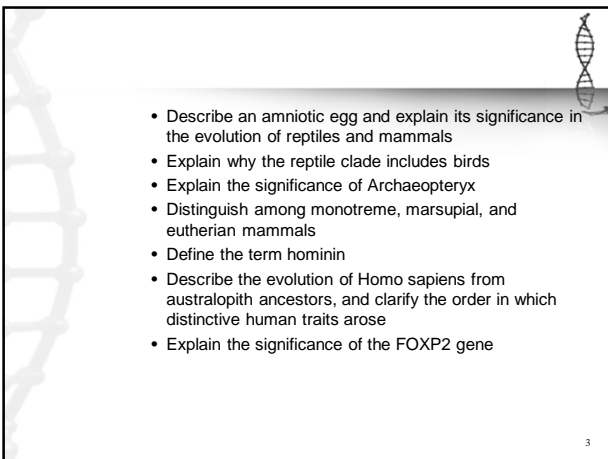


• Objectives

- List the derived traits for: chordates, craniates, vertebrates, gnathostomes, tetrapods, amniotes, birds, mammals, primates, humans
- Explain what Haikouella and Myllokunmingia tell us about craniate evolution
- Describe the trends in mineralized structures in early vertebrates
- Describe and distinguish between Chondrichthyes and Osteichthyes, noting the main traits of each group
- Define and distinguish among gnathostomes, tetrapods, and amniotes

2



- Describe an amniotic egg and explain its significance in the evolution of reptiles and mammals
- Explain why the reptile clade includes birds
- Explain the significance of Archaeopteryx
- Distinguish among monotreme, marsupial, and eutherian mammals
- Define the term hominin
- Describe the evolution of Homo sapiens from australopith ancestors, and clarify the order in which distinctive human traits arose
- Explain the significance of the FOXP2 gene

3

Introduction



- Half a Billion Years of Backbones
 - By the end of the Cambrian period, some 540 million years ago an astonishing variety of animals inhabited Earth's oceans
 - One of these types of animals gave rise to vertebrates, one of the most successful groups of animals

4



- The animals called vertebrates get their name from vertebrae, the series of bones that make up the backbone
- There are approximately 52,000 species of vertebrates which include the largest organisms ever to live on the Earth



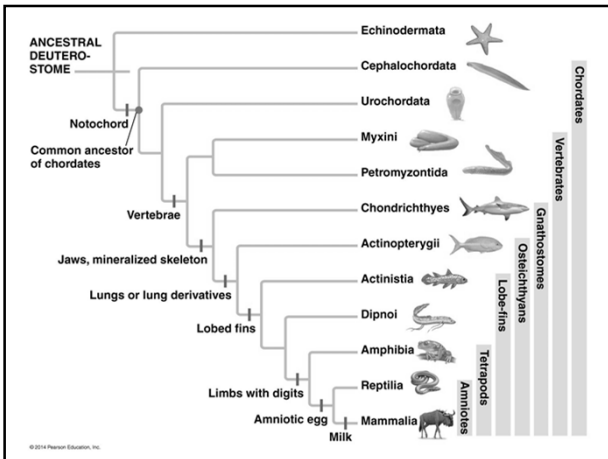
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Chordates have a notochord and a dorsal, hollow nerve cord

- Vertebrates are a subphylum of the phylum Chordata
- Chordates are bilaterian animals that belong to the clade of animals known as Deuterostomia
 - Two groups of invertebrate deuterostomes, the urochordates and cephalochordates are more closely related to vertebrates than to invertebrates



7

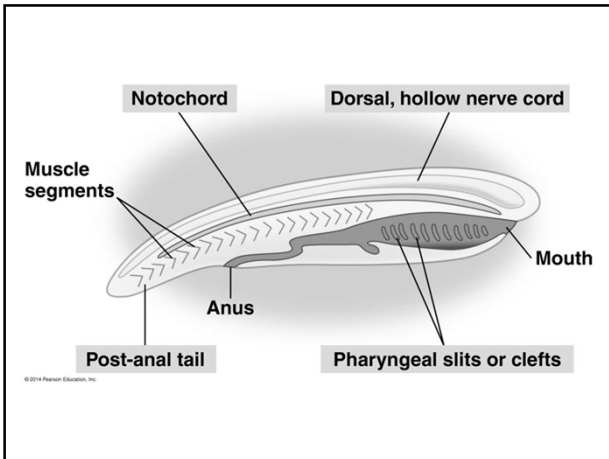


Derived Characters of Chordates

- All chordates share a set of derived characters although some species possess some of these traits only during embryonic development



9



Notochord

- The notochord is a longitudinal, flexible rod located between the digestive tube and the 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 neural tube develops into the central nervous system: the brain and the spinal cord

12

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
- These pharyngeal slits function as suspension-feeding structures in many invertebrate chordates
 - The pharyngeal slits are modified for gas exchange in aquatic vertebrates and develop into parts of the ear, head, and neck in terrestrial vertebrates

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Muscular, Post-Anal Tail



- Chordates have a tail extending posterior to the anus although in many species it is lost during embryonic development
- The chordate tail contains skeletal elements and muscles and it provides much of the propelling force in many aquatic species

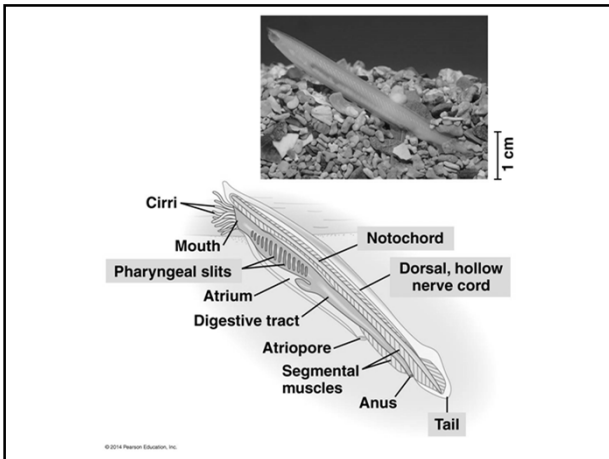
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Lancelets



- Lancelets, subphylum Cephalochordata, are named for their bladelike shape
- Lancelets are marine suspension feeders that retain the characteristics of the chordate body plan as adults

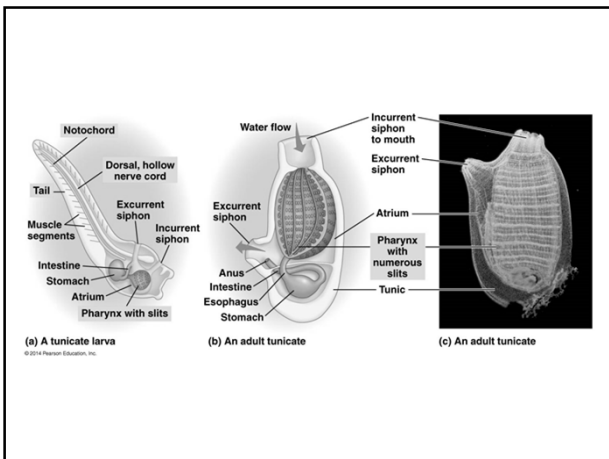
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Tunicates

