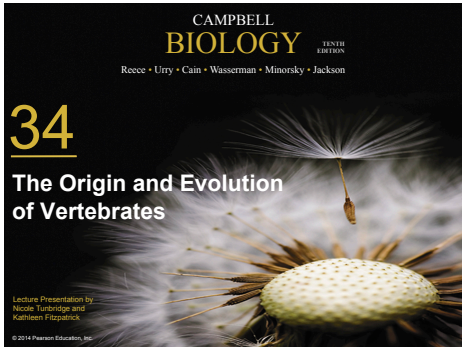

Half a Billion Years of Backbones

- Early in the Cambrian period, about 530 million years ago, an astonishing variety of invertebrate animals inhabited Earth's oceans
- One type of animal gave rise to vertebrates, one of the most successful groups of animals
- The animals called **vertebrates** get their name from vertebrae, the series of bones that make up the backbone

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Figure 34.1

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- One lineage of vertebrates colonized land 365 million years ago
- They gave rise to modern amphibians, reptiles (including birds), and mammals
- There are more than 57,000 species of vertebrates, including the largest organisms ever to live on Earth
- Vertebrates have great disparity, a wide range of differences within the group

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Concept 34.1: Chordates have a notochord and a dorsal, hollow nerve cord

- **Chordates** (phylum Chordata) are bilaterian animals that belong to the clade of animals known as Deuterostomia
- Chordates comprise all vertebrates and two groups of invertebrates, the urochordates and cephalochordates

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Figure 34.2

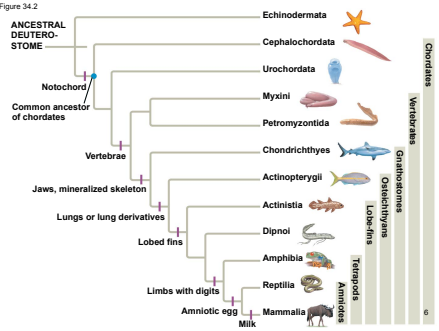

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Figure 34.2a

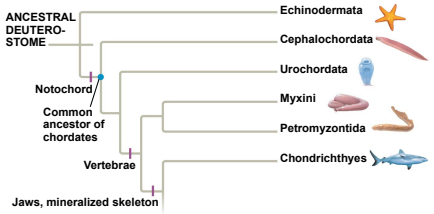

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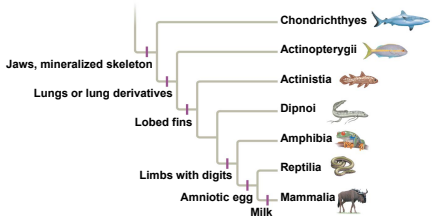
Figure 34.2b



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Derived Characters of Chordates

- All chordates share a set of derived characters
- Some species have some of these traits only during embryonic development
- Four key characters of chordates
  - Notochord
  - Dorsal, hollow nerve cord
  - Pharyngeal slits or clefts
  - Muscular, post-anal tail

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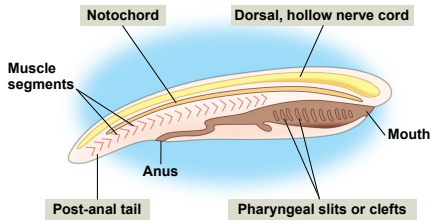
Figure 34.3



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Notochord

- The **notochord** is a longitudinal, flexible rod between the digestive tube and nerve cord
- It provides skeletal support throughout most of the length of a chordate
- In most vertebrates, a more complex, jointed skeleton develops, and the adult retains only remnants of the embryonic notochord

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Dorsal, Hollow Nerve Cord

- The nerve cord of a chordate embryo develops from a plate of ectoderm that rolls into a tube dorsal to the notochord
- The nerve cord develops into the central nervous system: the brain and the spinal cord

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Pharyngeal Slits or Clefts

- In most chordates, grooves in the pharynx called **pharyngeal clefts** develop into slits that open to the outside of the body
- Functions of **pharyngeal slits**
  - Suspension-feeding structures in many invertebrate chordates
  - Gas exchange in vertebrates (except vertebrates with limbs, the tetrapods)
  - Develop into parts of the ear, head, and neck in tetrapods

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Muscular, Post-Anal Tail

- Chordates have a tail posterior to the anus
- In many species, the tail is greatly reduced during embryonic development
- The tail contains skeletal elements and muscles
- It provides propelling force in many aquatic species

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Lancelets

- **Lancelets** (Cephalochordata) are named for their bladelike shape
- They are marine suspension feeders that retain characteristics of the chordate body plan as adults

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Figure 34.UN01

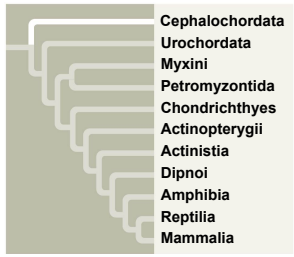

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Figure 34.4

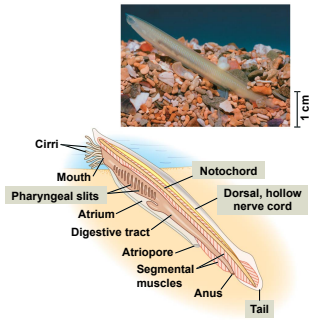

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Figure 34.4a

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Tunicates

- **Tunicates** (Urochordata) are more closely related to other chordates than are lancelets
- Tunicates most resemble chordates during their larval stage, which may last only a few minutes
- As an adult, a tunicate draws in water through an incurrent siphon, filtering food particles
- When attacked, tunicates, or "sea squirts," shoot water through their excurrent siphon

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Figure 34.UN02

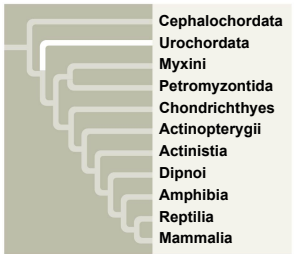

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Figure 34.5

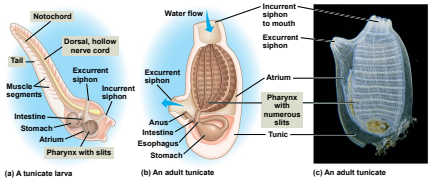

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Figure 34.5a

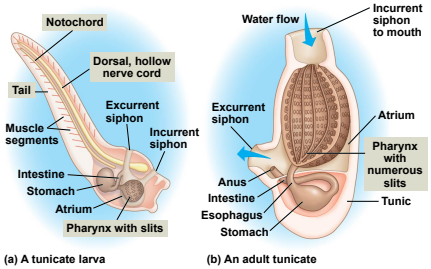

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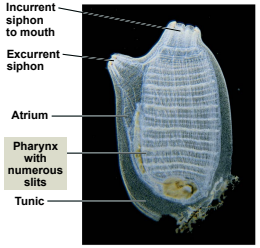
Figure 34.5b



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- Tunicates are highly derived and have fewer *Hox* genes than other vertebrates

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Early Chordate Evolution

- Ancestral chordates may have resembled lancelets
- The same *Hox* genes that organize the vertebrate brain are expressed in the lancelet's simple nerve cord tip
- Sequencing of the tunicate genome indicates that
  - Genes associated with the heart and thyroid are common to all chordates
  - Genes associated with transmission of nerve impulses are unique to vertebrates

