

1 IDEAS ABOUT EVOLUTION

In order to explore the myths of human evolution, we need to start with a brief review of how evolution works. It turns out that many of the myths of human evolution are related to misconceptions about the process of evolution in a general sense, starting with what is likely the biggest one of all—that evolution is “just a theory.” This section of the book examines some common misconceptions of the process of evolution.

Myth #1

Evolution is a theory, not a fact

Status: This is a myth based on a misunderstanding about the use of the word “theory” in the natural sciences. When we state something is a theory, such as evolutionary theory, atomic theory, or the theory of gravitation, we are not suggesting that it may or may not exist (a more popular use of the word “theory”). Instead, we are talking about a hypothesis that has been tested repeatedly and has stood the test of time without being rejected.

Of all the myths about evolution, perhaps the one that we hear more than any other is the idea that evolution is a theory and not a fact. Most often, this myth is expressed as the statement “It’s just a theory” or the somewhat longer “It’s a theory, not a fact.” By contrasting fact and theory, we are forced into an either-or situation. Either evolution is indeed a fact or it is a theory. We then must choose between one side and the other. According to popular logic, if we accept evolution as a theory then it is not necessarily a demonstrated fact. The logic works here only if we

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define the word “theory” as an unsupported or unproven hypothesis or explanation. In other words, if we classify evolution as “just a theory,” it implies that evolution may or may not exist. In terms of human evolution (that aspect of evolution that tends to upset folks more than, say, elephant evolution because it is personal), the statement that evolution is “just a theory” means that humans may or may not have evolved. If we cannot tell, then evolution (including human evolution) is therefore not a fact. It is, according to this logic, at best an opinion.

Although much of the above may seem logical and perfectly reasonable, the argument rests on an underlying assumptions that “theory” means an untested hypothesis or mere opinion and that something can be either a fact or a theory. It turns out that our more popular use of the word “theory” is not what it means in the context of scientific thought. Evolution is actually both a fact and a theory. In my introductory course on biological anthropology, I ask the class on the first day to raise their hands if they think evolution is a fact. I then ask the class to raise their hands if they think evolution is a theory. I then tell them “Congratulations! All of you are correct. Evolution is *both* a fact and a theory.” This statement can cause some consternation in anyone who is used to facts and theories being considered in terms of an either-or proposition. In order to see the mistake being made by this proposition, we need to consider a bit of the underlying philosophy and method of the natural sciences and explore briefly what we mean by fact, hypothesis, and theory.

To most of us, the definition of “fact” is pretty straightforward. A fact is a verifiable truth—something we can all observe and agree on. The key feature here is that facts must be capable of being verified. If I say that there are trees in my yard, you can actually look and see if this is true. Some facts are easy to verify and we will all agree with little or no argument. For example, if we drop an object, such as a pencil, it will drop to the ground. We call this fact gravity. Sometimes facts are contingent upon a more exact definition. In the case of gravity, the pencil would have to be dropped while standing on something of sufficient mass to generate sufficient gravitational force to attract the pencil. Sometimes facts are tricky because they are not directly observable with our senses. We can easily see a pencil dropping, but what of the fact that infectious diseases are caused by bacteria and viruses that are not visible to the human eye. Of course, we easily accept the existence of such microorganisms because we have developed microscopes and other technology to make our observations. However, imagine you were alive during the fourteenth century and someone explained to you that the Black Death (bubonic plague) was caused by a bacterium, something that could not be seen except with

a microscope (that had not yet been invented). I suspect that most people at that time would have rejected this idea because the plague bacterium could not be observed with the naked eye.

Observing something, either directly with our senses or with technology, is a start in establishing a fact, but you need to remember that facts must be verified. Sometimes in the history of science, we find that our basic facts change when more observations are made. At one time, for example, it was thought that humans had 24 pairs of chromosomes, but over time, more advanced methods revealed that we actually had 23 pairs of chromosomes. At one time, a fossil known as Piltdown Man (discussed in Myth 13) was thought to be a fact supporting the then-popular view that humans evolved large brains before losing certain ape-like features of the teeth. In this case, inconsistency with other facts, development of better ways to date the individual fossils making up Piltdown Man, and other pieces of evidence pointed out that it was not a fact, but instead a fake. Someone (whose identity is still not known with certainty) faked the whole thing. Again, such lessons show us that science requires verification even with basic facts.

What about theory? Before considering the different meanings of the word “theory,” we need to start with the idea of a hypothesis. Science is not simply an accumulation of facts about the physical universe. We also try to explain what we see. A hypothesis is just a tentative explanation of the facts. For example, why does a pencil fall to the floor when I let it go? In order to make my point about the nature of a hypothesis and how it ties into science, I am going to state an obviously ridiculous hypothesis to explain the falling pencil. Imagine that I have placed a magnet inside the pencil and then held it over a spot on the floor under which I have buried a very powerful magnet. When I let go of the pencil, the magnetic forces cause the pencil to drop to the floor. I imagine as you are reading this, you are thinking that this hypothesis is one of the silliest things you have ever heard, and so ridiculous that even discussing it is a complete waste of time. Yes, it is ridiculous and it is clearly false, but the interesting thing here is that my wacky idea is actually a good scientific hypothesis because it can be tested. There are a number of ways to test this hypothesis. Break open the pencil or dig under the floor to find there are no magnets. Use a device (such as a compass) and fail to detect any localized magnetic force. Or, in perhaps the most simple but also most elegant test, drop your own pencil (or shoe or baseball) and find that they all drop to the ground without any magnets being placed inside of them.

In each case, the hypothesis has been tested and has been rejected. We then have to move on to another hypothesis. Each time we develop a

hypothesis we try to determine some way to test it. Science is continually involved with the testing and retesting of hypotheses, looking for hypotheses that have stood the test of time. In the natural sciences, we use the word “theory” to indicate a hypothesis, or set of hypotheses, that has been tested repeatedly and has not been rejected. We might continue to refine the theory, but the basic elements are widely agreed upon and unlikely to change.

This definition of theory contrasts with the popular idea that a theory is a hypothesis or just a guess and that the subject of the theory may or may not exist. However, when you hear the phrase “theory of gravity,” do you think that gravity may or may not exist? Of course not. To take another example, consider atomic theory in chemistry. Does the inclusion of the word “theory” make you think, “Well, atoms are only a theory and they may or may not exist”? I doubt any reader takes this stand. The elements of atomic theory have been tested and have held up over time. The same is true for evolution. The basic ideas regarding the mechanisms of evolution (described in later myths) have been confirmed and form the basis for modern evolutionary theory. As with gravity and atoms, evolution is both a fact and a theory. Arguing that something has to be one or the other is a misuse of the scientific method.

Historically, we associate part of modern evolutionary theory with the insights of the nineteenth-century naturalist, Charles Darwin, who contributed to our understanding of both the fact of evolution and part of the underlying mechanism for evolutionary change. By Darwin’s time, many in the scientific community were coming to grips with evidence showing changes due to evolution. The spread of the Industrial Revolution had led to increased mining and quarrying activity. As people dug into the earth, they found many fossils of creatures that did not fit nicely and neatly into their views on variation. Imagine, for example, you were digging in your backyard and found the skull of a cow. How would you explain it? Depending on where you live, the explanation might be very simple—perhaps your property was once a farm where cows lived and died. Or, imagine you unearthed a skull of a modern human. Although such a discovery might lead to all sorts of speculations about the identity and fate of the person you found, the simple truth is that finding a modern human skull in the ground is not likely to be an earth-shattering discovery.

However, what would you do if you found the remains of a creature that no longer lived, such as the bones of a dinosaur? This discovery implies that there were creatures that once existed but have since become extinct (which turns out to be quite common—we now know that over

99 percent of all species that have ever lived have become extinct). How do you explain this extinction? You then notice upon further examination that the bones of the creature you discovered are similar to, but not identical to, living creatures. For example, if you look at fossil remains from many millions of years ago, you will find creatures that are clearly similar to horses, but instead have three toes on each foot, as compared with the single toe typically found in modern horses. Or, in the case of human evolution, we can go back 2 million years ago in Africa and find creatures that are very similar to us in terms of how they walked and their basic body anatomy, but have smaller brains and larger faces. As we examine the fossil record even further, we see examples of trends over time, such as a reduction in the number of horse toes or the increase in the brain size of bipeds. Such trends are clear examples of evolution (and more will be presented throughout this book). How do you explain such facts?

