

EVOLUTION

*BEYOND The Origin of life
through six kingdoms ending
with Animalia*

Monera & Protista

DR. KOFI OWUSU-DAAKU
POPULATION GENETICS &
EVOLUTION
LECTURE X

TAXONOMY : The branch of science concerned with **classification**, especially of organisms – also known as **systematics**.

There are seven main taxonomic ranks: **kingdom**, **phylum** or **division**, **class**, **order**, **family**, **genus**, **species**.

Making sense of evolution by classification

Robert Whittaker's 5 kingdom classification

1. **Monera**
 - ∞ Single-celled prokaryotes (bacteria).
 - ∞ Display great biochemical diversity but little internal complexity.
 - ∞ Includes producers and decomposers.
2. **Protista**
 - ∞ Mostly single-celled eukaryotes.
 - ∞ Photoautotrophs (algae) and heterotrophs (protozoa).
 - ∞ More internal complexity than bacteria.
3. **Fungi**
 - ∞ Multicelled eukaryotes that feed by extracellular digestion and absorption.
 - ∞ Heterotrophs; includes major decomposers; many are pathogens and parasites.
4. **Plantae**
 - ∞ Multicelled photosynthetic autotrophs.
 - ∞ Producers; form embryos.
5. **Animalia**
 - ∞ Diverse multicelled heterotrophs.
 - ∞ Range from sponges to vertebrates.
 - ∞ The latest scheme **uses six-kingdoms** in which the **Monera** are divided into the **Eubacteria** and the **Archaeobacteria**.

⌘ However, researchers have come to believe that evolution may often occur in a different way: brief periods of rapid evolutionary change immediately after speciation, followed by long periods with relatively little change. Thus the term "evolution by jerks."

⌘ This newer view of the pace of evolution, in which long periods of relatively little evolutionary change are punctuated by bursts of rapid change, is called punctuated equilibrium .

- ⌘ In a brief period of time, a small number of species diversified into a much larger number of species, able to live in a wide diversity of habitat following an explosive expansion. This is called an adaptive radiation
- ⌘ Such a large and rapid diversification has occurred many times throughout history.
- ⌘ Three different phenomena tend to trigger adaptive radiations.
- ⌘ After one of these events, surviving species find themselves in locations where they suddenly have access to plentiful new resources.



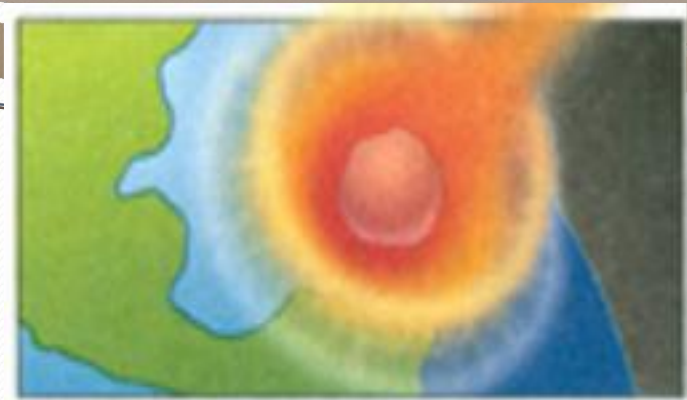
a. Mass extinction events

b. Colonization events.

c. Evolutionary innovations

MASS EXTINCTION EVENTS

With their competition suddenly eliminated, remaining species can rapidly diversify.



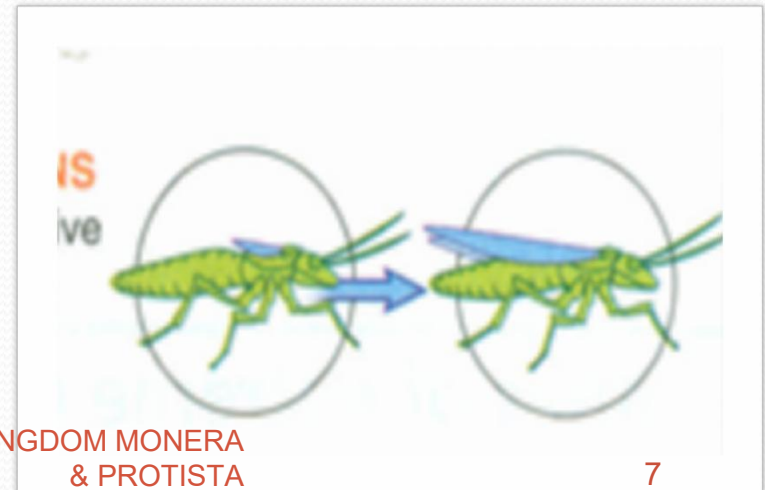
COLONIZATION EVENTS

Moving to a new location with new resources (and possibly fewer competitors), colonizers can rapidly diversify.



EVOLUTIONARY INNOVATIONS

With the evolution of an innovative feature that increases fitness, a species can rapidly diversify.



∞ Mass extinction events

- ∞ With the near total disappearance of the dinosaurs, a world of "opportunities" opened up for the mammals.
- ∞ Where previously the dinosaurs had prevented mammals from utilizing resources, mammals suddenly had few competitors.
- ∞ The number of mammalian species increased from a very small number, perhaps a few hundred to more than 4,000 species in about 130 genera.
- ∞ This happened following other large-scale extinctions,
- ∞ numerous other groups that suddenly lost most of their competitors experienced similar adaptive radiations.

⌘ Colonization events

- ⌘ In a rare event, one or a few birds or small insects will fly off from a mainland and end up on a distant island .
- ⌘ Once there, they tend to find a large number of opportunities for adaptation and diversification.
- ⌘ In the Galapagos, finch species evolved from a single species found on the nearest mainland, 600 miles away.
- ⌘ In Hawaii, there are several hundred species of fruit flies, all believed to have evolved from one species that colonized and experienced an adaptive radiation.

⌘ Evolutionary innovations

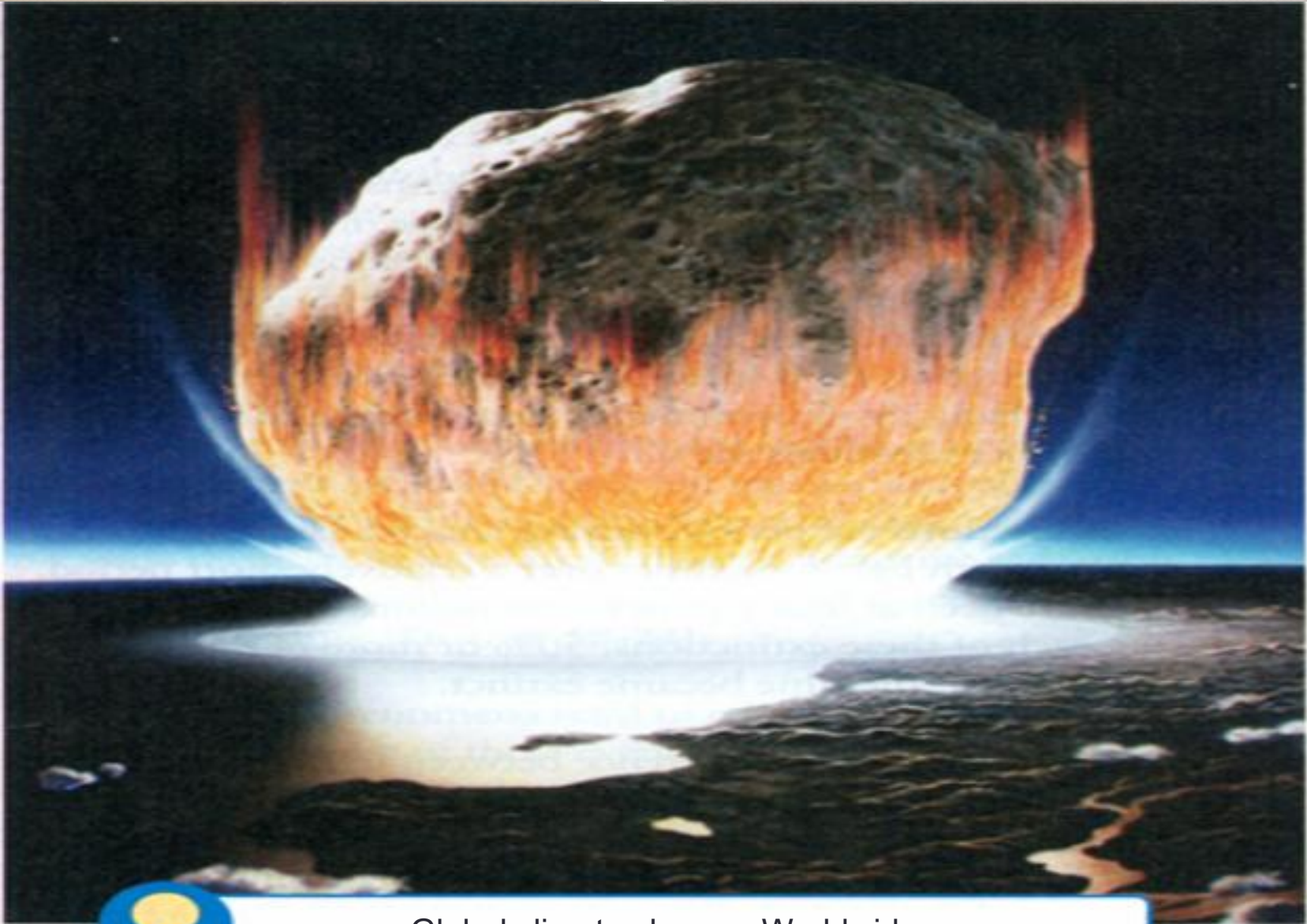
- ⌘ In nature, evolution sometimes produces great innovations
- ⌘ These are innovations such as the wings and rigid outer skeleton that appeared in insects and helped them diversify into the most successful group of animals, with more than 800,000 species today
- ⌘ The flower is another innovation that propelled an explosion of diversity and evolutionary success of flowering plants relative to the non-flowering plants, such as ferns and pine trees.
- ⌘ Today, about 9 out of 10 plant species are flowering plants.

