

CHAPTER 14: The Origin of Species

Name _____

CHAPTER 15: Tracing Evolutionary History

Introduction

1. Many species of cormorants in the world can fly, but Cormorants on the Galápagos Islands don't fly.
2. How did these flightless cormorants get to the Galápagos Islands? Why are these flightless cormorants found nowhere else in the world?
3. An ancestral cormorant species is thought to have flown from the Americas to the Galápagos Islands more than 3 million years ago.
4. Terrestrial mammals could not make the trip over the wide distance, and no predatory mammals naturally occur on these islands today.
5. Without predators, the environment of these cormorants favored birds with smaller wings, perhaps channeling resources to the production of offspring.

Defining Species

14.1 The origin of species is the source of biological diversity

1. Microevolution (natural selection, genetic drift and gene flow) is the change in the gene pool of a population from one generation to the next.
2. **Speciation** is the process by which one species splits into two or more species.
 - a. Every time speciation occurs, the diversity of life increases.
 - b. The many millions of species on Earth have all arisen from an ancestral life form that lived around 3.5 billion years ago.

14.2 There are several ways to define a species

1. The word species is from the Latin for "kind" or "appearance."
2. Although the basic idea of species as distinct life-forms seems intuitive, devising a more formal definition is not easy and raises questions.
 - a. How similar are members of the same species?
 - b. What keeps one species distinct from others?
3. The **biological species concept** defines a species as a group of populations, whose members have the potential to interbreed in nature, and produce fertile offspring.
4. **Reproductive isolation**
 - a. prevents members of different species from mating with each other, prevents gene flow between species, and maintains separate species.
 - b. Therefore, species are distinct from each other because they do not share the same gene pool.
5. The biological species concept can be problematic.
 - a. Some pairs of clearly distinct species occasionally interbreed and produce **hybrids**.
 - i. For example, mules ($2n=63$) are the offspring of a female horse ($2n=64$) and male donkey ($2n=62$). This is an example of a chromosome mismatch.

14.3 Reproductive barriers keep species separate & serve to isolate the gene pools of species and prevent interbreeding.

Mechanisms of Speciation

14.4 In allopatric speciation, geographic isolation leads to speciation

1. In **allopatric speciation**, populations of the same species are geographically separated, isolating their gene pools.
2. Isolated populations will no longer share changes in allele frequencies caused by natural selection, genetic drift, and/or mutation.
3. Gene flow between populations is initially prevented by a geographic barrier. For example the Grand Canyon and Colorado River separate two species of antelope squirrels

14.5 Reproductive barriers can evolve as populations diverge

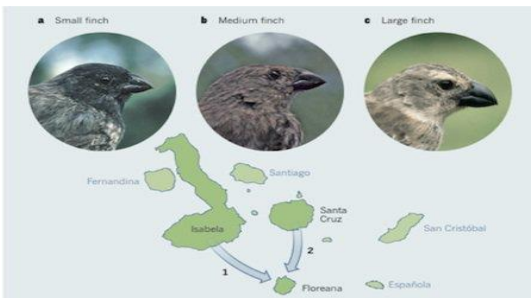
1. How do reproductive barriers arise?
2. Experiments have demonstrated that reproductive barriers can evolve as a by-product of changes in populations as they adapt to different environments.
3. These studies have included laboratory studies of fruit flies and field studies of color changes in monkey flowers and effects on their pollinators.

14.6 Sympatric speciation takes place without geographic isolation

1. **Sympatric speciation** occurs when a new species arises within the same geographic area as a parent species.
2. Gene flow in populations may be reduced by polyploidy, habitat differentiation, or sexual selection.

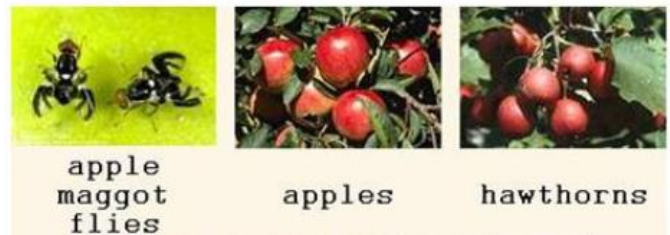
Allopatric Speciation

- Involves physical separation of populations
 - Populations occupy different geographical areas
- Example- Adaptive radiation of Galapagos



