

Surviving The Cyber Age

Chapter 8 – Hominid Coevolution

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Something changed with the emergence of hominids and their co-evolution with domesticated plants and animals and technology. A working assumption is that it has something to do with the changes in the body and brain¹ related to hominids as opposed to apes and other mammals. But in addition, the development by humans of technology has had a profound effect that is just starting to be realized, and it is a thesis of this book that this co-evolution is a process underway today.

1 <https://pmc.ncbi.nlm.nih.gov/articles/PMC3606080/>

Generating sets, development of complex life, and coevolution

Fundamental to the concept of evolution is a range of livable environments broad enough for enough changes in living creatures to find niches, with enough noise to generate enough change, enough stability for survival from generation to generation, and enough food and other needed stuff in enough close enough but not too close places, for vast numbers of possibilities to arise and occur. And because only a few existing molecular structures we know of can convert inorganic matter into organic matter (i.e., through photosynthesis² and chemosynthesis³), these have to be present to initiate life and, over time, to sustain it.

Development in mammals is a sequential process in a well controlled environment. It starts with sperm and egg meeting, and the machinery from there builds a body by reproduction. With the exception of the outer part of tooth enamel and nails, essentially every cell in the body is alive, developed in all of its specialization from the same genetic codes and the single cell that generated it. I was taught that the DNA is, essentially, the program that does this.

The modern human DNA⁴ (Deoxyribonucleic acid) 'program' is only about 3.1 billion instructions long in 24 chromosomes (22 shared for male and female and 1 that differs), if you count a base pair as an instruction.^{5 6 7} And when I say "about", I mean to say that I am unable to find an exact number. Despite the claim that the human genome has been fully sequenced, it apparently has not, and furthermore, neither an exact number or accurate statistical characterization of the number components in the composite is known... and it seems it might vary between individuals. Something like 0.1% variation in genomes of individuals has been found, and between humans and bonobos and chimpanzees, there is about a 1.1% variation. Various claims are that "less than 10% of the genome has a defined functional role and the rest (90%) is probably junk DNA." (with no biological function). In other words, we really don't know what the program is, and we certainly don't really understand it. But progress is being made.

Also, these base pairs that form 'instructions' might actually not be any such thing in that the base pairs may be thought of as the 1's and 0's of a binary computer, and the instructions might be longer and of varied length. Indeed the sequences might have multiple functions in different segmentations so that different subsequences covering the same overall sequence in different ways operate differently and are used in different circumstances during and after development. This is similar in concept to code obfuscation techniques in computers⁸, where "The number of encodings of a sequence [is] equivalent to the number of different sequences, or 2ⁿ encodings for an n-bit sequence.", but for DNA, this is just conjecture at this point.

And DNA is only one of the complex aspects involved in reproduction and development of human and other living cells and bodies. So the notion that this is the 'program' may be misleading, because reproduction of a 'program' is only applicable in the context of an environment.⁹ Furthermore, as the living creatures in an environment consume energy and

2 <https://en.wikipedia.org/wiki/Photosynthesis>

3 <https://en.wikipedia.org/wiki/Chemosynthesis>

4 <https://en.wikipedia.org/wiki/DNA>

5 <https://pmc.ncbi.nlm.nih.gov/articles/PMC6391780/>

6 https://en.wikipedia.org/wiki/Human_genome

7 <https://en.wikipedia.org/wiki/Pan-genome>

8 <https://www.all.net/books/tech/evolve.pdf> (Program Encodings)

9 <https://all.net/books/DissertationOCR.pdf>

produce waste, they change the environment. This happens within a living being as well as outside of them, and thus as the creatures change, so do their environments. These processes of sensing, communicating, actuating and controlling, build up into transportation, manufacturing, and infrastructures that change the environment and the creatures that can live within it. It's co-evolution... they evolve together... within cells, as single-celled living organisms reproduce, as multicellular organisms develop their phenome from their genome, as larger creatures develop, grow, live, and die, as the ecosystems of Earth change over time from within-planet, on-planet, and outer space events occur, and it all happens in parallel at each moment of time and in sequence over time.

Hominids and People

Before hominids, I have found nothing in the historical record or research to date to suggest tool use beyond hand tools made from naturally available components, like bones and rocks, or internal tools developed through evolutionary processes. This may be because of my lack of adequate research, a lack of research by those in the relevant fields, a lack of and actual evidence, or a lack of it ever having happened. But something about the emergence of hominids changed all of this.¹⁰

Co-evolving with what?

One of the key questions worth considering is what hominids were and are co-evolving with. This is where this book is starting to become less factual and more speculative. While facts about how cybernetic mechanisms operate can be tested and validated by experiment, as we talk about the mechanisms of evolution at a higher level of conceptualization, there is necessarily a good deal of speculation that cannot be proven by repeatable experimentation. It already happened and we cannot do it again. Some day we might be able to use simulation or even terraforming to try it in more controlled experimental or developmental environments, but we are where we are and cannot really go back.

The underlying concept of evolution is typically "random variation and selective survival". The notion of "survival of the fittest" is often misconstrued as a definition of survival in terms of fitness, which is to say, I should survive because I am more fit (taller, stronger, smarter, or whatever the criteria may be). But really, the definition is fitness, determined by survival, which is to say, we call you fit because you survived.

It may be repetitive here, but gene sequences (DNA) within cells that reproduce, survive the reproductive process at the cellular level. For complex life forms, the organisms that develop through gestation periods to become independently living life forms (separate from mother or egg shell) have to survive gestation. They are then phenomes that have to survive in the broader environment to an age where they can reproduce and find suitable partners who can also reproduce (for sexual reproduction), leading to a new set of specific genes that start the cycle again for the next pairings of genomes. So there are at least 3 differentiable phases of survival involved for any given cycle of the loop, and the genome can be thought of as the set of genes that can survive all three phases. In computer viruses, the set of sequences that produce a next generation of the virus are called a 'viral set' with respect to a set of

¹⁰ <https://www.liverpool.ac.uk/archaeology-classics-and-egyptology/research/projects/deep-roots/>

environments, with the specific instance called a 'virus'.¹¹ The genome for a species can be thought of in a theoretical sense as the same as a viral set; it is the set of all DNA sequences that can survive a specific environment. I may use the term genomic set from time to time.

Random variation and flexibility of the phenome

When we speak of random variation, there are; the variations produced by external phenomena like cosmic rays, diseases, reproductive errors in cellular reproduction, and other mechanisms that cause specific DNA sequences to be changed; and the variations caused by the pairing of genes from parents in sexual reproduction. The fertilizing pair of sperm and egg are selected based on the sequence of egg development in the female, typically making one egg available per period, and the swimming capacity of the sperm first reaching the egg and thus winning the race with the other sperm. Presumably, the sperm reasonably able to be competitive have essentially identical DNA sequences, and the genetic sequence therefore survives the race regardless of the winner. The mix of male and female DNA sequences produces a specific set of expressed genes in the single cell of the egg.

The next stage is development, and this is where plenty of things go wrong, which is why every act of sex doesn't produce a child. Different mixes of expressed genetic pairs don't make it through the process, and this limits the surviving genome that become independently living life forms. We will call each independently living life form a phenome.

The flexibility of the set of phenomes producible from a genomic set limits the variations of a species. In any given generation, only so much change can happen from phenome to phenome, but over multiple generations of breeding, there is a range of phenomes that can survive the process, and subsets of the genomic set can only survive in subsets of the phenomic set.

As an interesting example, let's take dogs vs cows.

- **Dogs:** As far as we can tell from history, dogs were first domesticated perhaps 20,000-40,000 years ago, and selective breeding started at least 10,000 years ago but really took off in the last 100 years.^{12 13} This has produced a wide variety of phenomes explicitly bred and trained for different useful purposes to humans. Today, there are recognized groups of dog breeds¹⁴ consisting of sporting, working, toy, herding, hound, terrier, and non-sporting groups. Within various groups there are specific breeds for specific purposes, and characteristics like size, shedding levels, guarding, barking, training capacity, speed, strength, friendliness, how good they are with children, and so forth. Dogs have learned the meaning of more than 1,000 human words to the extent where they can differentiate and take actions requested by humans on specific objects and types of objects, such as "fetch my shoes".^{15 16} Over the tens of thousands of years of association, dogs and people have collaborated for a wide range of mutually beneficial purposes and evolved together.

11 <https://all.net/books/DissertationOCR.pdf>

12 <https://www.morrisanimalfoundation.org/article/evolution-of-dogs>

13 https://en.wikipedia.org/wiki/Dog_breeding

14 <https://www.akc.org/dog-breeds/>

15 <https://www.smithsonianmag.com/smart-news/dogs-can-understand-the-words-for-several-objects-such-as-toys-and-leashes-study-finds-180984023/>

16 [https://en.wikipedia.org/wiki/Chaser_\(dog\)](https://en.wikipedia.org/wiki/Chaser_(dog))

- **Cattle (cows and bulls):** Domestication started something like 10,000 years ago, and selective breeding has produced four uses for live cattle (food, dairy products, draft a.k.a. pulling things, and pets) plus use of the skin of dead cows for material (leather). There are something more than 1,000 recognized breeds with various properties, but none work with people like dogs do, very few share living and sleeping quarters with people like dogs do, and none are trained with language skills on the same order as dogs.^{17 18} They do communicate with each other¹⁹ using hundreds of differentiable sounds, acting as groups to protect each other, run from danger as a herd, and otherwise work together.

The key takeaway here is that genomic sets produce phenomic sets that may flex over different time periods and numbers of generations to adapt over ranges of subsets of the full phenomic sets of the genomic set. This is the extent of so-called random variation in normal evolution. Add in some small number of reproductive errors, diseases, or other external events some of which survive gestation, but the range is limited in normal expansion periods.

Mass extinction events decimate large portions of the phenomic set for specific genomes, and survival of the genome depends on available variations of the phenome. More diversity leads to increased survival likelihood in mass extinction events, after which variations may return.

Selective phenome survival and niches over time

Of course the environment (e.g., temperature, water levels, oxygen levels, etc.) are key components in studies of the evolution and survival of species, but there are also other components to the co-evolution of recent time frames that might lead to survival across large-scale catastrophic events historically leading to mass extinctions:

- **Fire** and the ability to control it creates survival in harsher climates, but also enables cooking of food which changes food-borne diseases and may extend life by reducing disease, leads to changes in gathering patterns for example of wood and other combustible material, introduces smoke which may drive away some threats, creates potential weaponry; creates hearths and fire places for cooking, communications, family events, and guests; and enables cooked foods to be brought on longer periods away from central food supplies.
 - *As a control system, this involves managing the live mechanisms of fire to keep them going but prevent them from spreading beyond boundaries, and ultimately controlling temperature, light levels, and similar parameters, all in real time, and to produce different effects in different situations.*
- **Food supplies and agriculture** Food supply changes because of weather and time of year, but when agriculture emerges, it creates reliable plant-based food and allows for the formation of agrarian societies. Different muscle groups and thought processes are in use, learning how to work with crops is passed across generations leaving more importance and survival for those who can learn and communicate, there is more time and need for more advanced tools and associated manufacturing, and of course processing food with fire allows it to be stored and carried over longer distances.

17 <https://pmc.ncbi.nlm.nih.gov/articles/PMC6304694/>

18 <https://en.wikipedia.org/wiki/Cattle>

19 <https://www.worldanimalprotection.org.au/education/animal-facts/cows/>

- *As a control system, agriculture involves many complex feedback loops like; choosing, preparing, caring for, and protecting physical locations; investing resources in tools and remaining present over relevant time periods for planting, harvesting, and caring for plants; moving things from place to place like bringing water and seeds to fields and planting the seeds, cutting or picking harvest from fields; figuring out what you have to learn and when to do what for increased yield; surviving between planting and harvesting; and so forth. Over time, the tools become control systems as well, as people learn to automate parts of the process or make manual tasks more efficient by manufacturing planting, cutting, and transportation tools and more complex machines.*
- **Water** supplies are critical to survival, and the production of bowls and other contrivances to carry and store water lead to changes in physicality associated with the activity, longer distances from water supplies become viable, and the associated knowledge that is passed on. It also allows for jobs to be divided between different workers with different skills, so that small children may be able to carry water while older adults may do other things. Hot water from fire and containers and water brought together leads to cooking of various sorts, teas, rendering fat, and so forth.
 - *As control systems, finding water at larger distances and being able to transport it to storage and use over time gets adapted to usage as usage changes because of different availability, and more uses can be explored and implemented because of the increasingly available places it can be used. Added to fire, control over temperature of water enables a wide range of other uses for bathing, cooking, and food preparation.*
- **Clothing and shelter** are critical to survival in rapidly changing environments, and all the more so as fur goes away and is replaced by clothing, first from skins of dead animals, then from plant matter, then from manufacturing processes. As clothing develops, the need for body hair and fur decreases and they are not as favored in survival. Meanwhile, with clothing, life can succeed in places it could not live in before, travel becomes more feasible, and more environments are survivable. Shelter, once in caves, becomes something built from local plants, dirt, rocks, and similar available items, becomes portable so camps can be moved in seasons or under other threats, and larger day to night and weather variation can be more easily survived, again trading off learned methods and tool use for pure physicality.
 - *From a control system perspective, this involves mechanisms to get components, transform (manufacture) them into products that are made to measure for the individual, find ways to keep them in use while allowing other operational needs to be met (walking, using your arms, etc. under a range of rapidly changing environmental conditions.*
- **Threats** like larger animals likely initially forced separation, but early hominids apparently ate bone marrow from dead carcasses, evolving the need for stealth to observe other kills and await availability of the carcass. As smaller and weaker animals than many threats, the use of tools, from rocks and stones to pointed sticks to holes, to pointed sticks in holes, to spears, and so forth, again changed the physical and mental requirements for survival and supported evolution.

- *From a control systems perspective, detecting and responding to immediate threats, but more importantly over time, anticipating potential future behaviors and situations and constraining them by the actions of individuals and groups.*
- **Cooperating species** like dogs and possibly small cats emerged, first as participants in mutually beneficial activities like hunts (similar to marine group cooperative hunting) and protection. Dogs eventually were very close collaborators, sharing food, guarding, hunting, smelling out things, in fights, and ultimately in agriculture and many other areas as they co-evolved into breeds eventually through intentional selective breeding. For people this also meant cross-species communications including by verbal and hand signals and other behavioral methods.
 - *From a control systems perspective, multiple independent complex control systems interacting in a shared environment from different perspectives and coordinating activities to mutual advantage.*
- **Domestication** of all sorts of plants and animals led to changes in farming with select crops in different soils and seasons, animals used for milk, food, and transportation, and the development of mechanisms to hold, train, feed, and breed them represented favorable survival for different body characteristics, mental abilities, communications, and cooperation in group activities. Learning from generation to generation also stretched the need for better communications and documentation, leading to art as well as historical records and things that could be used to indicate where people were as they collaborated in larger groups when populations grew.
 - *From a control system perspective, a long-term process of feedback to train multiple control systems how to interact for mutual advantage in select situations.*
- **Learning, teaching, and memes** becomes increasingly important for survival as more and more of this tooling and group behavior enhances survival. As more and more information is required for successful co-evolution, more memory, better communications, and the ability to pass on more complex memes from parent to child, sibling to sibling, and over time, within and between family groups becomes a selection mechanism for survival. As strong as you may be, it is an advantage to be able to use domesticated animals and tools as the muscle, and knowledge, skills, training, education, and experience as the brains. Survival favors brains, but not 'over' brawn. Smarter, faster, and stronger are all benefits for survival, but in different portions and situations. The meme^{20 21 22} became more important to survival than the differences in the body within the genome.
 - *From a control system perspective, brains more capable of storing and applying more memory and processing power to more complex external events and better able to communicate linguistically becomes an advantage. Better use of specific skills aid in improved fighting and self-defense, leading to advantages over pure strength, and as it turns out, bigger bones and muscles are harder to accelerate so speed and precision of action along with the ability to anticipate futures and*

20 <https://richarddawkins.net/2014/02/whats-in-a-meme/>

21 Noun: (approximately) an element of a culture or system of behavior passed from one individual to another by imitation or other non-genetic means.

22 <https://en.wikipedia.org/wiki/Meme>

constrain them through actions becomes a strong advantage, and one that can be taught and learned. Thus far more complex model-based situation anticipation and constraint mechanisms in the mind became favored and education ultimately became central to success and survival. Meme processing capacity became the key component of the brain in this aspect of co-evolution.

- **Artifacts** (and **manufacturing**) that emerged from manipulating bones and rocks combined with fire and the need for manufacturing tools and components for things like barriers and moving larger and larger rocks, kills, and so forth, led to new artifacts like rope for attaching things, structures for dragging by individuals and groups, things like rolling cylindrical shapes and ultimately wheel and axle, mortar and pestle, and other similar tool sets with different uses. Again, mind over matter drove different body shapes and focus on things like fingers that are weaker but better suited for finer work, and more capacity to learn, experiment, teach, and otherwise communicate and collaborate became survival benefits. Manufacturing in particular was, at first an art perfected by experiment, and was taught in terms of processes from person to person, the processes not being taught dying off as the evolution of the memes did not survive the communications process central to meme reproduction.
 - *As a control system, survival depended and still depends on successful memes being reproduced over time and across generations of the phenome. Artifacts and the advancement of these artifacts and their applications was driven by the scientific method, even if it wasn't formally defined. Hypothesis, experiment, feedback, adaptation, all reproduced through spreading of memes.*
- **Social behaviors** (and **communications**) changed over time as societies emerged from small groups and came to depend more and more on language skills, documentary forms, and diversified skill sets, ultimately to the point where it took a long time to learn much of what others in the group knew, and specialization ultimately led to segmentation, specialization, and advantages for the ability to communicate to the point where many people survived by only communicating while others did the manual aspects of labor, others did planning, and others became accountable for leadership. The body types and mental capabilities of different people have led to selective breeding (people choose their mates) and is evolving the human race over time. Memes went from simple things like how to make a stick into a spear into more complicated things, like how to convince someone else to make spears, another person to hunt with them, another person to cook the results, while you directed the overall behavior and reproduced.
 - *Meme reproduction emerged and evolved into more complex influence tactics and, over time up through today, into narratives leading large populations and societies writ large into complex control schemes. The memoplex (per Dawkins) is equivalent to the the genomic set, the phenomic set, and the viral set, in terms of its evolutionary nature. We will call it the memonic set for consistency. As a control system, memes exist within an individual, but memes only survive over time and through evolution between individual phenotypes and successful ones across populations, not within the individual. The memotype evolves as it is reproduced because of the imperfection of communications and memory in the phenotypes it survives in. Thus the social structure is the environment in which memes reproduce*

and survive, and the memonic set forms the components by which the social structure as a composite operates.

