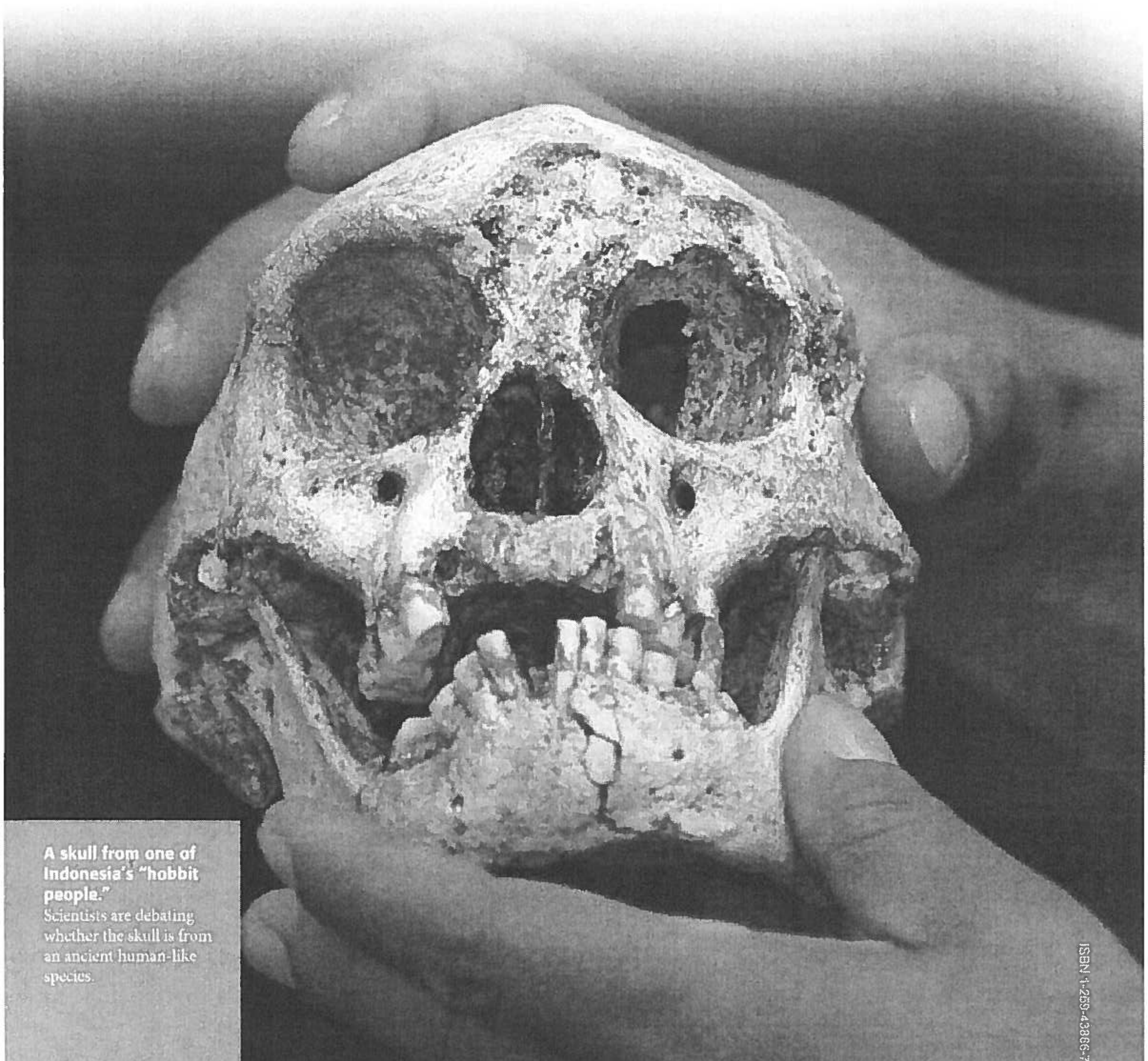
17 The Evolution of Animals



A skull from one of Indonesia's "hobbit people."
Scientists are debating whether the skull is from an ancient human-like species.

