September 29, 2025

Master Degree in Bionics Engineering

Course of Principles of Bionics and Biorobotics Engineering

Lesson title:

General Characteristics of Biological Kingdoms as Models

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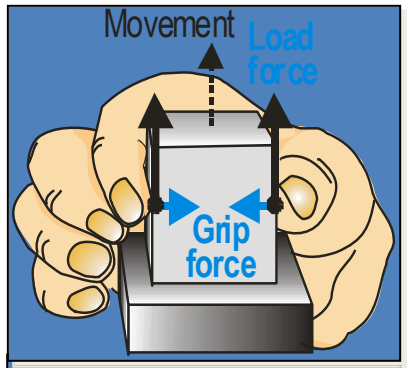
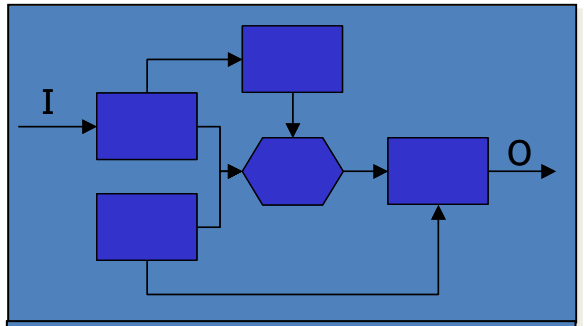
THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

Biorobotics Science



PHENOMENON TO BE EXPLAINED



HYPOTHESIS AND MODEL

IMPLEMENTATION IN A ROBOT

Validation of the model

EXPERIMENT
Comparison between robot and biological system performance

This approach can be used for:

Corroboration/falsification

… if the natural and the robotic system behave in the same/different way under the same external and internal circumstances

Deciding between two competing hypotheses

… if the behaviour of the robot built according to the theoretical model M1 is more similar to the target biological behaviour than the behaviour generated by the robot built according to the theoretical model M2

Generating new hypotheses on the functional structure of the biological system

• Barbara Webb, *Biorobotics*, MIT Press, 2001
• Datteri, E., Tamburrini, G., "Bio-robotic experiments and scientific method", in Magnani, L., Dossena, R. (eds), *Computing, Philosophy and Cognition*, College Publications, London, 2005.

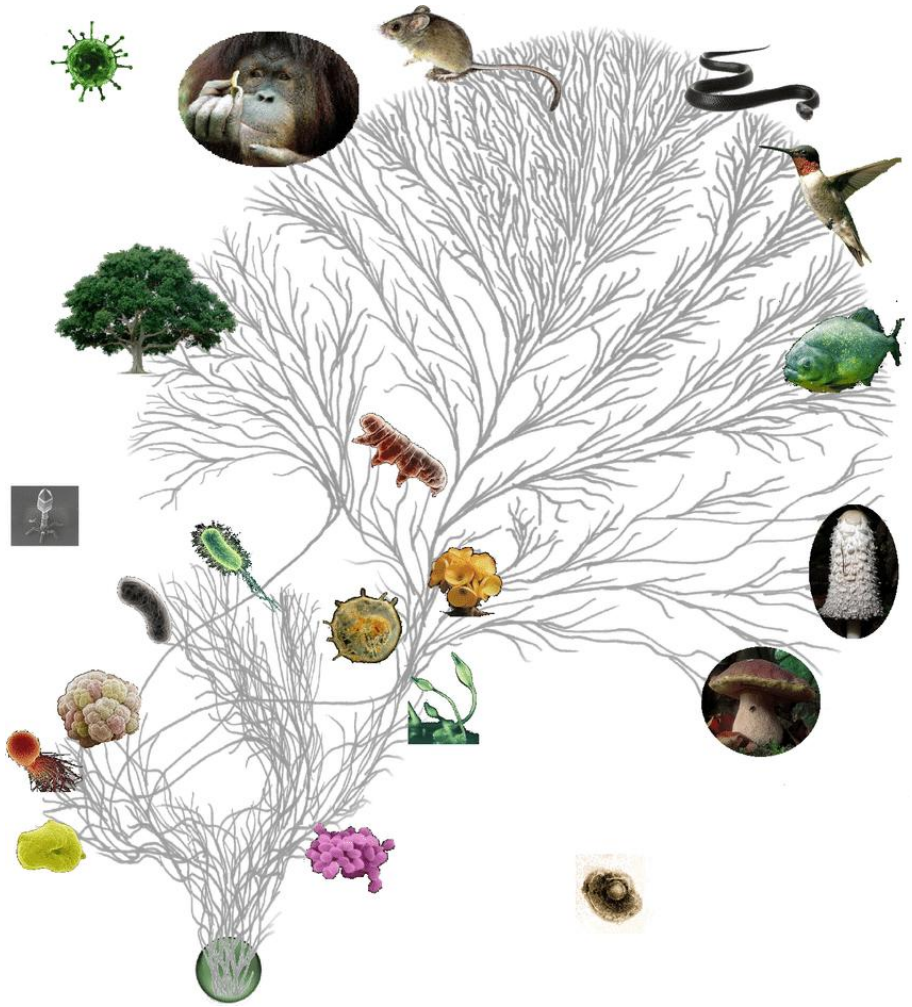
Robots can be used as “scientific instruments” to investigate different scientific problems in biology, and may lead to true scientific discoveries!

The Scuola Superiore Sant’Anna “Zoo” of robots for science

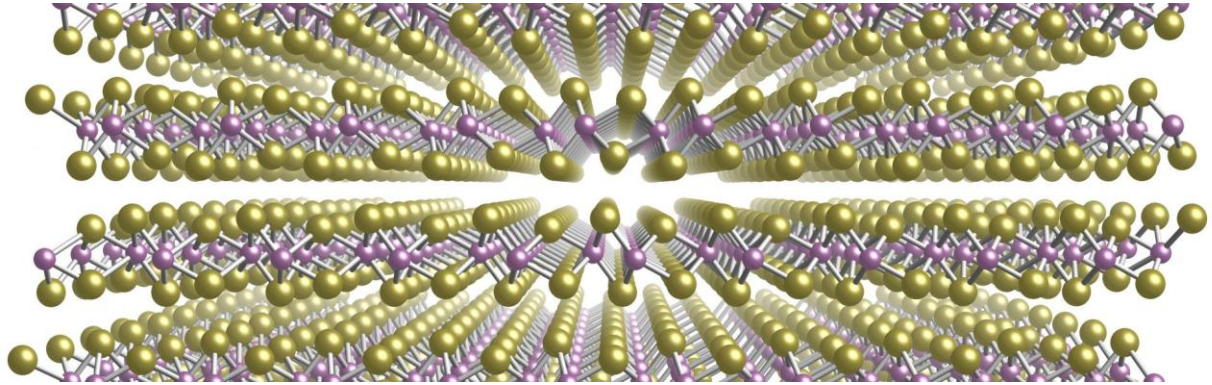
Biological model	Scientific problem
Oligochaeta	Role of friction in locomotion
Legged insects	Modeling compliant substrates
Polychaeta	New computational models of locomotion kinematics
Swimming cells	Swimming at low Re numbers
Cricket	Scale effects on locomotion
Lamprey	Neuroscientific models of goal-driven locomotion
Octopus	Motor performance of hydrostatic muscular limbs
Plant roots	Soil penetration mechanisms
Mouse	Animal-robot interaction
Homo sapiens	Model of the sensorimotor system

Natural living and nonliving bodies

Definition of life: open systems that maintain homeostasis, are composed of cells, have a life cycle, undergo metabolism, can grow, adapt to their environment, respond to stimuli, reproduce and evolve.



Inorganic bodies are in a state of rest which is not invariable but without autonomy of movements which allows the exchange of material



Natural living and nonliving bodies

Homeostasis: ability to maintain a constant state thought the regulation of internal factors.

Organization: organically composed of one or more cells.

Metabolism: transformation of energy by converting chemicals and energy into cellular components (anabolism) and decomposing organic matter (catabolism).

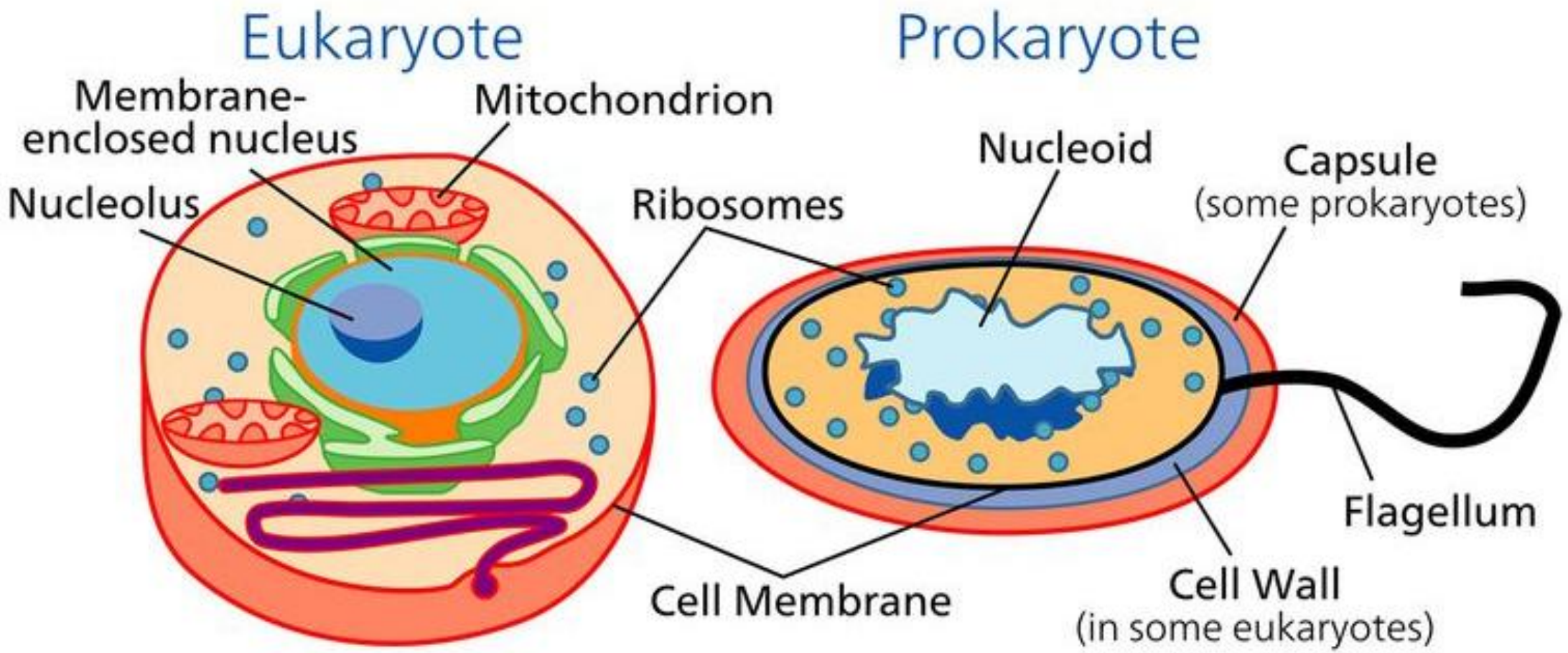
Growth: maintenance of a higher rate of anabolism than catabolism. A growing organism does not simply accumulate matter, but increases in size in all its parts.

