

DNA Self-organizes

How did the human brain evolve from Earth's first self-organizing molecules to the brain we inherited? Some Egyptians thousands of years ago believed that life could generate spontaneously from non-living matter virtually overnight. This view probably resulted from observing insects that grew from microscopic eggs, such as the scarab. The Greco-Roman view of how life began spontaneously (autogenesis) was recounted by the Roman philosopher and poet Titus Lucretius Carus (99‑55 BCE). It was believed that living things were made of lifeless atoms that, not by design, but by randomly combining, eventually formed living things. Over time, in addition to the creatures that then existed, the laws of how matter interrelated created a variety of lifeforms that went extinct for failure to meet Nature's selection process. A few ancient Greek philosophers pondered marine fossils and concluded that we evolved from fish.

Today, we know that RNA and DNA are the molecules of life that store the information that defines every life form. DNA (deoxyribonucleic acid), the now-famous double helix or twisted ladder, consists of two long, twisted chains of nucleotides made up of the amino acids adenine, thymine, cytosine, and guanine (ATCG). It is capable of replicating itself and of synthesizing RNA. RNA (ribonucleic acid), a molecule found in all living cells, consists of a long, usually single-stranded sequence made up of phosphate and ribose and the amino acids adenine, uracil, cytosine, and guanine (AUCG). In general, DNA produces messenger RNA that manufactures proteins such as enzymes, hormones, antibodies, muscle, and other tissues---the essential components of living organisms. The kind of protein produced is determined by the nucleotide sequences (genes) engaged in the protein's production.

The importance of DNA cannot be overstated. While shamans look to myths to explain the creation of life, scientists investigate DNA. Even though DNA is capable of making RNA, some scientists theorize that the first DNA derived from RNA, and that RNA might have derived from an even earlier and simpler molecule that RNA ultimately replaced.1 Whatever the process was, scientists engaged in researching the prebiotic chemistry of Earth are theorizing that the first self-replicating system was either simple or could be generated simply. One reason for this is that self-organizing molecules appeared soon after the Earth formed and cooled. Although the sequence of events that gave rise to DNA is not known, that sequence does not appear to be unknowable. Given the amount of knowledge accumulated in recent decades by molecular biologists, chemists, and biochemists, it's probably just a matter of time before self-replicating molecules that reproduce the origin of life are manufactured in someone's laboratory.

It's not likely, however, that the process that gave rise to the first self-replicating molecule is taking place somewhere in Earth's biosphere today. Reactions that create complex organic molecules do not fare well in the presence of oxygen. Earth's atmosphere contained little if any oxygen 4.5 billion years ago when the process that led to self-replication probably began. In addition, lightning, meteorites, comets, and interstellar dust could have provided more than enough amino acids for Nature to assemble them into the first self-replicating organic molecules in Earth's prebiotic environment.2

Once the first self-replicating molecule formed out of the primordial soup, well before 3.7 billion years ago,3 the mechanism for retaining trial and error knowledge was in place. Between 4.5 billion and 3.7 billion years ago, DNA strands had evolved to perhaps 256 genes, sufficient to produce the equivalent of modern bacteria or archaea.4 Primordial microbes would have lived in an atmosphere without oxygen, and some would have derived their energy from sulfur compounds, perhaps near volcanoes or hydrothermal vents at sea bottom tectonic boundaries.

Early DNA strands were circular loops attached to cell walls. These early cells had no nucleus, and their membranes or cell walls were rigid, providing both protection and structural support. They took nourishment from their surroundings by secreting enzymes to dissolve nearby debris and absorbing the nutrients, a method used by some insects today. By about 3 billion years ago, DNA in some organisms had evolved to define a cell that had lost rigidity in its outer cell wall. This type of cell was a flexible blob that supported itself with rigid internal structures. This amoeba-like cell was able to increase in size to 10,000 times the volume of a small bacterium. Its outer membrane could fold, and it had evolved a nucleus, perhaps formed by the outer membrane folding a pouch with DNA inside. The pouch then detached from the outer membrane to move freely within the cell. This cell could consume entire bacteria by enfolding them, sealing off the pouch at the other membrane, and discharging enzymes into the pouch to digest the prey. In other words, this cell could eat.

Some prey with protective characteristics settled into a symbiotic relationship with its host cell. They became cell organelles. The unique DNA of such acquired bacteria eventually migrated to the nucleus and became part of the ever-growing DNA strands that made-up the cell's genetic code. By now, the cell contained several thousand organelles, the size of small bacteria. One such plant-like organelle contained plastids (chlorophyll) capable of using the energy of sunlight to produce a source of energy for cell function. Another organelle, peroxisomes, which contained enzymes that catalyze the production and breakdown of hydrogen peroxide, helped in the conversion of food into energy and metabolized fatty acids. It's thought that this organelle, in particular, assisted its complex cell in dealing with the toxins created by the rising level of oxygen in the environment between 2 billion and 1.5 billion years ago. However, the organelle that energized cells to take advantage of newly available oxygen was the chondriosome (mitochondria). It contained enzymes important for cell metabolism, and particularly those enzymes responsible for the conversion of food to usable energy in the form of ATP (adenosinetriphosphate). ATP is the molecule that energizes muscle contraction and sugar metabolism. It was a pivotal event in cell evolution. Between 3.7 billion and 1.5 billion years ago, DNA had grown to produce complex single cells. The modern equivalent of such a cell has DNA with about 12.5 million nucleotide base pairs.5

These large single-celled creatures stored all their eating, survival, and reproduction knowledge in their DNA as ATCG nucleotide sequences. However, for multicellular animals to evolve, functions normally carried out completely by a single cell must be carried out by different groups of cooperating cells. For example, reproduction by cell division carried out by a unicellular organism must be performed by a specialized group of cells in a multicellular organism. Unlike the more or less fully utilized DNA of the unicellular organism, only portions of the DNA of multicellular organisms are used by specialized cells to accomplish their limited functions. Developing these specialized cells is called "differentiation." Clearly, single-cell DNA had to develop a means of intercellular communication to enable multicellular differentiation to occur.

If functions are to be divided successfully among groups of specialized cells, they must be able to coordinate their activities. To accomplish this, the DNA of one cell type must be able to regulate the activity of DNA in other cells. Such regulation can be accomplished if the DNA of one cell manufactures messenger molecules or proteins capable of regulating the activity of DNA in other cells. For example, in our bodies, the flight or fight response to fear involves the release of adrenaline and noradrenaline. The adrenal glands secrete these molecules into the bloodstream to increase the heart pumping rate, blood pressure, metabolic rate, blood sugar concentration, and blood flow to the muscles and to the primitive "reptilian" part of the brain. Blood flow to the thinking cerebral cortex decreases and other essential bodily functions are slowed.6 In much the same way, messenger molecules can regulate gene expression during gestation.

DNA Enables Cells to Cooperate

What took place in early unicellular evolution to set the stage for multicellularity? A clue might be found in the behavior of the Dictyostelium amoeba (commonly referred to as "Dicty"), which has a cellular structure similar in many ways to our own. Multicellular organisms such as plants, fungi, and animals evolved from what is called the "eukaryote" line of organisms. We are multicellular eukaryotes, and Dicty are unicellular eukaryotes. At some point in our ancestry, a unicellular eukaryote mutated to form multicellular eukaryotes. It's possible that our first multicellular eukaryote ancestor had functional characteristics very similar to the present day Dicty. What is interesting about Dicty is that they communicate with and influence each other on a grand scale to ensure their survival.