ISBN 1-269-43886-7

CHAPTER CONTENTS

CHAPTER THREAD

Human Evolution

Human Evolution BIOLOGY AND SOCIETY

The Discovery of the Hobbit People

In 2003, Australian anthropologists digging on the Indonesian island of Flores stumbled upon bones of some highly unusual people, including the nearly complete skeleton of an adult female. Next to a modern woman, this fully grown individual would stand about waist-high. Features of her skull, such as the shape and thickness of the bones, were human-like, but its size was proportional to her tiny body, and her brain was the size of a chimpanzee's. Surprisingly, the bones were accompanied by tools for hunting and butchering animals, along with evidence of cooking fires. Most astonishing of all, the remains dated to roughly 18,000 years ago, a time when scientists had thought that *Homo sapiens* was the only surviving human species. Since the initial discovery, researchers have unearthed the bones of a dozen or so more of these miniature humans.

The discoverers attributed their astonishing find to a previously unknown species, which they named *Homo floresiensis* and nicknamed "hobbits." They speculated that a band of ancestral humans arrived on Flores millions of years ago from Africa and, within the isolated environment of the island, evolved into the diminuitive *Homo floresiensis*. There is precedent for animal evolution of this type: Biologists have discovered island-bound dwarf populations of deer, elephants, and hippos. One hypothesis is that a lack of predators favors the evolution of smaller, more energy-efficient forms. Controversy erupted as soon as the team announced their findings. Skeptical scientists suggested that the bones were from *Homo sapiens* with diseases that cause skeletal malformations. As you'll find out in the Process of Science section, the more scientists learn about the "hobbit" people, the more puzzling their findings become.

Homo sapiens and *Homo floresiensis* are just two of the over 1 million species of animals that have been named and described by biologists. This amazing diversity arose through hundreds of millions of years of evolution as natural selection shaped animal adaptations to Earth's many environments. In this chapter, we'll look at the 9 most abundant and widespread of the roughly 35 phyla (major groups) in the kingdom Animalia. We'll give special attention to the major milestones in animal evolution and conclude by reconnecting with the fascinating subject of human evolution.

ISBN 1-269-43886-7

CHAPTER 17
THE EVOLUTION OF ANIMALS

The Origins of Animal Diversity

Animal life began in Precambrian seas with the evolution of multicellular creatures that ate other organisms. We are among their descendants.

What Is an Animal?

Animals are eukaryotic, multicellular, heterotrophic organisms that obtain nutrients by eating. This mode of nutrition contrasts animals with plants and other organisms that construct organic molecules through photosynthesis. It also contrasts with fungi, which obtain nutrients by absorption after digesting the food outside their bodies (see Figure 16.23). Most animals digest their food within their bodies after ingesting other organisms, dead or alive, whole or by the piece (**Figure 17.1**).

Animal cells lack the cell walls that provide strong support in the bodies of plants and fungi. And most animals have muscle cells for movement and nerve cells that control the muscles. The most complex animals can use their muscular and nervous systems for many functions other than eating. Some species even use massive networks of nerve cells called brains to think.

Most animals are diploid and reproduce sexually; eggs and sperm are the only haploid cells. The life cycle of a sea star (**Figure 17.2**) includes basic stages found in most animal life cycles. ❶ Male and female adult animals make haploid gametes by meiosis, and ❷ an egg and a sperm fuse, producing a zygote. ❸ The zygote divides by mitosis, forming ❹ an early embryonic stage called a **blastula**, which is usually a hollow ball of cells. ❺ In most animals, one side of the blastula folds inward, forming a stage called a **gastrula**. ❻ The gastrula develops into a saclike embryo with a two-layered wall and an opening at one end. After the gastrula stage, many animals develop directly into adults. ❼ Others, such as the sea star, develop into a **larva**, an immature individual that looks different from the adult animal. (A tadpole, for another example, is a larval frog.) ❽ The larva undergoes a major change of body form, called **metamorphosis**, in becoming an adult capable of reproducing sexually. ☑

