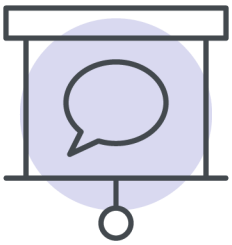
uOttawa

BIO2135

FINAL EXAM

STUDY GUIDE



Lecture Notes

Protozoan

- Single celled organisms
- Multicellular organisms arose from single celled organisms

Protist origins: Endosymbioont theory

- Endosymbiont theory accounts for:
  - Nuclear membrane
  - Intracellular membranes and spaces
  - Mitochondria (chloroplasts): the energy site for the cells

Origin of the nuclear envelope

- Membrane proliferation of the mitochondria created nuclear envelop and it also divided the cell into cytoplasmic space and non-cytoplasmic space
- Originally, bacteria had a nuclear material that was in the nucleoid region, with no separation of the cytoplasm
- Cytoplasm had to contain all of material and processes for protein production, digesting and breakdown of material, duplication of DNA, translation, transcription, etc
- In part of the enfolding inwards of the membrane, it completely surrounded the nucleus material formed plasma membrane
- Pores are also formed and the environment was chemically set up for all the things that are involved with DNA (replication, translation, transcription)
- The nuclear plasm specialized for all the processes for DNA and left cytoplasm to become the region where all the other cellular activities occurred
- The enfolding extended inside and got cutoff by the membrane creating endoplasmic reticulum with no cytoplasm in it

Endosymbiosis

- Bacteria fed on each other to survive
- Bacteria was engulfed by another and it did not get digested instead it provided the outer bacteria ATP by oxidative phosphorylation
- The cytoplasm of the host cell also breaks down the organic materials towards three carbon pyruvate which is ideal for mitochondria to use to generate high energy electron in the kreb cycle
- The host cells get ATP and the mitochondria gets unlimited supply of pyruvate three carbon molecules
- This became so successful

Origin of cellular motility – Cellular creeping

- Based on the unique structure found in the cell
- Centriole is thought to be at the base of the first form of motility in cells

Centriole

- Unique morphology: has triplet of **tubulin** molecules, which are cylindrical molecule of monomers
- There are nine of the tubulin ranged around the outside and a single one in the center
- They are always in pairs at right angles of each other
- They are important for cell division for eukaryotes

Spindle fibers and chromosomes

Protozoan

- In eukaryotes, genomes have grown bigger and contains chromosomes, which is a genomic strand that are broken into pieces
- During replication of the genome, fragments are replicated at faster rates
- Every chromosome is found in pairs, which is known as alleles
- This is advantageous because if there was mutation, the other could take over the system to mask the affect of the mutation
- The role of centriole is to separate chromosomes and migrate them to the opposite ends of the cells and shoot out microtubular arrays called spindle fibers
- Spindle fibers are attached to the chromosomes then little molecular motors drives chromosomes to the right end of the cell
- Does not end with the same sets of the same chromosomes

Microtubules and cytoskeleton

- When centrioles are not making the spindle fibers for chromosomal divisions, they are constantly laying down a cytoskeleton of tubulin structure to form the mash work of fibers in the cell
- Centriole is involved in directing and making of the cytoskeleton
- Polarity is involved when putting the dimers because one end is different than the other
    - This is important because when the centrioles are building fibers, they start adjacent to the centriole and they are added, lengthening it

Kinesin/Dyenin motors

- These protein motors have catalytic foot that interacts with the tubular molecule allowing them to walk along the microtubulin ends of the cytoskeleton
- When foot interacts with tubulin, it creates chemical reaction that stimulates and burns ATP resulting change of shape
- This changing of shape causes the other foot to move forward
- These motors also work as transport mechanisms
    - As they walk, their arms attach to the vesicles, chromosomes, or food vacuoles dispersing or moving the material across the cell
- The moving of chromosome results in moving of microtubules in the cell
- This simple diffusion is one of the success for eukaryotes

Origin of cellular motility

- Hypothesis: centriole sits and grow microtubules which extends and pushes against the cytoplasmic membrane with their rigid cytoskeleton
    - This pushing of the cytoplasmic membrane allowed cells to glide to new location
- THIS IS CELL GLIDING NOT AMOEBOID MOVEMENT
- Microtubules are highly organized and produced in 9+2 structure
- Over time, microtubules organized themselves in to a distinctive structure that allowed the extension to wiggle and move around allowing swimming motion
- This was the very first flagella or ciliary structure

Protist Supergroups

- Unikonts
    - Opisthokonta: ancestor of animalia and fungi
    - Amoebozoa
- Bikonts
    - Chromalveolata (Cilliophora and Apicomplexa)

Protozoan

- Archaeplastida (Plantae)
- Excavata (Euglenozoa)
- Rhizaria

Unikont & bikont protis

- The very first organism was unikont which is a flagellum that was attached to the substrate creating water current (in animals)
  - The water current removed metabolic waste, provided fresh supply of oxygen and food that was engulfed by phagocytosis
- Bikont: the centriole divides and gets another flagellum resulting in two flagella for one organism (in plants)
  - The extra flagellum allowed them to go up the water column and fed on photosynthetic bacteria and this is how the chloroplast was formed
  - All photosynthetic eukaryote cells share a bikont ancestors

Opisthokonta

- Ancestor of Animalia and fungi (shared morphology)
- They were unikont but the flagellum was used to push through water

Amoeba

- Group that developed better mobility than using flagellum
- Centriole provided transport system that allowed large eukaryote cells to be able to function
- Centiole can reproduce themselves without any genetic material involved
- During cel division, a pair of centriole splits, one of them moving to the opposite side which shoots out spindle fibers and the cell divides. The centrioles regenerate for form a pair
- Centriole is a compound protein structure that can replicate itself because the cell does not divide unless they have two centrioles
- Centriole also position all the organelles to the right location so that cell can function correctly
- Damage to the centriole = damage to the interior organizing cells (may lead to cancer and other types of disease)
- Centriole is triplet nine structure that is involved in shuffling chromosomes
- Basal body is the same structure at the bottom of the flagellum and genetic term for it is centrosome

Things that animals do

- Maintain water and salt balance
- Remove metabolic wastes
- Obtain food
- Be able to move
- Sense and react to the environment
- Reproduce and perpetuate the species

Advantages of small size

- Oxygen and metabolic waste happens all across the surface, obtaining food
- Cell surface is the most important part for maintaining water and salt balance, obtaining oxygen and removing metabolic wastes
- Small organisms have great surface to volume ratio which allows them to use simple diffusion

Water expulsion vesicle (**Contractile vacuoles**)

Protozoan

- Life evolved from the marine environment
- The cell encapsulated the aquatic environment of the marine environment.
  - The fluid is salty and has similar salt concentration to the marine environment = **isotonic**
- Life evolved in freshwater, which makes cells hypertonic to the freshwater environment
- This caused a problem since the water inundates in and swells up the cell resulting in bursting of the cell
- However, fungi and plant have solved this problem by having cell wall
- Animals had to take a part of the endomembrane system and use it with ATP pump to pump water out to the endomembrane space from cytoplasm
- Once vacuole was filled up with water then it was passed to the outside that opens and the pressure squirted the water out
  - Energy is burnt to pump out water
- Fluid filtering system is associated with nephric system
- Regulation of water can also dissolve oxygen from freshwater or marine water providing oxygen to the cell

Nitrogenous waste (not shits)

- Nitrogen have to be deaminated from molecules because they are extremely toxic
- High concertation of **ammonia** can shut down the cell cycle
  - Ammonia are kreb cycle inhibitor
  - Cells that are burning amino acid generates ammonia
  - In the marine environment, water can diffuse nitrogen but in a non marine environment, ammonia needs to be converted to less toxic material
  - All the protists use ammonia since they live in an aquatic environment
  - Large organisms cannot rely on simple diffusion. Thus, they need to pack ammonium into less toxic compound
- **Urea** is a classic example of less toxic compound that can take ammonium
  - This is present at the base of the nucleotide synthetic pathway. We can tolerate fair amount of it.
  - Can put nitrogen into urea and have it cumulate into much higher levels and excrete it out
- **Uric acid**
  - Insects pack up nitrogen in uric acid
  - Uric acid is not toxic. It crystalizes out of solution
  - All the egg laying vertebrates use this because otherwise all the toxic waste will start building up inside the egg results in poisoning the egg
- Guanine

Phagocytosis and pinocytosis

- Animals are ingestive heterotrophs (consume and bring the food inside the body to be able to access the nutrients)
- **Endocytosis** is used to swallow and surround the material to bring it inside = **intracellular digestion**
- There are two types: phagocytosis and pinocytosis
  - Phagocytosis is ingesting of particulate material
  - Pinocytosis is the complex carbon molecule that needs to be broken down by the oxidative force phosphorylation
    - Ex. Sugar is dissolved and ingested by pinocytosis

Digestion

Protozoan

- **Phagosome** (food vacuole) is a membrane bound structure with nutrients inside and needs to be broken down
- The ER produces digestive enzyme which transports phagosome to Golgi apparatus that wraps them up in membrane of lysosome
- Inside the lysosome is destructive enzyme that chews down molecules but they don't destroy the cells because they are wrapped inside the membrane
- Lysosome fuses with membrane of phagosome, which releases food content inside a new structure called **phagolysosome**
- Enzymes breaks food down and take starch and make glucose molecules, proteins, and amino acids which can pass through membrane, providing nutrients to cytoplasm
- Phagosome moves around the cells by molecular motors which distributes nutrients all over the cells
- The phagolysosome starts off with acidic pH inside and through acid digestion as phagosome matures, the enzymes change pH to alkaloid
  - Everything denatures and gets attacked by acid loving enzymes resulting in a shift in pH
- Initial digestion is acidic and the final digestion is alkaloid
- Some organisms have unique location called **cytostome** where the food is picked up
- Some have digestive tract where digestive enzymes are dumped and the nutrients are released and absorbed across the gut epithelium = **extracellular digestion**

Types of protozoan movement

- Pseudopods: uses myosin motor
- Udulipods: directly related to the centriole
  - Cilia
  - Flagella
- No movement: parasitic form (live inside the host and rely on the host movement)

Undulipodia: 9+2 Organization

- Contains a microtubular arrays of materials arranged in doublets, there are 9 outside and in the center a pair
- 9+2 organization is referred to the arrangement of the microtubules within the structure
- Sitting at the base is the basal body which is variant on a centrosome which is the structure that was key of the origin of the cells and their diversification
- Another centrosome is directing the microtubules structure that is inside the flagellum or cilia

Undulipods

- Cell gliding: microtubules pushing against the plasmic membrane, moving cell around
- Get a microtubular structure that allows to thrash and move around, creating a water current and swimming motion
- End up with uniform structure in all of the flagellum and all of the cilia of all organisms that have them (same structure in all plants and all animals)
- Undulipods are in the center, two sets of microtubules; each microtubules passing each other by dynein motor
  - As one goes up the other one goes back down to its original position
- The nine tubules around the outside are connected to each other through dynein motors and they can crawl up the microtubule adjacent to them
- Can can twisting of flagellum by making the molecular motor go in spiral way
- Some organisms have multiple undulipods across the entire surface and this is called cilia
- Cilia are different from flagella

Protozoan

- They are shorter and in numerous amounts
- They also beat differently from flagella

Reproduction

- Sexual reproduction
  - **Syngamy**: make gametes (egg and sperm) and when these fuse you get a zygote, which is a single cell
  - **Conjugation**: direct DNA genome material transfer from one cell to other
- Asexual
  - **Binary fission**: cells divide into two and mature to two brand new protis
  - **Multiple fission**: the cell sits intact and undergoes divisions and the results is multiple daughter cells

Chanozoan (Unikont: Opisthokonta)

- **Choanocyte** is the ancestor that sits at the very bottom of the evolutionary tree
- Zoa: animal-like Choano: collar cells
- It has a cell body and microvilli that extends in a collar around the perimeter of the cell and flagellum is located in the center, extending out
- When flagella beat, it creates water current, pushing water away which pulls water in at the base of the flagellum replacing the water
- Water goes between the fingers of the microvilli, trapping any small food material
- Microvilli has plasmic bridges between them to make the mesh extremely fine (interconnections between them to create rigid collar)
- Cytoskeletal arrangement is exactly like the microvilli surface of any absorptive surface on any animals

Colonial choanoflagellates (Unikont: Opisthokonta)

- Choanocytes often lived in colonies, multiple cells get together by cell division
- Colony can pump more water collectively than it can individually
- Water is a cohesive property; it is extremely dense (difficult to move)
- All nutrients are carried in the water = ingestive heterotrophs
- As colonies, they can pump more water = better fitness = better potential to increase and pass on genome to the next generation
- Sponges still have choanocyte cells

Flagellar beat (Opisthokonta)

- **Planar beat**: power stroke and recovery stroke is going to be in an exactly same plane
  - Power stroke is exposed of the large surface of the water and flips back on itself during recovery stoke to use less energy
  - Moving forward (pushing/pulling)
- **Helicoid beat**: spiraling beat; the molecular motors move along the arms in spiral and flagella starts to spin
  - In bacteria, the flagellum is in the cell that drove the whole thing resulting in spinning of the whole thing

Amoebozoa

- Able to extend cytoplasm and creepy around
- Descendants of the unikont ancestors
- Develop a different way of moving around which led to a disappearance of the flagellum

Protozoan

- Single celled portis with two dimorphic life cycle
- They crawl and slime around, stop, form a centriole and develop a flagellum allowing them to swim around
- The new locomotion involves with cytoplasmic streaming pushing cytoplasm to change the shape of amoeba and move it across the substrate
  - Cytoplasm exists in two forms: endoplasmic and ectoplasmic form
- Can head in any particular direction at any time

Pseudopod locomotion

- **Ectoplasm** is a gel-like rigid structure and **endoplasm** is more fluid (soluble) structure
- Ectoplasm is the polymerized mesh work of the endoplasm
- Actin molecules, which are protein monomers can float around but when given a signal, they form a chain
- If cytoplasm has polymerized fibers, those fibers give the cytoplasm rigidity
- If they are not polymerized, actin molecules fall apart and become independent, making the cytoplasm more liquid
- The polymerization of the cytoplasm occurs at the interior part of the pseudopods
- Cytoplasm moves forwards and hits the hyaline cap then it polymerizes
- Myosin motors are attaching to actin and starts to crawl along them
  - They are not transporting materials; they are squeezing the outer cylinder of ectoplasm causing cytoplasmic streaming moving the material forward
- Back end of the organisms gets opposite change; the rigid ectoplasm depolymerizes allowing them to squeeze forward along the cytoplasmic streaming

Molecular motors

- Myosin motor slide on actin filament
- Muscle is myosin motor making actin filaments slide past each other to change the length of the muscle cell which results in contraction
- It gives flexibility in locomotion (can move to any directions)

Vorticella: Myonemes

- Have muscle fibers (permanent strands of actin) on which myosin motors can move to change the shape of an organism
- When these strands occur in a single celled organism, it is referred to as **myonemes**
- Myonemes are muscle fibers organized in a cell
- Vorticella sits attached to the substrate that has a set of cilia used food in
- Escape mechanism: the whole stock coils as myoneme contracts, shortening the whole stock, pulling itself to the attached cellular debris
- Actin and myosin is capable of associating with fibers that are involved in locomotion

Chromalveolate (Ciliophora & Apicomplexa)

- They are bikont animal-like protozoans
- Contains plant like and animal like organisms (obligate heterotrophs)
- It has lost its chloroplasts

Protozoan

- Alveolates: organism that was photosynthetic in its past but lost chloroplast as it was able to develop a heterotrophic life cycle

Paramecium

- It is a ciliate
- All of the cilia that cover the organisms are anchored to each other by **pellicle**, a reinforcing microtubules underneath flagellum
- Woven cytoskeleton is not flexible, the mesh work microtubules that is formed in the pellicle is fixed
- Thus, this organism has uniform appearances
- There is a certain area of an opening in the mesh work for phagocytosis and this location becomes the **cytostome** (mouth)
- There is one fixed opening where the cell residue is removed, which is the **cytoproct**
- They have two different nuclei: micronuclei and macronuclei
- **Macronucleus** is polylploid = lots of genomic copies
  - Polylpoid is a way for small organisms to produce large amounts of gene product quickly
- **Micronucleus** is sat aside as the copy of the genome that is used for genetic mixing
  - It undergoes meiosis to a haploid product and fuses with two different haploid product
  - Used only for reproduction
- Transcription and translation process has a potential for the damage of the genome, which can be detrimental

Ciliar movement: Metachronal wave

- Beats completely different from flagella
- Cilia beats out of phase to prevent entanglement
- Cilia is out of sync with each other
- Power stroke is unidirectional but the recovery stroke is done at right angle to return
- Get very fluid movement
- They can stop, role etc

Pellicle structure

- A modified basal body that builds the 9+2 structure of the cilia but it is also sending microtubules on the basal side that go at right angles
- Each of microtubules weaves and connects to the adjacent to it
- All the cilia basal bodies grow microtubules that are inside each of the cilia and grow microtubules that eaves and anchors to the adjacent one
- The plasma membrane folds the bubble like structure called **alveoli**, folding the plasma membrane
- The anchoring of the structure is a key because the microtubules connect from cilia to the next provides reinforcement and they are coordinating all the cilia and the signal that causes the metachronal wave goes down the surface

Compound ciliature

- Can make all the cilia in a row and wrap them around the plasma membrane and have a membrane like structure that has the ability to move differently
- Roles: food gathering as they swim, has propulsive cilia moving through the water and another creating water current to bring the food in
- **Cirrus**: cilia fused into super cilia; very tough

Protozoan

Euplotes
- Some ciliates are used for locomotion and some for pumping water into food groove
- Ciliates modified 9+2 structure for completely different function: walking, gathering, food, swimming
- Ciliates are the dominant form of the protists

Conjugation
- Restricted to only ciliates in the group protists
- Gets its name from the bacteria conjugation: plasmid multiplies in one bacteria and goes across the cytoplasmic bridge and goes into the other one
- Micronucleus needs to undergo meiosis to be able to recombine with the haploid piece of genome from a separate individual
- **No gametes formed**
- **The cell starts out in the process is the same cell at the end, except it has been genetically transformed**
- Need to destroy macronucleus and its genetic material to prevent interfering of haploid exchange
- Conjugates join at the oral area and micronucleus undergo meiosis (cytoplasmic bridge created between the paramecium)
  1. 4 micronuclei formed (haploid), one large macronucleus remains
  2. Micronuclei exchanged
  3. Two micronuclei, macronucleus disappear along with other nuclear material
  4. One micronuclei from each fuse to form a diploid, **synkaryon**
  5. Three mitotic divisions produce 8 nuclei
  6. 4 micronuclei become macronuclei, 3 disappear and remaining become micronucleus
  7. Mitotic divisions of micronucleus. End up with a cell that is back to the original state

Malaria – human
- Caused by a single cell protist
- Malaria parasite controls the behaviour of the human host that has malaria and the mosquito transmits it
- Gamestes fuse together and these are called **syngametes**
- Binary and multiple fission
- The cycle begins by mosquito taking blood meal from someone who has malaria
- The blood meal in the mix are gametocytes that are the precursor of being male or female
- When the undifferentiated gametes get ingested, it signals the microgametocytes to turn into sperm and macrogametocytes to turn into egg and these two fuse forming zygotes

1. **Sporogony**
   - Zygote undergoes meiosis to haploid form and haploid product is not a gamete, spores are formed instead = **sporogony**
   - Meiosis turns diploid to haploid and these four cell products undergo mitotic divisions to increase the number of pathogens in the mosquito gut
   - Thousands of **sporozoites** are going to be located in the salivary gland so that mosquitoes can pass it onto the next generation of the host
   - **Oocysts** beome sporozoites that migrate into the salivary gland
   - The anti-coagulants in salivary gland contains sprozoites and end up inoculating the human host
2. **Schizogony**
   - Gametes are not produced in this life cycle

Protozoan

- Make schizonts which ultimately turn into gametes to fuse and complete the life cycle
- Sporozoites enter the liver cell and feed on the contents and undergo mitotic divisions to increase in number. These products are called **schizonts** (haploid)
- Little circulating plasmodium cells haave morphology to be able to survive in the blood and find red blood cells and these are called **merozoites**
- Merozoites invades the red cells and change their morphology to a feeding stage that is designed to break down all the hemoglobin in the blood cells and convert it into new plasmodium cells
- The new morphology is referred to as **trophozoites** (feeding zoites)
- Red blood cells become loaded with parasites and plasmodium bursts those red blood cells to get back out into the blood system and find another red blood cells
- The bursting of the cells is in synchronous
- The red blood cell count goes down and the body reacts to this by creating the fevers and chill which is a characteristic of the malaria

3. **Gametogony**
   - Gametes are produced and fuse quickly to turn into zygote
   - Some cells get kicked out of the cycle during RBCs cycle, and becomes gametes
   - Cells change their morphology and become presumptive gametes as micro and macro in the blood stream that is circulating

- When the mosquitos come along and takes the blood meal, it is going to pick up a whole wash of different plasmodium cells along with gametocytes

Archaeplastida (plantae)
- Photosynthetic bikonts
- Descendants of the green algae up to the plant

Excavata (**Euglenozoa**)
- A group that has food groove that is located in the flagellum
- Use their flagellum to feed
- Euglena is photosynthetic, it has chloroplast. They are able to store starch
- In the absence of light, it can use stored starch but it can also ingest food and dissolve materials from the surroundings (can be heterotrophs)
- Both autotroph and heterotroph
- Has little eye spot which is a mass of orange like pigment, a light sensitive pigment
  - It is a bikont but it has one of the flagella that is extremely long and the second one is fused to the surface of the first flagellum
  - The second flagellum is called the paraflagellar body
  - The big flagellum is sitting on the groove which gives the name excavate
  - They are able to move towards the light but if it is extremely bright, it moves away
- A protist reacting with the environment

Rhizaria
- A group that was problematic for a long time due to pseudopods that have long needle like structure and also contain microtubules
- They have cytoskeletal element that supports them
- They have radiating pseudopods sticking out of them
- Pseudopods used in the traditional way of capturing food but the internal structure is entirely different from the pseudopods and how amoebas work
- They always have shells

Protozoan

Protoazoan skeletons: **Tests**

- **Calcium Carbonate**
  - Granuloreticulosae: spiral interlocking casing
  - The pressure of water column above the organisms makes it impossible to precipitate the calcium out and turn it into material to build the shell with
  - In the shallower part of the ocean, shells are made out the calcium
  - They become geological features overtime (ex. Limestones)
- **Silica**
  - Rhizopods
  - Deep ocean organisms are going to have glassy shells

Cladistics – Useful terms

- **Apomorphies**: Derived characters within a group
- **Plesiomorphies**: primitive characters within a group
- **Synapomorphies**: Derived characters shared between groups
- **Symplesiomorphies**: Shared primitive characters that are shared between groups
- **Autopomorphies**: shared derived characters that defines a taxon
- **Autapomorphy** becomes plesiomorphy is you subdivide the group into prostome and deuterostome
- Arthropoda has a jointed appendage which is autapomorphies that define the arthropoda
- But Arthorpod is broken into two subgroups: Mandibulata and Chelicerata
  - They are defined by having mandibles or chelicera but they inherite the jointed appendages of the group as a symplesiomorphy but it does not define them
  - Can break two subgroups down again into three different groups
- An autapomorphy for a group becomes a symplesiomorphy for a group when it is broken into smaller groups

Monophyletic- A group of organisms, including the ancestor to that group, that all share a common evolutionary line of descent

Polyphyletic - A taxon that includes animals from two or more distinct evolutionary lineages and may not include the ancestor of either

- Ex. Arthropods were considered polyphyletic because we know it has subphylum but we have no idea what the common ancestor was

Paraphyletic- monophyletic group from which one or more subsidiary clades is excluded to form a separate group

- Ex. Birds and reptiles were in separate group; aves for birds and reptilia for reptiles

Animalia

- Multicellular ingestive heterotrophs
- Cells with different functions
- Choanocytes: opisthokonta that sits at the base of the evolutioinary tree
- Collagen: when the cells became multicellular and colonial, the cells glued themselves to each other with glue called collagen
  - The adhesive is found all the way to animal kingdom

Collagen

- Tropochollagen subunit
- High glycine/proline – gly-X-pro
- Only found in kingdom Animalia
- Triple peptide has a very unique pattern of glycine and proline alternating with other amino acids so it has very unique structure
- It is highly stabilized structure and it was primarily, the very first adhesive that allowed cells to stick together

Cellular organization

- **Unicellular**: single cells (small majority are unicellular)
- **Parazoans**: Without true tissues
  - Multicellular: cells are doing different functions but cells are not communicating
- **Metazoans/Eumetazoan** – with tissues or organs
  - Once we get tissues and organs, there is cell to cel communication

  - The side group of the metazoans are referred to as parazoans
- Parazoan partially on the way to be true animals

Basic animal body symmetries
- Symmetry is defined by being able to draw a line from the mouth to the opposite side of the organism to make a cut
- **Asymmetric**: no symmetry (Ex. Porifera, Placozoa)
  - No oral opening so can't draw a line; therefore, they have no symmetry
- **Radial**: can split organisms in multiple planes (Ex. Cnidaria, Ctenophora)
  - Do have oral opening and can cut between the two poles
  - Get identical parts in multiple planes
- **Bilateral**: vast majority are this type of symmetry (Ex. Rest of the evolutionary tree)
  - Get only one plane of symmetry (anterior, posterior, dorsal, ventral, left and right side)
  - Echinodermata have returned to the radial symmetry but their larval stage is bilateral

Phylum Porifera
- Comes in all kinds of shapes and forms
- They are very small persistent group
- Best **filter feeders** in the world of ocean

Poriferan diversity
- Sheet of cells that rolled itself up into tubular form
- Can be very big or small
- Finger sponges are the size of our finger
- Barrel sponge is really big; can fit a human (layers of cells being foiled onto itself)
- Sometimes they have great coloration or toxic chemicals to get away from predators
  - Particular interest to the pharmaceutical industry
- Glass sponge made entirely of glass with a single layer of cells spread across

Porifera (Autapomorphies)
- Asymmetric body plan
- Cells but not tissues: There are cells that have different functions but no cell to cell communication
  - No basement membrane for the cells to sit on, they are just stuck to a gluey matrix
- Use of choanocytes in an aquiferous system to pump the water
- **Totipotent cell**: can turn into any other type of cell

Cell layers NOT tisssues
- The inner surface is choanocytes
- **Choanoderm** is a layer of **choanocyte** cells
- Outer covering of the sponge outside is the series of cells that tare glued tightly together with a collagen and these cells are **pinacocytes** and they form **pinacoderm**
- Choanoderm and pinacoderm is held together by gel like matrix called **mesohyl**
- Because there is no basement membrane, they are held together with mesohyl

Cellular body wall
- Pinacoderm
  - **Pinacocytes**: making the outer covering that form the pinacoderm
  - **Porocytes**: cells that have opening and pores so that water can get from inside to outside
- Mesohyl

  - **Archeocytes**: **amoebocytes** that are the precursors of everything
  - **Sclerocytes**: makes needle and scales to hold the sponge up
  - **Spongocyte**: some sponges create proteinaceous matrix called **spongin**
- Choanoderm: on the inside
  - Chaonocytes
- All the cells are derived from the same ancestor cells

Sponge spicules – Skeleton
- Sclerocytes produces a skeleton
- Calcium carbonate
- Silica
- Spongin: Collagen like material that forms the skeletal system of some sponges.

Choanocyte function
- Food capture
- Ventilation
- Reproduction
- Creating water current, microvilli traps food and it is consumed by phagocytosis
- For all other types of cells that can't feed, amoebocytes take the foot vacuole from the choanocytes and distribute them around inside the sponge so that everybody gets the nutrients

Identifying sponge architecture (not taxonomic names just archetectures)
- Location of choanocytes
- How water reaches and leaves choanocytes
- Number of oscular: the exit point of water
- Presence of porocytes

Asconoid sponge
- Simple sponge
- Have **porocytes** that go across the body wall
- Water that have entered through porocyte goes in the to main cavity in the middle called **spongocoel** and out the **osculum**
- Not very efficient
- There will be water that gets into the central chamber and never gets the particles filtered out of it, just bypassing

Syconoid sponges
- Choanocytes are located in little **radial canal** side chambers
- Water no longer comes in from porocytes, it instead comes in from **incurrent canals**
- Water passes through a canal in the wall, where the choanoctes are so that it is filtered by the choanocytes in a very small volume
- Water is forced into the spongocoel and leaves through osculum
- Increased the efficiency by not lining the chamber with them but putting them in the little side chambers so that water comes through in a small volume to be filtered

Leuconoid sponges
- More complex due to multiple ways for water to go out = multiple osculum
- Still have incurrent bringing water in but instead of single route for water, it has multiple routes
- Always pulling water through the system

- Choanocytes are in chamber, the water is moving quickly through the small canals but when it hits the big chamber, it slows down
- The water ends up in another choanocyte chamber before leaving the sponge, so by the time the water exits, almost all the nutrients are extracted out
- Leuconoid sponge is an architecture that is extremely efficient at moving water through the sponge

Sponge sex

- Choanocytes become sperm
  - The cell has flagellum so changes morphology
- Archeocytes form egg
- Archeocytes become loaded with nutrient and stay within the sponge, when it is reproductive time for sponges, huge pile of sperm is released into the water from the derived choanocytes
- Smoking sponges: sperms releasing out of the sponge
- Other sponges nearby pumps water in and picks up the sperm and they can recognize if it is sperm of their species
- Engulf into vacuole and pass it to the wandering amoebocytes which carries the sperm packet to the archeotype that become the egg and get fertilization
- Sperm also gets ingested as a food source if they are not of the same species

Poriferna reproduction (asexual)

- **Budding**: process of the sponge that are initiated
- **Fragmentation**: when sponges gets scattered/broken and all the pieces are in fragments; these pieces can generate new sponges
- Freshwater species of sponges have to face the environmental circumstances that freshwater undergoes severe temperature swings
- Sponges go dormant for the winter
- Before they go dormant, they have packaged a bunch of **archeoctes** (**amoebocytes**) that can be anything and put them into special casing called **gemmules** that is covered with **spicules** which is a resistant to freezing
- When the parent sponge die, its cell is disintegrated and releases all the gemmules
- These gemmules are sitting tat the bottom and wait for the water to warm up in the spring
- Little amoebocytes that are hiding wander out and divide and starts growing antoher sponge again

Cnidaria

Animal innovations (Symplesiomorphies)
- **Gap (Septate) junctions**: cell to cell communication between the cells that make up the multicellular organisms
- Loss of the choanocytes

Gap (Septate) junctions (Connexon)
- Gap and septate junctions differ by whether or not they are found in vertebrate or invertebrates
- They have proteinaceous gates between the cells made up of **connexin** proteins, which can change their orientation to open gate between the two cells
- Due to this gates, cells can send chemical signals or messages

Animal innovations (Symplesiomorphies)
- There are two steps that occur before going into Cnidarian
- True tissues with all components
  - Cell connectors, **adherens** that hold cells together that are independent of the opening from septate junctions, but preventing things from seeping between the cells that are sitting on the surface of the basement membrane
- Internal digestive epithelium (**endoderm**)
  - Second type of epithelium
  - A hollow ball of cells that is single layered thick and it is referred to as blastula
  - Blastula is sitting on the basement membrane with cell junctions between and sticky junctions to hold everything together
  - Some cells move inward and end up with two layers of cells
  - Have opening in the opening that become blastopore, which is the first ancestral opening for digestive structure called mouth
- Oral-aboral axis and symmetry
  - Symmetry of the organisms is determined by the location of the moth
  - **Aboral** is the oral opening opposite of the oral side

Symmetry types
- **Radial**: body part arranged around the oral-aboral axis so that any plane passing though axis result in two identical halves
- **Biradial**: Appears radially symmetric but at leasto one set of structure is paired, resulting in only two planes of symmetry that pass through the oral-aboral axis of the organism
- **Bilateral**: only one way that the axis of symmetry can pass through the longitudinal axis and create two identical halves creating left, right, dorsal, and ventral sides.