Dicty normally eat bacteria and reproduce asexually by dividing. When bacteria become scarce, and a colony of Dicty is in danger of starving, the first to detect the scarcity begins to release waves of messenger molecules. When the messenger molecules reach other Dicty, they begin to move toward the source and also begin emitting their own waves of messenger molecules. As this process ripples through the colony Dicty accumulate into a mound. Once in a mound, the concentration of messenger molecules is high enough to trigger other changes. The Dicty attach to each other by means of cellulose and other proteins and travel as a mass by jostling past one another. The mass begins to take on a slug-like form, and it appears that the most recently divided Dicty rise to the top of a stem-like mass and move it through the soil by heading toward heat and light. Next, the cells at the stem tip rise up as different genes activate at different distances from the tip. After rising, cells at the tip travel down through the mass to form a stalk that supports the remainder of the colony that, by now, is acquiring a somewhat spherical shape. Some Dicty form a cup at the top of the stalk that supports the sphere, while others form a disk at the bottom, anchoring it to the soil. By this time, the entire mass has taken on a spore-like appearance. In time the top sphere of Dicty might be carried away on the feet of animals or by some other means to be relocated to a possible bacteria-rich environment where they can flourish. Keep in mind that the entire process began with the prospect of starvation, and it's likely that each genetic mechanism employed by the Dicty accumulated over time in a trial and error process of adapting to changing environmental conditions.7

What might we learn from these unicellular organisms about the evolution of multicellular animals? We know that Dicty can communicate, change their cellular properties (differentiate), and function in a coordinated way—all this without a common skin or a common first cell (egg). These independent cells contain DNA that evolved the capacity to manufacture messenger molecules capable of triggering all these effects. Is it possible that the first multicellular organism mutated from a unicellular organism that had already evolved DNA capable of triggering complex coordinations, behaviors, and physical differentiations?

Even if DNA can manufacture messenger molecules, how would a unicellular organism create extra cells that are not simply copies of itself? And even if a cell can make extra cells, how would the extra cells become different? DNA mutations had to occur that enabled a single cell to divide a number of times. Unlike cancers, which are clusters of continuously dividing cells, a multicellular organism stops dividing at some point. In addition, the extra cells produced had to respond to each other's messenger molecules as well as differentiate their functions in a way useful to the survival of the organism.

How did the extra cells differentiate into useful organs? By this stage in biological evolution, DNA sequences were getting to be quite long. Long sequences or strands of DNA are called "chromosomes." Nucleotide sub-sequences within chromosome strands that create specific proteins are called "genes." The complex arrangement of DNA with its messenger molecules was prerequisite to the development of cell differentiation. Messenger molecules have shapes that fit into specific sections of a DNA helix. Once in place, the molecules regulate the DNA's protein production by activating or deactivating nearby genes. The process becomes richly complex as molecules regulate genes that produce proteins that, in turn, regulate genes on the same DNA or on DNA in other cells that, in turn, produce other messenger proteins, and so on. For cell differentiation to occur, developmental genes must be activated to produce messenger molecules, and other genes must be deactivated in the proper ongoing sequence until differentiation is completed. In some cases, the presence of protein from one developmental gene can inhibit the function of protein from another developmental gene.8

A hierarchy of developmental genes acting sequentially accomplishes differentiation. Developmental genes that determine an embryo's overall characteristics, such as the head, thorax, and abdomen, are supplemented by developmental genes that determine specific characteristics within those primary domains. As developmental genes manufacture regulating proteins, the concentration of those proteins decreases with distance from the originating genes. This is called "a concentration gradient." A minimum concentration of regulating proteins is required for regulation to take place. For example, imagine that developmental genes in an oval embryo were to activate at each end of the oval's long axis as well as on opposite sides of the center of the oval. Messenger molecule gradients from those genes would spread throughout the embryo with protein concentrations greatest at their points of origin and progressively weaker away from those points. The different proteins would combine at various concentrations throughout the embryo. As the developmental proteins in high enough concentrations promote and inhibit gene activity in cells of the embryo, DNA in those cells creates its own local protein gradients. The overlapping gradients would provide a very complex matrix of DNA activation and inhibition capable of producing very complexly differentiated cells.9

One way of visualizing messenger molecule concentration gradients is to imagine two stones being dropped simultaneously into a still pond. As their ripples meet and overlap, a complex pattern of interacting ripples would develop. Now imagine the stones to be of different sizes. Although the pattern of interacting ripples would change, it would still be symmetrical in one axis, as symmetrical as the body patterns of complex differentiated organisms. A more robust and internally asymmetrical analogy would be created if you could imagine three-dimensional or spherical waves from two stones that spawn secondary spherical waves from a few asymmetrically placed pebbles, which in turn spawn tertiary spherical waves, et cetera.

The mathematical function that closely mimics this kind of sequential execution of multiple DNA instructions is the fractal or Mandelbrot set. Fractals are simple mathematical expressions that, by repeating each calculation beginning with the result of the previous calculation, can produce extremely complex irregular shapes and surfaces similar to those found in Nature.

A Small DNA Mutation Makes a Big Difference

Research indicates that very early in the evolution of multicellular organisms, the most fundamental developmental genes inverted their differentiation functions. The result of this DNA mutation was that the gut and central nervous systems in vertebrates were reversed relative to organisms with segmented bodies (lobsters, crabs, and shrimp).10 We humans are vertebrates with our spines at our backs and our intestines in front. A shrimp has its gut in back (opposite its legs) and its nervous system in front. It should be apparent that relatively small variations in developmental genes can produce large differences in body patterns. However, the complexity of large animals requires long DNA sequences (many genes) to provide the necessary code. This, combined with an unlimited potential for cell division, can produce all sorts of creatures.

How many genes does it take to produce different types of body patterns? Peter Holland, a molecular zoologist at the University of Reading in England, made the following observation:

You might expect that as you look at a range of different animals, you would see widely varying numbers of genes. If you looked through the vertebrates, you would expect mammals to have more genes than reptiles and reptiles to have more genes than fish. But that turns out to be wrong.

What our preliminary data suggest is that all the vertebrates have roughly the same number of genes, and all the invertebrates have roughly the same number of genes. But there was a jump [in the number of genes] between invertebrates and vertebrates.11

Holland suggested that a mutation in invertebrate reproduction could have doubled the number of chromosomes in its offspring and made the evolution of vertebrates possible. Inheriting an extra copy of one chromosome is common. It's the cause of Down's syndrome and other congenital disabilities. Doubling all of an organism's chromosomes would be extraordinarily rare. Rare or not, given hundreds of millions of years and innumerable reproduction opportunities, it might have happened twice. The first time is thought to have been prior to the appearance of vertebrates, about 520 million years ago, and the second just prior to the appearance of jaws in vertebrates, about 460 million years ago. It's thought that the extra DNA, and in particular the doubling of developmental genes, made it possible for more complex body plans to evolve. It's thought that a similar doubling was responsible for the evolution of flowering plants.

At about 520 million years ago, even though our DNA was producing differentiation proteins needed for our present fundamental body plan, our ancestors had no skeletal structure. It is theorized that a constant need for calcium in an environment with a changing availability of calcium led our freshwater marine ancestors to evolve a calcium storage capacity. In time, these calcium storage structures were put to good use by evolution and became our spinal columns and related skeletal parts. In addition, chromosome doubling provided sufficient genes to support the formation of a very complex head with paired sensory organs and a three-part brain. An alternative theory suggests that the first calcium concentrations evolved to protect sensitive neural structures and progressed to provide the protective armor seen in the fossils of bony fish.