- **Transportation** became increasingly important as domestication of horses and pack animals arose, and even before that as carrying material from place to place became part of the success for hunter gatherers. But then a few thousand years ago, with the creation of carriages and related transportation mechanisms, things changed far more dramatically. Much longer distances for many more people and their possessions, transportation of building materials that resulted in the pyramids, trade within and between continents, boats and other modes, all became critical to survival of substantial populations. More and more pressure on the ability to use tools, control animals and things in the environment, communicate, transmit over time through documentation, advanced languages for describing more complex things to others, and the mental requirements increasingly exceeded the physical requirements for survival and thriving.
 - *Transportation systems have become quite complex control systems, but even the relatively simple ones have things like shock absorption through springs which detects rapid changes and reconfigure mechanically to reduce shock on the carriage, with resonant frequencies that cause the system to exaggerate motion in some cases, and with the addition of various kinds of shock absorbers, mechanisms to reduce resonance and make for smoother rides, side to side controls to reduce sway, velocity control systems and limiters of various sort, and so forth. In addition to the individual control systems in each level of packaging for and movement of goods, the overall control systems grew as traffic increased to include signaling systems ranging from humans at intersections to control traffic flows to flags and lights to indicate traffic over shared infrastructure, and ultimately to the modern self-driving vehicles and other sorts of complex craft, sometimes described as a robot, and today even including actual robots.*
- **Infrastructures** became commonplace with well worn paths followed by roads, water systems and tanks, waste management, communications, education, and all manner of other commonly used shared capabilities of societies, and again, survival became dominated by those who could perform tasks involving mechanisms external to the body and who could anticipate futures and create capabilities to support them. Monetary systems emerged for consolidating trade and allowing more universal means of exchange, commerce became dominant so that no individual had to do many of the things required for individual or small group survival of old, and people became dependent on each other for survival. Evolution again favored those who had abilities to collaborate to build larger and larger projects over longer time frames based on more knowledge, and with understanding of more and more complex mental structures like mathematics and engineering, and who could teach and mentor others.
 - *Infrastructures are built, operated, and substantially composed of control systems. The typical really critical infrastructures we think of are air (you can survive a few minutes), water (you can survive a few days) food (you can survive a few weeks), shelter (you can survive a few seasons depending on where you are), and that's the real critical list, ignoring the co-evolution issues. But as you add co-evolution, many more things become critical, including power, communication, finance*

(money), transportation, energy, manufacturing, law enforcement, governance, and so forth, but these too tend to be short term dependencies as well.²³ Critical to longer-term genome, memome, and phenome survival over time are education, engineering, and science.^{24 25}

- **Automation** advancements turned human and animal labor and skills into mechanical composites, and survival started to depend increasingly on the ability to keep the automation going. And automation depends on people knowing how to build, operate, maintain, and adapt it to situations. Today, a significant portion of humans would not likely survive a year of outage of all automated systems. To get a sense of this, automation is not important in real day-to-day terms for about 3 of the 8 billion people on Earth who live off the land in China, Africa, India, on islands, in jungles, and elsewhere that modern civilization has not reached or largely ignores. They largely use hand tools to work the land and domesticate animals for food, labor, and transportation. If catastrophe hit all of modern society, they would still be around for a long time, unless the disaster was environmental in nature, as the major evolutionary changes in geological history have demonstrated. On the other hand, most of the remaining 5 billion people would likely die from lack of water or food pretty quickly, and in areas where it is cold, many would perish from exposure. The circumstances for this include some electromagnetic effects from solar or other space-related phenomena, nuclear war and electromagnetic pulses, and so forth. There are actually pretty good lists of these things. The real question of survival over time comes down to whether the automation could be regenerated after a disaster, which depends predominantly on survival of intellectual capacity and documentary content required for science, engineering, and related disciplines to re-emerge.

The extension of control systems:

These control systems demonstrate various levels of extension; from internal control systems of previous vertebrates and other animals including indirect controls, some of which are shown by other animals to limited extent; to communications-based controls, also displayed in select direct group behaviors such as flocks of birds, bees, ants, but not to the extent of hominids and eventually people; to social controls displayed to limited extent by packs and animal groups, but again, not to the extent displayed ultimately by humans.

- **From body to indirect mechanisms:** From mechanisms purely within the body like heart rate and pointing eyes in a direction; to direct control over external items by manual dexterity relating external physiological sensors and actuators communicating via the body to control mechanisms inside the body like ants cutting and carrying loads with their bodies; to direct control over tools that in turn control separate mechanisms, like apes manually forming and using branches to extract food from mounds; to more distant control in which direct physical control is over machines that themselves have control processes to manufacture and/or transport, like reins and brakes and wheels

23 F. Cohen, "Protection and Engineering Design Issues in Critical Infrastructures", pp67-153 in Thomas A. Johnson Ed. "CyberSecurity – Protecting Critical Infrastructures from Cyber Attack and Cyber Warfare", 2015, CRC Press, ISBN 978-1-4822- 3922-5.

24 F. Cohen, "What Makes Critical Infrastructures Critical?", International Journal of Critical Infrastructure Protection(2010), doi: 10.1016/j.ijcip.2010.06.002.

25 <https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/critical-infrastructure-sectors>

on horse drawn carriages or water systems that pump water up to pipe systems that flow and distribute it; to control over mechanisms that manufacture machines, and so forth.

- **From body to communications-based systems:** And of course similarly, the extension of control systems from; using your mouth and body to directly make sounds; to using tools to make sounds with external devices like hitting sticks together; to making tools to amplify and transmit sounds, like drums and musical instruments; to communicating within a local group to alert or alarm or indicate simple concepts; to using language to share experiences or teach processes to others; to using sounds and signals to train and express intent to domesticated animals; to telling others what to do in an organized group and having them do it, as in a class or group effort to move something from place to place; to instructing hierarchies to instruct others to do parts of a larger group activity, like creating repeatable processes for groups to do farming or hunting; to influencing larger groups and societies to move in a socially different direction, and so forth.
- **Socially controlled systems:** From small groups jointly operating simple mechanisms like working fields or keeping a fire going, to villages collaborating on self-defense, infrastructure, markets, and tradespeople with specialization in select areas of expertise, to fiefdoms and kingdoms operating taxation and protection systems with trade, to nation states supporting societies and implementing systems of governance and infrastructures, to global competition and cooperation; these systems are: controlled by groups rather than individuals, the control systems operate in hierarchies and networks requiring social sensors, actuators, communications, and controls; and they require very indirect controls with the associated governments and systems of governance associated with various forms of government.
- **Model-based situation anticipation and constraint:** At a conceptual level, people make models of situations and their changes over time relating to actions of themselves and others, and through their alternative actions, project outcomes they desire to control. They then take actions so as to constrain futures. This appears to be the result of the changes in brain makeup and, while it exists to a limited extent in other animals, it appears to be limited at best prior to the emergence of hominids. This seems like a reasonable way to describe what people do to control their world, and it makes sense in terms of control systems. There is, however, a very big difference between the concept and the mechanisms that can achieve it. While people appear to have done it over the time frames at issue, technology has only recently started to achieve it.

In other words, more and more indirect controls ultimately involving model-based situation anticipation and constraint over groups of systems each doing the same sorts of modeling, and ultimately coming to involve artifacts of increasing complexity that can only emerge when a wide range of conditions exist within and between the life forms.

And of course, we continue to co-evolve today. More details will be included as go through this discussion, but hopefully you will keep these in mind (in your brain?) along the way.

Changing your mind vs. changing your brain

All creatures with brains change their minds all the time as they respond to stimuli and remember things. It's the underlying concept behind the model of computing in which input and current state yield output and next state. These finite state automata (or machines) change their 'minds', but they do not change their 'brains'. The underlying mechanisms of the machines remain the same, even as the stored state content changes, potentially with each interaction.

Individual animals develop from a single cell to their ultimate phenotypes, and as they develop, they grow in size and the structures comprising their bodies and brains develop the connections and mechanisms that ultimately form their bodies including their brains. In addition to the learning in the sense of changing state associated with changing your mind, you also change your brain and the rest of your body. But that's just development in a single phenotype.

But that's not how evolution works. In evolution, the brains of species change in size, structure, makeup, and capabilities, and they do so in coevolution with their bodies and the environments their phenotypes live in. Somehow, and we don't really yet know the details, when hominids emerged, something changed in that the coevolution of their brains and bodies in context of their environments that allowed, enabled, and/or forced them create external artifacts beyond that of previous creatures, and in doing so, they/we coevolved with external transportation, manufacturing, and infrastructures, as we continue to coevolve with them.

What changed and is changing in our bodies and brains

The brain structures in humans²⁶ have been long studied but our knowledge of them has not yet been perfected. But what has increasingly been sought and understood to a limited extent is how human brains and bodies have evolved together with environmental changes over time.^{27 28 29} Looking back perhaps 100,000 years, humans have grown shorter, lighter, smaller boned, and most recently, smaller brained, with some of the causes asserted:

- **Average height:**
 - 40,000 years ago: European males 183 cm (6 feet)
 - 10,000 years ago: European males 162.5cm (5 ft 4 inches)
 - 600 years ago: European males 165 cm (5 ft 5 inches) [better food, interbreeding]
 - Today: European males 175 cm (5ft 9 inches) [better food and medicine]
- **Smaller brains:**
 - 100,000 years ago: average brain size: 1500cc
 - 12,000 years ago: average brain size: 1450cc

²⁶ <https://www.brainfacts.org/3d-brain>

²⁷ <https://australian.museum/learn/science/human-evolution/how-have-we-changed-since-our-species-first-appeared/>

²⁸ <https://www.cam.ac.uk/research/news/height-and-weight-evolved-at-different-speeds-in-the-bodies-of-our-ancestors>

²⁹ <https://pmc.ncbi.nlm.nih.gov/articles/PMC4920302/>

- Today: average brain size: 1350cc
- **Smaller teeth and jaws:** Changed in proportion to body size until a slight increase with the introduction of fluoride which slightly increased size by coating teeth.
- **Physical diversity:** All one species but looking different. Early homo sapiens lived in Africa and evolved similar physical characteristics.
 - 100,000 years ago, humans spread around the world and climatic conditions brought new physical adaptations.
 - DNA studies confirm genetic traits adapted and genetic changes to DNA accelerated over the last 40,000 years.
 - Some physical features appear to be inherited from interbreeding with other ancient human species including ancient Denisovans from cold climates in Central Asia.
 - **Climatic effects:**
 - **Short, stocky builds** are typical of cold climates with reduced surface area for weight retaining more body heat.
 - **Thin, long-limbed builds** are typical of hot regions where increased surface area for weight releases more body heat.
 - **Lighter skin** allows more UV absorption that helps synthesize vitamin D.
 - **Darker skin** limits UV absorption that, in excess, causes cancer and destroys important vitamins and minerals.
 - **Broad flat noses** allow increased moistening of inhaled air and retention of moistness from exhaled air that is beneficial in hot dry (desert) climates where relative humidity is lower.
 - **Narrow projecting noses** reduce the amount of water lost from the lungs during breathing and increases heating while inhaling and is beneficial for people living in cold dry climates.
 - **Tight, curly hair** keeps hair off the neck and exposes more areas of the scalp for better cooling and evaporation of sweat so more suitable for hotter climates.
 - **Straight hair** keeps the neck and head warmer and allows water to roll off the scalp more easily, beneficial for people living in colder climates.
 - **More layers of fat on the face** provide added warmth, associated with Inuits.
 - **Broad flat faces** reduce effects of frostbite in northern Asia and the arctic.
 - **Thick lips** have a large surface area to help evaporate moisture and cool the body and additional cooling by moistening of the lips.
 - **The epicanthic fold** common among Northern and Eastern Asian populations is an adaptation for protecting the eye from the hard driving snow typical in these regions, and reduces snow glare.
 - **Blue eyes** are better adapted for vision in regions where there is reduced light, because they let in more light than darker colors.

- **Aboriginals** of the Central Desert evolved the ability to drop their bodies to low temperatures without triggering the shivering reflex when exposed to very cold brief periods in their climate.

The diversity of human adaptations identified above reflect the range of climates they have adapted to, and the time frames of these adaptations are quite short compared to many notions of the slow pace of evolution over the enormous span of the history of life on Earth.

Brain changes

Of particular interest to this book is the changes in brains. One common theory is that human brains got smaller because they had less to do as life for humans got easier, while the opposite view is that brains got smaller because they got more efficient, because it is hard to conceive of modern humans being dumber than their ancient ancestors who had a much “simpler” life. But these are generally what I put in the realm of speculation. Physiological evidence suggests more specific differences in brain composition based both in limited archaeological evidence and the much more direct evidence of currently living mammals in general and apes in particular. The methodology is basically to look at capabilities of different species and their brain physiology and associated the capabilities with the physical structures present. Add to that the very recent ability of FMRI to do live imaging of brain activity during excitation, and we imagine we can get a better idea of what changes have what operational effects.

Studies included in this discussion include the references identified here. ^{30 31 32 33}

- A good summary of changes and the underlying methodology of determining them is provided in *“The Evolution of Brains from Early Mammals to Humans”*³⁴. Three major features are identified as distinguishing human brains from early monkey and ape ancestors are; (1) a dramatic increase in brain size (3x) particularly the neocortex (now 80% of the human brain); (2) some parts of neocortex have greatly enlarged relative to the rest of neocortex (prefrontal, insular, posterior parietal, and temporal cortex) which are also areas that continue to grow the most during postnatal development as opposed to the primary sensory and motor areas which did not expand; and (3) the number of cortical areas greatly increased with the evolution of human brains (somewhat less supported to date).
 - Early hominids were bipedal, had more distant vision, less exposure to overhead sun, and ultimately evolved toward changes in the hand with advantages in tool use and carrying food and offspring.
 - Over the last 2 million years, brains increased from the 400 – 600 cm³ to 1200 – 1600 cm³, at a considerable cost in metabolic requirements, **slower maturity, and later reproduction**. Higher-grade and processing of foods were needed for more efficient digestion by grinding, and by cooking over the last million years. Slower maturation limits motor and cognitive skills and **increases parental dependency**

30 <https://pmc.ncbi.nlm.nih.gov/articles/PMC3606080/>

31 <https://www.jneurosci.org/content/45/15/e2017242025>

32 <https://academic.oup.com/brain/article/147/3/794/7424860>

33 <https://elifesciences.org/articles/87780>

34 <https://pmc.ncbi.nlm.nih.gov/articles/PMC3606080/>

(from 5 years to 12+ years) and the need for more lipids and proteins. Large brains are associated with longer life-spans in primates. Neanderthals with current human brain size persisted until ~30,000 years ago, while smaller brained strains like homo floresiensis (sometimes called hobbits) died out only 12,000-50,000-190,000 years ago.^{35 36}

- Some differences in right and left cerebral hemispheres associated with **language** areas in humans also occur in chimpanzee brains, but chimpanzees do not have language, but MRI results suggest pathways from temporal to frontal areas in humans involved in language are differently organized in chimpanzees. Studies of split-brain patients have revealed many specializations in human right and left cerebral hemispheres.
- Some cortical regions of the human brain have increased in size more than others. The frontal lobes (cortex in front of the “central sulcus” 5-6 times larger than chimpanzees) are not disproportionately larger in humans than great apes, but the prefrontal cortex, especially **area 10 involved in ‘higher’ cognitive functions; like planning future actions, undertaking initiatives, and attention;** are disproportionately larger and have **pyramidal neurons with planning future actions, undertaking initiatives, and attention.** Part of the left frontal lobe, Broca’s area, is specialized for **language production.** The insula in humans is disproportionately larger than apes and other primates and includes regions and areas involved in **processing taste, pain, temperature, touch and internal state,** with regions for **mediating empathy and social awareness** not found in other species.
- The posterior parietal cortex is disproportionately large in humans and includes **somatosensory** and **visual** inputs and influence areas of cortex involved in **planning, imitation, and executing reaching, grasping, self-protection, and eye movements** via projections to motor and premotor cortex. They also help mediate **skilled use of many types of tools** that are particularly human, more subdivisions for functions like **eye control, defense of the head, reaching, grasping,** and other ethologically relevant movements via connections with motor and premotor cortex. The right and left regions are also differently organized so the right hemisphere networks have a dominant role in visuospatial attention.
- Human brains also have more **cortical areas,** perhaps 150-200 or more, about twice the number of related species. All areas did not simply get bigger, but more areas were likely added providing new functions and more levels of analysis.
- The superior colliculus of the visual midbrain receives cortical projections in all mammals, but the information relayed to the superior colliculus changes as the neocortex adds and modifies areas. The number of neurons in the cerebellum scales with the number of neurons in the neocortex of primates, providing evidence they are functionally interrelated. Changes in the organization and size of neocortex are also reflected in cortical projections to the basal ganglia, the dorsal thalamus, the amygdala, and the hippocampus. Humans have also lost some brain

35 <https://www.sciencedirect.com/referencework/9780128040966/evolution-of-nervous-systems>

36 https://en.wikipedia.org/wiki/Homo_floresiensis

functions with progressively **fewer functional** genes for **olfactory** receptors, but some olfactory processing in the orbital frontal cortex may be enhanced in humans.

- Functional MRI (fMRI) imaging has been used to examine operational mechanisms between primates and humans as described in “**Connectivity Profile and Function of Uniquely Human Cortical Areas**”³⁷ which includes images of some of the comparison studies for those interested in the pictures. Behavioral innovations like **collaborative social abilities, tool use, mental time travel, and spoken language** are asserted as the basis of uniquely human behavior based on comparison of our brain to our closest primate relatives by comparing size, differences, neuron counts, and so forth, but these fail to link behavioral changes to physiological changes. Neuroimaging measures brain organization at the level of connections with predictive value for functions of parts of the brain at a macro level, making activity of brain areas useful for between-species comparison of brain organization relating to behavioral differences. Connectivity is now studied at the whole-brain level using diffusion MRI and associated tractography algorithms, offering new data for comparative and evolutionary neuroscience. There are now standardized protocols for reconstructing major pathways of the primate brain, creating white matter atlases of human, chimpanzee, and macaque monkey developing brains, and characterizing and mapping cortical areas across species for quantitative comparison of brain organization.
 - When comparing the human with the chimpanzee brain, large zones of divergence in the **middle temporal lobe, temporoparietal cortex, and lateral frontal cortex** with a particular hotspot in the **dorsal frontal cortex** were found. The greatest differences were found in the **anterior ventral frontal cortex and posterior parietal cortex**.
 - The divergence between the human brain and both the chimpanzee and macaque brains was evident in the **dorsal frontal cortex**. **Strong SLF2 connectivity** in this part of the dorsal frontal cortex is driving the divergence in brain organization between the human and the other two primates.
 - Extensive differences between the human and nonhuman brains were found in the **ventral frontal cortex and middle temporal gyrus**. Both these hotspots of divergence were driven by more extensive connectivity of the **arcuate fascicle (AF)** in humans
 - On the medial wall, a hotspot of divergence in **medial parietal area 7** seems mostly driven by small changes in multiple tracts rather than a clear elaboration of a single tract, as is the case for some of the divergent areas discussed above. However, the strongest connection of this area, **SLF1**, seems more focal in the human than in the best-matching vertices in the other two species.
 - A database of functional neuroimaging studies³⁸ identified the functional role of these regions in terms of their involvement, but not necessarily a unique role.

