1758 A

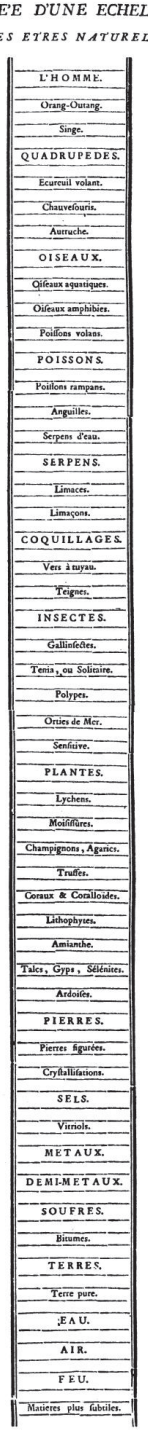
The Chain of Being and a New Taxonomy

In the 1700s, Charles Bonnet, a Swiss naturalist who studied plants and animals, organized the natural world in a ladder-like hierarchy that reflected common thought at the time.

Bonnet believed that a divine Being created materials that progressed by their own force into increasingly complex stages of existence. Written in French, his 1745 illustration of the Chain of Being (shown to the right) lists several stages of existence: fire, air, water, land, sulfur, metals, salts, stones, plants, insects, shells, serpents, fish, fowl, quadrupeds, and humans.

However, other early scientists in the mid 1700s were organizing life in a way that was based solely on observable traits rather than philosophy. They were concerned with creating a new taxonomy, or the defining and naming of groups of organisms based on shared characteristics.

Imagine that you are a biologist in 1735 who adopts this new taxonomy. The cards represent the types of organisms you could have observed at the time. How would you group these organisms? Use the cards to develop a taxonomic model that organizes these living things.


IDE'E D'UNE ECHELLE
DES ETRES NATURELS.

L'HOMME.
Orang-Outang.
Singe.
QUADRUPEDES.
Ecureuil volant.
Chauvefouris.
Autruche.
OISEAUX.
Oiſeaux aquatiques.
Oiſeaux amphibies.
Poiſſons volans.
POISSONS.
Poiſſons rampans.
Anguilles.
Serpens d'eau.
SERPENS.
Limaces.
Limaçons.
COQUILLAGES.
Vers à tuyau.
Teignes.
INSECTES.
Gallinſectes.
Tenia, ou Solitaire.
Polypes.
Orties de Mer.
Senſitive.
PLANTES.
Lychens.
Moiſiſures.
Champignons, Agarics.
Truffes.
Coraux & Coralloides.
Lithophytes.
Amianthe.
Talcs, Gypſe, Sélénites.
Ardoiſes.
PIERRES.
Pierres figurées.
Cryſtallisations.
SELS.
Vitriols.
METAUX.
DEMI-METAUX.
SOUFRES.
Bitumes.
TERRES.
Terre pure.
EAU.
AIR.
FEU.
Matieres plus ſubtiles.

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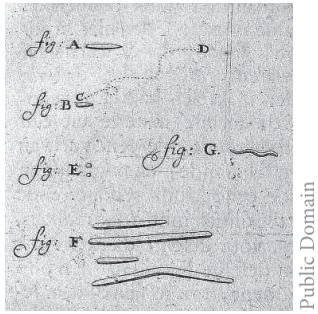
1866 A

Leeuwenhoek's "Animalcules"

In 1674, Antonie van Leeuwenhoek sent to the Royal Society of London the first ever observations of microscopic single-celled organisms. In one of his many letters, he wrote about the plaque between peoples' teeth:

> "I then most always saw, with great wonder, that in the said matter there were many very little living animalcules, very prettily a-moving. The biggest sort…had a very strong and swift motion, and shot through the water (or spittle) like a pike does through the water. The second sort… oft-times spun round like a top."



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Though his illustrations (such as the image above) and findings were initially met with skepticism, further investigation by other scientists showed that microorganisms did, in fact, exist. Subsequent advancements in technology made the microscope a common and valuable scientific tool.

In 1859, Charles Darwin published *The Origin of Species*, which proved to be very popular, though controversial at the time. The book contained one of the first arguments for the theory of evolution which was backed by evidence and proposed a mechanism for the descent of all living things from a common ancestor.

Evaluate your previous model of the tree of life in light of the two new pieces of information:
1) the existence of microorganisms and
2) the theory of evolution.

Can your model explain this new information? Use the cards to revise your model as necessary.