- ∞ Speciation is always producing new species, but extinction, the complete loss of all individuals in a species population, takes them away.
- ∞ Extinction, which is always occurring, is faced by all species.
- ∞ For any given time in earth's history, it is possible to estimate the rate of extinctions, and evidence reveals that these rates are far from constant.
- ∞ Extinctions generally fall into one of two categories: **background extinctions** or **mass extinctions**.

- ⌘ **Background extinctions** are the extinctions that occur at lower rates during periods other than those of mass extinctions.
- ⌘ Background extinctions occur mostly as the result of natural selection.
- ⌘ Competition with other species, for example, may reduce a species' size or the range over which it can roam or grow.
- ⌘ Or a species might be too slow to adapt to gradually changing environmental conditions and becomes extinct as its individuals die off.

- ⌘ **Mass extinctions** are periods during which a large number of species on earth become extinct over a relatively short period.
- ⌘ There have been at least **five** mass extinctions on earth and, during each of these extinctions, 50% or more of the animal species living at the time became extinct.
- ⌘ Mass extinctions are due to extraordinary and sudden changes to the environment (such as an asteroid impact).
- ⌘ Fit and unfit individuals alike perish

- ✧ Of the five mass extinctions during the past 500 million years, the most recent is the best understood.
- ✧ Sixty-five million years ago, an almost unimaginable catastrophe occurred.
- ✧ A massive asteroid smashed into the Caribbean near the Yucatan Peninsula of Mexico.
- ✧ The impact left a crater more than 100 miles wide, and probably created an enormous fireball that caused fires worldwide followed by a cloud of dust and debris that blocked all sunlight from the earth and disturbed the global climate for months.
- ✧ In the aftermath of this catastrophe, about 75% of all species on earth were wiped out, including almost all dinosaurs, a tremendously successful group that had been thriving for 150 million years.



Global climate change, Worldwide mass extinction
Catastrophic events set the stage for explosive
speciation of the remaining groups, including the
mammals.

KOTI OWUSU-BAARU - PH.D. KINGDOM MONERA
& PROTISTA

ORGANISMS ARE DIVIDED INTO THREE DOMAINS

- ✧ When Linnaeus first put together his system of classification, he saw a clear and obvious split: all living organisms were either plant or animal.
- ✧ Plants could not move and could make their own food.
- ✧ Animals could move but could not make their own food.
- ✧ So in Linnaeus's original classification, all organisms were put in either the animal kingdom or the plant kingdom

- ✧ With the refinement of microscopes and subsequent discovery of the rich world of microbes the two-kingdom system was inadequate.
- ✧ **Where did the microbes belong?**
- ✧ Some could move, but many of those could also make their own food, seeming to put them between plants and animals.
- ✧ The problems didn't stop with the microbes as mushrooms and molds among other organisms originally categorized as plants, didn't move but they didn't make their own food either-
- ✧ They digested the decaying plant and animal material around them.

- ✧ The two-kingdom system gave way in the 1960s to a five-kingdom system.
- ✧ The new system was a division based on the distinction between prokaryotic cells (those without nuclei) and eukaryotic cells (those with nuclei).
- ✧ The prokaryotes were put in one kingdom, where the only residents were the bacteria: single-celled organisms with no nucleus, no organelles, and genetic material in the form of a circular strand of DNA.
- ✧ The eukaryotes-having a nucleus, compartmentalized organelles, and individual, linear pieces of DNA-were divided into four separate kingdoms:
 - ✧ plants, animals, fungi, and protists.

Making sense of evolution by classification

Robert Whittaker's 5 kingdom classification

1. **Monera**
 - ∞ Single-celled prokaryotes (bacteria).
 - ∞ Display great biochemical diversity but little internal complexity.
 - ∞ Includes producers and decomposers.
2. **Protista**
 - ∞ Mostly single-celled eukaryotes.
 - ∞ Photoautotrophs (algae) and heterotrophs (protozoa).
 - ∞ More internal complexity than bacteria.
3. **Fungi**
 - ∞ Multicelled eukaryotes that feed by extracellular digestion and absorption.
 - ∞ Heterotrophs; includes major decomposers; many are pathogens and parasites.
4. **Plantae**
 - ∞ Multicelled photosynthetic autotrophs.
 - ∞ Producers; form embryos.
5. **Animalia**
 - ∞ Diverse multicelled heterotrophs.
 - ∞ Range from sponges to vertebrates.
 - ∞ The latest scheme **uses six-kingdoms** in which the **Monera** are divided into the **Eubacteria** and the **Archaeobacteria**.

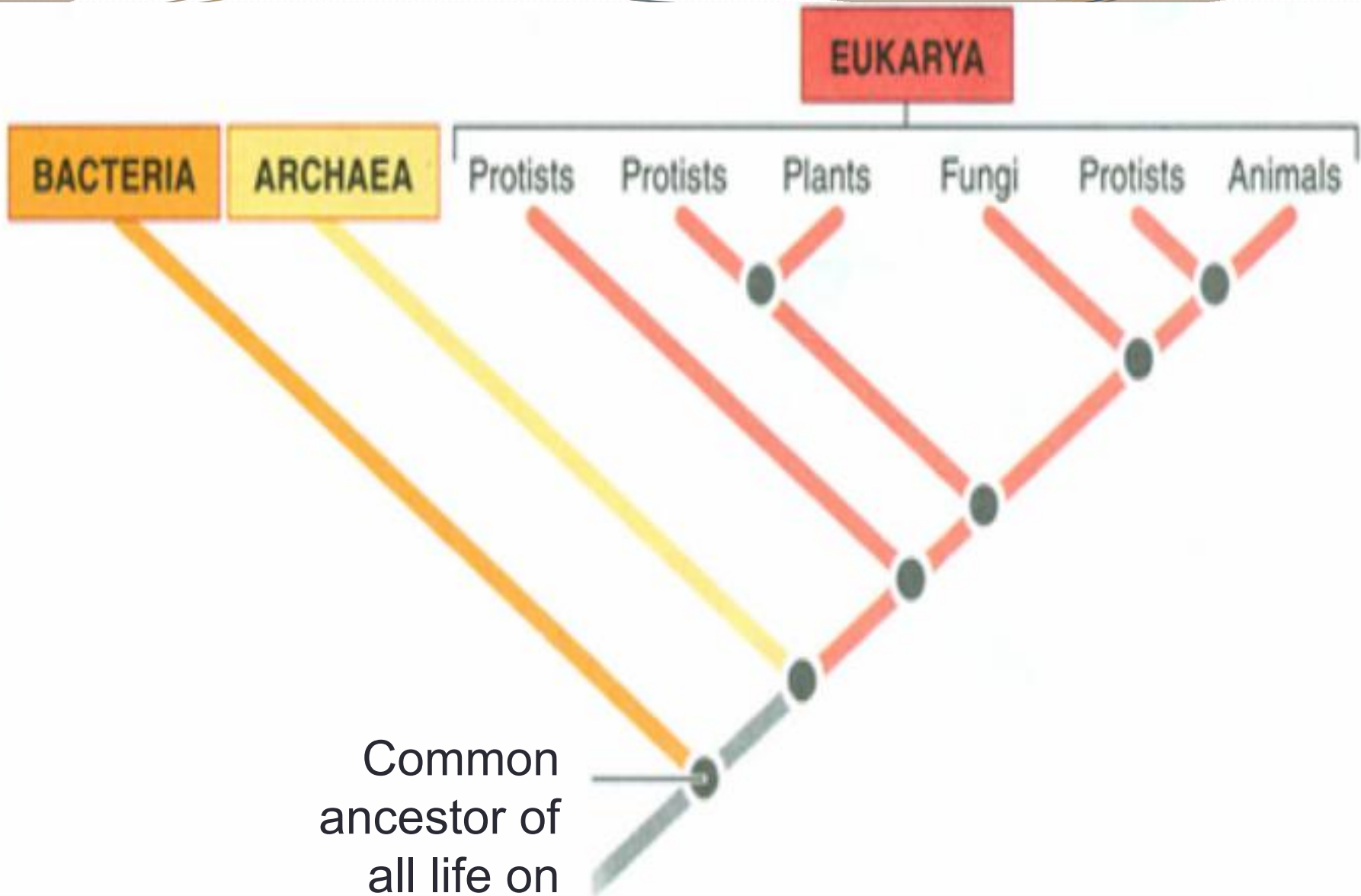
⌘ The five-kingdom system had to be discarded.

⌘ Until that point, organisms had been classified primarily based on their appearance.

⌘ But because the ultimate goal of classification had changed to reconstructing phylogenetic trees that reflected the evolutionary history of earth's diversity, Carl Woese, an American biologist, and his colleagues began classifying organisms by their nucleotide sequences.