Adaptation: the ability to change over time in response to the environment. This ability is fundamental to the process of evolution and is determined by the organism's heredity, diet, and external factors.

Responsive: a response can take many forms, from the contraction of a unicellular organism to external chemicals, to complex reactions involving all the senses of multicellular organisms. A response is often expressed by motion; for example, the leaves of a plant turning toward the sun (phototropism), and chemotaxis.

Reproduction: the ability to produce new individual organisms, either asexually from a single parent organism or sexually from two parent organisms.

Organisms


Eukaryote
Prokaryote
Membrane-enclosed nucleus
Mitochondrion
Nucleolus
Ribosomes
Nucleoid
Capsule
(some prokaryotes)
Flagellum
Cell Membrane
Cell Wall
(in some eukaryotes)

Organisms

Animalia

Multicellular organisms

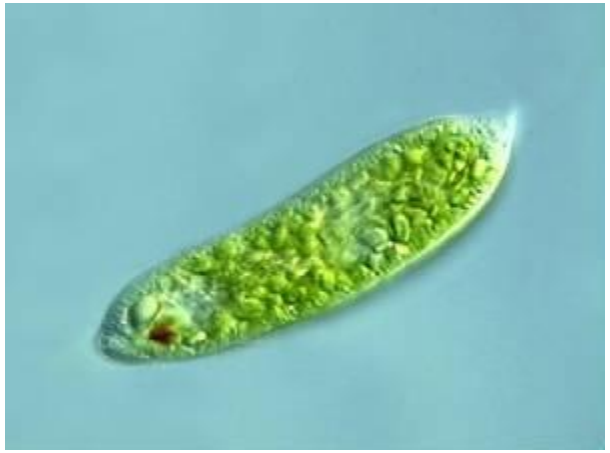
Fungi

Plantae

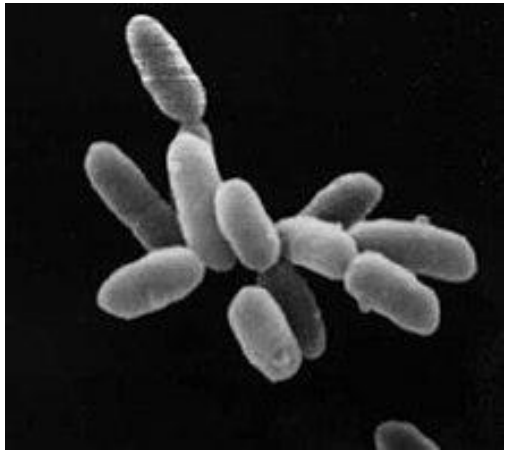
Organisms

Unicellular organisms

Bacteria



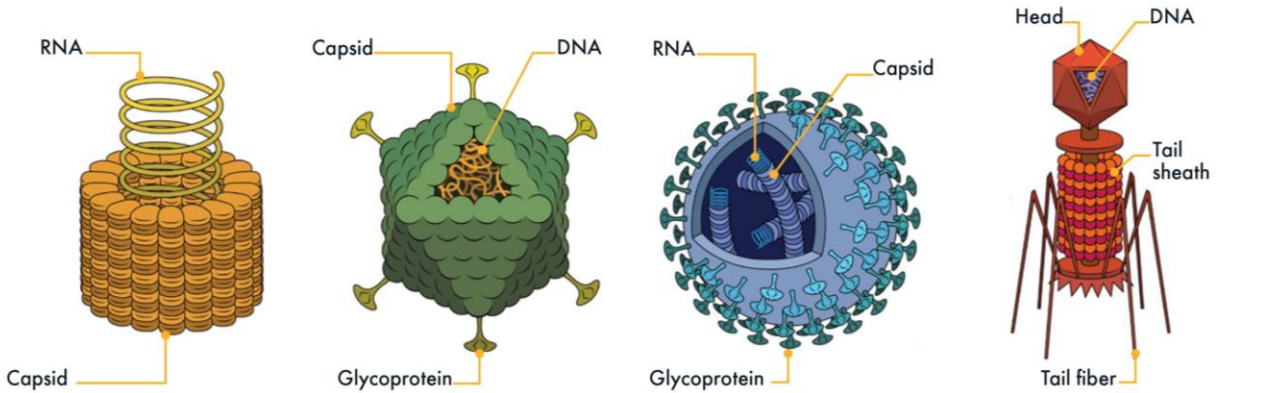
Protista



Archaea

Natural living and nonliving bodies

And viruses?



Helical viruses, like the Tobacco Mosaic Virus, which infects a number of different types of plants, have a slinky-shaped capsid that twists around and encloses its genetic material.

Polyhedral viruses, like adenoviruses, which are known to cause a range of illnesses from pink eye to pneumonia, are composed of genetic material surrounded by a many-sided capsid, usually with 20 triangular faces.

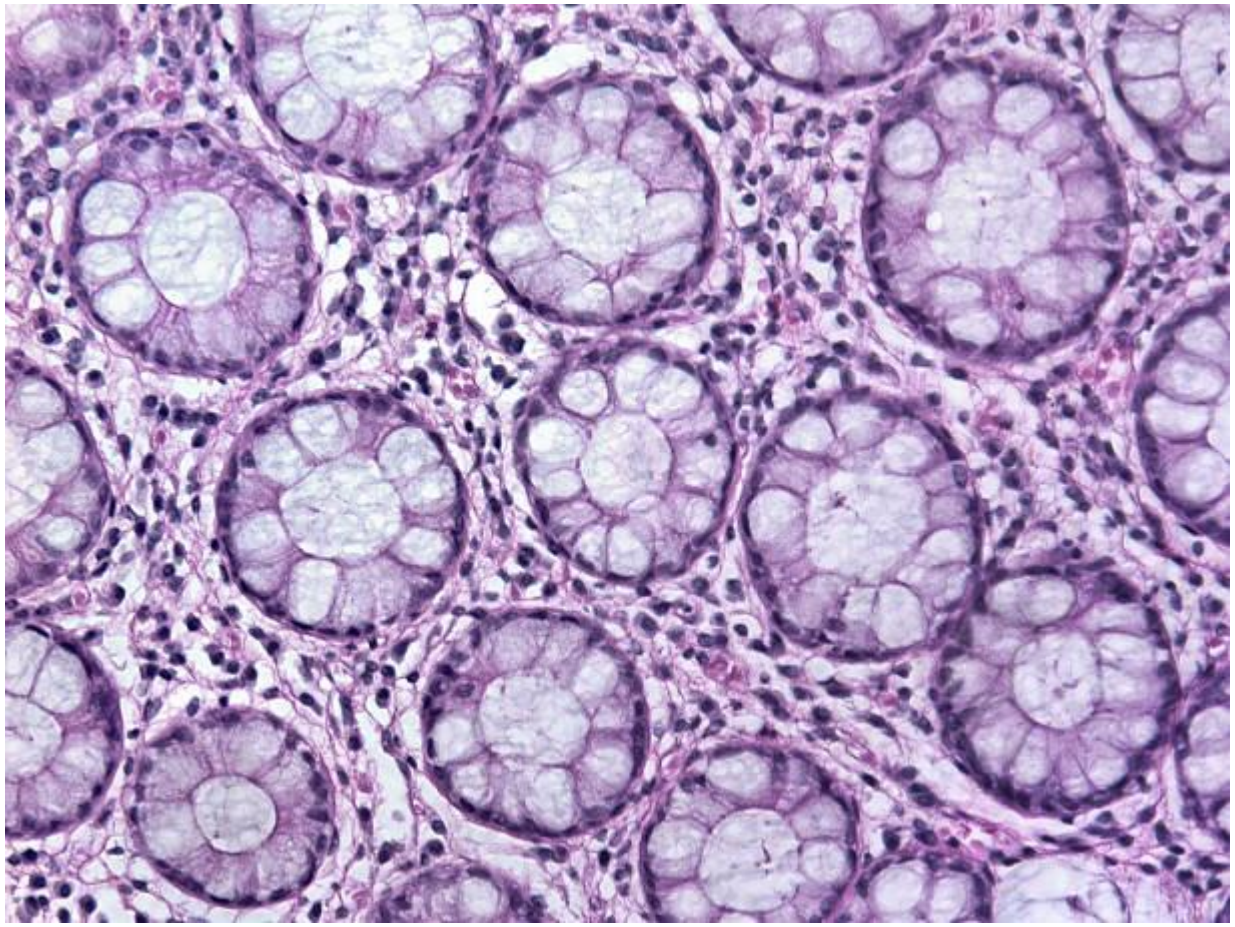
Spherical viruses, like the infamous Coronavirus, are essentially helical viruses enclosed in a membrane known as an envelope, which is spiked with sugary proteins that assist in sticking to and entering host cells.

