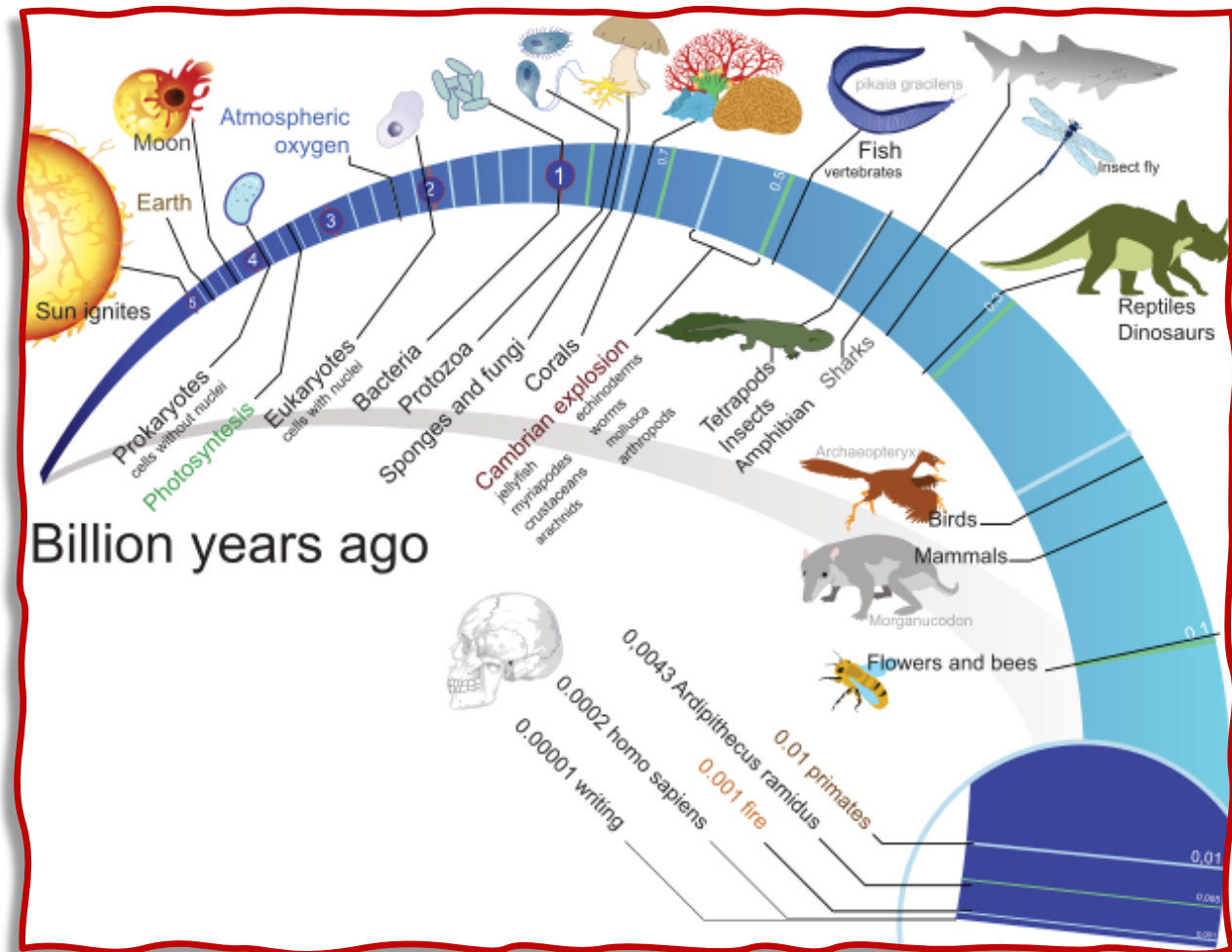


LECTURE NOTES FOR WEEK 4: EVOLUTION

(BASED ON THE READING., "THE EVOLUTION OF LIFE" BY HEWITT, ET AL)

"What we're watching in real time is evolution.
And it's a biological process, and it is, by definition, unpredictable."
—Laurie Garrett, on disease outbreaks, author of *The Coming Plague* (1995)



Credit: https://commons.wikimedia.org/wiki/File:Timeline_evolution_of_life.svg

Old News?