37 <https://www.jneurosci.org/content/45/15/e2017242025>

38 <https://brainmap.org/>

- For the three dorsal frontal regions mentioned above, the behavioral domains most likely to activate them include **spatial cognition, working memory, and reasoning**. Some of these regions have previously been identified as part of the so-called multiple demand network of mostly parietal and frontal regions that consistently activate for a range of **high-level cognitive tasks**. It has been suggested that human domain-general knowledge has a precursor in **parietal-frontal network** originally evolved for visuomotor control in early primates and these results directly link anatomical differences to functional domains associated with the multiple demand network.
- Consistent with the role of the **AF in human language**, functional decoding of both the middle temporal and **ventral frontal cortices** in the left hemisphere yielded the behavioral domain “**language**” prominently. However, it was clear that the AF extension, especially in the temporal cortex, was bilateral. Decoding of the right middle temporal cortex yielded the domain “**emotion**.” Although the function of right temporal association cortices is yet not well-characterized in the fMRI literature, lesion studies suggest they play a role in **nonverbal semantic social cognition**. Importantly, these results speak against a language-only interpretation of AF extensions in the ape and human brains.
- A prominent zone of divergence was in the posterior superior temporal cortex and inferior parietal lobule, together often referred to as the temporoparietal junction area (**TPJ**). This effect was particularly prominent in the right hemisphere. The right posterior **TPJ** especially has often been associated with the human **ability to entertain others’ belief states**, so-called **mentalizing or theory of mind**. The hotspot of divergence overlaps with this area, and functional decoding indeed shows “**social cognition**” as its most significant behavioral domain. The human posterior TPJ shows strong connectivity to the inferior longitudinal fascicle (**ILF**), which is not present in the other two species. The ILF is part of the ventral visual pathway but extends into the parietal cortex in anthropoid primates. It is thought that the ILF has expanded in great apes and that the dorsal component has a role in **social cognition**, allowing some of the temporal cortex machinery for **visual processing** to be **adapted for social information processing**. The current results connect these two findings of TPJ’s role in social cognition and ILF’s prominent expansion by showing that the TPJ is innervated by the ILF in the human.
- The right temporoparietal junction (TPJ) area in the human brain shows strong innervation of the ILF, labeled TPJp and TPJa, the posterior of which shows strong activation in **social cognition tasks**.

These results demonstrate the most differences in human language, complex information associated with human **social cognition, by entertaining either others’ belief states, or the difference between one’s own and other’s knowledge**. Findings support a two-step evolutionary process, in which changes in prefrontal cortex organization emerge prior to changes in temporal areas.

- A lot of study focuses on the prefrontal cortex, as examined in “**The prefrontal cortex: from monkey to man**”³⁹, a review that draws on the proximity between

39 <https://academic.oup.com/brain/article/147/3/794/7424860>

humans and other primates through comparative anatomical-functional analysis, identifies common and distinguishing cognitive functions involving **working memory**, components of **planning**, **problem-solving**, and **language production**, **interrelated cognitive changes**, **greater integration of past experiences and prospective futures**, **greater capacity to link discontinuous or distant data** (whether temporal or semantic), **a greater capacity for abstraction** (allowing knowledge classification in different ways), and **analogical reasoning** and **abstract values** giving rise to beliefs and morals. Together, they support **sophisticated social interactions based on language, enabling beliefs and moral judgments and conceptualization, creation, and extension beyond what we can physically grasp**. This is an excellent resource for details regarding specific differences and is much more specific than the other references provided. Here is a very brief extract (**emphasis** added):

*“Taken together, the anatomical data show that non-human primates and humans have in common: (i) the development of a **granular prefrontal cortex** that differentiates them from other mammals that have an agranular forebrain cortex (which in primates may correspond to the posterior ventromedial and orbital cortices); (ii) the presence of von Economo neurons (although this is not completely specific to primates); and (iii) similar **prefronto-subcortico-prefrontal connectivity**. In contrast, the human prefrontal cortex has developed dramatically compared with that of other primates, including the great apes. This development seems macroscopically to concern the most anterior part, the **frontopolar cortex** (whereas cross-species similarities can be established for the rest of the prefrontal cortex), and has allowed for a significant increase in the number of neurons, an extraordinary development in connectivity.”*

The overall summary is very informative as well:

“More than five decades of research have shown that goal-directed behaviours are based on macro-functions such as, among many others, decision-making, planning or reasoning, which in turn rely on more elementary processes common to all primates (e.g. working memory, response inhibition, arbitrary visuomotor mapping, similarity findings). These findings suggest that there is a continuum rather than a gap in prefrontal functions between non-human primates and humans.

*That said, it nevertheless appears that despite this continuity, cognitive abilities and achievements (the degree of civilization) are strikingly different between humans and non-human primates. First, although there is functional continuity, basic processes such as working memory are much more highly developed in humans than in monkeys. Second, working memory operations, which appear to occupy most of the lateral prefrontal cortex in rhesus monkeys, are shifted to the posterior portion of the lateral prefrontal cortex in humans, paving the way for the emergence of other, more developed, cognitive functions. Third, the spectacular development of the **frontopolar cortex (BA 10)** appears to be accompanied by the ability to process information in a more abstract manner (allowing links to be made between physically distant but semantically related information) and to extend the temporal space of representation by creating links between temporally distant information.*

*Therefore, we propose that three major cognitive changes differentiate humans from other primates: (i) the expansion of the mental space of representation in working memory, allowing greater integration of past experiences and prospective futures; (ii) interrelated to the first point, and largely due to the development of the **lateral frontopolar cortex**, a greater capacity to link discontinuous or distant data, whether temporal or semantic; and (iii) a greater capacity for abstraction, allowing us, beyond the concrete data immediately accessible to our perception, to classify knowledge in different ways (taxonomic classification), to engage in analogical reasoning or to acquire abstract values that give rise to our beliefs and morals.”*

Their “Hypotheses and speculations regarding cognitive changes over the course of human evolution” brings the history home:

These three major cognitive changes occurred during, and probably in concert with, the evolution of our species. Indeed, lithic technology (the manufacture of the first tools, about 2 to 3 million years ago) indicates that the creation of tools is associated with an understanding of the purpose for their use. Furthermore, the making of tools to create other tools indicates that the capability to represent abstract thinking in a mental space of representation and link temporally distant information was already well developed. Later, the manufacture of the first huts, 400 000 years ago, testified to the ability to draw up construction plans (i.e. the ability to represent a future and complex object that does not exist in the present). The first symbolic representations of the world such as the chimerical drawings (i.e. mixing features of different animals to produce a non-existing creature) painted in caves and the first sculptures (20 to 40 000 BC) testified to an even higher level of abstraction. One of the interesting ideas regarding the evolution of prefrontal functions in Homo species has recently been proposed by Read et al. It is assumed that the common ancestor to all Hominidae (humans and great apes) had a working memory span equal to that of chimpanzee (2 ± 1), and then in Homo species it increased linearly to 7 ± 2 , with an initial ‘jump’ from 2 to 3 that made a definitive cognitive difference. This assumption compares with archaeological evidence for qualitative changes marking different stages in the design and technological complexity of tool manufacture.

Language, defined as communication based on symbolic representations, appeared very late in the evolution of our species. Indeed, the first traces of symbolic communication were observed in the use of tokens as currency, 9000 BC, and then formally proven by cuneiform writing, 3500 BC. Communication based on symbolic representations (language) is only possible if the capacities for abstraction and working memory are particularly well developed. This indicates that the emergence of language depends to a large extent on the prior development of the three cognitive changes characteristic of the human prefrontal cortex. However, it is difficult to reduce human language to abstraction, distant semantic links and working memory. Indeed, for many linguists, the main characteristic of human language is its recursive and combinatorial syntax, although no consensus has been reached on this issue. However, combinatorial thinking also depends to a large extent on frontal functions and in particular on the ability to manipulate mental representations in working memory and to combine multiple rules.

From the idea that language is in part derived from the progressive increase of abstraction, we would like to make the assumption that each aspect of the most elaborate human behaviour is associated with the three cognitive changes described above. This is the case for those thoughts or behaviours that are specifically human and rely strongly on abstract thinking such as our moral beliefs and values or our complex social relationships, which are based on a cognitive construction of empathy and a high level of inference about other people's thoughts. Generally speaking, by enriching this mental space for deliberation and decoupling the immediate perception from the forthcoming action, we have become capable of creating additional degrees of freedom from our environment and our archaic, impulsive behaviour, conferring a source of imagination to represent alternative or new options (creativity), and therefore, what philosophers name, 'free will'."

- In "Linking the evolution of two prefrontal brain regions to social and foraging challenges in primates"⁴⁰ the linkage between brain structure and behavior is explored. This study combined comparative cognitive neurosciences and behavioral ecology; using brain imaging data to measured sizes of the frontal pole (**FP** involved in metacognition - the ability to be aware of and assess one's own thought) and the dorso-lateral prefrontal cortex (**DLPFC** involved in working memory - the ability to temporarily store information to solve a problem), examining their relation to socio-ecological variables; and showing body mass, daily traveled distance (surrogate for ecological constraints), and population density (surrogate for social constraints). The strong influence of ecological constraints suggests metacognition and working memory are critical for primate foraging. FP volume was far more sensitive to social constraints than DLPFC, consistent with laboratory studies implicating FP in complex social interactions. Diversity of social interactions (e.g. number of individuals an animal can remember), degree of social awareness, (i.e. knowledge and representation of the dominance hierarchy, kinship relations, or friendship associations), and foraging behaviors (e.g. food processing techniques, knowledge of harvesting schedules, extractive foraging) require cognitive flexibility. Based on the literature, it was hypothesized that FP and metacognition would be associated both with social interactions (by supporting theory of mind, i.e. the ability of an individual to conceptualize others' states of mind) and with foraging (by enabling complex planning). For example, group hunting involves social and foraging functions and only occurs in a few primate species where metacognition is thought to be particularly developed. The DLPFC has very clear implication in working memory and planning, but working memory and planning could readily be involved in complex social interactions in more natural conditions. Based on the known positive relation between the size of a brain region (the number of corresponding neurons) and relative importance of its associated function, both within and across species, brain region size was taken as a proxy for the weight of its associated function on behavior.
- A bit more on language processing seems important to our discussion.⁴¹ "Over decades, neuroscientists have revealed an elaborate and extensive language processing system in the human brain." There are apparently syntactic and semantic

40 <https://elifesciences.org/articles/87780>

41 <https://www.sciencedirect.com/science/article/pii/S1053811923001015>

networks that work with a phonological network to form the universal neural language network. But languages around the world encode sound, syntax, and meaning differently. The neural language network has a core system representing syntactic knowledge, lexicon, and sounds (phonology) of a language, with related structures that support speech (the speech network). Language use requires information exchange in those networks and their specialized regions via a system of white matter fiber pathways connecting language-relevant brain regions in the left frontal and temporo-parietal cortices via dorsally and ventrally located pathways that change as a function of use, or in other words, it adapts to specific processing requirements of languages.

- Approximately: *“A dorsal language pathway connects the posterior part of Broca's area, Brodmann Area (BA) 44 in the inferior frontal gyrus (IFG), and the inferior frontal sulcus (IFS) with parts of Wernicke's area in the posterior superior temporal gyrus (pSTG), [are] involved in syntax and grammatical relations. BA44 dominates syntactic processing and the IFS supports processing syntactic dependency relations in sentences. A ventral pathway connects the left temporal lobe to the left anterior IFG (BA45/47) and supports the analysis of semantic relations. The superior temporal sulcus (STS) and the middle temporal gyrus (MTG) play an important role in lexical-semantic access and processing. [...] Language processing recruits the inferior parietal lobe (IPL), with its posterior area (angular gyrus, AG) supporting the integration of incoming information into current contextual and sentence representations, while the anterior area (supramarginal gyrus, SMG) decodes phonological information. ... Phonetic information is processed in auditory areas in both hemispheres, and suprasegmental information, i.e. prosody, is mainly processed in the right hemisphere. The corpus callosum (CC) allows information transfer between hemispheres as the structural bridge. The speech production network involves the frontal aslant tract (FAT), which connects the pre-supplementary motor area (pre-SMA) and supplementary motor area (SMA) with sub-regions in the IFG, supports phoneme-level and syllable-level processing and is associated with speech fluency. This network for verbal language production can be segregated from the core language system responsible for semantic and syntactic processing. Taken together, the individual components reviewed above constitute the language system in the human brain.*

Previous functional studies have found systematic differences in brain activation patterns according to the language being processed and significant differences in the functional brain connectivity between the different native speakers that suggest that the organization of the functional nervous system is influenced by linguistic diversity during native language development. On the structural side, it has been shown that the gray and white matter of the brain adapts during language acquisition and development. The neural language system, which responds to different aspects of language processing, is established around the age of ten/eleven years. The particular processing demands of different languages during development and lifelong use may therefore be reflected and detectable in the language network in adults. Initial studies found localized structural brain differences between English and Chinese speakers in language processing areas that were attributed to the learned processing strategy. In addition, the white matter language network has been shown to differ between native English, German, and

Chinese speakers, reflecting the specific processing requirements of each language.”

- In other words, the brain organizes itself around environmental specifics as part of the development process, so different patterns, connectivity, and uses are individual to each person based on their experiences. This supports the general idea that nurture has a great deal to do with cognitive capabilities throughout life, and more specifically, that different individuals are more or less suitable for different tasks based on their development processes.

One more point relating to modern brains is that areas like computer programming involve multiple demand networks and thus are quite different from other natural language processing and learning.⁴² In addition, this is related to learning second languages of other types.

A comment on what we know and don't know about brains

It seems clear to me that as a society, we know to a limited extent what different parts of the human brain do, but not how the brain does it. Unlike most of the body and even the brain stem and select other parts of the brain, where we could reasonably construct control circuits to mimic or possibly replace sensors, actuators, communications, and control mechanisms, this would not be feasible today for the cerebrum. We simply do not know enough about how the components work, and our guesstimates about how the composite works remains imprecise and problematic. Our attempts at analogies using neural networks in computational models is yielding interesting results as analogies for some linguistic capabilities, but is in no way approaching the many functions identified as the differences between the vertebrates, emergent hominids, and modern humans (more on this in a later chapter).

Another subtle point is that it may be impossible for any single human to ever fully understand the human brain, because in order to understand that within the brain, it must hold all the details of its own makeup. It's analogous to a computer holding a complete design and operational status of itself within itself. While this is theoretically possible with an infinite memory, it is not possible with a finite memory. However, to the extent that there are repetitive structures and redundancy, computers and people may be able to trade time with space and model themselves completely in less space than the actual implementations but at slower speed, except of course for the memory. As a practical example, I cannot remember everything I have written in this book, even though I have written it all. Even ignoring the parts where I extracted content from other sources and summarized or rewrote, it is beyond my capacity to recall it all or go through the full set of thought processes without reviewing it. As I write it, I think of new sequences of things I want to express and express them, and I hope I gain understanding along the way, but I count on basic understandings that I express and reflect on in my writing to get my next page or ten.

We have a pretty good idea of many differences in brains and their functional elements between modern humans, distant ancestors, and current similar species. But there is plenty of distance left to go before we reach any sort of complete understanding. As an example, the notion of brain size correlating to intelligence (whatever that is), in computers, operations go faster when components are scaled to smaller sizes because signal propagation time goes up with distance. Smaller means less power and more speed, and perhaps more efficient design.

⁴² <https://neurosciencenews.com/computer-code-language-processing-17439/>

As a control system, the the human body grows and adapts to its environment as it develops, but much more adaptation appears to take place internally with regard to the brain than other aspects of physiology. Specifically, in areas of development where humans take longer than previous animals, these developments involve a complex of control systems that grow connections and linkages based on inputs from physiological sensors (*such as eyes, ears, touch, and so forth*), build out brain structures to enable production of actions (*like making sounds, coordinating actions, building social and communications skills, and other capacities*) that enable less and less direct control mechanisms, ultimately leading to indirect, communications-based, and social control capabilities and elements (*like increasingly direct empathy, social awareness, integration of past experiences and prospective futures, temporal and semantic distant data linkage, more ways to classify, analogical reasoning, collaborative social abilities, mental time travel, nonverbal semantic social cognition, the ability to entertain others' belief states, theory of mind, planning future actions, and other similar aspects of mental capabilities*) associated with brain differences between earlier primates and hominids and homo sapiens.

A timeline of emerging technology, society, and limits

A limited historical timeline of recent co-evolution may be revealing. Here are some of the changes we have a sense of and their timing and possible linkage to brain changes. Note the use of the “**Ya**” (years ago) notation is based on the common era being 2,000 Ya, and is assumed to be approximate. Because calendars became widely adopted in this time frame, we will shift from and between Ya (years ago), [B]CE ([before] the common era), and other notations from here forward. Periods strictly within the CE not otherwise designated indicate CE years (e.g., 2026 is this year).

Also note that if a new population of human children (i.e., a generation) happens every 20 years, that's only 5 generations starting per century, 50 per millennium, and 150 generations since 3,000 Ya. When we speak of ‘ancient’ history, recognizing that most people today are alive when their grandchildren are born and that was true of some people over most of the course of history, only about 50 people knowing each other over time extend over this full period. If they passed stories from one to the next, that's the extent of the narrative transition.

Before homo sapiens

These events came before homo sapiens emerged and up to our emergence from hominids. As such, they demonstrate to a limited extent the ability of prior species to do the things that are associated with current human brain structures.

Before 1M Ya^{STEM}: Stone tools, possible use of fire for cooking, bone tools.

1,200,000 Ya: The early hominids (Homo-erectus) were hunter gatherers in small groups.⁴³

475,000 Ya: Evidence found in Zambia includes 475,000 year old components of wooden structure using fitted wooden logs. Thus wooden structures were built 300,000 years before the emergence of homo sapiens.⁴⁴

⁴³ <https://en.wikipedia.org/wiki/Hunter-gatherer>

⁴⁴ <https://www.earth.com/news/wooden-log-structure-discovered-kalambo-falls-built-300000-years-before-homo-sapiens/>

400,000 Ya: The manufacture of the first huts 400,000 years ago testified to the ability to represent a future and complex object that does not exist in the present. ⁴⁵

400,000 Ya: Neanderthals mastered fire about 400,000 years ago^{46 47}

2-400,000 Ya: The first symbolic representations of the world such as the chimerical drawings (i.e. mixing features of different animals to produce a non-existing creature) painted in caves and the first sculptures demonstrated a higher level of abstraction. ⁴⁸

2-300,000 Ya: The first physiologically similar homo sapiens emerged. ⁴⁹

Pre-agrarian society (the 1st cognitive expansion)

In this time frame, hominid life spans averaged about 25 years largely due to infant mortality, with people reaching 15 years old living on average to 55.⁵⁰ As of and after about 60,000 years ago, humans appear to have demonstrated brain structure changes producing: increased working memory, components of planning, problem-solving, and language production; interrelated cognitive changes of greater integration of past experiences and prospective futures, greater capacity to link discontinuous or distant data (temporal or semantic), a greater capacity for abstraction (allowing knowledge classification in different ways), with analogical reasoning and abstract values giving rise to beliefs and morals. Together, these support sophisticated social interactions based on language, enabling beliefs, moral judgments, and conceptualization, creation, and extension beyond physical grasp.

