BIOL 01112
General Biology II Lecture

CHAPTER 34
The Origin and Evolution of Vertebrates

Dr. Adam Hrincevich

CH 34 Learning Objectives

1. Identify key derived characters of chordates.
2. Describe the evolutionary history of vertebrates.
3. Describe gnathostomes and explain the evolutionary advantages of having jaws.
4. Explain how the first tetrapods may have arisen.
5. Identify key derived characters of amniotes and give examples of amniote groups.
6. Differentiate between monotremes, marsupials, and eutherian mammals.
7. Identify key hominin lineages and describe their characteristics.

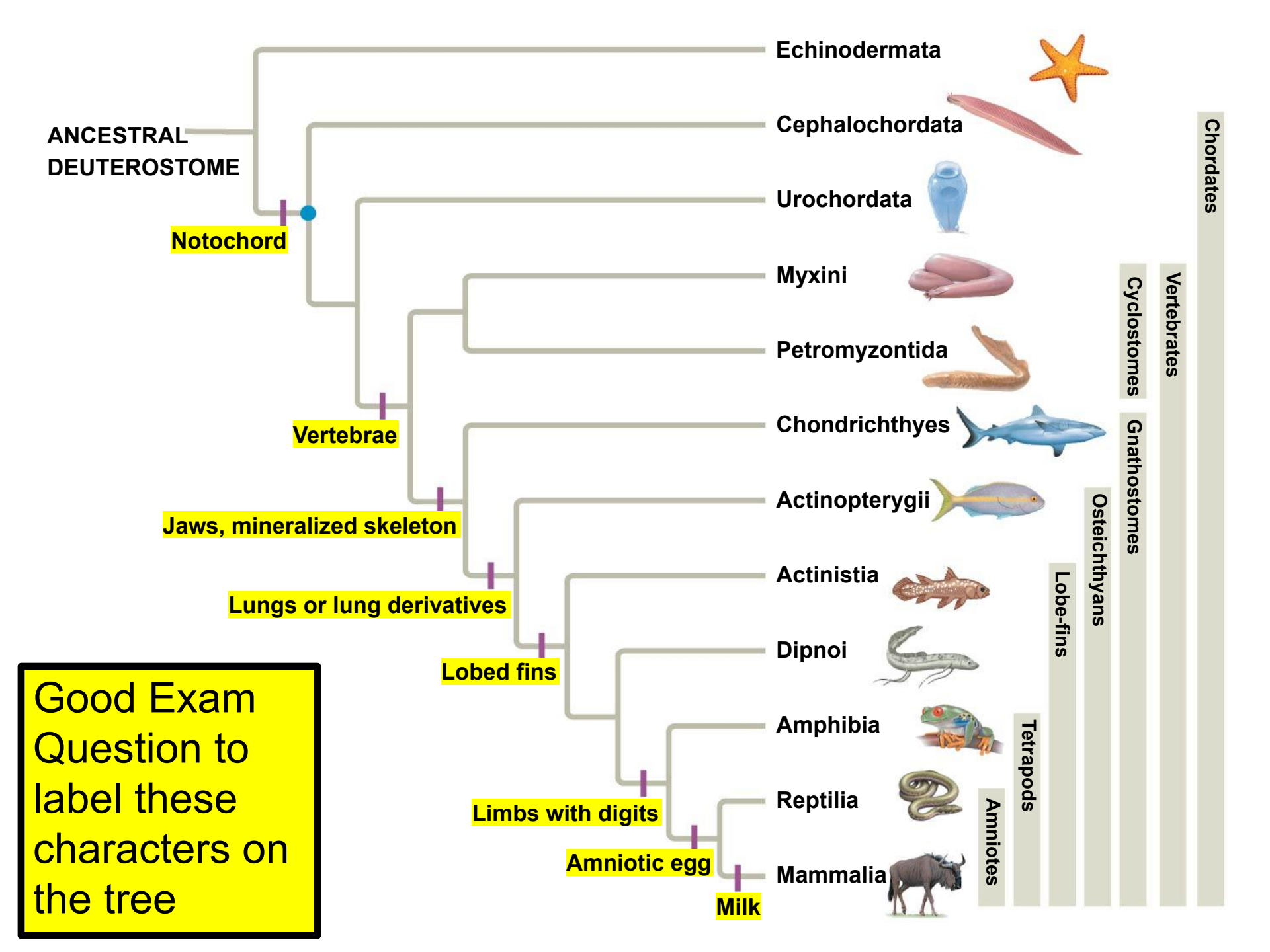
I would suggest completing the crossword puzzle to help you understand the terminology and correlate how the terms relate to topics covered in this chapter.

Half a Billion Years of Backbones

- In the Cambrian period (~530 MYA), an huge 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 **vertebrates** get their name from vertebrae, the series of bones that make up the backbone
- One lineage of vertebrates colonized land 365 MYA
- They gave rise to modern amphibians, reptiles (including birds), and mammals
- There are > 57,000 species of vertebrates, including the largest organisms ever to live on Earth

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
  1. Urochordates
  2. Cephalochordates

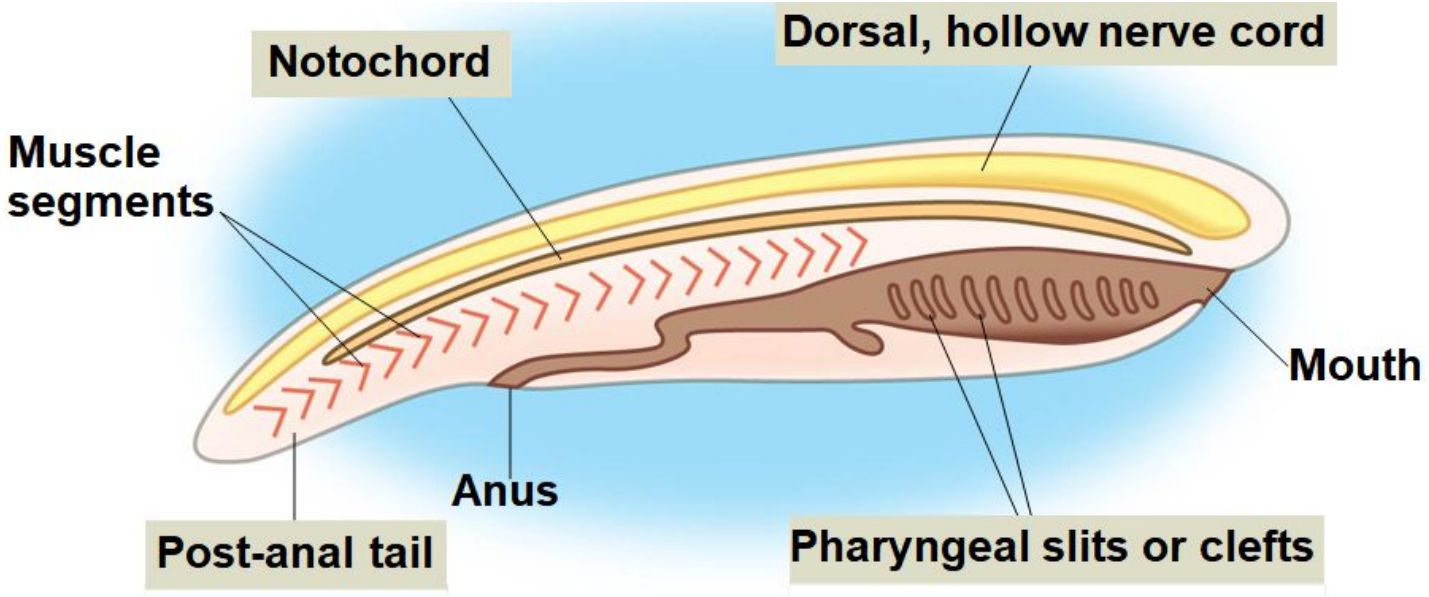


Good Exam Question to label these characters on the tree

Derived Characters of Chordates

- All chordates share a set of 4 traits; some only have a few of these traits during embryonic development

1. notochord
2. dorsal, hollow nerve cord
3. pharyngeal slits or clefts
4. muscular, post-anal tail



1. *Notochord*

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

2. *Dorsal, Hollow Nerve Cord*

- The nerve cord 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

3. *Pharyngeal Slits or Clefts*

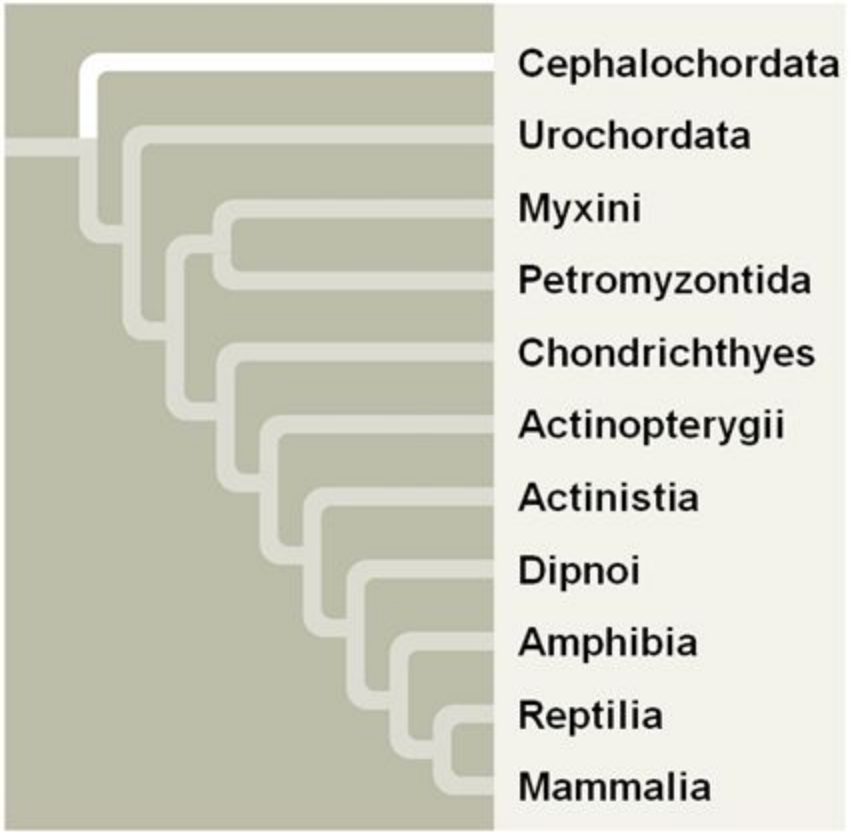
- In all chordate embryos, grooves form along the outer surface of the pharynx called **pharyngeal clefts**
- In most chordates, these grooves develop into **pharyngeal slits** that open to the outside of the body
- Functions of pharyngeal slits
  - Suspension-feeding structures in many invertebrate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