- Tunicates, subphylum Urochordata, were once thought to be the deepest-branching lineage of chordates
 - They are marine suspension feeders commonly called sea squirts
- Tunicates most resemble chordates during their larval stage which may be as brief as a few minutes
- As an adult a tunicate draws in water through an incurrent siphon, filtering food particles

17

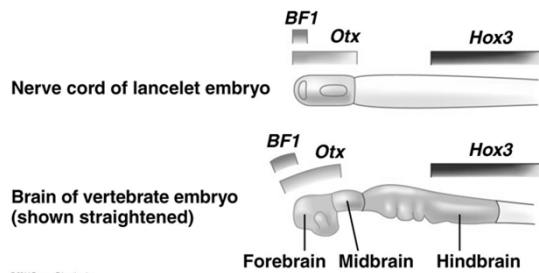


Early Chordate Evolution

- Ancestral chordates may have resembled lancelets
- Genome sequencing of tunicates has identified genes shared by tunicates and vertebrates
- Gene expression in lancelets holds clues to the evolution of the vertebrate form



19



Craniates are chordates that have a head

- The origin of a head opened up a completely new way of feeding for chordates: active predation
- Craniates share some common characteristics
 - All have a skull, brain, eyes, and other sensory organs

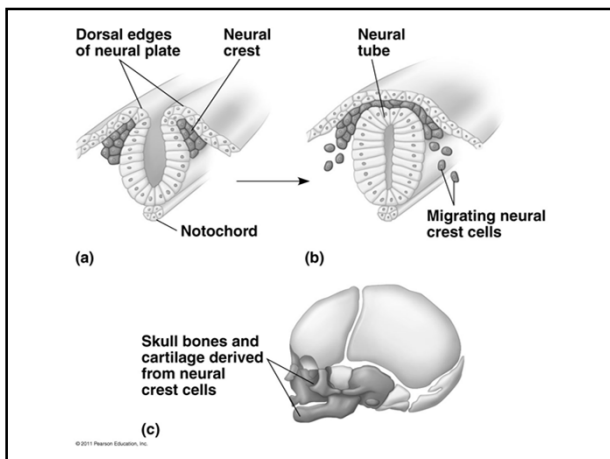


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Derived Characters of Craniates

- Craniates have two clusters of Hox genes; lancelets and tunicates have only one cluster
- One feature unique to craniates is the neural crest, a collection of cells near the dorsal margins of the closing neural tube in an embryo
 - Neural crest cells give rise to a variety of structures, including some of the bones and cartilage of the skull

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- In aquatic craniates the pharyngeal clefts evolved into gill slits
- Craniates have a higher metabolism and are more muscular than tunicates and lancelets
- Craniates have a heart with at least two chambers, red blood cells with hemoglobin, and kidneys

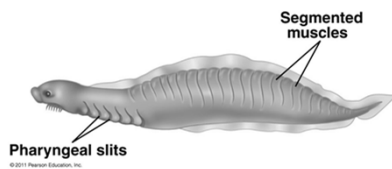
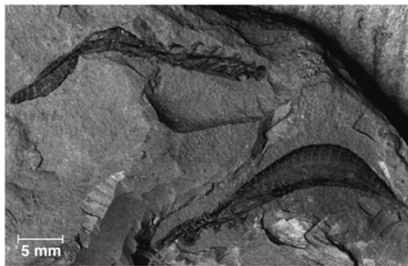
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The Origin of Craniates



- Craniates evolved at least 530 million years ago during the Cambrian explosion
 - 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 not a skull
 - In other Cambrian rocks paleontologists have found fossils of even more advanced chordates, such as Myllokunmingia
 - Myllokunmingia had a skull and was a true craniate

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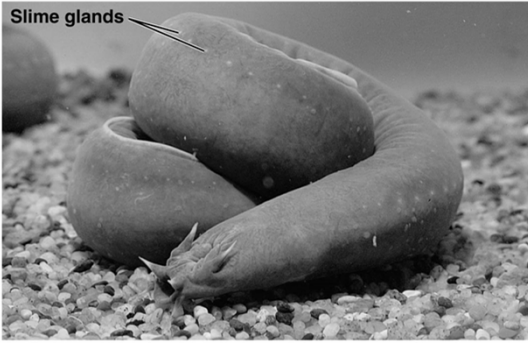
Hagfishes



- The least derived craniate lineage that still survives is Myxini, the hagfishes
 - Hagfishes are jawless marine craniates that have a cartilaginous skull and axial rod of cartilage derived from the notochord and lack vertebrae and jaws

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Slime glands



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Vertebrates are craniates that have a backbone



- During the Cambrian period a lineage of craniates evolved into vertebrates
 - Vertebrates became more efficient at capturing food and avoiding being eaten

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Derived Characters of Vertebrates



- Vertebrates underwent a second gene duplication involving the Dlx family of transcription factors
- Vertebrates have
 - Vertebrae enclosing a spinal cord
 - An elaborate skull
 - Fin rays, in aquatic forms

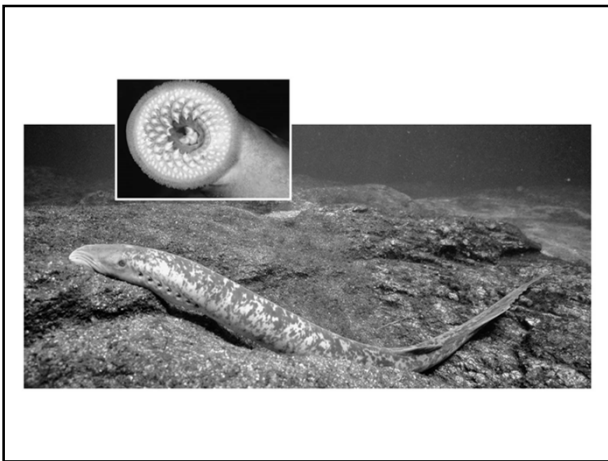
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Lampreys



- Lampreys, Petromyzontida, represent the oldest living lineage of vertebrates
 - They have cartilaginous segments surrounding the notochord and arching partly over the nerve cord
 - Lampreys are jawless vertebrates and inhabit various marine and freshwater habitats