As these few inch-long, fish-like invertebrates were evolving into vertebrates, bony arches that supported their gills evolved from their forward-most ribs. They had no jaws and ate by swallowing without biting or chewing, much like lamprey eels. It's theorized that, just prior to 460 million years ago, things changed with the second chromosomal doubling. The additional genes would have supported a number of complex innovations, including adapting the bony gill arches to close the mouth and allow water to oxygenate the gills more quickly. This trait would have improved breathing performance, energy production, and speed, and as an added benefit, it would have enabled these new vertebrates to suck in and clamp down on prey. Clamping became adapted with stronger muscles and various means to hold prey securely.12 It was a development that would define much of the world as we know it today.

In time, plant and flesh-eaters would evolve extraordinary capacities to maximize the benefit of their highly efficient jaws. These marine vertebrates gave rise to amphibians, birds, reptiles, and mammals. No evidence of chromosome doubling after 460 million years ago has been found. In the intervening 460 million years, mutations and natural selection pressures caused branching of DNA evolution that resulted in an enormous variety of life forms, most of which are now extinct.

Representative of the complexity of early bacteria, the DNA of E. coli bacteria of today contains about five million nucleotide base pairs, while yeast DNA contains about 12.5 million base pairs. Fruit fly DNA contains about 160 million base pairs, and the DNA of humans contains about three billion base pairs.13 Those three billion nucleotide base pairs make up about nineteen thousand genes, about half of which might be involved in some way with our central nervous system.

Evolution before Darwin

In the 19th century, Darwin was able to piece together the missing elements of biological evolution. Before Darwin, the early Greeks envisioned elements of the theory of evolution. Anaximander (610-546 BCE) thought that organisms arose by gradual stages and that land animals were once fish. Empedocles (500-430? BCE) believed that Nature produces every kind of organism with some capable of propagating themselves and meeting the conditions of survival. Anaxagoras (500?-428 BCE) said that all organisms were originally generated out of Earth, moisture, and heat, and thereafter from one another, and that the upright posture of humans freed their hands for grasping and enabled them to develop beyond other animals. Unfortunately, unlike most of his contemporaries, Aristotle preferred his concept of "entelechy" to that of natural selection. He rejected the accidental differences of natural selection and concluded that lifeforms evolved by an inherent "urge" or "entelechy" that causes them to achieve an entelechy-directed result.

In 1756, Karl von Linne (1707-1778) placed humans in the primate-order classification of animals in his work Systema Naturae. George de Buffon (1707-1788) suggested an ancestor common to all living beings in his work Natural History. Erasmus Darwin (1731-1802), the grandfather of Charles Darwin, proposed that "animals vary and transform through behavior which is provoked by need." Jean-Baptiste de Lamarck (1744-1829) proposed that an animal that travels on all four limbs might evolve to travel on two. The preface to On the Origin of Species by way of Natural Selection presents a more extensive review of theories leading up to Charles Darwin's work. In his book, Charles Darwin offers his view of the nature of evolution, to wit:

How do those groups of species, which constitute what are called distinct genera, and which differ from each other more than do the species of the same genus, arise? All these results…follow inevitably from the struggle for life. Owing to this struggle for life, any variation, however slight and from whatever cause proceeding, if it be in any degree profitable to an individual of any species, in its infinitely complex relations to other organic beings and to external nature, will tend to the preservation of that individual, and will generally be inherited by its offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive.14

In addition to observing accurately the result of DNA's constant refinement of genetic knowledge, to which he refers as "from whatever cause proceeding," Darwin realized that the competition for life begins with abundant offspring competing with each other for limited resources. A most extreme version of this was recently observed in a species of shark in which fully functioning siblings cannibalize each other during gestation. One might describe it as a kind of prenatal survival of the fittest. Another of Darwin's contributions to our understanding of biological evolution is his realization that offspring with genetic variations, which coexist with related offspring absent the variations, constitute branching in evolution's tree of life.

Early Life

In an attempt to reconstruct how the accumulation of slight variations over more than 3.5 billion years has produced the human brain, visualize in your mind's eye, if you will, the unseen changes in DNA that underlie overt changes in the fossil record we are about to consider.

There are three main branches on the tree of life. The bacteria branch, which includes cyanobacteria, the eukarya branch, which includes plants, animals, and fungi. The archaea branch, which are bacteria-like organisms, identified as distinct from bacteria in 1977. Archaea are the least understood of the three branches.15 Research shows that archaea differ from bacteria in the makeup of their DNA and in the fact that they derive their energy using, e.g., hydrogen and carbon dioxide. Bacteria employ, e.g., sulfates (anaerobic) and oxygen (aerobic) in their energy-generating processes. Whether archaea self-assembled prior to bacteria is unclear. What is clear is that self-assembly happened before 3.8 billion years ago. At that time, about 200 million years after the last meteorite bombardments, primitive organisms left their remains in what is now Greenland.16 Within another 300 million years; however, bacteria that derived their energy from sulfate reactions encountered what to them was an ecological disaster. Bacteria, much like today's cyanobacteria, adapted to use sunlight to convert water and carbon dioxide into glucose while producing oxygen as a byproduct. This began a process that displaced sulfate reactions as a dominant driving force of life. Since oxygen readily combines with many mineral compounds, newly evolving cyanobacteria began to create what would become our biosphere. Although oxygen to varying degrees was toxic to anaerobes, they were not destroyed. Instead, they were relegated to live in places where oxygen levels were low enough for them to exist away from oxygenated water and the atmosphere.

Primitive cyanobacteria thrived in the surface waters of the Earth's oceans, which, at that time, were filled with dissolved iron compounds. As oxygen was produced, it combined with iron compounds forming precipitates of iron oxides, and eventually transformed the oceans. Red deposits of iron-rich sediments layered the ocean bottoms leaving behind the clear water we see today. In time, with virtually no iron compounds remaining with which to combine, oxygen bubbled up from the oceans to transform the atmosphere.

      Early life forms survived a glacial episode that reached almost to the equator 2.2 billion years ago,23 and by about 1.3 billion years ago, simple bacteria had experienced an enormous number of mutations. These mutated descendants had acquired nuclei, were thousands of times larger than simple bacteria, and assimilated various bacteria symbiotically as organelles.

Perhaps these single-celled organisms developed the cooperative capabilities of present-day Dictyostelium amoebae, or "Dicty." Another 200 million years of mutations produced rudimentary multicellular organisms without nervous or circulatory systems. This line of cells gave rise to anemones and corals. Multicellular life survived another glacial episode about 700 million years ago. Some believe very low levels of atmospheric carbon dioxide during that time indicate that the planet surface froze completely for about 10 million years. 17, 18

At about this time, a developmental gene inversion is believed to have occurred. Such an inversion would have made possible body patterns with the central nervous system, and intestinal tract reversed relative to the direction of the limbs, such as is seen in shrimp today. Thereafter, about 50 major body patterns evolved, including segmented bodies, invertebrates, and vertebrates. Among these were the first jellyfish. Although the Burgess shale deposits in the Canadian Rocky Mountains contain many fossils from this period, the dearth of hard parts in these squishy life forms makes the fossil record incomplete and difficult to interpret. What is very clear is that life was proliferating dramatically, perhaps with the aid of two gene doublings at about 520 and 460 million years ago.19, 20

It's theorized that gill arches evolved into jaws. Heads and sensory organs became more complex. Three-part brains began to appear along with calcium-storing spines and skeletal parts. Filter feeders such as starfish and sea urchins evolved. Ammonite descendants of jellyfish developed well-defined tentacles, shells, and eyes. In turn, descendants of ammonites, such as the nautilus, retained the shell, while other descendants such as the cuttlefish, octopus, and squid successfully adapted without shells. Plantlife was coevolving and generally preceded animal life in exploiting new environments.