Darwin was one of those who sought an explanation for change over time. Darwin made two very important contributions. First, he collected data confirming the fact of evolution as revealed from field studies of living organisms, the fossil record, and the comparative anatomy of different species, among other sources of evidence. His result was a convincing argument that all living species were related through a process of what he termed “descent with modification.” The mechanism that Darwin proposed (natural selection) will be dealt with in later myths, but here we just focus on the fact that natural selection was a hypothesis relying on natural phenomena that explained the observed facts. As with all scientific hypotheses, Darwin’s idea has been tested repeatedly. Because it has survived without refutation, the concept of natural selection has been elevated to the status of a scientific theory. Once more, keep in mind that the word “theory” has a very specific meaning here and does not mean something that may or may not exist.

The final point about Darwin’s idea is that even though it forms part of modern evolutionary theory, his concept of natural selection is not the entire answer. Although Darwin got a lot right, he also had questions that remained unanswered during his life. The tentative nature of scientific explanation can be frustrating to those seeking a final definitive answer, but it is the basic nature of scientific inquiry with which we continue to refine our explanations. The theory of evolution is no exception. We do not have all the answers, but continue to seek them through the scientific process. However, although scientists continue to debate the details of the evolutionary process, there is agreement on both the fact of evolution as well as the basic explanation of how evolution happens. The details of the evolutionary process are described briefly in the next myth.

Myth #2

Evolution is completely random

Status: This is a myth because it implies that evolution is a chance event. Although some aspects of evolution (such as mutation) have a random element, other aspects, such as natural selection, are not random. Whether an individual survives and reproduces or not depends on their evolutionary fitness relative to their local environment. Like many natural processes, evolution has both nonrandom and random components.

A common misconception of the evolutionary process is that it is random; that is, due to chance. Taken to an extreme, this misconception can lead to a rejection of evolution altogether. After all, how could something as complex as the human body (or any other organism) be due to chance? That is analogous to scattering thousands of Scrabble™ tiles at random and having them spell out the Declaration of Independence. Complex sentences or biological structures, such as the human body, would seem to defy randomness, which many people equate with something “just happening.” Part of the confusion may lie with the fact that some parts of the evolutionary process are random. However, having some randomness in parts of a process is not the same as an entire process being random. To be more specific, the origin of initial genetic variation is random, but the outcome is not. To see the distinction here, we need to look more closely at how evolution works.

As described in the last myth, Darwin’s most significant contribution to the theory of evolution is the description of natural selection. Darwin noted that there is considerable biological variation in living creatures, something that we can all see easily. For example, not all birds look alike, but vary in terms of size, color, and other physical traits. As you walk down the street, you will see the same is true of humans; people vary in terms of size, shape, body proportions, skin color, hair color, and many other characteristics. This is even more apparent when looking beyond observable physical traits and we consider genetic traits where people vary in terms of blood types, blood proteins, and DNA markers, among others. Variation is all around us in the natural world; an observation that Darwin was able to tie to environmental differences.

Darwin also relied on the observation that more organisms are born than will survive to adulthood. For example, if a fish lays 100 eggs, it is a certainty that not all 100 offspring will survive to adulthood. Most will die, but some will survive. The same process of differential survival is true of all species—some individuals survive and reproduce, thus continuing the species, whereas others die before reaching reproductive age or fail to

reproduce. Darwin tied together the observation of differential survival with the observation of variation. Given variation within a species, in a specific environment some individuals will be more likely to survive and reproduce than others. Imagine, for example, that there is variation in the size and shape of the beak of a bird in an environment where the main source of food is large seeds that are tough to crack open to eat. In such a case, those birds that have the most powerful beaks are most likely to eat and hence to survive. Consequently, the birds that are better adapted will contribute more to the next generation than those that are less adapted to the specific environment. Over time, the genetic characteristics of the population will change and large, powerful beaks will become more common.

The principles of natural selection are often best understood by analogy to the process of animal domestication. Imagine, for example, that you have just inherited a pig farm and you decide to go into the business of raising pigs for sale as food. When you first arrive on your new farm, you will notice that there is variation in the size of the pigs. Some of the pigs may be large and fat whereas others may be small and scrawny. Over time, you will sell off some pigs and keep others for breeding stock (because you want to produce additional generations of pigs). Keep in mind that you get a better price for the larger pigs. Which pigs do you sell and which pigs do you keep as breeders? If you are interested in long-term profitability you will ignore an impulse to sell the large pigs right away and instead you will keep them as breeders because of the common knowledge that, all other things being equal, larger pigs will produce larger offspring. This is not a perfect correlation, but it is strong enough that people have relied on this principle of selective breeding to feed themselves in the 12,000 years since agriculture has existed. The idea is simple enough to use even without knowledge of the underlying genetics—breed for the characteristic of interest and it will become more common over time, be it the size of pigs, speed of a horse, disposition of a dog, or many other traits. This selection is not random—the farmer does not roll dice or flip coins to pick which pigs are breeders.

Darwin recognized how this process of selection could lead to evolution, where the change over time was due to the farmer selecting who lived to reproduce and who did not. He also recognized that the same process could happen in nature, but where the selection was not the product of conscious manipulation by a human being, but was instead due to interaction with the environment. Those organisms that are better adapted to a given environment are more likely to survive and reproduce and will then pass on their characteristics in greater numbers to the next

generation. Unlike the artificial selection that occurs due to the intervention of the farmer, this selection occurs in nature and is therefore termed natural selection.

A classic example of natural selection acting upon variation is found in studies of the coloration of the peppered moth in England. At one time, most of the moths of this species were light-colored, but a very small number were dark in color. The light color was more common because it was adaptive; the light color acted as camouflage when the moths rested on the light-colored tree trunks. Because these moths blended in, they were less likely to be seen by birds, unlike the dark-colored moths that were more visible and thus more likely to be eaten. Here, selection acted to maintain the light color over time and most dark-colored moths were selected out of the gene pool. Whether a moth was eaten or not was not random.

However, scientists also noted what happened when the environment changed because of industrial pollution killing off lichen on the trees, exposing the underlying dark color. At this point, the selective balance shifted and light-colored moths were then at a disadvantage and dark-colored moths were at an advantage. Each generation the proportion of dark-colored moths increased until they were the most common form as the population became better adapted to the environment.¹ Although this is a relatively small amount of change, the process of natural selection can apply to larger changes over geologic time, leading to major divergences.

Darwin's model of natural selection leaves out one important question—where does variation come from in the first place? Why are some pigs bigger than others? Why are some moths darker and some lighter? Darwin did not have the answer about the origin of variation; he noted its existence and then described how natural selection could act upon this variation, but lacked the insights of twentieth-century genetics that show us that the ultimate cause of genetic variation is the process of mutation.

A mutation is a random change in the genetic code, DNA. Mutations can occur for a number of reasons including the effect of background cosmic radiation, leading to an error in how the DNA is being copied. The DNA consists of sequences of four chemical bases and can be thought of as analogous to an alphabet with four letters that spells out the instructions that regulate all processes of life, ranging from the structure of proteins to the development of an organism. Some mutations involve a change in one of the letters (bases), while others can involve duplication or deletion of larger DNA sequences. Still other mutations involve movement of DNA sequences from one chromosome to another. Following the alphabet analogy, mutations act to change the message being transmitted.

Mutations can occur in any cell and interfere with biological function (such as leading to cancer). From an evolutionary perspective, we are interested in mutations that are transmitted through sex cells (sperm and egg in bisexually reproducing organisms).

