I. Evolution – change in allele frequencies in a population over time (successive generations)
   A. Gene – a unit of heredity that is transferred from a parent to offspring and encodes the
      instructions to produce a protein (which often controls a trait).
      1. A gene is one of many segments on an individual chromosome.
      2. e.g. In garden pea plants, a gene controls flower color.
   B. Alleles – two or more alternative forms of a single gene that arise by mutation.
      1. e.g. In garden peas, the alleles for flower color are purple and white.
   C. Natural Selection – Tendency of organisms with favorable adaptations to
      survive in their environment and produce new generations

II. A Brief Overview of the Early Development of Evolutionary Concepts
   A. Our current understanding of evolution didn’t spring, fully formed, into any one
      scientist’s mind. It developed over a long period of time.
   B. Aristotle (384-322 BC) - Arranged organisms from simplest to most complex, called
      the Scala Naturae (scale of nature or ladder of life)
      1. Implied organisms static and do not evolve
   C. Leonardo da Vinci (1452-1519) - Observed that fossils are part of previously
      existing organisms that had become extinct
   D. Count de Buffon (1707-1788) - Described all known plants and animals
      1. Presented evidence that organisms change across generations
   E. By end of 18th century many prominent biologists believed that hereditary changes in
      populations over long periods of time occurred as a result of inheritance of acquired
      characteristics.
      1. Jean Baptiste Lamarck (1744–1829) – Inheritance of Acquired
         Characteristics. Characters acquired during an organism’s life were passed on
         and became cumulative.
         a. His famous example tried to explain how giraffes got their long necks.
         b. By his reasoning, if I got a tattoo, I would pass that acquired
            characteristic onto my offspring. Pretty soon, all babies would be covered
in the tattoos of previous generations. YIKES! As we now know, this is not the way either heredity or evolution is actually working.

F. Major revolutions in evolutionary thought occurred in last 150 years.
   1. **First revolution - Charles Darwin, *Origin of Species*, 1859**
      a. Evolution by natural selection
   2. **Second revolution - 1930’s – an intersection of concepts provides better understanding of the mechanisms of evolution.**
      a. Darwinian natural selection
      b. Mendelian genetics
      c. Population genetics
      a. Organisms with nearly identical genomes can look very different because different developmental programs created them.
      b. Regulatory genes can act as developmental switches.
      c. **Homeobox genes** (hox genes for short) - Regulatory genes that act as developmental switches. These genes determine the body plan.
         1. The genes of a Chihuahua and a Great Dane are almost identical.
         2. The incredible difference in their body size is actually due to how long the operators (master switch) of the genes controlling bone growth remained active.
      d. Impact of mutations can alter master switches.
      e. There is a similarity of master switches in plants and animals

III. **Charles Darwin (1809-1882)**
   A. Born in Shrewsbury, England, the son of Dr. Robert Darwin
      1. Darwin attended Edinburgh Medical School, but dropped out after 2 years
      2. Studied at Cambridge University for ministry, graduating in 1831
      3. Accepted unpaid position as assistant naturalist on HMS *Beagle* to voyage around the world and chart coastlines, 1831–1836
         a. Collected plants and animals in South America, the Galápagos Islands, Australia and New Zealand
   B. Major contributors to the development of Darwin’s idea
      1. **Charles Lyell’s Principles of Geology** theorized the earth was much older than the roughly 6,000 years that was previously believed
         a. Lyell’s theory of **uniformitarianism** argued that the age of the earth must be measured in millions of years.
         b. It is now accepted that the earth is 4.5 billion years old.
         c. Life has existed on earth for more than 3.5 billion years.
      2. **Artificial selection** – Darwin had studied how man, through selective breeding, had produced new varieties of pigeons and new breeds of plants and animals.
      3. **Thomas Malthus** was an English economist. In *Essay on the Principle of Population* (1798) Malthus observed that the growth in human population rates would contribute to a rising supply of labor that would inevitably lower wages. He feared that continued population growth would lead to global poverty and epidemics.
         a. Malthus observed that farm more offspring are produced in nature than can survive. Man would be no exception to this.
         b. The “struggle for existence” that results from overpopulation (as described by Malthus) gave Darwin a mechanism for evolution in wild
species through natural selection. Darwin and Wallace applied Malthus’ premise to plants and animals in nature.

