

Emergence as cornerstone in understanding evolution: examples from zoology

François Durand

Department of Zoology, University of Johannesburg,
Auckland Park, South Africa

Introduction

Science is the way in which humankind explores and understands the physical universe.

The biological sciences and, especially, the zoological sciences provide us with an understanding of ourselves – how we function, how we evolved and how we relate to the rest of nature. During our first tentative steps on the road of rational thought, biology played a pivotal role in unlocking the nature of humankind, opened our eyes to natural processes and laid the foundation for the scientific method of inquiry.

Over the past three millennia, the biological sciences have evolved into many subjects including medicine, anatomy, comparative morphology, embryology, palaeontology, genetics, biochemistry and physiology.

Although biologists are interested in every aspect of life, it is primarily through the study of humans and human interests that we gain access to the natural world. Genetics grew from our interest in promoting agriculture and animal husbandry and the study of genetic deviations in humans. The study of human evolution dominates palaeontology. The study of embryology, comparative morphology and anatomy began with and is still dominated by the study of humans. Human needs dominate endeavours in the fields of biochemistry, physiology and medicine.

Since the time of Anaximander, Plato, Aristotle and Hippocrates, the biological sciences have given us a special insight into our relationship with nature. One of the most significant changes in human thinking occurred at this time – these scientists were the first people in recorded history who tried to explain different aspects of the universe by means of natural laws rather than supernatural forces. They were also the first who philosophised about the origin of humans. Indeed, Hippocrates (460–370 BCE) noted the similarity in the anatomy of monkeys and humans.

The concept of a hierarchy of progressive complexity, with humans at the pinnacle, was formulated by the classical Greeks. Anaximander of Miletus (610–546 BCE) was the first person in recorded history who speculated about the origin of life, animals and finally humans. According to Aristotle's *Scala Naturae*, there is a hierarchy in creation – from the non-living to the living, from plants to animals and from animals to humankind.

In the first biblical creation myth man is the end product of creation and, in both biblical creation myths, the whole purpose of creation was to accommodate humans. Even today the common view is that humans are the end product of evolution. This concept is reflected in fictional works such as those of H.G. Wells (1896) *The island of Dr Moreau* and Pierre Boulle (1963) *La Planète des singes* (The planet of the apes); in both these works, the inevitability of the evolution of animals to a human-like state is explored.

This mentality is also evident in modern science fiction, where every intelligent extraterrestrial and alien is depicted as a hominin. Of course, this is not a new trend: we have been doing this for thousands of years with our depictions and descriptions of metaphysical beings such as gods, angels, demons, titans, Valkyries – all of which resemble humans, albeit with a few modifications such as horns, wings or cloven hooves (see Fig.1). Aliens are depicted as bilateral symmetrical multicellular organisms with a dorsal head that houses a mouth, brain and special sense organs. The head is attached to the body with a neck. The body also sports four appendages, of which the upper two are modified into arms with hands with fingers – of which one is an opposable thumb. These aliens breathe air through their noses and can speak.

These assumptions about evolution are nothing short of incredible and reveal an ignorance of the process of evolution, an ignorance that deserves commentary.



External anatomy of angels and aliens:

Head with brain, eyes, eyelids, ears, nose and mouth.

Nostrils and chest cavity with lungs for oxygenated air breathing.

Head attached by neck to torso.

The torso has four appendages.

Hand with fingers and opposable thumb.

Plantigrade feet.

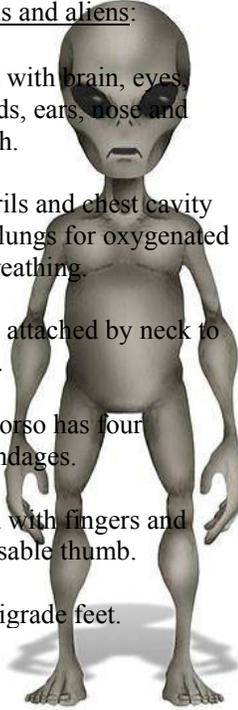


Figure 1

Angels and aliens as hominins (*Angel with whips* by Lazzaro Morelli (left); alien from: <http://en.wikipedia.org/wiki/File:Alienigena.jpg> (right))

Emergence of life

Our story starts 5 billion years ago, when a massive plume of gas and star dust, flung out into space by a supernova, collapsed under its own weight to form a spinning disk of matter orbiting an emerging second generation star. The matter that sprung from this explosion included heavy metals that were produced by means of the incredible forces generated during a supernova. Planets were formed in this spinning disk as matter gravitated towards heavier clumps of gas and dust. As matter accreted, these growing planetesimals heated up and became dense liquid. In time, a crust started to form amongst the lava flows as the early inner planets started to cool down. The gases released by volcanic activity formed a large part of the atmosphere.

Mars and Venus have carbon dioxide and hydrogen, gases that contain molecules such as methane, hydrogen sulphide and ammonia in their atmospheres – these are the gases released from volcanic activity. None of these planets have significant amounts of free oxygen in their atmospheres. Originally, this was also true of the earth.

On earth, organic chemicals were delivered by meteor impacts and were synthesised in the early atmosphere, pools, and deep hydrothermal vents. These organic chemicals combined spontaneously to form more complex organic compounds including proteins and nucleic acids – the building blocks of DNA (Miller & Orgel 1974). Life emerged very early in the history of earth and, by 3.5 billion years ago, life teemed in the shallow, lukewarm and slightly acidic oceans of the earth, as we can see from fossils of prokaryotes (*pro* – before, *karyon* nucleus), which are found in some of the oldest sedimentary rocks on earth (Barghoorn & Schopf 1966).

Life diversified early in the history of earth into two groups of prokaryotes – the archaea and bacteria. It is little wonder that there are bacteria, and especially archaea, living today in hot sulphuric lakes, in hot methane-rich springs, along the hydrothermal vents at the bottom of the ocean and in salt lakes. These extreme environments are similar to those that dominated the early earth billions of years ago. For more than half the earth's history, these prokaryotes were the only organisms on earth. If we could go back three billion years ago our planet would be totally unrecognisable. The radiation from the brilliantly burning young sun beat down mercilessly on the steaming plains and the warm red and purple coloured seas. White clouds of ammonia and carbon dioxide, brown clouds of methane and yellow clouds of hydrogen sulphide formed above volcanic

mountains only to be whipped away by searing winds and dissipated into streaky cloud formations in the mustard-coloured, ozone free sky.

Grasses, forests and animals would only appear billions of years later, yet every habitable niche at the time, three billion years ago, was full of life – in the form of bacteria. Purple and green bacterial blotches covered moist surfaces, sticky yellow granules collected in cracks, and there were swamps of bubbling, brown-black bacterial gel, while autotrophic geophagous bacteria burrowed kilometres into the crust, crumbling it in slow decay. Aquatic bacteria occurred in drifts of pink snow, ponds of azure water, brown gunk clogging hydrothermal vents, orange-red flakes settling on the sea floor and black rocky mounds rising from the sea margins.