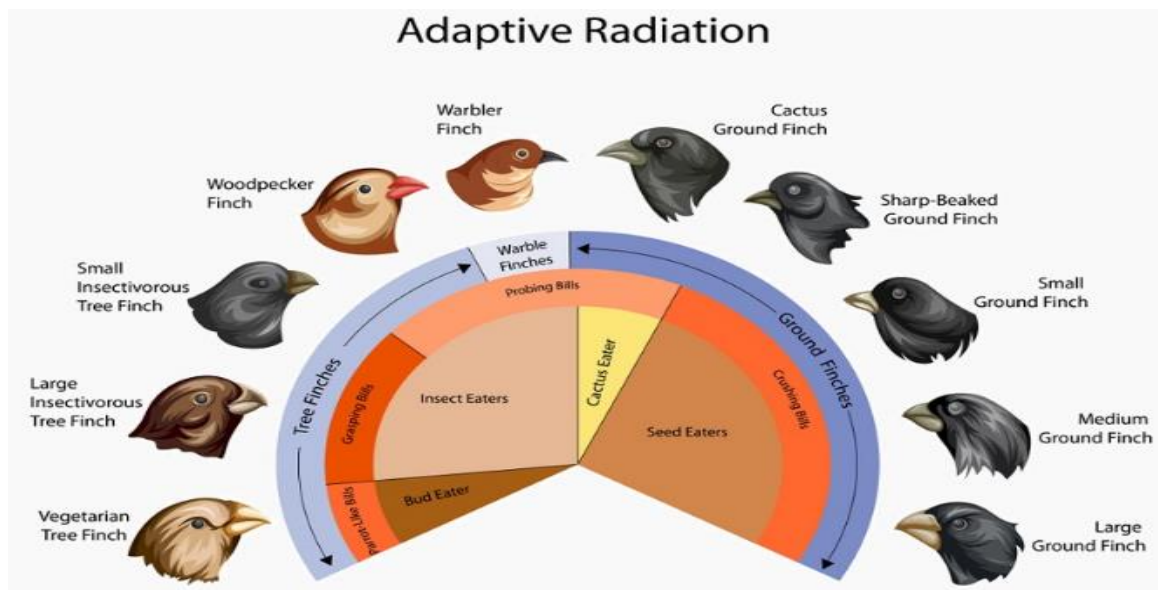
Sympatric speciation

- Involves a reproductive or behavioral separation
 - Populations occupy same geographical area
- Example- Flies lay eggs on only apples or Hawthorn fruit



14.8 Isolated islands are often showcases of speciation

1. Most of the species on Earth are thought to have originated by allopatric speciation.
2. Isolated island chains offer some of the best evidence of this type of speciation.
3. Multiple speciation events are more likely to occur in island chains that have
 - a. physically diverse habitats, islands far enough apart to permit populations to evolve in isolation, and islands close enough to each other to allow occasional dispersions between them.
4. The evolution of many diverse species from a common ancestor is **adaptive radiation**.



5. The Galápagos Archipelago was colonized gradually from other islands and the mainland

6. The Galápagos islands currently have 14 species of closely related finches, called

Darwin's finches, because Darwin collected them during his around-the-world voyage on the *Beagle*.

14.9 A long-term field study documents evolution in Darwin's finches; Peter and Rosemary Grant have worked for more than three decades, on medium ground finches, and on tiny, isolated, uninhabited Daphne Major in the Galápagos Islands.

14.11 Speciation can occur rapidly or slowly

1. There are two models for the tempo (timing) of speciation.

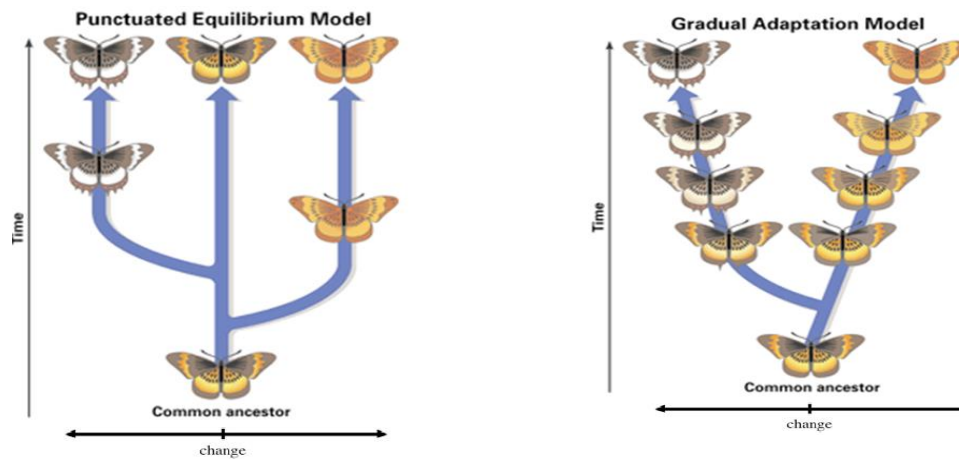
a. The **punctuated equilibria** model draws on the fossil record, where species

i. change most as they arise from an ancestral species and then

ii. experience relatively little change for the rest of their existence.

