ORGANISMIC BIOLOGY

I. Designed for understanding the origin of the diversity of life
a) It is hard to miss that there are many kinds of life organized in some logical pattern.
- mammals
- carnivores
- cats
- African lion
- trees
- conifers
- pines
- lodgepole pine

b) A primitive stone-age society in New Guinea was found to have 138 names for what modern taxonomists have given 139 species names to. It does not take modern science to make a good naturalist.
c) By the end of the 17th century Europeans were giving names to plants used for medical purposes and writing them along with plant descriptions in books called herbals.

II. Carolus Linnaeus = Swedish (1707-1778)
a) Formalized the modern scientific system of nomenclature.
b) Starts with “Species Plantarum” 1753 edition
c) Binomial system of nomenclature = 2 names per species
   1) First name is generic = genus which is capitalized
   2) Second name is specific = species starts with lower case letter
   3) Name given Homo sapiens, Homo sapiens, or Homo sapiens = in Latin = man wise = humans
d) Hierarchical system of nomenclature = grouping of similar species in the same genus, similar genera in the same order, similar orders in the same class.
   1) Later scientists added other categories (taxa)

III. The origin of species
a) Linnaeus thought that each species existed as God made it.
b) Linnaean taxonomy was based on the Greek philosophical idea of an ideal type as created by God
c) Type specimens, the first collection for a species, are still used by science to define a species.
d) By the 19th century, this idea of an ideal type was breaking down because
   1) Individual within species were seen to vary greatly
   2) Fossil collections were increasing and needed an explanation
   3) Embryological stages of different species were more alike than adults of the species.
e) Charles Darwin’s book “The Origin of Species” in 1859 gave an explanation consistent with these observations that is the foundation of the modern scientific understanding of biology.
f) Science did not well understand his ideas until 1930 and the ideas are still in conflict with the religious beliefs of many people.

African lion = Panthera leo

<table>
<thead>
<tr>
<th>taxon (taxa)</th>
<th>name</th>
<th>another group in the taxon</th>
</tr>
</thead>
<tbody>
<tr>
<td>species</td>
<td>leo</td>
<td></td>
</tr>
<tr>
<td>genus (genera)</td>
<td>Panthera</td>
<td>leopards (pardus)</td>
</tr>
<tr>
<td>family</td>
<td>Felidae</td>
<td>bob cats (Lynx)</td>
</tr>
<tr>
<td>order</td>
<td>Carnivora</td>
<td>dogs (Canidae)</td>
</tr>
<tr>
<td>class</td>
<td>Mammalia</td>
<td>rodents (Rodentia)</td>
</tr>
<tr>
<td>phylum (phyla)</td>
<td>Chordata</td>
<td>birds (Aves)</td>
</tr>
<tr>
<td>kingdom</td>
<td>Animalia</td>
<td>mollusks (Mollusca)</td>
</tr>
<tr>
<td>domain</td>
<td>Eucarya</td>
<td>plants (Plantae)</td>
</tr>
</tbody>
</table>

III. The origin of species
a) Linnaeus thought that each species existed as God made it.
b) Linnaean taxonomy was based on the Greek philosophical idea of an ideal type as created by God
c) Type specimens, the first collection for a species, are still used by science to define a species.
d) By the 19th century, this idea of an ideal type was breaking down because
   1) Individual within species were seen to vary greatly
   2) Fossil collections were increasing and needed an explanation
   3) Embryological stages of different species were more alike than adults of the species.
e) Charles Darwin’s book “The Origin of Species” in 1859 gave an explanation consistent with these observations that is the foundation of the modern scientific understanding of biology.
f) Science did not well understand his ideas until 1930 and the ideas are still in conflict with the religious beliefs of many people.

There are two basis parts to the evolution of the diversity of life.
1) Evolution of life, or the change of life over time, is driven in an adaptive direction by natural selection based on 6 general observation by Darwin.
   a) There is extensive variation among individuals of a species
   b) Some of this variation is inherited.
   c) All species have a geometric or exponential potential rate of population increase (from Malthus).
   d) Resources are finite (from Malthus).
   e) Some variants work better than others (are more adaptive)
   f) Those variants that work better in an environment will leave more progeny in that environment in the next generation and will make up a greater fraction of the population in the next generation.
   2) Natural selection explains the change of one species through time but it does not explain how one species becomes two reproductively isolated species = speciation.

a) Biological species definition = group of actually or potentially interbreeding individuals in natural populations which are reproductively isolated from other such groups
b) Speciation is a 3 step process in most cases.
   1) Separation of 2 subpopulations from one original species by a geographical barrier
   2) The 2 subpopulations evolve genetic differences in separate environments over time
   3) Removal of the geographic barrier and failure of the 2 subpopulations to interbreed = reproductive isolation.

a) Natural selection is a better explanation because the apparent design in nature is far inferior to what could be done by a competent engineer to make functional living structure. The human back bone in its vertical position makes crushed intervertebral discs while no such problem exists in
horizontal back bones in other vertebrate organisms. Life can only evolve from preexisting life so that when upright posture was of great advantage in freeing the hands from locomotion in human ancestors it brought along with it the lesser disadvantage of the potential for crushed discs.

IV. The origin of diversity is by repeated speciation and evolution between speciation guided in a large part by natural selection. The whole process is called adaptive radiation.

---

Idealized Adaptive Radiation of a Class of Organisms

---

V. The basis of grouping organism in a hierarchical system of nomenclature is now bases on common ancestry.

a) Linnaeus grouped species on the basis of similar morphological structures
   1) He placed all worms in the same class: Vermes, even though they have very different evolutionary origins.
   2) He did not place all flying animals in the same group
   3) He judged the importance of the character: having wings was less important than having 6 legs and a surface skeleton.

b) With Darwin’s evolution by natural selection and speciation, taxonomic groups (taxa) could be based on phylogeny = patterns of ancestry for species.
   1) Homologous characters = characters that are similar because they share a common ancestry or phylogeny,
      a) human arm, bird wing, bat wing, dolphin flipper, frog foreleg, lung fish pectoral fin all have the same proximal bone = the humerus evolved from the ancestral lung fish pectoral fin.
   2) Analogous characters = characters that are similar in function but do not have a common evolutionary origin.
      a) insect wing and bird wing are analogous because they do not have a common ancestor with a wing or an exoskeleton.

