Chapter 18 Classification

These butterflies look similar, but does that mean they are related? There is more to that answer than meets the eye.

Sometimes, butterflies that look different are actually members of the same species.

Scientists use systems for naming and grouping species. These butterflies have been classified as belonging to the family Pieridae.

Preview

Why It Matters

More than one million species on Earth have been given scientific names, but many more species exist that have not been identified.

Section 1

The Importance of Classification

Key Ideas	Key Terms	Why It Matters
❯ Why do biologists have taxonomic systems? ❯ What makes up the scientific name of a species? ❯ What is the structure of the modern Linnaean system of classification?	taxonomy genus binomial nomenclature	In order to study and make use of living things, we need a name for each specific thing.

The number of species that exist in the world is much greater than the number known. About 1.7 million species have been named and described by scientists. But scientists think that millions more are undiscovered. We have little knowledge of Earth's variety of species.

The Need for Systems

In biology, the practice of naming and classifying organisms is called **taxonomy.** Scientists use a logical system of classification to manage large amounts of information. Similarly, a library uses a system for organizing books. ❯ **Biologists use taxonomic systems to organize their knowledge of organisms. These systems attempt to provide consistent ways to name and categorize organisms.**

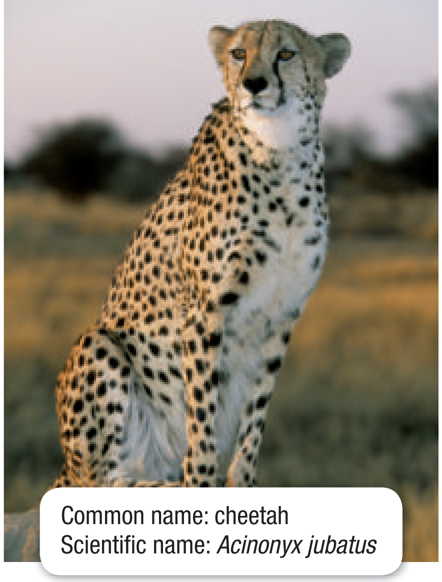
Common names of organisms are not organized into a system. One species may have many common names, and one common name may be used for more than one species. For example, the bird called a *robin* in Great Britain is a different bird from the bird called a *robin* in North America. To avoid confusion, biologists need a way to name organisms that does not depend on language or location.

Biologists also need a way to organize lists of names. A system that has categories is more efficient than a simple list. So, biologists group organisms into large categories as well as smaller and more specific categories. The general term for any one of these categories is a *taxon* (plural, *taxa*).

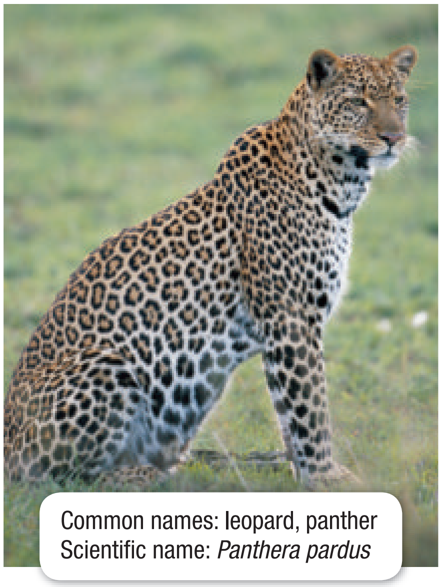
❯ **Reading Check** ***What is the problem with common names of species? (See the Appendix for answers to Reading Checks.)***

taxonomy (taks AHN uh mee) the science of describing, naming, and classifying organisms

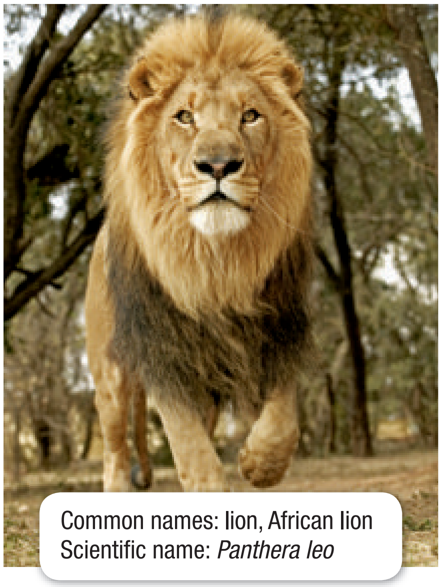
Figure 1 Museums are full of biological specimens, yet only a fraction of Earth's species have been scientifically named.



Common name: cheetah
Scientific name: *Acinonyx jubatus*



Common names: leopard, panther
Scientific name: *Panthera pardus*



Common names: lion, African lion
Scientific name: *Panthera leo*

Figure 2 Each species may have many common names but only one scientific name. The scientific name is made up of a genus name and a species identifier. Each genus is a group of closely related species. **To what genus do both lions and leopards belong?**

genus (JEE nuhs) a level of classification that contains similar species

binomial nomenclature (bie NOH mee uhl NOH muhn KLAY chuhr) a system for giving each organism a two-word scientific name that consists of the genus name followed by the species name

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Topic: Carl Linnaeus
Code: HX80226

Scientific Nomenclature

As biology became established as a science, biologists began to create systems for naming and classifying living things. A major challenge was to give each species a unique name.

Early Scientific Names In the early days of European biology, various naming systems were invented. Some used long, descriptive Latin phrases called *polynomials*. Names for taxa were inconsistent between these systems. The only taxon that was somewhat consistent was the **genus,** which was a taxon used to group similar species.

A simpler and more consistent system was developed by the Swedish biologist Carl Linnaeus in the 1750s. He wanted to catalog all known species. He wrote books in which he used the polynomial system but added a two-word Latin name for each species. His two-word system is called **binomial nomenclature.** For example, his two-part name for the European honeybee was *Apis mellifera*, the genus name followed by a single descriptive word for each species. **Figure 2** shows the binomial names of three other animals.

Naming Rules In the years since Linnaeus created his system, his basic approach has been universally adopted. The unique two-part name for a species is now called a *scientific name*. Scientific names must conform to rules established by an international commission of scientists. No two species can have the same scientific name.

All scientific names for species are made up of two Latin or Latin-like terms. All of the members of a genus share the genus name as the first term. The second term is called the *species identifier* and is often descriptive. For example, in the name *Apis mellifera,* the term *mellifera* derives from the Latin word for "honey." When you write the scientific name, the genus name should be capitalized and the species identifier should be lowercased; both terms should be italicized.