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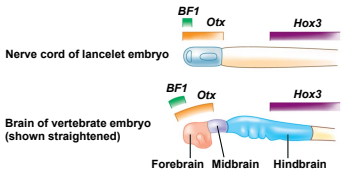
Figure 34.6



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Concept 34.2: Vertebrates are chordates that have a backbone

- A skeletal system and complex nervous system have allowed vertebrates efficiency at two essential tasks
  - Capturing food
  - Evading predators

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Derived Characters of Vertebrates

- Vertebrates have two or more sets of *Hox* genes; lancelets and tunicates have only one cluster
- Vertebrates have the following derived characters
  - Vertebrae enclosing a spinal cord
  - An elaborate skull
  - Fin rays, in the aquatic forms

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Hagfishes and Lampreys

- Fossil evidence shows that the earliest vertebrates lacked jaws
- Only two lineages of jawless vertebrates remain today: the **hagfishes** and the **lampreys**
- Members of these groups lack a backbone
- The presence of rudimentary vertebrae and the results of phylogenetic analysis indicate that both hagfishes and lampreys are vertebrates

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- Together, the hagfishes and lampreys form a clade of living jawless vertebrates, the **cyclostomes**
- Vertebrates with jaws make up a much larger clade, the **gnathostomes**

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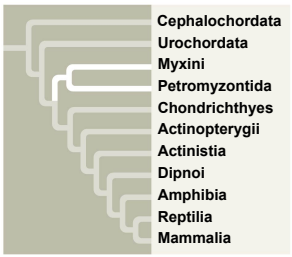
Figure 34.UN03



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Hagfishes

- Hagfishes (Myxini) are jawless vertebrates that have a cartilaginous skull, reduced vertebrae, and a flexible rod of cartilage derived from the notochord
- They have a small brain, eyes, ears, and tooth-like formations
- Hagfishes are marine; most are bottom-dwelling scavengers

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Figure 34.7

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Lampreys

- Lampreys (Petromyzontida) are parasites that feed by clamping their mouth onto a live fish
- They inhabit various marine and freshwater habitats
- They have cartilaginous segments surrounding the notochord and arching partly over the nerve cord

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Figure 34.8

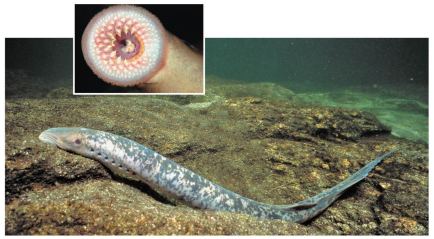

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Figure 34.8a

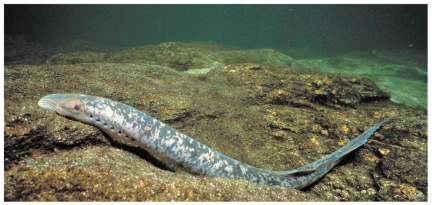

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Figure 34.8b

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Early Vertebrate Evolution

- Fossils from the Cambrian explosion document the transition to craniates
- The most primitive of the fossils are those of the 3-cm-long *Haikouella*
- *Haikouella* had a well-formed brain, eyes, and muscular segments, but no skull or ear organs

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Figure 34.9

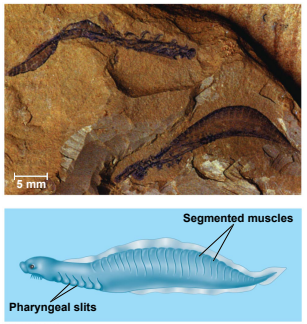

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Figure 34.9a

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- **Conodonts** were among the earliest vertebrates in the fossil record, dating from 500 to 200 million years ago
- They had mineralized skeletal elements in their mouth and pharynx
- Their fossilized dental elements are common in the fossil record

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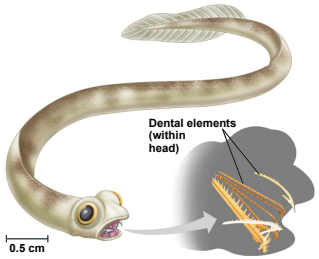
Figure 34.10



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- Other groups of jawless vertebrates were armored with defensive plates of bone on their skin

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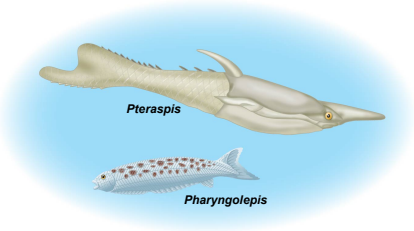
Figure 34.11



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Origins of Bone and Teeth

- Mineralization appears to have originated with vertebrate mouthparts
- The vertebrate endoskeleton became fully mineralized much later

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Concept 34.3: Gnathostomes are vertebrates that have jaws

- Today, jawed vertebrates, or gnathostomes, outnumber jawless vertebrates
- Gnathostomes include sharks and their relatives, ray-finned fishes, lobe-finned fishes, amphibians, reptiles (including birds), and mammals

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Derived Characters of Gnathostomes

- Gnathostomes ("jaw mouth") are named for their jaws, hinged structures that, especially with the help of teeth, are used to grip food items firmly and slice them
- The jaws are hypothesized to have evolved by modification of skeletal rods that supported the pharyngeal (gill) slits

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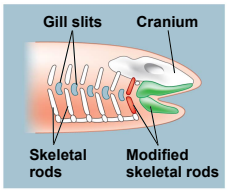
Figure 34.12



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- Other characters common to gnathostomes
  - Genome duplication, including duplication of *Hox* genes
  - An enlarged forebrain associated with enhanced smell and vision
  - In aquatic gnathostomes, the **lateral line system**, which is sensitive to vibrations

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Fossil Gnathostomes

- The earliest gnathostomes in the fossil record are an extinct lineage of armored vertebrates called **placoderms**
- They appeared about 440 million years ago

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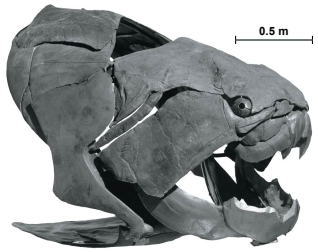
Figure 34.13



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- Another group of jawed vertebrates called **acanthodians** radiated during the Silurian and Devonian periods (444 to 359 million years ago)
- Three lineages of jawed vertebrates survive today: chondrichthyans, ray-finned fishes, and lobe-fins

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Chondrichthyans (Sharks, Rays, and Their Relatives)

- **Chondrichthyans** (Chondrichthyes) have a skeleton composed primarily of cartilage
- The largest and most diverse group of chondrichthyans includes the sharks, rays, and skates

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Figure 34.UN04

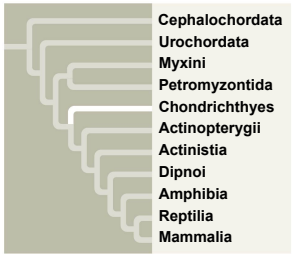

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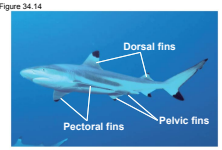
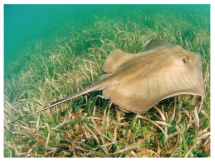
Figure 34.14



