prospects for the future. (in) Converging Technologies for Improving Human Performance – Nanotechnology, Biotechnology, Information Science and Cognitive Science, Roco, M.C., Bainbridge, W.S. (eds.). Kluwer Academic Publishers, Dordrecht, pp. 213-224 - http://tinyurl.com/bstxmta.
Longo, G., Montévil, M., Kauffman, S. 2012. No entailing laws, but enablement in the evolution of the biosphere. Proceedings of the fourteenth international conference on Genetic and evolutionary computation conference companion, 1379-1392 - http://tinyurl.com/k5zwyzq.
López, P., Hilbert, M. 2012. Methodological and statistical background on the world's technological capacity to store, communicate, and compute information 2012. http://www.martinhilbert.net/WorldInfoCapacity.html, 302 pp. - http://tinyurl.com/lmcbauu.
Lottor, M. 1992. Internet growth (1981-1991). Network Information Systems Center, SRI International No. 1296 - http://tinyurl.com/mowhek7.
Lordkipanidze, D., Jashashvili, T., Vekua, A., Ponce de León, M.S., Zollikofer, C.P.E., Rightmire, G.P., Pontzer, H., Ferring, R., Oms, O., Tappen, M., et al. 2007. Postcranial evidence from early *Homo* from Dmanisi, Georgia. Nature 449, 305-310 + suppl. 20 pp. - http://tinyurl.com/k6zkzjn
Lordkipanidze, D., Ponce de Leon, M.S., Margvelashvili, A., Rak, Y., Rightmire, G.P., Vekua, A., Zollikofer, C.P.E. 2013. A complete skull from Dmanisi, Georgia, and the evolutionary

biology of early *Homo*. Science 342, 326-331 - http://tinyurl.com/kbnwxnn + Supplementary Materials - http://tinyurl.com/m7cbz4z.

Lordkipanidze, D., Vekua, A., Ferring, R., Rightmire, G.P., Agustill, J., Kiladze, G., Mouskhelishvili, A., Nioradze, M., Ponce de León, M.S., Tappen, M., Zollikofer, C.P.E. 2005. The earliest toothless hominin skull. Nature 434, 717-718 – http://tinyurl.com/hx67735.

Lordkipanidze, D., Vekua, A., Ferring, R., Rightmire, G.P., Zollikofer, C.P.E., Ponce de Leon, M.S., Gusti, J., Kiladze, G., Mouskhelishvili, A., Nioradze, M., Tappen, M. 2006. A fourth hominin skull from Dmanisi, Georgia. The Anatomical Record Part A 286A, 1146-1157 - http://tinyurl.com/lo4rfej.

Louchart, A., Wesselman, H., Blumenschine, R.J., Hlusko, L.J., Njau, J.K., Black, M.T., Asnake, M., White, T.D. 2009. Taphonomic, avian, and small-vertebrate indicators of *Ardipithecus ramidus* habitat. Science 326, 26e, pp. 1-4 - http://tinyurl.com/o69uvbn.

Love, A.C. 2012. Hierarchy, causation and explanation: ubiquity, locality and pluralism. Interface Focus 2, 115–125 –

Lovejoy, C.O. 2009. Reexamining human origins in light of Ardipithecus ramidus. Science 326, 74, 74e1-74e8 - http://tinyurl.com/p8hl2re

Lovejoy, C.O., Latimer, B., Suwa, G., Asfaw, B., White, T.D. 2009a. Combining prehension and propulsion: the foot of *Ardipithecus ramidus*. Science 326, 72, 72e1-72e8 - http://tinyurl.com/nrypgfh.

Lovejoy, C.O., Simpson, S.W., White, T.D., Asfaw, B., Suwa, G. 2009. Careful climbing in the Miocene: the forelimbs of *Ardipithecus ramidus* and humans are primitive. Science 326, 70, 70e1-70e8 [+ Supporting online material - http://tinyurl.com/p5jp42c].

Lovejoy, C.O., Suwa, G., Spurlock, L., Asfaw, B., White, T.D. 2009b. The pelvis and femur of *Ardipithecus ramidus*: the emergence of upright walking. Science 326, 71, 71e1-71e6 - http://tinyurl.com/h4eqbto.

Lovejoy, C.O., Suwa, G., Simpson, S.W., Matternes, J.H., White, T.D. 2009c. The great divides: *Ardipithecus ramidus* reveals the postcrania of our last common ancestors with African apes. Science 326, 73, 100-106 - http://tinyurl.com/gmjf7ug.

Lubar, S. (1992). "Do not fold, spindle or mutilate": A cultural history of the punch card. Jounal of American Culture, Winter 1992 - http://tinyurl.com/246oq44.

Lucas, C. (2003). Attractors Everywhere - Order from Chaos. in CALResCo Complexity Writings. - http://tinyurl.com/23uhjyp.

Luhmann, N. 1986. The autopoiesis of social systems. In: Geyer, F., van der Zouwen, J. (Eds.), Sociocybernetic Paradoxes: Observation, Control, and Evolution of Self-Steering Systems. Sage, London, pp. 172-192 [reprinted in Journal of Sociocybernetics 5(2), 84-95 - http://tinyurl.com/mtsgo7q].

Luhmann, N. 1989. Ecological Communication. University of Chicago Press, Chicago.

Luhmann, N. 1990. Essays of Self-Reference. Columbia Univ. Press, New York.

Luhmann, N. 1992. The concept of society. Thesis Eleven 31: 67-80.

Luhmann, N. 1994. The modernity of science. New German Critique. No. 61, Winter, 1994, pp. 9-23.

Luhmann, N. 1995. Social Systems. Tr. J. Bednarz and D. Baecker. Stanford University Press, Stanford.

Luhmann, N. 1995a. The paradox of observing systems. (in) Rasch, W. (ed.) Theories of Distinction: Redescribing the Descriptions of Modernity. Stanford University Press, Stanford (2002), pp. 79-93.

Lui, Q., Simpson, K., Izar, P., Ottoni, E., Visalberghi, E., Fragaszy, D. 2009. Kinematics and energetics of nut-cracking in wild capuchin monkeys (Cebus libidinosus) in Piaui, Brazil. American Journal of Physical Anthropology 138, 210-220 - http://tinyurl.com/mupaf7d.

Lycett, S.J. 2009. Understanding ancient hominin dispersals using artefactual data: a phylogeographic analysis of Acheulean handaxes. PLoS ONE 4(10): e7404. doi:10.1371/journal.pone.0007404 - http://tinyurl.com/nyy3dg9.

Lycett, S.J., Bae, C.J. 2010. The Movius Line controversy: the state of the debate. World Arcaeology / Debates in World Archaeology 42(4), 521-544 - http://tinyurl.com/l7vj63b.

Lycett, S.J., Norton, C.J. 2010. A demographic model for Palaeolithic technological evolution: the case of East Asia and the Movius Line. Quaternary International 211, 55-65 - http://tinyurl.com/lgaxuyk

Lyman, P and Varian, H.R. (2000) How Much Information - http://tinyurl.com/mwetmxh.

Lyman, P and Varian, H.R. (2000a). How Much Information. Journal of Electronic Publishing. 6:2 – http://tinyurl.com/pgvzbcl.

Lyman, P. and Varian, H.R. 2003. – How Much Information 2003? - http://tinyurl.com/mwrysk6.

Lyn, H., Greenfield, P.M., Savage-Rumbaugh, E.S. 2010. Semiotic combinations in Pan: A comparison of communication in a chimpanzee and two bonobos. First Language 31(3), 300-325 - http://tinyurl.com/plr57yk.

Lynch Alfaro, J.W., Boubli, J.P., Olson, L.E., Di Fiore, A., Wilson, B., Gutiérrez-Espeleta, G.A., Chiou, K.L., Schulte, M., Neitzel, S., Ross, V., Schwochow, D., Nguyen, M.T.T., et al. 2012. Explosive Pleistocene range expansion leads to widespread Amazonian sympatry between robust and gracile capuchin monkeys. Journal of Biogeography 39, 272-288 - http://tinyurl.com/kjzfqhn

Lynch Alfaro, J.W., De Sousa E Silva Jr., J., Rylands, A.B. 2012a. How different are robust and gracile capuchin monkeys: An argument for the use of *Sapajus* and *Cebus*. American Journal of Primatology 74, 273-286 - http://tinyurl.com/hx43md2.

Maçarico da Costa, N., Martin, K.A.C. 2010. Whose cortical column would that be? Frontiers in Neuroanatomy 4, no. 16, 10 pp. - http://tinyurl.com/cdzl5a2

Maccone, L. 2009. A quantum solution to the arrow-of-time dilemma. – Physical Review Letters 103, 080401:1-4 - http://tinyurl.com/2a2n6lh.

MacDonald, K., Martinón-Torres, M., Dennell, R.W., Bermúdez de Castro, J.M. 2012. Discontinuity in the record for hominin occupation in south-western Europe: implications for occupation of the middle latitudes of Europe. Quaternary International 271, 84-97 - http://tinyurl.com/hwknd2z.

MacDonell, K.L. (1999). Naturae curiosi: origin of the scholarly journal. *from* The Scholarly Journal: Past, Present, Future. - http://tinyurl.com/2cjzt9y.

MacKinnon, K.C. 2013. Ontogeny of social behavior in the genus *Cebus* and the application of an integrative framework for examining plasticity and complexity in evolution. K.B.H. Clancy et al. (eds.), Building Babies: Primate Development in Proximate and Ultimate Perspective, Developments in Primatology: Progress and Prospects 37, Springer Science+Business Media New York, 387-408 - http://tinyurl.com/o23vkxq.

MacKinnon, K.C., Fuentes, A. 2011. Primates, niche construction, and social complexity: the roles of social cooperation and altruism. (in) R.W. Sussman, C.R. Cloninger (eds.), Origins of Altruism and Cooperation, Developments in Primatology: Progress and Prospects, DOI 10.1007/978-1-4419-9520-9_7, Springer Science+Business Media, LLC.

MacLatchy, L.M., DeSilva, J., Sanders, W.J. and Wood, B. 2010. Homini. In: Cenozoic Mammals of Africa, Eds. L. Werdelin and W. J. Sanders. pp. 471-545. University of California Press, Berkely, pp. 471-545 - http://tinyurl.com/qyo9g97

MacLean, D. and MacIntosh, R. (1997). Conditioned Emergence: An Approach to Transformation Using Business Process Re-engineering and Organisational Learning. British Academy of Management Conference 1997. - http://bprc.warwick.ac.uk/bam4.html [http://Web.archive.org/Web/20010808071247/http://bprc.warwick.ac.uk/bam4.html]

MacLennan, B.J. 2007. A review of analog computing. Department of Electrical Engineering & Computer Science, University of Tennessee, Knoxville, Tech Rept. UT-CS-07-601 - fhttp://tinyurl.com/7occ9xe.

MacLeod, C.E., Zilles, K., Schleicher, A., Rilling, J.R., Gibson, K.R. 2003. Expansion of the neocerebellum in Hominoidea. Journal of Human Evolutinon 44, 401-429 - http://tinyurl.com/7m9ja7k.

MacLeod, R. 2000. Introduction: Alexandria in history and myth. (in) The Library of Alexandria: Centre of Learning in the Ancient World. MacLeod, R (ed.). IB Tauris, London, pp 1-15.

Madl, T., Baars, B.J., Franklin, S. 2011. The timing of the cognitive cycle. PLoS ONE 6(4): e14803. doi:10.1371/journal.pone.0014803 - http://tinyurl.com/8j2tm5k

Magalhaes, R. (1996). Organizational Learning, Organizational Knowledge and Organizational Memory; New Proposals Towards a Unified View. Working Paper Series 20, London School of Economics, Department of Information Systems. - http://is.lse.ac.uk/wp/pdf/WP60.PDF.

Magalhaes, R. (1998). Organizational Knowledge and Learning. *in* von Krogh et al. (1998).

Magill, C.R., Ashley, G.M., Freeman, K.H. 2013. Ecosystem variability and early human habitats in eastern Africa. Proceedings of the National Academy of Sciences 110, 1167-1174 - http://tinyurl.com/pksq52w.

Magill, C.R., Ashley, G.M., Freeman, K.H. 2013a. Water, plants, and early human habitats in eastern Africa. Proceedings of the National Academy of Sciences 110, 1175-1180 - http://tinyurl.com/psqo66n

Maier, R.K. & Klosa, O.W.. (1999). Organizational memory systems to support organizational information processing: development of a framework and results of an empirical study. Proceedings of the 1999 ACM SIGCPR conference on Computer personnel research 1999 , New Orleans, Louisiana, United States . http://www-wi.uni-regensburg.de/(de)/forschung/engl_pub/sigcpr_maier.pdf.

Malafouris, L. 2010. Grasping the concept of number: how did the sapient mind move beyond approximation. (in) The Archaeology of Measurement: Comprehending Heaven, Earth and Time in Ancient Societies. Morley, I., Renfrew, C. (Eds). Cambridge University Press, Cambridge, pp. 35-42 - http://tinyurl.com/2ddzvpa.

Malafsky, G.P. (2002). Building a Knowledge Management Taxonomy for the Department of Navy. Defence Acquisition University Core Competency Taxonomies - http://taxonomy.dau.mil/know_taxon_don-malafsky.pdf [also via Federal CIO Council

(2002). Knowledge Management Working Group CD - http://www.fgipc.org/02_Federal_CIO_Council/default.htm].
Malassé, A.D., Singh, M., Karir, B., Gaillard C., Bhardwaj, V., Moigne, A.-M., Abdessadok, S., Sao, C.C., Gargani, J., Tudryn, A., Calligary, T., Kaur, A., Pal, S., Hazarika, M. 2016. Anthropic activities in the fossiliferous Quranwala Zone, 2.6 Ma, Siwaliks of Northwest India, historical context of thediscovery and scientific investigations. Comptes Rendus Palevol http://dx.doi.org/10.1016/j.crpv.2015.06.004 - http://tinyurl.com/j4h3x4u
Mallegni, F. 2011. The earliest European peopling after the recent discoveries: early Neanderthals or different lineages? (in) Continuity and Discontinuity in the Peopling of Europe: One Hundred Fifty Years of Neanderthal Study, S. Condemi and G.-C. Weniger (eds.), Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-94-007-0492-3_5, Springer Science+Business Media B.V., pp. 55-66 - http://tinyurl.com/hf8zast.
Mallegni, F., Carnieri, E., Bisconti, M., Tartarelli, G., Ricci, S., Biddittu, I., Segre, A. 2003. Homo cepranensis sp. Nov. and the evolution of African-European Middle Pleistocene hominids. Comptes Rendus Palevol 2, 153-159 - http://tinyurl.com/mg7gfxm.
Malone, N., Fuentes, A., White, F.J. 2012. Variation in the social systems of extant hominoids: comparative insight into the social behavior of early hominins. International Journal of Primatology 33(6), 1251-1277 - http://tinyurl.com/lnnm443
Mania, D., & Mania, U. 2005. The natural and socio-cultural environment of *Homo erectus* at Bilzingsleben, Germany. (in) The Individual Hominid in Context: Archaeological Investigations of Lower and Middle Palaeolithic Landscapes, Locales and Artifacts. Clive Gamble & Martin Porr (eds.). Routledge, London, pp 98- 114.
Mania, D., Mania, U., Vlcek, E. 1994. Latest finds of skull remains of Homo erectus from Bilzingsleben (Thuringia). Naturwissenschaften 81, 123-127.
Manica, A., Amos, W., Balloux, F., Hanihara, T. 2007. The effect of ancient population bottlenecks on human phenotypic variation. Nature 448, 346-348 - http://tinyurl.com/m53vxc9.
Mannu, M., Ottoni, E.B. 2009. The enhanced tool-kit of two groups of wild bearded capuchin monkeys in the Caatinga: tool making, associative use, and secondary tools. American Journal of Primatology 71, 242-251 - http://tinyurl.com/mhcyll6.
Manrique, H.M., Sabbatini, G., Call, J., Visalberghi. 2011. Tool choice on the basis of rigidity in capuchin monkeys. Animal Cognition 14,775-786 - http://tinyurl.com/maug5vo.
Manson, J.H., Perry, S., Parish, A.R. 1997. Nonconceptive sexual behavior in bonobos and capuchins. International Journal of Primatology 18, 767-786 - http://tinyurl.com/kznkje8
Manzi, G. 2011. Before the emergence of *Homo sapiens*: overview on the Early-to-Middle Pleistocene fossil record (with a proposal about *Homo heidelbergensis* at the subspecific level). International Journal of Evolutionary Biology 2011, art ID 582678 - http://tinyurl.com/n7exd56.
Manzi, G. 2012. On the trail of the genus *Homo* between archaic and derived morphologies. Journal of Anthropological Sciences 90, 99-116 - http://tinyurl.com/mzyt2wq.
Manzi, G., Bruner, E., Passarello, P. 2003. The one-million-year-old *Homo* cranium from Bouri (Ethiopia): a reconsideration of its *H. erectus* affinities. Journal of Human Evolution 44, 731-736.
Marchant, J. 2010. Mechanical inspiration. Nature 468, 596-498 - http://tinyurl.com/oamxxkq
Margulis, L. 1968. Evolutionary criteria in thallophytes: a radical alternative. Science 161(3845), 1020–1022 -

Margulis, L. 1970. Origin of Eukaryotic Cells. Yale University Press, New Haven, CT.
Markoff, J., Hansell, S. 2006. Hiding in plain sight, Google seeks more power. The New York Times, June 14, 2006 - http://tinyurl.com/mk9qofk.
Markram, H. 2006. The Blue Brain Project. Nature Reviews Neuroscience 7, 153-160 - http://tinyurl.com/cq4wqxd
Markus, M.L. (2001). Toward a theory of knowledge reuse: Types of knowledge reuse situations and factors in reuse success. Journal of Management Information Systems, Summer 2001. - http://tinyurl.com/jjunfjw.
Marshall, A.J., Wrangham, R.W. 2007. Evolutionary consequences of fallback foods. International Journal of Primatology 28, 1219-1235 - http://tinyurl.com/lgugcsf.
Marshall, E. 1999. Varmus defends e-biomed proposal, prepares to push ahead. Science 284:2062-2063.
Martin, J. (1996). Cybercorp : The New Business Revolution. Amacom, 326 pp.
Martin CP, Philp WR, Hall WP. (2009). Temporal convergence for knowledge management. Australasian Journal of Information Systems 15(2): 133-148 - http://tinyurl.com/kdtut3s.
Martin, R.D., MacLarnon, A.M., Phillips, J.L., Dussubieux, L., Williams, P.R., Dobyns, W.B. 2006. Comment on "the brain of LB1, Homo floresiensis". Science 312, 999b , pp. 1-2 [Included with Brown et al. 2004].
Martín-Francés, L., Martinón-Torres, M., Lacasa-Marquina, E., Fernández-Colón, P., Gracia-Téllez, A., Bermúdez de Castro, J.M. 2013. Palaeopathology of the Pleistocene specimen D2600 from Dmanisi (Republic of Georgia). Comptes Rendus Palevol 13, 189-203.
Martínez, K., Garcia, J., Carbonell, E. 2013. Hominin multiple occupations in the Early and Middle Pleistocene sequence of Vallparadís (Barcelona, Spain). Quaternary International 316, 115-122 - http://tinyurl.com/l3qfp26
Martínez-Navarro, B. 2010. Early Pleistocene faunas of Eurasia and hominin dispersals. (in) J.G. Fleagle et al. (eds.), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_13, © Springer Science+Business Media B.V., pp. 207-224.
Martinón-Torres, Dennell, R., Bermúdez de Castro, J.M. 2011. The Denisova hominin need not be an out of Africa story. Journal of Human Evolution 60, 251-255 - http://tinyurl.com/nlg5ezy
Martyushev, L.M., Seleznev, V.D. 2006. Maximum entropy production principle in physics, chemistry and biology. Physics Reports 426, 1-45 - http://tinyurl.com/knzbg9n.
Mashra, S., Chauhan, N., Singhvi, A.K. 2013. Continuity of microblade technology in the Indian subcontinent since 45 ka: implications for the dispersal of modern humans. PLoS ONE 8(7): e69280. doi:10.1371/journal.pone.0069280, 14 pp. - http://tinyurl.com/q37fzzb.
Maslin, M.A., Brierley, C.M., Milner, A.M., Shutlz, S., Trauth, M.H., Wilson, K.E. 2014. East African climate pulses and early human evolution. Quaternary Science Reviews 101, 1-17 - http://tinyurl.com/jny5kcd.
Mason, N.W.H., Mouillot, D., Lee, W.G., Wilson, J.B. 2005. Functional richness, functional evenness and functional divergence: the primary components of functional diversity. Oikos 111, 112-118.
Massaro, L., Lui Q., Visalberghi, E., Fragaszy, D. 2012. Wild bearded capuchin (*Sapajus libidinosus*) select hammer tools on the basis of both stone mass and distance from the anvil. Animal Cognition 15, 1065-1074 - http://tinyurl.com/l3xdlks.

Mast CB, Osterman N, Braun D. 2010. Disequilibrium first: the origin of life. Journal of Cosmology 10: 3305-3314 - http://tinyurl.com/4znqoot.
Masterman, M. 1970. The nature of a paradigm, pp. 59-89. *In* Lakatos and Musgrave (eds.), 1970. Criticism and the Growth of Knowledge. Proceedings of the International Colloquium in the Philosophy of Science, London, 1965, Vol. 4. London, Cambridge Univ. Press, 282 pp.
Mattessich, R. (????). Spreadsheet: Its First Computerization (1961-1964). JWalk & Associates. The Spreadsheet Page - http://tinyurl.com/25oejwm.
Maturana, H. R. (1958). The fine structure of the optic nerve and tectum of anurans. An electron microscope study. Ph.D. Thesis, Harvard University, Cambridge, Mass.
Maturana, H. R. (1959). Number of fibres in the optic nerve and the number of ganglion cells in the retina of anurans. Nature, 183(4672):1406–1407.
Maturana, H.R. (1970). Biology of cognition. Biological Computer Laboratory Research Report BCL 9.0. Urbana IL: University of Illinois. [Reprinted in Maturana, H.R., Varela, F.J. (Eds.). Autopoiesis and Cognition: The Realization of the Living. Dordecht: D. Reidel Publishing Co., 1980, pp. 5-58.] - http://tinyurl.com/26f8s4a.
Maturana, H.R. 1977. Biology of Language. *in* Rieber, R.W. (ed.), The Neuropsychology of Language. Plenum Press, New York.
Maturana, H.R. 1980. Man and society, (in) Benseler, F., P. Hejl, and W. Köck (eds.), Autopoiesis, Communication, and Society: The Theory of Autopoietic System in the Social Sciences, Frankfurt: Campus Verlag, 1980, 11-32.
Maturana, H.R. (1988). Ontology of Observing: The biological foundations of self-consciousness and the physical domain of existence, American Society for Cybernetics Conference, Felton, CA, 18-23 October 1988 - http://tinyurl.com/27phul3.
Maturana, H.R. 1995, The nature of time. Chilean School of Biology of Cognition, The Unofficial Web Page of Humberto Maturana, Santiago de Chile, Edited by Alfredo Ruiz, first web edition of this article of November 27, 1995 - http://tinyurl.com/qas3pby
Maturana HR. (2002). Autopoiesis, structural coupling and cognition: a history of these and other notions in the biology of cognition. Cybernetics & Human Knowing 9(3-4): 5-34 http://tinyurl.com/mc3jtel.
Maturana, H. R., Lettvin, J. Y., McCulloch, W. S., and Pitts, W. H. (1959). Evidence that cut optic nerve fibers in a frog regenerate to their proper places in the tectum. Science, 130(3390): 1709-1710.
Maturana, H.R. & Varela, F.J. 1973. Autopoiesis: the organization of the living. In Autopoiesis and Cognition: The Realization of the Living. Dordecht: D. Reidel Publishing Co., 1980, pp. 59-140. [first published as De Maquinas y Seres Vivos in 1972 by Editorial Universitaria, S.A.]
Maturana, H.R. & Varela, F.J. 1980. Autopoiesis and Cognition: The Realization of the Living. Boston Studies in the Philosophy of Science, Vol. 42. Dordrecht: D. Reidel Publishing Company - http://tinyurl.com/kp6l5et.
Maturana, H.R., & Varela, F.J. 1982. Colour-component responses in the avian lateral geniculate: a case study in the quail. Brain Research 247: 227-241. http://tinyurl.com/2en8bey.
Maturana, H.R. & Varela, F.J. 1987. The Tree of Knowledge: The Biological Roots of Human Understanding. New Science Library, Shambhala Publications, Inc., Boston, Mass.

Matsuzawa, T. 2011. Stone tools for nut-cracking. T. Matsuzawa et al. (eds.), The Chimpanzees of Bossou and Nimba, Springer. pp. 73-83 - http://tinyurl.com/jx4mmrv.

Maula, M. (2000). The senses and memory of a firm - implications of autopoiesis theory for knowledge management. *Journal of Knowledge Management*. 4, 157-161.

Maula, M. 2006. Organizations as Learning Systems: 'Living Composition' as an Enabling Infrastructure. Oxford: Elsevier.

Maxfield & Montrose Interactive Inc. (1998). A History of Computers. Maxfield & Montrose Interactive Inc., Madison, Alabama - http://tinyurl.com/27torlo.

Mayer, G. (2002). Bacteriology - Chapter 7: Bacteriophage; Chapter 8: Exchange of Genetic Information; 9: Genetic Regulatory Mechanisms. Microbiology and Immunology On-line - http://www.med.sc.edu:85/mayer/phage.htm; http://www.med.sc.edu:85/mayer/geneticex.htm; http://www.med.sc.edu:85/mayer/geneticreg.htm

Mayr, E. 1972. Populations, Species and Evolution. Harvard University Press, Cambridge, MA.

Mazor, S. (1995). The History of the Microcomputer - Invention and Evolution. Proceedings of the IEEE 83:12. - http://tinyurl.com/l4qbjym.

McBrearty, S. 2007. Down with the revolution. (in) Rethinking the Human Revolution, (eds.) Mellars, P., Boyle, K., Bar-Yosef, O., Stringer, C. McDonald Institute for Archaeological Research, Cambridge, UK, pp. 133-151 – http://tinyurl.com/kqohzvu.

McBrearty, S., Brooks, A. 2000. The revolution that wasn't: a new interpretation of the origin of modern human behaviour. Journal of Human Evolution 39(5): 453–563 - http://tinyurl.com/lqefn7q.

McBrearty, S., Tryon, C. 2006. From Acheulean to Middle Stone Age in the Kapthurin Formation, Kenya. (in) Hovers, E., Kuhn, S.L. (eds) Transitions Before the Transition - Evolution and Stability in the Middle Paleolithic and Middle Stone Age. Springer, pp. 257-277 - http://tinyurl.com/mo7wztw

McBride, G. 2012. Ethology, evolution, mind & consciousness. Journal of Consciousness Exploration and Research 3(7), 830-840 - http://tinyurl.com/956kofa

McDougall, I., Brown, F.H., Fleagle, J.G. 2008. Sapropels and the age of hominins Omo I and II, Kibish, Ethiopia. Journal of Human Evolution 55, 409-420.

McFarland, D.J., Wolpaw, J.R. 2011. Brain-computer interfaces for communication and control. Communications of the ACM 54(5), 60-66 - http://tinyurl.com/75yog57.

McGrew, W.C. 1974. Tool use by wild chimpanzees in feeding upon driver ants. Journal of Human Evolution 3, 501-508 - http://tinyurl.com/msvthde.

McGrew, W.C. 1992. Tool-use by free-ranging chimpanzees: the extent of diversity. Journal of the Zoological Society of London 228, 689-694 - http://tinyurl.com/l2u4y6q.

McGrew, W.C. 2007. Savanna chimpanzees dig for food. Proceedings of the National Academy of Sciences 104, 19167-19168 - http://preview.tinyurl.com/pe75czp

McGrew, W.C. 2010. In search of the last common ancestor: new findings on wild chimpanzees. Philosophical Transactions of the Royal Society B 365(1556), 3267-3276 - http://tinyurl.com/8gl6fcb.

