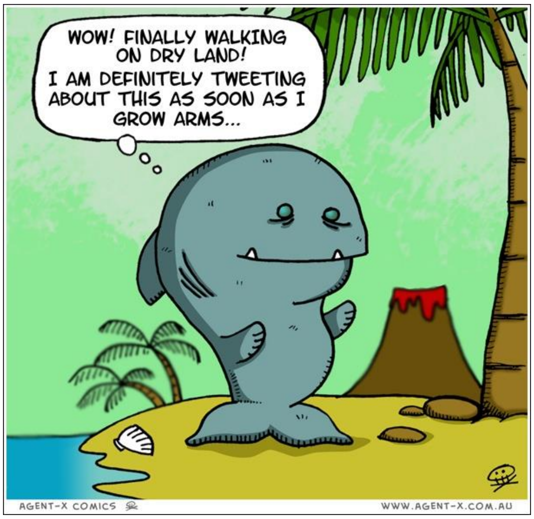
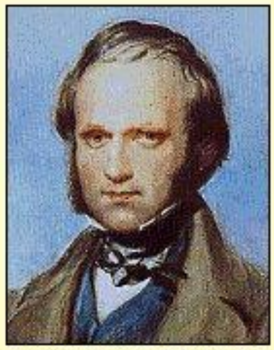
Bio 1101 Lecture 13
Chapter 13: How Populations Evolve

Evolution



- Charles Darwin: developed the theory of Evolution by Natural Selection
- As a young man, Charles studied medicine ("long stupid lectures"… And surgery?? ugh!), then theology (ho-hum) before eventually following his interests in natural history
- Always interested in observing creatures in the natural world:
  - *"One day, on tearing off some old bark, I saw two rare beetles, and seized one in each hand; then I saw a third and new kind, which I could not bear to lose, so that I popped the one which I held in my right hand into my mouth. Alas! it ejected some intensely acrid fluid, which burnt my tongue so that I was forced to spit the beetle out, which was lost, as was the third one."*
    - **CHARLES DARWIN,** Autobiography, written 1876

- Became ship's naturalist on the H.M.S. Beagle, and sailed around the world from 1831-1836



Darwin at age 31 in 1840

- Prior to Darwin's publication of his research on natural selection, the dominant world view regarding species was that they had been created and have remained unchanged
- In the 1700s, some advances in geology were beginning to challenge the idea of a static world

- Rocks occur in layers, and different types of fossils were found in different layers of rock
  - Fossils are preserved remnants or impressions left by organisms that lived in the past
  - Over long periods of time, strata of rock are formed.
  - The farther down in the strata you dig, the further back in time you go…

Fossils can take many forms:

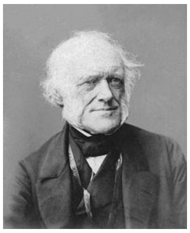
- Hard parts of animals, teeth and bones, are often fossilized
- Thin tissues such as leaves may be preserved as films

- Entire organisms may be preserved (e.g. frozen or in amber)
- Plant tissue is sometimes found petrified
- Imprints such as footprints of dinosaurs occur, but rarely.

Frozen Wooly Mammoth. Source: Wikipedia

Petrified wood. Source: Wikipedia

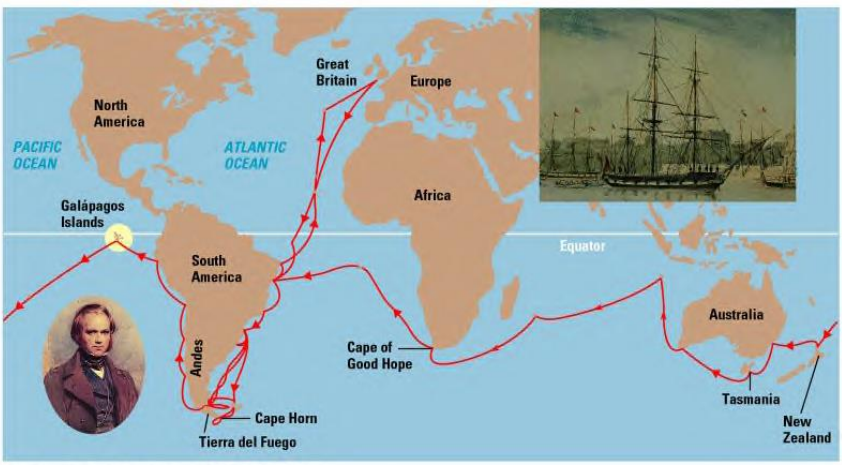
- Types of plants and animals that long ago had gone extinct were discovered in the fossil record… if species were created, why had so many gone extinct? And if species were created and remained fixed, why weren't any of today's species found in the ancient fossil record?



