Have a seat Kermit. What I'm about to tell you might come as big shock...
What phylum do you belong to? You and what else?

And these other groups you mentioned are...what...genuses, species, classes, orders, families???

And your mouth forms...first or second?

And what sub-phylum would that be??

Vertebrates can do things like this and this
• Here’s the chart…much less controversy about this
1. Four anatomical features characterize the phylum Chordata

- All chordates have these four…at least at some point in their life…what does that mean?

[Diagram showing muscle segments, notochord, dorsal hollow nerve cord, brain, mouth, postanal tail, anus, pharyngeal slits]
1. A **notochord**
2. found in all chordate **embryos**
3. longitudinal, flexible rod
4. between the digestive tube and the nerve cord.
   - It provides skeletal support throughout most of the length of the animal.
   - It remains as only a remnant in vertebrates with a more complex, jointed skeleton.
     - For example, it is the gelatinous material of the disks between vertebrae in humans.
2. The dorsal, hollow *nerve cord* develops in the vertebrate embryo from a plate of *ectoderm* that rolls into a tube dorsal to the notochord.

- Other animal phyla have a *solid* nerve cord, usually located *ventrally*.
- It develops into the central nervous system: the brain and spinal cord.
3. Pharyngeal gill slits connect the pharynx, just posterior to the mouth, to the outside of the embryo. They can...

- Allow water to come in the mouth and exit without going into the digestive tract (so it can pass over gills).
- function as suspension-feeding devices.
- become modified for gas exchange (in aquatic vertebrates), jaw support, hearing, and other functions during the “tinkering” of vertebrate evolution.
4. Most chordates have a muscular tail extending posterior to the anus.

- In contrast, nonchordates have a digestive tract that extends nearly the whole length of the body.
- The chordate tail contains skeletal elements and muscles. It can...
- Provide propulsive force in many aquatic species.
- Be a balance aid, as in when a cheetah is changing direction.
2. Invertebrate chordates provide clues to the origin of vertebrates

- Most **urochordates**, commonly called **tunicates**, are sessile marine animals that adhere to rocks, docks, and boats.

- Others are planktonic.

- Could you have come from something that looks like this?
Fig. 34.3a, b
• All four chordate trademarks are present in the larval forms of some tunicate groups.

• The larva swims until it attaches its head to a surface and undergoes metamorphosis, during which most of its chordate characteristics disappear.
Cephalochordates, also known as lancelets, closely resemble the idealized chordate.

- The notochord, dorsal nerve cord, numerous gill slits, and postanal tail all persist in the adult stage.
- They live with their posterior end buried in the sand and the anterior end exposed for feeding.
• The evolution of vertebrates from invertebrates may have occurred in two stages.
  • In the first stage, an ancestral cephalochordate evolved from an organism that would resemble a modern urochordate larva.
  • In the second, a vertebrate evolved from a cephalochordate – like thing
• This first stage may have occurred through **paedogenesis**, the precocious development of sexual maturity in a larva.

• Changes in the timing of expression of genes (Hox genes) controlling maturation of gonads may have led to a swimming larva with mature gonads before the onset of metamorphosis.
• Several fossil finds in China provide support for the change from cephalochordate to vertebrate.
  • They appear to be “missing links” between groups.
  • These fossils push the vertebrate origins to the Cambrian explosion.
The dorsal, hollow nerve cord develops when the edges of an ectodermal plate on the embryo’s surface roll together to form the neural tube.

Watch this.

In vertebrates, a group of embryonic cells, called the neural crest, forms near the dorsal margins of the closing neural tube.
• Neural crest contributes to the formation of certain skeletal elements, such as some of the bones and cartilages of the cranium, and other structures.
Section D: Fishes and Amphibians

1. Vertebrate jaws evolved from skeletal supports of pharyngeal slits
2. Class Chondrichthyes: Sharks and rays have cartilaginous skeletons
3. Osteichthyes: The extant classes of bony fishes are the ray-finned fishes, the lobe-finned fishes, and the lungfishes
4. Tetrapods evolved from specialized fishes that inhabited shallow water
5. Class Amphibia: Salamanders, frogs, and caecilians are the three extant amphibian orders
• Jaws and paired fins were major evolutionary breakthroughs. A little video from “Evolve” 1:35-9:10.

