Lectures 1 & 2 **Friday, August 24, 2012 & Monday, August 27, 2012**

An example of the relevance of evolution today

The usual story is that Alexander Fleming accidentally discovered penicillin; the story is that Fleming, working in St. Mary's hospital in London, was working with a culture of *Staphylococcus aureus*, a pathogenic bacterium on which he was doing some research, when he noticed that it had become contaminated by a species of *Penicillium*. He noted that the mold was inhibiting the bacterial growth. He writes a paper on his finding in 1929, and the rest is history.

The actual story is a bit different. Fleming was searching for antibacterial agents as early as 1920, and was largely motivated by his World War I experience where he witnessed the deaths of many soldiers from septicemia (blood poisoning). In 1922 Fleming discovered lysozyme (an enzyme that lyses bacteria). In 1928, while researching staphylococci, he benefited from chance, and a well-conditioned mind that was looking for agents that inhibited bacteria. His lab, evidently, was not a very orderly one, and cultures he worked on were often forgotten, and hence contaminated eventually. After returning from a month-long vacation, Fleming found many of his plates contaminated with a fungus. He noticed a zone of inhibition around the fungus. He thought he was on to something, and eventually isolated an extract from the mold that, by itself, could inhibit the growth of bacteria. He named the inhibitor 'Penicillin'.

By 1943, drug companies were mass-producing penicillin for the war effort. Thousands of lives were saved by this "miracle drug" over the course of the war. And of course, the lives of perhaps millions of people were saved by penicillin and related drugs after the war. For us, it is difficult to imagine living in dread of dying of a bacterial infection, of any kind. But, of course, this was not always the case. The last 50 years has been termed a golden age in medicine, mostly because of the better treatment of bacterial pathogens.

The year 1943 marks the beginning of the antibiotic error; 1947, however, marks the beginning of the emergence of antibiotic resistant bacteria. 1947 saw the first penicillin resistant pathogen, *Staphylococcus aureus*. By 1967 penicillin resistant pnemococci had surfaced and American military personnel in Southeast Asia were starting to bring home penicillin resistant gonorrhea.

The response by the medical community was a natural and reasonable one. If penicillin doesn't work as effectively, let's find another antibiotic. The 1950's saw chloramphenicol, neomycin, streptomycin, tetracycline, erythromycin and cephalosporins added to the list of antibiotics. The 1960's saw the addition of several new aminoglycosides, but resistance to one aminoglycoside was often accompanied by resistance to other aminoglycosides. (An aminoglycoside acts by tightly binding to a structural component of the 30S ribosomal subunit to inhibit protein synthesis.) The 1970's were bleak in terms of adding new antibiotics, but the 1980's saw the addition of an important new class of antibiotics called the fluoroquinolones, of which Ciprofloxacin is probably the most familiar. (Fluoroquinolones inhibit gyrase in bacteria, which is an enzyme that is necessary to separate DNA during cell division.)

Over the past 60 years, bacteria that are resistant to new drugs consistently appeared within a few years of the introduction of those drugs into clinical use. By 1994, researchers had identified in patient samples, bacteria that were simultaneous resistant to all currently available drugs.

Why?

First, the emergence of antibiotic resistance is an example of **evolution**. Biological evolution is the change over time of the traits of a species. The trait that the bacteria differ in is their individual resistance to antibiotics. Some bacteria are less susceptible than others to treatment by antibiotics. The observation is this: 60 years ago, antibiotics like penicillin were widely (in fact, wildly) successful at treating pathogenic bacteria. Today, those same drugs are less successful because the proportion of resistant bacteria "out there" has increased. Evolution in this sense is a statement of **fact**, not of theory. A fact is something that can be observed. We have observed (unfortunately) the evolution of antibiotic resistance in different bacterial species. We have also observed evolution in other species over longer periods of time, and have direct evidence in the forms of fossils that creatures in the past did not look like creatures alive today.

Second, the evolution of traits such as antibiotic resistance is often caused by natural selection. This is one of the big ideas that Charles Darwin had. The idea is really simple:

(1) Individuals within a population are variable.
(2) The variations among individuals are, at least in part, passed from parents to offspring. That is to say, offspring resemble their parents.
(3) In every generation, some individuals are more successful at surviving and reproducing.
(4) The survival and reproduction of individuals are not random, and are tied to the variation among individuals. The individuals with the most favored variations, those who are better at surviving and reproducing, are naturally selected.