31

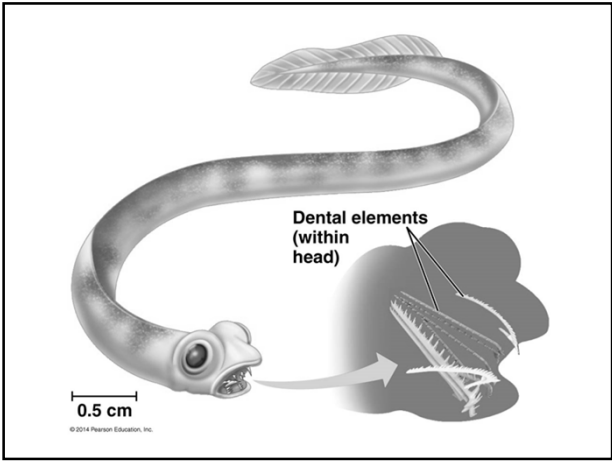


Fossils of Early Vertebrates



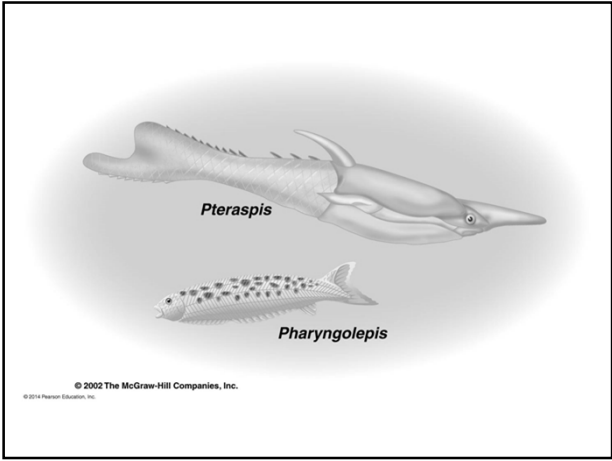
- Conodonts were the first vertebrates with mineralized skeletal elements in their mouth and pharynx

33



- Other armored, jawless vertebrates had defensive plates of bone on their skin

35



Origins of Bone and Teeth



- Mineralization appears to have originated with vertebrate mouthparts
 - The vertebrate endoskeleton became fully mineralized much later
- Today, jawless vertebrates, or gnathostomes, are far outnumbered by those with jaws

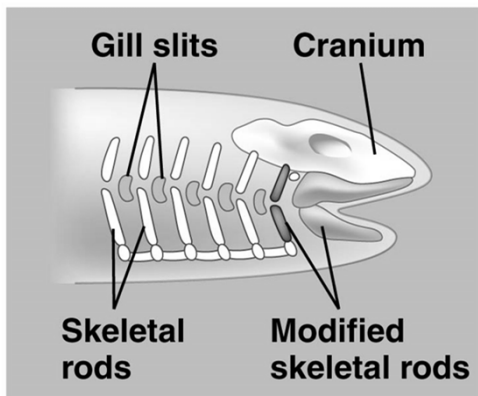
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Derived Characters of Gnathostomes



- Gnathostomes have jaws that evolved from skeletal supports of the pharyngeal slits

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Other characters common to gnathostomes include

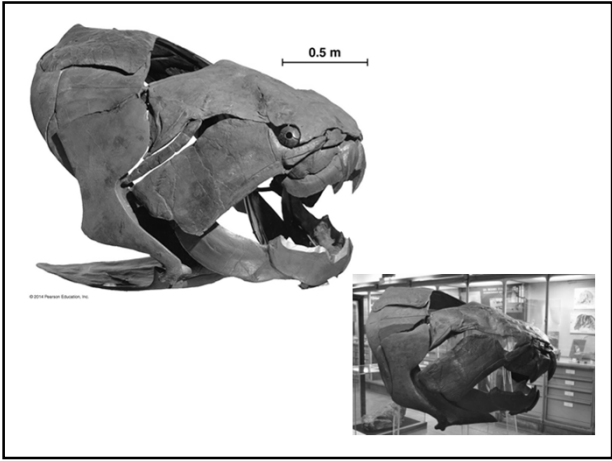
- An extensively mineralized endoskeleton
- Paired appendages
- An additional duplication of Hox genes
- An enlarged forebrain associated with enhanced smell and vision
- In aquatic gnathostomes, the lateral line system, which is sensitive to vibrations

40

Fossil Gnathostomes

- The earliest gnathostomes in the fossil record are an extinct lineage of armored vertebrates called placoderms
- Another group of jawed vertebrates called acanthodians which radiated during the Devonian period and were closely related to the ancestors of osteichthyans

41



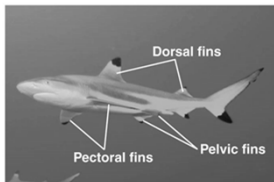
Chondrichthyans (Sharks, Rays, and Their Relatives)

- Members of clade Chondrichthyes have a skeleton that is composed primarily of cartilage
 - The cartilaginous skeleton evolved secondarily from an ancestral mineralized skeleton

43

- The largest and most diverse group of Chondrichthyans includes the sharks and rays
 - A second group is composed of a few dozen species of ratfishes

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




(b) Southern stingray (*Dasyatis americana*)




(c) Spotted ratfish (*Hydrolagus collieri*)

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- Most sharks
 - Have a streamlined body and are swift swimmers
 - Are carnivores
 - Have a short digestive tract; a ridge called the spiral valve increases the digestive surface area
 - Have acute senses


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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
- The reproductive tract, excretory system, and digestive tract empty into a common cloaca


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Ray-Finned Fishes and Lobe-Fins



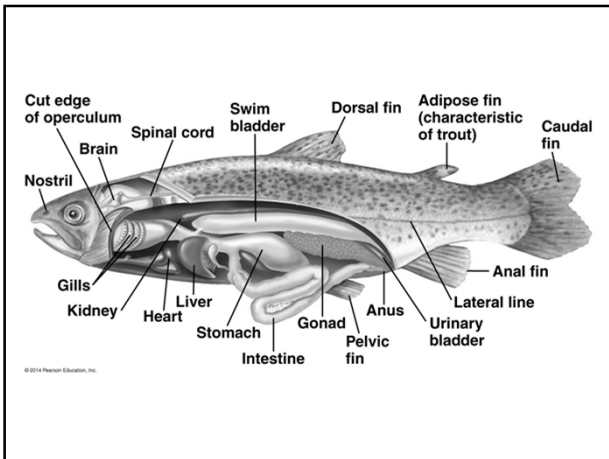
- The vast majority of vertebrates belong to a clade of gnathostomes called Osteichthyes
 - This clade includes all terrestrial vertebrates

48




- Nearly all living osteichthyans have a bony endoskeleton
- Aquatic osteichthyans are the vertebrates we informally call fishes which control their buoyancy with an air sac known as a swim bladder
- Fishes breathe by drawing water over four or five pairs of gills located in chambers covered by a protective bony flap called the operculum

