

Common misconceptions about evolution, and how it really works

The *fact* of evolution is straightforward: forms of life change over time, via descent with modification.

The basic principle of the *theory* of evolution is also easy to state: **the characteristics of a population are most strongly influenced by the individuals who leave the most viable offspring.** This seems so uncontroversial as to be almost tautological, but there is a lot of confusion about what evolution means. Admittedly, most of the confusion is promoted by people who feel that evolution threatens their worldview in some way, but there can be honest misunderstanding as well. Most of this class will therefore be a discussion of some common misconceptions, but first let's break evolution into a two-step process:

- Variation. Some variation is needed to produce changes that can lead to better adaptation. Mutation is an example: when a new organism is produced, there are sometimes errors in transcription of DNA. Sex is another: both parents contribute part of the genome, and mixing of characteristics can produce surprising differences sometimes (e.g., very tall children from ordinary-height parents). At the single-celled level there are other less-familiar mechanisms, such as lateral gene transfer, in which an organism gets part of its DNA or RNA from a separate organism (one mechanism for this is movement of the DNA by a bacterial virus). Another example is the incorporation of entire cells (which is thought by some to be the origin of the organelles in cells, e.g., mitochondria, which have their own separate DNA).
- Selection. Any time you have variation in a population, some individuals will produce more viable offspring than others. This isn't completely related to genetics, either: environment and luck play significant roles. However, if there are characteristics that make it easier to pass on genes, those characteristics will become more common in the population. Note that both "natural" selection (whether something survives to reproduce) and sexual selection (whether the individual can find a mate, in sexually reproducing organisms) play a role. Note also that except for the simplest characteristics there are tradeoffs: being able to run 40 miles per hour would obviously be advantageous to humans, but putting developmental energy into such fast running would take away from other abilities we would have, so the net result could be negative. Finally, note that there are many variations that have zero or negligible impact on reproductive success at the moment, but can later play key roles because of the genetic diversity they produce (this is called "neutral drift").

The "Understanding Evolution" site at Berkeley (<http://evolution.berkeley.edu/evolibrary/>) summarizes the process as variation + differential reproduction + heredity = natural selection.

Now let's address some misconceptions.

Misconception 1: Evolution is incompatible with religion or leads to bad behavior.

This is the big one, and it is at the basis of a never-ending series of attempts to kick evolution out of classrooms or raise invalid doubts about it. Fundamentally it comes down to two concerns that are raised. If I accept that evolution has occurred, do I have to be an atheist? Also, if we agree that we are descended from other animals, does that mean we have no ethical guides and therefore can or should act animalistically?

Even for people who think that atheists are automatically awful, the first concern can be dismissed easily: there are endless biologists and other scientists who are religious and also accept the overwhelming evidence for evolution. One can also go the other way. For example, check out

http://www.butler.edu/clergyproject/rel_evol_son.htm

This is a list of signatures from 11,945 different members of the clergy in the United States who have signed on to a statement that, among other things, says "We believe that the theory of evolution is a foundational scientific truth, one that has stood up to rigorous scrutiny and upon which much of human knowledge and achievement rests." The signatories come from all denominations, including even a few Southern Baptists. Think about this when you see people claiming that you can't be a good Christian if you accept evolution!

The second concern is also dealt with straightforwardly. Evolution, like any scientific concept, is a description of what *is*. It is *not* a guide to what *should be*. In other words, it is most definitely not something that should be used as a guide to human behavior. To make this clearer, suppose we use an analogy. Gravity is something that definitely exists. As with evolution, we can distinguish the factual part (things fall) from theoretical models of gravity (Newton's laws are generalized by Einstein's general relativity, and in the future we hope to have a theory of quantum gravity). However, suppose that someone says to you "Since gravity makes things fall, I am required to push old ladies down flights of stairs." Would your reaction be to blame gravity and curse Isaac Newton? I hope not! Gravity is simply a fact of the universe, and evolution is as well. You need to draw your behavioral guides from some other source (for example, your upbringing, or observations of how people interact, or religion).

Some people have gone even further in trying to attack evolution, e.g., by alleging that the Holocaust came from Darwinian principles. Given that Hitler never mentioned Darwin in *Mein Kampf* (not once!), and that unfortunately anti-Semitism and even massacres were common many centuries before Darwin was born, this is also emphatically not a conclusion that can be drawn.

Misconception 2: Evolution has never been observed.

