How Populations Evolve

How populations evolve?

- In the 1960s, the World Health Organization (WHO) launched a campaign to eradicate malaria.
  - They focused on killing mosquitoes by massive spraying of the pesticide DDT.
  - DDT resistance evolved in mosquito populations.
- Today, malaria causes more than a million deaths and 250 million cases of illness each year.

- The drug **chloroquine** was hailed as the miracle cure for malaria, but in some regions the drug is now powerless against the disease as the parasite evolved resistance to the drug.
- An understanding of evolution informs all of biology, from exploring life's molecules to analyzing ecosystems.

Currently, **artemisinin** is the most effective malaria drug

Child in Mozambique awaiting treatment for malaria

Chloroquine tablets

Artemisia (wormwood)

A sea voyage helped Darwin frame his theory of evolution

- Darwin called his theory descent with modification, which explains that
  - all of life is connected by common ancestry and
  - descendants have accumulated **adaptations** to changing environments over vast spans of time.

Figure 14.8

Seed-eater (medium ground finch)

Tool-using insect-eater (woodpecker finch)

Insect-eater (warbler finch)

The study of fossils provides strong evidence for evolution

- **Fossils**
  - are the imprints or remains of organisms that lived in the past,
  - document differences between past and present organisms, and
  - reveal that many species have become extinct.
- The fossil record reveals the historical sequence in which organisms have evolved.
  - Many fossils link early extinct species with species living today.

Homologies provide evidence for evolution

- Evolution is a process of descent with modification.
  - Evolution is a remodeling process.
  - Related species can have characteristics that have an underlying similarity yet function differently.
  - Similarity resulting from common ancestry is known as **homology**.
- Structural and molecular homologies reveal evolutionary relationships.
- An understanding of homology helps explain why early stages of development in different animal species reveal similarities not visible in adult organisms.

Figure 13.4a

Homologous structures: vertebrate forelimbs

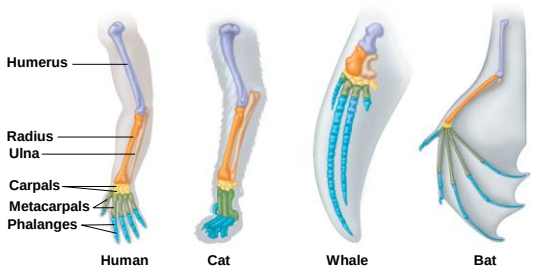
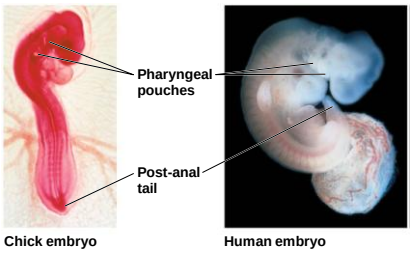


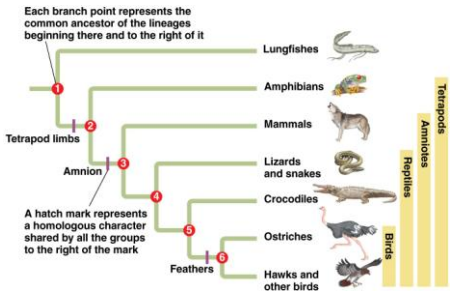
Figure 13.4b

Homologous structures in vertebrate embryos



Homologies indicate patterns of descent that can be shown on an evolutionary tree

- Today, biologists represent patterns of descent with an **evolutionary tree**.
- Homologous structures can be used to determine the branching sequence of an evolutionary tree.
- These homologies can include
  - anatomical structure and/or
  - molecular structure.



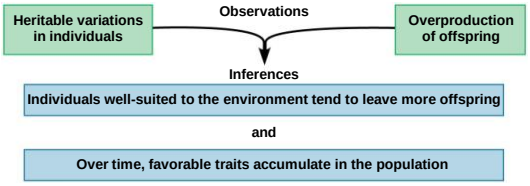
Checkpoint question Are amphibians more closely related to lungfishes or mammals?

