Am I a Monkey?

I AM A PRIMATE. Monkeys are primates, but humans are not monkeys. Primates include monkeys, apes, and humans. Humans are more closely related by descent to apes than to monkeys. That is, the apes are our first cousins, so to speak, while the monkeys are our second or third cousins. Among apes we are most closely related to the chimps, less so to the gorillas, and even less to the orangutans. The human lineage separated from the chimp lineage about 6 or 7 Ma (million years ago). We know about these matters in three ways: by comparing living primates, including humans, with each other; by discovery and investigation of fossil remains of primates that lived in the past; and by comparing their DNA, proteins, and other molecules. DNA and proteins give us the best information about how closely related we are to each of the primates and they to each other. But to learn how human lineage changed over time as our ancestors became more and more humanlike, we have to study fossils.

Darwin's theory of evolution asserted that humans and apes share common ancestors, which were not human. His contemporaries questioned where the "missing link" was, the intermediate organism between apes and humans. Darwin published his best-known book, *The Origin of Species*, in 1859; in 1871, he published *The Descent of Man*, which extends the theory of evolution to humans; he died in 1882. Primates that were ancestors to humans after our lineage separated from the chimp lineage are called hominids (or hominins). At the time of Darwin's death, no hominid fossils ancestral to modern humans were known, although he was persuaded that they would eventually be found. The first hominid fossil was discovered in 1889 by a Dutch physician, Eugene Dubois, on the island of Java. It consisted of a femur and a small cranium. Because he was expert in human anatomy, Dubois knew that these fossils belonged to an individual with bipedal gait; the femur was very similar to the femur of a modern human. But the capacity of the small cranium was about 850 cc (cubic centimeters), which could hold a brain weighing somewhat less than 2 pounds (a pound is 454 grams, equivalent to 454 cc), while the cranium of a modern human is about 1,300 cc (with a brain of about 3 pounds). The fossil discovered by Dubois was from an individual who lived about 1.8 Ma and is now classified in the species *Homo erectus*. Our own species is called *Homo sapiens*.

The "missing link" is no longer missing. The fossil from Java was the first one, but hundreds of fossil remains belonging to hundreds of individual hominids have been discovered in the twentieth and twenty-first centuries in Africa, Asia, and Europe and continue to be discovered at an accelerated rate. These fossils have been studied and dated using radiometric and other methods. Some fossil hominids are very different from others, as well as from humans, and are classified in different species. The record of fossil hominids that lived at different times shows that several changes occurred through time in the lineage of modern humans. One change was increase in body size; another was increase in cranial capacity (and brain size). The species names are sometimes exotic, referring in some cases to the place where the fossils were found or their morphological characteristics and determined in others by the whim of the discoverers.

The oldest known fossil hominids are 6 to 7 million years old, come from Africa, and are known as *Sahelanthropus* and *Orrorin*. Their anatomy indicates that they were predominantly bipedal when on the ground, but they had very small brains. *Ardipithecus* lived about 5.5 Ma, also in Africa. Numerous fossil remains from diverse African origins are known of *Australopithecus*, a hominid that appeared about 4 Ma. *Australopithecus* had an upright human stance but a cranial capacity of about one pound, comparable to that of a gorilla or chimpanzee and about one-third that of modern humans. The skull of *Australopithecus* displayed a mixture of ape and human characteristics—a low forehead and a long, apelike face but teeth proportioned like those of humans. Other early hominids partly contemporaneous with *Australopithecus* include *Kenyanthropus* and *Paranthropus*; both had comparatively small brains, although some species of *Paranthropus* had larger bodies. *Paranthropus* represents a side branch of the hominid lineage that became extinct.

Much more similar to us are hominids classified as *Homo habilis*, the earliest species classified in the same genus as our own, *Homo*. These ancient individuals made very simple stone tools, the first hominids to do so, which is why they were given the name *habilis*, Latin for "handy" or "skilled." They had a cranial capacity of about 600 cc, greater than that of any of the earlier hominids, but less than half the brain size of modern humans. *Homo habilis* lived in tropical Africa between 2.5 and 1.5 Ma. In *Homo habilis* we can see the modest beginnings of human technology.