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Photo: A model of an early microscope used by Leeuwenhoek to make the first observations of microorganisms..

Édouard Chatton and Prokaryotes

As microscope technology improved, more scientists studied cells and discovered new species of microbes. In 1938, the French biologist Édouard Chatton was the first to characterize cells as being with a nucleus (eukaryotic) or without a nucleus (prokaryotic). Over the next several years, further investigations by scientists popularized Chatton's work and defined more differences between eukaryotes and prokaryotes. The table below indicates whether each organism is a prokaryote or eukaryote.

Revise your previous model of the tree of life to 1) reflect this new piece of information about prokaryotic and eukaryotic cells and 2) incorporate the newly discovered organisms.

Prokaryotes (cells without nucleus)	**Eukaryotes (cells with nucleus)**
Archaeoglobus fulgidus	*Acinonyx jubatus*
Bacteroidetes spp.	*Agaricus bisporus*
Beggiatoa spp.	Bacillariophyceae (class)
Borrelia burgdorferi	*Cupressocyparis leylandii*
Clostridium difficile	*Dicksonia antarctica*
Cyanobacteria spp.	*Digitaria eriantha*
Desulfovibrio desulfuricans	*Equus quagga*
Enterococcus spp.	*Eudorcas thomsonii*
Geobacter metallireducens	*Giardia intestinalis*
Haloferax volcanii	*Gyps africanus*
Haloquadratum walsbyi	*Homo sapiens*
Lactobacillus spp.	*Liriodendron tulipifera*
Methanobrevibacter smithii	*Panthera leo*
Methanosarcina acetivorans	*Paramecium aurelia*
Methylococcus spp.	*Pyrus communis*
Rhodopseudonomas spp.	*Saccharomyces cerevisiae*
Sulfolobus islandicus	
Thiobacillus spp.	
Treponema pallidum	
Vibrio spp.	

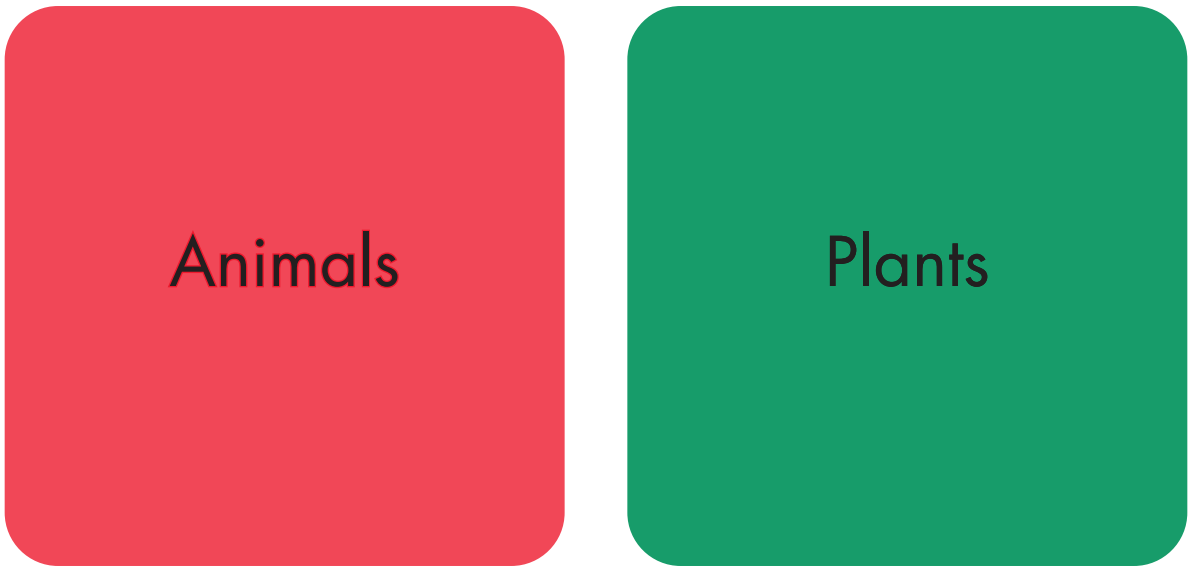
The Discovery of Archaea

In the 1970s, advances in science and technology allowed scientists to examine genetic information found in DNA or RNA to determine the relationships between species. Using the reasoning that groups of organisms with a lot of genetic information in common are more closely related to each other than others that have less in common, scientists began to reorganize the tree of life.

