

pithecus and *Homo*. Within these two groups, however, there were still many species and unknown relationships. The organizing principle that created a more coherent picture was the evolutionary tree.

Science and Discovery

The Evolutionary Tree and Taxonomy

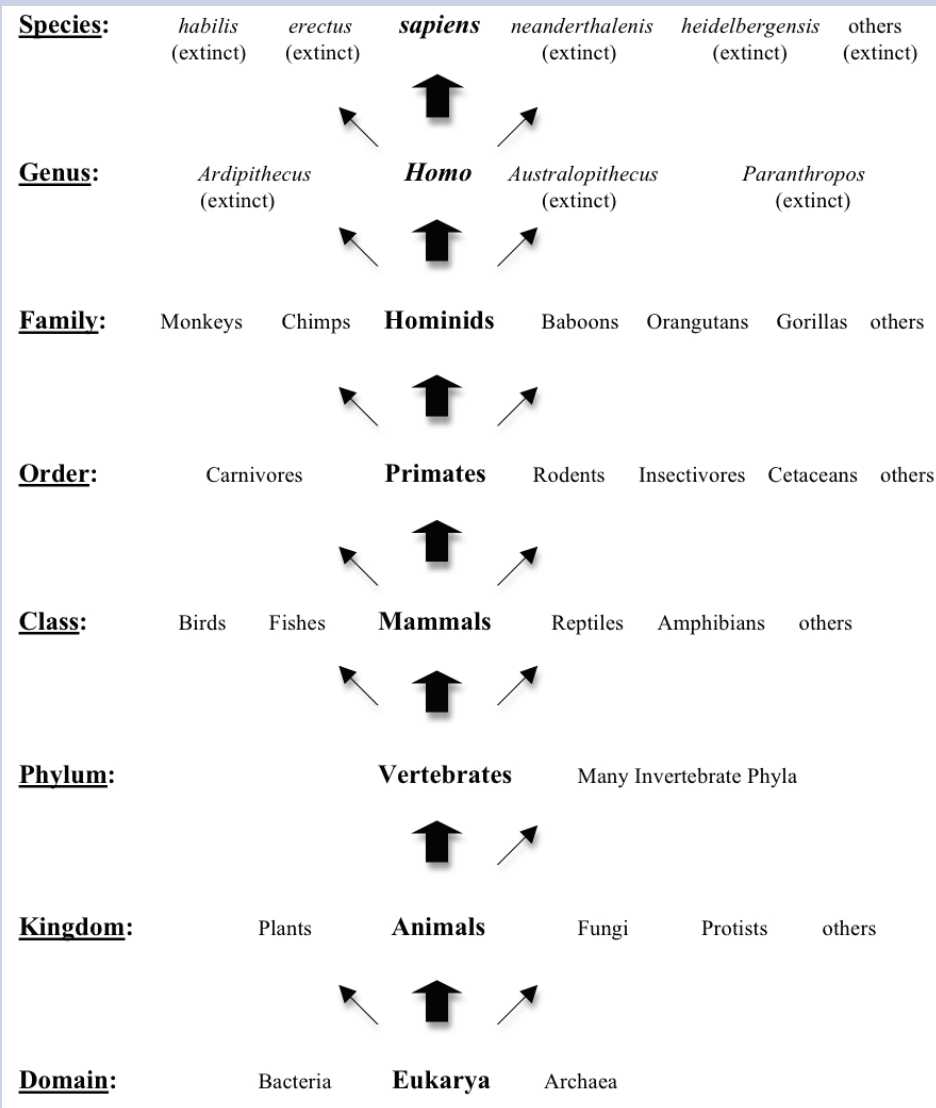
Hominid evolution and the evolution of all life on Earth begin to make sense when viewed as an evolutionary tree; the way in which scientists classify and name living things, called *taxonomy*, is based on the evolutionary tree of life. Today's system of taxonomy, using genus and species names, originated with the work of Carl Linnaeus in the mid-1700s, about a hundred years before Darwin solidified the concept of the evolutionary tree.