Cnidaria (Autapomorphies)
- **Cnidocytes**: unique stinging cells that is used to capture the prey and feed
- Polyp body plan
- Epitheliomusculature: unique muscle type cells that allow the polyp to change shape and to extend their tentacles to feed
- **Planula larva**: solid, free-swimming larval stage of cnidarians consisting of two cell layers-- an outer ciliated ectoderm and an inner endoderm

Cnidarian diversity
- Unique group that show radial symmetry
- Big coral reefs are examples of cnidarian
- Coral create unique habitat on the planet but only represent 1% of all the organisms

Cnidaria

Cnidocytes – nematocyst
- **Cnidocyte** is a stining cell
- Cnidocytes contain **nematocytst**, a special organelle that has stingers and barbs that form under pressure as it develops morphology
- The spring is being loaded and when **cnidocil** which is a modified flagellum that receives signal from an organic touch causing nematocyst to shoot out
- Some cnidocytes are barbed at the end allowing them to penetrate through the skin of the prey
- Others contain poison to immobilize the prey
- Once nematocysts are used, it is not re-usable, but they can grow another one

Polyp body wall
- **Polyp** is an organism that has mouth surrounded by tentacles to capture and place the food in the mouth and into the digestive tract
- There is no anus on the opposite side therefore it has an **incomplete gut**
- Any food that gets trapped is pushed into the gastrovascular cavity for digestion
- Undigested residues are exited out the same way they came from
- It has jelly like matrix called **mesoglea** that holds everything together

Body wall
- Outer epidermis
- Gasrodermis secretes digestive enzymes to breakdown the food inside the cavity
  - Once the broken down nutrients are small, it is absorbed by phagocytosis

Hydrostatic skeleton (Polyp)
- They create movement and no mesoderm yet
- Have contractile elements
- In the epithelia cells, both outer and inner is a **myoneme** of organelle that is contractile fiber
- The outer epithelial cells have contractile elements called **epithliomuscular cells** and
- The inner epithelial cells in the digestive tract are called **nutritive muscular cells**
- Epitheliomuscular cells contractile elements are arranged in length of the animal (oral to aboral) while nutritive muscular cells are arranged circularly
- These two muscles create shape changes in the hydra or polyp
- When circular muscles contract, the longitudinal muscles lengthen and vice versa creating a movement that is referred to as hydrostatic skeleton
- The main role of the skeleton is to return muscles to their original length

Body wall
- Gland cells secrete digestive enzymes
- Nutritive muscular cells are the circular contractile element where phagocytosis occurs
- Outside is the epithelial muscular cells hat have two role
- Cnidocytes are derived from ectodermal cells
- Can also see the first nerve cells associated with ectodermal layer

Epidermis
- Cell have unique shape where they have outer surface that has tight junction preventing anything from leaking through from the outside
- The cells extend into the cytoplasmic that are loaded with contractile elements

Cnidaria

- There are others that are wandering around are other types of nerve cells that are able to pick up sensory information

Planula larva
- Little ball of cell that have distinct outer layers compared to the inner layer cells
- It is the early multicellular stage
- Zygote is formed and it undergoes mitotic divisions which differentiates into planula
- Endo and ectoderm cells are present
- Planula settles along the substrate and starts to crawl along the substrate
- Some have morphology that has anterior and posterior ends (leading and trailing ends)
- Bilateral symmetric larval stage: there is never posterior and anterior on radial by definition

Anthozoan innovation (Autapomorphies)
- Biradial symmetry
- **Siphonoglyphs**: gastrovascular cavity
  - Has unique water pumping structure to get water into siphonolyphs
- **Muscular septa**: can contract and change their shape by using this muscle
- **Gonads** in gastrodermis
  - Usually gonads are located on the outside of an organisms so that things could be released
- Unique type of nematocyst

Biradial symmetry
- Modified radial caused by paired structures on radial body plan
- Variation on radial
- Can get identical parts going through the two planes of symmetry
- Within the anthozoa, the paired structures are siphonoglyphs that is located in the center

Anemone anatomy
- The pharynx (digestive tract) extends into the gastrovascular cavity
- If there is no mouth, there is a wall that extends down and it has an opening that moves down into the gastrovascular cavity
- On the surface of the pharynx is the siphonoglyphs. It will trap food with tentacles and push them down into the gastrovascular cavity

Anthozoan body wall
- Has muscular septa used to contract and use siphonoglyphs to return to its size
- The outer body wall connects through and there are muscular septa associated with it
- Can contract themselves into a tight ball to get way from the predators but they only way to re-inflate back to its original size is by pumping water into gastrovascular cavity
- Water is pumped through siphonoglyphs

Anthozoan septal wall
- The autaphomorphies for the anthozoans end up being retractor muscles because they shorten the size of the organism
- The planula was triploblastic and was moving in oriented form and settled on the substrate to become anthozoan with reduced septal wall muscles
- The body wall becomes increasingly simplified
- Gonads which are reproductive organs that produce gametes are also on septa

Cnidaria

Anthozoa: Corals
- Most of the groups are corals
- Anthozoans are corals: giant polyp that has modification for its size and has muscle contraction for the siphonoglyphs and biradial symmetry
- Extremely small polyps are interconnected to each other, creating big coral reef

Cnidarian innovations (Symplesiomorphies)
- Dimorphic life cycle: instead of having a life cycle that is only a polyp, going to get a new stage called medusa
- Medusa by strobilation: medusa is free swimming

Dimorphic life cycle
- Free floating/swimming polyp
- Basically the upside down of polyp
- The major difference between polyp and medusa is that medusa has more mesoglea
  - Mesoglea is jelly like structure that is important for locomotion of medusa
- When circular cells and nutritive epithelial cells contract, they take the dome shape and compress it in. The elasticity of the mesoglea is that such those myoneme inside the cells will relax and pop back open
- As the dome contracts, it is pushing water out = making forward movement
- The lips curl in so that when it opens, there is less resistance force than if it were completely open
- More propulsive force with power stroke than recovery stroke
- This unique locomotion allowed the organisms to disperse and move around

Strobilization (polyp only)
- Medusa is formed by **strobilization**
- Lateral divisions occur in the body of polyp and further along they are on the length, they start developing tentacles (undergo morphological change)
- At the base of the strobili is the disk of tissues that is produced
  - Another one gets produced and pushes the other one forward, this process repeats
- As they move forward, they mature and get tentacles out their sides and get organ system inside for digestive tract
- They end up with little medusa on the top
- Planula have created a mobile form that can swim away

Scyphozoan innovations (Autapomorphies)
- Rhopalia on medusa
- Rhopalia is a sensory structures found around the bell margin of the jellyfish medusa
- They always contain statocytst for balance (gravity)
- Contains ocelli for light detection

Aurelia (moon jelly) life cycle
- Planula settles and turns into a baby polyp called **scyphistome**
- scyphistome undergoes transverse fission to form the strobili (**tribalization**)
- **Ephyra** comes up on top of the strobili and they are released in the water and mature overtime
- Ephyra is the name for baby medusa formed by asexual budding

- Eggs and sperms are released into the water if they are fertilized, they settle down and planula starts crawling on the substrate again

Aurelia medusa
- Digestive tract that is set up in a unique way; it has little canals permeate all the way through the bell of the medusa
- No anus
- Instead of the food sitting on the gastrovascular cavity like polyp, it is branched and the good is caught by the tentacles and comes in trough the mouth and passes out into the tracts which follow uni-directional flow before coming back and being removed
- Developed a way to consume food in one direction and remove the resides at the same time so that it can continuously feed
- Gonads, the reproductive system, is right next tot the digestive system
- Ingestive heterotrophs that capture food and turn them into nutrients that can be used to produce gametes

Aurelia gastrovascular system
- End up having gonad sitting up against the wall of the endoderm of the gastrovascular cavity for access to nutrients

Rhopalia – Cnidarian sensory
- It has a pigmented cup that will sense the light and have gravity sensor called **statocysts**
- Rhopalia has a flap of tissue over called the **hood**
- When jellyfish are swimming, the rhopalia are detecting light levels
- Jellyfish can change the nature of the contraction to right itself and move up within the light
- They are looking for the primary herbivores that are feeing on the algae so they go up in the water column to sting and capture small crustaceans

Cnidarian innovations (Symplesiomorphies)
- Medusa produces a single medusa
- Not getting division or splitting
- Medusa is produced one at a time
- The differentiation of the polyp into medusa into a one to one form

Cubozoan innovations (box jellyfish) (Autapomorphies)
- Also have rhopalium light and gravity sensor
- Polyps undergo metamorphosis into medusa
- Unique eyes
- Pedalia

Cubozoa
- Bell margin and jelly like matrix
- On the wall of the bell is the rhopalium, which are unique **eyes**
- **Pedalium** is the way tentacles are attached to the body because when this organism feeds, it captures food and contracts the tentacles and the pedalia swings in from the outside to move the food into the mouth (part of the feeing structure)
- They have deadliest sting of the animals

Cubozoan rhopalium (polyp is hardly seen)

Cnidaria

- The eye detects light and gravity
- Gravity with the **statocyst**; usually contains some kind of closed structure inside
- **Statolith** is an object inside statocyst that senses the positional information of an organism and balance them (adjust tentacles and contractile of the bell to position)
- The eye is capable of creating image; they can see preys in water
- Cnidarians don't have central nervous system; they have **nerve net** which is a mesh work of nerve cells through out the whole body

Hydrozoan innovations (Autapomorhies)
- Medusa from lateral buds: have a reproductive structure and medusa is going to appear as buds
- Dimorphic life cycle: polyp and medusa is equally important
- Medusa with a velum: another unique way of swimming
- Modification of the radial and biradial to pure radial symmetry with a polyp stage that quickly forms medusa in the scyphozoan
  - Polyp stage that immediately turns into jellyfish or polyp that blab off the structure that form medusa

Obelia colony
- Obelia is a colonial hydrozoan
- There are polyp structures that have tentacles polyp structures don't
- Gonozoids: don't have tentacles, makes lateral buds to form medusa
- Gastrozooids: going to feed
- Every single polyp in the colony is connected to each other so that nutrients that are gastrozooid collected can be distributed to everybody in the colony

Obelia
- They com out as little baby medusa when time to mature off the gonozooids
- Little baby medusa swims and feeds in the ocean and when they mature, they release either sperm or eggs (sexes are separate)
- Get fertilized egg planula crawl against the bottom settles differentiates into a polyp
- A shelf of tissue that hangs down gives them extremely efficient way of swimming because they are squeezing water out
  - Shelf is pulled in as they contract = water is forced out of the small opening
- Push water as bell contracts when bell enlarges, bell collapses large opening where water moves
- Large opening vs. small opening
  - Small opening makes more propulsive force; large opening is less force due to opposite direction
- Much more efficient way of swimming because the little velum is creating ability to modify movement

Hydra
- They are plant feeing jellyfish, found in freshwater of the lakes and parks (hydrozoan)
- Hydrozoan that only exist in polyp stage (no medusa)
- Polyp becomes reproductive
- Polyp can be **hermatphrodite** or sexes can be different between species
- Gonads develop in the polyp and releases sperm and eggs into the water to produce zygote = new planula

- When they move from marine environment to freshwater environment, their life cycle dramatically changes
- It has lost its free swimming because it was not advantageous to the freshwater environment
  - Easily preyed upon by predators

Platyhelminthes

An acoelomate triploblast
- True animals, about 2% of all animals out in the world
- Platyhelminthes are referred to as platyzoa

Animal innovations (Symplesiomorphies)
- **Triplovlastic**: organisms formed from three layers: ectoderm, mesoderm, endoderm
- Mesodermal musculature: muscles present

Body plans
- **Diploblastic**: organism formed from only two primitive cell layers: endoderm and ectoderm
- Acoelomate: without body cavity
- **Eucoelomates**: organism that possess a true coelom with mesoderm lining the whole body cavity, unlike pseudocoelomates where the mesoderm is adjacent to ectodermal tissue
- **Pseudocoelomates**: body cavity that is not completely lined by mesoderm

Bilateria (Autapomorphies)
- Bilateral symmetry
- Ctenophora have radial symmetry + mesoderm
- They are the transition group and this is why the presence of mesoderm and bilateral symmetry is separate on the cladogram
- Bilateral symmetry is a harbinger of the directed motion

Symmetry types
- Radial: animals that are sessile, responding to the environment in all directions around them or pelagic (floating)
- Biradial: anthozoans which are intermediate case
- Bilateral: directed movement making sense that we have refined directed movement at the same time we get mesoderm and muscles that are dedicated towards the movement (ability to orient towards the environment)

Protostomia (Autapomorphy)
- Blastopore is mouth: important characteristic because before we had hollow ball of cells, all one type of epithelial gastrulation indentation
  - Blastopore was always the entrance to digestive tract due to no presence of anus
  - Later when the blastopore punches in and gets anus, the original opening of the digestion tract is retained as the mouth
- Paired ventral nerve cord: have nerve cord on the ventral side of the body
  - For deuterostome, the nerve cord is on the dorsal side
- Apical brain: on the dorsal side of the body

Protostomes vs. Deuterstomes
- When we have gastrulation, a hollow ball of cells that was all one type of epithelium has invigilated and ingested epithelium. This created blastopore and anus
  - Could be the opposite way around, the new opening can be the mouth and blastopore being anus

Platyhelminthes

Blastopore (Gastrulation)
- Ectoderm
- **Blastocoel**: cavity inside the hollow ball
- Endoderm
- **Blastopore**: the opening to the primitive gut that will develop into either mouth or anus

Types of cleavage
- Four cells that cleave through the middle either the four cells on the top will remain the same or they do a little twist
- **Spiral cleavage**: Pattern of cell division in the developing embryo where the products of the cell divisions shift by twisting so that the resulting daughter cells lie in the furrow of the underlying pair of cell
- **Radial cleavage**: during development as the cells of the zygote divide, the products of the cell division remain stacked directly on top of each other

Enterocoelous coelom
- Mesoderm arises in 2 different ways; the consequence is identical in both
- At the primitive gut, **archenteron**, little blab of cells come off and they become bigger and bigger and they fill the whole space
- When they do this, they already have the cavity in the coelomic space
- These two masses of tissues will meet in the middle and create the mesentrery that hold the organisms in place
- Mesoderm formed coming from gut tissues which already had cavity

Schizocoelous coelom
- During gastrulation, when invagination occurs, mesodermal cells get signals at the very lip of the blastopore and start to proliferate
- They proliferate and completely fill the space
- Get a block of mesoderm between the outer and inner tissue layers which splits later
- It will result in tissues that surrounds the whole system with cavities inside and mesentery holding internal organisms in place

Some advantages of a body cavity
- Space for organ system to enlarge
  - We have created a cavity that can enlarge when ingested a large meal without changing the body shape
  - Fluid that can be used for transport: can diffuse nutrients around
  - Acts as a hydrostatic skeleton
  - Gut can move independently of body wall

Spirialia (Autapomorphy)
- Spiral cleavage: one step away from the base of the tree
- The **ecdysozoa** have yolky eggs and as a consequence, cleavage occurs as the heat of cells on the surface of the egg

Platyzoa (Autapomorphy)
- Loss of coelom or reduced their coelom into a pseudocoelomate conditions
  - Functions that were involved with coelomic fluid disappeared along with coelom

Platyhelminthes

- Acoelomate or pseudocoelom
- Loss of **metanephridia** and circulatory system: an exclamatory structure that cleans and filters the coelomic fluid
  - No coelomic fluid = no metanephridia = no circulatory system

Platyhelminthes (Autapomorphy)
- Incomplete gut: not polyp
  - This group is bilaterally symmetric, the only bilaterally symmetric phylum with an incomplete gut
- Complex reproductive system associated with **hermaphrodism**

Planaris – free living
Digestive system
- This organism has flattened itself to a point where they have no tissue
- Can use simple diffusion to exchange oxygen and nitrogenous waste etc
- Diverticulum: branched out digestive system so that it extends to every single part of the body
- End up with an organism that rely on simple diffusion by optimizing surface: volume ratio
- The pharynx is located on the mid-ventral side and had sensory structures at the front of the organism (this is why people thought they had bilateral symmetry)
- The early ancestors of this group had ectoderm on the outside layer to protect and cover itself and digestive endoderm located as a mass of cells in the ventral side
- The animal was on the substrate with digestive surface pushed against the substrate
- Has a unique set of sticky gland to be able to stick without dislodging
- Flatworm ultimately internalizes the cells in the gut, and branch through the whole body

Reproductive system (**Monoecious –hermaphrodite**)
- Two distinct systems: male and female
- To prevent cell fertilization, we need to be sure that sperm transfer is completed before fertilizing egg
- The testis produces sperm which goes down the sperm duct and is stored in seminal vesicle
- When the two planaria meet, they have intermittent organ, penis which is placed inside the other individual
- Sperm is transferred between both individuals which means that there is potential of fertilization of egg at both individuals
- Maturation of egg begins once planaria have become separated
- Egg comes rolling down from the ovary through oviduct and it is provisioned by the yolk gland which will provide nutrients that it needs
- Small amount of sperm is released and the egg is fertilized egg is released outside and life cycle completes itself

Planarian body wall
- There are 2 layers of muscles inside flatworm: longitudinal always inside and circular always outside
- Also have **dorsoventral muscles** that are running from top to the bottom of the animal
- These muscles work in combination of the circular and longitudinal against hydrostatic skeleton except it is filled with squishy cells called parenchyma cells instead of coelomic fluid
- Parenchyma cells can compress and change shape under pressure
- Contracting circular muscle causes elongation; contracting longitudinal causes increase in width

Platyhelminthes

Body wall
- They have **dual gland** cells that are located on the ventral surface
- They also have very effective mechanism for swimming
  - The ventral surface of the flatworm is covered with cilia which beat in such a way that if the flatworm is not stuck on the substrate, it can also glide on the substrate
- Embbdded in the dorsal surface area are series of cellular exclusions called **rhabdites**
  - When flatworms are attacked or eaten by predators, planaria releases rhadbites and little needles which dissolves immediately, releasing chemicals that are distasteful
- Another way of protecting themselves: many planaria feed on cnidarian which uses cnidocytes that embeds itself up in the epithelium of the planaria allowing them to use nematocyst

Dual gland adhesive system
- One of the gland cells secrete the cement that glues the flatworm to substrate
- This gland secretes and dissolves the adhesiveness of the glue that is holding the flatworm in place
- Gland system is used for the flatworm to be able to attach and release from the substrate
- If you combine it with the muscle system, it becomes very specialized locomotion system
  - Releases the glue lift the head up contract longitudinal & circular muscles stick head back down
- It is still a hydrostatic skeleton but the fluid is not coelomic fluid it is the sponginess of the parenchyma cells

Nervous system
- The nervous system is described as being ladder like; ventral nerve cords are not running in parallel in the center of the body, they are at the peripheral
- Characteristic of all protostome is the paired ventral nerve cord. Each of the two nerve cords are adjacent to each other down the center of the side of the body
- There is a whole set of lateral connective that connects one cord to the other
- We also get cephalization; there is bilateral symmetry at the anterior end and have optic device called **eyecup** and **auricles**
- Auricles are involved in the chemical sensation and eyecups are involves in detecting light

Brain
- Behind the anterior end, the nerve cords swell into a large single mass of material that is called **cerebral ganglion** (brain)
- Paired nerve cords are coming up from the sides
- Light sensor is located right underneath the brain mass that deals with the light structure and auricles on the side
- Animal can orient towards the environment it is working with (sometimes by chemicals)
- **Chemoreception** is paired structure that get differential input in by putting head back and forth
- They have avoidance behaviours: can orientate yourself to avoid the certain circumstances

Pigmented eye cups
- First visual system that have moved beyond a simple sensory set of epithelia cells
- Have series of epithelial cells that are sensitive to light
- Nerve and sensory cells are all derived from the ectoderm
- Layer of sensory cells ultimately curls up on itself and becomes eye cup
- The whole point of eye cup is on one side is sensory cell and pigmented cell on the other to prevent light from penetrating the eye cup form one side

Platyhelminthes

- Pigmented eye cups consist of sensory cells, a masking structure
- Eye cups are seen as transitional state of what became the camera eye
  - Camera eye close pigment cup down to a small pin hole opening and image gets reflected
  - This is another reason why the flatworm was placed at the bottom of the evolutionary tree because they have full visual eyes

Excretory system
- Need to deal with nitrogenous waste (metabolic waste)
- Being flat is perfect position but not so perfect anymore in freshwater environment
- Under freshwater, they are being inundated by the water that is diffusing into their cellular tissues
- They develop excretory structure that removes all the excess of water

Excretory system – **protonephridia** (Flame cell)
- Have 2 cells, one cell on the top and one underneath that connects the structure to the rest of the tube that carry the material to outside of the organism this cell is called **tube cell**
- Tube and flame cells interdigitate all the way around and the membrane where this occurs is extremely thin that passive diffusion occurs
- The flame cell at the top is not only a cap cell but the center of it is whole bunch of cilia beating and pushing the water away from the flame cell
- Any fluid that is inside gets pushed down the tube cell into the duct work of the excretory system creating a vacuum or negative pressure within a flame cell
- This negative pressure allows interstitial fluid between the cells of parenchyma and pulling it into the flame cells and pushing it out of the body
- The primary role of this system is osmoregulation since it is dealing with water regulation
- Excretory system did not evolve to a point where they were able to remove nitrogenous waste
- **Flame cells**: hundreds of little flickering like cells all over that is beating inside the protenephridia, distributed all the way down the length of the organism

Syncytial tegument (Endoparasites)
- Most of the Platyhelminthes become parasitic due to high success
- Instead of being free-living in the fluid environment, most invaded the internal cavities and spaces of other animal
- Could flatten the surface and stick to the wall of the organisms and never interfere with the movement of the fluids at the duct
- They had nice adhesive system so it became very difficult to dislodge since they could go in and glue themselves to the wall, optically set up to exchange with fluid of the host and survive
- The group is what we call **pre-adapted** to being parasites and once animal diversity came, they started moving into the other animal's cavity
- Flatworms were resistant to the attack of the immune system of the host body
- It had tegument which is a middle layer of the chiton shell composed of organic material, calcium salts and colored pigments that protected them from the attack
- **Syncytial zone**: In the basement membrane is the circular and longitudinal muscles but on the outside is no individual cells, it is one continuous cell of plasma membrane and cytoplasm (no cell boundaries)
- It has unlimited repair potential because the whole genetic machinery and synthesis machinery below the muscles are protected by the host

Platyhelminthes

- Many of the parasites steal proteins fro the host and invade them in the cytoplasm in the membrane so that plasma membrane becomes similar to the membrane of the host cell and the host cell stops attacking it
- Some may have little microvilli to absorb nutrients from the host

Fasciola
- Sheep liver fluke
- It lives in the liver of sheep
- Sits in the ducts of the liver and attaches itself with two suckers that are loaded with dual gland adhesive system and is able to lodge itself in place and flatten
- It ends up with ovary with a duct that produces eggs
- Have yolk glands that are on the edges of the body that will bring the yolk in for the eggs when made
- Have testis make sperms and store them in seminal receptacles
- During mating, they have staging area for the egg that has duct coming out from seminal receptacle and ducts coming in from the ovary and vitelline glands
- In the staging area called **ootype**, egg comes down from the ovary which is loaded with vitelline and gets fertilized and shelled then passed out of the system
- In the ootype is another gland that is going to put the shell on and provide mechanism to get the eggs out

Fasciola life cycle
- Egg released into vile ducut □ digestive tract □ feces with eggs comes out
- Adult sheep liver fluke release eggs □ pass out into the environment □ embryo start to develop □ **miracidium**: ciliated larval swimming stage
- Eggs like moisture environment. Some eggs are in the puddle and miracidium comes out
- The puddle drain into more permanent body of water
- Miracidium changes morphology and going to invade snail by burrowing in and inside the snail, it undergoes mitotic divisions to multiply in number so larval stage (**larval amplification**) and becomes **sporocyte**
- Larval amplification only increases number of the larval stage
- Sporocyte fills up with new larval stage called **redia** which bursts and starts to invade the snail tissue
- Inside each redia= multiple larval stages develop and this is called **cercaria**
- Cercaria swims and at appropriate point, it will be released from the snail back into water
- Cercaria tries to find next host but if they don't they go dormant this stage is called **metacercaria**
- 3-4 weeks later sheep feeds on the grass that grew out of the puddle and pick up metacercaria
- Metacercaria burrows through the digestive tract and gets into the intestinal blood stream which leads from the digestive tract to liver and reinfect the liver
- **Definitive host** is the host in which reproduction occurs (sperm and gamete combines) Ex. Sheep
- Fluke life cycle: always involve snail at the first stage

Swimmer's itch
- Part of the fluke worm's life cycle
- Cercaria that comes out of certain specific snail inhabit ducks
- Cercaria digs into the skin of human thinking is it is duck's feet = results in rash

Tapeworm – Scolex and proglottids

Platyhelminthes

- They are flexible and can regrow and regenerate all of the tissues
- Tapeworm live primarily in the digestive tract of the vertebrates
- There is no point of having digestive tract since they lived within it
- It is a very hostile environment, but tegument repaired any damage
- Develop suckers and hooks associated with **scolex**, which is the head of the tapeworm
- They centralized the dual gland adhesive system into specialized location and these became the suckers
- Tapeworm is the scolex, the anterior end of an animal with distinct arrays of hooks around the **rostellum** that are anchored around the residual of the host
- Have attachment organ with small little neck and **proglottid** that is added on at the base of the neck
- The further and further proglottid go from the scolex, the older and more mature they are
- Matured proglottid has nothing but the eggs in them

Tapeworm proglottid (**Hermaphrodite**) – can mate itself
- Received sperms are brought in and stored in the **seminal receptacle**
- Have **testis** that has **sperm duct** which is used to transfer sperm
- Have ovary that is associated with yolk gland to provision eggs in **ootype**
- Eggs comes into the ootype that receives nutrients through vitelline and receives sperm to fertilize and put a shell on it and store it in the **uterus**
- **Uterus sac** is going to be filled in the proglottid and this is referred to as **gravid**
- Push proglottid down and they eventually break up and end up in the fecal material
- Can be 4 feet long and can coil back on itself to mate (get double fertilization)
- Eggs are never going to pass through oviduct to the outside
- Eggs are released by shattering of the proglottid to the outside

Tapeworm life cycle
- Within the intestine is big matured proglottid
- Proglottid released eggs released into the digestive environment
- Inside the eggs are little baby tapeworm that only consists of presumptive scolex, neck and body behind it
- Once it is inside the egg, it lies dormant until they are digested by other organisms and goes into the digestive tract
- When the sheep or pig consumes the tapeworm egg, the **cysticercus** comes out and it will burrow through the body wall into the muscle tissue (cyst) and they will be dormant
- When the meat is undercooked and eaten by human host, tapeworm will turn inside out and attach to the human digestive wall and start over again

Mollusc

- They are the second biggest animal out in the world
- They have unique feeing structure called **radula** that is used to scrape organic materials off the substrate of the ocean but also break through the bacteria algal mass that nobody can break through
- They live inside the calcareous shell and protect itself from the predators

Lophotrochozoa

- Either presence of a **U shaped gut** and **lophophore**

OR

- **Trochophore** larval stage

Trochozoans

- **Trochophore** larva: mollusc and annelids are two big phyla, which at some point after the egg hatches is the little multicellular larval stage called trochophore

Trochophore larva

- It has little spinning top that has ciliated band around the middle, which create locomotion and water currents to propel food inside the digestive system
- Series of tuft cilia at the top and bottom called **apical tuft**, they help to stabilize larvae so it is always in the same shape position as it swims around and it has rudimentary nervous system, where the mechanism filter fluids from body cavity
- It is very short lived
- It morphs into different shapes and ultimately convert into four phyla

Animal Innovations (Apomorphies)

1. Schizocoel and metanephridia filtering coelomic fluid
2. Dorsal heart and pericardial cavity: heart on the upper side of the body lying inside the pericardial cavity

Schizocoelous coelom

- A body cavity that contains coelomic fluid that is used as a transport fluid or hydrostatic fluid
- When it is used as a transport fluid, it is a great way for metabolic wastes to diffuse into

Metanephridia

- Nitrogenous wastes can diffuse from the blood tissues coelomic fluid
- There is no circulatory system yet, because coelomic fluid is bathing the tissue
- Inside the coelomic space is a funnel with **nephridiopore** opening inside to the outside
- The mouth of the funnel is called **nephrostome**, covered with cilia that constantly pull in coelomic fluid
- It is always associated with tubule system to conserve water or retain essential minerals/nutrients
- The tubule burns ATP to recover essential materials within the fluid
- The coelomic fluid with all of the contents are placed in the excretory structure and selectively pulls out what is needed and leave nitrogenous wastes to exit out of the **nephridiopore**
- This system is very different from protonephiridia in flatworms
    - For flame cells, they are sitting in the interstitial spaces between all the other cells of the body and filtering the water that builds up between the cells and the water flows across the plasma membrane of the cells and the plasma membrane keeps out everything that is big
    - Flame cell creates an ultra-filtrate that isn't really needed because they already have left the good things in the wall while they were in metanephridia
    - The autapomorphy for Platyhelminthes is the loss of coelom and loss of the metanephridia
- One of the most ancestral ways of filtering the fluid
- Metanephridia is also present in the enterlocoely space
- In this case, water is filtered with shizocoel

Mollusc

Mollusca

- Radula: unique feeding structure
- Dorsal mantle: tissue that runs across the dorsal surface called mantle, which secretes shells
- Calcareous spicules or shells
- Ventral ciliated muscular foot
- Retractor muscles: involved with hiding inside the shell
- Tentraneural nervous system: unusual nervous system: have body plane with two parts

Mollusc diversity

- 9% of all animal groups that are out there
- Adaptive radiation: they all have same architecture but look different
- Clams filter water (gone sessile) □ have completely disregarded the cephalization
- Steals cnidocyte cells to protect itself along with the coloration
- Octopus: tremendous brain capacities (can learn tricks)
- Clams that has opening and closing motion can create water current
- Has blue dots around the opening and they are known as eyes
- Have huge evolution history: the ammonites: key predator in the ancient ocean

H. A. M (Hypothetical aggregate ancestor)

- Have an organism that comprises of 2 parts: ventral muscular foot (autapomorphy) and viscera, where all the organ systems are associated
- The whole part of the body is devoted to locomotion (foot)

Radula

- A structure that is covered in teeth that matches the type of food that it feeds on
- The radula can pierce through tissues or the substrate using short teeth
- These teeth are sitting on the structure called **odontophore** (tongue)
- Radula muscles is muscles that are attached to the radula; odontophore muscles can push the odontophore out and in (changing the shape of the structure that is being pushed out)
- Teeth can slide on the surface of the odontophore, meaning they are not attached rigidly to it
- The odontophore is extended and glide it against the substrate □ creates particulate material □ secrete mucus to trap the food □ swept into the digestive tract
- The cecum attached on the sides absorbs the nutrients from the food and the rest exits out through the anus, which is on the opposite end

Dorsal mantle covers the visceral mass

- The dorsal mantle has an epithelial layer called mantle, which completely surrounds the organism
- Inside the cavity is where the posterior entrance exits to the digestive system that also secretes a shell
  - The first mollusc secreted calcareous spicules were deterrent for anything that wanted to feed on them
  - The calcareous secretion becomes a constant solid sheet produced by the mantle = protective mechanism
  - All of these are sitting on top of the ciliated central foot

Ciliated ventral foot

- Have retractor muscles that run from the shell to the ciliated ventral foot
- These muscles pull the shell down to the substrate on which the mollusc is living
- The organism can pull its shell and protect itself from the predators when being attacked
- It can still continue to feed using radula since the radula is at the front and underneath the shell, which allows the organisms to keep chewing away

Mollusc

Tetraneural nervous system
- It has four nerve cords (not the normal pair)
- There is a paired ventral nerve cord; one pair goes into the foot and the other into the visceral
- The brain ends up being a circular ring around the esophagus
- The division of the body into ciliated ventral foot, **dorsoviscera**, is being reflected in the system
- They have unique respiratory system