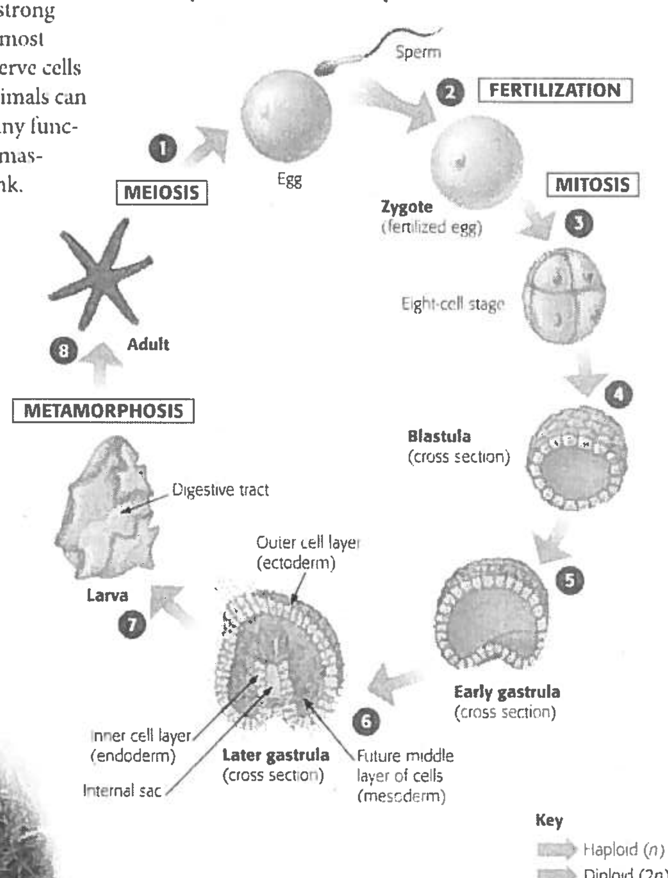
☑ CHECKPOINT

What mode of nutrition distinguishes animals from fungi, both of which are heterotrophs?

Answer: ingestion (eating)

▼ Figure 17.1 Nutrition by ingestion, the animal way of life. Few animals ingest a piece of food as large as the gazelle being eaten by this rock python. The snake will spend two weeks or more digesting its meal.

▼ Figure 17.2 The life cycle of a sea star as an example of animal development.



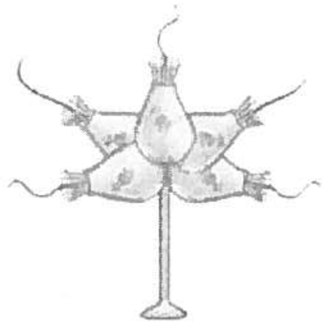
Early Animals and the Cambrian Explosion

Scientists hypothesize that animals evolved from a colonial, flagellated protist **(Figure 17.3)**. Although molecular data point to a much earlier origin, the oldest animal fossils that have been found are 550–575 million years old. Animal evolution must have already been under way for some time prior to that—the fossils reveal a variety of shapes, and sizes range from 1 cm to 1 m in length **(Figure 17.4)**.

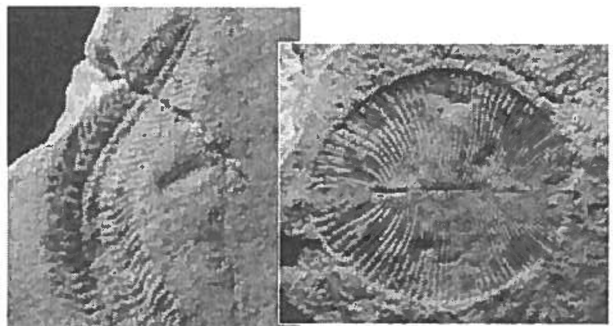
Animal diversification appears to have accelerated rapidly from 535 to 525 million years ago, during the Cambrian period. Because so many animal body plans and new phyla appear in the fossils from such an evolutionarily short time span, biologists call this episode the Cambrian explosion. The most celebrated source of Cambrian fossils is located in British Columbia, Canada. The Burgess Shale, as it is known, provided a cornucopia of perfectly preserved animal fossils. In contrast to the Precambrian animals, many Cambrian animals had hard parts such as shells, and many are clearly related to existing animal groups. For example, scientists have classified more than a third of the species found in the Burgess Shale as arthropods, the group that includes present-day crabs, shrimps, and insects **(Figure 17.5)**. Other fossils are more difficult to place. Some are downright weird, like the spiky creature near the center of the drawing, known as *Hallucigenia*, and *Opabinia*, the five-eyed predator grasping a worm with the long, flexible appendage that protrudes in front of its mouth.