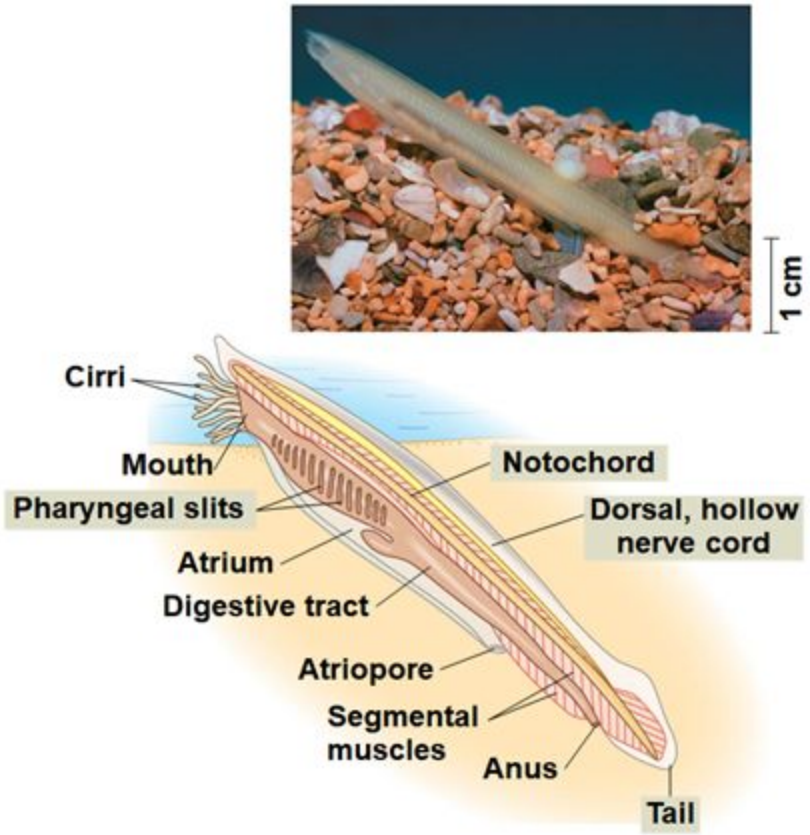
4. *Muscular, Post-Anal Tail*

- 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

Lancelets

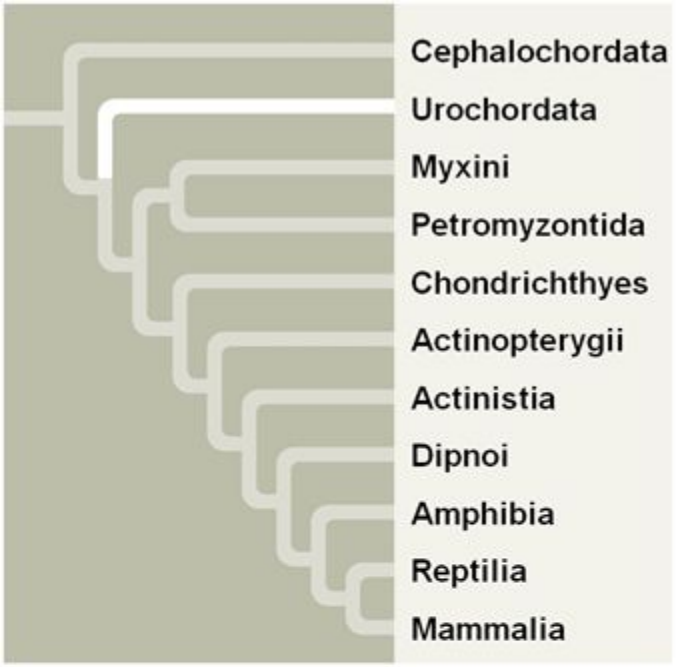
- **Lancelets** (Cephalochordata) are named for their <u>bladelike shape</u>
- They are marine suspension feeders that retain characteristics of the <u>chordate body plan as adults</u>





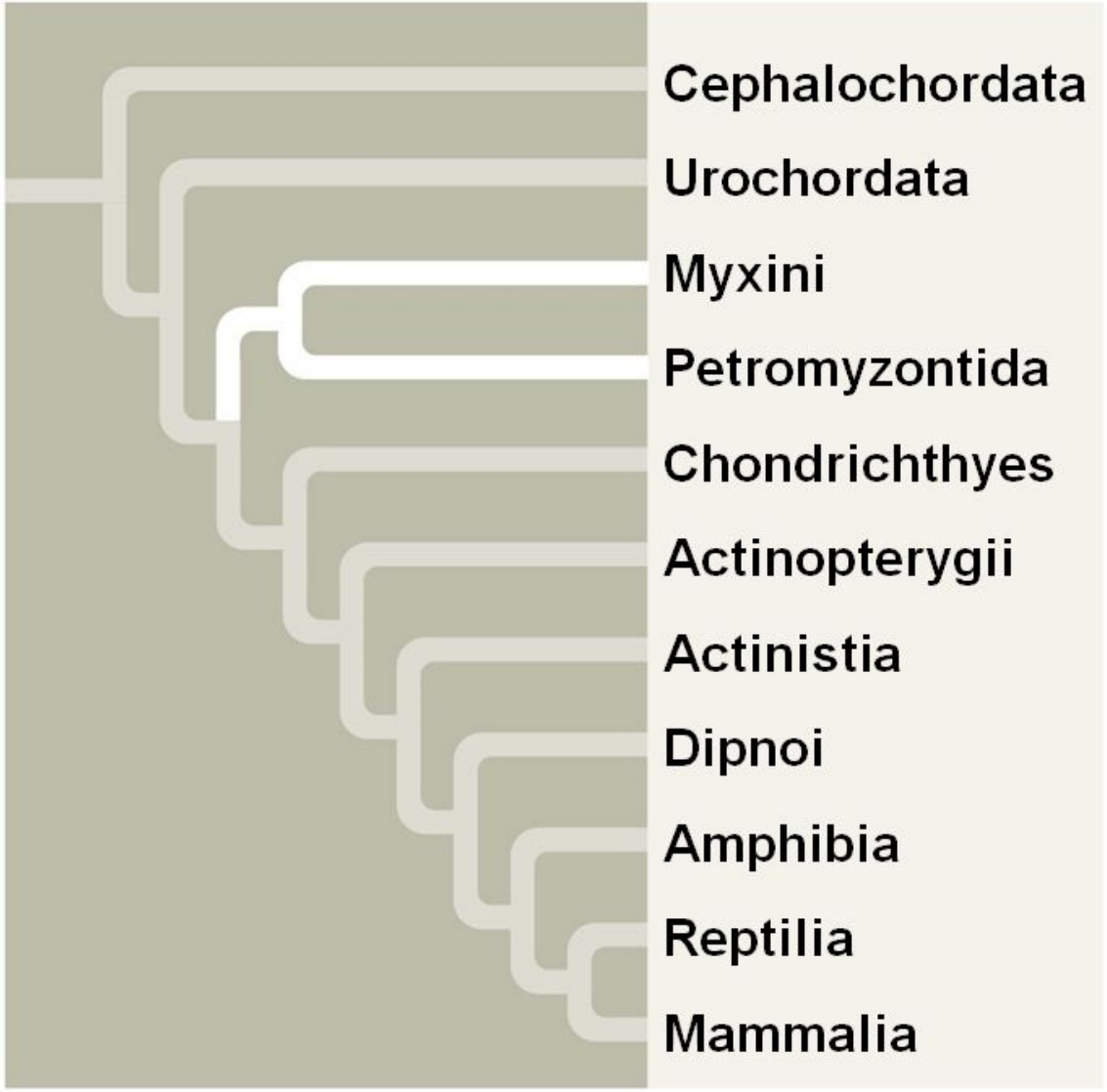
Tunicates or “Sea Squirts” (Urochordata)

- **Tunicates** are more closely related to other chordates than are lancelets
- Resemble chordates during their larval stage
- Metamorphosis from the larva to adult form involves the resorption of the tail and notochord
- Adult tunicates draw in water and filter food particles
- When attacked, they shoot water through their excurrent siphon



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
  1. Capturing food
  2. Evading predators



Hagfish & Lampreys (Myxini & Petromyzontida)

- 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

Hagfishes (Myxini)

- 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, a nasal opening, and tooth-like formations in their mouths
- All are marine; most are bottom-dwelling scavengers
- Produce slime to repel competitors and predators

Lampreys (Petromyzontida)

- Jawless vertebrates that inhabit SW & FW habitats
- Some are parasites that feed by clamping their mouths onto a live fish
- Free-living species feed as larvae for several years and then mature, reproduce, and die within a few days
- Have a notochord and cartilaginous skeleton

