**Phylogenetic Trees and Geologic Time**

* Define and use formal terminology to describe and interpret a phylogenetic tree
* **Taxon**: taxonomic unit
* **Branches**: a lineage or taxon which is at the tip of the tree
* **Nodes:** where lineages diverge
* **Root:** trunk at base of tree
  + **Root node**: most recent common ancestor
* **Outgroup**: least related taxon in a tree (included for its contrasting characteristics)
* **Monophyletic group (clade)**: group of taxa that includes common ancestor and all its descendants
* Time flows from root to tips, branching length can give the time (can be meaningful, not meaningful in a clatogram)
* Paraphyletic group: excluding some but not all
* Polyphyletic: randomly picking
* Interpret relatedness of extant and extinct species based on phylogenetic trees, including identifying monophyletic groups, identifying most recent common ancestors (MRCA), and using the MRCA to evaluate how closely species are related
* Name the different types of data used to create phylogenetic trees, and recognize that hypotheses represented by phylogenetic trees are revised as we gather more evidence
* Phylogenetic tree is a hypothesis about how taxa are related to each other
* The tree is constructed by data that was collected through observation of morphological or genetic traits (character slates)
  + Types of data (morphological): structural features, types of organs, and specific skeletal arrangements
  + Types of data (genetic): mitochondrial DNA sequences, ribosomal RNA gene sequence, and any genomic genes of interest
* This data is used to identify homology (similarity due to common ancestry)
  + This defines monophyletic groups
* Constructed based on parsimony (most likely branching pattern is the pattern that requires the fewest changes, ex. More likely a species had a specific trait the entire time vs. lost it and gained it again) or path of least resistance
* Define geologic time, list the four major eons in chronological order, and identify the major events of life (or absence thereof) that define each eon
* Hadean (4.6-4.0 BYA): before like
* Archean (4.0-2.5 BYA): evolution of early life
* Proterozoic (2.5 BYA-542 MYA): oxygen accumulation + flourishment of early microbial and multicellular life
* Phanerozoic (542 MYA-now): proliferation of animal and plant life

A table of names and numbers

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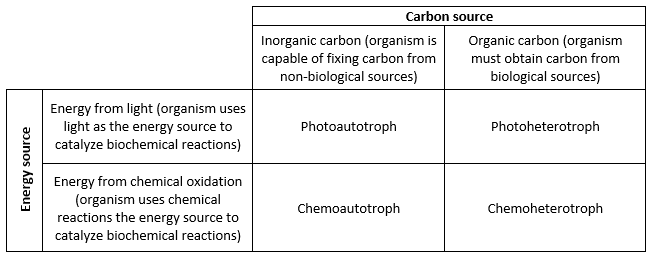
**Prokaryotes: Bacteria & Archaea**

* Differentiate between Bacteria, Archaea, and Eukarya
* Prokaryotes (Bacteria + Archea): single-celled microorganisms with no nuclei, unicellular, lack organelles + other internal membrane bound structures + nucleus, single circular chromosome, reproduce asexually through binary fission, have horizontal gene transfer, cell walls (different between Archea and Bacteria), can survive in inhospitable environments
  + Cell walls: bacteria have peptidoglycan cell walls and archaea have polysaccharides
* Eukaryotes: cells with nuclei enclosing DNA, have both unicellular and multicellular, nucleus separating genetic material, multiple linear chromosomes, reproduce asexually through mitosis and sexually through meiosis (reducing the number of chromosomes by half to produce haploid cells that fuse with other haploid cells to create new organism), some eukaryotes have a cell wall some don’t
* Draw and recognize the phylogenetic relationships between Bacteria, Archaea, and Eukarya

