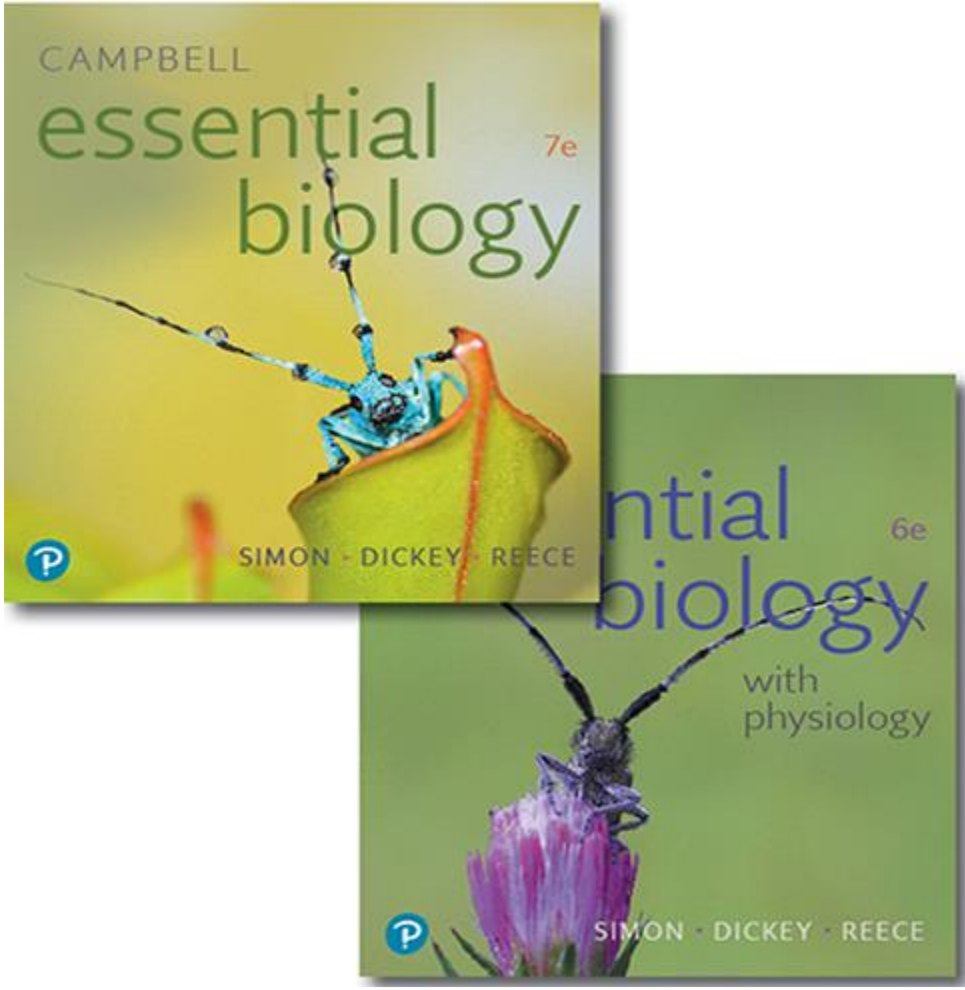
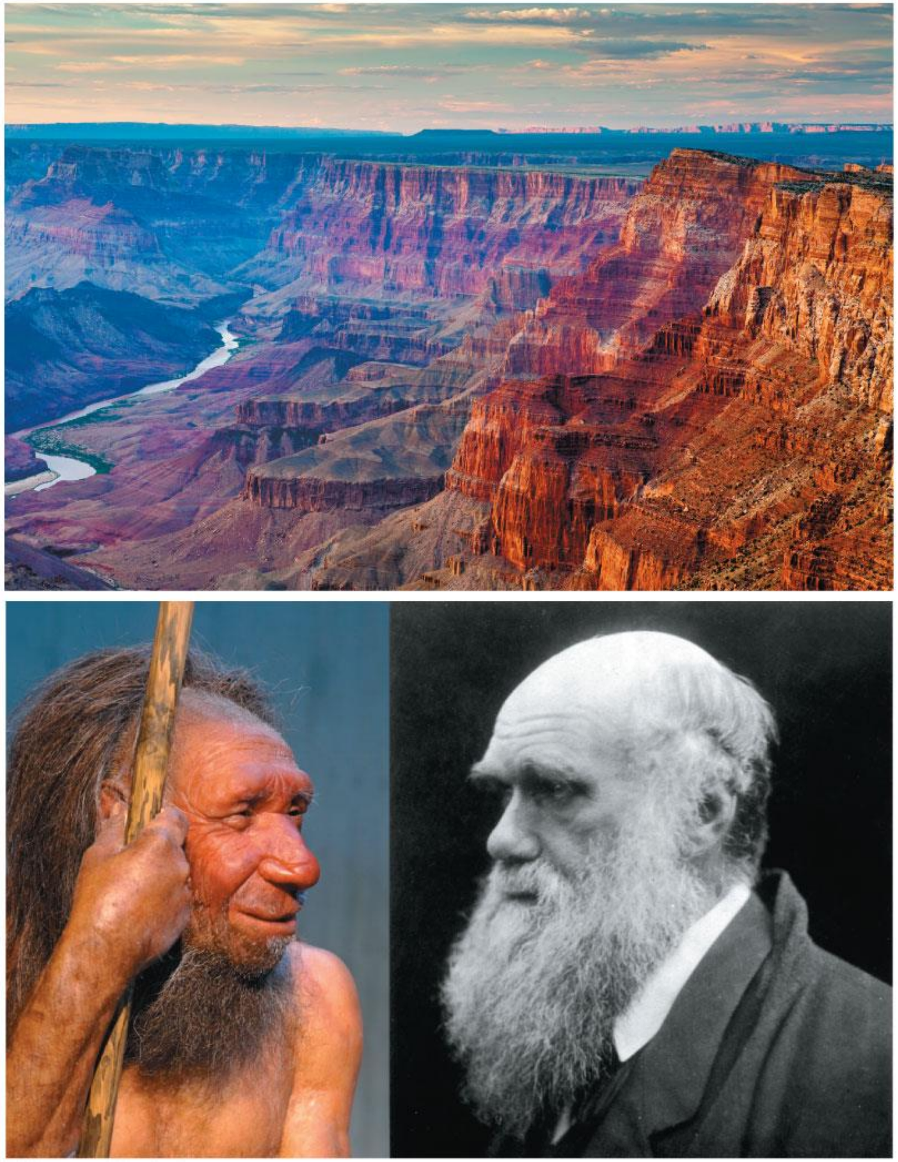
Chapter 14 Lecture



How Biological Diversity Evolves

PowerPoint® Lectures created by Edward J. Zalisko for
Campbell Essential Biology, **Seventh Edition, and**
Campbell Essential Biology with Physiology, **Sixth Edition**
– Eric J. Simon, Jean L. Dickey, and Jane B. Reece

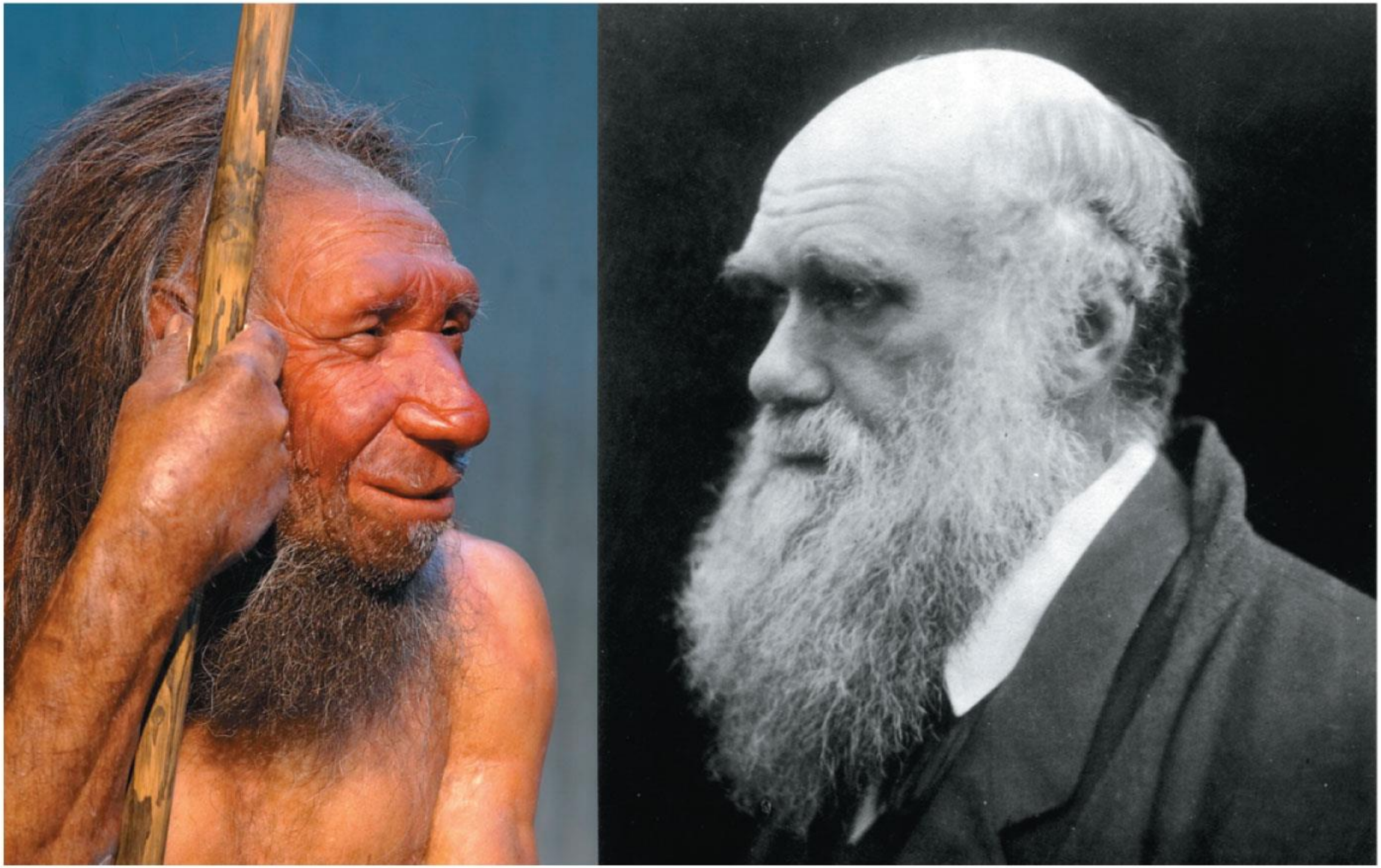
Why evolution matters



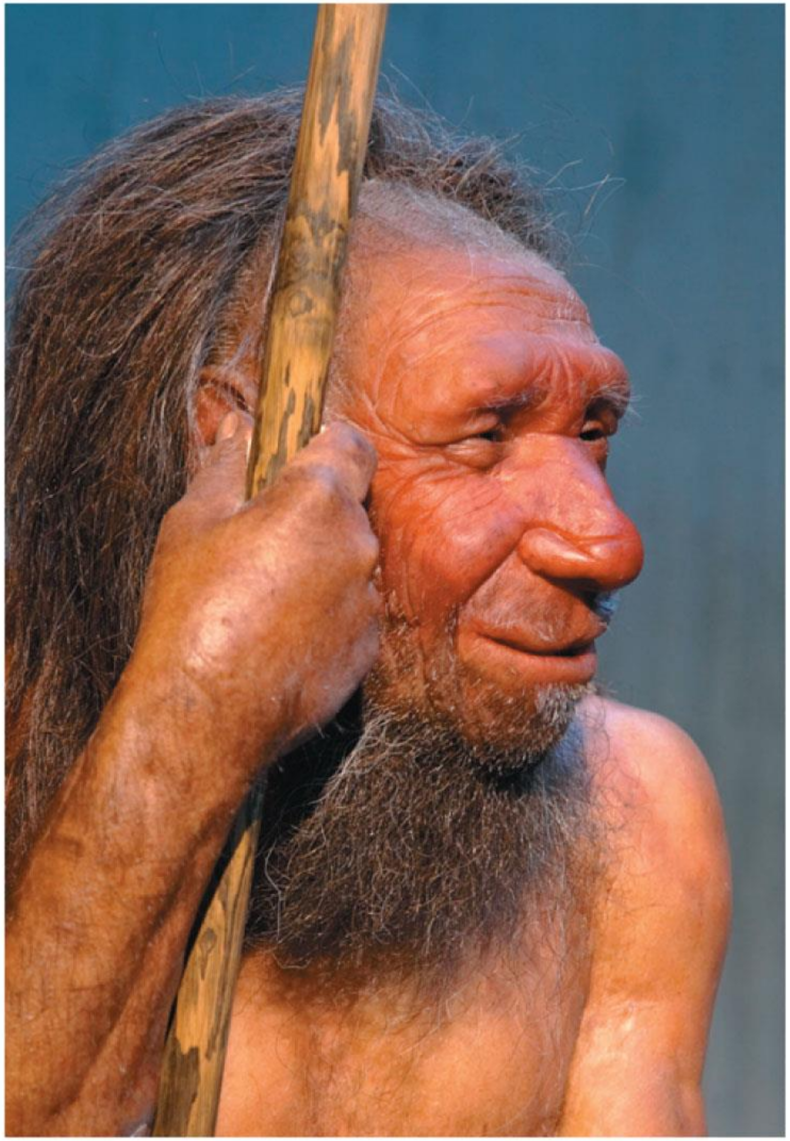
Why Evolution Matters

Why evolution matters (part 1: geologic history)

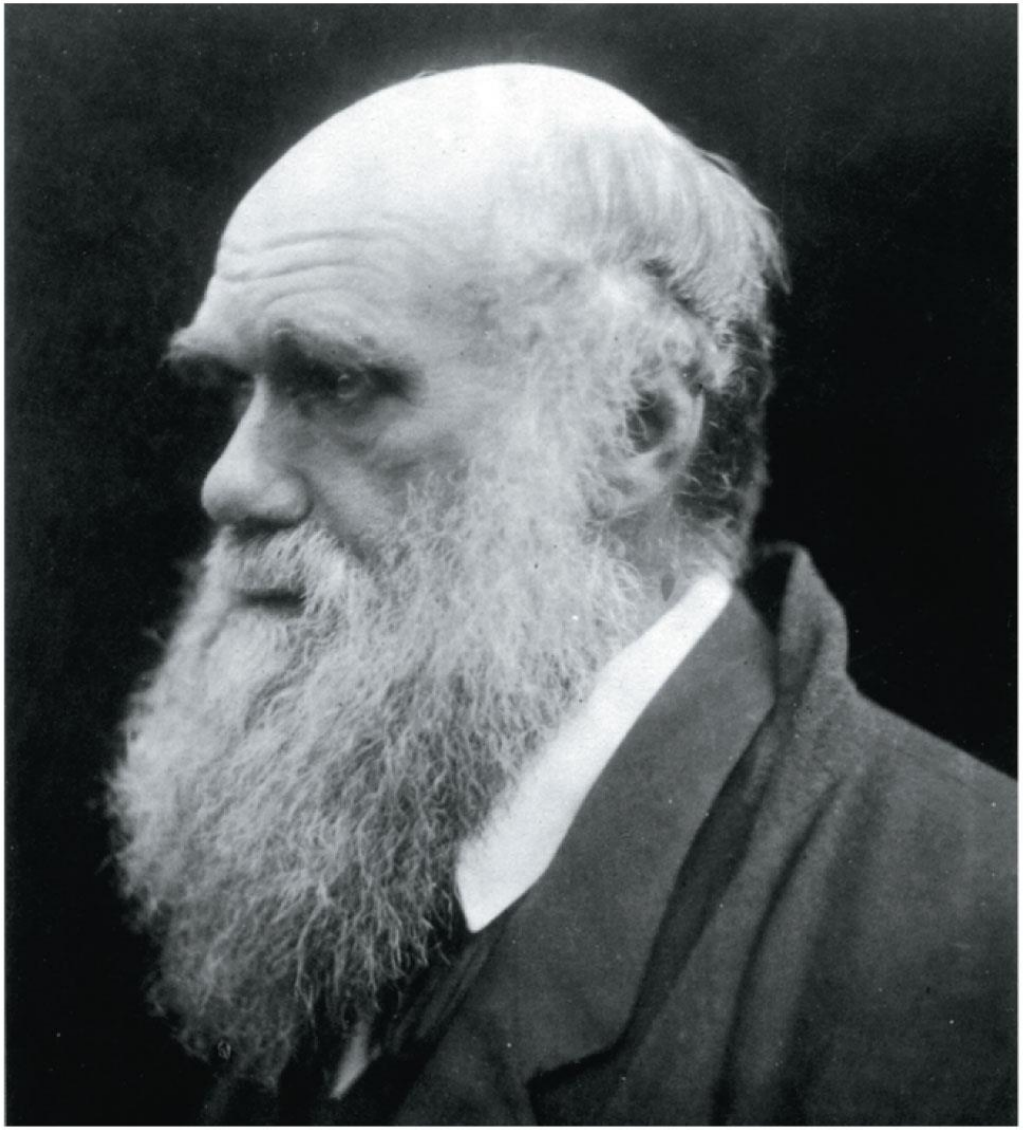
Why evolution matters (part 2: evolutionary history)



Why evolution matters (part 2a: evolutionary history, early man)



Why evolution matters (part 2b: evolutionary history, Darwin)



Why evolution matters (part 3: a better ear of corn)

If rocks could speak, what would they tell us? Several hundred million years of history is “written” in the layers of rock in the grand canyon

