Myth Six

People Come from Monkeys

It's the summer of 1860, in Oxford, England, and Darwin's *On the Origin of Species* has been in print for only seven months. Over five

hundred people—men in somber suits and women in summer dresses—have assembled to hear the latest scientific findings at a meeting of the British Association. At the podium Bishop Samuel Wilberforce (1805–1873) lays into Darwinism, the daring theory implying that humans are not divine creations, but instead evolving animals. Wilberforce achieves a crescendo when he pointedly asks, was it "through his grandmother or his grandfather that he was descended from a monkey?"[1]

Wilberforce's shrill comments could be expected from clergy in 1860. After all, Darwin's theory challenged some basic concepts that had been long held by Western civilization, and the Christian Church in particular, for nearly two thousand years: that life—including humans—was created by divine act, and that humans were divinely special, distinctly different from the rest of animal life. Even though the church had already backed away from a lot of clearly untenable positions—like the view that Earth is at the center of the universe—it still hadn't managed to let go of "human specialness."

Since 1860 the same basic scientific method that has identified how to make planes fly and computers calculate has thoroughly tested the validity of evolutionary theory, and the overwhelming consensus is that, yes, Darwin was right. With nearly a century and a half of experiments and observations supporting evolution, as well as the connections between humans and other primates, you wouldn't think that Wilberforce's old argument—against any human connection with "monkeys"—could still be dredged up in an attempt to discredit evolution. But in summer of 2004, in Dover, Pennsylvania, a disgruntled public school board member complained that evolution shouldn't be taught in public schools because it teaches that people "come from monkeys and chimpanzees."[2]

Neither in Oxford nor in Dover was any flaw of evolutionary theory itself pointed out. No evidence was produced that separated humans from other primates. What connects Oxford in the summer of 1860 and Dover in the summer of 2004 is that in both times and places, evolution was misrepresented, as well as criticized by a purely emotional reaction to its implications.

To evaluate this myth—that evolution claims "we come from monkeys"—we can start by asking what evolution really says about our connection to the rest of living things. Once our place in evolving nature is revealed, we can examine the second claim, that being related to monkeys is a degradation.

Our Place in Nature

The theory and study of evolution have cast light on a thousand fascinating facts that have helped flesh out our understanding of the natural world. For example, we know that viruses survive by hijacking the DNA of other organisms, that Antarctic penguins evolve very quickly, and that sea slug populations rocket and crash depending on the interactions of viruses and other small organisms that thrive inside them.[3] Each of these facts is astonishing and fascinating in its own right.

But one thing that science has discovered is so completely astonishing, especially to those who still see humans as special creations, that many widely reject it today. It is the fact that *humans are animals*. We often draw a conceptual line between ourselves and other living things, and the word *animal* is usually used to mean something decidedly nonhuman. As expressions of scorn, we talk of *animal nature*, or we say *those people behaved like animals*. But science and evolution tell us that the line between us and the rest of the animals is dotted, at best. It's not solid. Whether we like it or not, we're animals, something even Aristotle recognized over 2,200 years ago. We *have to be*: we're not minerals, as the saying goes, nor are we vegetables. Unless we believe we're special creations that popped up once and have lived on unchanged ever since—which the theory of evolution counters in principle, and which the fossil record refutes—we must be animals. And unless we want to ignore museum vaults full of geological and fossil discoveries showing that species evolve through time, then we must admit that we, too, have an evolutionary

past. How can we find out about our past and our position in the present world of living things? We can begin simply by surveying the world of living things and attempting to locate our position within it. Of the living things, what are we humans least like, and what are we most like?

Before we begin, we have to remember to be careful with how we interpret what we find. We humans have long recognized the differences between ourselves and every other kind of life, and what we've thought of those other kinds hasn't always been complimentary. In their book on human origins, *Shadows of Forgotten Ancestors*, Carl Sagan and Ann Druyan describe the Victorian attitude toward chimpanzees by quoting Boston physician Thomas N. Savage, who characterized chimpanzees as "vile," "degenerate," "filthy," and "depraved."[4] Throughout the history of Western civilization, we have looked suspiciously on nonhuman primates, sometimes envisioning them as devils, sometimes as misshapen, half-human wretches created by God as a warning against sin.[5] Even when we look at animals other than primates, we have an obvious hierarchy of preferences; we love mammals, particularly those with big eyes and soft fur a bit more than we love, say, fish, but we love fish more than ants or spiders.[6] In the past, as we groped for a meaning or explanation of apes and of all other living things, we kept them at a distance. But if we're going to take an honest look at the rest of life, and ourselves, and our connections with the rest of life, we have to leave these kinds of emotional evaluations behind. We have to have the courage to look not only into the mirror, but also through our family history, through trunks of ancient letters and newspaper clippings. And we must think about what we find in there.