C. Publication of *On the Origin of Species by Means of Natural Selection*

1. **Alfred R. Wallace** (1823-1913) independently arrived at the idea of natural selection
   a. Wallace came to this conclusion after extensive fieldwork in the Amazon River basin and then in the Malay Archipelago
2. In 1858 Darwin and Wallace simultaneously presented brief essays on natural selection
3. Darwin had already spent decades researching his idea.

III. Darwin’s Theory - Evolution by Means of Natural Selection

A. Darwin’s theory of natural selection consists of **four observations** and **three conclusions**:

1. **Observation 1**: Organisms have great potential fertility
   a. If all individuals produced survived, populations would explode exponentially.
   b. Darwin calculated that a single pair of elephants could produce 19 million offspring in 750 years. This is a SLOW breeding species!
   1) Elephant females breed at the earliest at 9 years, and bear one calf every four years until age fifty optimally. It would take a female 40 years to bear 10 calves.

2. **Observation 2**: Natural population sizes and their resources remain relatively constant
3. **Conclusion 1**: The struggle for food, shelter, and space becomes increasingly severe with overpopulation. There is competition for survival and reproduction.
   a. In each generation, many individuals must die young, fail to reproduce, produce few offspring, or produce less-fit offspring that fail to survive & reproduce in their turn.
   b. Survivors represent only a small part of those produced each generation.

4. **Observation 3**: All organisms show variation. Individual members of a population differ from one another in their ability to obtain resources, withstand environmental extremes, escape predators, etc.
5. **Conclusion 2**: The most well-adapted (the “fittest”) individuals in one generation will usually leave the most offspring. This is natural selection: the process by which the environment selects for those individuals whose traits best adapt them to that particular environment.
6. **Observation 4**: Some variation in adaptive traits is due to genetic differences that are heritable.
   a. Darwin only noted the resemblance of parents and offspring.
   b. Gregor Mendel's mechanisms of heredity were applied to evolution many years later.
7. **Conclusion 3**: Over many generations, differential, or unequal, reproduction among individuals with different genetic makeup changes the overall genetic composition of the population. This generates new adaptations and new species.
IV. Evidence for Evolution

A. The fossil record provides evidence of evolutionary change over time.
   1. The living world is constantly changing in form and diversity. Change in animal life is directly seen in the 600-700 million-year animal fossil history.
   2. A fossil is a remnant of past life.
      a. Insects in amber and frozen mammoths are actual remains.
      b. Teeth and bones can petrify or become infiltrated with silica and other minerals.
      c. Molds, casts, impressions and fossil excrement are also fossils.
   3. Most organisms leave no fossils; the record is always incomplete and requires interpretation.
   4. Interpreting the Fossil Record
      a. The fossil record is biased because preservation is selective.
      b. Vertebrate skeletons and invertebrates with shells provide more records.
      c. Soft-bodied animals leave fossils only in exceptional conditions such as the Burgess Shale.
      d. Fossils occur in stratified layers; new deposits are on top of older material.
         1) The law of stratigraphy dates oldest layers at the bottom and youngest at the top.
      e. “Index” or “guide” fossils are “indicators” of specific geological periods.

![Index Fossils Diagram]

B. Radiometric Dating
   1. In the late 1940s, radiocarbon dating was developed that determines age of fossils. Radiocarbon dating can be used to estimate the age of fossils up to about 60,000 years.
a. Most C (carbon) in the atmosphere is stable C-12. A small (but measurable) proportion of atmospheric C is unstable, C-14.
b. Carbon is incorporated into plants when they use CO₂ to make sugar.
c. During its lifetime, an animal will incorporate this C (carbon) in its body from eating plants.
   1) Once the animal dies, it no longer adds C to its body.
   2) The unstable C-14 begins to steadily break down into stable N-12
d. C-14 has a relatively short half-life of 5,730 years; meaning that the amount of C-14 is halved over the course of 5,730 years due to radioactive decay.
e. This provides a “clock” that tells us how long the animal has been dead.
f. Radioactive decay of naturally occurring elements is independent of heat and pressure.