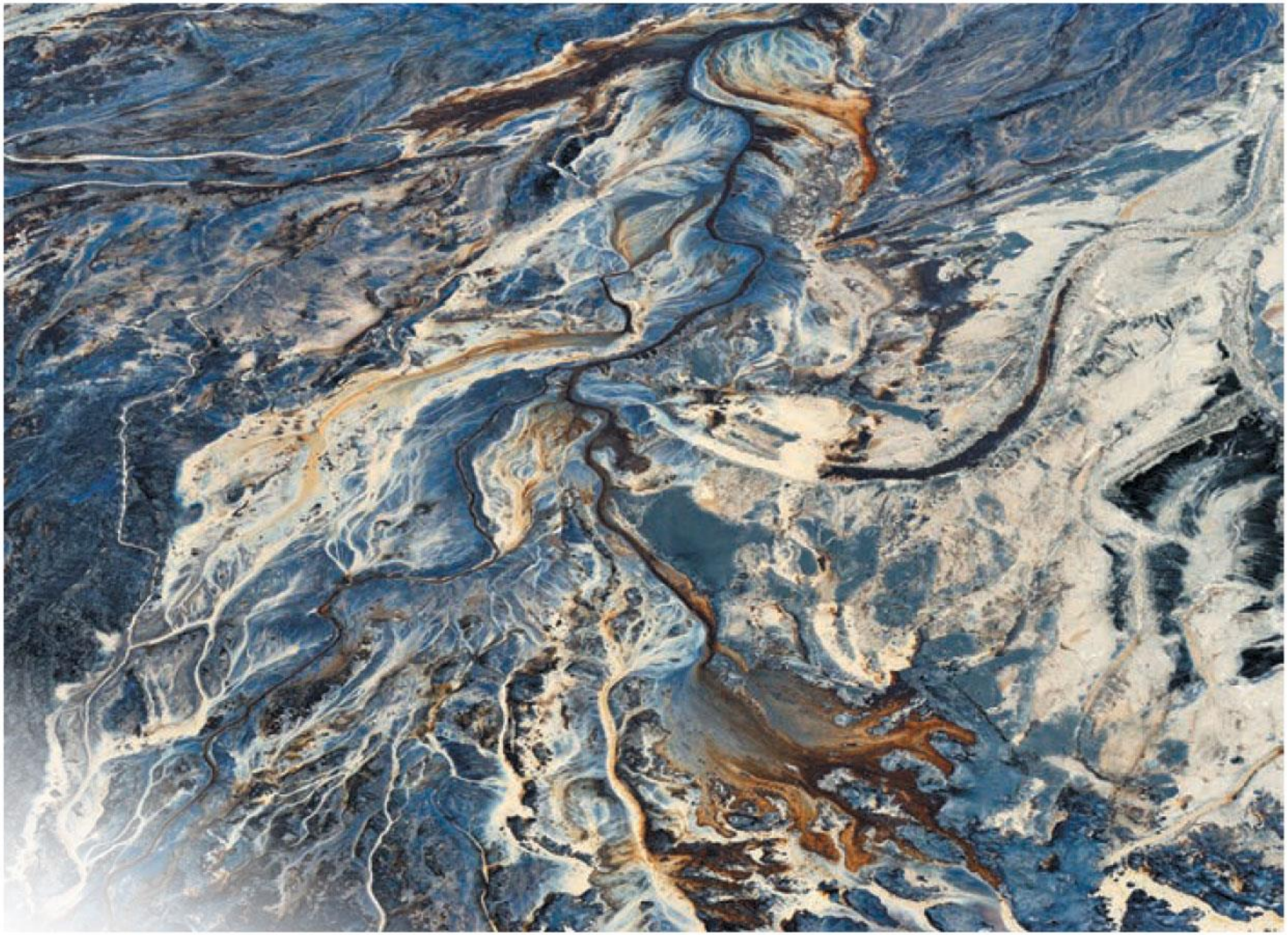
Biology and Society: Humanity’s Footprint

- Humanity has had an extraordinary effect on the ecology and geology of Earth.
- Our indelible footprint includes
  - the transport of organisms far from their natural homes,
  - the prevalence of agriculture and domesticated animals,
  - the existence of manufactured materials such as plastics and concrete,
  - radioactivity from testing nuclear weapons, and
  - climate-altering emissions from burning fossil fuels.

Biology and Society: Humanity’s Footprint

- The irreversibility of these changes has led some scientists to propose that a new epoch in Earth’s history has begun: the Anthropocene.
- The Anthropocene signals a significant shift in the geologic record that includes a high rate of extinction and accelerating change to Earth.
- Human-driven changes in the environment also bring about evolutionary change in populations of organisms, including pesticide-resistant insects and antibiotic-resistant bacteria.

Chapter Thread



Chapter Thread : Evolution in the Human–Dominated World

The Origin of Species

- In the 150 years since the publication of Darwin's book *On the Origin of Species by Means of Natural Selection*, new discoveries and technological advances have given scientists a wealth of new information about the evolution of life.
- The diversity of life evolved through **speciation**, the process in which one species splits into two or more species.

A marine iguana (right), an example of the unique species inhabiting the Galápagos

A marine iguana (right), an example of the unique species inhabiting the Galápagos (part 1: land-dwelling iguana)

A marine iguana (right), an example of the unique species inhabiting the Galápagos (part 2: marine iguana)

What Is a Species?

- *Species* is a Latin word meaning “kind” or “appearance.”
- The **biological species concept** defines a **species** as “a group of populations whose members have the potential to interbreed with one another in nature and produce fertile offspring (offspring that can reproduce).”
- The biological species concept cannot be applied in all situations, including asexual organisms and fossils.

The biological species concept is based on reproductive compatibility rather than physical similarity

Similarity between different species

Diversity within one species

The biological species concept is based on reproductive compatibility rather than physical similarity (part 1: different species)

Similarity between different species

The biological species concept is based on reproductive compatibility rather than physical similarity (part 2: one species)

Diversity within one species

What Is a Species?

- Biologists may also define a species
  - according to measurable physical traits,
  - solely on the basis of molecular data, a sort of bar code that identifies each species, or
  - as the smallest group of individuals sharing a common ancestor and forming one branch on the tree of life.

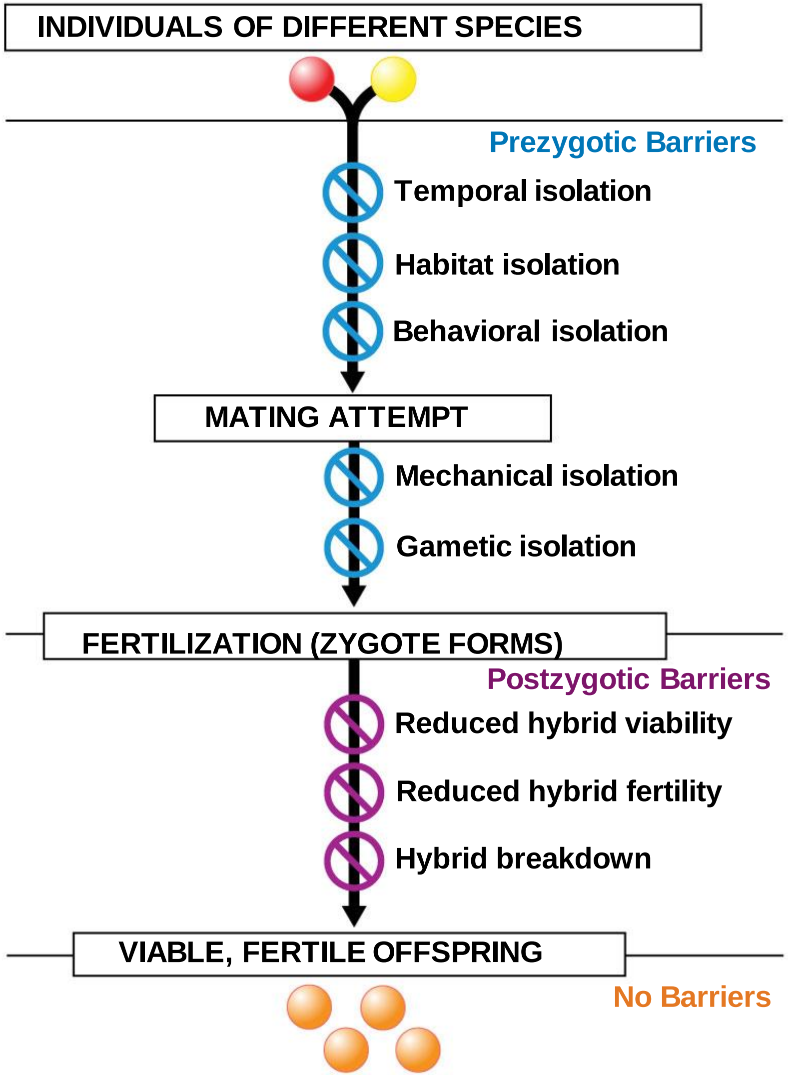
Checkpoint: According to the biological species concept, what defines a species?

Reproductive Barriers between Species

- A **reproductive barrier** is anything that prevents individuals of closely related species from interbreeding.
  - **Prezygotic barriers** prevent mating or fertilization between species.
  - **Postzygotic barriers** operate if
    - interspecies mating occurs and
    - hybrid zygotes form.

Checkpoint: Why is behavioral isolation considered a prezygotic barrier?

Reproductive barriers between closely related species



INDIVIDUALS OF DIFFERENT SPECIES

Prezygotic Barriers

Temporal isolation

Habitat isolation

Behavioral isolation

MATING ATTEMPT

Mechanical isolation

Gametic isolation

FERTILIZATION (ZYGOTE FORMS)

Postzygotic Barriers

Reduced hybrid viability

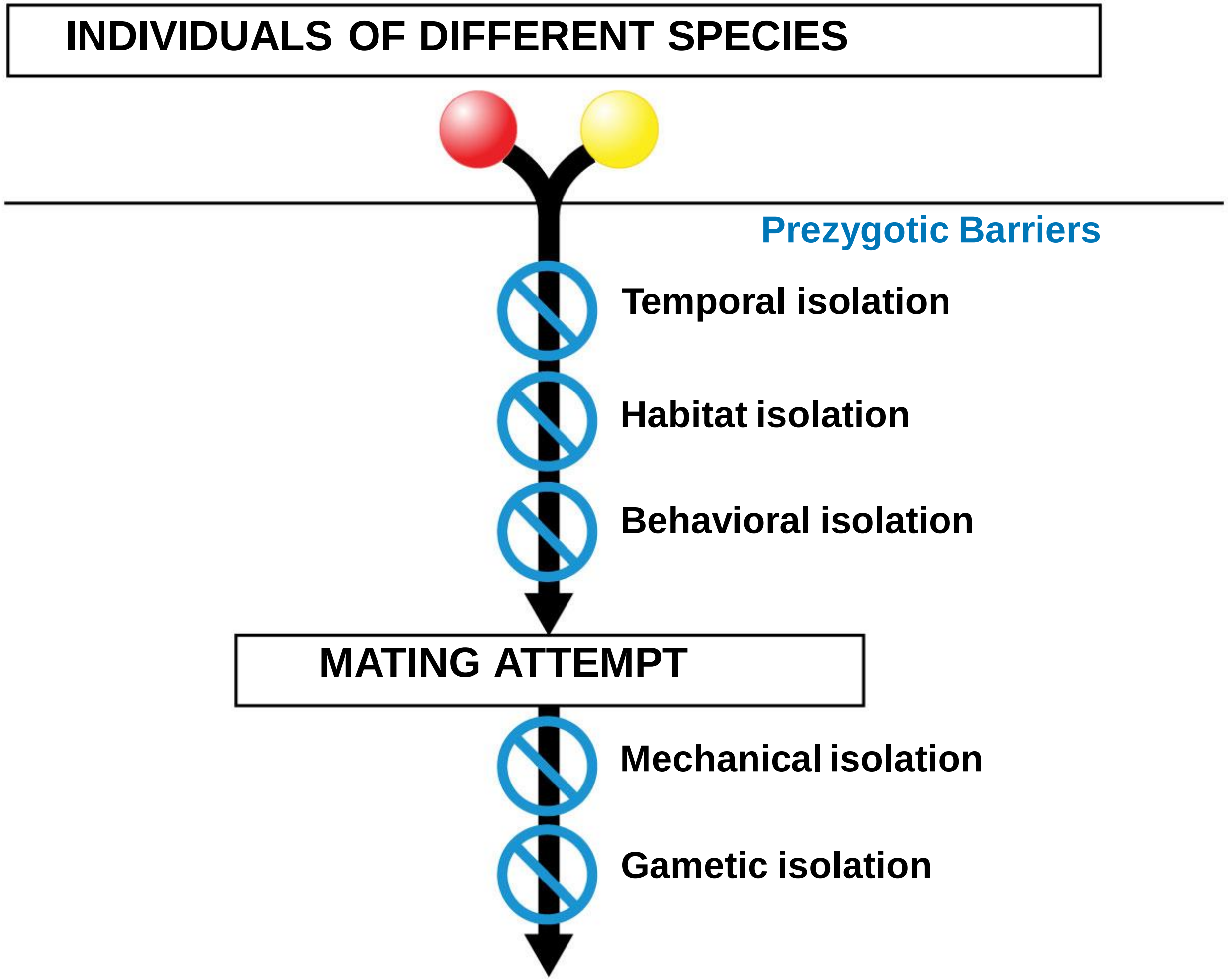
Reduced hybrid fertility

Hybrid breakdown

VIABLE, FERTILE OFFSPRING

No Barriers

Reproductive barriers between closely related species (part 1: prezygotic)



INDIVIDUALS OF DIFFERENT SPECIES

Prezygotic Barriers

Temporal isolation

Habitat isolation

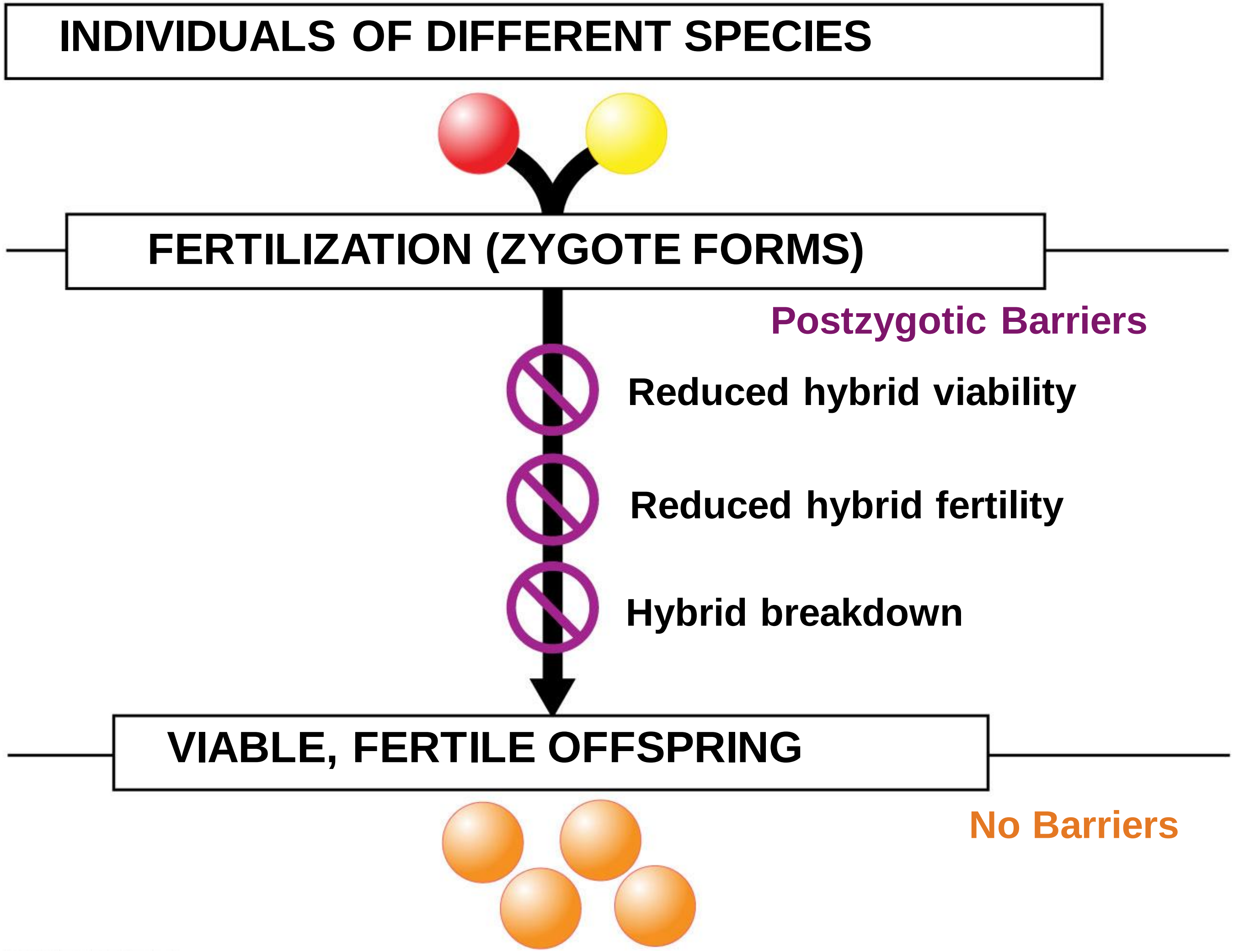
Behavioral isolation

MATING ATTEMPT

Mechanical isolation

Gametic isolation

Reproductive barriers between closely related species (part 2: postzygotic)



INDIVIDUALS OF DIFFERENT SPECIES

FERTILIZATION (ZYGOTE FORMS)

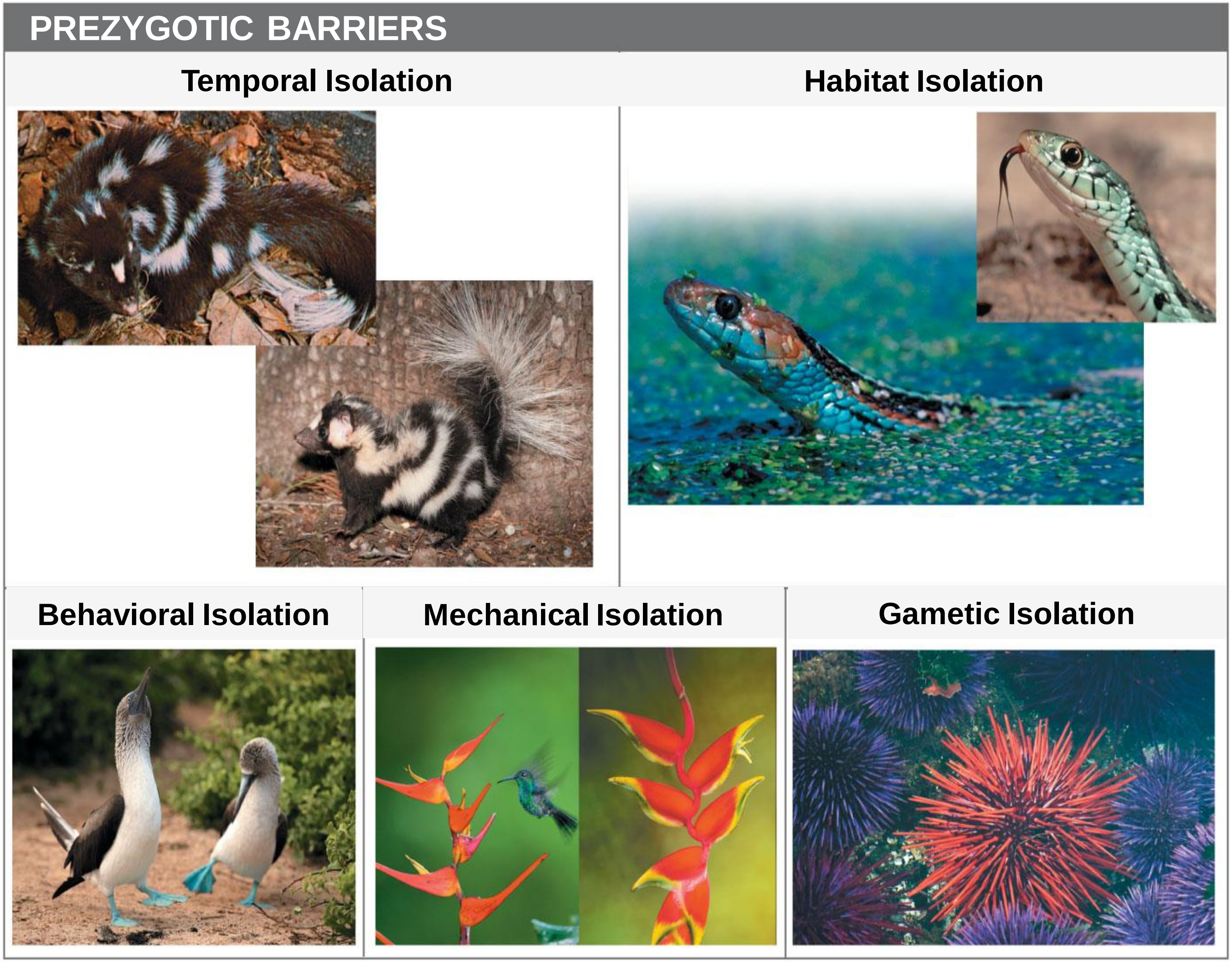
Postzygotic Barriers

- Reduced hybrid viability
- Reduced hybrid fertility
- Hybrid breakdown

VIABLE, FERTILE OFFSPRING

No Barriers

Prezygotic barriers



Prezygotic barriers (part 1: temporal Isolation)