b. Other species appear to have evolved more gradually- **gradualism**

2. What is the total length of time between speciation events (between formation of a species and subsequent divergence of that species)?



Word Parts

allo- = other

sym- = together

-patri = father

auto- = self

poly- = many

macro- = large

post- = after

pre- = before

zygo- = fertilized cell

Vocabulary

1. **speciation-** The evolution of a new species.

2. **biological species concept-** Definition of a species as a population or groups of populations whose members have the potential to interbreed in nature and produce viable, fertile offspring, but do not produce viable, fertile offspring with members of other such populations..

3. **species-** A group whose members possess similar anatomical characteristics and have the ability to interbreed and produce viable, fertile offspring.

4. **reproductive isolation-** The existence of biological factors (barriers) that impede members of two species from producing viable, fertile hybrids.

5. **hybrid-** The offspring of parents of two different species or of two different varieties of one species; the offspring of two parents that differ in one or more inherited traits; an individual that is heterozygous for one or more pairs of genes.

6. morphological species concept- A definition of species in terms of measurable anatomical criteria.

7. allopatric speciation-The formation of new species in populations that are geographically isolated from one another.

8. sympatric speciation- The formation of new species in populations that live in the same geographic area.

9. adaptive radiation- Period of evolutionary change in which groups of organisms form many new species whose adaptations allow them to fill new or vacant ecological roles in their communities.

10. punctuated equilibrium- In the fossil record, long periods of apparent stasis in which a species undergoes little or no morphological change interrupted by relatively brief periods of sudden change.

11. gradualism- species evolve slowly and continuously over long periods of geological time.

CHAPTER 15: Tracing Evolutionary History

Introduction

Different types of wings evolved from the same ancestral tetrapod limb.

1. Pterosaur wings consist of a membrane primarily supported by one greatly elongated finger.
2. Bird wings consist of feathers supported by an elongated forearm and modified wrist and hand bones.
3. Bat wings consist of a membrane supported by arm bones and four very elongated fingers.

Early Earth and the Origin of Life

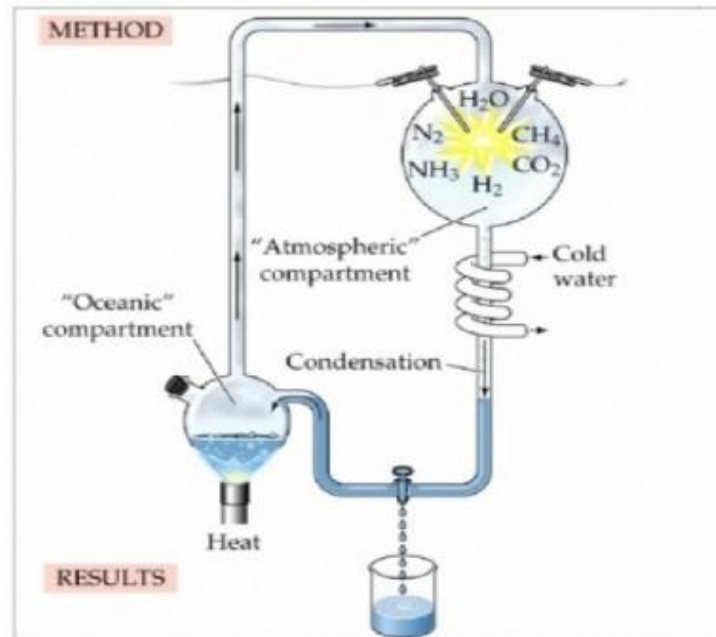
15.1 Conditions on early Earth made the origin of life possible