The following table roughly maps abilities with brain changes, summarizing the previous discussion. When we talk about the concept of nature vs. nurture, this is largely the end of the nature part of the evolutionary story of human brains at the gross level:

Demonstrated abilities	Brain changes
Increased working memory	Posterior portion of the lateral prefrontal cortex middle temporal lobe, temporoparietal cortex, lateral frontal cortex, especially dorsal frontal cortex, anterior ventral frontal cortex and posterior parietal cortex.
Spatial cognition	
Reasoning	
Components of planning, problem-solving	arcuate fascicle (AF), frontal pole (FP), posterior parietal cortex (planning and imitation)
language production	Left Frontal Lobe Broca's area (language)
processing taste, pain, temperature, touch and internal state, with regions for mediating empathy and social awareness	Insula
Interrelated cognitive changes of greater integration of past experiences and prospective futures; Greater capacity to link discontinuous or distant data (temporal or semantic); A greater capacity for abstraction (allowing knowledge classification in different ways); Analogical reasoning and abstract values giving rise to beliefs and morals.	frontopolar cortex (BA 10)
Emotion	right middle temporal cortex

45 <https://academic.oup.com/brain/article/147/3/794/7424860>

46 <https://www.nature.com/articles/d41586-025-04059-4>

47 <https://www.nature.com/articles/s41586-025-09855-6>

48 <https://academic.oup.com/brain/article/147/3/794/7424860>

49 https://en.wikipedia.org/wiki/Early_modern_human

50 https://en.wikipedia.org/wiki/Life_expectancy

Demonstrated abilities

nonverbal semantic social cognition
 ability to entertain others' belief states
 mentalizing or theory of mind
 social cognition
 social cognition
 Collaborative social abilities, tool use, mental time travel, and spoken language; Metacognition; Awareness of ones own thoughts; Mentalizing or theory of mind
 Reaching, grasping, self-protection, and eye movements
 planning future actions, undertaking initiatives, and attention;

Brain changes

right temporal association cortices
 posterior superior temporal cortex and inferior parietal lobule, (together 'temporoparietal junction area': TPJ)
 inferior longitudinal fascicle (ILF)
 frontal pole (FP)
 posterior parietal cortex
 Frontal lobes, more pyramidal neurons

- **1-200,000 Ya:** or thereabouts, the emergence of verbal and advanced visual signaling communication using words or other similar sounds or sequences of motions indicative of syntax and semantics relating to objects and actions on objects marks the beginning of communicated memes and non-physically enforced control systems.^{51 52 53 54} That is, the level of indirect control was extended to support sonic actuators causing effects in other humans (the environment) and responses sensed (sensors) producing control decisions as to next outputs to cause actions in the other human. Memes may have started as commands or collaborative coordination between people (and people with animals) and eventually transformed into more complex narratives to influence other humans into more complex actions. For this to work, there must be some sort of means to turn, for example, an observed visual object like a recognized face, into a sound sequence associated with it, and from there, to be able to transmit the sound vocally to another listener who can then make the association of the sound sequence to the mental concept of the object. By this time frame, the left Frontal Lobe Broca's area (language) had been developed, and these sorts of associations were possible.
- **72-100,000 Ya:** Over this period, it seem very likely that communication of memes and more complex narratives emerged.^{55 56} For coordination of long-distance group travel and group hunting, some sort of collaboration is required. One of the challenges with finding evidence at specific times is that verbal communication is not recorded in the archaeological record. By the end of this period, humans migrated in groups, not just as individuals, and as such, they must have communicated and coordinated activities. For example, preparing for a long trip would likely involve carrying things, sharing food, and working in groups for protection and support. This is done in pack animals of other sorts, and it seems almost certain that the capabilities must have emerged rather than sprung up at an instant in one individual and been taught to everyone else everywhere else. Some sort of syntax would have to exist for at least a notion like verbs and nouns (e.g., "lift rock"), and other rudiments of neural capabilities existed for activities like planning and anticipation of future events by this time frame. Also, nomadic hunter gatherer groups existing in this time frame, and because human child development

51 https://en.wikipedia.org/wiki/Origin_of_language

52 <https://neurosciencenews.com/genetics-language-origin-28489/>

53 <https://news.mit.edu/2025/when-did-human-language-emerge-0314>

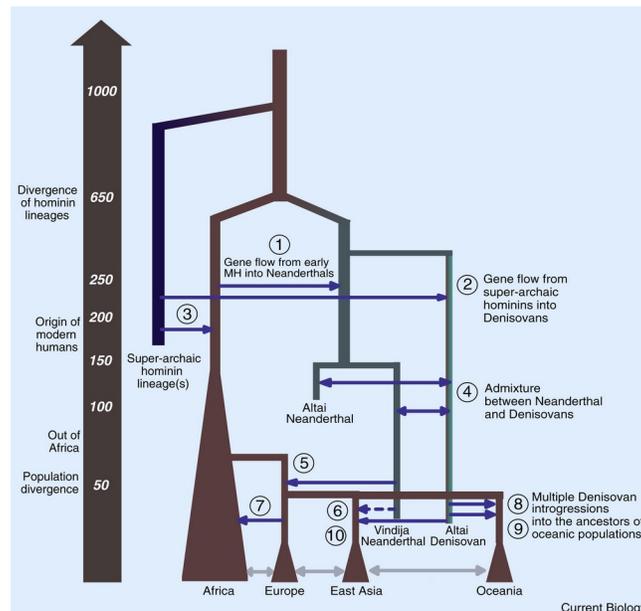
54 <https://link.springer.com/article/10.1186/s12915-017-0405-3>

55 <https://down.aefweb.net/WorkingPapers/w667.pdf>

56 <https://thevarsity.ca/2023/03/19/human-evolution-storytelling/>

requires parenting over a period of a dozen years or more, such groups would have to stay together over time for descendants to survive. Recent studies show that survival of children with storytelling is twice as likely as without, so evolution likely favored the survival of children whose parents told them stories, and groups with narratives likely come to dominate groups without or with fewer narratives. Sound also travels beyond line of sight and in the dark, and so is more effective for survival in these environments.

- **72,000 Ya:** African humans left Africa in a single migratory period north, from which all strains of humans outside of Africa were produced.⁵⁷ This happened in groups and as such, likely involved more complex narrative structures.
- **67,800 Ya:** Rock art found [Sulawesi]⁵⁸
- **50-60,000 Ya:** Aboriginal Australians arrived over water from Africa at about the same time humans moved out of Africa to the north, and no outside inter-breeding took place between then and very recently.⁵⁹
- **50,000 Ya:** Smaller brained strains like homo floresiensis (sometimes identified as hobbits) died out, per different sources, 12,000-50,000-190,000 years ago.^{60 61}
- **50,000 Ya:** Humans left Africa to the north and interbred⁶² with Neanderthals, and today, about 1–4% of the genome of people outside Africa are inherited from them.⁶³ Ancient Denisovians contributed DNA to current people in Oceania and East and Southeast Asia. Other DNA contributors are pictured below.



57 <https://www.cam.ac.uk/research/news/unprecedented-study-of-aboriginal-australians-points-to-one-shared-out-of-africa-migration-for>

58 <https://www.nature.com/articles/s41586-025-09968-y>

59 <https://www.unsw.edu.au/newsroom/news/2018/08/when-did-aboriginal-people-first-arrive-australia>

60 <https://www.sciencedirect.com/referencework/9780128040966/evolution-of-nervous-systems>

61 https://en.wikipedia.org/wiki/Homo_floresiensis

62 https://en.wikipedia.org/wiki/Interbreeding_between_archaic_and_modern_humans

63 <https://www.sciencedirect.com/science/article/pii/S0960982222013045>

- **40-50,000 YA^{STEM}**: This is where the first evidence of the emergence of mathematics, science, and engineering occurred and we will be relying on the following references from here forward.^{64 65 66 67 68}

I will be using a notation ^{STEM} for timeline events related to science, technology, engineering, and mathematics going forward, and indicate (disputed) for some of the earlier disputed items.

The origins of mathematical thought lie in the concepts of number, patterns in nature, magnitude, and form. Modern studies of animal cognition have shown that these concepts are not unique to humans and were part of everyday life in hunter-gatherer societies. The idea of the "number" concept evolving gradually over time is supported by the existence of languages that preserve the distinction between "one", "two", and "many", but not of numbers larger than two.

- **41-54,000 Ya**: Earlier ancestors of Eurasian humans mated with Neanderthals and Denisovans over between a 7,000 to 13,000 year period.^{69 70 71 72 73}
- **40,000 Ya**: The use of yarn possibly for some sort of record-keeping by Neanderthals suggests they knew basic concepts in arithmetic.
- **40,000 Ya**: Neanderthals had current human brain size and went extinct.⁷⁴
- **30-40,000 Ya**: Cave paintings and limited musical instruments appeared. Instruments are controlled by the musician listening to sounds and varying actions.
- **20-40,000 Ya**: Humans and dogs collaborated⁷⁵ and dogs were first domesticated.^{76 77} People control dogs (and dogs people) by watching, listening, acting, and talking.
- **35,000 Ya**: The last identified major changes in the human brain as reflected only by fossils that show the same globular shape as present-day humans.⁷⁸
- **15-30,000 Ya**: Ancestors of American Indians arrived in North America.⁷⁹ Various theories assert that populations moved from Russia to North America as recently as 15,000 years ago over the Bering Land Bridge.^{80 81}

64 <https://www.explainthatstuff.com/timeline.html>

65 <https://www.britannica.com/story/history-of-technology-timeline>

66 https://en.wikipedia.org/wiki/Timeline_of_historic_inventions

67 https://en.wikipedia.org/wiki/Timeline_of_scientific_discoveries

68 https://en.wikipedia.org/wiki/History_of_mathematics

69 <https://www.livescience.com/archaeology/modern-human-ancestors-and-neanderthals-mated-during-a-7-000-year-long-pulse-2-new-studies-reveal>

70 <https://www.nature.com/articles/s41586-024-08420-x>

71 <https://www.science.org/doi/10.1126/science.adq3010>

72 <https://pmc.ncbi.nlm.nih.gov/articles/PMC11118355/>

73 <https://indiandefencereview.com/dna-dragon-man-skull-denisovans-looked/>

74 https://en.wikipedia.org/wiki/Neanderthal_extinction

75 https://en.wikipedia.org/wiki/Human-canine_bond

76 <https://www.morrisanimalfoundation.org/article/evolution-of-dogs>

77 https://en.wikipedia.org/wiki/Dog_breeding

78 <https://www.sciencedaily.com/releases/2018/01/180125105444.htm>

79 <https://www.ox.ac.uk/news/2020-07-22-earliest-americans-arrived-new-world-30000-years-ago>

80 <https://www.nps.gov/bela/learn/historyculture/other-migration-theories.htm>

81 <https://www.history.com/articles/human-migration-americas-beringia>

- **20,000 Ya:** The first ground stone was in this time frame. Grinding is manual control by hands with feedback from eyes, ears, and nose.
- **20,000 Ya^{STEM}:** The Ishango bone has a series of carved marks in 3 columns running the length of the bone, interpreted by some as the earliest known demonstration of a six-month lunar calendar. (disputed)
- **18,000 Ya:** Human-built bone shelters existed (found in the Ukraine)⁸² Manufacturing.
- **40-12,000 Ya:** I found very little other useful information on the Upper Paleolithic period.⁸³ I found more diversity of human artifacts, larger settlements, geographical expansion throughout Eurasia, disappearance of closely related hominids, early proto-writing and symbols, hunting and gathering, and a glacial period that ended as this period ended. Different cultures appeared throughout this period as small groups worked together and grew settlements, and as the ice age receded, changes started.
- **12,000 Ya:** Descendants of American Indians arrived in South America.
- **12,000 Ya^{STEM}:** The concept of division may have been present, implying addition and subtraction. (disputed)

Are there differences in the split descendants?

An important issue in understanding co-evolution of technology and brains is the differences, if any, between separated human lineages. In particular, there are 4 distinct useful branches that can be defined as supported by the history of DNA^{84 85 86}. I choose these particular branches because of their isolation from other branches over long periods from their split through to recent times, leaving essentially independent breeds available for study today and with differentiated histories without substantial social contact before global travel at scale introduced social and technical components across the different branches.. It is important to note that the dates of these departures differ from source to source and continue to be updated today as new evidence is found from archeological exploration. The extent of the splits are also different in terms of the extent to which travel was limited and cultural and technical information was or was not exchanged.

- The original African emergence of homo sapiens remained somewhat separated from the other branches over time, although there was certainly substantial mixing. Some relatively isolated tribes continued to exist into the 20th century.
- The split 50-60,000 Ya of Aboriginal Australians kept them distinct from other branches until 1606.⁸⁷ Little, if any, cross-breeding took place between then and now.
- The split from Africa to Europe involving Neanderthal cross-breeding 50,000 Ya ended with the extinction of the Neanderthals, but breeding within this group was common for much of the intervening time. Because transportation over land was substantial from

82 <https://dailygalaxy.com/2025/12/humans-lived-inside-mammoth-bone-shelters/>

83 https://en.wikipedia.org/wiki/Upper_Paleolithic

84 <https://humanjourney.us/ancestors/genetics-and-human-evolution-2/tracking-human-movement-across-the-globe/>

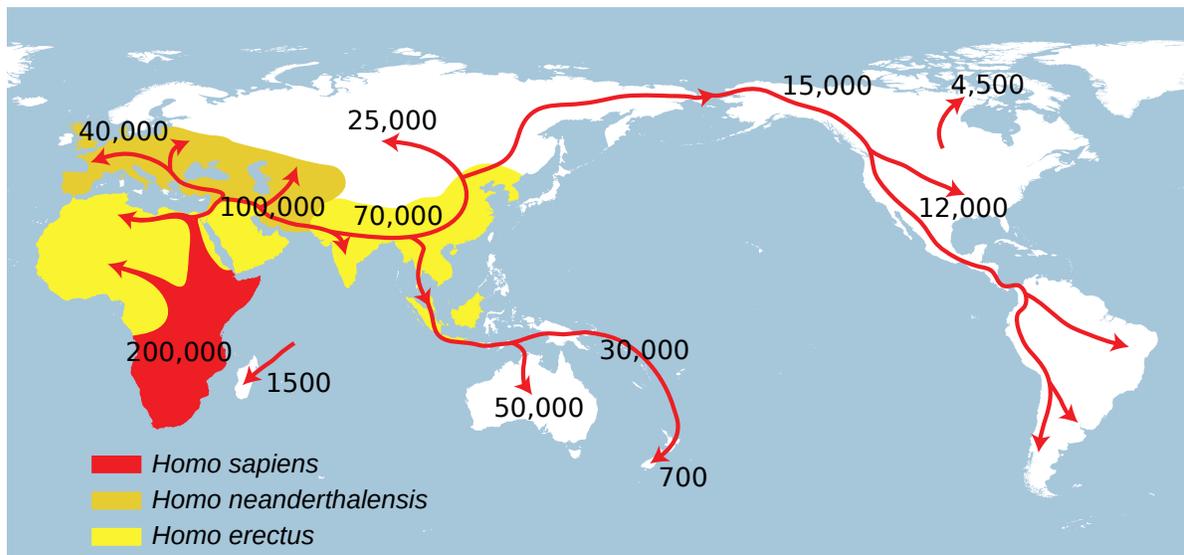
85 <https://livingdna.com/blog/tracing-ancient-migratory-routes-with-dna>

86 https://en.wikipedia.org/wiki/Early_human_migrations

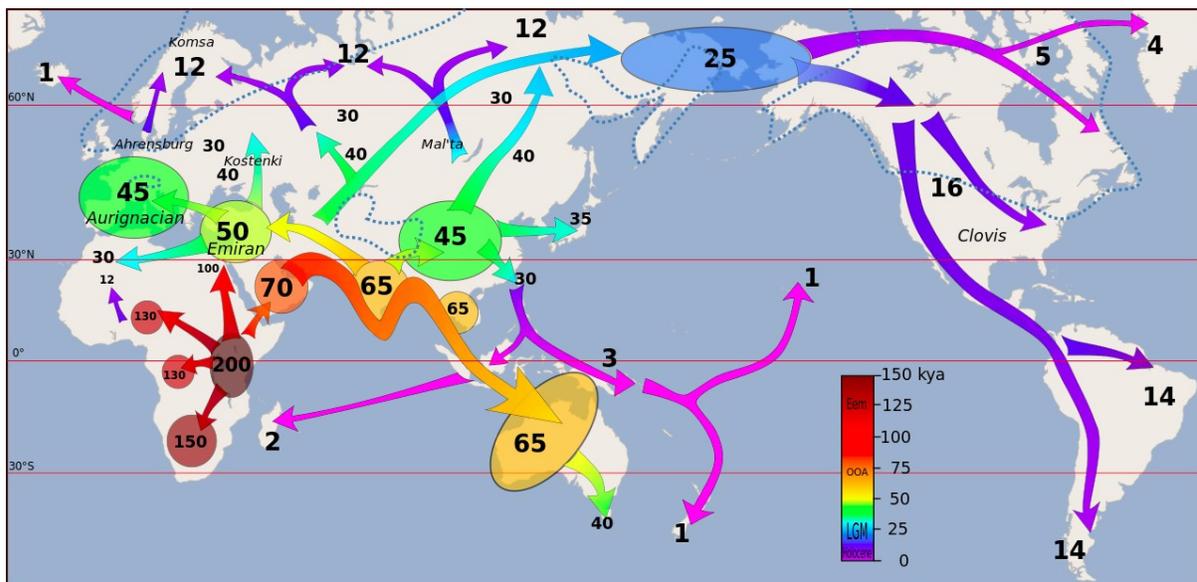
87 <https://www.qld.gov.au/about/about-queensland/history/timeline/pre-1700s>

then forward, little distinction justifies genetic and social differences reflective of brain evolution at the scale of the difference between earlier hominid and homo sapiens.

- The split of American Indians from the Neanderthal cross-bred humans about 20,000 Ya and was sealed by changes in the ice age about 15,000 Ya.^{88 89} This remained till at least the travel of Leif Erikson to Newfoundland in about 1,000 AD and the visitation of Columbus and subjugation of the Americas in the 1400s and forward. There remain some non-cross bred Indian Americans still today.



The above graphic and the references provide some sense of the lack of clarity surrounding actual dates, but it gives a visual sense of what happened as humans spread over time. The below graphic is another similar map from the same article. Note the time differences.



88 https://en.wikipedia.org/wiki/Last_Glacial_Period

89 <https://www.history.com/articles/human-migration-americas-beringia>

A critical issue in understanding co-evolution of brain and its environment is the date of separation, not the date of first appearance. Once separated, the groups act as independent samples regardless of how they may have interacted prior to their separation. An interactive graphic showing a version of this sequence including climate drivers is available online.⁹⁰

As it turns out, it is relatively easy to find studies of brain differences between populations like African Americans and European Americans, but most studies I found do not differentiate between populations separated from a breeding perspective and from different time frames.

Aboriginal Australians (always pre-agrarian)

Studies found include:

- Aboriginal vs Caucasian brains in Australia:⁹¹ An autopsy-based study involving only 19 deceased subjects (all male, 8 Aboriginal, 11 Caucasians) sectioned areas of the brains, stained, and measured areas of the brains.
 - *“Brain volume was significantly smaller for Aborigines (1199 +/- 84 ml) compared to Caucasians (1386 +/- 98 ml). Significantly smaller volumes were also found for cerebellum, prosencephalon-mesencephalon unit, cerebral cortex, frontal cortex, parieto-occipitotemporal cortex, and hippocampus. Volumes of ponsmedulla oblongata unit (21 +/- 3 ml for Aborigines and 22 +/- 3 ml for Caucasians) and visual cortex (14.9 ml +/- 2.6 ml and 14.6 +/- 2.2 ml, respectively) did not differ significantly. The **striate cortex extended further onto the lateral surface of the occipital lobe** in Aboriginal brains. The **frontal portion of cerebral cortex was larger** in Aboriginal than in Caucasian brains. According to the specific growth periods for the areas studied, these differences could be explained by the higher incidence of malnutrition and infectious diseases for Aborigines during the development of the brain in early childhood, especially after the 6th postnatal month. However, genetic influences cannot be excluded. The results for the visual cortex of Aborigines might represent an adaptation to living conditions in the bush and desert regions of Australia.”*
 - Aborigines had **larger pons-medula oblongata units, lateral part of the visual cortex, and lateral visual cortex.**⁹² ⁹³ These are associated with differences between primates in general and humans, but not specifically associated with relevant behaviors I have identified. They are associated with recognition and identification of objects, and contributes to spatial orientation and action recognition. The lateral visual cortex is primarily mapped to cognitive features related to the "where/how" visual processing stream, focusing on spatial tasks, motion perception, and object location, as well as certain aspects of object recognition that involve spatial characteristics or action.