Where to start? Everywhere we look, we see life. Stopping life from multiplying and overrunning us seems to be a constant task; we mow our lawns, weed our gardens, brush our teeth, and wash our dishes, all to keep down one kind of life or another. How do we find our place in the natural world, the world that teems with millions of living species?[7]

Clearly, we have to start by looking at obvious groupings; for example, things that we can eat and things that we can't eat. But there are so many types of life out there, from slime molds to pine trees to hawks. And, of course, we could classify things in any number of ways: by their size, for example, or where they're found, or even how they taste (sweet, sour, or tart)—like the English eccentric William Buckland, who attempted to eat his way ". . . right through the animal kingdom."[8] But are all of these ways of classifying equally valid? Obviously not. A lot of classifications would be transparently self-serving, and if we're intending to find our place in nature rather than assuming we're at its center, or pinnacle, then we need an objective way of grouping life—a way that doesn't judge species by their usefulness to us.

This was exactly what Carolus Linnaeus (1707–1778), a Swedish medical student, accomplished in 1735, when he published *Systema Naturae*, his classification of all known living things. The Linnean system was revolutionary. Like Darwin's later challenge to human specialness, it was a challenge to another ancient belief, the *Great Chain of Being*, which (as we saw in "Myth Three: The Ladder of Progress") classified living things by the degree of perfection they were thought to possess. But Linneaus classified things by how they looked and by their outward characteristics,[9] not their degree of perfection, and he did it because the Great Chain of Being simply couldn't stretch to account for new discoveries, such as species that weren't mentioned in the Bible.

Today we continually update the Linnean system with the discoveries of new species and the clarifications of relationships based on DNA studies.[10] But we haven't abandoned the basic approach of organizing living things by their physical characteristics. Let's see what that approach tells us about our relationship to the rest of the living things on Earth.

A Journey Through the Animal Kingdom

We can take a fantastical journey, now, to visit the constellation of life-forms on Earth. We can travel high into the air, squirm through the vines and roots of dripping jungles, or plunge down to the seafloor, and everywhere we go, we'll find life. In the real world, we'd need special equipment: scuba gear, ventilators for gas-choked caverns, insulating clothes to protect us from the Arctic cold. But in the mind, we can move freely. What do we find?

At the start of our journey through the Animal Kingdom, we stand at the first fork in the road. One sign points left, declaring: "Subkingdom Protozoa." The other points right: "Subkingdom Metazoa."

If we went left, we'd plunge into the world of unicellular microbes, bacteria that swarm and multiply in even the most unlikely places; we find them wherever we lift a rock, crack apart a piece of ice, spoon up a gob of boiling mud, or swipe through the air with a jar.[11] These are life's Xerox copies, organisms that bud off near replicas without combining their genetic material with a mate. They are innumerable and diverse. We know there are over fifty thousand species of bacteria.[12] They spawn in the air we breathe and within our own bodies. They can reproduce in a matter of hours, whereas we humans have to wait over a decade before reaching sexual maturity. And they're tiny, invisible to all humans until the invention of the microscope in the late seventeenth century.[13] We commonly know them for the harm they do to us: some are responsible for diarrhea, some for pneumonia. But others are beneficial to us; they break down nutrients in soil, making agriculture possible, and others aid in our digestion.

We don't follow the sign on the left, though; we don't belong in that world of anonymous blobs. We're composed of billions of cells, not just one, and we reproduce sexually, not asexually. So we step right, making our way into the *Subkingdom Metazoa*.

In this realm we find more familiar sights: creatures made of dozens or thousands or even billions of cells. Most are highly mobile, some able to pursue prey, others able to escape predation. It's an enormous realm, crowded with every multicellular mobile creature that has ever lived, or that lives today,[14] from whiplike nematode worms (they live in your backyard, at the bottom of the Mediterranean sea, and everywhere in between) to clicking lobsters, hairy spiders, and warm, furry guinea pigs. We search for familiarity in the chaos, and we find thirty-five major groupings, each called a *phylum*—things we're like, and things we're definitely not like.