McGrew, W.C. 2014. The 'other faunivory' revisited: Insectivory in human and non-human primates and the evolution of human diet. Journal of Human Evolution 71, 4-11 - http://tinyurl.com/q3n27ev.

McGrew, W.C., Marchant, L.F. 1997. Using the tools at hand: manual latgerality and elementary technology in *Cebus* spp. and *Pan* spp. International Journal of Primatology 18, 787-810 http://tinyurl.com/jxh9qrr.

McGrew, W.C., Marchant, L.F., Payne, C.L.R., Webster, T.H., Hunt, K.D. 2013. Well digging by Semliki chimpanzees: new data on laterality and possible significance of hydrology. Pan Africa News 20, 5-8 - http://tinyurl.com/le7fdd7.

McKemmish, S. (1997). Yesterday, Today and Tomorrow: A Continuum of Responsibility. *in* Proceedings of the Records Management Association of Australia 14th National Convention, 15–17 Sept 1997, RMAA Perth 1997. — http://rcrg.dstc.edu.au/publications/recordscontinuum/smckp2.html

McKemmish, S. and Acland, G. (1999) Archivists at Risk: Accountability and the Role of the Professional Society. *from* Archives at Risk: Accountability, Vulnerability and Credibility, 1999 Annual Conference of the Australian Society of Archivists, July 1999 — http://rcrg.dstc.edu.au/publications/archive1.html

McKenna, S. & Mondal, D. (1997). Bacterial Genetics, Chapter D. Microbiology - http://www.liu.edu/cwis/bklyn/acadres/facdev/FacultyProjects/WebClass/micro-Web/html-files/ChapterD-1.html

McNabb, J., Binyon, F., Hazelwood, L. 2004. The large cutting tools from the South African Acheulean and the question of social traditions. Current Anthropology 45(5), 653-677 - http://tinyurl.com/kzzoh6t

McPherron, S.P., Alemseged, Z., Marean, C.W., Wynn, J.G., Reed, D., Geraads, D., Bobe, R., Béarat, H. 2010. Evidence for stone-tool-assisted consumption of animal tissues before 3.39 million years ago at Dikika, Ethiopia. Nature 466, 857-860 – http://tinyurl.com/meeybgm

McPherron, S.P., Alemseged, Z., Marean, C.W., Wynn, J.G., Reed, D., Geraads, D., Bobe, R., Béarat, H. 2011. Tool-marked bones from before the Oldowan change the paradigm. Proceedings of the National Academy of Sciences USA 108(21), E117 - http://tinyurl.com/9rzb6zc

Medina, E. (2006) Designing freedom, regulating a nation: Socialist cybernetics in Allende's Chile. Journal of Latin American Studies 38: 171-606 - http://tinyurl.com/kfc8dvl.

Melin, A.D., Young, H.C., Mosdossy, K.N., Fedigan, L.M. 2014. Seasonality, extractive foraging and the evolution of primate sensorimotor intelligence. Journal of Human Evolution [http://dx.doi.org/10.1016/j.jhevol.2014.02.009] 10 pp. - http://tinyurl.com/ko6mqcs.

Mellars, P., Gori, K.C., Carr, M. Soares, P.A., Richards, M.B. 2013. Genetic and archaeological perspectives on the initial modern human colonization of southern Asia. Proceedings of the National Academy of Sciences 110(26), 10699-10704 - http://tinyurl.com/ptehryh

Messager, E., Lebreton, V., Marquer, L., Russo-Ermolli, E., Orain, R., Renault-Miskovsky, J., Lordkipanidze, D., Despriée, J., Peretto, C., Arzarello, M. 2011. Palaeoenvironments of early hominins in temperate and Mediterranean Eurasia: new palaeobotanical data from Palaeolithic key-sites and synchronous natural sequences. Quaternary Science Reviews 30, 1439-1447.

Messager, E., Lordkipanidze, D., Delhon, C., Ferring, C.R. 2010a. Palaeoecological implications of the Lower Pleistocene phytolith record from the Dmanisi Site (Georgia). Palaeogeography, Palaeoclimatology, Palaeoecology 288, 1-13 - http://tinyurl.com/lv4rhny

Messager, E., Lordkipanidze, D., Kvavadze, E., Ferring, C.R., Voinchet, P. 2010. Palaeoenvironmental reconstruction of Dmanisi site (Georgia) based on palaeobotanical data. Quaternary International 223-224, 20-27 - http://tinyurl.com/nh7k27q.

Meijer, H.J.M., van den Hoek Ostende, L.W., van den Bergh, G.D., de Vos, J. 2010. The fellowship of the hobbit: the fauna surrounding *Homo floresiensis*. Journal of Biogeography 37, 995-1006 - http://tinyurl.com/k4lqhjh.

Mellars, P., 2006. Archeology and the dispersal of modern humans in Europe: deconstructing the Aurignacian. Evolutinoary Anthropology 15, 167-182.

Mellars, P. 2011. The earliest modern humans in Europe. Nature 479, 483-485 - http://tinyurl.com/l8dq2q2

Mellor, C. 2007. Does Google have the biggest IT carbon footprint on the planet? Techworld 26 June 2007 - http://tinyurl.com/ktd7tdp.

Mendez, F.L., Watkins, J.C., Hammer, M.F. 2012. Global genetic variation at OAS1 provides evidence of archaic admixture in Melanesian populations. Molecular Biology and Evolution 29(6), 1513-1520 - http://tinyurl.com/q95sw6o.

Mendez, F.L., Watkins, J.C., Hammer, M.F. 2013a. Neanderthal origin of genetic variation at the cluster of OAS immunity genes. Molecular Biology and Evolution 30(4), 798-801 - http://tinyurl.com/pqe9qex

Mendez, F.L., Krahn, T., Schrack, B., Krahn, A.-M., Veeramah, K.R., Woerner, A.E., Fomine, F.L.M., Bradman, N., Thomas, M.G., Krafet, T.M., Hammer, M.F. 2013b. An African American paternal lineage adds an exgtremely ancient root to the human Y chromosome hylogenetic tree. American Journal of Human Genetics 92, 453-459 - http://tinyurl.com/q8ywuxy

Mentzas, G. and Apostolou, D. (1998). Towards a Holistic Knowledge Leveraging Infrastructure: The KNOWNET Approach. Paper accepted for presentation at the Second International Conference on Practical Aspects of Knowledge Management 29-30 October, 1998, Basel Switzerland. - http://project.know-net.org/documents/pakmknet.pdf

Merceron, G., Kaiser, T.M., Kostopoulos, D.S., Schulz, E. 2010. Ruminant diets and the Miocene extinction of European great apes. Proceedings of the Royal Society B 277, 3105-3112 -http://tinyurl.com/bsn53kv

Mergenthaler Linotype Company (1940). Linotype Machine Principles. Mergenthaler Linotype Company, Brooklyn, NY. 487 pp - http://tinyurl.com/l5jocqt.

Merolla, P., Arthur, J., Akopyan, F., Imam, N., Manohar, R., Modha, D.S. 2011. A digital neurosynaptic core using embedded crossbar memory with 45pJ per spike in 45nm. Custom Integrated Circuits Conference (CICC), 2011 IEEE, 19-21 Sept. 2011, 4 pp. - http://tinyurl.com/bqspf9v

Metz, S. (2000) Armed Conflict in the 21st Century: The Information Revolution and Post-Modern Warfare. Publ. No. 2000/8. The Strategic Studies Institute, Carlisle Barracks PA, 113pp - http://tinyurl.com/q433tx5.

Metz, S. and Kievit, J. (1995). Strategy and the Revolution in Military Affairs: From Theory to Policy. The Strategic Studies Institute, Carlisle Barracks PA, 45pp. - http://tinyurl.com/pt24hwp.

Meulman, E.J.M., van Schaik, C.P. 2013. Orangutan tool use and the evolution of technology. (in) Tool Use in Animals:Cognition and Ecology, (eds.) Crickette M. Sanz, Josep Call and Christophe Boesch. Cambridge University Press, pp. 176-202 - http://tinyurl.com/phf6cp6.

Meyer, M., Arsuaga, J.-L., Filippo, C.d., Nagel, S., Aximu-Petri, A., Nikel, B., Martínez, I., Gracia, A., Bermúdez de Castro, J.M., Carbonell, E., Viola, B., Kelso, J., Prüfer, K., Pääbo, S. 2016. Nuclear DNA sequences from the Middle Pleistocene Sima de los Huesos hominins. Nature doi:10.1038/nature17405 - http://tinyurl.com/jylgqqg.

Meyer, M., Fu, Q., Aximu-Petri, A., Glocke, I., Nikel, B., Arsuaga, J.-L., Martinez, I., Gracia, A., Bermúdez de Castro, J.M, Carbonell, E., Pääbo, S. 2014. A mitochondrial genome sequence of a hominin from Sima de los Huesos. Nature 505, 403-406 - http://tinyurl.com/mswaenb

Meyer, M., Kircher, M., Gansauge, M.-T., Li, H., Racimo, F., Mallick, S., Schraiber, J.C., Jay, F., Prüfer, K., et al., Pääbo, S. 2012. A high-coverage genome sequence from an archaic Denisovan individual. Science 337(6098), 1028-1029 - http://tinyurl.com/qa8c8dn.

Mgladze, A., Lordkipanidze, D., Moncel, M.-H., Despriee, J., Chagelishvili, R., Nioradze, M., Nioradze, G. 2011. Hominin occupations at the Dmanisi site, Georgia, Southern Caucasus: raw materials and technical behaviours of Europe's first hominins. Journal of Human Evolution 60, 571-596 - http://tinyurl.com/lq4ty9c.

Middleton, M.R. (1999). De la gestión de la información a la gestión del conocimiento. *in* Information management to knowledge management: some perspectives on development. El Profesional de la Información, 8(5), 10-17. [ISSN: 1386-6710]. (Version in English prior to translation - http://sky.fit.qut.edu.au/~middletm/publicns/IM_KM_Eng.doc)

Miklós, V. 2013. The mechanical beauty of early automatons. io9 - http://tinyurl.com/l2nr3j7

Miles, D.B., Dunham, A.E. 1993. Historical perspectives in ecology and evolutionary biology: the use of phylogenetic comparative analyses. Annual Review of Ecology and Systematics 24, 587-619.

Miller, F.J. 2002. I=0 (Information has no intrinsic meaning). Information Research 8(1) - http://tinyurl.com/24p7ysf.

Miller, J.G. (1955) Toward a general theory for the behavioral sciences. The American Psychologist 10(9): 513-531.

Miller, J.G. (1971). Living systems. Currents in Modern Biology 4: 55-256.

Miller, J.G. (1978) Living systems. McGraw-Hill Book Co., New York.

Miller, J.G., Miller, J.L. (1990) Introduction: the nature of living systems. Behavioral Science 35: 157–163.

Mingers, J. 1992. The problems of social autopoiesis, International Journal of General Systems 21: 229–236..

Mingers, J. 1995. Self-Producing Systems: Implications and Applications of Autopoiesis. Plenum Press, New York.

Mingers, J. 2002. Can social systems be autopoietic? Assessing Luhmann's social theory, Sociological Review 50: 278–299.

Mingers, J. 2002a. Observing organizations: an evaluation of Luhmann's organization theory. (In) Bakken, T., Hernes, T. (eds.), Autopoietic Organization Theory: Drawing on Niklas Luhmann's Social Systems Perspective. Copenhagen Business School Press, pp. 103-122.

Mingers, J. 2004. Can Social Systems be Autopoietic? Bhaskar's and Giddens' Social Theories. Journal for the Theory of Social Behaviour 34: 403-427 http://tinyurl.com/7n547yp.

Ministry of Defence (1999). AP 3000 - British Air Power Doctrine, Third Edition. Ministry of Defence, London. - http://www.raf.mod.uk/airpower/doctrine/ap3000/.

Mitani, J.C., Watts, D.P., Amsler, S.J. 2010. Lethal intergroup aggression leads to territorial expansion in wild chimpanzees. Current Biology 20, R507-508 - - http://tinyurl.com/o36lefn.

Mitchell, J., Moura, A.C. de A. 2003. Capuchin monkeys. YouTube Video. 17:30 min - http://tinyurl.com/qftmwom.

Mithen, S. 2007. Did farming arise from a misapplication of social intelligence? Philosophical Transactions of The Royal Society B 362, 705-718 - http://tinyurl.com/2dy26tr.
Modha, D.S., Singh, R. 2010. Network architecture of the long-distance pathways in the macaque brain. Proceedings of the National Academy of Sciences, USA 107(30), 13485–13490 - http://tinyurl.com/9vte99c + supporting info. - http://tinyurl.com/9cch94z.
Moncel, M.-H., Despriee, J., Voinchet, Pl, Tissoux H., Moreno, D., Bahain, J.-J., Courcimault, G., Falaguères, C. 2013. Early evidence of Acheulean settlement in northwestern Europe – La Noira Site, a 700,000 year-old occupation in the center of France. PLoS ONE 8(11): e75529. doi:10.1371/journal.pone.0075529, 22 pp. - http://tinyurl.com/kjjfw5k
Montgomery, S.H. 2013. Primate brains, the 'island rule' and the evolution of *Homo floresiensis*. Journal of Human Evolution 65, 750-760 – http://tinyurl.com/mk5s6lw.
Montgomery, S.H., Capellini, I., Barton, R.A., Mundy, N.I. 2010. Reconstructing the ups and downs of primate brain evolution: implications for adaptive hypotheses and Homo floresiensis. BMC Biology 8(9), pp. 1-19 - http://tinyurl.com/m9ehmrd
Moore, B.C.J. 2003. Coding of sounds in the auditory system and its relevance to signal processing and coding in cochlear implants. Otology and Neurotology 24, 243-254 - http://tinyurl.com/cebldpy.
Moore, G.E. (1965). Cramming More Components onto Integrated Circuits. Electronics 38:8 - http://tinyurl.com/mr8co72.
Moore, G.E. (1997). An Update on Moore's Law. Intel Developer Forum Keynote, September 30, 1997, San Francisco. - http://tinyurl.com/28ypqku.
Moore, J.W., Obhik, S.S. 2012. Intentional binding and the sense of agency: a review. Consciousness and Cognition 21, 546-561 - http://tinyurl.com/9w4sq33.
Moore, M.W., Brumm, A. 2007. Stone artifacts and hominins in island Southeast Asia: New Insights from Flores, eastern Indonesia. Journal of Human Evolution 52, 85-102 - http://tinyurl.com/ny4ldkq.
Moore, M.W., Sutikna, T., Jatmiko, Morwood, M.J., Brumm, A. 2009. Continuities in stone flaking technology at Liang Bua, Flores, Indonesia. Journal of Human Evolution 57(5), 503-526 - http://tinyurl.com/kr5b56z.
Morgan, M.S. 2005. Experiments versus models: new phenomena, inference and surprise. Journal of Economic Methodology 12(2), 317–329 http://tinyurl.com/23mqm8l.
Morgenstern. O., (1951) Prolegomena to a Theory of Organization. USAF Project Rand Research Memorandum. ASTIA Document Number ATI 210734 - http://qss.stanford.edu/~godfrey/Morgenstern/prolegom.pdf
Morely, I. 2010. Conceptualising quantification before settlement: activities and issues underlying the conception and use of measurement. (in) The Archaeology of Measurement: Comprehending Heaven, Earth and Time in Ancient Societies. Morley, I., Renfrew, C. (Eds). Cambridge University Press, Cambridge, pp. 7 – 18 - http://tinyurl.com/2e9d74v.
Morwood, M.J., Brown, P., Jatmiko, Sutikna, T., Saptomo, E.W., Westaway, K.E., Due, R.A., Roberts, R.G., Maeda, T., Wasisto, S., Djubiantono, T. 2005. Further evidence for small-bodied hominins from the Late Pleistocene of Flores, Indonesia. Nature 437, 1012-1017 - http://tinyurl.com/jwfo3fw.
Morewood, M.J., Jungers, W.L. 2009. Conclusions: implications of the Liang Bua excavations for hominin evolution and biogeography. Journal of Human Evolution 57, 640-648 - http://tinyurl.com/ka67qqt

Morwood, J.J., Soejono, R.P., Roberts, R.G., Sutikna, T., Turney, C.S.M., Westaway, K.E., Rink, W.J., Zhao, J.-x., van den Bergh, G.D., Due, R.A., Hobbs, D.R., Moore, M.W., Bird, M.I., Fifield, L.K. 2004. Archaeology and age of a new hominin from Flores in eastern Indonesia. Nature 431,1087-1091. [included with Brown et al. 2004].

Morwood, J.J., Sutkina, T., Saptomo, E.W., Hobbs, D.R., Westaway, K.E. 2009. Preface: research at Liang Bua, Flores, Indonesia. Journal of Human Evolution 57, 537-449 - http://tinyurl.com/mhojtmn [Slow link].

Morowitz, H. J. 1968. Energy Flow in Biology: Biological Organization as a Problem in Thermal Physics. New York: Academic Press. 179 pp.

Morowitz, H.J. 1999. A theory of biochemical organization, metabolic pathways, and evolution. Complexity 4(6): 39-53 - http://tinyurl.com/lg9hqcj.

Morowitz, H.J., Smith, E. (2007) Energy flow and the organization of life. Complexity 13(1): 51-59 - .http://tinyurl.com/kdnmjsr

Morwood, M., van Oosterzee, P. 2007. The Discovery of the Hobbit: The Scientific Breakthrough that Changed the Face of Human History. Random House Australia, Milsons Point, NSW.

Morris, H. ????. Does entropy contradict evolution? Institute for Creation Research - http://tinyurl.com/mhxdt2l.

Morriss, P. 1987. Power: A Philosophical Analysis. 1987. Manchester University Press, Manchester - http://tinyurl.com/2c3o2m7.

Morsella, E, Berger, C.C., Krieger, S.K. 2011. Cognitive and neural components of the phenomenology of agency. Neurocase: The Neural Basis of Cognition 17 (3), 209-230 - http://tinyurl.com/bowlu4n.

Mosquera, M., Olle, A., Rodriguez, X.P. 2013. From Atapuerca to Europe: tracing the earliest peopling of Europe. Quaternary International 295, 130-137 - http://tinyurl.com/z8dmnx9.

Moss, M.W. 2002. Why Management Theory Needs Popper: The Relevance of Falsification. presented at the Developing Philosophy of Management Conference, 26-29 June 2002, organised by Reason in Practice, The Journal of Philosophy of Management and the Forum for European Philosophy. - http://tinyurl.com/23eqeky.

Mouck, T. (2000). Neural networks, scaffolded cognition and the institutions of financial accounting. Sixth Interdisciplinary Perspectives on Accounting Conference - 9 - 12th July 2000, Manchester, England. - http://tinyurl.com/328ycou.

Mouck, T. 2004. Ancient Mesopotamian accounting and human cognitive evolution. Accounting Historians Journal 31(2), 97-124 – [downloads entire issue: http://tinyurl.com/lwa5fb8].

Moulton, S.E., Higgins, M.J., Kapsa, R.M.I., Wallace, G.G. 2012. Organic bionics: a new dimension in neural communications. Advanced Functional Materials 22, 2003-2014.

Mounier, A., Condemi, S., Manzi, G. 2011. The stem species of our species: a place for the archaic human cranium from Ceprano, Italy. PLoS ONE 6(4), e18821. doi:10.1371/journal.pone.0018821, pp. 1-11 - http://tinyurl.com/kuzun5u.

Mounier, A., Lahr, M. 2016. Virtual ancestor reconstruction: revealing the ancestor of modern humans and Neandertals. Journal of Human Evolution 91, 57-72 - http://tinyurl.com/jk2xbgp.

Moura, A.C.de A. 2004. The capuchin monkey and the Caatinga dry forest: a hard life in a harsh habitat. PhD Thesis, Darwin College, University of Cambridge – 222 pp. + 15 a. - http://tinyurl.com/pajt8fw.

Moura, A.C. de A. 2007. Stone banging by wild capuchin monkeys: an unusual auditory display. Folia Primatologica 78, 36-45 - http://tinyurl.com/hte6xxr.
Moura, A.C.de A., Lee, P.C. 2004. Capuchin stone tool use in Caatinga dry forest. Science 306, 1909 - http://tinyurl.com/gve4bgy.
Moura, A.C.de A., Lee, P.C. 2010. Wild capuchins show male-biased feeding tool use. International Journal of Primatology 31, 457-570 - http://tinyurl.com/p28op5y.
Moussas, X. 2011. The Antikythera Mechanism: the oldest mechanical universe in its scientific milieu. (in) The Role of Astronomy in Society and Culture. (eds.) Valls-Gabaud, D., Boksenberg, A. Proceedings IAU Symposium No. 260, 2009, pp. 135-148 - http://tinyurl.com/mf5tp24.
Movius, H. L. 1944. Early man and Pleistocene stratigraphy in Southern and Eastern Asia. Harvard University, Peabody Museum papers 19(3). Cambridge: Peabody Museum.
Movius, H. L. 1948. The Lower Palaeolithic cultures of Southern and Eastern Asia. Transactions of the American Philosophical Society, 38: 329–426 - http://tinyurl.com/mam2fwr.
Muehlenbein, M.P., Flinn, M.V. 2011. Patterns and processes of human life history evolution. In: Flatt and Heyland, eds. Mechanisms of Life History Evolution. Oxford University Press, p. 153-168 - http://tinyurl.com/kjbrrph.
Müller, A. 2007. A brief history of the BCL: Heinz von Foerster and the Biological Computer Laboratory. In Muller, A, Muller, K. (Eds.) An Unfinished Revolution? Heinz von Foerster and the Biological Computer Laboratory (BCL), 1958–1976. Vienna: Edition Echoraum, pp. 276-302 - http://tinyurl.com/kfch888.
Muller, M.N., Wrangham, R.W. 2014. Mortality rates among Kanyawara chimpanzees. Journal of Human Evolution 66, 107-114
Mulligan, M.E. (1997-2005). Genetic transfer in bacteria. Biochemistry 4103: Prokaryotic Gene Regulation - Lecture Notes - http://tinyurl.com/28neeus [scroll down for links to Conjugation, Conjugation (II), Bacterial transformation, and Bacteriophage transduction].
Mullins, P. 1997. Polanyi's Participative Realism. Polanyiana 6:2 - http://tinyurl.com/lg5kyrc.
Mullins, P. (????). Michael Polanyi 1891-1976. Gospel and Culture. - http://www.deepsight.org/articles/polanyi.htm
Munz, P.. (2002). 'Popper, Karl Raimund 1902 - 1994'. Dictionary of New Zealand Biography, updated 11 December 2002 - http://www.dnzb.govt.nz/dnzb [search for Popper]
Murphey, D.K., Maunsell, J.H.R., Beauchamp, M.S., Yoshor, D. 2009. Perceiving electrical stimulation of identified human visual areas. Proceedings of the National Academy of Sciences, USA 106(13), 5389–5393 - http://tinyurl.com/c43uxq6
Murphy, B. and Moore, A. (2000). Sizing the Internet. White Paper - July 2000. Cyveillance - http://tinyurl.com/lbpjm24.
Musson, A.E. 1958. Newspaper printing in the Industrial Revolution. The Economic History Review, New Series 10(3) 411-426.
Muttoni, G., Scardia, G., Kent, D.V. 2013. A critique of evidence for human occupation of Europe older than the Jaramillo subchron (~1 Ma): comment on 'the oldest human fossil in Europe from Orce (Spain)' by Toro-Moyano et al. (2013). Journal of Human Evolution 65, 746-749 - http://tinyurl.com/n6k5tor.
Muuss, M. (????). History of Computing Information. US Army Research Lab - http://tinyurl.com/2esnzxh.
Myers, B.A. (1998). A Brief History of Human Computer Interaction Technology. ACM interactions. Vol. 5, no. 2, pp. 44-54 - http://tinyurl.com/2coleuf.

Myslewski, R. 2011. Happy 40th birthday, Intel 4004! The first of the bricks that built the IT world. The Register 15th November 2011 - httphttp://tinyurl.com/kuqqful
Nadarajan, G. 2007. Islamic automation: a reading of Al-Jazari's The Book of Ingenious Mechanical Devices (1206) - http://tinyurl.com/mu5e7ga.
Nadarajan, G. 2008. Islamic automation: Al-Jazari's Book of Knowledge of Ingenious Mechanical Devices. MuslimHeritage.com - http://tinyurl.com/7cp6drk.
Nagy, B., Farmer, J.D., Trancik, J.E., Gonzales, J.P. 2011. Superexponential long-term trends in information technology. Technological Forecasting & Social Change 78(8), 1356-1364 - http://tinyurl.com/ld6bnl7.
Nahab, F.B., Kundu, P., Gallea, C., Kakareka, J. Pursley, R., Pohida, T., Miletta, N., Friedman, J., Hallett, M. 2011. The neural processes underlying self-agency. Cerebral Cortex 2011, 2148-2155 - http://tinyurl.com/d4aow8m.
Nakamura, M., Corp, N., Fujioto, M., Fujita, S., Hanamura, S., Hayaki, H., Hosaka, K., Huffman, M.A., Inaba, A., Inoue, E., Itoh, N., Kutsukake, N., Kiyono-Fuse, M., Kooriyama, T., et al. 2013. Ranging behavior of Mahale chimpanzees: a 16 year study. Primates 54, 171-182 - http://tinyurl.com/ltjm2xd.
Napper, B. (1998). Computer 50: The University of Manchester Celebrates the Birth of the Modern Computer - http://tinyurl.com/23cnkjn.
Nave, C.R. (2005). Hyperphysics [as archived April 2, 2013 - http://tinyurl.com/kfgdbsy [Note: This is an excellent demonstration of a hypertext educational tool - see Nave (2000) for additional details.]
Nave, R. (2000). Doing it By the Numbers: Javascript Calculations in a Web-Based Instructional Material - Part of the Hyperphysics Project. presentation to American Association of Physics Teachers, Guelph, Canada, July 29 - August 2, 2000. - http://tinyurl.com/2c69qes.
Nechansky, H. (2010) The relationship between: Miller's living systems theory and Beer's viable systems theory. Systems Research 27: 97-112.
Neil, S.D. 1982. Brooks, Popper, and objective knowledge. Journal of Information Science 4, 33-39.
Nelson, T.H. (1965). A file structure for the complex, the changing and the indeterminate. ACM 20th National Conference, 1965 - http://tinyurl.com/kxudkba
Nelson, R.R. & Winter, S.G. 1982. An Evolutionary Theory of Economic Change. Belknap Press of Harard University Press, Campridge, Mass.
Neuneck, G., Alwardt, C. 2008. The revolution in military affairs, its driving forces, elements and complexity. Interdisciplinary Research Group on Disarmament, Arms Control and Risk Technolgies, Institute for Peace Research and Security Policy at the University of Hamburg, Working Paper No 13 - http://tinyurl.com/m3aq7aq.
Newman, J. 2012. Google's 'Project Glass' teases augmented reality glasses. Today @ PCWorld, 4 April 2012 - http://tinyurl.com/7nnz5kq.
Nickols, F. (2000). The Knowledge in Knowledge Management (KM). *in* J.W. Cortada and J.A. Woods, eds. The Knowledge Management Yearbook 2001-2002. Butterworth-Heinemann. - http://home.att..net/~nickols/Knowledge_in_KM.htm
Niiniluoto, I. (2007). Scientific Progress, (in) Zalta E.N. (ed.) The Stanford Encyclopedia of Philosophy (Spring 2009 Edition) - http://tinyurl.com/2d3zj6l.
Nijholt, A. 2011. Towards multimodal, multi-party, and social brain-computer interfacing. (in) A. Camurri, C. Costa, and G. Volpe (Eds.) 2012, INTETAIN 2011, Lecture Notes of the

Institute for Computer Sciences, Social Informatics and Telecommunications Engineering (LNICST) 78, pp. 12–17 - http://tinyurl.com/6tzkxpv.
Nirenberg, S., Pandarinath, C. 2012. Retinal prosthetic strategy with the capacity to restore normal vision. Proceedings of the National Academy of Sciences USA, doi: 10.1073/pnas.1207035109, 6 pp. - http://tinyurl.com/9ujghkq.
Nishida, T., Hiraiwa, M. 1982. Natural history of a tool-using behavior by wild chimpanzees in feeding upon wood-boring ants. Journal of Human Evolution 11, 73-99 http://tinyurl.com/nx2rm5b.
Nishii, I., Miller, S.M. 2010. Volvox: simple steps to developmental complexity? Current Opinion in Plant Biology 13(6), 646–653.
NISS. (1997). UDC in Brief, Directory of Network Services. - http://tinyurl.com/26oh8ps.
Nissen, H.J., et. al. (1993) A short history of proto-cuneiform., *from* Hans J. Nissen, Peter Damerow and Robert K. Englund, Archaic Bookkeeping. University of Chicago Press: Chicago. - http://tinyurl.com/2dqocpa. [Note: although still under development this Website provides a comprehensive history of cuneiform and the peoples that used it.]
Nitschke W, Russell MJ. 2009. Hydrothermal focusing of chemical and chemiosmotic energy, supported by delivery of catalytic Fe, Ni, Mo/W, Co, S and Se, forced life to emerge. Journal of Molecular Evolution 69: 481-496.
Nitschke, W., Russell, M.J. 2010. Just like the universe the emergence of life had high enthalpy and low entropy beginnings. Journal of Cosmology 10: 3200-3216 - http://tinyurl.com/4a9nn5a.
Nonaka, I. 1991. The Knowledge Creating Company. Harvard Business Review, November 1991. - http://tinyurl.com/l3qcl69
Nonaka, I. 1996. Knowledge has to do with truth, goodness, and beauty. *in* Dialog on Leadership: Conversation with Professor Ikujiro Nonaka, Tokyo, Japan, February 23, 1996 and with Claus Otto Scharmer. - http://tinyurl.com/272ab79.
Nonaka, I. and Takeuchi, H. 1995. The Knowledge Creating Company: How Japanese companies create the dynasties of innovation. New York: Oxford University Press.
Norton, C.J., Gao, W.L., Braun, D.R., Wu, X. 2010. Central-East China – a Plio-Pleistocene dispersal corridor: the current state of evidence for homin occupation. (in) C.J. Norton and D.R. Braun (eds.), Asian Paleoanthropology: From Africa to China and Beyond, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9094-2_12, © Springer Science+Business Media B.V. - http://tinyurl.com/onhyteg.
Notess, G.R. (1990?-2007). Search Engine Showdown: The Users' Guide to Web Searching. - http://www.searchengineshowdown.com//
Notess, G.R. 2002a. Search Engine Statistics: Database Total Size Estimates. Search Engine Showdown [March 4-6, 2002] - http://tinyurl.com/24tnqse.
Notess, G.R. 2002b. Google Now Claims 4+ Billion Documents. Search Engine Showdown [Nov. 6. 2002]. - http://tinyurl.com/232rts3.
Nousala, S. (2006). Tacit knowledge networks and their implementation in complex organizations. PhD Thesis, School of Aerospace, Mechanical & Manufacturing Engineering, RMIT University, Melbourne, Vic, Australia - http://tinyurl.com/lr82s2w.
Nousala, S., Hall, W.P. 2008. Emerging autopoietic communities – scalability of knowledge transfer in complex systems. First IFIP International Workshop on Distributed Knowledge Management (DKM 2008), Oct, 18-19, 2008, Shanghai - http://tinyurl.com/k6oa5g7.

