Chapter 22 -- Origin of Species

Wednesday, January 30, 2019
11:01

Slide 1: Overview -- That "Mystery of Mysteries"

- In the Galápagos Islands, Darwin discovered plants and animals found nowhere else on Earth.

Speciation -- the process by which one species splits into two or more species

This explains the features shared between organisms due to inheritance from their recent common ancestor.

Speciation forms a conceptual bridge between microevolution and microevolution.

Microevolution refers to changes in allele frequency in a population over time.

Macroevolution refers to broad patterns of evolutionary chance above the species level.

To this day, there is a discussion on what merits a species --> at least 40 definitions

They can be defined in a way that:

22.1 The biological species concept emphasizes *reproductive isolation*

Species is a Latin word meaning "kind" or appearance.
Biologists compare morphology, physiology, biochemistry, ad DNA sequences when grouping organisms.
Biological species concept -- defines species as a group of populations whose members have the potential to interbreed in mature and produce viable, fertile offspring

They do NOT breed successfully with other populations.

This concept emphasizes the absence of gene flow.

However, gene flow can occur between distinct species. Example: grizzle bears and polar bears can mate to produce "grolar bears"

Reproductive isolation sy-- the existence of biological barriers that impede two species from producing fertile, viable offspring

Can be further classified whether these barriers are before and after fertilization

Prezygotic barriers -- block fertilization before any zygote is fertilized

- Habitat isolation -- relates to environment; two species encounter each other rarely, or not at all, because they occupy different habitats,
- Temporal isolation -- relates to time; species that breed at different times of the day, different seasons, or different years cannot mix their gametes (one species may be nocturnal, preventing mating in the day)
- Behavioral isolation -- courtship rituals and other behaviors unique to a species are effective barriers (example: blue-footed booby)
- Mechanical isolation -- morphological differences prevent successful mating; the genitals doesn't match up with each other in mating, it's physically not possible
- Gametic isolation -- Sperm of one species may not be able to fertilize eggs of another species

Postzygotic barriers -- prevent the hybrid zygote from developing into a viable, fertile adult by:

- Reduced hybrid viability -- genes of the different parent species may interact and impair the hybrid's development or survival
- Reduced hybrid fertility -- even if hybrids are vigorous, they may be sterile

- Hybrid breakdown -- some first-generation hybrids are fertile, but when they mate with another species or with either parent species, offspring of the next generation are feeble or sterile

By chance, fertilization can occur between different species. **Hybrids** are the offspring of crosses between different species. (Example: liger, mule -- horse and donkey)

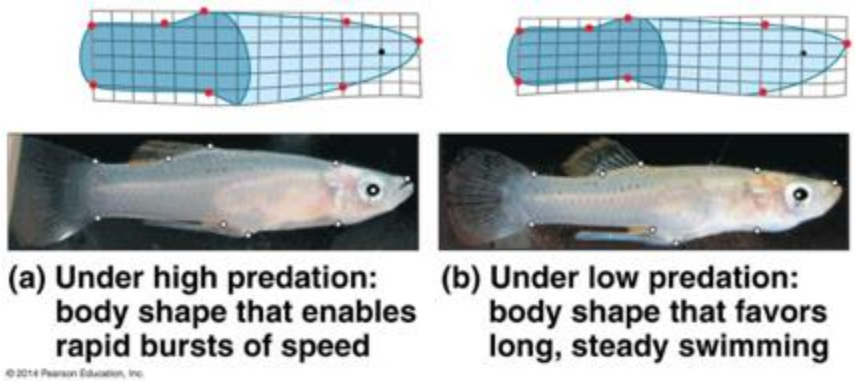
Limitations of the biological species concept
The biological species concept cannot be applied to fossils or asexual organisms (including all prokaryotes).

Other definitions of species
Morphological species concept -- defines a species by structural features
Species = groups of organisms that look really different from each other
It applies to sexual and asexual species but relies on subjective criteria.
Ecological species concept -- views a species in terms of its ecological niche
It applies to sexual and asexual species and emphasizes the role of disruptive selection.
Phylogenetic species concept -- defines a species as the smallest group of individual that share a common ancestor on a phylogenetic tree
It applies to sexual and asexual species, but it can be difficult to determine the degree of difference required for separate species.

22.2 Speciation can take place with or without geographic separation

Speciation can occur in two ways:

- **Allopatric "other country" speciation** -- forms a new species while *geographically isolated*
    - In this speciation, gene flow is interrupted when a population is divided into geographically isolated subpopulations.
        - Example: flightless cormorant of the Galápagos likely originated form a flying species on the mainland.
    - The definition of a geographic barrier depends on the ability of a population to disperse.
        - Example: a canyon may create a barrier for small rodents, but not birds, coyotes, or pollen
    - Evidence: Fifteen pairs of sister species of snapping shrimp *(Alpheus)* are separated by the Istmus of Panama
        - These specices originated from 9 million to 3 million years ago, when the Isthmus of Panama formed and separated the Atlantic and Pacific waters
    - Evolutionary processes in allopatry: separate populations may evolve independently through mutation, natural selection, and genetic drift
    - Reproductive isolation may arise as a result of genetic divergence.
        - Example: mosquitofish in Bahamas comprise several isolated populations in different ponds

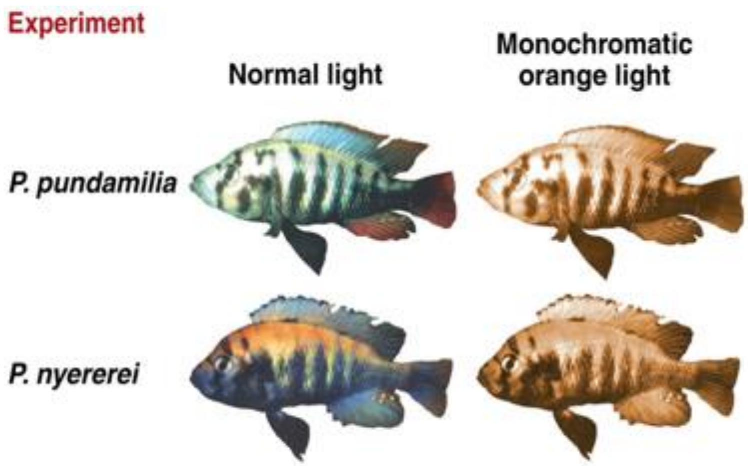
- 

LECTURE 2

- **<u>Sympatric speciation</u>** -- a subset forms a new species without geographic separation; speciation takes place in populations that live in the same geographic area
  - Occurs when gene flow is reduced between groups that remain in contact through factors including:
    - Polyploidy
    - Habitat differentiation
    - Sexual selection
      - **<u>Habitat differentiation</u>** -- a factor by which sympatric speciation occurs; the appearance of new ecological niches
        - <u>Example</u>: the North American maggot fly can live on native hawthorn trees as well as more *recently introduced* apple trees
        - <u>Another example</u>: Each Anolis morphotype Is adapted to each niche.

<u>Sexual selection</u> -- another driving force of sympatric speciation;

<u>Example</u>: sexual selection for mates of different colors has likely contributed to speciation in cichlid fish in Lake Victoria



<u>Polyploidy</u> - the presence of extra sets of chromosomes due to accidents during cell division

An <u>auto</u>polyploid is an individual with more than two chromosome sets, derived from one species.

The offspring of matings between autopolyploids and diploids have reduced fertility.

<u>Process</u>:

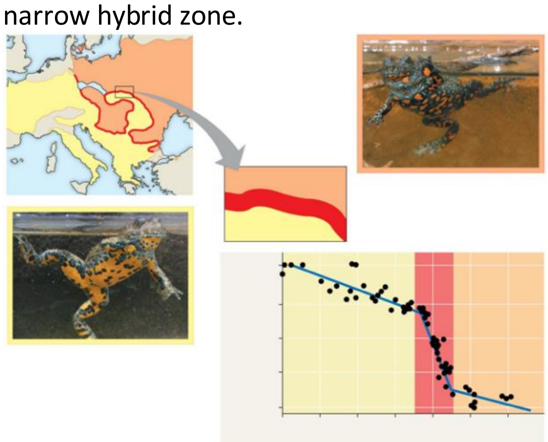
An <u>allo</u>polyploid is a species with multiple sets of chromosomes derived from ***different*** species.

These species ***cannot*** interbreed with either parent species.

Autopolyploids ***can*** but results in reduced fertility.
Asexual reproduction???

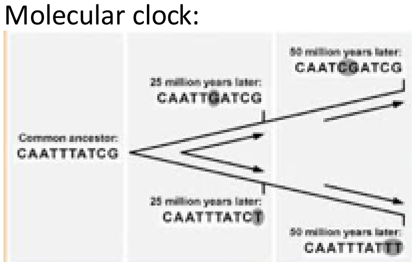
- In ***allopatric speciation***, geographic isolation restricts gene flow between populations.
    - Reproductive isolation may then arise by what in the isolated populations?
        - Natural selection
        - Genetic drift
        - Sexual reproduction
            - Even if contact is restored between populations, interbreeding is prevented by reproductive barriers.
- In ***sympatric speciation***, a reproductive barrier insolated a subset of a population without geographic separation from the parent species.
    - Can result from:
        - Polyploidy
        - Natural selection
        - Sexual selection

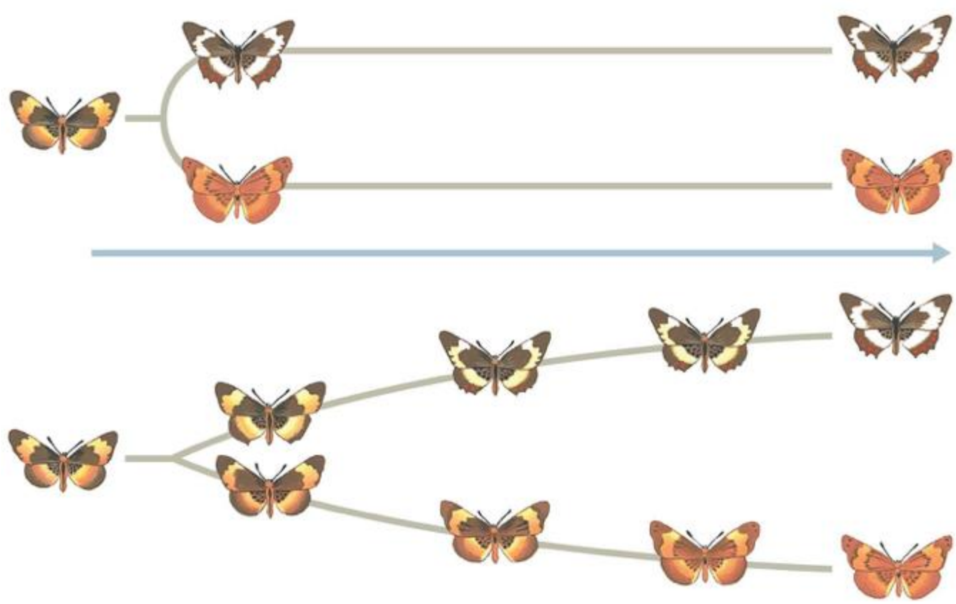
Concept 22.3: Hybrid zones reveal factors that cause reproductive isolation

- A ***hybrid zone*** is a region in which members of a different species mate and produce hybrids.
    - Hybrids are the result of mating between species with incomplete reproductive barriers. They often have reduced fitness compared with parent species.
        - Prezygotic or postzygotic barriers
    - These zones can occur in a single band where adjacent species meet. The distribution of hybrid zones can be more complex if parent species are found in patches *within the same* region.
        - Example: two species of toad in the genus *Bombina* interbreed in a long and narrow hybrid zone.
        - 
- When closely related species meet in a hybrid zone, there are three possible outcomes:
    - <u>Reinforcement</u> - Occurs when hybrids are *less fit* than the parent species; natural selection chooses the parent species and against the hybrids; a type of natural selection since the hybrids don't survive at the same rate as the parent species
        - Natural selection strengthens (reinforces) reproductive barriers, and, over time, the rate of hybridization *decreases*
        - Where reinforcement occurs, reproductive barriers should be stronger for ***sympatric*** than for allopatric species ---> prezygotic isolation
    - <u>Fusion</u> - there is a fusion of the parent species into a single species may occur if hybrids are as fit as parents, allowing substantial gene flow between species

- Example: researchers think that pollution in Lake Victoria has reduced the ability of female cichlids to distinguish males of different species.
  - Might be causing the *fusion of many species*
- Stability - when the hybrid zones remain; may be achieved if extensive gene flow from the outside the hybrid zone can overwhelm selection for increased reproductive isolation inside the hybrid zone
  - In a stable zone, hybrids continue to be produced over time.

Speciation can occur rapidly or slowly and can result from changes in few or many genes

- For humans, speciation didn't occur from one day to another.
- There are still several questions about how long it takes for new species to form, or how many gene need to differ between species.
  - Broad patterns in speciation can be studied using the fossil record, morphological data, or molecular data.
    - Molecular clock:
    - 

- The fossil record includes examples of species that appear suddenly, persist essentially unchanged for sometime, and then suddenly disappear.
  - These periods of apparent stasis punctuated by sudden change are called ***punctuated equilibria***.
    - This model contrasts with a model of gradual change in a species' existence.
      - 
  - The punctuated pattern in the fossil record and evidence from lab studies suggest that speciation can be rapid.

- The interval between speciation events can range from 4,000 years (some cichlids) to 40 million years (some beetles), with an average of 6.5 million years.

Genetics of speciation

Depending on the species in question, speciation might require the change of only a single allele or many alleles.

Example: in Japanese *Euhadra* snails, the direction of shell spiral affects mating and is controlled by a single gene.

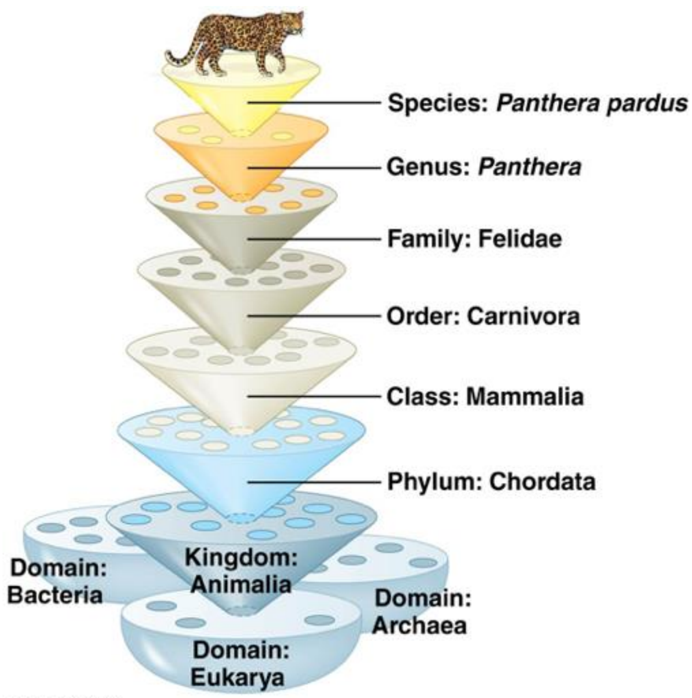
From speciation to macroevolution

Macroevolution is the cumulative effect of many speciation and extinction events.

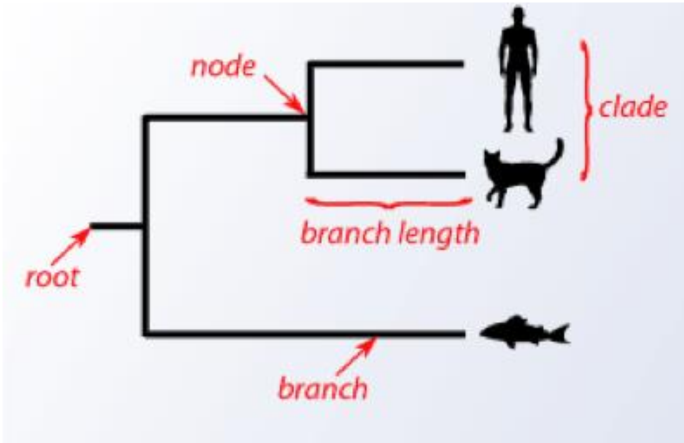
Chapter 20 -- Systematics, Phylogeny

Wednesday, February 6, 2019
11:00

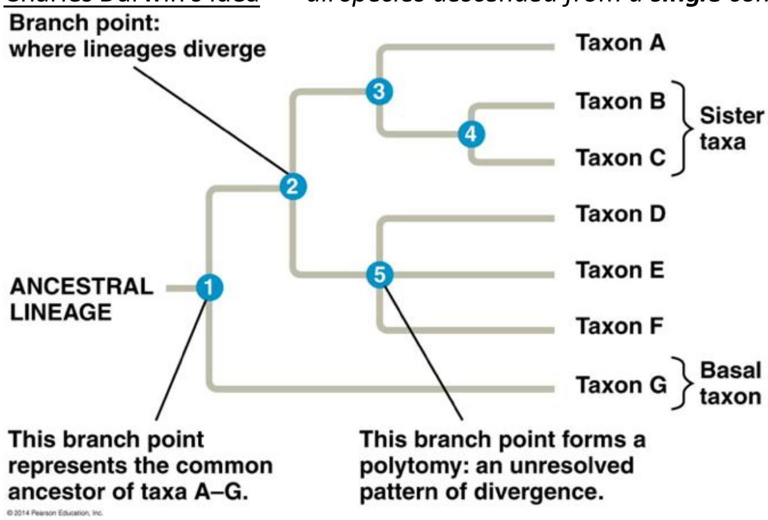
There is a tremendous diversity of life: bacteria, whales, sequoia trees.
Biologists groups organisms based on shared characteristics and new molecular sequence data.
Systematics - the reconstruction of study of evolutionary *relationships*
Taxonomy - the *ordered* division and naming of organisms
Binomial nomenclature -- genus name, species name, from Carl von Linne
--> Latin, has two parts
Genus (larger group, capitalized)
Specific epithet (unique)
Always italicize both
There is a need for both in order to name species.