We're not much like anything in the Arthropod phylum, but that just makes us the minority. A million arthropod species have been named, and it's been estimated that there could be nine million species of them in tropical forests alone,[15] and perhaps thirty million species worldwide. These multitudes of spiders, insects, crabs, and lobsters scuttle and skitter on jointed appendages, and, compared to us, they're very strange. They're inside out! Think of a scorpion, with its skeleton on the outside, protecting its soft tissues on the inside. No, we don't belong here.

We keep looking. There's the Mulluscan phylum, which includes ingenious octopi, hardy oysters, and slow-creeping garden snails. But the octopus's fluidity and the seashells that many mollusks inhabit have strikingly different characteristics from our four-limbed bodies; again we have to keep searching for something familiar. We find other phyla, one containing corals and jellyfish, but the coral's immobility and the jellyfish's watery, baglike form are equally alien. We don't find much in common in the Bryozoan phylum either, a group of about five thousand species of mosslike animals that live in colonies beneath the sea.

But now we come to something that does look familiar, if only vaguely: creatures with a nerve cord running down the middle of the body, a sort of spine. Although not all of the members of this phylum —the *Chordata*—have skeletons, they all do have a nerve cord, and humans share it and a few other characteristics with them. Of the thirty-five forks in the road, we take the path marked "Chordata," and immediately we come to another fork: "Invertebrate Subphylum," says one sign; "Vertebrate Subphylum," says the other.

Peering down the road of the Invertebrate subphylum, we see almost thirteen hundred species, from the sea squirts (inch-diameter "sea puffballs" that filter water for food particles) to the eel-like cephalochordates, first identified from fossils over five hundred million years old,[16] and today harvested and cooked as food in South Asia. We're more like any of these than we are like the jellyfish, worms, or bacteria we glanced at earlier, but they're still strange to us, and very different from what we see ahead on the road leading to the Vertebrates. There, we vaguely perceive another great swarm of life, millions of species, but all with one great similarity to ourselves—they have distinct spines. We follow the sign "Vertebrate Subphylum."

Here are the things we easily recognize as animals. There are seven main classes. Nearly four thousand species of amphibians hop and squirm in waterways and on muddy shores. They include species as surprising as the wood frog, which can survive being nearly frozen solid for weeks at a time.[17] But we've been out of the water and the mud for a long time, and so we keep looking for closer relatives. Other classes contain the bony fishes (like tasty salmon), and cartilaginous fishes (like sharks); the reptiles (everything from dinosaurs to tortoises, snakes, and crocodiles: they are the producers of hard-shelled eggs); the birds (who also produce hard-shelled eggs, but are mostly adapted to flying as their means of getting around); and the mammals, vertebrates with hair, self-warming bodies, mammary glands for feeding the young, and relatively large brains. The mammals—now we're getting close to home. Of the seven groups of vertebrates, of the seven forks of the road, we confidently stride down the one leading to the "Mammalian Class."

Soon we arrive at three more forks, but it's getting easier to find our way now. We see three main subclasses of the mammals: the Prototheria (including the platypus and the spiny anteater), the Metatheria (the marsupials, such as the kangaroo and the opossum), and the Eutheria (the mammals whose young spend a long time developing in the placenta). We go straight down the road of the Eutheria.

We find more wonders here, but they're less-alien wonders.

There are at least nineteen orders of eutherian mammals.[18] Among them are the Cetacea, the sea mammals in whom we recognize something familiar, but more immediate to us are the Perissodactyla (*periss*, which in Greek means "odd," and *dactyl*, which means "toed"), which are the tapirs, rhinos, and horses. We know zebras almost instinctually, having lived with them on the savannas of Africa for millions of years, but it's the sight of horses that touches us emotionally. We first domesticated them around six thousand years ago,[19] and since then they have accompanied us in countless triumphs and disasters. And there are the Artiodactyls (even-toed), including our beloved cows and pigs and handy camels, and another familiar group containing friend and foe alike, the Carnivora, characterized by teeth adapted for slashing meat. This group also contains animals that touch us emotionally: bears and dogs (first domesticated over fifteen thousand years ago),[20] and cats (certainly domesticated by the time of Egyptian civilization, over three thousand years ago, and maybe as early as nine thousand years ago).[21] It seems like we're home now among the animals that we know so well. But a moment of thought reminds us that we haven't taken this journey to find the animals we're comfortable with; it's a journey of self-discovery, an attempt to find what we're most like, and least like. So we have to keep looking down the roadways of the nineteen mammalian orders.