---

THE PROBLEMS OF LIFE: Thinking like a Protistan

In reality we cannot think like a single-celled Eucaryan.

But, as in trying to put yourself in the place of another person, you can gain from trying to understand the problems a Eucaryan has to overcome in order to make a living and leave offspring.

The first problem was not big enemies, but instead, little competitors in the domains of Bacteria and Archaea.

I. The fossil record is incomplete! We cannot get a complete picture of the past.

a) We know roughly:
   1) Earth 4.5 billion years old (byo)
   2) Bacteria 3.5 byo
   3) Single-celled Eucarya 1.5 byo
   4) Multicellular kingdoms 0.9 to 0.6 byo
   5) Invasion of land 0.4 byo

b) Each major step above made a large jump in organic diversity.

c) Fossils showing detailed anatomy are only about 0.6byo for the animals that first had hard parts like shells, skeletons, and teeth.
   1) All major phyla were already in existence at that time
   2) Our knowledge of the phylogenetic relationships of phyla comes from
      a) morphological similarity of phyla
      b) similarity of protein, RNA, and DNA sequences among phyla
      c) similarity of patterns in ontogeny (embryological development) among phyla
      d) developmental genetics
THE TIMING OF THE EVOLUTION OF KINGDOMS

<table>
<thead>
<tr>
<th>BYO</th>
<th>0.7</th>
<th>1</th>
<th>1.5</th>
<th>3.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>prokaryote</td>
<td>eukaryote</td>
<td>eukaryote</td>
<td>prokaryote</td>
<td>prokaryote</td>
</tr>
<tr>
<td>Bacteria</td>
<td>E. coli</td>
<td>Plantae</td>
<td>Plantae</td>
<td>Plantae</td>
</tr>
<tr>
<td>Archaea</td>
<td>Methanobacterium</td>
<td>E. coli</td>
<td>E. coli</td>
<td>E. coli</td>
</tr>
</tbody>
</table>

Prokaryotes: Domain Bacteria = both are single cells, no nuclear membrane or other membrane-bound organelles

Domain Archaea = membrane or other membrane-bound organelles

Eukaryotes: Domain Eucarya = about 16 kingdoms having single cells, with membrane-bound nuclei and other organelles

Kingdom Plantae = multicellular, chloroplasts, cellulose cell walls, chlorophyll b

Kingdom Animalia = multicellular, no cell walls, neuromuscular except sponges

Kingdom Fungi = multicellular, chitinous cell walls, extracellular digestion

Kingdoms Rhodophyta and Phaeophyta = multi-cellular sea weeds lacking chlorophyll b

Microbiology deals with prokaryotes.

Organismic Biology deals with eukaryotes.

II. The origin of Eucarya

a) What could Eucaryans do that bacteria could not do?

1) move and eat faster

b) Why didn’t bacteria just get bigger and bigger and move and eat faster and faster? What are the problems of big bacteria?

1) If the diameter of a cell is doubled then the rate of diffusion across the plasma membrane must be doubled in order for metabolism at the middle of the cell to continue at the same rate. It is most efficient to move material by diffusion if you are small.

2) Eucarya could increase in size because they bound things in membranes and moved the whole membrane around inside the cell. Membranes became a circulatory system in cells instead of diffusion.

a) mitochondria = energy factory for forming ATP from covalent bonds

b) chloroplasts = trap light energy to form ATP and make covalent bonds

c) endoplasmic reticulum = synthesize macromolecules and move them around

d) Golgi apparatus = generate membranes

e) microsomes or food vacuoles = digestion of macromolecules

f) nucleus = isolation of RNA production

g) 2+9 microtubule flagella = better cell locomotion

c) Lynn Margulis had the idea that Eucarya formed by fusion and cooperation of different kinds of bacteria in a symbiotic relationship, i.e. live together.

d) This symbiosis was mutualistic = benefiting all prokaryotic species participating.

e) evidence of prokaryotic mutualism

1) mitochondria have their own separate DNA

2) chloroplasts have their own separate DNA

3) flagella are modified from bacterial flagella

III. Why should faster movement be better for photosynthetic Eucarya?

a) movement against water current increases contact with minerals which are limiting because dead bodies fall out of the photic zone where light is.

b) movement also leaves wastes behind, i.e. ammonia and oxygen

IV. If Eucarya are better than Bacteria, why are bacteria still here?

a) Anaerobic conditions are only used by bacteria. 

b) Nitrogen-fixing photosynthetic bacteria make their own nitrile and are not nitrogen limited.

V. Domain: Eucarya

a) Old taxonomy grouped the single-celled Eukarya as “protozoa” (small animals) and algae (plants) and only had 2 kingdoms.

b) Some of the animal-like groups of Protists are

1) Kingdom: Ciliophora = ciliates (Paramecium) with a life style of engulfing bacteria and Protists

a) oral groove, food vacuoles, and cytopyge = gut in function

b) genetic recombination at fusion involves exchange of haploid nuclei = meiotic based reproduction

c) very analogous to small animals

2) Kingdom: Entamoeba = cause of amoebic dysentery. Amoeboid cells are found in other eucaryotic kingdoms with the life style of engulfing protists and bacteria or cell debris with ameboid or food vacuoles. Such cells are also found in animal phyla from sponges to chordates.

3) Kingdom: Euglenoza = Euglena has a photosynthetic life style with flagella for locomotion, but can also feed on macromolecules or bacteria and have parasitic forms like Trypanosoma that causes sleeping sickness.

4) Kingdom: Apicomplexa = malaria (Plasmodium) and other parasites of single cells in animals. A life stage in one animal cell can form many spores causing the cell to burst and the spores to spread to invade other cells.