Nousala, S., Hall, W.P., Hadgraft, R. 2011. Socio-technical systems for connecting social knowledge and the governance of urban action. 15th WMSCI, CENT Symposium, July 19-22, 2011, Orlando, Florida, USA - http://tinyurl.com/7qotalr.

Nousala, S., Miles, A., Kilpatrick, B., Hall, W.P. 2005. Building knowledge sharing communities using team expertise access maps (TEAM). Proceedings, KMAP05 Knowledge Management in Asia Pacific Wellington, N.Z. 28-29 November 2005. - http://tinyurl.com/ko3leeo.

Nousala, S., Miles, A., Kilpatrick, B., Hall, W.P. 2009. Building knowledge sharing communities using team expertise access maps (TEAM). International Journal of Business and Systems Research 3(3), 279-296 - http://tinyurl.com/o6nqkc9.

Nowell, A. 2010. Defining behavioral modernity in the context of neandertal and anatomically modern human populations. Annual Review Anthropology 39, 437-452

Noy, A. 2011. Bionanoelectronics. Advanced Materials 23, 807-820.

NPG 2010. Public statement from Nature Publishing Group regarding subscription renewals at California Digital Library (CDL). Nature.Com 9 June 2010 - http://tinyurl.com/k8zaf6r.

Nunberg, G. and Brownstein, D. [2001 - last indexed by Internet Archive on Apr. 18, 2001]. Timeline of the History of Information - http://tinyurl.com/7m9mgzc.

Nye, M.J. (1996). Scientific practice and politics: A preliminary look at Blackett and Polanyi in Manchester. Polanyiana, 5(2) - http://www.kfki.hu/~cheminfo/polanyi/9602/sci1.html.

Oberschulte, H. (1996). Organisatorische Intelligenz - Ein Vorschlag zur Konzeptdifferenzierung, in: Schreyögg, G., Conrad, P.: (eds.): Managementforschung, Band 6: Wissensmanagement. Berlin/New York 1996, p. 41-81 [not seen].

Odlyzko, A.M. 1994. Tragic loss or good riddance? The impending demise of traditional scholarly journals. [To be published in Intern. J. Human-Computer Studies (formerly Intern. J. Man-Machine Studies) and reprinted in "Electronic Publishing Confronts Academia: The Agenda for the Year 2000," Robin P. Peek and Gregory B. Newby, eds., MIT Press/ASIS monograph, MIT Press, 1995. Condensed version to appear in Notices Amer. Math. Soc., Jan. 1995] - http://tinyurl.com/2umfohx.

Odlyzko, A.M. 1994. 1999 The economics of electronic journals. *in* R. Ekman and R. E. Quandt, eds., Technology and Scholarly Communication, pp. 380-393, Univ. Calif. Press, http://www.dtc.umn.edu/~odlyzko/doc/economics.journals.pdf; earlier versions in First Monday 2(8) (August 1997) - http://www.firstmonday.dk/issues/issue2_8/odlyzko/and Journal of Electronic Publishing 4(1) (September 1998), http://www.press.umich.edu/jep/.

Odlyzko, A.M. 2012. The volume and value of information. International Journal of Communication 6, 920–935 - http://tinyurl.com/n22n8xe

O'Connor, J.J. and Robertson, E.F. (1999). Herman Hollerith *from* The MacTutor History of Mathematics Archive, School of Mathematics and Statistics, University of St Andrews, Scotland - http://tinyurl.com/2d9pqra.

O'Connor, J.J. and Robertson, E.F. (1999a). Alan Mathison Turing. The MacTutor History of Mathematics Archive, School of Mathematics and Statistics, University of St Andrews, Scotland - http://tinyurl.com/2ct7zmc.

O'Connor, J.J. and Robertson, E.F. 1999b. Archimedes of Syracuse. The MacTutor History of Mathematics Archive, School of Mathematics and Statistics, University of St Andrews, Scotland - http://tinyurl.com/7zu7ko4.

O'Connor, J.J. and Robertson, E.F. 1999c. Heron of Alexandria. The MacTutor History of Mathematics Archive, School of Mathematics and Statistics, University of St Andrews, Scotland – http://tinyurl.com/k6548hc
O'Connor, J.J. and Robertson, E.F. 1999d. Euclid of Alexandria. The MacTutor History of Mathematics Archive, School of Mathematics and Statistics, University of St Andrews, Scotland - http://tinyurl.com/mvd7hc2
Odhner, J.K. (????). Odhner Calculator Memorial Site. http://tinyurl.com/2d9nbcx.
Ogawa, H., Idani, G., Moore, J., Pintea, L., Hernandez-Aguilar, A. 2007. Sleeping parties and nest distribution of chimpanzees in the savanna woodland, Ugalla, Tanzania. International Journal of Primatology 28, 1397-1412 - http://tinyurl.com/n86nkag.
O'Grady, P. 2004. Thales of Miletus (c. 620 BCE – c. 546 BCE). Internet Encyclopedia of Philosophy - http://tinyurl.com/mxrbahh.
Ohtsuki H, Nowak, MA. 2009. Prelife catalysts and replicators. Proceedings of the Royal Society B 276, 3783–3790 - http://tinyurl.com/k7lcbsl.
Okasha, S. 2012. Emergence, hierarchy and top-down causation in evolutionary biology. Interface Focus 2, 49–54 – http://tinyurl.com/mlc3djw.
Ohashi, G. 2006. Behavioral repertoire of tool use in the wild chaimpanzees at Bossou. (in) Matsuzawa, T., Tomonaga, M., Tanaka, M. (eds). Cognitive Development in Chimpanzees. Springer, Tokyo, pp. 439-454.
Ollé, A., Mosquera, M., Rodríguez, X.P., de Lombera-Hermida, A., Garcia-Antón, M.D., García-Medrano, P., Peña, L., Menéndez, L., Navazo, M., Terradillos, M., Bargalló, A., Márquez, B., Sala, R., Carbonell, E. 2013. The Early and Middle Pleistocene technological record from Sierra de Atapuerca (Burgos, Spain). Quaternary International 295, 138-167 - http://tinyurl.com/l8ebk3p.
Oliver, J. and Perry, R. (2006). Definitely life but not definitively. Origins of Life and Evolution of Biospheres, 36(5):515–521 - http://tinyurl.com/lqb6ofh.
O'Malley, M.A., Simpson, A.G.B., Roger, A.J. 2013. The other eukaryotes in light of evolutionary protistology. Biology & Philosophy 28:299–330.
O'Neil, D. (2002). Synthetic Theory of Evolution: An Introduction to Modern Evolutionary Concepts and Theories. - http://anthro.palomar.edu/synthetic/.
Ong, J.M., da Cruz, L. 2012. The bionic eye: a review. Clinical and Experimental Ophthalmology 40, 6-17 - http://tinyurl.com/7o4k7nc.
Ong, W.J. 1982. Orality and Literacy: The Technologizing of the Word. Routledge, London [2002 ed. ebook –http://tinyurl.com/ledoljk].
Onunka, C., Bright, G. 2011. Robotics and the brain-computer interface system: critical review for manufacturing application. 4th Robotics and Mechatronics Conference of South Africa (ROBMECH 2011
Oparin, A.I. (1953). The Origin of Life. 2nd Ed. [1938 - with a new introduction by the translator]. Dover Publications, New York.
Oppenheimer, S. 2012. Out-of-Africa, the peopling of continents and islands: tracing uniparental gene trees across the map. Philosophical Transactions of the Royal Society B 367, 770-784 - http://tinyurl.com/9fkonax
O'Regan, H.J., Turner, A., Bishop, L.C., Lamb, A.L. 2011. Hominins without fellow travelers? First appearances and inferred dispersals of Afro-Eurasian large-mammals in the Plio-Pleistocene. Quaternary Science Reviews 30, 1343-1352 - http://tinyurl.com/louzap6.

Orgel, L.E. (1973). The Origins of Life: Molecules and Natural Selection. John Wiley & Sons, New York.

Orgel, L.E. (1994). The Origin of Life on the Earth, p 77-83 Scientific American, October 1994 - http://proxy.arts.uci.edu/~nideffer/Hawking/early_proto/orgel.html.

Orlando, L. 2014. A 400,000-year-old mitochondrial genome questions phylogenetic relationships amongst archaic hominins. Bioessays 36, 598–605 – http://tinyurl.com/k3asgfa

Orr, C.M., Tocheri, M.W., Burnett, S.E., R.D. Awe, Saptomo, E.W., Sutikna, T., Jatmiko, Wasisto, S., Morwood, M.J., Jungers, W.L. 2013. New wrist bones of Homo floresiensis from Liang Bua (Flores, Indonesia). Journal of Human Evolution 64, 109-129 - http://tinyurl.com/k99t5pr.

Osborne, W.B. et. al (1996). Information Operations: A New War-Fighting Capability. Air Force 2025. - http://www.maxwell.af.mil/au/2025/

Osinga, F.P. 2005. Science, Strategy and War: The Strategic Theory of John Boyd. Eburon Academic Publishers, Delft, Netherlands (also Routledge, Taylor and Francis Group (2007) – [download book: http://tinyurl.com/o8v4u23].

Osterloh, M. & Frost, J. 2000. Motivation in a Knowledge-Based Theory of the Firm. workshop "Learning, Incentives and Corporate Disaggregation: Theories and Methods for Understanding New Organizational Forms", organized by the "Learning, Incentives, and Knowledge" program, Copenhagen, 26-27 October 2000, Copenhagen Business School. - http://www.unizh.ch/ifbf/orga/downloads/publikationen/16Ost_Frost_LINKOctober.PDF.

Ottoni, E.B., Dogo de Resende, B., Izar, P. 2005. Watching the best nutcrackers: what capuchin monkeys (*Cebus apella*) know about others' tool-using skills. Animal Cognition 24, 215-219 - http://tinyurl.com/jhcg8ab.

Ottoni, E.B., Izar, P. 2008. Capuchin monkey tool use: overview and implications. Evolutionary Anthropology 17, 171-178 - http://tinyurl.com/jbbehxl.

Painkras, E., Furber, S. 2012. The impact of technology scaling in the SpiNNaker chip multiprocessor. Proceedings of the Seventh International Workshop on Unique Chips and Systems (UCAS'7) - February 26, 2012, New Orleans, Louisiana, USA, Pp. 20-27 - http://tinyurl.com/bpn6jr2

Pajares, F. (1998). Thomas Kuhn and scientific revolutions: A snapshot. The Philosophers' Magazine, 1(2), 30. - http://tinyurl.com/28ngsu7.

Palombo, M.R. 2013. What about causal mechanisms promoting early hominin dispersal in Eurasia? A research agenda for answering a hotly debated question. Quaternary International 295,13-27.

Panger, M.A., Brooks, A.S., Richmond, B.G., Wood, Bernard. 2002. Older than the Oldowan? Rethinking the emergence of hominin tool use. Evolutionary Anthropology 11, 235-245 - http://tinyurl.com/nlzl3b9.

Panger, M.A., Perry, S., Rose, L., Gros-Louis, J., Vogel, E., Mackinnon, K.C., Baker, M. 2002a. Cross-site differences in foraging behavior of white-faced capuchins (Cebus capucinus). American Journal of Physical Anthropology 119, 52-66 - http://tinyurl.com/kdjqcxg.

Papadopoulos, E., 2007. Heron of Alexandria. (in) Distinguished Figures in Mechanism and Machine Science, Their Contributions and Legacies, Springer Verlag, 217-245 - http://tinyurl.com/mcdnvu5.

Papathanassiou, M.K. 2010. Reflections on the antikythera mechanism inscriptions. Advances in Space Research 46, 545-551 - http://tinyurl.com/mpddxq5.

Pappu, S., Gunnell, Y., Akhilesh, K., Braucher, R., Taleb, M., Demory, F., Thouveny, N. 2011. Early Pleistocene presence of Acheulian hominins in South India. Science 1596-1599 - http://tinyurl.com/k47saan

Parés, J.M., Duval, M., Arnold, L.J. 2013. New views on an old move: Hominin migration into Eurasia. Quaternary International 295, 5-12 - http://tinyurl.com/ldrn5xd.

Parker, S.T., Gibson, K.R. 1977. Object manipulation, tool use and sensorimotor intelligence as feeding adaptations in cebus monkeys and great apes. Journal of Human Evolution 6, 623-641 - https://drive.google.com/open?id=0B2Z6nYMfgdWVUHJJcjROcFpEOHc.

Parviz, B.A. 2009. Augmented reality in a contact lens. IEEE Spectrum Sept. 2009 - http://tinyurl.com/l4ukfy

Pastore, G. 2010. Antikythera Calculator advances modern science of 19 centuries. Advances in Space Research. 46, 552-556 - http://tinyurl.com/q8eorjg.

Patajo, N.L. 1999. Winning Battlespace: The Command and Control Factor. OSS Digest 4.3 - http://tinyurl.com/d33v52o

Pattee, H.H. 1973. The physical basis and origin of hierarchical control. (in) Hierarchy Theory: The Challenge of Complex Systems. Ed. Pattee, H.H. George Braziller, New York, pp. 71-108Pattee, H.H. 1995. Evolving self-reference: matter, symbols, and semantic closure. Communication and Cognition - Artificial Intelligence, 12(1-2), 9-27. http://www.ws.binghamton.edu/pattee/sem_clos.html.

Pattee, H.H. 1977. Dynamic and Linguistic Modes of Complex Systems, International. Journal of General Systems 3, 259-266.

Pattee, H. H. 1995. Artificial life needs a real epistemology. In: Advances in Artificial Life. Moran, F., Moreno, A., Morelo, J. J., Chacon, P., (Eds.), Springer-Verlag, Berlin, pp. 23-38. http://tinyurl.com/k5gaxql.

Pattee, H.H. 1995a. Evolving self-reference: matter, symbols, and semantic closure. Communication and Cognition - Artificial Intelligence, 12(1-2), 9-27 - http://tinyurl.com/mdszkzy.

Pattee, H.H. 1996. The Problem of Observables in Models of Biological Organizations. In: Evolution, Order, and Complexity, Khalil, E.L., Boulding, K.E. (Eds.), Routledge, London. http://www.ws.binghamton.edu/pattee/boulding.html

Pattee, H.H. 1997. The physics of symbols and the evolution of semiotic controls. In: Workshop on Control Mechanisms for Complex Systems: Issues of Measurement and Semiotic Analysis, Las Cruces, New Mexico, Dec. 8-12,1996. To be published as Santa Fe Institute Studies in the Sciences of Complexity, Proceedings Volume, Addison-Wesley, Redwood City, CA, 1997. http://tinyurl.com/4fvve5

Pattee, H.H. 2000. Causation, control, and the evolution of complexity. (In) Anderson, P.B., Emmeche, C., Finnemann, N.O., Christiansen, P.V. (eds.), Downward Causation - Minds, Body and Matter. Arhus: Arhus University Press, pp. 63-77. http://tinyurl.com/42jksr

Pattee, H.H. (2001) Irreducible and complementary semiotic forms. Semiotica 134 (1-4), 341-358 - http://tinyurl.com/lpo99ze.

Pattee, H.H. 2001a. The physics of symbols: bridging the epistemic cut. Biosystems 60, 5-21 - http://tinyurl.com/lyed3u6.

Pattee, H. (2005) The physics and metaphysics of biosemiotics. Journal of Biosemiotics 1, 281-301 - http://tinyurl.com/logq5n5.

Pattee, H.H. 2006. The physics of autonomous biological information. Biological Theory 1(3), 224-226.

Pattee, H.H. 2007. The necessity of biosemiotics: matter-symbol complementarity. Introduction to Biosemiotics, Marcello Barbieri, Ed., Springer, Dordrecht, The Netherlands, 2007, pp. 115-132 - http://tinyurl.com/mjdxbov.
Pattee, H.H. 2007a. Laws, constraints, and the modeling relation – history and interpretations. Chemistry & Biodiversity 4(10), 2272-2295.
Pattee, H.H. 2008. Physical and functional conditions for symbols, codes, and languages. Biosemiotics 1(2), 147-168 - http://tinyurl.com/lqx6yzg.
Pattee, H.H. 2013. Epistemic, evolutionary, and physical conditions for biological information. Biosemiotics 6(1), 9-31 - http://tinyurl.com/mu7gfyt.
Patten, B.C., Straskraba, M. & Jorgensen, S.E. (1997). Ecosystems emerging: 1—Conservation. Ecol. Model. 96:221–284 - http://tinyurl.com/n6zbugg.
Patterson, J. (1996?). The history of computers during my lifetime. - http://tinyurl.com/2cjcms7.
Patton, P. 1994. Foucault's Subject of Power. Political Theory Newsletter , 6(1):60-71 - http://tinyurl.com/2683ev8.
Pauli, W. (1950). Die philosophische Bedeutung der Idee der Komplementaritat. Experientia 6, 72-81, [English translation (in) Enz, C.P., von Meyenn, K. (eds.), Wolfgang Pauli. Writings on Physics and Philosophy, Springer, Berlin, 1994, pp. 35-42].
Pauli, W. (1952) Der Einfluss archetypischer Vorstellungen auf die Bildung naturwissenschaftlicher Theorien bei Kepler. In Jung, C.G. and Pauli, W. (eds.), Naturerklarung und Psyche, Rascher, Zurich, pp. 109-194. [English translation (in) Enz, C.P., von Meyenn, K. (eds.), Wolfgang Pauli. Writings on Physics and Philosophy, Springer, Berlin 1994, pp. 219-279].
Pavia, M., Zunino, M., Coltorti, M., Angelone, C., Arzarello, M., Bagnus, C., Belluci, L., Colombero, S., Marcolini, F., Peretto, C., Petronio, C., Petrucci, M., Pieruccini P., et al. 2012. Stratigraphical and palaeontological data from the Early Pleistocene Pirro 10 site of Pirro Nord (Puglia, south eastern Italy). Quaternary International 267, 40-55 - http://tinyurl.com/lx6dl4y
Pawlowsky, P. 2001. Management Science and Organizational Learning. *in* Dierkes et al. (Eds). Handbook of Organizational Learning and Knowledge. Oxford University Press. - http://www.tu-chemnitz.de/wirtschaft/bwl6/habilitation/orga_learning.pdf
Penrose, R. 1989. The Emperor's New Mind: Concerning Computers, Minds and the Laws of Physics. Oxford University Press, New York.
Penrose, R. 1994. Shadows of the Mind: A Search for the Missing Science of Consciousness. Oxford University Press, New York.
Pecon-Slattery, J. 2014. Recent advances in primate phylogenomics. Annual Review of Animal Biosciences 2, 41-63 - http://tinyurl.com/pvjxrnd.
Pepperell, R. 1995. The Post-Human Condition. Exeter, UK: Intellect Books.
Perelman, P., Johnson, W.E., Roos, C., Seuánez, H.N., Horvath, J.E., Moreira, M.A.M., Kiessing, B., Pontius, J., Roelke, M., Rumpler, Y., Schneider, M.P.C., Silva, A., O'Brien, S.J., Pecon-Slattery, J. 2011 A molecular phylogeny of living primates. PLoS Genet 7(3): e1001342. doi:10.1371/journal.pgen.1001342 - http://tinyurl.com/mb8pfts.
Perez, S.I., Tejedor, M.F., Novo, N.M., Aristide, L. 2013. Divergence times and evolutionary radiation of New World monkeys (Platyrrhini, Primates): An analysis of fossil and molecular data. PLoS ONE 8(6): e68029. doi:10.1371/journal.pone.0068029, 16 pp. - http://tinyurl.com/oexgqh9

Perry, S. 2006. What cultural primatology can tell anthropologists about the evolution of culture. Annual Review of Anthropology 35: 171-190 - http://tinyurl.com/7v63nfl.

Perry, S. 2011. Social traditions and social learning in capuchin monkeys (*Cebus*). Philosophical Transactions of the Royal Society B. 366, 988-996 - http://tinyurl.com/q8a6jsn.

Perry, J.M.G., Kay R.F., Vizcaíno, S.F., Bargo, M.S. 2014. Oldest known cranium of a juvenile New World monkey (Early Miocene, Patagonia, Argentina): Implications for the taxonomy and the molar eruption pattern of early platyrrhines. Journal of Human Evolution 74, 67-81 - http://tinyurl.com/gsx5r6b.

Petersen, D.C., Libiger, O., Tindall, E.A., Hardie, R.-A., Hannick, L.I., Glashoff, R.H., Mukerji, M., Indian Genome Variation Consortium, Fernandez, P., Haacke, W., Schork, N.J., Hayes, V.M. 2013. Complex patterns of genomic admixture within Southern Africa. PLoS Genetics 9(3), e1003309. doi:10.1371/journal.pgen.1003309 - http://tinyurl.com/kfeajem.

Petraglia, M.D. 2010. The Early Paleolithic of the Indian subcontinent: hominin colonization, dispersals and occupation history. (in) J.G. Fleagle et al. (eds.), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_11, © Springer Science+Business Media B.V., pp. 165-179 - http://tinyurl.com/kxzn8nx

Petrie, M. (1999-2004). A Potted History of Wordstar. *in* WordStar Resource Site! - http://tinyurl.com/lu9kodj

Philippe, H., Derelle, R., Lopez, P., Pick, K., Borchellini, C., Bourey-Esnault, N., Vacelet, J., Renard, E., Houliston, E., Quéinnec, E., et al. 2009. Phylogenomics revives traditional views on deep animal relationships. Current Biology 19, 1–7 - http://tinyurl.com/mzr3ln6http://tinyurl.com/7xtb3tb.

Philp, W, Martin C, 2009. A philosophical approach to time in military knowledge management. Journal of Knowledge Management 13(1): 171-183 - http://tinyurl.com/mfkhpwl.

Philips, H. 2010. The Great Library of Alexandria? Library Philosophy and Practice 2010 (e-journal), 22 pp. - http://tinyurl.com/ob2sef8

Pickering, T.R. 2012. What's new is old: Comments on (more) archaeological evidence of one-million-year-old fire from South Africa. S Afr J Sci. 2012;108(5/6), no. 1250, 2 pages - http://tinyurl.com/5odkq4

Pickering, R., Dirks, P.H.G.M., Jinnah, Z., de Ruiter, D.J., Churchil, S.E., Herries, A.I.R., Woodhead, J.D., Hellstrom, J.C., Berger, L.R. 2011. *Australopithecus sediba* at 1.977 ma and implications for the origins of the genus *Homo*. Science 333, 1420-1423 - http://tinyurl.com/mja5426.

Pickering, T.R., Dominguez-Rodrigo. 2010. Chimpanzee referents and the emergence of human hunting 3, 107-113 - http://tinyurl.com/kemxbv2

Pickrell, J., Reich, D. 2014. Towards a new history and geography of human genes informed by ancient DNA. bioRxiv doi: 10.1101/003517 - http://tinyurl.com/ny5cvpr.

Pievani, T. 2011. Born to cooperate? Altruism as exaptation and the evolution of human society. (in) R.W. Sussman, C.R. Cloninger (eds.), Origins of Altruism and Cooperation, Developments in Primatology: Progress and Prospects 36, DOI 10.1007/978-1-4419-9520-_4, Springer Science+Business Media, LLC.

Pilot, M.J. 1999. Occupational Outlook Handbook: a review of 50 years of change. Monthly Labor Review, May 1999, 8-26 -http://tinyurl.com/pkkbhw9.

Pinyon, J.L., Tadros, S.F., Froud, K.E., Wong, A.C.Y., Thompson, I.T., Crawford, E.N., Ko, M., Morris, R., Klugmann, M., Housley, G.D. 2014. Close-field electroporation gene delivery using the cochlear implant electrode array enhances the bionic ear. Science Translational Medicine 6, 233ra54 - http://tinyurl.com/pjh6oyl

Pinotsis, A.D. 2007. The Antikythera mechanism: who was its createor and what was its use and purpose. Astronomical and Astrophysical Transactions 26(4-5), 211-216.

Pleše, B. 2012. The cyborg pocket. Humanity+Newsletter, 20 June 2012 - http://tinyurl.com/nybc7rv.

Plotkin, H. (1994). Darwin Machines and the Nature of Knowledge. Harvard University Press, Cambridge, MA - http://tinyurl.com/2d942qq.

Plummer, T. 2004. Flaked stones and old bones: biological and cultural evolution at the dawn of technology. Yearbook of Physical Anthropology 47, 118-164 - http://tinyurl.com/k5q7od5.

Pobiner, B.L., Rogers, M.J., Monahan, C.M., Harris, J.W.K. 2008. New evidence for hominin carcass processing strategies at 1.5 Ma, Koobi Fora, Kenya. Journal of Human Evolution 55, 103-130.