90 <https://legacy.calacademy.org/human-odyssey/map/>

91 <https://pmc.ncbi.nlm.nih.gov/articles/PMC1261675/>

92 https://en.wikipedia.org/wiki/Visual_cortex

93 <https://oecs.mit.edu/pub/8w58nrk1/release/2>

- Aboriginals had proportionally smaller **frontal cortex, parieto-occipitotemporal cortex, and medial visual cortex.**^{94 95 96} These are associated with involved in 'higher' cognitive functions; like planning future actions, undertaking initiatives, and attention; parieto-occipitotemporal (POT) cortex (part of the OTC occipitotemporal cortex) is an association area of the brain vital for integrating multisensory information into higher-order cognitive functions. It serves as a critical interface between visual, sensory, and motor processing streams. In particular, these areas are associated with recognition of things like social gathering, couples, faces, baby humans, baby animals, positive and negative arousal faces, various threats, injured humans, body parts, household objects, land scenery, fish, insects, land animals, and so forth. This result identifies that specific sorts of recognition are more or less complex, but does not mean anything specific based on the single study making a correlation both because of the small sample set and because of the lack of specificity of location results.
- Aboriginals have higher visual acuity, visual memory, and rely more on visual strategies and less on verbal strategies for problem solving.

Specific areas of lower brain volume have been loosely correlated to developmental periods and nutritional deficits and disease in the aboriginal populations.

Note that from earlier referenced studies, there is a global correlation between body size and brain size for humans, and average body sizes in Australia for these populations are significantly larger for Caucasians.

- Aboriginals in Australia prior to the Caucasian invasion lived largely as nomads and hunter gatherers, never significantly developing agriculture.^{97 98 99 100 101 102} On first European contact, Aboriginal population range from 300,000 to one million. They were complex hunter-gatherers with diverse economies and societies. There were about 600 tribes (nations) and 250 languages with various dialects. Groups had fire-stick farming and fish farming, and built semi-permanent shelters. They developed spear throwers, boomerangs, shields, grinding stones, fishing nets, wicker traps and baskets, canoes, water carriers, plant processing technologies including detoxification of cycads and the creation of thermoplastic resin, bush medicine, and developed artistically including hand prints, engravings, depicted humans and animals 20,000 years ago. They had tribal groups starting with small family groups of about 25 holding territories and doing foraging and hunting. Family groups interacted with neighbors and exchanged goods and intermarried. They used fire to deliberately shape their environment 46,000 Ya that may have caused dramatic climate change and fostered mass extinctions. They had and made musical instruments including the didgeridoo, moved from stone toward

94 <https://brainmap.org/pubs/GrosbrasHBM12.pdf>

95 <https://pmc.ncbi.nlm.nih.gov/articles/PMC4111924/pdf/joa0225-0132.pdf>

96 <https://www.nature.com/articles/s41467-024-49073-8>

97 https://en.wikipedia.org/wiki/History_of_Indigenous_Australians

98 <https://outlookreport.gbrmpa.gov.au/values/4-heritage-values/43-indigenous-heritage-values/434-indigenous-structures-technology-tools-and-archaeology>

99 <https://www.abs.gov.au/Ausstats/abs@.nsf/0/75258e92a5903e75ca2569de0025c188?OpenDocument>

100 https://en.wikipedia.org/wiki/Australian_Aboriginal_artefacts

101 https://en.wikipedia.org/wiki/Prehistory_of_Australia

102 <https://www.australiangeographic.com.au/history-culture/2015/03/aboriginal-australian-inventions/>

wooden tools with stone blades about 5,000 Ya, and had a diversified range of languages. They had complex laws and cultural norms, and developed “talking sticks” for sending messages and recording and transmitting information in written form had “Keeping Places” for storing cultural items and artifacts. They made toys including rattles and dolls. Their environment changed dramatically over this period; initially with large animals, widespread greenery, and water; but this changed about 25,000 Ya, effecting many changes in survival strategies.

- There was collaboration, but not apparently domestication with dingoes^{103 104 105 106 107}. Dingoes arrives in Australia as an introduced species about 12,000 Ya founded by a small population, perhaps as little as one female and her pups, and had a close relationship with First Nation humans that developed from about 3,500-5,000 Ya. They were hunting and living companions and the only early species with language skills enough for communication. Dingoes were buried with people starting about 2,000 Ya. Indigenous Australians tamed kangaroos, wallaroos, emu, cassowary chicks, and lizards.
- No evidence I have found identifies complex tools or machines, significant agriculture, use of electricity, manufacturing, non walking transportation, or shared infrastructure.

There may be a link between the development of more complex machines and the differences between Aboriginals associated with their notionally enhanced visual comprehension and recognition and their notionally reduced ability to integrate multi-sensory information into higher level functions, but the evidence for this is not conclusive. None of these differences with other global human development has any apparent causal link to brain structural changes, but some evolutionary differences correlate well to the lifestyle and environmental conditions and changes in the flora and fauna of the continent. In addition, the brain studies are very limited and more research would be required to get at these issues in sufficient depth for definitive understanding to emerge. However, there is some level of correlation with brain sizes and behavioral components.

IQ differences

One of the differences in identified studies is results on IQ (intelligence quota) tests. I have discounted these differences because of the extensive evidence that IQ results are often related to culture, education, and other factors than physiology or, in particular, brain function. Our concern here is brain evolution vs. cognitive capabilities, and except to the extent that it correlates or is causally related to brain structures, IQ is not relevant. Except for select dysfunctions associated with individual conditions, I have found no evidence suggesting that results of IQ tests are meaningful in terms of the coevolution issues at hand.

103<https://www.nma.gov.au/defining-moments/resources/arrival-of-the-dingo>

104<https://www.australiangeographic.com.au/history-culture/2017/08/cultural-history-of-the-dingo/>

105<https://www.sciencedirect.com/science/article/abs/pii/S0278416519301965>

106<https://www.uwa.edu.au/news/article/2023/october/did-australias-first-peoples-domesticate-dingoes>

107<https://www.researchgate.net/profile/Bradley-Smith-28/publication/>

[233608384_A_Review_of_the_Relationship_between_Indigenous_Australians_Dingoes_Canis_dingo_and_Domestic_Dogs_Canis_familiaris/links/53dc7e0e0cf216e4210c0b22/A-Review-of-the-Relationship-between-Indigenous-Australians-Dingoes-Canis-dingo-and-Domestic-Dogs-Canis-familiaris.pdf](https://www.researchgate.net/publication/233608384_A_Review_of_the_Relationship_between_Indigenous_Australians_Dingoes_Canis_dingo_and_Domestic_Dogs_Canis_familiaris/links/53dc7e0e0cf216e4210c0b22/A-Review-of-the-Relationship-between-Indigenous-Australians-Dingoes-Canis-dingo-and-Domestic-Dogs-Canis-familiaris.pdf)

Mememes and narratives in the 1st cognitive expansion

Before agriculture took off, there was little written record demonstrating language capabilities. The increase in diversity of human artifacts, larger settlements, geographical expansion throughout Eurasia, disappearance of closely related hominids, early proto-writing and symbols, hunting and gathering, and a glacial period that ended about 12,000 Ya with the resulting expansion in the agrarian age, all point to the emergence of language over this time frame. Different cultures appeared throughout this period as small groups worked together and grew settlements, and as the ice age receded, changes started.

From this period, there are very limited surviving recorded symbols, but those symbols did involve distinct objects that look like what they portray as opposed to abstract art, those symbols were put in relation to each other in the space of the depiction rather than as independent symbols, and in some cases they appear to indicate sequences of events rather than just a moment in time. All of these mechanisms are controlled by direct observation and actions plus practice (learning). Artifacts [found where *today] are evidence: ^{108 109 110 111 112 113}

- **90,000 Ya^{STEM}**: Harpoons [*Democratic Republic of the Congo].
- **82,000 Ya**: Shells with pierced holes and red ocre etched in geometric shapes [Israel].
- **70,000 Ya^{STEM}**: Compound adhesives, bow and arrow technology, and sewing needle of a form [*South Africa].
- **61,000 Ya^{STEM}**: Cave painting [*Spain by Neanderthals].
- **55,000 Ya^{STEM}**: Representational and Narrative art [*Indonesia].
- **45,000 Ya^{STEM}**: Mines extracted hematite to produce red pigment ochre [Eswatin].
- **45,000 Ya^{STEM}**: Fragments of an axe [*Australia and later *Japan].
- **42,000 Ya^{STEM}**: Tally sticks [Eswatini], Flute [*Germany], Spear-thrower (aka atlatl, woomera) [*France] (possibly only 17,500 Ya).
- **37,000 Ya^{STEM}**: Stone carvings of individual figures, mortar and pestle in [SW Asia].
- **28,000 Ya**: Cave carvings of individual animals in motion.
- **27,000 Ya**: Cave paintings show an apparent family with a form of grass skirt.
- **30,000 Ya**: Cave paintings show multiple animals in scenes, likely families as a group.
- **24,000 Ya^{STEM}**: Oldest known ceramic sculpture.
- **23,000 Ya^{STEM}**: Domestication of the dog [*Siberia].
- **22,000 Ya^{TRAN}**: Rafts are used on rivers. ¹¹⁴
- **22,000 Ya^{STEM}**: Fish hook [*Okinawa Island (Japan)].

108 https://en.wikipedia.org/wiki/Art_of_the_Upper_Paleolithic

109 <https://www.oerproject.com/OER-Materials/OER-Media/HTML-Articles/Origins/Unit2/Art-of-the-Paleolithic>

110 <https://education.nationalgeographic.org/resource/development-agriculture/>

111 <https://pressbooks.bccampus.ca/cavestocathedrals/chapter/paleolithic/>

112 <https://www.bradshawfoundation.com/spain/altamira/index.php>

113 https://en.wikipedia.org/wiki/Cave_painting

114 https://en.wikipedia.org/wiki/Timeline_of_transportation_technology heretofore TRAN

- **21,000 Ya^{STEM}**: First star charts.
- **20,000 Ya^{STEM}**: Pottery [*China].
- **14,500 Ya^{STEM}**: Bread [*Jordan].
- **16,000 Ya**: Extensive cave paintings showing hunting with groups of people and herds of animals, but no depiction of surrounding plants or scenery.
- **12,000 Ya^{STEM}**: Spindle whorl and oldest wheel-like tool [*Israel].
- **10,000 Ya**: Cave paintings depicted hunters with weapons, riding horses, hunting or otherwise interacting with apparently prey animals.

This progression appears to be consistent with the ongoing development of cognition, the development and expressions of memes at least in the form of animals and people on their own, followed by animals and people in relation to each other with indications of early apparel, followed by actions of groups of people interacting with semi-domesticated animals, prey, and weapons. It seems very likely that people of this time range developed languages, taught children, partitioned tasks, and collaborated in groups, all in increasing amounts and at increasing levels of sophistication over time. It appears that this involved the early extension of control systems from **body to direct** for most things, **body to indirect** mechanisms for tool use, from **body to communications-based systems** for animals, and started a limited form of **socially controlled systems**.

Agrarian and civilization social developments (the 2nd cognitive expansion)

In this time period, average human lifespan was about 26 years, with survivors to age 15 averaging about 48 years. Again, a historical timeline is a starting point to this emergence:

- **12,000 Ya**: Agriculture began leading to permanent settlements and farming, and agrarian societies started to emerge. This happened at slightly different times in different physically separated populations that experienced it, but it seems it was “*an idea whose time had come*”, and involved a combination of factors including the end of the last great ice age, the emergence of enhanced cognitive capabilities, and the development of language and communications.
- **10-12,000 Ya^{STEM}**: Agriculture [the Fertile Crescent], Domestication of sheep then pigs, goats, and cattle [SW Asia], Oldest known surviving building [*Turkey], Domestication of rice [*China], Mudbricks (unfired bricks) and clay mortar [Jericho], Selective breeding started,^{115 116 117} and cattle domestication started.^{118 119}
- **11,000 Ya**: The first traces of symbolic communication were observed in the use of tokens as currency.¹²⁰
- **10,400 Ya^{STEM}**: Oldest known water well [*Cyprus].

115 <https://www.morrisanimalfoundation.org/article/evolution-of-dogs>

116 https://en.wikipedia.org/wiki/Dog_breeding

117 <https://smarthistory.org/paleolithic-art-an-introduction/>

118 <https://pmc.ncbi.nlm.nih.gov/articles/PMC6304694/>

119 <https://en.wikipedia.org/wiki/Cattle>

120 <https://academic.oup.com/brain/article/147/3/794/7424860>

- **10,400 Ya^{WH}**: Animal domestication of sheep and goats. [Mesopotamia]
- **10,400 Ya^{WH}**: Crop cultivation of wheat and barley. [Mesopotamia]
- **10,000 (+/-) Ya^{STEM}**: Large permanent settlements like Tell es-Sultan [Jericho] and [Çatalhöyük, *Turkey].
- **10-9,000 Ya^{WH}**: Domesticated rice and pigs [Yangtze River Valley, China].¹²¹
- **10-7,000 Ya^{WH}**: Sorghum and other crops grown [Sahara].
- **10,500 Ya^{WH}**: Squash grown [S. America]
- **9,800 Ya^{WH}**: Arrowroot grown [Central America]
- **9,500 Ya^{TRAN}**: The earliest known use of wood working.
- **9,500 Ya^{STEM}**: Copper tools used by the people of the Old Copper Complex [*Great Lakes region of North America], domestication of potatoes, [*S. Peru and NW Bolivia] by pre-Columbian farmers [*Lake Titicaca].
- **9,500 Ya^{WH}**: Crops then cattle [Indus River Valley].
- **9,000 Ya^{TRAN}**: The earliest known shoes were in use (earlier suspected).
- **9,000 Ya^{STEM}**: Sled dog and Dog sled [*Siberia], evidence of lead smelting [*Çatalhöyük Turkey], Kiln [Mesopotamia (*Iraq)].
- **8,500 Ya^{STEM}**: Alcohol fermentation [*China], Irrigation in [*Khuzistan, Iran].
- **8,000 Ya^{TRAN}**: The earliest dugout canoes were in use.
- **7,900 Ya^{STEM}**: Salt production [SE Europe (*Moldova and Romania)].
- **7,500 Ya^{STEM}**: Cheese [*Poland and Dalmatian coast of Croatia], pottery depictions of sail boats [Mesopotamia].
- **7,000 Ya^{STEM}**: Predynastic Egyptians pictorially represent geometric designs. (disputed)
- **7,000 Ya^{STEM}**: Copper smelting [*Serbia], Seawall [Tel Hreiz (near Haifa Israel)], lacquer [*China], Cotton thread [*Mehrgarh, Pakistan], copper bead bracelet, rowing oars [*China].
- **6,500 Ya^{STEM}**: Fired bricks [China].
- **6,000 Ya^{TRAN}**: The earliest ox carts were in use. (disputed)
- **6,000 Ya^{STEM}**: First diamond-mines [*S. India], paved roads around city [Mesopotamian city of Ur (*Iraq)], Pipes (plumbing) made of clay [Temple of Bel, Nippur, Babylonia], water locks [Nineveh (ancient Assyria)], wheels [*Ukraine, Poland, and Germany].
- **5,500 Ya^{TRAN}**: Domestication of horses and invention of the wheel [*Near East].
- **5,500 Ya^{STEM}**: Silk garments [*China], domestication of horses [Eurasian Steppe], wine as general anesthesia [Sumer], Emblems used as seals [*Near East], Ploughing [*Bubeneč Czech Republic], tattoos [S. Europe].
- **5,500 Ya^{AMER}**: Domestication of alpacas [S America].

¹²¹ https://en.wikipedia.org/wiki/Human_history (herein WH)

- **5,500 Ya:** Cuneiform writing [Mesopotamia],¹²² Proto-writing [*Egypt, Iraq, Romania, China, India and Pakistan]. (5,200-8,000)
- **5,300 Ya:** The first city. [Uruk, Sumer, Mesopotamia (*Iraq)].
- **5,300 Ya^{STEM}:** The first documented swords [*Arslantepe, Turkey].
- **5,200 Ya^{STEM}:** Dry Latrines [*Uruk, Iraq], later dry squat Toilets, then raised fired brick foot platforms, and pedestal toilets, all over clay pipe constructed drains. Earliest actual wheel ever found (Ljubljana Marshes Wheel, made of wood) [*Slovenia].
- **5,000 Ya^{STEM}:** Megalithic monuments [*England and Scotland] incorporate geometric ideas like circles, ellipses, and Pythagorean triples in their design. (disputed)
- **5,000 Ya^{TRAN}:** Catamarans and outriggers [Austronesia], galley ships developed [Mediterranean].
- **5,000 Ya^{STEM}:** Units of measurement developed [Americas, Egypt, Mesopotamia, Elam, and the Indus Valley], First numeral system of Egyptian numerals, a sign-value system. Devices functionally equivalent to dice (flat two-sided throwsticks in the game of Senet) [Egypt], tin extraction [Central Asia], papyrus [Egypt], reservoir [Girnar, Indus Valley], receipt [Mesopotamia (*Iraq)], prosthesis [Near East, Egypt, *Iran], specifically eye prosthetics and rhinoplasty [Egypt].
- **5,000 YA^{AMER}:** Adobe buildings [N. America].¹²³
- **4,650 Ya^{STEM}:** The cubit-rod ruler [Nippur (*Turkey)].
- **4,600 Ya^{STEM}:** First units of weight (Deben), and balance weighing scales [Egypt, planned city in Indus Valley], public sewage and sanitation systems [Indus Valley sites such as Mohenjo-daro and Rakhigarhi], public bath and levee [Mohenjo-daro, Indus Valley (*Pakistan)], balance weights and scales [Egypt].
- **4,556 Ya^{STEM}:** Docks structure [Wadi al-Jarf, Egypt].
- **4,400 Ya^{STEM}:** Fork in Bronze Age Qijia culture [*China], Copper pipes, the Pyramid of Sahure, an adjoining temple complex at Abusir [Egypt]. Touchstone [Indus Valley Banawali (*India)].
- **4,300 Ya^{STEM}:** The first dictionary [Mesopotamia].
- **4,200 Ya^{STEM}:** Iron smelting [Kaman-Kalehöyük], protractor [Lothal, Indus Valley (*India)] a Xancus shell cylinder with worked grooves at right angles in its top and bottom surfaces as a possible angle marking tool.
- **4,100 Ya^{STEM}:** The concept of area [Babylonian clay tablets], 3-dimensional volume discussed [Egyptian papyrus]. The start of geometry, quadratic equations in rectangle areas and sides solved [Babylonia].
- **4,000 Ya^{TRAN}:** Cart mentioned in literature, chariot and spoked wheel [*Russia and Kazakhstan].

