Phylum Chordata

1. Deuterostomes (like the echinoderms)
2. All share four features:
   - Notochord supports body
   - Nervous system develops from dorsal nerve cord
   - Embryos have pharynx with slits
   - Embryos have tail that extends past anus

Three Subphyla

Two invertebrate subphyla
1. Urochordata (tunicates)
2. Cephalochordata (lancelets)
3. Subphylum Vertebrata (the vertebrates)
   - Have backbone of cartilage or bone
   - Brain is encased in protective skull

Eight Vertebrate Classes

1. Agnatha - jawless fishes
2. Placodermi - jawed armored fishes (extinct)
3. Chondrichthyes - cartilaginous fishes
4. Osteichthyes - bony fishes
5. Amphibia - Amphibians
6. Reptilia - Reptiles
7. Aves - Birds
8. Mammalia - Mammals
Recent Findings Suggest:

- Turtles in separate clade
- Birds in reptile clade

Trends in the Evolution of Vertebrates:

1. Shift from notochord to vertebral column
2. Nerve cord expanded into brain
3. Evolution of jaws
4. Paired fins evolved, gave rise to limbs
5. Gills evolved, gave rise to lungs

Evolutionary Trends in Vertebrates:

- 1. Paired Fins
- 2. Gills
- 3. Lungs
- 4. Jaws
- 5. Terrestrial Locomotion
- 6. Amniotic Egg
- 7. Diversity of Adaptations for land, air, and water

Divergence of Cephalochordates and Vertebrates:

- 1. CRANIATES: Head and heart (2 chambers)
- 2. FREE-SWIMMING
- 3. Molecular evidence suggests divergence 750 my ago
- 4. Undisputed fossil vertebrates ~500 my old
- 5. CRANIATES
- 6. AMNIOTES
- 7. TETRAPODS

Characteristics of Earliest Vertebrates:

1. Small jawless fish
2. Bony skeleton, including vertebrae
3. Bodies completely covered with bony armor plates
4. Air sea-floor invertebrates
5. Brain imprints reveal many “modern” brain features: forebrain, midbrain, hindbrain

Earliest Craniates

530 million year old fossilic transition between invertebrate and vertebrate

Extinct “agnathan”
Evolution of Fishes

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>540 mya</td>
<td>Jawless fishes</td>
</tr>
<tr>
<td>488 mya</td>
<td>Jawed fishes, cartilaginous fishes, placoderms</td>
</tr>
<tr>
<td>444 mya</td>
<td>Bony fishes</td>
</tr>
<tr>
<td>416 mya</td>
<td>Early amphibians</td>
</tr>
</tbody>
</table>

**Jawless Vertebrates: Lampreys, Hagfish**

- Lampreys
- Hagfishes

**Subphylum Vertebrata**

- Hagfish

**Evolution of Jaws**

- Supporting structures
  - Gill slits
  - Jaw support
  - Spinele (small gill slits)
  - Other gill slits

**Jawed Fishes**

1. Most diverse and numerous group of vertebrates
2. Two classes:
   - Chondrichthyes (cartilaginous fishes)
   - Osteichthyes (bony fishes)

**Cartilaginous Fishes: Class Chondrichthyes**

1. Most are marine predators
2. Cartilaginous skeleton
3. Main groups:
   - Skates and rays
   - Sharks
   - Chimaeras (ratfishes)
Subphylum Vertebrata
Chondrichthyes

Carcharadon carcharias
white shark

Subphylum Vertebrata
Cartilaginous fishes

Rhinobatos productus
shovelnose guitarfish

Subphylum Vertebrata
Cartilaginous fishes

MANTA RAY
Manta birostris

Bony Fishes:
Class Osteichthyes

1. Includes 96 percent of living fish species
2. Three subclasses:
   • Ray-finned fishes
   • Lobe-finned fishes
   • Lung fishes

Subphylum Vertebrata
Bony fishes

Sebastes atrovirens
kelp rockfish

Subphylum Vertebrata
Osteichthyes

Amphiprion melanopus
red and black anemonefish
Subphylum Vertebrata

**Sebastes chrysomelas**
black and yellow rockfish

**Sebastes miniatus**
vermillion rockfish

**Plectorhynchus goldmani**
sweet lips

**Lutjanid**
snapper

**Sebastes serranoides**
olive rockfish

**Epinephelus tukula**
potato cod
**TETRAPODA**

Invasion of the Land: Amphibians

- Body plan and reproductive mode between fishes and reptiles
- Eggs need water

**Evolution of Amphibians**

1. Lobe-finned fishes arose during the early Devonian
2. Used their fins to travel over land from pool to pool

**Subphylum Vertebrata**

*Latimeria menadoensis*

coelacanth

from fish to tetrapod

**Subphylum Vertebrata**

Ichthyostega - early amphibious tetrapod

**Early Amphibians**

1. Lungs became more effective
2. Chambers of the heart became partially separated, making circulation more efficient
Modern Amphibians