Reading Check ***Why did Linnaeus devise a new naming system?***

The Linnaean System

In trying to catalog every known species, Linnaeus devised more than just a naming system. He devised a system to classify all plants and animals that were known during his time. His system formed the basis of taxonomy for centuries. **❯ In the Linnaean system of classification, organisms are grouped at successive levels of a hierarchy based on similarities in their form and structure.** Since Linnaeus's time, many new groups and some new levels have been added, as **Figure 3** shows. **❯ The eight basic levels of modern classification are domain, kingdom, phylum, class, order, family, genus, and species.**

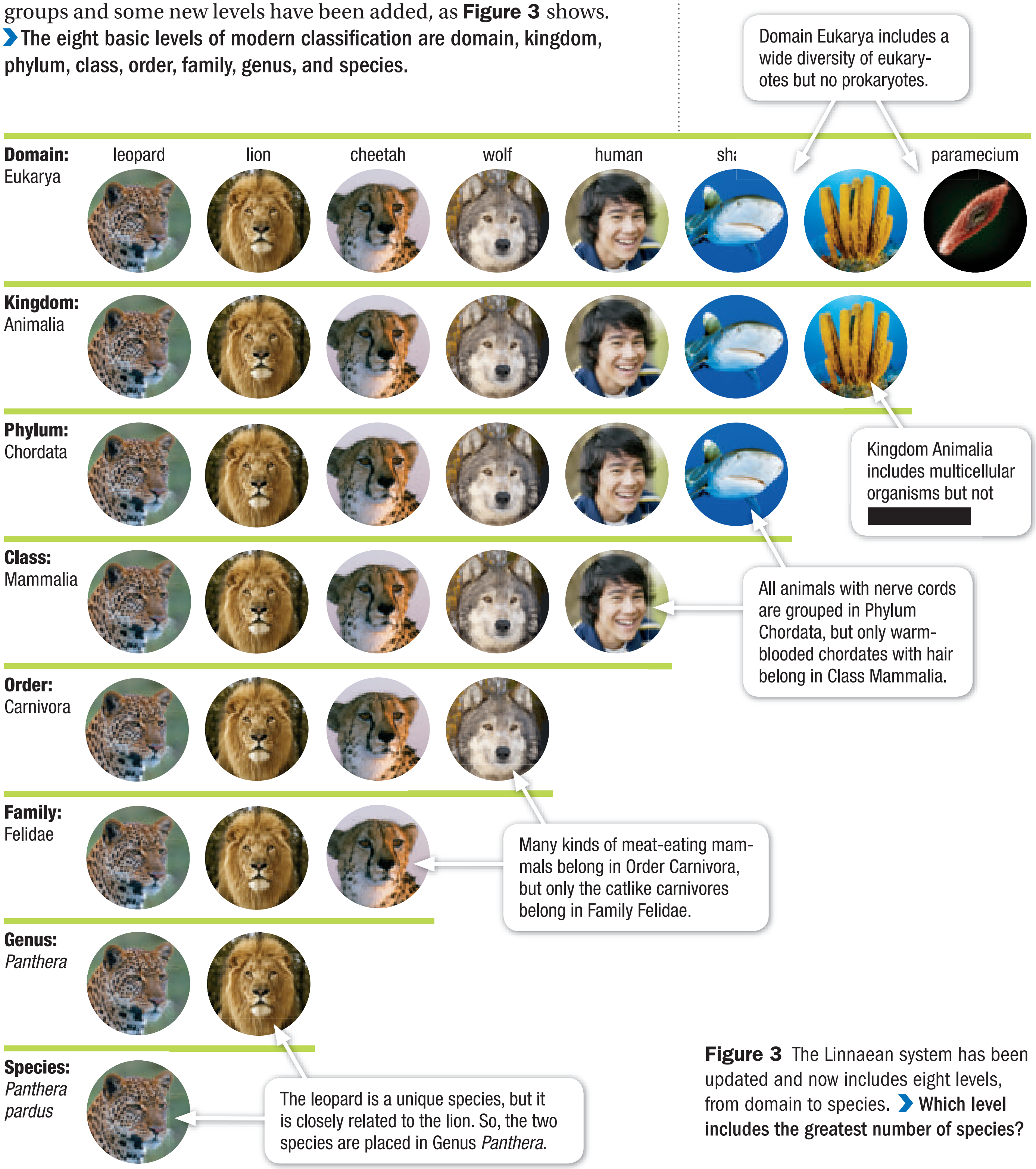


Figure 3 The Linnaean system has been updated and now includes eight levels, from domain to species. **❯ Which level includes the greatest number of species?**

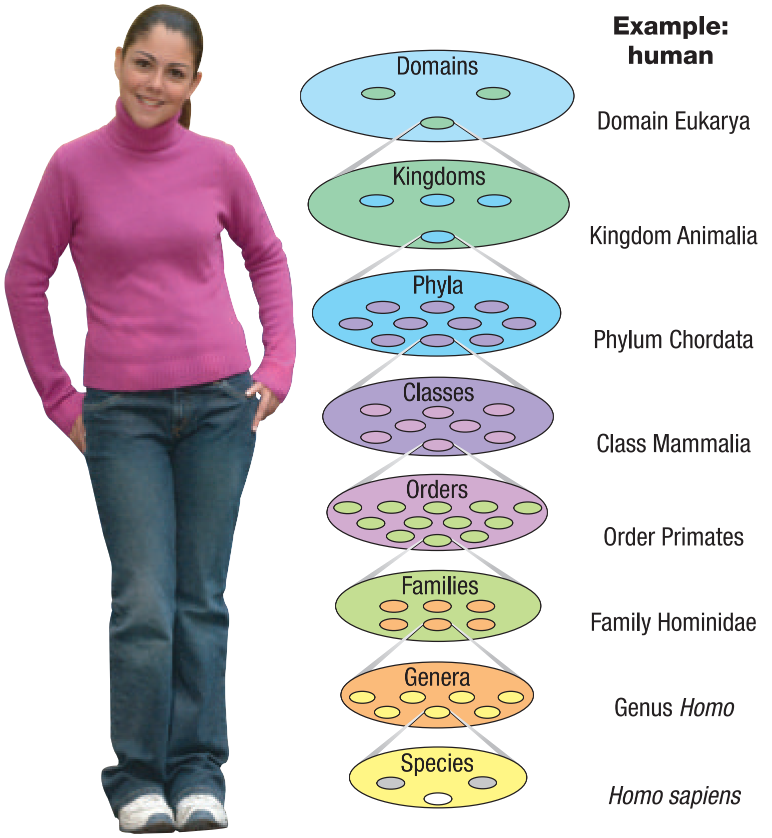


Figure 4 A species can be classified at each level of the Linnaean system.

Levels of the Modern Linnaean System

Each level has its own set of names for taxa at that level. Each taxon is identified based on shared traits. Similar species are grouped into a genus; similar genera are grouped into a family; and so on up to the level of domain. **Figure 4** shows the classification of humans in this system.