Under the *Linnean Classification*, there is a nested grouping of taxa.
Taxon - a named unit at any level of the system; generalized term for any sort of group
Phylogeny - hypothesis about patterns of relationship among species; how phylogenetic trees are formed; based on hypotheses



<u>Charles Darwin's idea</u> --> *all species descended from a **single** common ancestor*; *branching tree*



Branch points are also referred to as nodes: they're where lineages diverge.
Taxons that are paired are referred to as <u>**sister taxa**</u>.
    They have more in common with each other than anything else in the tree.
At taxons D-F, two of them have more in common with each other than the third (cannot tell from visual).
<u>**Basal taxon**</u> - the bottom level of the phylogenetic tree; other taxons have more in common with each other than with the basal taxon
Information is given by how many nodes are *shared*, NOT the order of the that the taxons are in.
    Commonality = number of shared nodes
Phylogenetic trees DO show patterns of descent, NOT phenotypic similarity.
    They do NOT generally indicate when a species evolved OR how much chance occurred in a linage.
    It should NOT be assumed that a taxon evolved from the taxon next to it. Must be related to the number of nodes instead.
<u>Real World Application</u>
    Whale meat sales --> there are only certain populations and regions which are protected by the law
        Flesh samples being compared from their mitochondrial DNA to species that are being protected to ensure that the correct populations are being protected.

<u>How do you make a phylogenetic tree</u>?

We consider homology (similarity due to shared ancestry) --> morphology or molecular homology

Also should be a consideration of analogy --> similarity NOT caused by shared ancestry

Also called homoplasy

Molecular homology

Is all a list of nucleotides (A, G, T, C)

A single deletion would misalign what are otherwise good matches

More than 25% similarity considered evidence for homology since so many based pairs are created that coincidental alignment occurs

Cladistics

This focuses on characters which can be any aspect of the phenotype or genotype.

Morphology

Behavior

Physiology

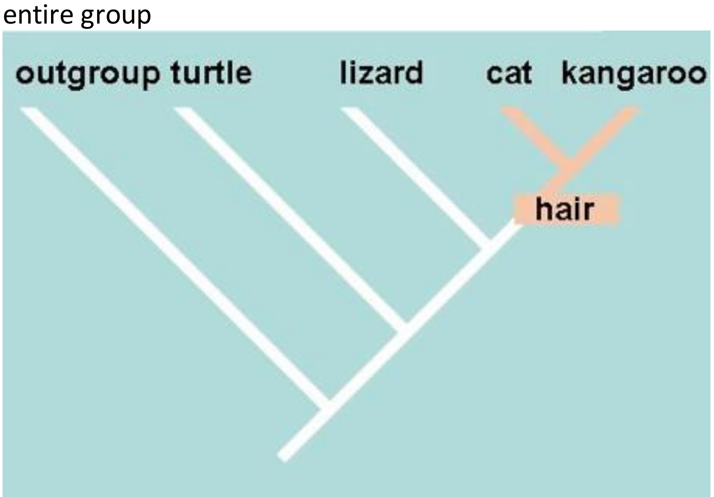
DNA

Characters should exist in recognizable character states.

Example: Character "teeth" in amniote vertebrates *present* in most mammals and reptiles, and *absent* in birds and turtles.

Used to "code" by possession of derived (1) or possession of ancestral (0) character states.

<u>Derived characteristic</u> - *similarity* that is inherited from the most recent common ancestor of an entire group



<u>Ancestral characteristic</u> - similarity that arose *prior* to the common ancestor of the group

In cladistics, only *shared derived characters* are considered informative about evolutionary relationships.

<u>How to Build a Cladogram?</u>

1. Polarized the characters (what is derived? Ancestral?)
    a. Outgroup comparison used
        i. Species or group of species that is closely related to, but not a member of, the group in question
    b. BUT, outgroup species do not always exhibit the ancestral condition

i. Most reliable if character state is exhibited by several different outgroups.
    1. Presence of teeth in mammals and reptiles is ancestral.
    2. Absence of teeth in birds and turtles is derived.

2. Organize taxa into clades
    a. **<u>Clade</u>** - group of species
        i. Shared a common ancestor
        ii. Include all the descendants of that ancestor (monophyletic)
        iii. Defined by shared derived characters (a.k.a. synapomorphies)
3. You have a cladogram!
    a. Hypothesis of relationships

Simple cladogram is a "nested set of clades," each characterized by its own synapomorphies.

<u>Etymology</u>

Apo --> to be away; far away

Sym/syn --> symmetrical, similar

Plesio --> near/close; something that's close to us, relating to an ancestor

Morph --> form/shape

<u>Apomorphy</u> - derived states

<u>Synapomorphies</u> - shared derived states

<u>Autapomorphy</u> - derived state seen in a single terminal taxon; under their own power (auta == to self)

Only ONE groups has it, unique state. Not useful for determining relationships/building trees

<u>Plesiomorphies</u> - ancestral states

<u>Symplesiomorphies</u> - shared ancestral states; are NOT informative phylogenetic relationships

<u>Homoplasy</u> - a shared character states that has NOT been inherited from a common ancestor

Homo = same

Characteristics that are the same but not inherited from a common ancestor

NOT the same as homology: homology related to having a common ancestor, homoplasy does NOT

Evolution is NOT always divergent --> directional, stabilizing, disruptive

Convergent evolution

<u>Homoplastic convergence</u> --> evolved independently in different clades of extinct mammals

Homoplasy is the product of convergent evolution; homoplasy combined with shared derived characters results in multiple solutions.

Character conflict!

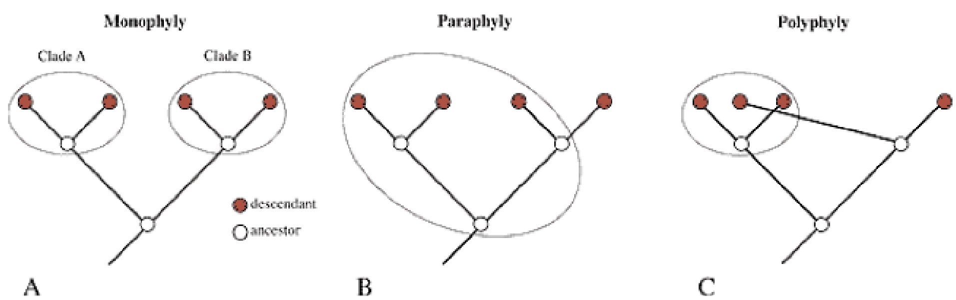
The simplest solution (the one that requires the least amount of jumps/evolutionary changes) is the one that is most likely.

Based on the **<u>principle of maximum parsimony</u>**, the cladogram that requires the *fewest* number of evolutionary changes is favored.

Systematics and Classification

Classification - how we name and organize species and higher groups
Monophyletic group - includes the most recent common ancestor of the group and all of its descendants (clade)
Paraphyletic group - includes the most recent common ancestor of the group but NOT all of its descendants
Polyphyletic group - does NOT include the most recent common ancestor of all members of the group

Example: flighted organisms like bats and hawks



Phylogenetic trees are essentially hypotheses.
Molecular clocks --> assumes that the number of nucleotides substitutions in related genes is proportional to the time elapsed since the genes branched from a common ancestor

They become highly inaccurate away from the fossil-validated branch points.
Natural selection still acts on many genes.
If a multiple (or hundreds) of genes are used, natural selection on any individual gene might be evened out inside.

Chapter 20 Concepts
20.1-.20.2- 20.3- 20.4

Chapter 23 -- Broad Patterns of Evolution

Monday, February 11, 2019
10:56

First slide overview: Lost Worlds

Past organisms were very different from those now alive.

The fossil record shows evidence of **macroevolution** --> macroevolution refers to broad patterns of evolutionary chance above the species level; in order to understand macroevolution, speciation is a basic concept that MUST be comprehended

Broad changes above the species level:

- The emergence of terrestrial vertebrates
- The impact of mass extinctions
- The origin of flight in birds

23.1 The fossil record documents life's history

The fossil record indicates that there have been great changes in the kinds of organisms on Earth at different points in time.

Few individuals have fossilized, and even *fewer* have been discovered.

There is bias when it comes to the fossils that we hear about. The fossil record is biased in favor of species that:

- Existed for a long time
- Were abundant and widespread; allowed for better odds of the organism being fossilized
- Had hard parts --> bony/calcified features, teeth, etc; those found could withstand the conditions that came with being fossilized (more difficult to find organisms such as plants)

Geology --> Rocks of every age are NOT preserved on all places on Earth.

Example: Geologic map of Pennsylvania

There is also an impact of human bias when it comes to collecting fossils:

Bone wars --> a period of intense and ruthlessly competitive fossil hunting and discovery during the Gilded Age of American history

There was the destruction/mistreatment of fossils that people felt were not important.

How Rocks and Fossils Are Dated --> Sedimentary strata reveal the relative ages of fossils (the lower it is located, the older that it is).

Not all rock slides are preserved the same way across all locations, depends on the environmental factors such as weather patterns.

Radiometric dating - a process in which the *absolute* ages of fossils can be determined; SEE ISOTOPE ACTIVITY ON BBL FOR PRACTICE

Isotope - an atom that has a different number of neutrons than it's average atom

Makes an atom radioactive which allows for it to be further analyzed.

Each isotope has a known **half-life**, the time required for half the parent isotope to decay.

One half-life = 50%

Two half-lives = 25%

Three half-lives = 12.5% and so on

A "parent" isotope decays to a "daughter" isotope at a constant rate.

Carbon-14 half-life = 5,730 years

Can be used to date fossils ***up*** to 75,000 years old.

For older fossils, some isotopes can be used to date volcanic rock layers above and below the fossil.

Example: Uranium-238: 4.5 billion years

Geologic record (timescale) - a standard time scale dividing Earth's history into 4 eons

- Hadean
- Archean
- Proterozoic
- Phanerozoic
    - This eon encompasses most of the time that *animals* have existed on Earth.
    - Is divided into three eras:
        - Paleozoic (older)
            - Characterized by massive change in a sudden increase in diversity of many animal phyla
        - Mesozoic
            - Characterized by dinosaurs beginning to dominate, plants emerging. By end of era, mammals begin to emerge around the extinction of other species.
        - Cenozoic (more recent)
            - Characterized by major radiation of mammals, birds, and pollinating insects

Major boundaries between geological divisions correspond to extinction events in the fossil records.

23.2 The rise and fall of groups of organisms reflect differences in speciation and extinction rates

The history of life on Earth has seen the rise and fall of many groups of organisms.

The rise and fall of groups *depend* on speciation and extinction rates within the group.

Reason why Lamarck's Theory of Evolution didn't work --> didn't take into account the extinction of species.

According to the theory of **plate tectonics**, Earth's crust is composed of plates floating on Earth's mantle.

The distribution of land masses at several points in geological time displays the breakup of the supercontinent **Pangea**.

LECTURE 2

Tectonic plates move slowly through the process of "continental drift" --> 2 cm/year

Oceanic and continental plates can separate, slide past each other/collide

Interactions between plates cause the formation of mountains and islands and earthquakes.

The oldest known fossils are **stromatolites**, rocks formed by the accumulation of sedimentary layers on bacterial mats.

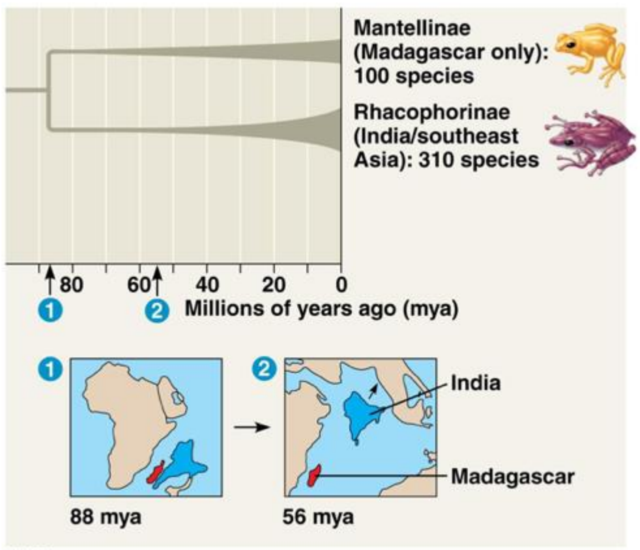
The Earth is 4.5 - 4.6 billion years old.

Stromatolites date back 3.5 billion years ago (Archean eon) before any multicellular organisms arose.
Prokaryotes were Earth's sole inhabitants for more than 1.5 billion years.

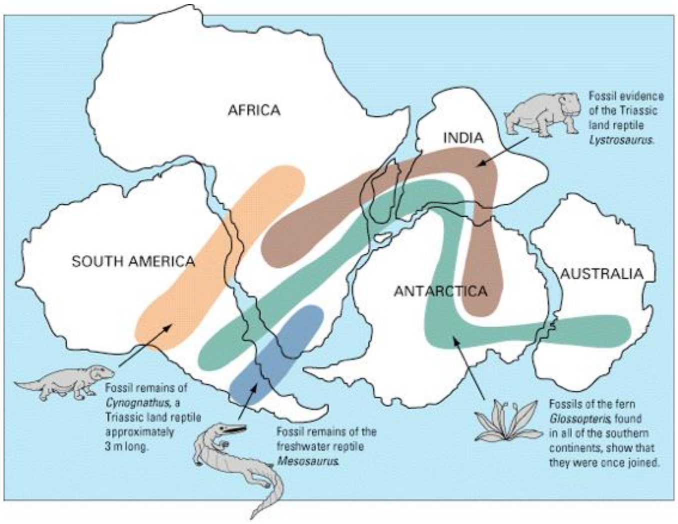
Early prokaryotes released oxygen into the atmosphere through the process of photosynthesis.
The increase in atmospheric oxygen that began 2.4 billion years ago led to the extinction of many organisms (survival of the fittest, natural selection --> sink or swim).
The eukaryotes *flourished* in the oxygen-rich atmosphere and gave rise to multicellular organisms.

Example: Collision of India with Eurasia

Biogeography (distribution) of **fossil** and **modern** organism is explained by plate tectonics.
With more gene flow, there is less of a variation in the gene pool. Allele frequency doesn't shift significantly.



The distribution of fossils and living groups reflects the historic movement of continents.
Again, the fossil record is biased: not all organisms had fossils left behind.
There is also the risk of human bias: lack of funding to find fossils, laziness when it comes to collecting fossils (could have missed finding fossils).



Possible Consequences of Plate Tectonic Activity

The fossil record shows that most species that have ever lived are now extinct.

Extinction can be caused by changes to a species' environment.

At times, the rate of extinction has increased dramatically and caused a **mass extinction**.

Mass extinction is the result of disruptive global environment changes.

The "Big Five" Mass Extinction Events

In each of the five mass extinction events, ***more than 50%*** of Earth's species become extinct.

Some species get hit harder than others. This is dependent on what resources are hit hard by the disruption in the environment.

The formation of supercontinent **Pangaea** about 250 million years ago had many effects (Permian, 250Ma).

The Cretaceous mass extinction 65.5 million years ago ***separates the Mesozoic from the Cenozoic.***

Organisms that went extinct include about half of all marine species and many terrestrial plans and animals, all *non*-avian dinosaurs.

The presence of iridium in sedimentary rocks suggests a meteorite impact about 65 million years ago.

Displayed in the fossils found. Lower layers of rock (dark grey mudstone) didn't have much iridium. However, middle layer in between top layer of coal and lower layer of mud has thin grey claystone that contains 1,000 times more iridium.

Iridium is rare on Earth, but common in asteroids, leading to a hypothesis about how the extinction of the dinosaurs occurred.