Plants and animals had become symbiotically dependent on an oxygen-carbon dioxide cycle. By 550 million years ago, while oceans were supporting evolving plants and animals, the land was lifeless. Plate tectonics, wind, and rain had created and reshaped continents and mountain ranges. The roughly 10,000 species that had evolved by this time were adapted to living in salty ocean water, not in freshwater runoff from the continents. Although rivers, lakes, wetlands, bays, and dry land were devoid of animals, plants were beginning to adapt to freshwater.

There were two fundamental changes needed for ocean creatures to adapt to living in fresh or brackish water. The first was to evolve a capacity to excrete water that accumulated in their cells in the absence of sufficient salt. The second was to evolve a capacity to store calcium that was not consistently available in freshwater environments. Without calcium, muscles cannot function.

By about 530 million years ago, soft-bodied vertebrates had evolved. The cartilaginous vertebrae of their rudimentary spinal columns were calcium repositories. Within 30 million years, vertebrates living in brackish water evolved fresh-water-adapted kidneys, calcium-regulating bone, and blood-salt-level-regulating circulatory systems. By 500 million years ago, proto-fish vertebrates with scales or thin bony plates and the beginnings of a limbic brain had evolved. With no pectoral or pelvic fins, they swam erratically, and, with no jaw, it's likely that they were like modern lamprey eels, or became filter feeders or scooped up nutrient-rich mud to sustain themselves.

About 440 million years ago, when trilobites dominated the oceans, when sharks were making their debut,21 and when much of Earth's land was predominantly in the southern hemisphere, terrestrial plants evolved from aquatic plants and took root along the water's edge. By 390 million years ago, fish with jaws and fins evolved, some with eyes and some without. They had well-developed spinal columns, jaws with teeth, and pectoral and pelvic fins suitable for swim control. Within another ten or so million years, bottom-dwelling fish began to use their pectoral fins to push themselves along the bottom of plant-thick, shallow, fresh, and brackish waters. Getting enough oxygen became a problem for fish living in waters that became oxygen-depleted.

Venturing onto Land

The next adaptations enabled them to supplement their gills by taking in oxygen from the air with a primitive lung organ associated with and perhaps evolved from the gills. Sturdy pectoral fins enabled them to "walk" over land to escape water-bound predators, and to partake of the insects, plants, worms, snails, invertebrates and segmented body creatures that had already adapted to living on land. A fish that succeeded in transitioning to living on land was Tiktaalik. Apparently, Tiktaalik adapted to living in shallow water by the trial and error process of evolving its fins, head articulation, and other features into forms that increased its likelihood of survival. It had basic wrist bones, finger-like features, and eyes on top of its flat head. It appears to have had primitive lungs in addition to gills, and a strong rib cage that made possible the transition to living on land without adverse gravitational effects on its organs. In addition, Tiktaalik had no bony plates in its gill area to restrict side-to-side head movement. It had a neck. These water environment adaptations served Tiktaalik well as it ventured onto land and eventually evolved into reptiles.

Within another 10 million years, a shallow water vertebrate, much like a salamander, evolved with complex bony limbs for locomotion and lungs adapted to breathing air. This vertebrate could walk over obstacles in its shallow water environment while breathing air. By 360 million years ago, strong rib cages evolved to protect vital organs and adapted what were pectoral and pelvic fins into limbs suitable for "walking."22 These walkers were marine amphibians, and the first vertebrates able to sustain terrestrial activity. Although a few of their present-day descendants are newts, salamanders, toads, and frogs, one ancient South African amphibian grew to 13 feet in length. The demise of these large amphibians probably resulted from competing with the reptilian branch of the family.

Reptiles evolved many adaptations that gave them advantages over amphibians. Amphibian reproduction in water enabled their tiny offspring to move about their environments in search of food and prevented them from dehydrating. Reproducing on dry land was another matter. Amphibian reproduction was accomplished in two stages. When first born, their offspring enjoyed the benefits of a water birth, but when they were large enough to survive on land, they discarded their aquatic characteristics and acquired appropriate land characteristics. Frogs have a tadpole stage before they become recognizable as frogs. By comparison, reptiles evolved a leathery egg that provided nourishment, prevented dehydration, and protected the developing offspring long enough for them to grow to a size suitable for survival on land. In addition, amphibians lost moisture through their skins and gulped air to breathe. Reptiles evolved moisture-resistant scales and a suction breathing system. Air intake for reptiles was not limited by the size of their mouths, but by the size of their lungs. The limbic brain that reptiles inherited evolved into the more capable reptilian brain with amygdalae and a hippocampus. With all their neural improvements, however, they were still driven by instinctive responses and learned emotional behaviors. Other adaptations in leg and foot structure provided reptiles with greater speed in seeking food both at the water's edge and in the nearby growths of grasses and ferns.

In time, plants evolved into tree ferns that used spores to propagate along the wet margins of land and water. As their roots and other features adapted to more arid conditions, tree ferns propagated inland, taking with them evolving vegetarian animals and their predators. The fossil record shows that by 320 million years ago when the present continents were all part of the supercontinent Pangea, conifers, and cycads (pine and palm-like trees called "gymnosperms") had evolved. As with modern conifers, their seeds are enclosed in cones, but unlike modern conifers, they had soft leaves. Fruit-bearing flowering plants were to evolve later.

Slowly, conifers began to cover the land. Their wind-blown pollen fertilized nearby trees, with seeds appearing a number of months after fertilization. Conifers had no insects that assisted in fertilization. Even so, they were better adapted than tree ferns and, in time, became the dominant vegetation. Eventually, great conifer forests covered the land. By 300 million years ago, the first flying insects evolved—the first of many events that would change the world again.

Early mammal-like reptiles appeared about 280 million years ago and evolved over about 210 million years from egg-laying to marsupial births, and eventually to full-term gestations. Many changes were required to evolve reptiles into mammals. For reptiles to function properly, their body temperatures must be high enough to support the biochemical processes that enable them to function. Without the ability to create and regulate their body temperatures, reptiles had to wait for the sun to heat their bodies before they could perform effectively. For reptiles to become independent of the sun's heat, they had to produce their own. To do this, reptiles required a number of evolved adaptations.