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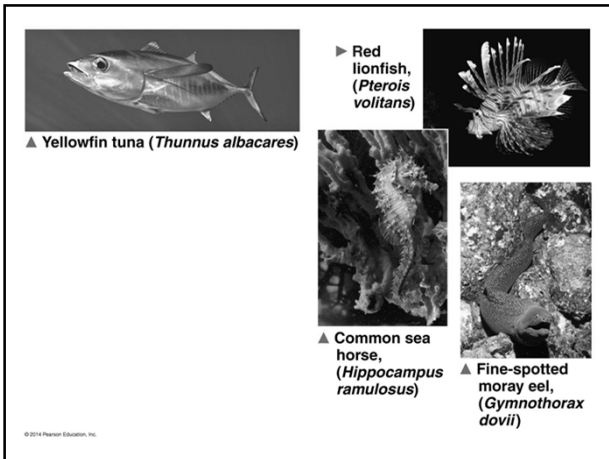


Ray-Finned Fishes



- Actinopterygii, the ray-finned fishes includes nearly all the familiar aquatic osteichthyans
 - The fins, supported mainly by long, flexible rays are modified for maneuvering, defense, and other functions

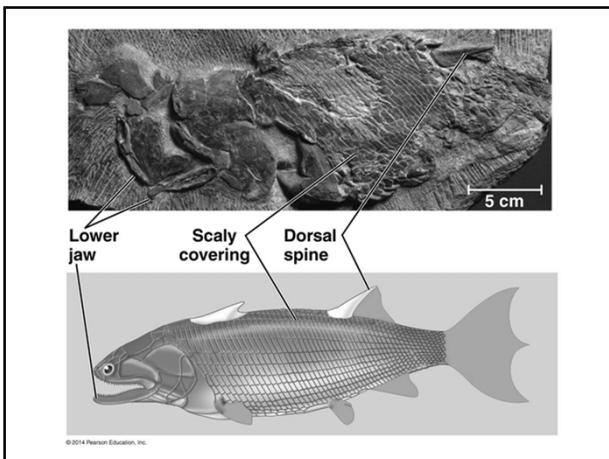
51



Lobe-Fins

- The lobe-fins, Sarcopterygii, have muscular and pectoral fins
 - Three lineages survive and include coelacanths (Actinistia), lungfishes (Dipnoi), and tetrapods

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Tetrapods are gnathostomes that have limbs and feet

- 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

56

Derived Characters of Tetrapods

- Tetrapods have some specific adaptations
 - Four limbs and feet with digits
 - Ears for detecting airborne sounds

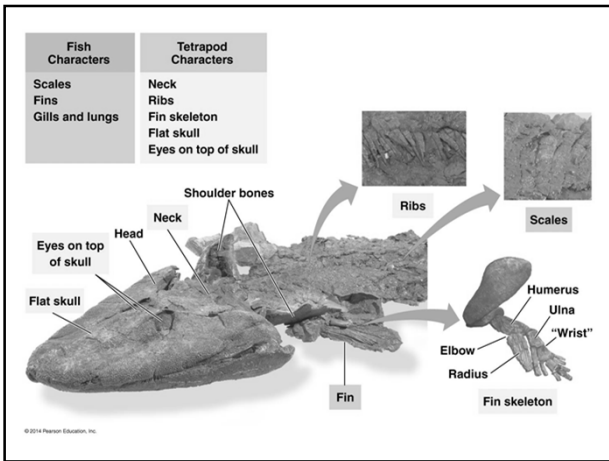
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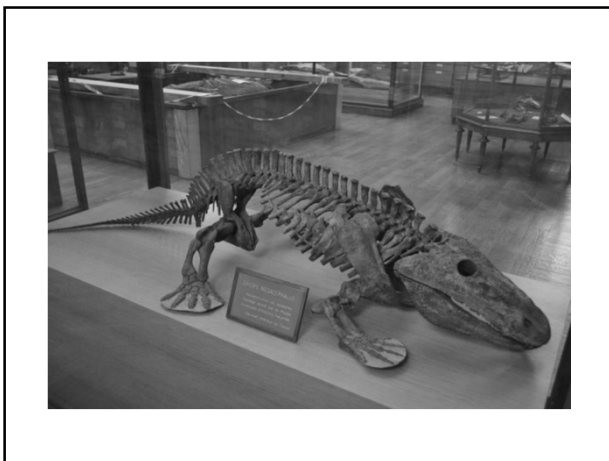
The Origin of Tetrapods



- In one lineage of lobe-fins the fins became progressively more limb-like while the rest of the body retained adaptations for aquatic life
 - For example, Acanthostega lived in Greenland 365 million years ago

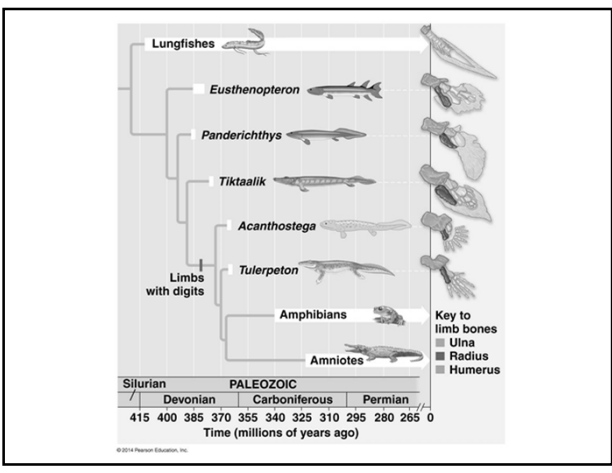
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61

- Extraordinary fossil discoveries over the past 20 years have allowed paleontologists to reconstruct the origin of tetrapods




Amphibians

- Class Amphibia is represented by about 6,150 species of organisms, divided into three orders

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• Order Urodela includes salamanders, which have tails

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(a) Order Urodela

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• Order Anura includes frogs and toads, which lack tails

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(b) Order Anura

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- Order Apoda includes caecilians, which are legless and resemble worms




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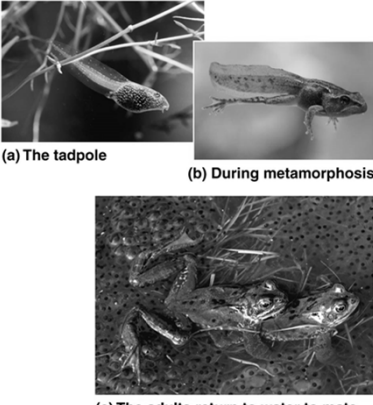
(c) Order Apoda

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- Amphibian means “two lives” which is a reference to the metamorphosis of an aquatic larva into a terrestrial adult
 - 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

70




(a) The tadpole

(b) During metamorphosis

(c) The adults return to water to mate.