Possibility of a Sixth Mass Extinction:

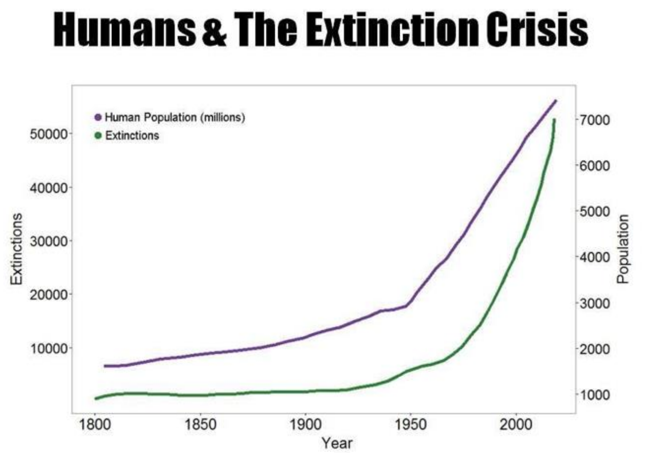
Scientists estimate that the current rate of extinction is 100 to 1,000 times the typical background rate.

Extinction rates tend to increase when global temperatures increase.

There are several factors which has caused extinction rates to increase:

- Pollution
- Water quality

- Poaching
  Certain types of species are more susceptible to extinction. Example: fish due to relying on water quality if there is more water pollution; depends on what is being changed.



Data source: Scott, J.M. 2008. *Threats to Biological Diversity: Global, Continental, Local.* U.S. Geological Survey, Idaho Cooperative Fish and Wildlife, Research Unit, University Of Idaho.

Consequences of Mass Extinctions

Mass extinction can alter ecological communities and the niches available to organisms.
  It can take 5-100 million years for diversity to recover following a mass extinction.
  The type of organisms residing in a community can change with mass extinction.
    Example: the % of marine predators increased after the Permian and Cretaceous mass extinction

Adaptive radiation -- the evolution of many diversely adapted species from a common ancestor; when the diversity of a group spikes
  This may follow:
- Mass extinctions
- The evolution of novel characteristics --> new characteristics in a species
- The colonization of new regions --> the inhabitance of new land

Mammals underwent an adaptive radiation **after the extinction of terrestrial dinosaurs**.
  The disappearance of most dinosaurs allowed for the expansion of mammals in diversity in size.
  Other notable radiations include: photosynthetic prokaryotes, large predators in the Cambrian, land plants, insects, and tetrapods.
    Mammals belong to the group of animals called tetrapods.
      The evolution of unique mammalian features can be traced through gradual changes over time.

Adaptive radiations can occur when organisms colonize new environments with little competition.
  Example: The Hawaiian Islands are one of the world's great showcases of adaptive radiation.
    We often see this because species relate to the one's on the mainland. Their genetics vary, however, because of genetic drift and lack of gene flow.

23.3 Major changes in body form can result from changes in the sequences *and* regulation of developmental genes

Developmental genes act as an order of operations --> a sequence of what is expressed where and when.

These genes decide when a organism will mature --> become sexually mature to reproduce more offspring

Studying genetic mechanisms of change can provide insight into large-scale evolutionary change.

Genes that program development influence the <u>rate, timing, and spatial pattern of changes</u> in an organism's form as it develops into an adult.

Changes in Rate and Timing

<u>Heterochrony</u> - an evolutionary change in the rate or timing of developmental events; all it is is the alternation of pacing

Can be the accelerations and retardations of the development of different regions/systems.

Can alter the timing of reproductive development relative to non-reproductive development.

It can have a significant impact on body shape.

<u>Example</u>: The contrasting shapes of human and chimpanzee skulls are the result of small changes in relative growth rates.

<u>Another example</u>: Heterochrony can be observed in the skeletal structure of bat wings, which resulted from the increased growth rates of their finger bones.

Heterochrony can also alter the development of reproductive tissues --> affects reproductive viability --> earlier maturity, more offspring

Heterochrony can also alter the timing of reproductive development *relative* to the development of nonreproductive organs.

In **<u>paedomorphosis</u>**, the rate of reproductive development accelerates compared with somatic development.

The sexually mature species may retain body features that were juvenile structures in an ancestral species --> Neoteny

Changes in Spatial Pattern

Substantial evolutionary changes can also result from alterations in genes that control the *placement and organization* of body parts.

<u>Homeotic genes</u> - genes which determine such basic features as where wings and legs will develop on a bird or how a flower's parts are arranged

Hox genes are a ***class*** of homeotic genes that provide positional information during animal development.

If these genes are expressed in the wrong location, body parts can be produced in the wrong location.

These genes are relatively conserved. If something goes wrong in the expression of this type of gene, it's likely the organism will not survive to reproduce, thus not allowing for the fatal mutation to enter the gene pool.

Changes in Gene Sequence

Adaptive evolution of both new and existing genes may have played a key role in shaping the diversity of life.

- New morphological forms likely come from gene duplication events that produce new developmental genes.
  - Example: A possible mechanism for the evolution of the six-legged insects *from* a many-legged crustacean ancestor has been demonstrated in lab experiments.
    - Specific changes in the Ubx gene have been identified that can "turn off" leg development.

Changes in Gene Regulation

Changes in morphology can also likely result from changes in the regulation (the difference in the expression of these genes) of developmental genes rather than changes in the *sequences* of developmental genes.

- Example: three-spine sticklebacks in lakes have fewer spines than their marine relatives
  - The gene sequence remains the same, but the regulation of gene expression is different in two groups of fish.
    - To put it simply, the genes are there for more spines, however, they are not regulated in a way for them to be expressed.

Chapter 24 -- Early Life and the Diversification of Prokaryotes

Monday, February 18, 2019
11:00

Overview slide: The First Cells

The oldest fossil organisms are **prokaryotes**, dating back to 3.5 billion years ago.

They're single-celled organisms in the domains Bacteria and Archaea.

Some of the earliest prokaryotic cells lived in dense mats that resembled stepping stones.

Prokaryotes - *pro* - before, *karyon* - kernel; are the most abundant organisms on Earth; a distinctive feature of these organisms is that they do NOT have a true nucleus as eukaryotes do

There are more in a handful of fertile soil than the number of people who have ever lived.

These organisms are capable of thriving almost everywhere, where other organisms struggle to survive such as habitats that are too acidic, salty, cold, or hot.

Some prokaryotes colonize the bodies of ***other*** organisms as displayed in Week 6's lab with the termites.

24.1 Conditions on early Earth made the origin of life possible

Chemical and physical processes on early Earth may have produced very simple cells through a sequence of ***four*** stages. It wasn't a quick process from nonliving to living: there was a sequence of events which occurred.

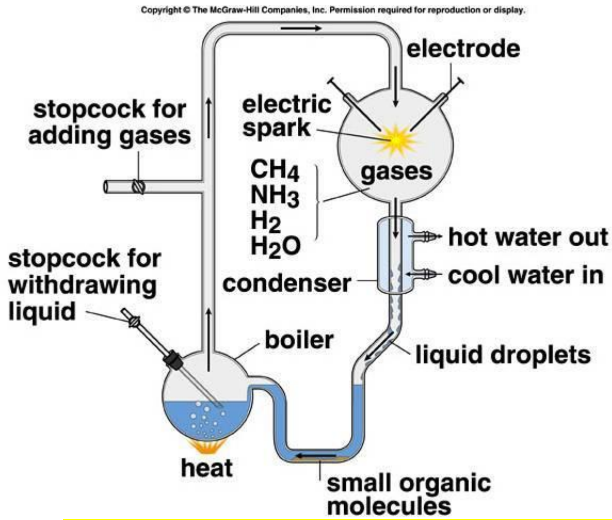
1. Abiotic synthesis of small organic molecules.
    a. Abiotic --> nonlife based; organic --> pure elements, no mixtures or compounds
        i. Present during early Earth was :
            1. Water vapor
            2. Volcanic gasses --> included nitrogen, nitrogen oxides, CO_2, methane, ammonia, and hydrogen ****Oxygen was not present until much later

This type of environment was tested out --> an experiment was carried out to recreate it:

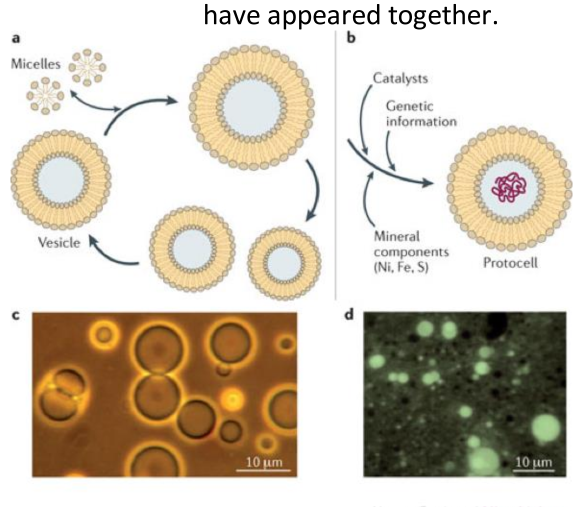
In the 1920s, A.I. Oparin and J.B.S. Haldane hypothesized that the early atmosphere was a reducing (electron adding) environment.

In 1953, Stanley Miller and Harold Urey conducted experiments that showed the abiotic synthesis of organic molecules in a reducing atmosphere is possible.

These experiments have been recreated to test whether the outcomes were dependent on a reducing environment --> displayed that there are *several possible atmospheres* in which these organic molecules could have been formed.



Organic molecules have also been found in meteorites.

2. Joining these small organic molecules into macromolecules --> large chains
    a. Abiotic synthesis of macromolecules --> RNA monomers have been produced *spontaneously* form simple molecules.
    b. Spontaneity is emphasized because there was no consciousness present at this time --> no living things to choose to have these small organic molecules synthesize into macromolecules
        i. Small organic molecules polymerize when they are concentrated on hot sand, clay, rock.
3. Packaging of molecules in ***<u>protocells</u>***, membrane-bound droplets that maintain a consistent internal chemistry. Without a membrane, there is no cell, just a bunch of material floating around.
    a. Protocells may have been fluid-filled vesicles with a membrane-like structure.
        i. In water, lipids and other organic molecules can spontaneous form vesicles with a lipid bilayer.
            1. Replication and metabolism are key properties of life and may have appeared together.
    b. 

        i. Source of the water in the vesicle is from the outside the vesicle, the environment. It contains the small organic molecules, minerals, etc.

    c. Adding clay can increase the rate of vesicle formation. Vesicles exhibit simple reproduction and metabolism and maintain an internal chemical environment.
        i. The more turbid the water is described to be, the more vesicles that exist.
4. Origin of self-replicating molecules
    a. Self-replicating RNA
        i. The first genetic material was probably RNA, NOT DNA. RNA molecules called ***ribozymes*** have been found to catalyze many different reactions.
            1. Example: Ribozymes can make complementary copies of short stretches of RNA.
        ii. Natural selection has produced self-replicating RNA molecules.
            1. These molecules that were more stable or replicated more quickly would have left the most descendant RNA molecules.
                a. The early genetic material might have formed an "RNA world."
        iii. Vesicles with RNA *capable* of replication would have been protocells.
            1. RNA could have provided the template for DNA which is considered to be a more *stable genetic material*.

Mentioned before, ***stromatolites*** are some of the oldest fossils we have, layered rocks that formed form the activities of prokaryotes up to 3.5 billion years ago.

Ancient fossils of individual prokaryotic cells have been discovered.

Example: Fossilized prokaryotic cells have been found in 3.4 billion year old rocks from Australia.

The cyanobacteria that form stromatolites were the main *photosynthetic organisms* for over a billion years.

Early cyanobacteria began the release of oxygen into Earth's atmosphere.

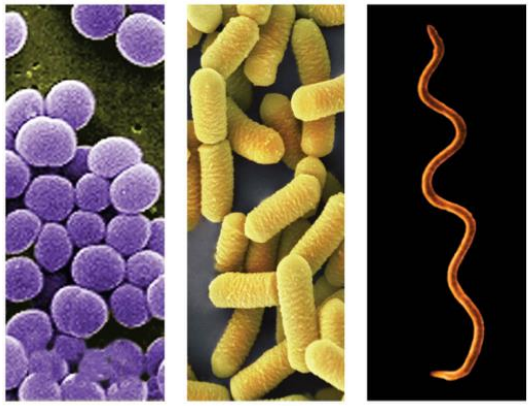
Surviving prokaryote lineages either avoided or adapted to the newly aerobic environment --> survival of the fittest, natural selection

24.2 Diverse structural and metabolic adaptations have evolved in prokaryotes

Most prokaryotes are *unicellular*, although some species form colonies.

Most are very small, much smaller than the diameter of many eukaryotic cells. Small but STILL VERY diverse. They have a variety of shapes.

The three most common shapes are spheres (cocci), rods (bacilli), and spirals.



A key feature of nearly all prokaryotic cells is their ***cell wall***, which maintains cell shape, protects the cell, and ***prevents it*** from bursting in a hypotonic environment. When a cell is in a hypotonic environment, there is a higher concentration of salt ***inside*** the cell than outside. As a result, water moves into the cell, and it swells and bursts. The cell is especially turgid.

Eukaryote cell walls are made of cellulose or chitin. These materials are complex and expensive to have.

- Bacterial cells walls contain **peptidoglycan**, a network of modified sugars cross-linked by polypeptides. The presence of this material contrasts that of eukaryotes, analogous structure to them, having homoplasy. Each organism has evolved independent of each other.
- Archaeal cell walls contain polysaccharides and proteins but ***lack peptidoglycan***. Scientists use the Gram stain to classify bacteria by cell wall composition --> what makes up their cell walls.
  - **Gram-positive** bacteria have ***simpler*** walls with a ***large amount*** of peptidoglycan.
  - **Gram-negative** bacteria have *less* peptidoglycan ***and*** an outer membrane that can be toxic. It has an additional plasma membrane, allows for it to adhere to tissue --> has the potential to cause damage to the tissue
- Many antibiotics target *peptidoglycan* and damage bacterial cell walls.
  - Gram-negative bacteria are more likely to be *antibiotic resistant*.
    - A polysaccharide or protein layer called a **capsule** covers many prokaryotes.

Some bacteria develop resistant cells called **endospores** when they lack an essential nutrient. This is a layer of cells which surround the bacteria and allow it to be in stasis when the bacteria is undergoing periods of environmental stress.

Other bacteria have **fimbriae**, which allow them to stick to their substrate or other individuals in a colony.

Think about someone trying to high-five other people down an aisle. You must have your arm outstretched in order to reach everyone else.

Pili (or sex pili) are longer than fimbriae and allow prokaryotes to exchange DNA. This allows for the possibility of diversification due to the exchanging of DNA, allowing for one prokaryote to replicate itself.

Mobility

The term **taxis** is used when describing movement of a bacteria.

In a heterogeneous environment, many bacteria exhibit **taxis**, the ability to move towards or away from a stimulus.

Chemotaxis is the movement toward or away from a chemical stimulus. It changes the immediate surroundings of the bacteria, thus the available resources. It can also protect from dangerous situations by fleeing.

Proteins along the membrane of the bacteria and archaea are what detect the stimulus surrounding these organisms.

Most mobile bacteria propel themselves by **flagella** scattered about the surface or concentrated at one or both ends. Example --> flagella on the end of a sperm

The flagella of bacteria, archaea, and eukaryotes are composed of different proteins.

The presence of flagella across all of these kingdoms are analogous structures.

When there is an extra outer membrane surrounding the bacteria, it is gram-negative.

Evolutionary Origins of Bacterial Flagella

Bacterial flagella are composed of a motor, hook, AND filament.

Many of the flagella's proteins are modified versions of proteins that perform OTHER tasks in bacteria.

Flagella likely evolved as existing proteins were added to an ancestral secretory system.

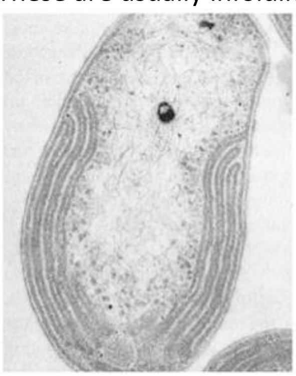
The evolution of the flagella is an example of **exaptation**, where existing structures take on new functions through descent with modification.

Internal Organization and DNA

Prokaryotic cells usually ***lack*** complex compartmentalization. This significantly contrasts eukaryotic cells as they are more organized and are more membrane bound organelles.

Some prokaryotes do have specialized membranes that perform metabolic functions.

These are usually infoldings of the plasma membrane.



^Aerobic prokaryote		^Photosynthetic prokaryote

The prokaryotic genomes has ***less DNA*** than the eukaryotic genome, however, is very high in density --> much higher in "true" DNA

Most of the genome consists of a circular chromosome.

