# Lecture Outline: The Origin And Diversification of Eukaryotes

I. **Introduction to Eukaryotes**
   A. **Distinctions from Prokaryotes**
      1. Eukaryotes possess a highly complex cytoskeleton, composed of three major kinds of proteins (microtubules, microfilaments, and intermediate filaments)
      2. This complex cytoskeleton enables drastic changes in cell shape, such as engulfing a cell as large as itself
      3. Prokaryotes (archaeal or bacterial cells) largely retain their cell shape
      4. Prokaryotes' claim to fame is their biochemistry, while the variety of forms (different shaped cells) is a claim to fame for eukaryotes, specifically the protests
   B. **The Protists Group**
      1. All protests are eukaryotes
      2. Not all eukaryotes are protests
      3. Some protests possess the most complex shaped cells among all living things

II. **History and Timeline of Eukaryotic Evolution**
   A. **Temporal Context**
      1. Life existed for over a billion years before the first simplest eukaryotes appeared
      2. Prokaryotes were the only life forms present for a long time
      3. The entire history of eukaryotes spans less than half the overall age of life
   B. **Three Major Eras of Eukaryotic History**
      1. **First Period: Emergence of Eukaryotes**
         a. Began at least 1.8 billion years ago, evidenced by fossilized remains
         b. Involved speciation and some diversification, but not extensive
         c. Organisms were unicellular
      2. **Middle Period: Age of Novelties**
         a. Roughly 1.3 billion years ago until a little over half a billion years ago
         b. Important new structures evolved in the oceans
         c. Some multicellularity evolved, although organisms remained generally small
         d. Key novelties evolved in specialized membrane-bounded organelles:
            (1) Eukaryotic cellular respiration
            (2) Eukaryotic photosynthesis

3. **Most Recent Period: Age of Hugeness**
    a. Roughly 600 million years ago to the present
    b. Very large organisms finally appeared
    c. Familiar groups originated: Plants, Animals, and Fungi

III. **Origin of Eukaryotic Complexity (Endosymbiotic Theory)**

A. **Origin of the Nucleus and Internal Membranes**

1. The ancestor to all eukaryotes was an ancestral prokaryote, most likely an anaerobic archaen
2. The first eukaryote cell lineage is genetically similar to archaens
3. Invagination (infolding) of the plasma membrane began to surround the nucleoid (the region where DNA is located in a prokaryote)
4. Fusing infoldings created a true nucleus, which is a membrane-bounded organelle
5. The resulting nuclear envelope is two membrane layers thick, consistent with the infolding scenario
6. Other membrane structures formed in continuity with the nuclear envelope:
    a. Endoplasmic reticulum (ER)
    b. Golgi complex or Golgi apparatus
7. The cell that resulted from this process was officially a eukaryote, but it was still anaerobic

B. **Primary Endosymbiosis: Origin of Mitochondria and Chloroplasts**

1. Endosymbiosis is the condition of living together where one organism lives specifically inside the other
2. This occurred in the unicellular anaerobic eukaryotic ancestor
3. **Mitochondria Origin (The First Event)**
    a. The anaerobic eukaryote engulfed an aerobic bacterium that was capable of cellular respiration
    b. The bacterium survived the engulfing process instead of being killed and digested
    c. The surviving aerobic bacterium became the first mitochondrion
    d. Evidence supporting this origin:
        (1) Mitochondria resemble bacteria in shape
        (2) Mitochondria have two membranes (outer host membrane, inner original bacterial membrane)
        (3) The inner membrane is molecularly similar to a bacterial membrane, while the outer membrane is similar to a eukaryotic membrane
        (4) Mitochondria possess their own circular DNA chromosome, separate from the nucleus
        (5) Mitochondria have their own ribosomes (with subunits similar to bacterial

ribosomes)

(6) Mitochondria reproduce themselves within the cell using binary fission

e. The resulting cell was an aerobic eukaryote, the ancestor to organisms like animals (which have mitochondria but not chloroplasts)

4. **Chloroplast Origin (The Subsequent Event)**
   a. The aerobic eukaryote (which already had mitochondria) engulfed a photosynthetic bacterium
   b. The surviving photosynthetic bacterium became the first chloroplast
   c. Evidence supporting this origin (multiple membranes, circular DNA, bacterial-like ribosomes) applies to chloroplasts as well
   d. Cells that underwent both events are ancestors to all photosynthetic eukaryotes (plants and algae)

C. **Secondary Endosymbiosis**

1. A chloroplast is one example of a general structure called a plastid
2. Some eukaryotes have plastids with three or more membranes
3. Secondary endosymbiosis involves serial engulfing, where a cell containing a plastid (from primary endosymbiosis) is engulfed by an even bigger cell
4. Each engulfing event builds up layers of membrane
5. In rare cases, structures like the chromatophore may perform photosynthesis due to independent convergent evolution rather than traditional chloroplast development

IV. **Transition to Multicellularity and Phylogenetic Clades**

A. **Multicellularity**

1. Multicellularity evolved gradually from a colonial lifestyle
2. A colonial lifestyle involves individual cells connected together, but all cells perform basically the same functions
3. True multicellularity is defined by having different kinds of cells performing different functions for the entire collection of cells

B. **Relationship between Animals and Choanoflagellates**

1. Animals and unicellular choanoflagellates are sister taxa, meaning they spring from the same node on the phylogenetic tree
2. A collar cell (choanocyte) from a sponge (a basal animal taxon) is morphologically almost indistinguishable from an individual choanoflagellate
3. A key evolutionary event (mutationally) in the animal lineage led to the development of the CCD protein domain
4. The CCD domain is important in cell-to-cell adhesion, which is required for a multicellular organism