Temporal Isolation

Skunk species that mate at different times

Prezygotic barriers (part 2: habitat Isolation)

Habitat Isolation

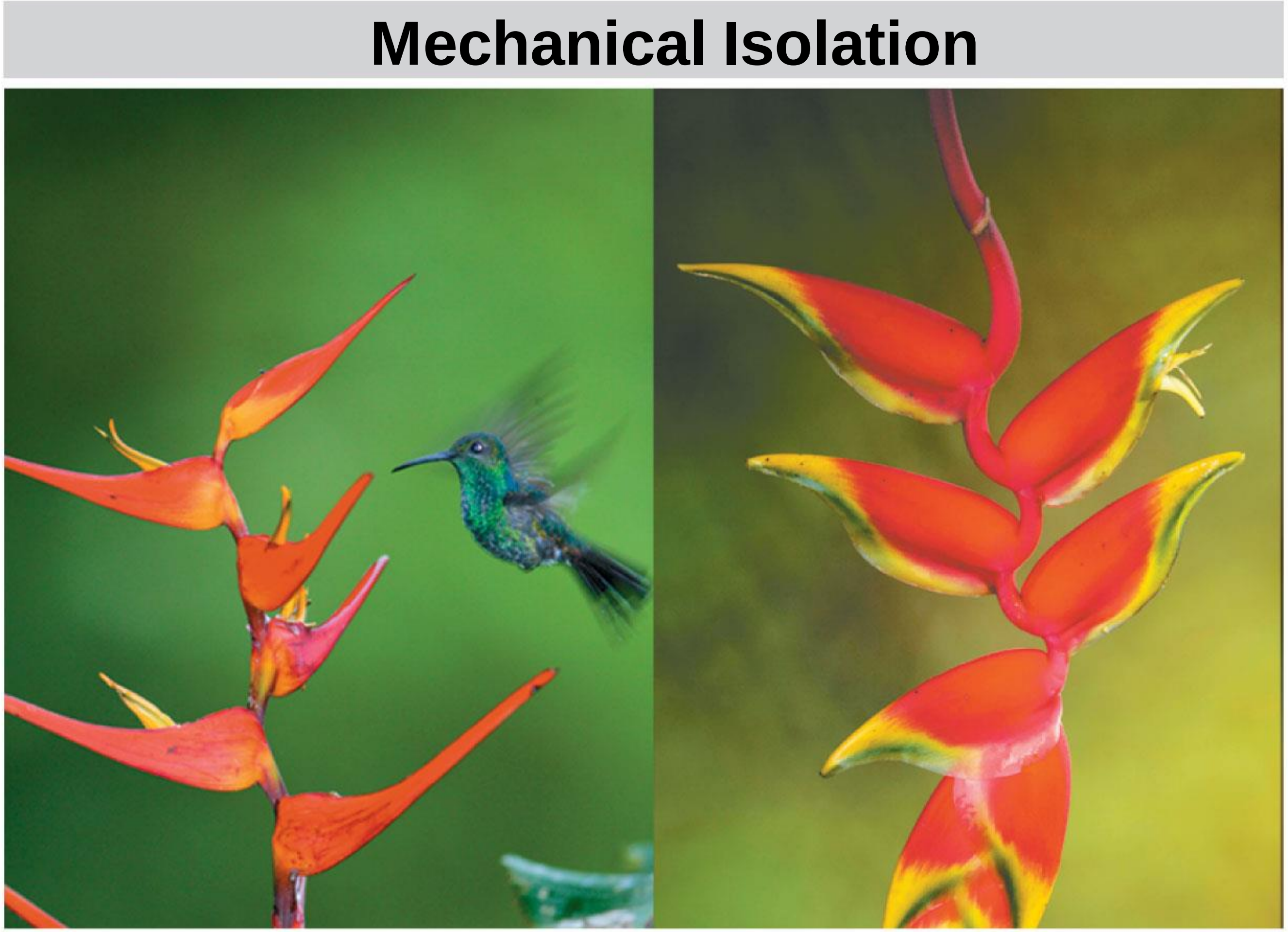
Garter snakes species from different habitats

Prezygotic barriers (part 1: Behavioral)

Behavioral Isolation

Mating ritual of blue-footed boobies

Prezygotic barriers (part 2: Mechanical)



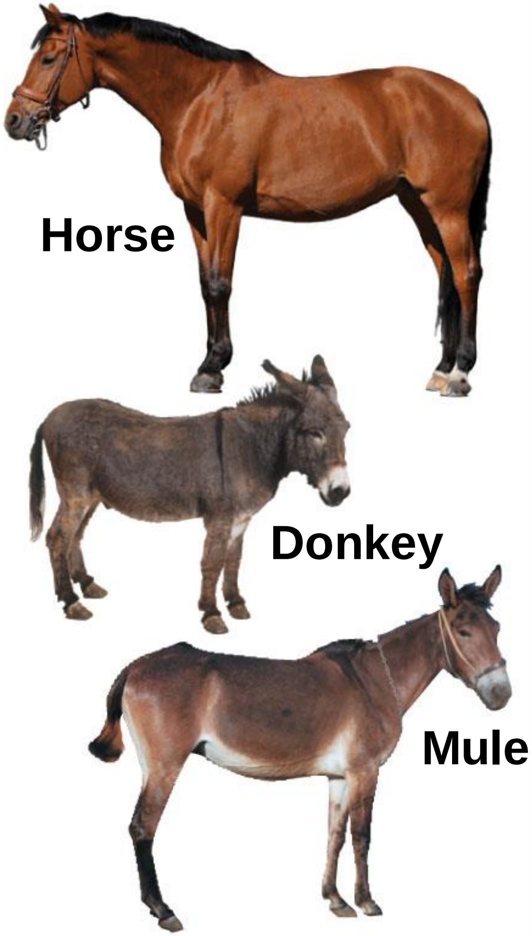
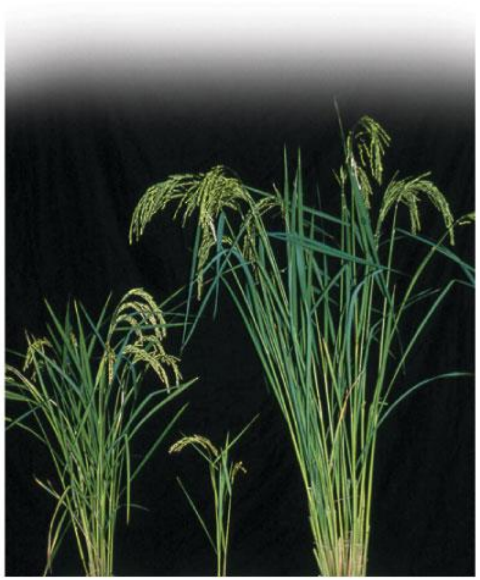
Hummingbird is compatible with the left flower but does not fit on the right flower

Prezygotic barriers (part 3: Gametic)

Gametic Isolation

Sea urchin species whose gametes cannot fuse

Postzygotic barriers

POSTZYGOTIC BARRIERS		
Reduced Hybrid Viability	**Reduced Hybrid Fertility**	**Hybrid Breakdown**
		

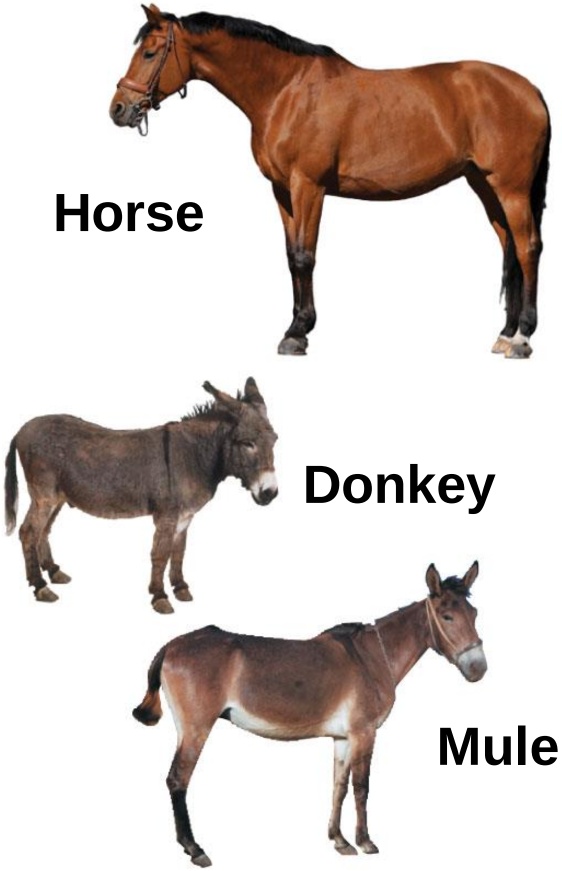
Postzygotic barriers (part 1: reduced hybrid viability)

Reduced Hybrid Viability

Frail hybrid salamander offspring

Postzygotic barriers (part 2: reduced hybrid fertility)

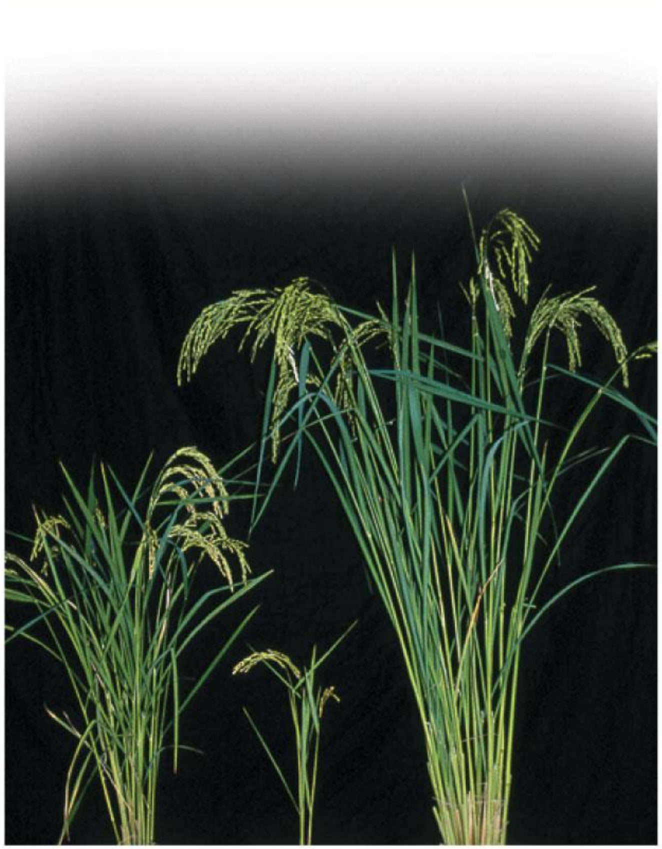
Reduced Hybrid Fertility



Mule (sterile hybrid of horse and donkey)

Postzygotic barriers (part 3: hybrid breakdown)

Hybrid Breakdown



Sterile next-generation rice hybrid

Video: Albatross Courtship Ritual

Video: Blue-footed Boobies Courtship Ritual

Video: Giraffe Courtship Ritual

Evolution: Mechanisms of Speciation

- A key event in the origin of a species occurs when a population is somehow cut off from other populations of the parent species.
- Species can form by
  - **allopatric speciation**, in which the initial block to gene flow is a geographic barrier that physically isolates the splinter population, or
  - **sympatric speciation**, without geographic isolation.

Allopatric Speciation

- A variety of geologic processes can isolate populations.
- Speciation occurs with the evolution of reproductive barriers between the isolated population and its parent population.
- Even if the two populations should come back into contact at some later time, the reproductive barriers will keep them as separate species.

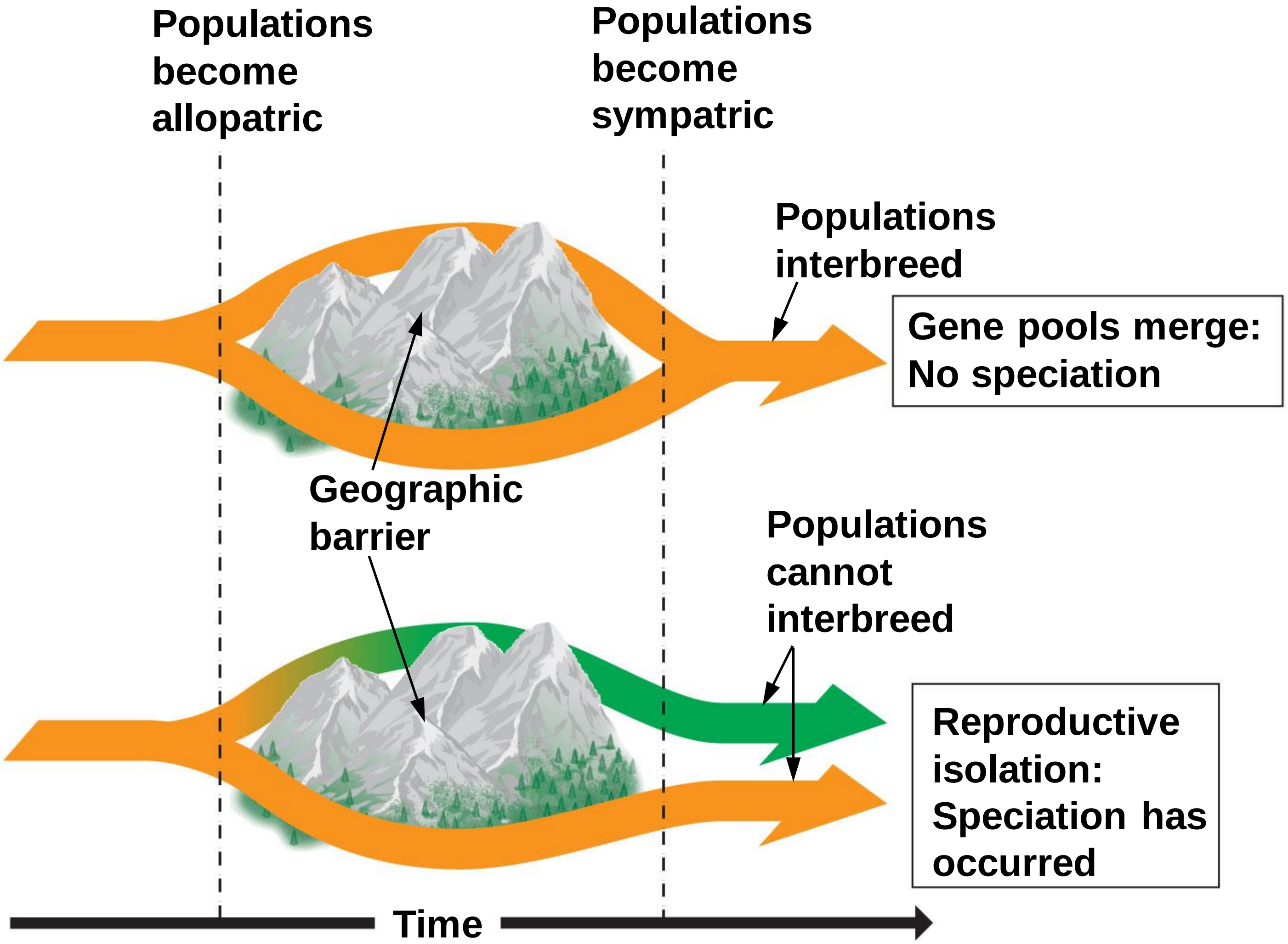
Checkpoint: What is necessary for allopatric speciation to occur?

Allopatric speciation of antelope squirrels on opposite rims of the Grand Canyon

Ammospermophilus harrisii

Ammospermophilus leucurus

Possible outcomes after geographic isolation of populations



Populations become allopatric

Populations become sympatric

Populations interbreed

Gene pools merge: No speciation

Geographic barrier

Populations cannot interbreed

Reproductive isolation: Speciation has occurred

Time

Video: Grand Canyon

Sympatric Speciation

- In sympatric speciation, a new species arises within the same geographic area as its parent species.
- Factors that can reduce gene flow in sympatric populations include
  - **polyploidy**, in which a species may originate from an accident during cell division that results in an extra set of chromosomes,
  - habitat complexity, and
  - sexual selection.

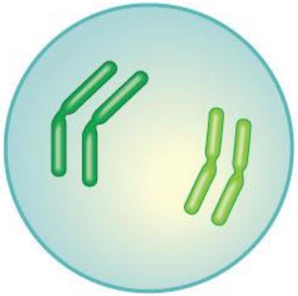
Sympatric Speciation

- Two distinct forms of polyploid speciation have been observed.
    1. In one form, polyploidy arises from a single parent species. A failure of cell division might double the chromosome number from the original diploid number ($2n$) to tetraploid ($4n$).
    2. A second form of polyploid speciation can occur when two different species interbreed and produce hybrid offspring.
- Many of the plant species we grow for food are polyploids, including oats, potatoes, bananas, strawberries, peanuts, apples, sugarcane, and wheat.