- **Domain** Since Linnaeus's time, the category *domain* has been invented in order to recognize the most basic differences among cell types. All living things are now grouped into one of three domains. For example, humans belong to the domain Eukarya.
- **Kingdom** The category *kingdom* encompasses large groups such as plants, animals, or fungi. Six kingdoms fit within the three domains.
- **Phylum** A *phylum* is a subgroup within a kingdom. Many phyla exist within each kingdom. Humans belong to the phylum Chordata.
- **Class** A *class* is a subgroup within a phylum.
- **Order** An *order* is a subgroup within a class.
- **Family** A *family* is a subgroup within an order. Humans belong to the family Hominidae.
- **Genus** A *genus* (plural, *genera*) is a subgroup within a family. Each genus is made up of species with uniquely shared traits, such that the species are thought to be closely related. Humans belong to the genus *Homo*.
- **Species** A *species* is usually defined as a unique group of organisms united by heredity or interbreeding. But in practice, scientists tend to define species based on unique features. For example, *Homo sapiens* is recognized as the only living primate species that walks upright and uses spoken language.

Reading Check ***How many kingdoms are in the Linnaean system?***

READING TOOLBOX

Mnemonics To remember the eight levels in their proper order, use a phrase, such as "Do Kindly Pay Cash Or Furnish Good Security," to represent *Domain, Kingdom, Phylum, Class, Order, Family, Genus,* and *Species*.

Section 1 Review

KEY IDEAS

1. **Explain** why biologists have systems for naming and grouping organisms.
2. **Describe** the structure of a scientific name for a species.
3. **List** the categories of the modern Linnaean system of classification in order from general to specific.

CRITICAL THINKING

4. **Logical Reasoning** Describe additional problems that might occur for biologists without a logical taxonomic system.
5. **Anticipating Change** Although the basic structure of the system that Linnaeus invented is still in use, many aspects of this system have changed. Suggest some possible ways that the system may have changed.

ALTERNATIVE ASSESSMENT

6. **Classification Poster** Create a poster that shows the major levels of classification for your favorite organism. Write a description of the general characteristics of the organism at each level. For each level, include a list of other organisms that belong to the same taxon.

Section 2

Modern Systematics

Key Ideas	Key Terms	Why It Matters
❯ What problems arise when scientists try to group organisms by apparent similarities? ❯ Is the evolutionary past reflected in modern systematics? ❯ How is cladistics used to construct evolutionary relationships? ❯ What evidence do scientists use to analyze these relationships?	phylogeny cladistics	Modern systematics unites evolutionary science with traditional studies of anatomy.

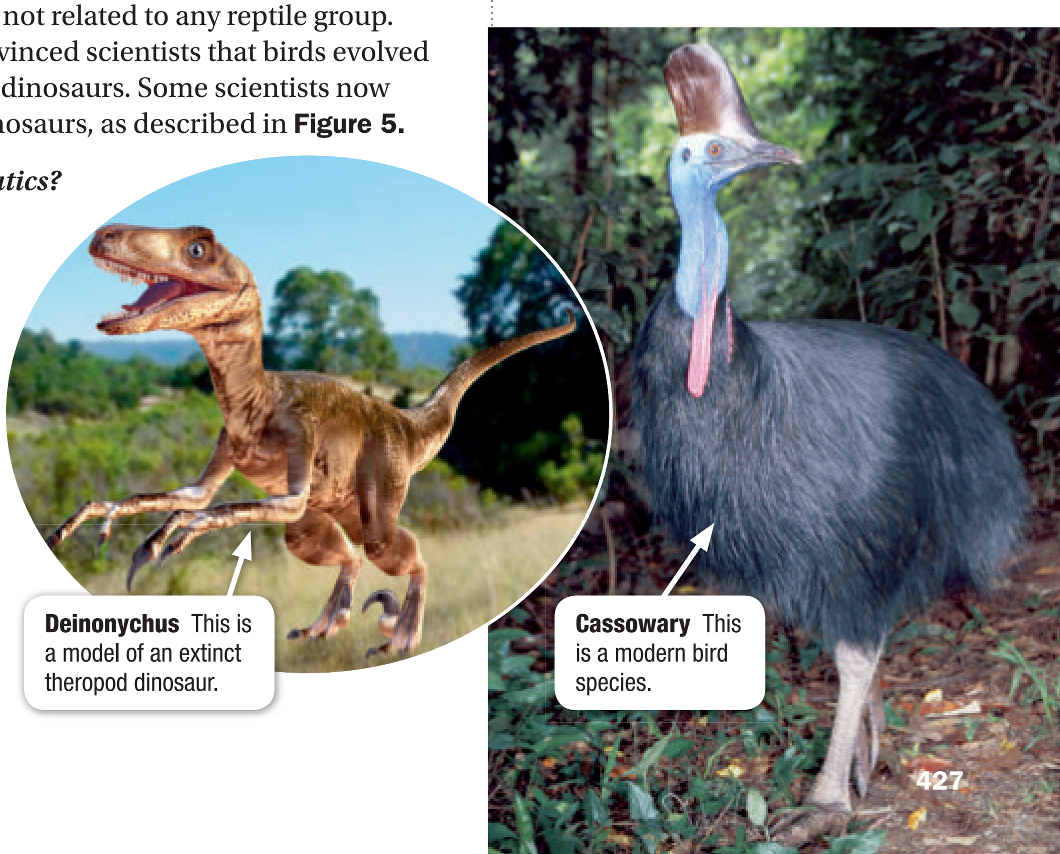
Have you ever wondered how scientists tell one species from another? For example, how can you tell a mushroom that is harmless from a mushroom that is poisonous? Identification is not easy, even for experts. The experts often revise their classifications as well as their procedures. This field of expertise is known as *systematics*.

Traditional Systematics

Linnaeus's system was based on his judgment of the importance of various similarities among living things. ❯ **Scientists traditionally have used similarities in appearance and structure to group organisms. However, this approach has proven problematic.** Some groups look similar but turn out to be distantly related. Other groups look different and turn out to be closely related. Often, new data or new analyses suggest relationships between organisms that were not apparent before.

For example, dinosaurs were once seen as a group of reptiles that became extinct millions of years ago. And birds were seen as a separate, modern group that was not related to any reptile group. However, fossil evidence has convinced scientists that birds evolved from one of the many lineages of dinosaurs. Some scientists now classify birds as a subgroup of dinosaurs, as described in **Figure 5.**

❯ **Reading Check** *What is systematics?*



Deinonychus This is a model of an extinct theropod dinosaur.

Cassowary This is a modern bird species.

Figure 5 In a sense, birds are dinosaurs. Scientists think that modern birds are descended from a subgroup of dinosaurs called *theropods*. This inference is based on thorough comparisons of modern birds and fossilized theropods.