- ✓ Evolution is not something that happened a long time ago (millions of years) and it's now finished. All life on Earth is still affected by its environment and the shifting balance among different species (from bacteria and viruses to human beings and disrupted ecosystems).
- ✓ Study of the human genome shows that our DNA has undergone changes recently as human beings react to different environmental pressures, even during recorded history.
- ✓ In over 150 years of testing, evolutionary theory has *not* been falsified (proven wrong)! Scientists don't disagree with the idea of evolution but do debate the mechanism. The attack that "evolution is only a theory" misses the definition of what a theory is in science ... it's not a guess or even a

hypothesis, it is a compilation of hypotheses and predictions that has undergone extensive testing (recall the idea of falsifiability from our lesson on science and the scientific method).

- ✓ Real time experiments (that we can see and measure directly, not taking thousands or millions of years) highlight the mechanism of evolution and natural selection:
 - mutations in bacteria, viruses; drug resistance ... superbugs.
 - controlled experiments: bacteria, guppies, rats, mice, finches, lizards, sparrows ... the myxoma virus (page 489 of reading) ...
 - => **changes are observable!**
- ✓ To see the effects of natural selection right now, we don't have to look farther than the field of antibiotic resistance or emergent diseases (in our assigned reading, see page 494 on antibiotic resistant bacteria, and think about the last couple of years of our lives ... *pandemics are nothing new and will (with high probability) happen again ...*).

Before Darwin

- ✓ Ideas of evolution, or species **changing through some natural process**, existed before Darwin; just look at fossils and see the similarities between extinct and living species.
- ✓ However, the prevailing view of the scientific *and* religious establishment in Darwin's day was that life on Earth was unchanging; there was a stable order to all life on our planet (a "fixity of species"), a hierarchy of importance, and a cherished stability in society as well.
- ✓ A (testable) paradigm about evolution and the transformation of species that existed before Darwin's refinements was Jean-Baptiste Lamarck's support for **Inheritance of Acquired Characteristics** (page 487 of reading; this idea existed even before Lamarck and was considered a commonsense description of reality).
- ✓ In this description of the natural, living world, Lamarck presented a mechanism/explanation where species would acquire the traits for survival during their lifetime, and then pass on those traits to their offspring. Species would become more complex with time as generation after generation changed.
- ✓ This paradigm had a lot of support until the 1930s, until modern genetics falsified it and supported Darwin's theory (think about the geocentric->heliocentric shift that occurred when evidence changed our worldview).
- ✓ One interesting contrast between Lamarck's and Darwin's paradigms was that Lamarck supported the idea that species changed by need or want (its purpose was to survive; a giraffe stretched its neck in order to eat and live) while Darwin underscored the role that luck and randomness had in building complexity and change.

Another Scientific Revolution

- ✓ As we learned in our lesson on science, new discoveries shifted our knowledge of our location in the Universe: **where** we are located in the cosmos, from a position of centrality to a demotion of our specialness. Charles Darwin struck the more emotional issue of our **origin, our transition, and our future.**
- ✓ In other words, we, as a species, have changed and are changing ... and will change. This was a direct attack on the assumptions of order and stability.

Charles Darwin (1809-1881) & A Scientific Revolution

- ✓ Naturalist and geologist; also studied theology (he knew how disruptive his ideas would be).
- ✓ His accomplishments are comparable to those of Copernicus, Galileo, Newton, and Einstein, once again shifting our "central position" in the Universe.
- ✓ **Paradigm Shift/A New World View:** The concept of evolution, or "Descent with Modification," connects us to "lowly," animal origins and connects us to all living things.
 - Parallels between the Two Revolutions: Geocentric (special, as interpreted by many) View of the Universe -> Heliocentric (non-special) View of the Universe
 - Fixed, unchanging (special) species -> changing (not special) "human" forms
- ✓ Darwin embarked on a five-year expedition with the *HMS Beagle* (1831); itinerary: Canary Islands, South America, **Galapagos Islands**, Tahiti, New Zealand, Australia, and back to England.
- ✓ During his journey, he saw evidence for:
 - new species,
 - fossils related to modern, living species,
 - biodiversity and speciation,
 - invasive species,
 - struggle for existence (both human and non-human),
 - and geological changes that required millions of years, demonstrating evidence for a very ancient Earth.