And then we find it, the group containing the mammals we most resemble, the monkeys and apes. Of the nineteen roads, we take the fork signposted "Primates."

Here we find the vertebrates that are eutherian mammals sharing an array of traits, including dexterous hands, nails rather than claws, and reliance on vision rather than sense of smell.[22] We're like these creatures, and we're close to home now.

But again we come to another fork almost immediately, the left fork posted "Suborder Prosimii," the right, "Suborder Anthropoidea." Looking down the prosimian road, we see lemurs—catlike primates stranded on the islands off East Africa—and lorises and galagoes (the *Star Wars* Ewoks must have been modeled on these

"bush-babies"), as well as the strange tarsiers. These prosimians resemble the earliest primates of all, known to exist over sixty million years ago, and while they're clearly primates, they're also very different from us. We take the right fork, down the road of the "Suborder Anthropoidea."

Of the 233 known and living species of primates, 145 (62 percent) are anthropoid (*anthropo* meaning "human," *oid* meaning "like"). These are the monkeys, the apes, and the species they most resemble —humans. We can almost jog now, easily picking the forks in the road. The fossil record and the DNA evidence make it clear that humans didn't originate in the Americas, so at the fork dividing the New and Old World primates, we head for the Old World, the world of the Catarrhinni (named by Linnaeus for their "downward-facing nostrils"), passing by more than thirty species of South American primates, many of which are tree-dwelling monkeys we call howlers, or spiders, depending on their lively vocalizations, or their use of a tail like a fifth hand.[23]

We hardly have to slow down as we find the next major fork in the road, one leading to the monkeys, the other to the apes. Of all the primates, we're clearly from the Old World, and of those from the Old World we're more like the apes (the Hominoidea) than the monkeys (the Cercopithecoidea). Although the monkeys are very familiar, and we can read emotion in their faces, we differ from them in important ways. Unlike baboons, for example, we don't have enormous canines or tails. Also, we're much larger than any monkeys, and of course, we walk upright.

So we jog right past the monkeys and down the road leading to the Hominoidea (the "humanlike" primates). But here we have to slow down. The species are starting to look similar to one another, and suddenly it's harder to tell which we're most like or unlike. Only one group is easy to rule out. These are the gibbons (found in South Asia), whose most striking difference from us is that they're brachiators, cruising like Tarzan through the treetops, swinging from branch to branch. Although many of us like to climb things, we don't live in

the trees, and we don't move by brachiation. We can also bypass the highly arboreal (tree-dwelling) orangutan of Southeast Asian islands. Although they're aboriginally known as the "Man [*orang*] of the Forest [*utan*]" for their similarity to people, they're tree-dwellers, while we're firmly committed to the ground. We move on once again.

Now we come to the terrestrial Hominoids, who first appeared in the jungle regions of Africa. Looking back at us, from their green and leafy habitats, are the gorillas and the chimpanzees. We know them well. They're more like us—in anatomy, genetics, and behavior—than any other living thing. And there, crouched behind a bush and also observing the chimps and the gorillas, is a creature even more similar to ourselves. The creature wears clothes and holds binoculars. Wanting a better view, it stands, and we know we've arrived—a human stands before us. We've found our place in the world of the living things, and in the world of mammals, primates, and hominoids.

Our Primate Ancestors

Our tour of the Animal Kingdom brings us right back to the original contention, often used by antievolutionists, that evolution states that "we come from monkeys." Given what we've seen in the Animal Kingdom and the Primate order, is this accurate?

We're certainly similar to living and fossilized monkeys, but we're much more similar to apes. We can look at the evolution of the Primate order to see why.