Concept 34.3: Gnathostomes are vertebrates that have jaws

- Today, jawed vertebrates, or **gnathostomes**, outnumber jawless vertebrates
- Includes sharks and their relatives, ray/lobe-finned fishes, amphibians, reptiles, birds, and mammals
- Have hinged jaws with teeth used to grip/slice food
- An enlarged forebrain associated with enhanced senses of smell and vision
- The **lateral line system**, rows of organs sensitive to vibrations that are located along each side of body of aquatic gnathostomes

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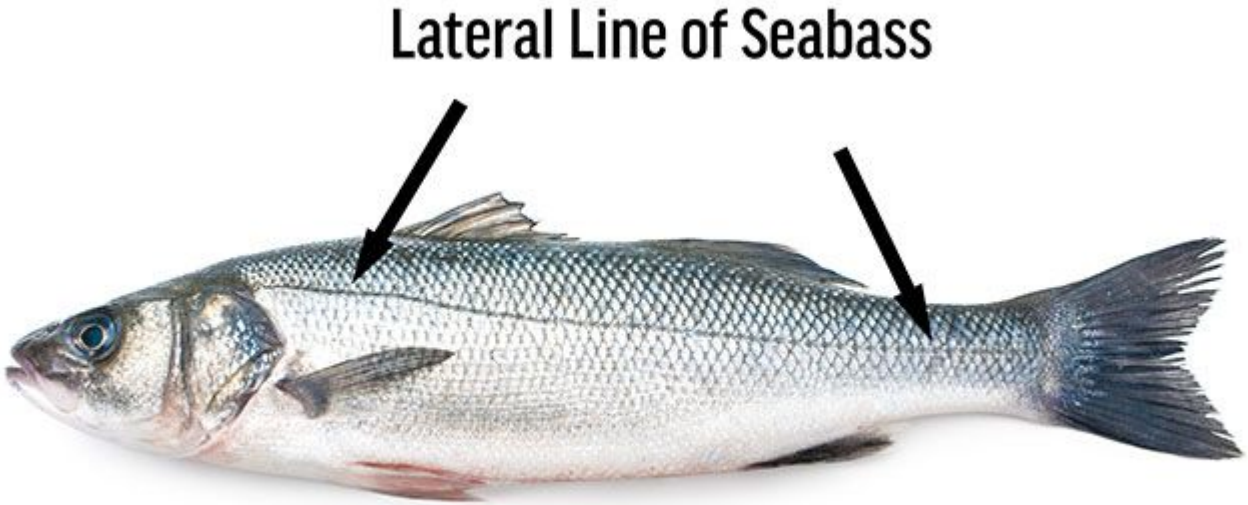
the **lateral line system**, rows of organs sensitive to vibrations that are located along each side of the body of aquatic gnathstomes

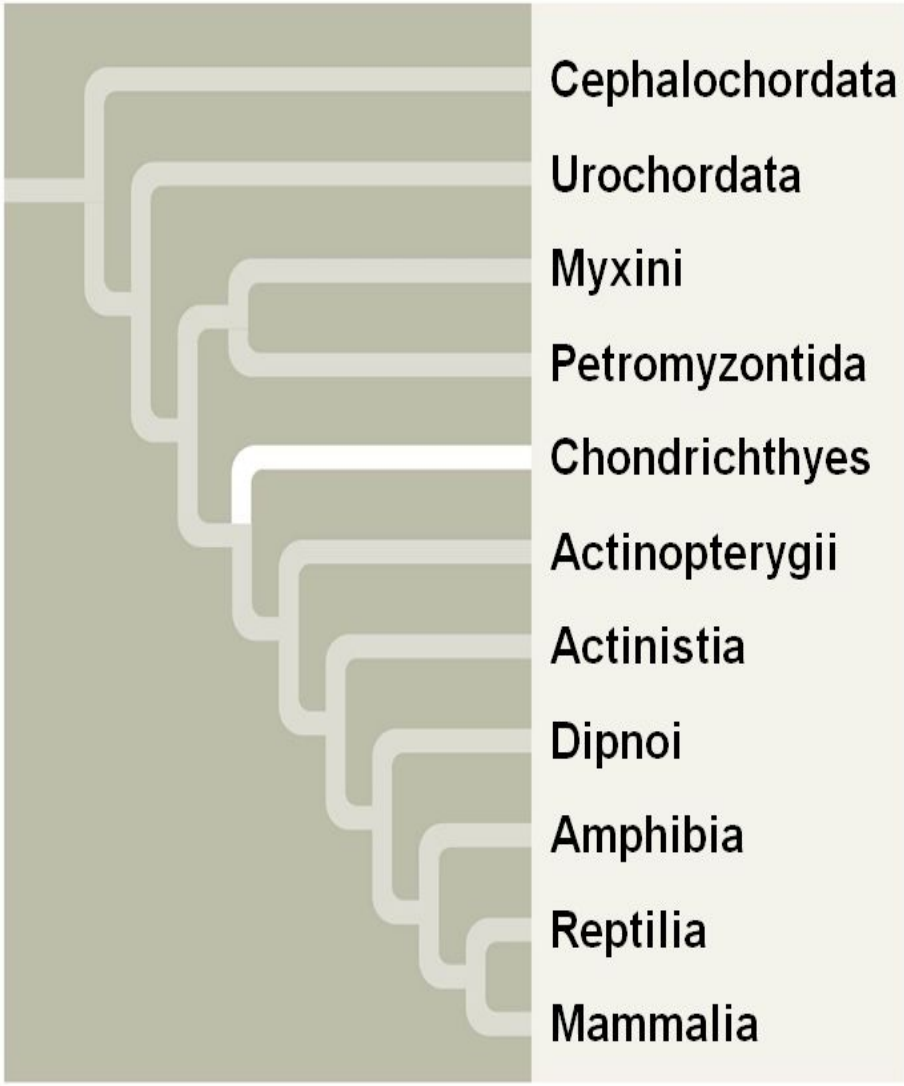


Fossil Gnathostomes

- The earliest gnathostomes appeared in the fossil record 440 MYA
- Over time, dorsal, ventral, and anal fins stiffened by bony structures called fin rays evolved
- Fin rays provided thrust and steering control for pursuit of prey and avoidance of predators
- The early gnathostomes included armored vertebrates called **placoderms**

Chondrichthyans (Sharks, Rays, and Their Relatives)

- **Chondrichthyans** have a skeleton composed primarily of cartilage
- The largest and most diverse group of chondrichthyans includes the sharks, rays, and skates
- A second group is composed of a few dozen species of ratfishes, or chimaeras

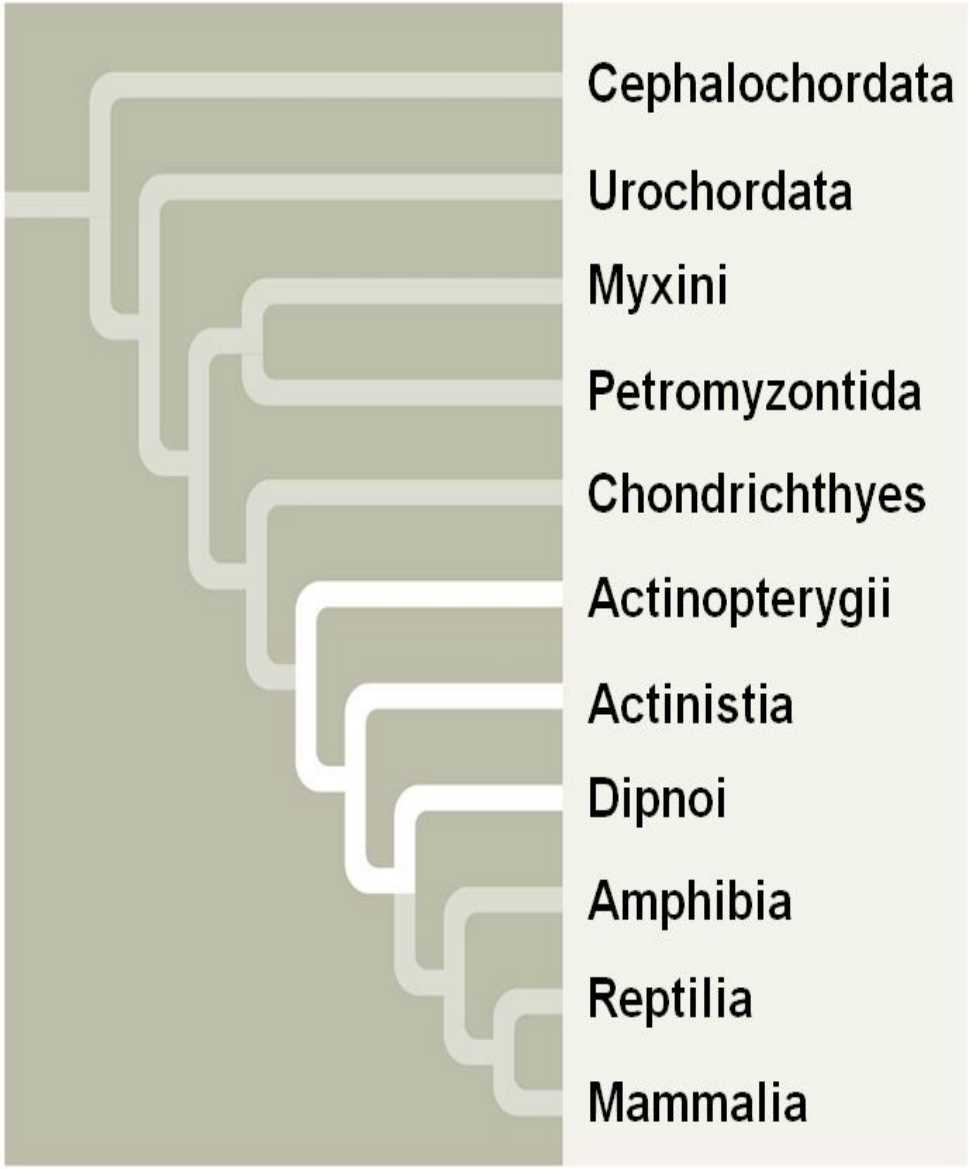


- Sharks have a streamlined body and swift swimmers
- Dorsal fins function as stabilizers, and paired pectoral and pelvic fins are used for maneuvering
- Continual swimming keeps sharks from sinking and maintains continuous flow of water over gills
- The largest sharks are suspension feeders, but most are carnivores
- Sharks have a short digestive tract with a spiral valve that increases surface area and slows the passage of food
- Acute senses including sight, smell, and the ability to detect electrical fields from nearby animals are adaptations for their active carnivorous lifestyle