1. All require water at some stage in the life cycle; most lay eggs in water
2. Lungs are less efficient than those of other vertebrates
3. Skin serves as respiratory organ

Living Amphibian Groups

1. Frogs & Toads
2. Salamanders
3. Ceacilians

Subphylum Vertebrata

*Ambystoma mexicanum*
Mexican axolotl

Subphylum Vertebrata

Salamander

Subphylum Vertebrata

Frog

Subphylum Vertebrata

Frogs
Evolution of Reptiles

1. Reptiles arose from amphibians in the Carboniferous
2. Adaptations to life on land
   - Tough, scaly skin
   - Internal fertilization
   - Amniote eggs
   - Water-conserving kidneys

Reptilian Radiation

1. Adaptive radiation produced numerous lineages
2. Extinct groups include:
   - Therapsids (ancestors of mammals)
   - Marine plesiosaurs & ichthyosaurs
   - Dinosaurs and pterosaurs

Therapsids

Posess many characteristics of both reptiles and mammals
Plesiosaurs
Up to 40 feet long

Ichthyosaurs
Fish-like reptiles
250 – 90 million years ago

Living Reptiles
Four orders made it to the present day
- Crocodilians
- Turtles
- Tuatars
- Snakes and lizards

Crocodile

Turtles and Tortises
1. Armorlike shell
2. Horny plates instead of teeth
3. Lay eggs on land

Lizards and Snakes
1. Largest order (95 percent of living reptiles)
2. Most lizards are insectivores with small peglike teeth
3. All snakes are carnivores with highly movable jaws
Tuataras

1. Only two living species
2. Live on islands off the coast of New Zealand
3. Look like lizards, but resemble amphibians in some aspects of their brain and in their way of walking

Tuatara

Sphenodon guentheri

Subphylum Vertebrata

Varanus goanna

Subphylum Vertebrata

Varanus goanna

Subphylum Vertebrata

Python curtus brongersmai

blood python with amniotic eggs

Subphylum Vertebrata

Aipysurus laevis

olive sea snake
Subphylum Vertebrata

Alligator mississippiensis
American alligator

Birds: Phylum Aves

1. Only birds have feathers
2. Arose from reptilian ancestors
   • Feathers are highly modified reptilian scales

Amniote Eggs

1. Like reptiles, birds produce amniote eggs
2. Inside the egg, the embryo is enclosed in a membrane called the amnion
3. Amnion protects the embryo from drying out

Adapted for Flight

1. Four-chambered heart
2. Highly efficient respiratory system
3. Lightweight bones with air spaces
4. Powerful muscles attach to the keel

From Dinosaurs to Birds

flying dinosaur  flying reptiles  flying bird

From Dinosaurs to Birds

adult
Opisthocomus hoazin
hoatzin

juvenile
From Dinosaurs to Birds

Evidence that Birds are Dinosaurs

- Birds and Reptiles have scales
- Birds and Reptiles lay eggs
- Birds and Reptiles have many similar bones including hips, feet and toes

Scales and Feathers are Similar

Bird and Reptile Scales

Bird and Reptile Feet

Bird and Reptile Scales

Bird leg

Snake skin

Bird leg

Snake skin

Owl talons

Deinonychus

Dinosaurs are NOT extinct!

Subphylum Vertebrata

They are birds!

Archaeopteryx

Alisterus scapularis

Australian King Parrot
**Subphylum Vertebrata**

- *Casuarius casuarius*
  - cassowary

- *Aptenodytes patagonicus*
  - King Penguin

- *Ninox boobook*
  - Southern Boobook (Australian owl)

**Mammals: Phylum Mammalia**

1. Hair
2. Mammary glands
3. Distinctive teeth
4. Highly developed brain
5. Extended care for the young

**Mammalian Origins**

1. 200 million years ago, during the Triassic, synapsids gave rise to therapsids
2. Therapsids were the reptilian ancestors of mammals
3. The first mammals had evolved by the Jurassic

**The first Mammal!**

*Scratchus mammalus*
Three Mammalian Lineages

1. Monotremes
   • Egg-laying mammals
2. Marsupials
   • Pouched mammals
3. Eutherians
   • Placental mammals

Living Monotremes

1. Three species
   • Duck-billed platypus
   • Two kinds of spiny anteater
2. All lay eggs

Living Marsupials

1. Most of the 260 species are native to Australia and nearby islands
2. Only the opossums are found in North America
3. Young are born in an undeveloped state and complete development in a permanent pouch on mother

Living Placental Mammals

1. Most diverse mammalian group
2. Young develop in mother’s uterus
3. Placenta composed of maternal and fetal tissues; nourishes fetus, delivers oxygen, and removes wastes
4. Placental mammals develop more quickly than marsupials