From the geological evidence it is clear that the atmosphere changed from a carbon dioxide and hydrogen-compound rich reducing atmosphere to an oxygen rich, carbon dioxide poor atmosphere. The activities of archaea and bacteria were responsible for the depletion of carbon dioxide and hydrogen compounds from the atmosphere on the one hand and the origin of an oxygenated atmosphere on the other. These two phenomena created an atmosphere anomalous to those found on other solar planets (Margulis & Sagan 1986).

Bacteria use hydrogen and carbon dioxide to form energy-rich compounds known as sugars. Everything went well for hundreds of millions of years on Earth until catastrophe struck approximately 2.5 billion years ago. Prehistoric archaea and bacteria gradually consumed the hydrogen compounds in the early reducing atmosphere. There was however a vast, and as yet unexplored, source of hydrogen in the form of water, but this was not originally available for bacteria owing to the strong ionic bonds between hydrogen and oxygen in the water molecule. During this hydrogen-shortage crisis, a certain strain of rod-shaped bacteria, the cyanobacteria, evolved the ability to harness sunlight to break the oxygen-hydrogen bond, which enabled these bacteria to consume the hydrogen. This process, called photosynthesis, evolved more than a billion years before the first plants (in the form of single-celled algae) came into existence.

This evolutionary breakthrough led to the diversification of the cyanobacteria, some strains of which are still alive today. Cyanobacteria have a blue-green colour and give fresh water an azure colour. Billions of years ago cyanobacteria occurred in vast colonies covering the sea floor up to the level where sunlight can penetrate. Cyanobacteria changed the chemistry of the mineral-laden warm water around them and caused the binding of carbon dioxide and calcium which precipitated as stromatolitic dolomite. The production of dolomite removed billions of tons of carbon dioxide from the atmosphere. More than 95% of the atmosphere of Mars and Venus consist of carbon dioxide, whereas that of earth contains only 0.03% carbon dioxide.

The one major ecological drawback is that oxygen is formed as a byproduct of photosynthesis, and oxygen is toxic to most prokaryotes. Tons of oxygen were released into the oceans of the earth and from there this oxygen bubbled into the atmosphere. It took cyanobacteria over a billion years to produce the bulk of the oxygen that make up 21% of our atmosphere and which we are currently breathing and burning. By 2.2 billion years ago, there was already a noticeable change in the atmosphere and rocks exposed to the atmosphere started to oxidise. Oxidisation occurs when oxygen binds to other molecules. Oxygen reacts with many substances, which is why rocks appear to be reddish brown and why iron rusts. There are even large quantities of oxygen in fresh water and in the sea, which is why metal, as in the case of the Titanic, rusts away underwater. Fire is the oxidisation of flammable matter. In fact, the oxygen in our atmosphere is so combustible that we have fire stations dotted around our cities to put down fires that start at the slightest provocation. This highly reactive characteristic of oxygen is the reason why it is toxic. The toxic properties of oxygen are utilised when we expose meat and fruit to air in order to preserve it, because the oxygen in the air kills bacteria. Bacteria that infest our respiratory system are protected from oxygen by capsules of slime. The oxygen crisis referred to above caused bacteria and archaea to die out on the land and the sea *en masse* and is the reason why, today, the majority of the prokaryotes occur underground and in other damp, unoxygenated environments.

Unlike other bacteria, aerobic purple non-sulphur bacteria use oxygen and excrete carbon dioxide during the production of the life-sustaining energy molecule adenine triphosphate (ATP). The only reason we breathe oxygen is to feed our mitochondria without which we, as eukaryotic organisms, would not be able to exist (see Fig.2). Microbiologists such as Margulis and Sagan (1986) propose that energy-rich purple bacteria were consumed by bigger cells, cells which became our eukaryotic unicellular ancestors more than a billion years ago. In time, the ingested purple bacteria developed a resistance to the enzymes of the host cell and became permanent residents inside the host cell, but now as organelles supplying energy to the host cell (Cavalier-Smith 2006; Martin & Mentel 2010). Mitochondria have their own DNA that is separate from the DNA of the host cell, and they replicate themselves by binary fission.

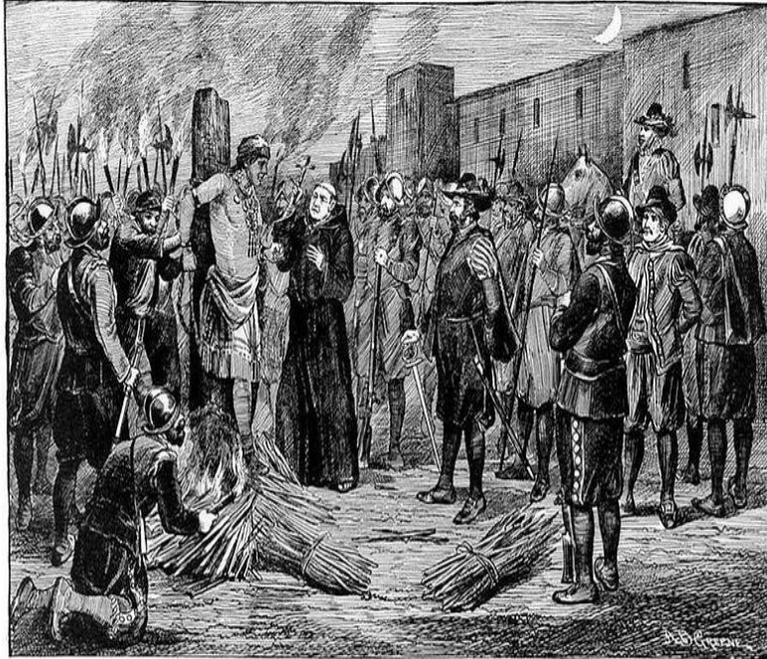


Figure 2

Just before the mitochondria of the Inca Atahualpa were deprived of oxygen as a result of the Inca being garrotted by the Spanish for rejecting the word of God and for practising polygamy (1533) (from:

<http://1.bp.blogspot.com/-3MuAIWZ7Cyc/UB8Nwh27azI/AAAAAAAAAPk/mZFRcJHT8XM/s1600/muerte-de-atahualpa.jpg>)

A similar process occurred when the unicellular ancestors of plants ingested energy-rich cyanobacteria which, in time, turned into chloroplasts. The presence of microtubules in the form of spindles, cilia and flagella in plants, animals and fungi suggests that their shared ancestor incorporated spirochaete bacteria, the most primitive possessors of flagella, in the same way as purple bacteria and cyanobacteria were ingested. Microtubules are essential for the existence of eukaryotic organisms. The spindles form to facilitate cell division but, more importantly, to facilitate the splitting of chromosomes which in meiosis is crucial for gene exchange. Cilia and flagella are important for locomotion in many unicellular organisms, as it is in spirochaete bacteria, but in the majority of multicellular organisms (including mosses, ferns, segmented worms, flat worms, insects, crustaceans and vertebrates) the sperm is mobilised by means of the flagella. In fact, the male organism is reduced for that part of his life cycle to a flagellated unicellular organism, similar to those he descended from.