5) Another life style is filter feeding on bacteria and small plankton by cells called choanoflagellates. These cells have a collar on top covered with mucus which traps small planktonic organisms drawn to the collar by a whipping flagellum coming out of the center of the collar. They have essentially the same structure as the feeding cells in sponges and are thought to have given rise to and are included in the Kingdom: Animalia even though they may function as single cells.
VI. Kingdom: Animalia = animals
   Phylum: Porifera = sponges
   a) Sponges are essentially colonies of choanocytes (collar cells) that are indistinguishable from choanoflagellates. The choanocytes are embedded in a proteinaceous matrix (mesohyle) formed from materials captured by the choanocytes and moved by amoeboid cells (amoebocytes). The amoebocytes also form either calcium carbonate or siliceous spines (spicules) or protein (spongina) which support and protect the animals. The channels of water in the sponge are lined by either choanocytes or an epithelium of pinacocytes.

   b) Although the level of organization of a sponge is a colony of cells, regeneration experiments show that individual cells recognize which individual sponge they come from and sponges compete with each other as genetic individuals.
   c) Sexual reproduction is by sperm fertilizing an egg in a different sponge and a ciliated larva forms from the zygote and swims to settle and form a new genetic individual.
   d) Asexual reproduction is by budding off pieces of a large individual sponge and also in fresh water by a resistant over-winter stage called a gemmule formed by an adult sponge.

Phylum: Cnidaria = hydra, jelly fish, anemones, corals, etc.

1. Tissue level of organization
   a) first phylum to have cells work together to accomplish one function
   b) 2 functional tissues
      1) epidermis = outer layer to sense and capture prey
      2) gastrodermis = inner layer to digest and absorb prey
      3) separated by a 3rd layer = mesoglea
         a) only a few amoeboid cells to move materials in watery matrix held together by protein
         b) has support and nutrient storage function
   c) These 3 layers may be either homologous or analogous to the 3 body layers of more organized animals.
      1) ectoderm ? = epidermis = lines the outside of the body
      2) mesoderm ? = mesoglea = main organs
      3) endoderm ? gastrodermis = lines the gut
   d) More organized animals have muscle, bone, excretory system, reproductive system, and circulatory system come from mesoderm

II. The 3 body layers are organized in two distinct body plans.
   a) sessile polyp
   b) swimming medusa
   c) both are radially symmetrical

   d) radial symmetry = symmetry around a line or axis that is usually vertical. Any plane that is parallel to and includes the central axis will cut the organism into two mirror images. An apple is radially symmetrical with the core as the central axis.
e) Polyps and medusae have vertical central axes which allow them to respond the same way in any compass directions at the same time. Only up and down are different. This is useful to organisms that cannot move towards specific stimuli, but rather have their food or predators move towards them from any side.

f) The two body plans are involved in a complex life cycle that is not like plants because in Cnidaria all stages except the gametes are diploid (have two sets of chromosomes = 2n).

g) The planula larval stage is also radially symmetrical, but has a horizontal central axis. It is radially symmetrical like a torpedo, only anterior and posterior ends of the larva are different as it moves horizontally along the substrate. The top and the bottom of the larva are not different as it moves horizontally. If the top and bottom were different, then the planula larva would be bilaterally symmetrical which could be how bilaterally symmetrical animals first evolved.

h) The planula larva uses cilia to swim to a place to settle and form a polyp.

---

CNIDARIAN LIFE CYCLE

III. So how does this body plan allow Cnidaria to make a living?

a) **Cnidocytes** = specialized cells that manufacture

b) **Nematocysts** = small harpoon-like structures that fire into and catch prey.

---

CNIDOCYTE WITH ITS NEMATOCYST FIRED

1) After manufacture the harpoon is hollow and inside out and under pressure inside its capsule. When fired the pressure is released which suddenly inverts the harpoon forcing its point and barbs into the outside of its prey.

2) It contains poison which quiets or kills prey even humans for some of the largest species of medusae.

3) It requires both chemical and physical stimuli in order to fire.

4) It can only be fired once and if stimuli were only physical it would fire on its own tentacles. If the stimuli were only chemical it would fire before its prey were close enough to be hit.

5) Some animals have evolved a chemical makeup that makes them immune to nematocysts

   a) **Damsel fish** live in anemones’ tentacles for protection.

   b) **Nudibranchs** (colorful sea slugs) feed on clonal polyps and incorporate the unfired nematocysts into their own back for defense.

---

c) Marine sunfish feed on medusae.

c) The cnidarian body bends by **epitheliomuscular cells** = epithelial cells with muscle fibers extending from the base. The muscle contraction is coordinated by a nerve net in among the muscle fibers.

1) The epitheliomuscular cells and nerve net move the tentacles to the mouth in feeding.

---

EPITHELIOMUSCULAR CELLS AND NERVE NET

d) The gastrodermis lines the gastrovascular cavity which is a blind pocket (i.e. mouth and anus are the same entrance).

1) Digestion of large animals (i.e. fish) is started by enzymes secreted into the gastrovascular cavity.

2) Small partially digested particles are taken into the gastrodermis by phagocytosis to finish digestion in microsomes.

IV. Three classes of Cnidaria

a) **Class: Hydrozoa**

1) Polyps and medusae in most marine forms like *Obelia* with fresh water (Hydra) having only a polyp

2) Most are marine with colonial polyps with interconnecting gastrovascular cavities like the vascular tissues of plants so that different parts of the colony can pass food to make reproductive polyps to bud off medusae. Feeding polyps are like leaves on a plant and reproductive polyps are like flowers.
b) **Class: Scyphozoa** = medusa and very small polyp in *Aurelia* or medusae only in many species. All are marine.
   1) Jelly fish can be very large (4 meters across) and swim by contraction of a ring of muscles around the medusa (can swim to light).

   c) **Class: Anthozoa** = polyp only which can be solitary like the sea anemone (*Metridium*) or colonial like most corals. All are marine.
   1) Corals lay down a subtending skeleton of calcium carbonate. The skeleton is the origin of atoll islands that we fought Japan for in WWII.

---

**V. Other general characteristics**

a) All three classes have many members that form **mutualistic symbiotic relationships with photosynthetic single-cell Eucarya**.
   1) Transparent tissue of Cnidarians let light through for photosynthesis and **protect the Eucarya from being eaten**.
   2) Cnidarians receive some carbohydrates formed by the single-celled photosynthetic Eucarya.

b) Many medusae are **bioluminescent** by catalyzed ATP dependent reactions.
   1) Most likely the light is a **sexual signal for joint spawning of gametes by male and female individuals**
   2) Medusae come to a night light on a pier like moths to a light on land, but for different reasons.