Complex viruses, like bacteriophages, which infect and kill bacteria, resemble a lunar lander, and are composed of a polyhedral "head" and a helical body (or "tail sheath"), and legs (or "tail fibers") that attach to a cell membrane so that it can transfer its genetic material.

General Characteristics of Animals

Eukaryotic multicellular organisms that comprise the biological kingdom of Animalia

Multicellular: The animal body is composed of several cells performing specific functions as opposed to bacteria and most protists that are unicellular. The cells may then be organized into various **animal tissues**, such as epithelial tissues, connective tissues, muscle tissues, nervous tissues, and vascular tissues.

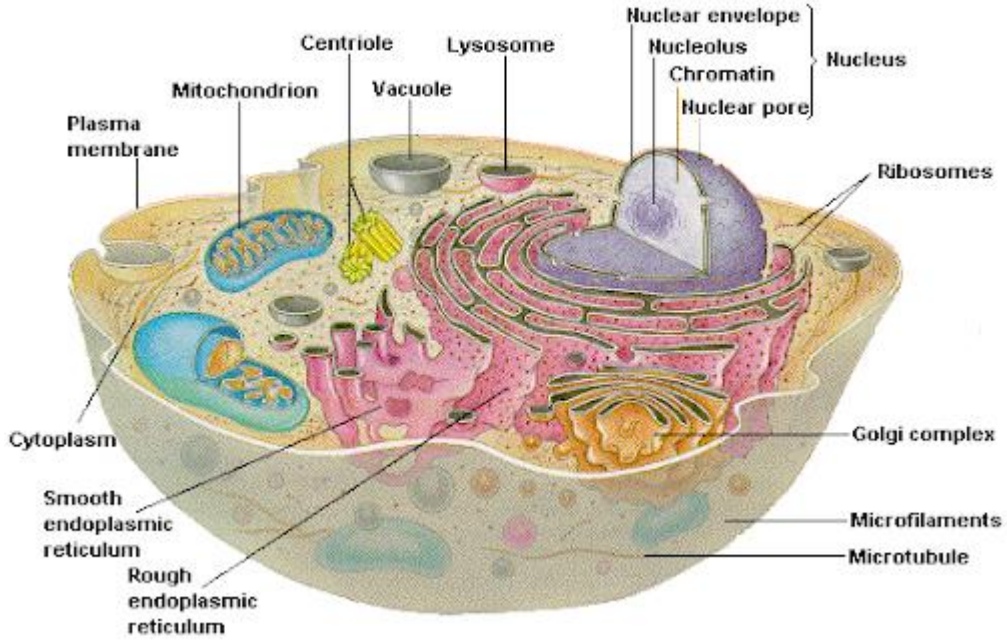


https://www.biologyonline.com/dictionary/animal

General Characteristics of Animals

Eukaryotic multicellular organisms that comprise the biological kingdom of Animalia

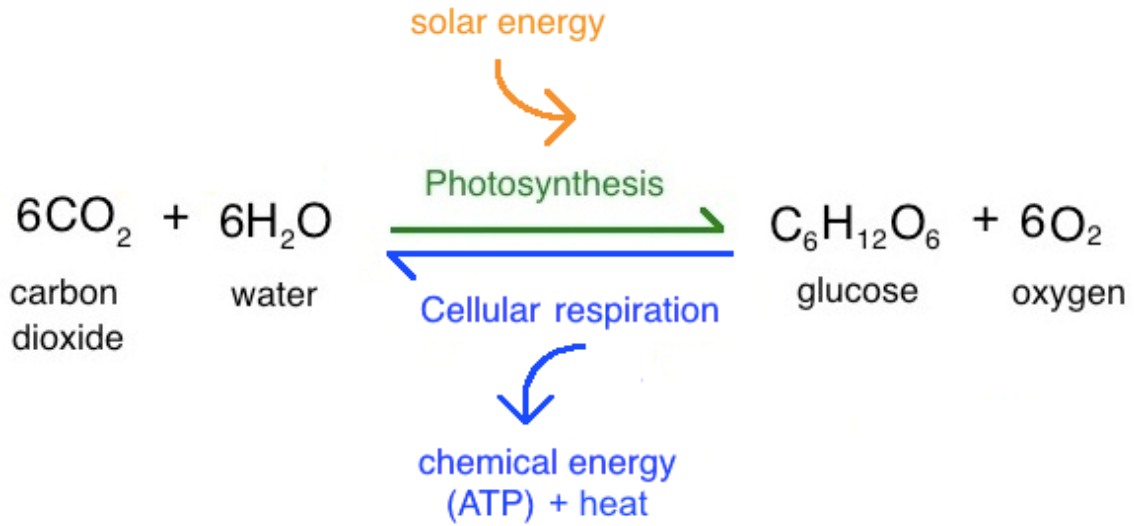
Eukaryotic: An animal cell contains a **membrane-bound nucleus**. The nucleus is the organelle that contains chromosomes that bear genes. Apart from the nucleus, there are other organelles suspended in the cytoplasm of an animal cell, such as the Golgi apparatus, endoplasmic reticulum, lysosomes, and peroxisomes. Animal cells lack plastids and cell walls, which are abundant in plant cells, algae, and certain fungi.

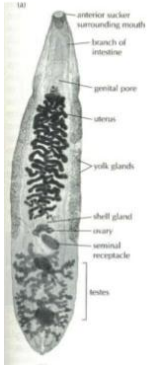


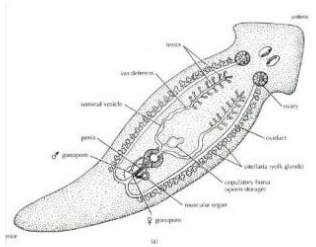
General Characteristics of Animals

Eukaryotic multicellular organisms that comprise the biological kingdom of Animalia

Heterotrophic: animals depend on another organism for food (unlike plants and algae that are autotrophic). Animal carnivores, for instance, are adapted to hunting their prey while others scavenge for animal carcasses or remains. Others feed on plants and as such are referred to as herbivores. Omnivores are animals that feed on both plants and animals. Most animals have an elaborate digestive system in the form of an internal chamber (a digestive tract) that processes ingested food to extract nutrients from it and then released it from the body in the form of excreta or a waste matter. Many animals have a mouth for ingestion and anus for excretion. Other animals (e.g. Platyhelminthes, cnidarians) have only one opening that serves both as a mouth and an anus. Poriferans, in contrast, lack a digestive system (as well as nervous and circulatory systems).



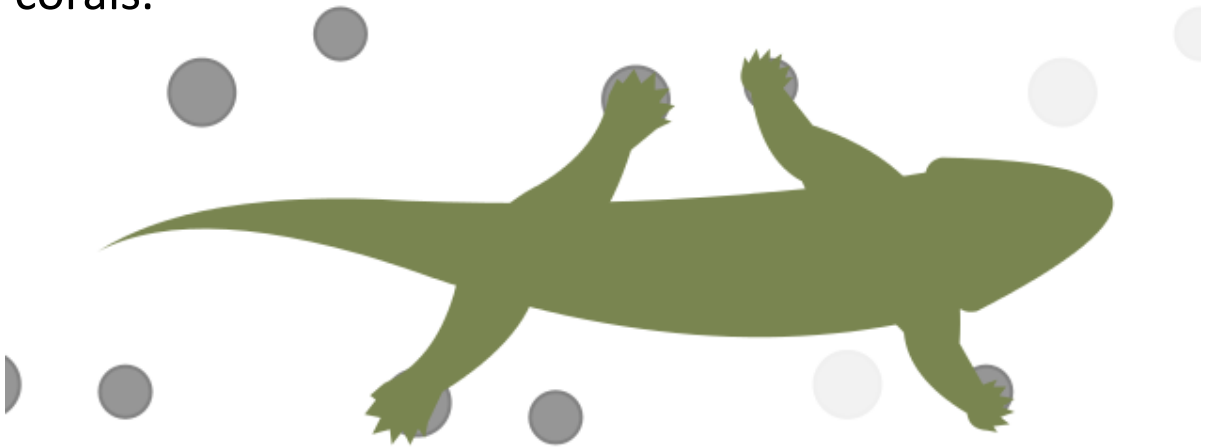




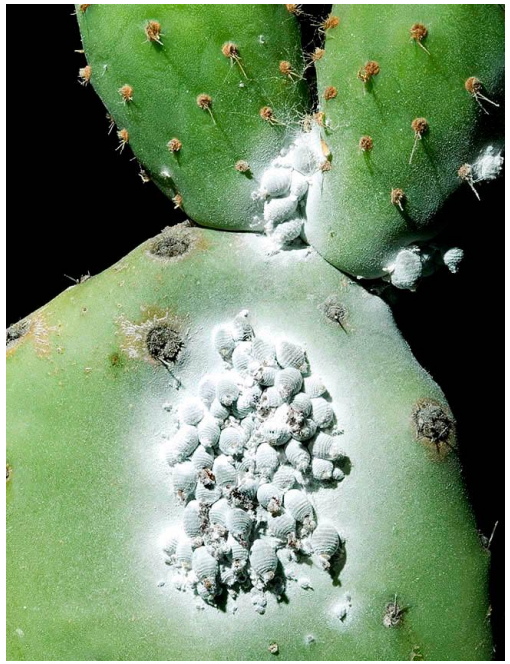
General Characteristics of Animals

Eukaryotic multicellular organisms that comprise the biological kingdom of Animalia

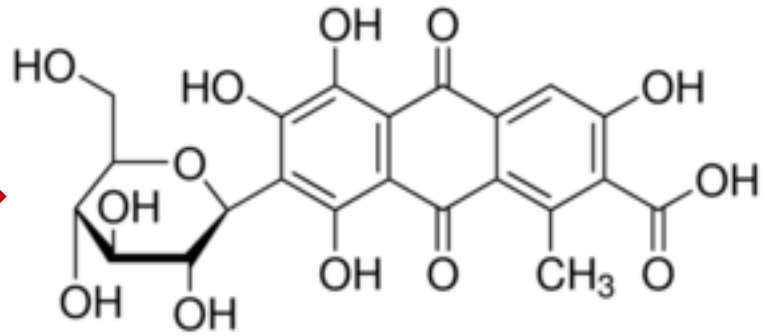
Motility: animals have the capacity to move at will. They can spontaneously and actively move by metabolically **utilizing energy** (e.g. ATP) during the process and with the aid of muscles and **locomotory structures** (e.g. arms, legs, wings, fins, tails, etc.). Animal locomotion refers to the variety of movements that animals use to move from one location to another. Some of these movements are running, walking, jumping, hopping, slithering, swimming, gliding, flying, soaring, and so on. Animals move for multifarious reasons. Some of the reasons animals move are to hunt prey, escape predators, and find a mate or a suitable habitat. There are animals, though, that have become sessile later in life. They become permanently attached to a substrate. Examples are barnacles, sponges, mussels, and corals.