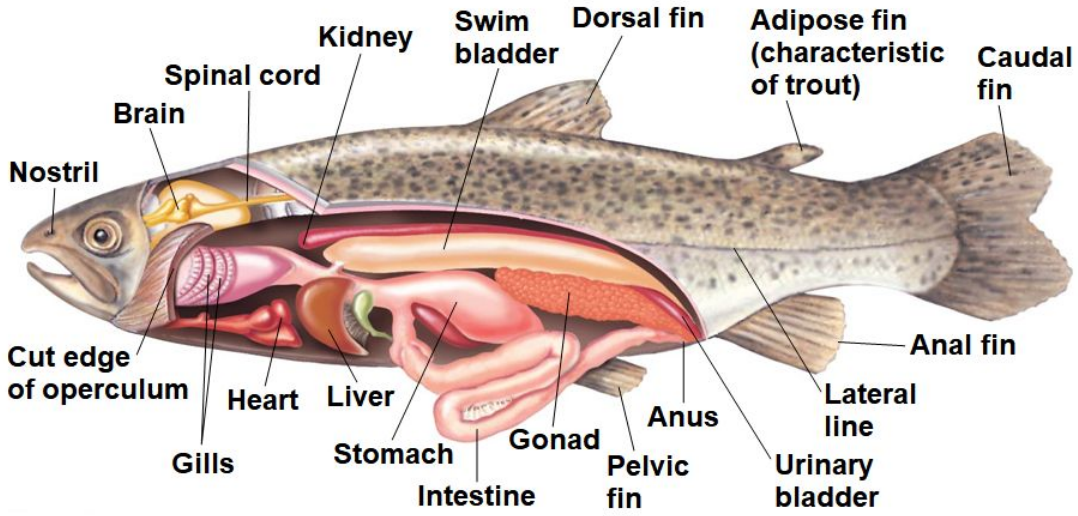
- Shark eggs are fertilized internally, but embryos can develop in different ways
  - **Oviparous**: Eggs hatch outside the mother's body
  - **Ovoviviparous**: Eggs are retained within the oviduct; young are born after hatching within the uterus
  - **Viviparous**: The embryo develops within the uterus and is nourished from the mother's blood through a yolk sac placenta
- The reproductive tract, excretory system, and digestive tract empty into the **cloaca**
- Most rays are bottom-dwellers that feed on molluscs and crustaceans
- They are flattened and have enlarged pectoral fins that function like water wings; tail may have barbs

Ray-Finned Fishes and Lobe-Fins

- The vast majority of vertebrates are **osteichthyans**, nearly all of which have a bony endoskeleton
- Osteichthyans include the bony fishes and tetrapods
- Aquatic osteichthyans are the vertebrates we informally call fishes



- 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**
- The skin secretes mucus and is covered by flattened, bony scales in most fishes
- Most species are oviparous, but some have internal fertilization and birthing

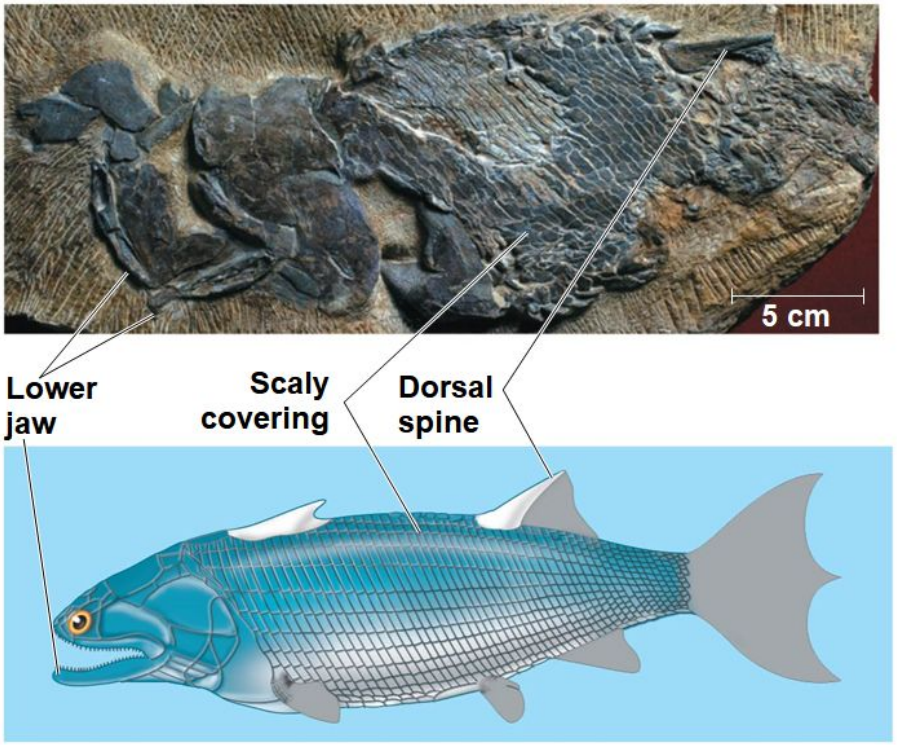


Ray-Finned Fishes

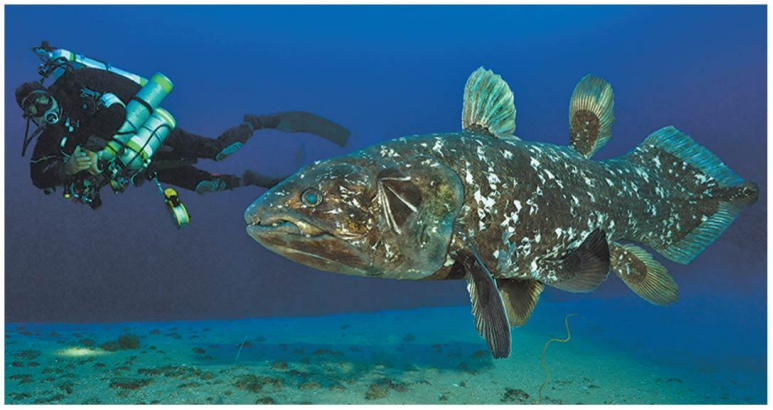
- The **ray-finned fishes** (Actinopterygii) include nearly all the familiar aquatic osteichthyans
- Ray-finned fishes originated during the Silurian period (444-419 MYA)
- The fins, supported mainly by long, flexible rays, are modified for maneuvering and defense
- Humans have harvested ray-finned fishes for thousands of years, but industrial-scale fishing has driven many fisheries to collapse
- Ray-finned fishes are also negatively impacted by dams that change water flow patterns, affecting prey capture, migration, and spawning

Lobe-Fins

- The **lobe-fins** (Sarcopterygii) also originated in the Silurian period
- They have rod-shaped bones surrounded by a thick layer of muscle in their pelvic and pectoral fins



- Three lineages survive and include coelacanths (Actinistia), lungfishes (Dipnoi), and tetrapods
- Coelacanths were thought to have become extinct 75 MYA, but a living one was caught off the coast of South Africa in 1938
- 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 is tetrapods, a group that adapted to life on land



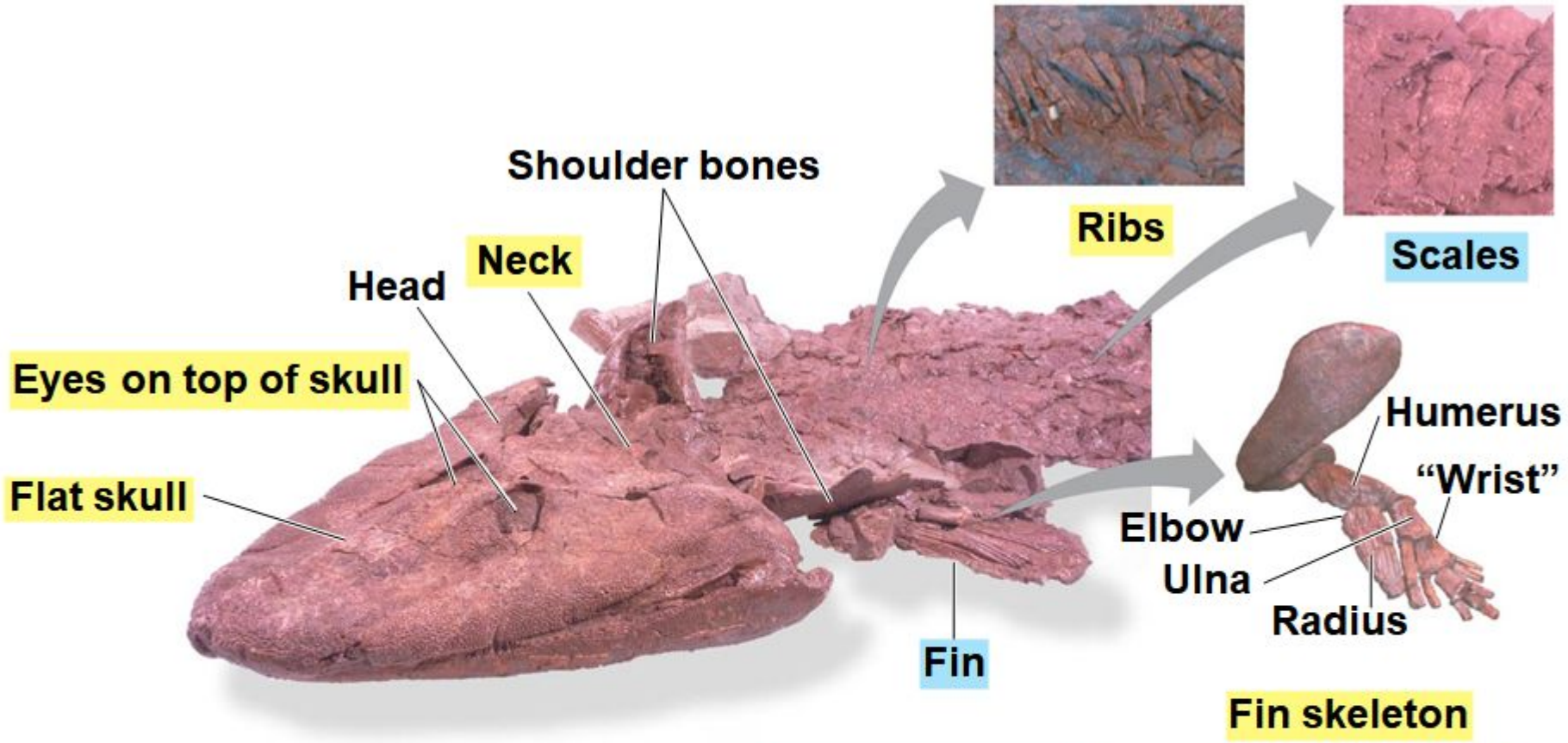
Concept 34.4: Tetrapods are gnathostomes that have limbs