(a) Blacktip reef shark (*Carcharhinus melanopterus*)



(b) Southern stingray (*Dasyatis americana*)

(c) Spotted ratfish (*Hydrolagus colliei*)

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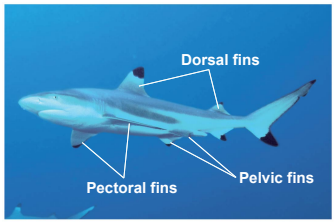
Figure 34.14a



(a) Blacktip reef shark (*Carcharhinus melanopterus*)

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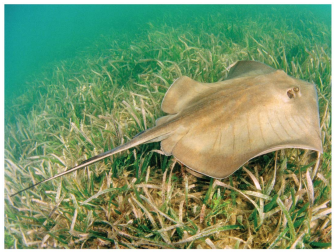
Figure 34.14b



(b) Southern stingray (*Dasyatis americana*)

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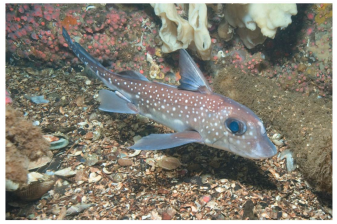
Figure 34.14c



(c) Spotted ratfish (*Hydrolagus colliei*)

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Video: Manta Ray

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- A second subclass is composed of a few dozen species of ratfishes, or chimaeras

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- Sharks have a streamlined body and are swift swimmers
- The largest sharks are suspension feeders, but most are carnivores
- Sharks have a short digestive tract with a ridge called the spiral valve to increase the digestive surface area
- Sharks have acute senses including sight, smell, and the ability to detect electrical fields from nearby animals

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- Shark eggs are fertilized internally but embryos can develop in different ways
  - **Oviparous**: Eggs hatch outside the mother's body
  - **Ovoviviparous**: The embryo develops within the uterus and is nourished by the egg yolk
  - **Viviparous**: The embryo develops within the uterus and is nourished through a yolk sac placenta from the mother's blood

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- The reproductive tract, excretory system, and digestive tract empty into a common **cloaca**
- Today, sharks are severely threatened by overfishing; Pacific populations have plummeted by up to 95%

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Ray-Finned Fishes and Lobe-Fins

- The vast majority of vertebrates belong to a clade of gnathostomes called Osteichthyes
- Nearly all living **osteichthyans** have a bony endoskeleton
- Osteichthyans include the bony fishes and tetrapods
- Aquatic osteichthyans are the vertebrates we informally call fishes

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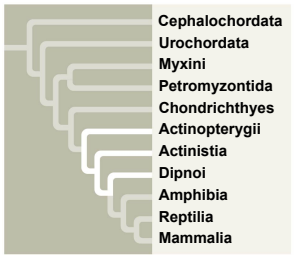
Figure 34.UN05



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- Most fishes breathe by drawing water over gills protected by an **operculum**
- Fishes control their buoyancy with an air sac known as a swim bladder
- Fishes have a lateral line system
- Most species are oviparous, but some have internal fertilization and birthing

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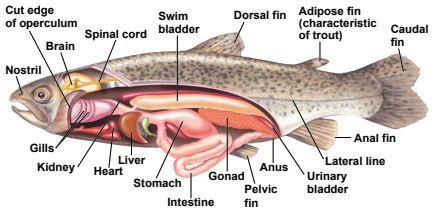
Figure 34.15



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Ray-Finned Fishes

- Actinopterygii, the **ray-finned fishes**, include nearly all the familiar aquatic osteichthyans
- Ray-finned fishes originated during the Silurian period (444 to 416 million years ago)
- The fins, supported mainly by long, flexible rays, are modified for maneuvering, defense, and other functions

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Figure 34.16

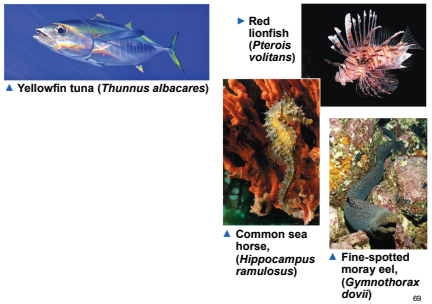

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Figure 34.16a

Yellowfin tuna (*Thunnus albacares*)

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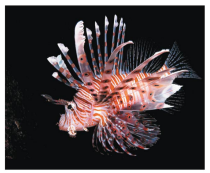
Figure 34.16b



Red lionfish, (*Pterois volitans*)

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Figure 34.16c

Common sea horse, (*Hippocampus ramulosus*)

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Figure 34.16d

Fine-spotted moray eel, (*Gymnothorax dovii*)

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Video: Clownfish and Anemone

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Video: Coral Reef

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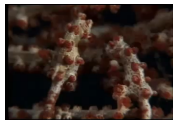
Video: Seahorse Camouflage



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- Industrial-scale fishing operations have driven many ray-finned fish populations to collapse
- Populations are also affected by dams that change water flow patterns, affecting prey capture, migration, and spawning

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Lobe-Fins

- The **lobe-fins** (Sarcopterygii) also originated in the Silurian period
- They have muscular pelvic and pectoral fins that they use to swim and "walk" underwater across the substrate

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Figure 34.17

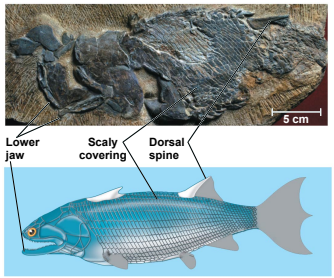

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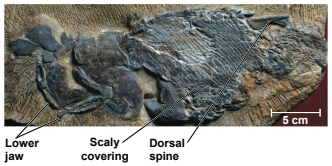
Figure 34.17a



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- Three lineages survive and include coelacanths, lungfishes, and tetrapods
- Coelacanths were thought to have become extinct 75 million years ago, but a living coelacanth was caught off the coast of South Africa in 1938

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Figure 34.18

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- The living lungfishes are all found in the Southern Hemisphere
- Though gills are the main organs for gas exchange, they can also surface to gulp air into their lungs
- The third surviving lineage of lobe-fins are tetrapods, a group that adapted to life on land

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Concept 34.4: Tetrapods are gnathostomes that have limbs

- One of the most significant events in vertebrate history was when the fins of some lobe-fins evolved into the limbs and feet of tetrapods

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Derived Characters of Tetrapods

- **Tetrapods** have some specific adaptations
  - Four limbs, and feet with digits
  - A neck, which allows separate movement of the head
  - Fusion of the pelvic girdle to the backbone
  - The absence of gills (except some aquatic species)
  - Ears for detecting airborne sounds

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The Origin of Tetrapods

- *Tiktaalik*, nicknamed a "fishapod," shows both fish and tetrapod characteristics
- It had
  - Fins, gills, lungs, and scales
  - Ribs to breathe air and support its body
  - A neck and shoulders
  - Fins with the bone pattern of a tetrapod limb