Biological taxonomy gives a two-part scientific name to every life form, past and present. The two parts are a genus name and a species name. Modern humans are in the genus *Homo*, and species *sapiens*. This two-part name is usually italicized when it is written, with the genus name capitalized and the species name in lower case. So our scientific name is *Homo sapiens*. The scientific name for the chimpanzee is *Pan troglodyte*; the domestic dog is *Canis familiaris*. However the genus and species are only the most specific levels of description. More completely, every life form belongs to a domain, a kingdom, a phylum, a class, an order, a family, a genus and a species. A complete classification of modern humans is shown in 8-3. You could say that the complete scientific name for you and me is *Eukarya Animalia Chordata Mammalia Primatae Hominidae Homo sapiens*; but let's stick with *Homo sapiens*!

Taxonomy, however, is more than just a naming scheme—it represents a pathway on the evolutionary tree. Notice in Figure 8-3 that moving from the domain at the bottom to species at the top depicts evolutionary history. Going from the domain to the species corresponds to moving up the evolutionary tree, from the trunk to the ends of branches. A living species, occupying the tips of the branches on the evolutionary tree, is the culmination of a long evolutionary path. The complete taxonomic classification for humans—Eukarya, Animalia, Chordata, Mammalia, Primatae, Hominidae, Homo, sapiens—describes the unbroken evolutionary path that led to modern humans.

Until recently our understanding of the evolutionary tree was based only on *morphology*, or the physical appearance of organisms. For example, common vertebrates can be easily classified by looking at some very obvious physical characteristics: those that have fins and swim in water are fishes, those that have feathers and fly are birds, those that have hair and suckle their young are mammals, and so on. Today, in addition to morphology, we use DNA analysis to determine the evolutionary relationships between organisms, mapping out the evolutionary tree from the information stored in the genes of the DNA molecule. We now see the evolutionary tree as a map of how DNA has changed and moved through time, as life evolved. Darwin, standing on the shoulders of Linnaeus, made a giant leap when he recognized that life was organized in a many-branching tree, and that all living things share a common ancestry. This view (sometimes called the Theory of Evolution) is now strongly supported by the information found in DNA.

Figure 8-3
The Complete Taxonomy of Humans



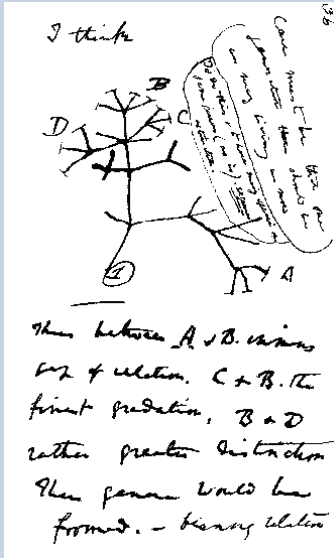
Early evolutionary trees like Edward Hitchcock's from 1840 (Figure 8-4b) had only two branches at the base, plants and animals, because these were the only two forms of life that were recognized before about 1860. By 1866 Ernst Haeckel (Figure 8-4c) identified the three main branches of life as plants, animals, and protists, and this view stood for the next 100 years or so.

In Figure 8-4e, a modern evolutionary tree is shown, with the three domains of life that are currently recognized; it is called a *phylogenetic tree* and is based on both DNA analysis (gene mapping) and morphology. The single stem or trunk at the very bottom represents the "last common ancestor" of all living things, which we think lived about 3.8 billion years ago (Chapter 4). Notice that in this modern tree, plants and animals occupy an inconspicuous place at the upper right corner.

Each of the branches in this tree split many more times, into classes, orders, families, genera, and finally species. To depict the entire tree of all life on a single page would be very difficult!

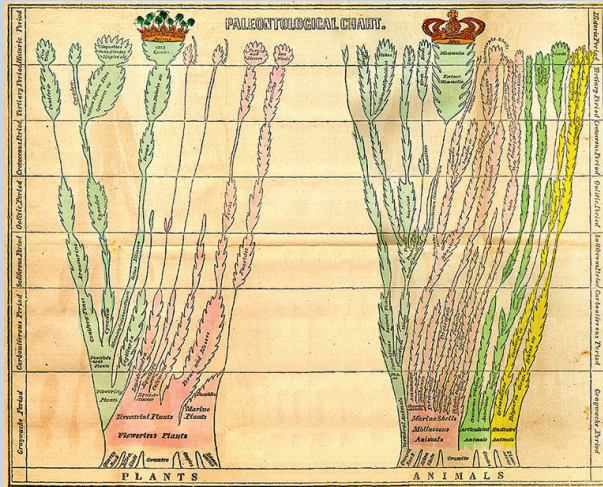
Figure 8-4
The Evolutionary Tree of Life Through History