1. The Earth formed about 4.6 billion years ago.
2. As the Earth cooled and the bombardment slowed about 3.9 billion years ago, the conditions on the planet were extremely different from those today.
 - a. The first atmosphere was probably thick with water vapor and various compounds released by volcanic eruptions, including nitrogen and its oxides, carbon dioxide, methane, ammonia, hydrogen, and hydrogen sulfide.
 - b. Lightning, volcanic activity, and ultraviolet radiation were much more intense than today.
3. The earliest evidence for life on Earth comes from 3.5 billion year old fossils of **stromatolites**, built by ancient photosynthetic prokaryotes still alive today.
4. Because these 3.5 billion year old prokaryotes used photosynthesis, it suggests that life first evolved earlier, perhaps as much as 3.9 billion years ago.
5. The first life may have evolved through four stages.
 - a. The abiotic synthesis of small organic molecules, like amino acids and nitrogenous bases.
 - b. The joining of these small molecules into polymers, such as proteins and nucleic acids.
 - c. The packaging of these molecules into “protocells,” droplets with membranes that maintained an internal chemistry different from that of their surroundings.
 - d. The origin of self-replicating molecules that eventually made inheritance possible.

15.2 Experiments show that the abiotic synthesis of organic molecules is possible

1. In the 1920s, two scientists, the Russian A. I. Oparin and the British J. B. S. Haldane, independently proposed that organic molecules could have formed on the early Earth.
2. Our modern atmosphere is rich in O₂, which oxidizes and disrupts chemical bonds.
3. The early Earth likely had a reducing atmosphere.

4. In 1953, Stanley Miller, working under Harold Urey, tested the Oparin-Haldane hypothesis- organic compounds were derived from inorganic chemicals; this would then lead to more and more complex organic molecules



5. After a week, Miller's setup produced abundant amino acids and other organic molecules.

Major Events in the History of Life

15.4 The origins of single-celled/multi-celled organisms & the colonization of land are key events in life history

1. **Macroevolution** is the broad pattern of changes in life on Earth
2. See 15.6 for Geologic Time Scale

15.5 The actual ages of rocks and fossils mark geologic time

1. **Radiometric dating** measures the decay of radioactive isotopes.
2. The rate of decay is expressed as a half-life, the time required for 50% of an isotope in a sample to decay.

Number of half lives passed: total time elapsed \div length of half-life = number of half-lives elapsed

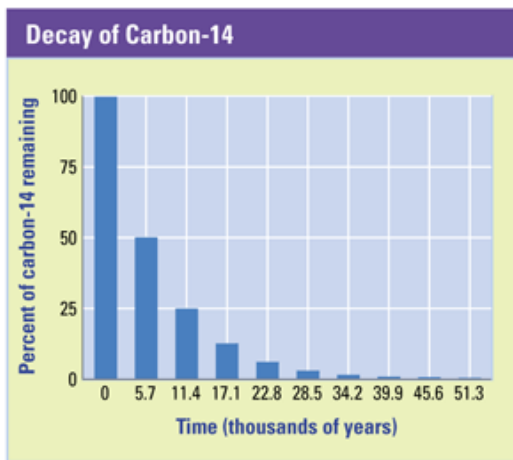
Amount of material remaining: $(1/2)^{\text{number of half-lives}}$ equals the decimal amount remaining.

Fraction of original material

F_{material} is $y = \frac{1}{2^{t/12}}$ where t= the number of half lives

3. There are many different isotopes that can be used to date fossils. These isotopes have different half-lives, ranging from thousands to hundreds of millions of years.
4. The age of a fossil can also be inferred from the ages of rock layers above and below the strata in which a fossil is found.

Calculation: A fossil is found to contain 1/8 its original Carbon-14. How old is the fossil based on the half life of carbon (5,730 years)?



Isotope		Half-life of parent (years)	Useful range (years)
Parent	Daughter		
Carbon 14	Nitrogen 14	5,730	100 - 30,000
Potassium 40	Argon 40	1.3 billion	100,000 - 4.5 billion
Rubidium 87	Strontium 87	47 billion	10 million - 4.5 billion
Uranium 238	Lead 206	4.5 billion	10 million -
Uranium 235	Lead 207	710 million	4.6 billion

15.6 The fossil record documents the history of life

1. The **geologic record** is based on the sequence and age of fossils in the rock strata.
2. The most recent Phanerozoic eon includes the past 542 million years and is divided into three eras
 - i. Paleozoic-
 - ii. Mesozoic-
 - iii. Cenozoic-
3. The boundaries between eras are marked by mass extinctions.