The chromosome is *not* surrounded by a membrane; it is located in the ***nucleoid*** region --> named similar to a nucleus but is not the same

It's just floating around and not protected by any kind of membrane.

Some species of bacteria also have smaller rings of DNA called **plasmids**. These plasmids have the possibility to allow for gene flow to occur. They can be exchanged horizontally between cells, allowing for an exchange of DNA.

There are some differences between prokaryotes and eukaryotes in DNA replication, transcription, and translation.

These allow people to use some antibiotics to ***inhibit*** bacterial growth ***without*** harming themselves.

Nutritional and Metabolic Adaptations (troph --> consumption)

Prokaryotes can be categorized by how they obtain energy and carbon:

- ***Photo***trophs obtain energy from *light*
- ***Chemo***trophs obtain energy from *chemicals* (what we do when we eat, breaking down nutrients to use as energy)
- ***Auto***trophs require CO_2 as a carbon source (auto --> self); they get this from themselves from performing processes such as photosynthesis
- ***Hetero***trophs require an organic nutrient to make organic compounds; cannot get it from themselves

Energy and carbon sources are combined to give four major modes of nutrition:

- Photoautotrophy (examples: plants and photosynthetic organisms)
- Chemoautotrophy (these organisms live in dark places such as deep in soil)
  - Are a very narrow group of organisms, not mentioned much but do exist
- Photoheterotrophy
- Chemoheterotrophy (examples: dogs, humans, birds, organisms that use chemical energy due to being unable to perform photosynthesis)

The Role of Oxygen in Metabolism

Prokaryotic metabolism varies with respect to O_2.

Obligate aerobes ***require*** O_2 for cellular respiration.

Obligate anaerobes are ***poisoned*** by O_2 and use fermentation or anaerobic respiration, in which substances other then O_2 act as electron acceptors.

Facultative anaerobes can survive with or without O_2.

May not always have an advantage against other obligate organisms, depends on the environment.

Nitrogen Metabolism

Nitrogen is essential for the production of amino acids and nucleic acids.

Prokaryotes can metabolize nitrogen in a variety of ways.

In **nitrogen fixation**, some prokaryotes convert atmospheric nitrogen (N_2) to ammonia (NH_3).

This helps us farm, bringing nitrogen into the soil in a form that plants can use.

Metabolic Cooperation

Cooperation between prokaryotes allows them to use environmental resources they could not use as individual cells.

In the cyanobacterium *Anabaena*, photosynthetic cells and nitrogen-fixing cells called **heterocysts** (or heterocytes) exchange metabolic products.

This is an example of an early form of cooperation among organisms.

In some prokaryotic species, metabolic cooperation occurs in *surface-coating colonies* called **biofilms**. Example --> the back of a person's teeth, the inside of a sink drain

This is an important to consider as it has a public health component since some biofilms can be harmful. Example --> dental plaque, endocarditis, cystic fibrosis

Reproduction

Prokaryotes include bacteria and archaea.

Prokaryotes reproduce quickly by **binary fission** and can divide every 1-3 hours. During this replication, there is the possibility for deletions, insertions, base-pair shifts, mutations. This opens the opportunity for mutation to occur quickly and be passed down generations. When it comes to developing antibiotics, it has the goal of hindering this binary fission.

Key features of prokaryotic biology allow them to divide quickly:

- They are small
- They reproduce by binary fission.
- They have short generation times.

Adaptations of Prokaryotes: A Summary

The ongoing success of prokaryotes is an extraordinary example of physiological and metabolic diversification.

Prokaryotic diversification can be viewed as a **first great wave of adaptive radiation** in the evolutionary history of life.

AFTER EXAM 3 (2-25-2019, Wednesday)

24.3 Rapid reproduction, mutation, and genetic recombination promote genetic diversity in prokaryotes

Prokaryotes have a considerable amount of genetic variation.

There are three factors that contribute ot this genetic diversity:

- Rapid reproduction
- Mutation --> introduces new alleles to the gene pool
- Genetic recombination

Prokaryotes reproduce by binary fission, and offspring cells are generally identical.

Mutation rates during binary fission are low, but because of rapid reproduction, mutations can accumulate rapidly in a population.

High diversity from mutations allows for rapid evolution.

Prokaryotes are not "primitive" but are highly evolved.

Cooper and Lenski experiment displayed how prokaryotes were able to evolve a subpopulation within their larger population to adapt to survive in the nutrient poor environment regardless of the conditions.

Genetic recombination, the combining of DNA from two sources, contributes to diversity. There are three major avenues that can cause genetic recombination:

- **Transformation** --> a prokaryotic cell can take up and incorporate foreign DNA from the surrounding environment in this process
- **Transduction** --> the movement of genes between bacteria by ***bacteriophages*** (viruses that infect bacteria, they specifically target bacteria)
    - These phages inject their own DNA within the bacteria to synthesize in the host cell. It also makes the cell create new phages to the point that the bacteria lyses.
        - Some viruses will introduce novel alleles into the circular chromosome of the bacteria.
- **Conjugation (conja == coming in together)** - the process where genetic material is transferred between prokaryotic cells
    - In bacteria, the DNA transfer is ***one*** way.
    - In *E. coli*, the donor cell attaches to a recipient by a pilus, pulls it closer, and transfers DNA.
    - Not all bacteria are able to produce a sex pilus. The **F factor** is a piece of DNA required for the production of pili. Cells without the F factor (F-) function as DNA ***recipients*** during conjugation. The F factor *is* transferrable during conjugation.
        - Cells containing the **F plasmid** (F+) function as DNA ***donors*** during conjugation. The F factor is present ON the F plasmid.
        - The F factor can also be integrated into the chromosome. A cell with the F factor built into its chromosomes functions as a donor during conjugation.
            - The recipient becomes a recombinant bacterium, with DNA from two different cells.

Horizontal gene transfer - the movement of genes among individuals from different species

R Plasmids and Antibiotic Resistance

Genes for antibiotic resistance are carried in **R plasmids**.

Antibiotics kill sensitive bacteria, but not bacteria with *specific* R plasmid.
Through natural selection, the fraction of bacteria with genes for resistance increased in a population exposed to antibiotics.
Antibiotic-resistant strains of bacteria are becoming more common.

24.4 Prokaryotes have radiated into a diverse set of lineages

Prokaryotes have radiated extensively due to diverse structural and metabolic adaptations. Prokaryotes inhabit every environment known to support life.

Applying ***molecular systematics*** to the investigation of prokaryotic phylogeny has produced dramatic results.

Molecular systematics led to the splitting of prokaryotes into bacteria and archaea.
Molecular systematists continue to work on the phylogeny of prokaryotes.

Bacteria

Bacteria include the vast majority of prokaryotes familiar to most people.

Diverse nutritional types are scattered among the major groups of bacteria.
Proteobacteria - gram-negative bacteria including photoautotrophs, chemoautotrophs, and heterotrophs

Some are anaerobic and other aerobic.

Gram-positive bacteria include:

- *Actinomycetes*, which decompose soil
- *Streptomyces*, which are a source of antibiotics
- *Bacillius anthracis*, the cause of anthrax
- *Clostridium botulinum*, the cause of botulism
- Some *Staphylococcus* and *Streptococcus*, which can be pathogenic
- Mycoplasms, the smallest known cells

Archaea

Archaea shared certain traits with bacteria and other traits with eukaryotes.

Some archaea live in extreme environments and are called **extremophiles**.

Extreme **halophiles** live in highly saline environments.

Extreme **thermophiles** thrive in very hot environments.

Methanogens product methane as a waste product.

Methanogens are *strict anaerobes* and are poisoned by O_2.

Methanogens live in swamps and marshes, in the guts of cattle, and near deep-sea hydrothermal vents --> they constantly decompose material (breaking down animal matter and other live organisms, living off of the methane byproduct)

24.5 Prokaryotes play crucial roles in the biosphere

Chemical Recycling

Prokaryotes play a *major* role in the recycling of chemical elements between the living and nonliving components of ecosystems.

Chemoheterotrophic prokaryotes function as **decomposers**, breaking down dead organisms and waste products.

Prokaryotes can sometimes increase the availability of nitrogen, phosphorus, and potassium for plant growth.

Prokaryotes can also "immobilize" or decrease the availability of nutrients.

Ecological Interactions

Symbiosis - an ecological relationship in which two species live in close contact --> a larger **host** and smaller **symbiont**

Prokaryotes often form symbiotic relationships with larger organisms.

Human intestines are home to about 500 - 1,000 species of bacteria.

Many of these are mutualists and break down food that is undigested by our intestines.

Prokaryotes cause about half of all human diseases.

For example, Lyme disease is caused by a bacterium and are carried by ticks.

Pathogenic prokaryotes typically cause disease by releasing exotoxins or endotoxins.

Exotoxins - are secreted and cause disease even if the prokaryotes that produce them are not present; are excreted *outside* of the cell

Endotoxins - are released only when bacteria die and their cell walls break down; can make the predators sick

Experiments using prokaryotes have led to important advances in DNA technology.

Example: *E. coli* is used in gene cloning.

Bacteria can now be used to make natural plastics.

Prokaryotes are the principal agents in **bioremediation**, the use of organisms to remove pollutants from the environment.

Bacteria can be engineered to produce vitamins, antibiotics, and hormones.

Bacteria are also being engineered to produce ethanol from waste biomass.

Chapter 25 -- The Origin and Diversification of Eukaryotes

Wednesday, February 27, 2019
10:58

25.1 Eukaryotes arose by endosymbiosis more than 1.8 billion years ago

The first, early eukaryotes were ***unicellular***.

Eukaryotic cells have **organelles** and are structurally *more complex* than prokaryotic cells.
A well-developed **cytoskeleton** enables eukaryotic cells to have asymmetrical forms and to change shape. Prokaryotes, on the other hand, have their shapes defined by a cell wall.

Chemical evidence for the presence of eukaryotes dates back to ***2.7 billion years ago***.

The earliest fossils of eukaryotic cell are ***1.8 billion years old***.

The initial diversification of eukaryotes occurred 1.8 to 1.3 billion years ago.

Novel features of eukaryotes, including complex multicellularity, sexual life cycles, and photosynthesis, arose 1.3 billion to 635 million years ago.

The first large, multicellular eukaryotes represented by the ***Ediacaran biota*** evolved 635 to 535 million years ago.

Eukaryotic cells exhibited greater structural complexity than prokaryotic cells as early as ***1.5 billion years ago***. From the beginning of their divergence from prokaryotes, they *immediately* increased in complexity.

The earliest multicellular eukaryotic fossils are of ***red algae***, which date back to ***1.2 billion years ago***, but large, multicellular eukaryotes did not arise until 635 million years ago.

Severe ice ages from 750 to 580 million years ago may have hindered the rise of large eukaryotes. After the destruction of several organisms after this event, eukaryotes began to flourish.

DNA sequences data indicate that eukaryotes are "***combination***" organisms.

Eukaryotic genes and characteristics show evidence of both ***archaeal*** and ***bacterial*** origins.

Evidence of mixed origins may be a consequence of **endosymbiosis**, a symbiotic relationship in which one organism lives inside the body or cell of another organisms.

Origin of Mitochondria and Plastids

Endosymbiont theory - proposes that mitochondria and plastids were formally small prokaryotes that began living within larger cells; occurred over billions of years, was a *random* event that occurred through ancestral prokaryotes digesting mitochondria and plastids

Endosymbiont - a cell that lives *within* a host cell; the relationship between these cells is *mutually beneficial*

Prokaryotes ancestors to mitochondria and plastids probably entered the host cell as undigested prey or internal parasites.

Outside of the cell, mitochondrion were *aerobic* bacterium and plastids were *cyanobacteria* (photosynthetic bacterium) that were able to perform photosynthesis.

Anaerobic host cells benefited from endosymbionts' ability to take *advantage* of an increasingly aerobic world.

Heterotrophic *host* cells benefited from the nutrients produced by photosynthetic endosymbionts.

In the process of becoming more interdependent, the host and endosymbionts would have become a *single* organism.

At this point, ancestral heterotrophic eukaryotes and ancestral photosynthetic eukaryotes are formed.

Serial endosymbiosis (serial meaning it's happening in multiple steps as we go) - supposes that mitochondria evolved *before* plastids through a sequence of endosymbiotic events

As displayed in the graphic on slide 14, slowly but surely, the prokaryotes evolved to become more complex in their structures --> folding into itself to create the endoplasmic reticulum, engulfing other bacterium to become the eukaryotes they are now.

Key evidence supporting an endosymbiotic origin of mitochondria and plastids:

- Inner membranes are ***similar*** to plasma membranes of prokaryotes.
  - Think of a fountain and passing through it --> you are covered in water --> in a sense, the inner membranes are from the plasma membrane from the ancestral prokaryotes: the parts of the eukaryotes had to *pass through* the plasma membrane of the prokaryotes.
- Division is similar in these organelles and some prokaryotes.
- DNA structure is similar to that of prokaryotes.
- These organelles transcribe and translate their *own* DNA.
- Their ribosomes are *more* similar to prokaryotic than eukaryotic ribosomes.

DNA sequence analysis indicates that mitochondria arose from an **alpha proteobacterium** (proteobacteria are a major phylum of gram-negative bacteria --> have an extra membrane surrounding it).

Eukaryotic mitochondria descended form a *single common ancestor*.

Plastids arose from an *engulfed cyanobacterium* --> able to perform photosynthesis.

Some photosynthetic protists (mostly unicellular groups of eukaryotes) may have been engulfed to become endosymbionts themselves.

Protists are NOT prokaryotes --> they are a ***type*** of eukaryote.

The diversity of plastids were produced by endosymbiosis.

At first, serial endosymbiosis occurred --> having the aerobic bacteria incorporated into early eukaryotes ***then*** cyanobacteria (can perform photosynthesis).

These now photosynthetic eukaryotes evolved and diversified into red ***and*** green algae.

On several occasions during eukaryotic evolution, red and green algae underwent **secondary endosymbiosis**, in which they were further ingested by a heterotrophic eukaryote.

After the red algae were engulfed, this new combined organism mutated and evolved into *different* groups of photosynthetic organism.

Green algae were engulfed by *different hosts*, that each mutated and evolved into *different* photosynthetic organisms.

Main idea: endosymbiosis occurred multiple times, leading to a wide diversity of photosynthetic organisms: some with red algae ancestors and others with green algae ancestors.

Later idea --> green algae ancestors eventually gave rise to plants

The plastid-bearing lineage of protists (unicellular groups of eukaryotes) evolved into red and green algae.

Like cyanobacteria, plastids of red algae and green algae have *two membranes*.

Transport proteins in the membranes of red and green algae are ***homologous*** to those found in cyanobacteria.

As explained above, on several occasions during eukaryotic evolution, red and green algae underwent ***secondary endosymbiosis***, in which they were *further* ingested by a heterotrophic eukaryote.

25.2 Multicellularity has originated several times in eukaryotes

The evolution of eukaryotic cells allowed for a greater range of unicellular forms.

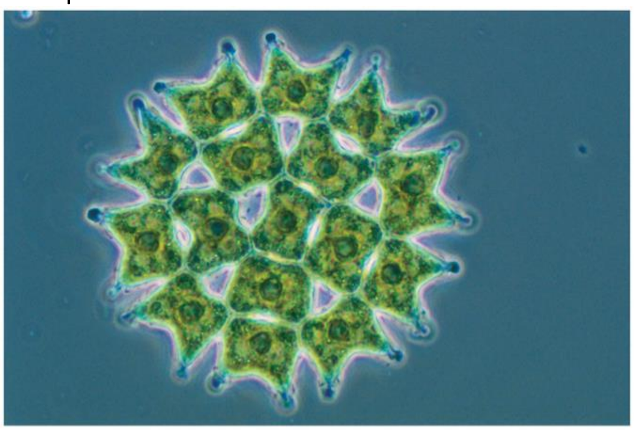
A *second* wave of diversification occurred when multicellularity evolved and gave rise to algae, plants, fungi, and animals.

The first multicellular forms were **colonies** --> collections of cells that are connected to one another but show ***little to no*** cellular differentiation.

Multicellular colonies consist of simple filaments, balls, or cell sheets.

Colonial cells may be attached by shared cell walls or, in cells that lack rigid walls, held together by proteins that physically connect adjacent cells.

Example: *Pediastrum*



Independent Origins of Complex Multicellularity

Multicellular organisms with differentiated cells originated ***multiple times*** over the course of eukaryotic evolution.

Genetic and morphological evidence indicates that the lineages of red, green, and brown algae, plants, fungi, and animals arose *independently from* ***different single-celled ancestors***.