Ctenidium (Respiration)
- Ctendia is gong to be completely covered in cilia and are going to pump water into the mantle cavity across the gill surface and out
- The organism can still breath through small opening even when it is clamped due to the cilia pulling water in across the gills and out
- The anal opening is excurrent flow and so is metanephridium
- They can live under the shell, protected from predators and feeding and be able to live while completely hidden away from the predators

Open circulatory system with a pericardial cavity
- Have pair of pericardial cavity that sits on the dorsal side with a heart sitting inside
- When the heart beats, it propels blood forward in a series of anterior arteries and towards the posterior arteries, which branch through the body and release blood into hemocoel
- Flow of the blood: body gills heart body
- Never going to get capillaries since they are all open; all of the organs are bathed in hemolymph

Pericardial cavity
- Have a pair pericardial cavity, it is the remnant of the coelom (main coelomic cavity) that has been reduced to small space
- All the organs are bathed in the hemocoel
  - Hemocoelic space is not a true body cavity; organs are suspended in there and the pumping and pipes from the heart squirts out blood supply that is coming in
- Need to recover blood from hemocoel; there is a vein that collects blood and pulling in the hemocoel, which retracts back towards the heart
- Have complete absence of the capillaries between the two structures because instead of exchanging blood to the organs through capillaries, the organs are bathed in the blood
- The tube connects back to the heart and when the heart beats, it pushes out blood and pull it back in (the circuit of the blood system)
- The blood is pulled just before it goes into the heart in atrium, which is a space connected to the blood vessel that goes to the ctenidium (unique gill) and out to where the blood is collected in the hemocoel

Excretory and reproductive systems
- There is a body cavity called metanephridia, where its funnel filters and removes materials that are needed and pass the excretory product out into the mantle cavity
- The ciliated funnel that picks up coelomic fluid has gonads developing on the wall and gametes are released into the coelomic fluid that travels down the metanephrida to the outside
- Nephridic system is not only transport system for removing metabolic wastes, but it also moves gametes to the outside of the organism
- Association of the gonads with the ducts of the metanephridia
- In metanephridia, blood is filtered, gametes are produced and ducts are used to send gametes outside and when all these open into the mantle cavity, they open in conjunction with the anus
- The excurrent flow washes and swipes away all the wastes from the body along with gametes

Mollusc

- These gametes are in their initial development that form the classic trochophore larvae that is associated with trochozoa but the mollusc produces unique larval stage called veliger larva

Veliger larva
- Giant velum, a big antennal dish that has a ciliated surface used to swim and collect food and feed
- The trochophore larvae metamorphosis into veliger larvae
- The remnants of the veliger larvae; the velum that is sitting on the side of the young clam has shells but it will ultimately become the body of the particular mollusc

Mollusc Phylogeny
Aplocophora(Autapomorphies)
- The whole group starts with a little worm like organisms, which was covered in mantle that were needle like structures
- Without a shell: the reason why they are called aplocophora
- Foot inside a ventral pedal groove
- Copulatory spicules

Symplesiomorphies
- Mantle makes a solid shell that covers the entire visceral mass; viscera with travelling muscular foot underneath
- Shell glands in mantle produce a solid shell
- Mantle surrounds viscera
- Digestive glands
- Rippling of muscular foot

Polyplacophora (Autapomorphies)
- Eight shell valves
- Chiton: have 8 segments to their shell and they live on rocky inter-tidal zones
  - Rigid shell with flat foot underneath; hard to be able to adhere to uneven surface
  - These joints create a hinge that the animal can bend and flex itself just a little bit so that they are able to adhere to their environment

Symplesiomorphies
- Univalve shell: shell made up of only one piece
  - Shell inherited by all the mollusc to come
- Periostracum, prismatic and nacreous shell layers
- Mantle margin trilobed: unique way of collecting food that radula made
- Crystalline style

Mollusc shell
- Mollusc shell has 3 parts
- Outer periostracum: organic material protein, which creates a waterproof barrier to the minerals of the shell
- Shells can be made out of calcium salts, which can dissolve in acid
- The mass of the shell is the prismatic layer, which is cut like little prism; it has angles of calcium mineral that have been laid down in an organized way where it gives the shell its bulk
- In the inner surface is the nacreous layer, which is referred to as the mother of pearl

Mollusc

- Nacreous layer is creating a perfectly smooth layer for the mental epithelium, which is underneath it, so that it does not experience any friction or abrasion
- The organism is underneath the shell but the nacreous layer ensures that any movements under creates a no of braiding forces against the mantle layer and may damage it

Pearl formation
- The pearl industry injects artificial spheres in between the mantle and nacreous layer, which irritates the level making mantle to produce the pearl (nacker) and coats the surface of the pearl
  - The longer you leave it in there, the deeper and bigger coating on the surface
- Natural pearls are made when the sand grave gets in and the animal starts to coat it with pearl
  - Rarely a perfect sphere
- The mantle that is making all of these have 3 lobes
  - Theses lobes are involved in enlarging the shell from the edges
  - Typically, there is a sensory lobe and another lobe that is associated with muscles
  - The trilobed edge
  - Mantle edge is going to make siphons, ways that water enters
  - Muscle is going to be important for the mantle of the squid since they use it to pump and produce water

Mollusc stomach
- Unique solution to brining particular food into the digestive tract
- Still going to consolidate the dust made with radula into mucus and cilia propels down the esophagus towards the stomach
- The mucus string that comes along ends up being attached to and wound in the crystalline style
- Insoluble structure is sitting in the style sac and cilia sitting in the middle of the stomach causes it to spin mucus string winds
- At the very tip of the crystalline style is a hard surface on the wall of the stomach called gastric shield
  - As the crystalline style winds, it is constantly embroidering against the gastric shield slowly starts to disintegrate
  - The material that braids off goes into the solution, which contains enzymes to break down the mucus and dissolves it
  - This is the process of freeing the particles into the stomach
- Depending on the size and positions of cilia, they are going to take all the particles that are released and send a certain sized particle up into the digestive glands
- Sorting areas determines what will go into the digestive system gland and what won't
- Anything that doesn't go into the digestive gland is moved into the intestine where enzymes are released once again and final digestion occurs

Mollusc phylogeny
Monoplacophora (Autapomorphies)
- Multiple paired structures
- Dome shaped shell
- Very ancient form of mollusc

Symplesiomorphies
- Take the body shape of the shell, radula at the front and mantle cavity at the back
- Visceral mass elongated on dorsal-ventral axis = become bigger
- Coiled shell
- Well defined head

Gastropoda (Autapomorphies)

Mollusc

- Muscular foot sticks out from underneath and used to crawl across the substrate
- Torsion
- Concentration of visceral mass
- Asymmetric body plan

Torsion
- Embryological and morphological development, a very phenomenal change, where the hole of the visceral mass rotates 100
- The mantle cavity sites on top of the head; it releases gametes, metabolic and fecal wastes on its head
- There are 2 theories: for defensive strategy of the larval stage and adult stage
- Before the torsion, they have retractor muscles that goes from top to the bottom of the shell, if the animal was to retract into the shell, the middle of the animal goes in and cephalized anterior and posterior part is the last two pieces to be dragged in
- In order for cephalized part of the body to drag into the shell, the muscles are crossed
- The assumption is that it was advantageous for the larval stage

Another advantage of torsion (adult explanation)
- Mollusc uses water quality to sense the quality of food and the environment they are in
- There is a whole array of sensory structures on the surface of the gills inside the mantle cavity
- Another hypothesis: chemosensitive cells within the mantle cavity detects the water qualities that is being pumped through
  - Before torsion, snails were essentially looking backwards from everywhere they went
  - They never sensed the water quality in the direction that they were moving in
- Torsion brought the mantle cavity forwards, meaning all the water sensing materials, parts of nervous systems were now sensing the water in the direction they were moving in
  - This offsets any disadvantage about having the fecal opening and nephridiopores on the head
- As the group evolved, the snail detorts a bit to the side of its head and crap on the other side of the head which is the advantage for the adults
- There is third explanation that relates to the adults, the water sweeping into the mantle cavity by cilia can also sweep particulates in and cloak the the surface of the gill or the sensory cells that are present
  - One of the consequences for the gastropods is that all structures are pairs and when they fold in on each other, many became a single structure (squeezed in the middle)
  - They have completely lost its oral-aboral axis because of the structure that sits on tops of the head

Snail
- The opening to mantle cavity on the sides are compensated
- Shell is not a result of torsion; they just coil up the visceral mass
- The digestive gland turns and is not on apex, which is all the way up at the top of the snail

Snail – Digestion
- Digestive tract goes up into the gland and comes back down on the other side
- They are very easy to retract into the shell for protection from the predators
- Waterproofing and protection from the shell allowed them to move up on terrestrial land
  - One of the first invaders on land and was very successful
- Twisting and banding affects the reproductive system

Snail – Reproduction
- This group is hermaphroditic (monoecious)
- They have an opening for the receiving sperm that comes through intermittent organ and pass the sperm up into seminal receptacle, the sperm storage

Mollusc

- Eggs are made and passed down the duct to be fertilized
- Not a lot of room in the shell therefore, any of the organ systems have been fused
  - Instead of having ovary and testis, they have a single organ called ovotestis
  - Instead of having sperm duct and oviduct, they have hermaphroditic duct
- Have tremendous compaction simplification to place all of the organs inside the shell
- Snails carry dart sac and they compete to see whose dart can penetrate deeper into the other snail
- The group is heading back towards being sexually distinct species
- The deeper dart that has penetrated the recipient changes the diameter of the pumping of the hermaphrodite system and makes it more receptive to receiving sperm
  - It opens up the storage for sperm when it is received and
- Turn the organism into essentially more functional female because it is more likely to receive sperm from the other organism

Terrestrial
- Gastropods without the shell = slugs
- They are restricted to extremely moist environment

Mollusc phylogeny
Cephalopoda (Autapomorphies)
- Extremely active predators
- **Closed circulatory system**
  - Can't rely of circulatory system where blood sloshes around; they need to ensure that all the tissues get their blood appropriately
- Ink sac: escape mechanisms from the predators
  - If something comes after, they release a cloud of ink that looks like a shadow and most predators go after the ink thinking that is what they were going after in the first place
- Modification of the foot: the muscular foot that was underneath modifies and becomes the tentacles that hang down from the opening to the mantle cavity
  - They are used to grasp and hold down preys (consequence of being extremely active predators)
- Beak-like jaw: developed bird like beak that is used to tare away the tissue of the large prey
- Cartilaginous brain case: most mollusc had nerve ganglion scattered around

Adaptations as predators
- Very intelligent and very affective organism in term of predators (octopods and squids)

Squid
- Elongated shell that is shared by gastropod and cephalopods
  - Earlier group: ammonites and nautiloids coiled it
- The mantle cavity went up inside and the visceralous is the middle of the cone and the edge of the mantle became elaborated into the tentacles and the feet that hang down
- Cephalopods: the elongation, the foot and the head come together, the head foot animals
- Going to pump water into the mantle cavity and squeeze it out = new propulsive mechanism
  - Always going to squeeze water out through a funnel so it is going to jet off in the opposite direction to the head
- Key elements are the arms and tentacles and mantle cavities surrounding it and the ability to pump water in and out
  - The disappearance of the shell allows the muscles of the mantle to expand to pull water and clamp the collar against the body and squeeze the muscles of the mantle
  - Ejecting water forces, the organisms to jet propel forward

Mollusc

Squid gas exchange

- Close circulatory system with distinct blood vessels
- Need to be able to extract oxygen from the water that is going through the mantle cavity efficiently
- They are high respiratory animal (high demand of oxygen)
- Regional heart is sitting inside the pericardial cavity and its contraction sucks up blood through the gills
- Whole new set of heart at the base of every gill that is going to push the blood through the ctenidium (gill) and the heart that goes to the pericardial cavity, which pushes the blood out to the body
- They have two hearts, one allocated to force the blood across the respiratory surface and another one across the body; in total three hearts are present
- Cilia is not needed for this organism since the the circulatory flow of the water through the cavity is very efficient
- Ctenedium: water is moving across it because cilia were the only way to move water across which has been replaced with the muscle movements
- Huge modification of the circulatory system for the predatory existence

Squid digestion

- Take ancestral digestive system that consists of cecum, anus and mouth
  - Food came in that was particulate that got sorted and the best food was sent to the cecum while the rest went other other way to anus
- Still has radula but not function compared to the giant beak
- Food torn up and end up with digestive systems that develops some side pockets called cecum and the digestive gland which is liver
  - Going to produce digestive enzymes to break down food small enough to be passed to the cecum
- Separated the digestion of the food into a compartment of its own so they can process large amounts of food which is combined by a second pocket called stomach
- The digestive gland produces large amounts of digestive enzyme to break the food down then going to pass them down into the cecum for final absorption
- Exit point is just in front of the funnel so that when water is pumped out the fecal waste also gets out

Male/Female squid

- The opening to the genital region is up inside the mantle cavity
- There are still perinephridia tha tis going to pour to the outside but we need to get gametes up in there
- They have specialized set of arms called hectocotylous arm which takes a package of sperm (spermatophore) and reach up inside the female and put sperm package up inside the mantle cavity next to the genital opening
  - The sperm will open and swim into genital opening and fertilizes the eggs

Colour production

- Dependent on interpreting colour and light
- Elastic capsule chromatophores
  - The wall of the squid is series of celled called iridiocytes which are covered with reflective surface
  - Over the surface, there is a chromatophore that are elastic which can become really big and selectively absorbs colours
- Can use colour as escape mechanisms by changing frequency or the consistency of the red, green, and the blue that bounces back (camouflage and disguise)
- Bioluminescence

Squid eye

- Have the camera eye, which is the optic cup that is completely closed with pin hole opening
- One opening and get inverted image

Mollusc

- Analogous to the vertebrate eye because they share totally different origins
  - The major difference is that optic nerves go back to the retina but for vertebrates, they move across the surface of the retina and back in through the blind spot

Squid – Nervous system
- Extremely complex brain; integrating visual field with all of the sensory information coming from all the other parts of the body
- One of the smartest organisms out in the world

Mollusc phylogeny
Symplesiomorphies
- Modifications for a sedentary life
- Digging foot
- Mantle and shell surrounds entire body
- They are going to filter feed

Scaphopoda (Autapomorphies)
- Mantle closed on ventral side forming a tusk-like shell
- Coiled mantle around their body and they live in the hollow

Bivalva (Autapomorphies)
- The shell appears to have two components: univalve is divided in half and held by a hinge regiment
  - A folded univalve is named bivalve
- Loss of radula: completely have lose its head
- Lateral compression of the body: going to pump water into shell using ctendia allowing thme to capture food that comes in on the water and use it as food source
- Ctenidia and mantle cavity specialized for filter feeding
  - Dome shell has folded in half and cause the foot to extend out and viscera has been pushed into the foot

Bivalve structures
- Have muscular foot that is going to extend out and mass of huge ctenidia
- Ctenidium is also used for food gathering and respiration
- Capture particulate food on the surface of the ctenidium and cilia is going to pass it to the edge and passed forward to the mouth
- Water pumped in through the incurrent siphon and the water passes through the ctenidia and out in excurrent siphon

Clam anatomy
- Food enters into the stomach, have crystalline style spinning in to bring the mucus in
- Particulate food is caught out of the water rather than generating themselves. Therefore, there is need for radula
- Have digestive gland and intestine with excurrent flow removing the fecal waste
- The viscera in the clam and everything is compressed into the foot
- There is no cephalization
- Heart is still in the pericardial cavity; wrapped around the intestine that is passing through
- Heart is going to pump blood forward and backward through all of the tissues that are there and the circulatory system picks up and also from coelomic space and the metanephridia picks up metabolic wastes and pass it out to the rest of the body

Mollusc

Circulatory system
- Hemocoel, the blood cavity of an open circulatory system is filled with spongy tissue, which is the muscle that is used by the foot to be able to move
- The spongy tissue surrounds everything

Clam ctendia
- Ctendia has a hollow core where water is going to come in and move through the pores in the wall into the hollow core and out the body
- As it moves through, cilia captures food to pass it to the digestive tract
- Cilia creates water current and traps food into the digestive system

Locomotion
- When it moves, it uses accommodations of the foot and its shell
- There are two big great retractor muscles at the front of the anterior shell and when they are contracted, the shell is closed. When they relax, the shell pops open
- They take their muscular foot and their hydrostatic skeleton and wedge it into the sediment and the very tip can expand into an anchor, which pulls the shell into the ground
- They hold a foot as extended form as an anchor and the retractor muscles goes all the way up into the shell that pull the shell into the ground
- They use their body plant o burrow into protective locations but they can still draw water in to be able to feed on the foods they are feeding on

Freshwater clam **Glochidia**
- Unique larval stage that are only found in freshwater forms
- When the eggs hatch, they form glochidia
- The little tooth at the front hook onto the gills of fish and they sit there and filter feed water on the gills of the fish until they grow large enough to be able to escape from the surface of the fish
- They can swim off and become large clam

Annelida

Animal innovations (Symplesiomorphies)

1. Schizocoel and metanephridia filtering coelomic fluid: the way water is filtered and how gametes are dispersed through the water
2. Dorsal heart and pericardial cavity: the ehart sitting inside the pericardial cavity

Annelids (Autapomorphies)

- Metamerism of mesodermal structures: repeat linearly in a sequence
  - Take schizocoelic coelom with metanephridia repeat it in linear array and you get a bigger organism and this is referred to metamerism
- Four bundles of setae formed from beta-chitin: involved with their locomotion
  - Have a set of bristles, setae hair that stick outside the body wall that give them a grip so that they can push against the substrate

Annelid development

- The trochophore larva might have developed into a mollusc, went through the veliger larva stage
- In annelids, between the posterior end with anal opening and anterior, where the mouth is, is going to insert extra segment
  - Like scolex of the tapeworm, where the proglottids were added down the length of the organism
  - Also have seen it in strobili, where there is one structure that start to divide and add more units to it
- Annelids are going to end up having identical segments that form and these become the metameres or the segments of the body that gives worms the impression that they form from series of rings stuck together

Metamerism

- **Metamerism** is reflected on the major features of the anatomy
- The three structures that come from the ancestor trochohpore are: **pygidium** (anal opening at the posterior end), **peristomium** (surrounds the mouth) and **prostomium** (mouth)
- Everthing else between the two are metameres, always separated internally by muscle tissues that creates septa wall

Chitin

- Setae hairs are made up of chitin that is universal compound that is associated with cell wall
- Arthropods use it as exoskeletal as a re-enforcing structure
- They are fundamental units, where N-acetylglucosamine are bonded together down in a series of sugar molecules that make one strand of chitin
- N-acetyl groups are alternating in pattern, giving the structure polarity
- Each of the chitin molecules can line up and interact with adjacent molecule and form hydrogen bonds

Beta-chitin sheets

- A chitin strands that is aligned to the neighboring chitin strand beside and their polarity is unidirectional (parallel to each other)
- Can form hydrogen bonds and make much more rigid and firm sheet of the chitin that can be rolled into bundles
- In annelids, setae hairs are made up of this chitin, which means they are aligned in parallel fashion

Alpha-chitin sheets

- Alignment of anti-parallel strand
- Large groups are sticking out through the sides and sit into pocket really nicely to the adjacent chitin molecule (almost lock and key effect)
- They are packed closer together, which means more hydrogen bonding
- Much more rigid and structurally strong

Annelida

- Arthropods and ecdysozoans are the only group that uses alpha chitin sheets

Annelid diversity

- Worms are adapted to the terrestrial environment and specialized to be able to come up on land
- In the ocean, annelids have modified into a huge array of different organism (found in different kinds of depth)
- Clam worms: found in the deepest ocean trench and live under extreme pressures
- Some have taken the peristomium and elaborated them into complex tentacles that can be unfolded to capture particulate food that is floating through water
- Others have taken setae and elaborated them into complex structures so that they can curl up and put all the tufts sticking to the outside as a defensive mechanism
- Leeches annelids that have returned to he parasitic existence

Extant Animalia

- About 1% of all the organism on planet
- Pretty high number

Earthworm body wall

- Consists of classic outer circular muscles and inner longitudinal muscles
- Have large coelomic spaces associated with it
- Have two pairs on either side of the setae that stick out from the body wall
- Each of the metameres with the septa walls in between become the hydrostatic skeleton
- Have a wall and a sheet of circular and longitudinal muscles and each of the squares can change shape independent of the one next to it

Earthworm locomotion

- Instead of one coelomic space and contracting all the circular muscles and changing the whole length of the animal, they can take certain metameres and change them
- Similar to flatworm sticking motion, but they don't stick, instead the body shape is changing
- Contracting circular muscle = setae is pulled in, the segment lengthens and pushes against the anchor point and the organism is able to move the whole anterior end
  - The anchoring allows the animal to move
- Pushes the head forward □ anchor □ pull the back segments (accordion like movement)
- New Cambrian group that has found a new way to penetrate through the impermeable algal mat at the bottom of the ocean
- Instead of pushing the food to the side, they open the mouth and ingest the medium through which they are moving (dig through by swallowing the substrate)
- Since they lived in the sediment, they were protected from the predators

Earthworm circulation

- Because metameres are independent, coelomic fluid is locked into the role of being hydrostatic fluid, thus it can't mix between each of the segments and be used as blood
- They have dorsal blood vessel that runs along the upper side of the animal, that pumps blood forward
- Ventral vessel is underneath which pumps blood back to the back of the organism
- In each segments, blood is brought from the ventral to dorsal
- The heart is located in the anterior part of the organism on the dorsal side of pericardial cavity pumping blood forward then peculating capillaries to vital organs and tissues down the ventral side
- As it moves through the back, it comes up through the lateral connectives and the process repeats

Annelida

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- Lateral connective ventral blood vessel lateral vessel across the body wall dorsal vessel digestive system dorsal vessel metanephridia ventral dorsal
- **Metanephridia** is where coelomic fluid is filtered and the blood vessels recover essential nutrients that are needed for the system to retain
  - At the same time, it is also cleaning out the circulating blood in terms of nitrogenous waste
- When the Blood goes from ventral to the dorsal side, it is going to be loaded with nutrients, oxygen and purged with any nitrogenous wastes (high quality blood called **premo blood**)
- This premo blood is received by the anterior end where all the cephalic structures are
- The system can reverse itself in one particular location, **the 5 aortic arches** that are present in a set of segments in the earthworm
  - The blood breaks the usual pattern and goes from dorsal to ventral (pumped down)
  - This occurs due to aortic arches surrounding the reproductive system and it is short circuiting some of good quality blood to the reproductive genital system
- Ancestrally, the gonads were in every segments (metamerically), there was a gonad that developed and sent its eggs out through metanephridia and every segment could produce eggs
- Earthworms have specialized and made certain segments reproductive, causing modification in the circulatory system to provide segments with adequate blood supply

Earthworm digestive system

- This is a tissue called **chloragogen tissues** that is related to the blood exchange where deamination occurs (breaking down the amino groups and getting nitrogen off of it)
- This is why they are associated with the blood vessels and the gut
- All the tissues are picking up dissolved nutrients and deaminating them and releasing amino group such as ammonia so metanephridia can deal with them
- Increased the whole absorptive surface by enfolding the gut called **typhlosole**
- The earthworm consumes food, which is passed down the digestive system and are constantly extracting nutrients

Digestive system

- At the anterior end of the digestive system are pharynx that pulls the food in and esophagus ends the food down to the sites for digestion
- Before going into the digestive tract, there is crop, where foods are stored and gizzard is where the food is ground (not going to get any nutrients until they are passed to the intestine)
- In all of the segments, the septa wall never get any nutrients because they are not adjacent to the part of the digestive system that releases nutrients
- Circulatory system at the end, where nutrients are being picked up by the blood moves to anterior end to supply tissues that are there
- The locomotion does not only occur due to the isolation of the septa coelom, the circulatory system moving nutrients around between all of the different structure also plays a role on movement
- Calciferous glands: used to take calcium out of the circulatory system so that it does not poison other parts of the system

Metanephridium (excretory system)

- Each segment has a metanephridia, which is a funnel inside the coelomic space that picks up fluids from the coelomic space and recovers any nutrients and going to pass them back to the blood before any of the contents are released through **nephridopore**
- This opening is important because it is how they keep themselves moist
- They live in a moist environment, but if they start to dry out, they will sacrifice coelomic fluid and increase the flow out of the nephridiopore to moisten the body surface
  - They moisten their surface because it is their respiratory surface

Annelida

- They sill suffocate if they dry out
- Melting snow fills their burrows, melting snow has no oxygen dissolved and because of this, the water is fixating the worms in their burrows

Nervous system

- They have brain located on the dorsal side
- Brain has large mass associated with it and there is another one underneath esophagus
- There is ventral nerve cord with epical brain, connectives come up around the sides
- Each of the connectives are important because the **ganglion** that is above the top is gong to be involved in anterior sensory activity and the ganglion that is below is going to be involved in feeding and movements that is associated with ingesting food
- There are two different ganglions: suprapharyngeal and subpharyngeal
- There is always a lateral nerve cord in each segment that are connected to each other in ventral nerve cord and it is how coordination of the peristaltic wave goes down the length of the worm
- Lateral connectives determines whether they are contracting circular or longitudinal
  - The contraction relative tot eh segment nearby is coordinated down the length of the nerve cord so they get the peristaltic movement

Nervous system

- The ventral nerve cord has **giant axon**s, which are present to carry a message rapidly on a long distance through a huge diameter
- Big diameter to create a lengthwise complete body response to some kind of stimulus
- Giant axons: when earthworm is in its burrow and goes out to feed, it pokes its head out and contract all of the body muscles down the length of the body to lengthen itself to be really long but at the bottom of the worm will turn around, which contracts all the longitudinal muscles to make a big anchor
- The anchor is holding the tail end of the organism in its burrow as it goes up and out to feed
- If something comes along and scares the earthworm, the giant axons are fired and the longitudinal muscles contact simultaneously and every metameres brings the worms down the hole
- The bottom posterior end of the earthworm swells to make the spatula like structure

Reproductive system

- They are hermaphrodites (monoecious)
- End up with concentration of the reproductive structures at the anterior end of the organism
- Have testis and funnel on the opposite side, the sperm is stored in the seminal vesicle and released outside
- There is an opening for the male reproductive material
- The ovary is also related to a funnel, which is separate opening to the outside
- There are two opening: one for sperm and the other for egg
- Earthworm align themselves in opposite direction so that opening to a male genitalia lines up with openings that goes to the receptacles
- No self fertilization
- There is two transport points between the two earthworms
- They have broad thick satellite called **clitellum**, which is used as a glue to bind themselves together while they transfer sperms
  - Making sure that sperm does not desiccate when it is being transferred
- They receive their sperm then they separate

Cocoon formation

- They have gelatinous cocoon, where clitellum plays a role

Annelida

- The earthworm movement is going to take the sleeve and slide it forward and as it moves, the eggs are released into it and it moves in front of the seminal receptacle where sperm is released from the seminal receptacle
- Sperm and eggs fertilize and get a little embryo; the clitellum is also filed with nutrients
- As it slides forward, it comes right off the front end of the worm and as it dries up, it pinches up its two ends and get waterproof container filled with nutrients in a fertilized egg
- Fertilized egg becomes a little baby worm, no larval stage (no water to swim) = **direct development**
- The cocoon provides protection until it is big enough to be able to escape and get out
- Earthworm is in the group called clitellata due to clitellum

Nereis Errent polychaete

- Ancestral worm looked like this
- The segments look the same all the way down the length of the body
- There is a set of fleshy extensions on each side of the body that gives it unique shape of the body

Nereid body wall

- They have structures called **parapodia** that sticks out from each side
- The four set of bristles are located at the ends of the parapodium
- They have chitinous rods supporting the bristle (holding up the parapodium)
- Have bands of circular muscles, which is very thin around the outside
- Longitudinal muscles are not organized in sheet anymore, they are organized in distinct blocks
- Have a set of oblique muscles: can contract, pull on the chitinous structures and parapodium can be raised or lowered
  - There is flap sticking out of the sides that has setae sticking out of it, it has chitinous rod with oblique muscles
- The structure is bilobed, upper lob is called **notopodium** and ventral lobe is the **neuropodium**

Nereid movement

- Have differential contraction of the longitudinal muscles on either side
- In the metamere, there is a band of muscles, dorsal and ventral left side and if only top part of the muscle is contracted, then the top is shortened while the bottom lengths and vice versa
  - Still have fluid filled cavity
- Using muscle bands to achieve hydrostatic skeleton
- Segments can be wedge shaped and the shape of the wedge can change based on the contraction of the bands of the muscles
- Get an animal that use sinusoidal movement to make pivot points to move across the substrate
  - As the segment changes its shape, it becomes the pivot point of the parapod
- The parapod allows them to move quickly across the substrate
- If the beat of the sinusoidal wave increase in amplitude, they can start swimming
- Much more mobile type of worm that can move across the substrate using the arrangement of the muscles and the bands on the two side = become active hunters

Nereid head

- Anterior end has sensory palps and tentacles and cirri which are involved in picking up sensory information from the water surrounding the worm
  - Sensing environment in which it is swimming and moving
- Series of eye cups that are located on the surface, which picks up basic visual information, horizon (overlapping visual field = get three dimensional)

Annelida

    - Exact distance in front of the head where they get three dimensional input is the exact distance that the retractable jaw has to shoot out to capture prey
- Have massive invertible jaw inside nereis that is coming shooting on
- There are teeth around the jaw to grab on the prey

Polychaete circulation
- Have ventral vessel, where the blood goes up and out into he parapods, allowing them to be oxygenated
- Have huge surface area that is exchanging across the marine environment (no issues with water balance)
- There will be metanephridia but they will be very small
- The only other branching from the ventral vessel, up through the digestive, across to pick up nutrients
- Have blood down through the ventral vessels, heading out to be oxygenated and coming up to the dorsal or go into the digestive nutrient transfer
- Every segment is the same down the length of the organism, everything happens in the first few segments
- Metanephridia is the exit point for the gonads; when it becomes time for producing gametes, the gonads form on the wall and release either eggs or sperms, which are then swept down the funnel
- They are active, mobile, visual hunters and as consequences easy to find mates
- Sexes are separate from each other (not a hermaphrodite)

Polychaete reproduction
- Get polychaete that will differentiate segments that is only going to be gametic
- They will fill with gametes and release segments as one small part of the body and will rise and wiggle and climb up through the water column when it is time for the worms to meet and find segments from other worm
- They will release eggs and sperm into the ocean
- No direct development; the trochophore larva puts segments behind the head

Leeches
Leech body wall
- Closely related to the earthworms
- Have clitellum that they use to produce egg cocoon
- Have completely surrendered body cavity, the coelomic cavity is gone (like plathyhelminthes)
- There is still a bit of coelomic space, even gonads too have a bit
- Shrunk the coeloimc cavity down in terms of size

Leech locomotion
- Have anterior and posterior sucker
- Can take the solid body and undulate it in its swim
- Can use suckers as they attach and detach as they move across the substrate as a mechanism to crawl across if they don't swim

Leech body wall
- It is going to use the space made by shrinking the coleomic cavity to enlarge the digestive system
- This is a predator that has to find food but can't find food at all times
- When the food is found, they have to tap into it affectively to be able to gather the food

Hirudinida feeding and digestion
- Consuming large amount of food and dropping off

Annelida

- Digestive tract developed have diverticular that replaces the space of the coelomic cavity
- Instead of having straight tube digestive system, the space generated by removing coelomic space, now is that space that the digestive tract can expand into and it is where the food is stored
- End up with very large crop with diverticular that mean we can store meal for a period of time until we find another host to feed upon
- It needs to compensate in the digestive region thus intestinal regions also expands
- Taken the space and put digestive system to fill it to store or digest meal
- Set of three jaws that cut into the tissues and leech sucks up the fluids that are generated when the tissue bleeds
- They produce anticoagulant to keep the blood meal liquid (even in cecum and crop)
- Synthetic coagulants are based upon on the proteins that is found in leeches for thinning blood
- Leeching is a common medical practice, they are grown and kept in bacteria free environment
    - They feed on venus blood, which is blood that is returning to the heart that pulls just before a wound
    - If the blood circulates and get damage capillaries in the blood vessels, blood pulls on the side away from the heart and pulling blood causes problems for the healing tissues
    - Leeches inject blood thinner in, which improves the circulation of the blood through the wound and enhance repairing and healing