Mechanisms of Macroevolution

15.7 Continental drift has played a major role in macroevolution

1. According to the theory of **plate tectonics**, the Earth's crust is divided into giant, irregularly shaped plates that essentially float on the underlying mantle.
2. In a process called *continental drift*, movements in the mantle cause the plates to move.
3. Since the origin of multicellular life roughly 1.5 billion years ago, there have been three occasions in which the landmasses of Earth came together to form a supercontinent.
4. About 250 million years ago plate movements brought all the landmasses together and the supercontinent of **Pangaea** was formed.
5. During the Mesozoic era
 - a. Pangaea started to break apart, the physical environment and climate changed dramatically
 - b. Australia became isolated, and biological diversity was reshaped.
6. Continental drift explains the distribution of lungfishes.
 - a. Fossils of lungfishes are found on every continent except Antarctica.
 - b. Today, living lungfishes are found in South America, Africa, and Australia.
 - c. This evidence suggests that lungfishes evolved when Pangaea was still intact.

15.8 Plate tectonics may imperil human life as volcanoes and earthquakes result from the movements of crustal plates.













1. The boundaries of plates are hotspots of volcanic and earthquake activity.
2. An undersea earthquake caused the 2004 tsunami, when a fault in the Indian Ocean ruptured.

15.9 During mass extinctions, large numbers of species are lost

1. Extinction is inevitable in a changing world.
2. The fossil record shows that the vast majority of species that have ever lived are now extinct.
3. Over the last 500 million years, five mass extinctions have occurred, and in each event, more than 50% of the Earth's species went extinct.
4. The Permian mass extinction- occurred about 251 million years ago
 - a. defines the boundary between the Paleozoic and Mesozoic eras
 - b. claimed 96% of marine animal species, took a tremendous toll on terrestrial life

- c. was likely caused by enormous volcanic eruptions.
- 5. The Cretaceous mass extinction
 - a. caused the extinction of all the dinosaurs except birds
 - b. was likely caused by a large asteroid that struck the Earth, blocking light and disrupting the global climate.

The Geologic Time Scale

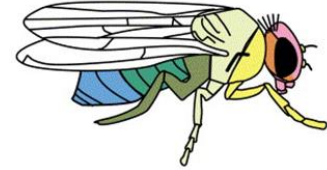
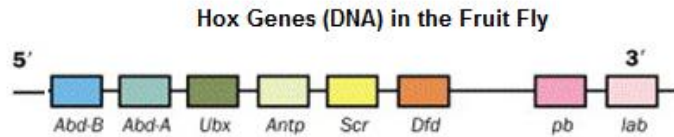
ERA	PERIOD	MILLION YEARS AGO	MAJOR EVOLUTIONARY EVENTS	MAJOR LIFE FORMS
Cenozoic	Quaternary		Humans evolve	
	Tertiary	1.6	First placental mammals	
Mesozoic	Cretaceous	66	Flowering plants dominant	
	Jurassic	144	First birds First mammals First flowering plants	
	Triassic	208	First dinosaurs	
	Permian	245	Conifers dominant	
Paleozoic	Pennsylvanian	286	First reptiles Great coal deposits form	
	Mississippian	320	First seed plants	
	Devonian	360	First amphibians	
	Silurian	408	First land plants First jawed fishes	
	Ordovician	438	Algae dominant First vertebrates	
	Cambrian	505	Invertebrates	
			544	Life diversifies
Precambrian Era				
		2000	Eukaryotes	
		3500	Prokaryotes	
		4000	Life evolves	

15.10 Adaptive radiations have increased the diversity of life

1. Adaptive radiations are periods of evolutionary change that occur when many new species evolve from a common ancestor that colonizes a new, unexploited area and often follow extinction events.
2. Radiations may result from the evolution of new adaptations such as
 - a. wings in pterosaurs, birds, bats, and insects
 - b. adaptations for life on land in plants, insects, and tetrapods.