Pohlmeyer, E.A., Wang, J., Jangraw, D.C., Lou, B., Chang, S.-F., Sajda, P. 2011. Closing the loop in cortically-coupled computer vision: a brain–computer interface for searching image databases. Journal of Neural Engineering 8, no. 036025, 14 pp. - http://tinyurl.com/d4qwu35

Polad, E., Twena, Y., Freiberg, D. and Elizov, G. (????). A Short History of Computers - http://tinyurl.com/mj8vqyt.

Polsson, K. (2001). Chronology of Events in the History of Microcomputers 1966-1979 - http://tinyurl.com/2afwkjk.

Polanyi M. 1958: Personal Knowledge: Towards a Post-Critical Philosophy. University of Chicago Press, 428 pp.

Polanyi M. (1966): The Tacit Dimension. Doubleday & Co.

Pollick, A.S., de Waal, B.M. 2007. Ape gestures and language evolution. Proceedings of the National Academy of Sciences USA 104(19), 8184-8189 - http://tinyurl.com/8sgkdbp.

Pontzer, H. 2012. Ecological energetic in early *Homo*. Current Anthropology 53(S6), S346-S358 - http://tinyurl.com/m944llb.

Pontzer, H., Rolian, C., Rightmire, G.P., Jashashvili, T., Ponce de Leon, M.S., Lordkipanidze, D., Zollikofer, C.P.E. 2010. Locomotor anatomy and biomechanics of the Dmanisi hominins. Journal of Human Evolution 58, 492-504 - http://tinyurl.com/khogog7.

Pontzer, H., Scott, J.R., Lordkipanidze, D., Ungar, P.S. 2011. Dental microwear texture analysis and diet in the Dmanisi hominins. Journal of Human Evolution 61, 683-687 - http://tinyurl.com/knlvdsk.

Poole, AM, Jeffares DC, Penny D. 1998. The path from the RNA world. Journal of Molecular Evolution 46: 1-17 - http://tinyurl.com/ktoplr6.

Poole, AM. 2006. Getting from an RNA world to modern cells just got a little easier. BioEssays 28:105–108.

Poon, C.-S. and Zhou, K. 2011. Neuromorphic silicon neurons and large-scale neural networks: challenges and opportunities. Frontiers in Neuroscience 5, no 108, pp 1-3. doi: 10.3389/fnins.2011.00108 - http://tinyurl.com/6vw4bhs

Popov, S.V., Shcherba, R.G., Ilyina, L.B., Nevsskaya, L.A., Paramonova, N.P., Khondkarian, S.O., Magyar, I. 2006. Late Miocene to Pliocene paleogeography of the Paratethys and its relation to the Mediterranean. Paleogeography, Palaeoclimatology, Paleoecology 238, 91-106 - http://tinyurl.com/z2925ub

Popper, K.R. (1945) The Poverty of Historicism. Routledge & Kegan Paul, London; Golden Jubilee Edition, Single volume version Routledge, 1995.
Popper, K.R. (1934, 1959). The Logic of Scientific Discovery, Sixth Impression (Revised) [First English Ed., Hutchinson, 1959. First published as Logik Der Forschung in Vienna: Springer, 1934]. London, Hutchinson & Co., Ltd., 480 pp - http://tinyurl.com/my7j6xb.
Popper, K.R. (1963). Conjectures and Refutations: The Growth of Scientific Knowledge, 4th Ed. (Revised) [1st Ed., 1963]. London, Routledge and Kegan Paul, 431 pp. - http://tinyurl.com/kes6msc
Popper, K.R. 1972. Objective Knowledge: An Evolutionary Approach. London, Oxford Univ. Press, 380 pp.
Popper, K.R. 1976. Unended Quest, Fontana Paperbacks; Routledge, London.
Popper, K.R. 1976a. A note on verisimilitude. British Journal of the Philosophy of Science. 27, 147-164.
Popper, K.R. 1978. Three worlds. The Tanner Lecture on Human Values. Delivered at The University of Michigan, April 7, 1978 - http://tinyurl.com/57j86j.
Popper, K.R. 1982. Postscript to the Logic of Scientific Discovery [in three volumes]. Bartley, W.W. (Ed.), Hutchinson.
Popper, K.R. 1986. The epistemological position of evolutionary epistemology. (in) Popper, K., All Life Is Problem Solving. Camiller, P. (Translator). Routledge, London (1999).
Popper, K.R. 1994 [1969]. Knowledge and the Body-Mind Problem: In Defence of Interaction (ed. Notturno, M.A.). Routledge, London.
Popper, K.R. 1999. All Life is Problem Solving. Routledge, London.
Popper, K.R., Eccles, J.C. (1977). The Self and its Brain: An Argument for Interactionism. Routledge & Kegan Paul, London.
Pór , G. 1997. Data to wisdom curve *in* designing knowledge ecosystems for virtual communities of practice. A presentation at the Institute for Research on Learning, 10 June 1997. - http://tinyurl.com/2a5e42b.
Postgate, N. 2005. New angles on early writing. Cambridge Archeological Journal 15, 275-280.
Potts, D.T. 2000. Before Alexandria: Libraries in the Ancient Near East. *In* The Library of Alexandria: Centre of Learning the Ancient Near East, MacLeod, R. (ed.), 19-33. London: I.B. Tauris.
Potts, R. 2004. Paleoenvironmental basis of cognitive evolution in great apes. American Journal of Primatology 62, 209–228 - http://tinyurl.com/javtluh.
Potts, R. 2012. Evolution and environmental change in early human prehistory. Annual Review of Anthropology 41, 151-167 - http://tinyurl.com/jxdcx3e.
Potts, R. 2013. Hominin evolution in settings of strong environmental variability. Quaternary Science Reviews 73, 1-13 - http://tinyurl.com/hns5dpe.
Potts, R. 2013a. Environmental and behavioral evidence pertaining to the evolution of early Homo. Current Anthropology 53(S6), S229-S317 - http://tinyurl.com/mcnje6c.
Potts, R., Teague, R. 2010. Behavioral and environmental background to 'Out-of-Africa 1' and the arrival of *Homo erectus* in East Asia. (in) J.G. Fleagle et al. (eds.), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_5, © Springer Science+Business Media B.V., pp. 67-85
Powell, J.R. 2008. The quantum limit to Moore's Law. Proceedings of the IEEE 96(8), 1247-1248 - http://tinyurl.com/la8sys8.
Power, D. J. 2004. A Brief History of Spreadsheets" - http://tinyurl.com/2fhr26h.

Poznik, G.D., Henn, B.M., Yee, M.-C., Sliwerska, E., Euskirchen, G.M., Lin, A.A., Snyder, M., Qintana-Murci, L., Kidd. J.M., Underhill, P.A., Bustamante, C.D. 2013. Sequencing Y chromosomes resolves discrepancy in time to common ancestor of males versus females. Science 341, 562-565 http://tinyurl.com/mu67v4u.

Pozzi, L., Hodgson, J.A., Burrell, A.S., Sterner, K.N., Raaum, R.L., Disotell, T.R. 2014. Primate phylogenetic relationships and divergence dates inferred from complete mitochondrial genomes. Molecular Phylogenetics and Evolution 75, 165-183 - http://tinyurl.com/ovascbm.

Prat, S., Brugal, J.-P., Tiercelin, J.-J., Barrat, J.-A., Bohn, M., Delagnes, A., Harmand, S., Kimeau, K., Kibunjia, M., Texier, P.-J., Roche, H. 2005. First occurrence of early Homo in the Nachukui Formation (West Turkana, Kenya) at 2.3-2.4 Myr. Journal of Human Evolution 49, 230-240 - http://tinyurl.com/nulbvrd.

Presnyakov, S.L., Belyaeva, E.V., Lyubin, V.P., Rodionov, N.V., Antonov, A.V., Saltykova, A.K., Brezhnaya, N.G., Sergeev, S.A. 2012. Age of earliest Paleolithic sites in the northern part of the Armenian Highland by SHRIMP-II U-Pb geochronology of zircons from volcanic ashes. Gondwana Research 21, 928-938 – http://tinyurl.com/pxctskk

Price, D.J.de S. 1959. An Ancient Greek Computer. Scientific American, June 1959: pp 60-67 - http://tinyurl.com/lmfox6g

Price, D. de S. 1974. Gears from the Geeks. The Antikythera Mechanism: a calendar computer from ca. 80 B.C. Transactions of the American Philosophical Society N.S. 64(7), 1-70.

Price, E.E., Lambeth, S.P., Shapiro, S.J., Whiten, A. (2009). A potent effect of observational learning on chimpanzee tool construction. Proceedings of the Royal Society B 276, 3377-3383 - http://tinyurl.com/6wy9vgb.

Prigg, M. 2012. Inside the internet: Google allows first ever look at the eight vast data centres that power the online world. MailOnline, 17 October 2012 - http://tinyurl.com/n8h9j3p.

Prigogine, I.. (1945). Etude thermodynamique des phénomines irreversibles, These. Bruxelles, 1945; published by Desoer, Liege, 1947. [not seen].

Prigogine, I. 1955. Introduction to the Thermodynamics of Irreversible Processes. C.C. Thomas, Springfield, Illinois.

Prigogine, I. (1977). Time, Structure and Fluctuations. Nobel Lecture, December 8, 1977. *From* Nobel Lectures, Chemistry 1971-1980. - http://tinyurl.com/m5zltur.

Prigogine, I. (1997). Non-linear Science and the Laws of Nature. J. Franklin Inst. Vol. 334B, No. 5/6, pp. 745-758. [Science Direct].

Prigogine, I. (1999). Laws of Nature, Probability and Time Symmetry Breaking. Physica A 263: 528-539. [Science Direct].

Prigogine, I. (2000). The Norbert Wiener Memorial Gold Medal address: Norbert Wiener and the idea of contingence. Kybernetes 29 No. 7/8, pp. 825-834. [Emerald Fulltext]

Prigogine, I. & Antoniou, I. (2000). Science, Evolution and Complexity. p. 21-36 in "Genetics in Europe - Open days 2000 (GEOD 2000)", Sommet européen, Bruxelles, 16 novembre 2000. - http://www.tyrrhenum..unisi.it/prigogine.doc

Prigogine, I., Nicolas, G., Babloyantz, A. (1972). Thermodynamics of Evolution, Physics Today, 23:11:23-28, 23:12:38-44.

Pringle, H. (1998). The Slow Birth of Agriculture. Science 282: 1446. - http://www.sciencemag.org/cgi/content/full/282/5393/1446

Pringle, H. (1998a). Reading the Signs of Ancient Animal Domestication. Science 282: 1448 - http://www.sciencemag.org/cgi/content/full/282/5393/1448

Pritchard, D. 2007. Recent work on epistemic value. American Philosophical Quarterly 44(2), 85-110 - http://tinyurl.com/24tnx95.
Pritchard, D. 2009. Knowledge, understanding and epistemic value. Royal Institute of Philosophy Supplement, no. 64, 19-43 - http://tinyurl.com/27445e4.
Prömmel, K., Cubasch, U., Kaspar, F. 2013. A regional climate model study of the impact of tectonic and orbital forcing on African precipitation and vegetation. Palaeogeography, Palaeoclimatology, Palaeoecology 369, 154-162 - http://tinyurl.com/h7bblce.
Pross, A. 2003. The driving force for life's emergence: kinetic and thermodynamic considerations. Journal of Theoretical Biology 220, 393–406 - http://tinyurl.com/233zsl6.
Pross, A. (2005) On the emergence of biological complexity: Life as a kinetic state of matter. Origins of Life and Evolution of Biospheres 35(2):151-66 - http://tinyurl.com/l8a3qqq.
Pross, A. (2009). Seeking the chemical roots of Darwinism: bridging between chemistry and biology. Chemistry-A European Journal 15(34): 8374-8381 - http://tinyurl.com/lzdtzto.
Pross, A., Khodorkovsky, V. (2004) Extending the concept of kinetic stability: toward a paradigm for life. Journal of Physical Organic Chemistry 17: 312–316 - http://tinyurl.com/kq9rfnw.
Prothero, D.R., (1992). Punctuated Equilibrium at Twenty: A Paleontological Perspective. Skeptic 1.3: 38-47 - http://tinyurl.com/khs4o54.
Pruetz, J.D., Bertolani, P. 2007. Savanna chimpanzees, *Pan troglodytes verus*, hunt with tools. Current Biology 17(5), 412-417 - http://tinyurl.com/qc98wqj.
Pruetz, J.D., Bertolani, P. 2009. Chimpanzee (*Pan troglodytes verus*) behavioral responses to stresses associated with living in a savanna-mosaic environment: implications for hominin adaptations to open habitats. PaleoAnthropology 2009, 252-262 - http://tinyurl.com/mqspk7a
Prüfer, K., Munch, K., Hellmann, I., Akagi, K., Miller, J.R., Walenz, B., Koren, S., Sutton, G., Kodira, C., Winer, R., et al. 2012. The bonobo genome compared with the chimpanzee and human genomes. Nature, doi:10.1038/nature11128 - http://tinyurl.com/9os7ewn.
Prüfer, K., Racimo, F., Patterson, N., Jay, F., Sankararaman, S., Sawyer, S., Heinze, A., Renaud, G., Sudmant, P.H., de Filippo, C., Li, H., et al., Pääbo, S. 2014. The complete genome sequence of a Neanderthal from the Altai Mountains. Nature 505, 43–49 – http://tinyurl.com/kfdn5s4
Pugach, I., Delfin, F., Gunnarsdóttir, E., Kayser, M., Stoneking, M. 2013. Genome-wide data substantiate Holocene gene flow from India to Australia. Proceedings of the National Academy of Sciences, USA, http://tinyurl.com/kyztszz, 6 pp.
Quigley, E. J. and Debons, A. (1999), 'Interrogative Theory of Information and Knowledge'. *in* Proceedings of SIGCPR '99, ACM Press, New Orleans, LA., pp. 4-10. - http://www1.acm.org/pubs/articles/proceedings/cpr/299513/p4-quigley/p4-quigley.pdf [http://Web.archive.org/Web/20000818143558/http://www.acm.org/pubs/articles/proceedings/cpr/299513/p4-quigley/p4-quigley.pdf]
Raggett, D., (1998). A History of HTML. Chapter 2, HTML 4. Addison Wesley Longman - http://tinyurl.com/24zcdn6.
Raghaven, M., Skoglund, P., Graf, K.E., Metspalu, M., Albrechtsen, A., Moltke, I., Rasmussen, S., Stafford, T.W., Jr, Orlando, L., Metspalu, E., et al. 2014. Upper Palaeolithic Siberian genome reveals dual ancestry of Native Americans. Nature 214, 87-91 - http://tinyurl.com/kce59e2.

Ramachandran, S., Deshpande, O., Roseman, C.C., Rosenberg, N.A., Feldman, M.W., Cavalli-Sforza, L.L. 2005. Support from the relationship of genetic and geographic distance in human populations for a serial founder effect originating in Africa. Proceedings of the National Academy of Sciences 102(44), 15942-15947 - http://tinyurl.com/kov95vq.

Randell, B. 1994. The origins of computer programming. IEEE Annals of the History of Computing 16(4), 6-14 - http://tinyurl.com/737dhkb.

Rasmussen, M, Anzick, SL, Waters, MR, Skoglund, P, DeGiorgio, M, Stafford jr., T, Rasmussen, S, Moltke, I, Albrechtsen, A, Doyle, SM, Poznik, GD, Gudmundsdottir, V, Yadav, R, et.al. 2014. The genome of a Late Pleistocene human from a Clovis burial site in western Montana. Nature 506, 225-229 - http://tinyurl.com/kjrkzzo.

Rasmussen, M., Guo, X., Wang, Y., Lohmueller, K.E., Rasmussen, S., Albrechtsen, A., Skotte, L., Lindgreen, S. Metspalu, M., Jobart, T., et al. 2011. An aboriginal Australian genome reveals separate human dispersals into Asia. Science 334, 94-98 http://tinyurl.com/n8nk6h3.

Rasmussen, S., Chen, L., Stadler, B.M.R., & Stadler, P.F. (2002). Proto-Organism Kinetics: Evolutionary Dynamics of Lipid Aggregates with Genes and Metabolism. Santa Fe Institute Working Paper. - http://www.santafe.edu/sfi/publications/wpabstract/200210054

Rasmussen, S., Chen, L., Nilsson, M., Abe, S. (2003) Bridging nonliving and living matter. Artificial Life 9(3):269-316 - http://tinyurl.com/lyfagts.

Redin, J. (2000). The Doctor and his Calculators. - http://tinyurl.com/mzo4mxe.

Reich, D. 2011. Evidence for at least four human dispersals between Africa and Eurasia. (in) Derevianko, A.P., Shunkov, M.V. (eds), Characteristic Features oof the Middle to Upper Paleolithic Transition in Eurasia. [see book].

Reich, D., Green, R.E., Kircher, M., Krause, J., Patterson, N., Durand, E.Y., Viola, B., Griggs, A.W., Stenzel, U., et al., Pääbo, S. 2010. Genetic history of an archaic hominin group from Denisova Cave in Siberia. Nature 468, 1053-1060 - http://tinyurl.com/noqwckt; Supplementary information - http://tinyurl.com/9usxf9a

Reich, D., Patterson, N., Kircher, M., Delfin, F., Nandineni, M.R., Pugach, I., Ko, A. M.-S., Ko, Y.-C., Jinam, T.A., Phipps, M.E., et al. 2011. Denisovan admixture and the first modern dispersals into southeast Asia and Oceania. American Journal of Human Genetics 89, 516-528 - http://tinyurl.com/kuyr5a7.

Reimann, A. (2001). COBOL, Language of Choice – Then and Now: Looking back to get a glimpse at the future - http://tinyurl.com/236usna.

Reiner, J.M. 1968. The Organism as an Adaptive Control System. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Rennie, D. 1990. Editorial peer review in biomedical publication: the first international congress. JAMA 263(10), 1317.

Reyes-Centeno, H 2016. Out of Africa and into Asia: fossil and genetic evidence on modern human origins and dispersals. Quaternary International http://dx.doi.org/10.1016/j.quaint.2015.11.063, 14 pp. - http://tinyurl.com/hjo99hu

Reyes-Centeno, H., Ghirotto, S., Detroit, F., Grimaud-Herve, D., Barbujani, G., Harvati, K. 2014. Genomic and cranial phenotype data support multiple modern human dispersals from Africa and a southern route into Asia. Proceedings of the National Academy of Sciences 111(20), 7248–7253 - http://tinyurl.com/mqve957.

Reynolds, T.S. (1983). Stronger Than a Hundred Men: A History of the Vertical Water Wheel. Johns Hopkins University Press, Baltimore, MD - http://tinyurl.com/266hrcc.

Reynolds, B.E. 1993. The algorists vs. the abacists: an ancient controversy on the use of calculators. The College Mathematics Journal 24(3), 218-223.

Rice, R.R. (1995). The Antikythera Mechanism: Physical and Intellectual Salvage from the 1st Century B.C. USNA Eleventh Naval History Symposium. - http://tinyurl.com/mlgbv9q

Richerson, P.J., Boyd, R., Bettinger, R.L. 2009. Cultural innovations and demographic change. Human Biology 81(2-3), 211-235 - http://tinyurl.com/2vdvy5t.

Richerson, P.J., Boyd, R., Henrich, J. 2010. Gene-culture coevolution in the age of genomics. Proceedings of the National Academy of Sciences USA, 107, Suppl. 2, 8985-8992 - http://tinyurl.com/966xjsl

Richmond, S. (1998). The Two Cultures Problem. Twentieth World Congress of Philosophy, in Boston, Massachusetts from August 10-15, 1998 as published in the The Paideia Archive - http://www.bu.edu/wcp/Papers/Scie/ScieRich.htm.

Richter, J., Hauck, T., Vogelsang, R., Widlok, T., Le Tensorer, J.-M., Schmid, P. 2012. "Contextual areas" of early Homo sapiens and their significance for human dispersal from Africa into Eurasia between 200 ka and 70 ka. Quaternary International 274, 5-24 - http://tinyurl.com/k6k4zcs

Rieger, R., et. al. 1976. Glossary of Genetics and Cytogenetics: Classical and Molecular. 4th Edition. Springer-Verlag, Berlin. 647pp

Riegler, A. 2001. The cognitive ratchet – the ratchet effect as a fundamental principal in evolution and cognition. Cybenetics and Systems 32, 411-427 - http://tinyurl.com/k7lyh7r.

Riggs, W. 2006. The value turn in epistemology, (in) New Waves in Epistemology, (eds.) V. Hendricks & D. H. Pritchard, Ashgate, Aldershot, pp. 300-323 - http://tinyurl.com/2avftvz.

Rightmire, G.P. 1998. Human evolution in the Middle Pleistocene: the role of *Homo heidelbergensis*. Evolutionary Anthropology 6(6), 218-177 - http://tinyurl.com/92cgehv.

Rightmire, G.P. 2004. Brain size and encephalization in Early to Mid-Pleistocene *Homo*. American Journal of Physical Anthropology 124, 109-123 - http://tinyurl.com/hpjnqp6.

Rightmire, G.P. 2012. The evolution of cranial form in mid-Pleistocene *Homo*. South African Journal of Sciene 108(3/4), Art. #719, pp. 1-10 - http://tinyurl.com/lwkcxzl

Rightmire, G.P. 2013. *Homo erectus* and Middle Pleistocene hominins: brain size, skull form, and species recognition. Journal of Human Evolution 65, 223-252 - http://tinyurl.com/zzcu924.

Rightmire, G.P., Lordkipanidze, D. 2009. Comparisons of Early Pleistocene skulls from East Africa and the Georgian Caucasus: evidence bearing on the origin and systematics of genus Homo. (in) F.E. Grine et al. (eds.), The First Humans: Origin and Early Evolution of the Genus *Homo*, pp. 39-48 - http://tinyurl.com/muyyb9z.

Rightmire, G.P., Lordkipanidze, D. 2010. Chapter 14: Fossil skulls from Dmanisi: a paleodeme representing the earliest *Homo* in Eurasia. (in) J.G. Fleagle et al. (eds.), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_14, © Springer Science+Business Media B.V. pp. 225-243 – [downloads book: http://tinyurl.com/omz74ut].

Rightmire, G.P., Lordkipanidze, D., Vekua, A. 2006. Anatomical descriptions, comparative studies and evolutionary significance of the hominin skulls from Dmanisi, Republic of Georgia. Journal of Human Evolution 50, 115-141. Vertebrate Paleobiology and Paleoanthropology, Springer Science + Business Media B.V - http://tinyurl.com/j7pnqfq.

Riley, H.N. (1987). The von Neumann Architecture of Computer Systems. - http://tinyurl.com/2amsv36.

Rilling, J.K., Insel, T.R. 1998. Evolution of the cerebellum in primates: differences in relative volume among monkeys, apes and humans. Brain, Behavior and Evolution 52, 308-314.

Rilling, J.K., Schotz, J., Preuss, T.M., Glasser, M.F., Errangi, B.K., Behrens, T.E. 2012. Differences between chimpanzees and bonobos in neural systems supporting social cognition. Social Cognitive and Affective Neuroscience 7(4), 369-379 - http://tinyurl.com/8d28aa6.

Rindler, R. 2014. Fallback strategy and tool use: floristic composition in the Caatinga Forest and Cerrado and its impact on diet and tool-using behavior of capuchin monkeys. MA Thesis, Ball State University, Muncie, IN, 61 pp. - http://tinyurl.com/nkxp2em.

Rito, T., Richards, M.B., Fernandes, V., Alshamali, F., Cerny, V., Pereira, L., Soares, P. 2013. The first modern human dispersals across Africa. PLoS ONE 8(11), e80031. doi:10.1371/journal.pone.0080031 - http://tinyurl.com/pgmclwz.

Rizzi, E., Lari, M., Gigli, E., De Bellis, G., Caramelli, D. 2012. Ancient DNA studies: new perspectives on old samples. Genetics Selection Evolution 44, no 21, pp. 1-19 - http://tinyurl.com/9xt53nw

RMGSAC 2007. Evolutionary and biomedical insights from the rhesus macaque genome. Science 316, 222-234 - http://tinyurl.com/8d4c88k

Robb, F.F., 1989. Cybernetics and suprahuman autopoietic systems. Systems Practice 2: 47-74.

Roberts, B.W., Thornton, C.P., Pigott, V.C. 2009. Development of metallurgy in Eurasia. Antiquity 83, 1012-1022 - http://tinyurl.com/n727qt8.

Roberts, R.G., Bird, M.I. 2012. Homo ‘incendius’. Nature 485, 586-587 – http://tinyurl.com/lb8qfpq.

Roberts, R.G., Westaway, K.E., Zhao, J.-x., Turney, C.S.M., Bird, M.I., Rink, W.J., Fifield, L.K. 2009. Geochronology of cave deposits at Liang Bua and of adjacent river terraces in the Wae Racang valley, western Flores, Indonesia: a synthesis of age estimates for the type locality of *Homo floresiensis*. Journal of Human Evolution 57(5), 484-502 – http://tinyurl.com/n4ogphp.

Robertson, D.S. 1998. The New Renaissance: Computers and the Next Level of Civilization. Barnes & Noble, 208 pp. [Robertson’s key ideas are also repeated in “Information Theoretic Analysis of the Development of Human Civilization” on his Philosophy of Science web page, “Using Modern Information Theory to Develop a Quantitative Philosophy of Science”]

Robertson, D.S. 2003. Phase Change: The Computer Revolution in Science and Mathematics. Oxford University Press, New York. [Robertson’s key ideas are also repeated in “Phase Changes and Paradigm Shifts” on his Philosophy of Science web page, “Using Modern Information Theory to Develop a Quantitative Philosophy of Science”].

Robson, S.L., Wood, B. 2008. Hominin life history: reconstruction and evolution. Journal of Anatomy 212, 394-425 - http://tinyurl.com/qa4xj9e

Roche, H., et. al. (1999). Early hominid stone tool production and technical skill 2.34 Myr ago in West Turkana, Kenya. Nature, 399, 57-60.

Rodhain, F. (1999). Tacit to Explicit: Transforming Knowledge Through Cognitive Mapping - An experiment. SIGCPR ‘99 New Orleans LA USA - http://tinyurl.com/b3px8k8

Roebroeks, W. (ed). 2007. Guts and Brains: An Integrative Approach to the Hominin Record. Leiden Univ. Press - http://tinyurl.com/8c9qrnc [Note: downloads entire book].

Roebroeks, W., Villa, P. 2011. On the earliest evidence for habitual use of fire in Europe. Proceedings of the National Academy of Sciences USA 108(13), 5209-5214 - http://tinyurl.com/kls3lmh

Roffman, I., Savage-Rumbaugh, S., Rubert-Pugh, E., Ronen, A., Nevo, E. 2012. Stone tool production and utilization by bonobo-chimpanzees (*Pan paniscus*). Proceedings of the National Academy of Sciences USA 109(36), 14500-14503 - http://tinyurl.com/92zo4cw [see associated video - http://tinyurl.com/8fk4yc9].

Rohlfing, D.L. & Oparin, A.I. [eds.]. (1972). Molecular Evolution: Prebiological and Biological. Plenum Press, New York.

Rojas, O.J., Hubbe, M.A. (2004). The dispersion science of papermaking. Journal of Dispersion Science and Technology 25(6), 713-732 - http://tinyurl.com/n2pmmnh

Rolland, J., Hua, H. 2005. Head-mounted display systems. Encyclopedia of Optical Engineering. Taylor & Francis, pp. 1-14 - http://tinyurl.com/7lpk27f

Rolland, N. 2004. Was the emergence of home bases and domestic fire a punctuated event? A review of the Middle Pleistocene record in Eurasia. Asian Perspectives 43(2), 248-280 - http://tinyurl.com/kxnd7zj

Rolland, N. 2010. The earliest hominid dispersals beyond Subsaharan Africa: a survey of underlying causes. Quaternary Intgernational 223-234, 54-64.

Rolland, N. 2013. The early Pleistocene human dispersals in the circum-Mediterranean Basin and initial peopling of Europe: single or multiple pathways? Quaternary International 316, 59-72 – http://tinyurl.com/z7gfd2m.

Ronen, A., 1991. The Yiron gravel lithic assemblage. Artifacts older than 2.4 my in Israel. Archälogisches Korrespondenzblatt 21, 159-164.