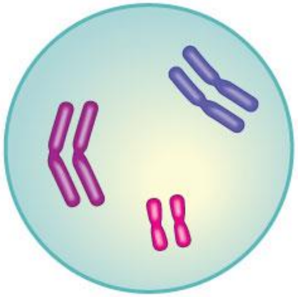
Gray tree frog

Chinese hibiscus

Sympatric speciation in a plant (step 1)

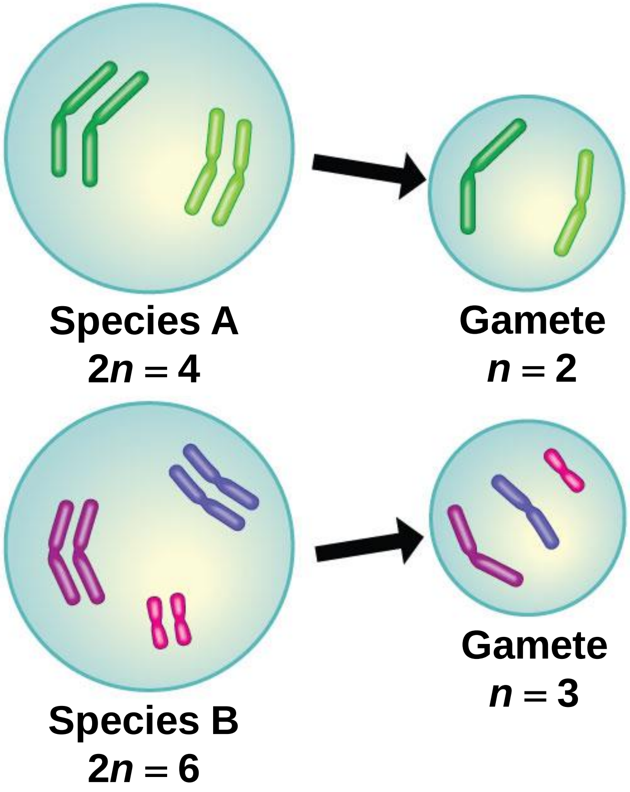


Species A
$2n = 4$



Species B
$2n = 6$

Sympatric speciation in a plant (step 2)

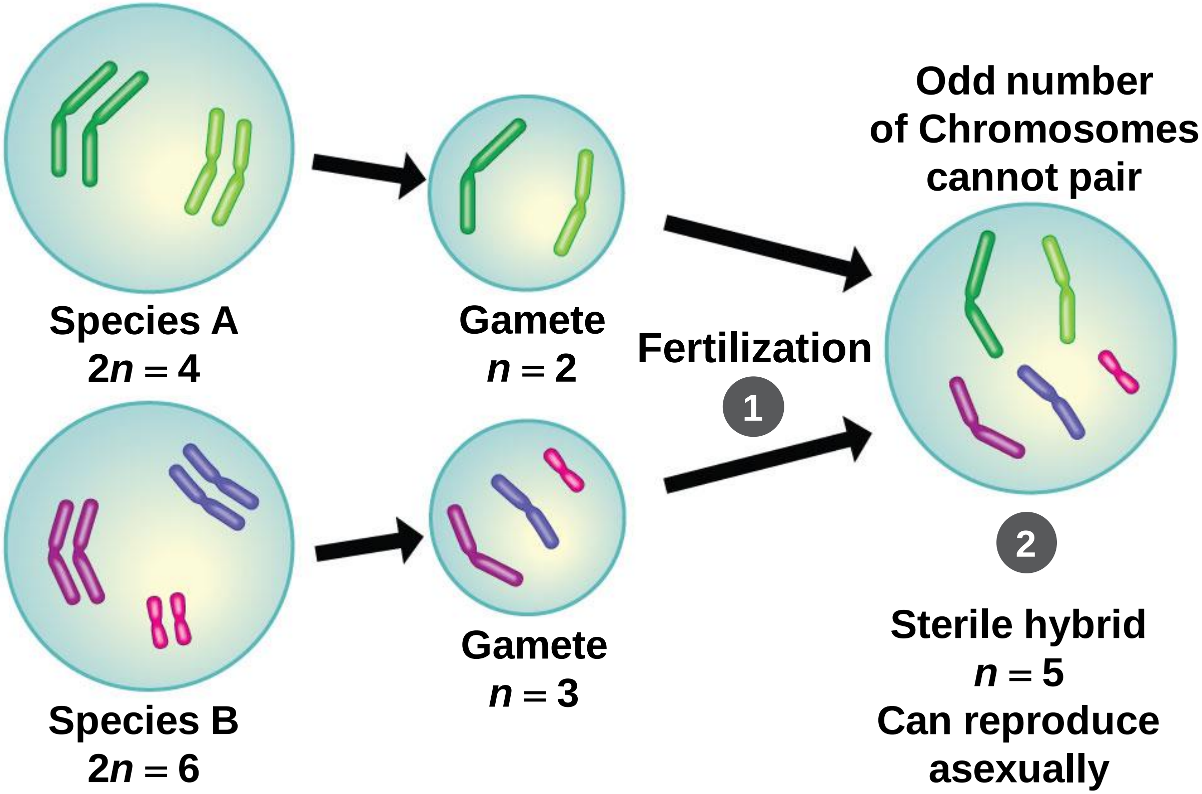

Species A
$2n = 4$

Gamete
$n = 2$

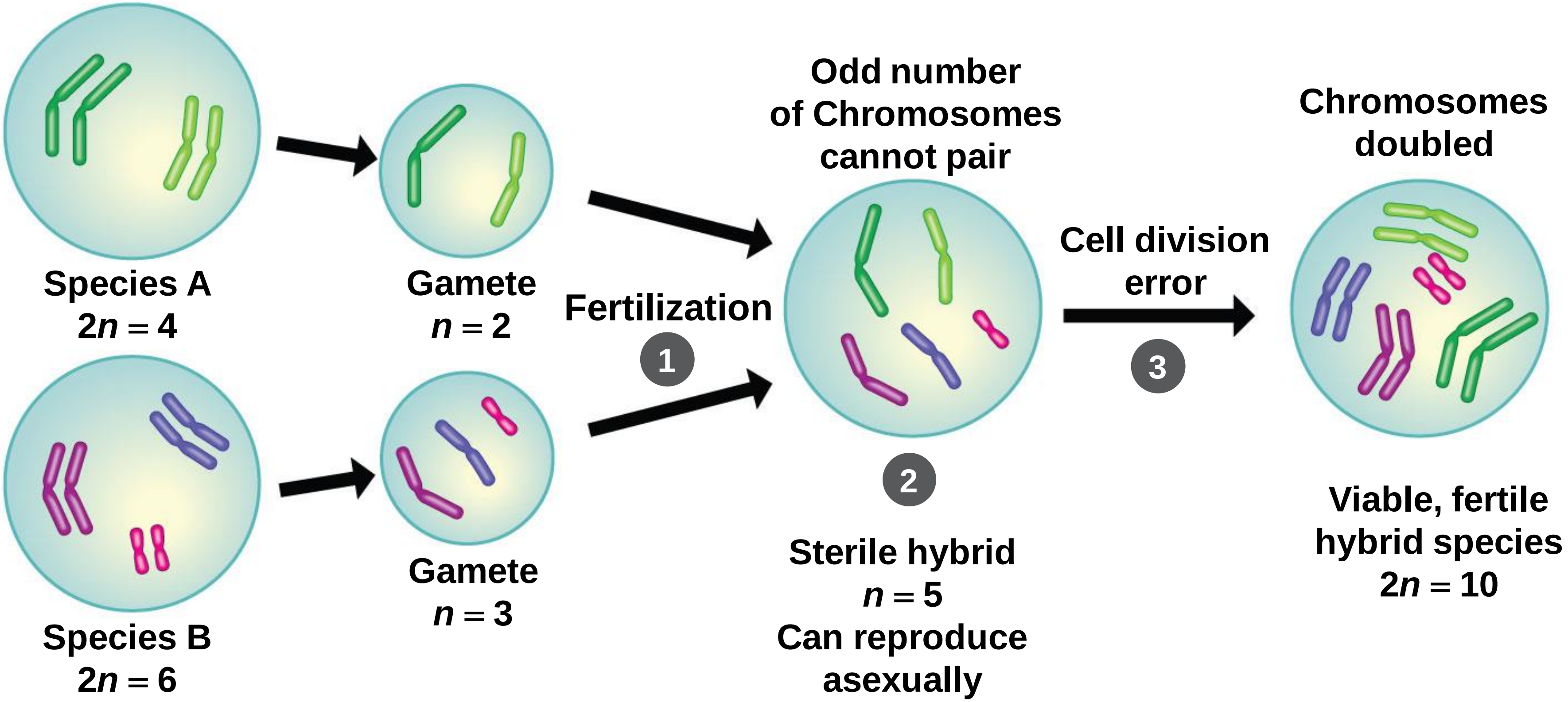
Species B
$2n = 6$

Gamete
$n = 3$

Sympatric speciation in a plant (step 3)



Sympatric speciation in a plant (step 4)



The Process of Science: Do Human Activities Facilitate Speciation?

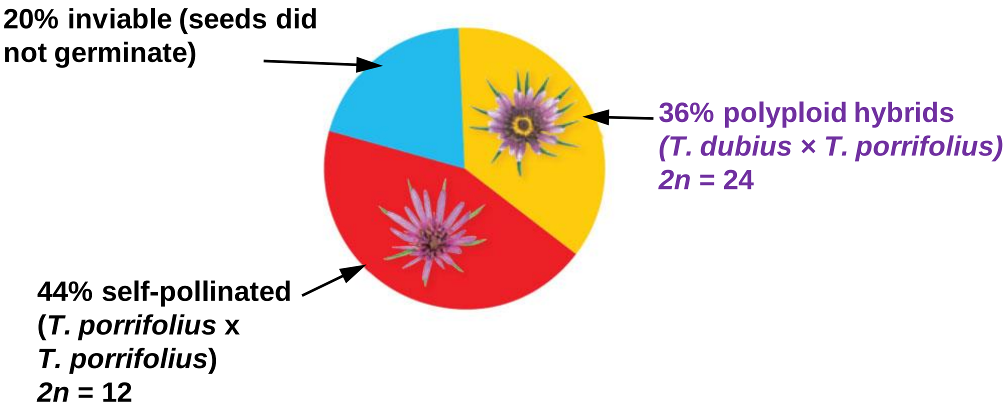
- **Background**: As humans travel the world, we often transport plants, animals, and other organisms to regions beyond their natural range.
- These activities create opportunities for hybridization that would not otherwise exist.
- Fifty years after the introduction of the plant goatsbeard (a weedy member of the daisy family) to the United States, a botanist discovered that hybridization had produced two new species.

The Process of Science: Do Human Activities Facilitate Speciation?

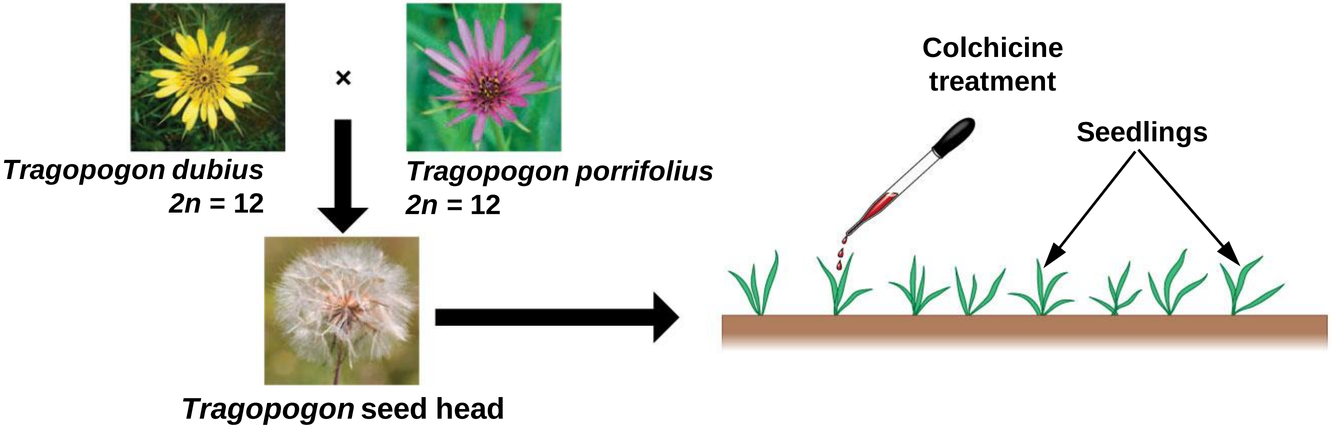
- **Method**: Researchers conducted tests to determine how one new species (*Tragopogon mirus*) formed.
- **Results:** Results supported the hypothesis that *Tragopogon mirus* originated by polyploid speciation.

Testing a hypothesis about speciation

(a) Researchers hypothesized that a new species of goatbeard, *Tragopogon mirus*, was formed by polyploidy speciation.



(c) Polyploid plants resulting from the hybridization of *T. porrifolius* and *T. dubius* were consistent with the new species, *T. mirus*.

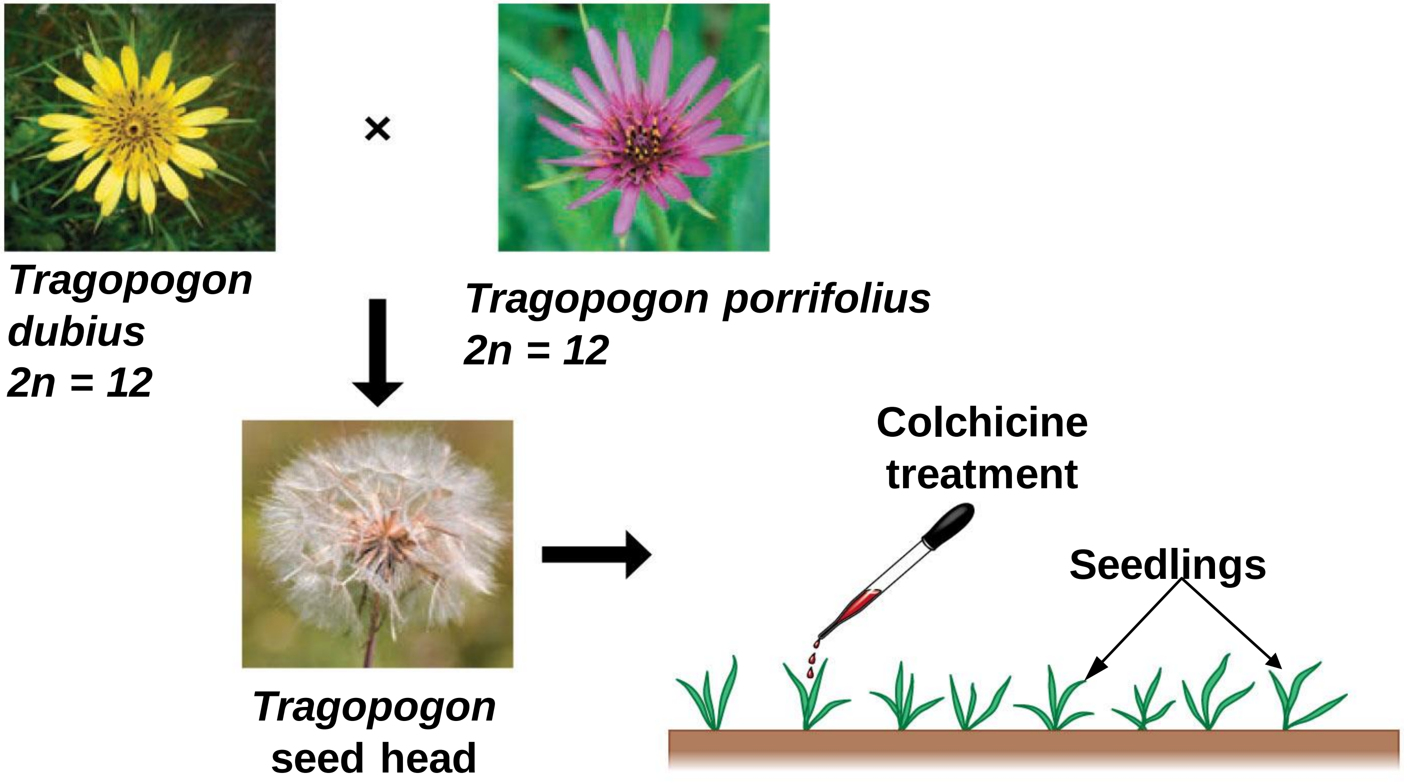


(b) After pollinating *Tragopogon porrifolius* with pollen from *T. dubius*, researchers collected and grew the seeds. Seedlings were treated with colchicine to encourage chromosome doubling.

Testing a hypothesis about speciation (part 1)

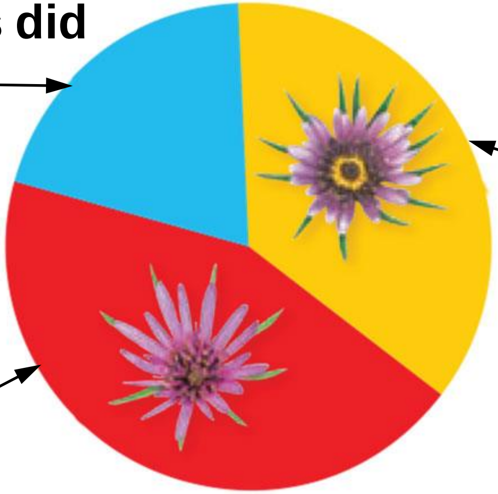
(a) Researchers hypothesized that a new species of goatbeard, *Tragopogon mirus*, was formed by polyploidy speciation.

Testing a hypothesis about speciation (part 2)



(b) After pollinating *Tragopogon porrifolius* with pollen from *T. dubius*, researchers collected and grew the seeds. Seedlings were treated with colchicine to encourage chromosome doubling.

Testing a hypothesis about speciation (part 3)



20% inviable (seeds did not germinate)

36% polyploid hybrids *(T. dubius* x *T. porrifolius)* *2n* = 24

44% self-pollinated (*T. porrifolius* x *T. porrifolius*) *2n* = 12

(c) Polyploid plants resulting from the hybridization of *T. porrifolius* and *T. dubius* were consistent with the new species, *T. mirus*.

Island Showcases of Speciation

- Volcanic islands, such as the Galápagos and Hawaiian island chains, are initially devoid of life.
  - Over time, colonists arrive via ocean currents or winds.
  - In their new environment, these populations may diverge significantly from their distant parent populations.
  - In addition, islands that have physically diverse habitats and that are far enough apart to permit populations to evolve in isolation but close enough to allow occasional dispersals to occur are often the sites of multiple speciation events.

Island Showcases of Speciation

- The Galápagos Islands are one of the world’s great showcases of speciation.
- For example, the islands have 14 species of closely related finches.
  - These birds share many finch-like traits, but they differ in their feeding habits, their habitats, and their beaks, which are specialized for what they eat.
  - The distinctive beaks adapted for the specific diets of the different species of finches are an example of the correlation between structure and function.

Galápagos finches with beaks adapted for specific diets

Cactus-seed-eater (cactus finch)

Insect-eater (warbler finch)

Tool-using insect-eater (woodpecker finch)

Galápagos finches with beaks adapted for specific diets (part 1: cactus finch)

Cactus-seed-eater (cactus finch)

Galápagos finches with beaks adapted for specific diets (part 2: woodpecker finch)

Tool-using insect-eater (woodpecker finch)

Galápagos finches with beaks adapted for specific diets (part 3: warbler finch)

Insect-eater (warbler finch)

Observing Speciation in Progress

- In contrast to microevolutionary change, which may be apparent within a few generations, the process of speciation is often extremely slow.
- But we can see speciation occurring.
- Researchers have documented at least two dozen cases in which populations are currently diverging as they
  - use different food resources or
  - breed in different habitats.