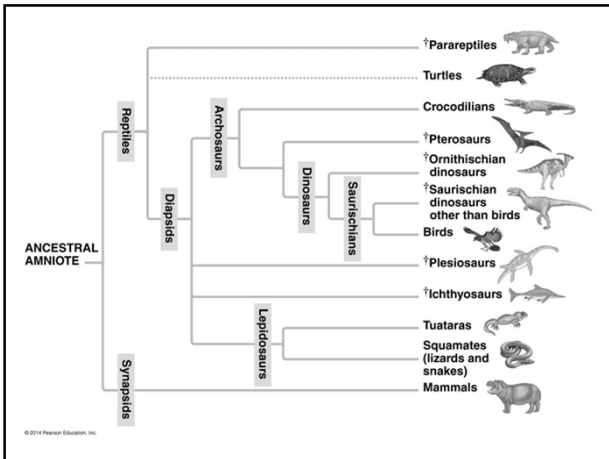
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Amniotes are tetrapods that have a terrestrially adapted egg



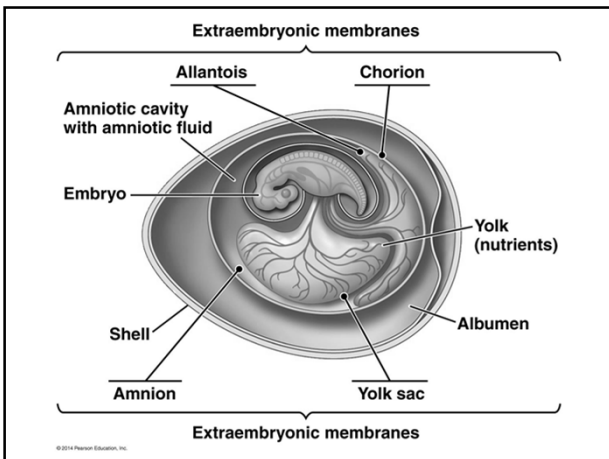
- Amniotes are a group of tetrapods whose living members are the reptiles, including birds, and the mammals


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Derived Characters of Amniotes

- Amniotes are named for the major derived character of the clade, the amniotic egg which contains specialized membranes that protect the embryo
 - The extraembryonic membranes have various functions






- Amniotes also 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 370 million years ago
 - Early amniotes appeared in the Carboniferous period and included large herbivores and predators
 - early amniotes were more tolerant of dry conditions than early tetrapods


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Reptiles



- The reptile clade includes the tuatara, lizards, snakes, turtles, crocodylians, birds, and the extinct dinosaurs

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- Reptiles have scales that create a waterproof barrier and lay shelled eggs on land
- Most reptiles are ectothermic, absorbing external heat as the main source of body heat
- Birds are endothermic and capable of keeping the body warm through metabolism

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The Origin and Evolutionary Radiation of Reptiles



- The oldest reptilian fossils date to about 310 million years ago
 - The first major group of reptiles to emerge were the parareptiles, which were mostly large, stocky herbivores
- As parareptiles were dwindling the diapsids were diversifying
 - The diapsids are composed of two main lineages, the lepidosaurs and the archosaurs


81



- The dinosaurs diversified into a vast range of shapes and sizes which included the long-necked giants (sauropods) and bipedal carnivores (theropods)
 - Traditionally, dinosaurs were considered slow, sluggish creatures but fossil discoveries and research have led to the conclusion that dinosaurs were agile and fast moving
 - Paleontologists have also discovered signs of parental care among dinosaurs


82

Turtles



- Turtles are the most distinctive group of reptiles alive today
 - Some turtles have adapted to deserts and others live entirely in ponds and rivers
 - 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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(a) Eastern box turtle (*Terrapene carolina carolina*)
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Lepidosaurs



- One surviving lineage of lepidosaurs is represented by two species of lizard-like reptiles called tuatara

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(b) Tuatara (*Sphenodon punctatus*)

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Lepidosaurs





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

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

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- Snakes are legless lepidosaurs that evolved from lizards

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

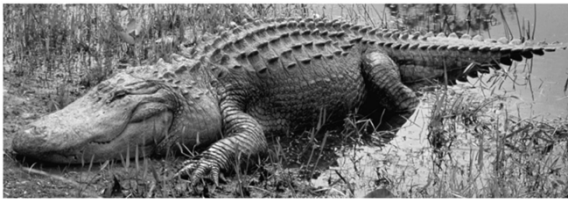
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Alligators and Crocodiles



- Crocodylians belong to an archosaur lineage that dates back to the late Triassic

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(e) American alligator (*Alligator mississippiensis*)

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Birds



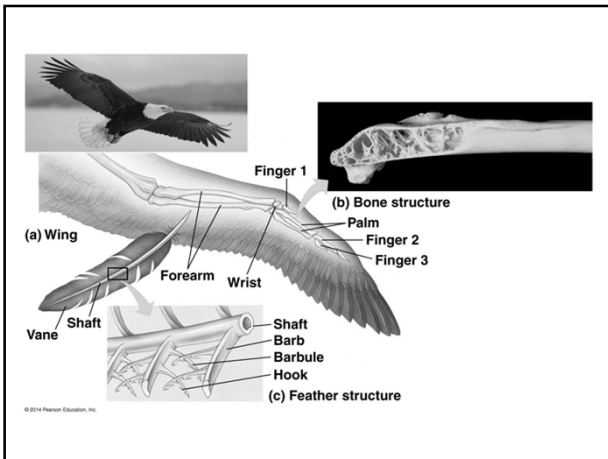
- Birds are archosaurs but almost every feature of their reptilian anatomy has undergone modification in their adaptation to flight

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Derived Characters of Birds

- Many of the characters of birds are adaptations that facilitate flight
 - A bird's most obvious adaptations for flight are its wings with feathers made of keratin
 - Other adaptations include lack of a urinary bladder, females with only one ovary, small gonads, and loss of teeth

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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

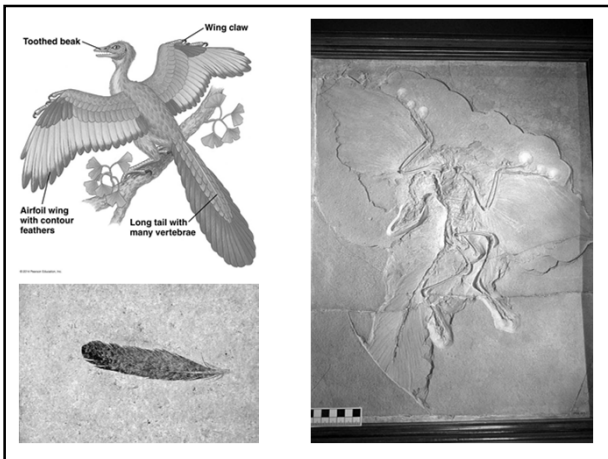
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The Origin of Birds



- Birds probably descended from theropods, a group of small, carnivorous dinosaurs
 - By 150 million years ago feathered theropods had evolved into birds
 - Archaeopteryx remains as one of the oldest birds known