Galapagos Islands – A Natural Laboratory

- ✓ A string of volcanic islands (relatively young; 5 million years old) with isolated (different) environments, about 966 km from the South American mainland (Ecuador).
- ✓ Four main ecosystems with a wide variety of wildlife surviving in specific niches.
- ✓ Not all of Darwin's ideas popped up on his visit to the Galapagos Islands, but this visit did provide a large part of the puzzle.

Darwin's New World View (Paradigm)

- ✓ Darwin noticed **variations** among the species of finch in the Galapagos, from island to island (by the way, he didn't know the different-looking birds were all species of finch until he took them back to England and had them analyzed by an ornithologist, John Gould).
- ✓ Each variation—particularly beak size and structure—seemed suited for a specific species' own food sources or environment. In other words, a particular bird species had a beak that made it easier for it to get food:

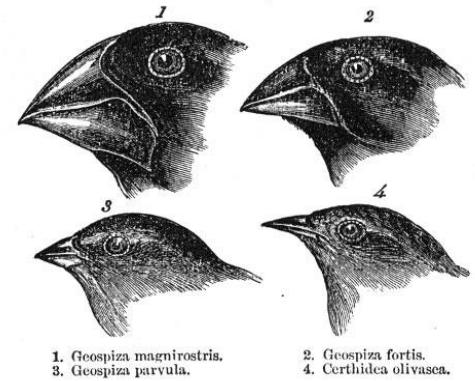


Image: public domain

http://www.pbs.org/wgbh/evolution/library/01/6/image_pop/l_016_02.html

- ✓ Different species seemed to fit in with their surroundings or environment: had an ecological niche or role. Darwin wondered how this was possible, and eventually came up with a natural explanation.
- ✓ The 13 finch species on the Galapagos seemed more closely related to each other than to their cousins on the mainland.
- ✓ This intriguing evidence implied that there was one original species on the islands—a **Common Ancestor** (like a shared great, great ... great grandparent among distant cousins)—and after a few million years there was a diversification (splitting) into multiple species for different niches; this is called *Adaptive Radiation* or *Speciation*.
- ✓ Original finch from mainland: a ground-dwelling, seedeater.

Puzzles

- ✓ So how do we get from a **Common Ancestor** to distinct species after a few million years?
- ✓ What was the mechanism that caused variations?
- ✓ How do we get accumulated changes in a species where a current generation looks and behaves drastically different from its ancestors?
- ✓ Darwin did not know the cause of the mutations in a species (we know today: altered DNA; however, Darwin did propose a falsified hypothesis that tried to explain variations and inherited traits), but he did understand the process of **Natural Selection** that allowed an accumulation of changes in a species over time. A special feature (mutation; luck) of survival could be passed on because individuals could live long enough to reproduce and pass on the same survival traits to the next generation.
- ✓ This was evolution through **Natural Selection ...**

Natural Selection

- ✓ The process of Natural Selection (compare with Artificial Selection, page 503) is based on the following observations:
 - **Variation:** Every population or species has **genetic diversity** among its members (from mutations). What happens if you change the environment where the population lives?
 - **Struggle for Survival:** Many more individuals are born than can possibly survive. Population growth versus limited resources means that there will be competition, sometimes a life-or-death struggle.
- ✓ If individuals survive long enough, then they increase their chances of reproducing and passing on their special "survivability" traits to their offspring (fitness). If the environment (food sources, predators, climate, etc) keeps changing generation to generation to generation, different survivability traits will be "selected" until generations down the line the surviving species can look different from its ancestors (see page 490-491 in reading)
- ✓ Imagine if you constantly change the "threat" conditions in Figure 17.14 on page 491, from hungry birds to cold climate to a nasty disease ... you will get a little creature (with time) that has the advantageous camouflage to hide from birds, to a thick shell to keep warm, to a lucky immunity to a disease that can wipe out most of the population. Change after change ("tweak" after "tweak") will lead to a new, distinct species.
- ✓ Individuals without an advantage will have a smaller probability of living and reproducing, meaning that those traits in a population may disappear with time.
- ✓ Darwin used these elegant ideas to explain **descent with modification** (his way of saying evolution), countering other competing ideas of "evolution" from Lamarck and Robert Chambers (Chambers wrote a popular, but controversial book called *Vestiges of the Natural History of Creation* before Darwin published *Origin of Species* in 1859—without the idea of Natural Selection).