Homo habilis was succeeded by *Homo erectus*, which evolved in Africa somewhat before 1.8 Ma, had a cranial capacity of 800 to 1,100 cc (2 to 2.5 pounds), and made tools more advanced than those of *Homo habilis*. Two features of *Homo erectus* deserve particular attention. One is that the species persisted (with relatively small morphological changes at various times and places) for a long time, from 1.8 Ma up to nearly 400,000 years ago (ya). A second distinctive feature of *Homo erectus* hominids is that they were the first intercontinental wanderers. Shortly after their emergence in Africa, they spread to Europe and Asia, reaching as far as northern China and Indonesia (where Dubois found the first hominid fossils ever discovered) as early as 1.6–1.8 Ma, and persisted until perhaps 250,000 ya.

Two hominid species that evolved after *Homo erectus* are *Homo neanderthalensis* and *Homo sapiens*, our own. Numerous *Homo neanderthalensis* ("Neanderthal man") fossils have been found in Europe, where they first appear about 200,000 ya and became extinct 30,000 ya. The most recent fossils of *Homo neanderthalensis* were found in Spain, where they seemingly had their last abode. Neanderthals had large brains, much like ours, and bodies also similar to ours but somewhat stockier.

The evolution from *Homo erectus* to *Homo sapiens* may have started about 400,000 ya, from which time fossils have been found that are considered "archaic" forms of *Homo sapiens*. Anatomically modern humans evolved in Africa around 200,000 or 150,000 ya and eventually colonized the rest of the world, replacing other hominids. The *Homo erectus* that had earlier colonized Asia and Europe did not leave any direct descendants. (A possible exception is *Homo floresiensis*, the minuscule hominids whose fossil remains were discovered in 2004 on the Indonesian island of Flores, where they lived 12,000–18,000 ya. They may have been direct descendants of Asiatic *Homo erectus*, although the matter is still being investigated.)

The colonization of the world continents by modern *Homo sapiens* is relatively recent: Southeast Asia and the region that is now China 60,000 ya and Australasia shortly afterward; Europe only about 35,000 ya; America about 15,000 ya by colonizers from Siberia. Ethnic differentiation among human populations is therefore relatively recent, a result of divergent evolution between geographically separated populations during the past 60,000 years.

The Human Genome Project of the United States was initiated in 1989, funded through two agencies, the National Institutes of Health and the Department of Energy. (A private enterprise, Celera Genomics, started in the United States somewhat later but joined the government-sponsored project in achieving, largely independently, similar results.) The goal was to get the complete sequence of one human genome in fifteen years at an approximate cost of $3 billion, coincidentally about one dollar per DNA letter. A draft of the genome sequence was completed ahead of schedule in 2001. In 2003, the Human Genome Project was finished.

Obtaining the DNA sequence of a human genome was a great technological feat. As pointed out in chapter 3, printing the 3 billion nucleotides sequence of the DNA of a human genome would require a thousand volumes of a thousand pages each. The feat of sequencing such an enormously long genome was made possible by the development of new technologies that now make it simple, relatively speaking, to sequence genomes of that size. The DNA genomes of a few human individuals have been sequenced in the last few years, at a cost each of only about $100,000 (compared with the cost of $3 billion for the first human genome sequenced) and requiring only about one month, rather than fourteen years.

The DNA genome sequences of many other species have now been completed, in particular that of the chimpanzee, first published on September 1, 2005. Comparisons between the two genomes are being made, seeking to understand what it is at the genetic level that makes us distinctively human. It came as a surprise to many that in the genome regions shared by humans and chimpanzees, the two species are 99 percent identical. This difference appears to be very small or quite large, depending on how one chooses to look at it: 1 percent of the total seems very little, but it would amount to a difference of 30 million DNA letters out of the 3 billion in each genome.

When we compare the genomes in greater detail, it turns out that 29 percent of the enzymes and other proteins encoded by the genes are identical in both species. Out of the one hundred to several hundred amino acids that make up each protein, the 71 percent of nonidentical proteins differ between humans and chimps by only two amino acids on average. If one takes into account DNA segments found in one species but not the other, the two genomes are only about 96 percent identical. That is, a large amount of genetic material—about 3 percent, or some 90 million DNA letters—has been inserted or deleted since humans and chimps initiated their separate evolutionary ways, 6 to 7 Ma. Most of this DNA does not contain genes coding for proteins.