- ✧ First and foremost, the sequences revealed that the biggest division in the diversity of life on earth was not between plants and animals nor was it between prokaryotes and eukaryotes.
- ✧ The new trees revealed that the diversity among microbes was much greater particularly because of the discovery of a completely new group of prokaryotes called archaea (sing. archaeon), which thrive in some of the most extreme environments on earth and differ greatly from bacteria.
- ✧ The tree was revised to show three primary branches, called domains: the bacteria, the archaea, and the eukarya

THE THREE DOMAINS OF LIFE



Common
ancestor of
all life on
earth

All living organisms are classified into one of

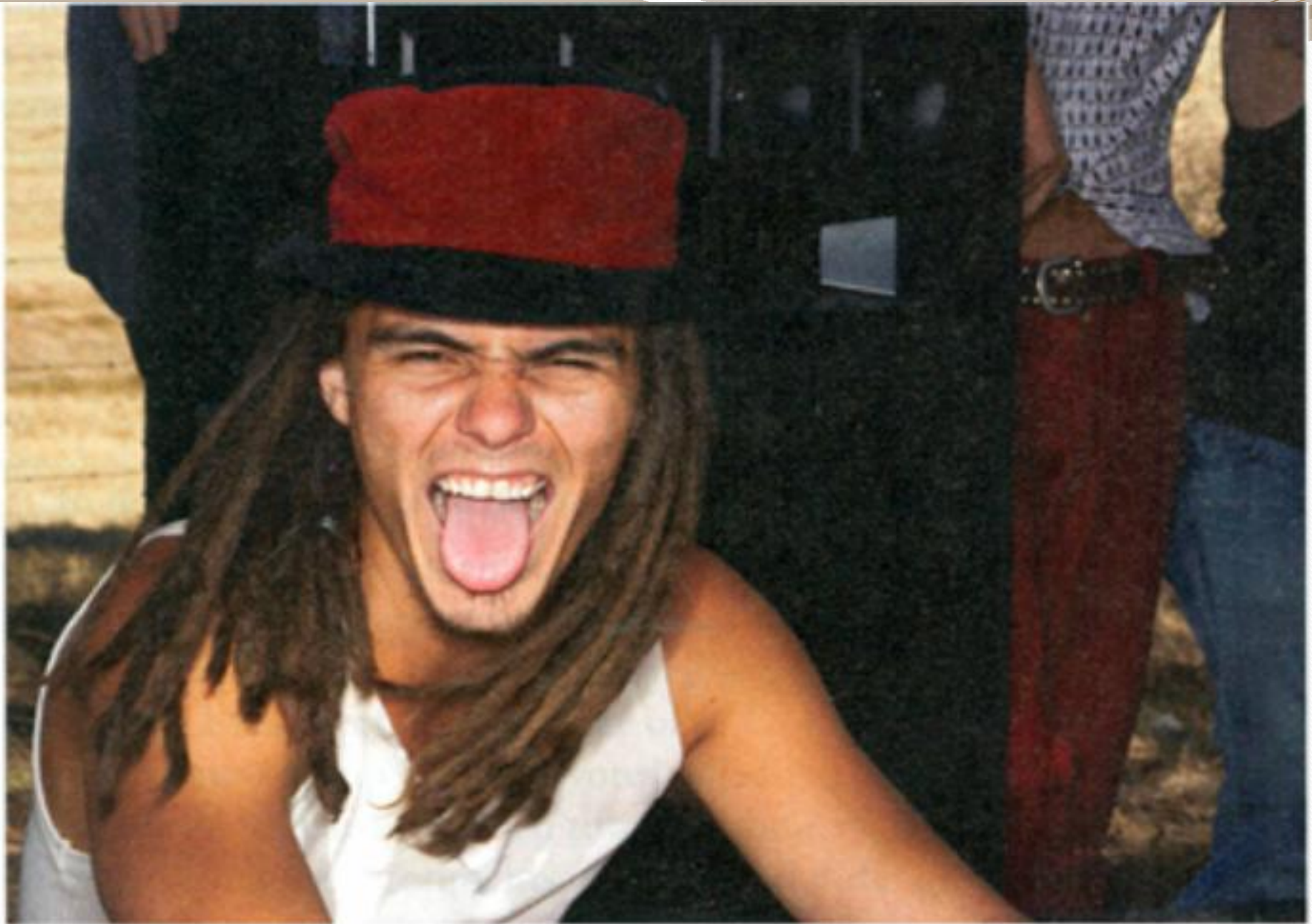
KOFI OMISULDAKU - Ph.D. KINGDOM MONERA
& PROTISTA

- ⌘ The three-domain, six-kingdom approach is not perfect and is still subject to revision.
- ⌘ for example, within the eukarya, the single-celled protists have turned out to be much more diverse than initially thought and, problematically, are not a monophyletic group.
- ⌘ Increasingly, it is recognized that they should be split into multiple kingdoms.
- ⌘ Also problematic is that bacteria sometimes engage in horizontal gene transfer, which means that, rather than passing genes simply from "parent" to "offspring," they transfer genetic material directly into another species.

- ⌘ This process complicates the attempt to determine phylogenies based on sequence data, because it creates situations in which two organisms might have a similar genetic sequence, not because they share a common ancestor, but as a result of a direct transfer of the sequence
- ⌘ Additionally, a fourth group of incredibly diverse and important biological entities, the viruses, is not even included in the tree of life, because they are not considered to be living organisms.
- ⌘ Viruses can replicate, but can have metabolic activity only by taking over the metabolic processes of another organism.

THE BACTERIA DOMAIN

- ✂ At any given time, there are several hundred species of bacteria in your mouth mostly on your tongue all competing for the resources you put there.
- ✂ Some of the bacteria are aerobic, requiring oxygen for their metabolism, and others are anaerobic.
- ✂ These bacteria metabolize food bits in your mouth, plaque on your teeth and gums, and dead cells from the lining of your mouth,
 - ✂ breaking down proteins in these materials to use as their energy source.
- ✂ Because proteins are made from amino acids, some of which contain the smelly chemical sulfur, their breakdown leads to the odor in the accumulating waste products.



KOFI OWUSU-DAKU - Ph.D. KINGDOM MONERA & PROTISTA
Bacteria thrive on your tongue and in

- ☞ On a small scale, your mouth reveals some of the tremendous biological versatility of the bacteria
- ☞ hundreds of species can live in a tiny area, a teaspoon of soil, for example, is home to more than a billion bacteria
- ☞ they can thrive in a variety of unexpected habitats, can utilize a variety of food sources, and can survive and thrive with or without oxygen.
- ☞ Looking around the world, we find the clear dominance of bacteria, by any measure, it is their planet

- ✧ the biomass of bacteria (if they were all collected, dried out, and weighed) exceeds that of all the plants and animals on earth.
- ✧ Bacteria live in soil, air, water, arctic ice, and volcanic vent.
- ✧ Many can even make their own food, utilizing light from the sun or harnessing energy from chemicals such as ammonia.
- ✧ Although bacteria are responsible for many diseases, including strep throat, cholera, syphilis, pneumonia, botulism, anthrax, leprosy, and tuberculosis, disease-causing bacteria are only a small fraction of the domain, and bacteria seem to get less credit for their many positive effects on our lives

- ⌘ Consider that bacteria (*E. coli*) living in your gut help your body digest the food you eat and, in the process, make certain vitamins your body needs available.
- ⌘ Other bacteria (actinomycetes) produce antibiotics such as streptomycin.
- ⌘ Others live symbiotically with plants as small fertilizer factories, converting nitrogen into a form that is usable by the plant.
- ⌘ Bacteria also give taste to many foods, from sour cream to cheese, yogurt, and sourdough bread.
- ⌘ Increasingly, bacteria are used in biotechnology, from those that can metabolize crude oil and help in the cleanup of spills to transgenic bacteria used in the production of insulin and other medical products



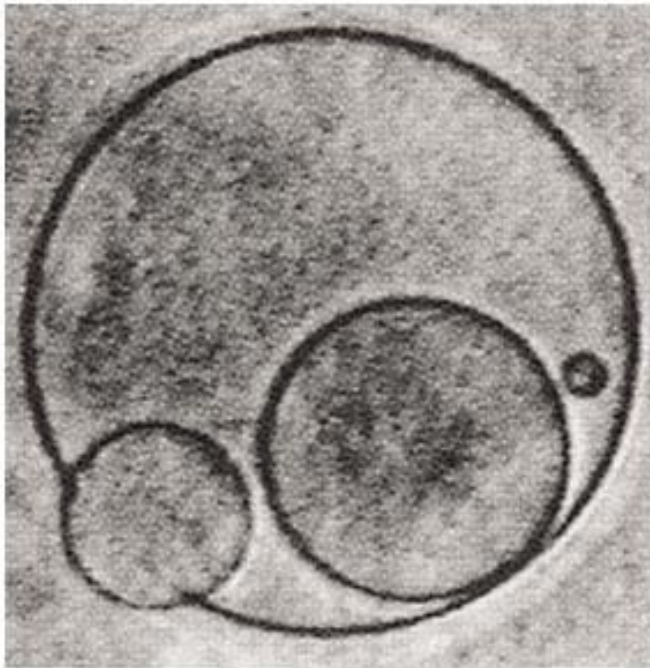
Bacteria have a biomass greater
than that of
all the plants and animals on