Components of a successful theory of evolution:

(1) The **fact** of evolution. We can observe that organisms change over time.
(2) The **pattern** of evolution. How exactly do species change over time? Is the change abrupt, or do species change gradually?
(3) The **mechanism** (process) of evolution. What causes species to change over time?

Also, note that evolutionary biology is a historical science (it attempts to explain events that occurred in the past). It seems quite simple to explore the fact and pattern of evolution through direct observation, using, for example, the fossil record. However, establishing a mechanism is not so easy. In order to establish a mechanism that caused a historical event, one must make an assumption. The assumption is this: *Processes we see acting today, also acted in the past*. This is not a particularly controversial assumption, but it is key. It underlies the sciences of geology, astronomy, and evolutionary biology, among others. The assumption of uniformity of processes over time is so important that the concept has a rather imposing name: **Uniformitarianism**.

A couple of notes about the idea of uniformitarianism: (1) The alternative to uniformatarianism is the idea that processes in action in the past were different than those today. This is a variant of supernaturalism, I think. (2) Uniformitarianism does not mean that all changes have to be slow or gradual. Some natural processes, active today (and yesterday), are abrupt. Consider, for example, volcanoes, floods, hurricanes, and impacts of asteroids. (3) Uniformitarianism does not imply that rules governing change in the past (and present) are perfectly understood or predictable.

Darwin's contribution

Charles Darwin founded the field of evolutionary biology. He is justifiably famous because he was the first to propose a successful theory of evolution.

He confirmed the fact of evolution, something that several people had argued for in the past. He called this "descent with modification." Here are some people who entertained (sometimes vague) ideas of evolution before Darwin.

(1) 1749, Comte de Buffon: Comte de Buffon, a French naturalist, developed the modern definition of a species; a group of organisms which can breed and produce fertile offspring. He thought that all organisms were created by god and arranged in a hierarchy with mankind at the top of creation. Buffon entertained the idea of evolution, specifically that different species arose from a common ancestor, but argued against it. Buffon also thought that the earth might be "old": as old as 168,000 years.

(2) 1794, Erasmus Darwin: Erasmus Darwin, English physician, poet and naturalist, developed one of the first theories of evolution in his book, *Zoonomia*. Erasmus thought that all life had evolved from one common ancestor, which over time, branched off into all the species we see today. Erasmus Darwin was Charles Darwin's grandfather.

(3) 1809, Jean-Baptiste Lamarck: Jean-Baptiste Lamarck's book, *Philosophie Zoologique* stated that animals evolved from simpler forms. Lamarck saw evolution as a goal oriented process striving towards perfection; analogous to species climbing a ladder. One result of this view was that he did not believe species became extinct, rather, they simply evolved into a different species. For Lamarck the process of evolution was a simple one—as the environment changes species need to modify how they interact with it in order to survive. As a species used a particular structure more often, that structure grew bigger

(or smaller if used less). Lamarck also supported the notion of inherited characteristics; any changes that occur through use or disuse are passed on to the next generation. Lamarck coined the term "invertebrates" and in 1802 he (with Trevirons) coined the term "Biology" for the first time.

Although there were some limited speculations about organic evolution, the preponderant idea was that species were immutable (fixed) and specially created by God.

Darwin also had something to say about the pattern of evolution. He argued (strongly) that species change gradually over time.

Most importantly, Darwin was the first to propose a mechanism of evolution, called natural selection.

A little about Darwin

(1) Born February 12, 1809 (the same day and year as Abraham Lincoln)
(2) Devoted naturalist, from an early age. He loved to hunt and collect things (such as beetles).
(3) Family was well-to-do. His grandfather was Erasmus Darwin (author of *Zoonomia*). His mother was a Wedgewood (the wealthy family of potters).
(4) Was set up to become a doctor, and went to Cambridge. But the sight of blood sickened him, and he asked his father to allow him another career. The clergy it was.
(2) However, at Cambridge, he was exposed to many ideas. First, he was heavily into beetle collecting. He also went "botanizing" with one of his professors, Henslow. Also, introduced to Lyell's works (Lyell was one of his professors), so he knew about the most modern principles in geology. Finally, he was involved in the Plinian Society, a group of free thinkers. He presented his first bit of science there (on the biology of a barnacle).
(3) His big opportunity came when Henslow recommended to the British Admiralty that Darwin be selected as the unpaid naturalist aboard the *Beagle*, a naval ship involved in surveying South America.
(4) Two hurdles: First, the Captain, Fitzroy, had to approve. Second, his father had to approve. His father thought he should be "getting on with his life", but his uncle Josiah Wedgwood helped Charles convince his father that this was an excellent opportunity. It was looking like a career in the clergy was out.
(5) Voyage of the Beagle, December 27, 1831 to October 2, 1836.
(6) Henslow gave Darwin a copy of Lyell's new book, *Principles of Geology*, before he left.
(7) The highlight of his trip was the visit to the Galapagos Islands. However, the visit was not revelatory; he did not come up with his ideas on natural selection there. In fact, he did not even sort the birds he collected by island!
(8) After he returned, he started to doubt the "fixity" of species, and started his work on the transmutation of species. People like John Gould pointed out to Darwin that the specimens that Darwin had labeled mockingbirds were