An overview of primate evolution, pieced together from the fossil record (and, more recently, DNA studies) sketches out a sixty-five-million-year history of the Primate order, divided into five main "adaptive radiations," periods of substantial change in biological lineages, often driven by environmental changes.[24]

The first primate adaptive radiation occurred shortly after the fall of the dinosaurs, around sixty-five million years ago, when the earliest primates were just diverging from their early mammal ancestors. The

primate pattern was being established, and at this time primates were small, insect-eating creatures similar to squirrels. The most important difference from their nonprimate ancestors is seen in their teeth, which show adaptations for processing new food sources. Seeds, fruits, and other vegetation, commonly found in trees and bushes, were added to the insect diet, and the Primate order was under way.

Roughly ten million years later we see the second radiation. Primate faces have changed, with snouts getting smaller and eyes moving closer together, toward the front of the face. Here we have the origins of binocular vision, and a premium on vision over the sense of smell; we also see the origins of extremely dexterous hands and the reduction of claws into fingernails and toenails.[25] There's a divergence here, as some primates remained rather insectivorous and squirrel-like (the ancestors of modern lemurs), while others continued to adapt to more varied diets (the ancestors of all other primates).

About forty million years ago the fossil record indicates the next adaptive radiation, in which we see the origins of larger brains (though they're still about thirty cubic centimeters: about a tenth of the volume of a soda can), and yet further reduction in the sense of smell, but a still greater premium put on vision. And there's a major geographical event here, as well, with the establishment of a new population of primates in the New World, specifically on the continent of South America.[26]

Yet another ten million years pass before we see the fourth significant primate radiation, this one taking place in Africa, around thirty million years ago. Here we see a major divergence in which some primates focus on leaves as their main diet, while others focus on fruits. This is the earliest differentiation between monkeys (the leaf-eaters) and apes, which were somewhat larger, and, at least at first, spent more time in the trees while monkeys came to the ground.

Then, between five and ten million years ago, we see another major radiation, in which environmental changes open new habitats, and the primates radiate again, adapting to new circumstances and environments. Around six million years ago we see the origins of our

own *hominid* lineage, characterized most strikingly by *bipedalism*, or standing upright.[27] As Earth's climate changed and grasslands began to fragment the tropical forests of Africa, some of the chimpanzee-human ancestor population moved into the newly emerging terrestrial habitats, where bipedalism succeeded as a new way of life for a new variety of primate: the hominid.[28]

By two million years ago, this lineage had itself diverged into three main types of African bipeds. These were the australopithecines, divided into the lightly built variety (the graciles) that had a varied diet and lived in wooded areas, and a vegetarian variety (the robusts) that spent more time in the open savannah, eating grasses, seeds, and roots.[29] There were also the earliest members of our genus (*Homo*), characterized by large brains, far more complex tool use, ever-smaller teeth, and ever-larger bodies in general. It's clear what happened to these three types of hominids. The robusts went extinct, possibly having overspecialized on a grassy or seedy diet. The graciles also vanished from the fossil record, but this occurs just before *Homo* is found in substantial numbers. It's widely believed that some variety of gracile australopithecines evolved into early *Homo*, our ancestors.[30] The evolution of the Primate order shows us why we look so similar to the other primates, including monkeys—because we share ancestors with them.

Do People Come from Monkeys?

The simplest investigation of the characteristics of living things makes it clear that we're mammals, and that of all the mammals, we're primates. So we can dismiss some critics' lamentation that believing in evolution will drag us into the world of the primates: we're already in it. And stacks of data make it equally clear, to any thinking person, that people *don't come from monkeys*. Around thirty million years ago, the African primates diverged into two distinct groups, taking up different diets, habits, and habitats, as their environments changed and opportunities arose.[31] One group developed

into apes, which included—much later—chimpanzees, gorillas, and humans. The other group developed into monkeys, and DNA and other studies prove that we belong in the ape group instead of the monkey group. Do people come from monkeys? Not at all. We do share a common ancestor with chimpanzees, and before them, with the group that became monkeys. But to say we come from monkeys is simply wrong, and evolution has never claimed it.

Early in this chapter, we saw that Samuel Wilberforce's argument against evolution, echoed again even in 2004, was obviously emotional rather than factual. Unless we want to live in a web of lies, we can't pick and choose what to believe, not when the raw data of genetics, fossil studies, and anatomical studies are laid before us.

Anyone is free to argue whether they *like* being primates or whether they *like* being related to chimpanzees—but that's not the question. The question is whether or not we're descended from monkeys, and the evidence is in: we're not, but we are related to them.