Phylogenetics

Today, scientists who study systematics are interested in **phylogeny,** or the ancestral relationships between species. **Grouping organisms by similarity is often assumed to reflect phylogeny, but inferring phylogeny is complex in practice.** Reconstructing a species' phylogeny is like trying to draw a huge family tree that links ancestors and descendants across thousands or millions of generations.

phylogeny the evolutionary history of a species or taxonomic group

cladistics a phylogenetic classification system that uses shared derived characters and ancestry as the sole criterion for grouping taxa

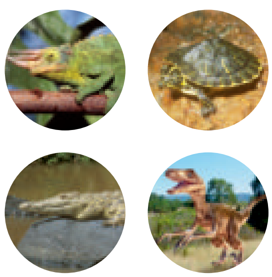
Misleading Similarities Inferring phylogenies from similarities can be misleading. Not all similar characters are inherited from a common ancestor. Consider the wings of a bird and of an insect. Both types of wings enable flight, but the structures of the two kinds of wings differ. Moreover, fossil evidence shows that insects with wings existed long before birds with wings appeared. Through the process called *convergent evolution,* similarities may evolve in groups that are not closely related to one another, often because the groups become adapted to similar habitats or lifestyles. Similarities that arise through convergent evolution are called *analogous* characters.

Judging Relatedness Another problem is that grouping organisms by similarities is subjective. Are all characters equally important, or are some more important than others? Often, different scientists may give different answers to these questions.

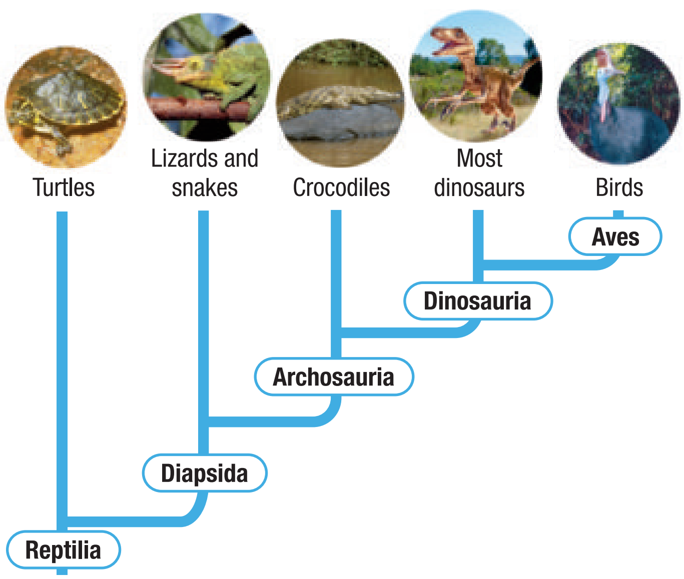
For example, systematists historically placed birds in a separate class from reptiles, giving importance to characters such as feathers, as **Figure 6** shows. But more recently, fossil evidence and detailed studies of bird and dinosaur anatomy have changed the view of these groups. **Figure 6** shows that birds are now considered part of the "family tree" of dinosaurs. This family tree, or *phylogenetic tree,* represents a hypothesis of the relationships between several groups.

Figure 6 Traditional systematics grouped birds separately from other reptiles by emphasizing the unique features of birds. However, modern phylogenetics places birds as a subgroup of reptiles on a phylogenetic tree. **How do these two systems differ in structure?**

Linnaean Classification

Classes of Animals	
Class Reptilia	Class Aves
egg-laying, exothermic, scales	egg-laying, endothermic, feathers
lizards, snakes, turtles, crocodiles, and dinosaurs 	birds 

Modern Phylogeny



Cladistics

To unite systematics with phylogenetics, scientists need an objective way to sort out relatedness. Today, the preferred method is cladistics. **Cladistics** is a method of analysis that infers phylogenies by careful comparisons of shared characters. **Cladistic analysis is used to select the most likely phylogeny among a given set of organisms.**

ACADEMIC VOCABULARY

objective independent of the mind; without bias

Comparing Characters

Cladistics focuses on finding characters that are *shared* between different groups of organisms because of shared ancestry. With respect to two groups, a shared character is defined as *ancestral* if it is thought to have evolved in a common ancestor of both groups. In contrast, a *derived* character is one that evolved in one group but not in the other group. Cladistics infers relatedness by identifying shared derived and shared ancestral characters among groups while avoiding the use of analogous characters.

For example, consider the relationship between flowering plants and conifers. The production of seeds is a character that is present in all living conifers and flowering plants and in some prehistoric plants. So, it is a shared ancestral character among these groups. The production of flowers, however, is a derived character that is shared only among flowering plants. Flowers evolved in some ancestor of flowering plants but did not evolve in the group that led to conifers.

READING TOOLBOX

Word Origins The word root *clad* means “shoot, branch or twig” and the word root *gram* means “to write or record.” Use this information to analyze the meaning of the term *cladogram.*

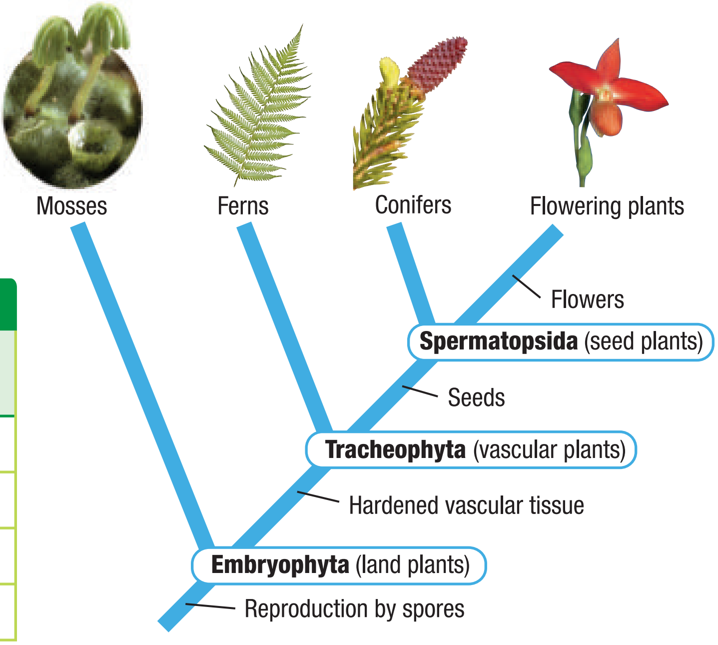
Constructing Cladograms

Cladistics uses a strict comparison of many characters among several groups in order to construct a cladogram. A *cladogram* is a phylogenetic tree that is drawn in a specific way, as **Figure 7** shows. Organisms are grouped together through identification of their shared derived characters. All groups that arise from one point on a cladogram belong to a clade. A *clade* is a set of groups that are related by descent from a single ancestral lineage.

Each clade in a tree is usually compared with an *outgroup,* or group that lacks some of the shared characters. For example, **Figure 7** shows that flowering plants and conifers share a character with each other that they do not share with ferns. So, conifers and flowering plants form a clade, and ferns form the outgroup.

Reading Check *What does a cladogram show?*

Figure 7 This cladogram organizes plants by using a strict comparison of the characters shown in the table. Each clade is united by a specific shared derived character. **Which groups are united by having seeds?**



Characters in Plants

Type of plants	Vascular tissue	Seeds	Flowers
Mosses	no	no	no
Ferns	yes	no	no
Conifers	yes	yes	no
Flowering plants	yes	yes	yes

Data

QuickLab

10 min

Cladogram Construction

Use this table of shared characters to construct a cladogram. Use the other cladograms in this section to help you draw your cladogram.