Mammals, because they share a more recent common ancestor with mammals (ancestor 2) than with lungfishes (ancestor 1)

13.6 Darwin proposed natural selection as the mechanism of evolution

- It is important to emphasize three key points about evolution by natural selection.
  1. Although natural selection occurs through interactions between individual organisms and the environment, individuals do not evolve. Rather, it is the population, the group of organisms, that evolves over time.
  2. Natural selection can amplify or diminish only heritable traits.
  3. Evolution is not goal directed; it does not lead to perfectly adapted organisms.

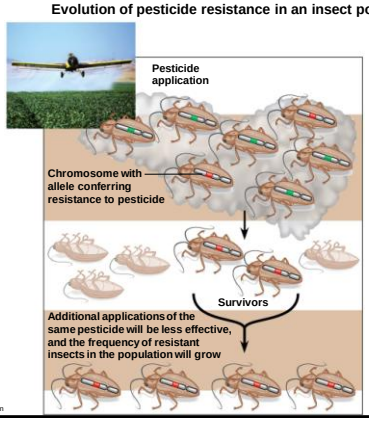
Natural selection



Scientists can observe natural selection in action

- Biologists have documented evolutionary change in thousands of scientific studies.
- An unsettling example of natural selection in action is the evolution of pesticide resistance in hundreds of insect species.

Evolution of pesticide resistance in an insect population



Scientists can observe natural selection in action

- These examples of evolutionary adaptation reveal two important points about natural selection.
  1. Natural selection is more of an editing process than a creative mechanism.
  2. Natural selection is dependent on time and place, favoring those heritable traits in a varying population that fit the current, local environment.

Mutation and sexual reproduction produce the genetic variation that makes evolution possible

- Organisms typically show individual variation.
- **Mutations** are the ultimate source of the genetic variation that serves as raw material for evolution.
- In organisms that reproduce sexually, most of the genetic variation in a population results from the unique combination of alleles that each individual inherits.

Mutation and sexual reproduction produce the genetic variation that makes evolution possible

- Fresh assortments of existing alleles arise every generation from three random components of sexual reproduction:
  1. crossing over,
  2. independent orientation of homologous chromosomes at metaphase I of meiosis, and
  3. random fertilization.

Variation within a species of garter snakes

Evolution occurs within populations

- A **population** is a group of individuals of the same species that live in the same area and interbreed.
- A **gene pool** consists of all copies of every type of allele, at every locus, in all members of the population.
- **Microevolution** is a change in the frequencies of alleles in a population's gene pool and evolution occurring on its smallest scale.

Checkpoint question Why can't an individual evolve?

Evolution involves changes in the genetic makeup of a population over time. An individual's genetic makeup rarely changes during its lifetime.

Lakes in Alaska contain isolated populations

Sexual selection may lead to phenotypic differences between males and females

- **Sexual selection** is a form of natural selection in which individuals with certain characteristics are more likely than other individuals to obtain mates.
- Secondary sex characteristics can give individuals an advantage in mating.

Extreme sexual dimorphism (peacock and peahen)

Sexual selection may lead to phenotypic differences between males and females

Checkpoint question Males with the most sophisticated decoration may get the most mates. How might choosing such a mate be advantageous to a female?

An elaborate display may signal good health and therefore good genes, which in turn could be passed along to the female's offspring.

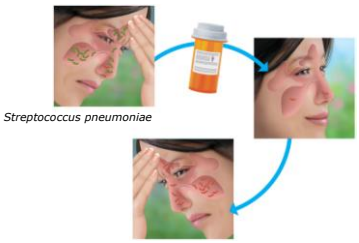
The evolution of drug-resistant microorganisms is a serious public health concern

- In the same way that pesticides select for resistant insects, antibiotics select for resistant bacteria.
- We contribute to the problem of antibiotic resistance when
  - doctors overprescribe antibiotics,
  - patients prematurely stop taking antibiotics, and
  - livestock producers add antibiotics to animal feed as a growth promoter and to prevent illness.