What ignited the Cambrian explosion? Scientists have proposed several hypotheses, including increasingly complex predator-prey relationships and an increase in atmospheric oxygen. But whatever the cause of the rapid diversification, it is likely that the set of "master control" genes—the genetic framework for complex bodies—was already in place (see Figure 11.10). Much of the diversity in body form among the animal phyla is associated with variations in where and when these genes are expressed within developing embryos.

In the last half billion years, animal evolution has to a large degree merely generated variations of the animal forms that originated in the Cambrian seas. Continuing research will help test hypotheses about the Cambrian explosion. But even as the explosion becomes less mysterious, it will seem no less wondrous. ☑



◄ **Figure 17.3 Hypothetical common ancestor of animals.** As you'll learn shortly, the individual cells of this colonial flagellated protist resemble the feeding cells of sponges.

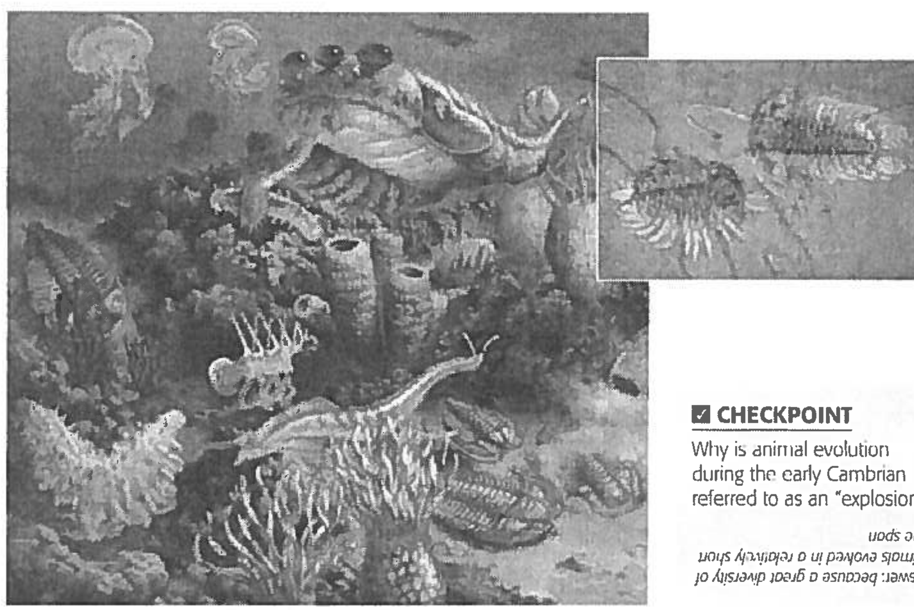


Dickinsonia costata (about 8 cm across)

Spriggina floundersi (about 3 cm long)

◄ **Figure 17.4 Precambrian animals.** All of the oldest animal fossils are impressions of soft-bodied animals. Most of them do not appear to be related to any living group of animals.

▼ **Figure 17.5 A Cambrian seascape.** This drawing is based on fossils from the Burgess Shale. The flat-bodied animals are ancient arthropods called trilobites. A photo of fossil trilobites is shown at the right.



