- **Deuterostomia** (superphylum)

First opening in the blastula becomes the anus, and blastula is cleaved radially.

  - **Ambulacraria** (phylum)

  Standard deuterostome (radially cleaved triploblast) blastula develops into a dipleura larval form

    - **Echinoderms** (phylum)

    Evolved from organisms with bilateral symmetry, as the larva are generally bilateral, these are organisms with (usually) 5 point radial symmetry as adults. The "left side" of the body grows "pentaradially" and the right side shrinks which is how they end up with radial symmetry.
    This is the largest phylum with NO TERRESTRIAL OR FRESHWATER members - mostly benthic. This phylum first started appearing at the start of the Cambrian. Most can reproduce asexually and regenerate organs and limbs. They have a mesodermal skeleton of plates of calcite. Their vascular system is based entirely on water.
    Sea stars, sea urchins, sea cucumbers, sea lilies

    - **Hemichordates** (phylum)

    Main member is the acorn worm.

  - **Chordata** (phylum)

  "During some period of their life cycle, chordates possess a notochord, a dorsal nerve cord, pharyngeal slits, and a post-anal tail: these four anatomical features define this phylum."
  This dorsal hollow nerve cord is the main component of the central nervous system.

    - **Cephalochordata** (subphylum)

    Lancelets

    - **Olfactores** (clade)

    Pharynx develops to include sensory and respiratory functions

      - **Tunicates** (subphylum)

      Formerly called Urochordates. Some are solitary, some replicate by budding and form colonies, most are sessile as adults, all are siphon/filter feeders.
      Earliest probable tunicate appeared at the beginning of the Cambrian

      - **Vertebrates** (subphylum)

      Possess a vertebral column - a stiffer structure with jointed segments (vertebra) that replaces the notochord. Unique to vertebrates are neural crest cells and neural cephalization.
      Big of the earliest known vertebrates is the Haikouichtys, which appeared 525 mya during the Cambrian Explosion
      (the hierarchy gets a bit messy here; basically it's jawed vs non jawed animals)

        - **Agnatha** (superclass)

        Lampreys and Myxini (hagfish). Ectothermic. The digestive track is long and relatively homogeneous; no distinctive gut.
        Haikouichtys, the earliest known vertebrate, falls in this category.
        Many extinct species

        - **Gnathostomata** (superclass)

        Jawed vertebrates - living representatives have a semicircular ear canal, myelin sheaths on neurons, and paired appendages.
        Jaws are believed to be derived from specialized gill arches which were adapted to push water into the mouth for gas exchange; over time, this resulted in the ability to bite.

          - **Placodermi †** (class)

          Armored fishes. Some placoderms have been observed with three pairs of paired appendages, which has not been seen in any other vertebrate group. They also developed the first pelvic fins (precursors to legs in tetrapods) and true teeth consisting of pulp, bone, and dentine.
          Some placoderms gave live birth; one fossil fossilized a mother in the process of giving birth with the umbilical cord intact. This pushed back the date of viviparity by ~200 my.
          Earliest fossils found in China and are from the Silurian

          - **Eugnathostomata** (superclass)

            - **Acanthodians †** (class)

            Paraphyletic group including the lineages leading to the extant Chondrichthyes.

            - **Chondrichthyes** (class)

            Cartilaginous fish
            "A 419-million-year-old fossil of a placoderm named Entelognathus had a bony skeleton and anatomical details associated with cartilaginous and bony fish, demonstrating that the absence of a bony skeleton in Chondrichthyes is a derived trait."
            Almost all have rough skin with dermal teeth. All use internal fertilization, but some lay eggs and some give live birth.

              - **Elasmobranchii** ∈

              Sharks, rays, skates, sawfish. Earliest elasmobranch fossils are from the Devonian.
              They don't have a swim bladder and instead use very oily livers to control buoyancy. Their eyes have tapetum lucidum.

              - **Holocephali**

              Includes the Australian ghostshark, which we believe to be the closest evolving vertebrate. Unlike most cartilaginous fish, the notochord is not replaced by a vertebral column.

            - **Osteichthyes** (class)

            Bony vertebrates.
            Early bony fish had simple lungs that in many cases later evolved into swim bladders (in other cases they became lungs for terrestrial vertebrates).

              - **Actinopterygii** (class)

              Ray-finned fish - fins are webs of skin supported by bony spines instead of fleshy limbs. Almost all species have separate sexes and external fertilization.

                - **Cladista**

                Only contains a few cell-like fishes out of many extinct representatives.

                - **Actinopteri**

                  - **Chondrostei**

                  Primarily cartilaginous fish that also show some ossification. The cartilage-ness is believed to be derived instead of elementary; ancestors of these species developed bones just like other Osteichthyes.
                  Have a heterocercal tail and no scales just like sharks and other Elasmobranchii.

                    - **Acipenseridae**

                    Sturgeon, 27 species. Have 5 rows of scutes instead of scales. Sturgeons are anadromous (live in the sea, migrate to freshwater to mate). Toothless benthic suction feeders. Sturgeon are sometimes seen leaping completely out of the water and splashing down which can be heard a mile away and it's unclear why they do this.

                    - **Polyodontidae**

                    Paddlefish

                  - **Neopterygii**

                    - **Holostei**

                    Gars and bowfins, both of which are freshwater.