KOFI OWUSU-DAKU - Ph.D. KINGDOM MONERA
& PROTISTA

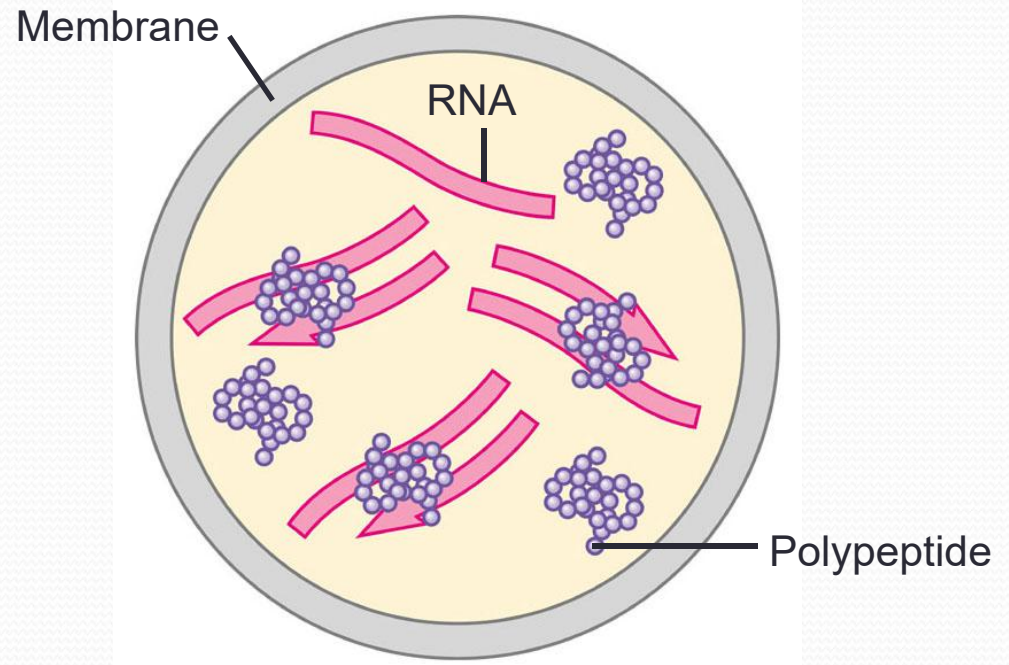
THE ARACHAEA DOMAIN

- ⌘ These are species living in extreme environments such as in a bubbling hot spring in Yellowstone National Park, where the temperature ranges from the 212 F (100 C) of boiling water down to a relatively cool 165 F (74 C) at the surface.
- ⌘ It would seem a most inhospitable place for life, yet researchers have found 38 different species of archaea thriving there
- ⌘ In the freezing waters of Antarctica, too, archaea abound.
- ⌘ More than a third of the organisms in the Antarctic surface waters are archaea

- Membranes may have separated various aggregates of self-replicating molecules
 - Which could be acted on by natural selection

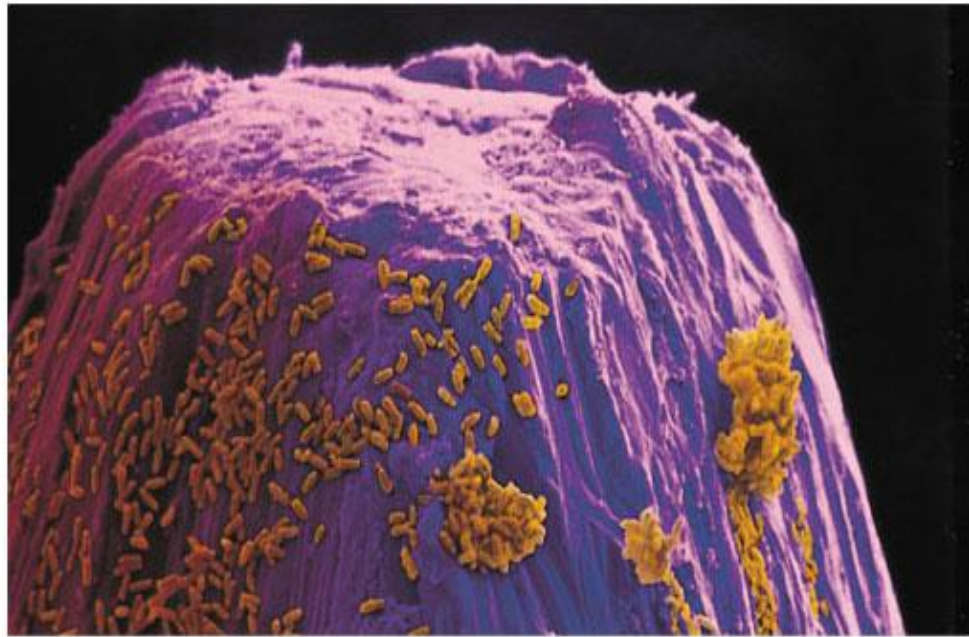


LM 650x



PROKARYOTES

- ⌘ Prokaryotes have inhabited Earth for billions of years
- ⌘ Prokaryotes are the oldest life-forms
 - ⌘ And remain the most numerous and widespread organisms



Colorized SEM 650 x

✧ Bacteria and archaea are the two main branches of prokaryotic evolution

✧ Domains Bacteria and Archaea

✧ Are distinguished on the basis of nucleotide sequences and other molecular and cellular features

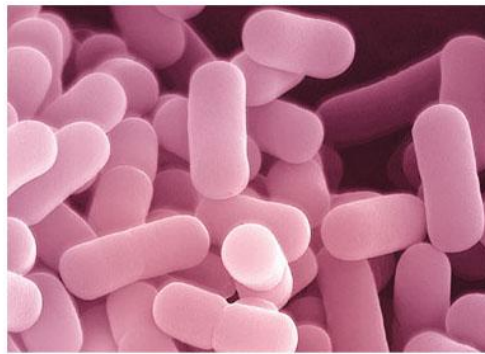
Prokaryotes come in a variety of shapes

Prokaryotes may be shaped as

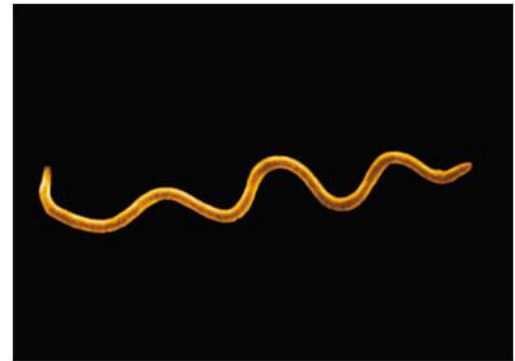
- Spheres (cocci)
- Rods (bacilli)
- Curves or spirals




Colorized SEM 12,000 ×



Colorized SEM 9,000 ×



Colorized SEM 3,000 ×

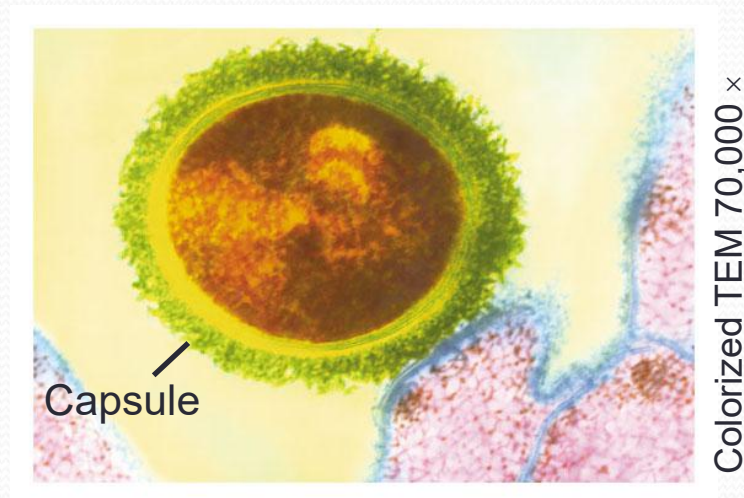


∞ Various structural features contribute to the success of prokaryotes

External Structures

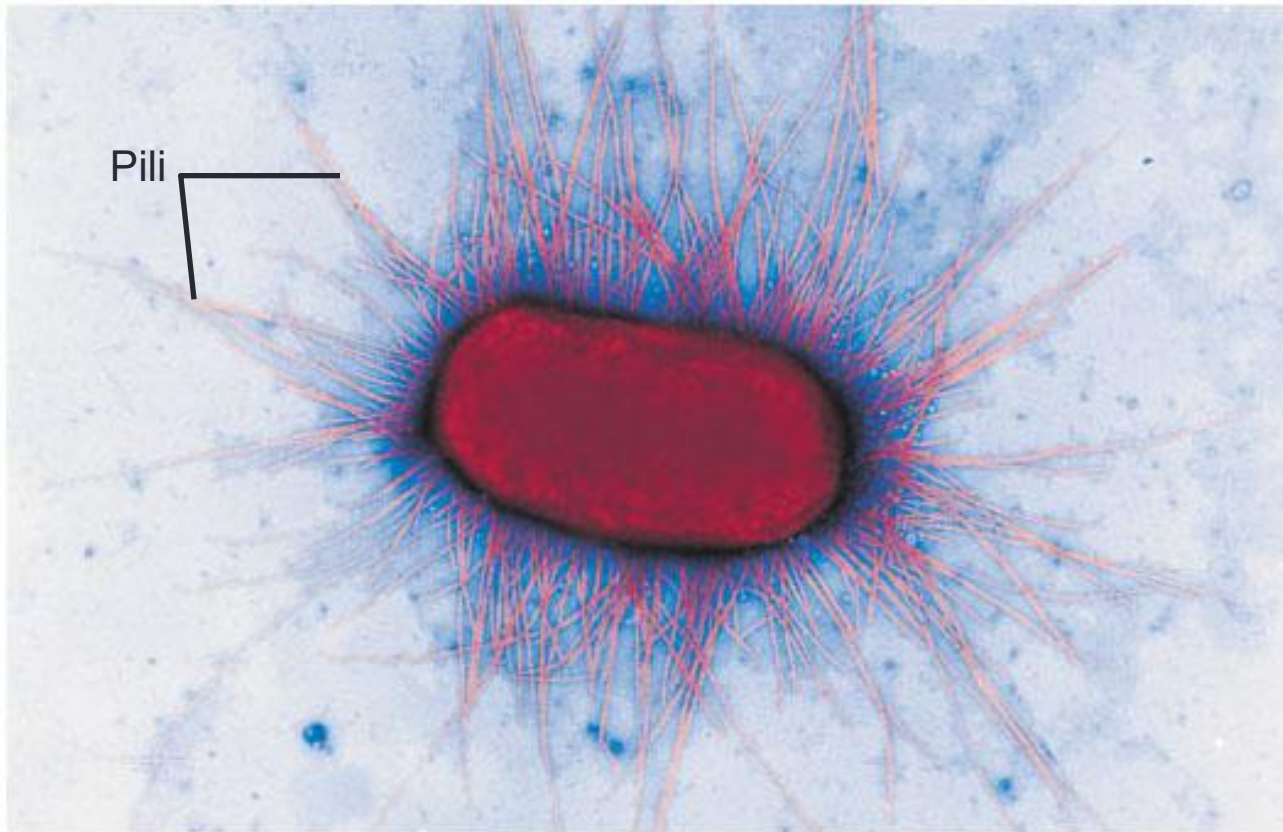
The cell wall

- Is one of the most important features of nearly all prokaryotes
- Is covered by a sticky capsule