Arthropods

Animal innovations

- Cuticle of alpha-chitin and noncollagenous protein
- Hemocoel with dorsal tubular ostiate heart
  - Replace body cavity with hemocoel that is associated with heart that runs through it and heart is going to be tubular instead of muscle contracting
  - Ostiate are opening to the heart, reflecting the original segmentation of the arthropod body
  - The heart is suspended in the hemocoel and going to pump the blood around
- Ecdysis: moult the whole of the structure in one shot
  - Animals are gong to become vulnerable as it escapes from the cuticle
  - Going to harden it up very quickly
- Food manipulated by limbs (KEY INNOVATION)
  - Going to use appendages to manipulate the food (either filter or grind up)
  - Have body plane that has appendages in every segment and some are going to be specialized for manipulating the food = mandible
  - More surface available to digest and more surface to absorb nutrients
  - Chordates: jawed chordates (preprocess the food before putting it into the digestive system)
- Saccate metanephridia: modified nephridia (filtering system)
  - Capable of absorbing the fluid from the hemocoel
  - No ceolomic space but still have fluid filled cavity

Chitin

- The position of the N-acetyl group of the glucose sugar gives polarity to the structure
- Alpha-Chitin: Each of he chitin molecule is aligned head to tail to the one adjacent to it (Anti-parallel) strands
- Beta chitin: the bumps sitting on the hollows of the other molecule
- With lots of hydrogen bonding, the alpha chitin interaction between the molecule is very strong and tough
- Alpha chitin is stable and indestructible

Animal innovation (Symplesiomorphies)

- Articulated limbs (the reason why they are named arthropods)
  - Limbs are now tubular structures made out of chitins
- Three segmented brain (always 3 segments)
- Exoskeleton with articulated plates: body is NEVER just solid skeleton
  - There is always membranous cuticle between the plates

Arthropoda (Autapomorphies)

- Muscles arranged in bands
- Compound eye
- One pair of preoral antennae
  - The three-parts of the brain: first part coordinates with optic visual system, the second part is the optic coordination of the first pair of antennae and the third is either going to coordinate the antennae or other structure
- Three pairs of post oral appendages
  - Always have one pair of oral antennae
  - Minimum of 3 found in the first part of the body

Cuticle layers (3 principle layers)

- Basement membrane: structure that holds the cellular integrity together
- Epidermis: the only living layer that secretes basement membrane
- Cuticle:
  - Outer epicuticle: outermost with no chitin

Arthropods

- Inner procuticle: inner most with chitin

Arthropod cuticle
- The largest bulk of the cuticle is called procuticle
- Little thin layer of epicuticle sitting on top of procuticle

Epicuticle
- It is covered in waxes that are produced in it
- There is cement layer and wax layer, giving cuticle its waterproof characteristic
- Cement layer is needed because waxes can be scratched and can lose the waterproof capability easily
- Cement layer is put on top of the wax layer but it can still have waxy layer come up from below and do some damage and repair
- Epicuticle prevents the arthropods from loosing water when they move into the terrestrial environment (not found in crustacean because they live in a marine environment)
- Ex. Lac insect produces a blood of epicuticle which it lives inside protected = away from the predators
  - In the lac industry, lac insect harvested dried pulverized into power extract water soluble materials by boiling it with water left with cellulose plant and insoluble materials filter the insoluble dry pulverize extract with ethanol filter again
  - As a result, get a clear organic solvent called shellac that is used to coat the furniture
- Another layer called cuticulin is important factor for moulding process

Arthropod cuticle
- When the insect first moulds, the procuticle is amorphous, no distinction in it
- There is no cross linking between the proteins or chitins, it is stretchy
- In a moult process, insect lays down a new cuticle that steps out of the old cuticle and it swallows either air or water depending on what environment the organism is living in
  - This swallowing causes the cuticle to puff up in size and the procuticle differentiates into an outer exocuticle or remain endocuticle inside
- The puffing is allowed because the procuticle is still flexible and the cement is not formed yet
- In exocuticle, the protein protein linkage occurs while endocuticle does not
  - Exocuticle is protein protein covalent cross linkage (highly indigestible and highly stable)
- The cross linking causes the cuticle to harden = fix in size = new shape and size
- It lets the air or water out that it has swallowed and has a space to grow into
- In crustacean, the middle layer called mesocuticle is present, which is where additional crosslinking with mineralization occurs
  - Crustaceans harden their cuticle with calcium salts break apart (crunchy sound)
- Epidermis programs and builds the whole structure that is found on the outside
- Ionic interaction can be seen in the procuticle, covalent protein interactions in the exocuticle and mesocuticle is due to mineralization

Moulting – Apolysis
- Want to recover as much of the building blocks of the old cuticle to make new cuticle
- N-acetylglucosamin can be used to build new proteins, new chitin and other proteins that can be broken down into amino acids for the component of the cuticle
- Try to recover and recycle as much material as possible = breakdown proteins and chitins
- Going to need proteinases to breakdown proteins and chitinases to breakdown chitins and want to make sure that it is only breaking down protein and chitin of the old cuticle

- Epidermal cells lining dormant receives a signal from the moulting hormone The epidermal cells swell in size become cellular active rough ER and mitochondria increase in numbers and Golgi apparatus material secretion kick up as well = cells become extremely active
- Then they create a space between themselves and the old cuticle and the gap
- The gap is the signal for moulting to start and this is referred to as apolysis

Moulting – New epicuticle
- Cells secrete protein crossed linked mesh and at the same time, they also secrete a set of enzymes to breakdown the old cuticle
- Once the cuticulin layer (protein crossed link mesh) is in place, cells send out activating components, Mg or Ca (salt), to turn enzymes on
- These enzymes are intact proteins that are dedicated to breakdown proteins or chitin
- Cuticulin layer is semipermeable, meaning small molecules can go through while big ones can't
  - This mesh is going to be produced and ultimately show up in the epicuticle to allow N-acetylglucosamine and amino acids to go through its pore
  - The cuticulin layer also protects the new cuticle from getting attacked by the enzymes
- Freeing up subunits to go across the cuticulin layer to be picked up by epidermal cell and make new cuticle

Moulting – digestion of old cuticle
- Cuticulin layer is in the middle keeping enzymes on one side and allowing the digestive product to come down to the epithelium and be recycled and re-used
- The procuticle is still a lose spongy matrix = poor enough for things to diffuse through
- This keeps going until it runs into the outer epicuticle (exocuticle)

Moulting – undigested exocuticle
- Exocuticle is where the cross linking occurs
  - The proteins are covalently bonded to each other and they are resistant to digestion that enzymes can't recover any more material
- Digestion of the old cuticle will stop

Moulting ecdysis
- When the cuticle is produced, the zones thin exocuticle was present
  - When the insect digests all of its cuticle and starts gulping air/water, it is going to puff itself up and the lines of weakness shatters
- The lines of weakness are not random along the surface, they are in distinct locations, going all the way up the dorsal surface, up and across the top of the head and whole cuticle splits open and arthropod climbs out of the old cuticle
- It continues to puff itself up until it reaches its final size then cuticle is hardened (protein cross link)

Moulting – Outer waxy layer
- The gland cells associated at the bottom are going to release up onto the surface of the waxes and cement layer
- Cuticulin layer stretches to their size protein protein cross link to get exocuticle put cement and wax on top of it and arthropod is now at its brand new size
- It lets out the air/water and have space for tissues to grow and organisms grow in size
- The whole thing is processed in single cell layer

Moulting sequence
- Get cell divisions, moulting enzymes are activated only after the cuticulin layer gets placed
- They then start to digest the old cuticle as they lay down the procuticle

Arthropods

- The escape of the old cuticle is called ecdysis
- Right after, we expand and hardened = moulting has been completed

Arthropod articulating limbs
- Every single arthropod has cylindrical form and it has 2 connections to the cylinders and the cylinder pivot against each other with membranous zones in between
- They all pivot in one direction
- All arthropods have 6 or 7 segments, seems to be the optimal to be able to move an appendage

Arthropod joints
- Can't have cylinders butting each other
- There is membranous cuticle in between that give them flex in their movement

Muscle organization
- No muscles are in sheets, they are banded
- Have fibers of muscle that pulls across the pivots of the joint; got leave like movement
- The tendon goes all the way down to the base of the foot; the muscle contraction allows the leg to move up
- Every single muscles are attached on either side of the joints

Mechanoreceptive setal hairs
- Unique sensory structure covered completely in a waterproof inflexible cuticle
- Other than the membranous zones, the waterproof barrier is present, making it unable to taste things
- There is a cuticular hair sits in a socket that is invaded in a cuticle and attached to the base of the hair is the nerve cell
- If the hair was deformed in one direction, it will stretch the nerve cell and the distortion of the nerve cell creates action potential the sends signal from the nerve cell down through nervous system
  - It is a simple mechanical distortion which can cause it to fire
- If the hair sits on a socket that only allows it to pivot in different directions, then you can get differential signal using the same mechanism to say this sensory hair being distorted in opposite directions
- In insects, they sense the environment through the setae hair on their feet
  - If the cuticle gets bent or distorted, the dome pops up or down and they can detect forces in the cuticle itself
- By modifying the cuticular structure, they can get all senses that would associate with mechanoreceptions in terms of picking up information

Chemoreceptive setal hair
- There is a hole at the end of the hair to sense smell
- When the hole comes in contact with something, chemicals will dissolve and hit the nerve cells that causes action potential to fire and the organism is going to able to taste and smell
- For smell, you perforate it with lots of holes so it ends up with very simple sensory apparatus all based on cuticular hair that is secreted by epidermal cells
- The same epidermal cells that make the cuticle, hair, socket and nerves are associated resulting in mechanorception and chemoreception

Compound eye/Ommatidium
- The compound eye is made up of ommatidium, a single optic lens
- Ommatidium is optically isolated by pigment cells from adjacent
- One part of the visual field is seen through the lens or the cornea
- The light is focused from the cornea crystalline cone = little image gets lost but they have certain level of colour that results in dots

Arthropods

- The dot of light shoots down into retinular cells, which are sensory cells and at the very core is the rhabdome, which is the sensory microvilli
- Rhabdome measures the amount of light (the brightness and colours) using cellular power
  - This structure is required because the light comes through a cuticle, so need a way to process light on a flat surface
- It creates a pixel that consists of three primary colour, these primary colour represents the visual field of one cornea
- As more and more pixels (ommatidium) is added, the resolution increases
- For human eye, one cell processes each dot of colour

Extant Animalia
- The biggest and diverse of all of the insect phyla on the planet
- Chelicerates, crustacea and atelocerates
- Atelocerates are 70% of the insects and have simple body plane (head, thorax, abdomen, wings and three pairs of legs)
- Crustacean are dominant in the ocean environment: figures out how to trap primary productivity of the ocean
- In land, chelicerates are predatory: scorpion like and feeds on worms or any soft bodied organisms
- The atelocerates dominate because they developed mechanism for flight, dispersion and superior water grouping

Arthropod taxa
- Subphylum Trilobita: massively common arthropod in Cambrian seas
  - They reached throughout Cambrian but they ultimately disappeared
- Subphylum Crustacea
- Subphylum Chelicerata
- Subphylum Atelocerata

Arthropod success (importance)
- Number of species
- Distribution: global distribution
  - Found EVERYWHERE (jungles, deep & shallow part of ocean, snowcaps, forest, deserts)
  - Arthropods developed as parasite (Ex. Follicle mites)
  - Have restrictions within the group:
    - Crustacean only found in marine environment (very few made to land)
    - Chelicerates, atelocerates are NEVER found in the marine environment
- Evolutionary history: Cambrian fossils that resemble organisms that still exist today
- Impact on man
  - Insects are responsible for many of the events of the history of earth
  - Ex. Insects that transmitted the black plague = changed the whole culture of Europe (dark ages)
  - Colonization of different part of world stopped by insect born disease (Ex. Malaria)
  - Ex. Typhus (Conquerors disease) transmitted by lice due to closed packed situations
  - About a third of harvested crop that are found in the world is affected by the pests that get into the stored grain or food
  - It is still a major issue today to protect agriculture crops
  - Compete with us for food and also for fiber: cellulose eating eats architectures built out of wood
  - Beneficial impact: pollinating insects pollinate ~70% of the agriculture crops
  - There is a massive collapse of the native bee population of pollinators and as well as the articial pollinators are collapsing as well

Subphylum Chelicerata

- They sit at the bottom of the evolutionary trees for arthropods
- The second appendage on the head is a feeding appendage, not a sensory
- Chelicerates include a broad spectrum of arthropods, all terrestrial and all predatory

Chelicerata (Autapomorphies)
- Two tagma: **prosoma** and **opisthosoma**
  - Metameres fuse together to carry out specific functions
  - Front tagma prosoma & Back tagma opisthosoma
- Prosoma with six pairs of appendages
- Chelicera, first pair of appendages
  - Feeding appendage that is so unique to the group, which gives its group name
- Loss of antenna and **deuterocerebrum**
  - The brain is composed of 3 parts (tripartite brain) and the first segment is coordinating the eye and second segment is always involved in nerves and coordination and third is sometimes involved in the coordination of antenna or it is connected to the ganglion below the esophagus and connects to the rest of the nerve cord
  - The brain has lost the second segment or the deuterocererum and antenna in the development sequence
  - In their embryological development, they have completely lost the second segment

Tagmosis (Chelicerates)
- **Prosoma**: first segment with 6 appendages followed by pedipals and 4 pairs of walking legs
  - One the first segment is the feeding appendage called **chelicera**
  - The **pedipalps** are sensory but they also have grinding base since they are fluid feeders, they are going to squeeze juices out of the organisms they feed on
- Four sets of locomotory appendages = **walking legs**
- **Opisthosoma**: reproductive, digestive structures and all of the things associated with internal function
  - They have opening called **spiracle**
  - A unique respiratory structure called **book lung**

Arthropods

- **Epigynum** is the access to the openings to the genital system
- At the tip of the organism is set of **spinnerets** involved in producing the silk

- This group develops a silken thread that can suspend initially on the ground so if something crawls over it, it will create a vibration of the silk and the spider will capture the prey
- They are heavily reliant on vibration in picking up sensory around them

Tagmosis (Chelicerates) [Closer look at prosoma]
- The grinding base associated with pedipalps is called **gnathobase**
- Often the chelicera in some groups have a sting to immobilize the prey (inject material to liquefy the prey)
- Ultimately, they are a fluid feeder
- Squeeze whatever is feeding on and suck up juices that are in the digestive system = the real role of gnathobase

Chelicera and simple eyes
- At the anterior end, there is a set of medial eyes and lateral eyes
  - Always **8**, but compound eye is not seen
  - Compound eyes are arthropod autapomorphy that is been lost to this particular group because they have specialized in picking up information from vibration transmitted along the silken thread
  - They do not require a visual system
- The first segment, brain, is still there and it is coordinating information that is coming out from the simple eyes
- There is a great big **fang** on the font associated with **poison claws**
  - They will immobilize their prey and either eat right after they killed it or they digest it and break it down then consume the residue
- Not all spiders use silk threads

Sensory – Simple eyes
- The wall spider & jumping spider have extremely big eyes where the lenses are actually creating visual image
- The eyes are embedded in the cuticle, thus spiders can't look in different directions
- The optic surface behind the lens can pivot to different positions so it can rotate to be able to look up, down, left and right
- They have complete visual field that allow them to be effective visual hunter

Male spider's pedipalp
- The male spider has very distinct pedipals where it is designed to be able to take sperm packet and pass it to the female
- The female picks up any vibration coming on the web as potential meal
- The male has loaded the pedipalp with sperm and it will get on the edge of the web and start plucking the web to send a signal that he wants to mate
- He keeps plucking and move across the web, he needs to be careful not to twig the web in the wrong way because the female will eat him mistaking him as food
- Once the male approaches the female, he needs to move fast and get the pedipalp inside the epigynum to transfer the cells and get away because there is 50% chance of the female eating him or not

Silk and spider webs
- **Spinneret** produces a variety of different types of silk for different types of roles (can be stretchy, sticky)
- **Spigots** in the spinneret produces the silk programmed to do the appropriate tasks at different times
- The silk is a protein fiber that is mixed with glue and it is very strong
  - It is not brittle, it can stretch and bend

Arthropods

- The silk comes up in a liquid form
- If the spider is hanging from the thread, the interphase between the spider and the solid silk thread is liquid

Orb webs
- Suspended the sticky lines in the air and trapped insects that developed flight = they tapped into a food source that no one was feeding on
- Spiders become aerial filter feeders and became dominant on feeding upon them
- Silk is important part for feeding and mating rituals in the behaviour

Feeding and digestion
- When the prey is captured, they are wrapped up in silk
- When the female captures the prey, the cocktail of hydrolytic enzymes are injected through the poison fangs to breakdown the proteins (carbohydrates) so that material in the prey could be drunk up
- Outside of the insect is covered by waxy box so that no body can get it and attach it to the web and leave it in the sun to heat up = results in insect tetra pak with insect slurpee inside
- The female comes back later and break open the “tetra pak” and squeeze it with the gnathobase and sucks up the fluid that was there

Book lung
- This is the opening of the **respiratory system**
- Inside a space of the body, the cuticle has elaborated into very thin folds and these folds are not waterproofed, which allows gas exchange across the surface and insect blood circulates within he structure = oxygenating
- Spiders make another evolutionary leap when vertebrate comes along

Ticks and mites
- They have completely modified their body plan
- Tick have become specialist at feeding on warm blooded vertebrates = new predatory niche

Tick
- It is impossible to identify the original prosoma and opisthosoma
  - The re-alignment of structure = chelicera & the first pair of legs are associated with the hardened cuticle that form **idiosoma**
  - The mouth part can anchor and leverage and use muscles to be able to pierce into the host in which it feeds on
- Behind it is another region where the cuticle has softened and this is because they are going to take very large amount of blood and blood is primarily water
- They are going to filter the water out and consume more blood and filter the water out so they end up with a big bag of essentially compacted blood in the digestive system
- The tick detaches and crawls into the leaf litter or into the substrate around it and slowly digest the blood and turn it into eggs
- Ticks also use anesthetic when they inject so the host doesn’t feel them when they stick to them
- In the seasonality of ticks, they undergo metamorphosis and as adult, they have behaviour signal that makes them crawl up vegetation and they wait for warm vertebrate to walk underneath them
  - The CO_2 that vertebrates give off is a signal for ticks to rain down and attach to them
- Change in climate and temperature = lyme disease transmitted from the ticks

Tick, ventral surface
- Chelicera has cutting blades and tongue like structure that anchors the whole thing in place

Arthropods

- It burrows into the tissue and ticks just sit there constantly pumping blood and filtering it out to be able to obtain nutrients that it needs to produce eggs

Mites
- Smallest predators in the world
- Most household allergies are to mites because mites are small enough that a dust particle is a full size meal for them
- They also have become omnivorous
- Follicle mites populates about 80% of any given population
- It sits at the base of the hair follicle and takes its four stubby little legs and holds on to the hair follicle and feeds on the oils that are produced at the base of the hair follicle
- A set of arthropod that have moved up on land and became successful on being predatory on insects and exploded in their diversity when warm blooded vertebrates exploded in their diversity
- Part of the colony collapse disorder: the death of huge number of bees
  - For the last 50 years, mites have been treated with honey bee colonies with an insecticide
  - Now mites have become resistance and there is nothing that can be done to protect the honey bees
- Mites are small enough to go down the respiratory tubes used for breathing in insects
  - They go down to the ends of the microscopic tubes and sit inside
  - They pierce through the wall of tube and drink their blood
  - They can build up in many number = block the respiratory capacity
- Smallest microscopic predators of any time of organisms (some are smaller than the protist)

Subphylum Crustacea

- Crustacea and Atelocerata are referred to as mandibulata
  - Crustacean have unique mandibles compared to the atelocerates (function and work entirely differently)
- Crustaceans are herbivores

Crustacea (Autapomorphies)
- Antennal and/or maxillary saccate metanephridia
  - Antennal gland is located at the anterior end or maxillary gland
  - Originally, within the group, every single segment had its own excretory structure, which is referred to as saccate metanephridia
  - As the hemocoel takes over and end up with one body cavity = only one metanephridia needed
  - Saccate metanephridia is ciliated funnel (no coelom) that covers the opening of the funnel that looks like a sac
  - Cilia is creating current of flow of fluid downward, which creates negative pressure = creating hemolymph = blood filtered across the surface
  - Saccate metanephridia is always located at the antennal or maxillary segment
- Nauplius larval stage
- Biramous appendages
- Gnathobasic articulated mandible
  - Mandible is going to be on appendage, modified for grinding

Arthropods

- The grinding appendage is going to be set up that grinds at the base where gnathobase comes from

Nauplius larva
- Can be seen when feeding hydra (little organisms in larval stage of sea monkeys)
- Hatching out of the egg is the 3 appendages on it and these are going to be the first 2 pairs of antenna and the mandible
- As the Nauplius matures, they are going to add more appendages down the length, developing into a large organism
- They fuse in the middle of the body

Biramous appendages
- **Biramous**: there is attachment point to the body, it often has several set of segments associated with it and this is called **protopodite**
- Have another segmented appendage in a pair extending from the attachment to the body
- Legs end up being referred to as biramous because they have two arms with it
- The spiders and atelocertaes have uniramsou limbs
- Crustacean are unique in developing biramous appendages

Feeding and digestion
- In the very simple and earliest crustacean, krills, had appendages still attached to every single segment
- As crustacea got more complex, the appendage took on specialized functions and their morphology and appearance became modified

Crustacean limb and serial homology
- Have a set of biramous appendages attached to every single segment down the length of the body and they peddled in a metachronal wave that propelled the organism through water
- The head had 2 pairs of antenna
- All of the appendages are attached to each metamere of the trunk down the back
  - These attachment of the appendages are large and leaf-like that has great exchange surface for gas exchange and it is gong to have oxygen transferring across them to be able to pick up oxygen
  - They have sensory hairs on them to sample water and try to understand nature of the water that gets pumped over the water as they swim
- Appendages used for: locomotion, feeding, respiration, and sensory

Filter feeding
- Had appendages that was attached to the body and had flaps on either side associated
  - When the organism swam, the power stroke made the flaps to spread out, which propelled forward
  - When you pulled back, the flaps were pulled in, which meant that recovery stroke has less resistance than power stroke
  - Metachronal wave made a nice even swimming within the group
- As the metachronal wave is going down the length of the body, the water is pulled into the box and it is being squeezed out
- The flaps on the sides are covered with setae hairs that filter the water that goes in to fill the box and depending on how they overlap, water can either move through them or can't
- Water if pulled in water comes on the mid lines goes into the box setae hair filters the water water exits from the sides
- The movement of the legs causes constant pumping of water from the anterior end of the organism across the inner surface of the biramous limb and out
- Water coming in has food in it and they get trapped on the inner surface of he setae hair

Arthropods

- Water pulls in moves across the setae hair traps food in the inner surface at the base of the limb ends up having setae hair clumped with food particles
- In the recovery stroke, the two bases come together and move forward, scrapping the food off the bases of each limb and moving it towards the mouth
- As water flows in, food is moving is opposite direction to the mouth = filter feeding
- Once the food gets to the front, the mandibles pulverize it before ingesting it into the digestive system
- Crustacea is the first organism to life themselves up off the substrate and swim through water column as they filter out primary productivity that is being generated in the marine environment

Tagmosis (Crustacea)
- Crayfish looks different from the ancestral form of Crustacea
- Appendages are no longer doing everything from locomotion, respiratory, feeding to sensory
- Some of the trunk segments joins the head and becomes involved in food gathering
  - The part of the body that lies over top is referred to as a cephalothorax and it is a reference to the fact that head appendages bind with thoraxic appendages to be able to gather food = **maxilliped**
- Trunks have lost some of its segments: one of the trunk appendage becomes a defensive mechanism to protect themselves and the other four become walking legs
- Crayfish has large **peropods** (walking legs) and the giant claws
- The tagma associated with walking appendages is called thorax, except some have been recruited for feeding
  - The new name for the walking legs is **pereon** and the legs are called **pereopods**
- The tail of the crayfish is called **pleon** because the little legs on it are called **pleopods**

Modified limbs (thorax)
- Every appendage had 2 parts to it: exopods and endopods
  - The biramous appendage that was always on the outside and inside
- Endopods are modified to do different functions
  - The big claw at the front is almost all endpod in terms of structure and exopodite is almost gone
- As walking legs, the ones that were on the outside slowly disappears since they only use the ones inside
  - Have a leg that looks like a uniramous, but in fact one part has disappeared

Modified limbs (head)
- Serial homology: each of the limbs have common embryological origin but it is carrying out different functions

Gastric mill
- Most of the large crustaceans, lobsters and crayfish, are scavengers, picking up large amount of debris from the ocean and passing it into digestive system to be broken down as food
- In the middle of the digestive system is the gastric mill made out of cuticles and it is involved in pulverizing and breaking down the debris
- When the digestive tract of any organism is built, it is always divided into 3 regions, the middle is the endoderm and 2 distal regions: mouth and anus that are derived from ectoderm
  - Ectoderm makes the cuticle, where the front and the back of the digestive tract is lined with cuticle
- The esophagus carries the food into the cardiac stomach, which is the first stomach where the food is grinded to make sure we can extract the organic material from the inorganic
- The stomach is lined with 3 great cuticular jaws that pulverize the food that is coming in into small particles
- They have a sorting field that determines what goes into the digestive gland and what goes into the intestine
  - Mollusca also had similar sorting field, but they used ciliary hairs to sort the material
  - Crustaceans use setae hairs to be able to sort food particles

Arthropods

- If any food makes into the intestine, they have last chance to break down food before passing it to the bad part of the organism

Respiration (Gill bailers in a crab)
- There is a large gill chamber on the side of the crayfish
- The carapace (cuticle) comes down over the side and legs are inserted into the body wall inside the cavity and endites and exites, pieces of cuticle expand up = no barrier to oxygen transfer and they become the gills
- Have external cavity that protects the gills that are attached to the legs
- Some of the gills comes off from the body wall
- There are set of gills for each of the walking legs and in that cavity, there is no mechanism to propel water across them (unlike mollusc gill that has cilia)
- Modification of the appendage = gill barrier
  - As the legs are moving, the gill bailers constantly sweep across the surface, propelling water over the gill
- Organism can sit on the substrate perfectly and be able to move part of the legs to be able to pump water over the surface
- Even though gills are enclosed in the cavity, it can still end with the ability to aerate them

Circulatory system
- **Open** circulatory system, no capillaries present
- Have dorsal positioned heart, which has blood vessels moving towards the anterior and posterior arteries
- Third artery is present that goes down tot the base of the animal called **sternal artery**
- All these arteries supply blood to the organ systems and these organs are not floating around the cavity anymore
- They have directed blood supply: funnel blood directly from the heart to the anterior end up towards the brain
  - There is another one that funnel down to the viscera, the main organ that are in the central part of the body
  - The ventral vessel passes the blood into the gills
- The posterior funnels out particular for the large muscles that are associated with the tail of the organism
- Blood ventral vessel gills heart pumped out into the rest of the organism
- Heart is sitting at the top and have external artery bringing the blood down to the bottom
- Similar to mollusc where the heart was in pericardial cavity and it squeezes blood out of the heart and pulls blood out of its gills back into the heart to distribute around the body
- Ostiate: an apomorphy of the arthropod (dorsal ostiate heart)
- Ostiate heart: when the heart expands, the ostia are open and that is when the heart is filled and it contracts making the valves to shut = getting unidirectional flow through the heart
- Heart is suspended in hemocoel and receives blood that has gone through the gill (oxygenated)
  - The elasticity of the musculature and its connection of the body wall, the heart just spans open when it relaxes and the ostium on the side opens up
  - When it receives the signal to contract, the ostium closes and the muscles close = squeeze blood out

Antennal gland
- Antennal gland is a large structure that sits at the base of the antennal segment
- It is equivalence of the saccate metanephridia, which is a funnel opening to the outside where the base of antenna opens and have membrane over at the surface to pick up filtrate of the hemolymph through the membrane and gong to create filtrate and send it out
- Crayfish is a freshwater organism, so it is constantly being inundated by water
  - The environment is hypotonic to its own blood fluids
  - As a consequence, the antennal glands are really large in crayfish and they are very elaborate

- Have a large elaboration of the membranes that are associated with the funnel to create a large **labyrinth** at one end
  - Huge surface area to pull the water coming in to the hemolymph out of there and do any recovery before sending it out the opening of the base of the antennal gland
- These animals are seasonal in terms of reproduction, if it is male, the testis are right next to the digestive gland to pick up nutrients
  - It it is female; the ovary is right next to the digestive gland to pick up nutrients
- When the female mate, they tie their eggs to the abdomen and swimmerets on the back aerate the eggs by creating water current

Subphylum Atelocerata (Tracheata)

- Used to be called uniramia because of their uniramous appendages but these appendages are also seen in chelicerates as well
- Then they were called tracheata but spiders and other insect related organisms have trachea
  - Trachea is a respiratory system that brings air directly into their bodies to supply tissues

Arthropods

- Atelocerata: reference to the head ancestrally, where the second pair of antennae have disappeared, so there is only one pair present

Atelocerata (Autapomorphies)
- Loss of second pair of appendages on the head
- Mandibles without articulation: there is one piece to the mandible
  - The whole length of the mandible is gong to be used for cutting and grinding
- **Malpighian tubules**: brand new excretory system
- Paired segmental tracheal system: carries oxygen directly to the different parts of the body

Chilopod head
- There are two groups that have many legs and these are referred to as **myriapods** and these include **centipedes** and **millipedes**
  - **Hexapods**: distinguishing the two groups that are within atelocerates that either have many legs or 6 legs
- Myriapods are dramatically different from each other:
  - Centipede are predators, they have taken a thoraxic leg and modified into a distinct poison fang or claw to be able to capture prey using the raptorial limbs
- They live in the dark, often in caves or leaf litter as a consequence, the big compound eye has disappeared and have small simple eyes associated with the head
- They live in moist environment, but they still need to maintain the moisture because they don't have super good waterproof cuticle
  - They haven't developed waxy coat that other groups are going to develop in terms of function
- Get effective predator with legs that provide all kinds of mobility (can be very rapid)

Diplopod head
- Millipedes have completely different lifestyle = vegetarian, feeds upon plants and plant material
- It has no waterproofing and no way of shutting its spherical to prevent water loss out of the respiratory system so it has forced to live in highly moist environment
- Modified the mouth parts with special **gnathochilarium (maxilla)**, which gives the mouthparts the ability to better process the foods that they are consuming
- They have great big segment called **collum** that makes their head tucked down and this is the escape response where they roll up to a ball
- The most distinguishing feature is that every segment has two pairs of legs (two nerve ganglia and pairing of everything)
- Get myriapd that have ability to hide by coiling up, forging away plant materials

Reasons for insect success
- **Small size**: can inhabit very small microenvironments
  - Little change of damaging due to their small size
- **Water proof exoskeleton**
  - Allows them to habit the terrestrial environment
  - Mostly scorpion like organism that move on land
- **Metamorphosis**: life cycle that involves larvae, pupil, and adult stage
- **Reproductive potential**
  - Can produce generations of some insects in periods of only 3 or 4 weeks, meaning they respond very quickly with variation within a population
- Co-evolution with plants
  - When flowering plants arrive, their strategy was to get someone to carry their pollen between the plant for them and not rely on wind
  - Plants developed nectar as a reward mechanism

Arthropods

- Evolution of light (not an ancestral character): came later

Insect – Tagma
- Chelicerates had prosoma and the opisthosoma; crustacea start with the head and the trunk and get a whole different set of tagma as they specialize and move around
- Insects have head (6 segments), thorax (3 segments) and abdomen (9 segments)