Characters in Vertebrates

	Four legs	Amniotic egg	Hair
Tuna	no	no	no
Frog	yes	no	no
Lizard	yes	yes	no
Cat	yes	yes	yes

Analysis

1. **Identify** the outgroup. The outgroup is the group that does not share any of the characters in this list. Draw a diagonal line and then a single branch from its base. Write the outgroup at the tip of this first branch.
2. **Identify** the most common character. Just past the "fork" of the first branch, write the most common derived character. This character should be present in all of the subsequent groups added to the tree.
3. **Complete** the tree. Repeat step 2 for the second most-common character. Repeat until the tree is filled with all of the groups and characters from the table.
4. CRITICAL THINKING **Applying Concepts** What is a shared derived character of cats and lizards?
5. CRITICAL THINKING **Applying Concepts** What character evolved in the ancestor of frogs but not in that of fish?

Inferringing Evolutionary Relatedness

As you have seen, phylogenetics relies heavily on data about characters that are either present or absent in taxa. But other kinds of data are also important. **Biologists compare many kinds of evidence and apply logic carefully in order to infer phylogenies.** They constantly revise and add details to their definitions of taxa.

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Topic: Phylogenetic Tree
Code: HX81141

Morphological Evidence *Morphology* refers to the physical structure or anatomy of organisms. Large-scale morphological data are most obvious and have been well studied. For example, the major characters used to define plant groups—vascular tissue, seeds, and flowers—were recognized long ago. But because convergent evolution can lead to analogous characters, scientists must consider many characters and look carefully for similarities and differences. For example, many animals have wings that are merely analagous.

An important part of morphology in multicellular species is the pattern of development from embryo to adult. Organisms that share ancestral genes often show additional similarities during the process of development. For example, in all vertebrate species, the jaw of an adult develops from the same part of an embryo. In many cases, studies of embryos bring new information to phylogenetic debates.

Molecular Evidence In recent decades, scientists have used genetic information to infer phylogenies. Recall that as genes are passed on from generation to generation, mutations occur. Some mutations may be passed on to all species that descend from a common ancestor. So, DNA, RNA, and proteins can be compared in the same manner as morphology is compared to infer phylogenies.

Reading Check *What is an example of morphological data?*

Sequence Data Today, genetic sequence data are widely used for cladistic analysis. First, the sequence of DNA bases in a gene (or of amino acids in a protein) is determined for several species. Then, each letter (or amino acid) at each position in the sequence is compared. Such a comparison can be laid out in a large table, but computers are best able to calculate the relative similarity of many sequences.

Genomic Data At the level of genomes, alleles may be added or lost over time. So, another form of molecular evidence is the presence or absence of specific alleles—or the proteins that result from them. Finally, the relative timing between genetic changes can be inferred.

Evidence of Order and Time Cladistics can determine only the relative order of divergence, or branching, in a phylogenetic tree. To infer the actual time when a group may have begun to "branch off," extra information is needed. Often, this information comes from the fossil record. For example, by using cladistics, scientists have identified lancelets as the closest relative of vertebrates. The oldest known fossils of vertebrates are about 450 million years old, but the oldest lancelet fossils are 535 million years old. So, these two lineages must have diverged more than 535 million years ago.

More recently, scientists have noticed that most DNA mutations occur at relatively constant rates. So, genetic change can be used as an approximate "molecular clock," as **Figure 8** shows. Scientists can measure the genetic differences between taxa and then estimate the time at which the taxa began to diverge.

Inference Using Parsimony Modern systematists use the *principle of parsimony* to construct phylogenetic trees. This principle holds that the simplest explanation for something is the most reasonable, unless strong evidence exists against the simplest explanation. So, given two possible cladograms, the one that implies the fewest character changes between branch points is preferred.

Reading Check ***What kinds of molecular data inform cladistics?***

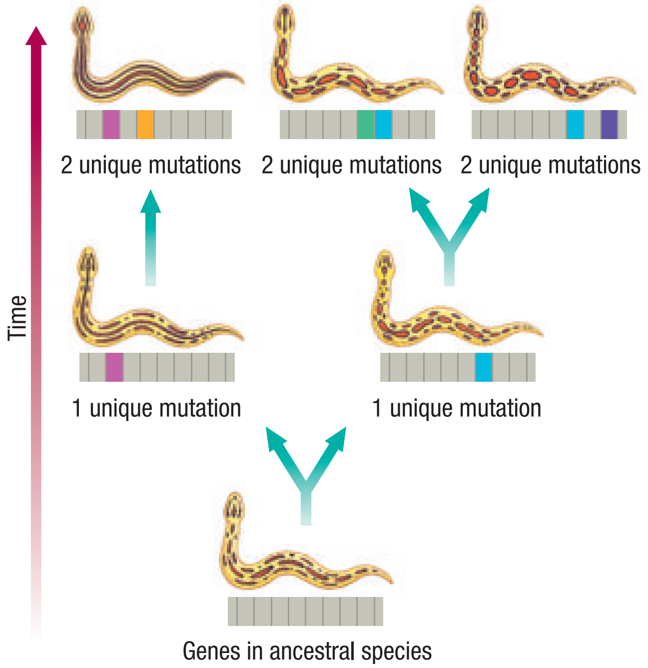


Figure 8 Because mutation occurs randomly at any time, an average rate of mutation can be measured and used as a "clock" to estimate the time any two species took to accumulate a number of genetic differences.

Section 2 Review

KEY IDEAS

1. **Identify** the kinds of problems that arise when scientists try to group organisms by similarities.
2. **Relate** classification to phylogeny.
3. **Describe** the method of cladistics.
4. **Identify** the kinds of evidence used to infer phylogenies.

CRITICAL THINKING

5. **Justifying Reasoning** Some scientists who study dinosaurs have stated that dinosaurs are not extinct. How could this statement be justified?
6. **Analyzing Relationships** Explain how the outgroup in a cladogram relates to the difference between ancestral and derived characters.

METHODS OF SCIENCE

7. **Taxonomic Challenge** In the past, mammals were identified as animals that have fur and give birth, and reptiles were identified as animals that have scales and lay eggs. Then, an animal was found that has fur and lays eggs. How might this problem have been resolved?

Section 3

Kingdoms and Domains

Key Ideas	Key Terms	Why It Matters
Have biologists always recognized the same kingdoms? What are the domains and kingdoms of the three-domain system of classification?	bacteria archaea eukaryote	The three-domain system is one of the latest revolutions in biology.

If you read old books or stories, you might read about plants and animals, or "flora and fauna," but probably not "fungi" or "bacteria."

Updating Classification Systems

For many years after Linnaeus created his system, scientists recognized only two kingdoms: Plantae (plants) and Animalia (animals). Relatively few of Earth's species were known, and little was known about them. **Biologists have added complexity and detail to classification systems as they have learned more.** Throughout history, many new taxa have been proposed and some groups have been reclassified.