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Figure 34.19

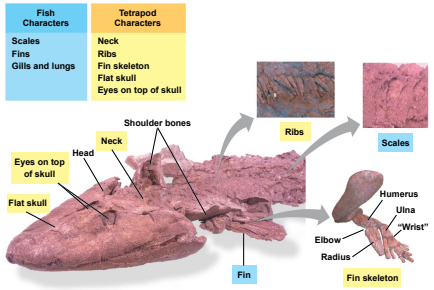

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Figure 34.19a

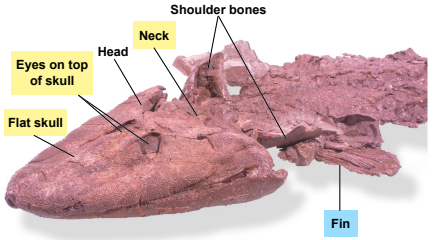

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Figure 34.19b

Ribs

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Figure 34.19c

Scales

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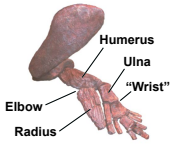
Figure 34.19d



Fin skeleton

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- *Tiktaalik* could most likely prop itself on its fins, but not walk
- The first tetrapods appeared 365 million years ago

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Figure 34.20

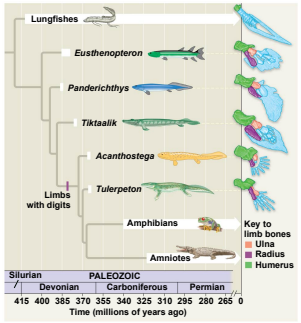

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Figure 34.20a

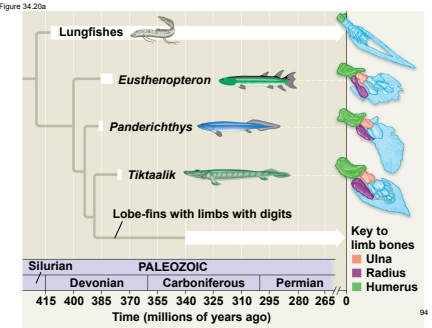

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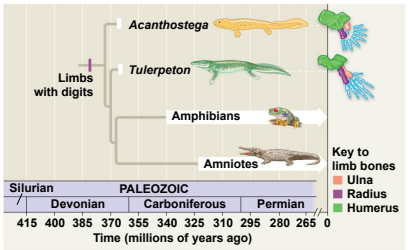
Figure 34.20b



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Amphibians

- **Amphibians** (class Amphibia) are represented by about 6,150 species in three clades
  - Urodela (salamanders)
  - Anura (frogs)
  - Apoda (caecilians)

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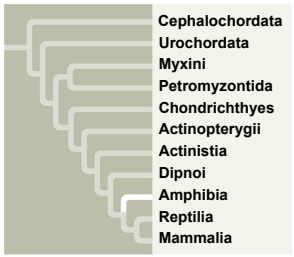
Figure 34.UN06



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Salamanders

- Salamanders (urodeles) are amphibians with tails
- Some are aquatic, but others live on land as adults or throughout life
- Paedomorphosis, the retention of juvenile features in sexually mature organisms, is common in aquatic species

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Figure 34.21

(a) Order Urodela

(b) Order Anura

(c) Order Apoda

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Figure 34.21a

(a) Order Urodela

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Frogs

- Frogs (anurans) lack tails and have powerful hind legs for locomotion on land
- Frogs with leathery skin are called “toads”

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Figure 34.21b

(b) Order Anura

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Caecilians

- Caecilians (apoda) are legless, nearly blind, and resemble earthworms
- The absence of legs is a secondary adaptation

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Figure 34.21c

(c) Order Apoda

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Lifestyle and Ecology of Amphibians

- Amphibian means “both ways of life,” referring to the metamorphosis of an aquatic larva into a terrestrial adult
- Tadpoles are herbivores that lack legs, but legs, lungs, external eardrums, and adaptations for carnivory may all arise during metamorphosis
- Most amphibians have moist skin that complements the lungs in gas exchange

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Figure 34.22

(a) The tadpole

(b) During metamorphosis

(c) The adults return to water to mate.

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Figure 34.22a

(a) The tadpole

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Figure 34.22b

(b) During metamorphosis

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Figure 34.22c

(c) The adults return to water to mate.

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- Fertilization is external in most species, and the eggs require a moist environment
- In some species, males or females care for the eggs on their back, in their mouth, or in their stomach

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Figure 34.23

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- Amphibian populations have been declining in recent decades
- The causes include a disease-causing chytrid fungus, habitat loss, climate change, and pollution

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Concept 34.5: Amniotes are tetrapods that have a terrestrially adapted egg

- **Amniotes** are a group of tetrapods whose living members are the reptiles, including birds, and mammals

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Figure 34.24

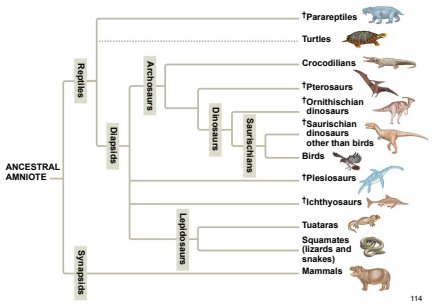

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Figure 34.24a

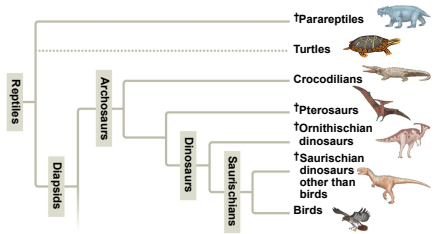

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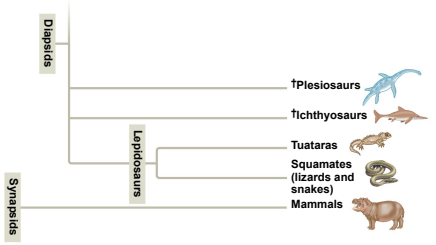
Figure 34.24b



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Derived Characters of Amniotes

- Amniotes are named for the major derived character of the clade, the **amniotic egg**, which contains membranes that protect the embryo
- The extraembryonic membranes are the amnion, chorion, yolk sac, and allantois

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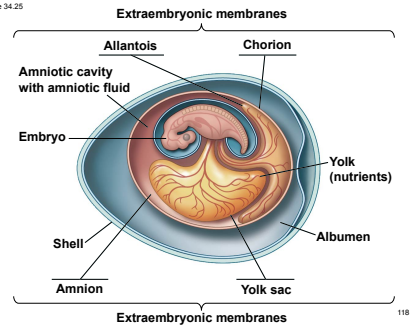
Figure 34.25



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- The amniotic egg was a key adaptation to life on land
- The amniotic eggs of most reptiles and some mammals have a shell
- Amniotes have other terrestrial adaptations, such as relatively impermeable skin and the ability to use the rib cage to ventilate the lungs

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Early Amniotes

- Living amphibians and amniotes split from a common ancestor about 350 million years ago
- Early amniotes were more tolerant of dry conditions than the first tetrapods
- The earliest amniotes were small predators with sharp teeth and long jaws

