The Other Eukaryotes…
Endosymbiotic Theory, Kingdom Protista

The Origin of Eukaryotic Cells

- eukaryotic cells appeared first around 1.7 billion years ago
  - eukaryotic cells possess an internal structure called a nucleus
- some bacterial cells have infoldings of their outer membranes extending into the interior
  - the endoplasmic reticulum (ER) and nuclear envelope of eukaryotes is thought to have evolved from this

Origin of the nucleus and endoplasmic reticulum.

- the **endosymbiotic theory** is a widely accepted explanation for the origin of energy-producing organelles in eukaryotes from bacteria
  - present-day mitochondria and chloroplasts still contain their own DNA
    - this DNA is remarkably similar in size and character to the DNA of bacteria

The theory of endosymbiosis.

The Evolution of Sex

- a profound difference between prokaryotes and eukaryotes is that eukaryotes have the capacity for sexual reproduction
  - **sexual reproduction** involves two parents contributing gametes to form the offspring
  - gametes are usually formed by meiosis and are haploid
  - the resulting offspring are diploid

- but sexual reproduction is not the only way that eukaryotes can reproduce
  - many eukaryotes reproduce by **asexual reproduction**, which is reproduction without forming gametes
  - the offspring of asexual reproduction are genetically identical to the parents
  - many eukaryotes reproduce mainly by asexual reproduction, switching to sexual reproduction only during environmental stress

Reproduction among paramecia.

- a different asexual strategy in eukaryotes is **parthenogenesis**, the development of an adult from an unfertilized egg

- many plants and marine fishes undergo a form of sexual reproduction that does not involve partners
  - this is called **self-fertilization** and involves one individual providing both male and female gametes

- the advantages of sexual reproduction are not immediately obvious

- the segregation of chromosomes that occurs in meiosis tends to disrupt advantageous combinations of genes

- sexual reproduction may have evolved in protists because the diploid cell stage allows for chromosomal repair
  - double-strand breaks occur in the DNA are induced by dessication
  - the environmental stress of drying out triggers the diploid stage
  - perhaps the pairing up of chromosomes in the early stages of meiosis evolved originally as a mechanism for repairing double-strand damage
    - the undamaged version as a template could be used as template to guide the fixing of the damaged one

- sexual reproduction is one of the most important evolutionary innovations of eukaryotes
  - it provides a means of shuffling genes, creating genetic diversity
    - genetic diversity is the raw material of evolution
    - the greater the genetic diversity, the more rapid the evolutionary pace

- the **sexual life cycle** involves the production of haploid gametes by meiosis, followed by the union of two gametes in sexual reproduction

- eukaryotes are characterized by three major types of sexual life cycles
  - zygotic meiosis
  - gametic meiosis
  - sporic meiosis

- in **zygotic meiosis**, the zygote formed by the fusion of gametes is the only zygote cell
  - this type of sexual life cycle is common to many algae
  - the zygote is the only cell that undergoes meiosis
  - haploid cells occupy the major portion of the life cycle

Three types of Eukaryotic Life Cycles

(a) Zygotic meiosis.

- in **gametic meiosis**, the gametes are the only haploid cells
  - this sexual life cycle is common to most animals
  - meiosis produces the gametes
  - the diploid zygote occupies the major portion of the life cycle

Three types of Eukaryotic Life Cycles

(b) Gametic meiosis.

- in **sporic meiosis**, the spore-forming cells undergo meiosis
  - this life cycle is common to plants

- in plants, there is a regular **alternation of generations** between a haploid phase and a diploid phase
- the diploid phase produces spores that give rise to the haploid phase
- the haploid phase produces gametes that fuse to give rise to the diploid phase

General Biology of Protists, the Most Ancient Eukaryotes

- protists are eukaryotes united on the basis of a single *negative* characteristic
  - they are not fungi, plants, or animals
  - in all other respects, they are highly variable with no uniting features

A unicellular protist.