5. Choanoflagellates, lacking this domain, remained freeliving solitary unicellular individuals

C. **Classification Definitions in Eukarya (Domain Eukarya)**
1. The phylogenetic tree of Eukarya often contains a polytomy (a node splitting into four major groups simultaneously), indicating insufficient evidence to resolve the exact relationships
2. **Definition of Protest**
   a. The word "protest" is retained but the group is no longer a monophyletic taxon (a true clade)
   b. A protest is defined as any eukaryote that is not an animal, a plant, or a fungus
   c. Protests form a paraphyletic taxon (a group that includes a common ancestor but excludes some descendants)
3. **Definition of Algae**
   a. Algae (plural of alga) is also a paraphyletic, catchall word
   b. Algae are defined as photosynthetic protests
   c. Plants are photosynthetic but are not considered algae because they are plants, not protests
   d. Non-photosynthetic protests are heterotrophs
4. **Four Major Clades (Monophyletic Taxa) of Eukarya**
   a. Excavata
   b. SAR clade (Stramenopiles, Alveolates, Rhizarians)
   c. Archaeplastida
   d. Unikonta

V. **Examples of Eukaryotic Clades and Protistan Diversity**

A. **Excavata**
1. Named because many species have a surface area that looks excavated (dug out)
2. Many members are unicellular parasites of humans (e.g., parabasalids causing sexually transmitted diseases, or those causing sleeping sickness)
3. The group also includes photosynthetic species like Euglenids

B. **SAR Clade**
1. **Stramenopiles (S)**
   a. Diatoms are ocean-dwelling, photosynthetic protests (algae)
   b. They are ecologically important globally for oxygen production
   c. Diatoms produce intricate glass cases called tests made of silicon dioxide
   d. Brown Algae are among the largest algae, some reaching the size of trees in the ocean
   e. Brown algae are not plants, and their structures are superficial resemblances: they use holdfasts (not roots), stipes (not stems), and blades (not leaves)

2. **Alveolates (A)**
    a. Named because many members have bag-like structures in their cells called alveoli
    b. Includes photosynthetic and parasitic species
    c. Dinoflagellates are ecologically important photosynthetic species that can cause red tide due to population spikes
    d. Ciliates (e.g., Paramecium) use cilia (hairs) to create water currents that sweep food particles toward an oral groove (mouth)

C. **Archaeplastida**

1. Includes three major groups of photosynthetic eukaryotes: Red Algae, Green Algae, and all Plants
2. **Red Algae**
    a. Look red because their pigments reflect red light
    b. These pigments absorb blue and green light well, allowing them to live deeper in the ocean where blue light penetrates
    c. Used in products such as sushi wrappers
3. **Green Algae**
    a. Appear green because their chlorophyll absorbs red and blue light, reflecting green light
    b. The Charophytes are the sister taxon to land plants

D. **Unikonta**

1. Includes Animals and Fungi, which are more closely related to each other than either is to Plants
2. Also includes protest groups like the Amoebozoans
3. An amoeba is a loose, paraphyletic term for any cell that moves by pseudopodal (false feet) locomotion
4. Slime molds are an example of an Amoebozoan:
    a. They live an asexual or sexual life cycle
    b. They exist as haploid (N) solitary unicellular amoebas when food is plentiful
    c. Sexual reproduction involves the fusion of haploid gametes to produce a zygote
    d. When food runs out, the individual amoebas aggregate into a large, moving multicellular mass (the slime mold)
    e. The cells in the mass cooperate, with some forming a stalk and others forming fruiting bodies that release haploid spores (the asexual part)

VI. **Ecological Interactions of Protists**

A. **Protists as Producers**

1. Autotrophs (producers) are necessary to sustain the base of any ecosystem
2. Unicellular algae are vital protistan producers, along with cyanobacteria (prokaryotic

producers)

3. These unicellular algae are plankton (small floating matter) that serve as food for consumers
4. A decrease in ocean producers (measured by greenness/chlorophyll) is observed globally, threatening the consumer organisms dependent on them

B. **Protists in Symbiotic Relationships**

1. Symbiosis is a close relationship between species, which may include mutualism or parasitism
2. **Mutualism (Mutual Benefit)**
   a. Example: A microscopic protist living inside the digestive tract of termites
   b. Termites are animals and cannot digest wood (cellulose, a polymer of glucose) because they lack the necessary enzymes
   c. The symbiotic protist continuously digests the cellulose for its own life, freeing up glucose that the termite can then use for nutrition
3. **Parasitism (Harm to One Host)**
   a. Many protests are important parasites of various eukaryotes, including humans
   b. Some parasites have complex relationships involving multiple hosts (e.g., a specific mosquito and a human)
   c. Example: The parasite causing sleeping sickness (a trypanosome) is never free-living
   d. The parasite's life cycle involves distinct stages in the human host:
      (1) Injected cells travel to the liver, invade liver cells (hepatocytes), and multiply into haploid merozoites, causing liver cell damage
      (2) Merozoites infect red blood cells and produce gametocytes
   e. The life cycle continues in the mosquito host:
      (1) The mosquito ingests gametocytes from the human
      (2) Gametes fuse in the mosquito during fertilization to form a zygote
      (3) The zygote undergoes meiosis to produce haploid sporozoites
      (4) Sporozoites are delivered to a new human host when the mosquito bites