Some prokaryotes

- Stick to their substrate with pili

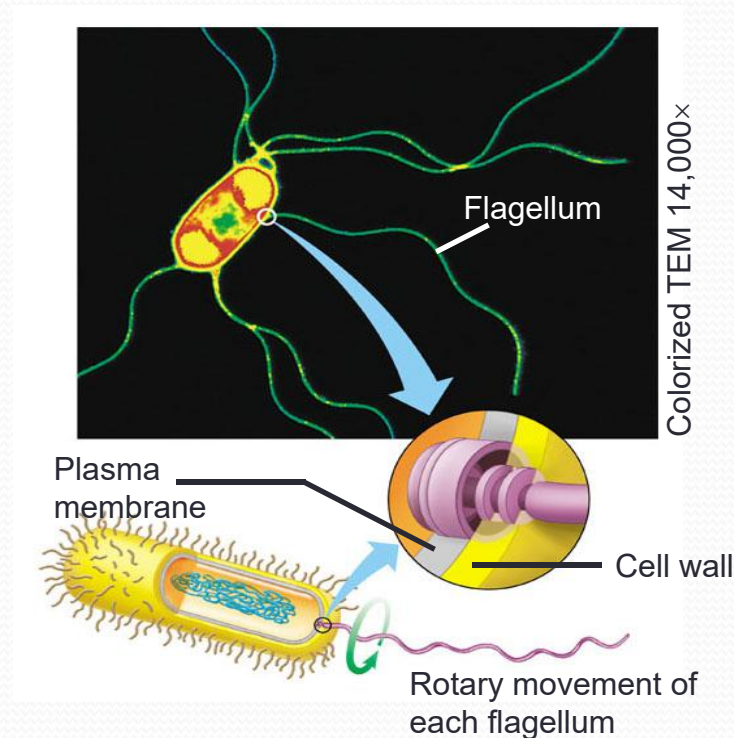


Colorized TEM 16,000 ×

⌘ Motility

⌘ Many bacteria and archaea

⌘ Are equipped with flagella, which enable them to move



⌘ *Reproduction and Adaptation*

⌘ Prokaryotes

⌘ Have the potential to reproduce quickly in favorable environments

- ∞ Some prokaryotes can withstand harsh conditions
 - ∞ By forming endospores

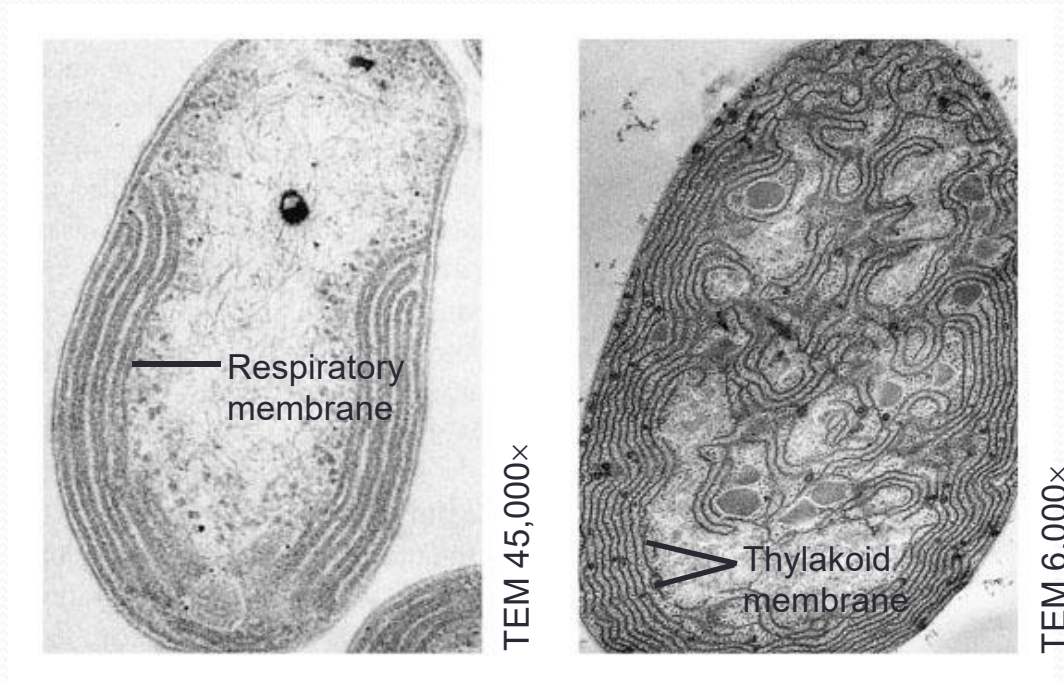


TEM 34,000 ×

Internal Organization

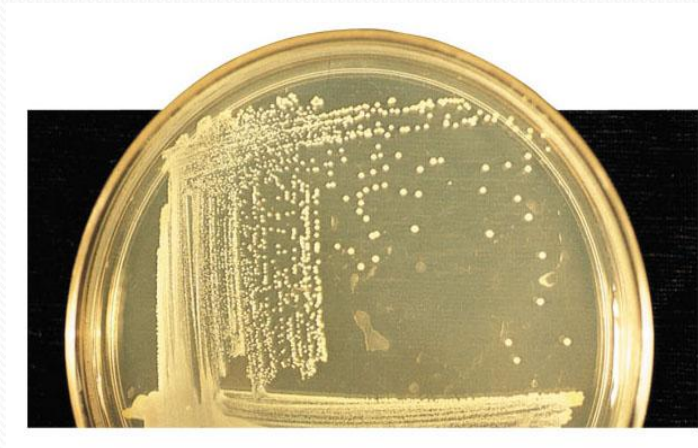
Some prokaryotic cells

- Have specialized membranes that perform metabolic functions



Types of Nutrition

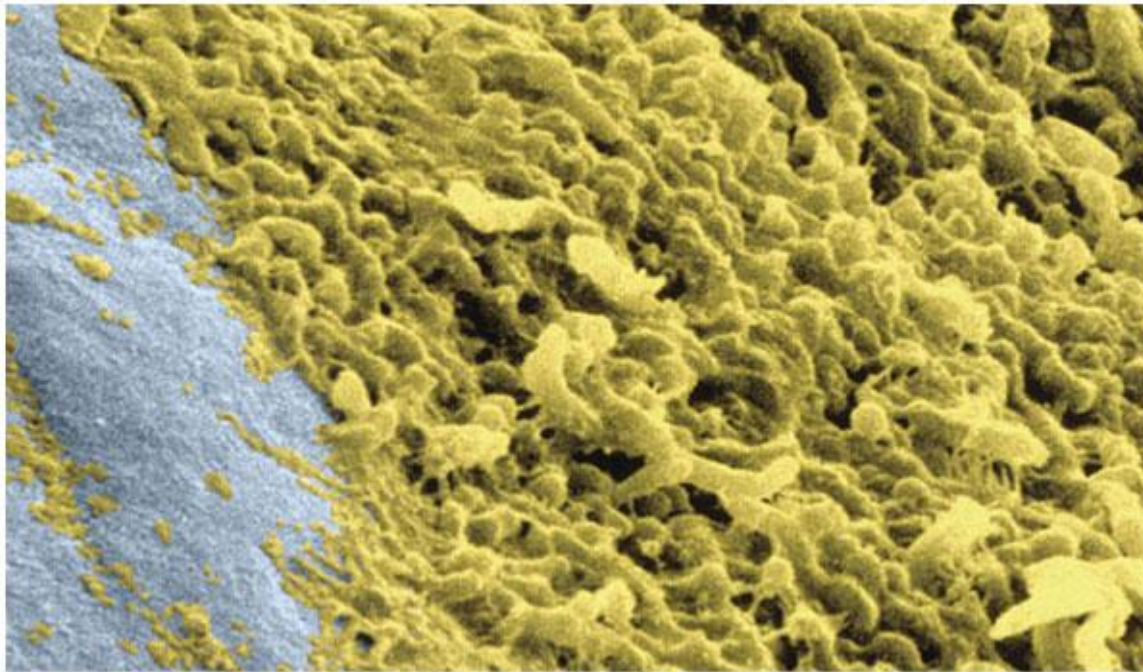
- ∞ Heterotrophs obtain their carbon atoms from organic compounds
 - ∞ Photoheterotrophs can obtain energy from sunlight
 - ∞ Chemoheterotrophs are so diverse that almost any organic molecule can serve as food for some species



⌘ *Metabolic Cooperation*

⌘ In some prokaryotes

⌘ Metabolic cooperation occurs in surface-coating colonies called biofilms



Colorized SEM 13,000 ×

Archaea thrive in extreme environments— and in other habitats (Extremophiles)

∞ Archaea are common in

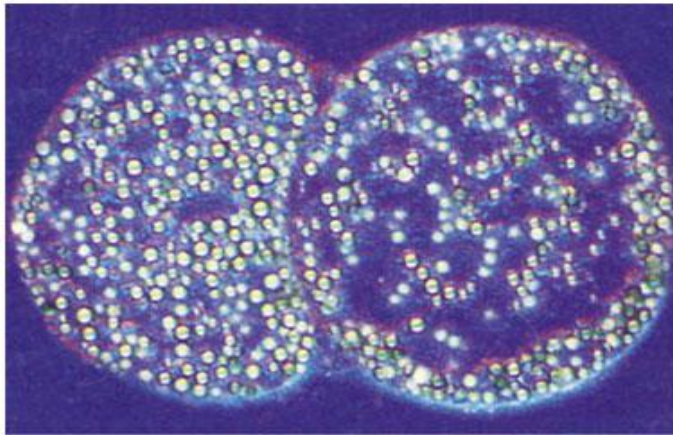
∞ Salt lakes, acidic hot springs, deep-sea hydrothermal vents