Observing Speciation in Progress

- Much of the evidence for evolution comes from the fossil record.
- In one survey of 84 groups of plants and animals, the time for speciation ranged from 4,000 to 40 million years.
- The cumulative effects of multiple speciations, as well as extinctions, have shaped the dramatic changes documented in the fossil record.

Earth History and Macroevolution

- **Macroevolution**
  - is evolutionary change above the species level and
  - includes the impact of mass extinctions on the diversity of life and the origin of key adaptations such as flight.
- An understanding of macroevolution begins with a look at the span of geologic time over which life's diversity has evolved.

The Fossil Record

- Fossils are evidence of organisms that lived in the past. The fossil record is the sequence in which fossils appear in rock strata and an archive of macroevolution.
- The **geologic time scale** divides Earth’s history into a consistent sequence of geologic periods.

Strata of sedimentary rock at the Grand Canyon

The Geologic Time Scale

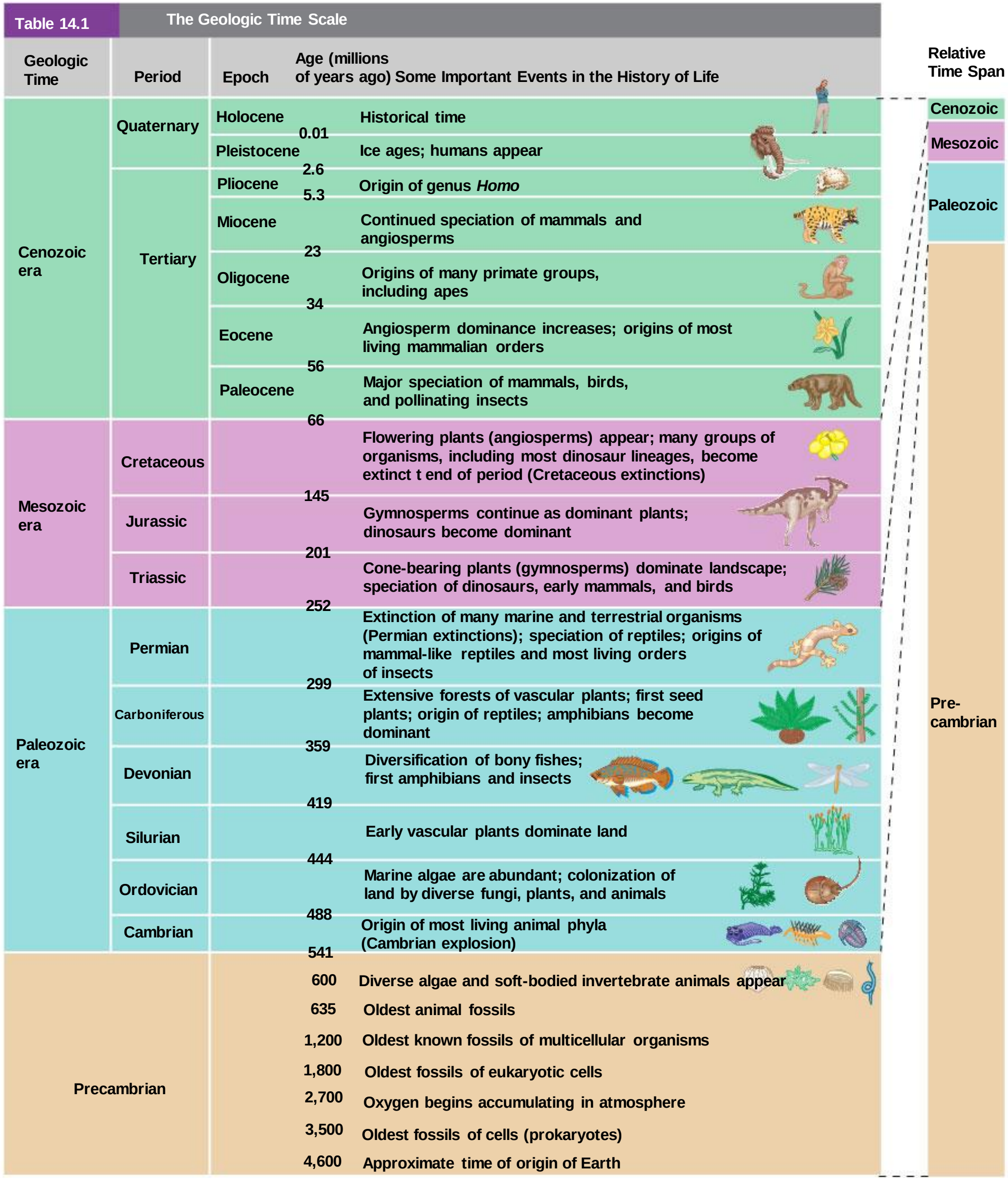


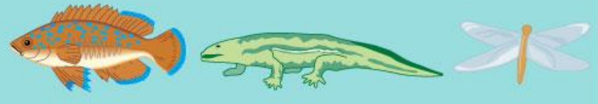
Table 14.1 The Geologic Time Scale

Geologic Time	Period	Epoch	Age (millions of years ago)	Some Important Events in the History of Life
Cenozoic era	Quaternary	Holocene	0.01	Historical time
		Pleistocene	2.6	Ice ages; humans appear
	Tertiary	Pliocene	5.3	Origin of genus *Homo*
		Miocene	23	Continued speciation of mammals and angiosperms
		Oligocene	34	Origins of many primate groups, including apes
		Eocene	56	Angiosperm dominance increases; origins of most living mammalian orders
		Paleocene	66	Major speciation of mammals, birds, and pollinating insects
Mesozoic era	Cretaceous		145	Flowering plants (angiosperms) appear; many groups of organisms, including most dinosaur lineages, become extinct t end of period (Cretaceous extinctions)
	Jurassic		201	Gymnosperms continue as dominant plants; dinosaurs become dominant
	Triassic		252	Cone-bearing plants (gymnosperms) dominate landscape; speciation of dinosaurs, early mammals, and birds
Paleozoic era	Permian		299	Extinction of many marine and terrestrial organisms (Permian extinctions); speciation of reptiles; origins of mammal-like reptiles and most living orders of insects
	Carboniferous		359	Extensive forests of vascular plants; first seed plants; origin of reptiles; amphibians become dominant
	Devonian		419	Diversification of bony fishes; first amphibians and insects
	Silurian		444	Early vascular plants dominate land
	Ordovician		488	Marine algae are abundant; colonization of land by diverse fungi, plants, and animals
	Cambrian		541	Origin of most living animal phyla (Cambrian explosion)
Precambrian			600	Diverse algae and soft-bodied invertebrate animals appear
			635	Oldest animal fossils
			1,200	Oldest known fossils of multicellular organisms
			1,800	Oldest fossils of eukaryotic cells
			2,700	Oxygen begins accumulating in atmosphere
			3,500	Oldest fossils of cells (prokaryotes)
			4,600	Approximate time of origin of Earth

The Geologic Time Scale (part 1: Precambrian)

Precambrian	**600**	**Diverse algae and soft-bodied invertebrate animals appear** 
	635	**Oldest animal fossils**
	1,200	**Oldest known fossils of multicellular organisms**
	1,800	**Oldest fossils of eukaryotic cells**
	2,700	**Oxygen begins accumulating in atmosphere**
	3,500	**Oldest fossils of cells (prokaryotes)**
	4,600	**Approximate time of origin of Earth**

The Geologic Time Scale (part 2: Paleozoic)

Paleozoic era	Permian	299	Extinction of many marine and terrestrial organisms (Permian extinctions); speciation of reptiles; origins of mammal-like reptiles and most living orders of insects	
	Carboniferous	359	Extensive forests of vascular plants; first seed plants; origin of reptiles; amphibians become dominant	
	Devonian	419	Diversification of bony fishes; first amphibians and insects	
	Silurian	444	Early vascular plants dominate land	
	Ordovician	488	Marine algae are abundant; colonization of land by diverse fungi, plants, and animals	
	Cambrian	541	Origin of most living animal phyla (Cambrian explosion)	

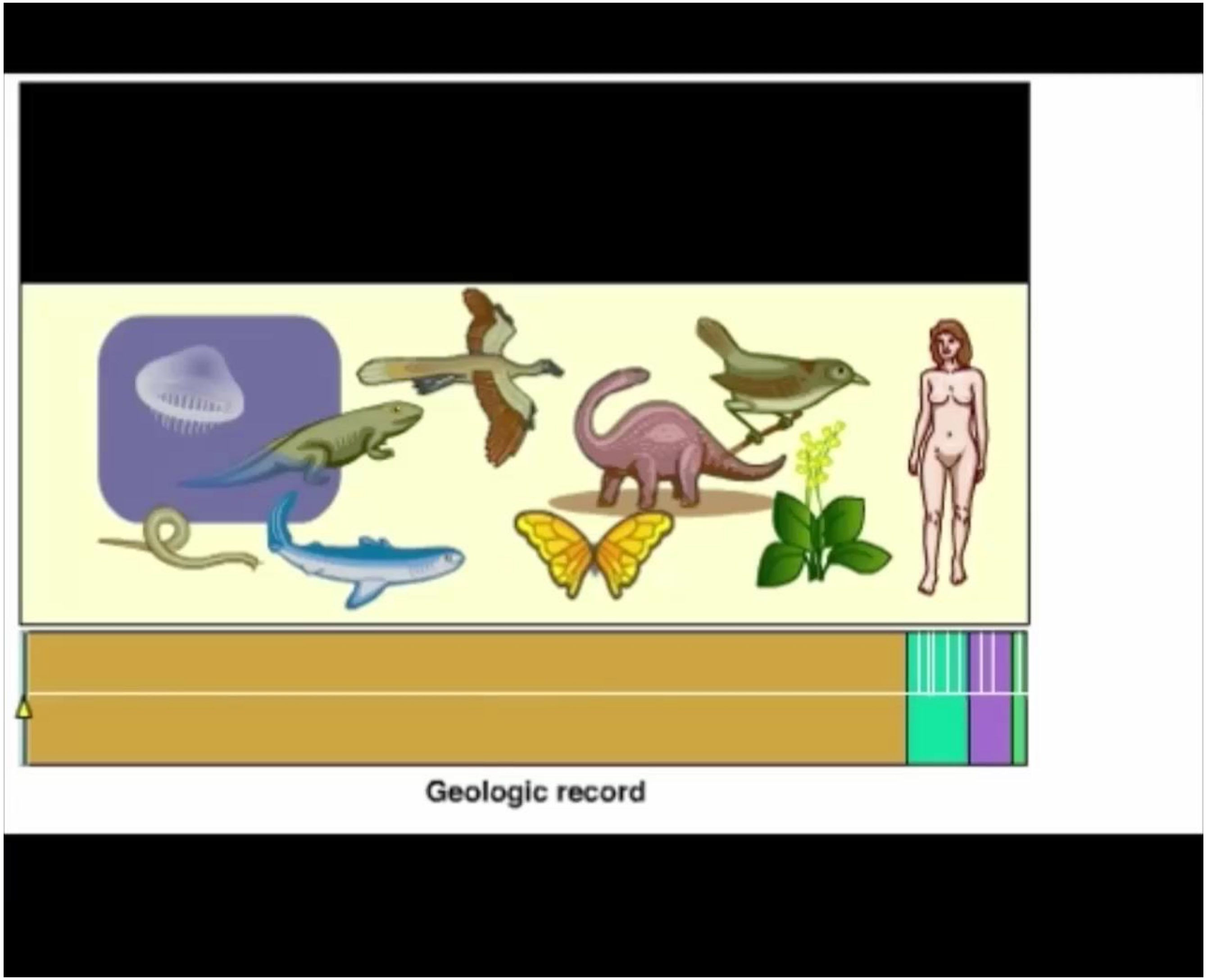
The Geologic Time Scale (part 3: Mesozoic)

Mesozoic era	Cretaceous	145	Flowering plants (angiosperms) appear; many groups of organisms, including most dinosaur lineages, become extinct at end of period (Cretaceous extinctions)	
	Jurassic	201	Gymnosperms continue as dominant plants; dinosaurs become dominant	
	Triassic	252	Cone-bearing plants (gymnosperms) dominate landscape; speciation of dinosaurs, early mammals, and birds	

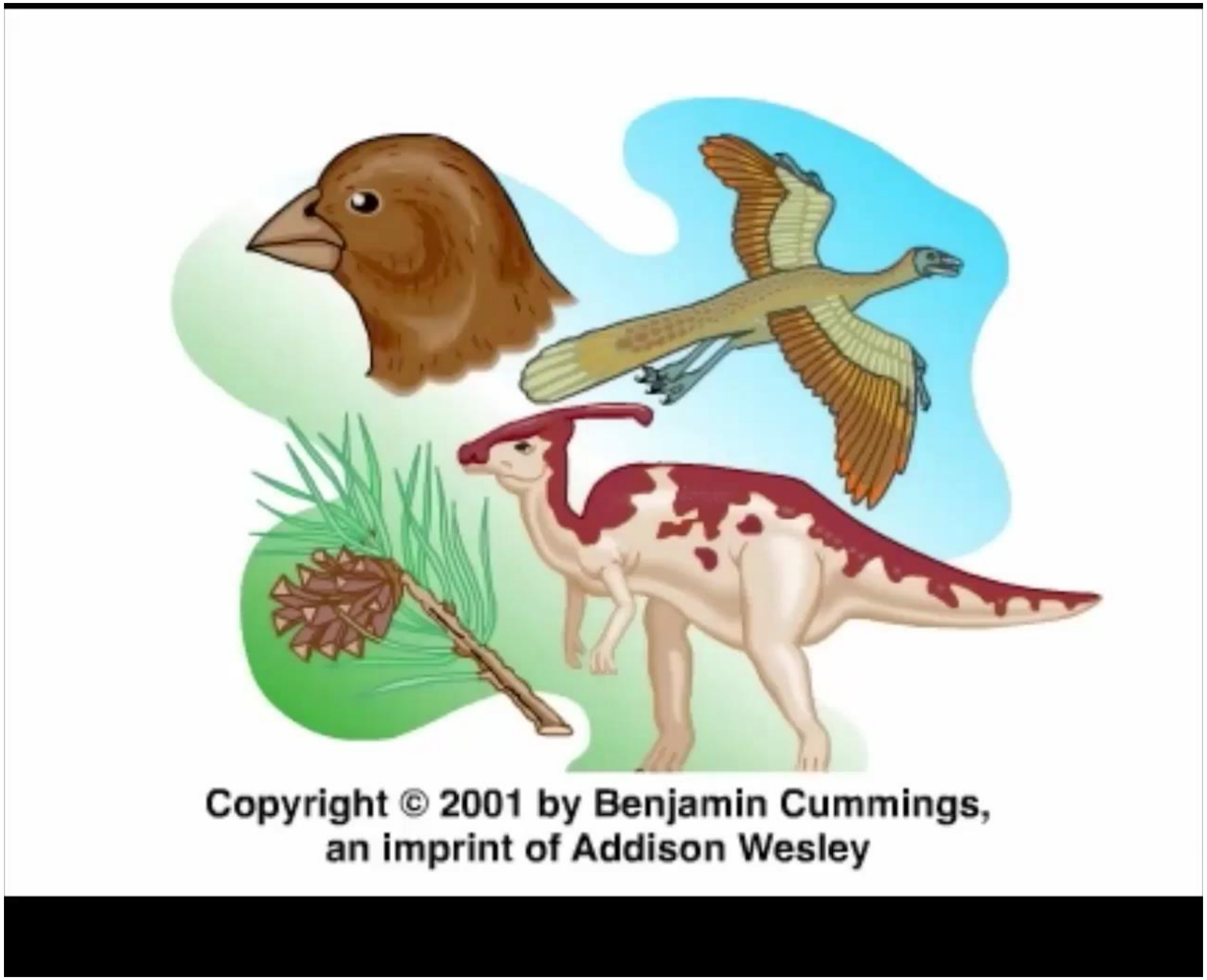
The Geologic Time Scale (part 4: Cenozoic)

Cenozoic era	Quaternary	Holocene	0.01	Historical time	
		Pleistocene	2.6	Ice ages; humans appear	
	Tertiary	Pliocene	5.3	Origin of genus *Homo*	
		Miocene	23	Continued speciation of mammals and angiosperms	
		Oligocene	34	Origins of many primate groups, including apes	
		Eocene	56	Angiosperm dominance increases; origins of most living mammalian orders	
		Paleocene	66	Major speciation of mammals, birds, and pollinating insects	

Animation: The Geologic Record



Animation: Macroevolution



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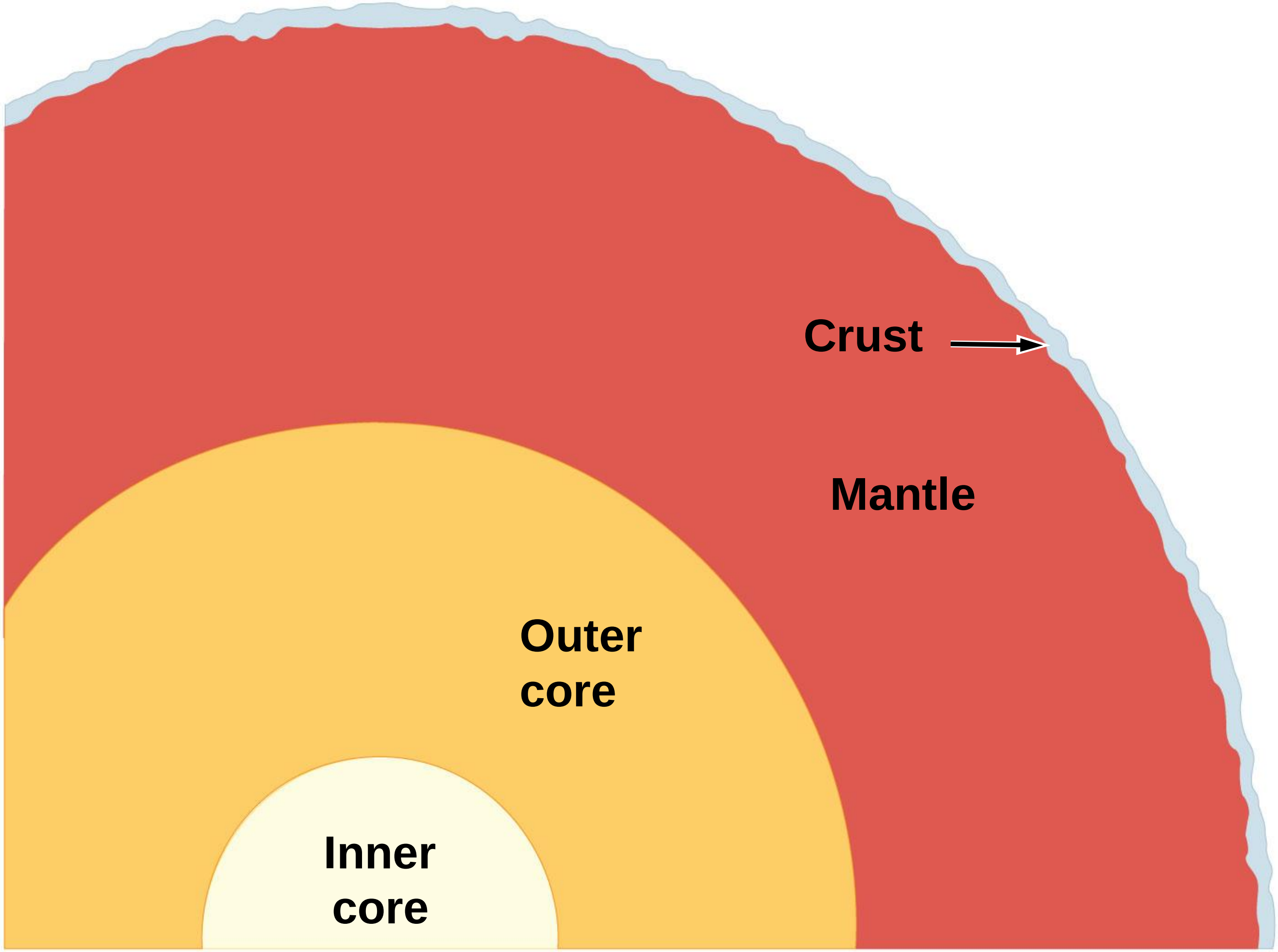
The Fossil Record

- The most common method geologists use to learn the ages of rocks and the fossils they contain is **radiometric dating**, a method based on the decay of radioactive isotopes.
- Another commonly used method is to date layers of volcanic rock or ash above and below the sedimentary layer in which fossils are found; by inference, the age of the fossils is between those two dates.

