Outline 7: Evolution and the Fossil Record
The Study of Evolution

• Two domains: the present and the past
• The present: Biology
  – Genetics
  – Comparative Anatomy
• The past: Paleontology or Paleobiology
  – Comparative Anatomy of Fossilized organisms
Natural Selection

• Natural selection is one of the prime mechanisms of evolutionary change. The other mechanism is mass extinction.

• Charles Darwin, 1859: The *Origin of Species by Natural Selection.*
One of the most famous books of science.
Artificial Selection vs. Natural Selection: Dog breeds produced by artificial selection

~10,000 years of evolution by artificial selection
Natural Selection: Key Points

• 3 facts lead to a conclusion:
  • Fact 1. Overproduction of offspring
  • Fact 2. Variation within populations
  • Fact 3. Competition for resources

• Conclusion: Survival of the fittest
Voyage of HMS Beagle, 1831-1836
Darwin’s finches: 13 different species evolved from a single ancestor from South America.
The beaks of Darwin’s finches are adapted to the variety of food types available on the different islands in the Galapagos Islands.
Type specimens of finches collected by Darwin in the Galapagos Islands
The Galapagos Islands. Darwin visited in October 1835
Yours truly in the Galapagos Islands, 1996, Fernandina Volcano
Charles Darwin in 1837, age 28, after voyage of the HMS Beagle
Darwin in 1879, age 70.
The evidence for Evolution is overwhelming.

By DAVID QUAMMEN
Photographs by ROBERT CLARK

Evolution by natural selection, the central concept of the life's work of Charles Darwin, is a theory. It's a theory about the origin of adaptation, complexity, and diversity among Earth's living creatures. If you are skeptical by nature, unfamiliar with the terminology of science, and unaware of the overwhelming evidence, you might even be tempted to say that it's "just" a theory. In the same sense, relativity as described by Albert Einstein is "just" a theory. The notion that Earth orbits around the sun rather than vice versa, offered by Copernicus in 1543, is a theory. Continental drift is a theory. The existence, structure, and dynamics of atoms? Atomic theory. Even electricity is a theoretical construct, involving electrons, which are tiny units of charged mass that no one has ever seen. Each of these theories is an explanation that has been confirmed to such a degree, by observation and
Darwin’s home, Down House, in England
Darwin’s study at his home Down House
Darwin’s grave in Westminster Abbey

CHARLES ROBERT DARWIN

BORN 12 FEBRUARY 1809

DIED 19 APRIL 1882
Near the Natural History Museum, London
Darwin on the 10-pound note. Lincoln is on our $5 bill. Both men were born on the exact same date: Feb. 12, 1809.
Sources of Variation

• Random mutations of DNA in the sex cells
  –>>99.9% are harmful or neutral
  –adaptive mutations are rare
• Sexual recombination
  –new variants created by mixing of genes
  –you have 4096 direct ancestors going back 12 generations ($2^{12}$)
Variations within Natural Populations are the Raw Materials for Natural Selection, including Sexual Selection.
If genetic mutations are random, then is evolutionary change within organisms random? Thus, is the history of evolution simply a series of random events?
Chromosomes contain Genes composed of DNA
The Anatomy of a Gene. Helical strands of DNA contain the blueprints for all forms of life.
The DNA molecule contains nitrogenous bases (A,T,C,G) that code for different amino acids, which form proteins.
Evidence of Evolution

- Homology, or homologous features
- Analogous organs/features, or Convergent Evolution
- Vestigial organs
- Adaptive radiation
Homology

• The recognition of common ancestry of features. e.g. all primates have 5 fingers; apes and humans lack a tail; all tetrapods have similar limb bones.