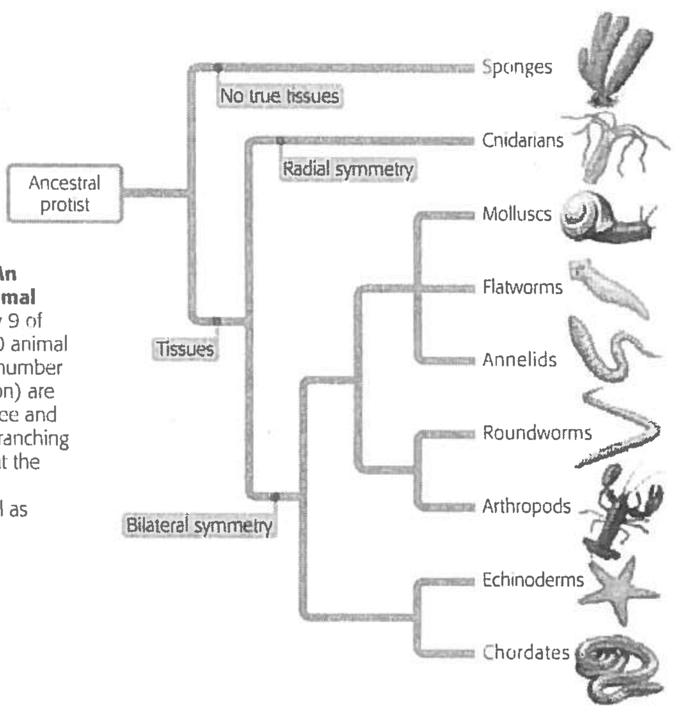
☑ CHECKPOINT

Why is animal evolution during the early Cambrian referred to as an "explosion"?

Answer: because a great diversity of animals evolved in a relatively short time span

Animal Phylogeny

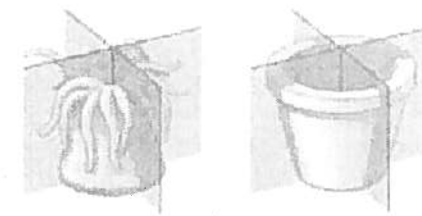
Historically, biologists have categorized animals by "body plan"—general features of body structure. Distinctions between body plans are used to help infer the evolutionary relationships between animal groups. More recently, a wealth of genetic data has allowed evolutionary biologists to modify and refine groups. **Figure 17.6** represents a set of hypotheses about the evolutionary relationships between nine major animal phyla based on structural and genetic similarities.



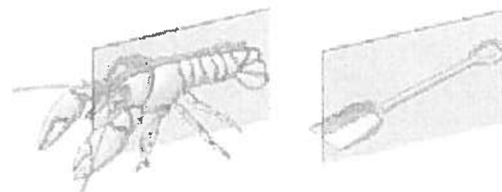
▸ **Figure 17.6 An overview of animal phylogeny.** Only 9 of the more than 30 animal phyla (the exact number is not agreed upon) are included in the tree and in the text. The branching takes into account the body plan of the organisms as well as genetic data.

A major branch point in animal evolution distinguishes sponges from all other animals based on structural complexity. Unlike more complex animals, sponges lack true tissues, groups of similar cells that perform a function (such as nervous tissue). A second major evolutionary split is based on body symmetry: radial versus bilateral **(Figure 17.7)**. To understand this difference, imagine a pail and shovel. The pail has **radial symmetry**, identical all around a central axis. The shovel has **bilateral symmetry**, which means there's only one way to split it into two equal halves—right down the midline. A bilateral animal has a definite "head end" that first encounters food, danger, and other stimuli when traveling. In most bilateral animals, a nerve center in the form of a brain is at the head end, near a concentration of sense organs such as eyes. Thus, bilateral symmetry is an adaptation that aids movement, such as crawling, burrowing, or swimming. Indeed, many radial animals are stationary, whereas most bilateral animals are mobile.

▾ **Figure 17.7 Body symmetry.**



Radial symmetry. Parts radiate from the center, so any slice through the central axis divides into mirror images.



Bilateral symmetry. Only one slice can divide left and right sides into mirror-image halves.

The evolution of body cavities also helped lead to more complex animals. A **body cavity** is a fluid-filled space separating the digestive tract from the outer body wall. The cavity enables the internal organs to grow and move independently of the outer body wall, and the fluid cushions them from injury. In soft-bodied animals such as earthworms, the fluid is under pressure and functions as a hydrostatic skeleton. Of the phyla shown in Figure 17.6, only sponges, cnidarians, and flatworms lack a body cavity.

Among animals with a body cavity, there are differences in how the cavity develops **(Figure 17.8)**. In all cases, the cavity is at least partly lined by a middle layer of tissue, called mesoderm, which develops between the inner (endoderm) and outer (ectoderm) layers of the gastrula embryo. If the body cavity is not completely lined by tissue derived from mesoderm, it is called a **pseudocoelom**. Among the animal phyla discussed in this chapter, only the roundworms (nematodes) have a pseudocoelom. A true **coelom**, the type of body cavity humans and many other animals have, is completely lined by tissue derived from mesoderm. (Despite its name, a pseudocoelom functions just like a coelom.)