Kermes vermilio



Dactylopius coccus



Carminic acid

as a deterrent to predators

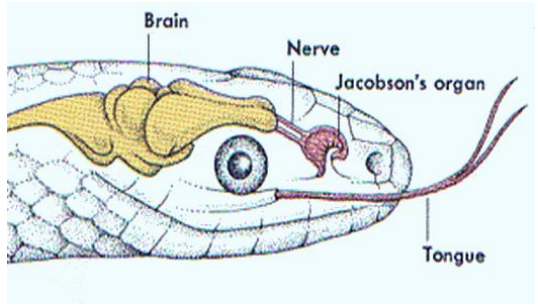
E120
food additive

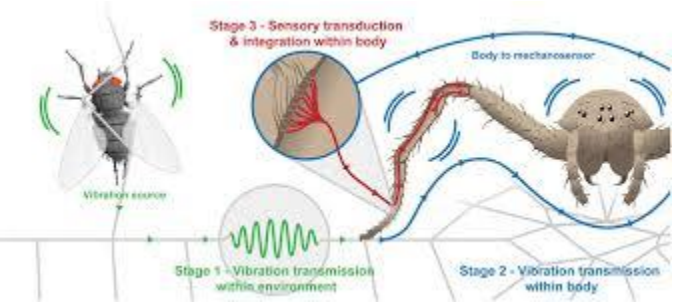
E122 - E124 - E132
(synthetic, less expensive)

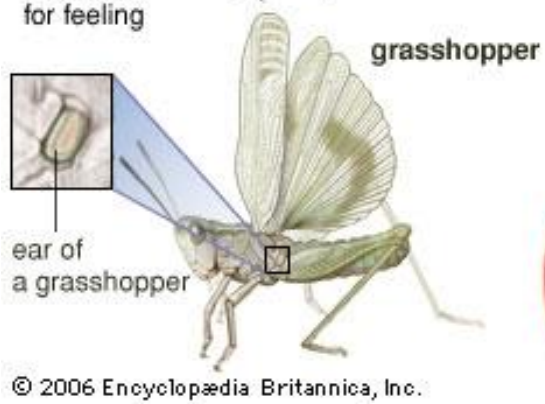
General Characteristics of Animals

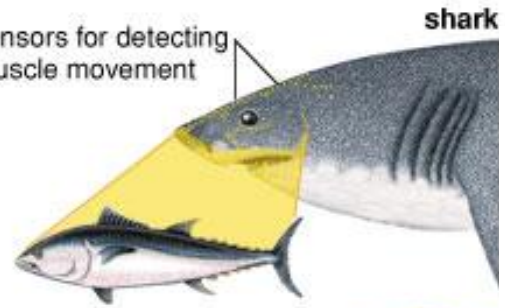
Eukaryotic multicellular organisms that comprise the biological kingdom of Animalia

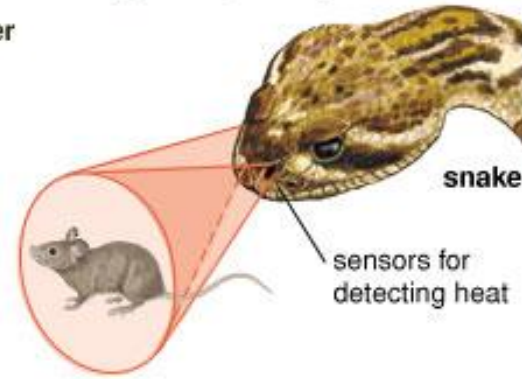
Sensing: animals possess specialized sensory organs such as eyes, ears, nose, skin, and tongue. These sensory organs are vital for use in recognizing and responding to stimuli in the environment. Each of these sense organs contains common and specialized receptors.





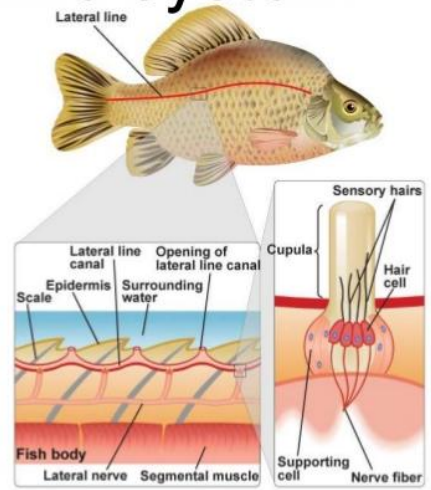






Lateral line system

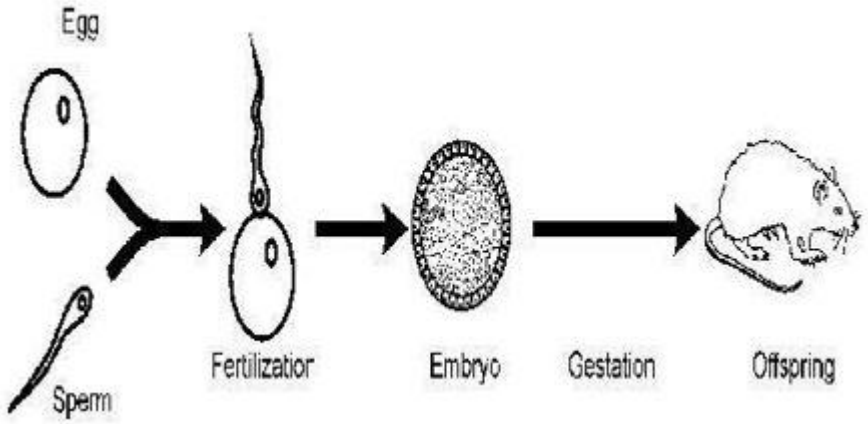
Used to sense movement of water.



General Characteristics of Animals

Eukaryotic multicellular organisms that comprise the biological kingdom of Animalia

Sexual Reproduction: animals produce a haploid sperm cell (a male sex cell) and a haploid ovum (a female sex cell) that unite at fertilization to form a diploid zygote. Conversely, some animals are capable of asexual reproduction. For instance, some cnidarians produce a genetic clone by budding. Others (e.g. aphids) are capable of **parthenogenesis** whereby they produce fertile eggs without mating.



October 2, 2025

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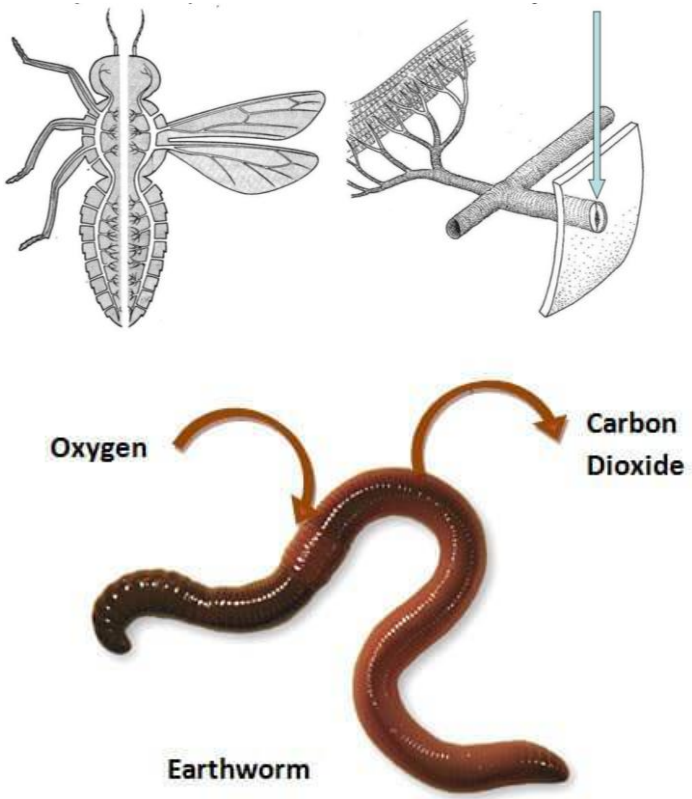
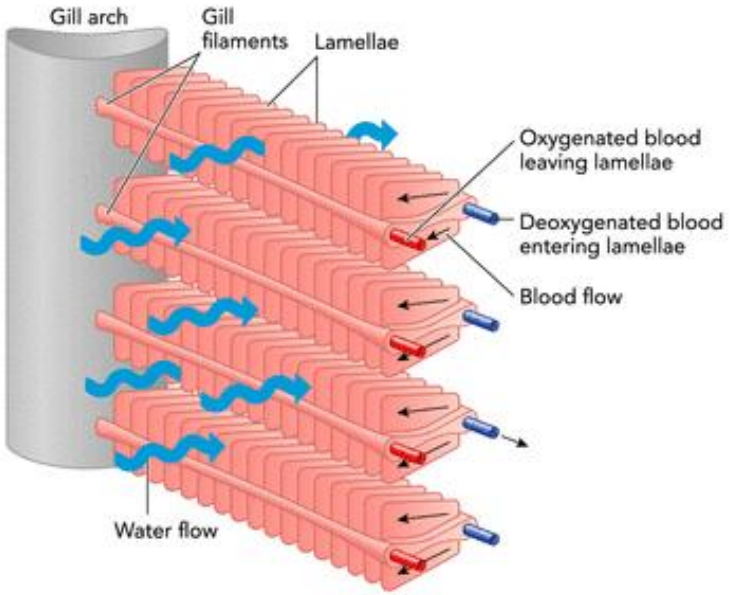
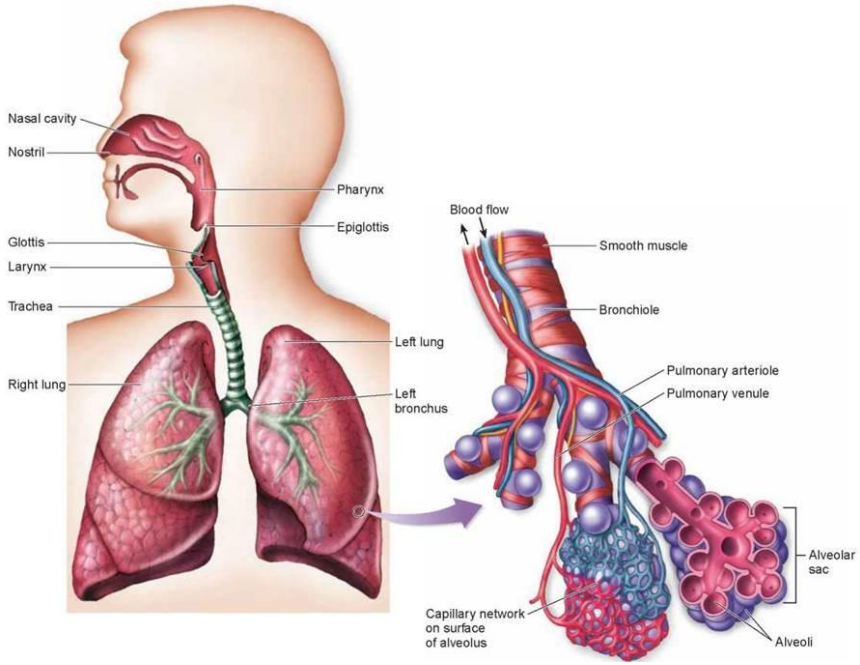
General Characteristics of Animals