- cell surface varies among protists
  - all protists have plasma membranes
  - some, like algae and molds, have cell walls
  - others, like diatoms and radiolarians, secrete glassy shells of silica

- locomotor organelles also vary among protists
  - protists move by means of cilia, flagella, pseudopods or gliding mechanisms

- cyst formation occurs in protists who, despite having delicate surfaces, persist in harsh habitats
  - **cysts** are dormant forms of a cell with a resistant outer covering
    - in dormancy, the cell metabolism is more or less completely shut down

- protists employ a variety of forms of nutritional acquisition
  - one exception, however, is chemoautotrophy, which is known only from prokaryotes
  - some protists are photosynthetic autotrophs, called **prototrophs**
  - among the heterotrophic protists, there are
    - **phagotrophs** that ingest visible particles of food
    - **osmotrophs** that ingest food in soluble form

- protists typically reproduce asexually
  - sexual reproduction is resorted only in times of stress
- asexual reproduction involves an usual form of mitosis
  - the nuclear membrane usually persists throughout mitosis and the spindle apparatus forms within the nucleus
- asexual reproduction in protists may involve spore formation or fission
  - the most common type of fission is **binary fission**, in which a cell simply splits into two nearly equal halves
  - another type of fission is called **budding**

- asexual reproduction in protists may involve spore formation or fission

- the most common type of fission is **binary fission**, in which a cell simply splits into two nearly equal halves
- another type of fission is called **budding**
  - In this case, the progeny cell is considerably smaller than its parent and then must grow to adult size

- multiple fission is called **schizogony** and is preceded by several nuclear divisions
  - this form of fission produces several individuals almost simultaneously

- sexual reproduction also takes place in many forms among protists
  - gametic meiosis occurs in ciliates and some flagellates
  - zygotic meiosis occurs in the sporozoans
  - sporic meiosis occurs in the algae, producing an alternation of generations similar to that of plants

- being a single-celled organism presents certain problems
  - size is limited due to surface-to-volume ratio problems

- the evolution of multicellularity alleviates the size constraints
  - a multicellular organism is composed of many cells
  - having multiple cells allows for specialization
    - distinct cell types can have different functions
    - this is a "division of labor"

- many protists form colonial assemblies consisting of many cells with little differentiation or integration

  - a **colonial organism** is a collection of cells that are permanently associated but in which little or no integration of cell activities occurs

A colonial protist.

- an **aggregation** is a more transient collection of cells that come together for a period of time and then separate
  - for example, individual amoeboid cells of cellular slime molds come together to form an aggregate called a slug
    - the slug allows the aggregrate of slime mold cells to move to a new feeding location as a unit

- true multicellularity occurs only in eukaryotes
  - it requires that the activities of individual cells be coordinated and that the cells be in contact

- three groups of protists have independently evolved multicellularity
  - brown algae (Phylum Phaeophyta)
  - green algae (Phylum Chlorophya)

- red algae (Phylum Rhodophyta)

- but not all types of algae are multicelluar; there are also unicellular varieties

Classifying the Protists

- protists are the most diverse of the four kingdoms in the domain Eukarya
  - there are 15 distinct phyla of protists
  - taxonomists group the protists into five general groups according to some of the major shared characteristics
  - the phyla of protists are, with very few exceptions, only distantly related to one another

The major protist groups.

- the characteristics used in broad attempts to classify the kingdom Protista include
  - the presence or absence and type of cilia or flagella
  - the presence and kinds of pigments
  - the type of mitosis
  - the kinds of cristae present in the mitochondria
  - the molecular genetics of the ribosomal "S" subunit
  - the kind of inclusions the protists may have
  - overall body form
  - whether the protists has a shell or other "body armour"
  - modes of nutrition and movement

Kinds of Protists

Heterotrophs with No Permanent Locomotor Apparatus

- the largest of the five groups of protists are distinguished by having no permanent locomotor apparatus

- they are all heterotrophic and comprise three phyla
  - Rhizopoda—amoebas
  - Foraminifera—forams
  - Actinopoda—radiolarians

- amoebas lack flagella and cell walls
- they move using **pseudopodia**, flowing projections of cytoplasm
- amoebas are abundant in soil and many are parasitic in animals
- reproduction is entirely asexual

- forams possess rigid cells and move by **cytoplasmic streaming**
- they are marine protists with pore-studded shells called **tests**
- long, thin, cytoplasmic projections called **podia** radiate through the test pores and are used for swimming and capturing prey

Heterotrophs with No Permanent Locomotor Apparatus

- radiolarians look like amoebas but have a glassy skeleton
- needlelike pseudopods look like thorns radiating out from the body

Heterotrophs with Flagella

- Sarcomastigophora is a strictly heterotrophic phylum
- the members of this phylum are called zoomastigotes and are flagellated
- the flagellated ancestor of all animals appears to have been a member of this group