- 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
- Tetrapods diversified greatly following the colonization of land
- **Tetrapods** have some specific adaptations
  1. four limbs and feet with digits
  2. A neck, which allows separate movement of the head
  3. Fusion of the pelvic girdle to the backbone
  4. The absence of gills (except some aquatic species)
  5. Ears for detecting airborne sounds

The Origin of Tetrapods

- *Tiktaalik*, nicknamed a "fishapod," shows both fish and tetrapod characteristics
- Traits it shares with fish include fins, gills, lungs, and scales
- Traits shared with tetrapods but not fish include
  - Ribs to breathe air and support its body
  - A neck and shoulders, allowing movement of the head
  - Front fins with the bone pattern of a tetrapod limb
  - Pelvis and rear fin that are larger and more robust than those found in fish
- *Tiktaalik* could most likely prop itself on its fins and walk in water, but it is unlikely that it walked on land

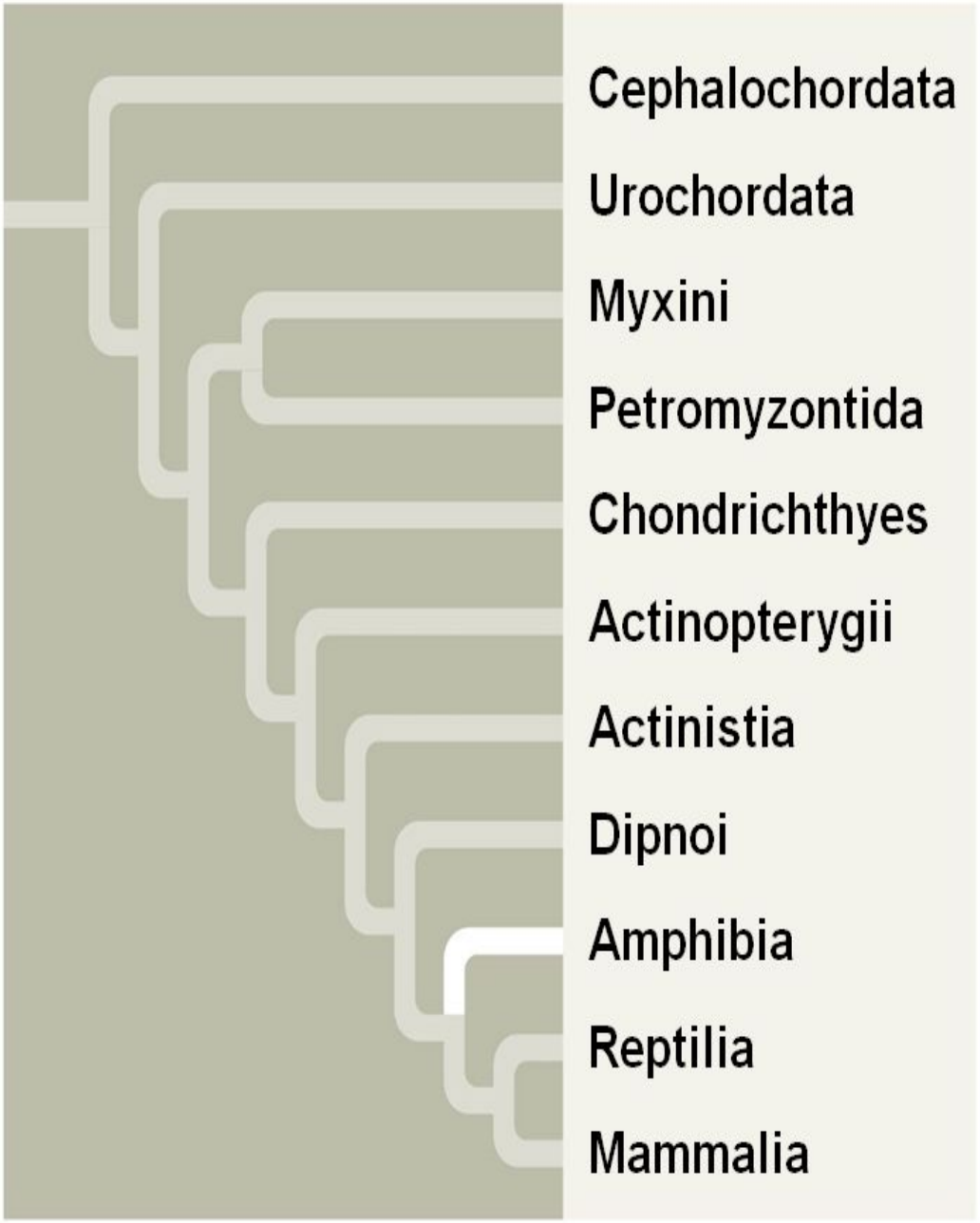
Figure 34.20



Fish Characters	Tetrapod Characters
Scales	Neck
Fins	Ribs
Gills and lungs	Fin skeleton
	Flat skull
	Eyes on top of skull

Amphibians

- **Amphibians** (class Amphibia) are represented by about 6,150 species in three clades
  - Salamanders (Urodela, " tailed ones")
  - Frogs (Anura, "tail-less ones")
  - Caecilians (Apoda, "legless ones")



Salamanders

- Salamanders (Urodela) 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 salamanders

(a) Order Urodela

Frogs

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

(b) Order Anura

Caecilians

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

(c) Order Apoda

Figure 34.23

(a) The tadpole

(b) During metamorphosis

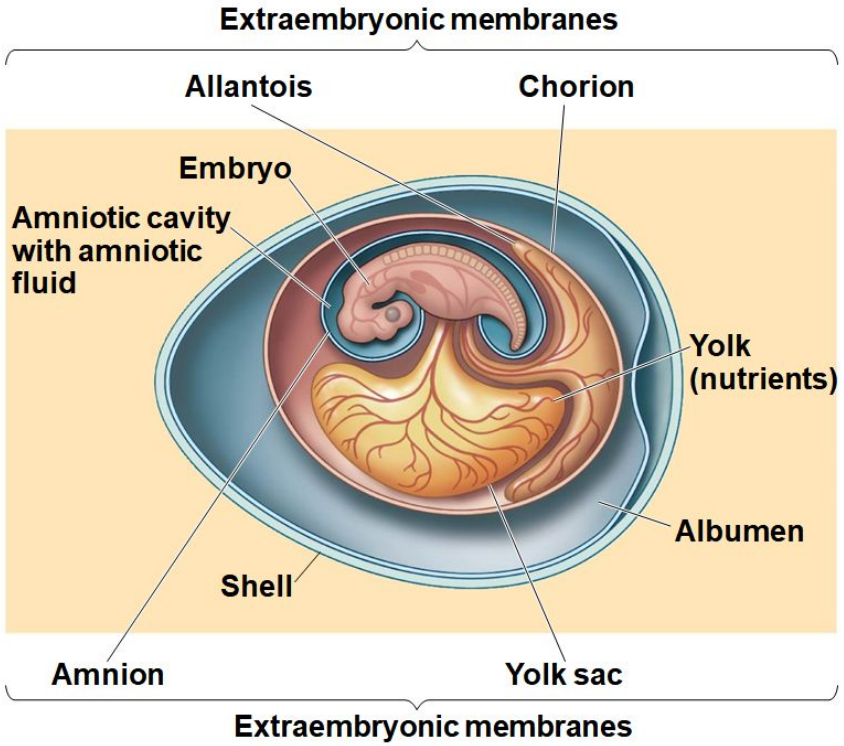
(c) The adults return to water to mate

- Some amphibians are strictly aquatic or strictly terrestrial, but most are found in damp habitats
- 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
- Amphibian populations have been declining in recent decades
- At least 9 amphibian species have become extinct in the past 40 years; more than 100 others have not been observed and may be extinct