(a) Early Darwin, circa 1837



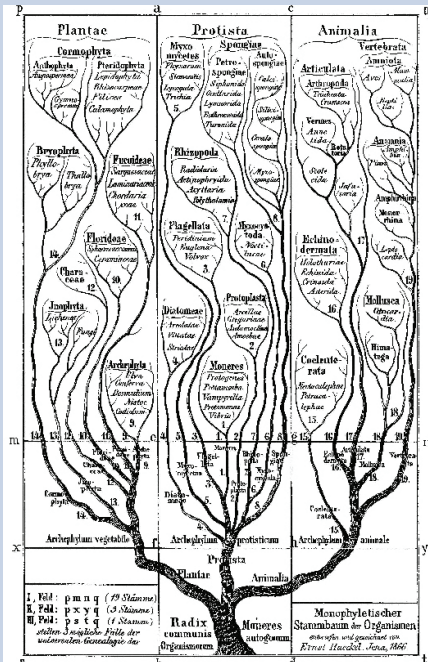
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(b) Hitchcock, 1840



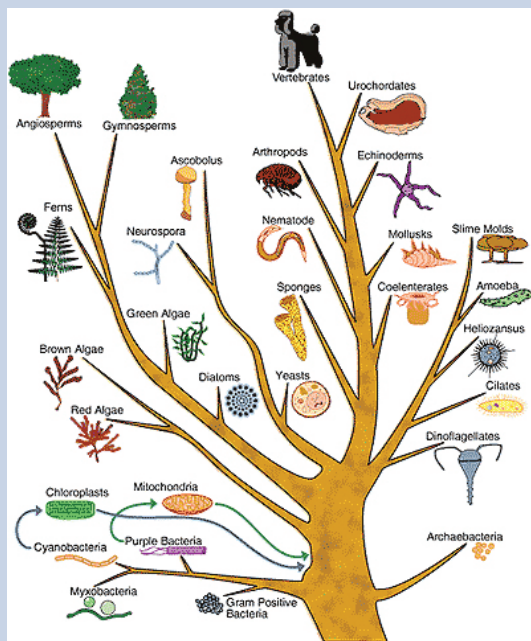
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(c) Haeckel, 1866



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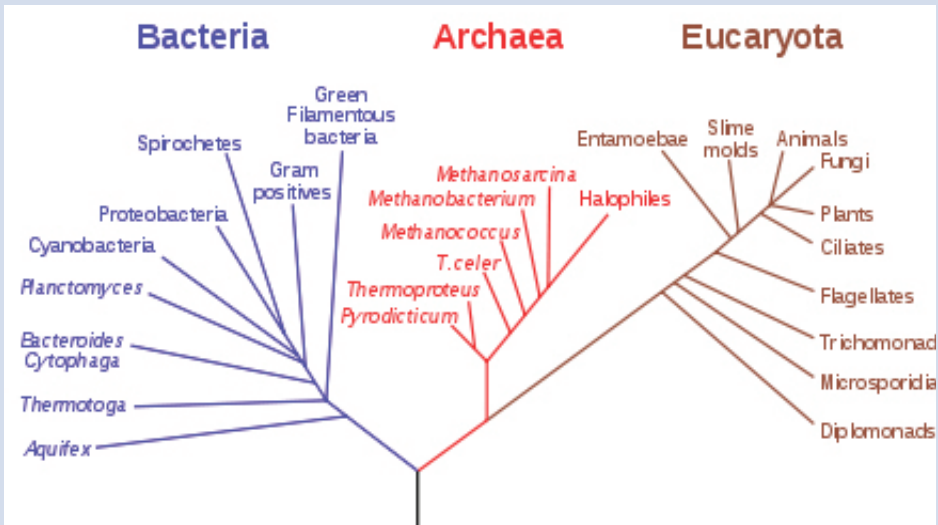
(d) Modern Pictorial



Courtesy: Consolidated Safety Services

(e) Modern Phylogenetic

Phylogenetic Tree of Life



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Exploring Deeper

Divergence, Speciation, and the Molecular Clock

As we move up the evolutionary tree, from the trunk to the tips of the branches, we are also moving through time. The history of life on Earth is recorded in the many branchings, with each split representing a new form of life. What causes a split on the evolutionary tree? That is, what causes new kinds of life to appear? This question is at the heart of how evolution works and is central to understanding hominid evolution. When a new lineage splits off from a branch of the evolutionary tree, it's called *divergence*, and the process that produces this split is generally referred to as *speciation*, or the making of a new species. Many lines of evidence suggest that a speciation event occurred about 7 million years ago when the great apes diverged into two lineages—the chimps and the hominids. What causes a divergence like this?