Natural selection acts upon mutations. If a mutation is harmful to the organism that inherits it, hindering survival or reproduction, it can be eliminated through natural selection. Selection thus acts to weed out harmful effects. On the other hand, if a mutation leads to an advantage, it can be selected for and increase in frequency over time. Putting mutation and natural selection together, we get a picture of mutations generating variation that is then filtered by natural selection, leading to the reduction in frequency of harmful mutations and the increase in frequency of helpful mutations. (The actual picture can get much more complicated, but this view suffices for now.)

We can now turn to the question asked at the beginning of this myth—is evolution a random process? This question does not have a single yes or no answer. Mutation is a random process. Mutations do not appear when they are needed. (For example, a dark-color moth mutation did not appear in the moth population just because the environment changed.) Although we can measure the probability of a mutation occurring in any given organism in any given generation, we do not know for sure whether a specific DNA sequence will mutate or not at any given point in time. Think of the analogy of flipping a coin. If you are using a fair coin (no magic tricks allowed), you know that the coin will land heads up or tails up. For our purposes, the outcome is random. Although we do know that the probability of getting heads or tails is 50 : 50, we do not know beforehand whether any specific coin flip will be heads or tails. In terms of the moth example, whether a mutation leading to dark coloration appeared in a given generation or not is a random process. It is a matter of luck.

Does this mean that evolution is random and everything we see around us resulted merely from a series of chance events? Absolutely not. The fact that mutation is random simply means that the initial generation of variation is random, not the outcome. Remember, natural selection is not a random process. Whether an organism will survive and reproduce or not is a function of its adaptive value (what we call “fitness”) in a given environment. When the trees in England became darker, the difference between survival of dark-colored and light-colored moths was not a matter of chance, but instead a direct outcome because of differences in fitness (because light-colored moths were more likely to be eaten). Although the direction of evolutionary change may change as the environment changes (as in the case of the peppered moth), this is not a

random change. Although evolution does have a random component (mutation), the direction of evolutionary change due to natural selection is not a random outcome. Think of this difference in terms of how humans domesticated corn (or any other plant or animal). Humans altered the evolutionary course of corn to produce kernels that were large and stayed on the cob. They did this by the process of artificial selection acting upon the variation in corn that was available in nature. Although the initial origin of this variation was a random event due to mutation, the outcome of domesticated corn was not.

The discussion of how evolution works continues with the next myth. For the moment, it is important to discard ideas that the evolutionary process has to be entirely random or nonrandom. Evolution has both random and nonrandom (deterministic) components. It does not have to be just one or the other. To pursue an analogy with life, consider the movie *Forrest Gump*, where the title character muses about whether people have a destiny (deterministic) or whether we are “all just floating around accidental-like on a breeze” (random). Forrest wisely concludes, “Maybe both is [*sic*] happening at the same time.”²

Myth #3

All evolutionary changes are adaptive

Status: This is a myth that results from equating the entire evolutionary process with natural selection acting upon mutations. Not all evolutionary changes reflect adaptation. There is also random fluctuation over time, known as genetic drift. Evolutionary biologists all agree that both selection and drift are important, although there is debate over the relative influence of each.

As described in the previous myth, natural selection is a powerful agent of evolutionary change, acting upon mutations to decrease the frequency of harmful mutations and increase the frequency of helpful mutations. Over time, species become better adapted to their environments, as seen in numerous field studies of living organisms. An example from the human species is the global distribution of skin color, where native populations at or near the equator tend to be the darkest, and populations farther away from the equator, north or south, are increasingly lighter. This pattern correlates with the global distribution of ultraviolet radiation. The story of skin color adaptation will be explored in detail in a later myth (Myth 42), but the point here is that variation in skin color can be explained by adaptation through natural selection to ultraviolet radiation.

The model of genetic variations introduced through mutation being acted upon by natural selection is both simple and elegant, and can explain the variation of many biological traits. Many examples from human evolution will be presented in later myths, including the origin of upright walking, the increase in brain size, and physical variations such as skin color. We also know that the long-term process of natural selection continues in recent times, as we have a number of examples of evolutionary changes in our species that have taken place within only the past 10,000 years or so.

It therefore may be tempting to explain all evolutionary change as the outcome of mutation and natural selection, and assess all physical and genetic changes in terms of their adaptive significance. Although this works for some traits, does it work for all? For example, some people have earlobes that are attached smoothly with the ear, and others have earlobes that are unattached and hang freely. Is there any adaptive significance to this variation? Could it possibly have anything to do with survival or reproduction? Should we postulate that some people are more attracted to potential mates depending on their earlobes? This seems a bit far-fetched to me. As another example, consider variation in different human blood groups (biochemical traits defined by reaction of surface molecules to various antibodies). There are a number of different blood group systems, with the ABO blood group and the Rhesus blood group being the best known because their biochemistry affects blood transfusion. (These are actually two distinct genetic systems, ABO and Rhesus, and when someone says their blood type is O negative, this is actually shorthand for type O blood for the ABO blood group system and Rh negative for the Rhesus blood group system.) There are many other blood group systems that are seldom typed for medical purposes, such as the MN, Diego, Duffy, and P blood groups, among others. All of these blood group systems show variation among human populations, and our job is to ask why these patterns exist. Can we explain differences in the frequencies of different blood group systems in terms of natural selection? For example, Native American populations typically have a higher frequency of blood type O for the ABO system than populations elsewhere in the world. Why? To take another example, the Basque populations in Europe have higher frequencies of Rh-negative type blood than elsewhere in the world. Does this reflect the past (or current) action of natural selection, or is something else going on?

There are many cases where natural selection provides the best explanation for patterns of biological variation. However, there are other cases where the evidence suggests that natural selection may not be the only

factor contributing to variation. There are also cases where natural selection does not explain anything about the variations that we see. Can some variation be explained by nonadaptive evolutionary change? The answer is yes.

In the early part of the twentieth century, scientists grappled with the question of what causes evolutionary change. Laboratory and field studies were demonstrating the importance of both mutation and natural selection, but it became apparent that one could explain genetic change within a population (defined as a change in the frequency of different genetic variants) through the action of four mechanisms, termed evolutionary forces. Mutation is one of these four forces, and natural selection is another. A third evolutionary force is known as gene flow, which is the movement of genetic material from one population to another. Let's say that you leave your hometown and move somewhere else, marry someone who is living there, and then have a child with your spouse. Gene flow has occurred because you have mated with someone in a different population and thus have connected two populations genetically. Gene flow can affect the genetic makeup of a population in two ways. First, new genetic variants can be introduced into the population from somewhere else. This process allows new mutations to be spread throughout a species. Second, gene flow acts to make populations more similar to each other over time, much like mixing paint from two cans of paint, say red and white, will make the paint in each can eventually a similar shade of pink.

The fourth evolutionary force is the key one in our discussion of adaptive versus nonadaptive evolution and is known as genetic drift. The definition of genetic drift is short and to the point—random fluctuation in the frequency of a genetic variant over time—but a bit harder to conceptualize. As an example, let us consider a simple genetic trait in human populations, the MN blood group. The gene that controls the MN blood group has two different forms, or alleles. (Different forms of genes are known as alleles.) These two forms are the *M* allele and the *N* allele, and they correspond to different sets of instructions that produce different types of molecules on the surface of red blood cells. The *M* allele codes for type M molecules and the *N* allele codes for type N molecules. If you have inherited an *M* allele from both parents, you will have type M blood, and if you have inherited an *N* allele from both parents, you will have type N blood. If you inherit an *M* allele from one parent and an *N* allele from the other parent, you will have both types of molecules on the surface of your red blood cells and will therefore have type MN blood; this is because unlike some other genetic traits, neither the *M* nor the *N* allele is dominant.

With an example such as the MN blood group, we could go into a human population, take samples of everyone's blood, determine how many *M* and *N* alleles each person had, and count the number of *M* and *N* alleles in the population. Let us say that we do this and find that 55 percent of the alleles in the population are *M* alleles and 45 percent are *N* alleles. Now, imagine you return a generation later and find that the frequency of the *M* allele is now 58 percent. You have detected (at a very low level) evolution, defined here as a change in the allele frequency over time. The frequency of the *M* allele has changed from 55 percent to 58 percent. The trick is figuring out why this change occurred. Did the frequency of *M* increase over time because of selection, or did something else happen? Under genetic drift, it is possible for a frequency to change by chance. This is an example of nonadaptive evolution—there has been a change, but not due to natural selection.