actually all different finches, and that the birds were also distinct enough to be called different species.

(9) His reading of Malthus's *Essay on the Principle of Population* (1798) was crucial in his forming ideas on natural selection. In Darwin's words "I happened to read for amusement Malthus on Population, and being well prepared to appreciate the struggle for existence which everywhere goes on from long-continued observation on the habits of animals and plants, it at once struck me that under these circumstances favourable variations would tend to be preserved and unfavourable ones destroyed" (September 28, 1838).

(10) Twenty years passed from his opening of his "transmutation" notebooks to the publication of the *Origin of Species*. What was he doing? He spent 8 years on barnacles. He spent a lot of time gathering evidence for his idea, realizing that he would have to be overwhelming in his arguments, amassing tons of evidence in his favor.

(11) Alfred Wallace sent him an essay, to be communicated to the Royal Society, in 1858. It was titled "On the tendency of varieties to depart indefinitely from the original type", which Darwin called a better abstract of his ideas than he could have produced.

(12) The solution was to read extracts from an 1844 essay he had written, mostly for himself, and Wallace's paper together on July 1, 1858, at the Linnaean Society of London. He then published an "abstract" of the big book he was working on, which he titled "The origin of species by means of natural selection, or the preservation of favoured races in the struggle for life" (1859). The book sold out its first printing in one day.

On the Origin of Species

The Origin of Species (1859) is one of the most important scientific works of all time. The book is a carefully argued thesis, with enumerable supporting observations. The argument Darwin made in the *Origin* is quite clever.

First, he started with observations that no one at the time found controversial. He used domestic animals and plants to show that:

(1) Individuals vary one from another.
(2) That the variation is inherited. That is, offspring tend to resemble their parents more than they resemble unrelated individuals.
(3) That the farmer/breeder could select for those traits he found desirable.

Specifically, Darwin uses horses, dogs and pigeons as examples. He also argues that there is no limit to the amount of change that can be caused by selective breeding.

Second, he pointed out that non-domesticated animals and plants also vary, and that this variation appears to be of the same degree as seen in domesticated animals. The argument is clever, as Darwin is linking the types of observations that a farmer might make in domesticated animals and plants to the types of observations a naturalist might make about a wild species. Darwin used species of British plants as examples here.

Third, Darwin argued that there is a struggle for existence among individuals in the wild. This is his first break with what many of his readers would find obvious. Many people at that time had a belief in "Natural Theology", which was the idea that organisms in nature had a harmonious existence, and that the world was ordered for human delight and use. Darwin argued instead that organisms tend to produce many more offspring than can survive. Here, Darwin was influenced by Thomas Malthus (1766–1834) whose most influential work was *An Essay on the Principle of Population*. Malthus argued that humans would face a crisis at some time in the future when human population outstripped food supply. He argued that human populations increase exponentially, whereas food supply can only be increased linearly. Darwin recognized that this argument also applied to animals and plants. Because animals/plants produce so many offspring, only a fraction of whom can survive to adulthood, there must be a struggle for existence.

Fourth, Darwin argued that individuals bearing a variation that allowed them to better survive or reproduce would have an advantage. These individuals would tend to leave more offspring in the next generation, and these offspring would also bear the variation that allowed better survival or reproduction. This process he called natural selection. Darwin argued that, given the vast amount of time available, that there was no limit to the amount of change that natural selection could cause. Note that it is the species that changes, not the individuals within a species (which either survive to reproductive age, or don't, or either reproduce, or don't). Also, Darwin argued that a characteristic could be present only because it enhanced an individuals chances to survive or reproduce; it could not be present only because it benefits another species.

Fifth, Darwin attempts to head off what he thinks will be objections to his theory. These objections include: "rarity of transitional varieties" and "organs of extreme perfection".