Comparison of the two genomes has provided insights into the rate of evolution of particular genes in the two species. One finding is that genes active in the brain have changed more in the human lineage than in the chimp lineage. On the whole, 585 genes, including genes involved in resistance to malaria and tuberculosis, have been identified as evolving faster in humans than in chimps. (Note that malaria is a much more severe disease for humans than for chimps.) There are several regions of the human genome that seem to contain beneficial genes that have rapidly evolved within the past 250,000 years. One region contains the *FOXP2* gene, involved in the evolution of speech, discussed in chapter 3.

We now know some basic features that contribute to human distinctness: the large brain and the accelerated rate of evolution of some genes, such as those involved in human speech. This knowledge is of great interest, but what we so far know advances but very little our understanding of what genetic changes make us distinctively human.

Extended comparisons of the human and chimp genomes and experimental exploration of the functions associated with significant genes will advance considerably our understanding, over the next decade or two, of what it is that makes us distinctively human. The distinctive features that make us human begin early in development, well before birth, as the linear information encoded in the genome gradually becomes expressed into a four-dimensional individual, an individual who changes in configuration as time goes by. In an important sense, the most distinctive human features are those expressed in the brain, those that account for the human mind and for human identity.

One outcome to take into account as we seek to know what makes us distinctively human and so different from other primates is that, with the advanced development of the human brain, biological evolution has transcended itself, opening up a new mode of evolution: adaptation by technological manipulation of the environment. Organisms adapt to the environment by means of natural selection, by changing their genetic constitution over the generations to suit the demands of the environment. Humans (and humans alone, at least to any significant degree) have developed the capacity to adapt to hostile environments by modifying the environments according to the needs of their genes. The discovery of fire and the fabrication of clothing and shelter have allowed humans to spread from the warm tropical and subtropical regions of the Old World, to which we are biologically adapted, to the whole earth except for the frozen wastes of Antarctica. It was not necessary for wandering humans to wait until genes providing anatomical protection against cold temperatures by means of fur or hair would evolve. Nor are we humans biding our time in expectation of wings or gills; we have conquered the air and seas with artfully designed contrivances—airplanes and ships. It is the human brain (or rather, the human mind) that has made humankind the most successful living species by most meaningful standards.

One exciting biological discipline that has made great strides within the past two decades is neurobiology. An increased commitment of financial and human resources to that field has enabled an unprecedented rate of discovery. Much has been learned about how light, sound, temperature, resistance, and chemical impressions received in our sense organs trigger the release of chemical transmitters and electric potential differences that carry the signals through the nerves to the brain and elsewhere in the body. Much has also been learned about how neural channels for information transmission become reinforced by use or may be replaced after damage; about which neurons or groups of neurons are committed to processing information derived from a particular organ or environmental location; and about many other issues concerning neural processes. But despite all this progress, neurobiology remains an infant discipline, at a stage of theoretical development comparable perhaps to that of genetics at the beginning of the twentieth century when Mendel's laws of heredity were rediscovered. Those things that count most remain shrouded in mystery: how physical phenomena become mental experiences (the feelings and sensations, called "qualia" by philosophers, that contribute the elements of consciousness) and how out of the diversity of these experiences emerges the mind, a reality with unitary properties such as free will and the awareness of self that persist throughout an individual's life.

I do not believe that the mysteries of the mind are unfathomable; rather, they are puzzles that humans can solve with the methods of science and illuminate with philosophical analysis and reflection. And I will place my bets that, over the next half century or so, many of these puzzles will be solved. We shall then be well on our way toward heeding the injunction "Know thyself."

Is evolution "just" a theory? In the next chapter I assert that evolution is indeed a theory. But it is a theory in the scientific sense, not just a guess or hunch but a well-integrated body of scientific knowledge supported by innumerable observations and experiments. Therefore, evolution is a fact as well as a theory.