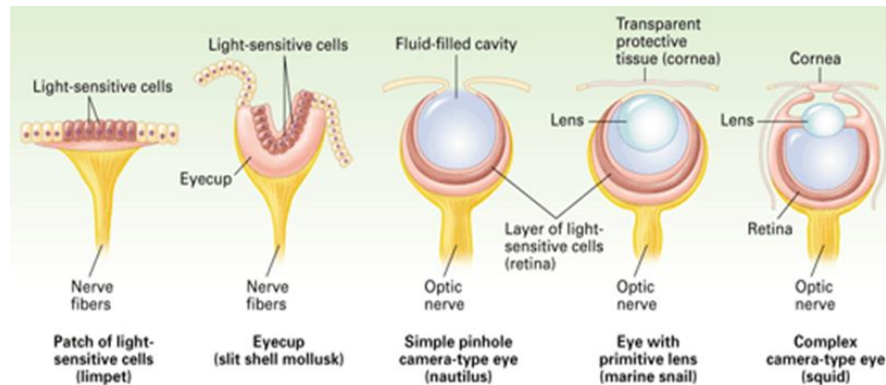
15.11 Genes that control development play a major role in evolution

1. **Homeotic genes**- are called master control genes and determine basic features, such as where pairs of wings or legs develop on a fruit fly.
2. Profound alterations in body form can result from changes in homeotic genes or how or where homeotic genes are expressed.
3. Duplication of developmental genes can also be important in the formation of new morphological features.



15.12 Evolutionary novelties may arise in several ways

1. In most cases, complex structures evolve by increments from simpler versions with the same basic functions.
2. In the evolution of an eye or any other complex structure, behavior, or biochemical pathway, each step must bring a selective advantage to the organism possessing it and increase the organism's fitness.



3. Mollusc eyes evolved from an ancestral patch of photoreceptor cells through a series of incremental modifications that were adaptive at each stage.
4. A range of complexity can be seen in the eyes of living molluscs.
5. Cephalopod eyes are as complex as vertebrate eyes, but arose separately.
6. In other cases, evolutionary novelties result from the gradual adaptation of existing structures to new functions.
7. Such structures that evolve in one context but become co-opted for another function are often called **exaptations**.
8. Examples of exaptations include
 - a. feathers that may have first functioned for insulation and later were co-opted for flight and
 - b. flippers of penguins that first functioned for flight and were co-opted for underwater swimming.

Phylogeny and the Tree of Life

15.14 Phylogenies based on homologies reflect evolutionary history

1. **Phylogeny** is the evolutionary history of a species or group of species.
2. Phylogeny can be inferred from the fossil record, morphological homologies, and molecular homologies.
3. Homologies are similarities due to shared ancestry, evolving from the same structure in a common ancestor.

4. Generally, organisms that share similar morphologies are closely related.
 - a. **Divergent evolution**- process in which a trait held by a common ancestor evolves into different variations over time; like the wing of bat and flipper of a whale (*homologous structures*)
 - b. **Convergent evolution**- the process whereby organisms not closely related, independently evolve similar traits as a result of having to adapt to similar environments; like the wing of a butterfly and wing of a bird (*analogous structures*)

15.15 Systematics connects classification with evolutionary history

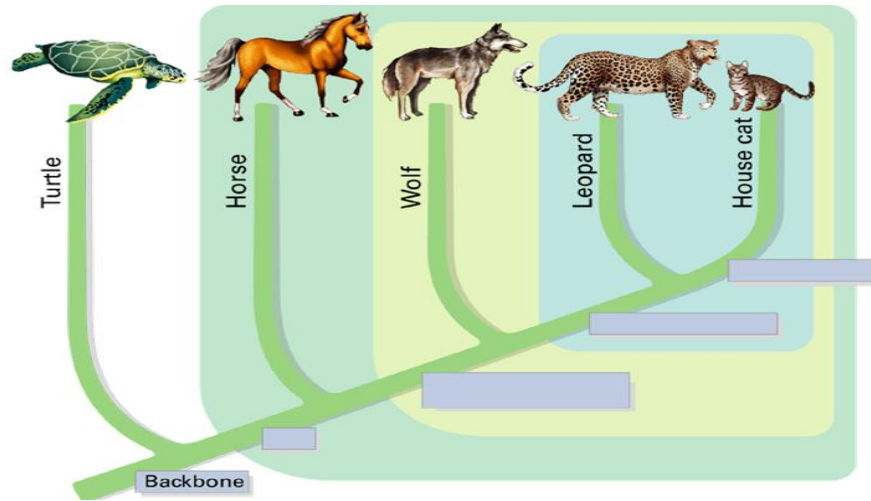
1. **Systematics** is a discipline of biology that focuses on classifying organisms and determining their evolutionary relationships.
2. Carolus Linnaeus introduced **taxonomy**, a system of naming and classifying species.
3. Biologists assign each species a two-part scientific name, or **binomial nomenclature**, consisting of a name combination that includes the **genus** and **species** for the organism.