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Figure 34.26

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Reptiles

- The **reptile** clade includes the tuataras, lizards, snakes, turtles, crocodilians, birds, and some extinct groups
- Reptiles have scales that create a waterproof barrier
- Most reptiles lay shelled eggs on land

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Figure 34.UN07

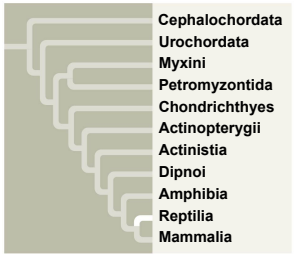

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Figure 34.27

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- Most reptiles are **ectothermic**, absorbing external heat as the main source of body heat
- Ectotherms regulate their body temperature through behavioral adaptations
- Birds are **endothermic**, capable of maintaining body temperature through metabolism

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The Origin and Evolutionary Radiation of Reptiles

- Fossil evidence indicates that the earliest reptiles lived about 310 million years ago
- The first major group to emerge were **parareptiles**, which were mostly large, stocky quadrupedal herbivores

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- As parareptiles were dwindling, the **diapsids** were diversifying
- The diapsids consisted of two main lineages: the lepidosaurs and the archosaurs
- The **lepidosaurs** include tuataras, lizards, snakes, and extinct mososaurs
- The **archosaur** lineage produced the crocodilians, **pterosaurs**, and **dinosaurs**

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- Pterosaurs were the first tetrapods to exhibit flight
- The dinosaurs diversified into a vast range of shapes and sizes
- They included bipedal carnivores called **theropods**, the group from which birds are descended

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- Fossil discoveries and research have led to the conclusion that many dinosaurs were agile and fast moving
- Paleontologists have also discovered signs of parental care among dinosaurs
- Some anatomical evidence supports the hypothesis that at least some dinosaurs were endotherms

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- Dinosaurs, with the exception of birds, became extinct by the end of the Cretaceous
- Their extinction may have been partly caused by an asteroid

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Turtles

- The phylogenetic position of turtles remains uncertain
- All turtles have a boxlike shell made of upper and lower shields that are fused to the vertebrae, clavicles, and ribs

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Figure 34.28

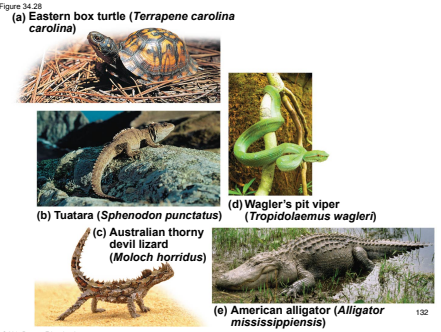

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Figure 34.28a

(a) Eastern box turtle (*Terrapene carolina carolina*)

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Figure 34.28b

(b) Tuatara (*Sphenodon punctatus*)

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Figure 34.28c

(c) Australian thorny devil lizard (*Moloch horridus*)

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Figure 34.28d

(d) Wagler's pit viper (*Tropidolaemus wagleri*)

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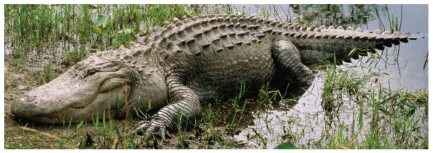
Figure 34.28e



(e) American alligator (*Alligator mississippiensis*)

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Video: Galápagos Marine Iguana

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Video: Snake Ritual Wrestling

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Video: Galápagos Tortoise

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- Some turtles have adapted to deserts and others live entirely in ponds and rivers
- The largest turtles live in the sea
- Many species of sea turtles are endangered by accidental capture in fishing nets or development of beaches where they lay eggs

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Lepidosaurs

- One surviving lineage of lepidosaurs is represented by two species of lizard-like reptiles called tuataras
- Living tuataras are restricted to small islands off the coast of New Zealand
- They are threatened by introduced rats, which consume their eggs

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- The other major living lineage of lepidosaurs consists of the squamates, the lizards and snakes
- Squamates are the most numerous and diverse reptiles, apart from birds

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- Snakes are legless lepidosaurs that evolved from lizards
- Snakes are carnivorous, and have adaptations to aid in capture and consumption of prey including
  - Chemical sensors
  - Heat-detecting organs
  - Venom
  - Loosely articulated jawbones and elastic skin

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Crocodilians

- Crocodilians (alligators and crocodiles) belong to an archosaur lineage that dates back to the late Triassic
- Living crocodilians are restricted to warm regions

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Birds

- Birds are archosaurs, but almost every feature of their reptilian anatomy has undergone modification in their adaptation to flight

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Derived Characters of Birds

- Many characters of birds are adaptations that facilitate flight
- The major adaptation is wings with keratin feathers
- Other adaptations include lack of a urinary bladder, females with only one ovary, small gonads, and loss of teeth

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Figure 34.29

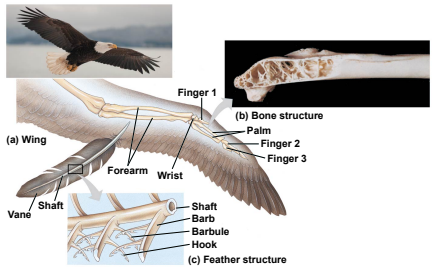

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Figure 34.29a

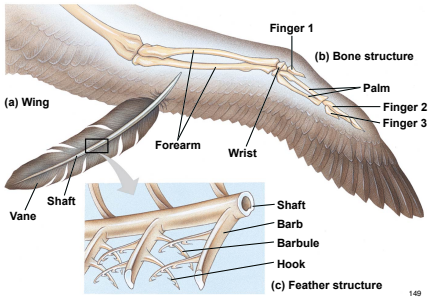

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Figure 34.29b

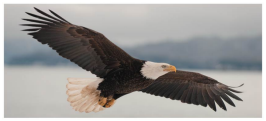

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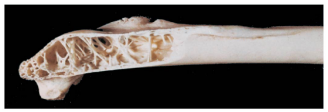
Figure 34.29c



(b) Bone structure

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Video: Flapping Geese

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Video: Soaring Hawk

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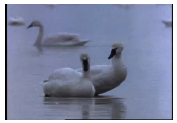
Video: Swans Taking Flight



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- Flight enhances hunting and scavenging, escape from terrestrial predators, and migration
- Flight requires a great expenditure of energy, acute vision, and fine muscle control

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The Origin of Birds

- Birds probably descended from small theropods, a group of carnivorous dinosaurs
- Early feathers might have evolved for insulation, camouflage, or courtship display

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- By 160 million years ago, feathered theropods had evolved into birds
- *Archaeopteryx* remains the oldest bird known

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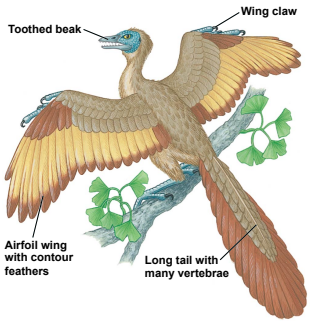
Figure 34.30



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Living Birds

- Living birds belong to the clade Neornithes
- Several groups of birds are flightless
  - The **ratites**, order Struthioniformes
  - Penguins, order Sphenisciformes
  - Certain species of rails, ducks, and pigeons