97

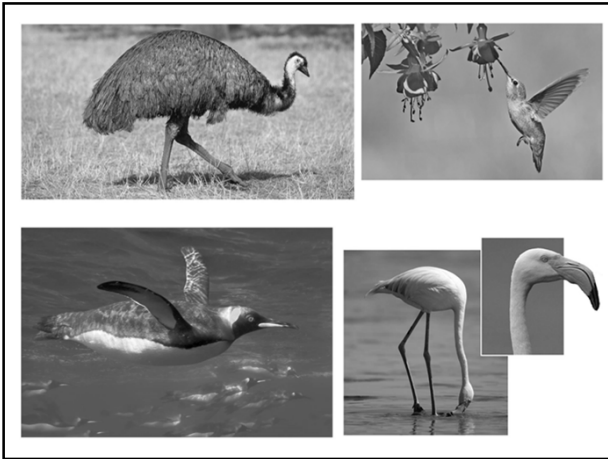


Living Birds



- 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
- The demands of flight have rendered the general body form of many flying birds similar to one another
 - Foot structure in birds shows considerable variation

99



Mammals are amniotes that have hair and produce milk

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

101

Derived Characters of Mammals

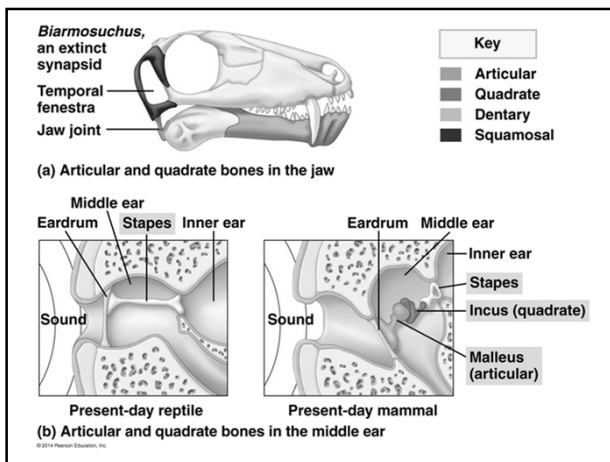
- Mammary glands, which produce milk are a distinctively mammalian character
 - Hair is another mammalian characteristic
 - Mammals generally have a larger brain than other vertebrates of equivalent size
 - Differentiated teeth

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Early Evolution of Mammals

- Mammals evolved from synapsids in the late Triassic period
 - The jaw was remodeled during the evolution of mammals from nonmammalian synapsids and two of the bones that formerly made of the jaw joint were incorporated into the mammalian middle ear

103



- Living lineages of mammals originated in the Jurassic but did not undergo a significant adaptive radiation until after the Cretaceous

105

Monotremes



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

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Marsupials




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

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(a) A young brushtail possum

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- In some species of marsupials, such as the bandicoot the marsupium opens to the rear of the mother's body as opposed to the front, as in other marsupials

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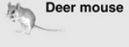










(b) A greater bilby

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- In Australia, convergent evolution has resulted in a diversity of marsupials that resemble eutherians in other parts of the world

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Marsupial mammals	Eutherian mammals
 Plantigale	 Deer mouse
 Marsupial mole	 Mole
 Sugar glider	 Flying squirrel
 Wombat	 Woodchuck
 Tasmanian devil	 Wolverine
 Kangaroo	 Patagonian cavy

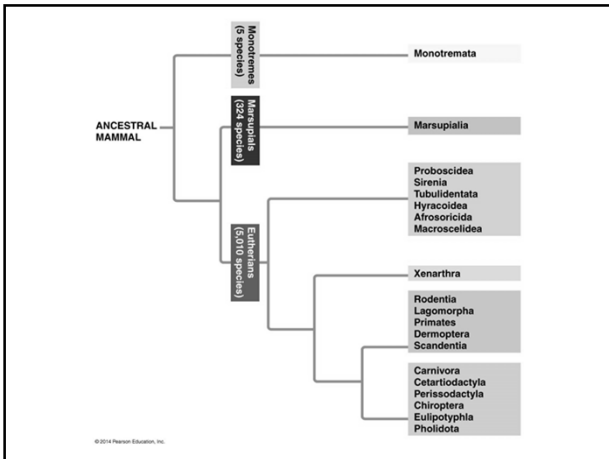
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
Eutherians (Placental Mammals)



- Compared to marsupials eutherians have a longer period of pregnancy
 - 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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Orders and Examples	Main Characteristics	Orders and Examples	Main Characteristics
Monotremata Platypuses, echidnas 	Lay eggs; no nipples; young suck milk from fur of mother	Marsupialia Kangaroos, opossums, koalas 	Complete embryonic development in pouch on mother's body
Proboscidea Elephants 	Long muscular trunk, thick, loose skin; upper incisors elongated as tusks	Tubulidentata Armadillos 	Teeth consisting of many thin tubes cemented together; eats ants and termites
Sirenia Manatees, dugongs 	Aquatic; fluke-like forelimbs and no hind limbs; herbivorous	Hyacoidea Hyraxes 	Short legs; stumpy tail; herbivorous; complex, multi-chambered stomach
Xenarthra Sloths, armadillos, tamandua 	Reduced teeth or no teeth; herbivorous (limited to carnivorous [ant-eaters, armadillos])	Rodentia Squirrels, beavers, rats, porcupines, mice 	Chisel-like, continuously growing incisors worn down by gnawing; herbivorous
Lagomorpha Rabbits, hares, pika 	Chisel-like incisors; hind legs longer than forelegs and adapted for running and jumping; herbivorous	Primates Lemurs, monkeys, chimpanzees, gorillas, humans 	Opposable thumb; forward-facing eyes; well-developed cerebral cortex; omnivorous
Carnivora Dogs, weasels, bears, cats, weasels, otters, coyotes 	Sharp, pointed canine teeth and molars for shearing; carnivorous	Perissodactyla Horses, zebras, tapirs, rhinoceroses 	Hooves with an odd number of toes on each foot; herbivorous
Cetartiodactyla Artiodactyls: sheep, pigs, cattle, deer, giraffes Cetaceans: whales, dolphins, porpoises 	Hooves with an even number of toes on each foot; herbivorous	Chiroptera Bats 	Adapted for flight; broad winged; feet extend from elongated fingers to body and legs; carnivorous or herbivorous
	Aquatic; streamlined body; breathe through blowholes and flipper-like limbs; thick layer of insulating blubber; carnivorous	Eulipotyphla "Gaw" insectivores; some moles, some shrews 	Eat mainly insects and other small invertebrates

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Primates

- The mammalian order Primates include 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
- Primates also have
 - A large brain and short jaws
 - Forward-looking eyes close together on the face, providing depth perception
 - Well-developed parental care and complex social behavior
 - A fully opposable thumb

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Living Primates



- There are three main groups of living primates
 - The lemurs of Madagascar and the lorises and pottos of tropical Africa and southern Asia
 - The tarsiers of Southeast Asia
 - The anthropoids, which include monkeys and hominids worldwide