Eukaryotic multicellular organisms that comprise the biological kingdom of Animalia

Animals respire **aerobically**, taking in oxygen (inspiration) and then releasing carbon dioxide (expiration). Oxygen is important to cell respiration as it serves as the final electron acceptor in redox reactions during the synthesis of metabolic energy. The different animal structures involved in the exchange of respiratory gases: (1) skin of tapeworms, earthworms, and leeches, (2) trachea of insects, (3) gills of fish, and (4) lungs of mammals, reptiles, and birds. Amphibians use different respiratory organs at different stages, i.e. gills at the tadpole stage and then skin and lungs at the adult stage.







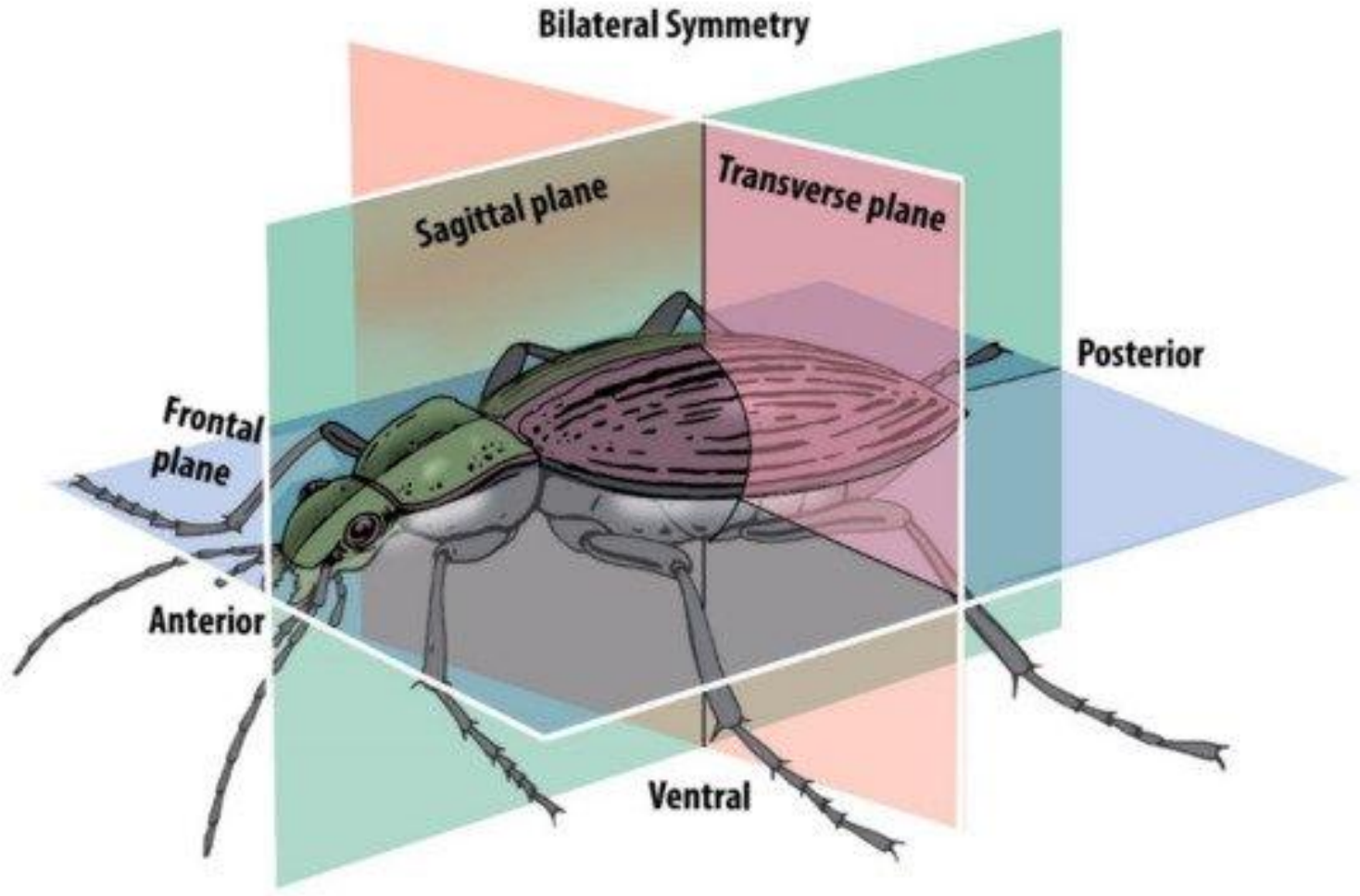
General Characteristics of Animals

Eukaryotic multicellular organisms that comprise the biological kingdom of Animalia

In general, animals possess the following biological systems: integumentary system, lymphatic system, muscular system, nervous system, reproductive system, respiratory system, skeletal system, and urinary system.

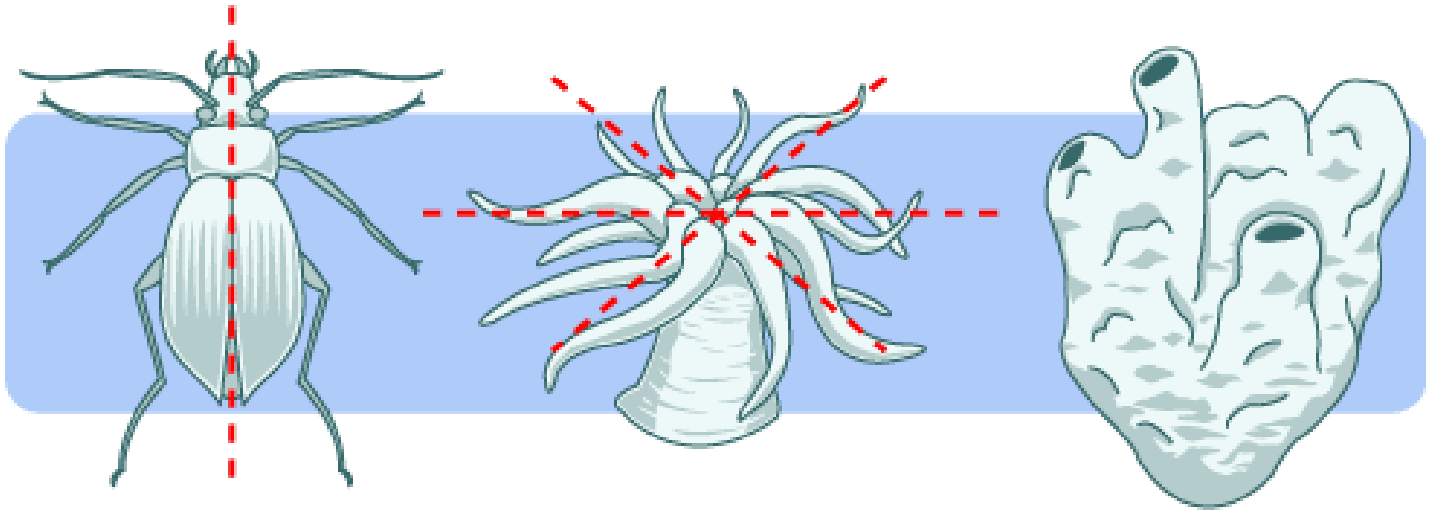
Animal Symmetry

If dividing the body of most animal species by a sagittal plane, the result is having two sides with roughly mirror images, at least morphologically (**bilaterally symmetry**). The appearance of bilateral symmetry in animal evolution was a major advancement, because bilateral animals are much better fitted for directional (forward) movement than are radially symmetrical animals. Bilateral animals form a monophyletic group of phyla called the **Bilateria**. Bilateral symmetry is strongly associated with **cephalization**.



Animal Symmetry

Radial symmetry applies to forms that can be divided into similar halves by more than two planes passing through the longitudinal axis. These are tubular, vase, or bowl shapes found in some sponges and in hydras, jellyfish, sea urchins, and related groups, in which one end of the longitudinal axis is usually the mouth.



Spherical symmetry means that any plane passing through the center divides the body into equivalent, or mirrored, halves. This type of symmetry is found chiefly among some unicellular forms and is rare in animals. Spherical forms are best suited for floating and rolling.