One of the most curious examples of this shared ancestry, where the progenitors of plants, animals and fungi combined with several different kinds of bacteria in symbiotic relationships, is the fact that plants are green. Chlorophyll, which is the green pigment in the chloroplast, absorbs light to photosynthesise but in the process of photosynthesis only the light in two narrow bands on opposite parts of the visible spectrum is used while green light is reflected, which is the reason why plants are green. If a plant is illuminated in a darkened room with only a green light, it dies, but if the same plant is illuminated with a red and or purple light, it thrives. If plants needed the whole visible spectrum to photosynthesise they would, of course, appear to be black. The interesting thing to note at this stage is that green is in the middle of the visible spectrum. This is just one example of the fact that the universe does not wrap itself around human needs; we should therefore guard against the delusion that these phenomena (e.g. plants being green) are the 'proof' that we are the crown of creation.

The earliest photosynthetic organisms were aquatic archaea, some of which are still alive today, frequenting extreme environments such as salt lakes. Archaea do not use sunlight to produce sugars such as chlorophyll in chloroplasts, but instead use sunlight to supply energy to their flagella in order to move about or to produce ATP. Bacteriorhodopsin is a red to purple pigment which turns salt lakes brick red to dark purple. The light that permeates the layer of water containing the archaea has a red to purple hue and this was the only light available to the cyanobacteria, which evolved after the archaea. Chlorophyll uses the part of the spectrum that bacteriorhodopsin does not use (see Fig.3).

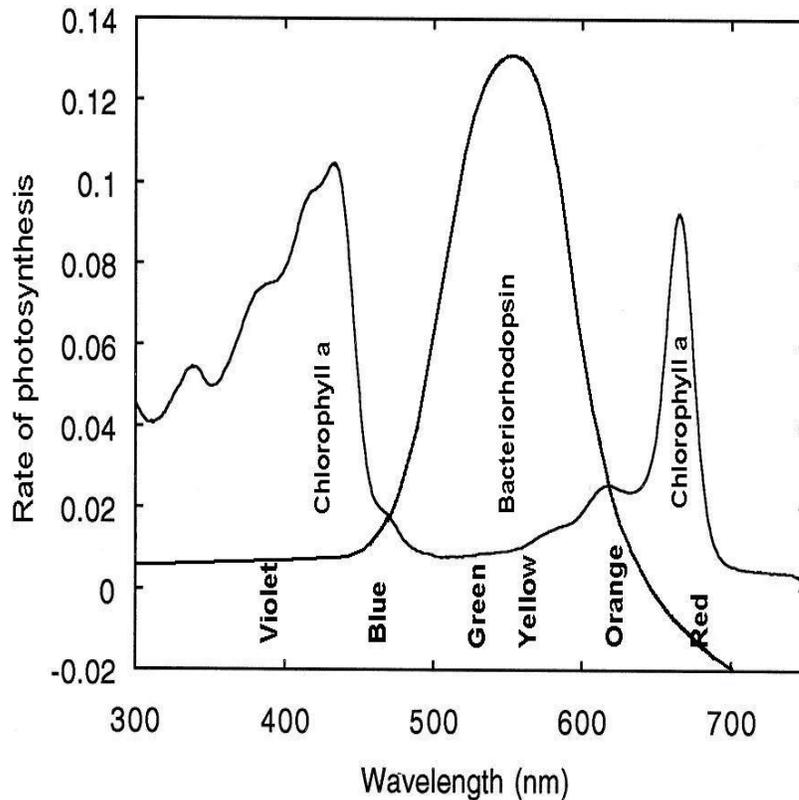


Figure 3
The photosynthetic frequencies of chlorophyll a and bacteriorhodopsin

Flagella and their shorter counterpart, cilia, consist of bundles of microtubules enclosed in a membrane sheath. There is something unique about the arrangement of the microtubuli – they almost always occur in nine pairs arranged like the spokes of a wheel around a central pair of microtubuli. This is the case in every flagella and cilia: from the sperm tails of humans, whales, snails, crayfish, mosses and ferns, to the cilia of every vertebrate lung and the flagella in the nephridia of earthworms, and to the flagella in unicellular algae such as *Chlamydomonas* and *Spyrochaete* bacteria. This arrangement is not evident in nerves, where only bundles of microtubuli occur, but the nine couplets surrounding the central pair of microtubuli still occur in the small nerve ends of retinal cells.

Bacteriorhodopsin is a purple pigment which is homologous to the light-sensitive pigment in our eyes called rhodopsin, also known as visual purple. Rhodopsin is extremely sensitive to light, enabling vision in low-light conditions. Light causes rhodopsin to discharge the energy created in the retinal cell by exposure to light as an electrical impulse that runs through the retinal nerve. This chemical-electrical mechanism makes sight possible by means of archaic pigments and flagella which were incorporated into our cells during the evolution of eukaryotic organisms. This would also explain why sight coincides precisely with the extremely narrow band of the electromagnetic spectrum used for photosynthesis (See Fig.4). If all life on earth, including humans, were not related to all the other organisms from bacteria to plants, to fungi, to animals, and evolved independently and different from one another, sight and photosynthesis could have evolved separately to make use of different parts of the electromagnetic spectrum and plants would appear to be black to our eyes.

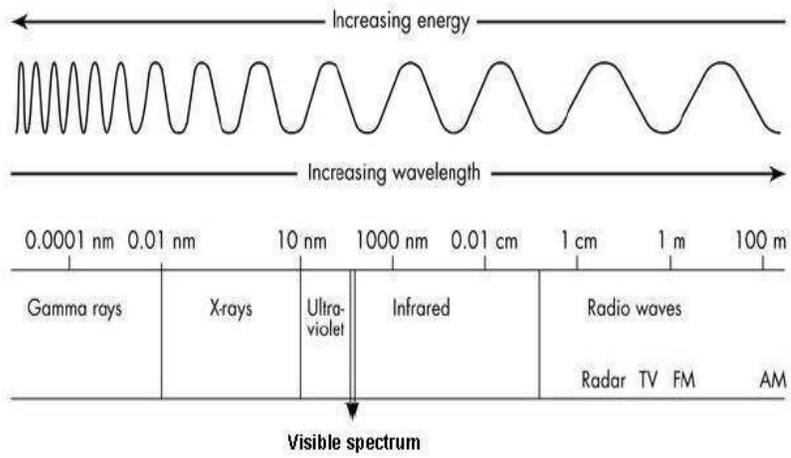


Figure 4
 The electromagnetic spectrum
 (from: <http://9-4fordham.wikispaces.com/Electro+Magnetic+Spectrum+and+light>)

The emergence of multicellular organisms

The origin of the eukaryotic organism approximately one billion years ago, with its DNA encased in a membrane to form the nucleus, the double membrane organelles and its increased ability to generate and use energy which enhanced its metabolism levels, paved the way to multicellularity.

The transition from unicellular protists to multicellular organisms is subtle and cryptic. The fact that individuals of some species occur in either form at different stages of their life makes it possible for us to understand how multicellular life evolved on the one hand although, on the other hand, it makes these organisms more difficult to classify. However, nature is not bound to human classification systems. The continuity of life breaches the synthetic borders humans have constructed around the different groups of organisms. The multicellular kingdoms – Plantae (plants), Animalia (animals) and Fungi – originated from unicellular precursors which resort under the Kingdom Protista, or single-celled eukaryotes. All organisms have ancestors or relatives in other taxonomic groups causing the borders to blur between them – so, too, with the unicellular organisms and their multicellular organisms descendants. There are several animal, fungi and plant species that occur as single-cell organisms at times, and form cell aggregates at others.