Ronen, A. 2006. The oldest human groups in the Levant. Comptes Rendus Palevol 5, 343-351 - http://tinyurl.com/opdmlk9.

Rorres, C. 1995. Archimedes. Courant Institute of Mathematical Sciences. New York University - http://tinyurl.com/76xw26p.

Rose, L.M. 1997. Vertebrate predation and food-sharing in *Cebus* and *Pan*. International Journal of Primatology 18, 727-765 - http://tinyurl.com/zw4c79b.

Ross, C. 1991. Life history patterns of New World monkeys. International Journal of Primatology 12, 481-502 – http://tinyurl.com/z2pkt6p.

Rostky, G. (1998). Disk Drives Take Eventful Spin. EE Times, July 13, 1998 - http://tinyurl.com/23ajzb7.

Rowley, J. 2007. The wisdom hierarchy: representations of the DIKW hierarchy. Journal of Information Science 33(2), 163-180 - http://tinyurl.com/oxoxxf7.

Rubenstein, G. (1994-1999) Printing: History and Development. from Jones Telecommunications & Multimedia Encyclopedia. - http://tinyurl.com/24n65x8.

Rumbaugh, D.M. (ed.). 1977. Language learning by a chimpanzee: The LANA project. New York: Academic Press.

Russell, C.J. (1995). Energy is Conserved: The First Law of Thermodynamics. - http://tinyurl.com/2953y76.

Russell, C.J. (1995a). Entropy of the Universe Increases: The Second Law of Thermodynamics. - http://tinyurl.com/29qzh4l.

Russell MJ, Kanik I. 2010. Why does life start, what does it do, where will it be, and how might we find it? Journal of Cosmology 5: 1008-1039 - http://tinyurl.com/494pz8g.

Russell, R. (2000). The Antikythera Mechanism. - http://www.giant.net.au/users/rupert/kythera/kythera.htm
Russo, E. (2001). A science publishing revolution. The Scientist, April 16, 2001 - http://tinyurl.com/owqmpy4.
Russo, M (????). Herman Hollerith: The World's First Statistical Engineer - http://tinyurl.com/2areg3u.
Russon, A.E., Compost, A., Kuncoro, P., Ferisa, A. 2014. Orangutan fish eating, primate aquatic fauna eating, and their implications for the origins of ancestral hominin fish eating. Journal of Human Evolution 77, 50-63 - http://tinyurl.com/gtwmz8w.
Sabbatini, G., Manrique, H.M., Trapanese, C., Vizioli, A.D.B., Call, J., Visalberghi, E. 2014. Sequential use of rigid and pliable tools in tufted capuchin monkeys (*Sapajus* spp.). Animal Behaviour 87, 213-220 - http://tinyurl.com/pmohvkv.
Sabbatini, G., Truppa, V., Hribar, A., Gambetta, G., Call, J., Visalberghi, E. 2012. Animal Cognition 15, 577-590 - http://tinyurl.com/kfnxdfk.
Savage-Rumbaugh, E.S., Rumbaugh, D.M., Boysen, S. 1978. Symbolic communication between two chimpanzees (*Pan troglodytes*). Science 201. 641-644.
Safranski, M. (ed.) 2008. The John Boyd Roundtable: Debating Science, Strategy, and War. Nimble Books, Ann Arbor
Sagan, L. 1967. On the origin of mitosing cells. Journal of Theoretical Biology 14, 225-274 - http://tinyurl.com/lzsfdbe.
Sahle, Y., Hutchings, W.K., Braun, D.R., Sealy, J.C., Morgan, L.E., Negash, A., Atnafu, B. 2013. Earliest stone-tipped projectiles from the Ethiopian Rift date to >279,000 years ago. PLoS ONE 8(11): e78092. doi:10.1371/journal.pone.0078092, 9 pp. - http://tinyurl.com/n2wb8n9.
Saint-Onge, H. (1996). Tacit knowledge: The key to the strategic alignment of intellectual capital. Strategy & Leadership. 24:2. - http://www.knowinc.com/saint-onge/library/tacitknow.htm
Salamini, F., Özkan, H., Brandolini, A., Schafer-Pregl, R., Martin, W. 2002. Genetics and geography of wild cereal domestication in the Near East. Nature Reviews Genetics 3, 429-441 - http://tinyurl.com/2g7m9k4.
Salthe, S. 1985. Evolving Hierarchical Systems: Their Structure And Representation. Columbia University Press, New York. 343 pp.
Salthe, S. 1993. Development and Evolution: Complexity and Change in Biology. MIT Press, Cambridge, Mass. 357 pp.
Salthe, S. 2002. The natural philosophy of entropy. SEED 2(3), 29-41 - http://tinyurl.com/n5qdz7s
Salthe, S.N. 2004. The spontaneous origin of new levels in a scalar hierarchy. Entropy 6, 327-343 - http://tinyurl.com/ord3nty.
Salthe, S.N. 2010. Maximum power and maximum entropy production: finalities in nature. Cosmos and History: The Journal of Natural and Social Philosophy 6(1): 114-121 - http://tinyurl.com/72ven67.
Salthe, S.N. 2012. Hierarchical structures. Axiomathes DOI 10.1007/s10516-012-9185-0 (published on-line).
Salthe, S., Fuhrman, G. 2005. The cosmic bellows: the big bang and the second law. Cosmos and History: The Journal of Natural and Social Philosophy 1(2), 295-318 - http://tinyurl.com/knbqgmz.

Salyers, A.A. & Whitt, D.D. (2001). Bacterial Genetics III: Horizontal Gene Transfer Among Bacteria. Microbiology: Diversity, Disease and the Environment Fitzgerald Science Press, Inc. Betheseda, MD . - http://www.fitzscipress.com/mdde_ch07.pdf.
Sanchez-Quinto, F., Lalueza-Fox, C. 2015. Almost 20 years of Neanderthan palaeogenetics: adaptation, admixture, diversity, demography and Extinction. Philosophical Transactions of the Royal Society B 370, no. 20130374 - http://tinyurl.com/k9f76uf.
Sankararaman, S., Patterson, N., Li, H., Pääbo, S., Reich, D. 2012. The date of interbreeding between Neandertals and modern humans. PLoS Genetics 8(10): e1002947. doi:10.1371/journal.pgen.1002947 [q-bio.PE] 10 Aug 2012 - http://tinyurl.com/lamas54.
Sankararaman, S., Mallick, S., Dannemann, M., Prüfer, K., Kelso, J., Pääbo, S., Patterson, N., Reich, D. 2014. The genomic landscape of Neanderthal ancestry in present-day humans. doi:10.1038/nature12961, (4 pp + supplement) - http://tinyurl.com/m8v9ter.
Sankararaman, S. Mallick, S., Patterson, N., Reich. 2016. The combined landscape of Denisovan and Neanderthal ancestry in present-day humans. Current Biology 26, http://dx.doi.org/10.1016/j.cub.2016.03.037, 7pp. - http://tinyurl.com/hnmc8et
Sanz, C., Call, J., Morgan, D.B. 2009. Design complexity in termite-fishing tools of chimpanzees (*Pan troglodytes*). Biology Letters 5, 293-296 - http://tinyurl.com/osouuxz
Sanz, C.M., Morgan, D.B. 2007. Chimpanzee tool technology in the Goualougo Triangle, Republic of Congo. Journal of Human Evolution 52, 4- http://tinyurl.com/37bt5ts.
Sanz, C.M., Morgan, D.B. 2009. Flexible and persistent tool-using strategies in honey-gathering by wild chimpanzees. International Journal of Primatology 30:411-427 - http://tinyurl.com/n48lug4.
Sanz, C.M., Morgan, D.B. 2013. Ecological and social correlates of chimpanzee tool use. Philosophical Transactions of the Royal Society B 368, no. 1630, 14 pp. - http://tinyurl.com/psqylrq.
Sanz, C.M., Schöning, C., Morgan, D.B. 2010. Chimpanzees prey on army ants with specialized tool set. American Journal of Primatology 72, 17-24 - http://tinyurl.com/oeth6gg.
Sao, C.C., Abdessadok, S., Dambricourt Malassé, Singh, M., Karir, B., Bhardwaj, V., Pal, S., Gaillard, C., Moigne, A.-M., Gargani, J., Tudryn, A. 2016. Magnetic polarity of Masol 1 locality deposits, Siwalik Frontal Range, northwestern India. Comptes Rendus Palevol 15,407-416 - http://tinyurl.com/z7kawqc.
Sarkissian, C.D., Brothergon, P., Belanovsky, O., Templeton, J.E.L., Llamas, B., Soubrier, J., Moiseyev. V., Khartanovich, V., Cooper, A., Haak, W., The Genographic Consortium. 2014. Mitochondrial genome sequencing in Mesolithic north east Europe unearths a new sub-clade within the broadly distributed human haplogroup C1. PLoS ONE 9(2): e87612. doi:10.1371/journal.pone.0087612 - http://tinyurl.com/pgx9l83.
Savage-Rumbaugh, E.S., Rumbaugh, D.M., Boysen, S. 1978. Symbolic communication between two chimpanzees (*Pan troglodytes*). Science 201. 641-644 http://tinyurl.com/jg56xpm.
Savage-Rumbaugh, E.S., Rumbaugh, D.M., Boysen, S. 1978a. Linguistically mediated tool use and exchange by chimpanzees (*Pan troglodytes*). Behavioral and Brain Sciences 4, 539-554 - http://tinyurl.com/jg56xpm.
Savage-Rumbaugh, E.S., McDonald, K., Sevcik, R.A., Hopinks, W.D., Rubert, E. 1986. Spontaneous symbol acquisition and communicative use by pygmy chimpanzees (*Pan paniscus*). Journal of Experimental Psychology: General 115(3), 211-235 - http://tinyurl.com/ltjdtyk.

Savage-Rumbaugh E.S., Shanker S., Taylor T.J. 1998. Apes, Language, and the Human Mind. Oxford Univ Press, New York.

Savage-Rumbaugh, S., Fields, W.M., Taglialatela, J.P. 2001. Language, speech, tools, and writing – a cultural imperative. Journal of Consciousness Studies 8 (5-7), 273-292 - http://tinyurl.com/k3oj7de

Sawyer, R.J. (1996). WordStar: A Writers Word Processor. *from* SFWRITER.COM - http://tinyurl.com/lxp8fq9.

Scally, A., Dutheil, J.Y., Hillier, L.W., Jordan, G.E., Goodhed, I., Herrero, J., Hobolth, A., Lappalainen, T., Mailund, T., Marques-Bonet, T. et al. 2012. Insights into hominid evolution from the gorilla genome sequence. Nature 483, 169-175 http://tinyurl.com/psmqu9o.

Scally, A., Durbin, R. 2012. Revising the human mutation rate: implications for understanding human evolution. Nature Reviews – Genetics 13, 745-753 - http://tinyurl.com/l72qfra.

Scerri, E.R. 2012. Top-down causation regarding the chemistry–physics interface: a sceptical view. Interface Focus 2, 20–25 - http://tinyurl.com/lttvhfa

Schaffer, J. 2009. The metaphysics of causation. In Zalta, E.N. (Ed.), The Stanford Encyclopedia of Philosophy (Spring 2009 Edition) - http://tinyurl.com/24ttkxt.

Schaffner, A.C. (1994). The Future of Scientific Journals: Lessons From the Past. Information Technology and Libraries. 13(4):239-247 - http://www.msri.org/activities/events/9495/fmc/Schaffner.html

Schermer, M. 2009. The mind and the machine: on the conceptual and moral implications of brain-machine interaction. Nanoethics 3, 217-230 - http://tinyurl.com/7hjl9ny.

Scherrer, S.J. 1984. Signs and wonders in the Imperial Cult: a new look at a Roman religious institution in the light of Rev 13:13-15. Journal of Biblical Literature 103(4), 599-610.

Schiffels, S., Durbin, R. 2014. Inferring human population size and separation history from multiple genome sequences. BioRxiv, http://dx.doi.org/10.1101/005348 - http://tinyurl.com/oxfcsfk.

Schick, K.D., Toth, N., Garufi, G., Savage-Rumbaugh, E.S., Rumbaugh D., Sevick, R. 1999. Continuing investigations into the stone tool-making and tool-using capabilities of a bonobo (*Pan paniscus*). Journal of Archeological Science 26, 821-832.

Schlebusch, C.M., Skoglund, P., Sjödin, P., Gattepaille, L.M., Hernandez, D., Jay, F., Li, S., De Jongh, M., Singleton, A., Blum, M.G.B., Soodyall, H., Jakobsson, M. 2012. Genomic variation in seven Khoe-San groups reveals adaptation and complex African history. Science 338, 374-379 - http://tinyurl.com/qevykk2.

Schlebusch, C.M., Lombard, M., Soodyall, H. 2013. MtDNA control region variation affirms diversity and deep sub-structure in populations from southern Africa. BMC Evolutionary Biology 13, 56, pp 1-20 - http://tinyurl.com/mxu23m3.

Schlosser, M.E. 2012. Causally efficacious intentions and the sense of agency: in defense of real mental causation. Journal of Theoretical and Philosophical Psychology doi: 10.1037/a0027618, 26 pp.

Schmandt-Besserat, D. 1977. The earliest precursor of writing. Scientific American 238(6), 50-58 - http://tinyurl.com/6qdrj9a.

Schmandt-Besserat, D. 1979. Reckoning before writing. Archaeology 32(3), 22-31 - http://tinyurl.com/mbcey39.

Schmandt-Besserat, D. 1980. The envelopes that bear the first writing. Technology and Culture 21(3), 237-385 - http://tinyurl.com/lhtp5cr.

Schmandt-Besserat, D. 1981. From tokens to tablets, a re-evaluation of the so-called “numerical tablets”. Visible Language 15(4), 321-344

Schmandt-Besserat, D. 1992. Before Writing: Vol. 1: From Counting to Cuneiform. University of Texas Press, Austin, Texas - http://tinyurl.com/2cus3cp.

Schmandt-Besserat, D. 1996. How Writing Came About. University of Texas Press, Austin, Texas.

Schmandt-Besserat, D. 2007. From tokens to writing: the pursuit of abstraction. Bulletin of the Georgian National Academy of Sciences 175(3), 162-167 - http://tinyurl.com/7dprlgy.

Schmandt-Besserat, D. 2010. The token system of the ancient Near East: its role in counting, writing, the economy and cognition. (in) The Archaeology of Measurement: Comprehending Heaven, Earth and Time in Ancient Societies. Morley, I., Renfrew, C. (Eds). Cambridge University Press, Cambridge, pp. 27-34 - http://tinyurl.com/2ec6a7t.

Schmid, P., Churchill, S.E., Nalla, S., Weissen, E., Carlson, K.J., de Ruiter, D.J., Berger, L.R. 2013. Mosaic morphology in the thorax of *Australopithecus sediba*. Science 340, 1234598, pp 1-5 - http://tinyurl.com/ow6nmgy.

Schmidt, K. 2010. Göbekli Tepe – the Stone Age sanctuaries. New results of ongoing excavations with a special focus on sculptures and high reliefs. Documenta Praehistorica 37, 239-256

Schneider, E.D, Kay, J.J., (1994). life as a manifestation of the second law of thermodynamics. mathematical and computer modelling, Vol 19, No. 6-8, pp.25-48. - http://tinyurl.com/nywnmsn.

Schneider, E.D, Kay, J.J. (1995). Order from disorder: the thermodynamics of complexity in biology, in Michael P. Murphy, Luke A.J. O'Neill (ed), What is Life: The Next Fifty Years. Reflections on the Future of Biology, Cambridge University Press, pp. 161-172 - http://tinyurl.com/ks5nnz3

Schneider, H., Sampaio, I. 2015. The systematics and evolution of New World primates – A review. Molecular Phylogeneics and Evolution 82B, 348-357 - http://tinyurl.com/zc9gdqv.

Schoffeniels, E. [ed.] (1971). Biochemical Evolution and the Origin of Life. Proceedings of the International Conference on Biochemical Evolution. North-Holland Publishing Co., Amsterdam

Scholl, H.J. (2002). Dynamics in the development of the firm's dynamic capabilities. Proceedings: The Third European Conference on Organizational Knowledge, Learning and Capabilities (OKLC), 5-6 April, 2002..Athens, Greece - http://www.alba.edu.gr/OKLC2002/Proceedings/pdf_files/ID396.pdf

Schopf, J.W. (1999). Cradle of Life: The Discovery of the Earth's Earliest Fossils. Princeton Univ. Press, Princeton, N.J.

Schrago, C.G., Mello, B., Soares, E.A.R. 2013. Combining fossil and molecular data to date the diversification of New World primates. Journal of Evolutionary Biology 26, 2438-2446. - http://tinyurl.com/zn829yx.

Schrago, C.G., Voloch, C.M. 2014. Performance of genomic data sets on the estimation of the divergence time of New World and Old World anthropoids. Genetics and Molecular Research 13 (1), 1425-1437 - http://tinyurl.com/ld83ag3.

Schultze, U. (1998). Investigating the Contradictions in Knowledge Management. IFIP WG8.2 & WG8.6 Joint Working Conference on Information Systems: Current Issues and Future Changes, Helsinki, Finland, December 10-13, 1998. http://www.bi.no/dep2/infomgt/wg82-86/proceedings/schultze.pdf

[http://citeseer.nj.nec.com/cache/papers/cs/12916/http:zSzzSzwww.bi.nozSzdep2zSzinfomgtzSzwg82-86zSzproceedingszSzschultze.pdf/schultze98investigating.pdf].
Schulman, J.-L. (2000). Using Medical Subject Headings (MeSH) to examine patterns in American medicine: Preliminary Consideration of Vocabulary Change as a Metric. STS 5206, May 2000 in Medical Subject Headings, United States National Library of Medicine.
Shumaker, R., Walkup, K., Beck, B. 2011. Animal tool behavior: the use and manufacture of tools by animals. John Hopkins University Press, Baltimore, MD:
Schurger, A., Sitt, J.D., Dehaene, S. 2012. An accumulator model for spontaneous neural activity prior to self-initiated movement. Proceedings of the National Academy of Sciences USA, www.pnas.org/cgi/doi/10.1073/pnas.1210467109, 10 pp. - http://tinyurl.com/9cspubm.
Schwaninger, M. (2006) Theories of viability: a comparison. Systems Research 23: 337-347 - http://tinyurl.com/l3ku464
Schwaninger, M., Groesser, S.N. 2012. Operational closure and self-reference; on the logic of organizational change. Systems Research and Behavioral Science 29, 342–367 - http://tinyurl.com/mnasnvf.
Schwartz, G.T. 2012. Growth, development and life history throughout the evolution of *Homo*. Current Anthropology 53(Suppl. 6), S395-S408 - http://tinyurl.com/la3oqka.
Schwarcz, H.P., Grün, R., Latham, A.G., Mania, D., Brunnaker, K. 1988. The Bilzingsleben archaeological site: new dating evidence. Archaeometry 30(1), 5-17.
Schwartz, J.H., Tattersall, I. 2010. Fossil evidence for the origin of *Homo sapiens*. Yearbook of Physical Anthropology 53, 94-121 - http://tinyurl.com/hyuhj4d.
Scott, E., (2000), Semantics the Study of http://libgen.org/scimag/get.php?doi=10.1002/ajpa.21443 Meaning *in* Linguistics 354 - Computers and Human Language, A course in the Linguistics Department, San Diego State University, Spring 2000 http://www-rohan.sdsu.edu/~ling354/semantics.html
Scott, J. 1988. Social network analysis. Sociology 22(1), 109-127 - http://tinyurl.com/89ky7yg.
Scott, J.E. 2013. Cranial size variation and lineage diversity in early Pleistocene *Homo.* Evolution 68(3), 909-915 - http://tinyurl.com/nezl3nm.
Scudellari, M. 2010. Support for UC-Nature ban. TheScientist.com 10 June 2010 - http://tinyurl.com/36yj9o6.
Scozzari, R., Massala, A., D'Atanasio, E., Myres, N.M., Perego, U.A., Trombetta, B., Cruciani, F. 2012. Molecular dissection of the basal clades in the human Y chromosome phylogenetic tree. PLoS ONE 7(11): e49170. doi:10.1371/journal.pone.0049170, pp. 1-5 - http://tinyurl.com/anwbjkw.
Scozzari, R., Massaia, A., Trombetta, B., Bellusci, G., Myres, N.M., Novelletto, A., Cruciani, F. 2014. An unbiased resource of novel SNP markers provides a new chronology for the human Y chromosome and reveals a deep phylogenetic structure in Africa. Genome Research 24, 535-544 - http://tinyurl.com/q69fz9j.
Sears, P. (1998). Chapter 13. HTML origins, owners, good practices *in* Abrams, M. (*Editor*), World Wide Web: Beyond the Basics. Prentice Hall, 483 pp. - http://tinyurl.com/24prcxg.
Segré, D. & Lancet, D. 2000. Composing Life. European Molecular Biology Organization Reports. 1(3): 217-222 - http://tinyurl.com/lcmlhz9.
Segré D, Ben-Eli D, Lancet D (2000) Compositional genomes: Prebiotic information transfer in mutually catalytic noncovalent assemblies. Proc Nat Acad Sci USA 97:4112–4117 - http://tinyurl.com/mn235kd.

Segré, D. Ben-Eli, D., Deamer, D.W., Lancet, D. (2001). The lipid world. Origins of Life and Evolution of the Biosphere 32:119-145 - http://tinyurl.com/4e4hzjo.
Segré D, Shenhav B, Kafri R, Lancet D (2001a) The molecular roots of compositional inheritance. J Theor Biol 213:481–491 - http://tinyurl.com/mt4y2q4.
Seidl, D., Becker, K.H. (eds.) 2005. Niklas Luhmann and Organization Studies. Lieber AB, Malmo, Sweden.
Senut, B. 2011. Origin of hominids: European or African origin, neither or both. Estudios Geológicos 67(2), 394-409 - http://tinyurl.com/mto8tf5
Seo, J., Brezzo, B., Liu, Y., Parker, B.D., Esser, S.K., Montoye, R.K., Rajendran, B., Tiemo, J.A., Chang, L., Modha, D.S., Friedman, D.J. 2011. A 45nm CMOS neuromorphic chip with a scalable architecture for learning in networks of spiking neurons. Custom Integrated Circuits Conference (CICC), 2011 IEEE, 19-21 Sept. 2011, 4 pp. - http://tinyurl.com/bwwqbr6.
Seyfarth, R.M., Cheney, D.L., Bergman, T., Fischer, J., Zuberbühler, K., Hammerschmidt, K. 2010. The central importance of information in studies of animal communication. Animal Behaviour 80, 3-8.
Sevick, R.A., E.S. Savage-Rumbaugh 1994. Languge comprehension and use by great apes. Language & Communication 14(1), 37-58.
Shankland, S. 2009. Google uncloaks once-secret server. Cnet News, April 1, 2009 - http://tinyurl.com/lbbx8ab.
Shannon, C.E. (1948). A Mathematical Theory of Communication. Bell System Technical Journal, vol. 27, pp. 379-423 and 623-656, July and October, 1948. - http://tinyurl.com/mb3ydou.
Sharma, N. 2008. The origin of the “data information knowledge wisdom” hierarchy - http://tinyurl.com/oe5oqkl.
Sharma, V., Annila, A. 2007. Natural process—natural selection. Biophysical Chemistry 127: 123-128 - http://tinyurl.com/lkltsej.
Shapiro, F.R. (1998). KeyCite and Shepard's-Coverage and Currency of Citations to Recent Cases: A Comparative Study. Legal Information Alert, Alert Publications, Inc., April 1998 - http://tinyurl.com/2686r9k.
Shea, J.J. 2009. The impact of projectile weaponry on Late Pleistocene hominin evolution. (in) Hublin, J.J., Richards, M.P. (eds), The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence. Springer Science + Business Media B.V., pp. 189-199.
Shea, J.J. 2010. Stone age visiting cards revisited: a strategic perspective on the lithic technology of early hominin dispersal. (in) Fleagle et al. (eds), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_4, pp. 47-64 - http://tinyurl.com/mu32pec
Shea, J.J. 2011. Refuting a myth about human origins. American Scientist 99(2), 128-135 - http://tinyurl.com/musuqws
Shea, J.J. 2011a. Homo sapiens is as Homo sapiens was - behavioral variability versus “behavioral modernity” in paleolithic archaeology. Current Anthropology 52(1), 1-35 - http://tinyurl.com/kbyt49q.
Shea, J.J. 2013. Lithic Modes A–I: a new framework for describing global-scale variation in stone tool technology illustrated with evidence from the East Mediterranean Levant. – Journal of Archaeological Methods and Theory 20, 151-186 - http://tinyurl.com/mfj7h8k.

Shepherd, G.M. 2011. The microcircuit concept applied to cortical evolution: from three-layer to six-layer cortex. Frontiers of Neuroanatomy 5, no 30, pp. 1-15 - http://tinyurl.com/9e5w4nz

Sheppard, N. (1999). Michael Polanyi and the Philosophy of Science: The Viewpoint of a Practising Scientist, Polanyiana 8:1–2 [Originally published in Appraisal Vol 2 No. 3 March 1999 107–115]. - http://www.kfki.hu/chemonet/polanyi/9912/sheppard.html

Sheridan, W. (1991-2003). Sensible Signage, 3rd Ed. - on The Thinking Persons Portal - http://tinyurl.com/23mbfp4.

Sherwood, C.C., Subiaul, F., Zawidzki, T.W. 2008. A natural history of the human mind: tracing evolutionary changes in brain and cognition. Journal of Anatomy 212, 426-454 - http://tinyurl.com/kajb35g.

Shevlin, E.F. (1999). "To Reconcile Book and Title, and Make 'em Kin to One Another": The Evolution of the Title's Contractual Functions. Book History 2.1:42-77.

Shi, Z. 2011. Foundations of intelligence science. International Journal of Intelligence Science 1, 8-16 - http://tinyurl.com/d5fxf7q

Short, J.E., Bohn, R.E., Baru, C. 2011. How much information? 2010 Report on enterprise server information. Global Information Industry Center, University of California, San Diego, pp. 36 - http://tinyurl.com/mocarfq.

Shultz, S., Maslin, M. 2013. Early human speciation, brain expansion and dispersal influenced by African climate pulses. PLoS ONE 8(10): e76750. doi:10.1371/journal.pone.0076750 - http://tinyurl.com/m38zfke.

Shultz, S., Nelson, E., Dunbar, R.I.M. 2012. Hominin cognitive evolution: identifying patterns and processes in the fossil and archaeological record. Philosophical Transactions of the Royal Society B 367, 2130-2140 - http://tinyurl.com/n2zgqql.

Skoglund, P., Jakobsson, M. 2011. Archaic human ancestry in East Asia. Proceedings of the National Academy of Sciences 108(45), 18301-18306 - http://tinyurl.com/nl7x3p3.

Skoglund, P., Malmström, H., Omrak, A., Raghaven, M., Valdiosera, C., Günther, T., Hall, P., Tambets, K., Parik, J., Sjögren, K.-G., Apel, J., Willerslev, E., Storå, J., Götherström, A., Jakobsson, M. 2014. Genomic diversity and admixture differs for Stone-Age Scandinavian foragers and farmers. Science 344, 747-750 - http://tinyurl.com/o8axcry.

Sikora, M., Carpenter, M.L., Moreno-Estrada, A., Henn, B.M., Underhill, P.A., Sánchez-Quinto, F., Zara, I., Pitzalis, M., Sidore, C., Busonero, F., Maschio, A., Angius, A., Jones, C., et al. 2014. Population genomic analysis of ancient and modern genomes yields new insights into the genetic ancestry of the Tyrolean Iceman and the genetic structure of Europe. PLoS Genetics 10(5): e1004353. doi:10.1371/journal.pgen. 1004353 - http://tinyurl.com/pz4d48a

Silberschartz, A. et. al., (1991) Database Systems: Achievements and Opportunities. Communications of the ACM, Vol. 34.10. - http://tinyurl.com/2dv4x22.