---

**Phylum: Platyhelminthes** (flat worms)

I. **Bilateral Symmetry**

a) anterior and posterior ends when moving, i.e. front and back
b) **dorsal and ventral** end of the organism
   1) cut by a **mid-sagittal plane** into right and left halves that are mirror images
   2) coupled with bilateral symmetry is **cephalization** = a tendency to concentrate most of special sensory organs at the anterior or head end of the organism
   1) smelling – olfactory – nose – chemical
   2) seeing – visual – eyes – light
   3) hearing – auditory – ears – sound
   4) balance – **orientation and proprioception** = semicircular canals, statocysts and muscle proprioceptors = gravity and posture.
   5) touch – **tactile** = less concentrated in the head – physical presence

   In addition to the anterior position of the sensory organs, the nervous control of the body is centered in the head in the form of the **anterior ganglion or brain**

---

II. **Organ systems** = groups or tissues that work together to achieve some larger general function.

a) **respiration** = gas exchange \(O_2\), uptake or \(CO_2\) release (ectoderm, mesoderm, and/or endoderm)
   b) **digestion** = break down and absorb food (endoderm)
   c) **circulation** = move gases and food products around the body, i.e. transport (mesoderm)
   d) **excretion** = 1) **osmotic regulation** = maintaining the ideal concentration of dissolved substances in the body fluids and 2) **voiding of nitrogenous wastes**, i.e. ammonia, urea, and uric acid (mesoderm)

   e) **nervous** = coordinate body activity (ectoderm)
   f) **sensory** = perceive the outside environment (ectoderm and mesoderm)
   g) **reproductive** = production and exchange of gametes between sexes and protection of developing offspring in some animals (mesoderm)
III. Three Body Layers

a) **ectoderm** = outer epidermis of the body, the nervous system, and parts of the sensory system and parts of the respiratory system in animals that have gills.

b) **mesoderm** = between the ectoderm and the endoderm to form parts of the respiratory and sensory systems and all of the circulatory, excretory, and reproductive systems.

c) **endoderm** = lining of the digestive system and vertebrate lungs of the respiratory system.

1) In a sense food in the digestive tract is not in the body until it broken down into sugars, amino acids, and fatty acids and other small molecules that can leave the digestive tract and enter the circulatory system. The lumen of the gut is continuous with the outside and materials like small glass beads pass through the gut as though they were not in the body. In that sense both the ectoderm and endoderm line the body and the mesoderm makes most of the structures in between, except for the nervous system.

IV. Flat worms are divided into 3 classes

a) **Class: Turbellaria** = flat worms = free living carnivores or carrion feeders = fresh water and marine.

b) **Class: Trematoda** = parasites in body tissues in 1 to 3 host species per fluke species, therefore with complex life cycles.

c) **Class: Cestoda** = tape worms = parasites in the guts of vertebrates and usually another host species.

1) The two parasitic classes are derived from Turbellarians by loss of feeding structures and expansion of reproductive structures.

V. Turbellarian biology

a) Locomotion is accomplished by cilia working against mucus secreted by many glands on the ventral surface.

b) **nervous system** = anterior ganglion and lateral nerve net.

c) **sensory organs**

1) eye is light sensitive to avoid dark, but forms no image.

2) olfactory and tactile cells over the whole surface of the body.

3) a few species with statocysts.

4) some species with special sense to detect currents.

5) no ear (the auricle is not an ear).

d) **digestive system** with

1) muscular pharynx that extends to suck in food.

2) three part branching gut.

3) one opening to gut serves as both mouth and anus as in cnidarians.

e) **excretory system** = protonephridium = flame bulbs with beating flagella in blind tubes extending to the outside at nephridiopores.

f) **reproductive system** = hermaphroditic with both sexes in one individual.

1) **internal fertilization** with complex organs.

g) **no circulatory or respiratory organs** = both functions are at the body and gut surfaces.
III. Nematode biology

a) The pseudocoelom may not be the primitive character, but rather a reduced function of circulation and respiration in phyla that tend to have very small individuals.

b) The pseudocoelomate phyla are also characterized by cell constancy. Each member of a species has the same number of relatively large cells and cannot form new cells to repair wounds.

1) very determinant development
2) used to study strict genetic control of development and the genetic control of senescence

b) The pseudocoelomate phyla are also characterized by cell constancy. Each member of a species has the same number of relatively large cells and cannot form new cells to repair wounds.

1) very determinant development
2) used to study strict genetic control of development and the genetic control of senescence

c) lack circulatory and respiratory systems which may be aided by their small size and the pseudocoelom

d) sexes are separate = dioecious with internal fertilization

e) locomotion by random whipping resulting from contraction of longitudinal muscles without counteracting circular muscles

f) natural history in soil, aquatic sediments, and parasites in animals and plants

1) parasites in vertebrate guts are large (Ascaris)

2) parasites through body tissues in filarial worms causing elephantiasis, trichinosis, river blindness, etc.

3) nematodes are common in soils where they eat bacteria

4) also related to soils, nematodes are parasites in plant roots

---

Phylum: Mollusca

I. This phylum is more diverse morphologically and has more named species than any phylum except Arthropoda

a) Some squid are larger than any other animals except baleen whales: A squid’s eye may be as much as 12 inches in diameter.

II. To put mollusks in evolutionary perspective we must digress to a consideration of embryological development.

a) In sexual reproduction a haploid sperm fertilizes a haploid egg to form a diploid zygote of one cell.

1) haploid = 1 set of a species’ genes
2) diploid = 2 sets of a species’ genes

b) In multicellular animals the zygote divides into many cells by the process called cleavage.

1) Cleavage occurs in two general forms.
   a) spiral cleavage where in going from 4 to 8 cells by a horizontal cleavage, the top 4 cells are only slightly smaller than the bottom 4 and they are lined up directly above the cells below. Future horizontal divisions are the same.
   b) radial cleavage where in going from 4 to 8 cells by a horizontal cleavage, the top 4 cells are only slightly smaller than the bottom 4 and they are lined up directly above the cells below. Further horizontal divisions are the same.
   c) The determination of the fate of these cells resulting from early cleavage also has 2 distinct patterns:
      1) determinant development = If one cell is removed from the 4 cell stage, it will develop abnormally and tend to make only ½ of the structures of a larva and will die before many more divisions.
      2) indeterminant development = If one cell is removed from the 4-celled stage, it will develop into a small, but otherwise, normal larva and into a normal adult. i.e. identical twins in humans

d) Cleavage proceeds until there are many (usually 100’s) of small cells which form a solid ball of cells called a morula. Later as the cells continue to divide they hollow out to form one surface layer of cells called a blastula.