Subphylum Vertebrata

mammal

Subphylum Vertebrata

Three groupings of mammals
Subphylum Vertebrata

*Dasypus novemcinctus*
armadillo

*Manis sp.*
pangolin

*Loxodonta africana*
African elephant

*Giraffa camelopardalis*
giraffé

*Trichechus manatus latirostris*
manatee
Subphylum Vertebrata

*Zalophus californianus*
California sea lion

Subphylum Vertebrata

*Ailuropoda melanoleuca*
Giant Panda

Subphylum Vertebrata

*Ursus arctos*
brown bear

Subphylum Vertebrata

*Ursus arctos*
grizzly bear

Subphylum Vertebrata

ocelot

Subphylum Vertebrata

jaguar
Subphylum Vertebrata

*Trichosurus vulpecula*
common brushtail possum

Subphylum Vertebrata

Kangaroo and joey

Subphylum Vertebrata

bat

Subphylum Vertebrata

Behavior

Earliest Primates

1. Primates evolved more than 60 million years ago during the Paleocene
2. First primates resemble tree shrews
   - Long snouts
   - Poor daytime vision

Subphylum Vertebrata

baby orangutan
**From Primates to Humans**

“Uniquely” human traits evolved through modification of traits that evolved earlier, in ancestral forms

---

**Hominoids**

1. Apes, humans, and extinct species of their lineages
2. In biochemistry and body form, humans are closer to apes than to monkeys
3. Hominids
   - Subgroup that includes humans and extinct humanlike species

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**Trends in Lineage Leading to Humans**

1. Less reliance on smell, more on vision
2. Skeletal changes to allow bipedalism
3. Modifications of hand to allow refined hand movements
4. Bow-shaped jaw and smaller teeth
5. Longer lifespan and longer period of dependency

---

**Adaptations to an Arboreal Lifestyle**

1. During the Eocene, certain primates became adapted to life in trees
   - Better daytime vision
   - Shorter snout
   - Larger brain
   - Forward-directed eyes
   - Capacity for grasping motions

---

**First Hominids**

1. Earliest known is *Ardipithecus ramidus*
   - Lived 4.4 million years ago in Africa
   - More apelike than humanlike
2. Numerous australopiths evolved during the next 2 million years
   - Large face, protruding jaw, small skull
   - Walked upright

---

**Australopiths**

1. Earliest known is *A. anamensis*
2. *A. afarensis* and *A. africanus* arose next
3. All three were slightly built (gracile)
4. Species that arose later, *A. boisei* and *A. robustus*, had heavier builds
5. Exact family tree is not known
### Hominid phylogeny

**Humans Arise**

1. First member of the genus *Homo* is *H. habilis*
2. Lived in woodlands during late Miocene

<table>
<thead>
<tr>
<th>Homo erectus</th>
<th>Homo sapiens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Evolved in Africa</td>
<td>1. Modern man evolved by 100,000 years ago</td>
</tr>
<tr>
<td>2. Migrated into Europe and Asia about 1.5 million - 2 million years ago</td>
<td>2. Had smaller teeth and jaws than <em>H. erectus</em></td>
</tr>
<tr>
<td>3. Had a larger brain than <em>H. habilis</em></td>
<td>3. Facial bones were smaller, skull was larger</td>
</tr>
<tr>
<td>4. Was a creative toolmaker</td>
<td></td>
</tr>
<tr>
<td>5. Built fires and used furs for clothing</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Homo Neanderthalensis</th>
<th>Earliest Fossils Are African</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Early humans that lived in Europe and Near East</td>
<td>1. Africa appears to be the cradle of human evolution</td>
</tr>
<tr>
<td>2. Massively built, with large brains</td>
<td>2. No human fossils older than 1.8 million years exist anywhere but Africa</td>
</tr>
<tr>
<td>3. Disappeared when <em>H. sapiens</em> appeared</td>
<td>3. <em>Homo erectus</em> left Africa in waves from 2 million to 500,000 years ago</td>
</tr>
<tr>
<td>4. DNA evidence suggests that they did not contribute to modern European populations</td>
<td></td>
</tr>
</tbody>
</table>
Where Did *H. sapiens* Arise?

1. Two hypotheses:
   - Multiregional model
   - African emergence model
2. Both attempt to address both biochemical and fossil evidence

Multiregional Model

1. Argues that *H. erectus* migrated to many locations by about 1 million years ago
2. Geographically separated populations gave rise to phenotypically different races of *H. sapiens* in different locations
3. Gene flow prevented races from becoming species

African Emergence Model

1. Argues that *H. sapiens* arose in sub-Saharan Africa
2. *H. sapiens* migrated out of Africa and into regions where *H. erectus* had preceded them
3. Only after leaving Africa did phenotypic differences between races arise

Genetic Distance Data