The emergence of animals – the origin of the mouth and what it implies

The most succinct definition of an animal is that it is a multicellular heterotroph. In other words, an animal is a multicellular organism which eats others. The split between plants, fungi and animals occurred perhaps a billion years ago, when three different nutrient acquisition pathways, which evolved amongst single-cell eukaryotes, were continued and embellished by the multicellular organisms that evolved from them. For plants it was the ability to use minerals from the soil and water and atmospheric gases to produce nutrients by means of chloroplasts in the presence of sunlight. For fungi, it was the ability to dissolve dead organisms and absorb the nutrients through pores in the cell walls. And, for animals, it was the ability to eat others.

The first animals were little more than cell aggregates without organs. These cell aggregates develop from single flagellated cells which resemble the single cell protists from which they evolved (see Fig.5). Sponges have canals and hollows in their “bodies” through which sea water moves in place of digestive systems. Small organisms and nutrients in the water are trapped and ingested by the flagellated cells (called choanocytes) that line these cavities. Some of the oldest animal fossils ever found are those of microscopically small sponges from Namibia, which are dated at 760 Ma (Brain *et al* 2012). Choanoflagellate protists, which resemble the choanocyte cells of sponges morphologically and genetically, are considered to be the closest living relatives of animals. These protists have the ability to form colonies of cells (see Fig.5).

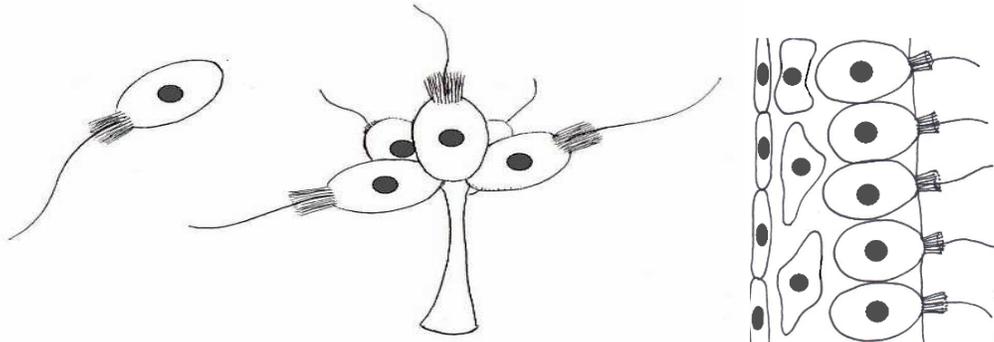


Figure 5

Single choanoflagellate protist (left) and *Proterospongia* consisting of a colony of a few choanoflagellates (middle), section through a sponge (right).

Digestive systems with mouths and mostly, but not always, an anus, are found in more morphologically complex animals. The purpose of the digestive system is to ingest food – mostly other organisms or parts thereof – and to digest it in order to absorb the nutrients in the same way as amoebas do – by engulfing the particles and taking it into the cells. This is one of the most important ways in which animals differ from plants and fungi. Animal cells do not have rigid cell walls around their cell membranes – instead, the naked membranes absorb or engulf the food particles.

Regardless of whether you are a sponge, a worm or a human, you are an animal because you eat (see Fig.6).

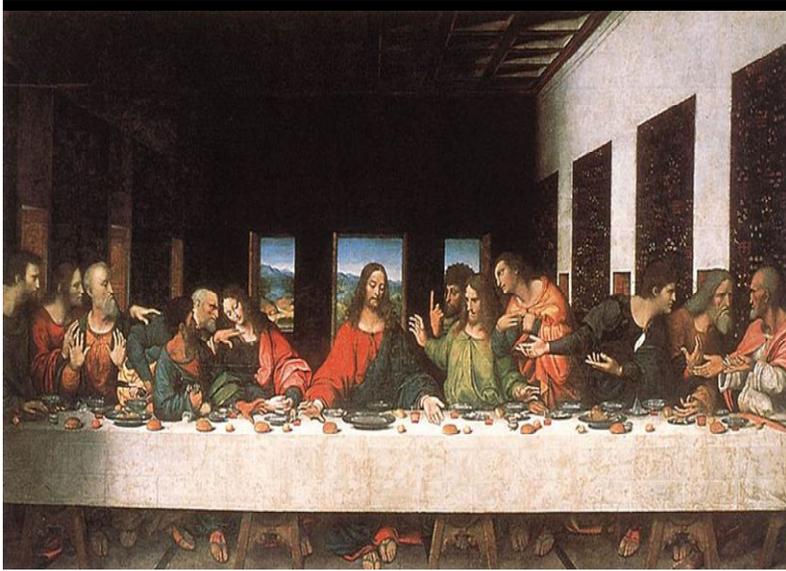


Figure 6

A meal where the guests were invited to ingest the body and blood of one of the members the party (*The last supper* by Leonardo da Vinci).

The emergence of chordates

Besides sponges and a few bizarre exceptions (e.g. tapeworms, which lost their digestive systems after adapting to life inside the digestive systems of others), animals have mouths. Jellyfish and free-living flat worms do not have an anus – the only entrance to or exit from the bag-like digestive system is the mouth. As animals became bigger, the logistics of shunting food and excreta through the same orifice became problematic and a new tube-like digestive system evolved to facilitate the movement of nutrients from the mouth, while the excreta were released through the anus. Amongst the first animals which acquired this new evolutionary innovation were the nematodes, which are some of the most numerous and most ubiquitous of all animals.

When animals started to pursue their prey, they had to swim in a certain direction, instead of just floating with sea currents dragging their tentacles behind them, like jellyfish. With self-propelled directional movement, a front and back, an upper and lower surface and a left and a right half of the body came into being. Bilateral symmetry appeared – which is the reason why more complex animals have two eyes, two ears, two legs, two wings, two kidneys etc., and the left hand does not know what the right hand does.

Mouths in bilateral symmetrical animals are mostly in front of the body and form part of the head, which makes sense because head originated in the first place to aid the animal in finding food. The head is little more than a concentration of sense organs surrounding the mouth which aid the animal in smelling, tasting, seeing, feeling and sometimes hearing its prey. The brain, which receives stimuli from the sense organs, is also found in the head.

During the Precambrian (>540 Ma) there were sponges, radially symmetrical jellyfish, and many different kinds of bilateral symmetrical animals, many of which seem bizarre to our eyes mainly because they went extinct millions of years ago and have left no descendants. A few small wormlike animals such as *Pikaia* (see Fig.7) with unique features appeared in the Precambrian fossil record. These filter-feeding animals, known as chordates, had unique features including a notochord – a gelatinous rigidifying bar running through the body, chevron-shaped muscle bundles attached to the notochord and a post-anal tail fin.