- Geologists like <u>Charles Lyell</u> suggested the concept of <u>uniformitarianism</u>
  - The gradual, geological processes that are at work today were also at work in the past
  - Very gradual changes, over very long periods of time, can result in very large physical features of geology (such as mountains and canyons)
  - If slow processes like sedimentation built deposits of rock thousands of feet thick, the earth must be <u>very</u> old (4.6 billion years!)

- Before Darwin, there were some naturalists who believed species changed over time
  - But the mechanisms they proposed were different from natural selection
  - Jean Baptiste Lamarck: organisms evolved by inheritance of acquired characteristics
    - An organism changes during its lifetime in some way to adapt to its environment (e.g. a giraffe stretching its neck, making its neck longer, and then passing on that trait to its offspring)

- Darwin's voyage on the *Beagle*



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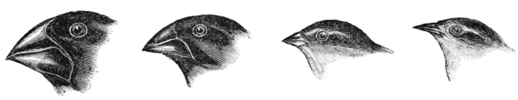
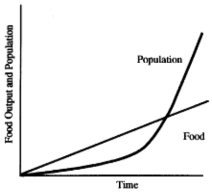
- Observed plants and animals along coasts of South America and the Galapagos Islands
- Observations
  - Plants and animals of the Galapagos Islands were similar to those on the South American continent – why not unique?
  - Plants and animals on the islands were adapted to each other (tortoises were adapted with long necks to reach the leaves of taller plants to eat; different species of finches were adapted with different sizes and shapes of beaks for eating specific types of foods)
  - Watch this video on natural selection (Natural Selection – Crash Course Biology #14): https://www.youtube.com/watch?v=aTftyFboC_M



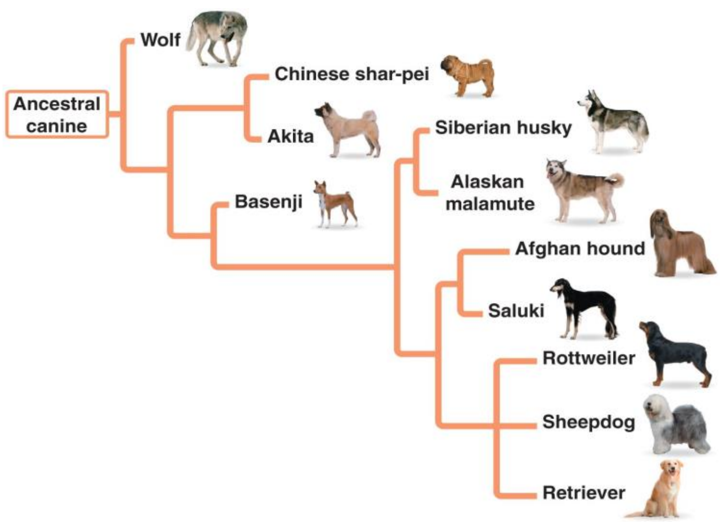
- In addition to his own observations of plants and animals, Darwin read books by Malthus and Lyell that influenced his theory of natural selection
  - Charles Lyell's writings indicated that the earth was very old – old enough for slow processes to eventually result in big changes over long periods of time

– Thomas Malthus was an economist, and wrote about the exponential population growth of humans, and the resulting famines
  - “The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race. “
– Darwin extrapolated the ideas of Malthus to all creatures; left unchecked, all species have the capacity to reproduce faster than their food supplies
  - This would set up competition between individuals



– Darwin was also aware of the use of artificial selection to create desirable varieties of plants and breeds of animals for human use
  - For example, vegetables of the species *Brassica oleracea* have been modified, from a kale-like ancestor, to a variety of forms today
  - Humans selected for desirable traits, creating vegetables including broccoli, cabbage, collards, cauliflower, and Brussels sprouts

- In the same way, artificial selection was used to create all the breeds of dogs we have today