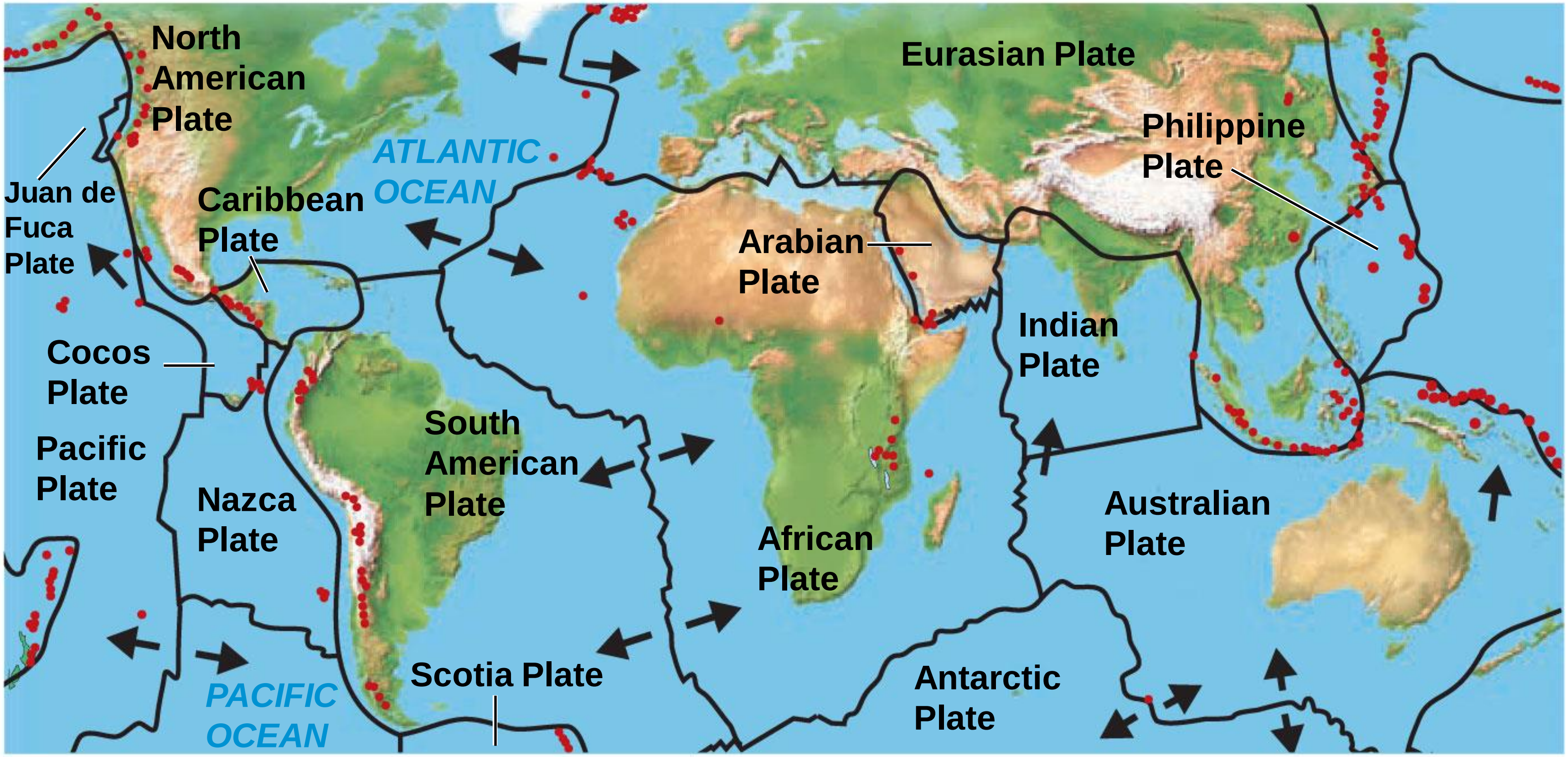
Plate Tectonics and Biogeography

- According to the theory of **plate tectonics**, the continents and seafloors form a thin outer layer of solid rock, called the crust, divided into giant, irregularly shaped plates that float atop the mantle, a mass of hot, viscous material.
- In a process called continental drift, movements in the mantle cause the plates to move.
  - The boundaries of some plates are hotspots of geologic activity.
  - Earthquakes signal that two plates are scraping past or colliding with each other.

Cutaway view of Earth



Earth’s tectonic plates

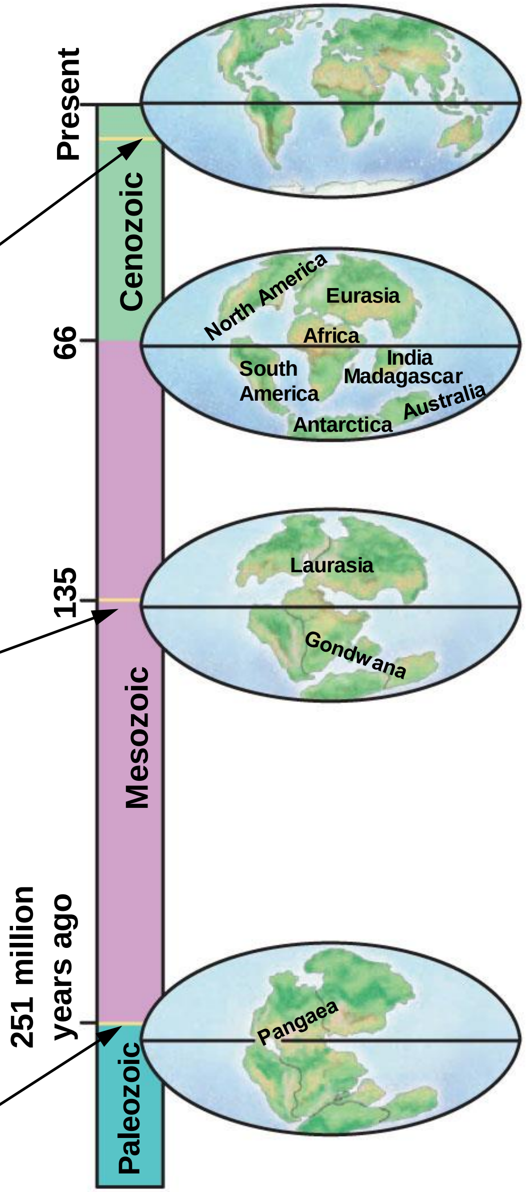


Key ● Zones of violent tectonic activity ↑ Direction of movement

Plate Tectonics and Biogeography

- Continental drift has had a tremendous impact on the evolution of life’s diversity by
  - reshaping the physical features of the planet and
  - altering the environments in which organisms live.
- About 250 million years ago, plate movements formed the supercontinent Pangaea,
  - reducing the total amount of shoreline,
  - deepening ocean basins, and
  - lowering sea levels.

The history of plate tectonics



India collides with Eurasia.

Pangaea splits into Laurasia and Gondwana.

Pangaea is formed.

Plate Tectonics and Biogeography

- The second dramatic chapter in the history of continental drift began during the mid-Mesozoic era.
  - Pangaea started to break up, causing geographic isolation of colossal proportions.
  - As the landmasses drifted apart, each continent became a separate evolutionary arena as its climates changed and its organisms diverged.

Plate Tectonics and Biogeography

- The history of continental mergers and separations explains patterns of **biogeography**, the study of the past and present distribution of organisms.
  - Continental drift also separated Australia from other landmasses.
  - Australia and its neighboring islands are home to more than 200 species of marsupials, most of which are found nowhere else in the world.

Checkpoint: If marsupials originated in Asia and reached Australia via South America, where else should paleontologists find fossil marsupials?

Australian marsupials

Sugar glider, an omnivore

Northern quoll, a carnivore

Koala, an herbivore

Australian marsupials (part 1: Northern quoll)

Northern quoll, a carnivore

Australian marsupials (part 2: sugar glider)

Sugar glider, an omnivore

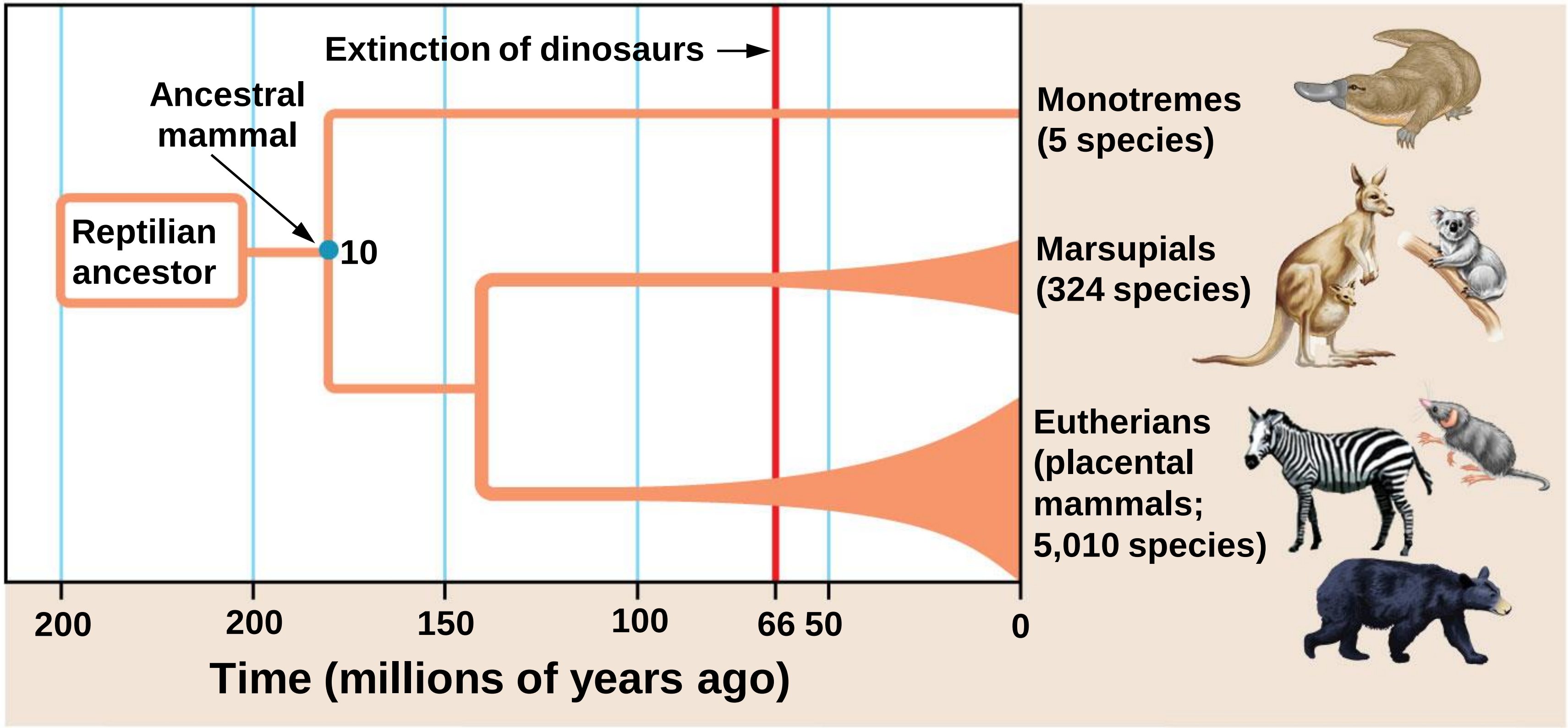
Australian marsupials (part 3: koala)

Koala, an herbivore

Mass Extinctions and Explosive Diversifications of Life

- The fossil record reveals five mass extinctions over the last 540 million years. In each of these events, 50% or more of Earth's species died out.
  - The Permian mass extinction, at about the time Pangaea formed, claimed about 96% of marine species and impacted terrestrial life as well.
  - The Cretaceous extinction occurred about 66 million years ago and included the extinction of all the dinosaurs except birds, permitting an explosive increase in diversity of mammals.
  - Extinctions seem to have provided the surviving organisms with new environmental opportunities.

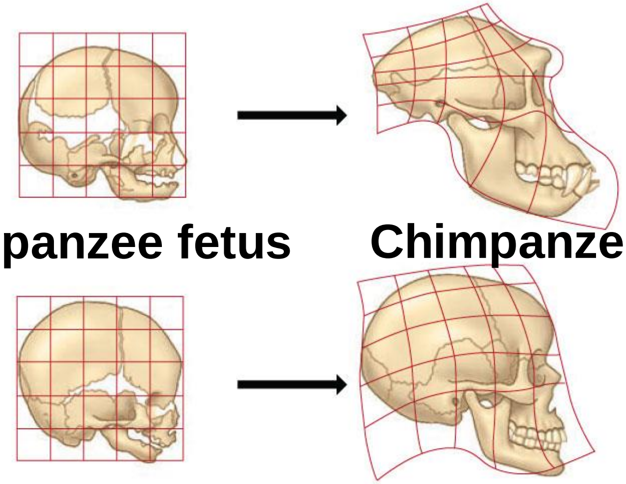
The diversification of mammals after the extinction of dinosaurs



Mechanisms of Macroevolution: Large Effects from Small Genetic Changes

- Scientists are increasingly able to explain the basic biological mechanisms of macroevolutionary changes seen in the fossil record.
  - Working at the interface of evolutionary biology and developmental biology (evo-devo) scientists are studying how slight changes in the flow of genetic information can become magnified into major structural differences among species.
  - Evolutionary transformations can result from genes that alter the rate, timing, and spatial pattern of changes in an organism’s form as it develops from a zygote into an adult.

Comparison of human and chimpanzee skull development



Chimpanzee fetus

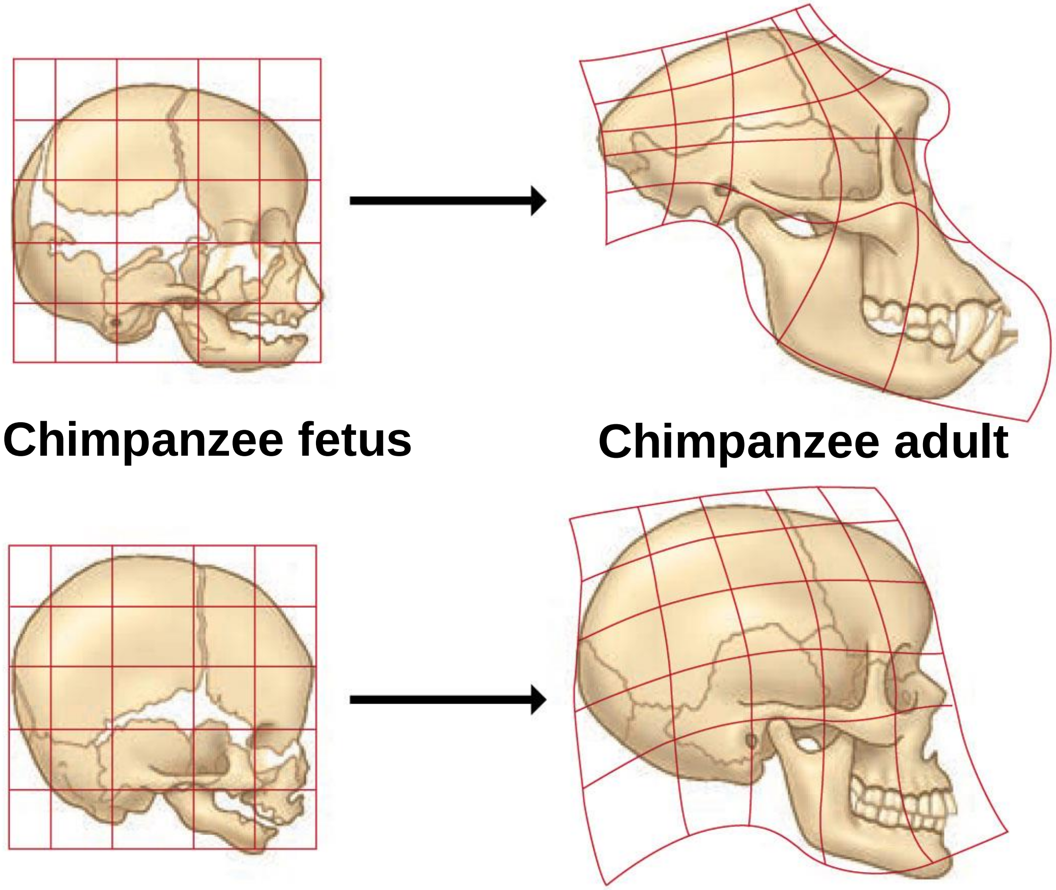
Chimpanzee adult

Human fetus

Human adult
(paedomorphic features)

Comparison of human and chimpanzee skull development (part 1: photo)

Comparison of human and chimpanzee skull development (part 2: detail)



Chimpanzee fetus

Chimpanzee adult

Human fetus

Human adult (paedomorphic features)

Identifying Major Themes

In the course of giraffe evolution, increased growth rates during development produced extra-long (11-inch) neck vertebrae.

Which major theme is illustrated by this action?