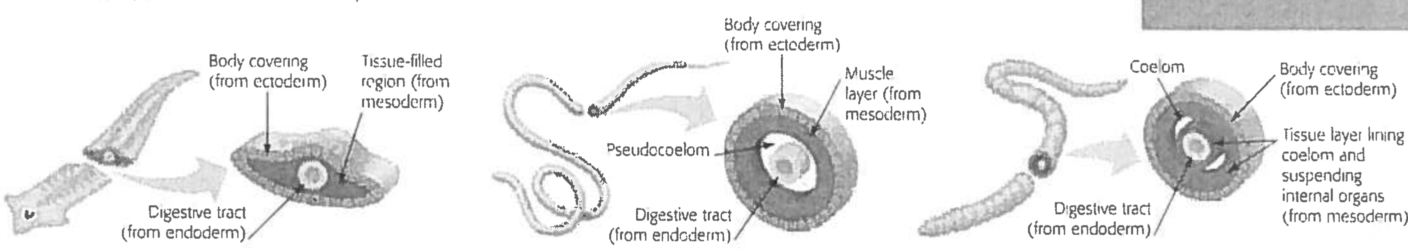
With the overview of animal evolution in Figure 17.6 as our guide, we're ready to take a closer look at the nine most numerous animal phyla. ☑

☑ CHECKPOINT

1. In terms of key body features, chordates are most like which other animal phylum?
2. A round pizza displays __________ symmetry, whereas a slice of pizza displays __________ symmetry.

Answers: 1. echinoderms 2. radial; bilateral

▼ **Figure 17.8 Body plans of bilateral animals.** The various organ systems of these animals develop from the three tissue layers that form in the embryo.



(a) No body cavity: for example, flatworm

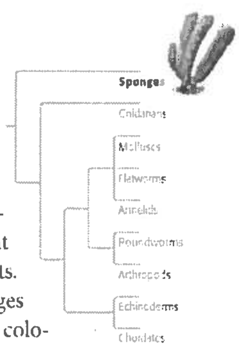
(b) Pseudocoelom: a body cavity only partially lined by the mesoderm, the middle tissue layer, for example, roundworm

(c) True coelom: a fluid-filled body cavity completely lined by mesoderm, for example, annelid

Major Invertebrate Phyla

Living as we do on land, our sense of animal diversity is biased in favor of vertebrates, animals with a backbone, such as amphibians, reptiles, and mammals. However, vertebrates make up less than 5% of all animal species. If we were to sample the animals in an aquatic habitat, such as a pond, tide pool, or coral reef, or if we were to consider the millions of insects that share our terrestrial world, we would find ourselves in the realm of **invertebrates**, animals without backbones. We give special attention to the vertebrates simply because we humans are among the backboned ones. However, by exploring the other 95% of the animal kingdom—the invertebrates—we'll discover an astonishing diversity of beautiful creatures that too often escape our notice.

Sponges



Sponges were once grouped into the single phylum Porifera. However, genetic evidence now suggests that there are multiple phyla. Sponges are stationary animals that appear so immobile that you might mistake them for plants. The simplest of all animals, sponges probably evolved very early from colonial protists. Sponges range in height from about 1 cm to 2 m. They have no nerves or muscles, but their individual cells can sense and react to changes in the environment. The cell layers of sponges are loose associations of relatively unspecialized cells that are not considered true tissues. Of the 9,000 or so species of sponges, only about 100 live in fresh water; the rest are marine.