• Jaws, with the help of teeth, enable the animal to grip food items firmly and slice them up.

• A jawed fish can exploit food supplies that were unavailable to earlier agnathans.

• Paired fins, along with the tail, enable fishes to maneuver accurately while swimming.

• With these adaptations, many fish species were active predators, allowing for the diversification of both lifestyles and nutrient sources.
Vertebrate jaws evolved from skeletal supports of the pharyngeal slits.

- Vertebrate jaws evolved by modification of the skeletal rods that have previously supported the anterior pharyngeal slits.
- The remaining gill slits remained as the site of respiration.
2. Class Chondrichthyes: Sharks and rays have cartilaginous skeletons

- The class Chondrichthyes, sharks and their relatives, have relatively flexible endoskeletons of cartilage rather than bone.
  - In most species, parts of the skeleton are strengthened by mineralized granules, and the teeth are bony.
  - All have well-developed jaws and paired fins.
• The cartilaginous skeleton of these fishes is a derived characteristic, not a primitive one.
  • The ancestors of Chondrichthyes had bony skeletons.
  • The cartilaginous skeleton evolved secondarily.
• During the development of most vertebrates, the skeleton is first cartilaginous and then becomes ossified as hard calcium phosphate matrix replaces the rubbery matrix of cartilage.
• Acute senses are adaptations that go along with the active, carnivorous lifestyle of sharks.

• Sharks can detect electrical fields, including those generated by the muscle contractions of nearby prey, through patches of specialized skin pores, ampulla of Lorenzini.(?)

• The **lateral line system**, a row of microscopic organs sensitive to pressure changes, can detect low frequency vibrations.

• Can you say – response to environmental stimulus??

• So don’t move too much when sharks are around…
Most fishes have an internal, air-filled sac, the swim bladder.

- The positive buoyancy provided by air counters the negative buoyancy of the tissues, enabling many fishes to be neutrally buoyant and remain suspended in the water.
- The swim bladder evolved from balloonlike lungs that may have been used to breathe air when dissolved oxygen levels were low in stagnant shallow waters.
• Bony fishes, including the ray-finned fishes, probably evolved in freshwater and then spread to the seas during their long history.

• Here’s how we measure fish in the South.
• Lobe-finned fishes (class Actinistia) have muscular pectoral and pelvic fins supported by extensions of the bony skeleton.

• Many lobe-fins were large, bottom dwellers that may have used their paired, muscular fins to “walk” along the bottom.

• Most Devonian coelocanths were probably freshwater animals with lungs, but others entered the seas during their evolution, including the only living genus, Latimeria.
4. Tetrapods evolved from specialized fishes that inhabited shallow water

- Amphibians were the first tetrapods to spend a substantial portion of their time of land.

- However, there were earlier vertebrate tetrapods that had relatively sturdy, skeleton-supported legs instead of paired fins, and which lived in shallow aquatic habitats.

- Let’s take a peek at the past and tetrapod evolution from the show NOVA – Intelligent Design on Trial.42:30.
Fig. 34.16
1. Evolution of the amniotic egg expanded the success of vertebrates on land

- The amniote clade consists of mammals, birds, and the vertebrates commonly called reptiles, including turtles, lizards, snakes, and crocodiles.
- The evolution of amniotes from an amphibian ancestor involved many adaptations for terrestrial living including:
  - the amniotic egg
  - waterproof skin
  - increasing use of the rib cage to ventilate the lungs.
The amniotic eggs enabled terrestrial vertebrates to complete their life cycles entirely on land.