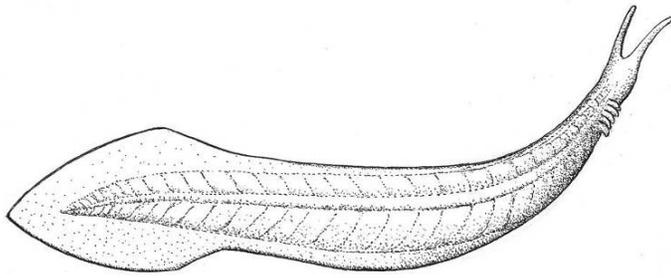


Figure 7
A reconstruction of the Precambrian chordate *Pikaia*

The notochord in the body prevented these animals from scrunching up their bodies in an antero-posterior direction, as do the segmented worms, and limited their movement to a sideways motion. This motion, in combination with the tail fin, enabled these animals to swim forwards. In essence, this design has remained so until today and can still be seen in fish and aquatic salamanders, albeit in a more elaborate form.

The notochord is shared by a small bizarre grouping of animals all of which are considered to be members of the Chordata. The chordates include red bait and its relatives, the cephalochordate *Amphioxus* and vertebrates (everything with a skeleton from fish to mammals). The chordates also have a post-anal tail, gill slits, a hollow dorsal nerve chord and an endostyle or thyroid gland at least at some stage of their development. In certain animals such as the rays and skates, all these characteristics can be seen even up to the adult stage. In others, such as land-living vertebrates, some of these characteristics – notably the gill slits and notochord – are found only in the embryonic or larval developmental stage.

The emergence of vertebrates

A few hundred million years ago, several new characteristics appeared in the heads and throats of chordates, such as bony bars with teeth in the conodonts. In the jawless fish, or Agnatha, cartilaginous plates evolved around the mouth to support the sucking and rasping action of the tongue during feeding. This, once large, group of organisms is only survived today by different hagfish and lamprey species. Although the jawless fish with their elongated, limbless bodies are little more than elaborate worms they are considered to be the most primitive vertebrates because of their complex brains, cranial nerves, sense organs, gills and cartilaginous structures in the head, all of which are considered to be the precursors of the skull (see Fig.8). As higher vertebrates, we have inherited many of our morphological and physiological adaptations from these fish.

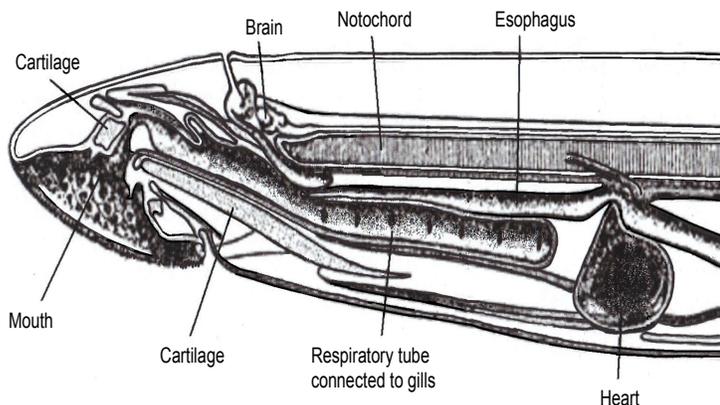


Figure 8
The morphology of the lamprey head region in medial section. Note the cartilage in the head region, which supports the head region around the mouth.

To have a mouth is not synonymous with having jaws, however. Jaws occur only in certain animals such as insects, some segmented worms and some of the vertebrates. The rest of the animals have jawless mouths. Jaws originated in insects to counteract the effect of gravity. In aquatic arthropods, such as crustaceans and their descendants the arachnids, there are no true jaws but instead specially adapted feet that surround the mouth (which is nothing more than a round hole).

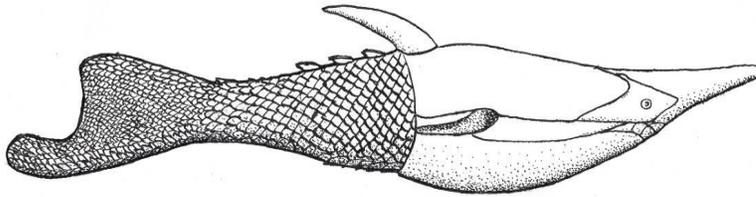


Figure 9

The Devonian placoderm *Pteraspis*

The Ostracodermi were small jawless fish that fed on small invertebrates on the sea floor 425-375 Ma. They were heavily armoured for protection against invertebrate predators such as sea scorpions, some of which grew 2.5m long. One of their most important evolutionary contributions was their head shields which were formed from ossified scales – these became the bones of the upper and front part of our skulls (see Fig.9).

The tables were turned when, in the vertebrates, jaws evolved. In the ancestor of the gnathostomata the first gill arch became the upper and lower jaws (see Fig.10). This adaptation allowed the Placodermi to become the top predators on earth during 420-360 Ma – one such was the apex predator *Dunkleosteus terrelli* that grew 10m long. This single adaptation allowed vertebrates to become the rulers of the world and since then vertebrates have dominated the food pyramid. In all gnathostomate embryos – including that of humans – one can still see how the first gill arch moves to surround the mouth, dragging with it the cartilaginous elements and the associated nerves and muscles (see Fig.10).

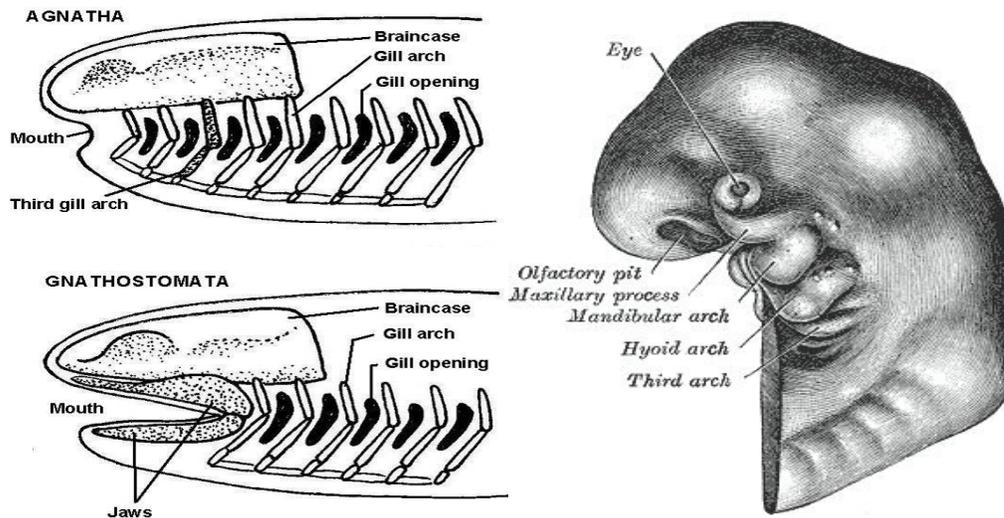


Figure 10

Diagrammatic depiction of the gill arches of a jawless fish (top left), and a gnathostomate fish (bottom left).

Note the position of the jaws relative to the gill arches. Human embryo showing the development of the branchial arches (right) from: http://en.wikipedia.org/wiki/Pharyngeal_arch.

The fish diversified and dominated the seas, and later moved via estuaries into fresh water bodies during the Silurian. There are currently 31 500 species of fish today and many more that are extinct. There are more extant fish species than all other extant vertebrates put together – amphibians (about 7100 species), reptiles (about 8 200 species), birds (about 10 000 species) and mammals (about 5200 species).