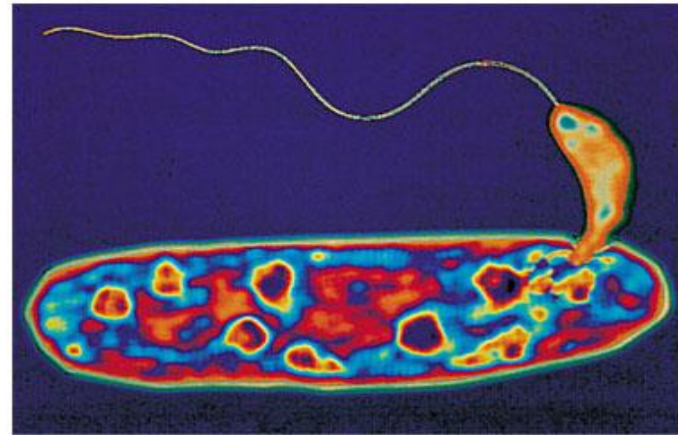
⌘ Archaea are also a major life-form in the ocean



- ❧ Bacteria include a diverse assemblage of prokaryotes
 - ❧ Bacteria are currently organized into several subgroups, including
 - ❧ Proteobacteria – Major phylum composed of many pathogenic organisms



LM 13,000 ×



Colorized TEM 5,000 ×

- ✧ Chlamydias – 3 species in the genus; most common STD in the US; most common cause of infectious blindness in the world
- ✧ Spirochetes – have long helical cells; pathogenic including syphilis and Lyme disease

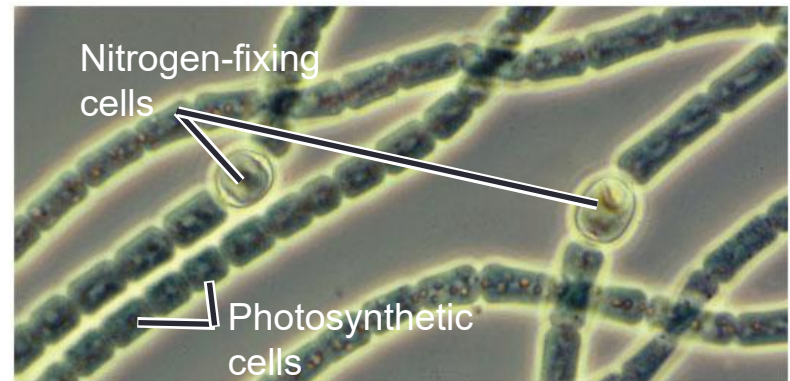
Other prokaryotes

- ☞ Gram-positive bacteria
- ☞ Cyanobacteria, which photosynthesize in a plantlike way, e.g.



Colorized SEM 2,800 ×

Streptomyces



LM 650 ×

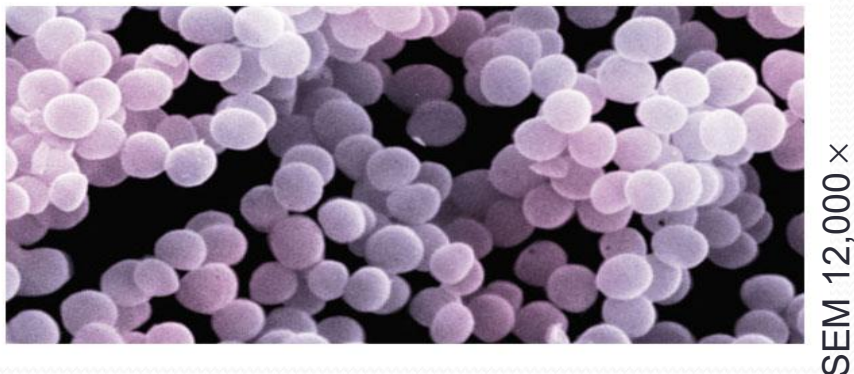
Anabaena

CONNECTION

⌘ Some bacteria cause disease

⌘ Pathogenic bacteria cause disease by producing

⌘ Exotoxins (excreted by bacteria) or endotoxins (component of bacteria)



CONNECTION

- ⌘ Bacteria can be used as biological weapons
 - ⌘ Bacteria (e.g. anthrax, smallpox, botulinum toxin, plague)
 - ⌘ Can be used as biological weapons



KOFI OWUSU-DAKU - Ph.D. KINGDOM MONERA
& PROTISTA

CONNECTION

- ⌘ Prokaryotes help recycle chemicals and clean up the environment
 - ⌘ Bioremediation
 - ⌘ Is the use of organisms to clean up pollution

Prokaryotes are decomposers in

- ⌘ Sewage treatment and can clean up oil spills and toxic mine wastes



Figure 16.16A, B

PROTISTS

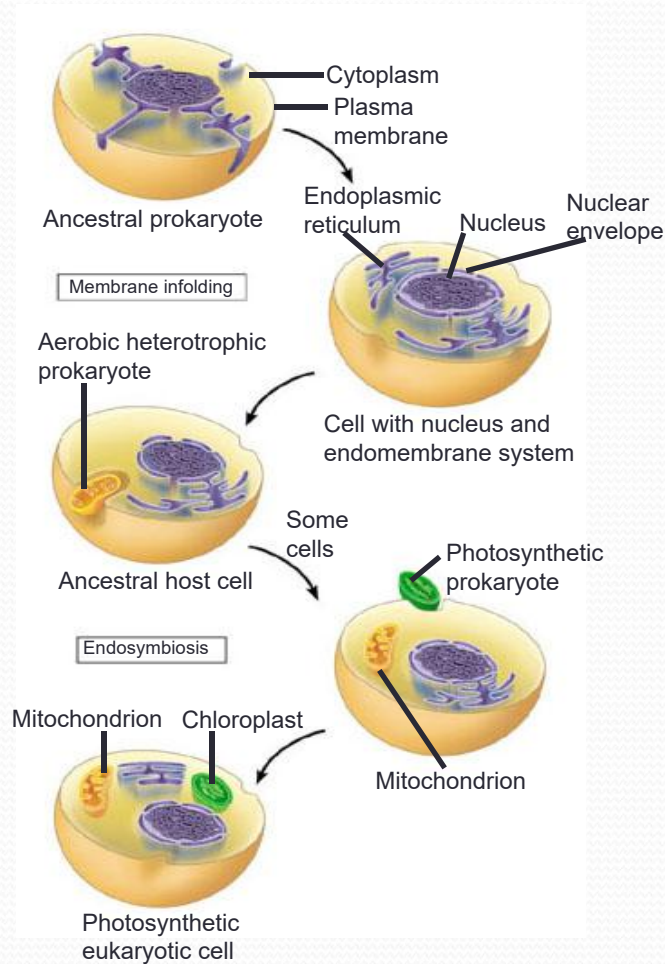
- ⌘ The eukaryotic cell probably originated as a community of prokaryotes
 - ⌘ Eukaryotic cells
 - ⌘ Evolved from prokaryotic cells more than 2 billion years ago

- ✧ The nucleus and endomembrane system
- ✧ Probably evolved from infoldings of the plasma membrane

✧ Mitochondria and chloroplasts

- ✧ Probably evolved from aerobic and photosynthetic endosymbionts, respectively
- ✧ **Endosymbiotic Theory:** according to this theory these organelles originated as separate prokaryotic organisms which were taken inside the cell as endosymbionts. *L. Margulis, 1981*
- ✧ Mitochondria → proteobacteria
- ✧ Chloroplast → cyanobacteria

Endosymbiosis Theory of the Origin of Eukaryotes - A model of the origin of eukaryotes



∞ Protists are an extremely diverse assortment of eukaryotes

∞ Protists

- ∞ Are mostly unicellular eukaryotes
- ∞ Protozoans → animal like protists
- ∞ Algae → plant like protists