As another example, imagine that you have gone to a population and measured everyone's head and found that the average length of a person's head was 180 millimeters. If you visit the population a generation later and find that the average head length is now 178 millimeters, what can you conclude? You might suspect natural selection, but we could also get changes of this magnitude due to random chance; that is, genetic drift.

Genetic drift is an example of what we call sampling error. To illustrate this, picture a large group of people where half have brown eyes and half have blue eyes. Now, imagine picking 10 people at random (in other words, not looking at their eye color). Although you might expect to get five people with brown eyes and five people with blue eyes, you also know that by chance you could get other outcomes, such as six people with brown eyes or three people with brown eyes, among other outcomes. (You can try this experiment by flipping coins, letting heads represent brown eyes and tails represent blue eyes.) Genetic drift works in a similar manner; this means that the frequency of an allele in the offspring generation can be different from the frequency in the parental generation because of chance.

As another simple example, imagine that you have type MN blood for the MN blood group. This means that you have two alleles, an *M* allele from one parent, and an *N* allele from your other parent. When you reproduce, you pass on one of these alleles in a sex cell (sperm for males, eggs for females). Is the *M* allele or the *N* allele passed on in any given sex cell? It is a 50 : 50 chance, just like flipping a coin to get heads or tails. If you have four children, you might expect to pass on the *M* allele half the time and the *N* allele half the time, just as you expect to flip a coin four times and get two heads and two tails. However, while this is the expected

outcome for a very large number of cases, by chance you might easily wind up passing the *M* allele to three children and the *N* allele to one child, or passing on the *M* allele to all four children. There are five different outcomes, and statistical theory³ allows us to predict the probability of each outcome.

Four children inherit your *M* allele and none inherit your *N* allele = $1/16$
= 0.0625

Three children inherit your *M* allele and one inherits your *N* allele = $4/16$
= 0.2500

Two children inherit your *M* allele and two inherit your *N* allele = $6/16$
= 0.3750

One child inherits your *M* allele and three inherit your *N* allele = $4/16$
= 0.2500

No children inherit your *M* allele and all inherit your *N* allele = $1/16 = 0.0625$

Now, consider this process happening for everyone in a population. The result is that the allele frequency among the children may not be the same as that of the parents. This is genetic drift.

Computers can be used easily to simulate the process of genetic drift⁴. Figure 1.1a shows an example of genetic drift in a simulated population of 50 individuals (25 couples) for 100 generations. I set the frequency of a hypothetical allele equal to 50 percent in the starting generation. In each generation each couple has two children, replacing themselves so that the population size remains constant at 50 adults each generation. (This restriction is not necessary, but makes the impact of genetic drift easier to see.) The computer program uses randomization to determine what alleles are passed to the next generation, much like flipping coins and counting the number of heads. In the first generation, the frequency changes from 50 percent to 47 percent due to random chance. In the second generation, the frequency remains constant at 47 percent, again due to random chance. In subsequent generations, the frequency drops to 40 percent, then rises to 48 percent, and then rises to 58 percent in the fifth generation. As shown in Figure 1.1a, the frequency of the allele drifts, sometimes going up, sometimes going down, and sometimes staying the same. The direction of change is random.

Because genetic drift is a random process, we could not predict the exact form of the graph in Figure 1.1a, although probability theory allows us to predict that there would be a fair amount of drift (though not the direction) because the population size is small. The random nature of drift also means that each time we conduct a simulation experiment

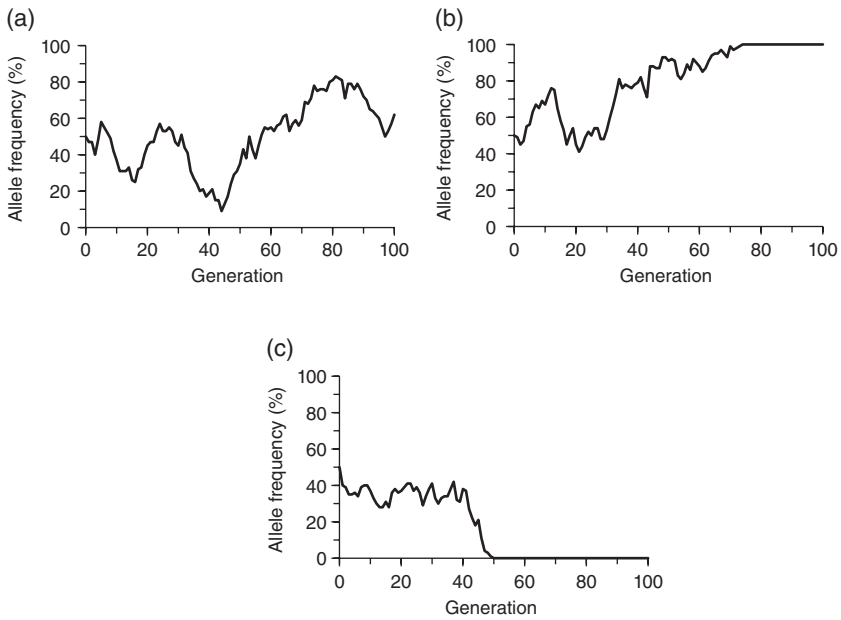


Figure 1.1 Three simulations (a, b, c) of genetic drift over 100 generations in a population of 50 reproductive adults, starting from an initial allele frequency of 50 percent. Genetic drift results in a random fluctuation of allele frequencies over time. Each time the simulation is run, a different picture results—compare Figures 1a, 1b, and 1c.

we are likely to get a different result, just as flipping a set of coins is likely to give us different outcomes from trial to trial. To illustrate this, Figure 1.1b shows a simulation of drift using the same exact starting point—50 adults and an initial starting frequency of 50 percent. In this case, the allele frequency drifts up and down, but in a different pattern, and drifts up to a frequency of 100 percent in the 74th generation. After this point, there is no further change because all the alleles in the population are the same. Figure 1.1c shows yet another example, although in this case the frequency drifts down to zero after 50 generations. Although we cannot predict beforehand the exact path of genetic drift in any specific example, probability theory does allow us to make some basic predictions. First, if enough time goes by, the frequency of an allele will ultimately drift up to 100 percent or down to 0 percent. Second, drift shows the greatest fluctuations from one generation to the next in small populations (just as it is more likely to get seven heads out of 10 flips of a coin than 700 heads out of 1,000 flips of a coin).

Geneticist Motoo Kimura extended the finding of genetic drift to his neutral theory of molecular evolution, which looks at the interaction of mutation and drift. Under this model, most neutral mutations are likely to be lost quickly due to drift—they are so rare to begin with that the odds are against them being passed on to the next generation. However, not all mutant alleles will be lost due to drift. By chance, some mutant alleles will drift up in frequency and become established in a population in the absence of natural selection. The neutral theory does *not* negate evolutionary change due to natural selection, but instead shows that evolutionary change need not always be adaptive. Evolutionary biologists debate the relative impact of drift and selection, but agree that both operate in populations in the real world.

For our purposes here, the take-home lesson is that not all evolution has to be adaptive. Some traits have evolved because of adaptation via natural selection and others are likely to reflect the balance between mutation and drift. In any specific case, such as the traits we will examine for human evolution, we need to examine all available clues to determine if the evolutionary change we see is primarily adaptive or nonadaptive in nature.

Myth #4

In evolution, bigger is always better

Status: This is a misconception. In a popular application of the idea of “survival of the fittest,” we tend to equate larger size as having the greater chance of evolutionary success because we assume biggest is the most fit. Although there are indeed many cases where larger individuals have a greater chance at survival and reproduction, there are also cases where being smaller gives one an evolutionary advantage. It all depends on the specific environmental circumstances.