2. Potassium-Argon Dating – to date even older fossils
   a. Potassium-40 (40K) decays to argon-40 (40Ar) and Calcium-40 (40Ca).
   b. Half-life of potassium-40 is 1.3 billion years; half of remainder will be gone at end of next 1.3 billion years, etc.
   c. Calculating the ratio of remaining potassium-40 to amount originally there provides mathematically close estimate of age of deposit.

C. Evolutionary Trends - The fossil record allows observation of evolutionary change over broad periods of time.
   1. Animals species arise and go extinct repeatedly. 99% of all species that have ever existed are now extinct.
   2. Animal species typically survive 1-10 million years; there is much variability.
   3. Horse Evolution Shows Clear Trends
      a. From Eocene to Recent periods, genera and species of horses were replaced.
      b. Earlier horses had smaller sized and fewer grinding teeth, and more toes.
c. Reduction in toes and increase in size and numbers of grinding teeth correlate with environmental changes.

D. **Common Descent** - Darwin proposed that all plants and animals descended from a common ancestor.

1. **Geographic Animal Distribution and continental drift**
   a. Large flightless birds exist only in the southern hemisphere
      1) extant rhea of South America & emu of Australia
      2) extinct giant moa of New Zealand & elephant bird of Madagascar
   b. These birds are flightless, their ancestor couldn’t have swum the oceans to these continents. The explanation is that their ancestor evolved on the southern continent of Gondwanaland. (The northern continent was Laurasia.)

2. **Comparative anatomy**
   a. All plants and animals descending from a common ancestor is **divergent evolution**.
      1) **Homologous structures** – structures that may differ in function
      2) but that have similar anatomy due to descent from a common ancestor.

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**Evolutionary History of Horses**

**Homologous Structures**

**Vestigial Structures**

Vestigial structures, such as pelvic bones in the baleen whale, are evidence of evolution because they show structural changes over time.
a) For example, vertebrate limbs show the same basic structures (one upper arm bone, two forelimb bones, wrist bones, and finger bones) modified for different functions (swimming in penguins & whales, flight in bats & birds, running in dogs & sheep, grasping in humans & shrews)
b) Darwin saw homology as major evidence for common descent.
c) It is inconceivable that nearly the same bone arrangements could be ideal for such different functions, as would be expected if each animal were created separately. **This is exactly what we would expect if the forelimbs of these animals evolved from a common ancestor.**

3) **Vestigial structures** – structures that serve no apparent purpose
   a) For example, vampire bats have molar teeth even though they live on a diet of blood & therefore don't chew their food.
   b) Pelvic bones exist in whales and certain snakes.
   c) This is “evolutionary baggage”
   d) The appendix is a vestigial structure in humans

b. Through **convergent evolution**, natural selection has shaped unrelated organisms into similar forms in similar environments.
   1) Natural selection predicts that, given similar environmental demands, unrelated organisms might independently evolve superficially similar structures.
   2) Such outwardly similar body parts in unrelated organism, called **analogous structures**, often have completely different internal anatomy because they are not derived from a common ancestor.
   3) For example: wings of flies & birds; also fat-insulated, streamlined shapes of seals (mammals) & penguins (birds)

### Convergent Evolution: Analogous Structures

![shark, ichthyosaurus, dolphin]

The shark (a fish), dolphin (a mammal), and ichthyosaurus (a reptile) all have a similar torpedo shapes to slice through water. These analogous shapes evolved independently as similar solutions to a shared environmental challenge.

E. **Modern Biochemical & genetic analyses** reveal relatedness among diverse organisms
   1. The amino acid sequences of proteins are remarkably similar across a huge spectrum of species.

F. **Artificial selection** demonstrates that organisms may be modified by controlled breeding
1. In a few hundred to at most a few thousand years, man has bred radically different dog breeds, from Chihuahua to Great Dane, from the wolf by selecting qualities that were found desirable & selectively breeding for them.
2. What man can do, cannot nature do by selecting for those individuals best adapted to that environment

G. Evolution by Natural Selection Occurs Today
1. We can literally see that evolution is occurring around us today
2. Peppered moths of England & the Industrial Revolution
3. 1990’s Florida’s cockroaches – Combat used corn syrup (glucose) as the bait for its poison. A rare mutation, in which cockroaches won’t eat glucose, became widespread after Combat was used.
4. Any pesticide, herbicide, or antibiotic & resistance is an example.