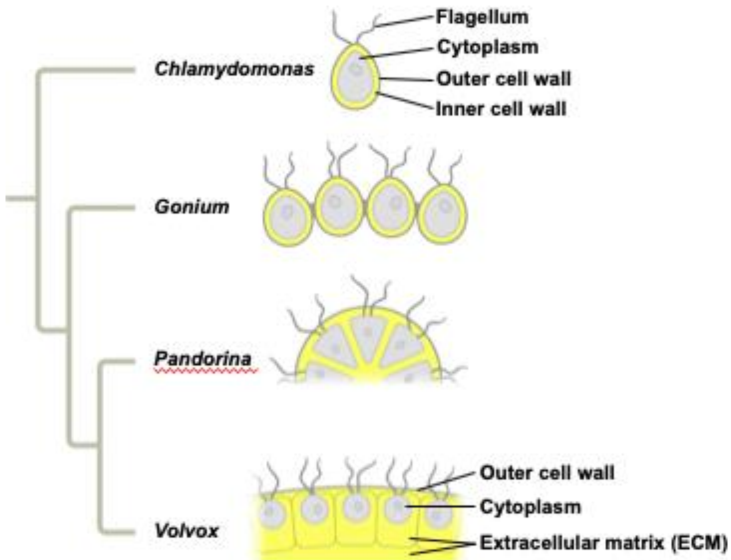
Example: although fungi and animals arose from single-celled ancestors, they arose from *different* single-celled ancestors

Volvox - a multicellular green algae with two types of differentiated cells --> because of these *differentiated* cells, most researchers refer to *Volvox* as multicellular rather than colonial

It forms a *monophyletic* (includes the *most recent common* ancestor of the group ***and*** *all* of its descendants) group with a single-celled alga *(Chlamydomonas*) and several colonial species.

Volvox and all colonial members of this group have proteins homologous to those ground in the cell wall of *Chlamydomonas*.

Multicellularity in *Volvox* may have originated through evolution of increasingly complex *colonial* forms descended from a single-celled common ancestor.



Only a few novel genes account for the morphological differences between *Volvox* and *Chlamydomonas*.

This transition to multicellularity may results from changes in how *existing* genes are used rather than the origin of large numbers of novel genes.

Steps in the Origin of Multicellular Animals

Choanoflagellates ("funnel flagellates") - the closest living relatives of animals

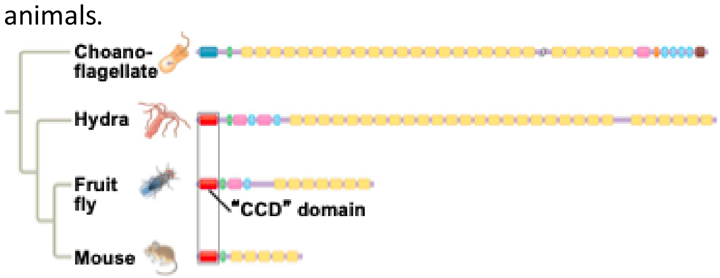
The common ancestor of choanoflagellates and living animals may have resembles present-day choanoflagellates.

An analysis of the genome of the unicellular choanoflagellate *Monosiga brevicollis* with representative animals uncovered 78 protein domains (domains are a key structural or functional region of a protein) that were otherwise only known to occur in animals.

In animals, many of these shared protein domains function in cell adherence or cell signaling.

The origin of multicellularity in animals required the evolution of new days for cells to adhere and communicate with each other (cell signaling).

Molecular similarities in domains of proteins functioning in cell adherence **(cadherins)** and cell signaling have been found between modern choanoflagellates and representative animals.



25.3 Four "supergroups" of eukaryotes have been proposed based on morphological and molecular data

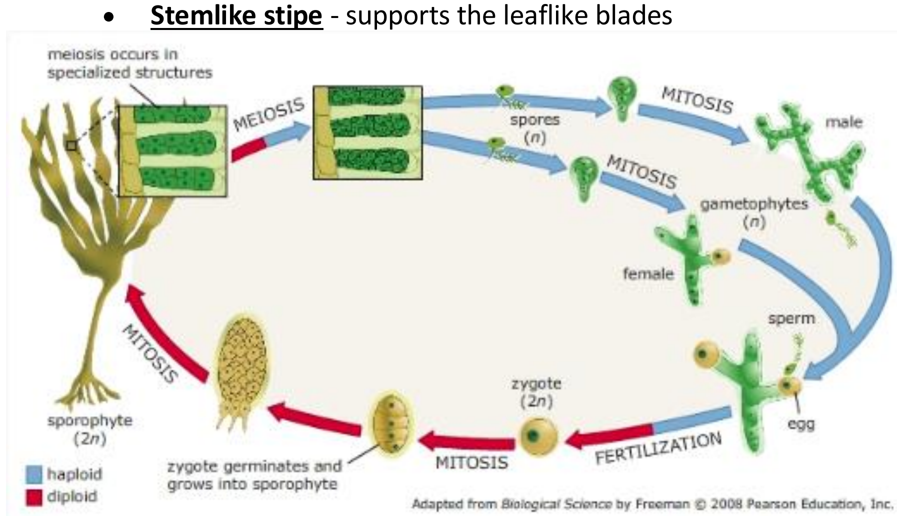
By their nature, eukaryotes are "combination" organisms. Having originated by *endosymbiosis*, they had archaeal and bacterial genes and they possessed endosymbionts with novel metabolic capabilities.
Supergroups:

- "SAR Clade"
- Archaeplastida
- Unikonta
- Excavata

SAR Clade

One supergroup of eukaryote is referred to as the "SAR" clade, named after three large and very diverse clades:

- Stramenopiles
    - This subgroup, **stramenopiles**, include the *most important photosynthetic organisms* on Earth.
        - Diatoms and brown algae are members of this clade.
            - **Diatoms** - highly diverse, unicellular algae with a unique two-part, glass-like wall of silicon dioxide
            - **Brown algae** - the largest and most complex algae; all are multicellular and most are marine; they include many species that are commonly called "seaweeds"
                - Brown algal seaweeds have plantlike structures (analogous plant similarities):
                    - **Rootlike *holdfast*** - anchors the alga
                    - **Stemlike stipe** - supports the leaflike blades



- Alveolates
    - This subgroup, **alveolates**, has membrane-bounded sacs (alveoli) just under the plasma membrane.
        - Dinoflagellates and ciliates are members of the alveolata clade.
            - **Dinoflagellates** - have ***two flagella*** and each cell is reinforced by cellulose plates; they are abundant components of both marine and freshwater phytoplankton
                - Toxic "red tides" are caused by dinoflagellate blooms.

- They are a diverse group of aquatic phototrophs, mixotrophs, and heterotrophs.
    - **Mixotrophs** - an organism that can use a mix of *different* sources of energy and carbon, instead of having a single trophic mode (not just heterotrophs, not just autotrophs)
- **Ciliates** - a large varied group of protists --> named for their user of cilia to move and feed; most ciliates are predators of bacteria or small protists (example: paramecium)

- Rhizarians
    - Many species within the **rhizarian** subgroup are amoebas. ***Amoebas*** move and feed by ***pseudopodia*** --> some but **not all** belong to the clade Rhizaria
        - **Forams** and **cercozoans** are members of the rhizarian clade. **Foraminiferans (forams)** - named for "porous" shells called **tests**; they include both marine and freshwater affinities
- Pseudopodia extend ***through*** the pores in the test.
- Many forams have endosymbiotic algae.
- **Cercozoans** - include amoeboid and flagellates protists with threadlike pseudopodia
    - Common in marine, freshwater, and soil ecosystems
    - Most are heterotrophs, including parasites and predators.
        - *Paulinella chromatophora* --> an autotroph with a unique photosynthetic structure called a chromatophore
            - Evolved from different cyanobacteria than most photosynthetics.

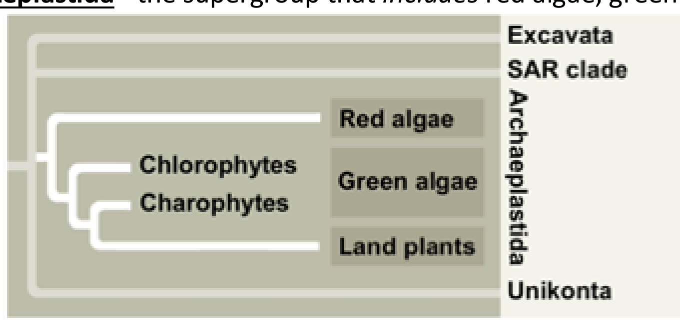
Archaeplastids

Plastids arose when a heterotrophic protist acquired a cyanobacterial endosymbiont.

The photosynthetic descendants of this ancient protist later evolved into *red algae* and *green algae*.

Land plants would later descend from the green algae.

Archaeplastida - the supergroup that *includes* red algae, green algae, *and* land plants



Red algae are reddish in color due to an accessory pigment called **phycoerythrin**, which *masks* the green of chlorophyll.

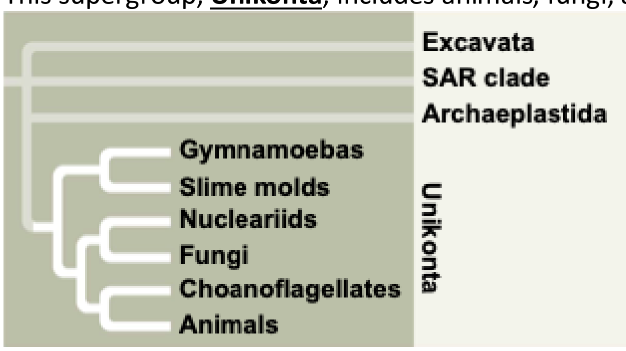
- The color varies form greenish-red in shallow water to dark red or almost black in deep water.
- Red algae are usually multicellular --> the largest are seaweeds
    - Red algae are also the *most abundant large algae* in coastal waters of the tropics. They also reproduce sexually.

Green algae are named for their grass-green chloroplasts. They are a ***paraphyletic*** (includes the most recent common ancestor of the group but NOT all of its descendants) group.

- Plants are descended from the green algae.
- The two main groups are **charophytes** and **chlorophytes**.
  - **Charophytes** are most closely related to land plants.
  - Most **chlorophytes** live in fresh water, although many are marine and some are terrestrial.
    - Nearly all species are chlorophytes reproduce sexually.
    - Some unicellular chlorophytes are free-living while others live symbiotically *within* other eukaryotes.
    - Larger size and greater complexity are found in multicellular species including *Volvox* and *Ulva*.

Unikonts

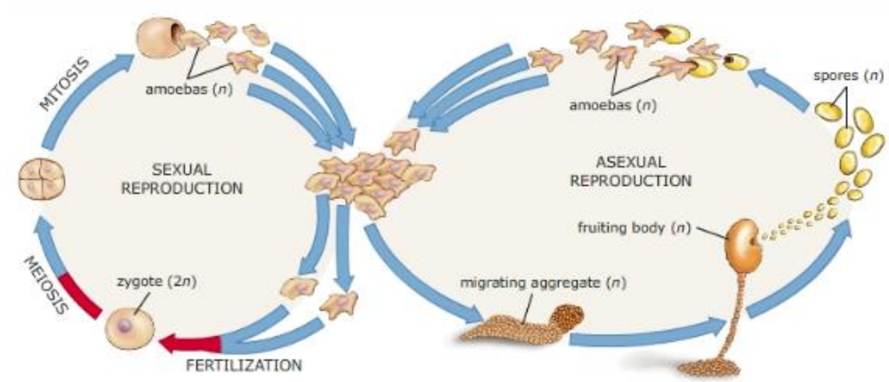
This supergroup, **Unikonta**, includes animals, fungi, and some unicellular protists.



This group includes two clades:

- **Amoebozoans (zoans --> animals, zoos)** - amoebas that have lobe-or-tube-shaped, rather than threadlike, pseudopodia; they have more in common rather than the amoebas that exist in the rhizarian subgroup.
  - Most amoebozoans are ***free-living***, but those that belong to the genus *Entamoeba* are parasites.
  - Slime molds are free-living amoebozoans that were once thought to be fungi.
    - DNA sequences analyses indicate that slime molds belong in the clade *Amoebozoa*.
      - *Dictyostelium* is an example of a cellular slime mold.
        - They have a sexual *and* asexual cell cycle.
          - During asexual reproduction, they begin as haploid spores which become emerging amoeba. From here, they become solitary amoebas in a feeding stage to where they begin to aggregate. They then migrate to form fruiting bodies and then stalks to branch up. These fruiting bodies then release new haploid spores.
          - During sexual reproduction, it begins as haploid spores which become emerging amoeba, and eventually solitary amoebas in a feeding stage. Some of these haploid amoebas will undergo

fertilization with each other which will merge to create a diploid zygote (this is an example of the sexual recombination of alleles). This zygote undergoes meiosis which recreates newly recombined haploid amoebas.



- Cellular slime molds consist of solitary cells that merge to form fertilization or feed individually with the possibility of aggregating to form a fruiting body (the part of the fungi which produces spores).
- **<u>Opisthokonts</u>** --> animals, fungi, and related protists

The root of the eukaryotic tree remains controversial.
It is unclear whether unikonts separated from other eukaryotes relatively early or late.

Excavata

Some members of this supergroup have an "excavated" groove on one side of the cell body. This groove helps members of these groups to gather food.

Two major clades have modified mitochondria:

- **<u>Parabasalids</u>**
- **<u>Diplomonads</u>**

Members of a third clade **<u>(euglenozoans)</u>** have flagella that differ in structure from those of other organisms.

Excavates include parasites such as *Giardia*, as well as many predatory and photosynthetic species.

25.4 Single-celled eukaryotes play key roles in ecological communities and affect human health

Structural and Functional Diversity in Protists

The *majority* of the eukaryotic lineages are composted of protists --> they are mostly single-cellular eukaryotes, NOT prokaryotes.

Single-celled protists can be very complex, as all biological functions are carried out by organelles in each individual cell.

Protists are found in *diverse aquatic environments*.

They reproduce:

- Asexually
- Sexually
- Sexual processes of meiosis and fertilization

Protists show a wide range of nutritional diversity including:

- **Photoautotrophs** - contain chloroplasts
- **Heterotrophs** - absorb organic molecules or ingest larger food particles
- **Mixotrophs** - combine photosynthesis ***and*** heterotrophic nutrition

Photosynthetic Protists

Many protists are important ***producers*** that obtain energy from the sun.

In aquatic environments, photosynthetic protists are prokaryotes are the *main* producers --> primary producers. Other producers are prokaryotes like cyanobacteria.

In this environment, photosynthetic protists are *limited* by nutrients.

These populations of protists can *explode* when limiting nutrients are added.

Example: Diatoms are a *major* component of the phytoplankton.

After a diatom population has bloomed, many dead individuals fall to the ocean floor undecomposed, wrapped in silicon.

As long as they perform photosynthesis, diatoms are taking the CO_2 out of the atmosphere to then further "pump" down to the ocean floor --> a further example of carbon sequestration.

Chlorophyll changes are measured as a proxy to the rates of photosynthesis in a certain environments' species.

More chlorophyll = more photosynthesis

Global Warming Ocean Effects on Marine Producers

The increase in global surface temperatures may prevent nutrient upwelling.

Warm water tends to stay on the surface of bodies of water while cooler water is on the bottom of the ocean --> upwellings occur with current changes in which cold, nutrient-rich water attempts to rise to the ocean communities

If surface water is too warm, these nutrients cannot reach these communities.

This lack of nutrients ***limits*** primary producers. Due to this, these communities run out of necessary nutrients over time, thus reducing their success in their environment, as well as a reduction in the production of chlorophyll (thus less photosynthesis)

These effects cascade to the ecosystem level issues, fisheries, and carbon cycle.

This displays a positive feedback loop.

Feedback loop - where the effect ends up interacting with the cause again

The "positive" in this term describes how there is a loop of something occurring and due to it continuing to happen, it's going to continue to further happen.

Example: As ocean temperatures rise, we'll have less upwelling, meaning nutrients won't reach primary producers. Then primary producers won't be able to produce chlorophyll and perform photosynthesis, meaning that they aren't extracting CO_2 from the atmosphere.

More CO_2 = higher global temperatures

Symbiotic and Parasitic Protists

Some protist symbionts *benefit* their hosts.

Dinoflagellates nourish coral polyps that build reefs.
Wood-digesting protists digest cellulose in the gut of termites.

Some protists are *parasitic*.

Plasmodium causes malaria.
Pfiesteria shumwayae is a dinoflagellate that causes fish kills.
Phytophthora ramorum causes sudden oak death.
Phytophthora infestans causes potato late blight.

Chapter 26 -- The Colonization of Land

Monday, March 4, 2019
10:58

The Greening of Earth

For more than the first 2 billion years of Earth's history, the terrestrial surface was lifeless.