- In contrast to the shell-less eggs of amphibians, the amniotic eggs of most amniotes have a shell that retains water and can be laid in a dry place.
- Most mammals have dispensed with the shell.
  - The embryo implants in the wall of the uterus and obtains its nutrition from the mother.
3. A reptilian heritage is evident in all amniotes

- Reptiles have several adaptations for terrestrial life not generally found in amphibians.
  - Scales containing the protein keratin waterproof the skin, preventing dehydration in dry air.
  - Reptiles obtain all their oxygen with lungs, not through their dry skin.
    - As an exception, many turtles can use the moist surfaces of their cloaca for gas exchange.
HIKERS and BIKERS
Move to the side of the road when a vehicle approaches
• Reptiles, sometimes labeled “cold-blooded,” do not use *their metabolism* extensively to control body temperature.

• However, many reptiles regulate their body temperature *behaviorally* by basking in the sun when cool and seeking shade when hot.

• Because they absorb external heat rather than generating much of their own, reptiles are more appropriately called *ectotherms*.

• One advantage of this strategy is that a reptile can survive on less than 10% of the calories required by a mammal of equivalent size.

• Some can get pretty big, like this cobra
More temperature regulation stuff

• Let’s visit that lower life form, the gator, again.
• Gators get to be boys or girls depending on the temperature while they are developing inside the egg. Males like it hot, females are cool.
• This is an example of an environmental factor influencing a trait.
• By the end of the Cretaceous, the dinosaurs became extinct.
4. Birds began as feathered reptiles

- Birds evolved during the great reptilian radiation of the Mesozoic era.
  - In addition to amniotic eggs and scales, modern birds have feathers and other flight equipment.
- Almost every part of a typical bird’s anatomy is modified in some way to enhance flight.
  - One adaptation to reduce weight is the absence of some organs.
    - For instance, females have only one ovary.
• Bird skeletons have several adaptations that make them light, flexible, but strong.

• The bones are honeycombed to reduce weight without sacrificing much strength.
The obvious adaptation for flight is wings.

Wings are airfoils that illustrate the same principles of aerodynamics as airplane wings.

- Pressure differences created by differences in air flow over the top and bottom of the convex wing lift the wing and the bird.

- Large pectoral (breast) muscles anchored to a keel on the sternum (breastbone) power flapping of the wings.
• Cladistic analyses of fossilized skeletons support the hypothesis that the closest reptilian ancestors of birds were **theropods**.

• These were relatively small, bipedal, carnivorous dinosaurs (such as the velociraptors of *Jurassic Park*).

• While most researchers agree that the ancestor of birds was a feathered theropod, others place the origin of birds much earlier, from an ancestor common to both birds and dinosaurs.

• An ancestor like a … *chainsaw??*

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• The most famous Mesozoic bird is *Archeopteryx*, known from fossils from Bavaria.

• This ancient bird lived 150 million years ago, during the late Jurassic period.

• *Archeopteryx* had clawed forelimbs, teeth, and a long tail containing vertebrae.

Fig. 34.27
In 1998, paleontologists described a diversity of Chinese fossils that may fill in the gap between dinosaurs and early birds such as *Archeopteryx*.

- These include feathered but flightless dinosaurs which may have evolved feathers for thermoregulation or courtship displays.
- Others have a much closer kinship to modern birds with a lack of teeth, a horny bill, and a short stubby tail.
- What ancestor do you think is in this one’s family tree?
5. Mammals diversified extensively in the wake of the Cretaceous extinctions

- With the extinction of the dinosaurs and the fragmentation of continents that occurred at the close of the Mesozoic era, mammals underwent an extensive adaptive radiation.

- There are about 4,500 extant species of mammals.
Vertebrates of the class Mammalia were first defined by Linnaeus by the presence of mammary glands.