A diagram of a plant

Description automatically generatedA diagram of a tree

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* Prokaryotes: before nucleus
* Prokaryotes are not monophyletic group, archaea and eukaryotes are
* Fusion of archaea and bacteria to make eukaryotes happened during the protozoic era
* Define horizontal gene transfer and explain the challenges presented by horizontal gene transfer for phylogenetic classification of prokaryotes
* Transformation: from environment
* Transduction: bacteriophage infection
* Conjugation: “sex”
* Causes challenges when using exclusively genetic approaches to resolving phylogenetic relationships because sharing a gene could be from horizontal gene transfer not being genetically similar
* Identify ways that Archaea and Bacteria get energy and carbon, and use this information to classify example organisms as photo-, chemo-, auto-, and/or hetero-trophs
* Prokaryotes can be any, eukarytes are either chemoheterotrophs or photoautotrophs
* Identify the fossil, chemical, and genetic evidence for key events for evolution of the three domains of life (Bacteria, Archaea, and Eukarya)
* Life arose during archaean era: physical and chemical energy (microfossils, 3.8 billion years ago, chemical signatures from living organisms, 3.6 billion years ago) + anoxic atmosphere so first organisms were unicellular anaerobic prokaryotes that were likely chemotrophic
* Explain why the flourishing of cyanobacteria led to the oxygenation of the atmosphere.
* Oxygen revolution: due to oxygen generating cynobacteria, first molecular oxygen 2.6 billion years ago (end of archaean era). Free oxygen reacted soluble iron in the ocean, creating iron oxide to precipitate out of the ocean. Evidence of slow accumulation of oxygen from the banded iron formations in sedimentary rocks. Fully oxygenated atmosphere in the Proterozoic era
* Place the evolution of the three domains of life on the geologic time scale

A chart of a dinosaur

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* Describe the importance of prokaryotes (Bacteria and Archaea) with respect to human health and environmental processes

A screenshot of a computer

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**A table with a list of bacteria

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**Eukaryotes and their Origins**

* Explain the endosymbiotic theory for the origin of eukaryotes
* 1.6-2.2 BYA during Proterozoic
* Endosymbiotic theory: eukaryotes arose as a result of a fusion of Archaean cells with bacteria, where an ancient Archaean engulfed through fogocytosis (but did not eat) an ancient, aerobic bacterial cell. The engulfed (endosymbiosed) bacterial cell remained within the archaean cell in what may have been a mutualistic relationship: the engulfed bacterium allowed the host archean cell to use oxygen to release energy stored in nutrients, and the host cell protected the bacterial cell from predators. Over many generations, a symbiotic relationship developed between the two organisms so completely that neither could survive on its own. The descendants of this ancient engulfed cell are present in all eukaryotic cells today as **mitochondria**.
  + Transitional stage: The original protokyrotic cell took in cell wall causing infoldings in cell membrane to make nuclear membrane (a eukaryote without mitochondria)
* Like mitochondria, chloroplasts appear to have an endosymbiotic origin and are derived from cyanobacteria that lived inside the cells of an ancestral, aerobic, heterotrophic eukaryote.
* Use evidence from the endosymbiotic theory to place the origin of mitochondria and chloroplasts on the tree of life

1. Mitochondria (and chloroplasts) are approximately the same size as prokaryotic cells, but they are located inside much much larger eukaryotic cells instead of free-living.
2. Mitochondria (and chloroplasts) each have their own DNA, their DNA is organized in a circular chromosome like typical prokaryotic genomes, and their genomes contain genes that are very similar to genes found in prokaryotic genomes.
3. Mitochondria (and chloroplasts) reproduce by **binary fission**, the process that prokaryotes use to reproduce. In contrast, eukaryotic cells reproduce by **mitosis**.
4. If the mitochondria (or chloroplasts) are removed from a eukaryotic cell, the cell has no way to produce new ones. In other words, the genetic “instructions” to make new mitochondria/chloroplasts is not present in the eukaryotic nuclear genome; they are present in the mitochondria/chloroplast genomes.
5. A diagram of a tree with arrows

   Description automatically generatedThe membrane composition of mitochondria (and chloroplasts) is more similar in composition to prokaryotic membranes than to eukaryotic membranes.

* Identify and describe the key traits and adaptations unique to eukaryotes (Sex/Meiosis, Mitosis, Mitochondria, Nucleus, Linear chromosomes)

1. **Cells with nuclei surrounded by a nuclear envelope with nuclear pores:**This is the single trait that is both necessary and sufficient to define an organism as a eukaryote. All extant eukaryotes have cells with nuclei.
2. **Mitochondria:** Some extant eukaryotes have very reduced remnants of mitochondria in their cells, whereas other members of their lineages have mitochondria.
3. **A cytoskeleton** containing the structural and motility components called actin microfilaments and microtubules. All extant eukaryotes have these cytoskeletal elements.
4. **Linear Chromosomes**: Many eukaryotic species have multiple linear chromosomes, in contrast to prokaryotic genomes which consist of a single circular chromosome.
5. **Mitosis**: a process of nuclear division wherein replicated chromosomes are divided and separated using elements of the cytoskeleton. Mitosis is universally present in eukaryotes.
6. **Sex**: a process of genetic recombination unique to eukaryotes in which diploid nuclei at one stage of the life cycle undergo meiosis to yield haploid nuclei and subsequent karyogamy, a stage where two haploid nuclei fuse together to create a diploid zygote nucleus.