• Studied by comparative anatomy of living and fossil organisms.
Homologous features are used to recognize common evolutionary ancestry. Horses and humans share a common ancestor.
Homologous features are used to recognize common evolutionary ancestry.
Examples of homologous features in the forelimbs of tetrapods.
Homologous development between different species indicates common ancestry.
Analogous Organs or Convergent Evolution

- Produced by evolutionary convergence. Independent origin of similar features is called convergent evolution.
- Shows natural selection in operation.
- e.g., insects, birds, bats, and pterosaurs all evolved wings independently
Analogous features, such as wings, indicate convergent evolution and not common ancestry.
Other examples of convergent evolution: armadillo and pangolin; or monotreme and placental anteaters
Vestigial Organs

- Organs no longer used show clear evidence of evolutionary change.
- e.g., pelvic bones of whales, vestiges of former legs
- e.g., human body hair, a vestige of former fur
vestigial
whale
hips
Vestigial Organs in Humans. Mostly useless now. e.g., appendix and tail bone.
Adaptive Radiation

- Natural selection can fill a variety of niches starting with a single species.
- e.g., Darwin’s finches in the Galapagos Islands, 13 species evolved from one ancestral species
- e.g., all birds evolved from *Archaeopteryx*
The beaks of Darwin’s finches are adapted to the variety of food types available on the different islands in the Galapagos Islands.
Archaeopteryx, the first bird; Jurassic age.
Archaeopteryx reconstructed

Reptilian Characteristics:
toothed beak, wing claw,
long tail with many vertebrae.

Vegan Characteristic:
airfoil wing with contour feathers.
Adaptive Radiation of Birds
The Origin of New Species: Speciation

- Natural selection by itself will not increase the number of species on the planet.
- **Species definition**: Interbreeding populations reproductively isolated.
- New species must be reproductively isolated from their ancestral species.
Lions and tigers share a common ancestor, but the hybrids are usually sterile. Thus, they are separate species.
Liger
Liger
Liger
Horses and donkeys share a common ancestor. Their hybrid, the mule, is sterile because of the odd number of chromosomes.

\[31 + 32 = 63\]
Zonkey – Zebra and donkey hybrid
Speciation, cont’d

• Allopatric speciation: produced by geographic isolation of populations.
• Natural selection causes an isolated population to adapt to its local environment.
• Given enough time, and no outside interbreeding, a new species will evolve.
Rates of Evolution

• Phyletic gradualism - continuous and gradual change over time

• Punctuated Equilibrium - long periods of stasis punctuated by rapid change, probably associated with a bottleneck in population size.
Geographic Separation and Isolation

Stasis Stasis

Punctuated Change

Populations with variations

Phyletic Gradualism

Punctuated Equilibrium
Rates of Evolution

• Large populations evolve very slowly or almost not at all. Advantageous mutations pass very slowly through a population.

• Small populations can evolve very rapidly. Advantageous mutations can be passed very quickly through the population.
Evolution in Action

• Passing through a bottleneck:
  – Pesticide resistant insects
  – Antibiotic resistant bacteria
An extreme selection event severely reduces population size and changes the composition of the gene pool of the species.

Bottleneck Effect

Small populations often go extinct, but some may survive with a changed gene pool.
Role of the Fossil Record

• Provides the only actual record of evolutionary change over geologic time.
• Provides data on the timing of evolutionary origins.
• Shows mass extinctions to be a major cause of evolutionary change.
• Provides information on rates of evolution.
Evolutionary Origins

- Oldest life: 3.5 BY
- Oldest nucleated cells: 2.1 BY
- First animals: 600 MY
- First tetrapods: 375 MY
- First dinosaurs: 220 MY
- First mammals: 220 MY
- First hominids: 4 MY
An example of the role of the Fossil Record: The Evolution of Tetrapods
Acanthostega and Ichthyostega
Another Example:
The Evolution of Whales
Mass Extinctions

• Survival of the luckiest?
• Over geologic time, mass extinctions may subvert the notion of survival of the fittest.
• Is evolutionary history predictable?
The Record of Mass Extinctions
Rates of Evolution

• Biologists cannot measure evolutionary rates. They have only the present. Darwin assumed gradual rates.

• Paleontologists can measure evolutionary rates. They have found punctuated equilibria to be the major pattern in fossil species rather than gradual change.