As we'll see especially in the next two lectures, this is entirely false! Most people who say such a thing are influenced by Misconception 1. To the degree that there could be honest misunderstanding, though, one possible source of confusion could be that many people don't have a good sense for the types of changes that they would expect, and thus by adding these incorrect expectations they violate observations. For example, people may not understand how many generations it takes to produce significant evolutionary change. As a result, they think that in the past few thousand years one would have expected to see cats turn into dogs, or something of that magnitude.

In reality, the fossil record and even experiments in the laboratory with bacteria and viruses have demonstrated evolution beyond question. We'll cover this in great detail in the next two classes.

Misconception 3: Evolution is random.

Now we pass from concerns that are emotional to ones that are often the result of genuine confusion. It is often said that evolution is random, and this is true in the sense that there is no final goal in mind. It is also true that mutations, which drive some but not all of the variability on which evolution acts, are basically random (it is actually the case that some parts of the genome are copied with greater fidelity than others).

However, the critical aspect of evolution that allows it to be so effective is that there is much more to it than pure randomness! Natural selection, in fact, is the opposite of randomness: individuals that are better adapted to their environment have a better chance of leaving offspring. These offspring inherit many characteristics of their ancestors, so in fact there is a strong drive towards better and better adaptation. This natural selection works on the variations produced by mutation and other mechanisms to produce evolution.

An example may help make this clearer. Suppose that we have a bank vault that is protected by a combination lock that has 100 dials that go from 0 to 9. If we try to break into the vault by spinning the dials again and again, and if only the right combination has any effect at all, we would expect to spin the dials 10^{100} times to have a decent chance of breaking in. At once per second, we would only get through about 4×10^{17} combinations in the current age of the universe, so obviously we'd have no chance.

However, let us say that the lock has a flaw such that if any one of the numbers is the right one, the dial sticks right there. Then on the first set of spins we'd expect to get 10 right numbers. On the next set, we only have 90 to spin, and we'd expect to get 9 more right numbers. At one set of spins per second, we'd have it all right in about a minute. This, in a simplified way, is the power of natural selection. Any time a change leads to an

advantage (defined as always in terms of leaving more viable offspring), that change tends to be incorporated into the population. Over long times (and remember that we have billions of years to play with!), this can diversify into the remarkable richness of life we have on Earth.

Misconception 4: Evolution is about the ladder of progress

Quick quiz: which is more evolved, a human being, or a current-day *E. coli* bacterium? We are tempted to answer that it is the human, and at first glance this seems entirely reasonable. We have many cells that do many different things, and the cells themselves are fairly large and complicated, with nuclei and various organelles that carry out sophisticated biochemical tasks. In contrast, bacteria have but a single cell, which doesn't even have a nucleus! How can anyone doubt that we are more evolved?

This, however, is not the most productive way to look at things. It is true that the *E. coli* is surely much more similar to the organisms that existed 2 billion years ago than we are (for example, at that time there was no multicellular life). However, the perspective we need to adopt is that evolution is all about reproductive success. In practice, this means that there are effectively a large number of ecological niches, and every organism adapts over time to best fill those niches. Note also that the niches can change, sometimes radically. A familiar example is that during the roughly 150 million years that dinosaurs roamed, mammals were essentially rat-sized things that mainly hid. When the asteroid hit 65 million years ago and killed off the dinosaurs (except for those that evolved into birds), luckily for us some mammals survived, and within a few million years we had the largest land mammals ever, e.g., 20 foot tall sloths! The death of the dinosaurs and other changes had opened up a niche that was filled, eventually, by evolving mammals.

With this perspective, we can understand that every current species of life on earth is *equally* evolved in the sense of adapting to their various niches. There are, of course, some niches that change fairly slowly, which is why current-day sharks are basically the same as their ancestors of nearly 300 million years ago. Really rapid evolution can occur when the time between generations is small and the environment changes rapidly. For example, nylon, a completely artificial substance, was invented in 1935. By 1975, scientists discovered bacteria that could metabolize some byproducts of nylon manufacture (which, to drive the point home, had never before been seen on Earth). The three main enzymes used by the bacteria are completely novel. A more tragic example is seen in the development of diseases; for example, HIV has developed new biochemical pathways in the last few decades.

Misconception 5: Natural selection involves organisms “trying” to adapt or getting what they “need”

This is sometimes phrased in a different, way, such as “It would obviously be advantageous for humans to be able to run 40 mph [the speed of an ostrich, the fastest two-legged animal]. Since we can’t, evolution has clearly not applied to humans.”