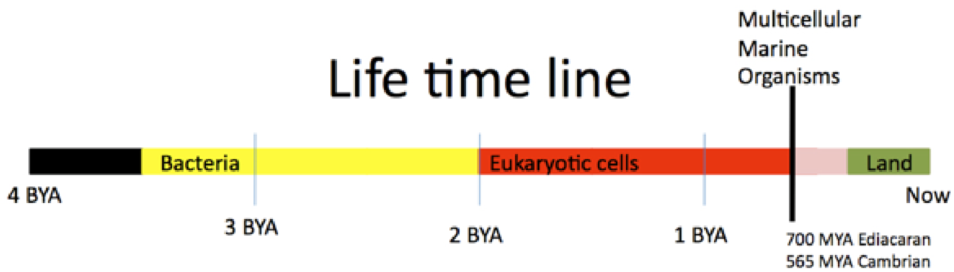
Cyanobacteria and protists (NOT prokaryotes --> are a ***type*** of eukaryote) likely existed on land 1.2 billion years ago.

Likely formed biofilms during the earlier years of Earth's existence.

Around 500 million years ago, small plants, fungi and animals emerged on land.

The first forests formed 385 million years ago.

The forests that exists are not like the ones we're seen today. Giant fungus structures emerged. From the beginning, plants and fungi are theorized to have helped each other colonize land.



Even though they aren't closely related, plants and fungi colonized the land as *partners* before animals.

Plants supply oxygen and synthesize organic molecules (food for themselves, for animals; the organic molecule created is glucose).

Example of autotrophs creating resources for themselves.

Fungi break down this organic material created and recycle nutrients.

The Colonization of Land by Plants and Fungi

1. Land Plants are specialized green algae

As you notice the phylogenic relationships between algae and plants, plants are very closely related to **charophytes** which is a type of algae.

Plants during this time were small due to having to adapt to the new environment they were in: having to deal with dehydration, gravity acting on them due to not being in the lower waters anymore.

Evidence of Algal Ancestry

Many characteristics of land plants also appear in some algae.

However, land plants share certain distinctive traits with *only* **charophytes**, including:

2. Rings of cellulose-synthesizing proteins
3. Structure of flagellated sperm
4. **Sporopollenin**
    - In charophytes, they protect zygotes.
        - Later, when plants evolved, they serve to prevent haploid spores from drying out.

Green algae called **charophytes** are the *closest* relatives of land plants.

The benefits of moving towards land was a significant drop in the amount of competition and in increase in exposure to direct sunlight. Through adaptation, this algae would evolve to become a land plant.

Adaptations Enabling the Move to Land

In charophytes, a layer of a durable polymer called **sporopollenin** prevents exposed zygotes from drying out.

This polymer is also found in plant spore walls to protect haploid spores from drying out.

The movement onto land by charophyte ancestors provided unfiltered sunlight, more plentiful CO_2, and nutrient-rich soil.

Land presented challenges however: a scarcity of water and lack of structural support.

Systematists are currently debating the boundaries of the plant kingdom.

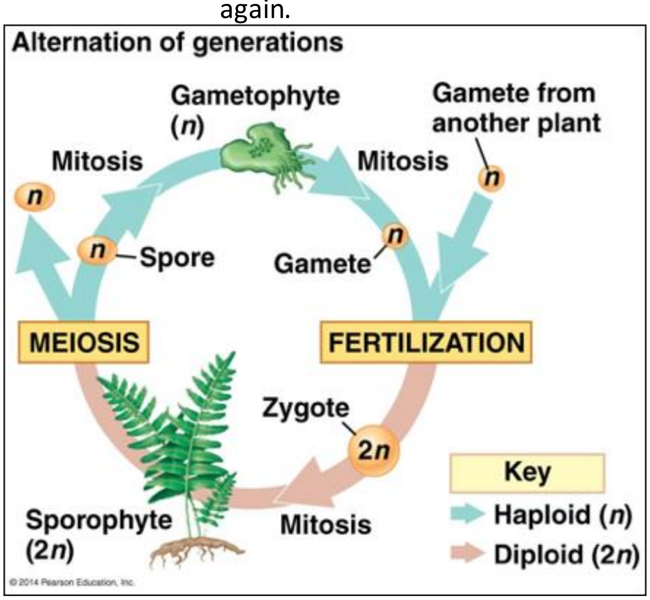
Until debate is resolved, plants are defined as **embryophytes** --> plants with embryos.

Derived Traits of Plants

5. Plant reproduction involved alternation of generations

Key traits that appear in nearly all land plants but are ***absent*** in charophytes include:

- Alternation of generations
    - The **gametophyte** is haploid and produces haploid gametes by *mitosis*.
    - The fusion of the gametes gives rise to the diploid **sporophyte**, which produces haploid **spores** by meiosis.
        - Sporulation occurs if the spore lands in a favorable environment to then form *back* into a gametophyte where the cycle of fertilization will occur again.



- Multicellular, dependent embryos
- Walls spores produced in sporangiac
- Apical meristems
    - This is where the plant grows first --> causes growth in the roots of plants; main function is to catalyze the growth of new cells in young seedlings at the tips of roots and shoot and forming buds

Additional derived traits within plants include:

- **Cuticle** -- a waxy covering of the epidermis that function in ***preventing*** water loss *and* microbial attacks
- **Stomata** -- an opening within the plants which allow for ***gas exchange*** with the environment; a way in which the plant is allowed to breath; specialized spores that allow for the exchange of CO_2 and O_2 between the outside air and the plant

Early Plants

Fossil evidence indicates that plants were on land for at least 470 million years ago.

  Fossilized spores and tissues have been extracted from 450 million year old rocks.

  Large plant structures, such as the sporangium of *Cooksonia*, appeared in the fossil record 425 million years ago.

    By 400 million years ago, a diverse assemblage of plants lived on land.

      Unique traits in these early plant ancestors were specialized tissues for water transport, cuticles, stomata, and branched sporophytes (a diploid that produces haploid spores by meiosis and aids in the alternation of generations).

Within the earliest land plants, it is noticed that they had *simple branching of photosynthetic stems*.

  They were short and small and first appeared approximately 400 million years ago.

    Terrestrial adaptations:

      Cuticle - a waxy protective coating that also limits water loss

      Stomata - openings that allow gas exchange through the cuticle

    They had no ***true*** roots. **Rhizoids** only anchored the plants to the substrate.

      Photosynthesis allowed for these plants to survive, however, more minerals were needed for their survival.

      Rhizoids wouldn't be enough to gather what they needed, thus calling for a different adaptation to emerge to help these plants.

- What is a fungus?

Fungi are *not* autotrophs. They are heterotrophs: they absorb their surroundings.

- They do not eat. They absorb the nutrients from their surroundings into their body. This makes them decomposers in our environment. This is helpful in catalyzing the recycling of resources in the environment. They absorb both living and dead food sources.
- They secrete enzymes outside their body.
- They have a rigid cell wall made up of chitin (same as crustaceans) and would burst without it.
    - Types of body form:
        - **Yeasts** - unicellular
        - **Hyphae** - multicellular filaments; it allows for the absorption of nutrients from the surrounding environment
            - Mycelium is a *network* of hyphae.

Mycorrhizae - a symbiotic association between a fungus and a plant; it grows in associations with the roots of a plant in a symbiotic *or* mildly pathogenic relationship

There are symbiotic associations between plant roots and fungi.

Haustoria - a specialized hyphae to extract or exchange nutrients with plants.

The plant is making a large amount of glucose through photosynthesis.

The plants are gaining minerals and ions from the fungi while the fungi are gaining glucose from this exchange.

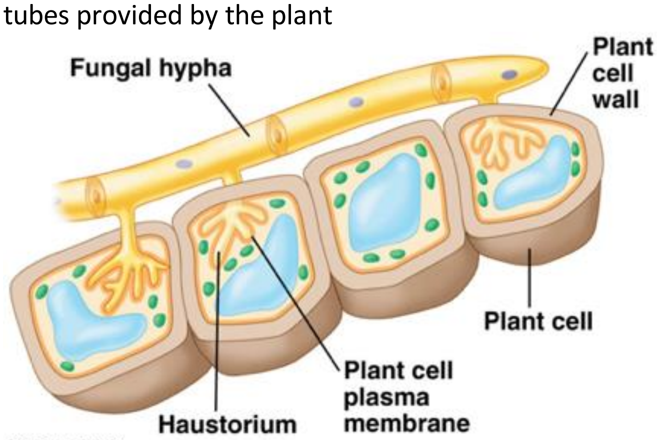
Fungi more efficiently gather mineral ions using their mycelium than plant roots.

Plants share carbs produced during photosynthesis.

Types of Mycorrhizal Fungi

Ectomycorrhizal fungi - hyphae (multicellular filaments; allows for absorption of nutrients) on the surface of roots

Arbuscular mycorrhizal fungi - extend branching hyphae *into* plant cell walls through the tubes provided by the plant



Fungi Reproduction

Fungi reproduction can be either sexual or asexual (with haploid individuals). Spores are involved in their reproduction.

For sexual reproduction, **plasmogamy** can occur --> the fusion of cytoplasm of two parent ***mycelial*** (mycelium is a network of hyphae) cells.

Karyogamy can also occur --> the nuclei of the two parent cells fusing which may happen hours or centuries later.

The zygote produces a haploid (n) spore by meiosis.

Fruiting body - the part of the fungi which produces spores

Mycorrhizal associations are ancient. Fossils exists from 405 million years ago.

The three genes in plants required to form mycorrhizal associations are found in all major plant lineages. **Mycorrhizae present in common ancestor of all land plants.**

A significant amount of fungal diversity exists. Thousands of more species exist within these taxa.

Examples:

Chytrid fungi -- there are unicellular and multicellular forms; they have a globular multicellular fruiting body

This fungi are most commonly found in lakes and soil. They pierce the skin of amphibians and grow from there. They absorb the nutrients from the amphibians, taking it from them.

Eventually, the fruiting body of the fungi will break off once the host is dead to integrate themselves back into the lakes/soil to find another host.

Climate change has an effect on the survival of the fungi as if the environment is too high.

Due to climate change, however, there are a higher rate of clouds in the tropics which causes a dip in the temperature during the day, thus creating an optimal environment for this fungi.

Zygomycetes - this is a rapidly growing hyphae; a decomposer (many food "molds")

Glomeromycetes - from arbuscular mycorrhizae (extend branching hyphae *into* plant cell walls through the tubes provided by the plant); they are symbionts with plants

Ascomycetes - they live in marine, freshwater, and terrestrial habitats

They produce fruiting bodies (bodies that produce spores) called ascocarps.

Basidiomycetes - they are decomposers; ectomycorrhizal fungi --> hyphae on ***the surface*** of roots (common example are mushrooms)

They are usually in the long-lived heterokaryotic stage of reproduction --> there are multiple nuclei in each cell.

LECTURE WEDNESDAY (3-6-2019)

- Vascular Systems allowed larger plants

A divergence exists between vascular plants that have seeds and those that do *not* have seeds.

Nonvascular Plants (bryophytes)

Bryophytes - this is a collection of early diverging lineages (not a clade); they ***lack*** a complex vascular system (ancestral character)

This includes liverworts, mosses, and hornworts.

They use ***rhizoids***, not *true* roots --> can't take up water/minerals --> they instead take up water/minerals through their cell membrane

This collection is gametophyte dominant --> the sphorophytes afterwards are dependent on gametophytes. They are typically short (no possibility of long distance transport). To be gametophyte dominant means that this collection spends the most time in this stage of development.

Their flagellated sperm is defendant on water thus forcing them to live in water-rich environments.

Bryophytes were the prevalent vegetation during the first 100 million years of plant evolution.

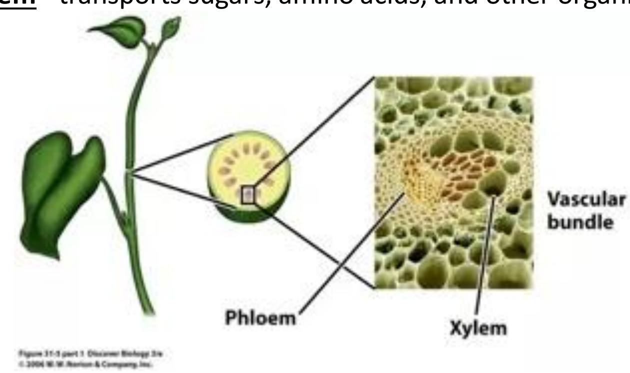
The earliest vascular plants date to 425 million years ago.

- Vascular tissue allowed for increased height, which provided an evolutionary advantage:
    - They are able to further capture more sunlight due to being taller and allows for them to outcompete their surrounding competition.
    - Their increased height also increases the success of their dispersal of spores.

Vascular Plants

Made up of vascular tissue made up of:

- **Xylem** - conducts water and minerals
    - Includes tube-shaped cells called **tracheids**
    - Water-conducting cells are strengthed by ***lignin*** and provide structural support
- **Phloem** - transports sugars, amino acids, and other organic molecules



Roots are now become prevalent --> they are organs that absorb water and nutrients from the soil they're in. These roots also serve to anchor the plant.

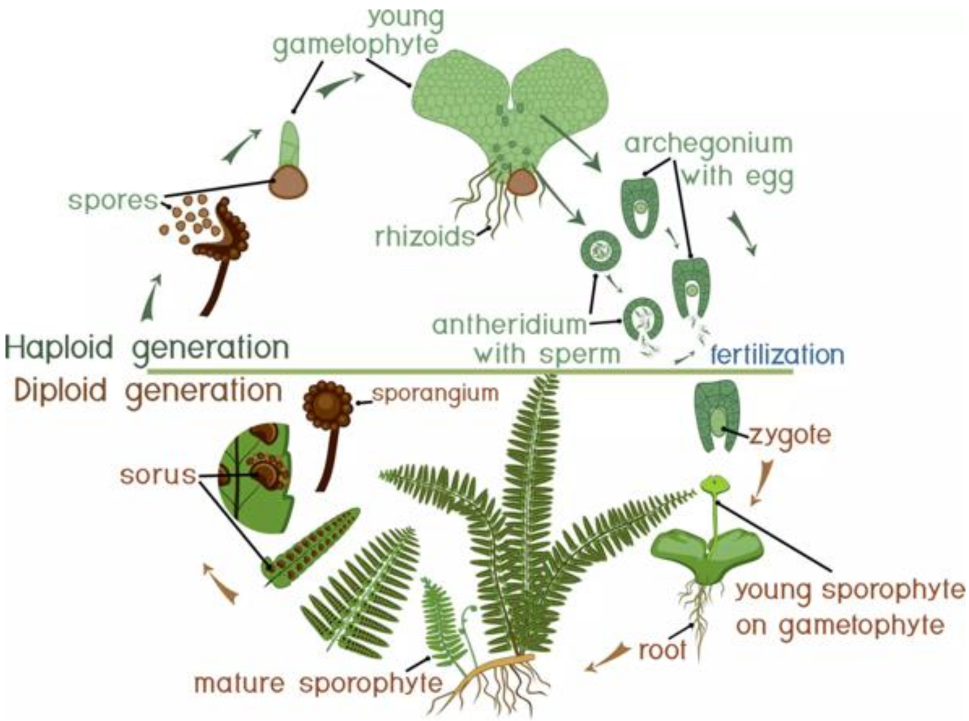
Leaves began to emerge too, which increases the surface area of the plant to further their processes of photosynthesis. Two types of leaves exist:

- **Microphylls** - small, spine-shaped, *single* vessel (relatively simple structure in comparison to megaphylls)
- **Megaphylls** - branched vascular network (more complicated than microphylls)

Vascular plants are ***sporophyte dominant***. They tend to live in water-rich areas due to the sperm of the gametophytes still needing a medium from which to travel to complete fertilization.

"Seedless Vascular Plants"

Examples: **Lycophytes** (club mosses) and **Monilophytes** (ferns)



Seedless vascular plants were abundant in the Carboniferous period (359-299 mya).

Early seed plants rose to prominence at the *end* of the Carboniferous period. As the Carboniferous period progressed, the environment was drying out, thus limiting the resources of the existing plants.

Seed Vascular Plants

Extant seed plants are divided into two clades:

- **Gymnosperms (gymno --> naked, stripped, bare)** - have "naked" seeds that are *not* enclosed in chambers; includes conifers and cycads
    - This clade was better suited than nonvascular plants to drier conditions (including colder climates due to their leaves staying closer to their body and not requiring moisture) due to adaptations including:
        - Seeds and pollen (as mentioned below)
        - Thick cuticles (waxy covering that prevents the plant from drying out in its environment by limiting water loss)
        - Leaves with small surface area
- **Angiosperms (angio --> covered or enclosed by a seed or blood vessel)** - have seeds that develop *inside* chambers called ovaries; they produce flowers and fruits
    - **Flower** - the sexual reproductive structure of angiosperms
        - They may or may *not* involve pollinators.
        - They are composed of floral organs --> modified leaves for specific adaptations

Phylogenetic tree:

- **Nonvascular plants (bryophytes)**
    - **Seedless vascular plants**
        - **Gymnosperms**

Angiosperms

These types of plants originated about 360 million years ago. They were adapted for spreading on land.