We often view the universe around us in terms that are familiar to us from our daily existence. An example is the tendency to view groups of animals as families even when their social structure is not equivalent to the nuclear family with which we are all familiar. Such misconceptions are particularly common when considering the nature of evolution. One such misconception is the idea that “bigger is better.”

There are many examples of people considering that “bigger is better” in different aspects of our life. We can see this principle when buying a computer and choosing the size of the hard disk or active memory. We know from experience that larger disks provide more rooms for all of

our files and that more computer memory often allows our programs to run faster. We can see the same principle when shopping at the market. For example, a larger box of breakfast cereal is more cost-effective than a smaller one so that, in terms of our budget, bigger is indeed better. Moreover, we often prefer larger items, be it automobiles, televisions, or diamond rings, for a variety of reasons.

Let us explore the extension of the basic idea of “bigger is better” to the biological world. Many people think of natural selection in terms of the phrase coined by the nineteenth-century sociologist, Herbert Spencer, that natural selection is “survival of the fittest.” Is this phrase accurate? The answer depends on the exact use of the word “fittest.” Often, the word conjures up an image of traits related to physical fitness, such as size, strength, and speed. Thus, when we say “survival of the fittest,” we may picture a situation where the largest, strongest, and fastest individuals are the most likely to survive and reproduce because their physical attributes make them better competitors for mates and food and better able to defend themselves. Given competition for mates or food, it seems reasonable to assume that the largest individuals will be best able to compete, and who in turn would pass on their genes more frequently to the next generation, leading to an evolutionary trend over time where the organisms become larger and larger.

Being bigger need not refer only to overall body size. A somewhat different example comes from examining the fossil record of human evolution, where the average brain size in the genus *Homo* has increased almost 60 percent in the last 2 million years.⁵ Because of the association of brain size in different ancestral species with various technological and cultural achievements, we see modern humans as more advanced by virtue of our larger brain, implying that bigger is again better. More will be said on the evolution of brain size in our ancestors in later myths (Myths 22 and 47).

In order to examine the idea that bigger is always better, we need to think in terms of pluses and minuses, costs and benefits. A large car may appeal to us in terms of available space, ruggedness, and speed, but the downside may be lower gas mileage. An 80-inch television might be great for some spaces, but could be overwhelming and difficult to watch in a small room. Large boxes and cans of food can be cheaper per unit cost, but might be more difficult to store. A large house might be desirable, but not affordable. The point here is that we need to consider both the pros and cons of any of the above purchases. In net value, bigger may not always be better.

The same is true of biological phenomena. Larger body size may have an advantage in terms of strength and competition for mates and food,

but has the disadvantage of requiring more food energy. Larger body size can thus have both a benefit and a cost. Natural selection operates to lead to a balance between the benefits and costs to maximize fitness. Here, we use the word fitness in the more precise evolutionary context as the probability of survival and reproduction. This probability reflects the net balance between benefits and costs. As an analogy, consider the benefits and costs of advertising in a business. If you own a small business, you have to spend money to make money by investing some funds for advertising. The benefit of advertising is that you will increase the pool of potential customers that otherwise might not be aware of your products or services. The problem is that it costs money to advertise. There is a balance between these benefits and costs. If you spend too little on advertising, you will not reach as many potential customers as you would with a larger advertising budget. However, you would not want to increase the advertising budget without limit; after a certain point, you may saturate your potential market such that more money spent on advertising will not necessarily increase the number of customers. Further, you do not want to keep increasing the amount spent on advertising until the point where it costs more than your profits! It is clear that there is a balance here, and you want to find the sweet spot that maximizes profit and minimizes expense.

Natural selection can be thought of in a similar manner. Body size, for example, can be related to both benefits and costs, which in turn affects overall fitness. If the benefits of larger body size outweigh the disadvantages of larger body size, then natural selection will favor larger size. This will certainly be the case in some environmental contexts, but not all. In cases where available food resources are limited, it might actually be better to be smaller because of lowered energy requirements. The actual fitness of large or small body-sized organisms thus depends on the specific environmental context and shows that bigger is not always better.

What about the example offered earlier concerning the increase in brain size in human evolution? Although the relationship between brain size and cognitive ability and fitness is often complex, we do see a general trend in the fossil record for increasing brain size over the past 2 million years (see Myth 22). At first glance, this trend appears to fit the idea of “bigger is better,” which then leads to the common science fiction misconception that future human species will have increasingly larger brains, culminating in the absurd notion that one day humans will resemble giant brains with tiny vestigial arms and legs. A classic example of this notion is found in the entertaining and thought-provoking episode

“The Sixth Finger” from the 1960s science fiction television series *The Outer Limits*.⁶ Here, a scientist feeling guilty about his role in the development of nuclear weapons constructs a machine that will allow humans to evolve into an optimistic future state where violence and war have disappeared. Over the course of several treatments, the young man who volunteers to be subjected to artificial evolution changes through a series of increasingly future species. One change is the appearance of a sixth finger, accounting for the title of the episode. The major change, and one expected by virtually any science fiction fan, is the increased size of the brain, ultimately reaching a point where it is obvious to the viewer that the actor had difficulty balancing such a large prosthetic on his head. Accompanying this increase in brain size was an incredibly enhanced intelligence, the development of telepathic and telekinetic powers, and, ultimately, a state of peace and serenity.

Although the specifics of mental abilities in this story are fictional, it is a common idea that our brain will continue to grow in size into the future, a notion tied in with the myth that bigger is necessarily better. In order to consider the relationship between brain size and fitness, we also have to look at the costs of larger brains. For one thing, larger brains consume more energy. The brain is a very expensive organ, requiring 20 percent of our total metabolic energy, a figure much higher than in other mammals.⁷ Second, larger brains are harder to cool, because a basic biophysical property of mammals is that larger bodies, limbs, and heads lose heat more slowly than smaller ones. Finally, our species has a limit on how much brains can grow. A certain amount of rapid brain growth in humans takes place before birth, and giving birth to large-brained babies can be hazardous to the mother. If brain growth continued in human evolution, there would be a time when any further advantage of larger brains was offset by the added disadvantage of larger brains. In other words, the costs would exceed the benefits. All other things being equal, natural selection tends toward an optimal balance between benefit and cost. In terms of human brain growth, it is interesting that we already may have peaked in brain size. Biological anthropologist Christopher Ruff and colleagues found that absolute brain size in *Homo sapiens* has actually decreased slightly over the past 35,000 years, in part the result of a similar decline in average body mass.⁸

Perhaps one of the best counterexamples to the myth that bigger is always better is a phenomenon known as island dwarfism, named for the finding that a number of large-bodied species trapped on islands or other isolated areas often show a reduction in body size over time. One of the more spectacular examples of island dwarfism is the fossil remains of

dwarf elephants found on islands around the world, and some of these extinct species are estimated to have weighed as little as 200 kilograms (441 pounds). A reasonable evolutionary explanation for island dwarfism is that in some cases of isolation (such as on an island) available food resources are limited and animals that are smaller actually have a better chance of surviving such limitation because smaller bodies require less food. (A possible example of island dwarfism in human evolution is described in Myth 35.) It is also interesting that the opposite pattern, known as island gigantism, sometimes occurs to initially small species, such as some birds and rats, move into an environment lacking predators. The complex factors affecting body size in relationship to food resources, predator–prey relationships, and population growth are beyond the scope of this book, but the main lesson here is that the evolutionarily optimal body size will depend on specific conditions and will not always lead to larger body size.

We see that the idea of “bigger is better” is sometimes true, but it is not an absolute and is very much dependent on the specific local environment to which a species adapts. Sometimes smaller is better. A broader implication of this discussion, which surfaces repeatedly in this book, is the concept that evolution through natural selection represents a compromise between costs and benefits of evolutionary change. We will see a number of examples in human evolution in later myths that reinforce this basic principle that, when it comes to evolution, nothing is free.