Evolution—Descent with Modification

To account for the change in a species over time—**Descent with Modification**—the essential ingredients are:

- ✓ **A Changing Environment**
- ✓ **Time** (there was enough time for these changes, according to modern science, but not according to many authorities in Darwin's day, both scientific and religious)
- ✓ **Mechanism of Change:** an automatic process of random variation (mutations) and Natural Selection.

With this great insight, Darwin saw how a species can change or evolve over long periods of time, and how many different species today share a common ancestor.

Implications: The Evolution of Human Beings

- ✓ If finches or plants or tortoises can change with time, why should human beings be exempt?
- ✓ If human beings were the result of Natural Selection and Descent with Modification, then we were not created fully formed and the process of human evolution, which needed the cumulative power of incremental changes, took a long, long time ... Darwin guessed several hundred million years.
- ✓ At the time of Charles Darwin, the concept of an old Earth already existed.
- ✓ Geologists (such as Charles Lyell, who Darwin read on his voyage), studying erosion, figured that the Earth was hundreds of millions of years old. Lyell explained the process of slow (not catastrophic), natural forces changing environments (Lyell used the word evolution before Darwin to describe his observations of the changes in fossils in different layers of rock).

Darwin's Predictions:

- ✓ As a scientific theory, evolution was (and still is) subject to experimentation and **falsification**. As Darwin said himself in his book *Origin of Species*, "If it could be demonstrated that any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down."
- ✓ The idea of human evolution is not even hinted at in Darwin's *Origin of Species* until the second last page of the book, where he writes, "Light will be thrown on the origin of man and his history."
- ✓ Darwin's (Testable) Predictions:
 - Human origins are in Africa
 - Earth must be very old
 - Transitional Fossils ("missing links") should be found
 - There must be a mechanism of change or mutation
 - **All life on Earth shares a common ancestor**
 - Visit: <http://www.pbs.org/wgbh/nova/evolution/darwins-predictions.html>

Evidence & Support (page 503 of reading):

- ✓ The Fossil Record/Transitional Fossils
- ✓ Evidence from Anatomy: Vestigial Organs (appendix and tailbone in humans, wings in penguins, and the hind legs of whales). Vestigial Organs have no (apparent) useful function today and negate the idea that every part of an organism is an indispensable part of a modern creature.

- ✓ Similarities among species, e.g., limbs, bone structures, genetic code ... inherited from a common ancestor.
- ✓ Old Earth (Billions of Years)
- ✓ The basic chemicals for the creation of life are available everywhere (not just Earth, by the way).
- ✓ “Real-time” evolution ... changes are observable!
- ✓ **Genetic Mutations & DNA (the mechanism of variation)**
 - Modern genetics has revealed that **all living things on Earth use the same genetic code/mechanism.**
 - We see great similarities with life sharing the most common recent ancestor.
 - Mutations (why we do not have exact copies) occur because of changes in the DNA of the parents ... luck is a factor that may provide an advantageous trait.

What are the Odds?

- ✓ An incredibly complex number of pathways, mutations, coincidences, and seemingly blind luck ends up with us!
- ✓ The probabilities are immense; the odds that humans should be here today (and dominate the planet) are astronomical.
- ✓ What happens if you replay the evolution of life on Earth? Probably no humans ...
- ✓ What are the odds that there will be human beings on Earth a million years from now? Since the beginning of life on Earth, most species that have ever existed have gone extinct ... are we an exception?
- ✓ What are the odds we will be here in a hundred years?

For Testing

- ✓ Why is Darwin’s Theory of Evolution (Descent with Modification) a paradigm shift?
- ✓ Describe the concept of Natural Selection and how it leads to accumulated changes in a species (from generation to generation).
- ✓ How does Natural Selection explain the emergence of disease resistance?
- ✓ How do we explain Darwin’s mechanism of mutation today?
- ✓ What is the importance of *Darwin’s Finches*?
- ✓ Describe Lamarck’s *Inheritance of Acquired Characteristics* and its flaws.
- ✓ What is a common ancestor?
- ✓ What are the implications of the phrase, “All life on Earth shares a common ancestor?” What does this say about our connection to all living things?
- ✓ What were Darwin’s predictions?
- ✓ What is the evidence for evolution?
- ✓ Contrast Natural Selection and Artificial Selection.
- ✓ See the video [The Tree of Life](#) (a summary of billions of years of Evolution on Earth (D. Attenborough)).



Image: public