- All mammal mothers nourish their babies with milk, a balanced diet rich in fats, sugars, proteins, minerals, and vitamins, produced in the mammary glands.
- All mammals also have hair, made of keratin.
  - Hair and a layer of fat under the skin retain metabolic heat, contributing to endothermy in mammals.
- Endothermy is supported by an active metabolism, made possible by efficient respiration and circulation and insulation.
  - Adaptations include a muscular diaphragm and a four-chambered heart.
In Australia, marsupials have radiated and filled niches occupied by eutherian mammals in other parts of the world.

Through convergent evolution, these marsupials resemble eutherian mammals that occupy similar ecological roles.
Section F: Primates and the Evolution of *Homo sapiens*

Here’s a classic study of chimps done by Jane Goodall. Try to pick out examples of:

Adaptive cooperative behavior.
Adaptive signals that change behavior in others.
Adaptive learned behaviors.
1. Primate evolution provides a context for understanding human origins

- Primates are difficult to define unambiguously in terms of morphological attributes.
  - Most primates have hands and feet adapted for grasping.
  - Relative to other mammals, they have large brains and short jaws.
  - They have flat nails on their digits, rather than narrow claws.
  - Primates also have relatively well-developed parental care and relatively complex social behavior.
• The earliest primates were probably tree dwellers, shaped by natural selection for arboreal (tree) life.
  
• The grasping hands and feet of primates are adaptations for hanging on to tree branches.
  
• All modern primates, except *Homo*, have a big toe that is widely separated from the other toes.

• The thumb is relatively mobile and separate from the fingers in *all* primates, but a *fully opposable thumb* is found only in anthropoid primates.

• The unique dexterity of humans, aided by distinctive bone structure at the thumb base, represents descent with modification from ancestral hands *adapted for life in the trees*. 
• Other primate features also originated as adaptations for tree dwelling.
  • The overlapping fields of vision of the two eyes (binocular vision) enhance depth perception, an obvious advantage when brachiating.
  • You aren’t born with this ability, your 3D vision develops about 4 months after birth.
  • Excellent hand-eye coordination is also important for arboreal maneuvering.
  • Let’s play catch and then watch some video – Evolve: Eyes 34:30
Earliest primate may have looked like one of these.
The oldest known anthropoid fossils, from about 45 million years ago, support the hypothesis that tarsiers are the prosimians most closely related to anthropoids.

Fig. 34.35
Homo floresiensis – the “Hobbit Person”

“Flo” was less than 3 ½ feet tall and had a very small brain, but has shown signs of tool use and culture that led us to put her in the genus Homo.

They lived on the Indonesian island of Flores from 90,000 – 14,000 years ago, possibly carried there on a tsunami, clinging to driftwood? Wild idea, eh?
And the Denisovans???

• Cousins to Neanderthals, known from a single finger bone found in a cave in Denisova, Siberia.
• Genomic analysis of DNA from the bone places them in our family tree, even showing that people in New Guinea have 5% Denisovan DNA, suggesting some cross breeding.
• All humans except those of purely African origin have 1 – 3% Neanderthal DNA.
• Paleoanthropology has a checkered history with many **misconceptions about human evolution**.

• First, our ancestors were not chimpanzees or any other modern apes.

• Witness this quote from a St. John’s county resident when asked about teaching evolution in school:

  • “Last time I went to the zoo I didn’t see any monkeys evolving into humans.”
Secondly, human evolution did not occur as a ladder with a series of steps leading directly from an ancestral hominoid to *Homo sapiens*.

If human evolution is a parade, then many splinter groups traveled down dead ends and several different human species coexisted.
Fig. 34.38
• Third, the various human characteristics, such as upright posture and an enlarged brain, did not evolve in unison.

• Our pedigree includes ancestors who walked upright but had brains much less developed than ours, suggesting that upright walking (bipedalism) set the stage for the evolution of larger brains.

• After dismissing some of the folklore on human evolution, we must admit that many questions about our own ancestry remains.
• Our anthropoid ancestors of 30 - 35 million year ago were still tree dwellers.