Notes

1. The quote is from I. Sidgwick, "A Grandmother's Tales," *Macmillan's Magazine* 78 (1898): 433–34, as referenced in J. R. Lucas, "Wilberforce and Huxley: A Legendary Encounter," *Historical Journal* 22, no. 2 (1979). A fuller account of Wilberforce's diatribe is found in W. Irvine, *Apes, Angels and Victorians* (New York: McGraw-Hill, 1955). J. R. Lucas notes that Wilberforce's speech has been embellished and exaggerated (Lucas, "Wilberforce and Huxley"), but it's clear that Wilberforce tried to slight evolutionists by implying that those who supported evolution would drag humanity into the world of monkeys.

2. See A. Badkhen, "Anti-Evolution Teachings Gain Foothold in U.S. Schools," *San Francisco Chronicle*, November 30, 2004, p. A-1.

3. For viruses, see A. G. Fettner, *Viruses: Agents of Change* (New York: McGraw-Hill, 1990); for penguin evolution, see D. M. Lambert et al., "Rates of Evolution in Ancient DNA from Adélie Penguins," *Science* 295, no 5563 (2002): 2270–73; for sea slugs, see S. K. Pierce et al., "Annual Viral Expression in a Sea Slug Population: Life Cycle Control and Symbiotic Chloroplast Maintenance," *Biological Bulletin* 197, no. 1 (1999): 1–6.

4. See C. Sagan and A. Druyan, *Shadows of Forgotten Ancestors: A Search for Who We Are* (New York: Ballantine Books, 1992), p. 270. In the same book the authors note that the Judeo-Christian-Islamic religious system arose in a region where nonhuman primates were rare or absent.

5. A winged ape-Devil carved from stone in eleventh-century Spain and remarkably resembling the terrifying winged apes in the 1939 film *The Wizard of Oz* is seen in H. W. Janson, *Apes and Ape Lore in the Middle Ages and the Renaissance* (London: Warburg Institute, 1952), pl. IIb.

6. Our attraction to animal cuteness is so strong that it's even exploited by advertisers: consider how many (and what kinds) of animals are used to market breakfast cereals and other products that have nothing to do with those animals in the first place. See a review in G. Feldhamer et al., "Charismatic Mammalian Megafauna: Public Empathy and Marketing Strategy," *Journal of Popular Culture* 36, no. 1 (2002): 160–67.

7. Linnaeus named nine thousand species of plants and animals; today we know of about five million species, but some have suggested this estimate may be ten times too low: see R. M. May, "How Many Species?" *Philosophical Transactions of the Royal Society of London B* 330 (1990): 293–304. We discuss the concept and definition of species in "Myth Four: The Missing Link."

8. For more on Buckland, see N. A. Rupke, *The Great Chain of History: William Buckland and the English School of Geology (1814–1849)* (New York: Oxford University Press, 1983).

9. While Linnaeus classified mostly by outward form, later evolutionists began to include other characteristics into species definitions, and by 1996 Mayr stated that "[d]egree of morphological difference is not an appropriate species definition. . . ." See E. Mayr, "What Is a Species and What Is Not?" *Philosophy of Science* 63 (1996): 262–77. Still, genetic and other modern studies show that Linnaeus correctly identified many species.

10. Since the 1930s, on average, a new mammal species has been discovered about every three years: see R. H. Pine, "New Mammals Not So Seldom," *Nature* 368 (1994): 593. For example, on Tuesday, December 6, 2005, the BBC online news reported the discovery of a new mammal species in Borneo's Kayan Mentarang National Park: see R. Black, "'New Mammal' Seen in Borneo Woods," http://news.bbc.co.uk/1/hi/sci/tech/4501152.stm

(accessed December 6, 2005). It was long assumed that New Zealand's moa and kiwi birds were very closely related, because of their appearance and habitat, but new DNA evidence suggests that kiwis are more closely related to some African birds, and that they and moas arrived in New Zealand many millions of years apart: see A. Cooper et al., "Independent Origins of New Zealand Moas and Kiwis," *Proceedings of the National Academy of Sciences* USA 89, no. 18 (1992): 8741–44.