---

b) radial cleavage where in going from 4 to 8 cells by a horizontal cleavage, the top 4 cells are only slightly smaller than the bottom 4 and they are lined up directly above the cells below. Further horizontal divisions are the same.

c) The determination of the fate of these cells resulting from early cleavage also has 2 distinct patterns:

1) determinant development = If one cell is removed from the 4 cell stage, it will develop abnormally and tend to make only ½ of the structures of a larva and will die before many more divisions.
2) indeterminant development = If one cell is removed from the 4-celled stage, it will develop into a small, but otherwise, normal larva and into a normal adult. i.e. identical twins in humans

d) Cleavage proceeds until there are many (usually 100’s) of small cells which form a solid ball of cells called a morula. Later as the cells continue to divide they hollow out to form one surface layer of cells called a blastula.

---

a) spiral cleavage

b) radial cleavage

e) The next stage rearranges this ball of cells by a process called gastrulation which is pushing in or indenting of one side of the blastula like poking in one side of a flaccid beach ball. This process of indentation of the blastula is given the scientific name of invagination. Therefore, gastrulation occurs by invagination of one side of the blastula. The resulting gastrula is a two layered cup shaped structure.
During the process of gastrulation a third layer, mesoderm, is formed between the ectoderm and the endoderm in two different ways.

1) Individual cells migrate into the blastocoel to form the mesoderm layer where a secondary cavity in the mesoderm becomes the coelom. This process of mesoderm and coelom formation is called **schizocoelous** coelom formation.

2) Mesoderm and coelom formed from outpocketing of the endoderm surrounding part of the archenteron is called **enterocoelous** mesoderm and coelom formation.

These various embryonic contrasts are not random; they are grouped into 2 main contrasting **phylogenetic lineages** or lines.

**GROUP I**
1. Spiral cleavage
2. Determinant development
3. Schizocoelous coelom
4. Blastopore becomes mouth
5. Trochophore larva

**GROUP II**
1. Radial cleavage
2. Indeterminant development
3. Enterocoelous coelom
4. Blastopore becomes anus
5. Dipleurula larva

Group I is the Lophotrochozoa line of evolution leading to the phyla Mollusca, Annelida, and a variety of other smaller phyla. Group II is the Deuterostomia (secondary mouth) line of evolution leading to the phyla Echinodermata, Hemichordata, and Chordata.

III. Why should we pay so much attention to embryology and early development?

a) Early stages are the most conservative (i.e. change the least) because a small change early in development will have a big effect in the adult and the bigger the change the more likely it will be maladaptive.

b) All major phyla were present 0.5 byo when good fossils are first present, thus fossils cannot show use the relations between phyla.

IV. Why worry about which phyla are most closely related to each other?

a) Mostly scientists are just curious, which is a very good trait for a scientist to have.

b) There could be practical uses by studying sea urchin development to understand the basis of indeterminant development in humans.
Phylum: Mollusca

I. The diversity of the body plan in Mollusca is based on a hypothetical common ancestor of Precambrian times (> 500 x 10^6 years ago).

a) The ancestral mollusk is thought to have evolved from a flat worm-like ancestor.

b) It had 4 main body areas that are modified to form modern mollusks.

1) foot = flat ciliated muscular bottom that glides along the solid substrate propelled by cilia and later in larger species by waves of muscle contraction always on secreted layers of mucus
   a) includes a paired pedal nerve cord

2) head = result of cephalization of sensory and feeding organization in bilaterally symmetrical animals
   a) nerve collar around the anterior gut serves as the brain = nervous system
   b) sensory organs = sensory system
      1) eyes = visual, from just light sensitive to advance images
      2) tentacles = tactile and olfactory

3) mantle = tissue layer, usually muscular, over the top of the animal which secretes a chitinous shell which can be filled with CaCO₃.
   a) Under the mantle is the mantle cavity where essential organ functions are performed.
      1) gills = respiratory system
      2) nephridiopore = exit of the excretory system
      3) anus = exit of the digestive system

4) visceral mass
   a) digestive system
      1) esophagus = food move from mouth to stomach
      2) stomach = food storage and partial digestion
   b) digestive gland = for digestion and some food absorption
   c) intestine = food absorption
   d) gonad = on the edge of the coelom
   e) circulatory system with heart
      1) 1 ventricle acts as a pump
      2) 2 auricles to collect O₂ rich blood from the gills
      3) primitively open circulatory system (no capillary connections)
   f) excretory system metanephridium = tube from coelom to mantle cavity with selective reabsorption of body fluid solutes
   g) coelom = surrounded by mesoderm
      1) nephrostome = start of metanephridium at opening into the coelom
      2) gonad expels gametes into the coelom and out the gonoduct to the mantle cavity
      3) heart moves blood while beating in the coelom

II. Modern classes in the phylum are each different modifications of the basic 4-part body plan.

a) Class: Polyplacophora = chitons

b) Class: Gastropoda = snails and slugs

1) most similar to common ancestor
2) 8 plates or shells on top of mantle
3) gills divided into a series along each side of the foot under the mantle
4) all are marine benthic periphyton-feeders

1) very variable in life style from periphyton grazers like chitons to poison dart projectiles made from the radula that kill fish, and terrestrial grazers = slugs and snails
2) Nudibranchs or sea slugs feed on sponges and Cnidarians and incorporate unfired nematocysts into dorsal tentacles on their back for protection
3) mostly marine, but some fresh water and terrestrial
4) During development the gastropods go through a 180° torsion so that the mantle cavity is anterior over the head instead of the posterior end of the body
5) The advantage is to be able to pull the whole body into the shell where the mantle cavity is and close the shell with the
6) The disadvantage of torsion is in having the digestive and excretory wastes dumped on the head and olfactory organs and mixed with the current over the gills.

7) The problem is solved in the advanced snails by dropping the gill on the right side (homologous to the primitive left gill) and having the current pass the enlarged present left gill from left to right and dumping wastes into the excurrent flow.