Heat is produced as oxygen combines with hydrocarbons from food. To produce more heat, one must take in more oxygen and food, and combine them rapidly. To take in more oxygen, larger lungs that could be filled and emptied rapidly were required. This would both provide more oxygen to the muscles and make more heat available by speeding digestion. The evolution of a breathing diaphragm made respiration more efficient and, if required, more rapid. To take in more food required better teeth and jaws, better locomotion, and a way to prevent eating from interfering with breathing—a constant supply of oxygen is much more important to high-oxygen-consuming mammals. The evolution of a bone shelf separating the nose from the mouth made it possible to take in oxygen while chewing. Three types of teeth evolved, permitting grasping, cutting, and grinding in a precision bite. Finely chewed food is more easily digested and more quickly available for use. With intense predation by reptiles, small size became an advantage as early mammals sought protection by hiding. However, small animals have higher surface areas per unit of body weight. All the effort required to produce heat would be compromised if it could escape readily. In time, efficient insulating pelts evolved from scales, as mammal-like reptiles evolved into mammals. Compared with cold-blooded reptiles, typical contemporary mammals are more agile, more intelligent, able to run faster, and have their all-important higher body temperatures regulated automatically, day and night. Although merely representative, these differences indicate the degree of adaptation mammal-like reptiles experienced as they evolved into higher performing mammals. It took time and good fortune.

About 250 million years ago, before mammal-like reptiles began to evolve, disaster struck the Earth. Although the mechanism is not clear, during a period of perhaps 5 to 10 million years, reef and shallow-water environments were devastated. Over 75 percent of reptiles, over 60 percent of amphibians, 8 of 27 orders of insects, and more than 90 percent of all ocean species became extinct. It's thought that volcanic eruptions in what is now Siberia and China occurred over at least 600,000 years. Ocean levels dropped, parts of the ocean became depleted of oxygen, and fungal growth suggests widespread terrestrial plant devastation.23 Mass extinctions were not new to the Earth. This extinction was the third to occur. The first occurred about 438 million years ago, about 60 million years after the first vertebrates evolved. The second occurred about 367 million years ago after plants and arthropods (insects) adapted to living on land. Other mass extinctions followed. The fourth at about 208 million years ago occurred a few million years before mammals evolved. The dinosaur age ended about 66 million years ago with an extinction that cleared the way for the evolution of our early primate ancestors.

During the Triassic period, beginning about 245 million years ago, the supercontinent Pangea had moved farther north, the percentage of atmospheric carbon dioxide was at least four times what it is today, and the average surface temperature was considerably warmer. It was an excellent time for plants and for animals that ate plants. While conifers were evolving, so too were reptiles. One branch of the lineage became the terror of the oceans when it readapted to aquatic life. The dinosaur branch of the reptile family was enormously successful, both as plant and meat-eaters. Two general types of dinosaurs are distinguished by their pelvic structures, those described as lizard-hipped and those described as bird-hipped. Among the adaptations that distinguished some dinosaurs from their reptilian ancestors was the ability to walk and run on their pelvic legs. The dinosaur branch that adapted to flight are the ancestors of modern birds.24

Some contend that fast-running dinosaurs had to be warm-blooded. Whether they were warm-blooded or cold-blooded is not clear. Today's warm-blooded creatures consume energy 12 times faster than cold-blooded creatures and have an energy-consumption rate that would have been unsustainable given the dinosaur's rate of food intake and body size. It's possible that at least some dinosaurs were warm-blooded, but with lower body temperatures than are possible today. To the extent that dinosaurs did not possess adaptations that mammal-like reptiles evolved, it is not clear how dinosaurs could have achieved high body temperatures.

From about 300 million to 250 million years ago, small dinosaurs evolved into many forms, including the enormous, long-necked, leaf-eating sauropods. While these evolutionary events were taking place, the center of Pangea had moved to the equator. As plant-eating dinosaurs (herbivores) evolved and flourished in a conifer-rich environment, so too did meat-eating dinosaurs in their new herbivore-rich environment. It was the dinosaur's golden age. But, as meat eaters chased plant-eaters through ancient conifer forests, a small change was taking place in plant evolution. It was a change that would dramatically alter the lush environment that supported the assent of the dinosaurs.

By about 200 million years ago, flowering plants (angiosperms) evolved. Scientists sequenced the Amborella genome and found conclusive evidence that about 200 million years ago, a "genome doubling event" occurred. Some duplicated genes made possible new functions, including the development of floral organs. Some believe that flower petals evolved from leaves. Flowering plants differ from conifers in that their seed is enclosed in fruit. Another difference is that flowering plants rely more on insects than on the wind for pollination. As they coevolved, insects and flowering plants adapted to each other's shapes or other characteristics. This meant that flowering plants had insect partners capable of delivering pollen to distant plants. Early mammals also played a role in speeding the propagation of flowering plants. Mammals at that time were about the size of tree shrews and probably foraged at night to avoid being eaten by small dinosaurs.25 In addition to eating insects and perhaps other small creatures, these mammals ate flowering-plant fruit and dispersed the seeds with their droppings.

Fertilization in flowering plants was extraordinarily fast. These new genetic traits, together with the coevolution of pollen- and seed-spreading animals, accounted for enormous variety among flowering plants and for their capacity to out-compete and displace conifers in temperate regions. This is not to say that conifers did not evolve as well. Over millions of years of ravaging by dinosaurs, conifers evolved defensive poisons and needle-like leaves. Unfortunately for conifers, they were still slow propagators and less well adapted than flowering plants. As you would expect, where flowering plants displaced conifers, they displaced conifer-eating dinosaurs as well.

At about 180 million years ago, Pangea separated near the equator with what would become North America and Eurasia moving north, and South America and Africa moving south. An equally significant change was taking place in the structure of reptilian brains. Additional brain capacity was forming as the neocortex began to grow larger, providing the reptilian brain with improved memory and with the beginnings of an ability to reason.

The First Mammals

The earliest known fossil record of mammals has been dated to about 160 million years ago.26 By 140 million years ago, our mammalian ancestors were evolving jaws with high flanges at the back of the jaw and larger jaw muscles connecting the jaw to the skull, permitting a more forceful bite. In time, to further the business of getting to and acquiring food and of avoiding predators, limb bones elongated or shortened and toes adapted with claws, nails, and feet. Some adapted for speed, others for climbing, and others with hoofs were suited for grazing. Grazing limbs lost their ability to turn to the side and found two primary toes (cloven hoofs) well suited to the task of escaping predators. Other limbs adapted for swimming, climbing, running, digging, walking, flying, and seizing. All of these adaptations placed new survival demands on the brain for speed and information processing. Relative to body weight, a larger brain began to evolve that could process large volumes of information from the senses and provide fine muscular control.

By 120 million years ago, Africa and South America separated as did Eurasia and North America. The Atlantic Ocean was in its infancy as a rift valley, and by about 70 million years ago, our mammalian ancestors probably weighed about 150 grams, had long tails, a body length of about seven inches, walked on all fours, had long snouts and ate fruit and insects. Among the animals that shared their environment were dinosaurs, but this would change.

By 90 million years ago, conifer-eating dinosaurs were forced to regions where colder temperatures gave conifers an advantage over flowering plants. The cycle was now complete. Those dinosaurs whose success followed the success of conifers over tree ferns were now experiencing hardship as conifers lost ground to flowering plants. Ironically, the fate of many awesome dinosaurs would be affected so profoundly by the evolution of fragile flowers. Triceratops, a dinosaur with a large head plate and three horns, was an exception. It was able to eat flowering plants and survived in great herds until about 65 million years ago. At that time, the Cretaceous period ended. A meteor about six miles across, traveling at about 50,000 miles per hour struck at a location that we know today as the town of Chicxulub in Mexico's Yucatan peninsula. Its energy was equivalent to about 6.6 billion Hiroshima bombs. Although the crater ultimately reached about 120 miles in diameter, computer simulations indicate that within ten seconds after impact, the crater was already 30 miles across, 15 miles deep, and was spewing molten rock in ballistic trajectories all over Earth. The impact fractured the Earth's crust and created earthquakes and tsunamis. The sky was filled with molten ejecta, and fires started everywhere. The vast quantity of limestone and sulfur in the impact area released vast quantities of carbon dioxide and sulfur dioxide into the atmosphere.27 This was doubly unfortunate. The first result was that sulfur dioxide combined with atmospheric moisture to form sulfuric acid droplets. Such droplets block sunlight, cool the Earth, and cause acid rain, possibly as strong as battery acid. Present-day volcanic studies indicate that the sulfur dioxide might have cooled the Earth as much as 10 degrees Celsius for a decade. Subsequently, carbon dioxide released by the impacted limestone could have caused the atmosphere to warm as much as 15 degrees Celsius for centuries.