                    - **Teleostei** ∈

                    Advanced Actinopterygians which have 96% of all extant fish species. All have leptoid scales, which are thinner and more transparent than other kinds of scales and new scales are added in concentric layers. Another distinguishing feature is movable premaxilla, which allow them to extend their mouths forward to pull in prey. They also have a second set of pharyngeal jaws.
                    Almost all diurnal teleosts have colored vision at least as good as a humans and most have good smell, taste, lateral line system.
                    All teleosts are ectotherms, and cold water teleosts have more unsaturated membrane fatty acids that allow them to maintain membrane fluidity in their cells. These adapted fish also have higher mitochondrial and capillary density to produce more aerobic ATP and counteract the lower metabolism due to a lower body temperature. Some also have mechanisms to keep their brains and eyes warm to maintain good vision. Fast swimming ocean fish like tuna use countercurrent exchange to maintain body temperatures as high as 11 degrees above the environment.
                    Teleosts have an egg, larval, juvenile, adult life cycle.

          - **Sarcopterygii** (class)

          Lobe-finned fish.
          All have teeth covered in true enamel, pectoral, and pelvic fins.
          This divergence of lobe finned fish from ray finned fish happened during the Devonian, approx 450 mya

            - **Onychodontida †** (order)

            Early diverging coelocanths

            - **Actinistia** (order)

            Coelacanth

            - **Dipnotetrapodomorpha** (infraclass)

            Tetrapods and extinct closest relatives

              - **Tetrapods** (order)

              Classification gets messy and largely hypothesis based here; the important features are stem tetrapods, amphibians, and amniotes, so that is how we present them here.
              Late tetrapods appeared 375 mya during the Devonian and were aquatic. It's not known how they colonized the land, but the development of amniotic sacs was crucial and drove many amphibious tetrapods to extinction.
              A notable development in Acanthostega is the absence of bones covering the gills, resulting in the appearance of a neck that is absent in other tetrapodomorphs.
              Terrestrial tetrapods had to adapt to retaining water and supporting their bodies against gravity, as they were no longer were aquatic. The tetrapod tongue is built form muscles that used to control gill openings.
              The development of respiration was probably influenced by the charcoal gap, a period of 20 million years when atmospheric oxygen was too low to sustain wildfires. Aquatic tetrapods had to develop air breathing abilities to deal with low oxygen water and probably used gills, lungs, breathing through skin, and breathing through the digestive tract.
              The early terrestrial tetrapods would've had to adapt their smell to the difference in density of chemicals in the air and water. The refractive index of air and water is also different so eyes had to change and eyelids emerged to keep eyes moist. All but some amphibians lost the lateral line system.

                - **Stem Tetrapods**

                "Branch" families of tetrapods with no significant evolutionary diversity or impact.

                - **Lissamphibia** ∈

                Amphibians
                Traditionally excludes the early Paleozoic tetrapods. Shared traits: two types of skin glands (mucous and granular), green rods for vision, ability to elevate eyes.

                - **Amniota**

                Amniotes, including reptiles and mammals, which lay eggs on land or retain them in the mother. They develop straight into a limbed form with a thick epithelium as opposed to a larval tadpole stage that develops with metamorphosis. Embryonic development involves the membrains amnion, chorion, allantois. The replacement of the amphibian gelatinous membrane with the sturdy fibrous shell allowed an increase in egg size and rate of gas exchange, permitting the embryo to become larger and more metabolically active and thus more advanced before birth.
                Endothermy in some mammals and reptiles is theorized to be a defense mechanism against fungi, which cannot survive high body temperatures. By comparison, insects and ectotherms tend to suffer from a lot of fungal infections.

                  - **Synapsida** ∈

                  Mammals and relatives, which have a temporal fenestra and differentiated teeth that sets them apart from sauropsids.
                  Early synapsids were the largest terrestrial vertebrates in the Permian (250 mya) but they were greatly reduced by the P-T extinction.
                  The mandible is a single bone instead of multiple and over time a second palate separating the nasal cavity and mouth began to form.
                  Early synapsids may have layed dry leathery eggs with needed to be incubated and kept moist with glands on the mother. These glands may have eventually evolved into mammary glands.

                  - **Sauropsida** ∈

                  Everything else; lizards, snakes, crocodiles. This term is broadly equivalent to "reptiles."
                  Reptiles first appeared during the Carboniferous and the two main branches, archosaurs and lepidosaurs, diverged during the Permian.
                  Of surviving reptiles, the non-bird ones are cold blooded and are thus restricted by a slower metabolism. In some larger reptiles like the leatherback turtle, a low surface area to volume ratio and muscular heat allows them to maintain a slightly higher temperature than their surroundings without being truly warm blooded. This is called gigantothermy.
                  The low food requirement associated with cold blooded-ness (a crocodile can go half a year without eating) allows reptiles to persist in areas where food expensive mammals cannot. Not clear though if cold bloodedness is a result of ecology.
                  Lepidosaurs have epidermal scales while turtles and crocodiles have dermal scales or scutes.
                  Digestion is usually slow but their digestive tracts are short because meat and insects are easier to digest than plants. All reptiles have a cloaca.
                  Reptiles have good vision and color vision that also allows them to see UV. Most reptiles have a nictitating membrane.