Myth #5

Natural selection always works

Status: One common misconception about evolution is that natural selection always works, and a species will always be able to adapt to changing environmental circumstances. This is not the case, and the fact that over 99 percent of all past species are now extinct shows that over the long term natural selection does not continue to work. Because new species are born at the same time that old species die, the process of life continues, but with new players over time.

When I was a teenager in the late 1960s, ecology and environmental issues were on many people’s minds. I recall hearing someone claim that we should not worry too much about environmental change because in the long run humans would adapt to a polluted planet. I have always taken this statement as faith in the ingenuity of humans that we will eventually learn to filter out toxins and develop clean energy sources.

Years later, I wondered if this comment actually reflected a belief in the power of biological evolution. I have found that some people have a very optimistic (though undeserved) faith in the ability of natural selection to solve all problems.

Natural selection *is* a remarkable process, but it is not perfect. Selection leads to an optimal solution in terms of the differences in survival and reproduction, but this does not mean it will lead to a perfect solution. As an analogy, consider economic competition between different companies. (I choose this as an analogy because economic competition is often viewed as an analog of the idea of “survival of the fittest.”) When one company outdoes another in a fair market competition, it does not have to be perfect, but just better than the competition. Likewise, natural selection will favor those individuals that are better at surviving and/or reproducing than others are, but that does not mean the winners will be perfect. Evolution provides us with countless examples of adaptations that are far from perfect, but instead are good enough and, consequently, involve compromises. An example from human evolution is the tradeoff between the benefits and costs of walking on two legs (covered in more detail in Myth 15). Walking on two legs is not a perfect solution but one that is good enough because it provides a net advantage.

When considering the so-called perfection of natural selection, we also need to acknowledge that there are times when it is not possible to adapt to new environmental conditions. There is no guarantee that natural selection will save a species if conditions change. For one thing, some solutions might be biologically impossible. If, for example, a habitat is flooded, air breathers cannot all of a sudden evolve gills from lungs. Instead, they drown. There are also constraints on all life, such as the need of animals to eat, and a reduction in food resources cannot result in the evolution of animals becoming able to subsist on sunlight.

Even when adaptations are in principle biologically possible, selection has to operate on the variation that is present, and if the variation is not present, then selection will not take place. For example, natural selection has acted on a number of insect species to give them resistance to pesticide. If these populations did not possess the genetic variants allowing resistance, they would be out of luck. New alleles are introduced into a population by mutation and gene flow, but both are independent from the need to have the allele. For example, if you are an insect species and do not have the genetic variation for pesticide resistance to begin with, your need for it cannot make it materialize out of nothingness. Mutation is a random process that is blind to the need for certain mutations to develop when they are needed. Even if the necessary mutation is present,

it may often take a long time to increase the frequency of a new allele to a level high enough to result in major changes in survival. If environmental conditions change too fast, a species' ability to adapt through natural selection may be compromised.

Thus, there are many times a population cannot adapt to changes in the environment through the process of natural selection. If the change is severe enough, or occurs too quickly for a species to adapt and recover, it can become extinct. Here, the species has failed to adapt. The extinction of a species is actually very common and happens much more than most people think. An examination of the fossil record shows that of all the species that have ever lived, over 99 percent of them are now extinct.⁹ This very large number is a good demonstration that over the long term natural selection may not keep pace in a species as the environment changes.

Extinction happens all the time as species fail to adapt to changing conditions. Incidentally, I do not view the fact that extinction occurs all the time as justification for human practices that increase the rate of extinction (i.e., "They would have died out anyway"). Paleontologists refer to the ongoing process of extinction as background extinction and contrast it with times in earth's history where the extinction rates increased dramatically and were widespread, known as mass extinctions. There have been five mass extinctions in the history of our planet, the most famous of which was the K/T (Cretaceous/Tertiary) extinction that took place a little over 65 million years ago and wiped out a number of plant and animal species, including the dinosaurs. The largest of the five mass extinctions occurred at the end of the Permian period of the Paleozoic Era a bit more than 250 million years ago, when between 80 and 90 percent of species then in existence became extinct.¹⁰ Possible causes include an impact event, severe volcanic activity, and other natural events. In times of catastrophic environmental change, natural selection may not be able to help.

Extinction is not rare and on occasion can wipe out the majority of species. Given the extremely high rate of extinction in the earth's history it might seem a wonder that there are any species still alive! It is also hard to reconcile the high rate of extinction with the fact that there has been an increase in diversity over time. This seemingly paradoxical view is resolved by remembering that as some species die out, others rise to take their place.

Consider an analogy with the number of humans alive on the planet right now, which is a bit more than seven billion. How long will these people live? Let's consider the oldest documented age of a human being,

which was a French woman who died in 1997 at 122 years of age. If we take this number as the maximum age of any human, we can safely say that *every* human on the planet today, including any babies born in the time you take to read this sentence, will be dead 122 years from now. Barring any medical miracles, we expect that every person alive right now will be dead before the middle of the twenty-second century. Do you expect that if we were suddenly able to travel into the future to that time that there would be no humans alive? Apart from imagining a scenario of global destruction, I do not think so, for the simple reason that before that time *new* people will be born that replace those who die in the interim. Like all organisms, human beings age and die, but many reproduce before dying, so that life continues.

The same thing applies to the fossil record. Old species die off and new species are born, a process described in more detail in Myth 8. Life undergoes a constant replenishment, and over time we see evolution move in different directions. There is no inevitable direction that natural selection leads to; conditions continue to change, and natural selection does not always work. Species do not live forever. Still, life goes on.

Myth #6

Some species are more evolved than are others

Status: It is common for people to think of some species as being “more evolved” than others, and to further rank species from less evolved to most evolved, with humans typically placed at the extreme position of most evolved. However, most definitions of “most evolved” rely on arbitrary characteristics that reflect our own biases of worth and value. From a purely evolutionary sense, all life shares a common origin and all species, by definition of evolutionary time back to a common ancestor, are equally evolved.

Which animal is more evolved—an ant or a chimpanzee? Given this choice, I imagine that most people would choose the chimpanzee. If the choice was between an ant and a human, I suspect that virtually everyone would argue that humans are more evolved. In fact, the same is likely to be true no matter what organism we compare humans with, be it trees, ants, birds, or chimps. We see similar placement even when we are not talking about evolution. Humans have long been considered the ultimate among living creatures, whether we try to define this position in an evolutionary scheme or not. For example, the primacy of humans in existence is clear from Psalm 8 in the Bible, where humans are described

as “a little lower than the angels” and created by God to “have dominion over the works of thy hands.” These statements point to the idea that humans have a special place in the universe. This specialness is of course defined here in a spiritual sense, but it is not uncommon to see similar thoughts when considering the biological nature of humanity.

The ranking of living creatures, and the subsequent high status of humans, is an old idea in Western thought. One early example of this type of thinking comes from the Greek philosopher Aristotle, who proposed that living creatures could be arranged in a linear sequence according to various criteria. His system, the *Scala Naturae*, or Ladder of Being, ranked organisms from the simplest to the most complex. At the base of this ladder, Aristotle had lower and higher plants, followed by sponges and jellyfish, and then by other invertebrates, and finally, by fish, amphibians, reptiles, and mammals. Humans were placed at the top of the ladder (after whales).¹¹ Although some might quibble with the specific placement of some creatures on the ladder, many agree with the basic notion that humans represent the most complex living creature. This view has been incorporated into popular views of evolution, where humans represent the most evolved of all species.

Such schemes seem at first intuitively obvious, but is this because of some special characteristics that humans possess, or does it simply reflect a bias toward elevating our own species above all others? The key problem here is deciding exactly what is meant by “more evolved.” What are the criteria for assessing whether one species is more evolved than another? Size? Strength? Visual acuity? Fertility? Camouflage ability? Any list is going to have a subjective element. For example, if we use criteria such as mathematical ability, technological skill, and linguistic prowess, we will certainly rank humans above other creatures. On the other hand, if we use criteria such as being able to have hundreds of offspring, have higher resistance to radiation, and being able to survive for up to a month without food, then the cockroach would rank higher than humans.