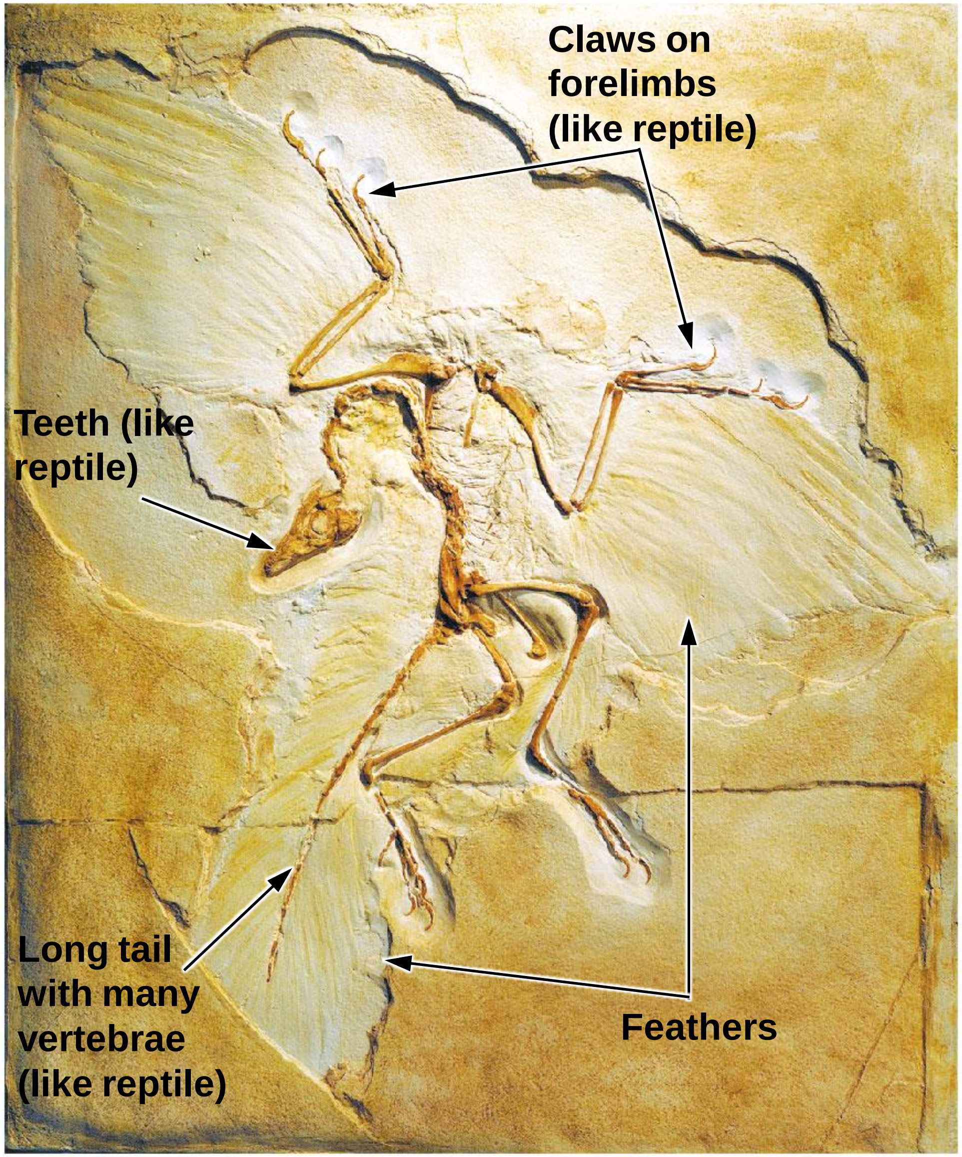
1) The relationship of structure to function
2) Information flow
3) Pathways that transform energy and matter
4) Interactions within biological systems
5) Evolution

The Evolution of Biological Novelty: Adaptation of Old Structures for New Functions

- The feathered flight of birds is a perfect marriage of structure and function. In flight, the shapes and arrangements of various feathers produce lift, smooth airflow, and help with steering and balance.

- How did such an intricate structure evolve?
  - Thousands of fossils of feathered dinosaurs have been found and classified into more than 30 different species.
  - But the feathers seen in these fossils could not have been used for flight. Their reptilian anatomy was not suited to flying.

An extinct bird



Structure/Function: Adaptation of Old Structures for New Functions

- The first utility of feathers may have been for insulation.
- Once flight itself became an advantage, natural selection would have gradually remodeled feathers and wings to fit their additional function.
- Structures such as feathers that evolve in one context but become co-opted for another function are called **exaptations**.

Identifying Major Themes

The thin membrane of skin stretched between the long “finger” bones of bats is an adaptation for flight.

Which major theme is illustrated by this action?

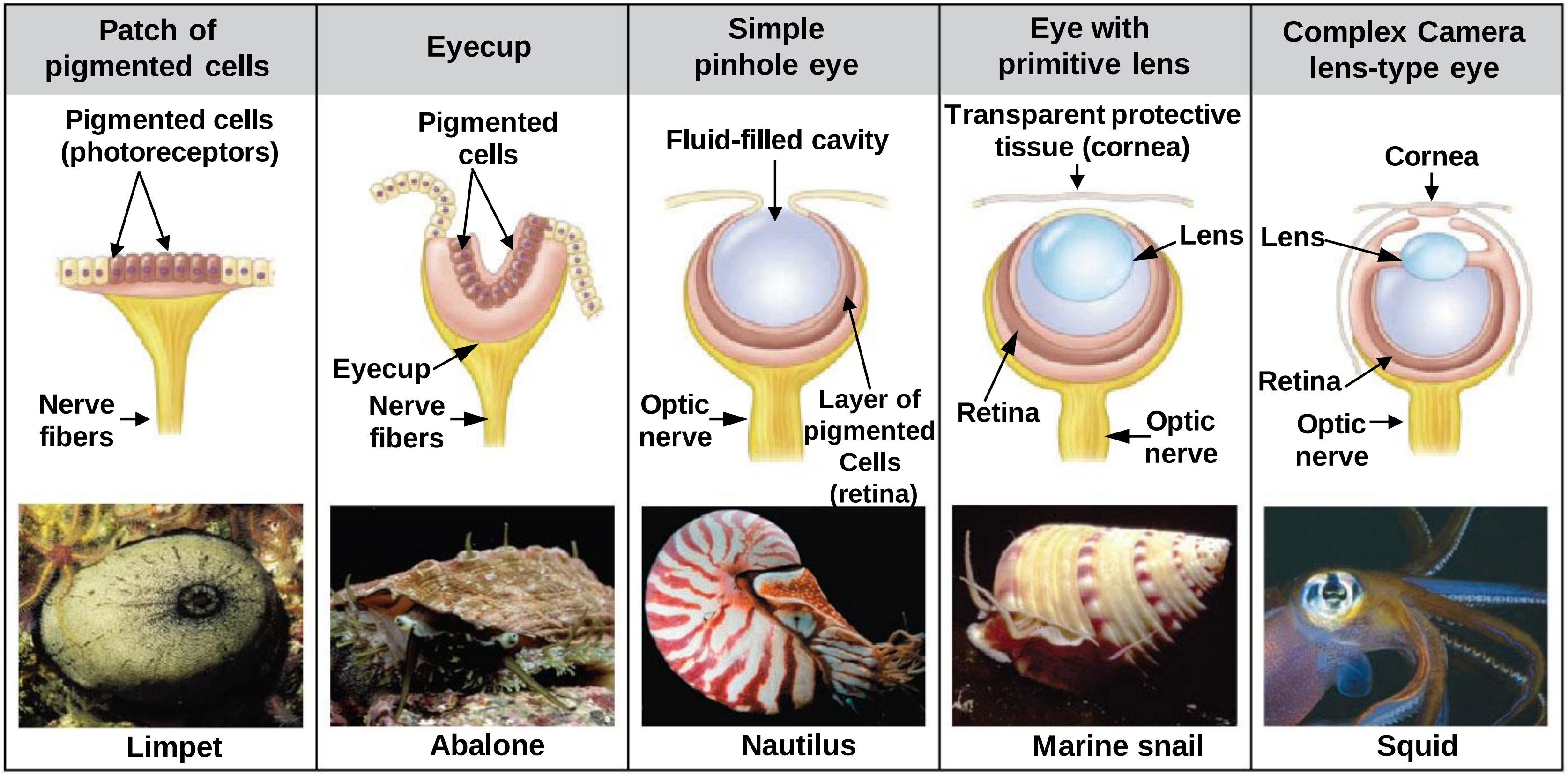
1) The relationship of structure to function
2) Information flow
3) Pathways that transform energy and matter
4) Interactions within biological systems
5) Evolution

From Simple to Complex Structures in Gradual Stages

- Most complex structures have evolved in small steps from simpler versions having the same basic function, a process of refinement rather than the sudden appearance of complexity.
- The evolution of complex eyes can be traced from a simple ancestral patch of photoreceptor cells through a series of incremental modifications that benefited their owners at each stage.

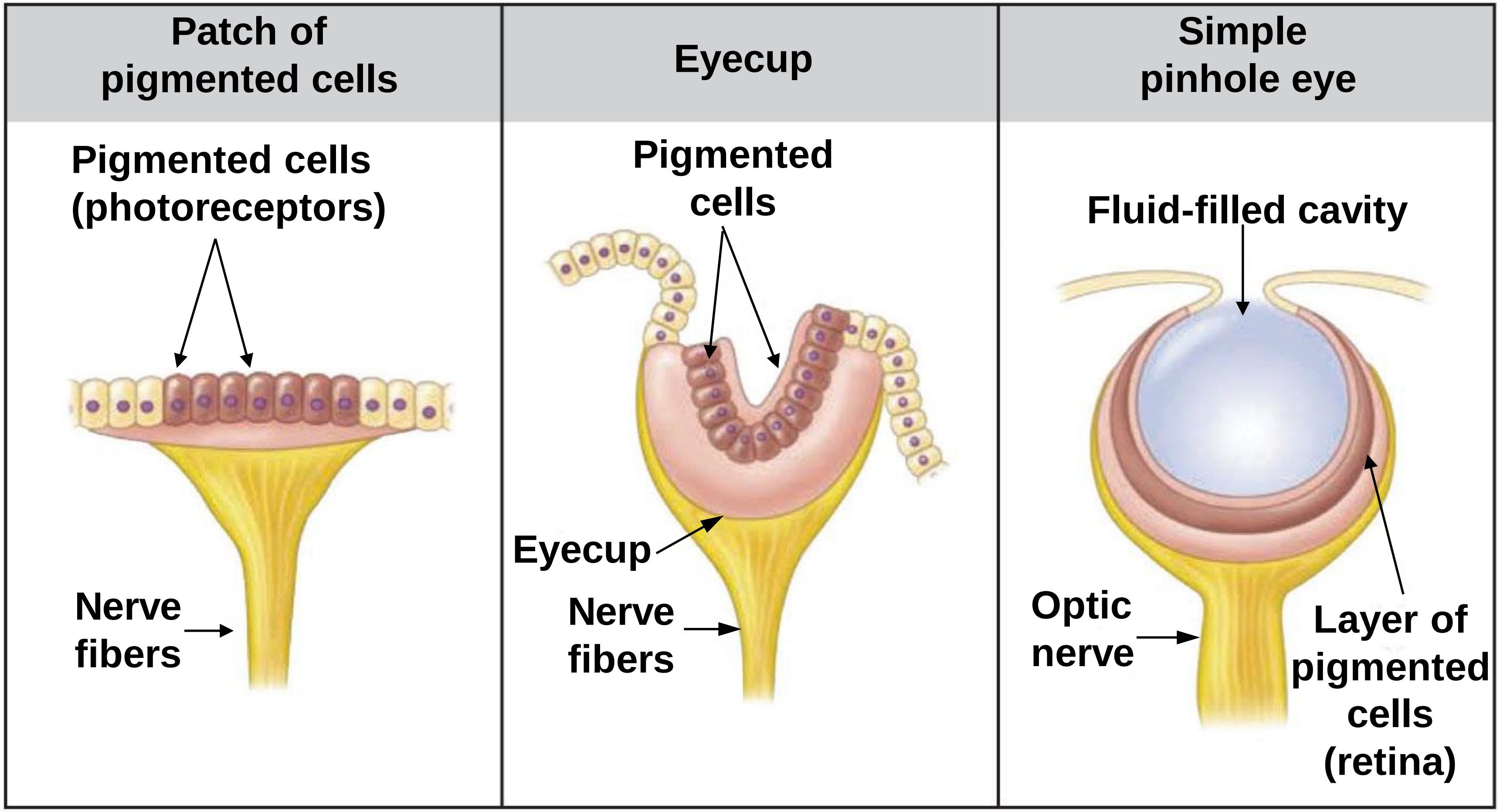
Checkpoint: Explain why the concept of exaptation does not imply that a structure evolves in anticipation of some future environmental change.

A range of eye complexity among molluscs



Patch of pigmented cells	Eyecup	Simple pinhole eye	Eye with primitive lens	Complex Camera lens-type eye
Pigmented cells (photoreceptors) Nerve fibers	Pigmented cells Eyecup Nerve fibers	Fluid-filled cavity Optic nerve Layer of pigmented Cells (retina)	Transparent protective tissue (cornea) Lens Retina Optic nerve	Cornea Lens Retina Optic nerve
Limpet	Abalone	Nautilus	Marine snail	Squid

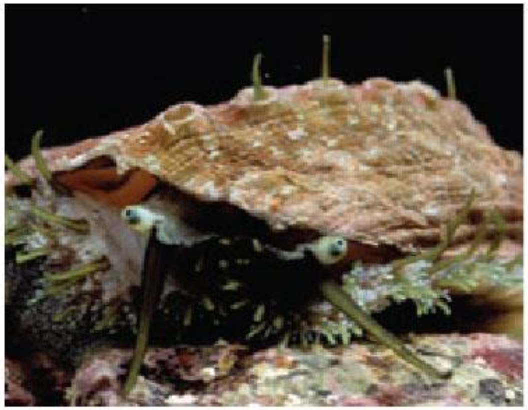
A range of eye complexity among molluscs (part 1: pigmented cells, eyecup and pinhole)



A range of eye complexity among molluscs (part 1a: limpet)

Limpet

A range of eye complexity among molluscs (part 1b: abalone)

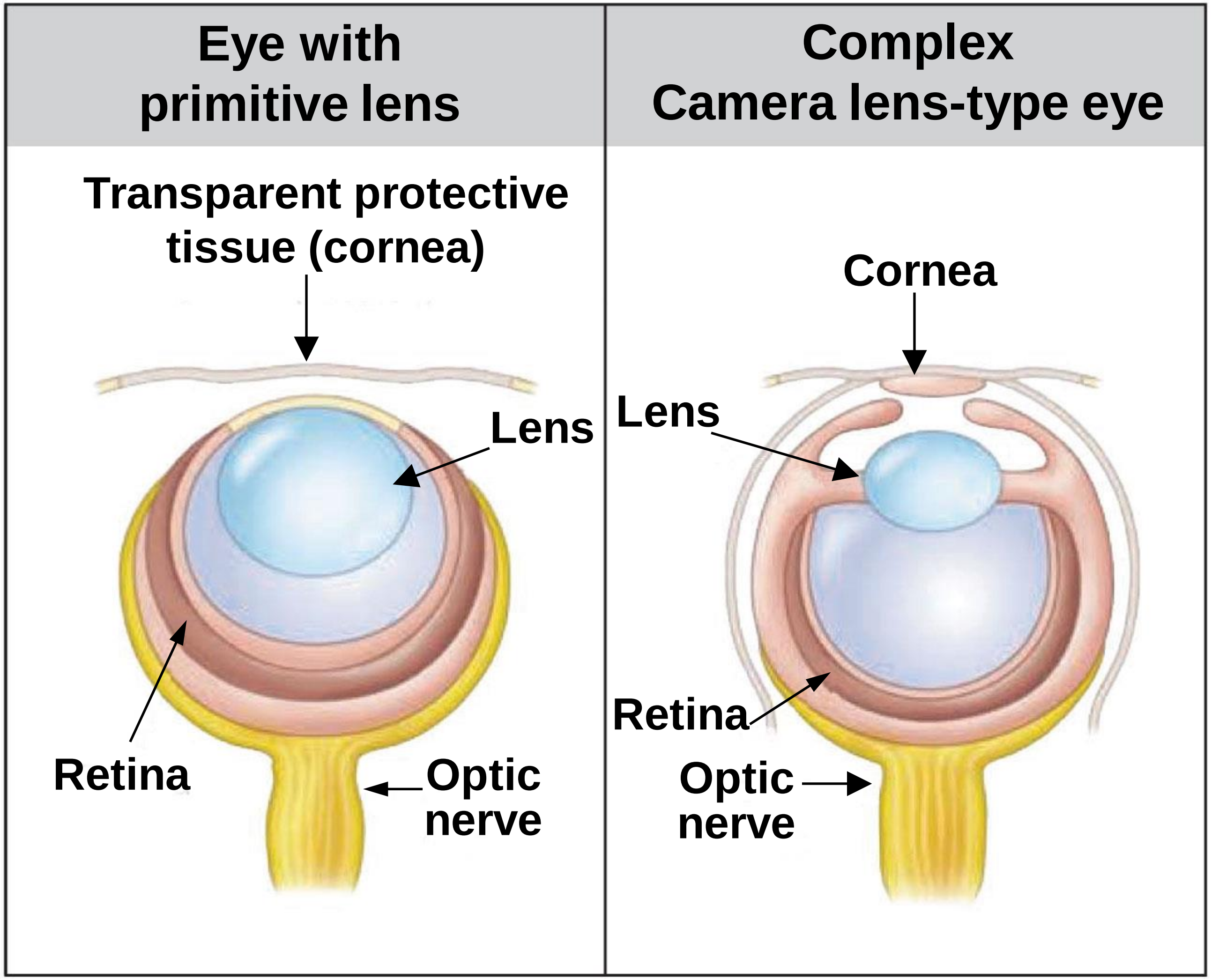


Abalone

A range of eye complexity among molluscs (part 1c: nautilus)

Nautilus

A range of eye complexity among molluscs (part 2: primitive lens and camera lens-type)



A range of eye complexity among molluscs (part 2a: marine snail)

Marine snail

A range of eye complexity among molluscs (part 2b: squid)