For example, **Figure 9** shows sponges, which were first classified as plants. Then, the invention of the microscope allowed scientists to look at cells. Scientists learned that sponges have cells that are much more like animal cells than like plant cells. So today, sponges are classified as animals. The microscope prompted many such changes.

From Two to Five Kingdoms In the 1800s, scientists added Kingdom Protista as a taxon for unicellular organisms. Soon, they noticed the differences between prokaryotic cells and eukaryotic cells. So, scientists created Kingdom Monera for prokaryotes and left single-celled eukaryotes in Kingdom Protista. By the 1950s, five kingdoms were used: Monera, Protista, Fungi, Plantae, and Animalia.

Six Kingdoms In the 1990s, Kingdom Monera came into question. Genetic data suggested two major groups of prokaryotes. So, Kingdom Monera was split into two new kingdoms: Eubacteria and Archaebacteria.

Reading Check *What were the original Linnaean kingdoms?*

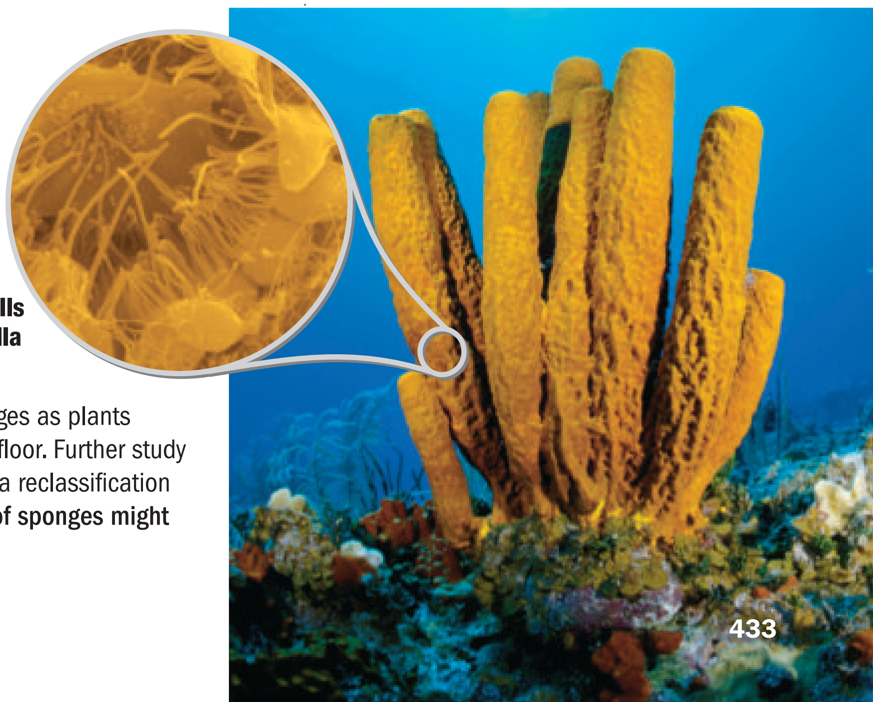


Figure 9 Early scientists classified sponges as plants because sponges are attached to the sea floor. Further study and microscopic views in particular led to a reclassification of sponges as animals. **What features of sponges might have led to this reclassification?**

Characteristics of Domains and Kingdoms

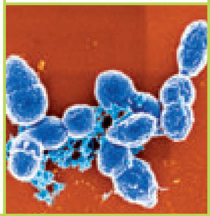
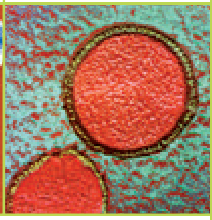
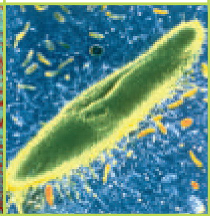
Domain	Bacteria	Archaea	Eukarya			
Kingdom	Eubacteria	Archae-bacteria	Protista	Fungi	Plantae	Animalia
Example	*Streptococcus pneumoniae*	*Staphylo-thermus marinus*	paramecium	spore cap mushroom	Texas paintbrush	white-winged dove
						
Cell type	prokaryote		eukaryote			
Cell walls	cell walls with peptidoglycan	cell walls with unique lipids	some species with cell walls	cell walls with chitin	cell walls with cellulose	no cell walls
Number of cells	unicellular		unicellular or multicellular	mostly multicellular	mostly multicellular	multicellular
Nutrition	autotroph or heterotroph			heterotroph	autotroph	heterotroph

Figure 10 This table shows the major characteristics used to define the domains and kingdoms of the modern Linnaean system. **What other kind of characteristic differs between kingdoms?**

The Three-Domain System

As biologists began to see the differences between the two kinds of prokaryotes, they also saw the similarities among all eukaryotes. So, a new system was proposed that divides all organisms into three domains: Bacteria, Archaea, and Eukarya. **Today, most biologists tentatively recognize three domains and six kingdoms. Figure 10** shows the major characteristics of these taxa.

Major Characteristics Major taxa such as kingdoms are defined by major characteristics. These characteristics include:

- **Cell Type** The cells may be either *prokaryotic* or *eukaryotic*.
- **Cell Walls** The cells may either have a cell wall or lack a cell wall.
- **Body Type** An organism is either *unicellular* or *multicellular*.
- **Nutrition** An organism is either an *autotroph* (makes nutrients from inorganic materials) or a *heterotroph* (gets nutrients from other organisms). Some taxa have unique means of nutrition.
- **Genetics** As you have learned, related groups of organisms will have similar genetic material and systems of gene expression. So, organisms may have a unique system of DNA, RNA, and proteins.

Domain Bacteria **Domain Bacteria is equivalent to Kingdom Eubacteria.** The common name for members of this domain is *bacteria*. **Bacteria** are prokaryotes that have a strong exterior cell wall and a unique genetic system. However, bacteria have the same kind of cell membrane lipid as most eukaryotes do.

Hands-On

QuickLab

20 min

Field Guides

Have you ever used field guides to identify animals or plants? Do you know how these guides are organized? Take a few guides outside, and take a closer look.

Procedure

1. Gather **several different field guides** for plants or other organisms in your area. Also gather a **magnifying glass** and a **specimen jar.** Take these items with you to a **local natural area.**
2. **CAUTION: Do not touch or disturb any organisms without your teacher's permission; leave all natural items as you found them.** Try to find and identify at least two organisms that are listed in your field guides. Make notes to describe each organism.

Analysis

1. **Analyzing Methods** How difficult was identifying your organisms? How certain are you of your identification?
2. **Comparing Systems** How are the field guides organized? What other ways could they be organized?

All bacteria are similar in physical structure, with no internal compartments. Traditionally, bacteria have been classified according to their shape, the nature of their cell wall, their type of metabolism, or the way that they obtain nutrients. Bacteria are the most abundant organisms on Earth and are found in almost every environment.