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

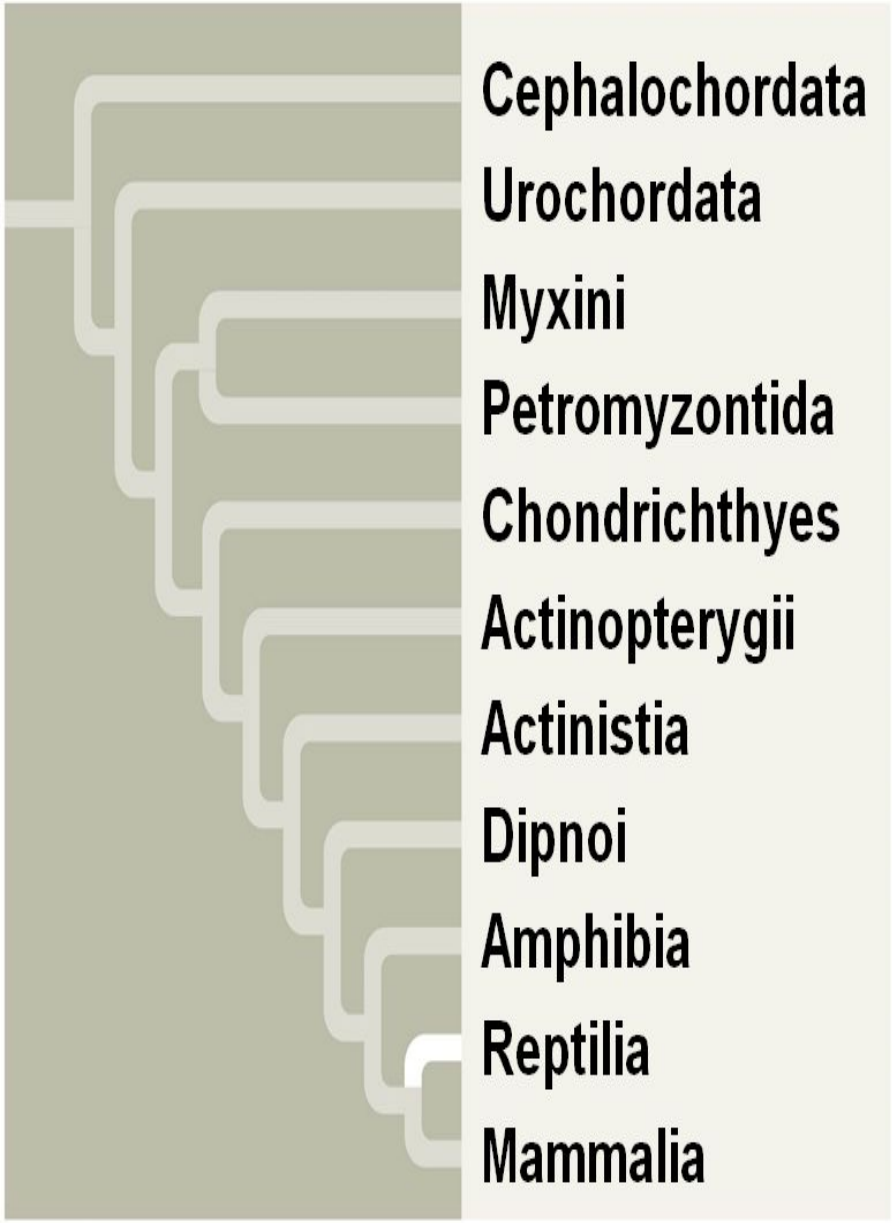
- **Amniotes** are a group of tetrapods whose living members are the reptiles, including birds, and mammals
- Amniotes are named for the major derived character of the clade, the **amniotic egg**, which contains membranes that protect the embryo
- The extraembryonic membranes are the amnion, chorion, yolk sac, and allantois
- The amnion encloses the embryo in a fluid-filled sac that reduces the dependence of tetrapods on an aqueous environment for reproduction

- 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



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 of land
- Fertilization occurs internally, before the eggshell is secreted



- 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 & Evolutionary Radiation of Reptiles

- Fossil evidence indicates that the earliest reptiles lived about 310 MYA and resembled lizards
- Like all living reptiles, early reptiles were **diapsids**
- A key derived character of diapsids is a pair of holes on each side of the skull behind the eye sockets through which muscles pass to attach to the jaw
- The diapsids are composed of two main lineages: the lepidosaurs and the archosaurs
- The **lepidosaurs** include tuataras, lizards, snakes, and extinct mososaurs
- The **archosaur** lineage produced the the turtles, crocodilians, pterosaurs, and dinosaurs

- **Pterosaurs** were the first tetrapods to exhibit flapping flight; they went extinct by 66 MYA
- The **dinosaurs** diversified tremendously in size/shape
- They included herbivores with diverse adaptations for defense and bipedal carnivores called **theropods**, which included the ancestors to birds
- Fossil discoveries concluded that many dinosaurs were agile and fast moving and had parental care
- Some anatomical suggests some were endotherms
- Dinosaurs, with the exception of birds, became extinct by the end of the Cretaceous (66 MYA)
- Their extinction may have been partly caused by an asteroid

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

(a) Tuatara (*Sphenodon punctatus*)

- The other major living lineage of lepidosaurs consists of the squamates, the lizards and snakes
- Squamates range in size from the tiny Jaragua lizard at 16 mm long to the Komodo dragon at 3 m long

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

- Snakes are legless lepidosaurs that evolved from lizards with legs
- 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

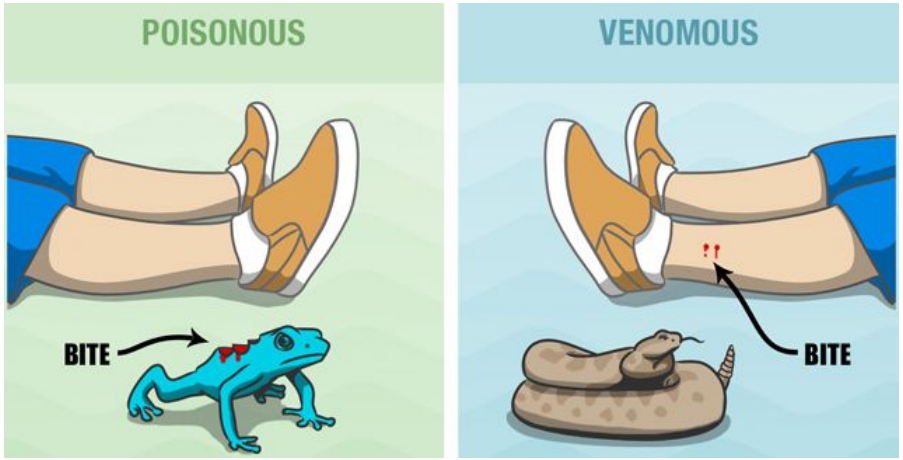
(c) Wagler's pit viper (*Tropidolaemus wagleri*)

Toxin vs. Poison vs. Venom?

- **Toxin** is a chemical substance produced within living cells or organisms. (Ex. viruses, proteins, or peptides)

- **Poison** is a substance that can cause illness or death when absorbed or ingested (Ex. Mercury, Puffer fish, Fugu, Ricin)

- **Venom** is a substance produced by an animal for self defense & injected into another animal (EX: Scorpion, Stingers, Fangs)



Short answer: If it bites you and you die it's venomous; if you bite it and you die it's poisonous. For more information, click ***HERE***

Turtles

- Turtles have several distinctive traits including the lack of holes in the skull behind the eye socket
- New fossil evidence indicates that turtles once had, but lost, the skull holes over the course of evolution
- All turtles have a boxlike shell made of upper and lower shields that are fused to the vertebrae, clavicles, and ribs
- Some have adapted to deserts and others live in ponds and rivers, and the largest 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

Crocodilians

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

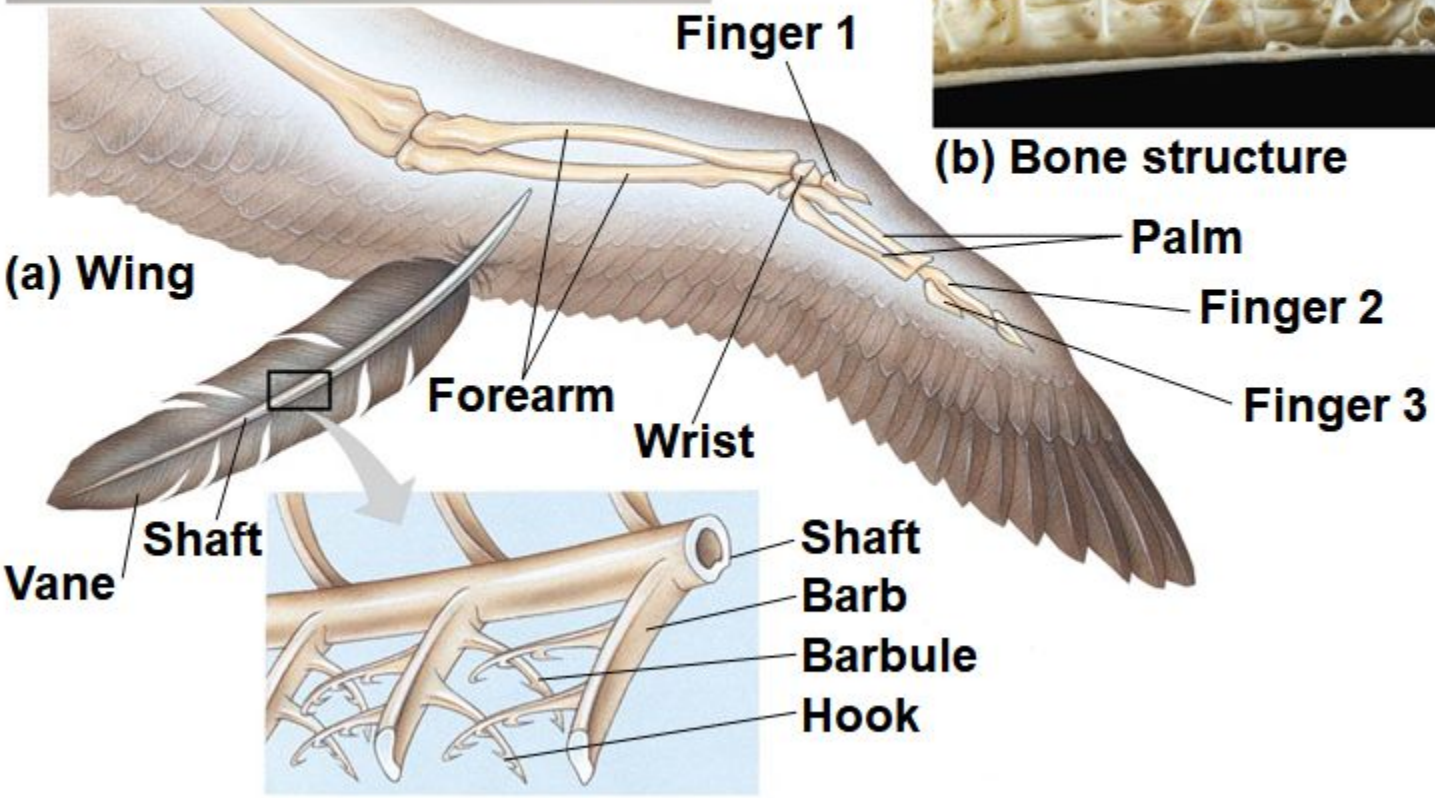
(e) American alligator (*Alligator mississippiensis*)