To understand speciation, we must first be clear about what a species is. It is, of course, the most specific grouping of life, in the way that we would probably think of roses as a species of plant. However this is not a workable definition in many cases. Although common sense might suggest that a horse and a donkey are so similar in their physical characteristics that they must be members of the same species, they are not; on the other hand, a Great Dane and a Miniature Poodle are so different looking that they would seem to be members of different species, yet they are the same species. More than similarities in appearance, the best criterion for membership in a species is *the ability to breed*. Biologists generally define a species as a *population that is able to interbreed with each other in nature and produce viable, fertile offspring*.*

* This definition of a species works fairly well for higher animals, but it does not work consistently for plants where separate species can sometimes be interbred, and it is even more problematic for simple forms of life like bacteria that share DNA quite freely.

Put more simply, an animal can mate and have healthy offspring only with members of its own species. The Great Dane and Miniature Poodle, if they find a way to mate, can actually produce a healthy fertile mutt, and therefore they are members of the same species. Yet the horse and donkey, although they can mate and produce a mule, are not members of the same species because the mule is infertile. The requirement for fertility in the offspring is not just an arbitrary rule—it's one of Nature's most important rules for living things: if you cannot pass along your genes, your lineage dies. So the horse and the donkey have no future lineage as interbreeding organisms. They are on different branches of the evolutionary tree, and the unfortunate mule is an evolutionary dead end because it cannot pass along its genes. In most cases, two organisms that are not closely related have different numbers of chromosomes in the cell nucleus (like humans with 23 pairs of chromosomes and goldfish with 40 pairs) and therefore cannot possibly interbreed. However, all humans on the Earth are members of the *same* species, because all can interbreed to produce viable fertile offspring; and we all have 23 chromosomes.

With our current knowledge of DNA, we can understand a species as a population that is so similar genetically that reproduction within the group is possible. Over many generations, however, the DNA within any population gradually changes—the slow random changes in DNA are called *genetic drift*. Eventually the DNA of two organisms whose ancestors were members of the same species may become different enough that they can no longer produce fertile offspring. If this happens, the two organisms would then be members of different species. A new species thus emerges (speciation) and a new lineage branches off of the evolutionary tree (divergence).

However, the process of speciation caused by genetic drift is very slow, probably taking millions of years to produce results. A much more powerful driver of speciation is geographic isolation, which biologists call *allopatric speciation*. To see how it works, let's imagine a population of gorillas becoming separated geographically—maybe a few members migrate to a distant place, maybe a cataclysmic event like a volcanic eruption drives the population apart, or maybe a few individuals get stranded on a log which floats across a body of water to a new land. The two separated populations will adapt to their new environments through natural selection, and underlying this will be changes in the DNA of the two populations. In a relatively short time, the original population will have diverged into two populations whose DNA is different enough that they can no longer interbreed. It was probably a scenario something like this that caused the divergence in the great ape lineage about 7 million years ago.

The process of speciation, and all of biological evolution, can now be understood as the change and flow of DNA through time. Scientists have learned to use DNA as a “molecular clock” because of the way it changes over time. When DNA is analyzed from humans living in all locations around the Earth, it is found to be about 99.9% similar. That is, all of our differences as humans are accounted for by only about 0.1% of our DNA! This remarkable similarity in the human genome also suggests that our species has not been around for very long, and that the various races of humans appeared quite recently (more on this later).

When human DNA is compared to chimp DNA, the two are found to be 98.4% similar (or 1.6% different). This tells us first of all that chimps and humans are closely related; DNA analysis confirms what we would suspect from looking at physical characteristics: chimps are our closest relatives. How long did it take human DNA and chimp DNA to become different by 1.6%? Scientists have now been able to estimate the rate of change of DNA, and that estimate turns out to be a change of about 1% every 4.4 million years. Using this rate, the 1.6% difference in chimp and human DNA translates into about 7 million years. This suggests that chimps and humans had a common ancestor about 7 million years ago, and then something caused the population to diverge into two different lineages.