8) Some, but not all, gastropods are hermaphroditic.

c) Phylum: Bivalvia = clams, scallops, oysters, etc.
1) They have no radula and gain food by filtering fine particles out of water passed by their much enlarged gills.
2. They hide within 2 large shells which shut to enclose the whole animal.
3) Water passes from incurrent siphon to mantle cavity through the gills to the suprabranchial cavity and then out the excurrent siphon.
4) Food passes from incurrent siphon to mantle cavity to being trapped in mucus on the gills to food groove to labial palps to the mouth and digestive tract. The gut empties at the anus into the excurrent siphon.
5) Marine and fresh water where many species are endangered.

6) Sexes are separate and gametes are spawned for external fertilization.

CROSS SECTION OF A BIVALVE

CLASS: CEPHALOPODA (HEAEDFOOT) = squid, octopus, nautilus

VIEW FROM THE LEFT SIDE OF A SQUID IN LIFE POSITION
(bold faced position in parentheses is homologous for other mollusk)
Phylum: Annelida = segmented round worms

I. Segmentation = metamerism  
segment = metamere  

a) Segmentation is repeating the same unit of body pattern or construction from the front to back of a bilaterally symmetrical organism.  
b) Segmentation probably evolved 4 times.  

1) class: Cestoda in the Platyhelminthes = Youngest segment (proglottid) develops at the front end of the organism just behind the scolex. The function of segmentation in Cestods is to increase the reproductive rate and not to aid in locomotion.  
2) Phylum: Annelida = youngest segment is the most posterior and the function of segmentation is to improve locomotion.  
3) Phylum: Arthropoda = youngest segment is the most posterior and the function of segmentation is to improve locomotion.  
4) Phylum: Chordata = youngest segment is the most posterior and the function of segmentation is to improve locomotion.  

II. Annelid general body plan for locomotion  
a) The coelomic cavities of successive segment are separated by a septum lined with parietal peritoneum. Each segment has two coelomic cavities separated by mesenteries.  
b) Locomotion works by hydrostatic pressure created by alternate contraction of circular and longitudinal muscles working against the fluid in the coelom.  

1) Circular muscles in the body wall narrow and lengthen the segment  
2) Longitudinal muscles in the body wall shorten and thus widen the segment.  
3) The alternate use of the circular and longitudinal muscles works well in burrows when the worm is anchored by setae.
III. Organ systems

a) circulation = **closed** (with capillaries)
   - pumping hearts, paired usually in several segments
   - hemoglobin = iron containing pigment to help carry O₂
   - respiratory = damp surface of body wall
     - marine species often have thin-walled extension of the body wall = gills
   - excretory = **metanephridia** = nephrostome instead of flame bulb
     - opens into the coelom of the segment in front of the nephridium, exits by nephridiopore to the outside

d) digestive system = gut is serially modified
   - mouth under the first segment = **prostomium**
   - muscular pharynx to suck material into the gut
   - esophagus = thin-walled passage to
   - crop = large food storage organ
   - gizzard = muscular wall for grinding food content
   - intestine with *typhlosole* to increase surface for absorption
   - anus in last segment


e) nervous system
   - brain = two-lobed dorsal ganglion over the mouth
   - double ventral nerve cord with segmental ganglia

IV. Class: Polychaeta

a) Marine benthic habitats
   - filter feeding
   - surface deposit feeding
   - burrowing deposit feeding
   - predators
   - commensal (helps the worm and is neutral for the animals creating the crumbs) = *crumb feeding*

b) Some of these life styles involve the beginning of **serial homology** where different appendages may be modified for different functions on the segments of the same individual

c) appendage = **parapodium** (plural = **parapodia**) relating to life style
   - fan-like projections for filter feeding
   - thin tentacles for surface deposit feeding
   - paddles for swimming
   - setae for pushing through burrows
   - loss of all appendages

d) sensory = eyes develop to varying extents in different species
   - absent in burrowing deposit feeders
   - light sensitive to detect shadows of predators for species emerging from tubes
   - image-forming eyes for predators

e) reproduction
   - sexes separate (dioecious)
   - external fertilization of spawn into the sea
   - few brood eggs in tubes that they aerate
   - communal spawning of **epitokeous** palolo worms
     - posterior body (epitoke) is modified for swimming after breaking off the front of the body that lives on
     - spawning swarms are timed by the phase of the moon
     - condensing spawning time swamps predators’ feeding ability

V. Class: Oligochaeta = earth worms and blood worms

a) habitats
   - terrestrial soils = earth worms
   - fresh water sediments = blood worms

b) feeding
   - burrowing deposit feeders of decaying plant materials.
   - come to the surface for litter food and to leave castings (feces)

c) sensory = tactile and olfactory with no large specialized organs

d) reproduction
   - hermaphroditic, often with **obligate cross fertilization**, but a few specie can self fertilize
   - stored sperm from another worm and its own eggs are released into a cocoon secreted by the **clitellum**

VI. Class: Hirudinea = leeches

a) habitats = fresh water

b) feeding
   - predator of small animals by sucking in whole animal with it muscular pharynx
   - external blood-sucking = *ectoparasite* of vertebrates
     - grasp prey with anterior sucker
     - open blood vessel with sharp teeth
     - suck blood with muscular pharynx
   - prevent blood coagulation with salivary enzyme

c) segments are not evident
   - more external annuli than segments
   - no internal segmental septa
   - moves like an inch worm using its two suckers and bending its body.

d) sensory system like earth worm, except a few species have rudimentary eyes

e) reproduction = hermaphroditic like earth worms, also with a clitellum
Phylum: Arthropoda

I. Arthropoda is the phylum with the most numerous and diverse species.
   a) Arthropods have invaded all major habitat and most minor ones
      1) Some are marine benthic and others pelagic.
      2) Some are fresh water benthic and others pelagic.
      3) The majority are terrestrial with the power of flight.
   b) How are Arthropods built to allow them to use all these habitats in millions of different ways?
      1) Arthropod evolution has a trend that is opposite to that found in vertebrates.
      2) Arthropods have most species small and specialized to use a narrow range of resources, but adaptive radiation has lead them to use most types of resources on the Earth.
      3) Vertebrates tend to have larger body size and in mammals especially, and humans in particular, the trend is to more diverse and learned behavior until finally one species (humans) use most of the kinds of resources on the Earth.

   c) Why are Arthropods generally small and narrow in their resource use?
      1) Narrow specialization in resource use tends to go with small body size.
      2) They are small partly because of their exoskeleton.
      3) Mollusks (snails) invaded land with armor (shells), but they cannot be active in dry places because the armor is inflexible.
      4) Arthropod skeletons are jointed like medieval suits of armor so that the animal can remain protected and move.
      a) Joints give the phylum its name: arthro = joint, pod = foot.
      b) The exoskeleton protects from what?
         1) predation
         2) parasites
         3) terrestrial desiccation
      5) They move by muscles contracting across a joint with the exoskeleton serving as the hard substrate for the muscle attachments. The joint is the only flexible area.