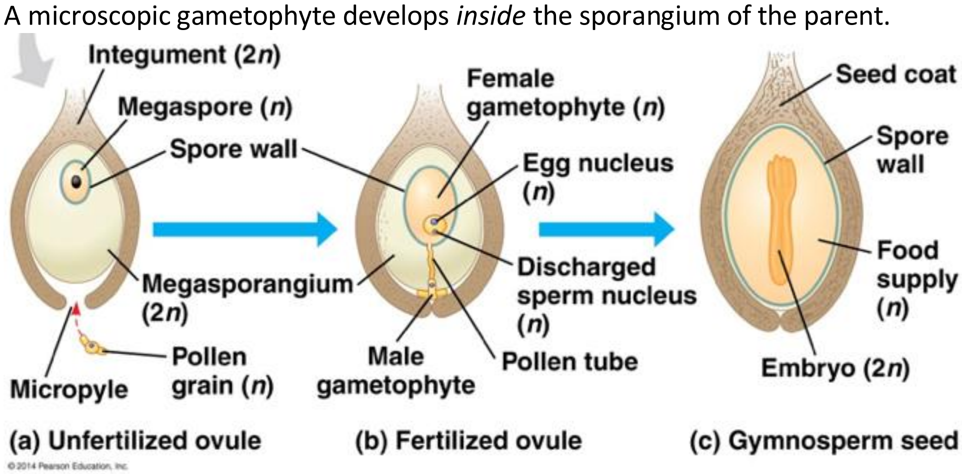
Seeds contain an embryo, food supply, and a protective coating which protects them as they are being dispersed among differing environments.

The seeds would be dispersed through wind and other means such as being carried by animals. This would be important for the propagation of the species.

It's important to note that some seeds require a very specific environment to propagate --> some seeds won't germinate for centuries to come or will germinate relatively quickly

Seed plants have reduced gametophytes, ovules, and pollen.

A microscopic gametophyte develops *inside* the sporangium of the parent.



The pollen includes the male gamete enclosed in the protective call of ***sporopollenin*** (a polymer found in plant spore walls to protect haploid spores from drying out.). This adaptation of pollen is capable of long-distance travel, mass produced, and is resistant to drying out immediately, which further allowed for these seed vascular plants to become adjust to living on land.

Floral Organs

Sepals - are green and enclose the flower

Petals - may be brightly colored in order to attract pollinators

Stamens - produces pollen for the flower

Carpels - make ovules, making it the female structure ; includes the stigma, style, and ovary

Ovules - a small or immature ovum; the part of the ovary in seed plants that contains the female germ cell and *after fertilization* becomes the seed.

Ovary - holds the ovules, will develop into fruit

Seeds develop *from* ovules *after* fertilization.

The ovary wall thickens and matures to form a ***fruit***.

Fruits protect seeds and *aid* in their dispersal.

1. Land Plants and Fungi fundamentally changes chemical cycling and biotic interactions

Lichens - the symbiotic associations of fungi and photosynthetic algae

Can break down rocks and is important for soil formation

Plants make up the habitats of animals and many other organisms. They affect soil formation --> their roots stabilize the soil and decaying plant parts *add* nutrients.

Much of the oxygen present in Earth's atmosphere was released by photosynthesizing plants.

Plants and fungi affect the cycling of chemicals in ecosystems --> they absorb nutrients, which are then passed on to the animals that eat them.

Decomposers, including fungi and bacteria, break down dead organisms and return nutrients to the physical environment.

Carbon Cycling

Plants draw CO_2 from the atmosphere --> they produce organic compounds.

This would further catalyze the first widespread forests:

Plants reduced the atmospheric CO_2 levels which further initiated a glacial period through cooling the Earth.

Biotic Interactions

Biotic interactions can benefit both species involved (**mutualisms**) or be beneficial to one species while harming the other **(parasitism)**.

Plants and fungi had large effects on biotic interactions because they increased the available energy and nutrients on land.

Example: **Endophytes** - fungi living inside issues of plants that benefit the host

In this situation, they may produce protective toxins to protect the plant from any type of parasites.

Look further at example of endophyte not being present but the pathogen being present still --> higher leaf mortality and leaf area damage.

Endophyte present and pathogen present --> lower leaf mortality and leaf area damage

Animals influence the evolution of plants, and vice versa.

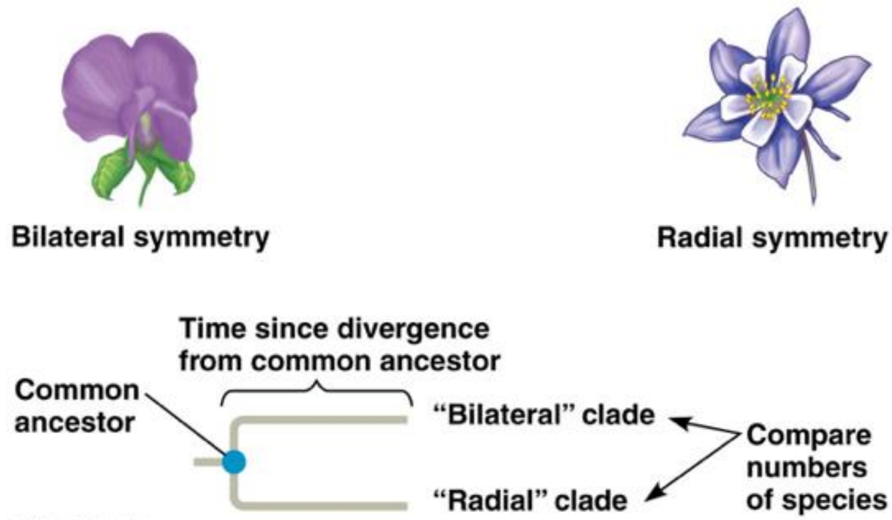
Example: animal herbivory (consumption of plants) selects for plant defenses

Another example: interactions between pollinators and flowering plants select for mutually beneficial adaptations.

Pollinators - animals visit flowers which further transfer pollen to other flowers

Angiosperm (have seeds that develop inside chambers called ovaries) clades are bilaterally symmetrical (being divisible into symmetrical halves on either side of a *unique* plane --> coordinate plane) flowers have *higher* rates of speciation in comparison to those flowers with radial symmetry (symmetry around a central axis --> like a starfish or tulip flower).

Flowers further restrict animal movement, thus making visits to other flowers ***more likely***.

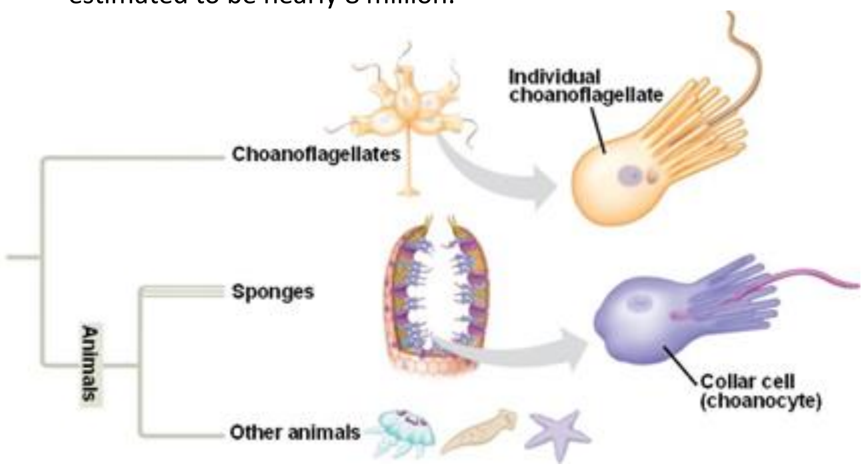

Bilateral symmetry
Radial symmetry
Time since divergence from common ancestor
Common ancestor
"Bilateral" clade
"Radial" clade
Compare numbers of species

Chapter 27 -- The Rise of Animal Diversity

Monday, March 11, 2019
11:01

Before multicellularity evolved, there only existed single-celled organisms that had a very limited amount of traits.
Most animals are mobile and use traits such as strength, speed, toxins, or camouflage to detect, capture, and eat other organisms -->there arose a fight to become the most competitive
Animals likely evolved *from* ***single-celled eukaryotes*** similar to present-day choanoflagellates.

More than 1.3 million animals species have been named to date --> actual number is estimated to be nearly 8 million.



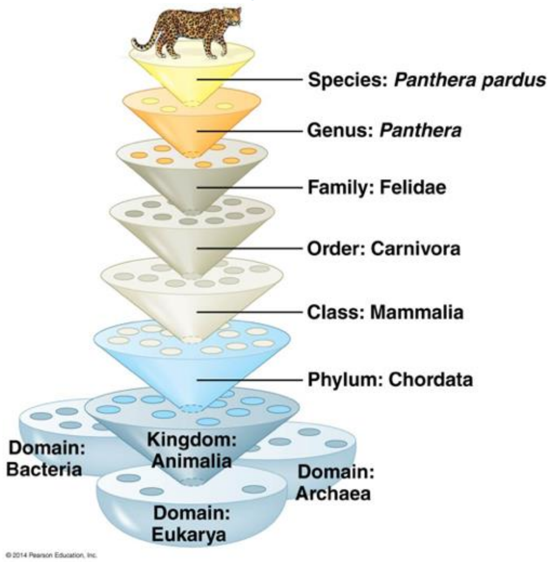
What is an Animal?

1. Heterotrophy - They exhibit heterotrophy, which is the obtainment of energy and organic molecules by *ingesting* other organisms (examples: bears, tigers, etc.).
    a. ***Carnivores*** consume other heterotrophs.
    b. ***Herbivores*** consume autotrophs.
    c. ***Detritivores*** consume decomposing organisms.
2. Multicellularity - Many animals have complex bodies, unlike unicellular organisms.
3. No cell walls - They *lack* rigid cell walls and are usually flexible. Compare the structure of an animal cell and a plant cell.
4. Active movement - Animals move more rapidly and move in more complex way, which is mentioned later by their radial symmetry.
5. Diversity of form - Animals very greatly in form, ranging in size from organisms that are too small to see with the unaided eye to *enormous*. Most are invertebrates.
6. Diversity of habitat - There are around 35-40 phyla of animals, most of which that occur only in the sea. Some animals occupy fresh water, fewer on land.
    a. Example: Arthopoda, mollusca, and chordata are both on land and water, while onychophora only occupy land.
7. Sexual reproduction - Most animals reproduce sexually (many asexually) --> Haploid gametes fuse to form zygote --> nonmobile animals eggs combine with mobile sperm
8. Embryonic development - During development, the zygote first undergoes cleavage that produces a blastula. How the embryo undergoes gastrulation will be important, as this is

the stage in which differentiation occurs --> many differentiating factors arise, deciding whether the organism will have an edge over others or not

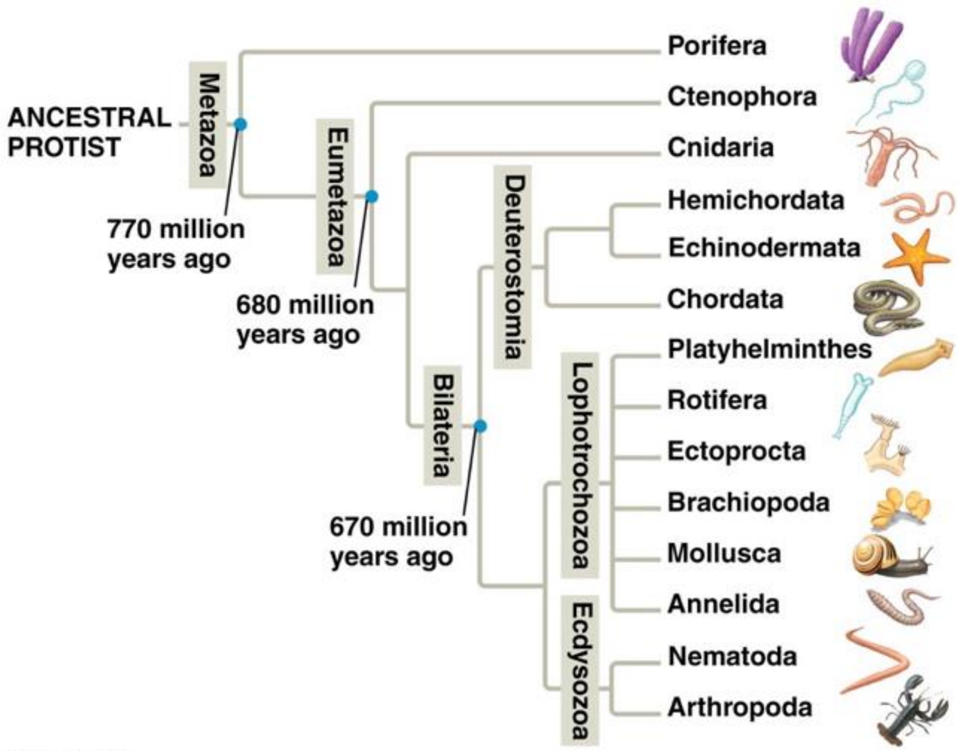
9. <u>Tissues</u> - The cells of most animals are organized into structural and functional units called tissues. Within animal tissue, there exists epithelial tissue, muscular tissue, as well as nervous tissue.

General Features of Animals



Animals are mobile, diverse in shape, size, habitat, reproduction, and development.

They belong to **<u>Metazoa (a major division of the animal kingdom)</u>**, which originated from an ancestral protist from 770 million years ago. Metazoans comprises of all animals *other than* protozoans and sponges --> they are multicellular animals with differentiated tissues.



Fossil and Molecular Evidence

Fossil biochemical evidence and molecular analyses date the common ancestor of all living things to 770 million years ago.

> <u>Evidence:</u> Steroid fossils found from the past are similar to steroids found today in sponges.
>
> > Molecular clock studies have also been performed on sponges (originated 700 mya) and the common ancestor of all animals (770 mya).
>
> The earlier animals fossils are from the **<u>Ediacaran biota</u>**, which dates from about 560 million years ago, which we would not be able to recognize due to the significant amount of evolution that has occurred with time.

Sponges and cnidarians are ***early-diverging*** groups of animals.

Sponges originate from the **<u>Porifera</u>** Phylum. They are suspension feeders --> water is drawn through pores into a central cavity and out through an opening at the top.

> They *lack* true tissues which can prove to be an advantage. If you were to chop up a sponge down to its individual cells, they would be able to aggregate into a shape that is most beneficial to them again. Sponges contain amoebocytes within their bodies that are mobile cells (moving like an amoeba) in the body which move by pseudopodia.
>
> > They consume their food through the process of phagocytosis.

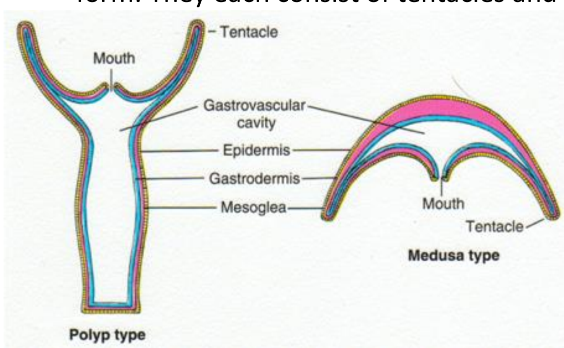
Cnidarians, like most animals, members of the phylum **<u>Cnidaria</u>** have ***true tissues*** and have diversified into a wide range of both sessile and motile (capable of motion) forms, including hydrozoans, jellies, and sea anemones.

This phyla has a gastrovascular cavity with a digestive compartment, consisting of a single mouth/anus. It has an extensive nerve network, tentacles, simple muscles, and exhibit radial symmetry (less advantageous than bilateral symmetry).

Cnidarians, as a whole, have two body plans:

- **Polyp** - has radial symmetry --> examples: hydra, sea anemone, coral
- **Medusa** - has radial symmetry --> examples: jellyfish

Many species alternate between the two forms during their lifecycle. Polyp is a typically asexual feeding stage and the medusa is typically a sexually productive form. They each consist of tentacles and nematocysts.



A characteristic feature of the cnidarians is the presence of **cnidocytes**, also known as stinging cells.

These cells further contain **nematocysts** --> powerful capsules with an inverted, coiled, and barbed thread. This feature allows for the cnidarian to protect itself from being consumed, as many jellyfish have these and cause tears in stomachs.

Cambrian Explosion --> Bilaterian Radiation

This explosion occurred 500 million years ago, for a 10 million year duration, there was an introduction of several new species.

During this, there was the first appearance of the first half of all living phyla like arthropods, chordates, echinoderms.

Some causes that factored into the Cambrian explosion was the first occurrence of widespread predation (defenses popped up such as mineralized skeletons --> hard shells), increase in atmospheric oxygen, and the origin of Hox genes.