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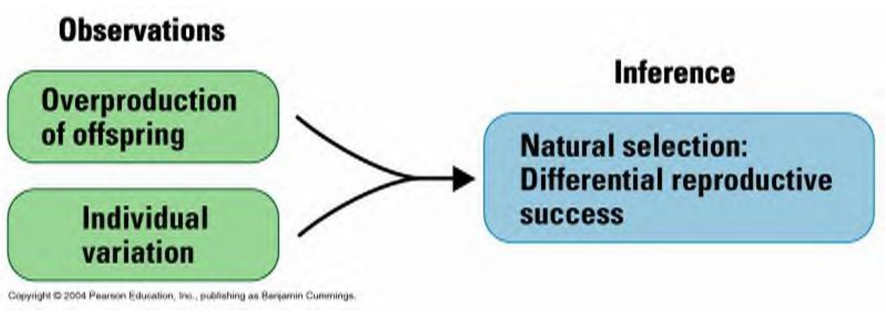
- Putting all of this together…

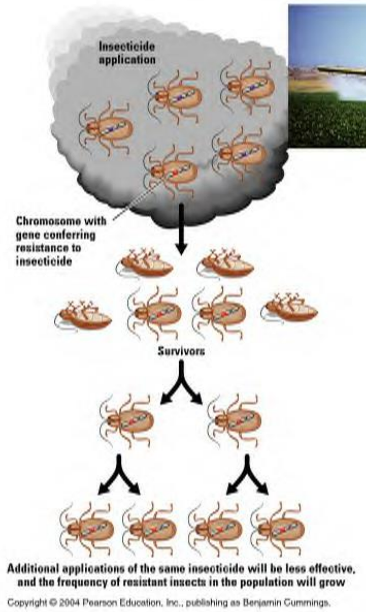


- Darwin developed his theory of evolution by natural selection
- Called it "Descent with Modification" (descendents were genetically modified through interaction with their environment)
- Natural Selection = "the differential survival and reproduction of individuals with different inheritable characteristics."

- Theory of Natural Selection:
  - Every species is capable of producing more offspring than can survive to maturity
  - But, population sizes don't grow exponentially! Population sizes tend to remain fairly constant, at a level that can be supported by the environment
  - There is competition between individuals for survival and reproduction
  - Individuals in populations vary in traits that affect their chances for survival
  - THEREFORE, individuals with the best traits will survive and reproduce better than other individuals

- Alfred Russel Wallace
  - Young British naturalist who was also investigating characteristics of various organisms and how they came to look the way they do; he was studying organisms in the East Indies
  - Wallace made similar observations to Darwin and ultimately developed theory of natural selection independently
  - When Wallace told Darwin of his discovery, it spurred Darwin to finally publish his book *On the Origin of Species* in 1859
  - Therefore, Wallace and Darwin are both credited with discovering the theory of natural selection, although Darwin had discovered it first

- Today, Darwin's theory of natural selection makes even more sense, in light of our knowledge of genetics
- The "Modern Synthesis" or "Synthetic Theory of Evolution"
  - This is just the combination of Darwin's theory of natural selection in combination with our modern understanding of the genetic basis of inheritance



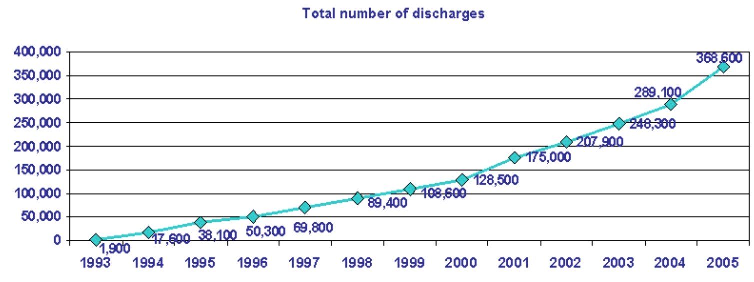
An example of natural selection at work:

As farmers spray their farm fields with the same pesticide over and over, the insect pests that happen to have a genetic trait that allows them to survive reproduce more

Over time, the population of insects contains more and more individuals that can survive the pesticide, until the pesticide is no longer effective

- In the news: MRSA infections
  - Our development of antibiotics in the 1940s allowed us to successfully treat many bacterial infections, like *Staphylococcus aureus* (which causes skin infections)
  - By the 1950s, *Staphylococcus aureus* started to evolve resistance to antibiotics like penicillin and methicillin in response to over-use of antibiotics
  - MRSA (methicillin-resistant Staphylococcus aureus) infections have now become common, spreading in places like schools, gyms, and hospitals