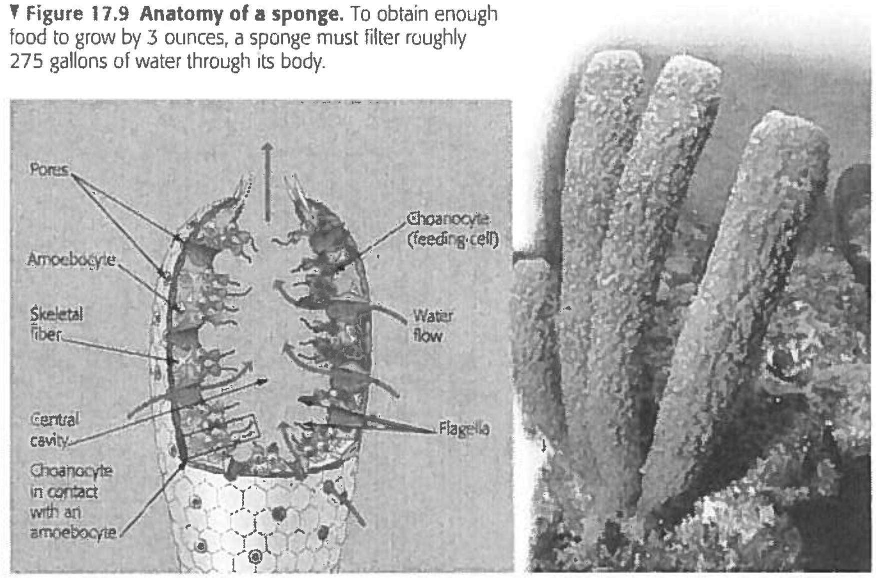
The body of a sponge resembles a sac perforated with holes. Water is drawn through the pores into a central cavity and then flows out of the sponge through a larger opening (**Figure 17.9**). Cells called choanocytes have flagella that sweep water through the sponge's porous body. Choanocytes trap bacteria and other food particles in mucus and then engulf the food by endocytosis (see Figure 5.18). Cells called amoebocytes pick up food from the choanocytes, digest it, and carry the nutrients to other cells. Amoebocytes also manufacture the fibers that make up a sponge's skeleton. In some sponges, these fibers are sharp and spur-like. Other sponges have softer, more flexible skeletons; these pliant, honeycombed skeletons are often used as natural sponges in the bath or to wash cars. ☑

☑ CHECKPOINT

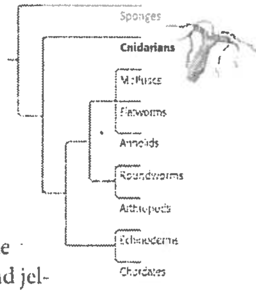
In what fundamental way does the structure of a sponge differ from that of all other animals?

Answer: A sponge has no true tissues.

▼ **Figure 17.9 Anatomy of a sponge.** To obtain enough food to grow by 3 ounces, a sponge must filter roughly 275 gallons of water through its body.



Cnidarians



Cnidarians (phylum Cnidaria) are characterized by the presence of body tissues—as are all the remaining animals we will discuss—as well as by radial symmetry and tentacles with stinging cells. Cnidarians include sea anemones, hydras, corals, and jellies (sometimes called jellyfish, though they are not fish). Most of the 10,000 cnidarian species are marine.

The basic body plan of a cnidarian is a sac with a central digestive compartment, the **gastrovascular cavity.** A single opening to this cavity functions as both mouth and anus. This basic body plan has two variations: the stationary **polyp** and the floating **medusa** (**Figure 17.10**). Polyps adhere to larger objects and extend their tentacles, waiting for prey. Examples of the polyp body plan are hydras, sea anemones, and corals. A medusa (plural, *medusae*) is a flattened, mouth-down version of the polyp. It moves freely by a combination of passive drifting and contractions of its bell-shaped body. The largest jellies are medusae with tentacles 60–70 m long (more than half the length of a football field) dangling from an umbrella up to 2 m in diameter. There are some species of cnidarians that live only as polyps, others only as medusae, and still others that pass through both a medusa stage and a polyp stage in their life cycle.