Squid

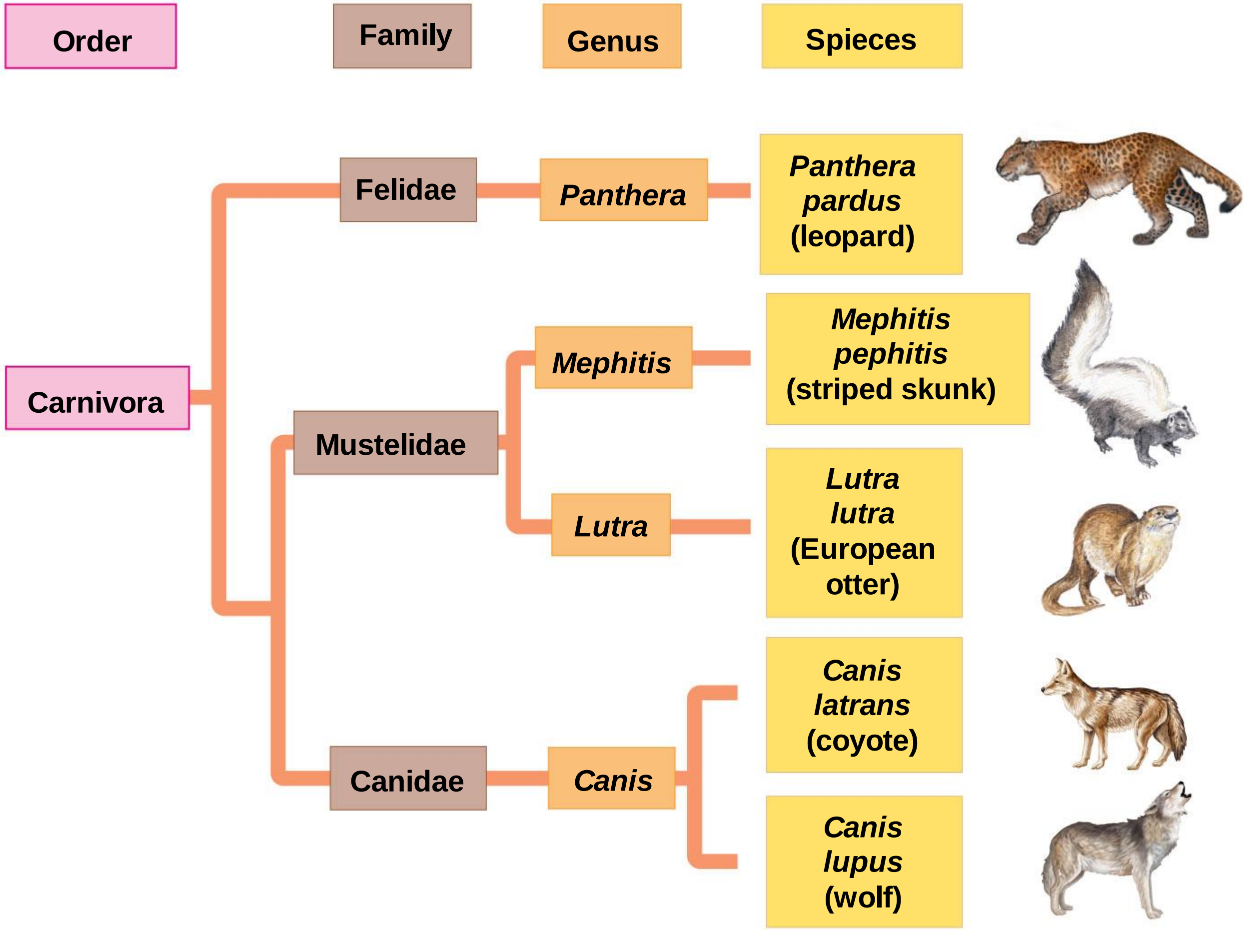
Classifying the Diversity of Life: Classification and Phylogeny

- Taxonomy is the naming and classification of species.

- **Systematics** includes taxonomy and focuses on
  - classifying organisms and
  - determining their evolutionary relationships.

- Biologists use **phylogenetic trees** to
  - depict hypotheses about the evolutionary history of species and
  - reflect the hierarchical classification of groups nested within more inclusive groups.

The relationship of classification and phylogeny for some members of the order Carnivora



Classification and Phylogeny

- Understanding phylogeny can have practical applications.
- By constructing a phylogeny of maize, researchers have identified two species of wild grasses that may be maize’s closest living relatives.
  - The genomes of these plants may harbor alleles that offer disease resistance or other useful traits that could be transferred into cultivated maize, insurance against future disease outbreaks or other environmental changes that might threaten corn crops.

Identifying Homologous Characters

- Homologous structures in different species may vary in form and function but exhibit fundamental similarities because they evolved from the same structure in a common ancestor.
- Homologous structures are one of the best sources of information for phylogenetic relationships.
- **Convergent evolution** involves superficially similar structures from different evolutionary branches that result from natural selection shaping analogous adaptations. Similarity due to convergence is called **analogy**, not homology.

Identifying Homologous Characters

- Comparing the embryonic development of two species can often reveal homology that is not apparent in the mature structures.
- If homology reflects common ancestry, then comparing the DNA sequences of organisms gets to the heart of their evolutionary relationships.
  - The more recently two species have branched from a common ancestor, the more similar their DNA sequences should be.
  - Some fossils are preserved in such a way that DNA fragments can be extracted for comparison with living organisms.

Artist’s reconstruction of Neanderthal

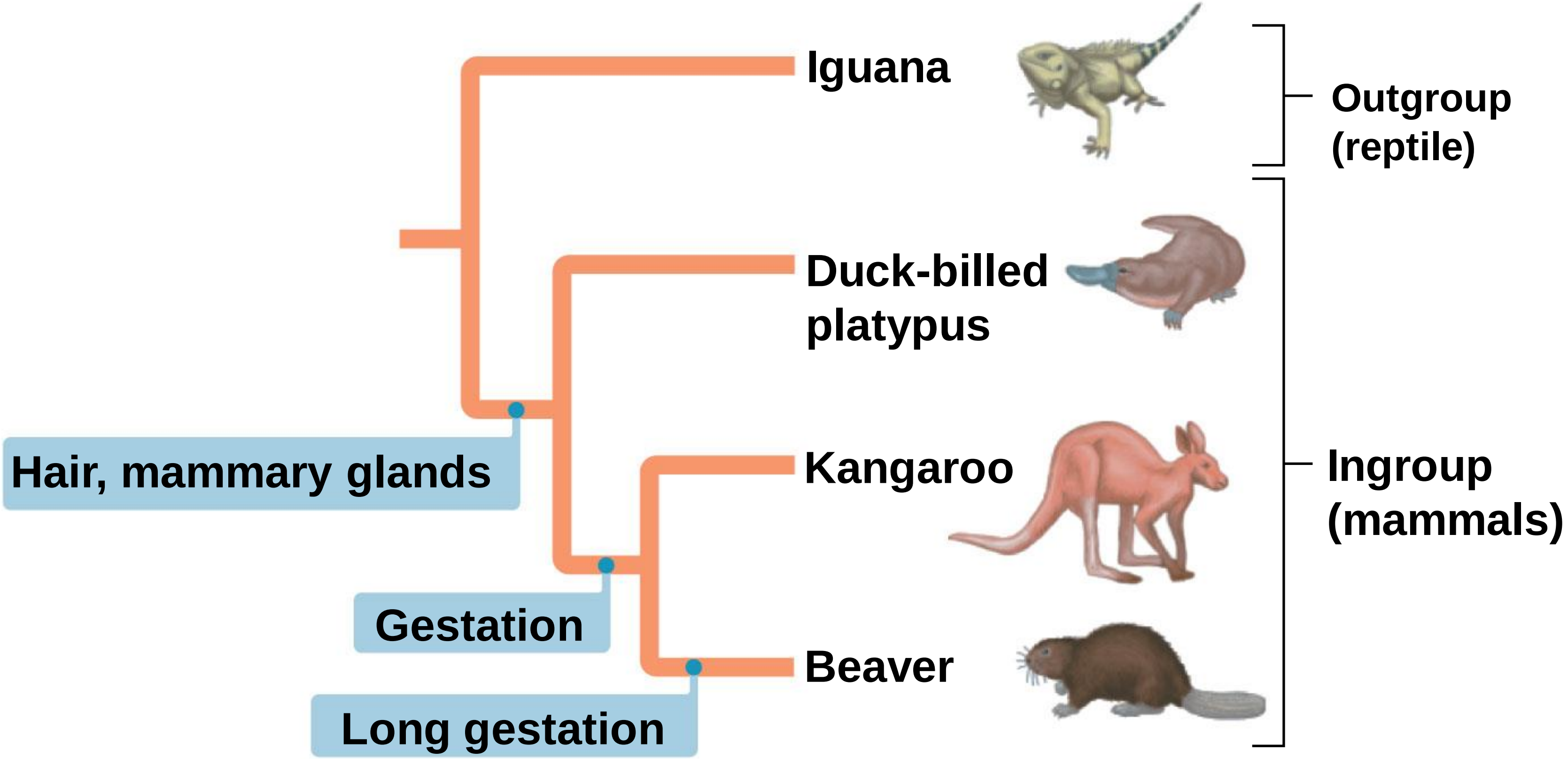
Inferring Phylogeny from Homologous Characters

- In **cladistics**, organisms are grouped by common ancestry.
    - A **clade** consists of an ancestral species and all its evolutionary descendants and forms a distinct branch in the tree of life.
    - Thus, identifying clades makes it possible to construct classification schemes that reflect the branching pattern of evolution.

Inferring Phylogeny from Homologous Characters

- Cladistics is based on the Darwinian concept of "descent with modification from a common ancestor."
- To identify clades, scientists compare an ingroup with an outgroup.
  - The ingroup is the group of species that is actually being analyzed.
  - The outgroup is a species or group of species known to have diverged before the lineage that contains the groups being studied.

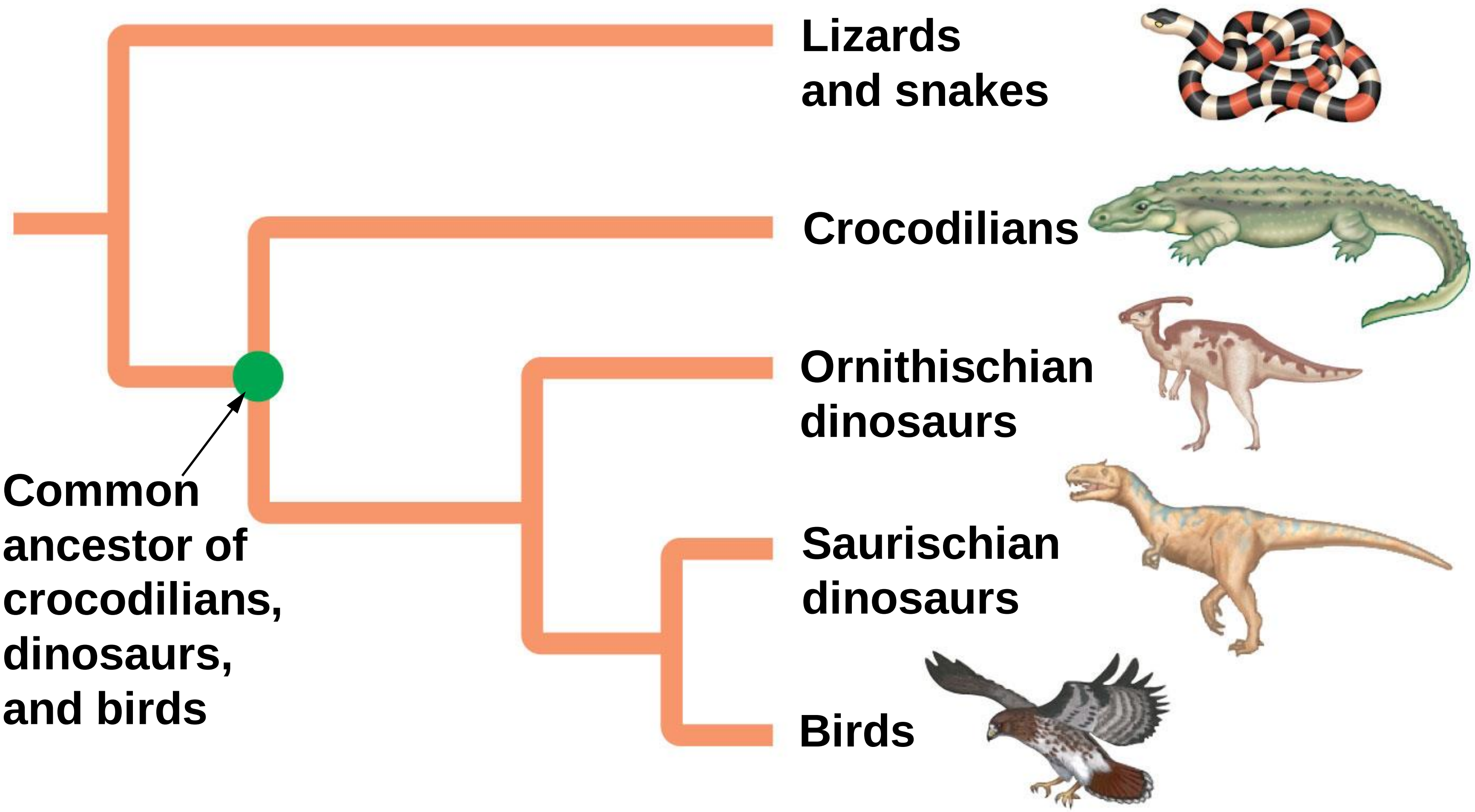
Simplified example of cladistics



Inferring Phylogeny from Homologous Characters

- The cladistics approach to phylogeny clarifies evolutionary relationships that were not always apparent in other taxonomic classifications.
  - For instance, biologists traditionally placed birds and reptiles in separate classes of vertebrates.
  - An inventory of homologies indicates that birds and crocodiles make up one clade, and lizards and snakes form another.
  - If we go back as far as the ancestor that crocodiles share with lizards and snakes to make up a clade, then the class Reptilia must also include birds.

How cladistics is shaking phylogenetic trees



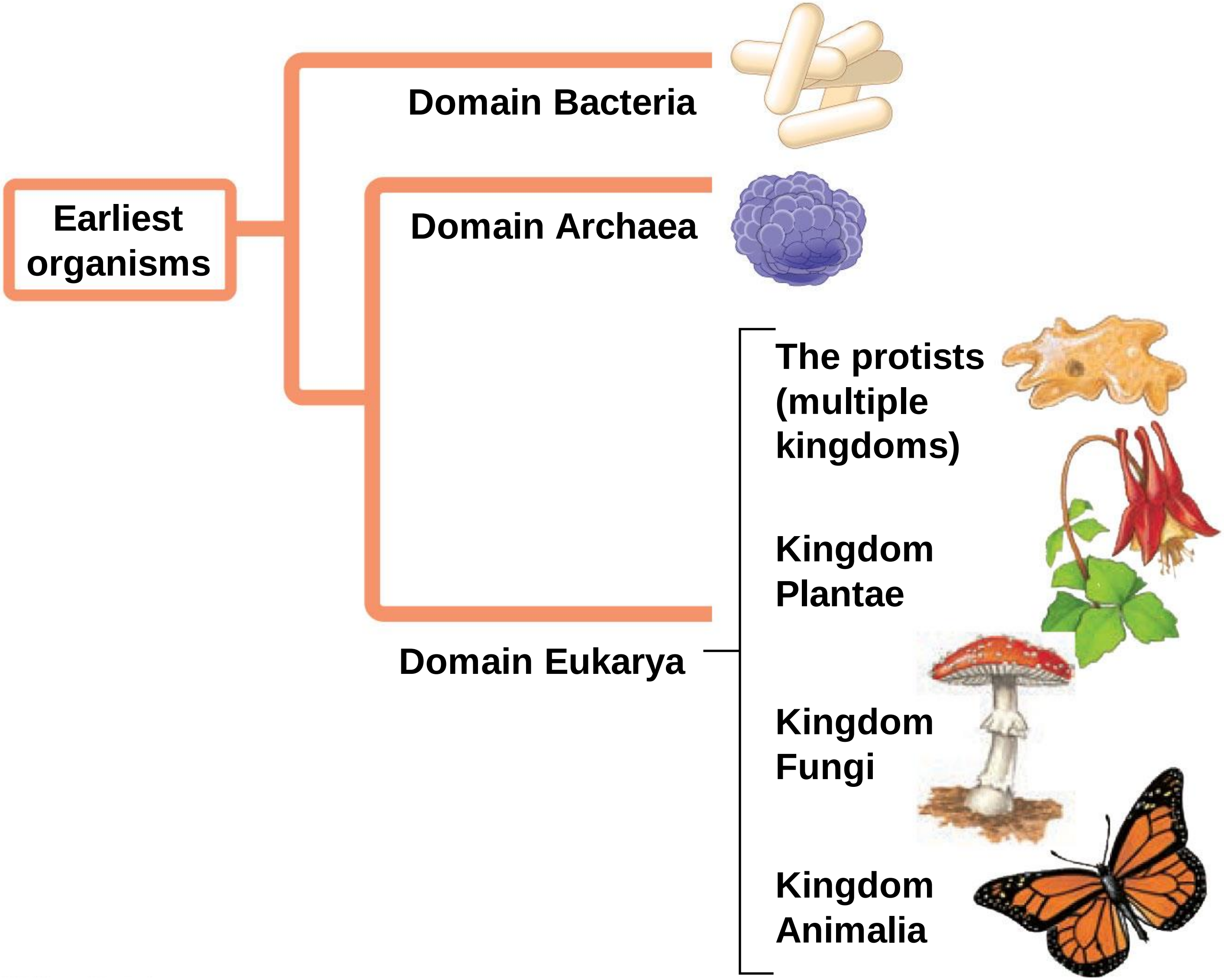
Classification: A Work in Progress

- Phylogenetic trees are hypotheses about evolutionary history.
- Linnaeus divided all known forms of life between the plant and animal kingdoms. This two-kingdom system prevailed in biology for over 200 years.
- In the mid-1900s, the two-kingdom system was replaced by a five-kingdom system that
  - placed all prokaryotes in one kingdom and
  - divided the eukaryotes among four other kingdoms.

Classification: A Work in Progress

- In the late 20th century, molecular studies and cladistics led to the development of a **three-domain system** that consists of
  - two domains of prokaryotes (Bacteria and Archaea) and
  - one domain of eukaryotes (Eukarya).
- The domain Eukarya is currently divided into kingdoms, but the exact number of kingdoms is still under debate.

The three-domain classification system



Identifying Major Themes

Plants make their own organic matter from inorganic nutrients by photosynthesis.

Which major theme is illustrated by this action?

1) The relationship of structure to function
2) Information flow
3) Pathways that transform energy and matter
4) Interactions within biological systems
5) Evolution

Evolution Connection: Evolution in the Anthropocene

- The Anthropocene is a time of environmental change on an epic scale. Consequently, habitats affected by human impacts are natural laboratories for studying evolutionary adaptation.
  - Some organisms have become resistant to toxic pollutants from industrial processes.
  - Urban crested anoles in Puerto Rico have more sticky scales, an adaptation to slippery surfaces such as concrete and metal.
  - Urban blackbirds sing at a higher pitch, an adaptation that enables them to be heard over traffic noise.

Urban-adapted animals

(a) Crested anole lizard

(b) European blackbird

Urban-adapted animals (part 1: Crested anole lizard)

(a) Crested anole lizard

Urban-adapted animals (part 2: European blackbird)

(b) European blackbird