At this stage it is important to note that, for every new adaptation, there was a precursor and at every nexus in the diversification of life on earth several different alternatives existed. The ancestral path leading to humankind has been a very tortuous road, in fact not more than a narrow twisting footpath that jumped from

unexpected byway to the next precarious enclave, narrowly missing extinctions at every step. Nothing on the evolutionary path of humankind, and indeed any organism, should be seen as obvious or predictable.

The emergence of tetrapods

Amongst the diversity of fish, a new group, the Sarcopterygii, appeared. They had the ability to breathe by means of a vascularised swim bladder in addition to their gills. The Sarcopterygii or fleshy-finned fish also had bones instead of fin rays in their pectoral and pelvic fins (see Fig.11). These bones are homologous to those in the limbs of the animals that came to live on land – the tetrapods (see Fig.12).

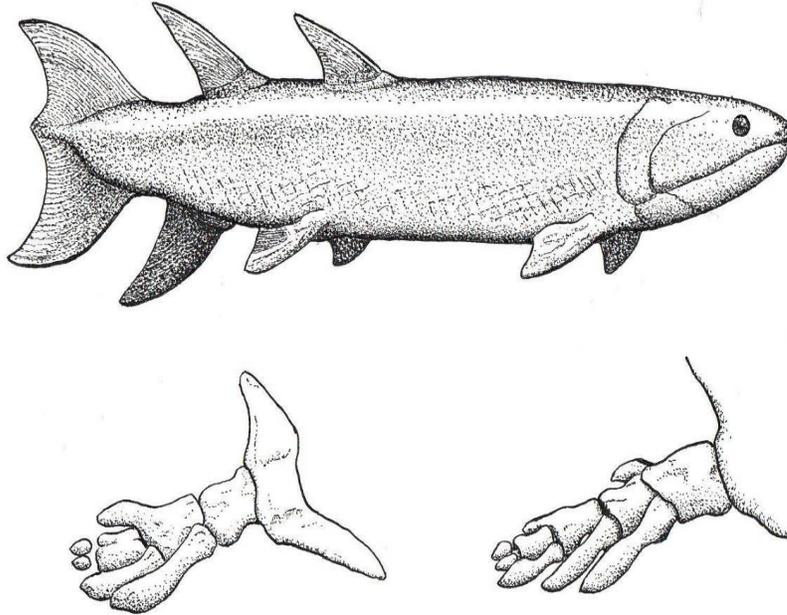


Figure 11

The sarcopterygian fish *Eusthenopteron* of the Late Devonian period, about 385 Ma, showing details of the skeletons of the front and hind limb.

The first of these tetrapods, commonly known as amphibians, moved from the water to land approximately 360 Ma by means of these and other new evolutionary innovations. The skeleton became more robust to support their weight on land, and the shoulder girdle evolved from the bones at the back of the fish skull to support the arms. In the process, the neck appeared – which allows the tetrapod to move its head.

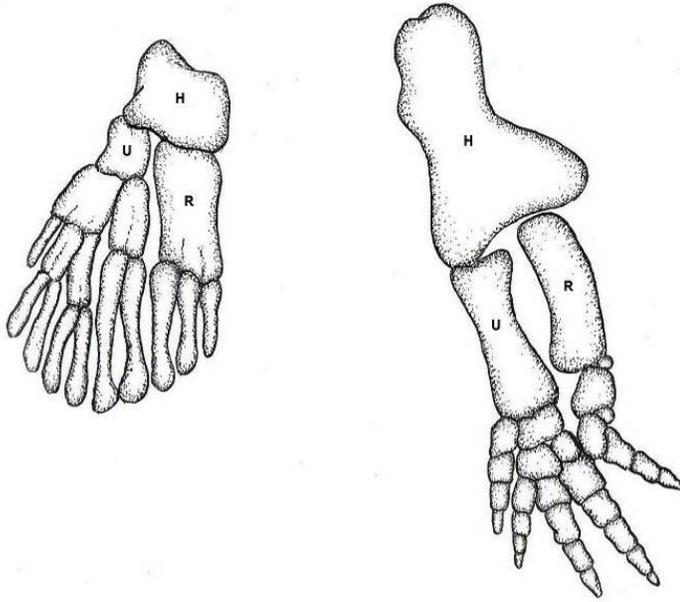


Figure 12

The front limb of the sarcopterygian fish *Eusthenopteron* (left) and the front limb of the early tetrapod *Turlepeton* (right). H = humerus, U = ulna, R = radius.

The word “tetrapod” is derived from the fact that the first vertebrates that became adapted to life on land and their descendants had four limbs. Even though certain groups such as whales, dugongs and snakes have lost some or all their limbs secondarily, they are still considered to be tetrapods. The cross shown in churches and depicted in many Christian religious paintings is designed to punish organisms with four limbs. If octopi developed politics they would probably use a wheel with eight spokes to punish their dissidents and would later on use the wheel as a religious symbol. The number of digits varied considerably during the time of the origin of tetrapods and hand and feet were adorned with anything from five to eight fingers and toes per limb. The fickleness of evolution gave the surviving tetrapods a pentadactyl ancestor – one with five fingers and toes. For this reason, and no other, we have a numeral system based on ten.

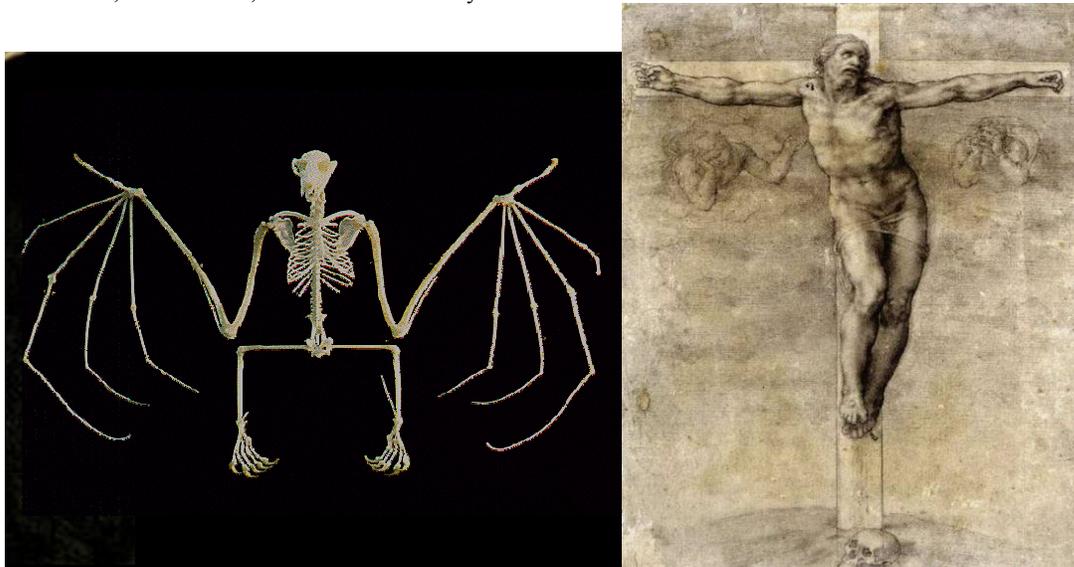


Figure 12

Depictions of two pentadactyl tetrapods. Bat skeleton (left) and *The crucifixion of Jesus* by Michelangelo (right).