Antibiotic-resistant bacteria

•Antibiotics change the environment of disease-causing bacteria in our bodies.

• Antibiotic-resistant bacteria are becoming increasingly common.



Streptococcus pneumoniae

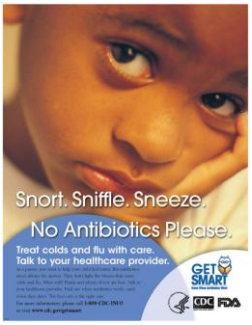
Streptococcus pneumoniae ?

Source: www.niaid.nih.gov/SiteCollectionImages/topics/sinusitis/sinuses

The evolution of drug-resistant microorganisms is a serious public health concern

- A gene that codes for an enzyme that breaks down an antibiotic or a mutation that alters the binding site of an antibiotic can make a bacterium and its offspring resistant to that antibiotic.
- Antibiotic use has increased the frequency of alleles for resistance that were already naturally present in bacterial populations.

Help prevent evolution of antibiotic resistance



- If your doctor doesn't prescribe an antibiotic, don't insist on getting a prescription.
- When you take an antibiotic, complete the prescribed course of treatment.
- Don't save or share leftover antibiotics.
- Don't take antibiotics that were prescribed for someone else.
- Antibiotics are not effective against viruses. They won't help, and they do have side effects.

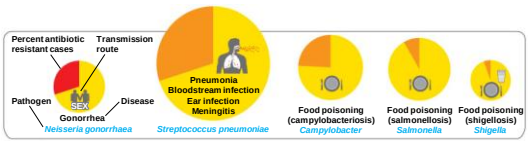
Photo credit: Centers for Disease Control and Prevention

The evolution of drug-resistant microorganisms is a serious public health concern

- In 2013, the Centers for Disease Control (CDC) reported that drug-resistant microorganisms infect more than 2 million people and cause 23,000 deaths in the United States each year.
- The CDC identified 15 microorganisms that pose urgent or serious threats to public health.

Checkpoint question Explain why the following statement is incorrect: "Antibiotics have created resistant bacteria."

Some of the infections are associated with health-care facilities ("superbug" known as MRSA-methicillin resistant *Staphylococcus aureus*); others are passed on by contaminated food and water, sexual contact, or droplets exhaled from the respiratory tract of an infected person.



Urgent (red) and serious (orange) threats from antibiotic-resistant bacteria. Circle area represents the total numbers of infections; slices show the percent caused by antibiotic-resistant strains.

Diploidy and balancing selection preserve genetic variation

- Diploidy preserves variation by "hiding" recessive alleles.
  - **Balancing selection** occurs when natural selection maintains stable frequencies of two or more phenotypic forms in a population.
  - **Heterozygote advantage** is a type of balancing selection in which heterozygous individuals have greater reproductive success than either type of homozygote, with the result that two or more alleles for a gene are maintained in the population.

Diploidy and balancing selection preserve genetic variation

Checkpoint question Why would natural selection tend to reduce genetic variation more in populations of haploid organisms than in populations of diploid organisms?

All alleles in a haploid organism are phenotypically expressed and are hence screened by natural selection.

Malaria and human microevolution

•Malaria exerts a strong selective pressure on human populations.

• Sickle hemoglobin and thalassemias are evolutionary responses to malaria.

Individuals who carry one sickle hemoglobin allele (heterozygotes) are thus protected against the deadly disease, giving them an evolutionary advantage over individuals who have no protection

Different mutations in the genes for hemoglobin lead to a group of blood disorders called thalassemias.