Peppered Moths come in light and dark colors.

V. Microevolution – Evolution within species
A. Microevolution is driven by natural selection, as described by Darwin.
B. The ingredients of variation that natural selection work upon can arise from mutations, migration, and genetic drift.
1. **Mutation** – change in a gene or chromosome
   a. Most mutations are harmful; some are silent, but some produce a characteristic that helps organism survive change.
   b. Chromosomal alternations include the following:
      1) **Deletion** - Part of a chromosome breaks off.
      2) **Translocation** - Piece of chromosome becomes attached to another.
      3) **Inversion** - Part of chromosome breaks off and then reattaches in an inverted position.
   c. Gene mutations involve a change in nucleotide pair(s)
      1) Mutator genes have been identified

C. Let us consider the following illustration, regarding the mechanics of microevolution (borrowed from http://evolution.berkeley.edu/evosite/evo101/IVBMechanisms.shtml)
1. Imagine that you observe an increase in the frequency of brown coloration genes and a decrease in the frequency of green coloration genes in a beetle population. Any combination of the mechanisms of microevolution might be
responsible for the pattern, and part of the scientist’s job is to figure out which of these mechanisms caused the change:

**Mutation:** Some “green genes” randomly mutated to “brown genes” (although since any particular mutation is rare, this process alone cannot account for a big change in allele frequency over one generation).

**Migration (or gene flow):** Some beetles with brown genes immigrated from another population, or some beetles carrying green genes emigrated.

**Genetic drift:** When the beetles reproduced, just by random luck more brown genes than green genes ended up in the offspring. In the diagram at right, brown genes occur slightly more frequently in the offspring (29%) than in the parent generation (25%).

**Natural selection:** Beetles with brown genes escaped predation and survived to reproduce more frequently than beetles with green genes, so that more brown genes got into the next generation.

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**VI. Macroevolution – How species evolve**

A. In order for a group of animals to accumulate differences and become a new species, there must be reproductive isolation from the parent species.
1. Prezygotic – isolation that occurs before fertilization
   a. **Geographic isolation** - Barrier prevents gene flow; Genetic changes accumulate.
      1) Random mutations spread only throughout the population in which they arise.
      2) Genetic changes become so great that gene flow between populations no longer can occur.
   b. **Ecological isolation** - factors such as climate or soils may play role in isolation, as do time and mechanical isolating factors.
      1) Results in sympatric species that occupy overlapping ranges of territories, and that do not exchange genes.
   c. **Mechanical isolation** – this can lead to sympatric speciation
      1) Example: pollinia of orchids
   d. Other isolating mechanisms: Sperm chemically or mechanically prevented from reaching egg.
2. Postzygotic isolating mechanisms – Isolation that occurs after fertilization
   a. Failure of embryos to develop
   b. Failure of hybrids to survive or breed
      1) Chromosomes may not pair normally at meiosis, resulting in sterile hybrids.

VII. The Role of Hybridization in Evolution
   A. **Hybrids** - Offspring produced by parents that differ in one or more characteristics
      1. May have gene combinations better suited to new environments
      2. Two related species may hybridize.
         a. **Introgression** - Intercrossing between hybrids and parents
   B. **Polyploidy** - Occurrence of double the normal chromosome number
      1. Result of failure of meiosis to halve chromosome number in gametes
      2. Polyploids produced when these gametes participate in fertilization.
   C. **Hybrids often sterile because chromosomes do not pair properly at meiosis.**
      1. If polyploid formed in hybrid, then chromosomes can pair and overcome sterility.
      2. Thought that more than half of flowering plant species originated this way
   D. **Sterile hybrids may reproduce asexually.**
   E. **Apomixis** - Production of seeds without fertilization.
      1. Combination of apomixis and sexual reproduction may be highly successful.
         a. e.g. in dandelions