Insect tagma
- Head: sensory and food acquisition
  - Manipulating the food before swallowing
- Thorax: locomotion
  - Muscles to derive legs/wings
  - Augment the respiratory system to make sure those muscles get lots of oxygens to be able to carry out the flight
- Abdomen: reproduction and general function
  - The main organ systems are here
  - Architecturally set up so that they can expand and change its shape because you need to have telescoping set of armor at the back to be able to make room for ovaries that become filled with eggs or a large meal to store

Generalized mouthpart
- The head consists of compound eye, antenna and set of mouth parts
- **Labrum**: upper lip of the mouth
- **Labium**: lower lip of the mouth
- Have **mandible** and **maxilla** around the sides: creating cuticular box in front of the oral opening
  - Have a set of appendages that are sticking forward, creating a box of buccal cavity that are going to manipulate the food in some way before putting it into the mouth

Head – lines and land marks
- There is whole series of lines on the head, which are important **land marks** because it identifies places where insect cuticles have been modified
- Ecdysis, the cuticle is really thin and this is the line that can be seen as a big Y
- Other lines are important because what they are providing a strengthening to the head
- There is a series of line going across, which are the articulation points for the mandibles
- Mandibles are very powerful in terms of the muscle and if you have a cylindrical/circular/spherical head of cuticle, it would be distorted or dimpled by the pressure that the mandibles are producing
- The lines that are seen on the surface of the face and thorax represent the inflection of the cuticle
  - This inflection means that it is very hard to crush from top down because it has re-enforcing ridge on the side
- It is providing rigidity to the body to the force of the muscles that are going to be pushing upon it

Reinforcing the head – **Tentorium**
- Inside the head, there is a whole tentorium of cuticle
- Ridge around the side, back and up that hits the top of the head capsule
- Not just an exoskeleton of cuticle, we have endoskeleton as well within the group to be able to carry out the functions

Insect mouth
- Depending on the shape of the mouthparts, can feed on whole variety of different things

Arthropods

- There is tongue like structure inside called **hypopharynx** and it divides the cavity into 2: above is where the mouth is going to be and below is where the salivary glands are
- End up with mouth cavity that is essentially made up with cuticular top of labrum and cutciular bottom of labium and sides: mandible and maxilla and tongue dividing into chamber above and below it
- Down below is where the salivary gland secretion and up above is where we are going to propel food into the mouth
- Sensory palps sticking out from the sides gives the insects information about the quality of the food
- Mandible and maxilla are creating environment that rip and tares the food (ancestral way of feeding)

Piercing mouthparts
- Cuticle modified and moulded in a completely different way
- The labium, has become curled up on itself and all the other mouthparts are sitting inside
  - Basically have sheath that is covering all the other mouthparts inside
- Both the maxilla and mandible have been elongated to be a needle like structures
  - These are important for the feeding of the mosquito
- It takes the mouthparts and pushes against the skin and uses muscles up in its head to push the mandibles and maxilla forward (cutting blades) and going to poke in through the skin and slowly cut through the skin
- They are creating a pathway for labrum, which has been folded in itself = food canal
- The mouthpart cuts its way through until they find capillary in the right diameter, then they anchor to the capillary wall and the mandibles push a hole through the capillary wall and the labrum with hollow core is pushed into the capillary
  - The diameter of the food canal is just a bit bigger than the diameter of the red blood cell
- When they suck the blood, they stack up the red blood cells end on end and bring that all through
- The hypopharynx has been elongated
  - Curled around itself for salivary secretion to enter into the channel and it is carried all the way down to the bottom
  - It has gone all the way down with the mandible and maxilla to the opening so that when labrum gets pushed into the capillary, so does the hypopharynx
  - The mosquito squeezes out salivary secretion that go all the way down and mixes the blood just before it gets sucked up in the tube and taken up all the way up into the mosquito to feed
- Get mouthpart specialized for piercing

Combination – Horsefly
- Mandible and maxilla are still present: they are like 2 pairs of scissor blades
- The labium, sheath that covers everything, tip has been enlarged into a great big sponging structures
  - It is dumping anti-coagulant and the sponge sucks up the blood that is pooling in the wound from the scissors that are reacting
- Get a cutting system as oppose to piercing system

Combination – honey bee
- Feed on nectar, which is a phenomenally good food (fructose sugar)
- The labium is elongated into a long structure and it is covered with thousands of little hairs
  - When put inside the nectar, the liquid adheres to it (acts like a wick)
- Stick it in and when you pull it out, it will be coated with nectar
- The labial palps, the sensory limbs on the sides have come down on the sides of the labium and have been combined with the maxilla on the opposite sides = four appendages surrounding it
- Once the wick is covered in liquid, they clamp up against it and squeeze, which squeezes the liquid up and into the digestive system of the worker honey bee
- When the bee has its head in a flower, the mouthparts are relaxing away to put the nectar on the wick and squeezing the nectar to be able to bring it up into the body

Arthropods

- Honey bees take all of the nectar it has collected and go back to the net and they throw it up into the little honey cells that are within the honey bee's nest
- When they vomit up the nectar, they also add enzymes that break up the fructose into sucrose and glucose then colony fans its wings to evaporate sugar solution down to the point where it is 80% sugar and this gets harvested

Butterfly
- Another nectar feeder that only has drinking straw
- It has jettisoned every single part of the mouthpart except for maxilla, which has been elongated with two sides stuck together
- Maxilla are hollow and channel in the center is filled with hemolymph
- It is able to extend its mouthparts and forces the hemolymph down the mouthparts and uncoil the maxilla
- Nectar is such a good food source that they don't need salivary gland secretion

Thorax
- Prothorax
- Mesothorax
- Metathorax

Insect leg
- Every single insect, the segment on the leg is six
- They are in order of coxa trochanter femur tibia tarsus claws at the end
- There are a lot of morphology that are constant for every single one of them in the group

Pronotum and leg articulation
- Legs articulate with the sides of the body
- The cylinder of the coxa articulates along with the side of the body
  - They have a set of joints, articulation points, so that cylinder can bend and flex against the side of the body
- See the membrane that is all around the trochanter where it is anchored in place and each of the joints extends out from the leg allows it to articulate in a number of directions

Insect flight – Pterothorax
- Mesothorax and metathorax is referred to as pterothorax
- Petro is a reference to wings

Wing articulation
- Thorax is extremely rigid and is very hard re-enforced box that have internal endoskeletal boxes to have make it doesn't collapse
- There is a line that goes from where the leg is up to the top and it is called perual suture = piece of cuticle that is extremely rigid
  - Up at the top is a little dome of cuticle and there are anterior and posterior nodal process on the cuticular plate
- The wing is between pleural suture, anterior and posterior nodal process
- The wing pivoting on the pleural suture with two little processes that stick out and if the muscle is pulled down, the two processes are going to push on that side of the wing and it is going to pivot
- There is a set of muscles that pull a turgum down and hits the two sides that causes the wings to go up
  - When the wing goes up, it stretches the cuticle that is along the side, which is folded inwards and there is a piece of cuticle with muscle attached to it and when the muscles are pulled with the cuticle, it causes the wing to go down

Arthropods

- The wing pushes the process back to the original position and we are ready for the muscle contraction again
- Those two sets of muscles (Basalar and subalar) work together to move the wing

Reinforcing the thorax
- The whole thing does not collapse, there is another internal skeleton in there as well

Direct flight musculature
- With direct flight, muscles are attached to the wing and this this gives the flight mechanism its name
- Have basalar, subalar and pivot point = pull on the muscle = change the position of the wing
- This is the earliest and first form of flight
- Each wing beat is generated by a single nerve impulse (perfect concordance between them)

Indirect flight musculature
- New form of wing beat that is associated with the fact that insects can also fold their wings
- Advantage for folding wings: can crawl against the substrate
- Multiple wing beat is generated in by a single nerve impulse
- A cuticular box is set up the same way, the wing is still pivoting on the same point and the top is still pushing down on two sides but as it pushes down, they are shortening and lengthen
- At the base of the wing is a set of cuticle that as the wing is pushed to the bottom, the cuticle is compressed like a spring (relax state compressed)
  - Once it gets across the middle, the spring is going to shoot out the rest of the way
- In the little spring is compound called resilin, which is a perfect protein elastic in the world
  - It returns over 98% of its compressible energy when it is released
- Wings tend to have appearance of clicking = referred to as a click mechanism

Indirect flight mechanism
- Had muscles that goes from the top to bottom, now have a pair that runs from the front to the back
- Compression in length causes distortion which results in cuticle to pop up
- This is called indirect because there are no muscles associated with the movement of the wing
- The pop pulls the myosin motors to the opposite ends of the filament, calcium is still there and they immediately start crawling along the myosin actin fibers
  - Stretch the muscle back to its original point = immediately fire
- The spring is so perfect that it osculates at such a rapid speed and in high frequencies that you hear wing beats as sound
- Beetles were the first to figure out how to modify the forewing to make a hard cover
  - They could unfold the wings to fly and fold when burrowing into a substrate

Insect abdomen
- The sides are not hardened
- There is a membrane around the sides and circulate plates on the top and the bottom are accordion with each other
- This allows the expansion of the abdomen to accommodate a large meal, to accommodate egg production or any other process for which space is required

Reproduction and development
- Mastered how to transfer sperm to female without drying it out = through the use of sperm packages called **spermatophores**
- Eggs are waterproofed

Arthropods

Female reproductive system
- The huge reproductive potential related to the fact that they have a single egg producing structure called **ovarioles**
  - Linear sequence of maturing eggs
- Don't get eggs all at once, start at the very top and as it moves down, it slowly gets bigger and bigger loaded with nutrients until it is mature enough to be fertilized
- The system is always producing continuous supply of eggs
- If a lot of eggs are needed to be produced, the number of ovariole is multiplied
- The eggs are passed down and have special storage region called seminal receptacle and when the female is mated with the male, sperm is transferred to female and they are stored in the receptacle
- The female provides nutrients to keep it alive
- As she produces eggs, she rashes in sperms from spermathecal for the eggs

Male reproductive system
- Males are built on the same system
- System of repeating follicles within testis
- If you need to produce lots of sperm, the production units are multiplied
- Pass the sperm down into the seminal vesicle where it is stored
- The accessory gland makes spermatophore and passes it down to the female

Insect eggs
- When the egg was being laid by female, it had its waterproof shell already on it
- For vertebrates, eggs are fertilized then the shells are put on, but for atelocerates, shell is placed on first and one opening is left for sperm to travel down and this is called **micropyle**
- When the egg passes down the seminal receptacle, the sperm is released and there is guiding signals on the surface of the egg shell to guide the sperm down in the hole
- The hole is small and as a consequence, insect sperm is the skinniest and longest in the animal kingdom

Malpighian tubules
- Water conservation
- Try to recover all or as much of water that is coming through the digestive tract as possible but at the same time, going to try to eliminate the nitrogenous waste
- In these organisms, the main nitrogenous waste is uric acid
- There is a junction between the midgut and the hindgut (rectum); tubules are suspended in the hemolymph, so insects blood is all around them
- There are special little molecules called antiporters that pump K+ into the lumen of the tubule
  - It burns some ATP to allow the K+ to go in
- As K+ builds, there will be a positive charge and this charge is going to attract negative ions (Cl-)
  - Thus, inside is going to have KCl (salt) = inside gets salty and water moves in
- Inside the water has uric acid dissolved in it, small amino acid and small sugars
- Uric acid passes down the tubule and meets up with any food that is coming from the digestive tract and heads into the rectum
- Exactly the same thing happens in the rectum: K+ is pumped out and electrochemical gradient brings Cl, which makes KCl = pulls water
  - But this is the hindgut and there is cuticle in there = uric acid does not pass through so water, salt is recovered while uric acid gets left behind
- Not only have we filtered the blood out, but have extracted moisture from undigested food
- Insects can do this so efficiently that the Mexican jumping bean can live in the bean = use Kreb cycle to obtain water (metabolic water)

Arthropods

- Insects are so efficient that water conservation with their waterproofed cuticle and Malpighian tubules that metabolic water is enough for them to be able to survive
  - Allows them to live in an environment that no other organism can live in

Tracheal system
- Spiracle: openings down on the sides of an insect that brings air directly into the tracheal system
- The tracheal system is highly organized; large tracheal trunks are continuously branching smaller and closer to the active tissue that demand oxygen
  - Oxygen delivery system that goes direct to the tissues, insects don't use oxygen transport protein, there is no respiratory system in the blood
- Tracheoles: the point where it is about to transfer oxygen to the tissues
  - Tracheoles vs. trachea: tracheole does not have waterproof surface that associate with cuticle
  - Epicuticle is extremely thin; it is permeable to gases which is needed to have oxygen diffuse across the surface into the tissues
- Gases diffuse independent of each other down the concentration gradient
  - When the spiracle opens, the atmospheric oxygen is around 21%, when the system is open, all the open tubes flood with oxygen and at the base of the tracheole is going to be 21% oxygen
- Spiracle closes to limit water lose = no water loss in trachea since it has waterproofing layer
- Muscles are going to contract and burn ATP to create energy, using up oxygen
  - The oxygen concentration declines, resulting in low concentration gradient for gas to diffuse independently
  - Diffuses so fast that it declines to 7%, doing the same thing on the spiracle end but they are constantly getting supply of oxygen
- When it detects low level of oxygen, it opens and the whole system immediately floods back to 21%
- This system allows insects to maintain constant flight for over long distance to migrate long distance
- The blood in the insect does not need to carry oxygen, thus it becomes fluid rich in nutrients that is bathed in the tissues = reason why circulatory system is not complex

Incomplete metamorphosis (Hemimetabolous)
- Young grasshopper looks much like an adult, the only difference is that adult has wings and can reproduce
- The little larval stage feeds on the exact same food source as the adult = in food competition
- Internally, as larva is growing bigger, it has to start growing the reproduction organ system and also have a little package of wing buds that builds the wings as it grows
- The larval stage has two tasks: absorb/digest nutrients in food to supply its own needs and the growing reproductive structure (doing adult growth and larval growth at the same time)
- When it reaches a certain stage, it will moult and the organ system inside gets matured and wings inside the package gets complex
-

Complete metamorphosis
- The most common for the 80% of the insects = holometabolous
- They have a resting stage called pupa = sets aside little cells that becomes different structures
  - Reproductive cell, germ cell set aside to become the legs, wings, gonads
- The larval stage is consuming food and processing it and turning it into fat & protein that gets stored
- When the insect goes into pupil stage, it becomes dormant
  - It is where all the storage protein and lipids gets mobilized, the old tissues of the larval stage disintegrate
  - Have giant medium rich in protein and lipids along with little buds of cells that have all the adult structures in place
  - They are going to be activated and start developing, building all of the adult characteristics from the cells that have been set aside earlier

Arthropods

- End up with larval stage that feeds and processes and creates storage materials
- Essentially building de novo, the adult inside the pupil case and when the time comes, the adult emerges out
- The larvae feed on a completely different food source than adult
- It is so efficient in larva that proteins, fats and lipids that were put aside are going to make the eggs for the adult when the adult emerges, so the female often only disperses

Social in insects
Honey Bee castes
- In the colony of honey bees, there is a queen bee who has mated and collected a package of sperm on her notua flight that will last her life and every single egg that she produces gets fertilized = all females
- All the workers are females and they come from diploid eggs
- Queen releases chemicals into the nest that keep her workers sterile
- Works forage and bring back nectar and pollen; also transfers the fertilized eggs to the cells and rear the larvae that are produced in the cells so the colony rejuvenates itself and continue to grow

Recruitment
- They are able to signal to each other where food source is located
- One of the only non-symbolic languages that exists outside of the human species and this is called the waggle dance
- Uses polarized light from the Sun to determine where the food source (nectar) is at what angle
- The dance goes like this: goes up through around the sides, up through the middle and around the side
  - The angle of the upward part of the dance determines the line of polarized light of the sun
  - The frequency in the waggle of the abdomen tells how far away the nectar is
- As the nectar diminishes, honey bee does not get to take anything back and it does not re-inforce the dance and everyone finds out that the nectar is gone
- Mechanism to make sure that colony (genetically related to each other) benefit from any high nutrient source that becomes available and it is exploited to its absolute optimum

Honey bee colonies
- There are always a few males that come from unfertilized eggs
- As much as the queen tires to keep all her workers sterile, there is always one or two that manage to produce unfertilized eggs
- Normally when unfertilized eggs are detected, the queen or the workers destroys it
- Males are present at low level, and as more males are present, the colony gets bigger and queen recognizes that she is losing control over workers
  - She takes all of the workers that are chemically bonded to her and leaves the colony
- Inside the nest, there is no control, there is males being produced and females being produces = can get a new queen and takes over the colony or start a colony somewhere else

Nematoda

- Unique muscle arrangement that is part of pseudocoelomate body plan
- It only has longitudinal muscles and has single fluid filled space
- Not a multiple hydrostatic skeleton

Pseudocoelomates

- They represent a form of simplicity of the organism that have miniaturized
- In becoming really small, the body have become simplified
- No need to retain coeloimc space, circulatory system because as they get smaller, the surface to volume ratio will work for them (diffusion)
- The condition of the pseudocoelom is unifying feature of the group
  - No longer monophyletic (scattered around)
  - Found out that pseudocoelomate is a common thing in the evolution of animal
- Platyzoa have simplified their body plans (flatworms represent unique set of adaptations)

Cavities in mesoderm

- When mesoderm makes its appearance, they get body cavities and it is always at the base of the evolutionary of the tree (both deuterstome and protostome)
  - Two different forms of how they are formed: enterocoel & schizocoel
  - Always end up with same result, body cavity that completely surrounded by mesoderm = **eucoelomate** condition
- Mesenteries are going to connect everything together to hold the organ system in place
- In the flatworm, the coelom fills itself in and become acoelomate and there are whole bunch of reasons that they did that (advantage of feeding)
- In the leech, most of the coelomic space is now down to very thin narrow part that are just tissues
- Mesoderm is associate with outer body wall, ectoderm but it is not associated with the digestive tract
  - This means that digestive tract has no muscles associated with them
  - Only way to propel food through digestive tract is by the wiggling motion which causes mixing and moving of the food
  - Contrast with real coelomate organisms: eucoelomate and have mesoderm surrounding the gut

Body plans

- Pseudocoelomates are small number
- Platyhelminthes represents one tract where they have completely lost the coelom and pseudocoelomate is the one that have reduced the internal organ system as a result

Ecdysozoa (Autapomorphies)

- The third great lineage of the protostomes, the ecdysozoa: get their name from the fact that they moult
- Moulted protein cuticle reinforced with alpha-chitin or collagen
  - Have an outer cuticle that surrounds the body which is solid
  - Need to shed the cuticle and produce a larger cuticle in order to increase in size
- No surface cilia: the outer epidermis is no longer exposed to the outside
  - Epidermis is glued to the outer exoskeleton
- Loss of the coelom: one of the circumstances is that outer epidermis has no cilia
  - Coelom itself becomes reduced or disappears
  - Replace with new body cavity, hemocoel, a blood cavity as opposed to a coelom

Symplesiomorphies

- Collagenous cuticle without microvilli
- Longitudinal but no circular muscles
  - Unusual body wall, longitudinal inside and circular outside

Nematoda

Nemtaoda (autapomorphies)

- One is a set of pair called **ampids**: there is a paired structure, a sensory set of pits
- Three is a common number in terms of symmetry of the head of the nematode
- In miniaturizing, they have condensed down the function between the cell
  - In terms of tissue, instead of having an epithelium and muscles associated with it, we have gone back to epithiomuscular cells
- Epitheliomuscular phaynx
  - Rather than in the pharynx, having epithelium on the inner surface and a band of muscles on the outside, now have one layer of cells called **epithiiomusculature**
  - Ncidarians have epithiomuscular cells on the digestive system and on the outside of the body because they have never developed a mesoderm
  - As they simplify their bodies and decrease cell complexity, they have gone back to a very ancestor type of cells in terms of contractile cells that is associated with pharynx
- Three circumoral rings with 6, 6, 4 sensilla in the rings

Extant Animalia

- In terms of number of species, the nematodes are not much diverse, but in terms of biomass, they are tremendously important
- They are important for the decomposition cycle because what they are doing is that they are feeding on bacteria and other organisms that are in the soil and the are extremely difficult to identify
- Most of them look the same morphologically, it is a hidden diversity because not a lot have been discovered
- They are associated with the disease (ring worms, hook worm)

Nematode mouth

- The anterior end of the nematodes has a **triradiate symmetry**
  - There are three lips associated with the mouth
  - There is a set of sensory bristles that are around the mouth
- Triradiate symmetry is broken by the pits, pairs of amphid that are found on the either side
- They are basically a long cylindrical animal

Ascaris body wall

- Have very distinct cuticular wall that covers the organism, they moult a couple of times
- The cuticle is not entirely rigid, the collagen fibers that re in the cuticle can stretch and distort a little so that this group can grow a bit and stretch their cuticle before they have to moult
  - They are going to discard the cuticle in a moult
- Underneath is the epidermis that is secreting the cuticle
- Underneath the epidermis is the longitudinal muscle that is only found in this organism

Ascaris body wall

- In terms of other structures, there is a nerve cord, dorsal and ventral nerve cord
- The dark stripe that runs down the length of the body is the lateral line and internally it is distinct by **renette** cells that are found in all namatodes
- If the nematodes are placed in a hypotonic medium (medium that is less salty) then all the renette cells are turned on to produce fluid that will come out of the pore at the rear end of the organism
- The renette cells are involved in some kind of osmoregulation process within the group
- Internally, there is a digestive tract, which has no muscles attached to it
- The nerve cord has extensions in the muscle cells that extends towards it

Nematoda

Ascaris body wall detail

- Get a cytoplasmic extension that goes and interacts with the nerve cord
- Missing axons and dendrites that are needed to communicate in the nerve cord to the muscle cells
- Peripheral nervous system is not present because muscle cells make their connections directly to the nerve cord with extensions
- All of the extensions come back towards the nerve cord and connects all the nerves into the system
- When the muscle contracts, we only have one fluid space, so the organism bends in that particulate directions, getting whip like motion

- This group does not swim
- They get their success by weaving through the soil particles in which they live
- The cuticle is not a smooth cuticle, it is covered in pits and rigid
- They are suing the body structure to weave between the soil particles, find bacteria and other small organisms to consume as they work their way through
- They can invade the tissues of animals, plants, or soils through soil particles
- They have jettisoned all of the muscles that are not needed for locomotion system and jettisoned nervous connections that take them to the nerve cord and even further simplification

Epitheliomuscular pharynx

- Muscles are kept under contractions all the time because it is hard to puncture the cuticles if it is under tension (muscles are never relaxing)
- Have pharynx that consists of two valves: one valve that sucks food in and the other that pushes it into the digestive tract
  - In this system, it is always under hydrostatic pressure from the pressure created by the muscles, then when the pharynx opens, everything that was in the digestive tract shoots out through the mouth and same problem occurs for the other end
- It is going to take posterior valve and close it then open the anterior valves of the pharynx and fill it with food because the posterior closes, there is no problem
- Can now spread open the pharynx and suck up food. Then close the one at the front, open one at the back, compress the pharynx and squeeze the food into the digestive tract
  - Can feed without losing food now

Triradiate pharynx

- It is made of a single cell layer
- Four radiation if better but for three, all of the muscles on one side contracts and it iig going to pull by contraction of the muscles with one or two units with maximum diameter
- Pharynx can open very efficiently with three units
- All the way through animals, triple valves are observed
- Tricuspid valve in the heart is one of the classic example of the triple valve
- Triradiate pharynx with really unusual set of muscles in terms of organization

Reproductive cells

- Digestive system is filled with pseudocoelomic space
- Female: egg filled paired of uteri and it is paired in female
  - At the very smallest diameter is the ovary and the tube is cylinder that gets wider and wider
  - Ovary □ oviduct □ uterus
  - Just a linear sequence of gamete producing structures
  - Also see gut in the middle without musculartur e
- Male: there is only one gonad, a single gonad winding back and forth

Nematoda

- In the female, it is going to open mid ventral on the mid side of the body and for the male, it is going to open at the tip fo the body

Mating nematodes

- The male curls the hooks of the body around the female
- Males have little paired hooks (spicules) used to insert inside the female to hold themselves in place to pass the sperm to the female
- Their sperm is amoebic, no flagellum

Echinodermata

Deuterostomia (Autapomorphies)
- Blastopore becomes the **anus**
- **Tripartite** coelom = enterocoelom
- **Dipleurula** larval stage: characteristic unique to deuterostomes

Blastopore (Gastrulation)
- Get a single epithelial layer invaginating inward to make second type of epithelium (digestive epithelium) and it is endoderm
- Endoderm is the gut = the opening to the cavity is the opening to the digestive tract, which is the blastopore
- Two fates:
  - Blastopore becomes the mouth for **protostome**
  - Blastopore becomes the anus for **deuterostome**

Enterocoelous coelom
- Commonly included in the development of the deuterostomes
- Body cavity back filling mesoderm at the lip of the blastopore and having it split open, had enteron, a little bubble of mesoderm forms and fills the space in between
- The problem is that **enterocoel** always has three pieces to it: **proteocoel**, **mesocoel**, and **metacoel** and also appears in the lophophorates

Tripartite coelom
- Tripartite coelom and entercocoelom shouldn't be used as deuterostome characteristics b/c it occurs up in the protostome lineage as well
- Have blastopore becoming the anus

Dipleurula larva
- Unique shape larval stage that has **ciliated band** of tissue around the bell
- Suspended in it is the organism with the anus and mouth on opposite sides
- Found in the ancestor to all of the deuterostomes, one of the swimming forms

Echinodermata (Autapomorphies)
- Pentaramous symmetry
  - **Radially** symmetric that is based on five arms that are present
- **Stereom spicules**: unique **endoskeleton**
  - Calcareous skeleton embedded in tissues and the tissue that surrounds the skeleton, when it forms the spicules are not solid, they are rather **perforated**
  - Appearance of perforated endoskeleton that is internal
- Water vascular system = **NOT** a circulatory system
- **Mutable** connective tissue: holds the stereom spicules together

Extant Animalia
- In terms of numbers, they are considered to be in the "others"
- Chordate is the most dominant of the deuterostome groups
- **Starfish**: distant five segmented arms that are present
- **Sea urchins**: variety of different shapes and forms
- **Pencil urchin**: has spines that can crawl into spaces and flex the spines to wedge themselves in place so no predators can dislodge them and feed upon them
- **Sand dollar**: within the sea urchin group; basically flattened; global/spiracle shape
- **Brittle stars**: mobile, when they are picked up, it shatters its arms so that it can get away = can regenerate the body parts

Echinodermata

- **Sea cucumber**: worm like organism that feeds with tentacles; when attacked, they open up the anal vent at the back of their body and throw out their whole lower digestive tract
  - Self eviscerate as a defensive mechanism; predators start feeding on eviscerated material

Ancient Echinoderms
- Bilateral symmetry had huge advantage = had cephalization and could use sensory structure to detect the direction they are going in
- In its embryology, the larval stage, **dipleurula** larva = **bilateral**
  - Undergoes metamorphosis and settles to the ground and it becomes radially symmetric
- Radial symmetry is the derived trait
- Echinoderm were combined with cnidarian 50-60 years ago in a group called **radialata**
  - Biologists thought that echinoderms were the triploblastic radial symmetry and cnidarians were the diploid symmetry organisms
  - There was natural transition from the simple radial symmetry diploblastic radial symmetry triploblastic radial symmetry (whole lineage)
- This group managed to re-adapt the sessile existence by living on short stocks
  - They are all anchored to the bottom with their arms radiating out; mouth is in the center
  - They are capturing food that is falling through the water column onto their arms and passing it to their mouth to feed = tapping into nutrient material that is **dead** or **pelagic** that is sinking in the water column
  - Organisms that are crawling against the substrate or burrowing into substrates, they are tapping in organic source before anybody else gets it

Ancestral echinoderms
- Not always based on 5s
- No one knows why five is the one that survived
- Star fish is covered in spine = where they get their name from
  - Echinodermata = reference to **spiny skin**

Echinoderm surfaces
- Have two sides; back to **oral and aboral surface**
- No anterior no posterior; no dorsal and ventral
- In the most primitive of starfish, had stocked oral facing up and arms radiating from the mouth, capturing food
- Series of little feet like structure called **tube feet** is capturing the food
  - Tube feet are miniature **hydrostatic skeletons**
  - As food particles fell down onto the arms, the tube feet pushed it down towards the mouth
- Most of them have oral surface facing down with their tube feet extending down and moving across the substrate
  - End up with characteristic appearance of this particular group

Water vascular system (Ambulacral system)
- Each of these tube feet has water in it and can independently isolate from the rest of the water vascular system
- Can work as little mini hydrostatic skeletons but the water itself is coming down; a series of arms and passage ways that bring the water to the tube feet
- Opening to the outside of the body is **madreportie**
  - Not a big opening, looks like a **sieve**
- Water vascular system, from the madreportie, a **stone canal** goes down **ring canal** goes out **lateral canal** and coming off of the **radial** is little lateral and tube feet
- There is pure sea water and nothing else
- **Tidemann's bodies** are producing some cells; cells in low numbers engulf any bacteria that are in there to destroy the bacteria
- Water reservoir of access of water = **polian vesicles**
- No transport mechanism seen; not a principle transport mechanism of nutrients

Echinodermata

- Simply a water system that connects everything together

Role of water vascular system
- Locomotion - Respiration
- Circulation - Excretion
- Nitrogenous wastes generated in body and are diffusing in the coelomic fluid and diffusing into water vascular system = could diffusing out the tube feet
  - The surface of all the tube feet are one of the major exchange surface for diffusion for the animal with surrounding marine animal environment
  - Nitrogenous wastes moved out and oxygen is pulled in = does have the circulatory role
- Lined with **cilia** = have a bit of current to move things around but it is not transporting masses of amounts of nutrients = not transporting blood in the respiratory pigment
- Never developed a circulatory system b/c tube feet were great for taking oxygen and moving nitrogenous wastes
  - Never developed metanephridia or gas exchange surface b/c diffusion worked
- These animals rely on **surface to volume ratio** and massive amount of diffusion that is occurring

Tube feet = extend down the oral side
- Lateral canal that is connected to the radial canal and one of every single way down
- Have a little valve to shut off so that it is small independent **hydrostatic skeleton**
- Have **ampulla** and tube foot extending down; when ampulla contracts, it forces water in the tube foot that will elongate the tube foot
- If the muscle on the one side contract to other, going to bend tube feet instead of elongating
- When attach to the substrate, move the tube foot over slam it down pull up in the middle with sucker and use ampulla and musculature to create leaver that moves the tube foot
- End result: tube foot can be coordinated down the length of the starfish so that we end up with **net forward movement**

Movement of the tube feet
- The tube feet are attaching to the side of the glass of the aquarium and they are moving back and forth
- Modified foot on the tube feet are not for locomotion, they are sensory
  - Have **light & gravitational detectors** = giving the starfish information about the sensory world
- Tube feet surrounds the mouth = tube feet levering to move the starfish along, disconnecting reattaching, reconnecting = net movement
  - Even though it is slow, using all the tube feet means that we can get motion with organisms
- **Ambulacral grooves**: grooves that house the tube feet that are on the ventral side
  - End up with motion being possible

Body wall
- **Calcareous spine** on the **aboral surface** of the organism
- Madreporite is seen
- Don't want other organisms to settle on them since they move slow
  - Also don't want fine dirt and debris that is falling through the water column to settle on the surface
- Not only do they have spines but it is covered in **cilia** and cilia are always moving and sweeping material off the surface, so that it is always available for gas exchange

Pedicellaria
- Another structure that is sitting on the wall that are pincher like structure called **pedicellaria**
- Little pinchers pinch and prevent anything from adhering to the surface
- It is not only bumpy spiny surface but also have whole bunch of pinchers that are pinching anything that tires to sit down on the surface
- **Dermal branchia** extensions of the coelomic cavity inside, not the water vascular cavity