Domain Archaea › **Domain Archaea is equivalent to Kingdom Archaebacteria.** The common name for members of this domain is *archaea.* **Archaea** have a chemically unique cell wall and membranes and a unique genetic system. The genetic systems of archaea share some similarities with those of eukaryotes that they do not share with those of prokaryotes. Scientists think that archaea began to evolve in a separate lineage from bacteria early in Earth's history and that some archaea eventually gave rise to eukaryotes.

Archaea were first found by scientists in extreme environments, such as salt lakes, the deep ocean, or hot springs that exceed 100°C. These archaea are called *extremophiles*. Other archaea called *methanogens* live in oxygen-free environments. However, some archaea live in the same environments as many bacteria do.

Domain Eukarya › **Domain Eukarya is made up of Kingdoms Protista, Fungi, Plantae, and Animalia.** Members of the domain Eukarya are **eukaryotes,** which are organisms composed of eukaryotic cells. These cells have a complex internal structure. This structure enabled the cells to become larger than the earliest cells and enabled the evolution of multicellular life. While eukaryotes vary in many fundamental respects, they share several key features.

› **Reading Check** *Which kingdoms are prokaryotic?*

bacteria (bak TIR ee uh) extremely small, single-celled organisms that usually have a cell wall and that usually reproduce by cell division; members of the domain Bacteria

archaea (ahr KEE uh) prokaryotes that are distinguished from other prokaryotes by differences in their genetics and in the makeup of their cell wall; members of the domain Archaea

eukaryote an organism made up of cells that have a nucleus enclosed by a membrane, multiple chromosomes, and a mitotic cycle; members of the domain Eukarya

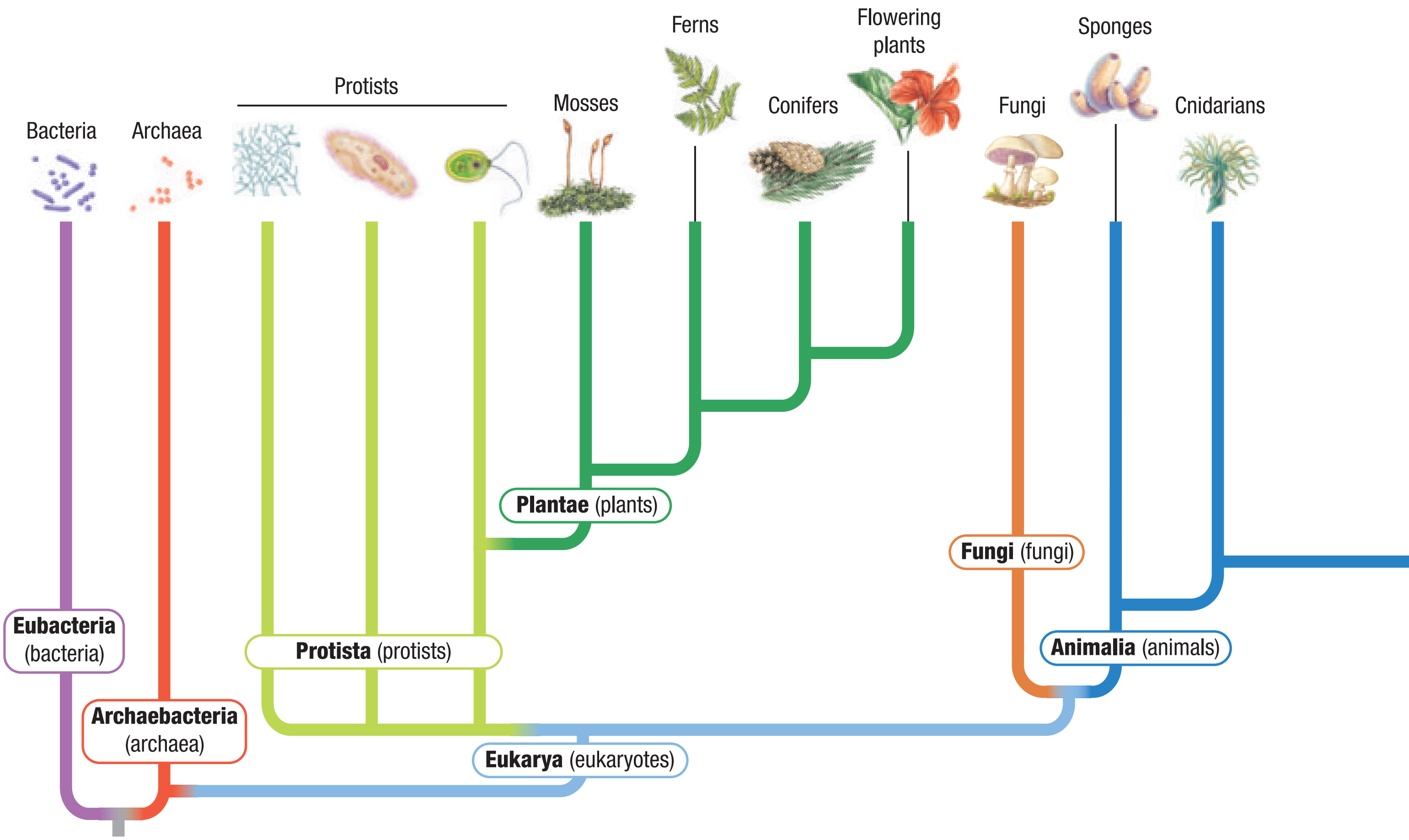


Figure 11 This tree of life shows current hypotheses of the relationships between all major groups of organisms. For updates on phylogenetic information, visit **go.hrw.com** and enter the keyword **HX8 Phylo.** **Why might this type of model be revised?**