II. The organ systems of Arthropods

   a) digestive system
      1) midgut = endoderm lining
         a) pyloric stomach
         b) digestive gland
         c) intestine
      2) foregut = ectoderm lining
         a) cardiac stomach with gastric mill
         b) is lined by exoskeleton which is molted as part of the whole exoskeleton
         3) hindgut = ectoderm lining
            a) fecal (frass) storage and also uric acid in terrestrial species

   6) The exoskeleton is made of chitin impregnated with minerals like CaCO₃. It is not living and cannot grow. Thus, if the animal is to grow it must shed the old skeleton and build a new bigger one.
   7) The processes of shedding is called molt or ecdysis which is the source of the name Ecdysozoa for the group of phyla that includes Arthropoda.
   8) The change of shape that sometimes goes with molting is called metamorphosis.
   9) Molting starts by reabsorbing some of the old exoskeleton by digestive enzymes and causes a weak line in the mid dorsal position.
   10) Next water or air is sucked in to swell the body and break the old exoskeleton along the back. Then the animal expels the water or air and steps out of the old exoskeleton and lays down a new bigger one that may or may not have a very different shape (i.e. pupa to adult in some insects).

11) The break in the old exoskeleton may be mid sagittal as in insects or across the back from left to right as in crustaceans.
12) One major problem with molt is that the animal is helpless during the process until the new exoskeleton is hardened.
13) THE GENERAL STRUCTURE OF EXOSKELETONS

   a) The epicuticle is made of protein and lipid which is hydrophobic to prevent water loss.
   b) The procuticle is the combination of the exocuticle and the endocuticle and is made of chitin which is a polysaccharide with glucosamines as building blocks. Glucosamines are sugars with a nitrogen bearing side group. It is also impregnated with mineral salts like CaCO₃.
   c) The hypodermis is the epidermal layer that secretes enzymes to digest the old cuticles and build the new ones.
   d) Tonofibrils act like a tendon to give strength for muscle attachment.
   15) The timing of molt is determined by a balance between two hormones:
      a) Juvenile hormone keeps the individual young and prevents molting.
      b) Ecdysone (the molting hormone) stimulates the stages of molt and works only when juvenile hormone is turned off.

16) Some plants produce chemicals that are essentially the same as juvenile hormones and it is thought that they may prevent insect larvae that are feeding on the plant from molting and, therefore, from feeding when they fill the larval exoskeleton and also from reproducing as adults.
b) also lined with molted exoskeleton
b) circulatory system
  1) open circulatory system without capillaries
  a) lies in the hemocoel = a body cavity derived from the embryonic blastocoel like a pseudocoelom
  b) blood enters heart from hemocoel by way of ostia (valves in the sides of the heart)
  3) major arteries from the heart dump blood in the hemocoel into various parts of the body
c) respiratory system
  1) gills in crustacea
  2) trachea in insects = blind tubes to all parts of the body opening to the outside at spiracles in the side of the body
  a) gas moves by diffusion (i.e. no pump) which limits the size of the body
  3) book lungs in terrestrial Chelicerates like spiders
d) excretory system
  1) green gland in crustaceans may be homologous with metanephridium, but there are no cilia in any Arthropods
  2) Malpighian tubules in insects
     a) a series of blind tubes in the hemocoel that empty into the gut where the mid and hind guts meet
     b) actively transport uric acid from the hemocoel
     c) uric acid is mixed with frass in the hind gut
e) reproductive system
  1) sexes separate = dioecious
  2) fertilization usually internal – always in terrestrial species
  3) mating behavior is elaborate because mating is often dangerous to the smaller sex (usually males)
     a) praying mantis males copulate more effectively after the females eat their head
     b) male web building spiders pluck the web with a species-specific rhythm to prevent being eaten
     c) male soil Arthropods deposit spermatophores (sperm packets) on stalks and dance to lead females over them so that larger females will not have to touch males
f) nervous system
  1) The dorsal brain acts as an inhibitory center for paired ganglia along the ventral nerve cord. This explains the greater activity of a beheaded male praying mantis.
  2) Behavior is often elaborate and very fast, but stereotyped with very small learned components.
g) sensory organs
  1) compound eyes each made up of many
     a) ommatidia (ommatidium = singular) each of which forms a separate image
     b) images of all ommatidia are coordinated in the brain
     c) eyes are better for detecting motion than for forming the outlines of images
  2) auditory
     a) important in communicating sexual recognition in species from crickets to shrimp

Phylum: Arthropoda
I. Subphylum: Trilobita
  a) oldest Arthropods first found in the early Cambrian Period about 0.5 billion years ago (bya)
  b) went extinct about 0.3 bya
c) dorsoventrally flattened, bottom-dwelling animals, probably a surface deposit feeder, but mouth parts are not preserved
d) The body is in three parts = tagmata (singular = tagma). A tagma is a group of segments working together for one general function

  cephalon = head - - -
  thorax = trunk - - -
  pygidium = tail - - -

  compound eye

II. Subphylum: Chelicerata
  a) body with two tagmata
     1) cephalothorax + abdomen
        prosoma + opisthosoma
     2) no antennae
     3) The first appendages is a pair of preoral chelicerae which can be in the form of claws as in scorpions or fangs as in spiders.
        The chelicerae are use to capture prey
     4) The second appendages are postoral pedipalps which have a tactile and olfactory sensory function. They are analogous, but not homologous with antennae in other subphyla

  b) predator defense
     1) some moth species can hear bats and take evasive action
     2) some distasteful moth species even signal back to the bats which leave them alone
     3) gravitational, visual, tactile, and olfactory senses allow honey bees to communicate the location and quality of food to fellow hive members in dark hives.
        a) they communicate information about the quality and quantity of food they have found by a dance that tells
           1) distance to food
           2) direction of food from the hive
           3) species of food
           4) quality of food

  e) It is still an open debate as to how close Trilobites were to the ancestry of other Arthropods.
     1) They have antennae like mandibulate groups
     2) They have biramous appendages (2 branches per appendage) with gills and walking rami like Crustaceans
     3) embryological development of body parts is like Chelicerata
b) **Class: Merostomata = horseshoe crabs**