Figure 1. Hospital stays with methicillin–resistant Staphylococcus aureus (MRSA) infections, 1993–2005



Source: AHRQ, Center for Delivery, Organization, and Markets, Healthcare Cost and Utilization Project, Nationwide Inpatient Sample, 1993-2005

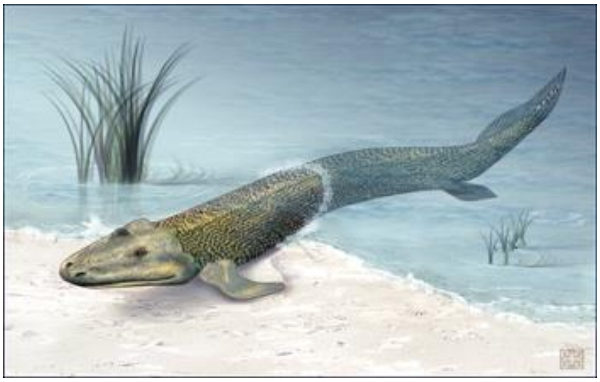
Evidence for Evolution

- Fossils
- The oldest known fossils are from ~3.5 billion years ago, and are prokaryotic cells
- Fossils trace macroevolutionary changes in a chronology of events
- Fossil evidence for evolution of vertebrates:
  - The oldest fossil vertebrates are fishes
  - then the amphibians…
  - then the reptiles…
  - then mammals…
  - then birds…

This is the chronology, as shown by the fossil record

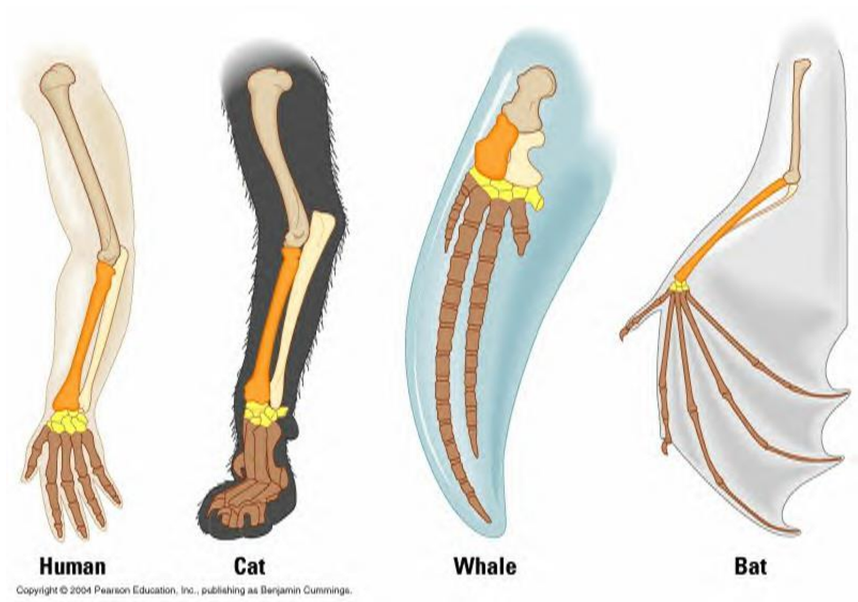
Missing Link from Sea to Land: *Tiktaalik*

- 375 mya
- transitional fish
- predecessor of amphibians

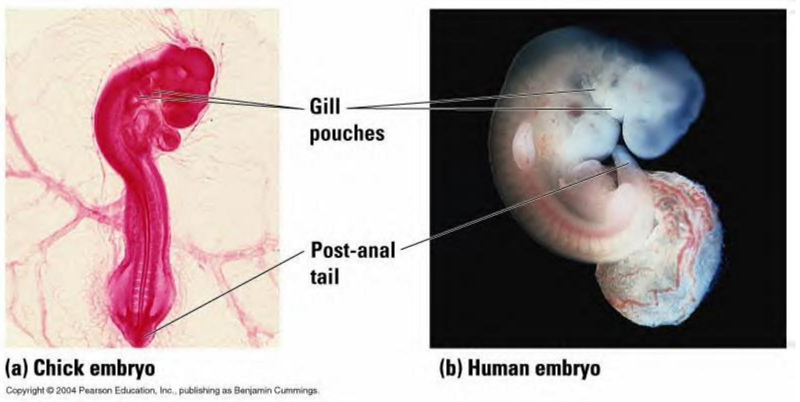


- Comparative Anatomy

- The comparison of body structures between species
  - Example: the forelimbs of different types of mammals
  - Although they may perform different functions, they are derived from the same bones… they have just been modified for use in different habitats
  - Homologous structures – structures that are similar in different species and evolved from the same ancestral structure (similarity due to common ancestry)