Classifying System	Gray Wolf	Meaning / Trait
Domain	Eukarya	
Kingdom	Animalia	
Phylum	Chordata	
Class	Mammalia	
Order	Carnivora	
Family	Canidae	
Genus	Canis	
Species	lupus	

4. Genera are grouped into progressively larger categories; With each taxonomic unit is a **taxon**.
5. Biologists traditionally use a **phylogenetic tree** to depict hypothesis about the evolutionary history of species.
 - a. The branching diagrams reflect the hierarchical classification of groups nested within more inclusive groups.
 - b. Phylogenetic trees indicate the probable evolutionary relationships among groups and patterns of descent **over time**.
 - c. Phylogenic trees are dynamic; they can change over time when new information become available

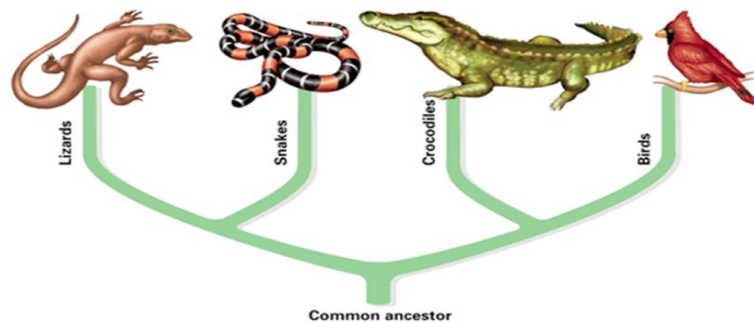
15.16 Shared characters are used to construct phylogenetic trees

1. **Cladistics** is the most widely used method in systematics and groups organisms into **clades**.
2. Each clade is a **monophyletic** group of species that includes an ancestral species and all of its descendants.
3. Cladistics is based on the Darwinian concept that organisms share characteristics with their ancestors and differ from them. Thus, there are two main types of characters.
 - a. **Shared ancestral characters** group organisms into clades.
 - b. **Shared derived characters** distinguish clades and form the branching points in the tree of life.
4. An important step in cladistics is the comparison of the
 - a. **ingroup** (the taxa whose phylogeny is being investigated) and
 - b. **outgroup** (a taxon that diverged before the lineage leading to the members of the ingroup),
 - c. to identify the derived characters that define the branch points in the phylogeny of the ingroup.
5. The presence or absence of traits is indicated as
 - a. “1” or “+” if the trait is present or “0” or “-“ if the trait is absent.
 - c. In our example, the phylogenetic tree is constructed from a series of branch points, represented by the emergence of a lineage with a new set of derived traits.
 - d. When constructing a phylogenetic tree, scientists use **parsimony**, looking for the simplest explanation for observed phenomena.



Organism	Backbone				
?					
Turtle	1				
Horse	1				
Wolf	1				
Leopard	1				
House cat	1				

6. Systematists use many kinds of evidence. However, even the best tree represents only the most likely hypothesis.
7. The phylogenetic tree of reptiles shows that crocodylians are the closest *living* relatives of birds.
 - a. They share numerous features, including four-chambered hearts, “singing” to defend territories, and parental care of eggs within nests.
 - b. These traits were likely present in the common ancestor of birds, crocodiles, and dinosaurs.



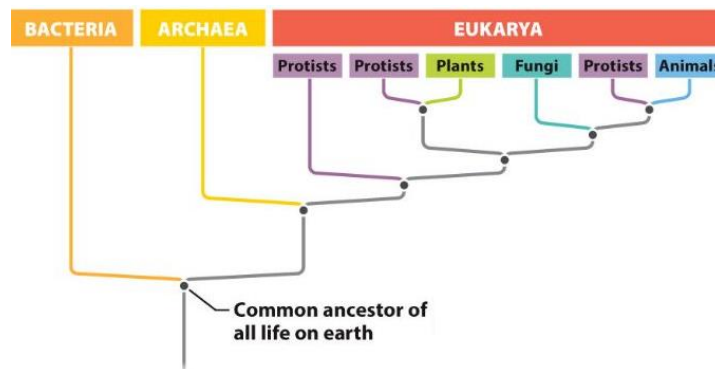
15.17 An organism’s evolutionary history is documented in its genome

1. **Molecular systematics** uses DNA and other molecules to infer relatedness.
 - a. Scientists have sequenced more than 110 billion bases of DNA from thousands of species.
 - b. This enormous database has fueled a boom in the study of phylogeny and clarified many evolutionary relationships.
2. The more recently two species have branched from a common ancestor, the more similar their DNA sequences should be.