1) These are referred to as living fossils because their basic anatomy has been unchanged since 0.3 baya.
2) They are marine benthic feeders on carrion and detritus which being dead has not evolved changing defenses against horseshoe crabs. Living fossils usually eat detritus.

3) The telson is a projection of the abdomen and not a new tagma. It allows the flat animal to turn over when on its back.
4) Shore birds evolving much later are dependent on eating its eggs in Delaware Bay for food during the birds’ migratory trip.

c) **Class: Arachnida = spiders, scorpions, ticks and mites**

1) Their tagmata are cephalothorax and abdomen.
2) They have 6 pairs of appendages on the cephalothorax.
   a) 1 pair chelicerae = fangs or claws
   b) 1 pair pedipalps
   c) 4 pairs walking legs
3) Ticks and mites tend to fuse the two tagmata and have a loss of obvious segmentation. They have a flat, round body outline.
4) Scorpions and some close relatives have chelicerae modified as claws or pinchers for grasping prey that are stung by the last abdominal segment.
5) Spiders, ticks, and mites have chelicerae modified as poison fangs to subdue prey.

---

II. **Subphylum: Crustacea = shrimp, crabs, barnacles, crayfish, etc.**

a) They are one of two mandibulate subphyla, i.e. have mandibles as head appendages functioning as chewing mouth parts.

b) They are mainly aquatic (pill bugs and land crabs only exceptions).

c) The diversification of serially homologous appendages is most striking in this group.

1) **head = anterior tagma**
   a) 2 pair antennae = sensory
   b) 1 pair mandibles = food grinding
   c) 2 pair maxillae = food handling

d) Crustaceans include the largest Arthropods because the large gills allow more effective gas exchange than diffusion through trachea or enclosed book lungs for terrestrial Arthropods. Large size is also possible because protoplasm has the same density as water and thus is easier to support in the Crustacean aquatic medium.

1) Alaskan king crabs with long legs are 2 meters across
2) Lobsters have been found that weigh 60 pounds
3) Lobsters, crayfish, crabs, and shrimp are large enough to be of commercial value

f) Other crustaceans are very small. **Copepods** are known as the insects of the sea and are the main primary consumers in marine and fresh water plankton.

g) **Barnacles** are marine sessile filter feeders enclosed in CaCO$_3$ shells which they secrete.

b) Copepods and barnacles have evolved some parasitic species that grow as a shapeless mass through the tissues of fish and crustaceans. They are removed from the surface of fish shortly after settling by specialized species of **cleaner shrimp and fish**.
IV. **Subphylum: Uniramia** = insects, millipedes, and centipedes  
   a) They are mainly terrestrial mandibulate Arthropods with walking legs with only one main stalk = **uniramous** as opposed to biramous.  
   b) **Class: Diplopoda** = millipedes ~1000 legs  
      1) detritus feeder in leaf litter and rotting wood.  
      2) 2 pairs of legs per segment (but each segment is derived from 2 embryonic segments)  
      3) two tagmata  
         a) head  
            1) 1 pair antennae  
            2) 1 pair mandibles  
            3) 1 pair maxillae fused to form a lip-like structure  
         b) trunk  
            1) very many pairs of walking legs.  
      4) generate a distasteful defensive chemical call mercaptan that is held in a repugnatorial gland  
      5) They roll up like a fire hose for protection with their legs inside.  
   c) **Class: Chilopoda** = centipedes = “100 legs”  
      1) They are terrestrial fast moving carnivores eating mainly small Arthropods, but even frogs or young mice.  
      2) 2 tagmata  
         a) head  
            1) 1 pair antennae  
            2) 1 pair mandibles  
            3) 2 pair maxillae  
         b) trunk  
            1) 1 pair maxilliped = poison fangs  
            2) many pairs of walking legs  
   d) **Class: Insecta** = insects  
      1) most numerous species of any group of animals; $10^6$ named and perhaps $10^7$ alive  
      2) Insects along with mammals are the main terrestrial herbivores and they are our most serious competitors for food. Variation in the shape of grasshopper mandibles in relation to their food parallels the variation in the shape of mammalian jaws.  

3) Insects feed on just about all kinds of organic resources on land or in fresh water, but no insects are found in oceans.  
4) Their body is in 3 tagmata  
   a) head appendages  
      1) 1 pair antennae  
      2) **labrum** = single front lip, perhaps fused appendages  
      3) 1 pair mandibles  
      4) 2 pair maxillae – second pair are fused to from the **labium** = back lip  
   b) thorax  
      1) 3 pairs of walking legs, one on each of 3 segments  
      2) 2 pairs of **wings** on first 2 segments  
   c) abdomen  
      1) no appendages  
      2) in the last segment females have a highly modified **ovipositor** which has appendage-like function of placing eggs in appropriate chemical and physical environment  

5) Major insect orders radiated with the Angiosperm plants in the **Cretaceous Period** about 150 to 70 x 10^6 years ago.  
   a) Most of these major orders have complete metamorphosis.  
   b) **Complete metamorphosis** goes from egg to larva to pupa to adult, usually with several larval molts  
      1) **Coleoptera** = beetles  
      2) **Lepidoptera** = butterflies and moths  
      3) **Hymenoptera** = ants, bees, and wasps  
      4) **Diptera** = flies, midges, and mosquitoes  
   c) Other groups with **incomplete metamorphosis** go through many nymphal stages that look like adults  
      1) **Orthoptera** = grasshopper  
   d) The herbivorous species of these five orders are most of the worst crop pests for humans.