¹²² <https://academic.oup.com/brain/article/147/3/794/7424860>

¹²³ <https://pmc.ncbi.nlm.nih.gov/articles/PMC11118355/>

- **4,000 Ya^{STEM}**: Pythagorean triples first discussed [Babylon and Egypt], multiplication tables in base-60 [Babylon], primitive positional notation for numerals [Babylon cuneiform numerals], water clock (possibly earlier) [Mohenjo-Daro, Indus Valley], scissors [Mesopotamia].
- **3,850 YA^{STEM}**: Proto-alphabet (Proto-Sinaitic script) [Egypt].
- **3,800-5,000 YA^{STEM}**: Triangles and side-ratios studied for the construction of pyramids leading to trigonometry [Egypt], published study anatomy and identifies the heart and its vessels, liver, spleen, kidneys, hypothalamus, uterus, and bladder, and that blood vessels emanate from the heart (and incorrectly identified some other things) [Egypt].
- **3,600 YA^{STEM}**: Surgical treatise [Egypt].
- **3,600-3,800 YA^{STEM}**: Fraction notation [Egypt], numerical approximation of the square root of two accurate to 6 decimal places [Babylon clay tablet believed to belong to a student], a tablet uses $25/8 = 3.125$ as an approximation for π (0.5% error) [Babylon].
- **3,500 Ya**: Humans used boats to transport rice roughly 1,430 miles (2,157 km) [*the Philippines to Guam].¹²⁴
- **3,500 YA^{STEM}**: Sundial [Egypt | Babylonia], glass manufacture [Mesopotamia | Egypt], seed drill [Babylonia].
- **3,500 Ya**: Human brain (and skull and body) sizes started shrinking, now down by about 13% from the peak perhaps 100,000 Ya.¹²⁵
- **3,400 YA^{STEM}**: Rubber used in ballgame [Mesoamerica], concrete in Tiryns (Mycenaean Greece)
- **3,300 YA^{STEM}**: Lathe [Egypt].
- **3,200 YA^{STEM}**: Distillation described on tablets about perfumery operations [Akkadia].
- **3,100 YA^{STEM}**: Star catalogue (3 stars each) earliest known in the long-running tradition of astronomy [Babylon].

The acceleration of invention and its range over locations indicated a substantial change, of amount but ultimately of kind, as the world started to move toward a technological revolution. But the Bronze Age collapsed around 3,200 Ya, wiping out most Near Eastern cultures and the Indus Valley Civilization. You can see the reduction in inventions toward the end of this time frame, and that correlates to social collapse. The causes of these collapses are disputed but generally attributed to the violent destruction of cities and towns by climate change, volcanic eruptions, earthquakes, 150-300 year droughts and resulting famines and disease, then invasions by the Sea Peoples who were not suffering as much from these effects, economic disruptions due to iron working, and changes in military technology and strategy reducing chariot warfare.^{126 127} These events destroyed or changed trade routes as well, making interdependency brittle and helping to disrupt and then collapse civilizations. Writing was severely deprecated as well, for more than 100 years, which means that nobody alive by

124 <https://www.earth.com/news/humans-transported-rice-to-guam-thousands-miles-across-the-sea-over-3500-years-ago/>

125 <https://www.frontiersin.org/journals/ecology-and-evolution/articles/10.3389/fevo.2021.742639/full>

126 https://en.wikipedia.org/wiki/Late_Bronze_Age_collapse

127 <https://www.history.com/articles/bronze-age-collapse-causes>

the end of the disruptive period knew the knowledge from before it, and thus much of it was lost to global civilization in Eurasia at that time. Following the collapse, gradual changes in metallurgic technology led to the subsequent Iron Age and the use of other metals across Europe, Asia, and Africa about 2,000 Ya.

Isolated subpopulations

These events are examples of larger developments, but the difference between aboriginals and American indigenous groups seem to show that something changed between 50,000 Ya and 12,000 Ya (before the split of the Americas from Eurasia) that enabled the parallel development of agrarian society, many technical innovations, and larger scale communities, ultimately leading to cities and larger scale infrastructure. It was not Eurasian and American communities moving forward together, but rather that whatever happened from about 50,000 Ya and about 12,000 Ya resulted in an increased or at least different cognitive capacity.

One theory of how this happened is based on genetic differences that developed over a 7,000 year period when other human ancestors mated with Neanderthals and other ancient now extinct hominids.

- (quote is approximate) *“The sequencing of the Neandertal and Denisovan genomes revealed extensive gene flow between the ancestors of modern humans and archaic hominins. As a result, most non-Africans harbor 1–2% of Neandertal ancestry, with East Asians exhibiting ~20% more Neandertal ancestry compared to West Eurasians. This gene flow has been inferred to have occurred between 41,000–54,000 years ago, but it remains debated if there were secondary interactions between Neandertals and early modern humans or in the ancestors of East Asians or potential dilution in ancestors of West Eurasians from a group without Neandertal ancestry. Moreover, previous studies have identified that the distribution of Neandertal ancestry is not uniform across the genome: some regions are significantly depleted of Neandertal ancestry (referred as “archaic deserts”), while other regions contain variants at unusually high frequency possibly because they harbor beneficial mutations (“candidates of adaptive introgression”). The evolutionary forces—e.g., genetic drift or natural selection— that have shaped these patterns are not fully understood.”*¹²⁸
- Gene sequencing has identified a range of different genetic factors in different populations, and this may explain some of the results in terms of the creation of civilizations and the related cognitive capabilities. But on the whole, there is no current justification I could find for asserting that any current human population cannot thrive in and operationalize the sorts of cognitive capabilities required to fit into modern society.

128 <https://pmc.ncbi.nlm.nih.gov/articles/PMC11118355/>

Native Americans (agrarian societies and cities)

I have found very little information on research into brains of American Indians, and what I have found has been largely oriented toward discriminatory practices and IQ testing, which has problems associated with favoring certain cultural and educational backgrounds. What I have found is summarized here, along with their advancements in technology, housing, transportation, manufacturing, and other areas, all invented independently after the end of the land bridge and before the arrival of Europeans in the late 1400s:¹²⁹ (throughout referenced as ^{AMER})

- **North American Indians:** Innovations included¹³⁰:
 - **7,500-4,200 Ya:** Cold-hammering of native copper to 95% purity and into tools and ornaments by hunter-gatherers of the Old Copper Complex in the Great Lakes region, particularly around Lake Superior
 - **5,000 Ya:** abstract art and adobe buildings
 - **2,600 Ya:** anesthetics, complex multistory apartment complexes (Pueblo communities), domesticated and cultivated avocados, rubber balls, bottle gourds for bowls, scoops, colanders, ladles, spoons, canteens, and dippers; calendars, canoes, domesticated cranberries, breeding dogs, harpoons, hominy, igloos, cultivated maize, maple syrup, the concept of zero and arithmetic functions (add subtract, multiply, divide), popcorn, artistic pottery, domesticated pumpkins, rubber and rubber balloons, smoking tobacco and pipes, snow shoes, sunflowers, tipi and wigwam, toboggan and sled dogs, tomatoes.
 - **2,500 Ya:** domesticated turkeys.
 - **2,000 Ya:** writing systems.
 - **900 Ya:**, fermented beverages, wooden maps representing coastlines, the 'game' of LaCrosse (a warring methodology)
- **South and Central American Natives:** Innovations more than 2,000 Ya included metallurgy including smelting, soldering, annealing, plating, sintering, alloying, low-wax casting, and many other techniques, hammering and shaping gold, silver, copper, and bronze into intricate ornamental objects and chisels, astronomy, painting, elaborate multi-story palaces and pyramids, many other domesticated fruits, vegetables, and animals, nut butter, pepper, and a variety of other foods and spices, domesticated potatoes, and more. Specific timelines are attempted^{131 132}:
 - **17,500-14,600 Ya:**¹³³ People reached the southern tip of South America and diversified independently of other populations.
 - **8,000 Ya:** The first cultivation of cassava.^{134 135}

129 https://en.wikipedia.org/wiki/List_of_pre-Columbian_inventions_and_innovations_of_Indigenous_Americans

130 https://gropedia.com/page/Metallurgy_in_pre-Columbian_America

131 https://gropedia.com/page/Metallurgy_in_pre-Columbian_America

132 https://en.wikipedia.org/wiki/Metallurgy_in_pre-Columbian_America

133 <https://pmc.ncbi.nlm.nih.gov/articles/PMC6327247/>

134 <https://www.sciencedirect.com/topics/food-science/cassava>

135 <https://www.tandfonline.com/doi/full/10.1080/19438150903090509>

- **8,000 Ya:** Freeze drying potatoes, domesticated pigs for food.
- **7,000 Ya:** Embalming and mummifying.
- **7,000 Ya:** 20,000 mi road system [Inca], domesticated llamas.
- **5-6,000 Ya:** Domestication of Alpacas.
- **6,700-5,300 Ya:** Canals for irrigation [Peru].^{136 137}
- **6,000,5,700 Ya:** Urban centers arose [Banduria] then [Aspero] and started to expand into smaller centers in the same region.¹³⁸
- **5,000 Ya:** The first real city emerged from an urban center with more than 20,000 people in the greater area. [Caral]^{139 140}
- **4,160 Ya:** The great pyramid, amphitheater, and huge circular sunken court [Caral].
- **4,100 Ya:** Working of gold [Andes].
- **3,900 Ya:** Chocolate.¹⁴¹
- **3,600-3,820 Ya:** Caral abandoned likely from unforeseen disruptive and cumulative effects; an earthquake estimated at 7.2 on the Richter scale (3,820) destroyed much of Caral and Aspero likely followed by successive tremors leading to more unstable rock and mud slides into the valleys; this exacerbated an unstable food supply, a shift in ocean temperatures with La Niña pushing schools of fish farther and deeper offshore; sands blown inland from the coast to agricultural fields in the valleys; regional similar problems; the loss of cotton, produce, and fishing led to economic collapse. There was also religious disruption leading to new religious ideas and new leaders often emerge taking the culture in new directions.
- **3,000-4000 Ya:** Copper smelting [*Chile, Ecuador, NW Argentina].
- **3,500 Ya:** Abstract art and almanacs.
- **3,500 Ya:** Working jadeite and other green stones through carving [Olmec culture].
- **3,428 Ya:** Compulsory education.
- **3,325 Ya:** Dams and complex water and other city systems for 250,000 population.
- **3,000 Ya:** Wind-drafted furnaces [Andes] enabled smelting of copper ores from mines [Capillitas in *Argentina], producing pure copper objects like a hammered mask from Bordo Marcial.
- **2,900 Ya:** Abacus [Mesoamerica]
- **2,600 Ya:** The Nazca Lines (art that can be seen from space), espionage, cattle raiding, and using attack waves in the battlefield to exhaust the enemy; astronomy

136 <https://news.vanderbilt.edu/2005/11/29/ancient-canals-reveal-underpinnings-of-early-andean-civilization-59158/>

137 <https://www.historynewsnetwork.org/article/oldest-known-irrigation-canals-in-south-america-fo>

138 <https://popular-archaeology.com/article/caral-americas-oldest-city/>

139 <https://en.wikipedia.org/wiki/Caral>

140 <https://leadingperutravel.com/blog/caral-the-oldest-city-in-south-america>

141 In the eyes of the author, this indicates the pinnacle of civilization and religion, but few agree with this.

to accurately predict events like eclipses hundreds of years into the future; domestication of beans, squash, and maize; board games; bolas, armor capable of stopping spears, arrows, and swords which eventually stopped musket shots; and calendars.

- **2,500 Ya:** Ornamental gold and platinum work but no viable iron artifacts [Tumaco-La Tolita culture].
- **2,100 Ya:** Chemical plating, artistic pottery, various medicines, accounting systems using knots and strings (and taxation of course), rope suspension bridges, sun dials, various metal knives and cutting tools, wheel and axle (as toys), writing systems, and certainly many other things.
- **2,000 Ya:** Pressurized water system

It is particularly noteworthy that while North American Indians did not develop; large cities, structures, large-scale transportation, or other similar things; natives from South America, who migrated there from North America and thus had the same genetic starting point, did develop these sorts of capabilities. From this I think it is reasonable to conclude that it was not the effect of genetics that caused or withheld the development of these capabilities, but rather, a combination of environmental and social factors.¹⁴² This coevolution was not so much genetic, but social and memetic in nature. There remain a small number of human groups in forests of South America that remain largely separate from modern society, but I have not found any studies with meaningful information about brain development or other differences between any of the remaining populations and those who developed in Europe and Asia.

Eurasia and other agrarian societies, cities, and civilization

Developments over this time frame (12,000 Ya to 2,500 Ya) were similar to those around the world¹⁴³

- **9-12,000 Ya:** the ‘Neolithic Revolution’ started with the global and independent development of agriculture and the related social changes. Agriculture began independently around the world with at least 11 centers of origin¹⁴⁴ ¹⁴⁵(North America [2], South America [3], Africa [4], Middle East [1], Asia [5], and New Guinea [1]).
- **7-9,000 Ya:** Agricultural communities emerged and grew into cities as trade and manufacturing became more centralized as transportation and travel emerged, leading to roads and similar infrastructure elements, like specialization around trades and manufacturing. Metalworking was used to create copper tools and ornaments around 8,400 Ya. Gold and silver followed, primarily for use in ornaments.

As such, it was “an idea whose time had come”, I presume related to evolution and cross-breeding not present in Australia, where it never happened; climate changes associated with the end of the ice age; and resulting in increased population centers resulting from the

142 Continuing with the chocolate theory, it was just after 3,900 Ya that much of the rapid expansion occurred.

143 https://en.wikipedia.org/wiki/Human_history

144 <https://pmc.ncbi.nlm.nih.gov/articles/PMC4035915/pdf/pnas.201323964.pdf>

145 <https://www.pnas.org/action/downloadSupplement?doi=10.1073%2Fpnas.1323964111&file=pnas.201323964SI.pdf>

increased availability of food. “*The transition to agriculture created food surpluses that could support people not directly engaged in food production, permitting far denser populations and the creation of the first cities and states.*”¹⁴⁶

- **4,200-6,500 Ya:** Bronze (a copper/tin alloy) appeared 6,500 Ya but was not widely used until about 5,000 Ya. The Bronze Age coincides with the development of cities and civilizations. Starting close to rivers and oceans, Mesopotamia (5,300 Ya) at the Tigris and Euphrates, then Egyptian civilization on the Nile River (5,200 Ya), the Norte Chico civilization in coastal Peru (5,100 Ya), the Indus Valley civilization in Pakistan and northwestern India (4,500 Ya), and the Chinese civilization along the Yangtze and Yellow Rivers (4,200 Ya).
- **5,000 Ya 3,000 BCE^{STEM}:** The Mesopotamian states of Sumer, Akkad, and Assyria, followed by Ancient Egypt and the Levantine state of Ebla began using arithmetic, algebra and geometry for taxation, commerce, trade, and in astronomy, to record time and formulate calendars. The earliest evidence of written mathematics is from the ancient Sumerians, who built the earliest civilization in Mesopotamia. They developed a complex system of metrology from 3,000 BCE chiefly concerned with administrative and financial counting, like grain allotments, workers, weights of silver, liquids, and other such things.
 - They each independently developed central governments, complex social structures and economies, and documentary record-keeping systems. They invented the wheel and axle, mathematics, bronze-working, pottery wheels, woven cloth, large buildings and monuments, and systems of writing, and had boats and sailed them. They also independently developed religions with male and female religious leaders, central places of practice, and ceremonies.
- **4,600 Ya^{TRANS:147 148}** Heavy battlewagons with solid wheels drawn by wild asses. [Sumaria]
- **4,500 Ya^{TRANS:149 150}** The Standard of Ur shows horse drawn carriages used in war. [*Iraq]
- **4,500 Ya 2,500 BCE^{STEM}:** The Sumerians wrote multiplication tables on clay tablets and dealt with geometrical exercises and division problems. The earliest traces of the Babylonian numerals also date back to this period.
 - Writing was apparently central to success in that records were required to: support bureaucracy as the scale of these cities increased; preserve and pass methods between people and across generations; and support the expression and communication of ideas. At least 4 different civilizations developed independent writing systems; Mesopotamian cuneiform (5,300 Ya), Egyptian hieroglyphs (5,250 Ya) and pyramids containing such writing (4,700 Ya), written Chinese in the Shang dynasty (3,200 Ya), and lowland Mesoamerica (2,650 Ya). The earliest versions of

146 https://en.wikipedia.org/wiki/Human_history

147 <https://www.historyonthenet.com/the-wheels-of-war-evolution-of-the-chariot> (TRANS)

148 <https://africame.factsanddetails.com/article/entry-1024.html> (TRANS)

149 <https://www.worldhistory.org/image/8427/detail-of-the-war-scene-of-the-standard-of-ur-show/> (TRANS)

150 https://en.wikipedia.org/wiki/Standard_of_Ur

the Sumerian Epic of “Gilgamesh” (4,100 Ya) and Stonehenge (3,600 Ya) are also from this period.

- The growth of cities led to the establishment of states and empires. The initial division into Upper and Lower Egypt was followed by the unification of the whole valley around 5,100 Ya. Around 4,600 Ya, the Indus Valley civilization built major cities at Harappa and Mohenjo-daro. Mesopotamia had frequent wars between city-states in this period. 4,500-2,100 Ya Akkad and the Neo-Sumerians empires arose. Minoan civilization in Crete emerged by 4,000 Ya as the first civilization in Europe.
 - Transportation was facilitated by waterways, including rivers and ocean routes that led to projection of military power and exchange of goods, ideas, and inventions. New land-based technologies emerged, like horse-based cavalry and chariots, allowing armies to move further faster. Trade became increasingly important as urban societies exchanged manufactured goods for raw materials from greater distances, leading to wide area commercial networks and the beginnings of archaic globalization. As an example, bronze production in Southwest Asia required tin imports from as far as England.
- **4,000 Ya^{TRANS}**: Spoked wheel carriages spread to Mesopotamia, Iran, Syria, Persia, and Egypt.
- **4,000 Ya^{TRANS}**: Composite bow first seen.
- **3,700 Ya^{TRANS}**: Animal-drawn carriages spread to Greece, Asia Minor, India, and China. Chariots included a driver and composite-bow armed archer in war.
- **4,000 Ya 2,000-1,900 BCE^{STEM}**: The earliest mathematical texts available are from Mesopotamia and Egypt.
- **3-4,000 Ya 2,000-1,000 BCE^{STEM}**: The oldest now undisputed mathematical documents are from Babylonian and dynastic Egyptian sources.
 - In the time frame from 3-4,000 Ya speakers of the Bantu languages also began to expand across Central, Eastern, and Southern Africa (as early as 5,000 Ya - 3000 Ya). Their expansion and encounters with other groups resulted in the displacement of the Pygmy peoples and the Khoisan, and in the spread of mixed farming and ironworking throughout sub-Saharan Africa, laying the foundations for later states. Pastoral societies based on nomadic animal herding also developed, mostly in dry areas unsuited to plant cultivation, like the Eurasian Steppe and the African Sahel. Conflict between nomadic herders and sedentary agriculturalists was frequent and became a recurring theme in world history. These developments became important later in the progress of civilization as the era of Genghis Khan unified and drove these groups across Eurasia dramatically changing civilization about 800 Ya.
 - The Rhind Mathematical Papyrus (Egyptian), and the Moscow Mathematical Papyrus (Egyptian 1890 BCE) mention the Pythagorean triples, so by inference the Pythagorean theorem seems the most ancient and widespread mathematical development after basic arithmetic and geometry. Egyptian language mathematics text includes a papyrus (1,650 BCE) likely a copy of a Middle Kingdom (2,000–1,800 BCE) version of an instruction manual for students. It gives area formulas

and methods for multiplication, division and working with fractions, and evidences knowledge of: composite and prime numbers; arithmetic, geometric and harmonic means; simplistic understanding of the Sieve of Eratosthenes and perfect number theory; and shows how to solve first order linear equations and arithmetic and geometric series. The Moscow papyrus (1,890 BCE) consists of word or story problems, apparently intended as entertainment. One problem gives a method for finding the volume of a frustum (truncated pyramid). The Berlin papyrus (1,800 BCE) shows that ancient Egyptians could solve a second-order algebraic equation.