The first tetrapods evolved many other new characteristics which enabled them to live on land. These evolutionary innovations included tear ducts to lubricate the eyes, eyelids to protect the eyes from desiccation, ear drums to detect air-borne sounds, and extra cranial nerves and a bigger brain to coordinate their actions on land. They could breathe on land by means of their lungs and skin but were still dependent on water for reproduction. They, like the surviving amphibians, laid their eggs in water. In primitive tetrapods the eggs are fertilised externally in the water – where an extended larval existence is completed before they change into land-dwelling animals.

The emergence of amniotes

The transition from primitive tetrapod to the reptilian stage is difficult to pin down in palaeontology because of the subtle nature of the characteristics involved. The gradual transformation of the skeletal characteristic in the transitional forms does not supply us with a clear-cut division between the two groups. The characteristic which was decided upon in the end cannot be found in the fossil record because it does not fossilise; however, this characteristic is evident in all extant amniotes (reptiles, birds and mammals) while it is absent in amphibians. This characteristic is the amnion membrane in the shelled egg. The origin of the amniotic egg enabled vertebrates to lay eggs on land and no longer depend on water.

The amniote egg is unique in many ways – it has a hard calcareous or tough leathery shell that protects the contents. Underneath the porous shell is a vascularised chorion membrane by means of which the embryo breathes. Now, for the first time, there is no larva that has to fend for itself and find food on its own. The embryo inside the amniote egg is instead supplied a food source for its long stay inside the egg in the form of a bag filled with yolk which is connected to the digestive system, while waste is captured in another bag – the allantois. The yolk and allantois cause the amniote egg to be much bigger than those of the amphibians and much fewer are laid at a time; this, in turn, paves the way for parental care.

The origin of the amniote egg also caused a revolution in mating strategies. The eggshell is formed while the egg is in the mother's uterus. This implies that fertilisation now has to be internal and not external, as in the case of the fish and amphibians. This implies that copulation has to take place to deliver sperm to the ovum inside the female – and this is where society and, especially, all religions lose their objectivity. Copulation seems to be more personal than releasing sperm in the water in the proximity of eggs and regulations to control sperm donation sprung up in every walk of life. Religions throughout the world have had an unhealthy obsession with reproduction over thousands of years, an obsession which manifests itself in initiation ceremonies, the ritual mutilation of sexual organs, fertility rites, enforced celibacy, etc. (Durand 2010). If the amnion membrane never evolved, people might not be stoned or beheaded for adultery but for coveting their neighbour's Jacuzzi – especially if there were eggs in it.

The origin of the amniote egg was one of the most important adaptations for life on land because it finally freed tetrapods from the need to reproduce in water. The amniotes diversified into a wide variety of reptiles, including the synapsids, which gave rise to the mammals and the dinosaurs and which, in turn, gave rise to the birds.

The emergence of mammals

The synapsids, or mammal-like reptiles, were the first group of reptiles to evolve from the early stem reptiles in the Carboniferous period, approximately 300 million years ago (see Fig.13). The synapsids provide us with a range of characteristics which documents the transition of primitive reptile into mammal over a period of 100 million years. Some of these transformations can be seen in the skeletons of synapsids, which include the development of a new differentiated dentition, the reorientation of the legs, and the enlargement of the braincase. There are other subtle skeletal characteristics by means of which we can infer soft-body modifications such as the origin of the diaphragm, the origin of suckling, hair, and warm-bloodedness.

Mammals are known for characteristics such as warm-bloodedness, live birth and possessing hair, external ears and milk glands. These characteristics are not all equally useful for the definition of mammalness. Birds, for instance, have a higher body temperature than mammals and maintain a more stable body temperature than mammals such as bats, which experience a drop in their body temperature to a few degrees above the ambient temperature when they hibernate, similar to that of hibernating frogs and reptiles. Mammals such as moles, whales, dolphins, dugongs, manatees and pangolins do not have external ears. The platypus and echidnas of Australia and New Zealand lay eggs like reptiles do, and therefore give birth to young, as do the marsupials and placental mammals. Mammals such as whales and dolphins have retained only rudimentary hair around their lips. The only characteristic of those mentioned which is valid for defining mammalness is the possession of milk glands because all mammals, and only mammals, possess milk glands. Unfortunately, the nature of milk glands is such that they have left us with no trace in the fossil record.

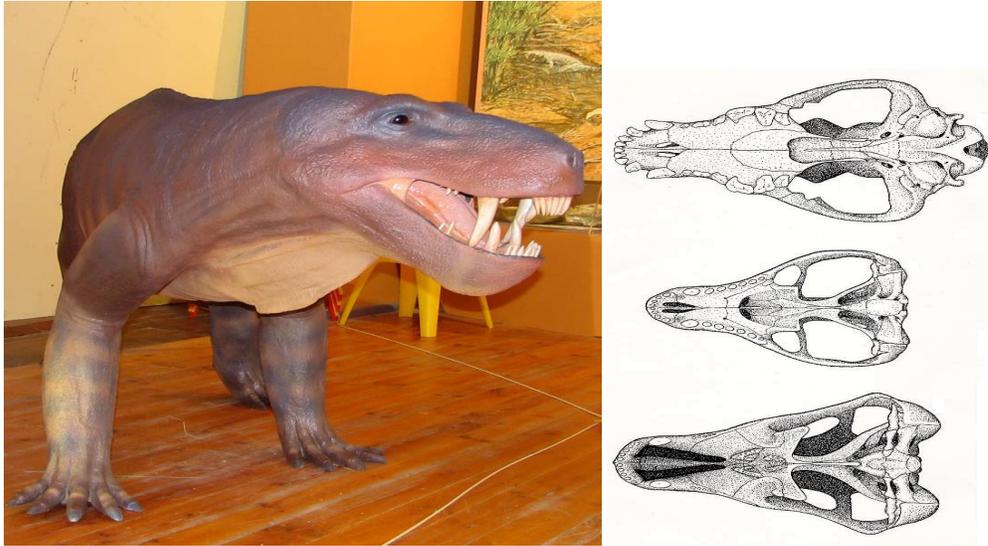


Figure 13

Synapsids or mammal-like reptiles

Left: Carnivorous synapsid of the Permian period.

Right: ventral view of the skulls of *Gorgonops* a primitive synapsid (bottom), *Thrinaxodon* an advanced synapsid (middle) and dog (top) showing the closure of the palate.

Most fossils of vertebrates consist of skeletons and therefore our search for the origin of mammals has had to be based on skeletal evidence. Most of the mammalian characteristics evolved so gradually, over 100 million years, that none of it could be used as a well-defined border between mammals and reptiles. The morphology of the middle ear is completely different in extant mammals and reptiles and, although this transition can also be seen in synapsid fossils, there is a cut-off point between those with only one ear ossicle – the stapes or stirrup – in the middle ear, and those who have an additional two ear ossicles – the malleus (hammer), incus (anvil) besides the stapes. The synapsids with only one ear ossicle are regarded as reptiles, even though some of the more advanced forms were warm-blooded, had hair and suckled their young. Those with three ear ossicles are regarded as mammals, even though the extra two were still attached to the lower jaw and not encased inside the bulla, as is the case in modern mammals.