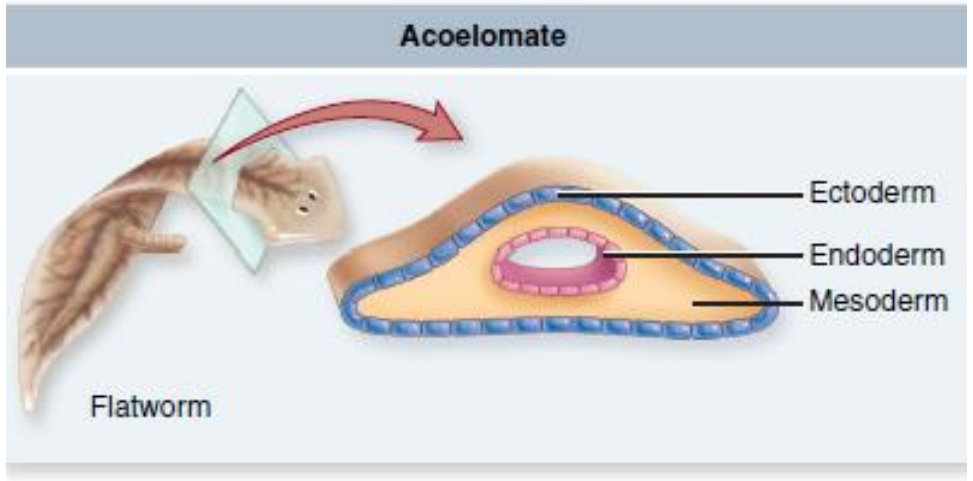
Triploblasty

Many animals produce three embryonic tissue layers as they develop.
Flatworms, ribbon worms, humans, etc. have all three tissue layers, and are triploblastic.

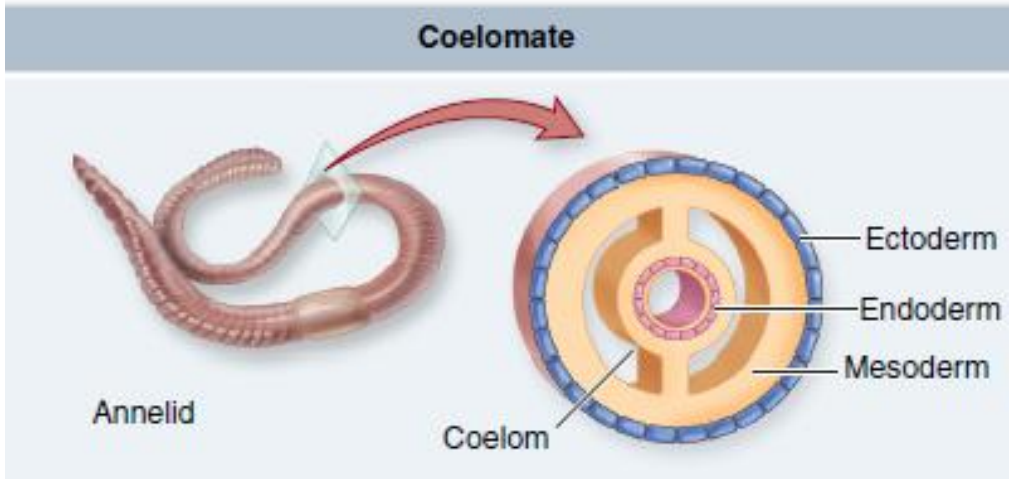
Animal embryonic tissue layers

Endoderm	Digestion and respiration structures
Mesoderm	Muscles, bones, blood, skin, and reproductive organs
Ectoderm	Skin, brain, and nervous system

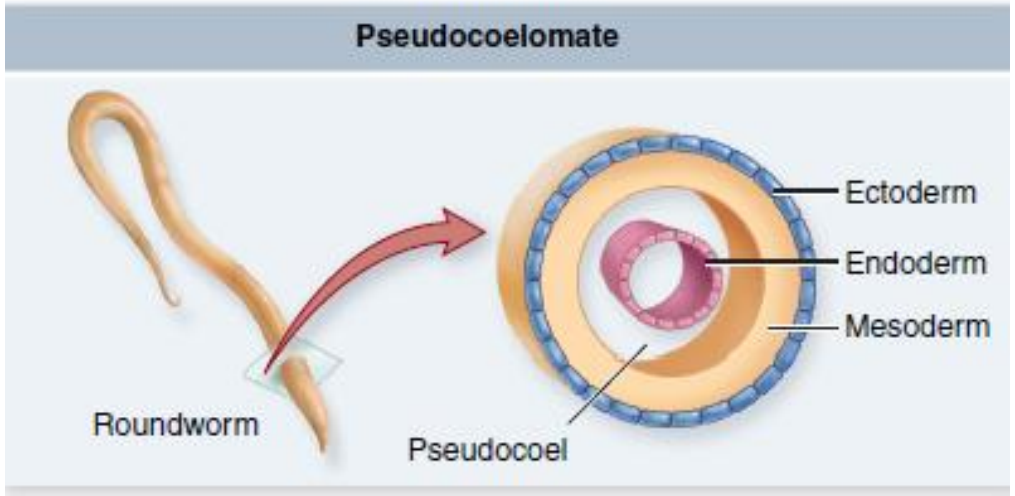
Body Cavities



No body cavity surrounding the gut. The region between the ectoderm and the endoderm digestive tract is filled with mesoderm called **parenchyma.**



Presence of a true coelom lined with mesodermal peritoneum.



Presence of a cavity surrounding the gut, but it is not lined with mesodermal peritoneum.

Metamerism

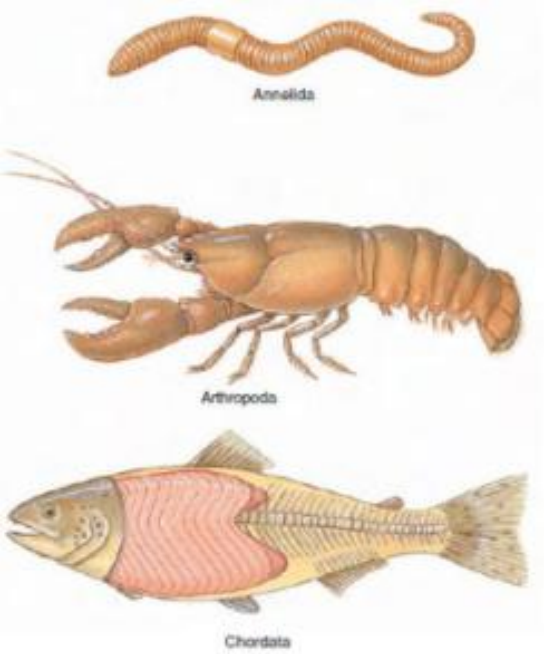
- Repetition of similar body segments along the longitudinal axis of the body.

- Each segment is called a **metamere**, or somite.

- The segmental arrangement includes both external and internal structures of several systems. There is repetition of muscles, blood vessels, nerves, and setae of locomotion.

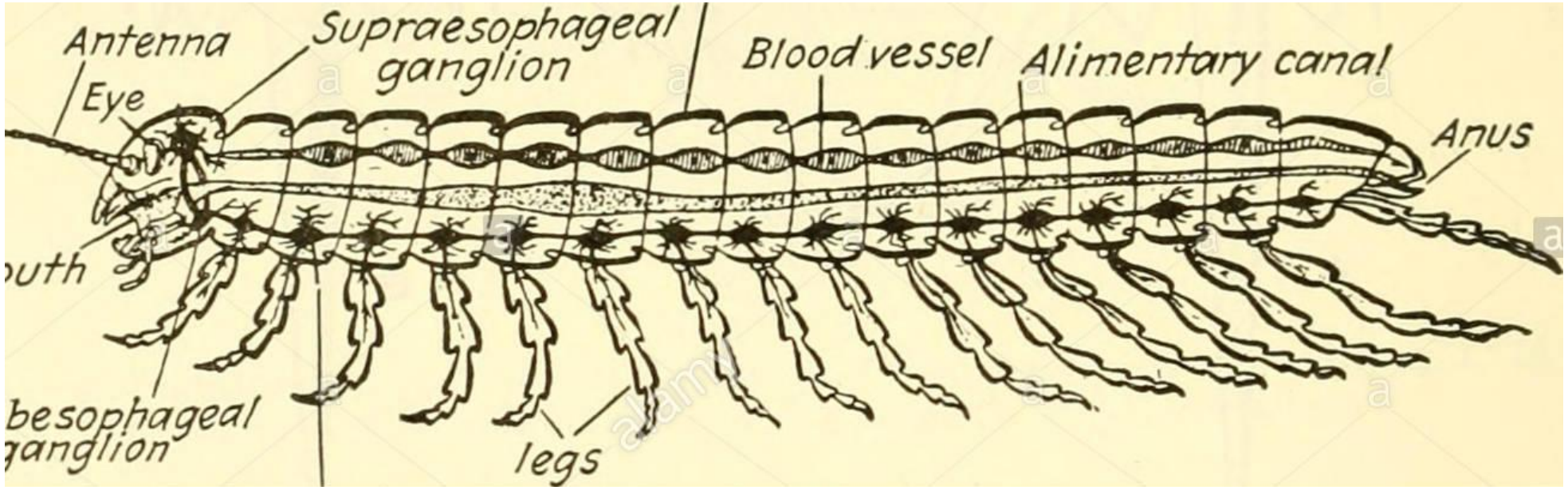
- Evolutionary changes have obscured much of the segmentation in many animals, including humans.