Echinodermata

- Have finger like extensions of the coelom sticking out that are covered with cilia = creating water current on the surface (great surface for gas exchange)
- They are referred to as dermal branchia b/c they are skin gills

Digestive system
- Have digestive system that has two stomach, cardiac and pyloric, nearest the mouth and farthest the mouth
- They are connected to the digestive glands that are connected to the arms
- The **cardiac stomach** can invert when they feed so they can invert and wrap it around prey to be able to feed upon the prey

Sea star
- **Pyloric stomach** is connected to the **pyloric cecum (digestive ceca)**
- Massive digestive system that is diffusing nutrients into the coelomic cavity
- There is an anus on the opposite side but it is non functional
- Basically liquefies its food before consuming
  - When consumed, there is no large particulate material
- They are predators

Feeding
- Two major groups that they prey upon:
  - **Coral**: they lie on to of the coral, invert their cardiac stomach which then covers the coral secrete enzymes and liquefy the little baby coral polyps in there and ciliary current sweeps up into digestive glands
  - **Bivalves**: organism that is chasing down another extremely slow organism
- Bivalve hunting:
  - Clams can only push with their foot against the substrate
  - Starfish captures the clam and wraps itself around the clam with all of the suction cups on the tube feet to grab hold of the clam
  - Clam spreads its arms
  - **Mutable connective tissues**: connects all of the **stereom** spicules, **ossicles** that form the internal skeleton
  - Under nervous control, connective tissue can either be flexible or rigid
  - Starfish uses its muscles to pull apart turns all of the connective tissues and skeleton into rigid material = can stop using muscles b/c they are being stretched into being extended form and can hold the clam open
  - It turns around, takes the cardiac stomach, turns inside out, puts it inside the clam and start spilling in digestive juices that liquefies the clam into highly nutrient broth = gets swept into the digestive system of the starfish
  - **Pyloric ceca**, final digestion occurs = creates very little wastes = small anus to remove the material

Reproductive system
- Have **gonads** sitting on top of the **digestive glands**
- In the arm of the starfish, digestive glands and gonad sitting on top of it
- All of the nutrients that it ingests can be turned into the reproductive potential

Sea star arm
- The pyloric cecum is suspended in the coelomic cavity of the starfish
- Coelomic cavity going up into the dermal branhia and going all the way around
  - Good gas exchange and elimination of the nitrogenous wastes
- Digestive glands are releasing nutrients into the coelom and this is where the gonads are sitting to take them up and turn them into gametes
- The coelomic system is the circulatory system o the starfish b/c that is where the nutrients end up to bath the internal organs
- Water vascular system: basic water reservoir to move tube feet and incidentally assist with diffusion due to close proximity to the coelomic space

Echinodermata

- Ampulla and tube foot to the outside; the layer is two cell layers thick
- One cell layer for the water vascular system and the other for the wall of the coelom
- Free exchange of small molecular weight materials across the surface
- Moving nitrogenous wastes, oxygen, can't move nutrients b/c they are too big
- Have extended the whole of the coelomic surface as the diffusion surface for the animal = perfect link to the water vascular system as diffusive surface and two work together as one giant diffusion surface for the organism to function

- **Water vascular system** is the **metacoel** of the three coelomic spaces
- **Body cavity** is the **mesocoel** and in fact they have original tripartite coelom
- Mesocoel was the tentacles that surrounds the mouth and the metacoel was the cavity that surrounds the organ system of the bryozoans

Echinoidea
Sea urchins

- Took five arms ad curled them up = tube feet up and fill that in in giant sphere
- Sphere with mouth in the bottom and tube feet running up the sides
- Have taken their spines made them movable, they can use them as the locomotory structure
- Tube feet are extending out and they are waving around as gas exchange or diffusive surface
- Some of the spines are moving = wiggling
- Mutable connective tissues allow them to lock themselves in place and they can't be pulled out
- Some have barbs so that they stay embedded
- Still have elaborate tube feet for gas exchange but the reason it has to protect itself from the predators is that the vast majority of sea urchins are herbivores unlike the starfish

Water vascular system

- Highly modified for feeding on **plant material** = poor nutrition
- Cell walls that are loaded with cellulose and those cellulose are not available as nutrient
- To get nutrient, have to shatter the cell walls
- These organisms consume large amounts of food but receive very little nutrients from it
  - Process large amounts of volume of food overtime but little nutrients are received
- Water vascular system is still present and can still see a ring canal around the oral opening and see radial canals that are going out
  - Little lateral canals and tube feet are all present

Echinoid spines and pedicellaria

- Big defensive spine called pedicellaria; there is one that sits around the oral opening, mouth, that has three claws to it instead two in terms of being able to ward off predators

Oral surface

- An oral opening showing **pentaradiate symmetry**
- **Five teeth** that are located there and they are the **ambulacrum** groups that are coming down with tube feet in them
- Sitting in the middle is a unique feeding structure called **aristotle's lantern**

Aristotle's lantern

- Consists of series of teeth (five of them) all the way around the edge
- Teeth are going to project outward and going to open and close to tare vegetative material in
- Feeding structure that has the whole set of muscles, lantern can be pushed out to feed and pulled in; push the lantern out and twist to feed and each of the teeth consists of very large pyramid with tooth in the middle

Echinodermata

- Chomping away = tooth is going to wear down and this structure creates a constantly renewing that regrows from the top and projects down = always being replaced at the bottom of the surface
- Have five segmented structure only made out of **calcified bone** that uses to be able to harvest material

Digestive system
- Material is poor quality food and end up with massively large digestive tract inside the sea urchin
- Has to process plant material and want to leave it in there long enough to extract nutrients
- Have **esophagus** that is leading to the digestive surface and it does two loops before leaving out the anus on the other end
- Problem: end up taking in water at the same time and don't want to dilute the food
  - It is bad enough that there is not a lot of substrate to break down that is digestible
  - If you dilute it, biochemistry of the digestion slows down
  - Develop a structure called **siphon** that takes the water out to bypass and as the food is being digested, it is highly concentrated = really good extraction
  - At the very end, where there are undigested wastes, water is added to facilitate the movement through the digestive tract and out
- Slow moving **herbivorous** sea urchin
- Very distinctly large global spherical body to house everything inside

Hemichordates & Invertebrate chordates

Animal innovations (symplesiomorphies)

- **Pharyngeal gill slits**
  - Have pumping mechanism that brings water into the buccal cavity and across the slits and out the pharynx
  - Use the movement of water through the mouth cavity to trap food
  - Food that are trapped are going to propel through digestive tract
  - If the blood vessel is enriched in the walls of the opening = efficient gas exchange mechanism
  - Going to move water trap food in variety of different ways aerate the gill surface to a certain extent
- Dorsal hollow nerve cord
  - In the protostome lineage, the nerve cord was always paired on the ventral side
  - In this group, it is always on the dorsal side with hollow cord to it

Hemichordata (Autapomorphies)

- **Stomochord proboscis complex**
  - Placed at the front used for feeding
- **Glomerulus**: filters blood

Hemichordate

- Acorn worm
- Can burrow into the substrate using three main parts to the body:
  - **Proboscis** associated with the anterior end
  - **Collar** associated with neck like region
  - Trunk following behind
- In the deuterostome, thus they have tripartite coelom: **mesocoel**, **proteocoel** and **metacoel**
- The **proboscis** = **protocoel**, **collar** = **mesocoel**, and the rest of **trunk** = **metacoel**
- There is some division in the trunk, where the gill slits
  - Openings are where water comes out b/c of gas exchange and aeration that is referred to as branchial part of the trunk
- Gonads are where highly enriched water full of oxygen are = **branchiogenital trunk** that is recognized by the perforation of the gill slits
- Further back is where the digestive system enlarges and get breakdown of nutrients and food
- **Hepatic** is reference to the liver, where the final digestion/absorption of the nutrients occurs
- **Intestinal trunk**: consolidate the food before reaching anus
- Three parts of trunk: branchiogenital trunk, hepatic, and intestinal trunk

Stomachord proboscis complex

- The **proboscis** is a large fleshy structure associated with cartilaginous ridge behind the collar opening that is held open by a cartilaginous ridge
  - Always assured that the opening is available = never collapse or close

Ascorn worm burrow

- It sits in a burrow and creates a water current with cilia that is on the surface of the proboscis propelling food into its mouth that is held open by the **stomochord** in the collar
- Water moves across the gill openings and the food stays in the gut
- They are **substrate feeders**, extracting organic materials in its burrow and this is done using proboscis complex

Feeding

- **Cilia** is present all over the surface of the proboscis
- Cilia are carrying particles to **preoral ciliary organ** and it is going to put the particle in the **mucus string**
- Preoral complex makes mucus string and fills it with food particles
  - It is like ciliary sorting field, where it decides if the particle is suitable enough in terms of size to be able to send into the digestive system or rejected

Hemichordates & Invertebrate chordates

- **Preoral complex** = consolidation site + ciliary sorting field
- The mucus string generated passes into the digestive system and at the same time, water is gong to leave = mucus concentrated and the mucus string with food is digested and nutrients are absorbed for production of gametes in gonads and other structures
- Mucus string is made outside of the mouth = food is consolidated outside of the body
- These organism has closed circulatory system with blood vessels
  - Circulatory flow and little heart vesicle are present
- The heart vesicle is the mechanism propelling blood through the system
- Vessels have contractibility = major blood vessels and heart vesicle pushes on the blood vessel = works like a parasitotic pump
  - Rolls the blood forward and it keeps moving it forward
- Muscle contraction: **blood vessel pinched squeeze blood forward blood vessel pinched**
  - This cycle is repeated and it is done by **glomerulus**
- Closed circulatory system when the heart vesicle pushes down on the blood, it is creating blood pressure
  - The blood vessel in front of the heart vesicles are very thin walled small ions, salts, minerals and few amino acids gets squeezed out of the membrane
- A pressure generated by squeezing the blood through a thin walled area of blood vessels causes filtrate of the blood to force into a coelomic phase of the protocoel (the proboscis in the front)
- Glomerulus is a place where blood pressure is used to filter blood creating filtrate
- Filtrate then moves into a protocoel, and there is metanephridum that is going to filter it = recovering materials and sending the liquid outside
- The stomochord proboscis complex combines with glomerulus to create new type of feeding mechanism, ability to sort and filter food, ability to cleanse and remove metabolic wastes from blood

Locomotion

- The glomerulus musculature inside is complex with circular muscles, longitudinal muscle, diagonal muscles = **hydrostatic skeleton**
- Can change the shape of the proboscis complex and drag themselves across the substrate
- There is little or no musculature in the trunk = the whole musculature is associated with proboscis

Chordates?

- Distant relatives
- Jelly like sitting at the bottom of the ocean

Chordata (Autapomorphies)

- **Neurotube-notochord-mesoderm complex**
  - **Notochord** is chordate characteristic
- **Pharyngeal slits** and **endostyle**
  - Homologous
  - Gill slits works differently
- Post-anal tail and tadpole-like swimming
  - Swim with unique undulating motion that is not seen in any other living animals

Pikaia: The chordate ancestor

- Invertebrate organism
- Ancestor to the whole phylum
- When the explosion of the Cambrian occurred, this group did not explode
- Invertebrates, Arthropoda and Mollusca prevented pikaia from exploding to become the big chordate group

Neurotube – notochord-mesoderm complex

- Replaces what used to be just notochord; the reason of the success

Hemichordates & Invertebrate chordates

- In deuterostomes, the cells in the early embryo, their fate is not defined
  - In protostome, they have determinant cleave or mosaic development
    - D cells generate every single piece of mesoderm
    - Kill D cells = kill embryo b/c mesoderm is not developed
    - Fates of every single cells are sealed, can not be changed
- Identical twins are possible in deuterostome, but impossible in protostome
- In deuterostome, cells are sending signal to each other and cell's fate is not determined by itself but its proximity to other cells
- One of the classic one is development of the 3 structures: neurotube, notochord and mesoderm
  - End up with a tube within the body of tube
  - The tube that runs across the top, dorsal side of the endoderm, as soon as it touches the ectoderm up above, there is an induced charge of cells where the contact is made
  - Cells that were endoderm notochord, signalling the epidermal cells on the outside to become dorsal nerve cord
  - Little cells are going to ball up and epithelial cells on the dorsal side start building up little piles on each side to create a crest crest rolls across the top forming a notochord and end up with dorsal hollow nerve cord with a notochord underneath
  - End up with dorsal hollow nerve cord, nerve cord and mesoderm
  - All are induced between each other

Neurotube-notochord-mesoderm complex

- The ectoderm that are on the outside has received signal and ectodermal cells become a plate
- End up with folding and a hollow dorsal nerve cord with specialized cells called **neural crest cells**
- Neural crest cells on top of the hollow dorsal **nerve cord**
- The neural crest cells are going to migrate to different regions of the body and are going to signal the structure to turn into various developmental components such as eye
  - These are messenger cells that are going to spread throughout the body and going to determine the morphology that is going to occur

Neurotube-notochord-mesoderm complex

- Nerve cord coming up pinching neural crest cells start to proliferate important for later on development
- The origin of the hollow nerve tube/chord and also the origin of the notochord

Notochord

- Consists of **cartilaginous** structure surrounded by an **elastic sheath**
- Biomechanically, it is strengthened in a way that can't be compressed (can't make it shorter/longer)
- However, it can bend to the side to contribute to the new form of locomotion
- **Mesoderm** is forming at the exact same time as notochord and neurotube

Neurotube- notochord-mesoderm complex

- Going to differentiate into 2 blocks at early stage: a block that is mesoderm and another that contains a hollow, coelom
  - Mesoderm differentiates into solid mesoderm and mesoderm that has coelomic space
- This wraps around the edge of the body but from the dorsal side down, the muscles are in blocks
- These muscle blocks are going to allow to generate new form of locomotion
- Have blood supply nearby and coelomic cavity; inside coelomic cavity is metanephridia
- This group also inherits the glomerulus

Evolution of the nephros

- Blood pressure is sending metabolic wastes into coelomic cavity
- There is filter that is going to take coelomic fluid and filter it = **nephrostome**

Hemichordates & Invertebrate chordates

- Have body cavity over on one side is glomerulus that is forcing water through the filtrate into the coelomic fluid and on the other side is metanephridia funnel that is taking coelomic fluid and cleaning it up, removing wastes out the **nephridiopore**
- Like earthworm but with glomerulus added
- Wrap the metanephridium around the glomerulus filtrate goes right into the metanephridia can modify it as required before releasing it outside
  - There is segmentation in this animal and **somite** in every single block and metanephridia connected by a common duct to the outside
- Have connection to the coelomic space and have glomerulus wrapped around the metanephridia that is leading to a common duct, leading all the way out the organisms and the duct is the ancient nephric duct, the **archinephric duct**
- The exact origins that glomerulus combined with metanephrida = **nephron**

Nephron
- In all of the vertebrate kidneys
- Glomeruli surrounded by ancient metanephridia

Origin of segmentation
- End up with a **notochord**, **nerve cord**, a block of muscles, mesoderm with cavity in it and a filtration system that takes wastes to the outside and repeated all the way down the length of an animal
- It is not just a notochord, it is also an induction system between three types of tissues that put in place the nephric system, the muscle system, the notochord and a brand new type of nerve cord
- Archinephric duct is the funnel and the openings that are the ancient way to get gametes to the outside

Neurotube-notochord-mesoderm complex
- In the developing embryo, there is a series of **nephrostomes** draining below the hollow mesoderm that sits below the solid mesoderm that creates the blocks of tissue

Pharyngeal gill slits
- Gill bars sits on an angle
- Water flows through the space and there is a path that takes flow out of the body
- There is a set of cells on the ventral surface, on **endostyle**, that are going to start weaving mucus
- When they make mucus, they weave it across the inner surface of the opening to the pharyngeal cavity and cilia are constantly pulling it towards the top so all the way across the bottom of the pharyngeal cavity is wall of mucus that is being taken all the way to the top (a wall of mucus lining the surface of the pharynx)
- In hemichordates, mucus is made outside food is put in pull everything in
  - Bag is inside and going to pump water through the centre and across the bag of mucus and outside the openings for respiration but all the food gets trapped on the inner surface
- On the dorsal surface, cilia that are scrunching the bag together and sending it into the digestive tract
  - Mucus bag constantly being produced and constantly being rolled up and the top
  - Get the mucus and food, send it to the digestive system = constantly regenerating it
- The earliest one fed by swimming with their mouth open to collect food
- Pharyngeal gill slits combine with the movement of swimming

Segmentation
- The muscle block, **somites**, are laid segmentally down the side of the organism
- Arrangement is in such that they can't shorten the notochord when they contract
  - But can contract one side all the way down the length = bend the notochord
- Can stretch the muscle on the other side and relax on the other side = **bending of notochord**
- By alternating the contraction of the muscle set, you get the tadpole swimming motion that is characteristic of the chordate ancestor

Hemichordates & Invertebrate chordates

- Swimming through the water column, up in the water column, trapping water full of food and using it as the food source = advantage to the chordates = success
- Chordates came out of water column and started to swim = incidental
- They survived but were out competed by crustacean, so survived as minimal group
- Extend the segmentation of their body beyond the anal opening = increase the motor that makes them swim through water = referred to as **tail**
  - Has whole set of region that is dedicated for propulsion, there are no other organ system, just muscular motor at the back of the organism

Chordate phylogeny
Cephalochordata (Autapomorphies)

- **Asymmetric planktonic** larval stage
- Extension of muscular notochord beyond neural tube
- Staggered **myomeres** and mouth = modified gill slits
  - Development of the nerve cord appear dorsally
  - Ancestor represent the switch from ventral nerve cord dorsal nerve cord due to symmetry
- The original embryonic cavity, the original opening to the mouth is not used
  - They have rotated the body to a certain degree and very first pharyngeal slit became the mouth
  - They are asymmetric
  - When they rolled and adapted their mouth, kept their notochord on the other side and extended it forward because mouth = mouth no longer on the anterior part of the animal
  - Notochord extending beyond the neutrotube

Cephalochordata

- Spend most of their life **sessile**
- Dig into sand and sediment and sat up in the burrow
- Part of the extension of the strengthened notochord allows to burrow
- **Notochord** that runs down the length of the body with nerve cord above it
- Have many openings to the **pharyngeal gill slits**
- Have **atripore** so water does not come out of slits, it is recovered over this
- Tail is not too long = not powerful swimmers

Feeding

- At the anterior end is a whole set of mechanism creating water currents, being selective of the foods that they produce and pass into the digestive system = consolidate into **endosytle** and feed
- Have **notochord** extending beyond the **nerve cord**, giving strong rigidity to the anterior of the animal
- Have ability to use body material anterior to the new mouth to be able to create hoods, rostrum, structures created to feed with

Circulatory system

- Simplified = no hearts due to blood vessels being pumped
- **No nephridia** b/c they are so small = able to use diffusion
- **Cecum** has rich blood supply where the transfer of the nutrients to the blood stream occurs = what liver does in vertebrates

Cross section

- In the front = characteristics of the group
- Back = muscle blocks and tail = anal segmentation

Chordate phylogeny (Symplesiomorphies)

- Change in notochord from "**stack of coins**" to hollow elastic tube

Hemichordates & Invertebrate chordates

- When notochord developed, it developed small little blocks that matched the sematic blocks down the length of the animal
- Visible notochord, sematic arrangement is called stack of coins
- Notochord formed in a smoother structure = no longer able to see divisions = improvement of notochord

Urochordata (Autapomorphies)

- **Reduction of genome**
  - Massive genome deletion in the animal's genetic material
  - Many of the features associated with hox gene, patterning of bilaterally symmetric organism
  - Instead of organism dying, enough of genome remained to be able to survive
- **Tunicin** cuticle = unique casing
  - The chemical in the tunic extremely unusual = it is **cellulose**
  - Cellulose coded in the genome of this organism = only animal that makes cellulose genetically
- **Reversible heart beat**
  - Blood flows in one direction stops flows in a completely different direction

Reversible heart beat

- The heart supplies the blood to tunic (outer body wall), the endostyle is making mucus string pharyngeal basket that has slits and feeding cilia that are pumping to brain, not too great because as blood passes, all the nutrients are taken out = brain getting high oxygen but low nutrient
- Blood leave brain gut = blood getting nutrients and oxygen is taken out gonads = gets moderately high nutrient but depleted oxygen
- Gonad needs lots of rich nutrient and rich oxygens
- The tunic, endostyle, the basket gets food oxygenated blood and cerebral ganglion benefits but the nutrients are coming in from the gut and being used up by gonads
- Depending on the location of the loop, getting lots of oxygen with no nutrient or lots of nutrients and no oxygen
- The secrete is the reversible heart = goes the other way, now the gut passes the nutrient to the cerebral ganglion, picking up missing nutrients and goes the other way
- Depending on where the tissue is in the cycle, blood cycle = receiving high oxygenated blood & low nutrient, reverse cycle = receive high nutrient blood with low oxygen
- As the heart reverses in each direction, you never end up being deprived of either oxygen or nutrient
- Neither of oxygen nor nutrient is in high demand due to the sessile lifestyle

Urochordates

- Sessile organism sitting at the bottom of the ocean that secretes a casing called **tunic**
- Pumps water into a **pharyngeal basket** across, filtering the food and shooting it out in **exit siphon**
- They form a colony; the pharynx is enlarged and has pharyngeal slits
- Has endostyle and it is constantly weaving mucus across the opening that is gong to be collected on the opposite side and balled up and sent into the digestive system
- In the digestive system, the nutrients are absorbed = supplying blood that is in connection with the digestive system to absorb the nutrients
- Nutrients are going to pass back out but since they are sessile, they are going to pass out where the water left the basket to create **excurrent flow**
- Basically have a giant feeding basket sitting in a cellulose tunicate casing that is pumping piles of water in the chordate and trapping the mucus string where it is going to digest the food and take the undigested food and put it in the excurrent siphon
- Lying on the digestive system close to it are gonads, which needs nutrients to be able to function and there is going to be heart to pump
  - Need to supply body wall and basket with blood
  - Just a linear system

Urochordate larva

Hemichordates & Invertebrate chordates

- When it produces the egg and larvae matures, it consists of pharyngeal basket where the anal opening is and have incurrent siphon and endostyle all attached to the chordate swimming motor
- **Dorsal hollow nerve cord = no nerve cord in the adult**
- **Notochord = no notochord in the adult**
- Segment in the muscle, tadpole like swimming motion, post anal is the tail
- The basket is not functioning = it is sealed over
- Larval stage in a swimming distributive pharyngeal basket and has little eye spots so it can tell which direction it is moving in
- They are **chordate characteristics**

Urochordate metamorphosis

- Urochordate larva settles to the ground glues itself in place with 2 adhesive pili undergoes metamorphosis where it loses tails, the pharyngeal basket expands adult
- In the catastrophic genomic event, the chordate characters were all still there but they were only being turned on in the larval stage and have managed to distribute a miniature adult feeding stage that was attached to them

Urochordate morphology

- **Benthic** (Sessile)
  - Solitary & colonial: all double structures are anchored together
- **Pelagic** (Swimming)
- Always have 2 funnels

Vertebrate (Autapomorphies)

- Replacing the notochord with different structural skeletal element that support for locomotion
- Hole of nerve cord expanding and enlarging to become a brain and surrounded by a brain case
- Craniata came first
- **Neural crest cells**: form **placoids**, which are cells that move to different parts of the body and regulate the development of the internal structures
  - These cells come along and interact with other cells, where complex structures are formed within the group
- Placodes, tripartite brain and cranium
- Axial skeleton with vertebrate

Cephalochordata & Ammocoete (lamprey) larva

- Never see chordate characteristics in any of the vertebrates
- The **pharyngeal gill slits modified into gills**
- Endostyle present but not involved in feeding
- Still retain post-anal segmentation = but only seen within the larval stage called **ammocoete**
- Many comparable structures that are present in the cephalochordates
- Mouth located at the anterior, swollen brain
- See a notochord present in the larval stage and hollow nerve cord above it
- Gill slits also present

Fish

Chordate Phylogeny
Vertebrata (Autapomorphies)

- **Neural crest cells**: part of induction system where specialized cells move to locations while interacting with other cells and generate specific fate for other cells in terms of its form
  - Set of cells along that crest that governs the whole program of the sensory when the folding of the neurotube occurs
  - Some of them as plakoids are going to migrate and are instrumental in creating a complex sensory structures around the body
- Placodes, tripartite brain and cranium
  - Brain locked inside the **cranium**
  - **Tripartite**: three parts to the brain
- Axial skeleton with vertebrae
  - This characteristic is removed and placed between mixini and pteromyzontida b/c the ancestral characteristic is to have cranium and later on get vertebrae that replaces the notochord down the length of an organism (under some consequences, two are considered synonyms)
  - **Mixini**: no evidence of vertebrae being present
    - Main structure element is the notochord
    - There are vertebrae remnants, which means that they are the remains of vertebrae
    - Hagfish = unusual group in terms of how they function and how they live
    - Hagfish are able to knot which is an important function defense and feeding mechanism
    - For maximum flexibility, vertebrae diminish = becoming remnants (Ex. Tail of hagfish)
    - Hagfish and lampreys, the closest relatives to them, are in a group called cyclostomata
  - **Cyclostomata** = animals with circular mouth; jawless fishes

Lateral line

- Unique sensory structure in fish designed to pick up vibration that is moving through water
- Not really a unifying characteristic b/c it is missing in some of the lower vertebrates (ex. Hagfish)
- **Low frequency sound** can move through very solid media in the **subsonic** environment
- Fish can pick up compressive forces that are moving in water
- Water pressure or vibration moving through water is transmitted into the canal system, which has little sensory domes where it is compressed turning into nerve impulse signal integrated fish gets information about the surroundings
- There is one line of sensory structures down the trunk of the fish and also covering the whole face = the reason why they are called lateral line
  - Covering the face provides the fish information about things in front of it
- They are not only **vibration sensitive**, but **electrically sensitive** because every single organism when it is in water give off a small voltage current and these structures become adapted to be able to pick up

Vertebrate phylogeny
Mixini (Autapomorphies)

- Three pairs of barbells: used to be able to pick up sensory information from the food that they are feeing on and their environment
- Single nostril
  - Bring air into their respiratory system
  - Often attached to the things that they feed on and can't carry water through the mouth
  - Ancestor used mouth to carry water out and through pharyngeal splits
  - When attached to what they are feeding on, can't aerate the gills unless they have second opening to that and this becomes the nostril
- **Loss of the pineal gland**
  - Part of the brain on the dorsal side that picks up light
- Reduction of the eyes and lateral line system

Fish

- Affected by where they live; burrow in the sediments in the ocean and dead carcasses of animals

Hagfish
- Notochord, gills, and post anal segmentation present
- Worm and eel like organism
- Organism that has external gill opening with nostril on the top to aerate the respiratory surface
- Have mouth that are going to attach to the things they are feeding on
- Down the side is **slime** sac opening = defensive strategy
  - When grabbed on by something, they immediately release highly dehydrated protein into the water and when it hydrates, it hydrates so rapidly that it becomes extremely mucilaginous and the protein uncoils instantly = huge amount of slime and goo that covers a hagfish completely
  - To clean the slime off itself, they turn itself in a knot and uses the muscle contraction to slide it off

Hagfish knotting behaviour
- Feeding mechanism
- **Cyclostomata** = their mouth is constantly open, circular mouth with no jaw
- Ties itself into a **knot** and push the knot down against where the mouth is attached and hold = anchoring them in place
- Tie in the knot slide all the way down and pressure that is created by the knot allows the hagfish to pull the tissue up that is underneath

Hagfish head
- Has vicious little teeth on its tongue
- When hagfish attaches, it wags its tongue back and forth to saw away at the tissue that it wants to feed upon and swallows it
- When carcasses of the marine animal sink to the bottom of the ocean, hagfish crawl in the anal of the digestive opening through the gills to get inside, where they are protected from the predators and start eating from the inside out

Hagfish
- Have **nostril** through which air can get through and out the respiratory system
- Only vertebrate that still has intact notochord but the brain is still housed in **cranium cartilaginous case**
- This fish is highly adapted, thus it does not look like the first **jawless** fish
- If they had bony vertebrae casing, it would be extremely difficult to have the flexibility to tie in knots

Vertebrata? (Symplesiomorphies)
- Axial skeleton with vertebrate
  - The reason why vertebrae came second but evidence doesn't seem to agree
  - Mixini becomes cyclomata lineage

Pteromyzontida (Autapomorphies)
- Another fish without mouth
- Highly adapted predator = feeding on the outside
- Unique feeding structure with circular suction mouth with keratinized teeth
- Tongue covered in teeth: big circular mouth with keratinized teeth that allow them to feed upon their prey

Lampreys
- Active **ecotoparasites**, feeding on fluids that it generates
  - Munching away at tissue of an organism but it is trying to create a wound that seeps blood and liquids that they can feed upon

Fish

- Traditional life cycle = adult lives in the ocean and when it is time to spawn, they come up river system to smaller rivers streams stream beds and lay their eggs in the stream beds
  - When eggs hatch, they live in the freshwater system for a period of time and then migrate down and back out to the ocean
  - Exact same thing as salmon
- Lampreys are not behaving to their normal life cycle anymore; in the large lakes, they migrate up the river system to creeks and spawn then they come back down into large lakes (never going back out into ocean)
  - Subspecies of lampreys that only inhabits the great lakes

Lamprey mouth
- Giant suction mouth, **keratinized teeth**
- Changing the shape of the buccal cavity to assist with the suction
- Tongue and giant teeth inside are constantly rasping on the tissues to which they are attached

Lampreys
- Continuously grinding and tearing at the tissues
- Trying to create a wound that constantly oozes, blood or puss = any kind of liquid and will suck the liquid up as the main food source
- Leave a circular scar on the fish, but it is mild indentation thus no major damage is done

Lamprey skeleton
- A lot of similarities to the hagfish
- Have nostril at the top to get water in and across the respiratory surface
- **Notochord** still in play and have brain in the case
- Have vertebrae in this group = one of the innovation that separates two groups

Lamprey skeleton
- Elaborate cartilaginous system that is used to keep the respiratory openings always clear = water moving through the respiratory system
- Always ensures that the digestive cavity is open = constantly passing food in
- Major skeleton element associated with the nerve cord although they are reduced

Agnatha
- **Without a jaw**
- Gnathostome: having a jaw

Gnathostomata (Autapomorphies)
- Genome duplication
- Jaw
- Paired fins
  - There was no paired fin, they were using lateral tadpole undulation of the body when swimming = not great swimmers
  - Paired fins = stabilize the swimming motion

Homeotic genes: **Hox genes**
- Amphioxus are little cephalochordate at the beginning
  - Have one set of hox genes
  - When get past the agnatha and go into cartilaginous fish that are coming, the whole genome duplicates twice
  - End up with every hox gene occurring a second time and get a second round of genome duplication so that hox genes are there in sets of four
- Urochordates: whole set of hox genes missing = the reason why they look so unusual

Fish

- But somewhere around the time between agnatha and gnathosome, two rounds of duplication occur
  - The only animal group that has ever done genome duplication and survived
- Polyploidy in animals is rare = perfect genome duplication first time and it was detrimental, thus it happened again
- In chordate lineage, there are two interesting stories
  - One group that is the survivor of thee massive geomatics mishap
  - Another group that has experienced the massive genetic mishap but worked to their advantage being able to duplicate their genomes twice
- Organisms that live in marine environment comes up on land and adapt to terrestrial environment
- Freshwater space fishes re-invade the marine environment
- One group that is most diverse in terms of species, types or numbers are the bony fish
- Bony fish have **8 copies** of everything and it is thought that it is one of the reason why they are diverse
- Where it occurs is done by gnathostomes; cephalochordates don't have it so it has to be somewhere in the ancestor to the cyclostomatas