• By about 20 million years ago, the climate became drier and what was forest with many trees turned into savannah with grasslands and sparse trees.

• Some of the major evolutionary changes leading to our species may have occurred as our ancestors came to live less in the trees and spent more time walking on the ground between them.

• But even this “savanna hypothesis” is disputed by evidence that Ardi walked upright but lived in the forests, and Ardi is now seen as a direct ancestor.
• Human evolution is marked by the evolution of several major features.

  • **Brain Size.** Based on skull measurements, researchers have estimated that brain size in hominoids tripled over the past 6 million years. Except for Flo.
    • It increased from about 400-450 cm³ in hominoids (and similar to modern chimpanzees) to about 1,300 cm³ in modern humans.

  • **Jaw Shape.** Our hominoid ancestors had longer jaws - **prognathic jaws** - than those of modern humans.
    • This resulted in a flatter face with a more pronounced chin.
Paedomorphogenesis, or Neoteny

- Neoteny is the maintenance of juvenile characteristics into the adult stage, not uncommon in the animal kingdom.
- Humans are bipedal, neotenous apes, best seen in skull structure comparisons. Chimp baby, adult, and human.
• **Bipedal Posture.** Based on fossil skeletons, it is clear that our hominoid ancestors walked on all four limbs when on the ground, like modern apes. Let’s watch Great Transformations – Bipedalism (47:40).

• The evolution of bipedalism - upright posture and two-legged walking - is associated with key skeletal changes seen in early hominid fossils.

• Position of the foramen magnum (where your backbone connects to your skull) is more centered in humans so the head sits on top of the spine.

• Feet with arches and a non-opposable big toe

• Longer, stronger legs/leg bones

• Larger muscles on legs – gluts, hamstrings, quads, gastrocnemius

• Wider pelvis, knees close together for support

• S-curve in lumbar spine to support weight above
So this bipedal thing....

- **Is it really all ours?**
- **How about this cool cat?**
• **Some Key Changes in Family Structure.** Fossils are effective at documenting evolutionary changes in morphological features, but not changes in social behavior, or what is called *cultural evolution*.

  • In contrast to most ape species, monogamy, with long-term pair-bonding between mates, prevails in most human cultures.

  • Newborn humans infants are exceptionally dependent on their mothers, and the duration of parental care (and opportunities for enhanced learning) is much longer in humans than in other hominoids.

  • This ability to learn and pass on info sets the stage for…
Cultural evolution events:

- Tool making (wood, bone and metal)
- Organized hunting and gathering
- Agriculture
- Industrial revolution
- Commerce and technology
- These are examples of adaptive learned behavior.
- These changes were as drastic and usually faster than genetic evolution
Comparing cultural and genetic evolution

- Genetic is slower, cultural faster.
- Genetic is inherited vertically, cultural can be inherited both vertically and horizontally.
- Genetic component of a trait comes before the cultural, eg – brain size, then language.
- Genetic controlled and passed on by genes, cultural controlled and passed on by teaching and learning.
- Now let’s check out a cultural/genetic example of co-evolution.  
  
  [Got Lactase?](#)
• The various pre-\textit{Homo} hominids are classified in the genus \textit{Australopithecus} (“southern ape”) and are known as australopithecines.

• The first australopithecine, \textit{A. africanus}, was discovered in 1924 by Raymond Dart in a quarry in South Africa.

• From this and other skeletons, \textit{A. africanus} probably walked fully erect and had humanlike hands and teeth.

• However, the brain was only about one-third the size of a modern human’s brain.
In 1974, a new fossil, about 40% complete, was discovered in the Afar region of Ethiopia.

This fossil, nicknamed “Lucy,” was described as a new species, *A. afarensis*.

These were considered to be our direct ancestors, but are no longer

It appears they evolved into other Australopithecines, like *africanus*, but then they became extinct.