- Babylonian mathematics covered multiplication (including multiplication tables), fractions, algebra, methods for solving linear, quadratic and cubic equations, and the calculation of regular numbers and their reciprocal pairs. Tablets also contain the earliest known statement of the Pythagorean theorem, but shows no awareness of the difference between exact and approximate solutions, or the solvability of a problem and no explicit statement of the need for proofs or logical principles. They used a sexagesimal (base-60) numeral system leading to the modern usage of 60 second minutes, 60 minute hours, the 360 (60×6) degree circle, and the use of seconds and minutes of arc to denote fractions of a degree. It is thought the system was initially used by Sumerian scribes because 60 can be evenly divided by 2, 3, 4, 5, 6, 10, 12, 15, 20 and 30, and for scribes (doling out grain allotments, recording weights of silver, etc.) this makes it easy to calculate by hand; however, it is possible that this was an ethno-linguistic result and not a mathematical/practical decision. They had a place-value system, where digits written in the left column represented larger values, much like the systems of today, and it could be used to represent fractions as easily as whole numbers, so multiplying two numbers that contained fractions was no different from multiplying integers, and it allowed good computational accuracy (one tablet approximates $\sqrt{2}$ to five decimal places. They lacked a decimal point, and while they had a zero placeholder in the middle of numbers (e.g., 101) it wasn't a terminal 0 (100 vs 1) so magnitude was not shown.
- **3792-3750 Ya:** The Code of Hammurabi written [Babylon]^{151 152}. Most crimes are punished by death.
- **3,274 Ya^{TRANS}:** The Hittites and the Egyptians (superpowers) had the Battle of Kadesh with thousands of chariots on each side manned by archers shooting composite bows.
- **2-3,500 Ya:** Civilizations developed across the world along with religions, writing and languages, and technological breakthroughs like simple manufacturing, written and signaled communications, larger scale wars, and a wide range of specializations that grew the minimum size for a viable society to unprecedented scale.
 - By 2,600 Ya, Mycenaean Greece began to develop until it collapsed along with other Mediterranean civilizations from 2,300 to 3,000 Ya as the bronze age ended. The Vadic period in India (3,750-2,600 Ya) included the emergence of Hinduism. Many independent kingdoms and republics known as the Mahajanapadas from 2,600 Ya.

151 https://en.wikipedia.org/wiki/Code_of_Hammurabi

152 <https://avalon.law.yale.edu/ancient/hamframe.asp>

Scaling of civilization (empires - Eurasia, India, Africa, China, S. America)

Average human life spans varied between civilizations. Classical Greece had about a 27 year life span with those surviving to age 15 averaging about 55, ancient Rome averaging 25 with those surviving to 15 averaging about 60. In South America, averages were about 30 before the Aztecs and for the Aztecs about 42.¹⁵³ It is noteworthy that life expectancy increased over time along with advances in societies and in science, technology, engineering, and math. This is a form of a virtuous cycle (positive feedback), where living longer gives more time for individuals advancing their respective fields to gain insight, come up with new understanding, and teach it to others, while advancing these fields yields longer life expectancy.

Clearly, this era had rapid and widespread formation of religion, formalization of documentary forms, and as part of the cognitive expansion of the time, represented elements of narrative and cognitive capabilities extending into the domain of moving from communications-based systems to socially controlled systems. Increasingly, cognition and communication was being used as a control mechanism for larger populations and ultimately control over the creation, operation, and growth of transportation, manufacturing, and infrastructure, with these then driving more progress in spreading memes and narratives in a positive feedback loop growing them together as a form of co-evolution.

Mathematics is necessary for the success of a scaled social system because without it, disputes will arise in trading and economic activity that cannot be settled in a systematic or demonstrably fair manner, and engineering compatible systems and goods across vast populations and areas of land is infeasible. It is one thing to trade some grain for a tool in a personal exchange, but in order to support a civilization; the inability to uniformly weigh and measure things, unfair allotments, an inability to account for actions, and a lack of documentary proof that can be independently verified; lead to corruption, disputes, and a widespread inability to demonstrate any sort of fairness, which ultimately leads to the spread of disintegrative memes and narratives, and destroys a society from within by undermining trust and the social contract of participation.

And then there is the climate... volcanoes, earth quakes, tsunamis, droughts, and similar things have also dramatically altered the course of civilizations by disrupting progress, and when conditions persist for long enough, destroying the civil memory and narrative.

And did I mention war...

2,500-1,500 Ya: Continental empires developed with well-trained professional armies, largely unified ideologies, and bureaucracies allowing emperors to rule over about 4 million square miles of Europe, 17 million square miles of Asia, and smaller but still quite large areas of other continents with populations in the range of 10s of millions of people. Global trade was integrated into this as a necessity for shared production and distribution, and of course this required transportation systems ultimately reaching a multi-continental scale. The largest of these trade routes involved the Mediterranean Sea, the Indian Ocean, and the Silk Road across Europe and Asia. They grew and fell through wars, and the technology of war and training of warriors means success or not.

153 https://en.wikipedia.org/wiki/Life_expectancy

3,500-2,200 Ya: Organized religion emerged independently around the world along with philosophical ideas.^{154 155}

- **3,000 Ya:** Persian Zoroastrianism began and was institutionalized by the Achaemenid Empire, Indian Hinduism started, Jewish monotheism started, Jainism started.
- **2,500+ Ya:** Greek philosophy emerged in the persons of Plato, Aristotle, and others.
- **2,800 Ya:** The first Olympic Games held.
- **2,600 Ya:** Chinese Confucianism started, Buddhism started.
- **2,800-2,500 Ya:** The Chandogya Upanishad has the earliest to date mention of Krishna; the possible start of Zoroastrianism; the first five books of the Jewish Tanakh (the Torah) are likely compiled;
- **2,600 Ya:** Mahavira, the 24th and last Tirthankara of Jainism lived.
- **~2,500 Ya:** Confucius, founder of Confucianism born (551 BCE); Pythagoras, founder of Pythagoreanism born (570 BCE); Siddhartha Gautama, founder of Buddhism born (2,500 Ya); The second Jewish temple built (515 BCE - 70 CE); the Parthenon dedicated to the goddess Athena (447 BCE).

Greece

Greece is one of the earliest governmental bodies to develop in many areas, and is the mold from which many current governmental structures arose. But by Greek (in mathematics) we mean the material was written in the Greek language.

- **2,600 Ya^{STEM}:** The study of mathematics as a "demonstrative discipline" began with the Pythagoreans, who coined the term "mathematics" from the ancient Greek μάθημα (mathema), meaning "subject of instruction". Greek mathematics refined the methods by introducing deductive reasoning and mathematical rigor in proofs, and expanded the subject matter of mathematics.
 - Ancient Romans used applied mathematics in surveying, structural engineering, mechanical engineering, bookkeeping, creation of lunar and solar calendars, and arts and crafts.
 - Chinese mathematics made early contributions, including a place value system and the first use of negative numbers.
 - Prime numbers became a concept of interest in this time frame.
- **2,600 Ya:** Thales of Miletus added deductive reasoning to prior inductive reasoning. He used geometry to solve problems like calculating the height of pyramids and the distance of ships from the shore and is credited with the first use of deductive reasoning applied to geometry. Asserted as the first true mathematician.
- **2,550 Ya:** Pythagoras, probably inspired by travel there, learned Egyptian and Babylonian mathematics, geometry, and astronomy; and established the Pythagorean School, with doctrine: mathematics rules the universe, and motto "All is number".

¹⁵⁴<https://www.oerproject.com/OER-Materials/OER-Media/HTML-Articles/Origins/Unit4/World-Religions-Before-c-1450/820L>

¹⁵⁵ https://en.wikipedia.org/wiki/Timeline_of_religion

- **2,500 Ya:** The first democratic government emerged [Athens].
- **2,428-2,347 Ya^{STEM}:** (Greece) The Platonic Academy in Athens became the mathematical center of the world producing the leading mathematicians of the day, including Eudoxus of Cnidus (390-340 BCE). Plato also discussed the foundations of mathematics, clarified some of the definitions (e.g. a line). Eudoxus developed the method of exhaustion, a precursor of modern integration, a theory of ratios allowing calculations of areas and volumes of curved figures, and the problem of incommensurable magnitudes that enabled subsequent advances in geometry. Aristotle (2,384-2,322 Ya) contributed significantly to the development of mathematics by laying the foundations of logic.
- **2,287 Ya 2,120 Ya^{STEM}:** (Greece) Euclid's "The Elements", considered by some the most influential textbook ever, introduced mathematical rigor through the axiomatic method initiating the format still used today; definition, axiom, theorem, and proof. Euclid arranged known approaches into a single, coherent logical framework. The book introduced number theory, algebra, and solid geometry, including proofs that the square root of two is irrational and that there are infinitely many prime numbers. Euclid also wrote extensively on other subjects, like conic sections, optics, spherical geometry, and mechanics, but only half of it survives.
 - **2,287-2,212 Ya^{STEM}:** Archimedes used the method of exhaustion to calculate the area under the arc of a parabola with the summation of an infinite series, in a manner similar to modern calculus. He showed that the method of exhaustion could be used to calculate the value of π with as much precision as desired, and obtained the most accurate value of π then known ($3+10/71 < \pi < 3+10/70$). He studied the spiral bearing his name, obtained formulas for the volumes of surfaces of revolution (paraboloid, ellipsoid, hyperboloid), and founded a method of exponentiation for expressing very large numbers. He is also known for his contributions to physics and several advanced mechanical devices, but placed far greater value on the products of his thought and general mathematical principles. He viewed his greatest achievement as finding of the surface area and volume of a sphere, which he obtained by proving these are $2/3$ the surface area and volume of a cylinder circumscribing the sphere.
 - **2,262–2,190 Ya^{STEM}:** Apollonius of Perga made significant advances to the study of conic sections and coined the terms used today for conic sections; parabola ("place beside" or "comparison"), "ellipse" ("deficiency"), and "hyperbola" ("a throw beyond"). His work Conics derives many theorems invaluable to studying planetary motion (Isaac Newton).
 - **2,276–2,194 Ya^{STEM}:** Eratosthenes of Cyrene devised the Sieve of Eratosthenes for finding prime numbers.
 - **2,190–2,120 Ya^{STEM}:** Hipparchus of Nicaea founds trigonometry by compiling the first known trigonometric table and the systematic use of the 360 degree circle.

South East Asia

- **4,500-3,900 Ya:** The Indus Valley Civilization thrived [*Pakistan and NW India].

- **3,500-2,500 Ya:** Persistent drought scattered this civilization from urban centers to villages [Vedic period] with its hymns (Vedas). The social structure was loosely stratified ultimately leading to today's Jāti system.
- **2,600 Ya:** Urbanization returned leading to a new inter-regional culture with smaller janapadas (realms) consolidated to form mahajanapadas (great states). Jainism and Buddhism arose from there.
- **2,300 Ya:** The oldest known version of the Tao Te Ching written on bamboo tablets.
- **2,300 Ya:** Theravada Buddhism introduced to Sri Lanka.
- **2,250 Ya:** The Third Buddhist council was convened by Ashoka.
- **2,200 Ya:** The Hebrew bible is canonized in writing
- **2,140 Ya:** The earliest grammar of Sanskrit literature was composed by Pāṇini.
- **2,400-2,000 Ya:** The Yoga Sutras of Patanjali composed.
- **320-400:** The Maurya Empire ended with the assassination of the emperor by his general (Shunga) who led the Shunga empire (no surprise), followed by a series of invasions, ultimately leading to no real empire for a time.
- **400-500:** The Gupta Empire led India's golden age where Hindu and Buddhist culture thrived along with major advances in science and mathematics. Again, invasions ultimately destroyed the empire, leading to...
- **500-700:** more invasions and the formation of the Pratihara dynasty.
- **700-1100:** more invasions leading to the Chola dynasty...
- **1100-1600:** more invasions and changes leading to ...
- **1600-1947:** The East India Company started to take over the continent and ultimately turned (now) India and Pakistan into a part of the British Empire.

Eurasia except the Steppe

- **2027 Ya – 1,453 CE:** The Roman Empire formed around 27 BCE from the Roman Republic, and ran till about 476 BC in the West and 1453 in the East (Constantinople fell).¹⁵⁶ It covered much of Europe, Western Asia, and North Africa, but not the areas of the Eurasian "steppe". Its expansion was largely due to; its creation of a system of roads ("All roads lead to Rome"); its systematic and standardized domestication of animals for transportation pulling carts of various sorts; the use of the transportation system for communication and coordination; its control of currency and monetary system to support trade; its ability to build large buildings, arenas, water systems, waste systems, and other infrastructure; and its hierarchical system of governance. Its longevity resulted in major cultural developments around the world because of the exchanges over long time frames of language, religion, art, architecture, science, technology, literature, philosophy, law, and forms of government.

¹⁵⁶ https://en.wikipedia.org/wiki/Roman_Empire

China

Chinese historians have traditionally used the names of dynasties (a family of kings or emperors) to trace the history of their civilizations.¹⁵⁷ ¹⁵⁸ ¹⁵⁹ An outline of the Chinese Dynasties identifies the following organization. Note the date differences between this and other sources.:

- Shang (Yin) Dynasty 商 (ca. 1300–1046 bce)
- Zhou Dynasty 周 (ca. 1046–256 bce)
 - Western Zhou 西周 (ca. 1046–771 bce)
 - Eastern Zhou 東周 (770–256 bce)
 - Spring and Autumn Period 春秋 (770–481 bce)
 - Warring States Period 戰國 (481–221 bce)
- Qin Dynasty 秦 (221–207 bce)
- Han Dynasty 漢 (206 bce–220 ce)
 - Former/Western Han 前漢 / 西漢 (206 bce–8 ce)
 - Xin Dynasty 新 (9–23)
 - Later/Eastern Han 後漢 / 東漢 (25–220 ce)
- Wei 魏 Dynasty (220–265) / Three Kingdoms 三國
- Jin 晉 Dynasty (265–420)
 - Western Jin 西晉 (265–316)
 - Eastern Jin 東晉 (317–420)
- Northern and Southern Dynasties 南北朝 (420–589)
- Sui Dynasty 隋 (581–618)
- Tang Dynasty 唐 (618–907)
- Five Dynasties 五代 (907–960)
- Song Dynasty 宋 (960–1279)
 - Northern Song 北宋 (960–1127)
 - Southern Song 南宋 (1127–1279)
- Yuan Dynasty (Mongols) 元 (1271–1368)
- Ming Dynasty 明 (1368–1644)
- Qing Dynasty (Manchus) 清 (1644–1911)

¹⁵⁷ https://en.wikipedia.org/wiki/Dynasties_of_China

¹⁵⁸ <https://pacificasiamuseum.usc.edu/chinese-dynasties/>

¹⁵⁹ <https://academic.oup.com/edited-volume/28107/chapter/212213471>

8,000-3,650 Ya: The first archaeological evidence of Chinese civilization is from ceramic objects of farmers living in small settlements along the Yellow, Wei, and Yangzi rivers. They made simple containers of coiled clay strips and painted them with geometric designs and clay models of the human body.

- **3,650-3,050 Ya:** The Shang dynasty represents the first written record of ruling families with archaeological evidence. It was in northern China and the potter's wheel technology was used for manufacturing. Very large Shang dynasty burials contain human and animal bones and ornamented bronze vessels.
- **3,050-2,256 Ya:** The Zhou dynasty conquered the Shang and lasted for almost 800 years of war and chaos. Confucianism and Daoism arose, ceramic objects replaced more expensive bronze in tombs, and ceramics continued to advance.
- **2,256-2,221 Ya:** Chaos ruled China as society broke down due to conflict between warring factions.
- **2,221-2,206 Ya:** China, which was temporarily united in the Qin (pronounced "Chin") dynasty created a centralized bureaucratic government and built systems of roads, waterways, and started the "Great Wall". It had huge armies and mass produced life-size terracotta warriors and horses found in the tomb complex of Qin Shihuangdi.
- **2,206-1,880 Ya:** The Han dynasty brought stability and growth, expanded to what is now part of southern China, northern Vietnam, and parts of Korea. They adopted Confucianism as the official ideology, supported scientific and technological developments including paper, the rudder, and the compass, created trade routes (the Silk Road) and economic expansion to Central Asia, India, and Persia. A wealthy elite class emerged creating elaborately furnished tombs that led to molds to make mass production ceramic figures and colored glazes fired at low temperatures. The Han dynasty was comparable in power and influence to the Roman Empire at the other end of the Silk Road.
- **220-265:**¹⁶⁰ The Wei Dynasty / Three Kingdoms was marked by a comparatively stable arrangement between Cao Wei, Shu Han, and Eastern Wu but was also one of the most dangerous periods in Chinese history. There were multiple plagues, widespread famines, and civil war. A national census taken in 280 showed a total of 2,459,840 households and 16,163,863 individuals, compared to 10,677,960 households, and 56,486,856 individuals before this period, or only 28% of the population and 42% of the households 45 years after this dynasty came into power. Technology advanced with inventions of the wooden ox (an early wheelbarrow), improved repeating crossbow, a hydraulic-powered, mechanical puppet theater, square-pallet chain pumps for irrigation, and the south-pointing chariot, a non-magnetic directional compass operated by differential gears.
- **266-420:**¹⁶¹ The Western Jin (266–316) was established as the successor to Cao Wei after Sima Yan usurped the throne from Cao Huan. The capital of the Western Jin was initially in Luoyang, but later moved to Chang'an (modern Xi'an). In 280, after conquering Eastern Wu, the Western Jin ended the Three Kingdoms period and

¹⁶⁰ https://en.wikipedia.org/wiki/Three_Kingdoms

¹⁶¹ [https://en.wikipedia.org/wiki/Jin_dynasty_\(266%E2%80%93420\)](https://en.wikipedia.org/wiki/Jin_dynasty_(266%E2%80%93420))

reunited China for the first time since the end of the Han dynasty. From about 291-306 chaos ruled China in a series of civil wars till 331-420 when the Eastern Jin Dynasty regained and maintained control.