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Figure 34.32

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- The demands of flight have rendered the general body form of many flying birds similar to one another
- Bird species can be distinguished by characters including profile, color, flying style, behavior, beak shape, and foot structure

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Figure 34.34

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Figure 34.34a

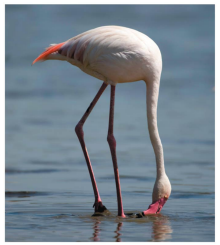

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Figure 34.34b

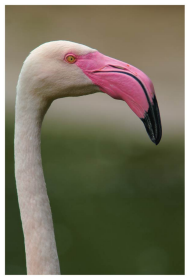

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Figure 34.35

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Concept 34.6: Mammals are amniotes that have hair and produce milk

- **Mammals**, class Mammalia, are represented by more than 5,300 species

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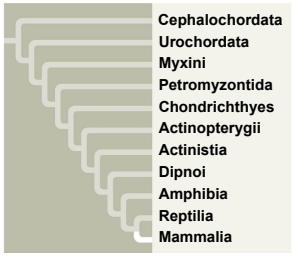
Figure 34.UN08



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Derived Characters of Mammals

- Mammals have
  - Mammary glands, which produce milk
  - Hair
  - A high metabolic rate, due to endothermy
  - A larger brain than other vertebrates of equivalent size
  - Differentiated teeth

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Early Evolution of Mammals

- Mammals are **synapsids**
- In the evolution of mammals from early synapsids, two bones that formerly made up the jaw joint were incorporated into the mammalian middle ear

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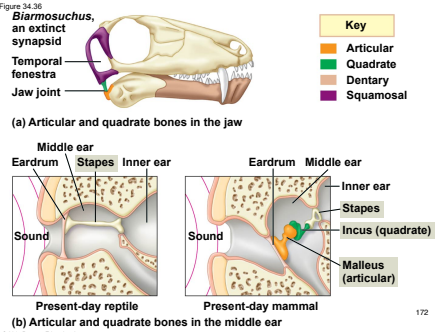
Figure 34.36



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- By the early Cretaceous, the three living lineages of mammals emerged: monotremes, marsupials, and eutherians
- Mammals did not undergo a significant adaptive radiation until after the Cretaceous

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Monotremes

- **Monotremes** are a small group of egg-laying mammals consisting of echidnas and the platypus

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Figure 34.37a

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Figure 34.37b

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Marsupials

- **Marsupials** include opossums, kangaroos, and koalas
- The embryo develops within a **placenta** in the mother's uterus
- A marsupial is born very early in its development
- It completes its embryonic development while nursing in a maternal pouch called a marsupium

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Figure 34.38

(a) A young brushtail possum

(b) A greater bilby

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Figure 34.38a

(a) A young brushtail possum

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Figure 34.38b

(b) A greater bilby

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- In some species, such as the bandicoot, the marsupium opens to the rear of the mother's body
- In Australia, convergent evolution has resulted in a diversity of marsupials that resemble the eutherians in other parts of the world

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Figure 34.39

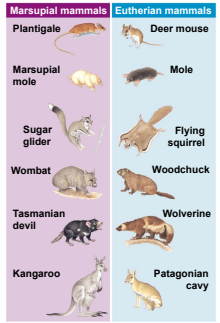

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Figure 34.39a

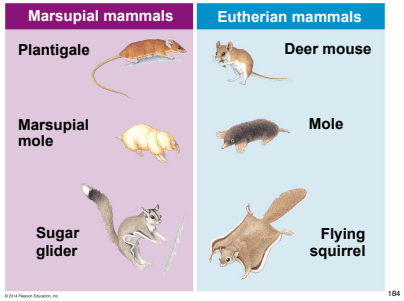

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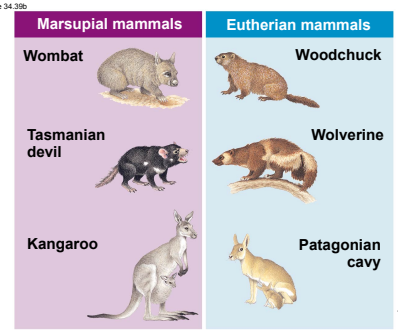
Figure 34.39b



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Eutherians (Placental Mammals)

- Compared with marsupials, **eutherians** have a more complex placenta
- Young eutherians complete their embryonic development within a uterus, joined to the mother by the placenta
- Molecular and morphological data give conflicting dates on the diversification of eutherians

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Figure 34.40a

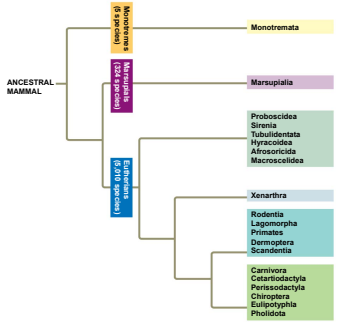

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Figure 34.40aa

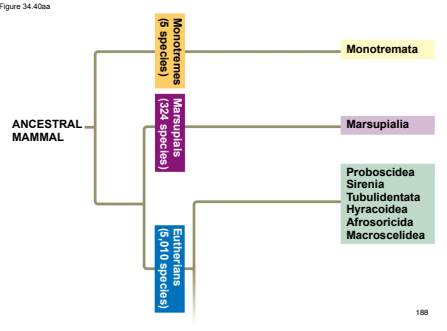

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Figure 34.40ab

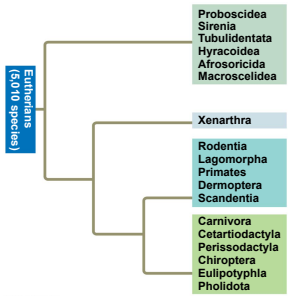

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Figure 34.40b

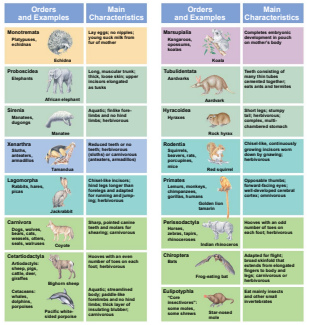

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Figure 34.40ba

Orders and Examples	Main Characteristics
Monotremata Platypuses, echidnas Echidna	Lay eggs; no nipples; young suck milk from fur of mother
Marsupialia Kangaroos, opossums, koalas Koala	Completes embryonic development in pouch on mother's body

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Figure 34.40bb

Orders and Examples	Main Characteristics
Proboscidea Elephants African elephant	Long, muscular trunk; thick, loose skin; upper incisors elongated as tusks
Sirenia Manatees, dugongs Manatee	Aquatic; finlike forelimbs and no hind limbs; herbivorous
Tubulidentata Aardvarks Aardvark	Teeth consisting of many thin tubes cemented together; eats ants and termites
Hyracoidea Hyraxes Rock hyrax	Short legs; stumpy tail; herbivorous; complex, multichambered stomach