Birds

- Birds are actually modified reptiles, designed for flight
- The major adaptation is wings with keratin feathers
- Weight-saving adaptations for flight include lack of a urinary bladder, single ovary, small gonads, no teeth
- Flight enhances hunting and scavenging, escape from terrestrial predators, and migration
- Flight has high energy demands, acute vision, and fine muscle control
- Birds generally display complex behaviors including elaborate courtship rituals
- Fertilization is internal; Eggs must be kept warm through brooding by one or both parents

Figure 34.30

(b) Bone structure



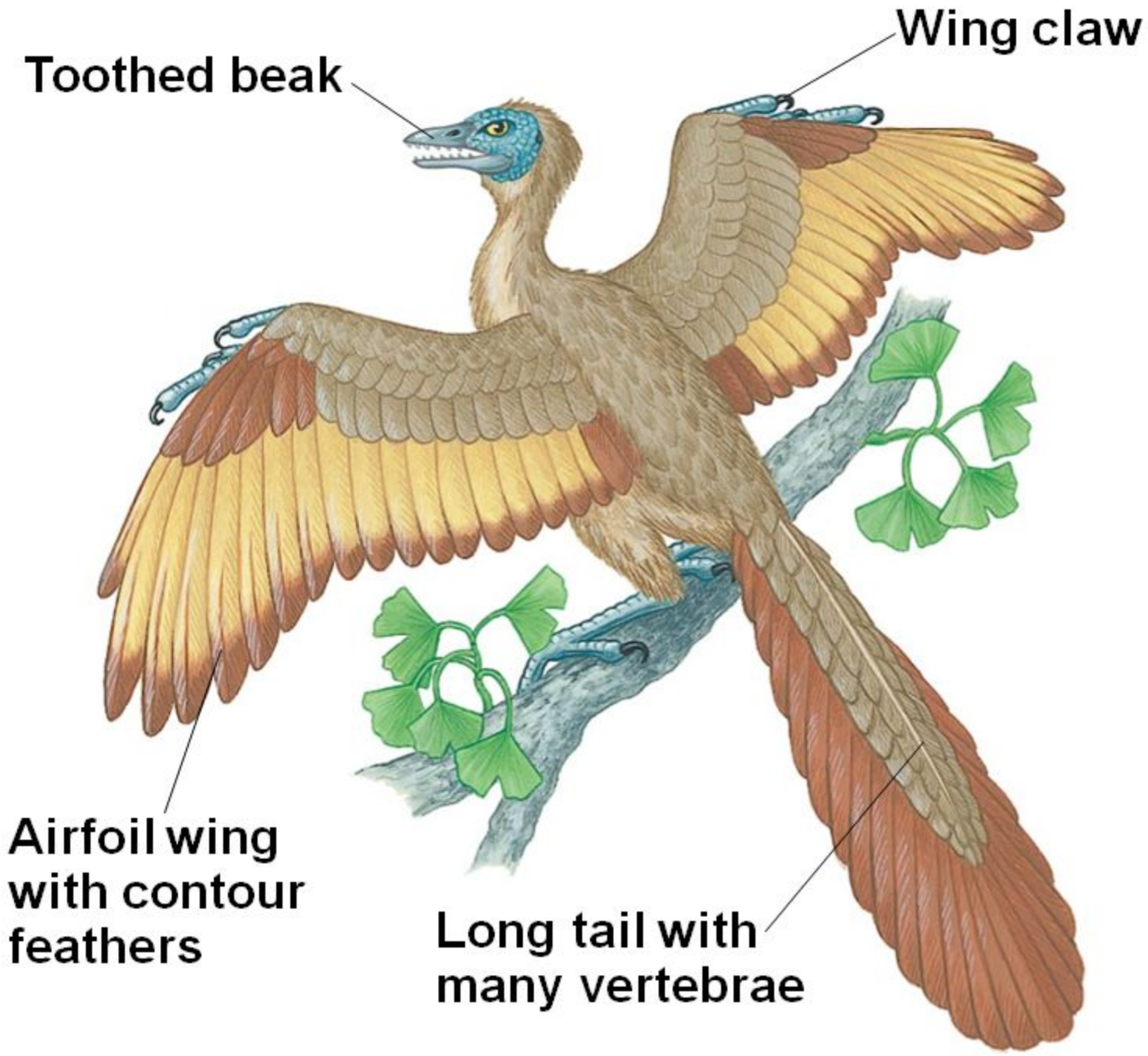
(a) Wing

(c) Feather structure

The Origin of Birds

- Birds probably descended from small theropods, a group of carnivorous dinosaurs
- Feathers evolved long before powered flight
- Early feathers might have evolved for insulation, camouflage, or courtship display
- By 160 MYA, feathered theropods had evolved into birds
- *Archaeopteryx* remains the oldest bird known
- It had feathered wings, but retained ancestral characters such as teeth, claws, and a long tail

Figure 34.31


Wing claw
Toothed beak
Airfoil wing with contour feathers
Long tail with many vertebrae

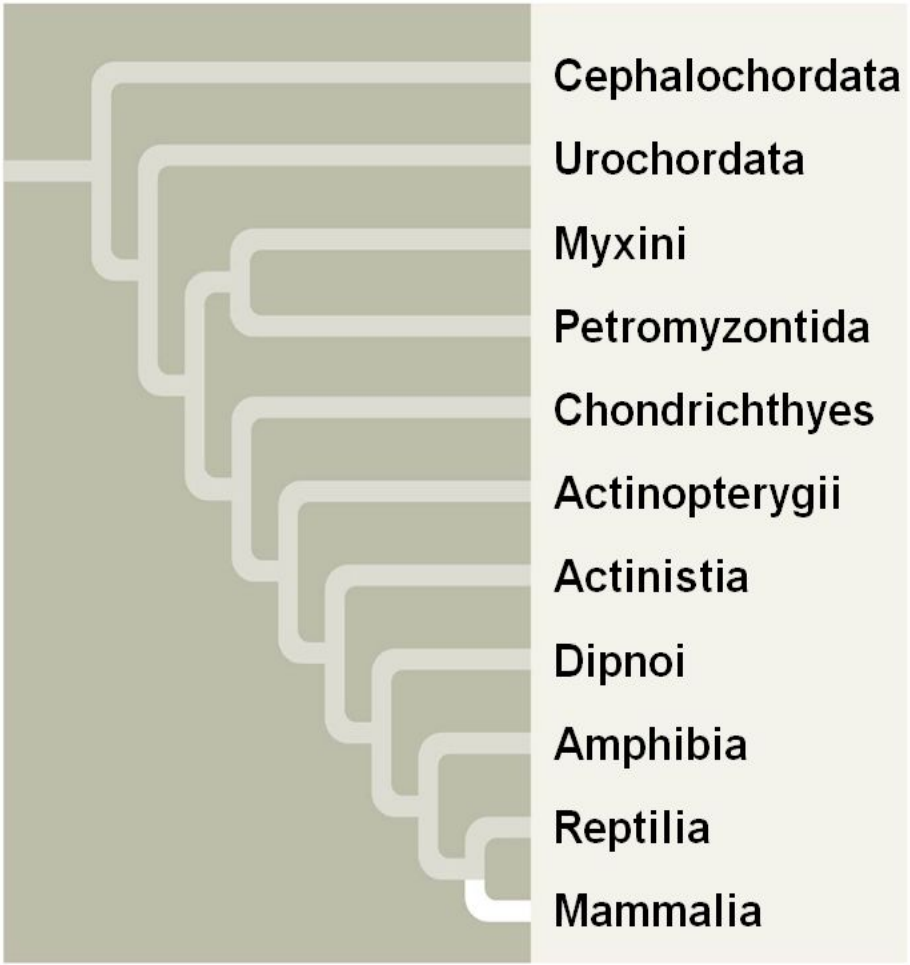
Living Birds

- Living birds belong to the clade Neornithes
- Several groups include one or more flightless species
  - The **ratites** are all flightless birds
  - Penguins use powerful pectoral muscles to "fly" in water
  - Certain species of rails, ducks, and pigeons are also flightless

- 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

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

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



- Mammals have many derived characters
  1. Mammary glands, which produce milk
  2. Hair and a fat layer under the skin for insulation
  3. Kidneys, which conserve water from wastes
  4. Endothermy and a high metabolic rate
  5. Efficient respiratory and circulatory systems
  6. A large brain-to-body-size ratio
  7. Extensive parental care
  8. Differentiated teeth