Using the simulated DNA sequences determine how the organisms are related. Observe how this new information influences the tree of life model.

Illustrated interpretation of Linnaeus' model

1758 B



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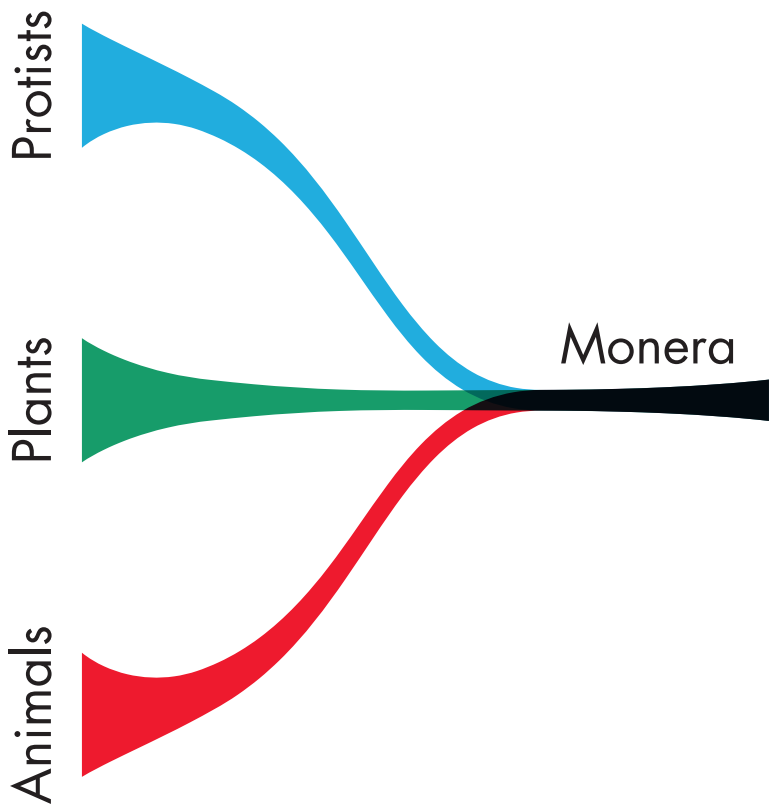
Illustrated interpretation of Haeckel's model

1866 B



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1969 B

Illustrated interpretation of Whittaker's model

1990 B

Illustrated interpretation of Woese's model

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Carolus Linnaeus' *Systema Naturae*

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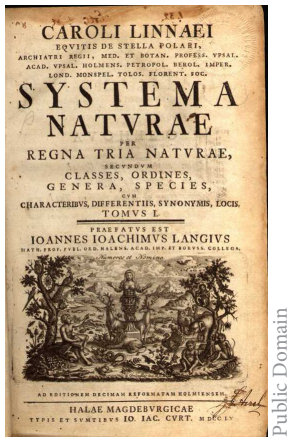
Carl Linnaeus is the founder of modern taxonomy, the naming and classification of life forms. He started using two-part names for living things, a method that is still used today. For example, he used the genus and species name of *Panthera leo* for the lion.

Linnaeus' interests in biology originated with plants. Growing up, his father would show Linnaeus flowers in the garden and tell him their names. As an adult, Linnaeus continued to study plants and animals on expeditions across Europe before publishing his work in several books.

In his book *Systema Naturae* (Latin for "The Systems of Nature"), Linnaeus classified over 12,000 plants and animals. During his lifetime, the contents were constantly being updated and revised based on new knowledge. For instance, whales were originally classified as fish in the first edition (1735), but in the tenth and definitive edition (1758), they were reclassified as mammals.


CAROLI LINNAEI
EQVITIS DE STELLA POLARI,
ARCHIATRI REGII, MED. ET BOTAN. PROFESS. VPSAL.
ACAD. VPSAL. HOLMENS. PETROPOL. BEROL. IMPER.
LOND. MONSPEL. TOLOS. FLORENT. SOC.

SYSTEMA
NATVRAE
PER
REGNA TRIA NATVRAE,
SECVNDVM
CLASSES, ORDINES,
GENERA, SPECIES,
CVM
CHARACTERIBVS, DIFFERENTIIS, SYNONYMIS, LOCIS.
TOMVS I.

PRAEFATVS EST
IOANNES IOACHIMVS LANGIVS

AD EDITIONEM DECIMAM REFORMATAM HOLMIENSEM.