3. The longer two species have been on separate evolutionary paths, the more their DNA should have diverged.
4. Different genes evolve at different rates.
 - a. DNA coding for ribosomal RNA (rRNA) changes slowly and is useful for investigating relationships between taxa that diverged hundreds of millions of years ago.
 - b. In contrast, DNA in mitochondria (mtDNA) evolves rapidly and is more useful to investigate more recent evolutionary events.
 - c. What could account for these differences in rates?
5. Remarkable commonality of molecular biology demonstrates that all living organisms share many biochemical and developmental pathways and provides overwhelming support of evolution.
 - a. The genomes of humans and chimpanzees are amazingly similar.
 - b. About 99% of the genes of humans and mice are detectably homologous.
 - c. About 50% of human genes are homologous with those of yeast.

15.19 Constructing the tree of life is a work in progress

1. Molecular systematics and cladistics are remodeling some trees.
2. Biologists currently recognize a **three-domain system** consisting of
 - a. two domains of prokaryotes: Bacteria and Archaea
 - b. one domain of eukaryotes called Eukarya including fungi, plants, and animals.



Word Parts

analog- = proportion bi- = two clado- = branch -geny = origin -lite = a stone	macro- = large morph- = form mono- = one nom- = name paedo- = child	parsi- = few phylo- = tribe proto- = first stromato- = something spread out
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Vocabulary

1. **stromatolite-** Layered rocks that result from the activities of prokaryotes that bind thin films of sediment together.
2. **radiometric dating-** A method for determining the absolute ages of fossils and rocks, based on the half-life of radioactive isotopes.
3. **geologic record-** A time scale established by geologists that divides Earth's history into time periods, grouped into three eons— Archaean, Proterozoic, and Phanerozoic— and further subdivided into eras, periods, and epochs.
4. **plate tectonics-** The theory that the continents are part of great plates of Earth's crust that float on the hot, underlying portion of the mantle. Movements in the mantle cause the continents to move slowly over time.
5. **Pangaea-** The supercontinent consisting of all the major landmasses of Earth fused together. Continental drift formed Pangaea near the end of the Paleozoic era.

6. **phylogeny**- The evolutionary history of a species or group of related species.
7. **convergent evolution**- Adaptive change resulting in nonhomologous (analogous) similarities among organisms. Species from different evolutionary lineages come to resemble each as a result of living in very similar environments.
8. **analogy**- The similarity between two species that is due to convergent evolution rather than to descent from a common ancestor with the same trait.
9. **systematics**- A scientific discipline focused on classifying organisms and determining their evolutionary relationships.
10. **taxonomy**- The branch of biology that identifies, names, and classifies species.
11. **binomial nomenclature**- A two-part, Latinized name of a species; for example, *Homo sapiens*
12. **genus (plural, genera)**- In classification, the taxonomic category above species; the first part of a species' binomial; for example, Homo.
13. **kingdom**- In classification, the broad taxonomic category above phylum.
14. **domain**- A taxonomic category above the kingdom level. The three domains of life are Archaea, Bacteria, and Eukarya.
15. **taxon**- A name for any unit of a given level of classification.
16. **phylogenetic tree**- A branching diagram that represents a hypothesis about the evolutionary history of a group of organisms.
17. **cladistics**- An approach to systematics in which common descent is the primary criterion used to classify organisms by placing them into groups called clades.
18. **clade**- A group of species that includes an ancestral species and all its descendants.
19. **monophyletic**- Pertaining to a taxon derived from a single ancestral species that gave rise to no species in any other taxa.
20. **shared ancestral character** - A character, shared by members of a particular clade, that originated in an ancestor that is not a member of that clade.
21. **shared derived character**- An evolutionary novelty that is unique to a particular clade.
22. **outgroup**- In a cladistic study of evolutionary relationships among taxa of organisms, a taxon or group of taxa known to have diverged before the lineage that contains the group of species being studied.
23. **ingroup**- In a cladistic study of evolutionary relationships among taxa of organisms, the group of taxa that is actually being analyzed.
24. **parsimony**- In scientific studies, the search for the least complex explanation for an observed phenomenon.
25. **three-domain system**- The branch of biology that identifies, names, and classifies species.