Sickled RBCs

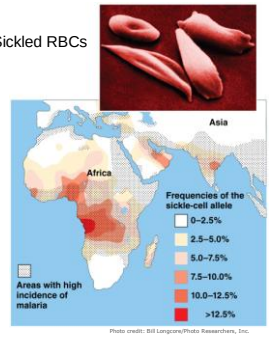
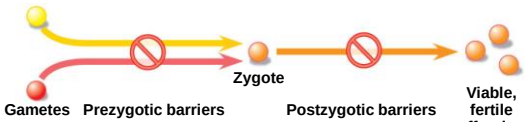


Photo credit: Bill Longcore/Photo Researchers, Inc.

14.3 VISUALIZING THE CONCEPT: Reproductive barriers keep species separate

- Reproductive barriers
  - serve to isolate the gene pools of species and
  - prevent interbreeding.
- Depending on whether they function *before* or *after* zygotes form, reproductive barriers are categorized as
  - **prezygotic** or
  - **postzygotic**.

Figure 14.UN04



Gametes

Prezygotic barriers
- **Habitat isolation**
- **Temporal isolation**
- **Behavioral isolation**
- **Mechanical isolation**
- **Gametic isolation**

Postzygotic barriers
- **Reduced hybrid viability**
- **Reduced hybrid fertility**
- **Hybrid breakdown**

Viable, fertile offspring

Figure 14.3

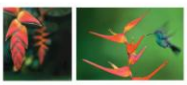
PREZYGOTIC BARRIERS

Habitat isolation (different habitats)

Temporal isolation (breeding at different times)

Behavioral isolation (different courtship rituals)

Mechanical isolation (incompatible reproductive parts)



Gametic isolation (incompatible gametes)

POSTZYGOTIC BARRIERS

Reduced hybrid vitality (short-lived hybrids)

Reduced hybrid fertility (sterile hybrids)

Hybrid breakdown (fertile hybrids with sterile offspring)

Figure 14.3_1

Habitat isolation
(lack of opportunities to encounter each other)

The garter snake *Thamnophis atratus* lives mainly in water.

The garter snake *Thamnophis sirtalis* lives on land.

Figure 14.3_2

Temporal isolation
(breeding at different times or seasons)

The eastern spotted skunk (*Spilogale putorius*) breeds in late winter.

The western spotted skunk (*Spilogale gracilis*) breeds in the fall.

Figure 14.3_3

Behavioral isolation
(different courtship rituals)

The blue-footed booby (*Sula nebouxii*) performs an elaborate courtship dance.

The masked booby (*Sula dactylatra*) performs a different courtship ritual.

Figure 14.3_4

Mechanical isolation
(physical incompatibility of reproductive parts)

***Heliconia pogonantha* is pollinated by hummingbirds with long, curved bills.**

***Heliconia latispatha* is pollinated by hummingbirds with short, straight bills.**

Figure 14.3_5

Gametic isolation
(molecular incompatibility of eggs and sperm or pollen and stigma)

Purple sea urchin (*Strongylocentrotus purpuratus*)

Red sea urchin (*Strongylocentrotus franciscanus*)

Figure 14.3_6

Reduced hybrid viability
(hybrid development or survival impaired by interaction of parental genes)

Some species of salamander can hybridize, but their offspring do not develop fully or, like this one, are frail and will not survive long enough to reproduce.

Figure 14.3_7

Reduced hybrid fertility
(vigorous hybrids that cannot produce viable offspring)

The hybrid offspring of a horse and a donkey is a mule, which is robust but sterile.

Figure 14.3_8

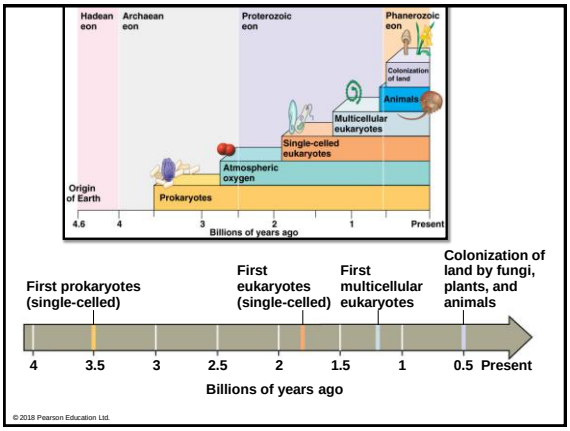
Hybrid breakdown
(viable and fertile hybrids with feeble or sterile offspring)

The rice hybrids on the left and right are fertile, but plants of the next generation (middle) are sterile.

