Vertebrates are chordates with a backbone

- A skeletal system and complex nervous system have allowed vertebrates efficiency at two essential tasks: capturing food and evading predators

**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
  - Vertebræ enclosing a spinal cord
  - An elaborate skull
  - Fin rays, in the aquatic forms
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.

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.

<table>
<thead>
<tr>
<th>Cephalochordata</th>
<th>Urochordata</th>
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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.

Slime glands
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.

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.

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

Origins of Bone and Teeth

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

Gnathostomes are vertebrates that have jaws

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

![Diagram of Gill slits and Cranium with Modified skeletal rods](image)

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.

![Fossil Placoderm](image)

- 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.
- Three lineages of jawed vertebrates survive today: *chondrichthyans*, *ray-finned fishes*, and *lobe-fins*.
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
- A second subclass is composed of a few dozen species of ratfishes, or chimaeras

Figure 34.14

(a) Blacktip reef shark
(Carcharhinus melanopterus)

(b) Southern stingray
(Dasyatis americana)

(c) Spotted ratfish
(Hydrolagus colliei)

- 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
- 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
- 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 osteichthyan have a bony endoskeleton
- Osteichthyan include the bony fishes and tetrapods
- Aquatic osteichthyan are the vertebrates we informally call fishes

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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
Ray-Finned Fishes

- **Actinopterygii**, the ray-finned fishes, include nearly all the familiar aquatic osteichthyan.
- 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.

Yellowfin tuna (*Thunnus albacares*)

Red lionfish (*Pterois volitans*)

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.

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.
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.

4. Vertebrate Chordates – Tetrapods

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
The Origin of Tetrapods

- **Tiktaalik**, nicknamed a “fishapod,” shows both fish and tetrapod characteristics
  - 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

- **Tiktaalik** could most likely prop itself on its fins, but not walk

- The first tetrapods appeared ~365 million years ago
Amphibians

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

Salamanders (Urodela)

- 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

Frogs (Anurans)

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

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

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
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.

Amniotes are tetrapods that have a terrestrially adapted egg.

Amniotes living members are the reptiles, including birds, and mammals.

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.

![Amnion]
The amniotic egg was a key adaptation to life on land.

- The amniotic egg 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.

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.
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

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

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
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**.

Dinosaurs, with the exception of birds, became extinct by the end of the Cretaceous.

Their extinction may have been partly caused by an asteroid.
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
- Some turtles have adapted to deserts and others live entirely in ponds and rivers
- The largest turtles live in the sea

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

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
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

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

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

Figure 34.29
- Flight enhances hunting and scavenging, escape from terrestrial predators, and migration
- Flight requires a great expenditure of energy, acute vision, and fine muscle control

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

Mammals
- Mammals are amniotes that have hair and produce milk
- Mammals, class Mammalia, are represented by more than 5,300 species
- Cephalochordata
- Urochordata
- Myxini
- Petromyzontida
- Chondrichthyes
- Actinopterygii
- Actinistia
- Dipnoi
- Amphibia
- Reptilia
- Mammalia

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
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
- 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

Monotremes

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

![A young brushtail possum](image1)

![A greater bilby](image2)

- 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

<table>
<thead>
<tr>
<th>Marsupial mammals</th>
<th>Eutherian mammals</th>
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<td>Marsupial mole</td>
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<tr>
<td>Sugar glider</td>
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<tr>
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<td>Woodchuck</td>
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<tr>
<td>Tasmanian devil</td>
<td>Wolverine</td>
</tr>
<tr>
<td>Kangaroo</td>
<td>Patagonian cavy</td>
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</tbody>
</table>

**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
**Primates**

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

**Derived Characters of Primates**

- Most primates have hands and feet adapted for grasping, and flat nails.
- 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).
There are three main groups of living primates:
- Lemurs, lorises, and bush babies
- Tarsiers
- **Anthropoids**
  (monkeys and apes)

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

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.

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

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

**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
- The oldest fossil evidence of hominins dates back to 6.5 million years ago
- Early hominins show evidence of small brains and increasing bipedalism
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
  - “Robust” australopiths had sturdy skulls and powerful jaws
  - “Gracile” australopiths were more slender and had lighter jaws

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

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

Early species in the genus 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”
- 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
Homo ergaster fossils were previously assigned to Homo erectus; most paleoanthropologists now recognize these as separate species.

Homo erectus originated in Africa by 1.8 million years ago and was the first hominin to leave Africa.

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.

Homo Sapiens

Homo sapiens appeared in Africa by 195,000 years ago.

All living humans are descended from these African ancestors.

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