What is behind this misconception is that in some sense we want to think about organisms controlling their destiny. Indeed, in this idea we see echoes of Lamarck’s concept that, e.g., giraffes stretch their necks to get at high leaves, so their offspring will have longer necks.

However, this isn’t how evolution works. The variations produced by mutations are entirely random, meaning that if some of them make it easier to leave viable offspring that’s great, but there is no direction or plan. Sexual selection can be directed by intelligent enough organisms (i.e., humans!), but there are enough complicated things going on in our genomes that there can be unintended negative consequences. For example, hemophilia is a very rare blood disease in which clotting is ineffective, so if you get a pinprick you are in danger of bleeding a lot. It happens in perhaps 1 in 5,000 males (and fewer females), but in the mid to late 1800s it was highly prevalent in the royal families of Europe due to many generations of inbreeding! Overall it’s better to have a wide-ranging genetic population.

We can therefore say that evolution gropes blindly in innumerable directions at once, rather than seeing a goal. Some of those directions are advantageous, and thus naturally larger numbers in the population go that way.

Misconception 6: Some structures have been demonstrated to be too complex to have arisen one small step at a time.

Given that evolution proceeds one small step at a time, without foreknowledge of the goal, and that all the myriad steps have to be at worst neutral in selectability, how can one explain the origin of complex structures such as the eye? This is an argument that goes back to William Paley in 1802, but has been recently resurrected as a “new” argument by opponents of evolution.

Michael Behe, one of the more prominent members of the anti-evolution movement, has phrased this as an analogy. Consider a standard mousetrap: it has five essential components (a base, a hammer, a spring, a catch, and a metal bar to hold back the hammer). If any of these are removed, one has a non-functional mousetrap. Now, says Behe, consider any number of biological structures such as the eye, or more obscurely, the bacterial flagellum. These have many interleaved components and removing any of them prevents functionality.

Essentially, Behe and others like him are promoting a disguised version of the classic “God of the gaps” approach. What this essentially says is that if we don’t *currently* understand how something happens, God must have done it and we should stop investigating. This is unproductive scientifically (why should we cease searching?), and dangerous theolog-

ically because if your religion relies on there being no other explanation for a phenomenon but then an explanation is obtained, your faith is weakened.

Indeed the complexity argument poses no problems to evolution, because the fundamental assumptions of people such as Behe are misguided in two important ways. The first is to note that although our eyes are very sophisticated, there are examples throughout the animal kingdom that range from simple light sensors to eyes that are arguably better than ours (e.g., octopus eyes, which don't have a blind spot on their retinas). Having a sensor that tells you if it is light or dark is better than having none; having one that tells you the direction of the light is better than one that can't; having one that can discriminate colors is better than having one that can't; and so on. For example, although my eyes are far from perfect, even without glasses I'll happily accept my out-of-focus vision in preference to complete blindness! The same thing is true with Behe's favorite example of flagella (these are the hairlike things that can propel bacteria and archea). Looking throughout the bacterial and archeal domains, one finds that many of the proteins that Behe thought critical are absent in a number of cases, and there are major differences between bacterial and archeal flagella that prove that there is more than one path that can be taken.

The second point is that Behe's approach has the implicit assumption that evolution was somehow "aiming" towards a given complex feature, in contradiction to our discussion about the previous misconception. What I mean by that is that he is effectively assuming that if the system can't function as its final goal, it's useless. This, however, is emphatically not the case, as has been demonstrated in endless laboratory and computer experiments. For example, consider the mousetrap. Maybe if we remove all but the spring and hammer we don't have a functioning mousetrap, but we could use it as a tie pin. For the bacterial flagellum, parts of the system are extremely similar to other aspects of the bacteria, and much simpler, which thus provide stepping-stones to more complicated structures.

Evolution is opportunistic, and works with what it can get. This is one reason why there are many *non-optimal* structures in nature. A classic example is the thumb of the giant panda. This is a clumsy structure that the panda uses to strip off bamboo. If one designed this from the start, one would use a much more efficient system. However, the panda's ancestors were carnivorous, and when the environment changed and they adapted to a new diet, they used the claws they have.

In summary, evolution is a profound and elegant mechanism, and in broad sweep it isn't that difficult to understand. Of course, to be scientific it has to confront data, and there may well be no theory that has done that more successfully, with more diversity, than evolution. In the next two lectures we will discuss the fossil evidence and evidence from experiments and molecular genetics.