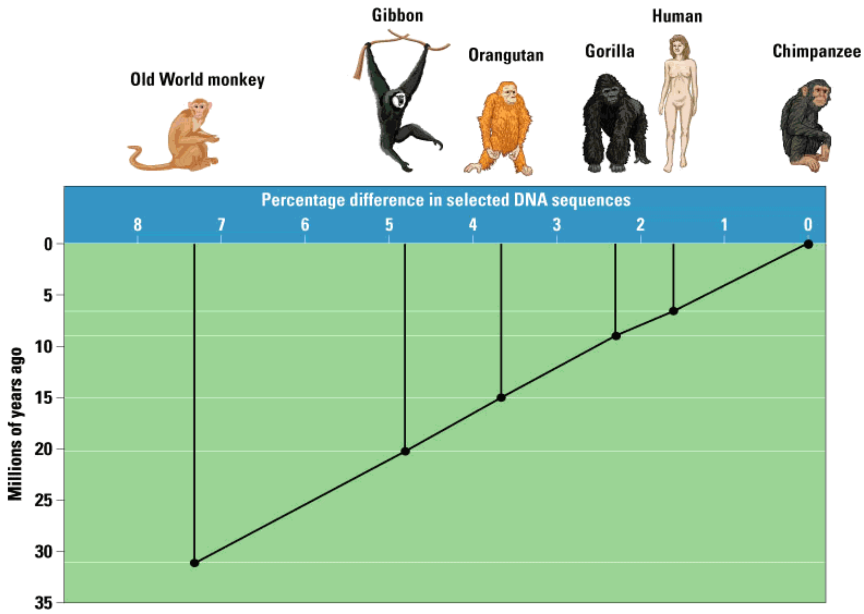
- <u>Comparative Embryology</u>
  - Comparison of structures that appear in early development of different organisms
  - All vertebrates have similarities in their embryonic development
    - e.g., gill pouches and post-anal tail



- Exploring comparative embryology: Guess the Embryo interactive website!
  - http://www.pbs.org/wgbh/nova/evolution/guess-embryo.html

- 5-minute break

- Molecular Biology
  - Comparing the genes and proteins of different species
  - The more similar the genetic code is between two species, the more closely they are related
  - All species use the same genetic code



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- <u>Biogeography</u>
  - The study of the geographical distribution of species
  - Some of the most important evidence Darwin had to work with
    - For example, he noted the animals looked more like animals on the South American continent than animals on other, more distant islands
    - Species that are geographically close to each other are more likely to be more closely related than species that are very distant geographically

Microevolution and Population Genetics

- What is evolution, and how does it happen?
  - Evolution = a change in allele frequencies in a population over time
    - A population is defined as all the individuals of a single species living in a particular area
  - Microevolution (evolution on its smallest scale) = a change in the genetic makeup of a population from generation to generation

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- Note that evolution occurs at the population level (NOT the individual level).
  - If an individual changes over its lifetime, that is an acquired trait and isn't genetically coded
  - Only genetically coded traits are passed on to offspring and influence future gene pools
  - A population is the smallest biological unit that can evolve.
  - Again, Evolution is the change in allele frequencies in a population

- Mutations are the source of all genetic variation
  - Single genes may mutate
  - Entire segments of chromosomes may be deleted or added, or entire chromosomes may be duplicated or omitted from the genome, resulting in more drastic forms of mutation

- The Hardy-Weinberg Equilibrium
  - A theoretical state in which a population does not evolve. It is purely theoretical; natural populations are never truly in Hardy-Weinberg Equilibrium
  - 5 Conditions must be met for a population to be in Hardy-Weinberg Equilibrium (and therefore not evolve):
    - The population is infinitely large (no genetic drift)
    - There is no mutation (no creation of new alleles)
    - There is no gene flow between populations
    - Random mating
    - No natural selection
  - If all these conditions are met, the frequencies of alleles in the population will stay the same over time