This DNA clock technique has been used to date other divergences over the last 20 million years or so (the technique is probably not valid for times much longer than this). When gorilla DNA is compared to human DNA, a difference of 2.3% is found, showing that we are less closely related to gorillas and that our lines diverged about 10 million years ago. However the technique is limited to things that we can extract DNA from—organisms that are either living or that lived fairly recently. Scientists have now been able to extract DNA from 35,000-year-old Neanderthal bones and this has revealed important information about our relationship to Neanderthals, as we will see later in Chapter Nine. For anything much older than this, it has not yet been possible to extract viable DNA. If this *was* possible, many of the open questions in the field of paleoanthropology would be resolved.

First Hominids

It's been about 7 million years since the human lineage diverged from the chimpanzee lineage, and for the first few million years of this time we have very little evidence to show us exactly what our ancient ancestors looked like. Hominid fossils older than 4 million years were not found until 1992 and very few have been found since then (see Appendix IV for a summary of hominid fossils). We do know that early hominids were probably about 4 feet tall and very ape-like. If they walked upright on two legs, it was probably awkward because they lived in the forest and spent most of their time swinging from tree branches, as their primate ancestors had done for millions of years.

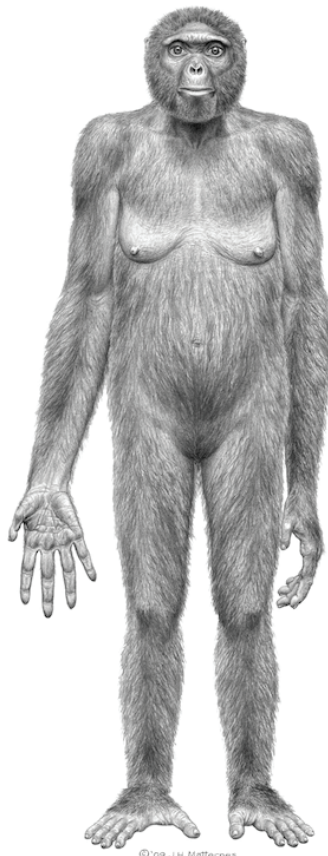
The oldest hominid fossil to date is called *Sahelanthropus tchadensis*, nicknamed Toumai. It was found in the desert of southern Chad in 2001 and has been dated to between 6 and 7 million years old. Its discoverers believe that it falls on our side of the human-chimp split, but this remains controversial. Toumai is undoubtedly very close to being the last common ancestor of humans and chimps. The partial skull indicates that it had a chimp-like brain with a size of about 350 cc, but no bones below the skull have been found so it is not known whether it was bipedal.

In the year 2000, a 6-million year old hominid fossil was found in Kenya and given the name *Orrorin tugenensis*. The fossil remains consisted of a partial femur, bits of a lower jaw and a few teeth, but no skull fragments. It is thought that *O. tugenensis* stood about 4 feet tall and had small teeth that were more human-like

than chimp-like. Grooves on the femur from muscle attachments suggest that it was bipedal, but the very limited evidence leaves much uncertainty about this species.

Teams working in Ethiopia between 1992 and 2001 unearthed fossil fragments of two different species that are thought to have been members of the same genus, which was given the name *Ardipithecus*. *Ardipithecus kadabba* lived about 5.5 million years ago and *Ardipithecus ramidus* dates to about 4.4 million years ago, and both species were clearly becoming bipedal. Tim White and his team worked for 15 years to reconstruct a badly crushed *ramidus* specimen, and finally in October of 2009 revealed it to the world, having dubbed it “Ardi” (*Science Magazine* 2009). Ardi, presumably female, stood about 1.2 meters (4 feet) tall, weighed in at about 50 kilograms (110 pounds), and had a small brain with a volume of 300-350 cc. She displayed a surprising mix of apelike and monkeylike features but she did not look like a chimp, making it clear that humans did not evolve from chimps; instead, chimps and humans had a common ancestor, and Ardi offers a very good glimpse of what it looked like (see Figure 8-5).

Figure 8-5
Artist's Conception of Ardipithecus ramidus



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