- True metamerism is found in only three phyla: Annelida, Arthropoda, and Chordata

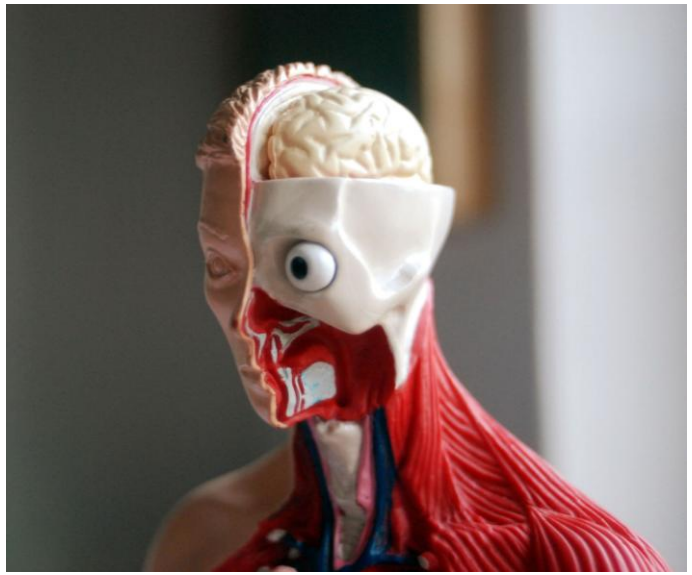


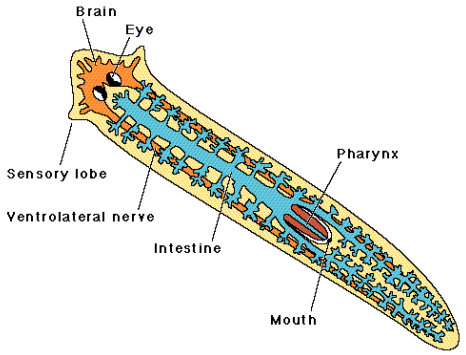
Metamerism

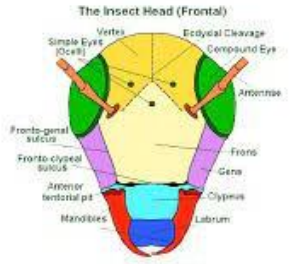
	True Metamerism	Pseudo-Metamerism
Definition	In true metamerism, the parts of the bodywork collectively work for the entire organism.	In pseudo-metamerism, the repeated part of the body may perform the independent task from each other.
Coordination	In true metamerism, the segmented body parts are well coordinated.	In pseudo-metamerism, there is zero coordination between the fragments.
Examples	Earthworms (annelids)	Tapeworms (Cestoda)

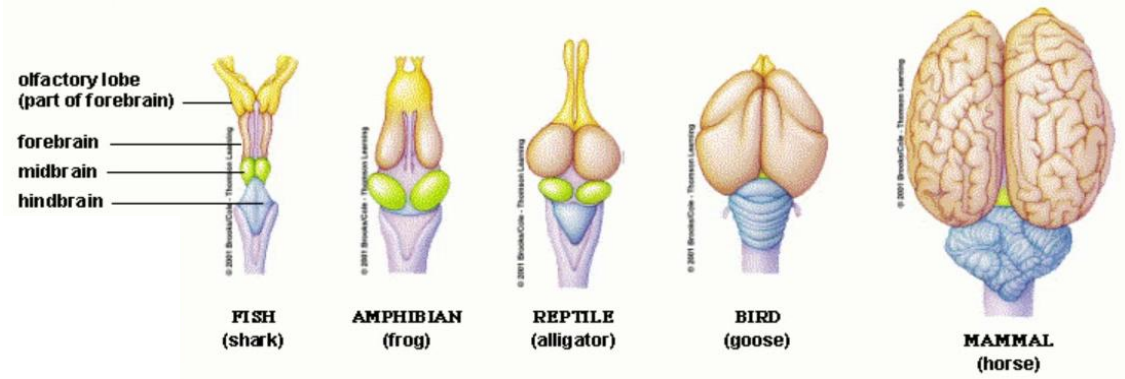


Cephalization









Differentiation of a head is called cephalization and is found chiefly in bilaterally symmetrical animals. The concentration of nervous tissue and sense organs in the head allows obvious advantages to animals moving through its environment. This is the most efficient positioning of organs for sensing the environment and responding to it. Usually, the **mouth** of the animal is **located on the head** as well, since so much of an animal's activity is concerned with procuring food. Cephalization is always accompanied by differentiation along an **anteroposterior axis** (**polarity**). Polarity usually involves gradients of activities between anterior and posterior ends.

https://biocyclopedia.com/index/general_zoology/the_hierarchical_organization_of_animal_complexity.php

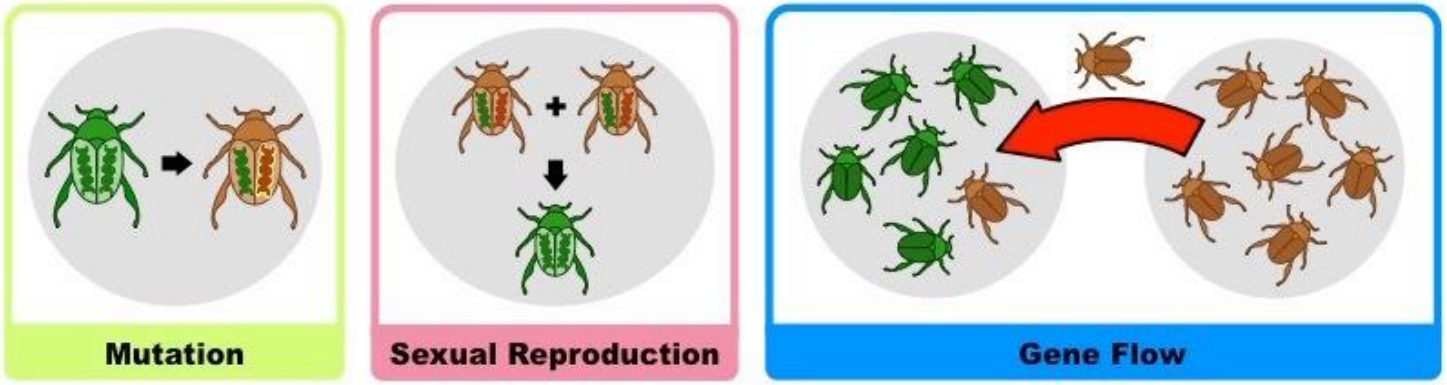
https://biocyclopedia.com/index/general_zoology/types_of_tissues.php

Evolution

Evolution is change in the heritable characteristics of biological populations over successive generations. These characteristics are the expressions of **genes** that are passed on from parent to offspring during reproduction. Different characteristics tend to exist within any given population as a result of **mutation**, **genetic recombination** and other sources of **genetic variation**.

Evolution occurs when evolutionary processes such as **natural selection** and **genetic drift** act on this variation, resulting in certain characteristics becoming more common or rare within a population. The circumstances that determine whether a characteristic should be common or rare within a population constantly change, resulting in the change in heritable characteristics arising over successive generations. It is this process of evolution that has given rise to biodiversity at every level of biological organization, including the levels of species, individual organisms and molecules.

Mechanisms of Variation:



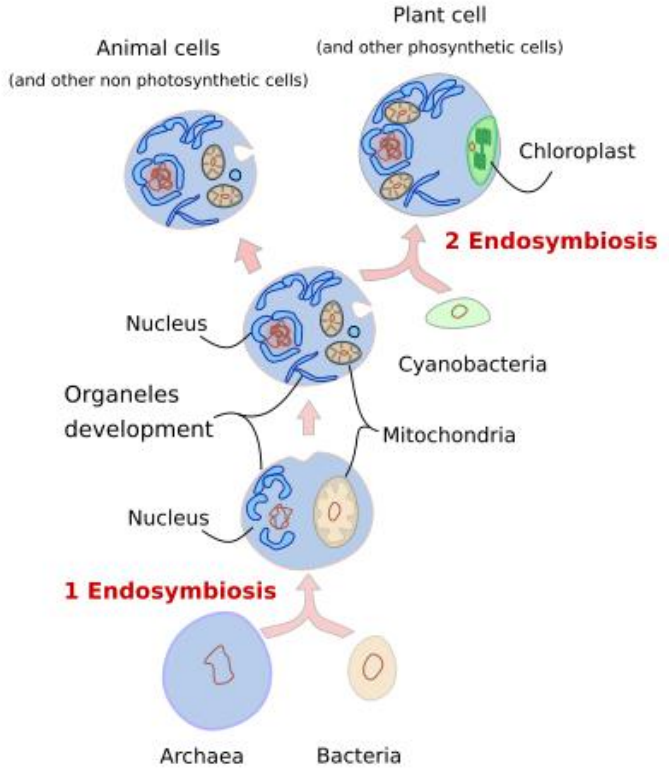
Mechanisms of Change:

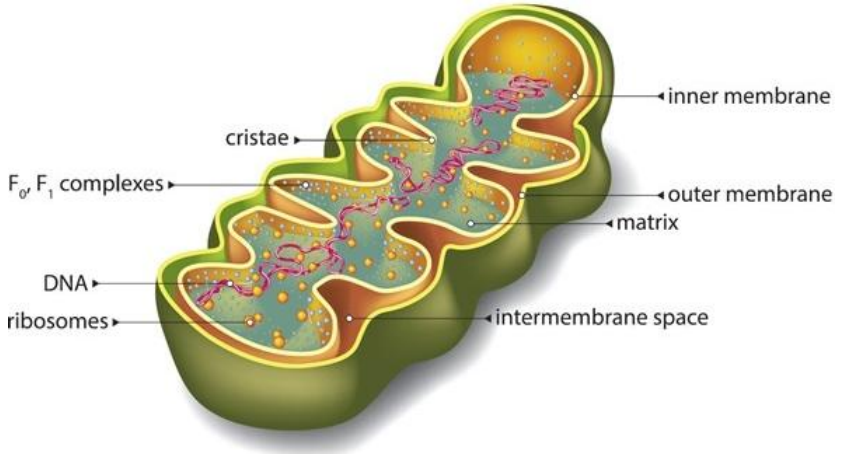
Year	% dark	% light	
1848	5	95	←clean air, light-colored bark
1895	98	2	←pollution, dark-colored bark
1995	19	81	←Clean Air Act, light-colored bark

industrial melanism

Evolution

Animals (and Plants) owe their origins to **endosymbiosis**, a process where one cell ingests another, but for some reason then fails to digest it. The evidence for this lies in the way their cells function. Both plant and animal rely on structures called **mitochondria** to release energy in their cells, using aerobic respiration to produce the energy-carrying molecule ATP. There is considerable evidence that mitochondria evolved from free-living aerobic bacteria: they are the size of bacterial cells; they **divide independently** of the cell by binary fission; they have their **own genome** in the form of a single circular DNA molecule; their **ribosomes** are more similar to those of bacteria than to the ribosomes found in the eukaryote cell's cytoplasm; and like chloroplasts they are enclosed by a **double membrane** as would be expected if they derived from bacterial cells engulfed by another cell.