- So what causes evolution?
  - Any deviation from any of the five conditions of Hardy-Weinberg equilibrium
  - So, how often do populations meet these?
    - NEVER in nature
    - However, it can be modeled using computer simulations
    - AND, the Hardy-Weinberg Theorem has provided mathematical equations that can be used to calculate approximate allele and genotype frequencies in real populations

- Calculating Allele Frequencies
  - "The gene pool consists of all alleles… in all the individuals making up a population."
  - Consider a population of 100 wildflowers, where purple flowers are dominant to white flowers
    - In those 100 wildflowers, there will be 200 copies of any gene, because individuals are diploid
    - If 20 plants are "PP", 60 are "Pp" and 20 are "pp" then:
    - There are 100 copies of the "P" allele and 100 copies of the "p" allele in this gene pool

– Therefore, we know the proportion of each allele in the population:
  - p = frequency of dominant allele = 0.5
  - q = frequency of the recessive allele = 0.5
  - p + q = 1

– If you know the proportion of one allele in the population, and there are only 2 different alleles for the trait, you can calculate the frequency of the other allele

SAMPLE PROBLEM

- If the frequency of the dominant allele in the population (p) is 0.8, what is the frequency of recessive allele (q)?

Solution: Because p+q = 1, and because we are given p=0.8, then we can solve for q:

q = 1-p

q = 1-0.8

q = **0.2**

– If we know the frequency of each allele in the population, we can also calculate the frequency of each genotype, using the Hardy-Weinberg formula:

$$\mathbf{p^2 + 2pq + q^2 = 1}$$

– Let's consider each part of the Hardy-Weinberg equation separately:

- p^2 = the frequency of homozygous dominants
- 2pq = the frequency of heterozygotes
- q^2 = the frequency of homozygous recessives

- Because these are the only possible genotypes, they must add up to "1" (or 100%)

SAMPLE PROBLEM

- Consider a population of wildflowers, where flowers may be purple (P) or white (p), and the proportion of purple alleles is 0.6. What is the frequency of individuals in the population that are homozygous dominant?

Solution: We are given p, and we are asked to solve for p^2 (the frequency of homozygous dominants).

Therefore, the frequency of homozygous dominants is

$p^2 = 0.6^2 =$ **0.36**

SAMPLE PROBLEM

- Consider a population of wildflowers, where flowers may be purple (P) or white (p). 25% of the flowers are white. What is the frequency of the recessive allele?

Solution: White flowers must be homozygous recessive, and the part of the Hardy-Weinberg Equation that solves for homozygous recessives is q^2. So we set $q^2 = 0.25$. The question asks us to solve for q. To do that, we take the square root of q^2. So, q = square root of 0.25 = **0.5**

- Here is a video to help you understand how to work Hardy-Weinberg problems:
- https://www.youtube.com/watch?v=xPkOAnK20kw

Activity

- This is where we would normally do an in-class activity. Instead, you will log in to Carmen Canvas, click on "quizzes" and complete the quiz titled "Hardy-Weinberg Problems." You will have 25 minutes to do this activity, and it will be worth 5 activity points. Be sure to complete this activity by the end of the day, Monday, March 16.

- Natural Selection and Adaptive Evolution
  - Natural selection makes populations better adapted to their environment
  - Although a new trait first appears through random mutation, the process of natural selection is not itself random
  - Genes that confer fitness for a given environment become more common in the population over time
  - Fitness – *the contribution an individual makes to the gene pool of the next generation relative to the contributions of other individuals*
  - 3 possible outcomes of natural selection: directional, stabilizing, or disruptive