We are back to the basic question of what it means to be “more evolved,” as the word *more* implies some feature of evolution that allows comparison between two or more species. Is it possible to compare species in terms of which have changed more? To some extent, we do have a measure of evolutionary change, where traits are referred to as “primitive” or “derived.” A primitive trait is one that has changed little since the time of a distant ancestor, whereas a derived trait is one that has changed since the time of a common ancestor. Characterizing a trait as primitive or derived is relative to the species being examined.

For example, when we examine tetrapod species (vertebrates with four limbs), we see that five digits (fingers and toes) is very common, seen in numerous amphibian, reptile, bird, and mammal species, including humans. We also know from the fossil record that the first tetrapods had five digits. The widespread occurrence of five digits throughout tetrapods shows us that having five digits is a primitive trait in tetrapods. However, not all tetrapods have five digits; for example, horses have lost four of the digits and have only a single digit. The loss of digits in this context is a derived trait, showing something that has changed in the evolution of horses (and related creatures) since the origin of mammals.

Evolutionary biologists distinguish between primitive and derived traits as a way of determining evolutionary relationships to allow us to reconstruct the evolutionary history of species. However, they are not meant to rank species on a continuum from less to more evolved. For example, if we used absence of five digits in tetrapods (a derived trait) as a measure of how evolved a species is, then we would conclude that horses are more evolved than humans, something that runs counter to what people consider as a ranking of “most evolved.”

If we find a species that has a large number of primitive traits, we might call it a primitive species relative to related species. Consider, for example, different kinds of primates, the group of mammals that include monkeys, apes, and humans, as well as tarsiers, lorises, and lemurs. Lemurs are a form of primate that are in a number of ways more similar to the earliest known primates than other forms of primates, such as monkeys and apes. When discussing primate biology and evolution, we might want to summarize the relative difference in evolutionary change by referring to lemurs as more primitive than monkeys or apes. In some features, lemurs have changed less than other primates have. However, does this therefore imply that they are less evolved? No, because by doing so we are implying that evolution can be measured in terms of the amount of change. Evolution is a process that can include different rates of change, including at times a lack of change. For example, in terms of natural selection, a species can evolve in a new direction (say an increase in the size of teeth) to adapt to a new set of environmental conditions, a process known as directional selection. On the other hand, selection might lead to the status quo being maintained, a process known as stabilizing selection, when changes away from the average might reduce fitness. (For example, birth weight in humans, which can be hazardous if the baby is too small or too large.) Both directional and stabilizing selection are different ways in which one of the evolutionary forces (natural selection) can play out, but both are part of the evolutionary process.

The difference is that one leads to directional change and one leads to stability. Using the actual amount of change is therefore not a measure of whether one species is more evolved than another. All species evolve, and the speed at which any given trait changes, while interesting in its own right, is not a relevant measure that can be used to rank species.

What about looking at how long a species has existed? Is it possible to rank species according to their longevity rather than the degree of change so that we can then state that older species are more evolved than younger species? Again, some select examples could provide unflattering contrasts that most people would disagree with, because they do not wind up placing humans as the most evolved. For example, what happens when we compare our species, *Homo sapiens*, which has been around about 200,000 years, with polar bears, which were around 600,000 years ago?¹² Should we conclude that polar bears are more evolved by virtue of having been around three times as long as modern humans? Again, this does not match up with most people's ideas of what "more evolved" means.

We cannot use the longevity of a species as a measure of the amount of evolution because evolution does not start or stop with the divergence of a new species. As will be shown in later myths, *Homo sapiens* arose from an earlier species, *Homo heidelbergensis*, which in turn arose from a still earlier species, *Homo erectus*, and so on into the past. We can do the same for any living species; as we go back in time, we will see different ancestral species. At some point in the past, any two species will have a common ancestor. For example, if we trace both humans and chimpanzees back, we find from genetic and fossil evidence that both lines share a common ape-like ancestor about 6 to 7 million years ago (see Myth 10). At that point, we see that both the human and chimpanzee lines date back to the same point, and the evolutionary lines have equal longevity. We can extend this to all species and, given evidence that all life shares a common origin, we see that no single line has been around longer than another has been.

In truth, there is no way to rank one species above another in terms of how evolved they are relative to each other. The question itself has no direct meaning in terms of how the process of evolution works any more than dropping two identical objects and talking about one being more affected by gravity. When we talk about some species being more evolved than others, we are actually talking about comparison of specific biological and behavioral traits, all of which have an evolutionary history. Thus, I have no difficulty arguing that humans show the greatest achievements in problem solving and technology, but even though these abilities have

an evolutionary origin does not mean that we can be characterized as “more evolved.” *Differently* evolved would be more accurate.

Myth #7

Humans lived at the same time as the dinosaurs

Status: Some cartoons and movies show modern humans and dinosaurs living at the same time, and some polls have shown a substantial percentage of Americans believe this to be a fact. In reality, dinosaurs first evolved over 200 million years ago, but died out (except for birds) 65 million years ago. Our first bipedal ancestors did not appear in the fossil record until only 6 to 7 million years ago, showing absolutely no overlap in time. Modern geoscience provides many ways of deriving the dates of fossils, which allows us to reject human–dinosaur coexistence and gives us an accurate history of life on earth.

I recall an evening when I was a young child in the early 1960s, when my older brother had a number of friends over at our house clustered around our small black-and-white television set to watch an episode of the animated show, *The Flintstones*, one of the first prime-time cartoon series. *The Flintstones* focused on the lives of two working-class suburban families, but it was set in the Stone Age. One of my favorite parts of the show was how humans and dinosaurs interacted, including the domestication of dinosaurs for labor and as pets. Although this was for me a fun cartoon (and shown in prime time), I never considered it to be a realistic depiction of what life was like for our Stone Age ancestors. Indeed, I recall a brief unit in first grade a few years before where we were shown filmstrips about dinosaurs and it was made very clear to all of us that the dinosaurs lived and died a *long* time before humans were on the scene.

Over the years, I can think of many books and movies that had both humans and dinosaurs coexisting. Sometimes this coexistence was explained by dinosaurs surviving in “*The Lost World*,” the title of a novel by Sir Arthur Conan Doyle. Other plots involve time travel (including the classic story, *A Sound of Thunder*, by Ray Bradbury) or cloning of extinct dinosaurs (the book and movie, *Jurassic Park*). Sometimes the coexistence is not explained, as in the 1966 remake of *One Million Years BC*, a date much too young for dinosaurs and too old for the modern humans in the film. These inaccuracies can be ignored in this context because it is fiction, and a large part of fictional enjoyment involves the temporary suspension of disbelief.

However, not everyone seems to realize that the idea of humans and dinosaurs coexisting is fiction and not fact. For example, one survey reports 40 percent of respondents agreeing with the statement “Dinosaurs lived at the same time as people.” (An additional 13 percent were not sure.)¹³ Further, there have been arguments for evidence of human–dinosaur coexistences, such as the claim that human footprints have been found alongside dinosaur footprints in ancient deposits of limestone in the Paluxy River riverbed in Texas. It turns out that these footprints are not human, but are instead misinterpreted dinosaur tracks, and in some cases have been altered.¹⁴

It has long been known that dinosaurs lived and died long before the first human-like creatures appeared. Geologic strata containing dinosaur remains occur below those containing remains of early humans. The geologic principle known as the Law of Superposition states that layers of sedimentary rocks are deposited over time such that the older strata are below younger strata. Dinosaurs are found in the geologic time period known as the Mesozoic Era, which is subdivided into three geologic periods: the Triassic, Jurassic, and Cretaceous periods. Dinosaurs appeared during the Triassic period, became dominant during the Jurassic period, and died out at the end of the Cretaceous period. The Mesozoic Era was followed by the Cenozoic Era, often referred to as the Age of Mammals because it is in this time that modern groups of mammals evolved from earlier mammals. The Cenozoic Era is divided into three periods, which are divided into seven geologic epochs. The first mammals included some ancestors of later primates, but no humans (or monkeys or apes). Over time, primates diversified, and human ancestors, the first bipedal apes, do not appear until much later, toward the end of the fourth of the seven geologic epochs (the Miocene epoch) of the Cenozoic Era.