HALAE MAGDEBVRGICAE
TYPIS ET SVMTIBVS IO. IAC. CVRT. MDCCLIX

Public Domain

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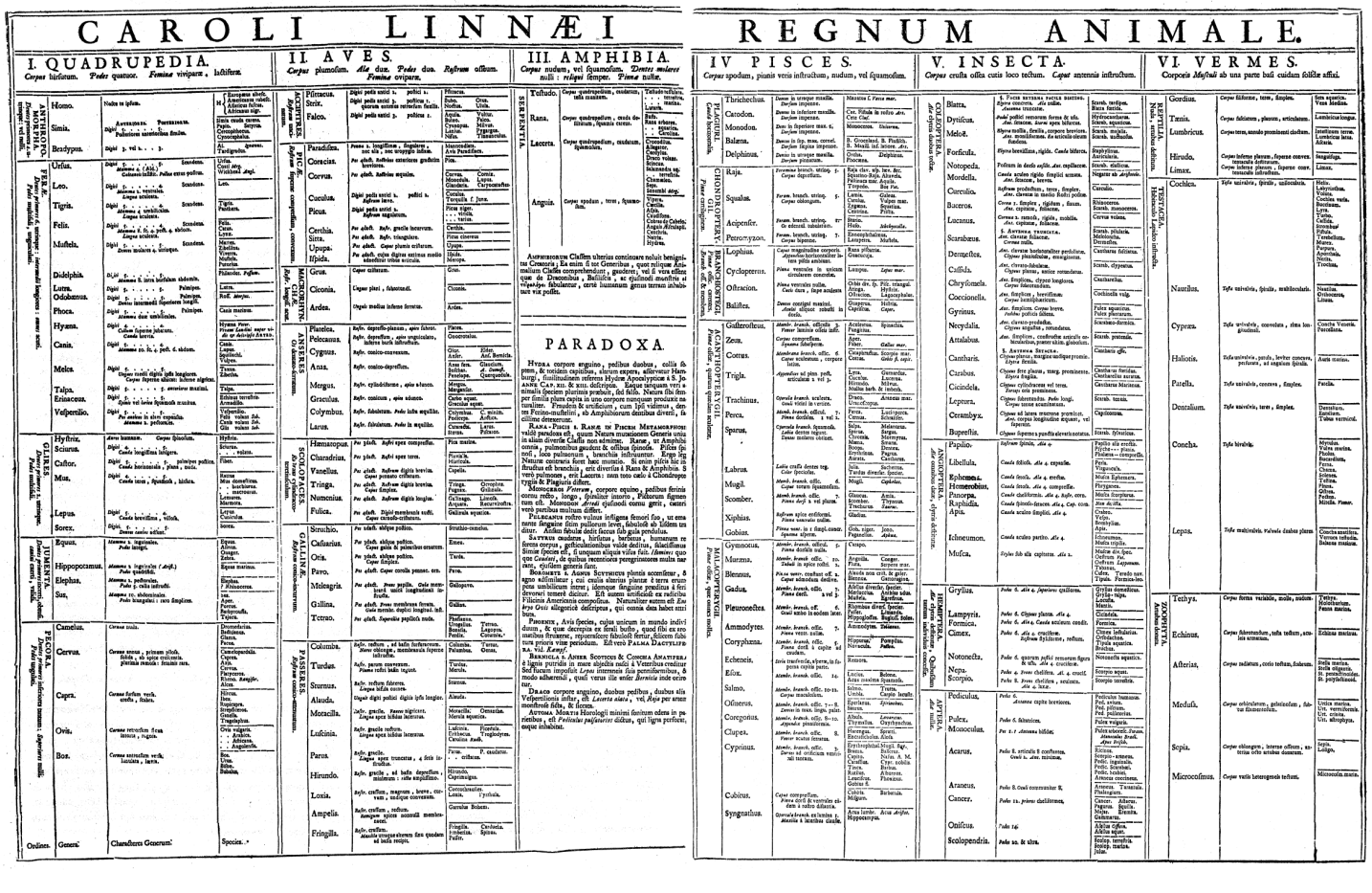
Linnaeus arranged life into two main categories, called "kingdoms": plants and animals. Plants were grouped into 24 classes based on their reproductive structures and included "true" plants as well as fungi, algae, and lichen. His classification of animals included subgroups of mammals, birds, amphibians, fish, insects, and "vermes," or all other invertebrates that were not insects, such as worms, slugs and clams.