Silver, D.L. and Shakshuki, E. (2002). Knowledge Management: Integrating Perspectives. - http://plato.acadiau.ca/courses/comp/dsilver/KM_IP_Abstract_4.doc.

Simberloff, D., Dayan, T. 1991. The guild concept and the structure of ecological communities. Annual Review of Ecology and Systematics 22, 155-143 - http://tinyurl.com/ltq6onj

Simon, H.A. 1947. Administrative Behavior (3rd edition, 1976), New York: Macmillan.

Simon, H.A., 1955, A behavioral model of rational choice. *Quarterly Journal of Economics*, **69**, 99-118 - http://tinyurl.com/qax7t88.

Simon, H.A., 1957, Models of Man. Wiley.

Simon, H.A. 1962. The architecture of complexity. Proceedings of the American Philosophical Society 106(6):467-482 - http://tinyurl.com/nqy3v8s.
Simon, H.A. 1973. The organization of complex systems. (in) Hierarchy Theory: The Challenge of Complex Systems. Ed. Pattee, H.H. George Braziller, New York, pp. 1-27.
Simon, H.A. 1979. Rational decision-making in business organizations]Nobel Memorial Lecture Economic Sciences, Dec. 8, 1978]. American Economic Review 69(4), 493-513. - http://tinyurl.com/pj8ko3l
Simon, H.A. 2002. Near decomposability and the speed of evolution. Industrial and Corporate Change 11(3), 587-599 - http://tinyurl.com/nbvhco2
Simon, H.A., Ando, A. (1961) Aggregation of variables in dynamic systems. Econometrica 29, 111-138 - http://tinyurl.com/m4mne7s
Simoncini E, Kleidon A, Gallori E. 2010. The emergence of life: thermodynamics of chemical free energy generation in off-axis hydrothermal vent systems and its consequences for compartmentalization and life's origins. Journal of Cosmology 10: 3325-2244 - http://tinyurl.com/49ap2ao.
Sirakov, N., Guadelli, J.-L., Ivanova, S., Sirakova, S., Boudani-Maligne, M., Dimitrova, I., Fernandez, Ph., Ferrier, C., Guadelli, A., Iordanova, D., Iordanova, N. Kovatcheva, M. et. al. 2010. An ancient continuous human presence in the Balkans and the beginnings of human settlement in western Eurasia: a lower Pleistocene example of the Lower Palaeolithic levels in Kozarnika cave (North-western Bulgaria). Quaternary International 223-224, 94-106 - http://tinyurl.com/k7gfc6m.
Sites, J.W., et. al. (1992). A review of phylogenetic hypotheses for lizards of the genus *Sceloporus* (Phrynosomatidae): Implications for ecological and evolutionary studies. Bull. Am. Mus. Nat. Hist., No. 213, 110 pp.
Skerry, A.E., Sheskin, M., Santos, L.R. 2011. Capuchin monkeys are not prosocial in an instrumental helping task. Animal Cognition 14, 647-654 - http://tinyurl.com/lwwr8b7.
Skinner, M.M., Gordon, A.D., Collard, N.J. 2006. Mandibular size and shape variation in the hominins at Dmanisi, Republic of Georgia. Journal of Human Evolution 51, 36-49 - http://tinyurl.com/mezz4e2.
Sloan, E. 2000. Canada and the revolution in military affairs: current response and future opportunities. Canadian Military Journal. Autumn 2000, p. 7-14 - http://tinyurl.com/kqyuyzg
Slocombe, K.E., Kaller, T., Turman, L., Townsend, S.W., Papworth, S., Squibbs, P., Zuberbühler, K. 2010. Production of food-associated calls in wild male chimpanzees is dependent on the composition of the audience. Behavioral Ecology and Sociobiology 64,1959–1966 - http://tinyurl.com/9u2qzc8
Smart, P.R. 2012. The web-extended mind. Metaphilosoply l43(4), 446-463 - http://tinyurl.com/cs6wreq.
Smil V. 2002. The earth's biosphere: evolution, dynamics, and change. MIT Press, Cambridge, MA.
Smillie, K. 2010. Some Topics in Computing: Chapter 2. - http://tinyurl.com/kw58am5.
Smith, K., Kirby, S. 2008. Cultural evolution: implications for understanding the human language facility and its evolution. Philosophical Transactions of the Royal Society B 393, 3591-3603 - http://tinyurl.com/29jowyp.

Smith, T. 2010. Golly: how an open source project took over the study of cellular automata. Presented at Open Source Developer's Conference, Melbourne, Australia, 24-26 November, 2010 - http://tinyurl.com/kcj4zlq.

Smolin, L. 2001. The present moment in quantum cosmology: challenges to the arguments for the elimination of time. [Slightly revised version of an essay published in Time and the Instant, Robin Durie (ed.) Manchester: Clinamen Press, 2000], arXiv:gr-qc/0104097, pp 29 - http://tinyurl.com/lnfdxpn.

Smolin, L. 2004. Atoms of space and time. Scientific American 290(1), 65-75.

Smolin, L. 2007. The Trouble with Physics: The Rise of String Theory, the Fall of a Science. New York: Houghton Mifflin.

Smolin, L. 2008. An invitation to loop quantum gravity. (In) P. C. Argyres, T. J. Hodges, F. Mansouri, Joseph J. Scanio, P. Suranyi, L. C. R. Wijewardhana (eds), pp. 655-683, Quantum Theory and Symmetries, Proceedings of the 3rd International Symposium, Cincinnati, USA10 - 14 September 2003 - http://tinyurl.com/p8cowt6.

Smolin, L. 2013. Time Reborn: From the Crisis of Physics to the Future of the Universe. Allen Lane, London.

Smolin, L. 2013a. The Perimeter Institute founder rethinks the nature of the universe in his new book, Time Reborn, with Robert J. Sawyer. Toronto Public Library video, 29 April 2013 - http://tinyurl.com/mybaosw

Snowden, D. (2000). Story telling: an old skill in a new context. Business Information Review 16(1): 30-37. - http://www.la-hq.org.uk/directory/training/wkshop2.pdf

Snowden, D. (2002). Complex acts of knowing: paradox and descriptive self-awareness. Journal of Knowledge Management, 6:2, pp 100-111. - [http://80-rudolfo.emeraldinsight.com.ezproxy.lib.monash.edu.au/vl=820197/cl=15/nw=1/fm=html/rpsv/cw/mcb/13673270/v6n2/s1/p100]

Soares, P., Alshamali, F., Pereira, J. B., Fernandes, V., Silva, N.M., Aflonso, C., Costa, M.D. Musilova, E., Macaulay, V., Richards, M.B., Cerny, V., Pereira, L. 2011. The expansion of mtDNA haplogroup L3 within and out of Africa. Molecular Biology and Evolution 29(3), 915-927 - http://tinyurl.com/jvt9tc3.

Solomon, D. (1999). Is it Time to Take the Paper out of Serial Publication? Medical Education Online 4(7). - http://tinyurl.com/lgzpg8w.

Souto, A., Bione, C.B.C., Bastso, M., Bezerra, B., Fragaszy, D., & Schiel, N. 2011. Critically endangered blonde capuchins fish for termites and use new techniques to accomplish the task. Biology Letters,7(4), 532-535 - http://tinyurl.com/l7e4fve.

Spagnoletti, N., Prieto, J., Verderane, M., Mendonça-Furtado, Izar, P., Wasterlain, S.N., Carvalho, S., Visalberghi, E. 2013. Vertebrate consumption by wild bearded capuchin monkeys (*Sapajus libidinosus)* from Fazenda Boa Vista (Piauí, Brazil). Poster, II Congresso Latina Americano, XV Congresso Brasileiro de Primatologia, 4-9/8 2013, Recife (PE) Brazil – http://tinyurl.com/kh5xnqv

Spagnoletti, N., Visalberghi, E., Ottoni, E., Izar, P., & Fragaszy, D. 2011. Stone tool use by adult wild bearded capuchin monkeys (*Cebus libidinosus*). Frequency, efficiency and tool selectivity. Journal of Human Evolution, 62(1), 97-107 - http://tinyurl.com/k3yqj4y

Spagnoletti, N., Visalberghi, E., Verderane, M.P., Ottoni, E., Izar, P., Fragaszy, D. 2012. Stone tool use in wild bearded capuchin monkeys, *Cebus libidinosus*. Is it a strategy to overcome food scarcity. Animal Behaviour 83, 1285-1294 - http://tinyurl.com/lt2hzkv.

Sperberg-McQueen, CM and Burnard, L., *eds.* (1994). TEI Guidelines for Electronic Text Encoding and Interchange: A Gentle Introduction to SGML Part I.2., TEI Guidelines for Electronic Text Encoding and Interchange (P3), Electronic Text Center at the University of Virginia. - http://tinyurl.com/22jvfrm.

Spek, R. v.d. and Spijkervet, A. (1997). Knowledge Management: Dealing Intelligently with Knowledge, CIBIT, Utrecht. [Not seen - not in Voyager]

Spender, J.C. 1998. The Dynamics of Individual and Organizational Knowledge. in Eden C. and Spender, J.-C. eds In Managerial and Organizational Cognition: Theory, Methods and Research. SAGE, Thousand Oaks, Calif. [Not seen].

Spinney, F.C. 1997. Evolutionary Epistemology: A Personal Interpretation of John Boyd's Destruction and Creation. [Presentation starting at http://tinyurl.com/2866657]. *from War, Chaos and Business*, Kettle Creek Corporation.

Spinney, F.C. 1997a. Genghis John. Proceedings of the US Naval Institute, July 1997, pp. 42-47 - http://tinyurl.com/lllgkdo.

Sponheimer, M., Almseged, Z., Cerling, T.E., Grine, F.E., Kimbel, W.H., Leakey, M.G., Lee-Thorp, J.A., Manthi, F.K., Reed, K.E., Wood, B.A., Wynn, J.G. 2013. Isotopic evidence of early hominin diets. Proceedings of the National Academy of Sciences 110, 10513-10518 - http://tinyurl.com/lvj2sgt

Spoor, F. 2011. Malapa and the genus *Homo*. Nature 478, 44-45 - http://tinyurl.com/lfgjp5n.

Spoor, F., Leakey, M.G., Gathogo, P.N., Brown, F.H., Antón, S.C., McDougall, I., Kiarie, C., Manthi, F.K., Leakey, L.N. 2007. Implications of new early Homo fossils from Ileret, east of Lake Turkana, Kenya. Nature 448, 688-691 - http://tinyurl.com/p4k4g5z.

Springer, M.S., Meredith, R.W., Gatesy, J., Emerling, C.A., Park, J., Rabosky, D.L., Stadler, T., Steiner, C., Ryder, O.A., Janeĉka, J.E., Fisher, C.A., Murphy, W.J. 2012. Macroevolutionary dynamics and historical biogeography of primate diversification inferred from a species supermatrix. PLoS ONE 7(11): e49521. doi:10.1371/journal.pone.0049521 - http://tinyurl.com/kdynbas.

Sprochi, A.K. 2004. Archives and libraries in ancient Mesopotamia. MLIS Thesis, Kent State University School of Library and Information Science.

Stahlschmidt, M., Miller, C.E., Ligouis, B., Hambach, U., Goldberg, P., Berna, F., Richter, D., Urban, B., Serangeli, J., Conard, N.J. 2015. On the evidence for human use and control of fire at Schöningen. Journal of Human Evolution. Evolution (2015), http://dx.doi.org/10.1016/j.jhevol.2015.04.004, pp. 21.

Staikos, K.S. (????). Libraries: History of the Private, Royal, Imperial, Monastic and Public Libraries - http://tinyurl.com/2f7xy9k.

Stamos, D.N. 2007. Popper, laws, and the exclusion of biology from genuine science. Acta Biotheoretica 55:357–375.

Stanford, C.B. 2012. Chimpanzees and the behavior of *Ardipithecus ramidus*. Annual Review of Anthropology 41:139-149 – http://tinyurl.com/p8oxdu2.

Steiper, M.E., Seiffert, E.R. 2012. Evidence for a convergent slowdown in primate molecular rates and its implications for the timing of early primate evolution. Proceedings of the National Academy of Sciences 109, 6006-6011 – http://tinyurl.com/po3udjo.

Stenmark, D. (2001). Leveraging Tacit Organisational Knowledge. Journal of Management Information Systems, Vol. 17:3. - http://www.viktoria.se/results/result_files/146.pdf.

Stenmark, D. (2001a). The Relationship between Information and Knowledge. *in* Proceedings of IRIS 24, Ulvik, Norway, August 11-14. - http://w3.informatik.gu.se/~dixi/publ/iris24-DS.pdf
Stenmark, D. 2002. Information vs. knowledge: the role of intranets in knowledge management. In Proceedings of HICSS-35, Hawaii, January 7-10, 2002 - http://tinyurl.com/kp4mkbw.
Stephenson, S. 2010. Ancient computers. IEEE Global History Network - http://tinyurl.com/76kh9a9.
Sterelny, K. 2007. Social intellighence, human intelligence and niche construction. Philosophical Transactions of the Royal Society B 362, 719-730 - http://tinyurl.com/k8fs97t.
Sterelny, K., 2011. From hominins to humans: how sapiens became behaviourally modern. Philosophical Transactions of the Roysal Society B 266, 809-822 - http://tinyurl.com/n6u2swr.
Sterelny, K. 2012. Language, gesture, skill: the co-evolutionary foundations of language. Philosophical Transactions of the Royal Society B 267, 2141-2015 - http://tinyurl.com/m5664re.
Sterelny, K. 2014. A Paleolithic reciprocation crisis: symbols, signals, and norms. Biological Theory DOI 10.1007/s13752-013-0143-x.
Stewart, F.A. 2011. The evolution of shelter: ecology and ethology of chimpanzee nest building. PhD Thesis, University of Cambridge. 211 pp - http://tinyurl.com/nrfozpm
Stoneking, M., Harvati, K. 2013. Early Old World migrations of *Homo sapiens*: human biology. (in) Ness, I. (ed), The Encyclopedia of Global Human Migration. Blackwell Publishing Ltd, London, 12 pp.
Stotz, K. 2010. Human nature and cognitive-developmental niche construction. Phenomenological and the Cognitive Sciences 9: 483-501.
Stout, D. 2010. The evolution of cognitive control. Topics in Cognitive Science 2, 614-630 - http://tinyurl.com/m8w37wc.
Stout, D. 2011. Stone toolmaking and the evolution of human culture and cognition. Philosophical Transactions of the Royal Society B 366, 1050-1059 - http://tinyurl.com/8nza59s.
Stout, D., Semaw, S., Rogers, M.J., Cauche, D. 2010. Technological variation in the earliest Oldowan from Gona, Afar, Ethiopia. Journal of Human Evolution 58, 474-491 - http://tinyurl.com/kg3fp9k
Stout, D, Toth, N., Schick, K., Chaminade, T. 2008. Neural correlates of Early Stone Age toolmaking: technology, language and cognition in human evolution. Philosophical Transactions of the Royal Society B 363, 139-149 - http://tinyurl.com/or94992.
Stove, D. 1982. Popper and After: Four Modern Irrationalists. Pergamon – [full text] http://tinyurl.com/283gtrr]. Reprinted as Stove, D. 1988. Anything Goes: Origins of the Cult of Scientific Irrationalism. Macleay Press: Sydney, including new forward by Keith Windschuttle
Stranahan, P. & Stranahan, L. (1999). BASIC - Beginner's All-purpose Symbolic Instruction Code. in Jones Telecommunications and Multimedia Encyclopedia. - http://tinyurl.com/2ckl8lz.
Straskraba, M., Jorgensen, S.E., & Patten, B.C. (1999). Ecosystems emerging: 2—Dissipation. Ecol. Model. 117: 3–39 - http://tinyurl.com/n4hpekh.
Street, M., Terberger, T., Orschiedt. J. 2006. A critical review of the German Paleolithic hominin record. Journal of Human Evolution 51, 551-579.

Stringer, C. 2012. What makes a modern human. Nature 485, 33-35 - http://tinyurl.com/ku45trh.
Stringer, C. 2012a. The status of *Homo heidelbergensis* (Schoetensack 1908). Evolutionary Anthropology 21, 101-107 - http://tinyurl.com/lh2oley.
Stringer, C. 2014. Why we are not all multiregionalists now. Trends in Ecology & Evolution 29(5), 248-251 - http://tinyurl.com/ost77a9.
Stringer, C. 2015. The many mysteries of *Homo naledi*. eLife doi: doi: 10.7554/eLife.10627, 3 pp. - http://tinyurl.com/zyqtaj6.
Su, D.F. 2013. The earliest hominins: *Sahelanthropus*, *Orrorin*, and *Ardipithecus*. Nature Education Knowledge 4(4):11 - http://tinyurl.com/n5hnmks
Suber, P. 2002. Where does the free online scholarship movement stand today? ARL Bimonthly Report 220, February 2002. - http://tinyurl.com/236wnnl.
Suchak, M., de Waal, F.B.M. 2012. Monkeys benefit from reciprocity without the cognitive burden. Proceedings of the National Academy of Sciences 109, 15191-15196 - http://tinyurl.com/or4zty3.
Sugden, K.F. 1981. A history of the abacus. The Accounting Historians Journal 8(2), 1-22 - http://tinyurl.com/qyjo6su.
Sugiyama, Y. 1995. Drinking tools of wild chimpanzees at Bossou. American Journal of Primatology 37, 263-269 - http://tinyurl.com/kdcgoen.
Sugiyama, Y. 1997. Social tradition and the use of tool-composites by wild chimpanzees. Evolutionary Anthropology 6, 23-27 - http://tinyurl.com/lqpnyce [very slow].
Sugiyama, Y., Koman, J. 1979. Tool-using and -making behavior in wild chimpanzees at Bossou, Guinea. Primates 20, 513-524 - http://tinyurl.com/o8x4ovv [very slow].
Sullivan, D. *ed.* 2000. Numbers, Numbers -- But What Do They Mean? Search Engine Report Newsletter, March 3, 2000 - http://tinyurl.com/2dju87f.
Sullivan, D. (2000a). Invisible Web Gets Deeper. The Search Engine Report Newsletter - http://tinyurl.com/l8hemxm.
Sullivan, D. *ed.* (2002), SearchEngineWatch.com, 1996-2002. internet.com Corp - http://searchenginewatch.com/
Summit, R. 2002. Reflections on the beginnings of Dialog: The birth of online information access. Chronolog Archives, Dialog, June 2002 - http://tinyurl.com/d32wn.
Sundarasaradula, D and Hassan, H. 2004. A unified open systems model for explaining organisational change, in Information Systems Foundations: Constructing and Criticising Workshop at The Australian National University from 16 to 17 July 2004 - http://tinyurl.com/obkubsc.
Susman, R.L. 1994. Fossil evidence for early hominid tool use. Science 265, 1570-1473 - http://tinyurl.com/q3bwtwy.
Sutkina, T., Tocheri, M.W., Morwood, M.J., Saptomo, E.W., Jatmiko, Due Awe, R., Wasisto, S., Westaway, K.E., Aubert, M., Li, B., Zhao J.x, Storey, M., Alloway, B.V. Morley, M.W. et al. 2016. Revised stratigraphy and chronology for Homo floresiensis at Liang Bua in Indonesia. Nature doi:10.1038/nature17179 - http://tinyurl.com/hm3z9ae.
Suwa, G., Asfaw, B., Kono, R.T., Kubo, D., Lovejoy, C.O., White, T.D. 2009. The *Ardipithecus ramidus* skull and its implications for hominid origins. Science 326, 68e, pp 1-7 - http://tinyurl.com/gt6867l.
Suwa, G., Kono, R.T., Simpson, S.W., Asfaw, B., Lovejoy, C.O., White, T.D. 2009a. Paleobiological implications of the *Ardipithecus ramidus* dentition. Science 326, 94-99 - http://tinyurl.com/mhurlzl

Sveiby, K-E. 1994. Towards a Knowledge Perspective on Organisation. PhD Thesis. University of Stockholm S-106 91 Stockholm: Part 1 - http://tinyurl.com/muf2guj, Part 2 - http://tinyurl.com/kp8q3z2.

Sveiby, K-E. 1997. Tacit Knowledge - An Introduction to Michael Polanyi. Sveiby Knowledge Associates. - http://tinyurl.com/2fv69ju.

Sveiby, K-E. 2000. Frequently Asked Questions [re "objective knowledge". in Sveiby Knowledge Associates Web site. - http://tinyurl.com/25c2fzq.

Sveiby, K-E. 2001. A knowledge-based theory of the firm to guide strategy formulation. Journal of Intellectual Capital 2(4) - http://tinyurl.com/m86smmq.

Swartz, A. (2002). The Semantic Web In Breadth. -http://tinyurl.com/n524uv9.

Swenson, R. 1992. Autocatakinetics, yes-autopoiesis, no: steps toward a unified theory of evolutionary ordering. International Journal of General Systems 21: 207-228 http://tinyurl.com/7kstawc.

Swenson, R. 1992a. Galileo, Babel, and autopoiesis (It's turtles all the way down). International Journal of General Systems 21: 267-269)

Swenson, R. 2000. Spontaneous order, autocatakinetic closure, and the development of space-time. Annals New York Academy of Sciences 901, 311-319 - http://tinyurl.com/kgu9jrv.

Swisher, C.C., III, Curtis, G.H., Jacob, T., Getty, A.G., Suprijo, A., Widiasmoro. 1994. Age of the earliest known hominids in Java, Indonesia. Science 236, 1118-1121 - http://tinyurl.com/zv9cpwe.

Sykes, M. Hall, W. P. 2003. Generating fleet support knowledge from data and information. Australian Conference for Knowledge Management & Intelligent Decision Support ACKMIDS 2003 Melbourne, Australia, 11 and 12 December 2 - http://tinyurl.com/ltn2x.

Synofizik, M., Vosgerau, G., Newen, A. 2008a. Beyond the comparator model: a multifactorial two-step account of agency. Consciousness and Cognition 17, 219-239 - http://tinyurl.com/99slz9b

Synofizik, M., Vosgerau, G., Newen, A. 2008b. I move, therefore I am: a new theoretical framework to investigate agency and ownership. Consciousness and Cognition 17, 411-424 - http://tinyurl.com/9y8cld9

Számadó, S. 2010. Pre-hunt communication provides context for the evolution of language. Biological Theory 5(4) 366-382 - http://tinyurl.com/lmsh82z.

Szathmary, E. 2010. Evolution of language as one of the major evolutionary transitions. (In) Evolution of Communication and Language in Embodied Agents, Nolfi, S., Mirolli, M. (Eds.). Springer, Berlin, pp. 37-53 [download book - http://tinyurl.com/l5tnmu4.

Talk.Origins Archive. (????). Thermodynamics, Evolution and Creationism - http://tinyurl.com/kha5naj.

Tafoya, W.L. (2002). A Brief History of Computers, Personal Computers, Networked Computing, the Internet, and New Media. Chapter 1 in Greek (2002). - http://tinyurl.com/24j2z2n.

Tanner, D. (1999). From VisiCalc to Cybernetic Babylon. Switch 5.3. CADRE Institute of the School of Art and Design, San Jose State University - http://tinyurl.com/2dwefh9.

Tattersall, I. 2011. Before the Neanderthals: hominid evolution in Middle Pleistocene Europe. (in) Condemi, S., Weniger, G.-C. (eds), Continuity and Discontinuity in the Peopling of Europe: one hundred fifty years of Neanderthal study, Springer Scienve+Business Media, Dordrecht. Pp, 47-53 - http://tinyurl.com/zv5pl7z.

Tattersall, I. 2012. Masters of The Planet – the Search for our Human Origins. Plagrave Macmillan, New York.
Taycher, L. 2010. Books of the world, stand up and be counted! All 129,864,880 of you. Inside Google Books Aug. 5, 2010 - http://tinyurl.com/mjha45r.
Taylor, W.L. 2000. Comparing KeyCite and Shepard's for Completeness, Currency, and Accuracy. Law Library Journal 92(2), Spring 2000 - http://tinyurl.com/23vro2l.
Tessier-Lavigne, M. 2000. Visual processing by the retina. (in) Principles of Neural Science. Kandel, E.R., Schwartz, J.H., Jessell, T.M. (eds.). McGraw-Hill, New York, pp. 508-522 - http://tinyurl.com/cral38g.
Tennie, C., Call, J., Tomasello, M. 2009. Ratcheting up the ratchet: on the evollution of cumulative culture. Philosophical Transactions of the Royal Society B. 364, 2405-2415 - http://tinyurl.com/9a2z8o6.
Tennie, C., O'Malley, R.C., Gilby, I.C. 2014. Why do chimpanzees hunt? Considering the benefits and costs of acquiring and consuming vertebrate versus invertebrate prey. Journal of Human Evolution 71, 38-45 - http://tinyurl.com/odc9zhd.
Testa, J. (2001/2). The ISI® Database: The Journal Selection Process - http://tinyurl.com/2vn7dmc.
Texas Instruments Inc. 2000. What if he had gone on vacation: Jack Kilby describes how he developed the world's first integrated circuits - http://tinyurl.com/237lstm.
Texas Instruments Inc. 2000a. Solid Circuit(tm) Semiconductor Network Computer, 6.3 Cubic inches in Size, is Demonstrated in Operation by U.S. Air Force and Texas Instruments - http://tinyurl.com/22trtmy.
Thelen, E. 2008. Babbage Difference Engine #2 – how to initialize the machine. Ed Thelen.Org - http://tinyurl.com/236cqen.
Thieme, H. 1997. Lower Palaeolithic hunting spears from Germany. Nature 385, 807-810.
Thieme, H. 2005. The Lower Palaeolithic art of hunting: the case of Schöningen 13 II-4, Lower Saxony, Germany. (in) Gamble, C., Porr. M. (eds), The Hominid Individual in Context: Archaeological investigations of Lower and Middle Palaeolithic landscapes, locales and artifacts. Routledge, Oxford, pp. 115-132
THOCP (2010). The History of Computing Project - http://www.thocp.net/
Thornton, S. 2009. Karl Popper, (in) The Stanford Encyclopedia of Philosophy (Summer 2009 Edition), Edward N. Zalta (ed.) - http://tinyurl.com/2fjllp9.
Thurston, R.H. (1878). A History of the Growth of the Steam Engine. D. Appleton and Co., New York. - http://tinyurl.com/29kl8kx.
Tobias, P.V. 1987. The brain of *Homo habilis*: a new level of organization in cerebral evolution. Journal of Human Evolution 16, 741-761 - http://tinyurl.com/lmgxjg8.
Tomasello, M. 1999. The Cultural Origins of Human Cognition. Harvard University Press, Cambridge, MA.
Tomasello, M. 2008. Origins of Human Communication, MIT Press, Cambridge, Mass – [download book: http://tinyurl.com/q6ro6l6].
Tomasello, M., Carpenter, M., Call, J., Behne, T., Moll, H. 2005. Understanding and sharing intentions: the origins of cultural cognition. Behavioral and Brain Sciences 28, 675-731 - http://tinyurl.com/mrb8hcj
Tomasello, M., Kruger, A.C., Ratner, H.H. 1993. Cultural Learning. Behavioral and Brain Sciences 16, 495-552.

Tomasello, M., Melis, A.P., Tennie, C., Wyman, E., Herrmann, E. 2012. Two key steps in the evolution of human cooperation – the interdependence hypothesis. Current Anthropology 53(6), 673-692 - http://tinyurl.com/kfjtxp8.

Toro-Moyano, I., Martinez-Navarro, B., Agusti, J., Souday, C., Bermudez de Castro, J.M., Martinon-Torres, M., Fajardo, B., Duval, M., Falgueres, C., Oms, O., Pares, J.P., Anadon, P., Julia, R., Garcia-Aguilar, M., Moigne, A.-M., Espigares, M.P., Ros-Montoya, S., Palmqvist, P. 2013. The oldest human fossil in Europe, from Orce (Spain). Journal of Human Evolution 65, 1-9 - http://tinyurl.com/lgb78rc

Toth, N., Schick, K. 2009. The Oldowan: the tool making of early hominins and chimpanzees compared. Annual review Anthropology 38, 289-305.