From computer simulations and various evidence, we now know that the Chicxulub impact in the Yucatan caused a wave over one mile high to sweep over what is now Cuba, and a layer of seafloor rubble about three feet deep to cover parts of Texas. Ocean bed core samples taken 320 kilometers east of Jacksonville, Florida, recorded the event. Before impact, the core sediments were rich in fossil remains, characteristic of a healthy ocean ecosystem. Deposited on top of that layer is about ten centimeters of gray-green impact debris topped by a thin red layer rich in iron, indicating that the meteor probably contained iron since the Yucatan site had little iron. On top of the red layer is about five centimeters of sediment with no evidence of fossils. It's estimated that this layer took 5,000 years to deposit. Sediments above the five-centimeter layer show the return of fossils and evidence that the ocean near Florida had reestablished an ecosystem.28 Virtually everywhere on land, a layer of iridium containing soot about 1/2 inch thick marks the end of the Cretaceous period. Iridium is an element uncommon on Earth's surface but commonly found in meteors. In the late 1970s, the dark layer of iridium covering Cretaceous period soil led Luis and Walter Alvarez to unlock the mystery of how the Cretaceous period ended.29

It's estimated that six million years before the Chicxulub impact, there were about 60 kinds of dinosaurs. That number dropped to less than 20 by about 2 million years before the impact. About 90 percent of Earth's biomass burned in the impact fires, and some believe that the remaining dinosaurs eventually starved. Of the other species then on Earth, about two-thirds were destroyed. Whether the demise of dinosaurs was due solely to an "impact winter" is not clearly understood. It's said that some dinosaur species survived the impact and later became extinct for other reasons. What is clear is that their demise changed the status of our mammalian ancestors from dinosaur snacks to precursors of apes that would dominate the Earth. Food scarcity resulting from the post-impact blockage of sunlight devastated animals directly or indirectly dependent on fresh vegetation. However, insects survived on the remains of decomposing plants, and at that time, our ancestors ate insects.

When the meteor struck, North and South America were not yet joined at what we call Panama, and where the Mediterranean would be formed was open water from the Atlantic to the Pacific. By about 50 million years ago, our ancestral mammals' limbs had grown longer; their snouts had become shorter, they lived in trees, developed protruding ears, weighed about 300 grams (about 10 ounces), and had long tails. Small though they were, their tiny neocortices were providing them with enhanced mental capabilities well suited to ensure their survival in a meteor-altered world. The dinosaurs, as such, were gone, and tapir-like mammals weighing about 200 pounds was among the animals that shared our ancestor's habitat. About 55 million years ago, when the Himalayan Mountains formed as present-day India collided with Asia, huge limestone formations were exposed to the weather. As carbon dioxide in the atmosphere combines with rain, it forms carbonic acid. Although weak, carbonic acidic rain would have reacted with the exposed limestone of the Himalayas to form carbonate particulates, trapping atmospheric carbon and washing it into the sea. It's thought by some that a reduction in atmospheric carbon dioxide by this means contributed to global cooling and might have precipitated relatively recent glaciation cycles, of which there have been about 12 in the past 20 million years.

Between 40 and 20 million years ago, the Mediterranean was formed as Africa collided with Eurasia. Salt domes found at the bottom of the Mediterranean, deep cuts in the rock at the bottom of the Nile and other rivers feeding the Mediterranean, and other evidence suggests that the Mediterranean went dry. Rivers flowing into the Mediterranean didn't, and still don't provide enough water to equal its evaporation rate, and it gradually went dry. About five million years ago, the Gibraltar Strait was formed where the Atlantic cut a channel to the Mediterranean. Lighter, less salty water from the Atlantic now flows in at the upper portion of the Strait, and heavier evaporation-concentrated saltier water flows out in the lower portion. Phoenician sailors discovered these currents and lowered drag devices into the lower out-flowing water to pull their ships against the surface current into the Atlantic.

By about 30 million years ago, our ancestors looked monkey-like, weighed about 7 kilograms (about 15 pounds), had 32 teeth as do we, were arboreal, and ate fruit. They coexisted with a herbivore that looked like a rhinoceros with side-by-side horns. By 17 million years ago, they evolved a chimp-like appearance and weighed about 18 to 50 kilograms. They were apes with no tails, a more substantial jaw, shortened faces, rounded skulls that were rotated to look forward while standing, but with an unimpressive brain size. An elephant-like mammal was among the animals that shared their environment. A large mammal with a horse-like head and gorilla-like legs was among the animals that shared our primate ancestor's environment 14 million years ago. This ancestor began to stand on its pelvic limbs and was functioning with a neocortex that was increasingly sharing decision-making with the older amygdala and hippocampi. By 4 million years ago, our hominid ancestors had shortened arms, could walk with a waddle, and had a brain slightly larger than a chimpanzee's. Lucy is the name given to fossil remains of one of these Australopithecus Afarensis ancestors found in Ethiopia. By 3.5 million years ago, hominins left their footprints in the volcanic ash of present-day Tanzania.

About three to ten million years ago, North and South America were joined with the formation of present-day Panama. It's theorized that this formation cut off warm ocean currents that flowed to the Arctic. Similarly, flow through what is now the Bering Strait was reduced as North America moved closer to Asia. Over about 300 million years, the internal dynamics of Earth had moved the continents by plate tectonics from an essentially north-south mass concentrated mostly in the southern hemisphere to a distributed east-west arrangement centered closer to the equator. In addition to influencing biological evolution in other ways, it's thought that this massive reforming of the continents resulted in the restriction of warm currents flowing to the Arctic and might have contributed to recent periodic glaciations.

By two million years ago, Homo Habilis (handyman) were probably the first recognizable humans. Weighing about 40 kilograms (88 pounds) with an upright stance, they were about four feet tall, had a brain about half the size of ours, and were able to make tools. Recent research indicates that humans evolved lower levels of testosterone, which, compared with chimps, made our ancestors less aggressive, more cooperative, not as strong, and more inclined to rounded facial features compared with chimps.

By 1.7 million years ago, Homo Erectus (the standing human) had a less massive jaw and a much larger brain (from 900 to 1000 cubic centimeters). Homo erectus built shelters, made flint tools and hunted and gathered food. By one million years ago, Homo Erectus were able to live in previously uninhabitable territory because they were able to make fire. By 800,000 years ago, up to five people left a series of footprints in mud on the bank of an ancient river estuary on what is now the English shore.