The increase in atmospheric oxygen allowed for larger bodies to emerge, as well as an increase in the rate of metabolism.

Taking into account the bias of fossil studies, there has been some argument amount when the Cambrian explosion occurred since this is when organisms began to harden in their skeletons.

According the molecular clock studies, however, the Cambrian explosion occurred 670 million years ago.

Armored single-cell eukaryotes may indicate mobile, predatory, bilaterians with true guts. Size became to emerge as an evolutionary trait due to its advantage among surrounding organisms, allowing them to survive in their environments.

Animal Body Plans

Body plans - sets of integrate morphological and developmental traits which provide a basis for comparing key animals features

There are three important aspects of animals body plans: symmetry, tissues, and body cavities.

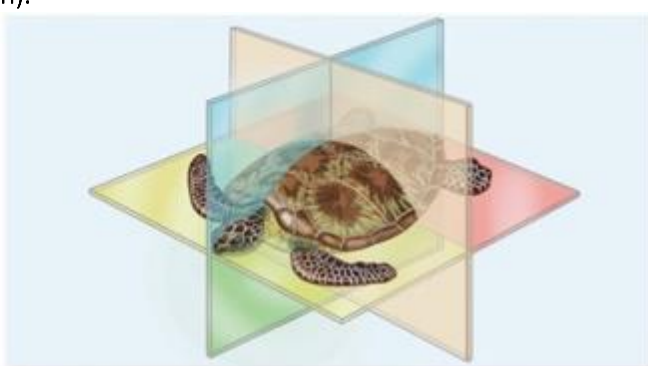
Two types of symmetry:

Radial symmetry - Body parts are arranged around a central axis. In this type of symmetry, organisms can be bisected into two equal halves in any 2-D plane.

Bilateral symmetry - Body has right and left halves that are mirror images of each other. Only the sagittal plane bisects the animal into two equal halves.

In this image, the blue glass separated the sagittal plane. The transverse plane is cut by the semi-orange plane of glass.

Some echinoderms have bilateral larvae and radially symmetrical adults (example: starfish).



Bilaterally symmetrical animals have two advantages over radially symmetrical:

1. Enhanced mobility - Radially symmetrical animals are often not mobile and only move when absolutely possible, in the case of running away from a predator. Bilateral animals can move in a specific direction, while other organisms, run away without thinking about the direction that they move towards --> left to the tides
2. Cephalization - The evolution of a nervous system that has begun to be concentrated in a certain area in the organism.

Evolution of Tissues

Basal Metazoans - (sponges --> the simplest animals) *lack* defined tissues and organs

These groups have the ability to disaggregate and aggregate their cells, thus allowing them to differentiate, de-differentiate, and re-differentiate.

Eumetazoa - (all other animals) *have* distinct and well-defined tissues

These groups have ***irreversible*** (terminal) differentiation for most cell types.

Evolution of the Animal Body Plan

Evolution of a Body Cavity

Eumetazoa have germ layers that have developed within their body cavities:

Diploblastic - Consists of the outer ectoderm and inner endoderm

Outer ectoderm --> body coverings and nervous system

Inner endoderm --> digestive organs and intestines

Triploblastic - Consists of the ectoderm, endoderm, and mesoderm --> skeleton and muscles

Body Cavities

Most bilaterians posses a **body cavity** (coelom), a fluid or air-filled space between the digestive tract and outer body wall.

The body cavity may cushion suspended organs, act as a hydrostatic skeleton, and enable internal organs to move independently of the body wall.

Three body plans for bilaterally symmetrical animals:

1. Acoelomates -> have ***NO*** body cavity existing
2. Pseudocoelomates -> have a body cavity ***between the mesoderm and endoderm***
3. Coelomates -> have a body cavity ***entirely within the mesoderm***

Zoologists recognize about three dozen animal phyla.

Phylogenies now combine molecular data from multiple sources with morphological data to determine the relationships *among* animal phyla.

The following points are reflected in the animal phylogeny:

1. **All animals share a common ancestor (choanoflagellates)**
2. **Sponges are basal animals (lack tissues)**
3. **Eumetazoa is a clade of animals (eumetazoans) with *true* tissues**
4. **Most animal phyla belong to the clade *Bilateria***
5. **Most animals are invertebrates --> lacking a backbone**
    a. Chordata is the only phylum that *includes* **vertebrates**, animals with a backbone

An Overview of Invertebrate Diversity

Bilaterian invertebrates account for 95% of known animal species.

They are morphologically diverse and occupy almost every habitat on Earth.

Protostomes, diverging from deuterostomes, are categorized into two clades where a vast majority of invertebrate species belong to (a few invertebrates belong to the Deuterostomia --> Echinodermata --> sea urchins and a sea star):

- **Lophotrochozoa** - the most morphologically and taxonomically diverse group of *bilaterians*, provides an example of invertebrate radiation;
- **Ecdysozoa** - contains eight phyla, including Arthropoda and Nematoda; among most abundant of all animal groups
    a. ALL ecdysozoans must molt to grow due to their cuticle (tough external coats) covering --> this shedding is called ecdysis.
        - Nematodes are unsegmented pseudocoelomate worms that ***lack*** a circulatory system --> some are known to be parasitic
        - Arthropods have a reduced coelom and an open circulatory system --> have segmented bodies that enable specialization of body structures such as appendages

The Lophotrochozoan phylum **Mollusca** includes 100,000 species.

The body of a mollusc has three main parts that vary in size and form:

A muscular ***foot***, usually used for movement

A ***visceral mass***, containing most of the internal organs

A ***mantle***, a fold of tissue that drapes over the visceral mass and secretes a shell (if present)

a. They also include radula -> a teeth-like structure which is used for scraping food particles off a surface and drawing them into the mouth for consumption
    - Examples: Bivalves and Cephalopods like octopus

Arthropod Origins

More than 1 million arthropod species have been described --> about a billion billion (10^{18}) are estimated to exist on Earth.

Members of the phylum **Arthropoda** are found in nearly *all* habitats in the biosphere.

The diversity and success of this group are attributed to their body plan.

The arthropod body plan consists of a segmented body, *hard* exoskeleton, and joined appendages.

This body plan dates back to the Cambrian explosion (535-525 million years ago).

Early arthropods show little variation from segment to segment.

Arthropod evolution is characterized by a decreasing number of body segments and *increasing* appendage specialization.

The increasing complexity of the body plan likely resulted form changes in the sequence or regulation of existing *Hox* genes.

LECTURE (3-13-2019, Wednesday)

Chordates

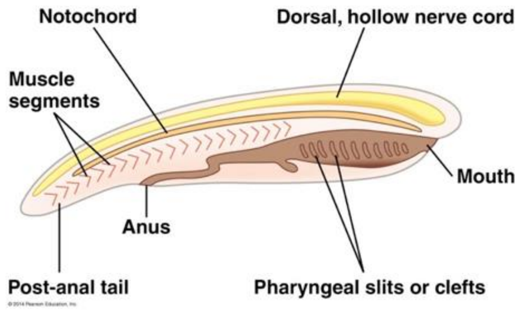
Vertebrates are technically a subphylum.

They are ***part*** of the phylum Chordata. They are a part of the phylum Bilateria (have bilaterial symmetry) and deuterostomia (a separation of the mouth/anus, the gastrointestinal tract; **stoma** --> mouth, **deutero** --> second). They have true body cavities.

Chordates are deuterostome coelomate bilaterians.

Four derived chordate features (must have them to be considered a chordate):

- **Nerve cord** - Running along the dorsal aspect, will be very hollow --> says something about how its developed
- **Notochord** - May be replaced by vertebral column; is NOT a spine/nerve cord, is structural, protective tissue that *protects* the nerve tissue
- **Pharyngeal slits/pouches** - Can become gills later on, began as digestive feature; present in all vertebrate embryos
- **Post-anal tail** - Extra tissue at the end of the developed anus; this extra tail can be integral to the organism's method of locomotion (taxis --> movement) to move away from predators, move towards resources, and find mates for reproduction

○ 

Other characteristics also distinguish chordates:

Muscles are arranged in segmented blocks called somites (means body; soma --> body).

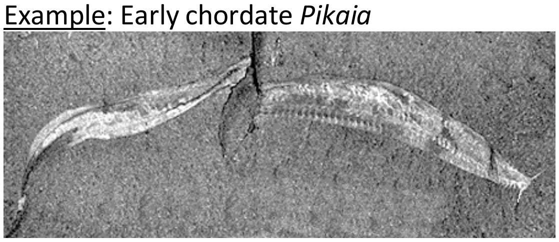
Internal skeleton against which the muscles work.

Not all chordates are vertebrates.

Earliest Fossils

Fossils exist representing the transition to vertebrates formed during the Cambrian explosion.

<u>Example</u>: Early chordate *Pikaia*



Living Chordates (can be referred to as evolutionary cousins to vertebrates)

Lancelets are a ***basal*** group of blade-shaped animals.

They may represent ancestral chordate condition.

Tunicates are filter feeding chordates with *highly derived adult phases*. Humans are more genetically related to the tunicates than the lancelets.

They only display chordate traits during their larval stage, however, are still non-vertebrates.

Early Vertebrates

Early vertebrates have chordate features. The head region, slowly but surely, became complex, as it housed the brain and more nerves --> this would allow for more complex movement to occur

These early vertebrates also had a backbone and a well-defined head with sensory organs and a skull. They also had no jaws developed.

Jawless vertebrates possess skulls. While they do not have jaws, they do have other defensive mechanisms present --> connective tissues exist

Most are extinct lineages, such as the conodonts --> one of the first ancestral species to begin to develop jaws/teeth There are extant lineages such as lampreys and hagfish.

<u>Example</u>: Myxini --> meaning slime, due to it being its defense mechanism

With the development of jaws, <u>**Gnathostomes**</u> would emerge.

Characteristics of this group are jaws, paired pectoral and pelvic fins, and a mineralized skeletons.

Through their jaws moving to eat something, water enters their mouth, causing their gills to work, thus allowing for more oxygen to be collected, thus further allowing for more energy for movement to happen.

This group includes chondrichthyes, **actinopterygia (means ray --> they have rays for fins)**, and lobe-fined fish.

All terrestrial vertebrates evolved from lobe-fined fish.

This began to emergence of body support, allowing for the fish to have bulky forelimbs.

Chondrichthyes - ancestors that have lost their cartilage skeleton (mineralized skeleton); secondarily lost bone (example: sharks)

This has occurred in humans as well with a loss of a secondarily loss tail.

Osteichthies - fish with their skeletons made of bone; includes actinopterygii (ray-finned fishes) --> the most diverse group and lobe-finned fish (which is where from all terrestrial vertebrates came from)

Tetrapods

Vertebrates with jointed limbs and digits.

Will come back to later

Colonization of Land by Animals: Arthropods

Features of Arthropods:

- Segmented body
- Jointed appendages
- Ecdysis
- Cuticle
    - Protein and chitin
        - They shed their shells as they grow due to having these cuticle layers protect them from outside resources (allowing them to take over new habitats with less of a risk from drying out)
        - Varied thickness
        - Already waterproof --> letting them take over more habitats
- Exoskeleton
    - Built-in support
- Multiple ways to breathe air
    - Tracheae
        - Pipes/openings to the outside environment
    - Book lungs
        - Prominent in spiders
    - Through the cuticle

Arthropods are one of the most diverse clades of extant animals. There are 1,000,000 species or more. They are mostly morphologically distinguished.

- Chelicerata
    - There is a modification of their first two appendages: chelicerae and fangs/pincers
    - Their segments are clumped into two regions:
        - Prosoma (soma --> body) - all legs
        - Opisthosoma - reproductive organs; legless

        - Examples: Spiders, ticks (are modified to dig into the skin of their prey), mites, scorpions, daddy-long-legs, horseshoe crabs (are *not* a crustacea, in a sense are arthropods), and sea spiders
- Crustacea
    - Segments are separated into two regions:
        - Cephalothorax - their head regions/chest
        - Abdominal segments
    - They have a reinforced cuticle.
        - In some groups and are made up of $CaCO_3$.
    - Have 2 antennae
    - Have 3 pairs of legs for chewing.
    - They have gills when they're in their aquatic forms.
    - Examples: Crabs, shrimps, lobsters, crayfish, barnacles, copepods, isopods
- Myriapoda
    - Their head region is followed by many segments.
    - Centipedes:
        - Have one pair of legs per segment
        - Carnivorous --> eating a bat
    - Millipedes:
        - Have two pairs of legs per segment
        - Herbivorous
    - Examples: Centipedes and millipedes; centipedes can use only a fraction of their body length to climb up to the top of a cave in order to reach their prey, displays an efficiency of their legs --> their body parts are specialized for very complex actions
- Hexapoda (insects)
    - First appeared about 400 million years ago
    - Extremely successful
    - Three body regions:
        - Head
        - Thorax --> has three segments, each with a pair of legs
            - May have one or two pairs of wings --> outgrowths of the body wall
        - Abdomen
    - Most insects have compound eyes.
    - They breathe with tracheae.
    - Many insects undergo ***metamorphosis***.
        - Simple metamorphosis --> grasshoppers; immature stages similar to adults
        - Complete metamorphosis --> butterflies; immature larva are wormlike; they undergo a resting stage, pupa or chrysalis which precedes the final mole into adult form

Key innovations of insects, slowly but surely, emerged.

Example: ***Elytra*** --> a protective layer of wings

Colonization of Land by Vertebrates

This event occurred in stages, beginning 365 million years ago.

This is when tetrapods began to emerge --> modifications emerged against gravity:

- "Four feet"
- Have true limbs
  - They are necessary for support on land.
- Emerged from lobe-finned fish
  - Lobe-finned fish began the emergence of body support, allowing for the fish to have bulky forelimbs.
- Transitional forms emerged (example: *Tiktaalik*)
  - There appears to be an emergence of an independence of moving the head with the body.
- Basal forms (example: amphibians) --> when they move their head, they move their body as well

Upon analyzing the fossil record, there is a change in the bones that *exists* (there is no new emergence of new bones). With time, the radius and ulna came together and the humerus began to grow in size.

Amphibians

Amphibians are able to survive on land and water.
Their skin requires a damp environment.
Reproduction takes place near water --> relatively water dependent

Some don't need water --> **<u>oviparous</u>** (retain eggs in their reproductive tract and give birth to live young [example: Salamander])

The juvenile stages of development are relatively conserved more than the adult stages due to their embryonic stages being integral to how they'll differentiate. These developmental stages as a juvenile are ancestral in comparison to the adult stages of development which are more derived than anything.

Vertebrate Terrestrial Adaptations --> Amniotes

This group of amniotes includes reptiles (including birds) and mammals.
They are now adapted to dry climates, allowing them to expand the habitats that they take over.
The emergence of the amniotic egg sets this group of organisms apart:

- Portable pond --> allows for the egg to be constantly moisturized
- Extra embryonic membranes
- Reproduction in dry environments --> allows for the egg to survive in any environment, not just aquatic environment
- Modified to internal development in mammals
  - With time, in an egg, the embryo will continue to consume the nutrients within the egg (yolk sac)and give off waste in the **<u>allantois</u>** --> the embryo will grow and the yolk sac will be depleted.
  - In humans, the yolk sac is replaced by the umbilical cord and the mother is the one who releases the waste.

<u>Adaptations of Amniote Terrestrial Organisms</u>:

- Keratinized skin
  - Scales, hair, feathers
  - Is waterproof, doesn't allow for water to enter the skin
- Thoracic breathing

- Greater lung volume --> more surface area for more exchange of oxygen, allowing for more metabolism thus the allowance of a more active lifestyle and the ability to grow larger
    - More active
- Kidney adaptation
    - Concentrates urine
    - Saves water
- Internal fertilization
    - A shift from gelatinous eggs to amniotic eggs would be a significantly new behavior set to emerge. This shift changes the way that female and male organisms interact with each other in mating rituals.

Amniotes have now have varied metabolic adaptations. Focus on the source of the energy for your metabolism.

- **Ectotherms**
    - Derive energy for temperature regulation primarily from sources ***outside*** the body
- **Endotherms**
    - Us***e metabolic energy*** to help regulate body temperature --> derive energy for temperature regulation primarily from sources ***inside*** the body

Exam Review

Deuterostomes have ***three*** germ layers.

In this group, there is a development of the internal core (endocore).

Ferns do ***not*** have flowers. They do, however, have spores, vascular tissues and lack seeds.
It is false that more derived complex body plans always outlast more ancestral body plans.
Photosynthetic eukaryotes came from endosymbiosis of a cyanobacteria.

What is the difference between red/green algae and plants?

Plants evolved from green algae (they have chloroplasts), ***not*** red algae (do not have chloroplasts). Also, the differences in dyes relate to their difference in colors.

What is adaptive radiation?

An increase in diversity among species due to the introduction of novel characters, mass extinction, or the introduction of a new niche.