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Figure 34.40bc

Orders and Examples	Main Characteristics
Xenarthra: Sloths, anteaters, armadillos (Tamandua)	Reduced teeth or no teeth; herbivorous (sloths) or carnivorous (anteaters, armadillos)
Lagomorpha: Rabbits, hares, picas (Jackrabbit)	Chisel-like incisors; hind legs longer than forelegs and adapted for running and jumping; herbivorous
Rodentia: Squirrels, beavers, rats, porcupines, mice (Red squirrel)	Chisel-like, continuously growing incisors worn down by gnawing; herbivorous
Primates: Lemurs, monkeys, chimpanzees, gorillas, humans (Golden lion tamarin)	Opposable thumbs; forward-facing eyes; well-developed cerebral cortex; omnivorous

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Figure 34.40bd

Orders and Examples	Main Characteristics
Carnivora: Dogs, wolves, bears, cats, weasels, otters, seals, walruses (Coyote)	Sharp, pointed canine teeth and molars for shearing; carnivorous
Cetartiodactyla: Artiodactyls: sheep, pigs, cattle, deer, giraffes (Bighorn sheep)	Hooves with an even number of toes on each foot; herbivorous
Cetaceans: whales, dolphins, porpoises (Pacific white-sided porpoise)	Aquatic; streamlined body; paddle-like forelimbs and no hind limbs; thick layer of insulating blubber; carnivorous

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Figure 34.40be

Orders and Examples	Main Characteristics
Perissodactyla: Horses, zebras, tapirs, rhinoceroses (Indian rhinoceros)	Hooves with an odd number of toes on each foot; herbivorous
Chiroptera: Bats (Frog-eating bat)	Adapted for flight; broad skinfold that extends from elongated fingers to body and legs; carnivorous or herbivorous
Eulipotyphla: "Core insectivores": some moles, some shrews (Star-nosed mole)	Eat mainly insects and other small invertebrates

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Video: Bat Licking Nectar

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Video: Bat Pollinating *Agave* Plant

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Video: Galápagos Sea Lion

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Video: Wolves Agonistic Behavior

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Video: Shark Eating a Seal

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Primates

- The mammalian order Primates includes lemurs, tarsiers, monkeys, and apes
- Humans are members of the ape group

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Derived Characters of Primates

- Most primates have hands and feet adapted for grasping, and flat nails

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- Other derived characters of primates
  - A large brain and short jaws
  - Forward-looking eyes close together on the face, providing depth perception
  - Complex social behavior and parental care
  - A fully **opposable thumb** (in monkeys and apes)

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Living Primates

- There are three main groups of living primates
  - Lemurs, lorises, and bush babies
  - Tarsiers
  - **Anthropoids** (monkeys and apes)

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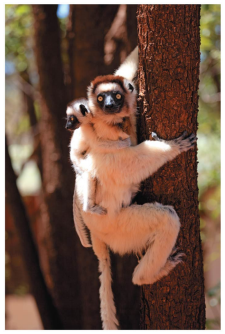
Figure 34.41



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- The oldest known anthropoid fossils, about 45 million years old, indicate that tarsiers are more closely related to anthropoids than to lemurs

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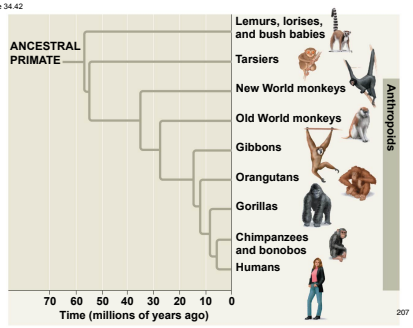
Figure 34.42



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- The first monkeys evolved in the Old World (Africa and Asia)
- In the New World (South America), monkeys first appeared roughly 25 million years ago
- New World and Old World monkeys underwent separate adaptive radiations during their many millions of years of separation

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Figure 34.43

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Figure 34.43a

(a) New World monkey: spider monkey

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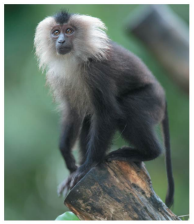
Figure 34.43b



(b) Old World monkey: macaque

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- The other group of anthropoids consists of primates informally called apes
- This group includes gibbons, orangutans, gorillas, chimpanzees, bonobos, and humans
- Apes diverged from Old World monkeys about 25–30 million years ago

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Figure 34.44

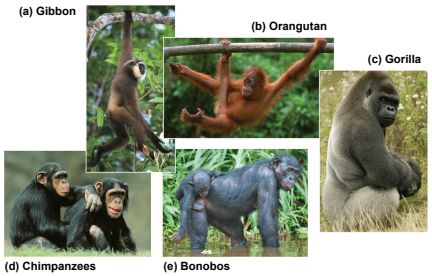

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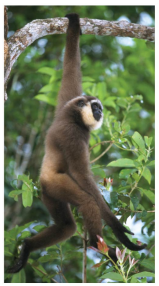
Figure 34.44a



(a) Gibbon

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Figure 34.44b

(b) Orangutan

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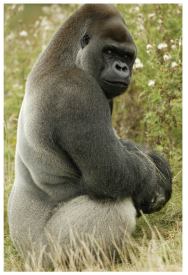
Figure 34.44c



(c) Gorilla

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Figure 34.44d

(d) Chimpanzees

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Figure 34.44e

(e) Bonobos

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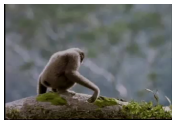
Video: Gibbons Brachiating



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Video: Chimp Agonistic Behavior

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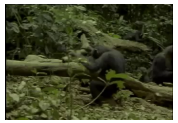
Video: Chimp Cracking Nut



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Concept 34.7: Humans are mammals that have a large brain and bipedal locomotion

- The species *Homo sapiens* is about 200,000 years old, which is very young, considering that life has existed on Earth for at least 3.5 billion years

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Derived Characters of Humans

- A number of characters distinguish humans from other apes
  - Upright posture and bipedal locomotion
  - Larger brains capable of language, symbolic thought, artistic expression, the manufacture and use of complex tools
  - Reduced jawbones and jaw muscles
  - Shorter digestive tract

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- The human and chimpanzee genomes are 99% identical
- Changes in regulatory genes can have large effects

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The Earliest Hominins

- The study of human origins is known as **paleoanthropology**
- **Hominins** (formerly called hominids) are more closely related to humans than to chimpanzees
- Paleoanthropologists have discovered fossils of about 20 species of extinct hominins

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Figure 34.45

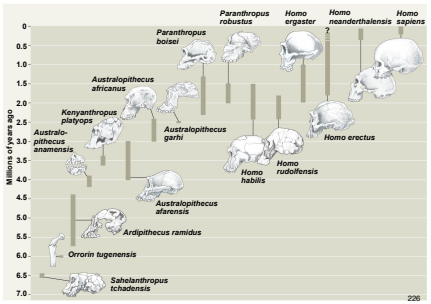

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Figure 34.45a

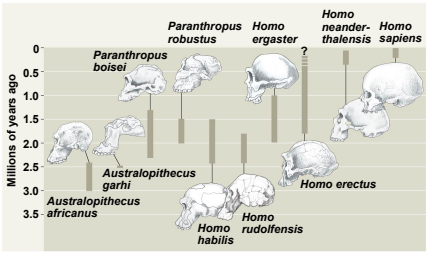

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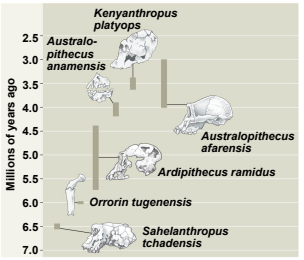
Figure 34.45b