Evolution of the jaw
- Jaw is the major innovation; same in every single organisms
- Have a set of **7 gill arches**
- The front front two gills begin to articulate with each other
- In the development of the set of bones, the cartilage in the ancestor hold up the pharyngeal openings, the bone forms from the dorsoventral side and meets in the center = not a solid rod of bone
- Over time, if you can change the size of the buccal cavity (mouth cavity) by compressing and expanding, it means that water can be pumped in and out
- First innovation: allow the rigid rods that were holding the buccal cavity perfect cylinder to allow them to flex a bit = changing the shape of mouth
- Close the mouth or limit the flow when squeezing out = start to pump water over to the gills
  - Being able to aerate the gills
  - Jaw is adaptation for enhancement of respiration
- Two of the gill arches become articulated to a point where they can close
- The closure comes about b/c they want to make sure to get the unidirectional flow = make front opening smaller and smaller = meaning we are going to get the flow and ultimately close
- Able to trap food = can swim along and grab food and trap in the buccal cavity
  - First jaw in use: just hold on the prey instead of chopping them up into little pieces
  - Feeding becomes the secondary event in terms of the benefits of the jaw

Chondrichthyes (Autapomorphies)
- Cartilaginous **tesserate** skeleton
  - Tesserate: form of the cartilage
- **Placoid scales**: related to efficient swimming
- **Heterocercal** tail: new propulsive mechanism
  - Have lateral fin that comes along to help stabilize
- Claspers in the mantle
- Upper jaw formed from **paleoquadrate cartilage**, but not fused to the cranium
  - Jaw not attached to the skull

Chondrichthyes (Cartilaginous fish)
- Sharks
- Rays are part of this particular group
- Paired lateral fin combined with dorsal fin
- Lateral fin is the **pelvic fins**, which are going to be the appendages of the vertebrae
- The dorsal fins and lateral fins gives the sharks a profile that looks like an airplane

Fish

- Going to move through three-dimensional media and are being propelled forward, need to be able to prevent twisting and roll
  - Have large flat surfaces that stabilize all three directions
  - Biomechanical stabilization system moving in three dimensions
- **Heterocercal tail** = top is larger than the bottom
- If two lobes were the same = **homocercal**

Heterocercal tail
- The big flap on top; when the tail beats = back and forth in the lateral motion, it comes all the way from the ancestor (top of the tail flaps over)
  - Pushes down as it undulates
- The downward push of the back causing lift to make the front rise = not only getting forward propulsion, but heterocercal tail is generating lift as well and they are combined with the fins that is sticking out laterally to be able to make it rise in the water column
- All the fish battling to not sink b/c they are denser than water, if they stop swimming = they sink
- Tail prevents shark from sinking when it swims = also have cartilaginous skin
- There is no mineral salt = cartilage has density very similar to water
  - The reason why all of the bones have turned into cartilage
  - Adaptation to the existence, it is not the cartilage is the primitive type of skeleton
- Have large liver that is filled with shark oil and this oil combined with the cellular density of the body also makes them more neutrally buoyant
- Got skeleton, oil and heterocercal tail that are helping the organism to lift itself and move though water

Placoid Scales
- They are embedded in the epidermis and they consist of protein mixture that is produced forming structure with outer dentin and inner pulp core
- Like teeth; exact same biochemistry that forms these structures
- When the smooth surface moves through water, it develops a suction or drag and pull the water closer to it = resulting in **laminar flow** of water over the surface
  - The laminar flow is going to drag, causing the animal to slow down
- Laminar flow is what the airplane needs to stay up in the air, however, when swimming, laminar flow is not wanted
- End up with modification on the surface of the shark and it is going to come back in all the fish in different ways to disrupt the laminar flow = the scale does this
- Scale sticking out creates a little vortices of water and these can't interact laminarly with surface that is moving underneath it = don't get the pull
- For airplane, when they are in an area of non-laminar air, it is called **turbulence**
  - The flow doesn't work across the wing and it can't generate the lift = plane falls around in turbulence
- Palcoid scales are adaptation to allow the movement to occur

Unique jaw
- Only group where the two bones that form the jaw still articulated with the head
- Upper jaw fuses with the cranium = fish and other vertebrates
- Gives ability to open the jaw really big and extend it out = more **flexible** jaw

Feeding
- On the surface of the jaw is placoid scales
- Very big on the surface of the jaws as teeth; they are not embedded in the epidermis, they are not attached to the bones, thus can easily to dislodged
- When sharks feed, they grab hold of the prey → clamp down on the prey tightly → generate swimming motion → pieces fly off that are small enough to be consumed
- Used only to hold on the prey, not to preprocess the food

Fish

- The reason why the musculature is strong to clamp down, but doesn't use a lot of musculature to open the jaw = **too weak to open the jaw**

Vertebrate digestive system
- **Pharynx**: muscular mouth propelling food into the digestive system
  - **Salivary gland**: lubricate the food preprocess
- **Esophagus**: tube that connects the pharynx to the digestive site
- **Stomach**: acidic digestion
- **Small intestine**: alkaloid digestion
  - **Pancreas**: produce enzymes that are needed to break down the food
- **Liver**: detoxification centre where it destroys any toxic chemicals that come in and cleaning up the blood before circulating it to the rest of the body
  - **Gall bladder**: deals with the wastes that process and make agents that deal with li[pids and keep the lipids soluble
- **Large intestine**: compact up the meals and store in a rectum before releasing
- **Rectum**

Digestive system
- Large stomach; covered with many folds that are involved with increasing the digestive area for acid digestion
- Stomach is followed by intestine and it looks very short but in reality, it is very special structure b/c it is designed to slow down the movement food through it so that we can get complete absorption
  - Two ways to do this: can have a great big long structure or slow it down to have more time to process what they are feeding on
- Predators are feeding on highly nutrient **proteinaceous diet**
- End up with structure inside the stomach called the **spiral valve** = circular stair case
  - Tubular structure and the food is spilled down the stair case to the bottom and it takes longer to get the bottom than if the tube was straight
- The great big liver is making the oil that is used to attain neutral buoyancy

Ampullae of Lorenzini
- **Electrosensory ability**
- Sharks and cartilaginous fish are experts at picking up electrical signals of prey at any particular point in time

Pharyngeal gills
- Inside the mouth
- Cartilaginous support, gill splits in between, water is moved across the surface
- Ancestral sharks didn't figure out how to aerate their gills other than to swim with their mouths open = **buccal/ram ventilation**
  - Must continuously swim
- There are sharks that have developed to remain stationary but that is a derived trait
- Sharks don't really sleep = no reason to stop swimming but it is their limitation

Gill surface
- **Gill** are designed for constant flow of water over them but also have teeth inside
- Teeth inside is not designed to do anything for the food, they are designed to keep the food inside the mouth once it is ingested little fences to make sure only water goes across the gills

Circulatory system

Fish

- Sharks simple circulatory system
- A heart with one auricle that receives blood of ventricle that is muscular that pump it out to the rest of the body
- Always pumps to the gills first to get **oxygenated capillaries in the body return to the heart**
- There is signal circulatory loop

Fish heart
- **Sinus venosus**: place where the blood pools
- **Atrium**: blood sits before pumping to ventricle
- Up inside the conus arteriosus is where blood vessels deliver blood the various parts of the bodies = regulation

Aortic arches
- Circulatory system where the blood comes out and leaves the heart and travels across the arches that are associated between the gills = **aortic arches**
- Meets on the one side to head back the length of the body

Arterial circulation
- Have the heart, sinus venosus, auricle, ventricle, pumping out to the ventral aortic that is common and going to split and go up through each gills aortic arches and it is going to be at the very top
  - Systemic arches going to move to the back and fuse = head down a single dorsal aorta to the tail
- When moved on land, lungs are generated and animals adapt them into this type of structure
- The original structure: one of the aortic arch is present even though there is no spiracle between it
- There are two blood vessels that are moving forward, outer external carotids and internal carotids
  - Two pairs of carotids going forwards and they are going to supply the brain and other tissues
- Always end up with dorsal aorta moving back
- Pumping pattern: heart oxygenation blood vessels moving forward as carotids and dorsal aorta moving back
- Coming off = blood vessels that are going to supply **subclavian**, which is going to be the **pectoral caudal** and also have blood vessel supplying the posterior fins, **pelvic & caudal** = **iliac**
- Blood vessels also supplying the mesenteries on the way to the liver, gonads, kidney and general body cavity
- Coming off the dorsal aorta are blood vessels paired for pectoral and pelvic, not always paired but supplying the **mesenteries** to pick up nutrients
- Always picking up and supplying the blood to the liver, gonads and renal

Venous circulation
- Biggest changes occurring
- In shark, the **sinus venosus**: all blood pools from everywhere in the body before it is placed into the atrium then the ventricle and back out again
  - Pooling from the anterior and from the anterior, there are anterior and exterior **jugulars** bringing it back
  - The companion blood vessel brings blood back to heart for the **carotids** are jugulars
- Have **subclavian** that is going to bring the blood back from the pectoral caudal
- Going to see **iliac** bringing back from pelvic
- Have caudal which is going to blood back from the tail
- Have **mesenteric artery** that supply the digestive system and can't let the blood circulate until it is cleaned up
  - Thus, we have capillaries in the mesenteries where nutrients are picked up from the epithelial wall of the digestive tract and pulling it into blood and sending it to liver
    - Need another set of capillaries to be able to exchange
  - There is a set of **capillaries** at one end of blood vessel and another set in the liver, so the blood vessels that have capillaries at both ends but no connection to the heart
- Arteries are connected at one end at the heart and they have capillaries at the far end and a vein has capillaries at the far end that connected to the heart at the other end
- This one has capillaries at both ends so it is referred to as a portal system

Fish

- Blood is picked up and transport to another location to liver where high level of nutrients is removed and either stored as **liver** tissue or detoxify it
- There is another portal system that comes from the caudal vein involved with the **kidneys**
- Kidneys are where blood is filtered and metabolic wastes are removed
- Portal system associated with kidneys due to great big heterocercal tail
  - It undergoes tremendous amount of metabolic activity in which nitrogenous wastes are generated and it is cleansed in the kidney through a special transport portal
  - Kidney is also cleaning all the blood coming from the tail before getting it out to the rest of the body
  - End up with kidney cleansing caudal blood
- Have anterior stuff coming through, but also have extra blood loop (lateral abdominal) that are running up the side and also a set of extensions of the posterior vena cavity that go all the way back to the kidney
- Different from arterial, which has one blood vessel going backwards and two blood vessels going forward
  - Venous system is picking thing from all over the place

Reproduction

- Males with **claspers**: when sharks mate, males hold on to the females and claspers anchor them in position = passing sperm to the female
- Females only produce a few young in their life time
  - 1 or 2 eggs provided with large amount of nutrients and they invest huge amount of reproductive potential then placed in the **mermaid's purse**
  - Female anchors the egg by the using **tendrils** into a secure location = it is leathery and protects the organism inside
  - Has enough openings for gas exchange and everything else
  - Egg develops based on the nutrients available = turn into baby sharks
- When the shark escapes from the mermaid's purse, they can start feeding on prey and start to grow
- Some sharks don't have mermaid's purse, eggs hatch in the utero and there are mammary glands
- One shark doesn't even have milk gland; they set up a blood brain placental barrier with the developing young to be able to nourish it

Vertebrate phylogeny (Symplesiomorphies)

- Bony skeleton replaces cartilage
- Teeth embedded in the jaw, swim bladder or lung formed from the gut

Actinoptergli (Autapomorphies)

- Fins supported with **bony rays**: fins are now mobile, flexible and supported by rays of bones
  - Fins can be opened and closed
  - In sharks, fins were attached to the body rigidly and have little or no flexibility
  - No have fins that are going to articulate with the body wall and can be folded or unfolded
- **Swim bladder**: packet of air that accounts density of the animal so that they are not spending any energy in swimming motion to stop sinking, it is done physiologically
  - They can now hover = be able to rest in one location
- Modification of the jaw for suction feeding

Actinopetergli (Bony fish)

- Ray fin fish
- Their bones are set up completely different from their fins

Bony fin rays

- All of the fins has bones to support the fin and inherit the flexibility
- Even the pectoral & pelvic fin and hind, caudal fins all have bony rays associated with them

Fish

- Bones extend right into the muscle mass of the fish

Osterichthyes skeleton
- Two major fins: **pectoral** and **pelvic fins** move forward and they are not directly anchored to the main axial skeleton that runs the length of the organism
- For cartilaginous fish, there were cartilaginous support for the fins, but it wasn't attached to the main **axial skeleton** so fins were not anchored to the musculature of the body wall = maneuver is impossible
- Now have folding and expanding of fins with needle like rays = attached directly to the surface
  - Allows fins to move independently of the body
- Able to achieve two different types of locomotion: major propulsive locomotion, which is associated with the tail and the tadpole like lateral undulation that are typical of chordates and can maneuver
- Using pectoral fins to hover in one location, keeping an eye on the environment
  - Tail is still the major propulsive structure
- Fish tucks other fins out of the way and use undulation of the body wall to move
- Fish morphology: rapid swimmers = large distances with powerful swimming are all tail
- When searching and moving around = all pectoral and pelvic fin & less tail
- End up with a group that is extremely powerful swimmer = not just propulsive force but also the agility and acuity

Swim bladder
- Take up almost **40% of the body cavity**; it is the **air sac**
- Air sac is completely isolated = no connection to the outside world = completely closed sac
  - No way air can go down nostrils or any of the digestive system at the front or the mouth
- As fish sinks deeper into the ocean swim bladder size decreases less ability to support the body to float = ability to maintain neutral buoyancy decreases and start to sink
- Solution: put air/gas into the bladder as they sink
  - As they go down, gas is added to the bladder = now bladder is filled with sufficient air to support the body at the depth
- It is called **rete organ** and the blood vessel is called **rete mirable** = pulling dissolved gases (oxygen) out of the blood and putting it into the bladder
- Oxygen that is getting into the blood across the gills = no losing circulating oxygen by filling the bladder
- As fish rises above the water column, oxygen is taken out of the bladder by **ovale body** on the other side
- A perfect system and works as a nerve reflex
- Fish can detect the pressure on its body and it automatically adjusts the bladder accordingly
- Sharks had to deal with light support structure and shift to cartilage & use oils to maintain neutral buoyancy

Suction feeding and pharyngeal jaw
- Need to be able to capture the prey and get them inside the **buccal cavity**
- Bones in the jaw of fish are hinged differently can open extremely wide
- Instead of having V shaped jaw, there is upper and lower jaw and whole set of bones between that allow the opening to spring open
- As fish is approaching its prey, it is pushing water in front of itself and stirs the prey away = as they approach the prey, mouth springs open so fast that they suck water into it
- Mouth has to open huge and rapidly to create back flow of water current to capture the prey
- Jaw can shoot out as well
- Sneak up open the mouth suck in the prey as fast as possible
- Speeding mechanism so successful for this group = tapping onto the food source that nobody can tap into
- When the suction pulls the food in, gills on the surface o the inner side has a whole set of teeth and those teeth that are aligning on the inner side shred and tare the prey
  - No need to use the jaw to chomp down on the food
- There are some fish that have taken one of the gill arches and re-evolved into a jaw that has teeth on it

Fish

- In the gnathostomes, the jaw was a gill arch that ultimately get teeth for holding on to the prey
- Hovering ability along the sucking feeding are seen in sea horses
  - They are pure suction feeder and the snout is used to suck in small crustaceans and small fish fires that are larval invertebrates in the water column

Fish integument
- Have to deal with the laminar flow of water over the body = have scales
- Same process as sharks, but a little different on a sense that they are **dermal bone**
- **Calcareous** bone present

Fish scales
- Rigid suit of armour scale: **ganoid**
- **Ctenoid**: more flexible in terms of interacting with each other, very light weight
- Very ancestor of fish is called armoured fish and their dermal bone was solid plate of armour = heavy and didn't provide much rigidity
- Sturgeon and some of the most primitive fish = got scales but they are tremendously overlapping = huge amount of redundancy
  - Ctenoid scales – found on a trout
  - They are there to create turbulence but they are very light weight
  - Barely overlap with each other and they don't have any impact on flexibility but they are doing exactly the same thing as seen before

Trunk musculature
- Muscles down the length of the trunk have overlapped with each other
- Bending the vertebrae
- Muscles overlap instead of blocks, they are twisted and lie underneath each other
- The reason of overlapping = if there is contraction down through the depth of the animal, some of the muscles are fully contracted, making for much more fluid and powerful stroke involved
  - Much more powerful swimming motion

Opercular gills
- Sharks had to move to get oxygen to flow across their gills
- Bony fish developed mechanism to pump water
- Came from the mechanism of suction feeding because even if they didn't use it to capture prey, they were enlarging their buccal cavity and contracting it to force water across their gills
- Adaptation for the respiration to be able to suck water in and squeeze it out, unidirectional matter became exaggerated to a point where it was used to capture the food and became further augmented with protrusible jaw to capture food
  - Figured out how to pump water across their gills
- Added opercular = flap of tissue

Opercular gill
- Flap of tissue used to augment the pumping by the mouth
- When the fish goes through its respiratory cycle, it is going to open its mouth (pulling water in) □ increase its buccal cavity then when it closes, it will squeeze the buccal cavity and operculum on the side is going to swing out
  - When it swings out, it pulls water out of the cavity
- Two mechanisms for getting the water out □ decreasing the size of the buccal cavity & getting the last of it out by pulling the operculum away
- when the fish is breathing, mouth opens and operculum closes = respiratory cycle that carries the oxygen

Gill arch

Fish

- On the gills, there are filaments associated with it
  - Artery that carries the blood and vein that is going to bring it back
  - Going to oxygenate across the surface but the circulatory system is set up in a unique way

Counter current exchange
- Water is flowing across the fills but the gill filaments have disk shaped structures associated with it, so water is coming between and have capillaries inside = flow is **unidirectional**
- End up with blood always flowing in one direction while the water is flowing in the opposite direction = counter current exchange
  - Allows for maximum extraction of oxygen from water

Concurrent exchange
- Fluids flow in the same direction
- Equilibrium between the two fluids occur
- Blood coming in is depleted of oxygen and it is meeting water that is 100% saturated
  - Where they meet = there is concentration gradient between the tubes
  - Get oxygen diffusing through the blood
  - Blood going up in the concentration of oxygen while water is dropping
- Two comes to an **equilibrium** at some point
  - Blood is extracting oxygen from water
- The hit the same value and there is no more diffusion
- Blood never gets higher than 60% saturation
- Oxygen present in water that has not been extracted

Counter current exchange
- Fluid flow in the opposite directions
- Equilibrium between the two fluids never occurs = always extracting oxygen from water no matter what
- Blood is entering, but it is low on oxygen and water entering from the opposite side, so when it meets with blood entering, the oxygen level is lower but still higher than what is in the blood thus, diffusion occurs
- As blood picks up oxygen, it is going to flow by blood that is higher b/c it hasn't had oxygen extracted from it
- Even if the blood has 80% of oxygen, 100% water is coming in, thus oxygen is still extracted from water
- These animals with high mobility, high metabolism need maximum supply of oxygen and they are guaranteed by counter current exchange
- Squids do **NOT** use this exchange = the gill is concurrent exchange system

Circulatory system
- Basic pattern wit single ventral heart
- A **sinus venosus** where blood is pulled from **atrium ventricle aortic arches extend up out to dorsal aorta and to the rest of the body**
- Lose one of the aortic arches = **down to 4 aortic arches**

A tale of two fishes
- **Problem: water balance**
- Biggest mass extinction in the ocean was Permian = 90 – 95% of all animal groups lost from the ocean
  - Including early ancestor to fish; everything starts back over in the ocean
- Mass extinction in the ocean did not affect the large freshwater bodies where the bony fish have evolved
  - They repopulated in the ocean; all of the fish today are descendants of the fish that started off in freshwater environment

Fish

- In freshwater environment, gills that are gas exchange surface = deadly surface for water to inundate the body b/c they are salty compared to the freshwater environment
  - Getting rid of water while not losing the salt that are there
- One of the adaptations overtime in freshwater environments: fish developed osmoregulation but also **decreased** the **osmolarity** of blood salts solved part of the problem by becoming less salty
- However, less saltiness does not solve everything = end up in the freshwater fish that are constantly absorbing water
  - One of the solution is not consuming water b/c if they are absorbing on their body surface, they don't want to consume food with water in it
  - Need to get water out across the gills, concentrate the food and get it into digestive system
- If water is consumed, water inundates blood fluid from the gills and internal organs of the digestive tract = don't absorb water
- Set kidney up at the **nephric system** to be able to produce a lot of **dilute urine**
  - Shunt water from percolating in and into the blood and they are going to filter it out and going to produce a large amount of dilute urine
- Never going to be able to prevent and recover all the salts
- Even though **hyperosmotic urine** is created consisting with little salt, end up in a situation **deficit** for **minerals** particularly for Na and its counter ion Cl
- In freshwater fish, they have gill surfaces that can absorb Na and Cl
  - While all of the water is inundating the gills, percolating into the body, gill surfaces are selectively pulling Na and Cl out to augmenting the body to compensate what we are going to lose when diluted urine is made
- Freshwater fish modification to the environment were: don't drink water, get the water out but produce a lot of urine = going to lose minerals thus, going to absorb them across the gills
  - These are fish that moved into the ocean
- Fish was slightly less osmotic as the marine environment b/c it has spent so much time in a freshwater environment when it went back to colonize in the oceans
- Problem: fish is less salty than the marine environment = going to be inundated by salt and going to lose water
- Reversed problem = in the marine environment: water goes out thus **need to drink up water** and flush the system with water = constantly compensating for water that is being removed
  - Drinking whole pile of water = consuming whole pile of minerals
  - The pump in the metabolism that is used to absorb minerals have reversed and now used to **excrete** the **minerals** and removing them
- End up removing mineral from the body; want water to retain b/c it is being diffused out of the body, so it also means they don't produce much urine to limit water loss = **hypo-osmotic regulation**
- Now consume water, don't produce much urine and b/c they are consuming whole bunch of water, take the minerals out and take the gills and pump them in opposite directions
  - The origins of all the fish
- Physiology between the two groups allows them to have conquered all types of environment (from freshwater to salt water to intertidal to deep sea) due to the flexibility of dealing with mineralization
- End result: very highly adaptive organism that is still diversifying

Reproduction

- Producing large numbers of eggs hoping that there will be survivors
- Larval fish and fish eggs are part of the major food chain associated with marine environments
- In most cases, there is **external fertilization**
- Many fish population is considered sustainable b/c they produce many offspring that are over abundance in terms of how they function

Vertebrate phylogeny (Symplesiomorphies)

1. Fins supported by muscles and bones that extend into the fin

Fish

- In the fin of the ray fin, there was membrane, a set of bony rays that allow to collapse and expand to be able to move
  - No muscle associated at all
  - There was musculature that associated with the attachment of the body to be able to make it move

2. **Lobed fins**: turns itself into a lobe to be used like a paddle as locomotion

Transition to land (lobe fins)
- A set of bones that can also be homologized perfectly to the bones that are associated with the human limbs
- There is typically a single bone that attaches to the whole body, a pair of bones that are attached to series of bones = where the vertebrate limb is
- This is the ancestor to the vertebrates with limbs
- Have three chambered heart like amphibians; ancestor to animals

Lungfish
- Found in Africa and Australia; Eel like appearance
- Fins are **delicate** (**African**) or very distinctly **lobed** (**Australian**)
- **Australian** is more primitive b/c it spends its whole life **under water**
- **African** lungfish = can **survive outside of water**
- They arrive in the **Devonian** time when the earth was very dry
- In the period of time, freshwater environments were either drying up or warming up and getting **anoxic**
- This group had little extra tissue of lung = able to lift its head up and be able to breath oxygen and live in the anoxic water b/c they could get oxygen from another source
- Still be able to respire and feed
- Fins had extra bone = able to move up on land and by using lateral undulation of the body and pushing with the fins, they were able to move across the soil and move into another body of water
- Able to survive by gulping air by lifting its head and by being able to move between two bodies of water

Coelocanth
- Mythic creature in zoology
- The musculature of the coelacanth = could move the fins independent of each other
  - The pectoral and pelvic can move independently
- Could be the precursor of the ancestor of the tetra pods
- Haven't changed in time, highly adapted to where they live
- Live in extremely deep water = no light = dependent on **electrical signal**
  - Morphology is distinct but they have ray fins and have lobed fins
- Spend most of tis time perpendicular b/c it is using the electronical signals on its face to be able to prey on the substrates

Amphibians

Ichthyostega

- Very large animals that dominated the planet
- New way of movement referred to as tetrapod stance

Vertebrate phylogeny

Tetrapoda (Autapomorphies)

- **Tetrapod stance** with appendicular skeleton
- Have set of **hind limbs** that are attached to the **pelvic girdle** and the **forelimbs** represents the tetrapod stance and the eight appendages that extend from them represents a whole new skeletal system
- Up until now, we have axial skeleton with minor appendages, now they are going to become very large and very prominent

Vertebrae

- They are perfect disks that can slide by each other
- All the appendages are going to take structural element; the axial skeleton lift it to components where each of the appendages are
- One of the major modification that occurs if we end up with boy extensions that extend forwards and backwards that **parapophysis** and **zygapophysis** structures lock the vertebrae together so that when we lift, we lift the whole axial skeleton all the way down the length of an animals
- End up with distinct major modification in the vertebrae in all the tetrapods

Skeletal support

- Organisms with appendages sticking out laterally because originally, the fins were on the side of the body and organism sit on the ground in direct contact with the stomach
- When walking, it is going to push itself up
- Inefficient mechanism for lifting body but it is where it all started
- This group does a lot of work to hold itself off the ground starts to move forward
- Going to shift appendage straight underneath the body
- Does little push up like motion to be able to lift themselves
- As they lift, the vertebrae attached to the pectoral and pelvic girdle are modified in their bony structure and make sure that everything is anchored in place
- End up with sacral vertebrae associated with the hind limbs trunk vertebrae and cervical vertebrae

Axial skeleton

- Doing push up to lift is an inefficient form of locomotion
- Pelvic girdle and its attachment: have axial skeleton running down the length and have a whole set of bones sticking out from the sides trying to be able to lift it into place = inefficient

Walking and respiration

- Locomotion is related to the lateral undulation that were in the original fish
- When this group comes up on land, they are still doing **lateral undulation** of the body
- Lateral undulation of the body: setting one leg forward and the other forward = end up with same tadpole like movement occurring on land
- Problematic: they are now respiring with lungs, when they move one limb forward, the side of the cavity is compressed squeeze air out of their lungs but as you move the other, air fills in the lung
  - As they move forward, the air is going to go from one lung to the other and back to the other = not necessarily going to come through the nostrils
  - Have inefficient respiratory system as a consequence
- Their principle **respiratory surface** is going to be their **skin**

Tetrapod stance

- Pectoral girdle

Amphibians

- Joints: shoulder, elbow, wrist
- Bones: humerus, radius, ulna

- Pelvic girdle
  - Joints: hip, knee, ankle
  - Bones: femur, fibula, tibia = limb
- It is an organism that has come up on land and has its appendages with similar structures in all of the appendages lifts the axial skeleton to be able to start to move

Amphibia (Autapomorphies)
- The global climate changes, head into carboniferous, head into moist swamps
- Starts adapting to land, but does not have to anymore due to moisture availability
- **Pedicellate teeth**
- Secondary **acoustic pathway**: going to be able to pick up sounds that are coming through their jaws that are sitting on the ground (soil vibration)
- Buccal-force mechanism for breathing
- Skin as primary respiratory surface limitation for the group
  - Vertebrates had scaly skin to protect the skin, but this group got rid of the scale and respire through skin, which is going to limit them to moist environments

Pedicellate teeth
- There are two components to the tube: stem pedicel and the rest of the tooth sitting on top of it
- Don't have a simple matrix that penetrate all the way down into the bone
- Tooth is anchored in the jaw but has a pin and the rest of the tooth are attached on top of the pin

Secondary acoustic pathway
- One of the bone that is typically associated with the haw = **hyoid bone** that is associated with the tongue has become attached to the jaw itself connecting up into the ear
  - Going to have **tympanum** that is going to bring sound in but also have another bone that is bringing vibration into the inner ear located and associated with the jaw
  - As a consequence, the amphibians are able to place their jaw on the ground and be able to pick up low frequencies of sounds
- Tympanum of the ear picks up loud noises or the singing noises
- Becomes totally new auditory set up and this is the only group that has it

Buccal force mechanisms of respiration
- Going to swallow air to inflate their lungs
- All amphibians except toads have moist skin = going to get oxygen through the skin but when up on land, going to push air into the lungs
- Fill the buccal cavity with air close the mouth & nostril squeeze the buccal cavity and force air in
  - the reason of doing this is b/c ribs, diaphragm or other structure are not present
- In the synapsid and diapsid that are going to come, ribs are present with intercostal muscles that can inflate the thoracic cavity and suck air in
- This group does not have this, thus they have to force air into their lungs
  - They sit and gulp air for about 3 or 4 rounds and use the muscles of the body wall to squeeze and exhale
- **Buccal pumping** is the only way that they can get air into their lungs and they are the only ones that force/push air in while everybody has to pull it in

Amphibian skin
- Have skin structure that is not protected by scales
- Have respiratory surface over their entire body and must keep them moist

Amphibians

- They have waterproofed the skin with keratin, the protein associated with skin and going to make appearance in the reptiles and mammals that are going to come
- Very first amphibians were not able to do that and produced glands and mucus that cover the surface if they are out wondering to keep the moist
- Have animal that are restricted to moist environment or can leave the moist environment for very short period of time
- They are subjected to predation due to no protection of their surface, thus some of the glands have evolved into **poison glands**, they have produced mucus on the surface that is unctuous, deleterious or down right deadly
  - Protecting themselves by producing poisons and covering their bodies in them
  - They often end up with bright colouration in them
- Skin is important respiratory surface that must be kept moist (also o**smoregulatory surface**)
- Very thin keratin when gas exchange is used
- Like the freshwater fish, they are constantly being inundated with water that the kidney removes
  - Loss of essential salts is countered by absorbing them across the skin surface (replacing fish gills)

Body wall
- Nothing but muscles so everything is basically held in by muscles that are there
- When the ancestor amphibian does the push up, the body sags and muscles are going to try to hold everything in place
- As a consequence, of having ribs, there is vertebrae column, but everything is basically hold with the muscles (holding viscera in place of ribs)
- Get a sternal or sometimes get a bone that runs in the middle that helps
  - End up having to try to hold everything in place with muscles

Skeletal support
- Frogs are highly adapted amphibian = looks different from ancestor
- Part of the major adaptation is the enlargement of the sternum that assists the body wall holding viscera in place
  - **Sternum**: a great big bony structure that holds the wall with all the musculature in place
- If you are jumping, want to support the inner organ so they are not being bounced around
- Modification for the highly adapted jumping form
- High modification to the **vertebrae** = generate so much propulsive force from the jump that we can't risk having small little overlapping vertebrae to transfer that force to the body = unique urostyle
  - **Urostyle**: connection between the jumping legs and the solid bone that is going to carry the propulsive force and lift its organism off the ground

Hind limb
- Normally pattern is: single bone □ double bone □ small bone □ phalanges
- Modified pattern: singe □ single □ double and phalanges = another linear bone added
  - It is the fusion of the original paired bones of the tibia and fibula = **tibiofibular**
  - The extension extends the limb = more forceful jump
- Some of the wrist bones have been elongated to become double pair
- There is three and phalanges that have huge surface are to push against the ground to provide the lift for it to propel forward
  - End up with unique form of locomotion within the group
- Forelimb: modified for landing and added bones to absorb the impact of the landing

Lingual flip
- The early amphibians and lobed fin fishes snapped at the insects that were flying around for protein meal = whole new food source
- Amphibians: with the absence of the hyoid bones, that usually restricts the movement of the tongue, the group have developed a new way to flip their tongue out = lingual flip

Amphibians

- Tongue hinged at the front, when shot out = get more length that is able to capture prey
  - Shot out really quickly and have sticky ends = going to nab the prey
- It is probable that second acoustic path and lingual flip occurred at the same time
- This is important innovation because this group is effectively trapping a protein food source that is abundant in the terrestrial environment that nobody is feeding on = ensure the success of the group