- **420-581**:¹⁶² Different groups of the Wei, Qi, Liang, and Chen dynastic families ruled different regions of China. In addition to the chaos of the time, arts, culture, and technology advanced along with the spread of Taoism and Buddhism.
- **581-617 and 618-907**: The Sui and Tang Dynasties reunited China, first under Yang Jian, a powerful military leader, that laid the foundation for the Tang dynasty which had economic prosperity, military security, supremacy in foreign relations, territorial expansion, and cultural sophistication. At the peak, China was the largest and most powerful empire in the world, traders and diplomats traveled to China to participate, arts and literature prospered, China embraced Buddhism from India and Nepal, ceramic production grew with influences from the Middle East and Central and West Asia. Kiln technology produced the first translucent white ceramics (porcelains) and fine green-glazed material (later called “celadons”) that were prized by wealthy Chinese and foreigners. They created woodblock printing (~868 CE) then movable type and with paper, this led to larger scale manufacturing of printed works.
- **907-960**:¹⁶³ The five dynasties period was a time of chaos with different leaders ruling different parts of China with war between them essentially all the time.
- **960-1279**: The Song dynasty unified China leading to a period of widespread prosperity, scientific inventions including gunpowder-fueled rockets for war and watertight bulkheads for shipping and overseas trade; and through patronage from the Song emperors, arts and literature flourished as well. In the Southern Song dynasty (1127-1279), porcelain kilns were established and Jingdezhen dominate the Chinese porcelain industry through proximity to mineral deposits, two major river systems for transport, and assembly line manufacturing. They also started the use of paper currency, matches, and natural gas supply for fires.
- **1215-1279**: Genghis Kahn^{164 165}, in his spread from the steppe through China and later Europe, invaded China in 1215, resulting in the Yuan Dynasty (AD 1279–1368). The Mongols created new governance and increased trade, science, writing and documentation, and created unprecedented commercial and cultural exchange over a vast geographical area.
- **1368-1644**: The Ming Dynasty reinstated historically Chinese rule. In the later half of the Ming dynasty, European traders established direct contact with China producing a growing ceramics market for objects with new shapes and designs, including things like blue and white porcelains with complex painting and glazing techniques before firing.
- **1644-1911**: Qing Dynasty (AD 1644–1911) At the end of the Ming dynasty, the Manchus from Central Asia invaded from the north and established China’s last imperial dynasty. The “last imperial golden age”, vastly expanded population, and

162 https://en.wikipedia.org/wiki/Northern_and_Southern_dynasties

163 https://en.wikipedia.org/wiki/Five_Dynasties_and_Ten_Kingdoms_period

164 https://en.wikipedia.org/wiki/Genghis_Khan

165 Jack Weatherford, “Genghis Khan and the Making of the Modern World” (c)2004, ISBN 9780609809648

proliferated trade and visitors from other parts of the world. Colorful enamel porcelain over-glazes were invented and ceramic production soared along with other technical expertise and refinement of polychrome ceramics.

Africa

Many of those in Western society think of Africa as the origin of the species but don't associate it with technological or social advancement. They think of it as Southern Africa. But of course, Egypt is in Africa, so all of the accomplishments of Egypt are African.^{166 167 168 169} African history of civilizations and inventions is rich and diverse.^{170 171} Africa had at least 5 kingdoms or empires, has more than 1,200 languages, and many different religions. It is where homo sapiens first emerged, and they spread from there over the millennia. Before about 700 AD, when there was an Arab invasion, the native population was not taken over by forces from other continents. And native populations living in less settled areas were relatively isolated until the last few hundred years. They predominantly don't have Neanderthal DNA or other non-African DNA from other hominids that emerged into Eurasia. Much of the growth of civilization in Africa formed along the coasts, along the Nile river, and around some inland lakes; with water being fundamental to life including drinking, plant and animal food, and transportation.

- **18,000 Ya:** Wild grains, nuts, grasses, and tubors were collected for food.
- **12,000 Ya:** Cultivation of wild grains, wheat and barley, and domestication of sheep and cattle.
- **11,400 Ya:** Pottery present [*Central Mali].
- **8-10,000 Ya:** Domesticate wild millet, African rice, and sorghum and capturing and holding wild cattle.
- **9,000 Ya:** Wet climate changed the ecosystem [*Ethiopian highlands].
- **6,000 Ya:**, The Tichitt culture [*Mauritania and Mali] complex organized society with a four tiered hierarchical social structure.
- **6,000 Ya:** The Congo Basin inhabited by the Bambenga, Bayaka, Bakoya, and Babongo in the west, the Bambuti in the east, and the Batwa widely scattered and also present in the Great Lakes region; together grouped as Pygmies. [*Swahili] coast had Cushitic-speaking peoples, and the Khoisan (the Khoekhoe and San) with San society in Southern Africa. These people migrated across Africa in the 3,000 Ya time frame.
- **5-6,000 Ya:** Independent development of agriculture [Mande peoples].
- **5,500-4,668 Ya:** Nomes (territorial groups run by rulers) coalesced to take over different areas eventually forming the "Old Kingdom of Egypt" (building pyramids among other things). The Kingdom of Kerma emerged as the dominant power in Nubia.

166 <https://www.asbmb.org/asbmb-today/science/020113/great-achievements-in-stem-in-ancient-africa>

167 <https://news.mit.edu/2014/clapperton-mavhunga-book-african-technology-1006>

168 <https://pmc.ncbi.nlm.nih.gov/articles/PMC3049100/pdf/rstb20100350.pdf>

169 https://link.springer.com/chapter/10.1007/978-3-031-62979-2_2

170 https://en.wikipedia.org/wiki/History_of_Africa

171 https://en.wikipedia.org/wiki/General_History_of_Africa

- **5,000 Ya:** Smelting and bronze as well as copper and gold refined and used [*Egypt].
- **5,000 Ya:** Smelted copper independently developed with unique process [*Niger].
- **4,500 Ya:** Metalworking [*West Africa and Egaro].
- **4,500 Ya:** Kintampo culture [*Ghana].
- **4,350 Ya:** Egypt established direct relations with Punt after trading via middle-men. Trading included gold, aromatic resins, black wood, ebony, ivory and wild animals. This trading partnership lasted for about 1,000 years.
- **4,200 Ya:** Decentralisation led to anarchy exacerbated by drought and famine, leading to numerous nomarchs ruling simultaneously.
- **4,055 Ya:** The 11th dynasty conquered all of Egypt to form the Middle Kingdom
- **4,000 Ya:** Iron smelting [*Nigeria].
- **3,700 Ya:** The 12th dynasty oversaw advancements in irrigation and economic expansion in the Faiyum Oasis and into Lower Nubia against the Kerma. Egypt split in two In 3,700 BCE Ya starting the Second Intermediate Period.
- **3,500 Ya:** Iron working was practiced [*Nigeria].
- **3,500 Ya:** Nok culture [*Nigeria].
- **3,200 Ya:** Sizable urban populations [*West Africa] with iron metallurgy in smelting and forging for tools and weapons. This was across large deserts from other populations.
- **2,900 Ya:** Iron metallurgy from a reduction furnace (~2,890 Ya) and blacksmith workshop (2,900 Ya) [* Gbabiri – Central African Republic].
- **2,980 Ya:** Northern Ethiopia and Eritrea led to the Kingdom of D'mt which developed irrigation schemes, used ploughs, grew millet, and made iron tools and weapons.
- **2712-2650 Ya:** The Kingdom of Kush ruled Egypt as the 25th dynasty, then continued as an agricultural and trading state based in the city of Meroë until about 400 CE. Lots of other conquests happened during this period.
- **2,550 Ya:** The Sao were skilled workers in bronze, copper, and iron, including bronze sculptures, terracotta statues of human and animal figures, coins, funerary urns, household utensils, jewelry, highly decorated pottery, and spears.
- **2,550 Ya:** Daima culture [*Lake Chad].
- **2,264-2,202 Ya:** The First Punic War began when Carthage met Roman expansion on the island of Sicily, leading to “the greatest naval war of antiquity”, with heavy casualties on both sides, ending in Carthage's defeat and loss of Sicily. The Second Punic War started when the Romans took Sardinia and Corsica whilst the Carthaginians were putting down a Libyan revolt. Carthage initially had success when Hannibal crossed the alps into northern Italy and, over 14 years, conquered most of Italy, but they were recalled after a Roman naval invasion of the Carthaginian homeland, Rome defeated them (2,202 Ya).
- **2,250 Ya:** Djenné-Djenno culture [*Mali].

- **~2,100 Ya:** Small cities on the Red Sea transported cargo via Beden, exporting myrrh, frankincense, spices, gum, incense, and ivory, to India without Roman control, so India gave those cities a lucrative monopoly on cinnamon.
- **2,030 Ya:** Rome took over Egypt
- **100 CE:** The Kingdom of Aksum, centered in present-day Ethiopia, established as a major trading empire, dominating South Arabia and Kush and controlling Red Sea trade. It minted its own currency and carved enormous monolithic stelae to mark its emperors' graves.
- **800 CE:** Trans-Saharan trade routes, symbiotic trade relations north–south diversity in ecosystems, trading meats, copper, iron, salt, and gold.

South America

Descriptions are provided above up till the point where the invasion from Spain took place in the 1500s. ^{172 173 174 175}

The emergence of mathematics, science, engineering, and medicine

The timeline of mathematics, science, and engineering, medicine, etc. ^{176 177 178 179 180} really started to accelerate only about 2,500 Ya. Starting with mathematics, a field consisting largely of number theory, geometry, algebra, calculus, analysis, logic, set theory, arithmetic, probability, statistics, and decision theory; advancements lead to advancements in physics, chemistry, metallurgy, geosciences, computation, biology, linguistics, economics, philosophy, medicine, education, psychology, and I probably missed a few. In each case, the development of mathematics led to and was part of the evolution of those societies by enabling the ability to more precisely and accurately describe, explain, design, and implement the things those societies depended on for their success. And because these developments were necessary for the success of those societies and similar systems were developed in disparate locations around the world before there was communication between them, it seems like they were the result of an inevitable situation driving focus of attention of societies toward individuals with abilities and interests to develop such systems. The same seems to be true throughout history in that necessity of societies combined with people having skills and interests drive the development of all of these fields.

Put another way, the societies that survived were the ones that developed the STEM fields, because of the direct effects of these developments on their ability to fight wars, feed their people, survive events of the world, and develop technologies that made life better for their people. Increased interaction with other societies increased the pressure for progress.

172 <https://www.history.com/articles/mayan-scientific-achievements>

173 <https://smarthistory.org/reframing-art-history/early-south-america/>

174 <https://www.cambridge.org/core/journals/antiquity/article/ancient-metalworking-in-south-america-a-3000yearold-copper-mask-from-the-argentinian-andes/80E3CFE81BC10CFFA5602230A16B40DF>

175 <https://technology.matthey.com/docserver/fulltext/pmr/24/4/pmr0024-0147.pdf>

176 <https://www.explainthatstuff.com/timeline.html>

177 <https://www.britannica.com/story/history-of-technology-timeline>

178 https://en.wikipedia.org/wiki/Timeline_of_historic_inventions

179 https://en.wikipedia.org/wiki/Timeline_of_scientific_discoveries

180 https://en.wikipedia.org/wiki/History_of_mathematics

I have moved from a path based on dates to a path based on areas of STEM because I think the case has been established for coevolution of STEM with societies and advances in the human condition, and because the developments across these fields were spread around the world in shorter time frames as transportation became faster (people could travel much of the world over a period of years if they had a desire and the means to do so). As transportation facilitated communications and documentation allowed reliable and authentic records to be made available worldwide, the advancements anywhere became advancements everywhere, at least to a reasonable approximation.

- **Physics** developed into understanding of force and motion and what is commonly called Newtonian physics provided enough information to apply mathematics to solve most problems associated with transportation, manufacturing, and infrastructure dealing with things in normal human experience and desired of the ages at issue. It provides the underlying limitations and properties that limit and enable control mechanisms.
- **Chemistry**, while still largely alchemy, developed into a large number of methods for combinations of matter allowing the creation of a wide range of materials with desired properties able to meet most needs of the times, particularly dealing with preservation and preparation of materials and their processing. Chemistry and its use in these time frames was successful to the extent the conditions of the chemical reactions could be kept within control parameters like temperature, pressure, and relative quantities of components forming the composites. And that meant a control system was required for their success, typically operated by humans with expertise as the control mechanism, limited sensors and actuators, and communications by human physical mechanisms.
- **Metallurgy** was one of the earliest fields to expand, largely leading to the development of the bronze age and following ages of advancement, because of the ability to make more and more materials with different mechanical properties of strength, hardness, and elasticity and chemical properties of corrosion resistance and solubility useful for different applications. These were experimentally developed by people who taught it to others in a mentorship and apprenticeship approach, and the mechanisms of manufacture were control systems with humans as the controllers using tools for actuators and their sensory capability consisting of direct indicators (like color) and indirect indicators (instruments).
- **Geoscience** was largely developed in understanding where to find and how to mine, move, break up, or otherwise use different sorts of rocks and materials found in nature and useful after processing for creating things for people. People learned to use their senses to observe and test with tools including chemical compounds to determine what comprised the things they were observing and testing.
- **Computation** was largely human for a period but ultimately had to be made machine operable for efficiency and accuracy of results. It was ultimately used for all manner of engineering, design, calculations for financial transactions, weighing and measuring things to meet anticipated needs for construction, manufacturing, and transportation, and implementing the methods of mathematics to carry out decision-making for the other fields identified here. Typically, inputs were provided by other people and outputs were to other people, with analysis by the people doing the computations.

- **Biology** learned about selective breeding of plants and animals, pest control, disease spread, and a range of other applications, among them medicine. Tools were knives, saws, chemicals, and similar things in the hands of the biologists who tested various ideas and produced diagrams and written documents.
- **Medicine** moved from the province of religion and magic to the scientific exploration of the human body and its parts, and learned how to help people survive all manner of physical damage from accident or malice, saving lives, and mitigating disease. It was largely an experimental science involving the delivery of mechanical actions and chemical compounds to patients based on observations and feedback for diagnosis and treatment.
- **Linguistics** in the form of scribes, scholars, and translators was vital to the advancement of STEM across the world because advancements were made in different languages in different places. Learning more languages meant you were better able to learn and understand the state of the art and advance it. The tools were typically writing materials, dictionaries, and memorization.
- **Economics** is an area where mathematics was a basic enabler but the other fields of STEM were built based on their economic value to their societies. At the level of buying and selling, pricing, discounts, and so forth, economics grew from the necessity of trade, taxation, and surviving the bad times by efforts during the good times. The tools were mathematics and writing materials with inputs coming from problem specifications and answers in terms of numbers associated with strategic options or simple quantities of different material, people, etc.
- **Psychology and sociology** are core elements of understanding how memes and narratives work in a society, and despite their lack of formalization for much of the advancement of societies, they were at the heart of the social control system that allowed such systems to exist, survive, thrive, and brought about the downfall of their leaders and ultimately the societies themselves. The fields at that time largely involved listening to others, thinking about how to communicate with them, and doing so. A lot depended on who you knew and what they could tell you, and thus spies and other intelligence apparatus were at play.
- **Philosophy** in ancient times was, at its core, a rationalization of why things are how they are, and is tightly linked to religion. In that sense they are both closely tied to narratives that are core to success of leadership in societies. In addition to its power to convince and influence, it was core to the social fabric that held societies together or tore them apart. Feedback from the available sources within the society reflected the results of actions, and adaptation was critical to success.
- **Education** was and is at the core of the capacity to build societies through STEM. As more and more has to be understood and learned to be successful in more and more complex societies, more and better education forms the core of survival over the long term and the advancements that enable survival. One of the best ways to predict what will happen to a society is by its standing in education. As a control system, education allows control over the focus of attention and things people think about when at school, with knock-on effects in non-school hours and indirect knowledge spread across the population.

Memes and narratives in the 2nd cognitive expansion

The rapid and widespread growth of cognitive and narrative mechanisms and their effect on moving from communications-based systems to socially controlled systems with increasing specialization and craftspeople, separation of duties and division of labor, the build-up of education and training methodologies, skilled labor with increased expertise, the increase in segregated manufacturing by specialty and location, transportation as a necessity, trade and monetary systems as foundational to survival, and all of the health and safety advantages and risks associated with large-scale societies. A very important change is related to the spread of memes and narratives.

- In order for trades to flourish, information sharing is required, and the venues in which this takes place are typically private and use a language associated with those trades.
- Conditions changing within a trade spread throughout the trade, to their families, and from there to their friends, and from there to others, with the message evolving as it is retransmitted, like the game of telephone, all within the context of the social environment.
- The large volume of contacts a few levels from the initiation of an idea, which grows exponentially like a disease in high population areas until a substantial portion of the clique of the population is infected with the meme, leads to very rapid rumors spread compared to any ability to tamp it down by 3rd parties.
- If there is economic strife, or if a key material required for production is lacking or getting very expensive, this can end up creating larger market impacts in such an environment by changing confidence levels within the locality.

Things like rumors spreading throughout a civilization had relatively long time frames in this era, being limited by the limitations on transportation as communication. These become aspects that have to be controlled by the political system or civilization can collapse from narrative destruction of trust, which is a requirement for groups to collaborate. There are various strategies that emerged for control over narrative within societies, including as examples:

- Religion, which creates a hierarchy of trust in defiance of what you see in front of you, and sets of memes and their expressions that can be used in narratives to quell problems or incite them. These are generally run by religious leadership in a hierarchy and use specific belief systems (leaps of faith and expressions to invoke them) to keep the mass of believers within desired behavioral limits (e.g., thou shalt not kill, steal, lie, cheat, speak badly of others, riot, etc.), or for some religions, thou shalt sacrifice a member of your community to fix the problem with the water system, or whatever the religious leader points the masses toward.
- Social structures, like legal systems, policing, and other group activities controlled by the political management that provide sensors (people distributed throughout society taking reports), communications back to the political leadership of different groups within societies, control through decision-making and deployment of narratives countering undesired and supporting desired memes, communication back to the group doing sensing or other groups for different approaches, and actuation in the form of expressed narratives keeping the society within the desired control region.

Skills and abilities of orators, control over military forces, means of production, transportation systems, and so forth all provided power bases that could be used in different ways through cognitive control over groups. And coalitions between religious leaders and political leaders became an example of how these cognitive controls could be aligned for mutual benefit.

Whereas family membership was and remains to this day a basis for loyalty and trust, social groups created alternative trust models, often leveraging family or religious trust models to allow for the formation of armies and similar groups to which loyalty became of higher priority. God could be more important than family, and people would end up in the military from a young age so their learned experiences would lead to loyalties with fellows over those with family. Groups would leave their families and end up in armies where survival depended on trust in the person next to you, training and fighting together, enjoying the spoils of war together, and so forth.

Then what?

The level of detail in the discussion is going down, for good reason. While we can list many key things that happened when populations were small and localized, gross trends tend to take over as civilization grows. The lack of space in a writing like this (reading all the recursive references certainly gets you far more detail) and the rate of change and complexity of what took place far exceed the available space. Relatively small portions of the overall population had reading and writing skills for much of this period¹⁸¹ ¹⁸² (up till the 1800s), travel reached a maximum effective velocity of a horse (about 44 mph in sprints¹⁸³ and they cannot sprint for very long) and for long journeys, only so many hours a day can be traveled on horses, while wagons with loads can go perhaps 20 miles per day¹⁸⁴), Simple machines with things like gears, pulleys, or Archimedes screws were powered by inherent or redirected water flows, air flows, animals pulling or pushing, and similar mechanisms. It included substantial scalability and dug down into the level of learned and experimental ways of processing ingredients. It used systematic approaches to growing, making, transporting, and supporting these systems as forms of infrastructure. It had monetary instruments with fungible properties, and the ability to do calculations to determine amounts, weights, sizes, prices, and so forth, so that a building could be designed in terms of appearance, size, and location, and parts identified and purchased in advance from multiple suppliers; all brought together for final fitting and assembly. Inventories for orders, shipments, and deliveries were used increasingly from tally sticks (11,000 Ya) to accounting on tablets in Cuneiform 5,300 Ya, to detailed supply lists in the Byzantine era 2,500 Ya, to Greek temple inventories and catalogs of books in libraries 2,400 Ya, and forward, all manual systems involving people counting things.

Throughout this age, transportation, manufacturing, and infrastructures thrived, grew, scaled, and innovated along with civilization, but there was no stark change in this time frame, and a reasonable question is "Why?". There were various events that effected large populations, like wars, ecological changes, different forms of government, and even the Eurasian and beyond growth of the mongols from the Steppe. And there were plenty of resulting changes. But then... something happened...

181 <https://ehrmanblog.org/how-many-people-were-literate-in-antiquity/>

182 <https://ourworldindata.org/data-insights/two-centuries-ago-only-1-in-10-adults-could-read-today-its-almost-9-in-10>

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