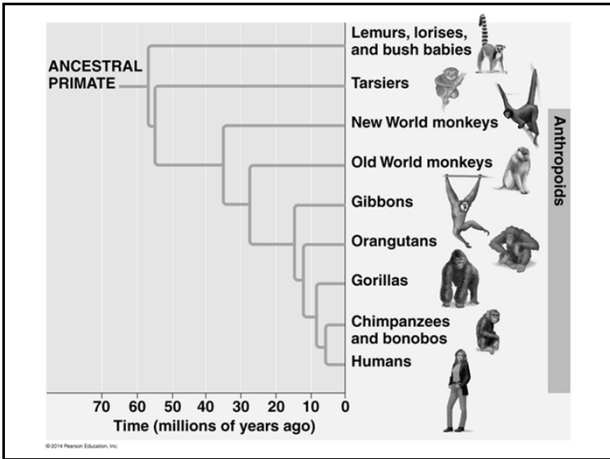
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- The oldest known anthropoid fossils, about 45 million years old indicate that tarsiers are more closely related to anthropoids

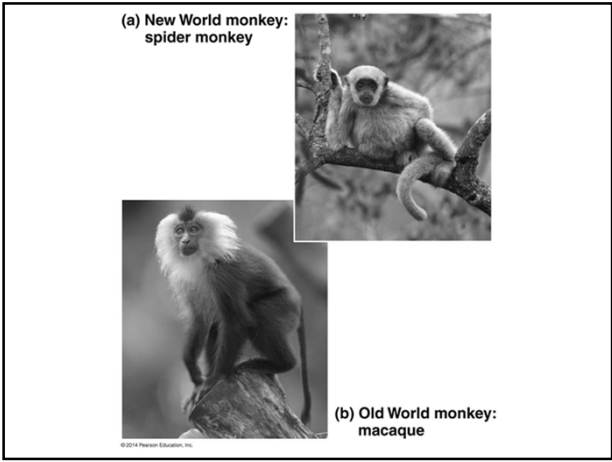
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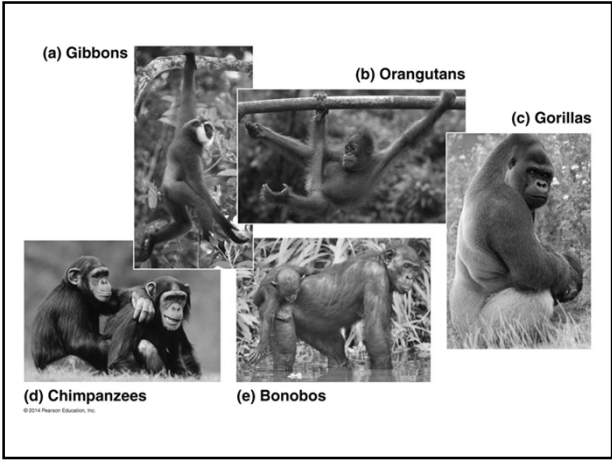
- The fossil record indicates that monkeys first appeared in the New World (South America) during the Oligocene
 - The first monkeys evolved in the Old World (Africa and Asia)
 - in the New World (South America), monkeys first appeared roughly 25 million years ago
 - New World and Old World monkeys underwent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

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- The other group of anthropoids consists of primates informally called apes
 - Apes diverged from Old World monkeys about 20–25 million years ago

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Humans are bipedal hominoids with a large brain



- *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 Hominids



- A number of characters distinguish humans from other apes:
 - Upright posture and bipedal locomotion
 - Larger brains
 - Language capabilities
 - Symbolic thought
 - The manufacture and use of complex tools
 - Shortened jaw
 - Shorter digestive tract

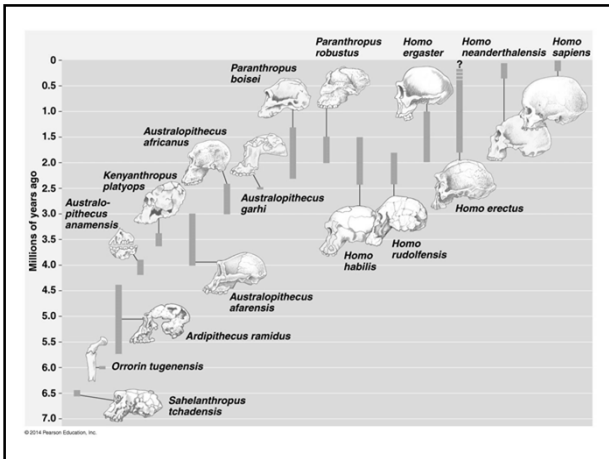
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The Earliest Humans



- The study of human origins is known as paleoanthropology
 - Paleoanthropologists have discovered fossils of approximately 20 extinct species that are more closely related to humans than to chimpanzees
 - These species are known as hominins (previously hominids)

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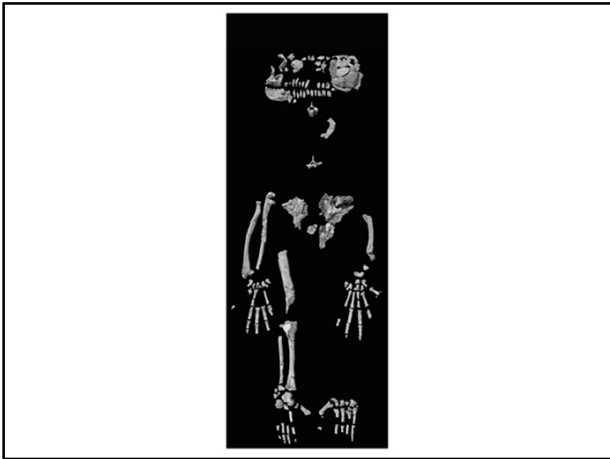
- Hominins originated in Africa approximately 6–7 million years ago
 - Early hominins had a small brain, but probably walked upright, exhibiting mosaic evolution
- Two common misconceptions of early hominins include
 - Thinking of them as chimpanzees
 - Imagining human evolution as a ladder leading directly to *Homo sapiens*

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Australopiths

- Australopiths are a paraphyletic assemblage of hominins that lived between 4 and 2 million years ago
 - Some species walked fully erect and had human-like hands and teeth
 - “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

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(a) The Laetoli footprints

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

Tool Use

- The oldest evidence of tool use—cut marks on animal bones is 2.5 million years old



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Early Homo

- The earliest fossils that paleoanthropologists place in our genus *Homo* are those of the species *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”