Homo Sapiens Archaic lived 200 to 100 thousand years ago. They looked like stocky humans, weighed about 50 to 70 kilograms (110 to 154 pounds), and some lived in caves and as hunting nomads. Some contended with cave hyenas, which were much larger than their present-day relatives. By 35 thousand years ago, some Homo Sapien Sapiens (the thinking human) lived in tents made of wood or bone frames covered with animal hides. Isolated groups had evolved characteristics suited to their environments. Long noses, skin with varying degrees of pigmentation, and flat noses were a few of the obvious adaptations. They organized, tanned hides, made flint and reindeer-antler tools, created cave and rock paintings, buried their dead, and apparently believed in the existence of a spirit world. What was happening in brain evolution to make the foregoing developments possible?

Evolving the ability to reason

The pre-human brain, from which our brain evolved, was able to function emotionally but was not able to reason. For us to reason, Nature had to evolve our brain from what it was millions of years ago to what it is today. Brain parts of particular interest are shown in Figures 1 and 2 below. In the process of acquiring the ability to reason, evolution grew existing parts and added new parts and capabilities as it adapted our brains to environmental challenges.

The primitive brain began as a brain-stem that was one step above a rudimentary nervous system. It surrounded the top of the spinal cord and controlled basic body functions, such as breathing, metabolism, reflexes, and coordinated movement. It could react to stimuli such as the smells of prey, enemies, danger, sex partners, and the like. As it was evolving to become better at discerning water-borne and air-borne molecules, the smell-sensing part (olfactory bulb) was growing larger and beginning to encircle the top of the brain-stem.

Adapting the body to respond to things in the environment was becoming more complex and more specialized. The few neurons that orchestrated emotional responses gradually evolved into large almond-shaped structures (amygdalae) on either side of the brain-stem. Similarly, neurons that began to recognize and "remember" the factual information associated with smells and other sensory information evolved into the hippocampus (short-term memory). The combination of remembering factual details and their associated emotions enabled the amygdala and hippocampus in a crude way to recognize patterns in incoming sensory information and to produce a remembered response appropriate to the incoming pattern. The process was fast enough to initiate an attack or avoidance response in a few milliseconds (milli- is 1/1000).

Over time, sensory information flow was becoming complex, and the few neurons that converted sensory information into a form usable in the brain evolved into the thalamus. Smell information, for example, was received by the thalamus, converted into a usable form, and sent to the amygdala and hippocampus. As this team of organized brain parts was evolving, the olfactory bulb was beginning to form around the brain-stem. The word "border" in Latin is limbus, and the bordered brain-stem became known as the "limbic system."

Additional neurons in the limbic system provided enhanced emotional capabilities that improved survival. In addition to rage and sex drive, the limbic system had enhanced learning and memory. Smells could be remembered, compared, and recognized, and emotional responses appropriate to the smell could be implemented. As the limbic system evolved, it became more broadly involved with communication throughout the brain. Our ancestors were beginning to perceive their environments, and what they perceived was a competitive and dangerous place with extreme survival challenges.

As brain evolution continued, the amygdala and hippocampus of the limbic brain, which are primarily responsible for our emotions, learning, and remembering, became capped by the neocortex—a large mass of folded neurons that, in part, processes reasoning. This occurred about 100 million years ago when mammals were becoming established. As the neocortex formed, neural pathways connecting it to the thalamus provided it with information necessary to enable the prefrontal lobes to analyze what should be done about incoming sensory information. With this new arrangement, the thalamus now fed sensory information directly to both the amygdala and the neocortex. However, studies using rats show that information moves from the thalamus to the amygdala in about twelve milliseconds, while information from the thalamus to the neocortex and then to the amygdala takes about 24 milliseconds. This means that the amygdala can provide an emotional response to a situation before the reasoning neocortex can respond. In essence, the reasoning neocortex is not "wired" to prevent the implementation of a response from the emotional amygdala. While this arrangement provides fast survival responses in life-threatening situations, the more circumstances evoke an emotional response; the less rational thought will prevail. For this reason, crimes of passion (committed in "hot blood") are punished less harshly than premeditated or rational crimes (committed in "cold blood"). The law recognizes that we need to consider how the human brain functions.

Medial view of right brain hemisphere

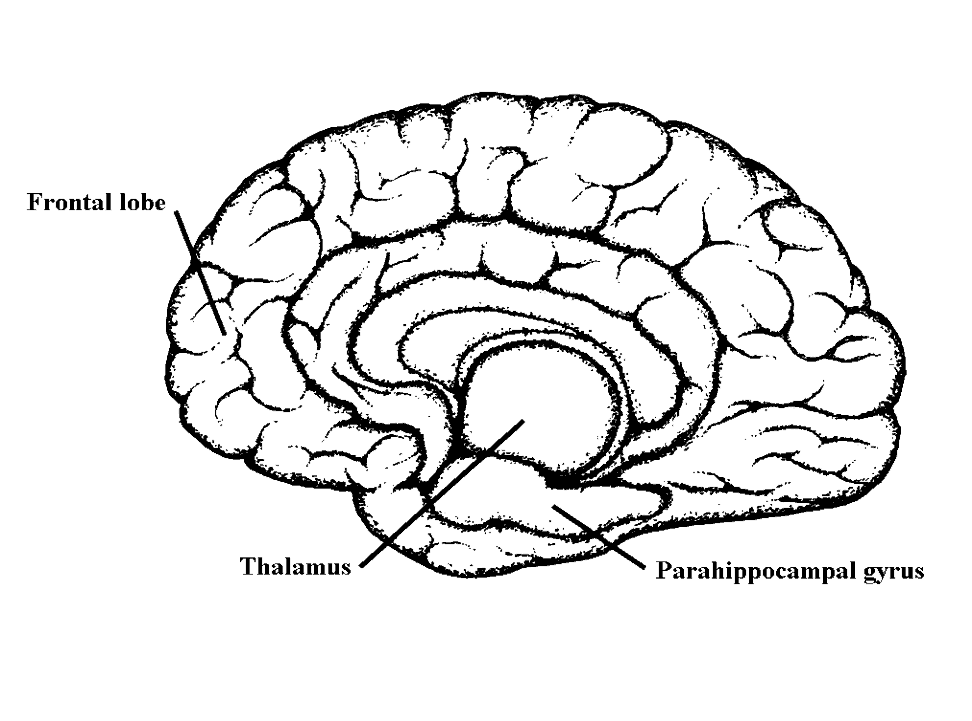


Figure 1

Specific limbic brain components

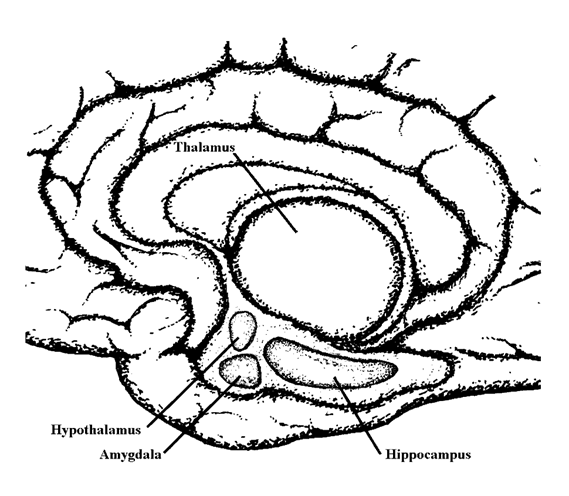


Figure 2

Large-scale Social Evolution Begins

The first coming together of scattered Western settlements occurred in the Middle East. Why in this region? Perhaps the following happened. In a process similar to the drying of the Mediterranean, it's thought that glaciation lowered sea levels caused the Black Sea to become a brackish-water lake dammed off from the Mediterranean at what is now the Bosporus strait in Turkey. About 8,200 years ago, the enormous glacial Lake Agassiz in North America suddenly emptied into Hudson Bay and the Atlantic Ocean. The resulting rise in sea level inundated the land bridge between Britton and Continental Eurasia. As the Mediterranean Sea rose, water flowed across what is now the Bosporus Strait into the Black Sea, where the water level rose about 270 feet. Today, saline water from the Mediterranean flows into the Black Sea at the Bosporus Strait, which is about 20 miles long and 1/2 mile wide at its narrowest.