Below is a table from an earlier edition of *Systema Naturae* showing some groups from the kingdom "Animale." Do you recognize any of the organism names?


CAROLI LINNÆI

I. QUADRUPEDIA.

II. AVES.

III. AMPHIBIA.

REGNUM ANIMALE.

IV PISCES.

V. INSECTA.

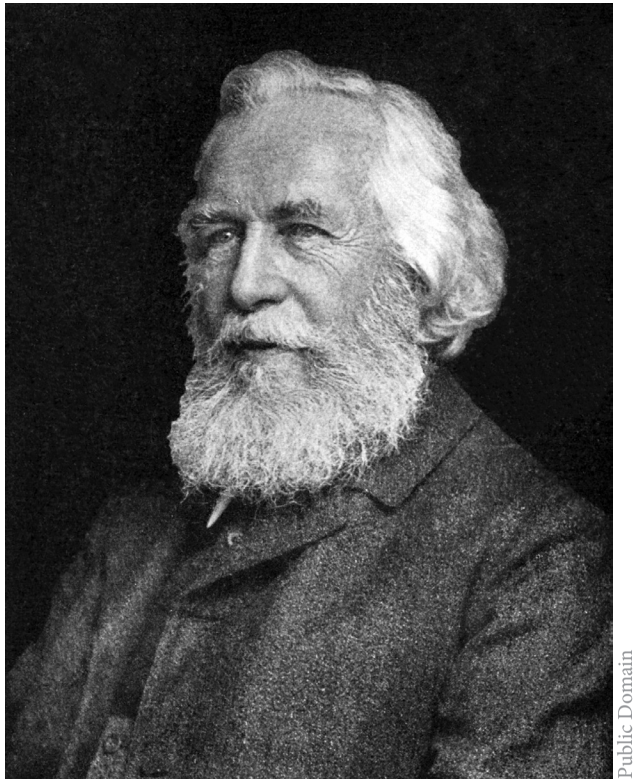
VI. VERMES.

Public Domain

Ernst Haeckel

Ernst Haeckel was formally trained as a medical doctor before becoming a zoologist. During his life, including the time he was a professor at the University of Jena, Germany, he studied many invertebrate groups such as sponges and radiolarians, tiny zooplankton with mineral skeletons. Haeckel was an accomplished illustrator and made extensive journeys around the world, naming thousands of new species in his lifetime.

Haeckel's contributions to the discovery of new species and the organization of life proved influential. In his book *Generelle Morphologie der Organismen* (German for "General morphology of organisms") published in 1866, Haeckel depicted a tree (see illustration) with three kingdoms: Plantae, Animalia, and Protista. At the time, Protista included all microscopic organisms. At the origin of the tree he put "Moneres" or Monera, a group of simple microbes poorly understood at the time. Haeckel thought these organisms were similar to the first living organisms from which all life evolved.