15.4 The origins of single-celled and multicellular organisms and the colonization of land were key events in life's history

- **Macroevolution** is evolutionary change above the species level. Macroevolution encompasses
  - the origin of a new group of organisms through a series of speciation events and
  - the impact of mass extinctions on the diversity of life and its subsequent recovery.

- Bird feathers and flight are a marriage of structure and function.
- Birds were not the first feathered animals on Earth—dinosaurs were.
- The evolution of birds is an example of macroevolution, the major changes recorded in the history of life over vast tracts of time.



PHYLOGENY AND THE TREE OF LIFE

Taxonomy names and classifies the diversity of life

- **Taxonomy** is the branch of biology concerned with identifying, naming, and classifying species.
- Taxonomists assign each species a two-part scientific name, or **binomial**.
  - The first part of a binomial is the **genus** (plural, *genera)*.
  - The second part of a binomial, the specific epithet, is used to distinguish each **species** within a genus.
- Genera are grouped into progressively broader categories.

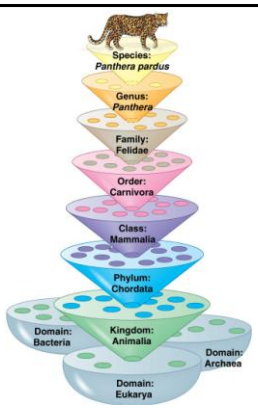
Panthera pardus = leopard

Panthera leo = lion

Linnaean system

by Carolus Linneus

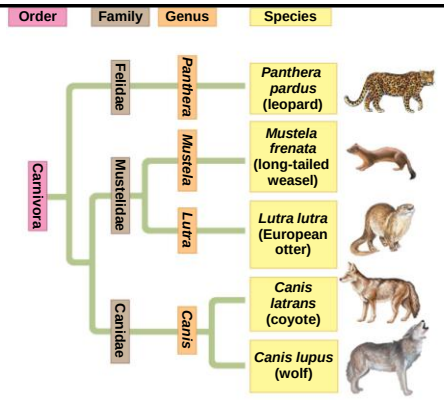
Our hierarchical classification system is analogous to sorting mail first by zip code, then by street, house number, and, finally, individual name. Such a system of classification based on hierarchical categories is also common in the military and many other places in our lives



Phylogenies based on homologies reflect evolutionary history

- How an organism is named and classified should reflect its place within the evolutionary tree of life.
- The evolutionary history of a species or group of species is called **phylogeny**.
- **Systematics**, which includes taxonomy, is a discipline of biology that focuses on
  - classifying organisms and
  - determining their evolutionary relationships.
- A **phylogenetic tree** is a hypothesis of evolutionary relationships.

- To construct phylogenetic trees, systematists gather morphological and molecular data about the relevant organisms, including evidence from the fossil record.
- Similarities with shared ancestry are called **homologies**
  - Similarity in the forelimb bones of mammals
  - Genes are homologous if they are descended from genes carried by a common ancestor
- Homologous structures and molecular sequences provide the evidence of common ancestry used to determine phylogeny.



Hierarchial connection between classification and phylogeny

Phylogenies based on homologies reflect evolutionary history

- **Checkpoint question** Which two species depicted in the phylogenetic tree of Figure 15.15A have the closest common ancestor?