Monotremes

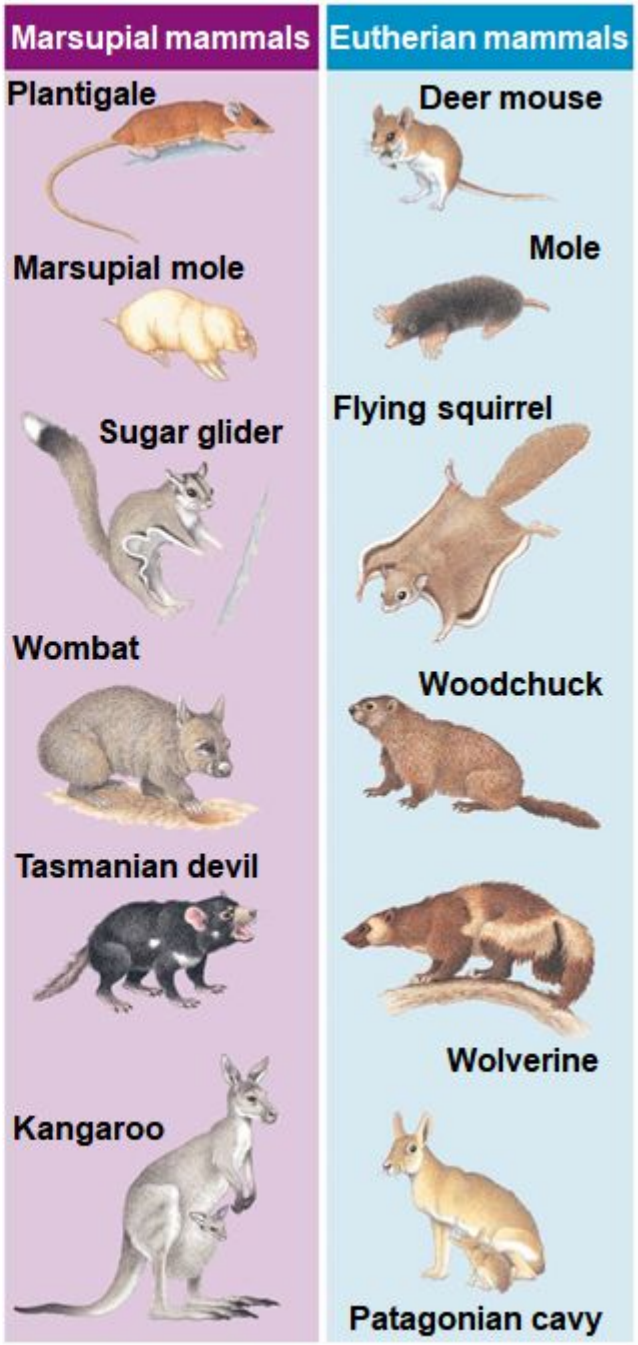
- **Monotremes** are a small group of egg-laying mammals consisting of echidnas and the platypus
- Females lack nipples and secrete milk from glands on their bellies; the baby sucks milk from the mother's fur

Marsupials

- Includes the opossums, kangaroos, and koalas
- The embryo develops within the mother's uterus and is nourished by the **placenta**
- A marsupial is born very early in its development
- It completes its embryonic development while nursing in a maternal pouch called a marsupium
- In some species, the marsupium opens to the front of the mother's body; in other species it 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

(a) A young brushtail possum

(b) A greater bilby



Eutherians (Placental Mammals)

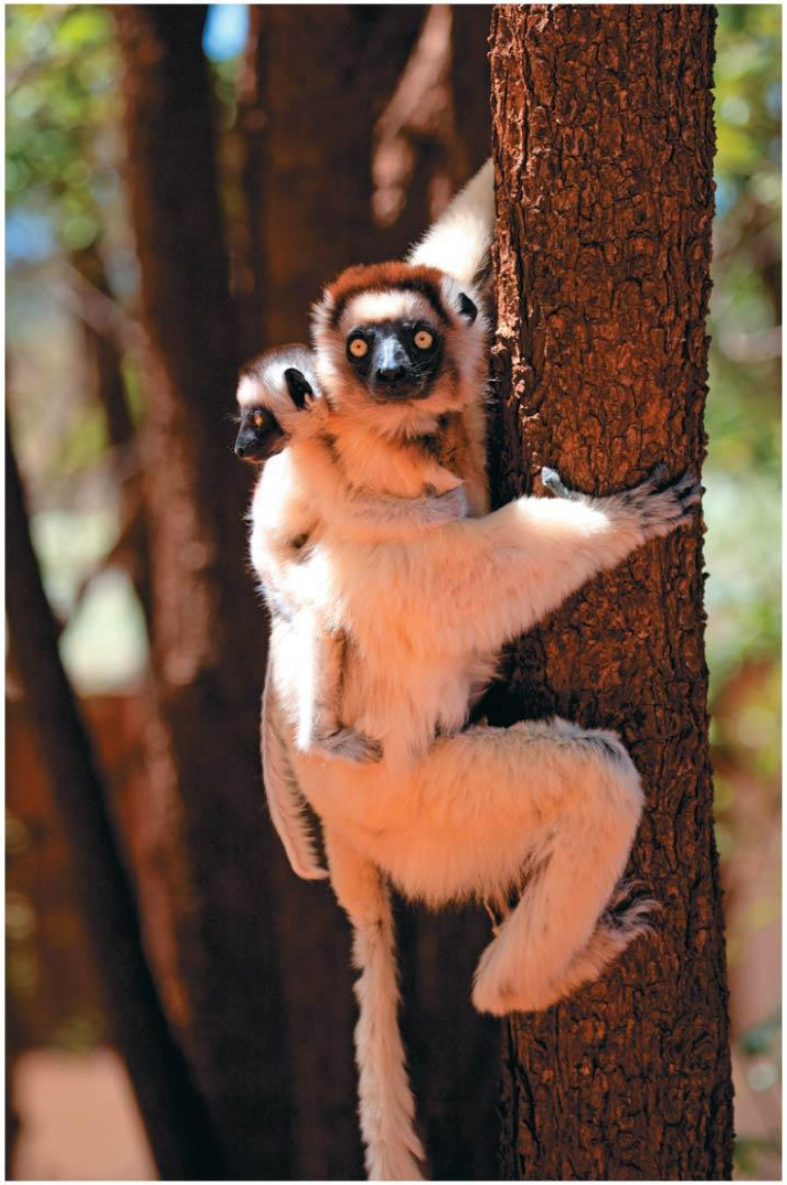
- Compared with marsupials, **eutherians** have a more complex placenta
- Young eutherians complete their embryonic development within a uterus, joined to the mother by the placenta
- Molecular and morphological data give conflicting dates on the diversification of eutherians
  - Molecular data suggest it occured about 100 MYA
  - Morphological data indicate 60 MYA

Primates

- The mammalian order Primates includes lemurs, tarsiers, monkeys, and apes
- Humans are members of the ape group
- Most primates have hands and feet adapted for grasping, and flat nails instead of claws
- Other derived characters of primates
  1. A large brain and short jaws
  2. Forward-looking eyes close together on the face, providing depth perception
  3. A fully **opposable thumb** (in monkeys and apes)

Living Primates

- There are three main groups of living primates
  1. lemurs, lorises, and bush babies
  2. tarsiers
  3. **anthropoids** (monkeys and apes)
- The oldest known tarsier fossils date to about 55 million years old and indicate that tarsiers are more closely related to anthropoids than to lemurs



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
- Several characters distinguish humans from apes
  1. Upright posture and bipedal locomotion
  2. Larger brains capable of higher learning and language
  3. Reduced jawbones and jaw muscles
  4. Shorter digestive tract
- The human & chimpanzee genomes are 99% identical
- Humans and chimpanzees differ in the expression of 19 regulatory genes

The Earliest Hominins

- **Paleoanthropology** is the study of human origins
- **Hominins** are extinct species that 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 MYA
- Early hominins show evidence of small brains and increasing bipedalism
- They were also small in stature; *Ardipithecus ramidus* (4.4 million years old) was only about 1.2 m tall

- *Misconception*: Early hominins were chimpanzees or evolved from 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

Australopiths

- Australopiths are a paraphyletic assemblage of hominins living between 4 and 2 MYA
- Some species, such as *Australopithecus afarensis,* walked fully erect
- "Robust" australopiths had sturdy skulls/powerful jaws
- "Gracile" australopiths were more slender/lighter jaws
- Hominins began to walk long distances on two legs about 1.9 MYA
- Bipedal walking was energy efficient in the arid environments inhabited by hominins at the time
- The oldest evidence of tool use, cut marks on animal bones, is 2.5 million years old

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"
- *Homo ergaster* was the first fully bipedal, large-brained hominid
- The species existed between 1.9 to 1.5 MYA
- *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 and was the first hominin to migrate out of Africa
- The oldest fossils of hominins outside Africa date back to 1.8 MYA

Neanderthals

- Neanderthals, *Homo neanderthalensis*, lived in Europe and the Near East from 350,000 to between 40,000 and 28,000 years ago
- Neanderthals were thick-boned with a larger brain than modern humans
- They buried their dead, and they made hunting tools
- The lineages leading to *H. sapiens* and *H. neanderthalensis* diverged about 400,000 years ago
- Genetic analysis indicates that subsequent gene flow occurred between Neanderthals and *Homo sapiens*

Homo sapiens

- The oldest fossils of *Homo sapiens* are found at two different sites in Ethiopia and include specimens that are 195,000 and 160,000 years old
- All living humans are descended from African ancestors
- 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 2015, a new member of the human family was discovered, *Homo naledi*

- Scientists cannot determine the age of these fossils using radioactive isotopes
- In 2004, 18,000-year-old fossils were found in Indonesia, and a new small hominin was named: *Homo floresiensis*
- Most studies support the designation of *H. floresiensis* as a new hominin species
- *Homo sapiens* were the first group to show evidence of symbolic and sophisticated thought
- A 77,000-year-old artistic carving was recently discovered in a cave in South Africa
- By 30,000 year ago, humans were producing spectacular cave paintings