* List and differentiate between the general steps of a sexual life cycle (meiosis, fertilization, change in ploidy)
* Sexual reproduction therefore always involves two changes in ***ploidy***(the number of copies of each chromosome)
* **haplontic life cycle**: organisms with this life cycle have a *multicellular haploid stage* (the organism you see by eye is haploid), and the *diploid stage exists only as a single cell* (the fertilized egg); the zygote (fertilized egg) then undergoes meiosis immediately after fertilization. Meiosis in the zygote produces haploid *spores*, which then undergo mitosis to grow into multicellular, haploid organisms. These organisms then produce gametes by *mitosis* rather than meiosis because the organism’s cells are already haploid. This life cycle is typical of most fungi: the large, multicellular mushroom that you can see by eye is usually haploid, not diploid!
* **diplontic life cycle**: organisms with this life cycle have a *multicellular diploid stage* (the organism you see by eye is diploid), and the *haploid stage exists only as a single cell* (the gametes – typically called sperm or eggs). The gametes are produced by *meiosis* from the multicellular diploid organism. After fertilization of the egg, the zygote undergoes mitosis to grow into a multicellular organism that produces its own haploid gametes by meiosis. Spores are never produced in the diplontic life cycle. This life cycle is typical of animals: the multicellular animal that you can see is diploid.
* **alternation of generations** life cycle (also **haplodiplontic**life cycle): organisms with this life cycle have *both a multicellular diploid stage and a multicellular haploid stage.* Diploid multicellular organisms called “sporophytes” produce haploid spores by meiosis (sporophytes are named for the fact that they produce spores); the haploid spores undergo mitosis to produce multicellular haploid organisms called “gametophytes” (named gametophytes for the fact that they produce gametes). These haploid gametophytes then produce gametes by mitosis (because their cells are already haploid), and the gametes fuse to produce a zygote. The zygote reproduces by mitosis and grows into a diploid, multicellular sporophyte, and the process continues. This life cycle is typical of plants, and there are multiple variations on this life cycle in different plant lineages which we will discuss in future class sessions.
* Describe the importance of single-celled eukaryotes with respect to human health and ecosystem services
* Protist: many are unicellular some are multicellular, used to refer to any eukaryote that is not classified as a plant, animal, or fungus
* Primary producers (photosynthesis): algae  
  perform ~40% of primary production on Earth  
  (and LOTS of organisms eat them!)  
  • Decomposition: it’s not just for fungi – fungal-  
  like protists are decomposers; without  
  decomposers, organic molecules and essential  
  nutrients would be stuck in dead bodies  
  • Parasites and pathogens: various species  
  cause disease in animals (incl. humans) or  
  plants (e.g. affect our food supply)
* Earliest eukaryote: 1.6 and 2.2 BYA (Proterozoic eon) and multicellularity happened during mid Proterozoic but larger visible organisms didn’t appear until the Cambrian explosion
  + Multicellularity made possible: multiple cells that made possible differentiation which brought about division of labor
  + Can happen due to minor genetic change (cell wall modification, cells lose ability to reproduce)

# Land Plants

* Place and identify land plants on a phylogenetic tree within the domain Eukarya
* Define and recognize traits and adaptations common to (nearly all) land plant taxa, including cuticle, stomata, roots/root-like structures, and mycorrhizal fungi
* Identify how key key land plant adaptations including true roots, vascular tissue, lignin, pollen, seeds, and flowers are adaptations to increasingly drier environments
* Define, draw, and label the general alternation of generations life cycle
* Differentiate major land plant taxa (bryophytes, lycophytes, gymnosperms, and angiosperms) using the key adaptations to life on land and the dominant life cycle stage (gametophyte or sporophyte)
* Identify the geologic time periods when the major land plant taxa were dominant and why these periods are important to humans

A screen shot of a chart

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Fungi

A screenshot of a chart

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A screenshot of a computer screen

Description automatically generatedInvertebrates

A screen shot of a chart

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Vertebrates

A chart of life cycle

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Tree of life over geologic time

A chart with different colors of text

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A close-up of a list of biomes

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