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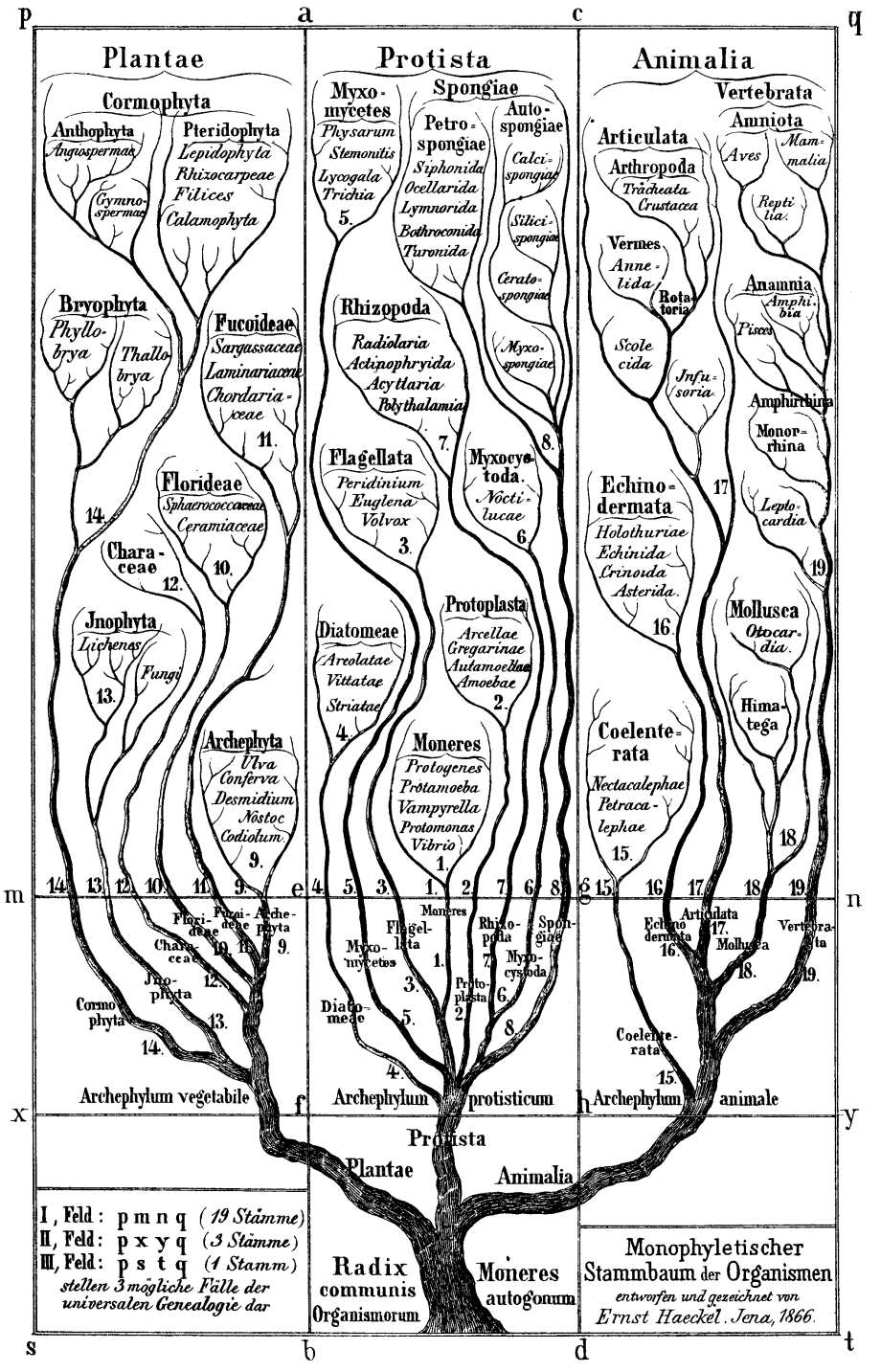

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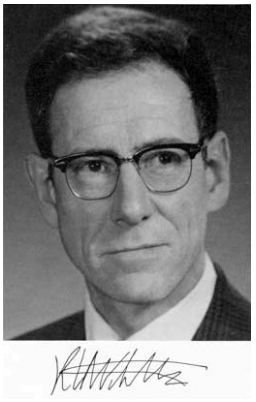
Robert H. Whittaker