Amphibian heart

- **Three chambered heart**

Heart

- Inefficient heart: ventricle receiving blood both from the body and the oxygenation source at the same time = not the reality
- There is a special valve located in the upper part of the heart = **spiral valve**
  - It is going to regulate where the blood is going to flow
- Blood pooling from the body and gets into ventricle = it needs to go where it is going to get oxygenated (either skin or lungs)
  - Have valve that is going to determine whether blood is going to send to oxygenation surface
- When the blood comes back from being oxygenated, it needs to be pumped out to the body, need to able to direct it differently = the big aorta that comes out of the heart has internal components to it that the spiral valve decides whether the blood will be shunt to respiration or out of the body
- Ventricle always fills with one type of blood; blood returns from the body that is sent for oxygenation or blood that is coming back have being oxygenated (there is no inefficiency)
- The only inefficiency is that if the frog were to dive and go below water, lungs don't function because it is a waste to send blood to the lungs
  - The spiral valves turn into a single that doesn't send anything to the lungs, it sends it out to the skin and back out to the body again
- Able to completely regulate or control whether we are going to use cutaneous respiration or pulmonary respiration depending on land or down in the water

Circulatory system (frog)

- Got dorsal aorta going back into the body
- Heart: spiral valves are going to either send blood to the lungs and back in or out to the rest of the body
- Out to the **rest of the body up the aortic arches ventral aorta**
- The original fish system where the heart can send blood out, goes out and up the aortic arches to the dorsal arteries that flow forward and there are carotids at the front and they join at the back as dorsal aorta and go to the back
- When it becomes time to incorporate the lungs, there is little shunt, which connects the lung onto the **sixth aortic arch**
- Aortic arches 1 and 2 have disappeared = down to four aortic arches present
- Once perfect being up on land, six is going to be the shunt that only goes to the lungs, but in amphibians, it is stuck between the two

Arterial circulation

- Got 6th aortic arch and got the great big systemic arch, have carotids come out of the front and other little ones are still there but they are not massive
  - Still have systemic arches that are going to come back to a dorsal aorta
- Everything else is pretty much the same
  - Carotids coming to the front, subclavian coming out to the limb and one blood vessel coming out to the skin, shunt between the skin and lungs
- Dorsal aorta posterior looks the same but at the front, decreasing the number of aortic arches and dedicating them to different functions even though 3, 4, 5 and 6 are there

Amphibians

- 4 and 6 are becoming most important
- **4th** is sending blood to the body from the heart (oxygenated blood)
- **6th** is sending it to oxygenated surfaces

Venous circulation

- **Anterior vena cava**: pooling point for blood before it goes into the heart from the anterior
- Carotids take it out and jugulars bring it back = pooling
- It pools with blood that is coming back from the **subclavian**, from pectoral girdle, from the skin
  - Blood that is oxygenated = important blood if lungs are not used
- Clean up to a certain degree, some of the veins are coming in before two lateral, abdominal coming up the sides and another one coming up the middle picking up kidneys and gonads and things
  - Now laterals have become single domino and at the same time, beginning to see the posterior vena cava is the pooling point for blood that was there before it is still present
- Looking at sharks and fish, had three roots for brining blood back to the heart, now down to two and are simplifying the system
- It is picking up blood from gonads, picking up blood from mesenteries, but when blood is picked up from the mesenteries, going to put into the hepatic portal system so that it can be cleaned in the liver before putting it into sinus venosus or the posterior vena cava and send it out to the rest of the body
- Blood is coming back from the pelvic girdle through the iliac arteries
- If there was a tail it goes into caudal arteries or another wise, they would just loop but also have blood coming into the kidney and that blood in the kidney is being cleaned up from metabolic waste just like in the shark, where we have high metabolism thus they deal with it before sending the blood with high level of nitrogenous waste to the rest of the body
- Transition: simplifying the aortic, some simplification of the venous blood system as it makes its way back

Male urogenital system

- **Somites** appear when the notochord is formed
- Endoderm comes up from the gut, hits the ectoderm and rolls into notochord = causing ectoderm to roll up and make the neutral tubes = makes differentiation of the gut where it loops up with mesoderm
- The **mesodermal block** was solid with cavity and had **nephron** in it and it was repeated all the way down the length of the vertebrate embryo
- The duct that went all the way through was the **archinephric duct**
  - This duct is still present, which is used to pick up the filtrate from the excretory system
- All the nephrons fused together into a kidney but it is exactly the same thing
  - Instead of them being perfectly linearly arranged down the length of the animal, they have become fused together perfectly linearly arranged down the length of the animal and draining into archinephric duct
- The metanephridia is where gonads released gametes to outside
  - Gonads are formed on the wall of the coelom and the gametes are released into the coelomic fluid and down the metanephridia and out
- Instead of having every single metanephridia interact with the glomerulus to make nephron, a few stayed as funnels
  - Gonads are in close association with open funnels that share the ducts to outside
  - In our ancestor, there were little metanephridia funnels that ran around the glomeruli, all the way down the length of the animal archinephric duct
- If the funnels were still present, then gametes can be released into the funnels and end up using the same duct to get the gametes to outside
- Still occurring in the male and it is one of the reason why we refer to it as urogenital system b/c it is part of the urinary tract and it is part of the genital tract

Female urogenital system

- Has a set of ducts dedicated to drain the kidney and has another set of ducts dedicated to carry eggs to outside
- Male are using the original duct for transporting sperm outside and for excretory wastes

Amphibians

- Female set up two different set of pluming; as consequence, end up with **oviduct**
- But it is still a funnel; at the anterior end is opening of the funnel to the female reproductive system that is ultimately going to receive eggs from the ovary and there is necessity for eggs to move into gonad into the funnel and out to outside
- Every single female vertebrate that descents from amphibians are going to use exactly the same mechanism to get the eggs to outside of the body through the fallopian tubes and funnel

Amphibian life cycle

- One of their limitation
- Must return to water to lay their eggs and fertilize them
- They couldn't solve the problems of:
  - Waterproofing in terms of skin = dries out
  - Architecture to lift off the ground = tremendous influence of gravity & inefficient locomotion
  - Have to come back to water to lay their eggs in water
- End up with life cycle that consists of metamorphosis between a **tadpole** that is adapted for swimming in water **herbivore**, feeding on algae and plant material
  - It undergoes metamorphosis and comes out of the water **insectivore**
  - Division of different food types
- Exceptions:
  - Some frogs have blisters on the back of their body and eggs are inserted in the blisters and live inside water filled with blisters
  - Others take their eggs and put them in their mouths and keep them moist in their mouth while their tadpole swims around = nourishment
  - Others swallow the fertilized eggs and it releases hormone that shuts down the acidic production in the stomach of the frog = becomes water filled container where tadpole grows, the mother swallow and puts more food down for it and when the tadpole completes its metamorphosis, she opens the mouth and out jumps little frogs

Diapsida (Reptilia, Saurosida)

- First reptiles appeared in the late carboniferous 360 million years ago
- Different names used for taxon reflect inclusion of the birds
- **Sauropsids** are the combination of birds and reptiles
- In tree, synapsids are usually placed as a **sister group** to the diapsid

Vertebrate phylogeny
Amniota (Autapomorphies)
- **Costal ventilation**
  - Modified their bone structure, so their pectoral and pelvic girdles are more centered underneath = can stand up right but as well have ribs
  - Rib cage holds viscera in place; also has intercostal muscles = when it expands and contracts, can increase and decrease the size of the rib cage = inhale and exhale
- **Amniote egg**
  - Able to place eggs on land; suspend the embryo in amniotic sac water providing another sac with nutrients and wrap around the shell to protect the egg on land
  - Can put up egg on land and be guaranteed that nothing will eat it or attack it = huge advantage
- **Keratinized skin** = waterproofed skin
  - Tough protein; as epidermal cells move away from the base, where they grow towards outside = slowly fill with keratin and become glued together
- **Temporal fenestra** in the skull
  - Going to attach muscles to the jaw in very different way and the way they are going to be attached is going to allow for very powerful jaw to be able to feed

Amniote egg
- Membrane: extra membraes
  - **Yolk sac**: house nutrients
  - **Amnion**: house embryo
  - **Allantois**: house wastes = don't poison the environment
  - **Chorion**: surround other protective surface as well as producing the shell

Amniote eggs
- Embryo suspended in the embryonic fluid = basically compartmentalized piece of ocean in which this larval stage is developing
- Attached to the **yolk sac** = attached to where it is going to connect into the digestive system and that nutrient is being supplied to the embryo for growth development and building new tissues
- **Embryo** is going to metabolize and generate nitrogenous wastes, don't want to poison the fluid = need a very non toxic high nitrogen compound and what we end up with is **uric acid**
  - Uric acid and wastes are put into **allantois bag** = not fecal wastes just nitrogenous wastes
- **Albumin** = white of the egg; the protein that is not so much nutrient but when it is metabolized, it generates as metabolism = a whole pile of **water**
  - Albumin has nutrient role and also gives embryo water that it needs to be able to survive
  - Self contained structure that is completely surrounded by an egg shell
- One difference between insect and vertebrate = vertebrates have to fertilize the egg before putting shells on, but for insects = shells are pout on the egg with an opening for sperm to go in

Keratinized skin
- Keratin is a complex **alpha helical protein** that are wound on themselves
- They are **covalently bonded** to each other to make an extremely durable protein = hard to break it down
  - Ex. Nails, hair, bird's beak
- Often referred to as **horny structures** b/c they are made out of keratin
- Keratin can impregnate cells: glue cells together and make regenerating layer of waterproof dead cells that are constantly slurping outside of the body to waterproof the surface

Diapsida (Reptilia, Saurosida)

Temporal fenestra
- Skull has jaw and muscles that open and close; jaw attached to the inner surface of the skull
- Want more muscle mass for power of the jaw = end up with muscles that start taking up space in **cranial cavity**
- Two solutions: the reason why amniotes share temporal fenestra
  - To take the jaw muscles and have tendons move through an opening in the brain an insert muscles on the surface of the brain = just pulling the tendon inside the cranial cavity = not changing the shape
  - Diapsid do it with two holes and synapsids do it with one hole
  - For both of the groups, meant that cranial capacity was not available for the enlargement of the brain = more complex behaviours and all kinds of different things that could be done
- **Anapsid**: no opening at all; without cavity
  - They are **turtles** = don't have teeth, have beak made out of keratin similar to bird's beak
  - The carapace, shell underneath is all fused bones from vertebrae and everything else and it is believed that turtles in the fusion of their bones altered
- **Diapsids:** dinosaurs, pterosaurs, birds, snakes and lizards (Turtles)
- **Synapsid**: modern mammals

Major diapsid groups
- **Archosauria**: fossilized ones that are mostly disappeared
  - Pterosaurs
  - Dinosaurs
  - Crocodiles and birds
- **Lepidosauria**
  - Snakes, lizards and turtles
- Reptiles have tremendously diverse group of organisms of which almost all of them have disappeared in the mass extinction of the end of the crustacean or before and only have some weird survivors in the group

Reptilia, Sauropsida, or Diapsida (Autapomorphies)
- Diapsid skull: origin of the term diapsida
- **Faveolar lung:** have lateral perforation instead of branchy
  - Don't have alveoli, bag filled with air and compressed
  - Air comes down and moves through tissues and back out
- **Beta-keratinized** scales, claws and feathers
  - Going to use beta keratin as their keratinizing protein in skin for their waterproofing
  - **Synapsids use alpha keratin**

Scales and feather
- Scales and feathers are closely related to each other
- Modification on an extreme of a keratinized structure
- A plate of keratin is a **scale** (scale elongates and becomes keratinized bristle)

Beta-keratinized scales, claws and feathers
- On of the way how the birds and reptiles are related to each other
- Use the same keratin
- Scale present = thickens the plate of keratinized tissue and form a protective surface, often are interspersed with membranous areas so that there is flexibility but it is dead material
  - Makes them waterproof, tough and highly resistance to abrasion damage = coat the organism
- As a consequence, organisms have to **moult** their keratinized scales

Growth of a feather

Diapsida (Reptilia, Saurosida)

- Have little **placoid**, piece of keratinized tissue, that domes itself up and elongates = becomes the equivalence of feather in terms of structure

Evolution of feathers
- Have bristles that were hairs of feathers that were sensory
  - If they move, they distorted the receptor
- **Bristles** ultimately become tufts that provided insulative surface that were important for **thermoregulation**
  - Tufts become elaborate and end up with things like contour feathers that have very rigid shapes
- First **contour feathers** were there to protect **the downy feathers** underneath to maintain the insulative layer
- Feathers were coloration used in mating rituals and various other behaviours that are associated with the groups
- These feathers became insulative that led to **homeothermy** = keeping the body warm
- Feathers associated with flight as well
  - Flight feather = amount of branching or feathering on either side of the central vein becomes unequal
  - One side thicker than the other

Feather structure
- The main **shaft** has **vanes** off of it
- **Quills** = anchors feather to the skin
- Vanes has little **hooks** and **barbules** that lock the feather together so that organism is capable of holding the feather structure solid together
  - Part of the secrete of flying = hooks and barbules are interlocking and porous (membranous surface) that is actually extremely light
  - Membranous surface can push against and provide lift = end up with flight that is associated with the group
- The reason why birds spend so much time grooming b/c they are making sure the surface of the feather is always intact and available for flight

Feather
- **Bristles**: often on displays tops
- **Down feathers**: associated with warmth
- **Contour feathers**: associated with flight
- **Filoplumes**

Moulting
- Feathers have to be moulted as well
- The moult does not happen all at once, it is seasonal so that all feathers are not missing at one particular point in time

Origin of flight
- Insects
- Bats
- Pterosaur flight
- Brid flight 2 theories
  - **Tree-down theory**
  - **Ground up theory**

Pterosaur flight
- Not related to birds, they are independent evolution of flight
- Animal that is taken last digit of the hand and lengthened it and stretched membrane down towards the hind legs along the whole side of the body
  - Flapping with their fingers; have to fold it out of the way

Diapsida (Reptilia, Saurosida)

- When they are on the ground, they are **quadropods** = put their front forelimbs on the ground and curl their fingers up to get the membrane out of the way
- They are tremendously big organism = thus in order to fly, they have to run or jump off the cliff
  - Not agile; inefficient flying
  - They are better at gliding with a bit of lift from flapping than maneuvering

Archaeopterynx (Transition fossil)
- **Feathers with reptilian characters**; has tails with feathers on it
- When we get to modern birds, tail is gone = lightening the load
  - Going to lose teeth and beak is made out of keratinized structure that is used for ripping and tearing
- They have a lot of more bones associated with limb than birds
- In general sense, they were more of a runner
  - Used the feathers on its limbs as mechanism to sweep the air to capture insects to feed on them
- Start of the flap = escape from predators, get all of the mechanism in place for the origin of the flight
  - This is the **ground up theory**
- **Tree down theory** = fall out of the tree and stick the wings out with feathers and glide to the ground
  - When mouth is held open, got to eat insects that they ran into on the way to the ground
- the only reason diapsids are flying is b/c insects were already in the air and these vertebrates were after them as food

Feathers
- Wings have huge surface area that is created by not membrane or bones but feathers = giving light lifting powerful structure to the birds
- All of these are associated with the power to be able to create the lift that is associated with the flight

Sternal keel
- Birds have concentrated most of their mass into centralized region
- Bird's wing without feathers = a lot of tissues = legs also don't have a lot of tissues
- Everything locked in the muscles that power fly suspended right under the wings
  - What we have to lift is centralized with the lifting source
- End up with great big flight muscles that curve down on to the breast plate
- Chicken fillet is the inner muscle that lift the wings and lift the other muscle to pull it down = tremendous power associated with the organization

Body temperature

	Heat source	
	External	Internal
No	Ectothermic heterotherm	Endothermic heterotherm
Yes	Ectothermic homeotherm	Endothermic homeotherm

- End up with the situation where they need to be able to keep the body temperature at tight conscience setting
- Need to be able to ensure that all of the biochemistry of life is going to function at a predictable level
- Organisms that keep heir body temperature at a single temperature = **homeotherm** and there are 2 types:
  - Human are **endothermic homeotherm** = generate heat internally and regulate temperature specifically
  - Temperature regulated behaviourally = regulating through the environment (external heat)
    - Sitting on the warm rock to warm up and on cool space to cool down = **exothermic homeotherm**
- Animals that let their temperature fluctuate = cold blooded (reptiles, lizards)
  - Most can regulate their temperature fairly well

Environmental heat exchange
- Loss
  - Respiratory evaporation

Diapsida (Reptilia, Saurosida)

- Surface and evaporation
- Conduction
- Long wave radiation
- Convection (wind): stand on the breeze

- Gain
  - Radiant
  - Metabolic
  - Conduction: sit on something cool and let heat transfer occur
- Mammals adds sweat glands
- To generate heat: sit on the sun, pick up radiant heat or use metabolism homeotherm

Walking and respiration
- Problem on the amphibian: to be able to walk with the gate and not squeeze the lungs on each side
  - If you squeeze the lung on one side going to force air into another lung and it will expand
  - When the other side contracted and expand = going to get short air circuiting
- Reptiles and diapsids all end up with intercostal muscles
  - Added muscles to their ribs so that they can circumvent things to a certain extant

Crocodiles
- They are ancient reptiles in a sense that are still using the gate, but they have connected the liver and internal organs to a muscle
- Their **diaphragm muscle** is not for lifting and changing thoracic cavity, instead it pulls the internal organs back
- When the animal is walking, it pulls back on the liver = filling the lung and in the next movement of the leg, it pushes it forward = have set of bellows that are pulling air in and out as animal moves
- Leg movement is facilitating the oxygen transfer and are not compressing the gills

Turtles and tortoises = fused all their bones
Turtle skeleton
- Lineage of only four diapsids that come forward today = **crocodiles, turtles, lizards and birds**
- Turtles have built themselves an armoured case in which they live in and it is formed from the fusion of their **ribs**, **vertebrae** and various bones of their body to be able to make highly protective surface
  - They can't use intercostal muscle
- Turtles pump with their legs to expand **thoracic cavity**
- They often move up on land or on the edge of their front legs up and leave hind leg back in the water and pump their legs
  - Basically expanding and contracting thoracic cavity
- Turtles in fusion have take the jaw and fused the bones = have beak that is made out of keratin as their mechanism for being able to acquire food

Saurischian dinosaurs
- Dinosaurs are divided into two:
  - **Saurischian**: ischium and pubis bone are sort of parallel to each other
  - **Ornithischian**: ischium and pubis projected backwards to each other
- The example of solving the oxygen breathing issue by becoming bipedal
  - Get the limbs underneath and put the body on top
  - Moving front limbs = not going to change the thoracic cavity at all and able to use very food intercostal respiration to achieve that

Skeletal organization
- Birds is all about **compaction**, **improvement**, **light weight** and **power**
  - Making sure they can lift the mass of the body that is there
- Bones are **porous** = air filled = lighter

Diapsida (Reptilia, Saurosida)

- Little stretch and supporting rods are there to resist pressure from different directions
- Vertebrae have almost all fused and also have gotten rid of the tail
- There is **neck vertebrae**, which is elaborated **with cervical vertebrae** that allows fair amount of **flexibility**
- Added extra bone with great big **sternum** bone that allows for the attachment of the flight muscle
- Reduced bone in the limbs to support feathers

Perching
- Feet are highly modified due to perching
- The reason why digits extend and one digit extends backwards allowing them to be able to perch
- Whole leg has been modified with strong muscles

Air sacs
- **Faveolar lungs**
- Not going to fill by tidal like alveoli lungs in mammals
- Walls of the lung cavity are **perforated** and the air can move through according to perforation
  - Instead of pumping air in and out of the box, going to push air in one side and it is going through all of the openings and come out through the other
- Lungs are combined with a series of air sacs; **air sacs** divided into anterior and posterior

Avian lungs
- System that consists of the lung and passage ways
- When the intercostal muscles expand = slightly different things occur
- Expand the intercostal muscles going to expand air sac and pull air from outside down the **trachea** to **posterior air sac**
- When we squeeze the **intercostal muscle**s, going to squeeze air sac and it is going to force air into the lungs
- Fill the posterior air sac and push it into the lungs
- Next time = expand the intercostal muscles, going to pull air out of the lung and fill the anterior air sac
- Takes two cycles of expansion and contraction of air sacs to be able to move a packet of air completely through the system
- Blood inside the passage way is moving in a counter direction
- Have **unidirectional flow** of air with maximum exchange of oxygen inside very small respiratory surface
  - Unique to birds: how they take lung and put it together to be able to pump
- Fueling of the flight with tremendously food supply of oxygen to be able to do that

Bird songs – the **syrinx**
- Birds have unique sound box that is located in each of the two parts of the tracheal branches that are going to the lung
- Have a set of membranes that vibrate in four different locations
- These membranes are able to vibrate differently from each other
  - Can sing different notes; potentially produce four different notes at one time
  - These four different notes can be complex and are origin of the social behaviour that is associated with the group
- With extra vibrating membrane, can get complex song and complex behaviours
  - Adding colour and plumage – can start to understand the social behaviours that are so typical of where they arise from the tremendous communicative skills

Circulatory system
- **3 chambered heart = most reptiles**
- **4 chambered heart = crocodiles and birds**

Reptilian heart
- Have fully dedicated **dual circuit system**

Diapsida (Reptilia, Saurosida)

- Started to appear in the amphibians but it was not used consistently
- Get into the diapsid and going to be the same with synapsid: have **pulmonary circuit** that is going to take blood **lungs return back to heart rest of the body**
- In the **lepidosaurs** with three chambered heart, the same issue that were thought to be problematic in the amphibians is occurring: send a pulse of blood out to the **lungs come back and put it in the ventricle squeeze the ventricle send it out to the body**
- Fourth chamber: every time heart beats, going to send blood to the pulmonary and **systemic circuit**
  - Not doing heart beat pulmonary heart beat systemic
  - Supplying both of them at once with four chambered heart
- Valves of the lepidisaurs do assist with that a bit but most efficient with four chamber

Circulatory system
- Everything is gone = still got carotids that moves forwards, lost first and second, lost part of sixth
  - Have a set that is going to the lung and only one of the pairs of arches are now involved
  - Arch is not sending out to the body and to lung; got one that is dedicated to the lung

Arterial circulation
- Aortic arch **fourth** is going up to become the two systemic arches that are going to join to be dorsal
- Remnants of other two are still moving forward as carotids
- Number **six** is supplying the lungs only
- Gone from six aortic arches five four two
- Everything else if the same except they are down to **two aortic arches**

Venous circulation
- **Posterior vena cava** is extending the whole length of the body and collecting blood from the kidneys, from the hepatic, from intestine and still have some lateral abdominals that are associated with the blood coming from the limbs but for the most part, all of the area is starting to simplify
- Got **jugulars** coming back and supplying

Circulatory system
- Get one aortic arch that is going to supply the whole body
- Number six is going out to the lung
- Number four = instead of being paired in both directions, now one blood vessels

Arterial circulation
- Have **carotids** going forward, but instead of having two systemic arches that have to form to meet the dorsal aorta, have one that is coming out and everything else is branching off of that
- Stream lining the whole arterial supply = one vessel that goes all the way to the back and **subclavian** and everything else comes off that like it did before
- In reptiles, always the right arch that is retained
- For synapsid, it is the left

Venous circulation
- Posterior vena cava is one large blood vessel that kicks in where the renal kidneys are and everything from the posterior are moving into the kidneys
- There is small artery that is associated with coelomic space in the **mesenteries**
- Now have one blood vessel bringing back blood all the way to the heart = shunting through **hepatic and renal systems** on the way
- Improving circulatory system

Crushing jaws

Diapsida (Reptilia, Saurosida)

- Jaws are powerful crushing jaws designed to immobilize prey
- The whole point of immobilizing the prey is so that you can thrash around and tare it
- Not at the point where they are chewing small pieces off, this is the synapsid thing
- Mammals are going to be best known for the fact that they have set of teeth that do entirely different things
  - Those set of teeth preprocess the food
- The best that the diapsids are going to be able to do is to be able to clamp down on food and hope to tare a piece off of it
- Powerful jaw that clamp shut but very weak for opening

Snake venoms
- Lost its skeleton (no appendicular skeleton present)
- How did they survive mass extinction? Due to their burrowing habitat = much more stable environment
- Have no arms or limbs to be able to deal with prey
- All of the snakes have to immobilize their prey = very powerful venoms present
- Or they wrap themselves around the prey and clamp down on the lungs of the prey to fixate them so they can't breathe

Snake's jaw
- Unique jaw with extra joints in it
- Extra joint = can take their double hinged jaw and open it up wide and completely ingest the food that they are feeding on

Bird beaks
- Gotten rid of the bony jaw and bony teeth
- End up with series of beak or bills that are made out of keratins (horny structures)
- Beak shape is modified for what it feeds on
- Feeding diversity met by the beak

Digestive system
- Not preprocessing the food or tearing it to any degree
- They always have **crop** where food is stored as birds move in different locations
- Have **gizzards** consisting of small stones or pebbles and muscular action of the gizzard grinds up the food that are ingested
  - Some birds have keratinized surface within the gizzard
  - Gizzard is where the final grinding of the material occurs

Reproduction
- Biggest different between the two are: reptilian egg is leathery and keratinized whereas the bird egg has been mineralized by adding calcium in it
- Either case, the developing embryo develops and there is some form of parental care associated

Female
- In bird, there is simplification of the reproductive system as a way to be light
- There is only **one ovary** = ovary not paired anymore
- An ovary also disappears down to a rudiment when it is not the reproductive season for the bird
- Grow ovary structure as they require them and if going to only make few eggs, there is no reason of having two ovaries

Parental care
- Birds incubate and take care of their eggs and protect them = thus, only few offspring are produced
- Those offspring may fledge and disappear right away

Diapsida (Reptilia, Saurosida)

- Other birds, the young hang around for about a year or so to be able to learn how to hunt and how to find prey, learn to figure out the migration pathways
- Migration is the key to particular group

Synapsida (Mammalia)

Reptiles – **Therapsids**
- Warm blooded
  - How to use metabolism to keep the body warm (can go out at night and hunt)
- Nocturnal
- **Glandular skin**
  - Communicated with each other by sense and smell
  - Tied to the fact that they are thermo-regulating their bodies b/c there were some cases with a bit of hairs on the organism
- Specialized teeth and chewed their food
  - Teeth that did different things down the length of the jaw

Mammalia (Autapomorphies)
- Synapsid skull
- Glandular alpha-keratinized skin: waterproofed with alpha keratin
- Lactation from mammary glands: how they nourish their young
- **Heterodont**, deciduous teeth: teeth are different on different locations on the jaw
  - **Deciduous**: animal tend to grow and jaw gets bigger = have set of teeth and shed the teeth and grow adult teeth
- **Alveolate lungs**: sac like alveoli that are filled and empty
  - Tidal flow of air
- **Nephric loop-of-Henle**
  - Special water conserving loop of Henle
  - In dry environment = need a big loop of Henle

Integument
- Skin contains the outer layer of **keratinized dead cells** = waterproofing the skin
- At the base of the follicle, keratinized structure is built and this is called **hair**
- First one was probably tactile = **sensory whisker** that gives information about the surrounding when they burrow in dark environment
- As animals evolve, hairs appear all over the surface and becomes insulative = part of the holding onto the heat that animals generate by being **nocturnal**
- End up with **rector muscles** that make the hair rise as the organism chills and get insulation occurring
- Have glands that have to keep the keratinized structure well conditioned so it doesn't become brittle
- Have **sebaceous glands** that adds wax to the hair to prevent them from becoming brittle
- Have glands that are going to secrete **sweat** to the surface for evaporating = cooling and also glands that are going to **secrete odours/smell** to the surface for communication

Types of hair
- First hair = whiskers for sensing in the dark insulative surface with guard hairs, which are thicker hairs
- **Vibrissae**
- **Quills**
- **Underfur**
- **Guard hairs**

Countercurrent heat exchange
- Maintain constant core temperature and let the extremities cool down
- Arctic wolf:
  - Its feet at the tip are just below freezing, but what is happening is that cold blood circulating up into the core
  - Cools the warm blood that is coming out and the warm temperature remains constant and these organisms are ultimately able to function in all of the different environments

Synapsida (Mammalia)

Mammalian dentition
- Deciduous and diphyodont
- Types of teeth
  - **Incisors**: tare pieces of food apart
  - **Canines**: piercing teeth for bringing down prey; puncturing lungs and being able to hit major blood vessels
  - **Premolars**
  - **Molars**
- Group capable of pre processing the food
- Cow = capable of grinding the plant material up and being able to pulverizing to release nutrients
- It is supplemented by a ruminant stomach, get bacteria to help with it

Shrews
- **Insectivores**
- Don't see much change in teeth = much like the chronical teeth that are associated with reptiles

Rodent skull – Squirrel
- **Massive incisors**
- Incisors designed to chew away wood or one of the plant defence was to coat the seed in a hard nut
- Whole point of incisor is to break the nuts inside

Skull of an herbivore – Rabbit
- Nothing but **clipping teeth**
- **Incisors** are at the front and **molars** to grind at the back to be able to deal with plant materials
- Eat the plant material, pass it through the digestive system and put the rabbit pellets at the back
- They re-consume the pellets b/c they are loaded with bacteria, which becomes the food

Skull of an herbivore – Deer
- Same situation but different stomach

Ruminant stomach
- Ruminants use the grinding teeth to be able to take the plant material and place it into the stomach to ferment for awhile then regurgitate it back forward = **chewing the cud**
- Inoculating the plant with bacteria to bring about the digestion so that they can get nutrients out

Predators – Cats
- **Big canines** to be able to puncture lung or major blood vessels

Omnivores – Raccoon
- Eat anything
- Jaw has little bit of everything in there

Kidney
Nephron
- **Loop of Henle**: going to take the filtrate and plunge it into high salt concentration and bring it back out
- Loop of Henle is permeable to water on the descending loop as it's going down in the loop, any water is being pulled into the region of the **kidney** b/c the core is loaded with **urea**
- Excretory duct moves out of the kidney, urea that is being concentrated is leaking out = every time we are filtering bringing the urea concentration up
- The duct comes down, loses its water and descend up then becomes impermeable to water (water can't get out)
- What have been done: pull water out concentrate urea come up the other side recover some of the minerals, but have to turn it to a very highly concentrated urea solution
  - Scavenging every single little bit of water with loop of Henle

Synapsida (Mammalia)

- **The longer the loop = better scavenging at water = dry environment**
- Instead of having kidney that has a fixed capacity, it has the capacity to concentrate urea very high

Respiration
- Have **diaphragm**, **intercostal muscles**
- **Trachea** leading to **bronchi** with **alveoli** at the end

Dual circuit heart
- **Four chambered**, directing everything to locations just like crocodiles and birds

Circulatory system
- Biggest difference is when reducing, **one aortic arch** is on the **left** side this time instead of right

Arterial circulation
- Everything is pretty much the same as birds, except that it is on left in terms of the pressures that create unique flow all the way through the length of the body

Venous circulation
- Like the birds, but starting to really clean itself up
- Have one large cavity where all the **blood is collected from the posterior region** of the body
- All of them lead into all the appropriate locations and still have situation at the front, where anterior is collecting through jugular

Reproduction
- **Oviparous**
  - Monotremes: still lay eggs
- **Viviparous**
  - Marsupial
  - Placental mammals

Monotremes (Prototheria)
- Females of all the mammalian species: **mammary gland** with feeding tits appear wherever the holding point is for the young

Marsupials (Metatheria)
- Internal production of the egg that produces a little embryo called **joey**
- Joey is extremely small and climbs out of the uterus up into the pouch and attaches itself to the tit where it is going to get mammary secretion that is going to nourish it
- Live in there until it is mature enough
- Has stalled embryo in development that will not develop until the mature young leaves
- If joey were to stay in the uterus too long, it would be seen as a foreign object and will be rejected

Placental mammals (Eutheria)
- Able to get the embryo through the blood barrier of the placenta to be nourished by the female without being rejected
- **Placental barrier** allows to be able to cooperate with each other
- There is blood supply that is attached

Fetal circulation
- Shunt everything through the fetus and placenta
- The young offspring born is going to be able to change the blood circulation flow and respiratory system kicks in