Tourkakis, C.A. 2009. Savanna chimpanzees (Pan troglodytes verus) as a referential model for the evolution of habitual bipedalism in hominids. MA Thesis, Iowa State University, Ames, pp. 114 - http://tinyurl.com/o3brhfp

Tout, N. (2000-2008). Mechanical Calculators in Vintage Calculators Web Museum. - http://tinyurl.com/247oyez.

Treangen, T.J., Rocha, E.P.C. 2011. Horizontal transfer, not duplication, drives the expansion of protein families in prokaryotes. PLoS Genetics, 7(1): e1001284. doi:10.1371/journal.pgen.1001284 - http://tinyurl.com/cgrbtoh.

Treloar, A. (1996). New Wine into Old Wineskins: Accessing the Internet and Lessons from the Past. Presented at VALA '93, Melbourne, Australia, November 1993- http://tinyurl.com/235k8ck.

Treves, A., Palmqvist, P. 2007. Reconstructing hominin interactions with mammalian carnivores (6.0 – 1.8 Ma). (in) Gursky, S.L., Nekaris, K.A.I. (eds), Primate Anti-Predator Strategies. Springer Science+Business Media, LLC. (2007), pp. 355 - 381 –http://tinyurl.com/za2p4jf.

Trigger, B.G., 2004. Writing systems: a case study in cultural evolution. (in) The First Writing: Script Invention as History and Process, Houston, S.D. (ed). Cambridge Univ. Press, Cambridge - http://tinyurl.com/zg7qsdh.

Tsokolov, S.A. 2009. Why is the definition of life so elusive: epistemological considerations. Astrobiology 9(4), 401-412.

Tsokolov, S.A. (2010) A theory of circular organization and negative feedback: defining life in a cybernetic context. Astrobiology 19(10): 1031-1041.

Tuomi, I. (1999): Corporate Knowledge: Theory and Practice of Intelligent Organization. Helsinki, Metaxis, 453 p. http://tinyurl.com/n96k6lr

Turchin, V. (1991). Knowledge. *in* Principia Cybernetica Web - http://tinyurl.com/n95prvo

Turner, J.H. 1951. Roman elementary mathematics: the operations. The Classical Journal 47(2), 63-74 + 106-108 - http://tinyurl.com/83oc8cb [no server 28/12/2014].

Twomey, T.M. 2011. Keeping fire: the cognitive implications of controlled fire use by Middle Pleistocene humans. PhD Thesis. School of Social and Political Sciences, University of Melbourne - http://tinyurl.com/9vx34y9

Tylén, K., Weed, E., Wallentin, M., Roepstorff, A., Frith, C.D. 2010. Language as a tool for interacting minds. Mind & Language 25(1), 3-29 - http://tinyurl.com/kujlphw

Umair, M. 2012. Adaptivity, emotion, and rationality in human and ambient agent models. PhD Thesis, Vrije Universiteit Amsterdam, 273 pp. - http://tinyurl.com/8zkhagg.

Ungar, P.S., Scott, R.S. 2009. Dental evidence for diets of early *Homo.* (in) F.E. Grine et al. (eds.), The First Humans: Origin and Early Evolution of the Genus *Homo*, Vertebrate

Paleobiology and Paleoanthropology, © Springer Science + Business Media B.V., pp 121-133 - http://tinyurl.com/nxokzfo.
Upward, F. (1996). Structuring the Records Continuum – Part One: Postcustodial principles and properties. Archives and Manuscripts, 24:2 — http://rcrg.dstc.edu.au/publications/recordscontinuum/fupp1.html
Upward, F. (1997). Structuring the Records Continuum – Part Two: Structuration Theory and Recordkeeping. Archives and Manuscripts, 25:1 — http://rcrg.dstc.edu.au/publications/recordscontinuum/fupp2.html
Urrestarazu, H. 2004. On boundaries of autopoietic systems. Journal of Autopoietic Theory. 19 May 2004 - http://tinyurl.com/omvl8eg.
Urrestarazu, H. 2011.Autopoietic systems: a generalized explanatory approach – part 1. Constructivist Foundations 6(3), 307–324 - http://tinyurl.com/7yw88ny.
Urrestarazu, H. 2011a. Autopoietic systems: a generalized explanatory approach – part 2. Constructivist Foundations 7(1): 48–67 - http://tinyurl.com/6p9dyvr.
Urrestarazu, H. 2012. Autopoietic systems: a generalized explanatory approach – part 3. The scale of description problem. Constructivist Foundations 7(3): 180-195 - http://tinyurl.com/l7dcduo
Urrestarazu. H. 2013. Autopoietic systems: a generalized explanatory approach – part 4. Social systems. Constructivist Foundations [forthcoming].
Vaesen, K. 2012. The cognitive bases of human tool use. Behavioral and Brain Sciences 35, 203-262 - http://tinyurl.com/l5qs965
Valavanis, K.P., Vachtesevanos, G.J., Antsaklis, P.J. 2007. Technology and autonomous mechanisms in the Mediterranean: from ancient Greece to Byzantium. Proceedings of the European Control Conference, Kos, Greece, July 2-5, 2007 - http://tinyurl.com/p3q3lea.
Vallianatos, E. 2012. Deciphering and appeasing the heavens: the history and fate of an ancient Greek computer. Leonardo 45(3), 250-257.
Van Arsdale, A.P. 2013. Homo erectus - a bigger, smarter, faster hominin lineage. Nature Education Knowledge 4(1):2 - http://tinyurl.com/kuob3me
van Arsdale, A.P., Lordkipanidze, D. 2012. A quantitative assessment of mandibular variation in the Dmanisi hominins. Paleo Anthropology 2012, 134-144 - http://tinyurl.com/nyxvtnh
van Arsdale, A.P., Wolpoff, M.H. 2012. A single lineage in Early Pleistocene Homo: size variation continuity in Early Pleistocene Homo crania from East Africa and Georgia. Evolution 67(3), 841-850 - http://tinyurl.com/ojonllo.
van den Bergh, G.D., Meijer, H.J.M., Awe, R.D., Morwood, M.J., Szabó K., van den Hoek Ostende, L.W., Sutikna, T., Saptomo, E.W., Piper, P.J., Dobney, K.M. 2009. The Liang Bua faunal remains: a 95 k.yr. sequence from Flores, East Indonesia. Journal of Human Evolution 57(5), 537-537 - http://tinyurl.com/mlbawcg [click download - slow link].
van der Gulik P, Massar S, Gilis D, Huhrman H, Rooman M. 2009. The first peptides: The evolutionary transition between prebiotic amino acids and early proteins. Journal of Theoretical Biology 261(4): 531-539 - http://tinyurl.com/l5omug2.
van der Made, J. 2011. Biogeography and climatic change as a context to human dispersal out of Africa and within Eurasia. Quaternary Science Reviews 30, 1353-1367 - http://tinyurl.com/lzgzsbm
Van Essen, D.C., Ugurbil, K. 2012. The future of the human connectome. NeuroImage (in press), 12 pp. - http://tinyurl.com/cxvt28v

van Gaal, S., de Lange, F.P., Cohen, X. 2012. The role of consciousness in cognitive control and decision making. Frontiers in Neuroscience 6, no. 121, 15 pp.
van Heteren, A.H. 2012. The hominins of Flores: insular adaptations of the lower body. Comtes Rendus Palevol 11, 169-179 - http://tinyurl.com/kp3xk9p.
van Schaik, C.P., Ancrenaz, M., Borgen, G., Galdikas, B., Knott, C.D., Singleton, I., Suzuki, A., Utami, S>S., Merrill, M. 2003. Orangutan cultures and the evolution of material culture. Science 299, 102-105 - http://tinyurl.com/ltqgaff.
van Schaik, C.P., Burkart, J.M. 2010. Mind the gap: cooperative breeding and the evolution of our unique features. (in) Mind the Gap: Tracing the Origins of Human Universals. Kappeler, P.M., Silk, J.B. eds. Springer Verlag, Heidelberg, pp. 477 – 496 - http://tinyurl.com/23gdehf.
van Schaik, C.P., Burkart, J.M. 2011. Social learning and evolution: the cultural intelligence hypothesis. Philosophical Tansactions of the Royal Society B 388, 1008-1016 - http://tinyurl.com/9uwpeud
van Schaik, C.P., Deaner, R.O., Merrill, M.Y. 1999. The conditions for tool use in primates: implications for the evolution of material culture. Journal of Human Evolution 36, 719-741 - http://tinyurl.com/lmzcxjo.
van Schaik, C.P., Pradhan, G.R. 2003. A model for tool-use traditions in primates: implications for the coevolution of culture and cognition. Journal of Human Evolution 44, 645-664 - http://tinyurl.com/lr5pjwj
van Schaik, C.P., Isler, K., Burkart, J.M. 2012. Explaining brain size variation: from social to cultural brain. Trends in Cognitive Science 16(5), 277-284.
Van Valen, L. 1973. A new evolutionary law. Evolutionary Theory 1: 1–30 - http://tinyurl.com/h88ublu.
Vandermeersch, B., Garralda, M.D. 2011. Neanderthal geographical and chronological variation. (in) Condemi, S., Weniger, G.-C. (eds), Continuity and Discontinuity in the Peopling of Europe: one hundred fifty years of Neanderthal study, Springer Science+Business Media, Dordrecht. pp, 113-125 - http://tinyurl.com/h3cukgb.
Varela, F. (1979). Principles of Biological Autonomy. Elsevier (North Holland), New York.
Varela, F. (????). Autopoiesis and a Biology of Intentionality. Essay 1 in Workshop on Autopoiesis and Perception. - Technical Report bmcm9401, Dublin City University School of Electronic Engineering http://www.eeng.dcu.ie/~alife/bmcm9401/varela.pdf
Varela, F.J., Maturana, H.R., & Uribe R. (1974). Autopoiesis: the organization of living systems, its characterization and a model. Biosystems 5:187-196 - http://tinyurl.com/kbfxs3b.
Varki, A. 2016. Why are there no persisting hybrids of humand with Denisovans, Neanderthals, or anyone else? Proceedings of the National Academy of Science www.pnas.org/cgi/doi/10.1073/pnas.1602270113, 1 p.
Varmus, H. (1999). E-Biomed: A proposal for electronic publications in the biomedical sciences. 5 May 1999 - http://tinyurl.com/26bwhy9.
Vasconcelos, J., Kimble, C. & Gouveia, F. R. 2000. A design for a Group Memory System using Ontologies. Proceedings of 5th UKAIS Conference, University of Wales Institute, Cardiff, McGraw Hill, April 2000, http://www.cs.york.ac.uk/mis/docs/ontologies.pdf
Vasconcelos, J., Kimble, C., Gouveia, F. R., & Kudenko, D. (2000a). A Group Memory System for Corporate Knowledge Management: an Ontological Approach. Proceedings of the 1st European Conference on Knowledge Management (ECKM'2000), Bled School of

Management, Slovenia, October 2000, ISBN: 0 9510066 4 9, pp. 91-99. http://www-users.cs.york.ac.uk/~kimble/research/ECKM-2000-paper.pdf.

Veeramah, K.R., Hammer, M.F. 2014. The impact of whole-genome sequencing on the reconstruction of human population history. Nature Reviews – Genetics 15, 149-162.

Veeramah, K.R., Wegmann, D., Woerner, A., Mendez, F.L., Watkins, J.C., Destro-Bisol, G., Soodyall, H., Louie, L., Hammer, M.E. 2012. An early divergence of KhoeSan ancestors from those of other modern humans is supported by an ABC-Based analysis of autosomal resequencing data. Molecular Biology and Evolution 29(2), 617-630 - http://tinyurl.com/lwmctcz

Vehkavaara, T. (1998). Extended concept of knowledge for evolutionary epistemology and for biosemiotics: hierarchies of storage and subject of knowledge *in* George L. Farre and Tarkko Oksala (eds.): Emergence, Complexity, Hierarchy, Organization. Selected and edited papers from ECHO III. Acta Polytechnica Scandinavica: Mathematics, computing and management in engineering series No. 91; Espoo 1998, pp. 207-216. - http://tinyurl.com/le7xmzk.

Vekua, A., Lordkipanidze, D. 2010. Dmanisi (Georgia) – site of discovery of the oldest hominid in Eurasia. Bulletin of the Georgian National Academy of Sciences, 4(2), 158-164 - http://tinyurl.com/m9twpjk.

Vekua, A., Lordkipanidze, D. 2011. Evolution of paleosituation in Georgian Anthropogene. Bulletin of the Georgian National Academy of Sciences 5(3), 116-122 - http://tinyurl.com/jwdyyyp

Vekua, A., Lordkipanidze, D., Rightmire, G.P., Agusti, J., Ferring, R., Maisuradze, G., Mouskhelishvili, A., Nioradze, M., Ponce de Leon, M., Tappen, M., Tvalchrelidze, M., Zollikofer, C. 2002. A new skull of early Homo from *Dmanisi*, Georgia. Science 297, 85-89 - http://tinyurl.com/mx4r63u.

Venzin, M., Krogh, G.v. & Roos, J. 1998. Future Research into Knowledge Management. *in Krogh, et. al. (eds.)* Knowing in Firms: Understanding, Managing and Measuring Knowledge. SAGE Publications, London. [no link]

Verbeek, P.-P. 2009. Ambient intelligence and persuasive technology: the blurring boundaries between human and technology. Nanoethics 3, 231-242 - http://tinyurl.com/9a8czow.

Verderane, M.P., Izar, P., Visalberghi, E., Fragaszy, D.M. 2013. Socioecology of wild bearded capuchin monkeys (*Sapajus libidinosus*): an analysis of social relationships among female primates that use tools in feeding. Behaviour 150, 659-689 - http://tinyurl.com/kxrf57w.

Vericat, F.L. (2000) Ghostly Objectives: Metaphysics and Style in T.S. Eliot's "Hamlet and His Problems". Nomadas 1 - Revista Critica de Ciencias Sociales y Juridicas - Registro de Pasajes y Mapas en la Cultura y el Conocimiento - http://tinyurl.com/2cmzht4.

Vernot, B., Akey, J.M. 2014. Resurrecting surviving Neandertal lineages from modern human genomes. Science 343, 1017-1021 - http://tinyurl.com/kzny9la.

Vernot, B., Tucci, S., Kelso, J., Schraibler, JG., Wolf, A.B., Gittelman, R.M., Nannemann, M., Grote, S., McCoy, R.C., Norton, H., Scheinfeldt, L.B., Merriwether, D.A., Koki,G., et al. 2016. Excavating Neandertal and Denisovan DNA from the genomes of Melanesian individuals. Science 10.1126/science.aad9416 - http://tinyurl.com/hn59hvn

Villa, P., Roebroeks, W. 2014. Neandertal demise: an archaeological analysis of the modern human superiority complex. PLoS ONE 9(4): e96424. doi:10.1371/journal.pone.0096424 - http://tinyurl.com/lfgpbrf

Vines, R., Hall, W.P. 2011. Exploring the foundations of organizational knowledge. Kororoit Institute Working Papers No. 3, 1-41 - http://tinyurl.com/nxwz6ud.

Vines, R., Hall, W.P., McCarthy, G. 2011. Textual representations and knowledge support-systems in research intensive networks. (in) Cope, B., Kalantzis, M., Magee, L. (eds). Towards a Semantic Web: Connecting Knowledge in Academic Research. Oxford: Chandos Press, pp. 145-195 - http://tinyurl.com/mbbfaap

Vines, R., Hall, W.P., Naismith L. 2007. Exploring the foundations of organisational knowledge: An emergent synthesis grounded in thinking related to evolutionary biology. actKM Conference, Australian National University, Canberra, 23-24 October 2007 - http://tinyurl.com/3xpmbc.

Vines, R., Firestone, J.M. 2009. Interoperability and the exchange of humanly usable digital content across a global economy. KMCI.org, Resources and Links - [in Cope, W., Kalantzis, M., Magee, L. (eds), Connecting Knowledge in Academic Research. Chandos Publishing (2009)] - http://tinyurl.com/mdwkrpt.

Visalberghi, E. 1997. Success and understanding in cognitive tasks: a comparison between Cebus apella and Pan troglodytes. International Journal of Primatology 18, 811-830.

Visalberghi, E., Addessi, E. 2013. Selectivity in stone tool use by wild bearded capuchin monkeys – field observations and experimental evidence. Nova Acta Leopoldina NF 111, Nr. 380, pp. 191–204 [in Quo Vadis, Behavioural Biology? Past, Present, and Future of an Evolving Science. International Symposium of the Humboldt-Universität zu Berlin and the German National Academy of Sciences Leopoldina, Berlin April 30 to May 4, 2009 - http://tinyurl.com/onz9hvg].

Visalberghi, E., Addessi, E., Truppa, V., Spagnoletti, N., Ottoni, E., Izar, P., Fragaszy, D. 2009. Selection of effective stone tools by wild bearded capuchin monkeys. Current Biology 19, 213–217 - http://tinyurl.com/mnkgpyp.

Visalberghi, E., Fragaszy, D. 2011. Learning how to forage. Socially biased individual learning and “niche construction” in wild capuchin monkeys. In The Primate Mind, eds. F. de Waal and P.F. Ferrari, pp. 81-98. Harvard University Press, Cambridge, MA, pp. 81-98 - http://tinyurl.com/kko27zf

Visalberghi, E., Fragaszy, D. 2012. What is challenging about tool use. The capuchin’s perspective. In Comparative Cognition: Experimental Explorations of Intelligence, 2nd Edition, eds. E. Wasserman and T. Zentall, Oxford University Press, pp. 777-799 - http://tinyurl.com/nb7u6uv.

Visalberghi, E., Fragaszy, D. 2013. The Etho-Cebus Project: stone-tool use by wild capuchin monkeys. In Multidisciplinary Perspectives on the Cognition and Ecology of Tool Using Behaviors, eds. Sanz, C., Call, J. & Boesch, C. Cambridge University Press, Cambridge, pp. 203-222 - http://tinyurl.com/mf5knlx.

Visalberghi, E., Fragaszy, D., Ottoni, E., Izar, P., de Oliveria, M.G., Andrade, F.R.D. 2007. Characteristics of hammer stones and anvils used by wild bearded capuchin monkeys (Cebus libidinosus) to crack open palm nuts. American Journal of Physical Anthropology 132, 426-444 - http://tinyurl.com/ncd63yg.

Visalberghi, E., Haslam, M., Spagnoletti, N., Fragaszy, D. 2013. Use of hammer tools and anvils by bearded capuchin monkeys over time and space: construction of an archeological record of tool use. Journal of Archaeological Science 40, 3222-3232 - http://tinyurl.com/pn5fle3.

Visalberghi, E., McGrew, M.C. 1997. *Cebus* meets *Pan*. International Journal of Primatology 18, 677-681 - http://tinyurl.com/z3bdud5.

Visalberghi, E., Sabbatini, G., Spagnoletti, N., Andrade, F.R.D., Ottoni, E., Izar, P., Fragaszy, D. 2008. Physical properties of palm fruits processed with tools by wild bearded capuchins (Cebus libidinosus). American Journal of Primatology 70, 884-981 - Physical properties of palm fruits processed with tools by wild bearded capuchins (*Cebus libidinosus*) - http://tinyurl.com/h58kg6l.

Visalberghi, E., Spagnoletti, N., Ramos da Silva, E.D., Andrade, F.R.D., Ottoni, E., Izar, P., Fragaszy, D. 2009a. Distribution of potential suitable hammers and transport of hammer tools and nuts by wild capuchin monkeys. Primates 50, 95-104 - http://tinyurl.com/k4ptnxl.

Visalberghi, E., Truppa, V., Sabbatini, G. 2011. Analogical reasoning: what capuchin monkeys can tell us? Kokinov, B., Karmiloff-Smith, A., Nersessian, N. J. (eds.) European Perspectives on Cognitive Science. New Bulgarian University Press. 4 pp. - http://tinyurl.com/n6zhngj

Vivelo, A. 2013. Characterization of unique features of the Denisovan exome. MS Thesis, California State University, East Bay - http://tinyurl.com/lyqxnkn

Vlcek, E. 1978. A new discovery of *Homo erectus* in central Europe. Journal of Human Evolution 7, 239–251.

Vlcek, E., Mania, D., Mania, U. 2000. A new find of a Middle Pleistocene mandible from Bilzingsleben, Germany. Naturwissenschaften 87, 264-265

Voge, C.M., Stegemann, J.P. 2011. Carbon nanotubes in neural interfacing applications. Journal of Neural Engineering 8, no 011001, 10 pp.

Voloch, C.M., Vilela, J.F., Loss-Oliveira, L., Schrago, C.G. 2013. Phylogeny and chronology of the major lineages of New World hystricognath rodents: insights on the biogeography of the Eocene/Oligocene arrival of mammals in South America. BMC Research Notes 6, no. 160, 9 pp. - http://tinyurl.com/zvojykc.

von Krogh, G. & Roos, J. (1995). A perspective on knowledge, competence and strategy. Personnel Review, 24(3) 1995 pp. 56-76. - [http://rudolfo.emeraldinsight.com/vl=7418400/cl=56/nw=1/fm=html/rpsv/cw/mcb/00483486/v24n3/s5/p56]

von Krogh, G. & Roos, J. 1995. Organizational Epistemology. Macmillan, Basingstoke [not seen]

von Krogh, G., Roos, J. & Kleine, D., *Eds.* (1998). Knowing in Firms: Understanding, Managing and Measuring Knowledge. Sage Publications Ltd, London.

von Krogh, G., Roos, J. & Slocum, K. (1996). An Essay on Corporate Epistemology, in G. van Krogh and J. Roos (eds.), Managing Knowledge. Sage: London [Not seen]

von Lohmann 2009. Google books settlement 2.0: evaluating access. Electronic Frontier Foundation, Deeplinks Blog, Nov. 17, 2009 - http://tinyurl.com/kj792wf.

W3C (2010). W3C Semantic Web Activity. Technology and Society Domain. W3C World Wide Web Consortium (current) - http://tinyurl.com/ldfqood.

Waddell, P.J. 2013. Happy New Year Homo erectus? More evidence for interbreeding with archaics predating the modern human/Neanderthal split. arXiv:1312.7749 [q-bio.PE] – pp. 1-29 - http://tinyurl.com/muue9d6

Wadley, L. 2013. Recognizing complex cognition through innovative technology in Stone Age and Palaeolithic sites. Cambridge Archaeological Journal 23(2), 163–83 - http://tinyurl.com/m2ldygy.

Wagner, G.A., Krbetschek, M., Degering, D., Bahain, J.-J., Shao, QW., Falaguères, C., Voinchet, P., Dolo, J.-M., Garcia, T., Rightmire, G.P. 2010. Proceedings of the National Academy of Sciences 107(46), 19726-19730 - http://tinyurl.com/ks28kpr
Walker, R., Markram, H., and many others. 2012. The Human Brain Project: A Report to the European Commission. The HBP-PS Consortium, Lausanne, 106 pp. - http://tinyurl.com/boasdtu
Walker, T.J. (1997) - The future of scientific journals: Free access or pay per view - http://tinyurl.com/2vjfw83.
Walker, T.J. (1998). Free Internet Access to Traditional Journals. American Scientist. 86(5) - http://tinyurl.com/2a4usqa.
Wall, J.D., Yang, M.A., Jay, F., Kim, S.K., Durand, E.Y., Stevison, L.S., Gignoux, C., Woerner, A., Hammer, M.F., Slatkin, M. 2013. Higher levels of Neanderthal ancestry in East Asians than in Europeans. Genetics 94, 194, 199–209 - http://tinyurl.com/ntuoh65.
Wallace, D. (2010) The Everett interpretation (in) The Oxford Handbook of Philosophy of Physics, (ed) Batterman, R.W. Oxford Univ. Press, New York, pp 460- - http://tinyurl.com/pz3jxng.
Wallace, G.G., Higgins, M.J., Moulton, S.E., Wang, C. 2012. Nanobionics: the impact of nanotechnology on implantable medical bionic devices. Nanoscale 4, 4327-4347.
Wallace, G.G., Moulton, S., Kapsa, R.M.I., Higgins, M. 2012. Chapter 1, Medical Bionics (in) Organic Bionics. Wiley-VCH, Weinheim, pp. 1-39 - http://tinyurl.com/73goaek
Wallace, M., Kalleberg, A.L. 1982. Industrial transformation and the decline of craft: the decomposition of skill in the printing industry, 1931-1978. American Sociological Review 47(3), 307-324.
Wallace, T. 2007. Thermodynamics vs evolutionism. *In* The True.Origin Archive: Exposing the Myth of Evolution - http://tinyurl.com/mugcq9l.
Walsh, J.P. & Ungson, G.R. (1991). Organizational Memory. The Academy Of Management Review, Briarcliff Manor; 16(1) [Full text via Proquest]
Walsh, N. (1998). What is XML? – XML.COM - http://www.xml.com/pub/98/10/guide1.html
Wang, C.-C., Farina, S.E., Li, H. 2012. Neanderthal DNA and modern human origins. Quaternary International [in press], doi:10.1016/j.quaint.2012.02.027, 4 pp.
Wang, W., Lycett, S.J., von Cramon-Traubadel, Jin, J.J.H., Bae, C.J. 2012a. Comparison of handaxes from Bose Basin (China) and the Western Acheulean indicates convergence of form, not cognitive differences. PLoS ONE 7(4): e35804. doi:10.1371/journal.pone.0035804 - http://tinyurl.com/l4f7oz9
Wang, W., Bae, C.J., Huang, S., Huang, X., Tian, F., Mo, J., Huang, Z., Huang, C., Xie, S., Li, D. 2014. Middle Pleistocene bifaces from Fengshudao (Bose Basin, Guangxi, China). Journal of Human Evolution 69, 110-120 - http://tinyurl.com/pz9jffy
Wang, Y., Li Z., Wang, J., Li, J., Lin, Y. 2011. Graphene and graphene oxide: biofunctionalization and applications in biotechnology. Trends in Biotechnology 29(5), 205-212 - http://tinyurl.com/coavxkg
Warburton, D.A. 2009. Economics, anthropological models and the ancient near east. Anthropology of the Middle East 4(1), 65-90
Ward, J.O. 2000. Alexandria and its medieval legacy: the book, the monk and the rose. (in) The Library of Alexandria: Centre of Learning in the Ancient World. MacLeod, R. (ed). I.B. Tauris, London.