Although we have long known that dinosaur fossils are older than human fossils, we did not always know exactly how much older. Using modern geologic methods that have been developed since the middle of the twentieth century, we can now provide actual dates to events in earth’s history. The start of the Triassic period is now dated to 252 million years ago, the start of the Jurassic period to 201 million years ago, and the start of the Cretaceous period to 145 million years ago. The end of the Cretaceous period, when the dinosaurs and many other species died out, is dated to 66 million years ago.¹⁵ Primates, including humans, evolved after this time. The earliest evidence of the first bipeds (human ancestors, but not modern humans) dates to at least 6 million years ago and perhaps as much as 7 million years ago (see Myth 10). The first fossils assigned to the same genus as us (*Homo*) date to a bit more than 2 million years ago.

The first modern humans date to 200,000 years ago. It is clear that dinosaurs and humans, even the earliest human ancestors, do not overlap in time with dinosaurs, or come anywhere near it.

A reasonable question here would be—how do we know these dates? Although the Law of Superposition gives us relative ideas of age (which fossils are older), there are a number of methods that provide us with precise estimates of age.¹⁶ The oldest of these methods to be discovered was carbon-14 dating, developed by chemist Willard Libby in 1949, an accomplishment for which he was awarded a Nobel Prize. Carbon-14 dating is one of several dating methods that use the principle of radioactive decay. During their lives, all living organisms (including us), absorb ordinary carbon (^{12}C) as well as the radioactive isotope carbon-14 (^{14}C), which has two more neutrons. Both forms of carbon are found in the atmosphere, but when an organism dies it no longer absorbs carbon, and its carbon-14 begins to decay into nitrogen-14. This decay occurs at a geometrically decreasing rate, known as a half-life, which is the amount of time it takes for half of the radioactive carbon-14 isotope to decay. The half-life for carbon-14 is 5,730 years, which means that after 5,730 years, half of the carbon-14 is gone, and it takes another half-life for half of the remaining carbon-14 to decay. Thus, it takes *two* half-lives ($5,730 \times 2 = 11,460$ years) to have 75 percent of the carbon-14 to decay. (One half-life = 50 percent and the second half-life is half the remainder, 25 percent, adding up to 75 percent.) After three half-lives ($5,730 \times 3 = 17,190$ years), half of the remaining 25 percent is gone, and $75 + 25/2 = 87.5$ percent of the original carbon-14 has decayed. In practice, geologists measure the amount of radioactive emissions in a sample and compare it to the rate in living organisms to determine how many half-lives have gone by, thus giving us a date.

Like all dating methods, carbon-14 dating has several restrictions. First, it can only be applied to organic matter, such as bone, wood, or charcoal from a fire. It would be useless for dating rock. Second, the amount of carbon-14 in the atmosphere had fluctuated in the past due to climate change, although calibration curves are available to adjust for this problem. Third, the half-life for carbon-14 is short, which means that the amount of carbon-14 in a sample will be very small after a few half-lives, until it is too low to measure accurately. In general, carbon-14 dating is good for samples from the last 50,000 years. We do not use carbon-14 to date the last days of the dinosaurs. However, many other dating methods have been discovered followed the invention of carbon-14 dating, and these methods extend our ability to measure geologic dates.

One widely used method is argon dating, which also involves the principle of radioactive decay. As originally developed, argon dating makes use of the decay of an isotope of potassium (^{40}K) into argon gas (^{40}Ar). Because the half-life is very long (1.25 billion years), this method is very useful for dating events older than about 100,000 years. A variant of the method is often used that first converts a different isotope of potassium (^{39}K) to an argon isotope (^{39}Ar), which turns out to be more accurate. Argon dating allows geologists to date volcanic rock because argon gas builds in volcanic rock over time. When a volcanic eruption occurs, the molten lava is very hot and any existing argon gas is driven out, thus resetting the clock. After the lava has cooled, the process of radioactive decay begins again, allowing us to measure how much radioactive argon accumulates over time, which provides us with the date of the volcanic eruption. This method is useful for dating fossils of organisms that died between two volcanic eruptions. For example, if we find a fossil above one layer of volcanic rock dated at 16 million years and below a layer dated to 16.2 million years, we know that the fossil died between those dates. Argon dating has been very useful in studies of early human evolution in East Africa, a region that was very volcanically active in the past.

Obviously, argon dating is not useful in cases where there have been no volcanic eruptions, but there are other dating methods that could be used in different cases. For example, uranium-lead dating also uses the principle of radioactive decay, has a very high half-life, and can be applied to a number of different minerals. Still other dating methods make use of different physical properties besides radioactive decay. Fission-track dating is a method that counts the number of tracks left in volcanic glass when uranium decays. Electron spin resonance dating is a method that utilizes the number of radioactive atoms in calcite crystals found in bones and shells. Another method known as thermoluminescence dating can provide dates based on the accumulation of electrons in objects that have been heated, including, for studies of human evolution, pottery and other objects.

There are also dating methods that make use of correlations established from other dating methods. One example is biostratigraphy, which compares distributions of animal bones from different sites to get an idea of the age of a given site. Suppose, for example, you see a particular anatomical trait in a species that you know from other dating methods only lived 3 million years ago. If you find this trait in fossils at a site where other dating methods are not available, it is a pretty good inference that this particular site is also dated around 3 million years ago.

One of the more elaborate correlational methods makes use of the fact that the magnetic pole of the earth has changed from being at the north magnetic pole to the south magnetic pole periodically in earth's history. For example, a compass would point to the north magnetic pole for the last 780,000 years, but would point south for tens of thousands of years before that. These shifts can be detected in minerals and occur at irregular intervals in the past. Other dating methods have been used to develop a timeline for these reversals, allowing geologists to date a site relative to the calibrated record of past magnetic reversals.

These are but a few of the examples that we can use to date past events in earth's history, including many in the course of human evolution. When possible, multiple methods are used to provide as accurate a record as possible. In the case of the dinosaurs, modern geologic methods have confirmed what had been known all along—the dinosaurs died out a long time before the earliest human ancestor walked the planet.

As a final note, I have to mention that although the classic dinosaurs that we are all familiar with are long gone, a related form of life is still with us—the birds. A number of paleontologists have proposed that birds are descended from avian dinosaurs, which means that some dinosaur descendants are still with us. However, seeing a sparrow on a tree is a far cry from the usual idea of human–dinosaur existence, as we will not be seeing (thankfully) *Tyrannosaurus* or *Velociraptor* walking down the street except in the movies.

Notes

- 1 See Cook *et al.* (1999) for more details regarding the evolution of the peppered moth.
- 2 “*Forrest Gump* Quotes.” Available at <http://www.imdb.com/title/tt0109830/quotes> (accessed July 1, 2014).
- 3 See any college statistics book.
- 4 See Relethford (2012: ch. 5).
- 5 This figure is based on a brain size of 850 cubic centimeters (cc) in early *Homo erectus* (Rightmire 1990) compared with an average brain size of 1350 cc in modern humans.
- 6 Schow and Frentzen (1986).
- 7 Armstrong (1983).
- 8 Ruff *et al.* (1997).
- 9 Raup (1991).
- 10 Benton (2003).
- 11 Kennedy (1976).

- 12 Hailer *et al.* (2012).
- 13 Bishop *et al.* (2010).
- 14 Milne and Schafersman (1983).
- 15 Dates are taken from the version of January 2015 of the International Chronostratigraphic Chart published by the International Commission on Stratigraphy. Available at <http://www.stratigraphy.org/ICSchart/ChronostratChart2015-01.pdf> (accessed June 9, 2015). These dates are periodically revised slightly as more accurate estimates of geologic boundaries are developed. The most recent version at any point in time is available at <http://www.stratigraphy.org/index.php/ics-chart-timescale> (accessed July 5, 2016).
- 16 Dating methods are described in a large number of introductory texts in archaeology, biological anthropology, paleontology, and geology.