11. The conditions in which we find life can be astounding: on the frigid, lightless, intensely high-pressured seafloor, we find life flourishing among "extremes in temperature, hypoxia [lack of oxygen], sulfide, and heavy metals." See E. R. McMullin et al., "Metazoans in Extreme Environments: Adaptations of Hydrothermal Vent and Hydrocarbon Seep Fauna," *Gravitational and Space Biology Bulletin* 13, no. 2 (2000): 13–24. For an introduction to life's most extreme adaptations, see D. A. Wharton, *Life at the Limits: Organisms in Extreme Environments* (Cambridge: Cambridge University Press, 2002).

12. One biologist has estimated that an ounce of forest soil contains over five hundred thousand species of bacteria, and that worldwide there are probably a billion species! See D. E. Dykhuizen, "Santa Rosalia Revisited: Why Are There So Many Species of Bacteria?" *Antonie van Leeuwenhoek International Journal of General and Molecular Microbiology* 73 (1998): 25–33. The actual count of species of bacteria is less important, according to Ward, than the fact that the count is very large. See B. B. Ward, "How Many Species of Prokaryotes Are There?" *Proceedings of the National Academy of Sciences USA* 99, no. 16 (1999): 10234–36.

13. A wide range of magnifying devices was invented around the late seventeenth century; Dutchman Antonie van Leeuwenhoek is generally credited with devising the first functional microscopes, opening the doors to an astounding world of *animalcules*, his word for microbes. See C. Wilson, *The Invisible World: Early Modern Philosophy and the Invention of the Microscope* (Princeton, NJ: Princeton University Press, 1995).

14. As early as 1954, Simpson estimated that between fifty million and five billion species have existed since the origins of life on Earth: see G. G. Simpson, "How Many Species?" *Evolution* 6, no. 3 (1954): 342. His estimate is probably low.

15. See C. D. Thomas, "Fewer Species," *Nature* 347 (1990): 237.

16. See J. Y. Chen et al., "A Possible Early Cambrian Chordate," *Nature* 377 (1995): 720–22.

17. D. A. Wharton, *Life at the Limits*, pp. 180–85.

18. In an example of how molecular biology is refining our understanding of relationships of living things, a recent attempt to use genetic data to classify the eutherian mammals groups them into four major *clades*: the *Afrotheria* (mostly in Africa), the *Xenartha* (New-World [North and South American] sloths, anteaters, and armadillos), the *Gilres* (rodents and lagomorphs [rabbit-like creatures]), and *Group IV*, which is basically "everything else," from the Cetacea (sea mammals) to the Carnivora, the Chiroptera (bats), and the Insectivora (such as shrews and moles). See W. J. Murphy et al., "Molecular Phylogenetics and the Origins of Placental Mammals," *Nature* 409 (2001): 614–18.

19. Most scientists believe that early horse domestication took place in central Asia. For example, see M. A. Levine, "Botai and the Origins of Horse Domestication," *Journal of Anthropological Archaeology* 18, no. 1 (1999): 29–78. Recent DNA studies, however, suggest that although central Asia was one center of horse domestication, horses may have been domesticated in several different places at different times in prehistory: see T. Jansen et al., "Mitochondrial DNA and the Origins of the Domestic Horse," *Proceedings of the National Academy of Sciences* USA 99, no. 16 (2002): 10905–10.

20. It's hard to be sure when dogs were first domesticated, because early domesticated dogs and wild dogs (wolves) would not be very different skeletally. Some suggest that dogs were first domesticated over three hundred thousand years ago, while others suggest it was closer to twenty thousand years ago, but almost nobody argues it was less than fifteen thousand years ago. For an overview, see J. Serpell and P. Barrett, eds., *The Domestic Dog: Its Evolution, Behaviour, and Interactions with People* (Cambridge: Cambridge University Press, 1995).

21. For an overview of the domestication of mammals, see J. Clutton-Brock, *A Natural History of Domesticated Mammals* (Cambridge: Cambridge University Press, 1999). For new evidence for possible cat domestication long before Egyptian civilization, see T. Rothwell, "Evidence for Taming of Cats," *Science* 305, no. 5691 (2004): 1714.

22. A slightly dated but enjoyable overview of the primates is found in M. Kavanaugh, *A Complete Guide to Monkeys, Apes, and Other Primates* (New

York: Viking, 1984). A more technical overview is available in R. Jurmain et al., *Introduction to Physical Anthropology* (Belmont, CA: Wadsworth, 1999): 106–42.