Wason, P.C. 1960. On the failure to eliminate hypotheses in a conceptual task. The Quarterly Journal of Experimental Psychology, 12(3), 129-140.
Wässle, H. 2004. Parallel processing in the mammalian retina. Nature Reviews – Neuroscience 5 (October), 1-11 - http://tinyurl.com/dyglm6z.
Watkins, J. 1997. Obituary of Karl Popper, 1902–1994. Proceedings of the British Academy, Volume 94, pp. 645–684 - http://tinyurl.com/29a92da (and following).
Watts, D.P. 2008. Tool use by Chimpanzees at Ngogo Kibale National Park, Uganda. International Journal of Primatology 29, 83-94 - http://tinyurl.com/l6wezdz
Weaver, T.D. 2014. Tracing the paths of modern humans from Africa. Proceedings of the National Academy of Sciences 111(20), 7170-7171 - http://tinyurl.com/mhc69bp.
Weber, J., Czarnetzki, A., Pusch, C.M. 2005. Comment on ‘‘The brain of LB1, Homo floresiensis.’’ Science 310, 236 [included with Brown et al. 2004].
Weber, K. 2012. Surveillance, sousveillance, equiveillance: Google Glasses. Social Sciences Research Network Working Paper, pp. 1-3 - http://tinyurl.com/6nh74jl
Wedeen, V.J., Hagmann, P., Tseng, W-Y., Reese, T.G., Weisskoff, R.M. 2005. Mapping complex tissue architecture with diffusion spectrum magnetic resonance imaging. Magnetic Resonance in Medicine 54, 1377-1386 - http://tinyurl.com/d9yw7f4
Wedeen, V.J., Rosene, D.L., Wang, R., Dai, G., Mortazavi, F., Hagmann, P., Kaas, J.H., Tseng, W.-Y.I. 2012. The geometric structure of the brain fiber pathways. Science 335, 1628-1534 - http://tinyurl.com/bwf2nhd; Supplementary materials/methods, SOM text, figs. S1 to S9 - http://tinyurl.com/cb36qj4
Wegner, D. M. 2002. The illusion of conscious will. MIT Press, Cambridge, MA.
Weik, M.H. (1955). A Survey of Domestic Electronic Digital Computing Systems. Report No. 971, December 1955 - Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland - http://tinyurl.com/2a62m4o.
Weik, M.H. (1961). The ENIAC Story. ORDNANCE, The Journal of the American Ordnance Association. January-February 1961 - http://tinyurl.com/2do3adh.
Weik, M.H. (1961a). A Third Survey of Domestic Electronic Digital Computing Systems. Report No. 1115, March 1961 - Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland - http://tinyurl.com/27dydcm.
Weik, M.H. (1964). A Fourth Survey of Domestic Electronic Digital Computing Systems. Report No. 1227. January 1964. Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland - http://tinyurl.com/2d72uvh.
Weinberg, B.H. (1996). Complexity in Indexing Systems -- Abandonment and Failure: Implications for Organizing the Internet. ASIS 1996 Annual Conference Proceedings, October 19-24, 1996 - http://tinyurl.com/24mp6ns.
Weinberg, G.D., Grace, V.R., Edwards, G.R., Robinson, H.S., Throckmorton, P., Ralph, E.K. 1965. The Antikythera shipwreck reconsidered. Transactions of the American Philosophical Society, N.S. 55(3), 3-48.
Wells, J.K.C., Stock, J.T. 2007. The biology of the colonizing ape. Yearbook of Physical Anthropology 50, 191-222 - http://tinyurl.com/khx4ndv
Welser, M. 1682. Opera Historica et Philologica, Sacra et Profana. Typis ac sumtibus W. Mauritii, & filiorum J. Andreae, Endterorum, [in] Norimbergae – read online - http://tinyurl.com/7xcjbxt.
Wenning, W.B. (1997) Birthplace of the First Business Computer: a Time Line 409 Time Line: Related People, Facilities & Events - http://tinyurl.com/2anury9.

Wenning, W.B. (????) Remington Rand's First Computer: A Short History - http://tinyurl.com/24wj4av.
Werdelin, L. 2013. King of beasts. Scientific American. November 2013, 35-39.
Werdelin, L., Lewis, M.E. 2013. Temporal change in functional richness and evenness in the Eastern African Plio-Pleistocene carnivoran guild. PLoS ONE 8(3), e57944. doi:10.1371/journal.pone.0057944 - http://tinyurl.com/kndo34t.
Westaway, K.E., Roberts, R.G., Sutikna, T., Morwood, M.J., Drysdale, R., Zhao, J.-x.,Chivas, A.R. 2009. The evolving landscape and climate of western Flores: an environmental context for the archaeological site of Liang Bua. Journal of Human Evolution 57(5), 450-464 - http://tinyurl.com/m4nhmgk [slow link].
Westaway, K.E., Sutikna, T., Saptomo, W.E., Jatmiko, Morwood, M.J., Roberts, R.G., Hobbs, D.R. 2009a. Reconstructing the geomorphic history of Liang Bua, Flores, Indonesia: a stratigraphic interpretation of the occupational environment. Journal of Human Evolution 57(5), 465-483 - http://tinyurl.com/n436rzb [slow link].
Westergaard, G.C. 1998. What capuchin monkeys can tell us about the origins of hominid material culture. Journal of Material Culture 3, 5-19 - http://tinyurl.com/hsodz3m.
Westergaard, G.C. 1999. Structural analysis of tool-use by tufted capuchins (*Cebus apella*) and chimpanzees (*Pan troglodytes*). Animal Cognition 2, 141-145 - http://tinyurl.com/ha3mdws.
Westergaard, G.C., Evans, T.A.E., Howell, S. 2007. Token mediated tool exchange between tufted capuchin monkeys (*Cebus apella*). Animal Cognition 10, 407-414 - http://tinyurl.com/hdzzxrw.
Westergaard, G.C., Fragaszy, D.M. 1987. The manufacture and use of tools by capuchin monkeys (*Cebus apella*). Journal of Comparative Psychology, 101, 159-168 - http://tinyurl.com/jl6o7np.
Westergaard, G.C., Greene, J.A., Babitz, M.A., Suomi, S.J. 1995. Pestle use and modification by tufted capuchins (*Cebus apella*). International Journal of Primatology 16, 643-651 - http://tinyurl.com/z3nzn62.
Westergaard, G.C., Kuhn, H.E., Babitz, M.A. Suomi, S.J. 1998. Aimed throwing as a means of food transfer between tufted capuchins (*Cebus apella*). International Journal of Primatology 19(1), 123-131 - http://tinyurl.com/jr2xd6q.
Westergaard, G.C., Liv. C., Haynie, M.K., Suomi, S.J. 2000. A comparative study of aimed throwing by monkeys and humans. Neuropsychologia 38, 1511-1517 - http://tinyurl.com/gvdmar6
Westergaard, G.C., Liv, C., Rocca, A.M., Cleveland, A., Suomi, S.J. 2004. Tufted capuchins (*Cebus apella*) attribute value to foods and tools during voluntary exchanges with humans. Animal Cognition 7, 19-24 - http://tinyurl.com/z9yq94q.
Westergaard, G.C., Lundquist, A.L. Haynie, M.K., Kuhn, H.E., Suomi, S.J. 1998a. Why some capuchin monkeys (*Cebus apella*) use probing tools (and others do not). Journal of Comparative Psychology 112, 207-211 - http://tinyurl.com/jnd8ov7.
Westergaard, G.C., Suomi, S.J. 1993. Use of a tool-set by capuchin monkeys (*Cebus apella*). Primates 34, 459-462 - http://tinyurl.com/jl6o7np.
Westergaard, G.C., Suomi, S.J. 1994. A simple stone-tool technology in monkeys. Journal of Human Evolution 27, 399-404 - http://tinyurl.com/hwzan6j.

Westergaard, G.C., Suomi, S.J. 1994a. The use of probing tools by tufted capuchins (*Cebus apella*): evidence for increased right-hand preference with age. International Journal of Primatology 15, 521-529 - http://tinyurl.com/zdo7e3e.

Westergaard, G.C., Suomi, S.J. 1995. The stone tools of capuchins (*Cebus apella*). International Journal of Primatology 16(6), 1017-1024 - http://tinyurl.com/hquc5zh.

Westergaard, G.C., Suomi, S.J. 1995a. The production and use of digging tools by monkeys: a nonhuman primate model of a hominid subsistence activity. Journal of Anthropological Research 51(1), 1-8 - http://tinyurl.com/lbbtudn.

Westergaard, G.C., Suomi, S.J. 1997. Capuchin monkey (*Cebus apella*) grips for the use of stone tools. American Journal of Physical Anthropology 103, 131-135 - http://tinyurl.com/guo8rrp.

Westergaard, G.C., Suomi, S.J. 1997a. Transfer of tools and food between groups of tufted capuchins (*Cebus apella*). American Journal of Primatology 43, 33-41 - http://tinyurl.com/hg2gaxx.

Weston, K.R. (1997). UNIVAC: The Paul Revere of the Computer Revolution. Student paper *from* The History of Computing. Department of Computer Science, Virginia Tech. - http://tinyurl.com/28ue78y.

Westwood, C.J., (1996). Military Information Operations in a Conventional Warfare Environment. APSC Working Paper 47. Air Power Studies Centre, Australia.

Wetzel, K.A. (2002). Portal Functionality Provided by ARL Libraries: Results of an ARL Survey. ARL Bimonthly Report 222, June 2002. - http://tinyurl.com/2fwjmrp.

Weyhrich, S. (1991-2008). Apple II History. - http://tinyurl.com/23vh2zt.

Whallon, R. 2006. Social networks and information: non-"utilitarian" mobility among hunter-gatherers. Journal of Anthropological Archaeology 25, 259-270 - http://tinyurl.com/knnwg5t.

Whitaker, R. (1995). Self-Organization, Autopoiesis, and Enterprises - http://tinyurl.com/2e6zjvf.

Whitaker, R. (2001...). The Observer Web: Autopoiesis and Enaction. - http://tinyurl.com/m2krzq5.

Whitaker, R. (2001a). Encyclopaedia Autopoietica: An Annotated Lexical Compendium on Autopoiesis and Enaction - http://tinyurl.com/lyp3nfw.

White, S., Gowlett, J.A.J., Grove, M. 2014. The place of the Neanderthals in hominin phylogeny. Journal of Anthropological Arcaheology 35, 32-50 - http://tinyurl.com/gpvvk4u.

White, T.D. 2013. Paleoanthropology: five's a crowd in our family tree. Current Biology 23(3), R112-R115 - http://tinyurl.com/zovyd5h.

White, T.D. 2014. Delimitating species in paleoanthropology. Evolutionary Anthropology 23, 30-32 - http://tinyurl.com/lfldzjh.

White, T.D., Ambrose, S.H., Suwa, G., Su., D.F., DeGusta, D., Bernor, R.L., Boisserie, J.-R., Delson, E., Frost. S., Garcia, N., Giaourtsakis, I.X., Haile-Selassie, Y., Howell, F.C., et al. 2009a. Macrovertebrate paleontology and the Pliocene habitat of *Ardipithecus ramidus*. Science 326, 87-93 - http://tinyurl.com/lgcye3p

White, T.D., Asfaw, B., Beyene, Y., Haile-Selassie, Y., Lovejoy, C.O., Suwa, G., WoldeGabriel, G. 2009. *Ardipithecus ramidus* and the paleobiology of early hominids. Science 326, 75-86 - http://tinyurl.com/n6426qy.

White, T.D., Asfaw, B., DeGusta D., Gilbert, H., Richards, G.D., Suwa, G., Howell, F.C. 2003. Pleistocene *Homo sapiens* from Middle Awash, Ethiopia. Nature 423, 742-747 - http://tinyurl.com/mqhvwjp

Whiten, A. 2000. Primate culture and social learning. Cognitive Science 24(3), 477-508 - http://tinyurl.com/oxxvgju.

Whiten, A. 2005. The second inheritance system of chimpanzees and humans. Nature 437, 52-55 - http://tinyurl.com/lw27ptg

Whiten, A. 2010, Ape behavior and the origins of human culture. Chapter 20 (in) Mind the Gap: Tracing the Origins of Human Universals. Kappeler, P.M., Silk, J.B. (Eds.). Springer, Heidelberg, 429-450 - http://tinyurl.com/now22kh [downloads entire book].

Whiten, A. 2011. The scope of culture in chimpanzees, humans and ancestral apes. Philosophical Transactions of the Royal Society B 366, 997-1007 - http://tinyurl.com/8epgvp2.

Whiten, A., Erdal, D. 2012. The human socio-cognitive niche and its evolutionary origins. Philosophical Transactions of the Royal Society B 367, 2119-2129 - http://tinyurl.com/ljgssnd

Whiten, A., Goodall, J., McGrew, W.C., Nishida, T., Reynolds, V., Sugiyama, Y., Tutin, C.E.G., Wrangham, R.W., Boesch, C. 1999. Cultures in chimpanzees. Nature 399, 682 – http://tinyurl.com/p59odcx.

Whiten, A., Goodall, J., McGrew, W.C., Nishida, T., Reynolds, V., Sigiyama, Y., Tutin, C.E.G., Wrangham, R.W., Boesch, C. 2001. Charting cultural variation in chimpanzees. Behaviour 138, 1481-1516 - http://tinyurl.com/osw8hsh

Whiten, A., van Schaik, P. 2007. The evolution of animal ‘cultures’ and social intelligence. Philosophical Transactions of the Royal Society B 362,603-620 - http://tinyurl.com/me9qnj3.

Whiten, A., et. al. 2009. The evolution and cultural transmission of percussive technology: integrating evidence from palaeoanthropology and primatology. Journal of Human Evolution 57, 420–435.

Wieland, C. (1980). Evolution, Creation, and Thermodynamics. Creation Ex Nihilo 3(2):9–11, May 1980. - http://www.answersingenesis.org/docs/3810.asp.

Wilfried, E.E.G., Yamagiwa, J. 2014. Use of tool sets by chimpanzees for multiple purposes in Moukalaba-Doudou National Park, Gabon. Primates. DOI 10.1007/s10329-014-0431-5 - http://tinyurl.com/lpan2st

Wig, G.S., Schlagger, B.L., Petersen, S.E. 2011. Concepts and principles in the analysis of brain networks. Annals of the New York Academy of Sciences 1224, 126–146 - http://tinyurl.com/cyeeqom.

Wiig, K. M. (1993). Knowledge Management Foundations: Thinking About Thinking – How People and Organizations Create, Represent, and Use Knowledge, Schema Press, Arlington, TX. [http://library.monash.edu.au/cgi-bin/PWebrecon.cgi?v2=1&ti=1,1&SEQ=20030108100242&Search_Arg=Knowledge+Management+Foundations%3A+Thinking+About+Thinking&SL=None&Search_Code=TALL&PID=10697&CNT=10&SID=1 - not seen]

Wilkins, A.S., Holliday, R. 2009. The evolution of meiosis from mitosis. Genetics 181: 3–12 - http://tinyurl.com/kmq9p6c.

Williams, J. 2006. John Williams’ shadow government statistics, 22 (21 August 2006) - http://tinyurl.com/m4pgbk6.

Williams, R.J.P. & Faústro da Silva, J.J.R.. (2002). The systems approach to evolution. Biochemical and Biophysical Research Communications 297 (4): 689-699.
Williams, R.J.P., Faústro da Silva J.J.R.. (2003). Evolution was chemically constrained J. THEOR BIOL 220 (3): 323-343 FEB 7 2003
Williams, R.V. (2002). Chronology of Information Science And Technology - http://tinyurl.com/lw6v95x.
Williams, S.A., Ostrofsky, K.R., Frater, Nakita, Churchill, S.E., Schmid, P., Berger, L.R. 2013. The vertebral column of *Australopithecus sediba*. Science 340, 1232996, pp 1-5 - http://tinyurl.com/mevarum
Williamson, O.E. (1999). Strategy research: governance and competence perspectives. Strategic Management Journal. Volume 20, Issue 12, 1999. pp 1087–1108. - http://www3.interscience.wiley.com/cgi-bin/fulltext?ID=67501344&PLACEBO=IE.pdf.
Wilkins, J., Chazan, M. 2012. Blade production ~500 thousand years ago at Kathu Pan 1, South Africa: support for a multiple origins hypothesis for early Middle Pleistocene blade technologies. Journal of Archeological science 39, 1881-1900 - http://tinyurl.com/la3gf74
Wilkins, J., Schoville, B.J.,Brown, K.S., Chazan, M. 2012. Evidence for early hafted hunting technology. Science 338, 942-946 – http://tinyurl.com/pfeesmg.
Wills, P. (1997). Turning a Corner in the Search for the Origin of Life. Santa Fe Institute Bulletin 12:2 - http://www.santafe.edu/sfi/publications/Bulletins/bulletin-summer97/turning.html
Wilson, E.O. 1971. The Insect Societies. Harvard University Press, Cambridge Mass.
Wilson, E.O. 1975. Sociobiology: The New Synthesis. Cambridge Mass: Harvard University Press.
Wilson, M.L., Hauser, M.D., Wrangham, R.W. 2001. Does participation in intergroup conflict depend on numerical assessment, range location, or rank for wild chimpanzees. Animal Behaviour 61, 1203-1216 - http://tinyurl.com/mpwmb7j
Wilson, T.D. 2002. The nonsense of 'knowledge management'. Information Research 8(1) - http://tinyurl.com/2lupn
Winegrad, D. and Akera, A. (1996). ENIAC 50: A Short History of the Second American Revolution. University of Pennsylvania Almanac 42:18. -http://tinyurl.com/2erurs6.
Winograd, T. (1980). What Does it Mean to Understand Language. Cognitive Science 4:209-241.
Wittgenstein L. (1995): Philosophical Investigations. (Orig 1953). Blackwell. [not seen]
Wobber, V., Hare, B., Wrangham, R. 2008. Great apes prefer cooked foods. Journal of Human Evolution 55, 340-348 - http://tinyurl.com/8r2hx9m.
WoldeGabriel, G., Ambrose, S.H., Barboni, D., Bonnefille, R., Bremond, L., Currie, B., DeGusta, D., Hart, W.K., Murray, A.M., Renne, P.R., Jolly-Saad, M.C., Stewart, K.M., White, T.D. 2009. The geological, isotopic, botanical, invertebrate, and lower vertebrate surroundings of *Ardipithecus ramidus*. Science 326, 65e, pp. 1-5 - http://tinyurl.com/k8qlq4j
Wolfe, C. 1995. In search of post-humanist theory: the second-order cybernetics of Maturana and Varela. Cultural Critique No. 30, The Politics of Systems and Environments, Part I (Spring, 1995), pp. 33-70.
Wolff, J. 2010. John Wolff's Web Museum. VICNET, State Library of Victoria, Melbourne, Australia - http://tinyurl.com/n959wga.

Wood, B. 2010. Reconstructing human evolution: achievements, challenges, and opportunities. Proceedings of the National Academy of Sciences USA 107, 8902-8909 - http://tinyurl.com/8rsq5knf

Wood, B., 2011. Did early Homo migrate "out of " or "in to" Africa? Proceedings of the National Academy of Sciences USA 108, 10375–10376 - http://tinyurl.com/9exrcof

Wood, B. 2012. Facing up to complexity. Nature 488, 162-163 - http://tinyurl.com/k53ofwy.

Wood, B., Baker, J. 2011. Evolution in the genus Homo. Annual Review of Ecology, Evolution and Systematics 42, 47-69 http://tinyurl.com/kf5dg5q.

Wood, B.A. and Bauernfeind, A.L. 2012. Evidence for the production of speech in the fossil record. In: Oxford Handbook of Language Evolution. Eds. Tallerman, M and Gibson, K. pp. 258-272. Oxford and New York: Oxford University Press.

Wood, J., Guth, A. 2013. East Africa's Great Rift Valley: a Complex Rift System. Geology.com - http://tinyurl.com/k3fdu6l

Wood, B., Harrison, T. 2011. The evolutionary context of the first hominins. Nature 470, 347-352 - http://tinyurl.com/lvy86mb.

Wood, B., Leakey, M. 2011. The Omo-Turkana Basin fossil hominins and their contribution to our understanding of human evolution in Africa. Evolutionary Anthropology 20, 264-292 - http://tinyurl.com/l3wrf5v.

Woods, M.C. 1989. An unfashionable rhetoric in the fifteenth century. Quarterly Journal of Speech 75(3), 312-320 - http://tinyurl.com/mlk3fab.

Woudhuysen, H.R. 2004. Writing-Tables and Table-Books. Electronic British Library Journal 2004, article 3, 11 pp. -http://tinyurl.com/n9xjotw.

Wrangham, R., Carmody, R. 2010. Human adaptation to the control of fire. Evolutionary Anthropology 19, 187–199 - http://tinyurl.com/8pmbzfz

Wrangham, R., Conklin-Brittain, NL. 2003. Cooking as a biological trait. Comparative Biochemistry and Physiology A 136, 35-46 - http://tinyurl.com/8k4uor4.

Wright, B. W., Wright, K. A., Chalk, J., Verderane, M. P., Fragaszy, D., Visalberghi, E., Izar, P., Ottoni, E. B., Constantino, P., & Vinyard, C. 2009. Fallback foraging as a way of life: using dietary toughness to compare the fallback signal among capuchins and implications for interpreting morphological variation. American Journal of Physical Anthropology, 140, 687-699 - http://tinyurl.com/k6r2c34

Wright, M.T. 2012. The front dial of the Antikithera Mechanism. History of Mechanism and Machine Science 15 (4), 279-292 - http://tinyurl.com/p3fr7eb.

Wu, M., Higgs, P.G. (2009) Origin of self-replicating biopolymers: autocatalytic feedback can jump-start the RNA world. Journal of Molecular Evolution 69: 541-554 - http://tinyurl.com/k5xoskn.

Wu, X., Holloway, R.L., Schepartz. L.A., Xing, S. 2011. A new brain endocast of Homo erectus from Hulu Cave, Nanjing, China. American Journal of Physical Anthropology 145, 452-460 - http://tinyurl.com/lbqkmuq

Wurz, S. 2013. Technological trends in the Middle Stone Age of South Africa between MIS 7 and MIS 3. Current Anthropology 54(S8), S305-S319 - http://tinyurl.com/lkhqtrw

Wynn, J.G., Sponheimer, M., Kimbel, W.H., Alemseged, Z., Reed, K., Bedaso, Z.K., Wilson, J.N. 2013. Diet of Australopithecus afarensis from the Pliocene Hadar Formation, Ethiopia. Proceedings of the National Academy of Sciences, USA 110(26), 10495-10500 - http://tinyurl.com/l7opcxj

Wynn, T., Coolidge, F.L. 2011. The implications of the working memory model for the evolution of modern cognition. International Journal of Evolutionary Biology 2011, Art. ID 741357, 12 pp. - http://tinyurl.com/l4dv6cd

Wynn, T., Hernandez-Aguilar, A., Marchant, L.F., McGrew, W.C. 2011. "An ape's view of the Oldowan" revisited. Evolutionary Anthropology 20, 181-197

Xagoraris, Z. 1991. The Automaton Theatre. MS Thesis in Visual Studies, Department of Architecture, Massachusetts Institute of Technology, Cambridge, MA - http://tinyurl.com/qf8wf8u.

Yakhlef, A. 2008. Towards a post-human distributed cognition environment. Knowledge Management Research & Practice, 6, 287-297 - http://tinyurl.com/nkwbft4.

Yamakoshi, G., 1998. Dietary responses to fruit scarcity of wild chimpanzees at Bossou, Guinea: possible implications for ecological importance of tool use. American Journal of Physical Anthropology 106, 283-295 - http://tinyurl.com/hfakkpz.

Yamakoshi, G. 2011. Pestle-pounding behavior: the key to the coexistence of humans and chimpanzees. (in) Matsuzawa, T., Humle, T., Sugiyama, Y. (eds). The Chimpanzees of Bossou and Nimba. Springer, pp. 107-116 - .

Yamamoto, S., Takimoto, A. 2012. Empathy and fairness: psychological mechanisms for eliciting and maintaining prosociality and cooperation in primates. Social Justice Research 25, 233-255 - http://tinyurl.com/kvxe38u.

Yarus, M. 2010. Getting past the RNA world: the initial Darwinian ancestor. Cold Spring Harbor Perspectives in Biology. doi: 10.1101/cshperspect.a003590 - http://tinyurl.com/kss9h4e.

Yatsuhashi, A.V. 2010. In the Bird Cage of the Muses: Archiving, Erudition, and Empire in Ptolemaic Egypt. PhD Thesis in Classical Studies, Duke University - http://tinyurl.com/oc33tjc.

Yeo, B.T.T., Krienen, F.M., Supulcre, J., Sabuncu, M.R., Lashkari, D., Hollinshead, M., Roffman, J.L., Smoller, J.W., Zöllei, L, Polimeni, J.R., et al. 2011. The organization of the human cerebral cortex estimated by intrinsic functional connectivity. Journal of Neurophysiology 106, 1125-1165 - http://tinyurl.com/cxt5bqu

Zachary, G.P. (1997). The Godfather. Wired Magazine, 5.11 - November 1997. - http://tinyurl.com/jwy8xsg.

Zaft, G. (1997). Von Neumann Architecture as a Kuhnian Paradigm. - http://tinyurl.com/2dau5zo.

Zaim, Y. 2010. Geological evidence for the earliest appearance of hominins in Indonesia. (in) J.G. Fleagle et al. (eds.), Out of Africa I: The First Hominin Colonization of Eurasia, Vertebrate Paleobiology and Paleoanthropology, DOI 10.1007/978-90-481-9036-2_7, © Springer Science+Business Media B.V. – http://tinyurl.com/mb42xq5

Zaim, Y., Ciochon, R.L., Polanski, J.M., Grine, F.E., Bettis, E.A., III, Rizal, Y., Franciscus, R.G., Larick, R.R., Heizler, M., Aswan, Eaves, K.L., Marsh, H.E. 2011. New 1.5 million-year-old *Homo erectus* maxilla from Sangiran (Central Java, Indonesia). Journal of Human Evolution 61,363-376.

Zakon, R.H. (2010). Hobbes' Internet Timeline v. 10 - http://tinyurl.com/yfdh [http://tinyurl.com/2avoeo9]

Zalta, E.N., (2008), Stanford Encyclopedia of Philosophy. Stanford University Center for the Study of Language and Information.

Zeitoun, V., Barriel, V., Widianto, H. 2016. Phylogenetic analysis of the calvaria of *Homo floresiensis*. Comptes Rendus Palevol http://dx.doi.org/10.1016/j.crpv.2015.12.002.

Zeitoun, V., Détroit, F., Grimaud-Hervé, D., Widianto, H. 2010. Solo man in question: convergent views to split Indonesian *Homo erectus* in two categories. Quaternary International 223-224, 281-292 - http://tinyurl.com/l8m3hwv
Zeleny, M. 1977. Self-organization of living systems: a formal model of autopoiesis. International Journal of General Systems 4: 13-28.
Zeleny, M., Hufford, K.D. 1992. Application of autopoiesis in systems analysis: are autopoietic systems also social systems? International Journal of General Systems, 21: 145 – 160.
Zhang, J., Norman, D.A. 1995. A representational analysis of numeration systems. Cognition 57, 271-295 - http://tinyurl.com/nfz9az9.
Zhirnov, V.V., Calvin, R.K., III, Hutchby, J.A., Bourinoff, G.I. 2003. Limits to binary logic switch scaling – a gedanken model. Proceedings of the IEEE 91(11), 1934-1939 - http://tinyurl.com/pjyrd2f.
Zhu, R.X., Potts, R., Pan, Y.X., Yao, H.T., Lü, L.Q., Zhao, X., Gao, X., Chen, L.W., Deng, C.L. 2008. Early evidence of the genus Homo in East Asia. Journal of Human Evolution 55, 1075-1085 - http://tinyurl.com/zdpbzcc.
Zins, C. 2006. Redefining information science: from "information science" to "knowledge science". Journal of Documentation 62(4), 447-461
Zins, C. 2007. Conceptions of information science. Journal of the American Society for Information Science and Technology 58(3), 335-350 - http://tinyurl.com/2dfpmn4.
Zins, C. 2007a. Conceptual approaches for defining data, information and knowledge. Journal of the American Society for Information Science and Technology 58(4), 479-493 - http://tinyurl.com/2675sbd.
Zins, C. 2007b. Knowledge map of information science. Journal of the American Society for Information Science and Technology 58(4), 526-535 – http://tinyurl.com/23ac49w.
Zins, C. 2007c. Classification schemes of information science: twenty-eight scholars map the field. Journal of the American Society for Information Science and Technology 58(5), 645-672 - http://tinyurl.com/267zkjw.
Zipfel, B., DeSilva, J.M., Kidd, R.S., Carlson, K.J., Churchill, S.E., Berger, L.R. 2011. The foot and ankle of Australopithecus sediba. Science 333, 1417-1420 - http://tinyurl.com/mnsemrk
Zipser, J. (1998). MEDLINE to PubMed and Beyond. *from* United States National Library of Medicine, Bibliographic Services Division
Zollikofer, C.P.E., Ponce de León, M.S. 2013. Pandora's growing box: inferring the evolution and development of hominin brains from endocasts. Evolutionary Anthropology 22, 20-33.
Zolo, D., 1990. Autopoiesis: Critique of a post-modern paradigm, Telos 86: 61-80.
Zuberbühler, K., Ouattara, K., Bitty, A., Lemasson, A., Noë, R. 2009. The primate roots of human language Primate vocal behaviour and cognition in the wild. (in d'Errico, F., Hombert, J-M. (eds). Becoming Eloquent: Advances in the Emergence of Language, Human Cognition, and Modern Culture. John Benjamins Publishing Company, Amsterdam - http://tinyurl.com/lj64fx3. [This link downloads the whole book.]
Zuse, H. (????), The Life and Work of Konrad Zuse. EPE Online - http://tinyurl.com/274h8aw.