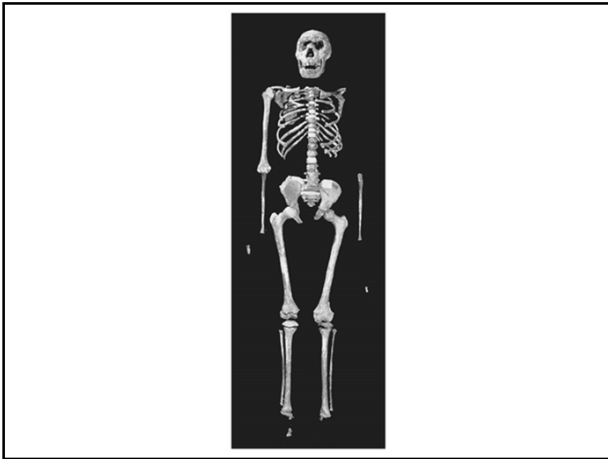



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- *Homo ergaster* was the first fully bipedal, large-brained hominin
 - This species existed between 1.9 and 1.6 million years
- *Homo ergaster* shows a significant decrease in sexual dimorphism (a size difference between sexes) compared with its ancestors
- *Homo ergaster* fossils were previously assigned to *Homo erectus*; most paleoanthropologists now recognize these as separate species



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

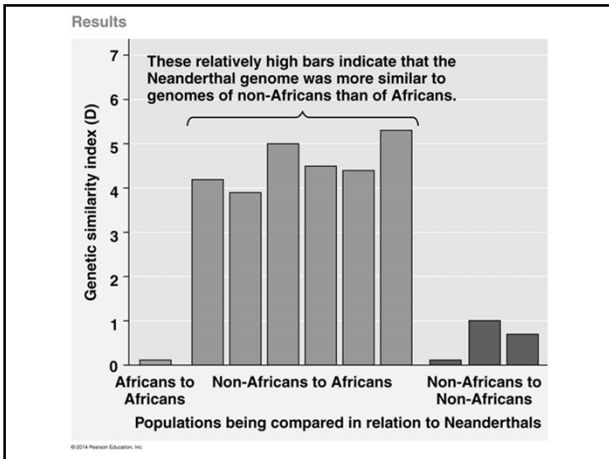
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Neanderthals



- Neanderthals, *Homo neanderthalensis* lived in Europe and the Near East from 200,000 to 28,000 years ago
 - They were large, thick-browed hominins adapted to the colder climate of Europe
 - They became extinct a few thousand years after the arrival of *Homo sapiens* in Europe
 - It is clear that interbreeding occurred between Neanderthals and early *Homo sapiens*
 - Approximately 4% of non-African human DNA is of Neanderthal origin

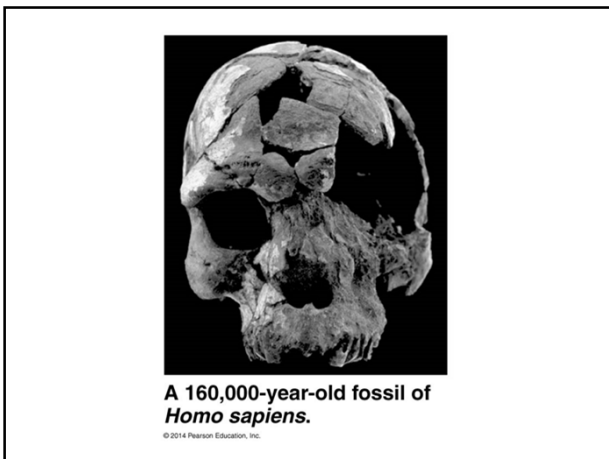
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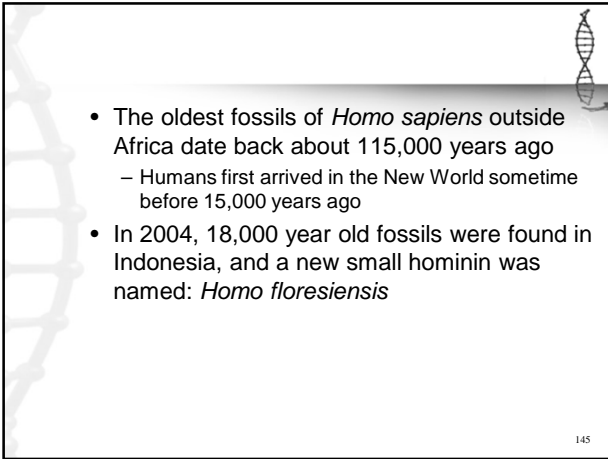


Homo sapiens

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

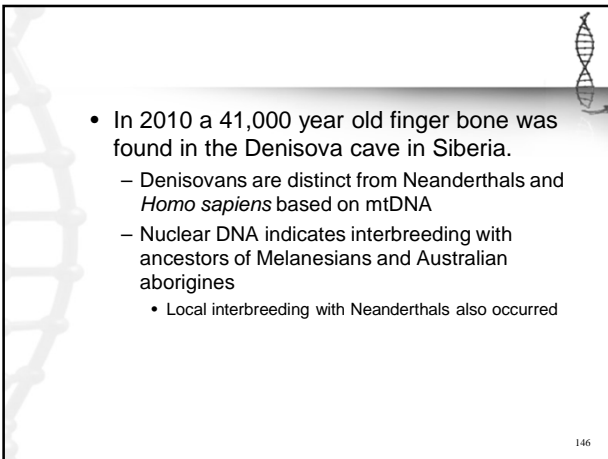
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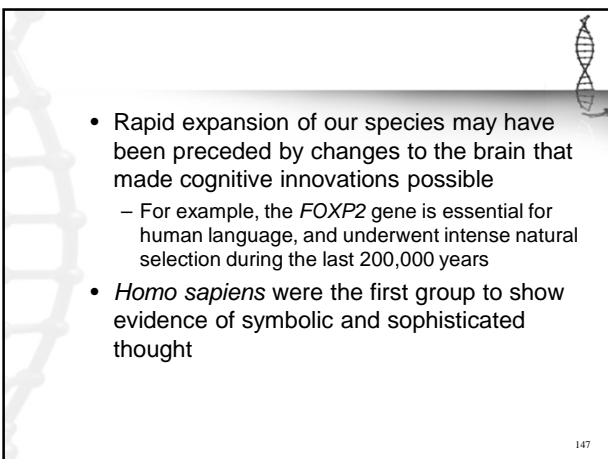
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- The oldest fossils of *Homo sapiens* outside Africa date back about 115,000 years ago
 - Humans first arrived in the New World sometime before 15,000 years ago
- In 2004, 18,000 year old fossils were found in Indonesia, and a new small hominin was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



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- In 2010 a 41,000 year old finger bone was found in the Denisova cave in Siberia.
 - Denisovans are distinct from Neanderthals and *Homo sapiens* based on mtDNA
 - Nuclear DNA indicates interbreeding with ancestors of Melanesians and Australian aborigines
 - Local interbreeding with Neanderthals also occurred



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- Rapid expansion of our species may have been preceded by changes to the brain that made cognitive innovations possible
 - For example, the *FOXP2* gene is essential for human language, and underwent intense natural selection during the last 200,000 years
- *Homo sapiens* were the first group to show evidence of symbolic and sophisticated thought