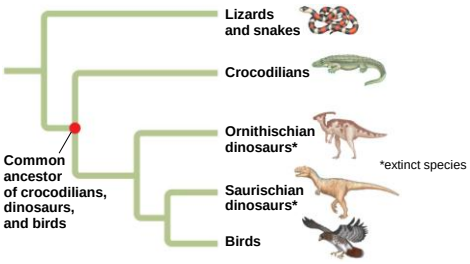
Shared characters are used to construct phylogenetic trees

- **Cladistics** method groups organisms by common ancestry.
- Each **clade (branch)** is a **monophyletic (single tribe)** group that consists of an ancestral species and all its evolutionary descendants—a distinct branch in the tree of life.
- Identifying clades makes it possible to devise classification schemes that reflect the branching pattern of evolution

Phylogenetic Trees as Hypotheses

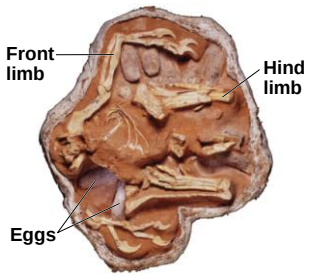
- As new data accumulate, hypotheses may be revised and new trees drawn.
- In traditional vertebrate taxonomy, crocodiles, snakes, lizards, and other reptiles were classified in the class Reptilia, while birds were placed in the separate class Aves.
- However, many lines of evidence support that birds belong to the clade of reptiles.

A phylogenetic tree of reptiles



Each branch point in a tree represents the divergence of two groups from a common ancestor and the emergence of a lineage possessing a new set of derived characters.

Hypothesis: dinosaurs built nests and exhibited brooding



Fossil remains of *Oviraptor* and eggs. The orientation of the bones, which surround the eggs, suggests that the dinosaur died while incubating or protecting its eggs during sandstorm.

An organism's evolutionary history is documented in its genome

- The more recently two species have branched from a common ancestor, the more similar their DNA sequences should be.
- Genetic relationships provide one strong line of evidence for the ancestral relationships of life.
- Fossils, anatomy, embryology, and biogeography can also be used to test these same relationships.
- Homologous genes are found across distantly related species.

Molecular clocks help track evolutionary time

- The longer two groups have been separated, the greater the divergence of their genes.
- Biologists have found that some genes or other regions of genomes appear to accumulate changes at constant rates.

Figure 15.18

- In 2011, researchers studied the divergence of human body lice from head lice.

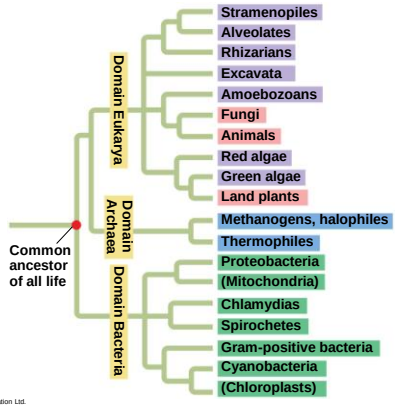
Human body louse (*Pediculus humanus humanus*)

• The loss of body hair restricted lice to the head—bare skin deprived the parasites of their refuge. When clothing offered a new habitat, populations diverged into two types (head lice and body lice), each with adaptations specific to its habitat.
• The researchers estimated that people began to wear clothing between 83,000 and 170,000 years ago.

Constructing the tree of life is a work in progress

- Phylogenetic trees are hypotheses about evolutionary history.
- Life is currently classified into three domains:
  1. Bacteria,
  2. Archaea, and
  3. Eukarya.

Figure 15.19a



Constructing the tree of life is a work in progress

- Why are mitochondria and chloroplasts, the cellular organelles, found only in eukaryotes, shown as lineages in the domain Bacteria?
- Comparisons of complete genomes from the three domains show that especially during the early history of life, there have been substantial interchanges of genes between organisms in the different domains.
- Multiple **horizontal gene transfers** occurred during the early history of life, including transfers that resulted in the origin of eukaryotic cells
  - via plasmid exchange, viral infection, fusion.

Figure 15.19b