Heterotrophs with Flagella

- ciliates belong to the phylum Ciliophora and all members possess large numbers of cilia
- ciliates have a defined cell shape and two nuclei per cell
- the **pellicle** is a proteinaceous scaffold, found inside the plasma membrane, that confers flexible support
- asexual reproduction is by fission while sexual reproduction is by conjugation

Heterotrophs with Restricted Mobility

- slime molds and water molds are heterotrophic protists and not fungi
  - protistan molds have cell walls made of cellulose
  - protistan molds carry out normal mitosis
  - there are three unrelated phyla of protistan molds

Heterotrophs with Restricted Mobility

- cellular slime molds belong to the phylum Acrasiomycota
  - although more closely resembling amoebas, the members of this phylum can form aggregates in times of stress

Heterotrophs with Restricted Mobility

- plasmodial slime molds belong to the phylum Myxomycota
- the cells in members of this phylum stream long as a **plasmodium**, a nonwalled multinucleate mass of cytoplasm
- the plasmodium can withstand drying out or starvation by dividing into spore-producing mounds

Heterotrophs with Restricted Mobility

- water molds belong to the phylum Oomycota
- all members of this grouping either parasitize living organisms or feed on dead organic matter

- many water molds are important plant pathogens

Photosynthetic protists

- dinoflagellates are members of the phylum Pyrrhophyta
- they are photosynthetic unicellular protists, usually bearing two flagella of unequal

length
  - These flagella beat uniquely, beating the body like a spinning top
- dinoflagellates reproduce asexually using a unique type of mitosis in which their chromosomes remain condensed

Dinoflagellates.

Photosynthetic Protists

- euglenoids belong to the phylum Euglenophyta and have two flagella
  - about one-third are photosynthetic and have chloroplasts
  - the remaining types lack chloroplasts and are heterotrophic
  - the photosynthetic forms can become heterotrophic when light levels are low

Photosynthetic protists

- some dinoflagellates produce powerful toxins
  - "red tides" are population explosions of these kinds of dinoflagellates

Photosynthetic Protists

- *Euglena* is a representative euglenoid
- it possesses a pellicle like ciliates
- it has a contracticle vacuole to help regulate the osmotic pressure within the organism
- it has a light-sensitive stigma which helps this photosynthetic form find light
- reproduction in this group is entirely asexual

Photosynthetic Protists

- diatoms are photosynthetic protists that belong to the phylum Chrysophyta
- they are encased by unique double wall of silica
- they reproduce by either asexual or sexual reproduction

Photosynthetic Protists

- the phylum Chrysophyta, in addition to diatoms, also includes the golden algae
- the golden algae do not resemble the three phyla of true algae in any important aspect
- they are named because pigments in their chloroplasts give them a golden color
- they can be unicellular or colonial and occur in freshwater only
- they can form resistant cysts when ponds and lakes dry out in summer

Photosynthetic Protists

- red algae comprise the phylum Rhodophyta and have red pigments
- most are multicellular and marine
- they grow more deeply than other photosynthetic algae

- the laboratory medium component, agar, is made from red algae

Photosynthetic Protists

- green algae are members of the phylum Chlorophyta and are of evolutionary interest because the ancestor of plants belonged to this group

    - green algal chloroplasts are similar to plants and contain similar chlorophyll types
- green algae are mostly mobile and aquatic but a few species occur in moist soil or on tree trunks

Green algae.

Photosynthetic Protists

- most green algae are microscopic and unicellular, but some are intermediate or colonial, while others are large and multicellular
- some green algae, like *Ulva*, exhibit an alternation of generations between a multicellular haploid gametophyte and a multicellular diploid sporophyte

A green algae life cycle: *Ulva*.

Photosynthetic Protists

- brown algae comprise the phylum Phaeophyta
- these algae are the longest, fastest-growing, and most photosynthetically productive living things
- they are conspicuous seaweeds in the ocean
    - for example, kelp may grow to over 100 m
- all are multicellular and most are marine
- their life cycle has alternating generations

Nonmotile Spore-Formers

- sporozoans belong to the phylum Apicomplexa
- they are nonmotile, unicellular, parasites that form spores
- they cause many diseases in humans and domestic animals
- they have complex life cycles that involve both asexual and sexual phases, often involving an alternation between different hosts

A sporozoan life cycle.