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- The oldest fossil evidence of hominins dates back to 6.5 million years ago
- Early hominins show evidence of small brains and increasing bipedalism

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- Misconception: Early hominins were chimpanzees
  - Correction: Hominins and chimpanzees shared a common ancestor
- Misconception: Human evolution is like a ladder leading directly to *Homo sapiens*
  - Correction: Hominin evolution included many branches or coexisting species, though only humans survive today

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Australopiths

- Australopiths are a paraphyletic assemblage of hominins living between 4 and 2 million years ago
- Some species, such as *Australopithecus afarensis* walked fully erect

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Figure 34.47

(a) The Laetoli footprints **(b) An artist's reconstruction of *A. afarensis***

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Figure 34.47a

(a) The Laetoli footprints

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Figure 34.47b

(b) An artist's reconstruction of *A. afarensis*

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- "Robust" australopiths had sturdy skulls and powerful jaws
- "Gracile" australopiths were more slender and had lighter jaws

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Bipedalism

- Hominins began to walk long distances on two legs about 1.9 million years ago
- Bipedal walking was energy efficient in the arid environments inhabited by hominins at the time

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Tool Use

- The oldest evidence of tool use, cut marks on animal bones, is 2.5 million years old
- Fossil evidence indicates tool use may have originated prior to the evolution of large brains

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Early *Homo*

- The earliest fossils placed in our genus *Homo* are those of *Homo habilis*, ranging in age from about 2.4 to 1.6 million years
- Stone tools have been found with *H. habilis*, giving this species its name, which means "handy man"

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- *Homo ergaster* was the first fully bipedal, large-brained hominid
- The species existed between 1.9 and 1.5 million years ago
- *Homo ergaster* shows a significant decrease in sexual dimorphism (a size difference between sexes) compared with its ancestors

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- *Homo ergaster* fossils were previously assigned to *Homo erectus*; most paleoanthropologists now recognize these as separate species

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- *Homo erectus* originated in Africa by 1.8 million years ago
- It was the first hominin to leave Africa

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Neanderthals

- Neanderthals, *Homo neanderthalensis*, lived in Europe and the Near East from 350,000 to 28,000 years ago
- They were thick-boned with a larger brain, they buried their dead, and they made hunting tools
- Recent genetic analysis indicates that gene flow occurred between Neanderthals and *Homo sapiens*

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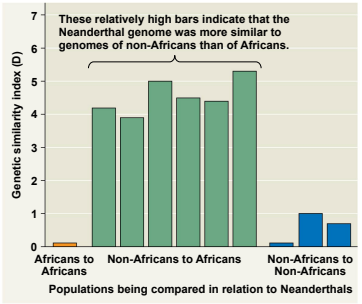
Figure 34.49 **Results**



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Homo Sapiens

- *Homo sapiens* appeared in Africa by 195,000 years ago
- All living humans are descended from these African ancestors

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Figure 34.UN10

A 160,000-year-old fossil of *Homo sapiens*.

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- The oldest fossils of *Homo sapiens* outside Africa date back about 115,000 years and are from the Middle East
- Humans first arrived in the New World sometime before 15,000 years ago
- In 2004, 18,000-year-old fossils were found in Indonesia, and a new small hominin was named: *Homo floresiensis*

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- *Homo sapiens* were the first group to show evidence of symbolic and sophisticated thought
- In 2002, a 77,000-year-old artistic carving was found in South Africa

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Figure 34.50

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Figure 34.UN09a

Hominin Species	Mean age (millions of years; x)	$x_i - \bar{x}$	Mean Brain Volume (cm^3; y)	$y_i - \bar{y}$	$(x_i - \bar{x}) \times (y_i - \bar{y})$
Ardipithecus ramidus	−4.4		325		
Australopithecus afarensis	−3.4		375		
Homo habilis	−1.9		550		
Homo ergaster	−1.6		850		
Homo erectus	−1.2		1,000		
Homo heidelbergensis	−0.5		1,200		
Homo neanderthalensis	−0.1		1,400		
Homo sapiens	0.0		1,350		

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Figure 34.UN09b

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Figure 34.UN11

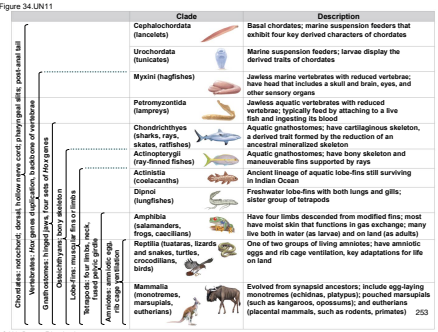

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Figure 34.UN11a

Clade	Description
Cephalochordata (lancelets)	Basal chordates; marine suspension feeders that exhibit four key derived characters of chordates
Urochordata (tunicates)	Marine suspension feeders; larvae display the derived traits of chordates
Myxini (hagfishes)	Jawless marine vertebrates with reduced vertebrae; have head that includes a skull and brain, eyes, and other sensory organs
Petromyzontida (lampreys)	Jawless aquatic vertebrates with reduced vertebrae; typically feed by attaching to a live fish and ingesting its blood
Chondrichthyes (sharks, rays, skates, ratfishes)	Aquatic gnathostomes; have cartilaginous skeleton, a derived trait formed by the reduction of an ancestral mineralized skeleton
Actinopterygii (ray-finned fishes)	Aquatic gnathostomes; have bony skeleton and maneuverable fins supported by rays
Actinistia (coelacanths)	Ancient lineage of aquatic lobe-fins still surviving in Indian Ocean
Dipnoi (lungfishes)	Freshwater lobe-fins with both lungs and gills; sister group of tetrapods

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Figure 34.UN11b

Clade	Description
Amphibia (salamanders, frogs, caecilians)	Have four limbs descended from modified fins; most have moist skin that functions in gas exchange; many live both in water (as larvae) and on land (as adults)
Reptilia (tuataras, lizards and snakes, turtles, crocodilians, birds)	One of two groups of living amniotes; have amniotic eggs and rib cage ventilation, key adaptations for life on land
Mammalia (monotremes, marsupials, eutherians)	Evolved from synapsid ancestors; include egg-laying monotremes (echidnas, platypus); pouched marsupials (such as kangaroos, opossums); and eutherians (placental mammals, such as rodents, primates)

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Figure 34.UN12

Deviation from Expected Brain Size*	−2.4	−2.1	2.0	−1.8	−1.0	0.0	0.3	0.7	1.2	1.3	2.0	2.3	3.0	3.2
Mortality Rate	0.9	0.7	0.5	0.9	0.4	0.7	0.8	0.4	0.8	0.3	0.6	0.6	0.3	0.6

D. Sol et al., Big-brained birds survive better in nature, *Proceedings of the Royal Society B* 274:763–769 (2007).

* Values < 0 indicate brain sizes smaller than expected; values > 0 indicate sizes larger than expected.

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Figure 34.UN13

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