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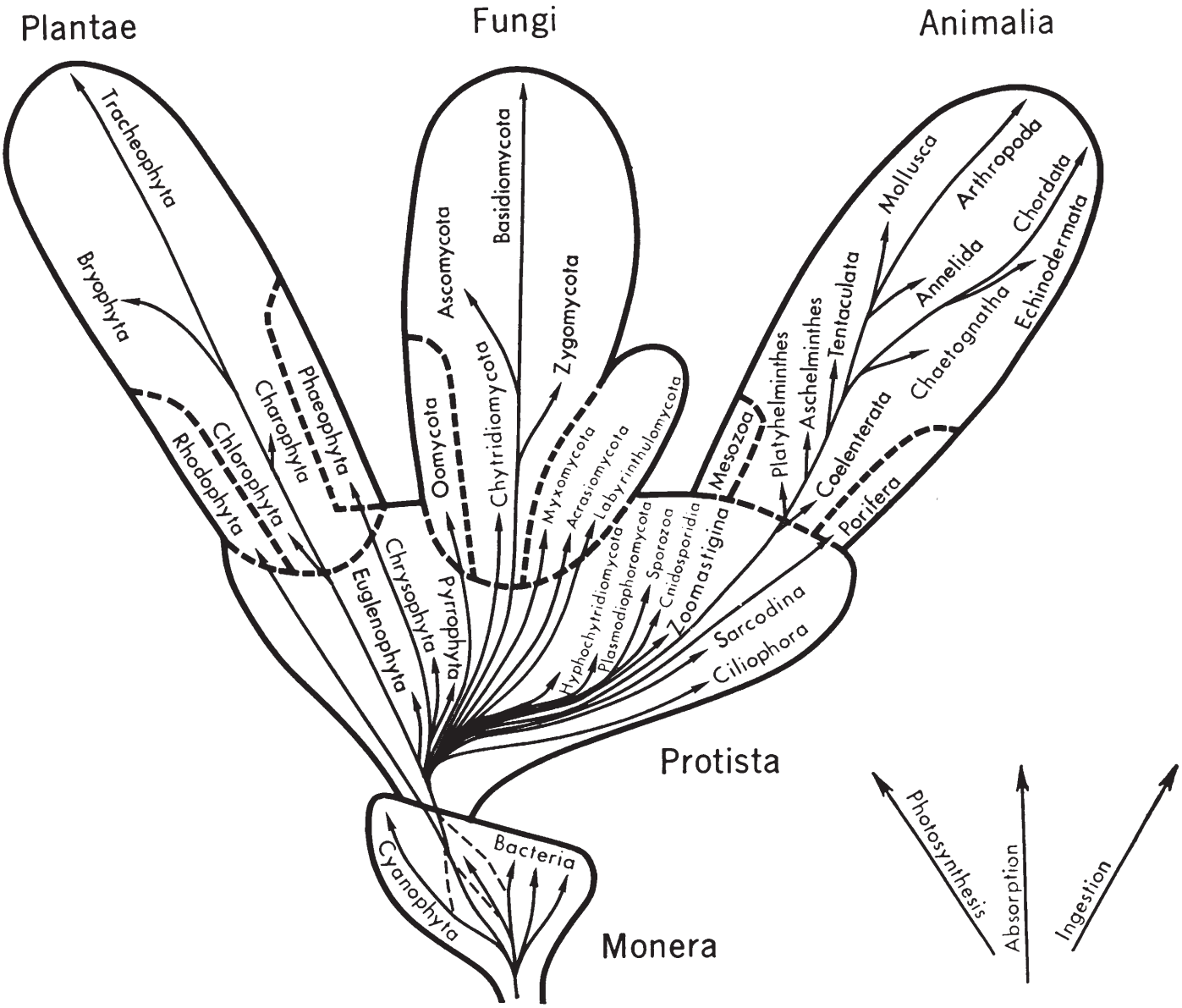
In 1969, Robert Whittaker published a scientific paper in which he proposed a new five-kingdom model of the tree of life. In his model, Whittaker incorporated work of Chatton and other scientists who distinguished prokaryotes from eukaryotes. He also established a new kingdom for fungi, which had mostly been grouped with plants in the past. The separation of fungi was mostly based on the evidence that fungi consume decaying or dead matter whereas plants produce their own food.

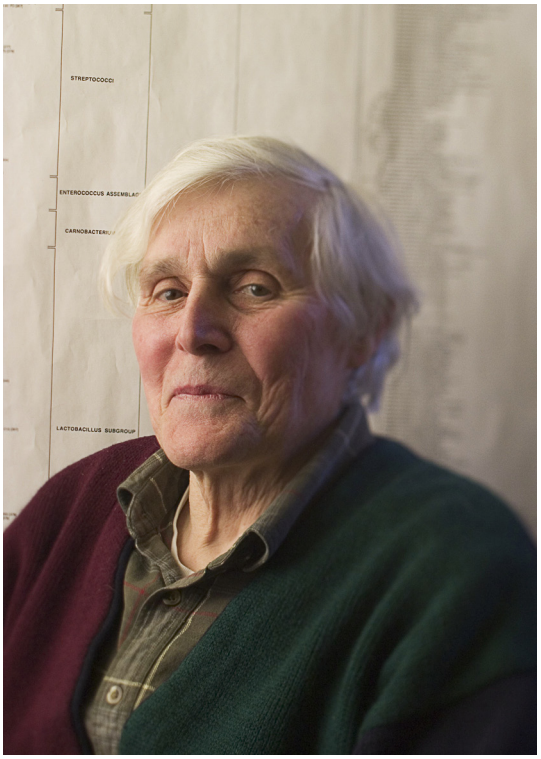
In Whittaker's model (shown below), there were five kingdoms: Monera (prokaryotic organisms), Protista (eukaryotic unicellular organisms), Plantae, Animalia, and Fungi (all eukaryotic multicellular organisms). As seen in his illustration, the arrangement suggested that some kingdoms, such as Monera and Protista, contained present-day species as well as the ancestors of other kingdoms. The arrows in the bottom right also indicate how he organized species based on whether they photosynthesize, absorb, or ingest food.