Before the Black Sea flooded, it's inflow of water was from the Danube, Kuban, and other rivers. The inflow flooded what is believed to have been an inhabited region of considerable size, especially in the northwestern part of the present Black Sea. Pre-flood inhabitants would have been forced to higher ground during the time it took to bring the Black Sea to its present level. Based on discoveries of submerged pre-flood shorelines and related findings, some scientists believe that the cataclysm might be the source of Middle Eastern myths involving disastrous floods.30

If a pre-Sumerian population lived on the shores and in the marshes of a pre-flood Black Sea, they would have been displaced and traumatized by the deluge. Water could have risen more than nine inches per day, on average, and completely flooded the region within about 12 months. In their common plight, people from small scattered settlements could have combined and built large villages or cities away from the rising sea. Such a process would have been contemporaneous with the appearance of "city-kings" in the history of the region. If events occurred in this way, pre-Sumerians who migrated south through the high ground of the Turkish mountains and into the fertile crescent of the Tigris-Euphrates region would have built their cities in what is present-day Iraq, where cities dating to about 5,000 BCE have been found. Such a traumatic flood would have been recorded in the oral history of the survivors, and stories about the flood would have filtered through many generations and might be the source of the sages' description of the great flood in the Sumerian story of Gilgamesh. The Sumerians believed the flood to be retribution for the sin of an ancient Sumerian king. Apparently, the same story was subsequently reinterpreted by the Babylonian and Hebrew cultures, and in turn, became part of the Christian tradition involving Noah. Recent research suggests that the Persian Gulf also flooded about 8,200 BCE.

By 5,000 BCE, Sumerians in the Fertile Crescent were evolving language, writing, technology, and social organization. They created social hierarchies, irrigation farming, currency, law, sophisticated scripts, libraries, schools, literature, poetry, cosmetics, jewelry, sculpture, palaces, temples, arches, columns, slavery, and ecclesiasticism. Evidence of similar, contemporaneous cultural evolution has been found in Indus culture.

After billions of years of accumulating molecular knowledge in the form of evolving DNA, self-organizing knowledge had crossed a threshold with the Sumerian, Indus, and other civilizations of that time. From a reflexive emotional brain suited for survival in a hostile environment, trial and error evolution had produced a thinking organ capable of evolving knowledge in the form of organized understanding and beliefs, instead of organized nucleotides. A few millennia later, the Axial Age invented natural philosophy, employing a rational thought process to organize knowledge and belief systems. In just over two millennia following the death of Aristotle, that process evolved into a scientific method of analysis that has enabled us to discover the history of life on Earth and to begin understanding the biology of belief. After eons of evolving organic life by refining DNA using Nature's test of survival value, the process of self-organizing knowledge began to evolve human culture and wisdom by refining human beliefs, not by selecting for their survival value, but by selecting based on their perceived value to those who would acquire them.

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Brain Evolution

Endnotes

1. Zimmer, Carl, "Life Takes Backbone," in Discovery Magazine, December, 1995,

p. 38—9.

2. "Origin of Life on the Earth," in Scientific American, October, 1994, pp. 77—83.

3. de Duve, Christian, "The Birth of Complex Cells," in Scientific American, April,

1996, pp, 50-57.

4. Travis, John, "How many genes does a bacterium need?" in Science News,

September 28, 1996, Vol. 150, No. 13, p. 198.

5. Lipkin, R., "Early life: In the soup or on the rocks?" in Science News, May 4,

1996, Vol. 149, No. 18, p. 278.

6. Fackelmann, Kathleen, "The Cortisol Connection," in Science News, November

29, 1997, Vol. 152, No. 22, p. 350.

7. "The Slime Alternative," in Discover Magazine, September, 1998, pp. 86—93.

8. "The Origin of Species," in The Economist, November 25, 1995, pp. 85—87.

9. Nusslein-Volhard, Christianne, "Gradients That Organize Embryo

Development," in Scientific American, August, 1996, pp. 54-55, 58-60.

10. Travis, John, "The Ghost of Geoffroy Saint-Hilaire," in Science News,

September 30, 1995, Vol. 148, No. 14, pp. 216-18.

11. Monastersky, Richard, "Jump—Start for the Vertebrates," in Science News,

February 3, 1996, Vol. 149, No. 5, pp. 74-7.

12. Zimmer, Carl, "Breathe Before You Bite," in Discover Magazine, March, 1996,

p. 34.

13. Travis, John, "Yeast genetic blueprint publicly unveiled," in Science News, May

4, 1996, Vol. 149, No. 18, pp. 278-8.

14. Darwin, Charles. On The Origin of Species. 1859, p. 61.

15. Travis, John, "Third Branch of Life Bares Its Genes," in Science News, August

22, 1996, Vol. 150, No. 8, p. 116.

16. "Earliest Earthlings," in Scientific American, January, 1997, p. 29.

17. "When glaciers covered the entire Earth," in Science News, March 29, 1997,

Vol. 151, No. 13, p. 196.

18. Monastersky, Richard, "Popsicle Planet," in Science News, August 29, 1998,

Vol. 154, No. 9, pp. 137-41.

19. Monastersky, Richard, "Jump-Start for the Vertebrates," in Science News,

February 3, 1996, Vol. 149, No. 5, pp. 74-7.

20. Zimmer, Carl, "Breathe Before You Bite," in Discover Magazine, March 1996, p.

34.

21. Monastersky, Richard, "The first shark: To bite or not to bite?" in Science

News, February 17, 1996, Vol. 149, No. 7, p. 101.

22. Monastersky, Richard, "Walking away from a fish-eat-fish world," in Science

News, July 30, 1994, Vol. 146, p. 70.

23. Erwin, Douglas H., "The Mother of Mass Extinctions," Scientific American,

July, 1996, pp. 70-78.

24. Padian, Kevin, and Chiappe, Luis M., "The Origin of Birds and Their Flight," in

Scientific American, February 1998, pp. 38-47.

25. Monastersky, Richard, "The Lost Tribe of the Mammals," in Science News,

December 14, 1996, Vol. 150, No. 24, pp. 378-9.

26. Monastersky, Richard, "The pushy side of mammalian brains," in Science News,

November 18, 1995, Vol. 148, No.21, p. 330.

27. Monastersky, Richard, "Impact Wars," in Science News, March 5, 1994, Vol.

145, pp. 156-7.

28. Cowen, Ron, "51 Pegasi: A star without a planet?" in Science News, March 1,

1997, Vol. 151, No. 9, p. 133.

29. "The Doomsday Asteroid," WGBH Educational Foundation, Nova program

#2212, Air Date 10-31-95, Journal Graphics, Inc., Transcript, p.4.

30. Ryan, William and Pitman, Walter, Noah's Flood, Simon & Schuster, New

York, 1998.