What drove these smaller brained primates to evolve into bigger brained humans? Here’s an idea from Evolve – Guts (38:15 – 42:00)
In the past few years, paleoanthropologists have found hominid species that predate *A. afarensis*.

- The oldest fossil that is unambiguously more human than ape is *Australopithecus anamensis*, which lived over 4 million years ago.
- Other fossils of putative hominids go back 6 million years, closer to the ape-human split that molecular systematists estimate occurred about 5 - 7 million years ago.
- *Ardipithecus ramidus*, found in Ethiopia and dating back to 4.4 million years ago, is a full million years older than Lucy.
The earliest fossils that anthropologists place in our genus, *Homo*, are classified as *Homo habilis*.

- These fossils range in age from 2.5 to 1.6 million years old.
- This species had less prognathic jaws and larger brains (about 600 - 750 cm³) than australopithecines.
- In some cases, anthropologists have found sharp stone tools with these fossils, indicating that some hominids had started to use their brains and hands to fashion tools.
- But *Homo habilis* is also considered to be a cousin of ours, not a direct ancestor.
• *Homo erectus* was the first hominid species to migrate out of Africa, colonizing Asia and Europe.
  
  • They lived from about 1.8 million to 500,000 years ago.
  
  • Fossils from Asia are known by such names as “Beijing man” and “Java Man”.
  
  • In Europe, *H. erectus* gave rise to the humans known as Neanderthals, as well as Denisovans.
  
  • Compared to *H. habilis*, *H. erectus* was taller, had a larger brain (averaging about 1,100 cm³), and had about the same level of sexual dimorphism as modern humans.
• The term Neanderthal is now used for humans who lived throughout Europe from about 200,000 to 40,000 years ago.

• Fossilized skulls indicate that Neanderthals had brains as large as ours, though somewhat different in shape.

• Neanderthals were generally more heavily built than modern humans.
Two alternative hypotheses have been proposed for the origin of anatomically modern humans.

In the **multiregional hypothesis**, fully modern humans evolved in parallel from the local populations of *H. erectus*.

In this view, the great genetic similarity of all modern people is the product of occasional interbreeding between neighboring populations.
• The other hypothesis, the “Out of Africa” or replacement hypothesis, argues that all *Homo sapiens* throughout the world evolved from a second major migration out of Africa that occurred about 100,000 years ago.

• This migration completely replaced all the regional populations of *Homo* derived from the first hominid migrations.

Fig. 34.41b
A recent idea of how all these are related
• Both hypotheses recognize the fossil evidence for humanity’s African origin.

• The multiregional hypothesis places that last common ancestor in Africa over 1.5 million years ago, when *H. erectus* began migrating to other parts of the world about 100,000 years ago.

• According to the replacement hypothesis, all of the world’s populations diverged from anatomically modern *Homo sapiens* that evolved from an African *H. erectus* population and then migrated throughout the world.

  • All of the regional descendents of *H. erectus* are therefore evolutionary dead ends.
To choose among these competing hypotheses, comparisons of Y chromosomes in 2001 provide perhaps the most important genetic data so far.

- The Y chromosome is passed from male to male through the generations of a family with a minimum of crossing over with the X chromosome.

- The diversity among Y chromosomes is limited to mutations.

- By comparing the Y chromosomes of males from various geographic regions, researchers were able to infer divergence from a common African ancestor less than 100,000 years ago.
So let’s look at this a little more closely..

- Start with chapter 11 of this lecture.
- [http://media.hhmi.org/hl/11Lect2.html](http://media.hhmi.org/hl/11Lect2.html)
- This is [the most updated model](http://media.hhmi.org/hl/11Lect2.html).
So to summarize

• Is this how we got here? (Scene 8 from One Voice in the Cosmic Fugue, please)
• Or was it like this that we all got here.
• Another neat one. 1 min.
• Will we continue to evolve?
• How about a little cladogram refresher compliments of an IB style worksheet??