Whittaker, R.H. (1969)

Carl Woese

Carl Woese, a scientist at the University of Illinois, was one of the first to use molecular data to investigate the evolutionary relationships of organisms. The illustration below is from a 1990 publication he wrote with colleagues, titled “Towards a natural system of organisms: Proposal for domains Archaea, Bacteria, and Eucarya.” A “domain” is a taxonomic group even larger than a kingdom. There were now six kingdoms in the new model, revised from Whittaker’s five kingdom model. The Plantae, Animalia, Protista, and Fungi kingdoms were grouped in the Eukarya domain, and the Bacteria and Archaea domains contained the Bacteria and Archaea kingdoms, respectively.



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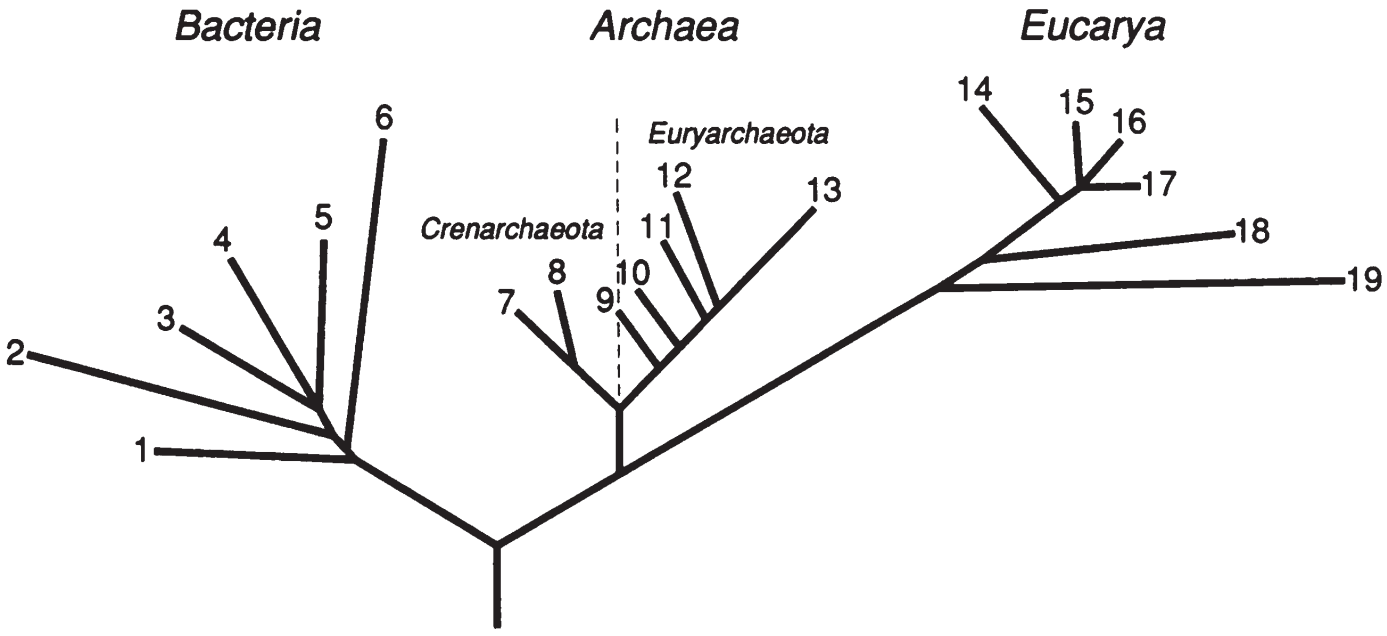
In previous models of the tree of life, archaea had been classified with bacteria, and both under the category of monera. Although archaea are visually similar to bacteria, studies indicate that archaea have genes and cellular functions more similar to eukaryotes. The earliest discovered archaea were in extreme environments such as volcanic hot springs and salt lakes, but since then they have also been found in places such as soils and human intestines. Archaea species derive energy from compounds ranging from sugars to metal ions, and they have unique components in their cell membranes not found in the other domains.



Woese, C.R., Kandler, O. & Wheelis, M.L. (1990)