∞ Molecular systematics

- ∞ Is exploring eukaryotic phylogeny

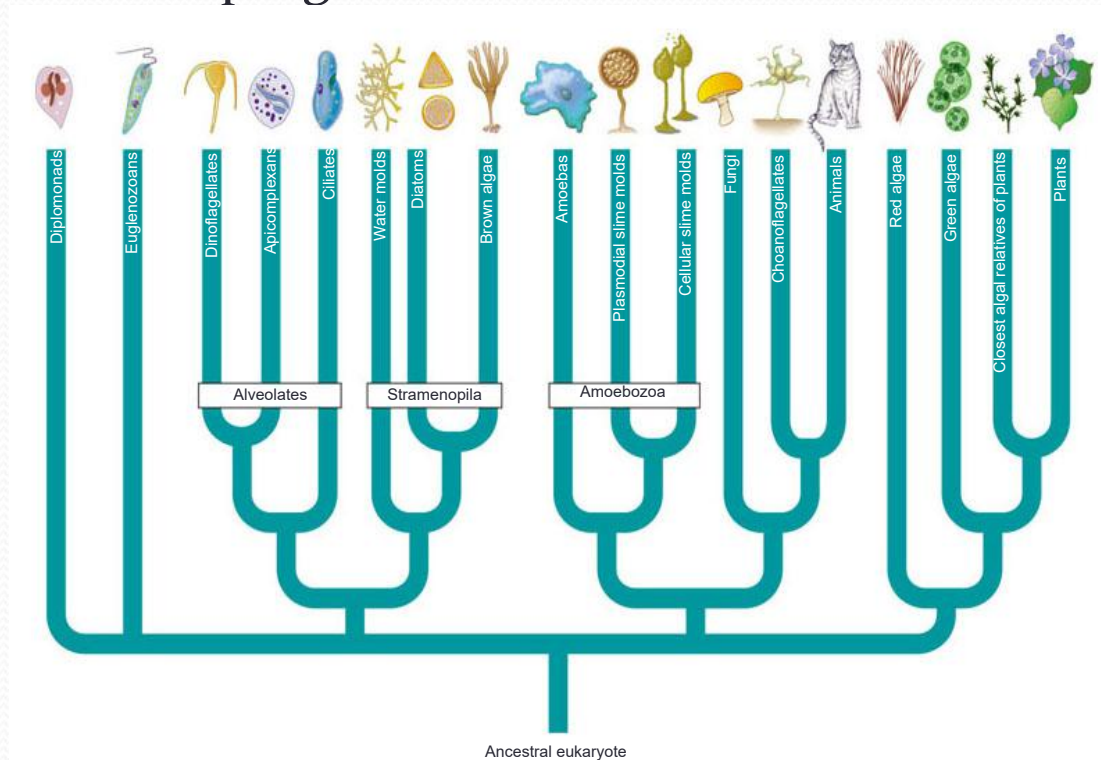
LM 275 ×



✧ A tentative phylogeny of eukaryotes includes multiple clades of protists

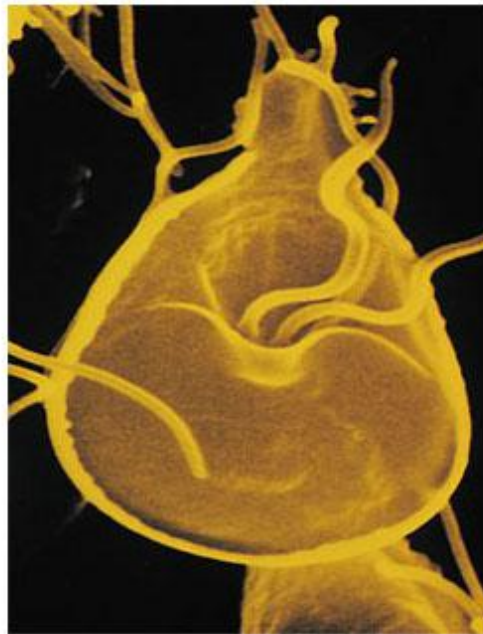
✧ The taxonomy of protists

✧ Is a work in progress



Protists

- ⌘ Diplomonads and euglenozoans include some flagellated parasites
- ⌘ The parasitic *Giardia*
 - ⌘ Is a diplomonad with highly reduced mitochondria



Colorized SEM 4,000 ×

Protists

Euglenozoans

∞ Include trypanosomes and *Euglena*



Colorized SEM 1,300 ×



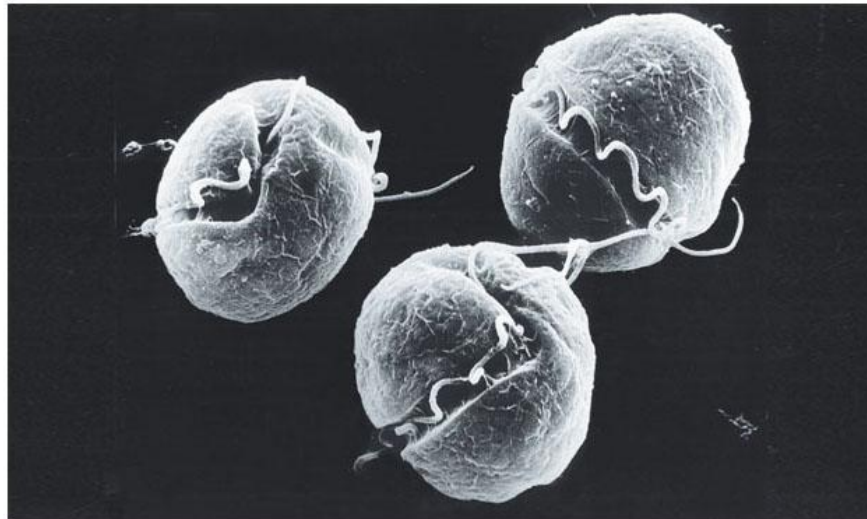
Colorized SEM 1,300 ×

Protists

⌘ Alveolates have sacs beneath the plasma membrane and include dinoflagellates, apicomplexans, and ciliates

⌘ Dinoflagellates

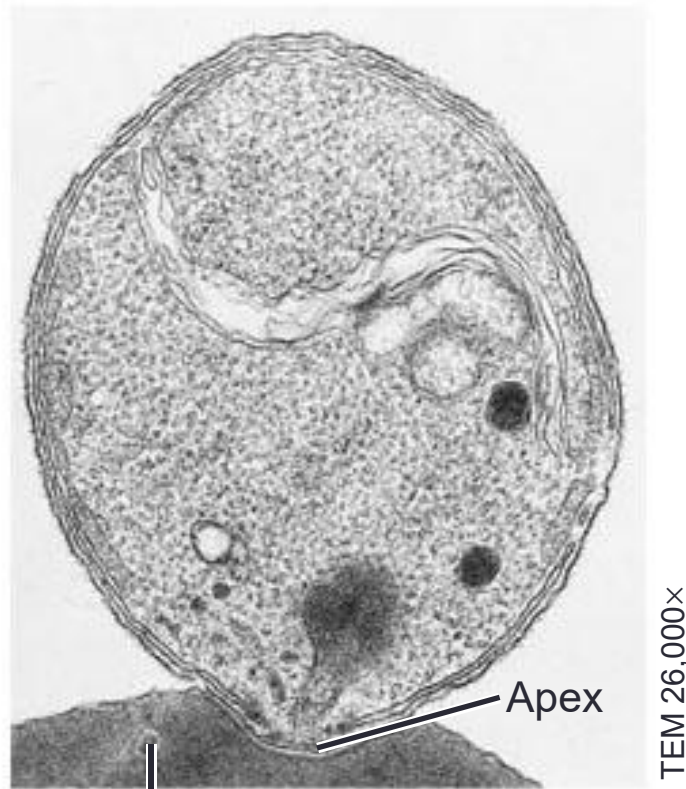
⌘ Are unicellular algae



SEM 2,300x

Protists

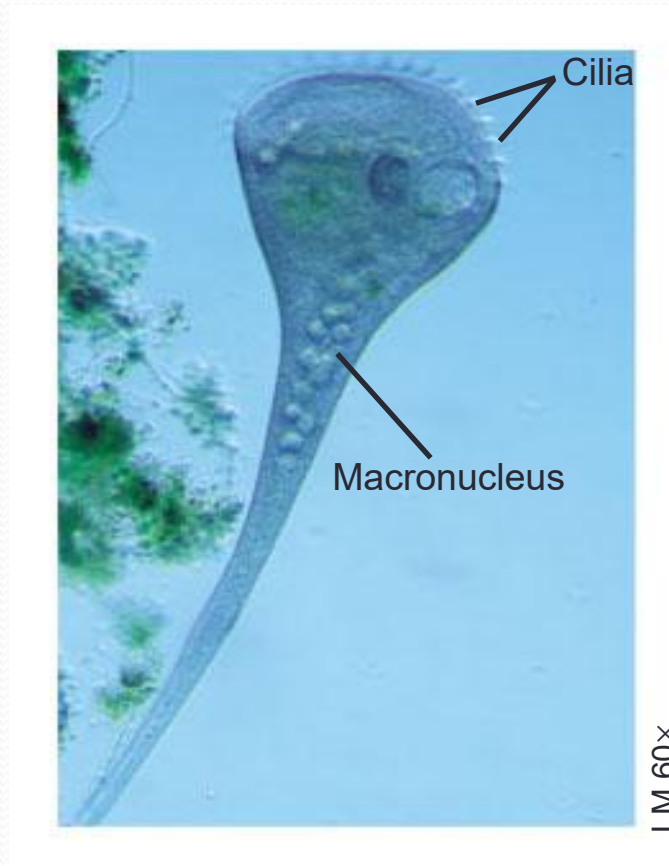
- ∞ Apicomplexans are parasites
 - ∞ Such as *Plasmodium*, which causes malaria



Protists

∞ Ciliates

- ∞ Use cilia to move and feed



Protists

- ⌘ Stramenopiles are named for their “hairy” flagella and include the water molds, diatoms, and brown algae
- ⌘ This clade includes
 - ⌘ Fungus-like water molds



Protists

- ☞ Photosynthetic, unicellular diatoms



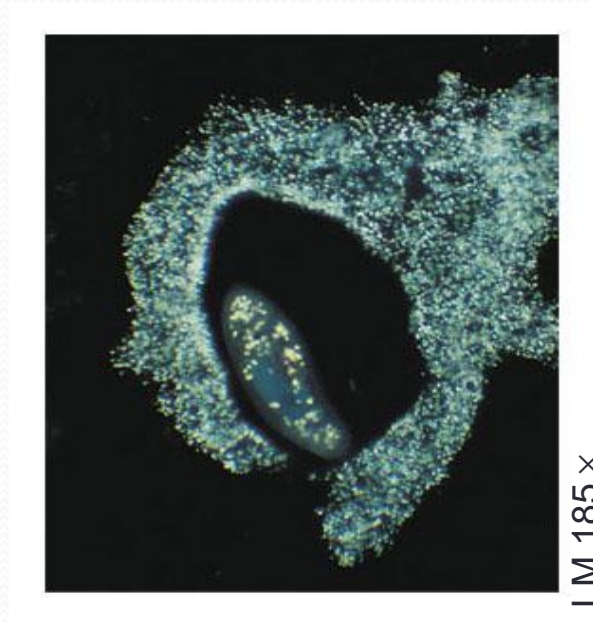
LM
400×

Protists



Protists

- ⌘ Amoebozoans have pseudopodia and include amoebas and slime molds
 - ⌘ Amoebas
 - ⌘ Move and feed by means of pseudopodia