Transitional forms can be of two sorts. First, transitional forms can occur in the rock record, as fossils that are intermediate in form between two living groups. The lack of transitional forms in the fossil record Darwin attributed to the rarity of fossilization, stating that the fossil record is "incomparably less perfect than is generally supposed." Second, transitional forms might be present as living organisms. The potential concern, still stated by some today, is "Why isn't there a continuous gradation of forms between two species?" Darwin argued that living intermediate forms would not usually be seen because species would continue to change; you wouldn't see an intermediate form, because the characteristics of the species continued to change, leaving no living descendants (of that form). That said, some living intermediate forms exist (platypus comes to mind). Similarly, the fossil record, as it is understood today, is littered with transitional species.

Large transitions also posed a potential problem for his theory. Darwin argued that during the evolution of a complex structure, such as the vertebrate eye, that all of the transitional forms of the eye must have been an improvement on the previous type. Darwin's argument about the evolution of “organs of extreme perfection” relied on plausibility. He also emphasized that organs arising for one function can later serve another.

Sixth, Darwin points out that his theory explains a lot of unrelated observations in an elegant way. He can explain: biogeographic patterns, homology, rudimentary organs, among other things. Darwin argued that:

(1) The fossil record was incomplete, but what was known at the time was consistent with his theory. For example, new groups don’t all appear at once, but rather in succession.
(2) Darwin argued that it makes sense to see closely related (similar) species in one geographic area, because the species shared a common ancestor that lived in that area too.
(3) Darwin argued that the Linnaean classification scheme makes sense in the light of his theory. The hierarchical classification scheme simply reflected varying degrees of relationship among different species.

Throughout the *Origin*, Darwin contrasts his theory of evolution by natural selection to the leading competing theory at the time: separate creation of species in their current form. Darwin points out that there are many observations that are predicted by his theory, but difficult to explain by special creation.

(1) Imperfection of adaptation. Darwin emphasized that “Natural selection tends only to make each organic being as perfect as, or slightly more perfect than, the other inhabitants of the same country with which it has to struggle for existence.” One argument for the lack of perfection is simply the result of common ancestry: “He who believes that each being has been created as we now see it must occasionally have felt surprise when he has met with an animal having habits and structures not at all in agreement.” He cited the webbed feet of geese that rarely go near water as an example.
(2) Homology—the similarity of structures in different species often used for different purposes—is another observation that is difficult to explain by special creation, but predicted by evolution as a simple consequence of descent with modification. Living species share similar structures because their ancestors had those structures.
(3) Similarities during development. Some species that appear quite different as adults often look alike early in development. He argues that this similarity is caused by common ancestry.
(4) Rudimentary organs. Darwin described rudimentary pelvic and hind limbs found in some snakes as evidence that snakes are descended from species with fully developed limbs. Rudimentary organs are difficult to explain via special creation.

Darwin and his status in the field of evolutionary biology

Darwin is justly revered for his contributions to science. He founded evolutionary biology as a field of science, and evolution unites many disparate observations made even today. Many ideas of great importance can be traced to Darwin's seminal work, *On the Origin of Species* (1859) or to his later work *The Descent of Man, and Selection in Relation to Sex* (1871). He rightfully was buried in Westminster Abbey, near Newton.

That said, the field of evolutionary biology has progressed way beyond what Darwin could have imagined. Imagine what a boring area of science evolutionary biology would be if nothing new had been discovered or learned since Darwin's work! The rest of my section in Biology 1B will be devoted to covering what has been learned since Darwin's time about the pattern and process of evolution.

Example test questions

Q1. In the *Origin of Species*, what was the point of Darwin's discussion of the rudimentary legs of some snakes?

A. There must be some purpose they serve.
B. They indicate descent from a species with fully developed legs.
C. They must have evolved because of sexual selection.
D. They would not be present in a domesticated species of snake.
E. They do not present a problem for his theory because some species of snaes do not have rudimentary legs.

Answer: B

Q2. Uniformatarianism is an important assumption in historical sciences because

A. without the uniformitarian assumption, scientists cannot determine what occurred in the past.
B. without the uniformitarian assumption, scientists cannot determine what processes caused past events.
C. without the uniformitarian assumption, scientists cannot determine if past events occurred gradually or abruptly.
D. without the uniformitarian assumption, scientists cannot predict what will occur in the future.

Answer: B

Q3. Which one of the following statements best describes the importance of homologous structures for Darwin's argument?

A. Homologous structures are evidence of a shared function.
B. Homologous structures indicate shared ancestry.
C. Homologous structures indicate that organisms share a common habitat.
D. Homologous structures are consistent with an independent creation model.

Answer: B