23. New World primates probably arrived in the Americas, from Africa, more than thirty million years ago. They likely rode natural "rafts" of floating vegetation across the South Atlantic (see note 26), or opportunistically spread from one island to another as the two continents drifted apart. By thirty million years ago, however, African and New World primates were totally isolated. See R. Jurmain et al., *Introduction to Physical Anthropology*, pp. 126–27.

24. For a discussion of adaptive radiation, and an example, see D. Schluter, "Ecological Causes of Adaptive Radiation," *American Naturalist* 148 (November 1996): S40–S64. This review of primate evolution is based on R. G. Klein, *The Human Career* (Chicago: University of Chicago Press, 1999).

25. Binocular vision is most developed in the primates, allowing extremely acute perception needed in their leafy, three-dimensional world of branches and limbs. See C. P. Heesy, "On the Relationship between Orbit Orientation and Binocular Visual Field Overlap in Mammals," in T. D. Smith et al., *Evolution of the Special Senses in Primates: The Anatomical Record Part A: Discoveries in Molecular, Cellular, and Evolutionary Biology* 281A, no. 1 (2004): 1104–10. The "Visual Predation Hypothesis" suggests that binocular vision and other characteristics were important adaptations reflecting the primates' focus on eating hard-to-catch insects.

26. It has been suggested that the fundamental differences between New World and Old World monkeys could have occurred in Africa *before* the two populations split. See M. Takai et al., "New Fossil Materials of the Earliest New World Monkey, *Branisella boliviana,* and the Problem of Platyrrhine Origins," *American Journal of Physical Anthropology* 111, no. 2 (2000): 263–81. One recent study suggests that New World primates could have survived floating on rafts of vegetation from the Old World, across the Atlantic to the New World; they would not, of course, have been doing this as a conscious decision. See A. Houle, "The Origin of Platyrrhines: An Evaluation of the Antarctic Scenario and the Floating Island Model," *American Journal of Physical Anthropology* 109, no. 4 (1999): 541–59.

27. How and why bipedalism (walking habitually on two legs) evolved is one of the greatest questions of anthropology. The topic is introduced in

Jurmain et al., *Introduction to Physical Anthropology*. A recent review finds that while we have a good idea of the dating and the sequence of the evolution of bipedalism, different varieties of bipedalism occurred in hominid evolution, and no current explanations are entirely convincing. See W. E. H. Harcourt-Smith and L. C. Aiello, "Fossils, Feet and the Evolution of Human Bipedal Locomotion," *Journal of Anatomy* 204, no. 5 (2004): 403–16.

28. Evidence from a wide array of fossilized plants and animals clearly shows that by sixteen million years ago, grasslands began to expand in Africa, gradually replacing more forested habitats. By eight million years ago, grasslands were widespread, and many plant and animal species (including ancestors of the early hominids) were adapting to these conditions. For an overview, see B. F. Jacobs, "Palaeobotanical Studies from Tropical Africa: Relevance to the Evolution of Forest, Woodland, and Savannah Biomes," *Philosophical Transactions of the Royal Society of London B* 359 (2004): 1573–83.

29. The earliest discoverers of australopithecine fossils were South Africans, and they named the hominids Southern (*austral*) Apes (*pithecus*). Later, australopithecine fossils were found as far north as Ethiopia. Of the discovery in South Africa in August 1936, paleontologist Robert Broom wrote: "I was again at Sterkfontein, and when I saw Barlow, he handed me a beautiful brain-cast, and said 'Is this what you're after?' I replied, 'Yes, that's what I'm after.' It was clearly the anterior two-thirds of the brain-cast of an anthropoid ape or ape-man, and in perfect condition." See R. Broom, *Finding the Missing Link* (London: Watts, 1950), p. 45. For more on australopithecines, see "Myth Four: The Missing Link."

30. Evidence for the transition from gracile australopithecines to early *Homo* is reviewed in H. M. McHenry and C. Coffing, "*Australopithecus* to *Homo*: Transformations in Body and Mind," *Annual Review of Anthropology* 29 (2000): 125–46.

31. Fossil and genetic data place the divergence of the ancestors of modern Old World monkeys and apes to around thirty million years ago. See M. E. Steiper, N. M. Young, and T. Y. Sukarna, "Genomic Data Support the Hominoid Slowdown and an Early Oligocene Estimate for the Hominoid-Cercopithecoid Divergence," *Proceedings of the National Academy of Sciences USA* 101, no. 49 (2004): 17021–26.