Protists

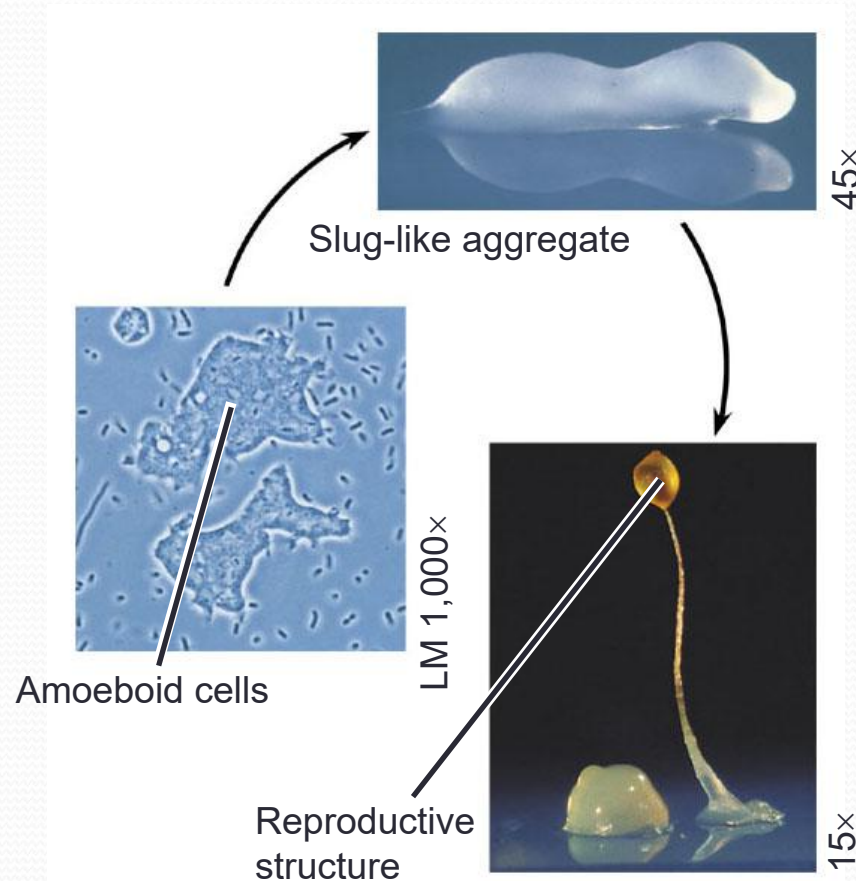
- ⌘ A plasmodial slime mold is a multinucleate plasmodium
 - ⌘ That forms reproductive structures under adverse conditions



Protists

Cellular slime molds

- Have unicellular and multicellular stages



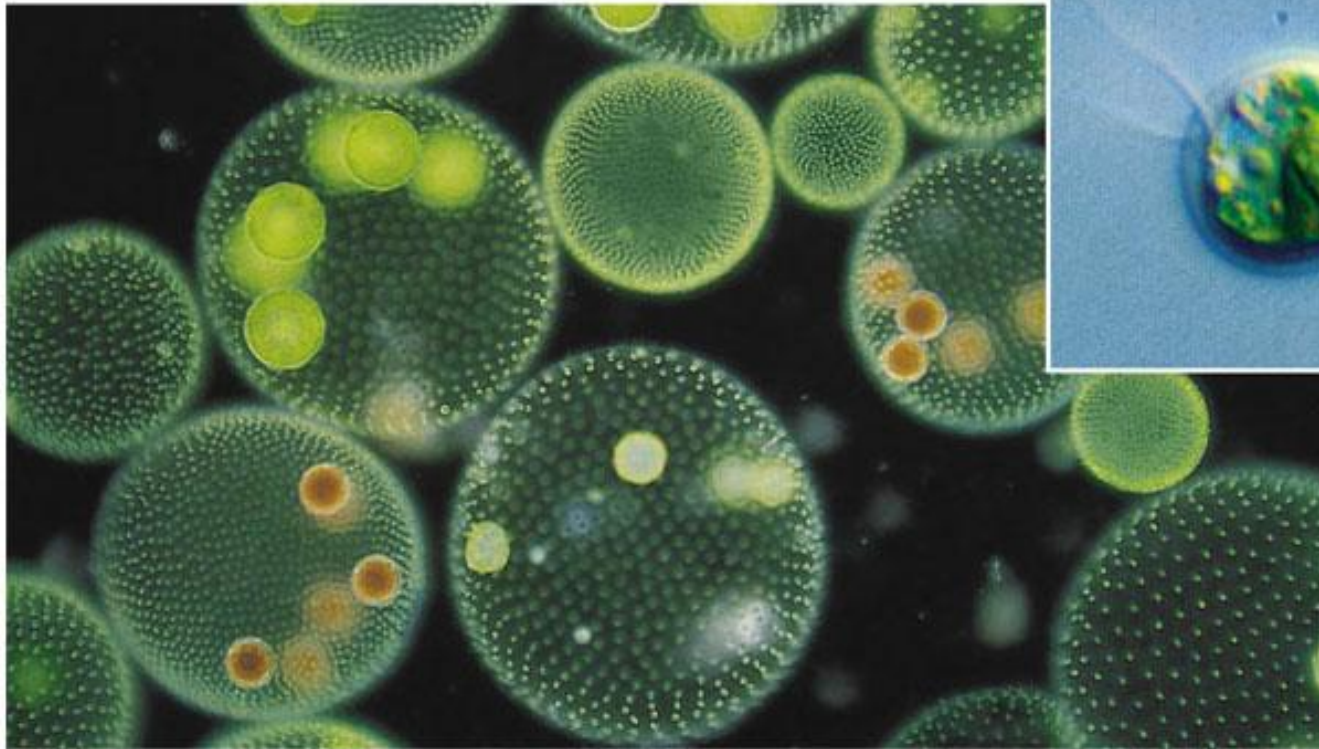
Protists

- ⌘ Red algae and green algae are the closest relatives of land plants
 - ⌘ Red algae
 - ⌘ Contribute to coral reefs



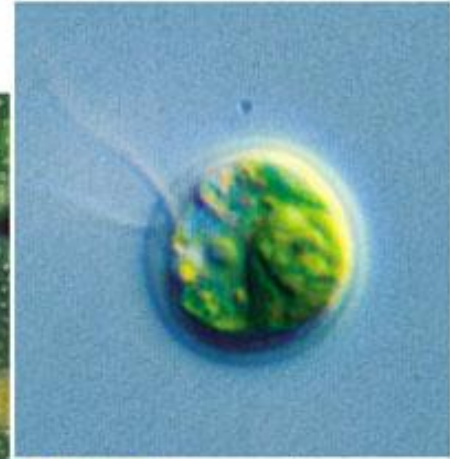
Protists

Volvox colonies



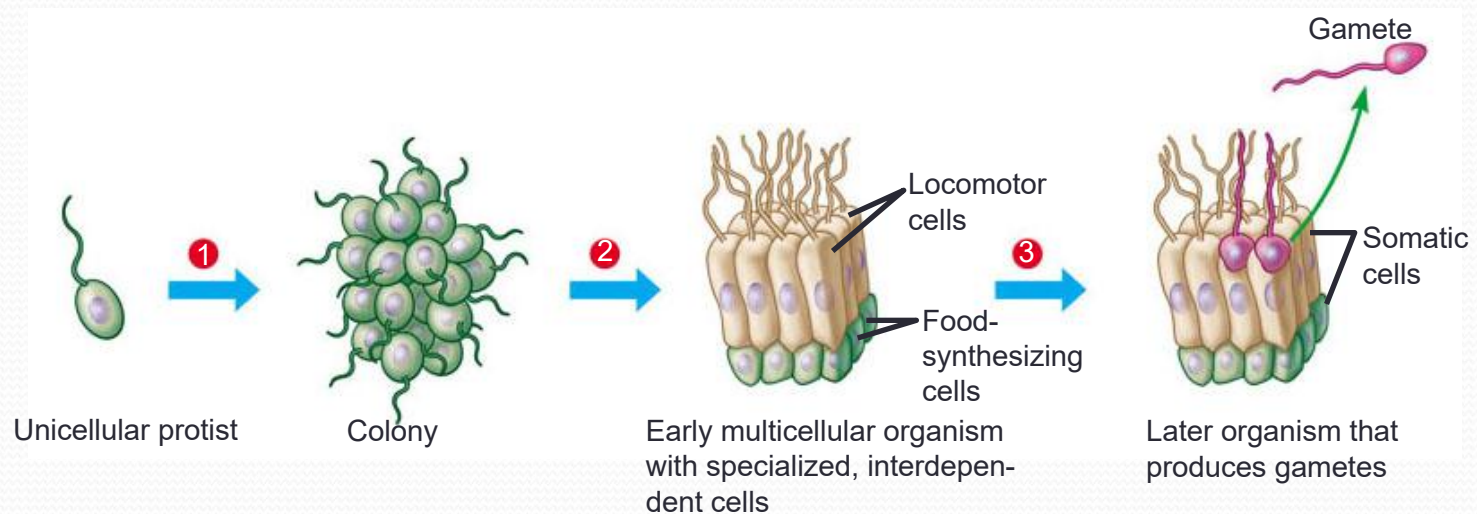
LM 80 ×

Chlamydomonas



LM 1,200 ×

- ⌘ Multicellularity evolved several times in eukaryotes
- ⌘ Multicellularity evolved in several different lineages
 - ⌘ Probably by specialization of the cells of colonial protists





∞ Multicellular
life arose over a
billion years ago