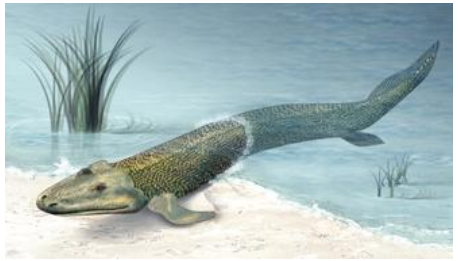


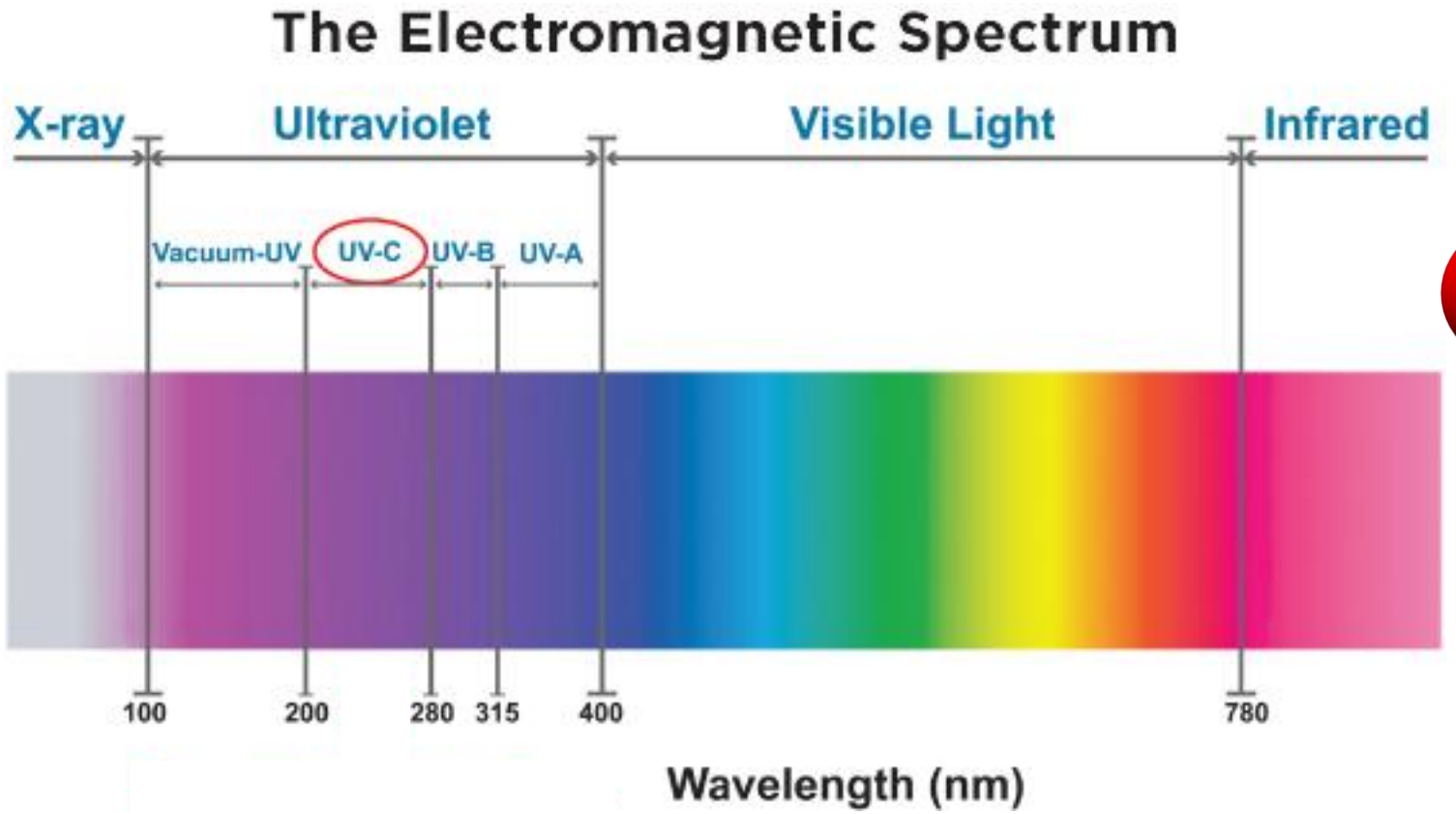


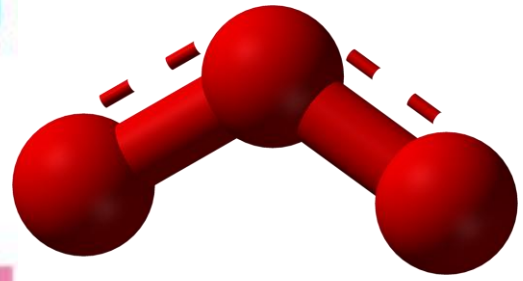
Pea aphids are commonly infested by parasitic wasps. Their secondary endosymbionts attack the infesting parasitoid wasp larvae promoting the survival of both the aphid host and its endosymbionts.

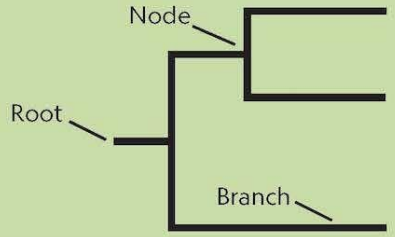
Evolution

Like the plants, animals evolved in the sea. And that is where they remained for at least 600 million years. This is because, in the absence of a protective ozone layer, the land was bathed in lethal levels of UV radiation. Once photosynthesis had raised atmospheric oxygen levels high enough, the ozone layer formed, meaning that it was then possible for living things to venture onto the land.









THE TREE OF LIFE

A phylogenetic tree shows the evolutionary relationships among different organisms. The branches of the tree show where genetic or physical similarities and differences between organisms begin or end.

A phylogenetic tree is like a family tree. The root of the tree represents a distant ancestor of the species that appear at the ends of the branches. The branches separate at nodes, or points where ancestral lines split into new lines of evolution.

Deuterostomia

Protostomia

Chordata
(vertebrates, mammals, humans)
~60,000 species

Echinodermata
(starfishes, sea urchins)
~7,000 species

Arthropoda
(insects, crustaceans, spiders, ticks)
~1,500,000 species

Nematoda
(roundworms)
~20,000 species

Tardigrada
(water bears)
~1,200 species

Mollusca
(clams, snails, squids)
~8,500 species

Annelida
(earthworms, leeches)
~12,000 species

Brachiopoda
(lamp shells)
~300 species

Platyhelmintha
(flatworms)
~13,000 species

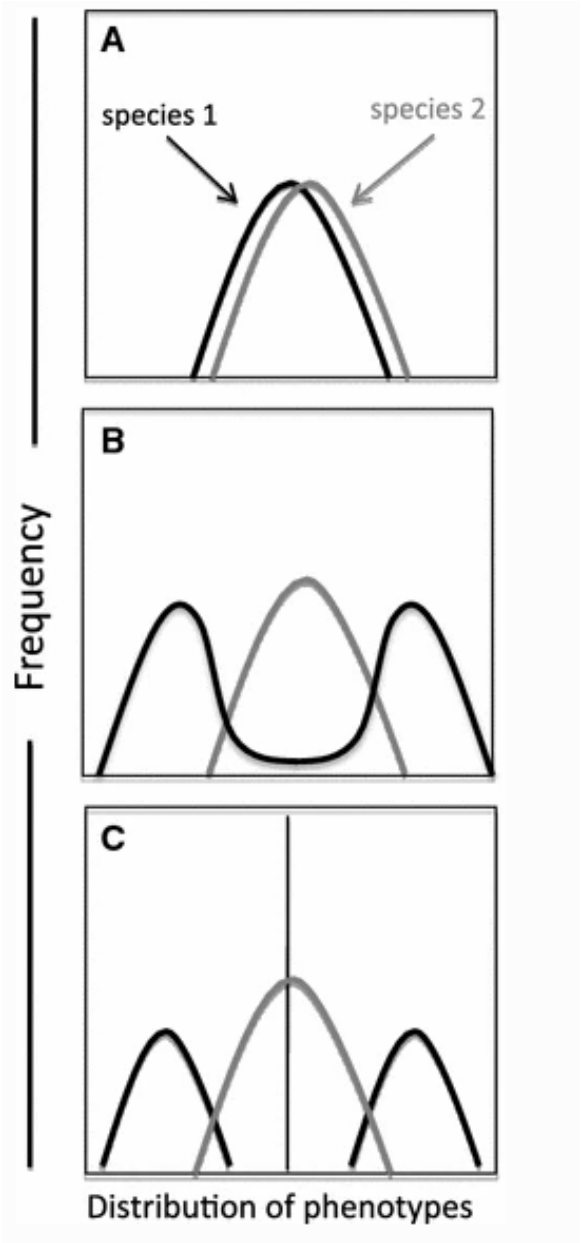
~700 million years ago

Porifera
(sponges)
~5,000 species

Cnidaria
(sea anemones, corals, hydra, jellyfishes)
~9,000 species

This tree of life shows the relationships among common groups of animals. The main branch in this tree, which separates the animals into two distinct groups, *Deuterostomia* and *Protostomia*, split about seven hundred million years ago. This tree shows how today's animal species have diverged over time from common ancestors.

NATIONAL GEOGRAPHIC



Model in which interspecific competition fosters ecological divergence and speciation in a single habitat