Unfortunately, in our attempt to provide a clear-cut definition for taxonomical reasons we missed the most important characteristic, which may have changed too slowly over time to be useful for classification, but which is so important for mammals that it cannot be ignored. This characteristic is the closure of the palate, which is a necessary prerequisite for suckling (Maier *et al.* 1996) (see Fig.13). Without a palate and lips, the baby animal cannot generate the vacuum necessary for suckling. This is the single most important evolutionary innovation of mammals and the one characteristic after which they were named. Milk provides the young not only with water, but also a wide range of nutrients and also has anti-bacterial properties, which boosts the baby's immune system. This characteristic gave mammals a huge evolutionary and ecological advantage.



Figure 14
Suckling synapsids

The mammal-like reptile *Thrinaxodon* suckling her young (left);
the mammal Mary suckling her's in Andra Solario's *Madonna with the green cushion* (1507-1510) (right).
The emergence of primates

The term "Primate" (Latin: prime, first in rank) was coined by Linnaeus (Carl von Linné) in 1758 to denote a member of the mammal order in which humans, which he considered to be the crown of creation, and their allies resorted. Primates are known for their five-fingered (pentadactyl) hands with an opposable thumb and, in most cases, pentadactyl feet with an opposable big toe (see Fig.15). In most cases, the fingers and toes are equipped with nails. Their forward-orientated eyes, which allows for stereoscopic vision, are enclosed in eye sockets which are encircled in bone. The muzzle of monkeys and apes has become shorter than that of the prosimians such as lemurs, thus providing them with a flatter face and limited olfactory abilities compared with those of other mammals. This shortening of the muzzle is accompanied by a reduction of incisors to four from the original six in the upper and lower tooth row as found in the prosimians. Primates have larger brain to body ratios than other mammal groups, and possess a large cerebrum with a calcarine fissure and a well-developed cerebellum with a posterior lobe. We have not only descended from the apes – we are morphologically and physiologically still apes.



Figure 15

Primate hands and feet showing opposable digits from Lydekker, R. *et al.*, 1893 (left) and *Christ cleansing the temple* by Valentin de Boulogne 1618 (right).

The emergence of humankind

Between 5.4 and 6.3 million years ago, hominins arose from an ancestor that we share with the chimpanzees (Patterson *et al* 2006). Hominins are characterised by bipedalism which, we think, was an adaptation to life on the African savannah. The upright posture, which came with bipedalism, enabled hominins to see over the grass in order to detect predators and which made it possible for them to find their way in the veld. The face of the apemen became flatter to facilitate peripheral vision which enabled them to see down to the ground immediately in front of them, a characteristic that was essential for moving around without tripping over obstacles. The teeth, but especially the canines, became smaller during the foreshortening of the muzzle and, with this adaptation, apemen lost their most important method for defence. The only way they managed to survive for more than a million years before the origin of technology was to breed as fast as the predators could kill them (Durand 2010).

Hominins diversified on the African savannah, especially after the invention of technology, approximately 2 million years ago. Even in the absence of many probable branches which either have not been preserved in the fossil record, or which have not yet been discovered, the family tree of hominins is rather bushy and does not resemble a ladder (see Fig.16). There were even, at one stage of hominin evolution, at least four hominin species living in Africa at the same time. The characteristic which sets early *Homo* and *Australopithecus* apart is not so much a dramatic increase of the braincase or any other physical attribute, but rather the invention of technology. *Homo* was the first genus to manufacture tools and notably not pottery, writing, beads or huts – but tools for killing.

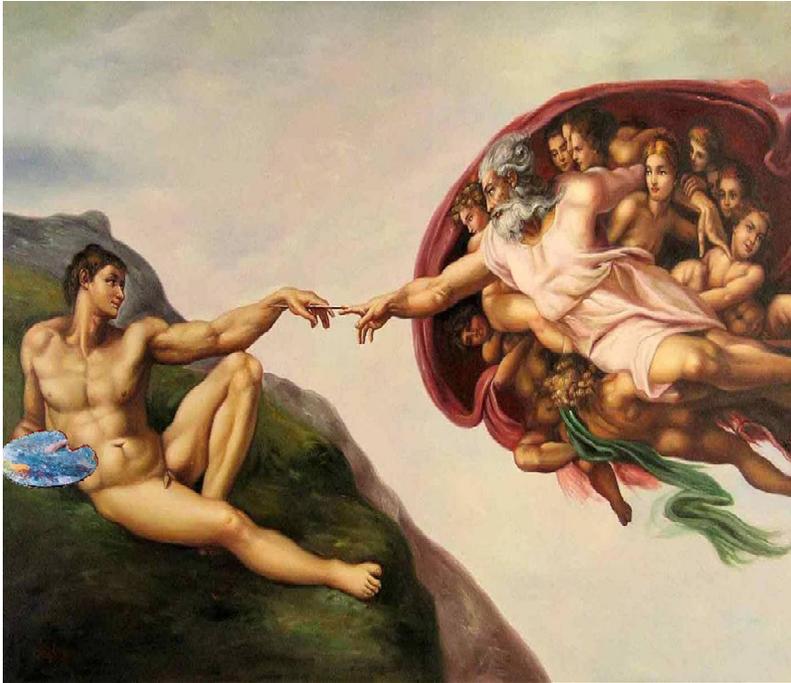


Figure 17

Man creating god after his own image
(based on *God creates Adam* by Michaelangelo)

Summary

Humans have a very subjective outlook on nature and our position in it. Our imagination is evidently severely limited: even our most bizarre dreams of supernatural beings, aliens and gods are mere elaborations of the known and familiar.

According to Greek legend, Prometheus created humankind after his brother Epimetheus, who was tasked to create the animals, gave away all the good attributes to them. Prometheus then created humankind in an upright posture like that of the gods. According to Semitic legends, gods created humankind in their own image. This strongly implies that the gods must be eukaryotic, multicellular, animal, chordate, vertebrate, tetrapod, mammal, primate and hominin.

Emotionally or psychologically our gods also resemble humankind – they are as terrible, compassionate, loathsome, good, evil, benevolent and indifferent as we are. Our views of the gods are mere projections of our own hopes and fears. The belief that the gods have a special relationship with us over all the other millions of species on earth has skewed our view of our position in nature where we regard nature as something we can subjugate for our needs. It has filled us with an arrogance which not only is reflected in our treatment of the environment but also each other because not only are the gods species specific, but also ethnic and culture specific. Every religion on earth believes that its gods are the only true gods and that these gods favour them above all others. These gods look, think and behave just like the people that created them (see Fig. 17).

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Explanatory notes:

Apeman: a pre-cultural or pre-*Homo* hominin.

Hominin: an organism on the evolutionary branch extending from the common ancestor of the chimpanzees and humankind to modern humans. This includes all the species belonging to *Australopithecus*, *Paranthropus* and *Homo*.

Ma: million years.

Primitive humans: members of the genus *Homo* that are older than *Homo sapiens*.