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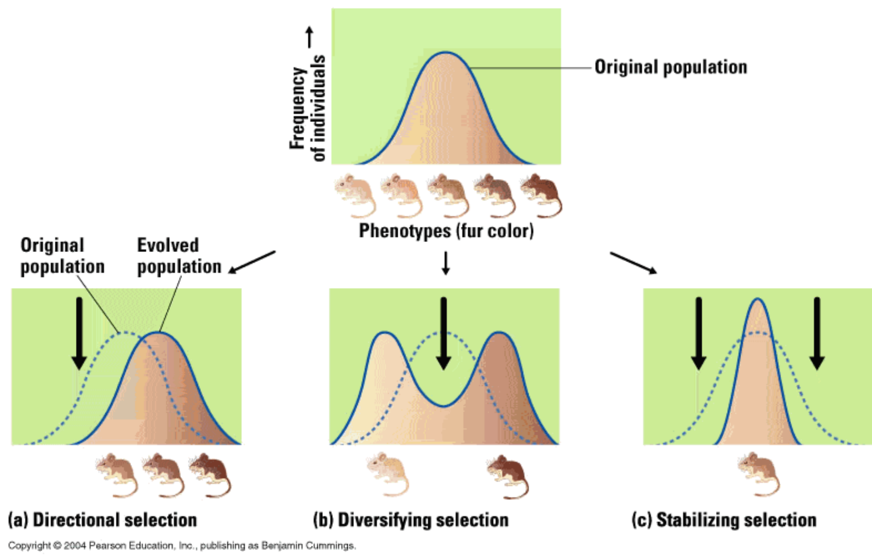
- Given a range of phenotypes for a particular trait, which part of the spectrum of phenotypes for that trait is most adaptive?
- In Directional Selection, the phenotypes at one extreme or the other are selected for and become more common
- In Stabilizing Selection, the phenotypes in the middle of the range are the most adaptive and become more common
- In Diversifying Selection (aka Disruptive Selection), the phenotypes at both extremes are most adaptive and are selected for
- (See Figure 13.29)



Other Mechanisms of Evolution

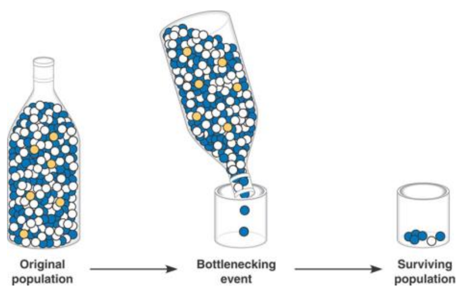
1. Genetic Drift

- A random change in allele frequencies (usually resulting in a loss of genetic diversity)
- Alleles may be lost from the population
  - Deterioration in genetic diversity
- More likely to occur the smaller the population
  - A particular concern for endangered species

- Special cases of genetic drift:
  - May occur when a new population is being established by just a few individuals (the founder effect)
  - May occur when a population goes through a genetic "bottleneck"
    - A large population suddenly collapses; for example, a large number of individuals are killed in a natural disaster

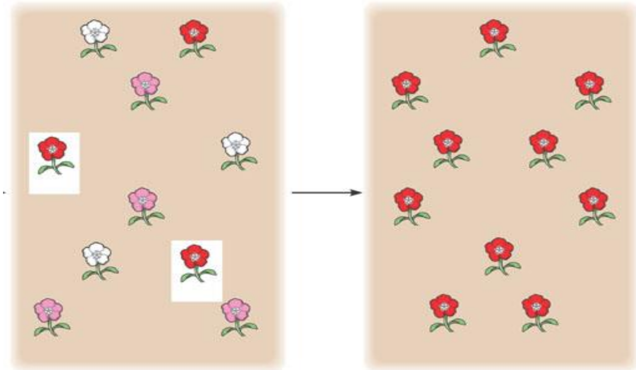
Bottleneck Effect

- Bottleneck: the size of a population is suddenly and drastically reduced so only a few individuals remain to contribute genes



Founder Effect

- Founder effect: isolated colonies are founded by a very small population



2. Sexual Selection

- – Non-random mating and competition for mates
- – The fundamental asymmetry of sex.
  - Female fitness is limited by an ability to gain the resource
    required to produce eggs and rear young.
  - Male fitness is limited by the ability to attract mates.

– Intrasexual selection: competition among members of the same sex over mates
  - Male/male competition: males compete for the attention of females

Males compete for the opportunity to mate with females.

Figure 24-9a Biological Science, 2/e
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– Intersexual selection: "mate choice;" individuals of one sex are choosy in selecting mates of the opposite sex
  - Female mate choice: females are picky and choose a breeding partner

Figure 24-7a Biological Science, 2/e
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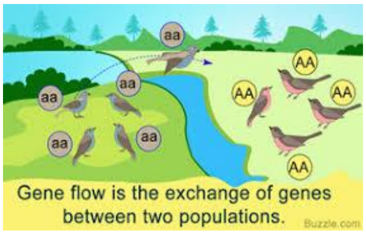
3. Gene Flow

- The exchange of genes between populations of a species
- Enables beneficial alleles to spread



- If gene flow is cut off, can result in
  - In-breeding and loss of genetic diversity in small populations
  - Over long periods of time, genetically isolated populations may diverge into new species

- All for today