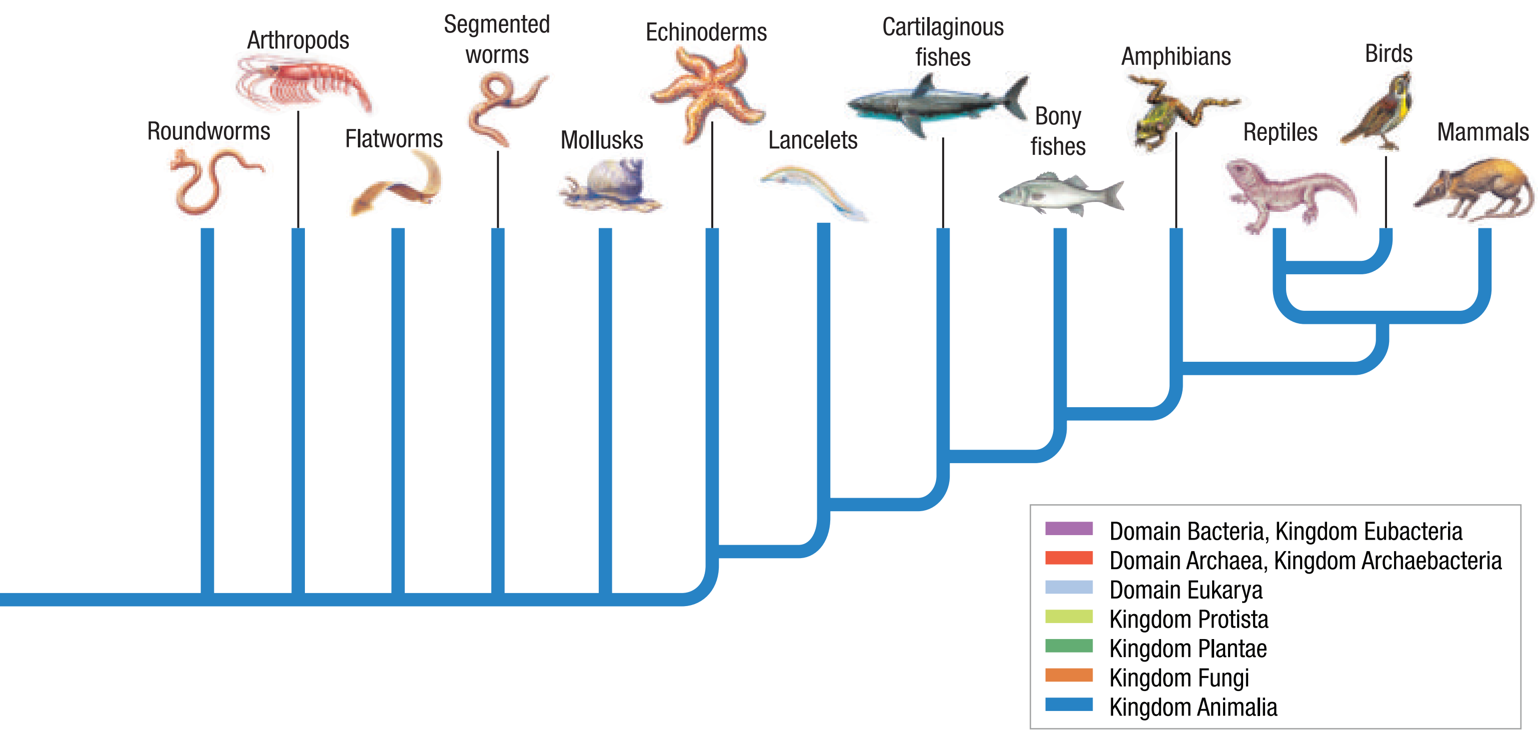
READING TOOLBOX

Phylogenetic Tree Look carefully at **Figure 11.** Try to identify which groups are most closely related to each other. Which label includes lineages that do not share a unique common ancestor?

Characteristics of Eukaryotes Eukaryotes have highly organized cells. All eukaryotes have cells with a nucleus and other internal compartments. Also, true multicellularity and sexual reproduction occur only in eukaryotes. True multicellularity means that the activities of individual cells are coordinated and the cells themselves are in contact. Sexual reproduction means that genetic material is recombined when parents mate. Sexual reproduction is an important part of the life cycle of most eukaryotes.

Kinds of Eukaryotes The major groups of eukaryotes are defined by number of cells, body organization, and types of nutrition.

- **Plantae** Almost all plants are autotrophs that produce their own food by absorbing energy and raw materials from their environment. This process is *photosynthesis,* which occurs inside chloroplasts. The cell wall is made of a rigid material called *cellulose*. More than 350,000 known species of plants exist.
- **Animalia** Animals are multicellular heterotrophs. Their bodies may be simple collections of cells or highly complex networks of organ systems. Animal cells lack the rigid cell walls that plant cells have. More than 1 million known species of animals exist.
- **Fungi** Fungi are heterotrophs and are mostly multicellular. Their cell wall is made of a rigid material called *chitin*. Fungi are considered to be more closely related to animals than to any other kingdom. More than 70,000 known species of fungi exist.



- **Protista** Kingdom Protista is a diverse group. Unlike the other three Kingdoms of Eukarya, Protista is not a natural group but rather a "leftover" taxon. Any single-celled eukaryote that is *not* a plant, animal, or fungi can be called a *protist*. Protists did not descend from a single common ancestor.

For many years , biolgists recognized four major groups of protists: flagellates, amoebas, algae, and parasitic protists. More recently, biologists have proposed to replace Protista with several new kingdoms. These kingdoms would classify protists that seem to be unrelated to any other groups. However, some protists are being reclassified into other kingdoms. For example, algae that have chloroplasts are thought to be most closely related to plants, as shown in **Figure 11.** Biologists have not yet agreed how to resolve all of these issues.

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Reading Check *Which kingdoms are heterotrophic?*

Section 3 Review

KEY IDEAS

1. **Outline** how biologists have changed the major levels of the Linnaean system over time.
2. **List** the three domains, identify the kingdoms that align with each domain, and list the major characteristics of each kingdom.

CRITICAL THINKING

3. **Finding Evidence** The *theory of endosymbiosis* proposes that eukaryotes descended from a primitive combination of both archaea and bacteria. What evidence supports this theory?
4. **Science and Society** Microscopes led scientists to recognize new kingdoms. What other technology has impacted classification?

ALTERNATIVE ASSESSMENT

5. **Tree of Life Poster** Make a poster of the tree of life. At appropriate places on the tree, add images of representative organisms, along with labels. Include all domains and kingdoms as well as at least three major taxa within each kingdom.

Chapter 18 Summary

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SUPER SUMMARY
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Key Ideas	Key Terms

1 The Importance of Classification

- Biologists use taxonomic systems to organize their knowledge of organisms. These systems attempt to provide consistent ways to name and categorize organisms.
- All scientific names for species are made up of two Latin or Latin-like terms.
- In the Linnaean system of classification, organisms are grouped at successive levels of a hierarchy based on similarities in their form and structure. The eight levels of modern classification are domain, kingdom, phylum, class, order, family, genus, and species.

Key Terms: **taxonomy** (423), **genus** (424), **binomial nomenclature** (424)

2 Modern Systematics

- Scientists traditionally have used similarities in appearance and structure to group organisms. However, this approach has proven problematic.
- Grouping organisms by similarity is often assumed to reflect phylogeny, but inferring phylogeny is complex in practice.
- Cladistic analysis is used to select the most likely phylogeny among a given set of organisms.
- Biologists compare many kinds of evidence and apply logic carefully in order to infer phylogenies.

Key Terms: **phylogeny** (428), **cladistics** (429)

3 Kingdoms and Domains

- Biologists have added complexity and detail to classification systems as they have learned more.
- Today, most biologists tentatively recognize three domains and six kingdoms. Domain Bacteria is equivalent to Kingdom Eubacteria. Domain Archaea is equivalent to Kingdom Archaebacteria. Domain Eukarya is made up of Kingdoms Protista, Fungi, Plantae, and Animalia.

Key Terms: **bacteria** (434), **archaea** (435), **eukaryote** (435)