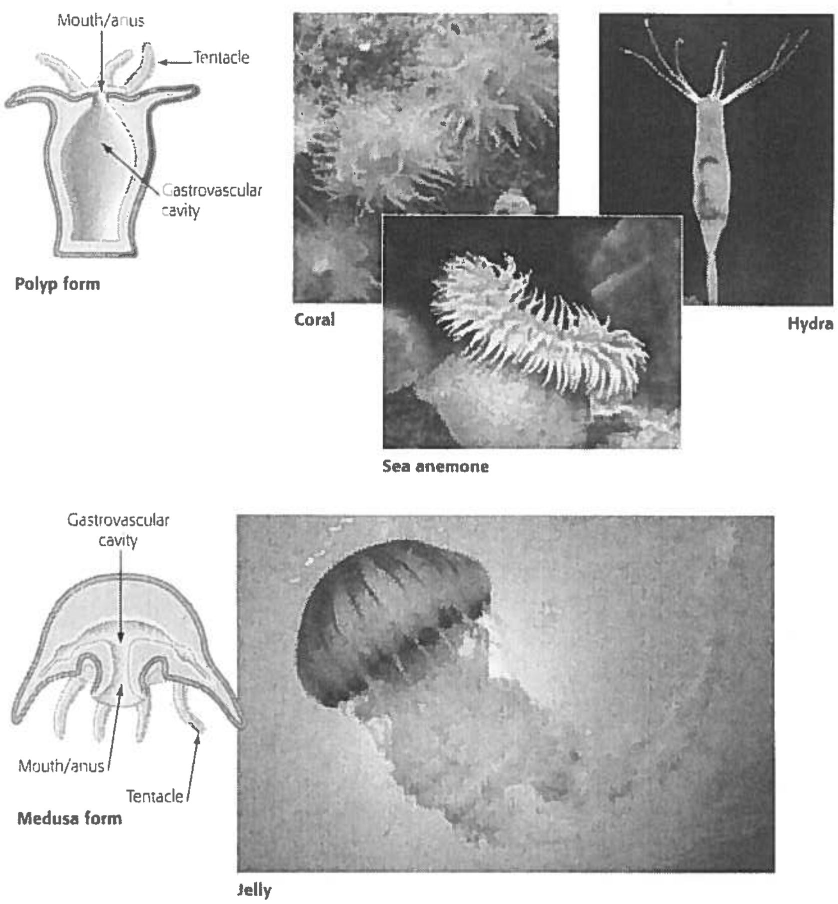
Cnidarians are carnivores that use tentacles arranged in a ring around the mouth to capture prey and push the food into the gastrovascular cavity, where digestion begins. The undigested remains are eliminated through the mouth/anus. The tentacles are armed with batteries of cnidocytes ("stinging cells") that function in defense and in the capture of prey (**Figure 17.11**). The phylum Cnidaria is named for these stinging cells. ☑

☑ CHECKPOINT

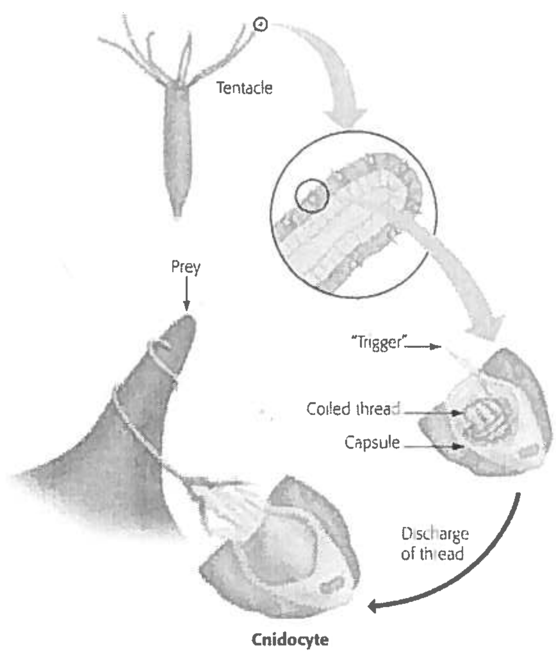
In what fundamental way does the body plan of a cnidarian differ from that of all other animals?

Answer: The body of a cnidarian is radially symmetric.

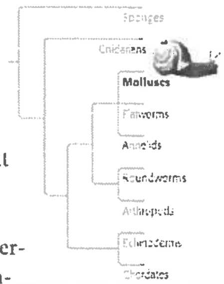
▼ Figure 17.10 Polyp and medusa forms of cnidarians. Note that cnidarians have two tissue layers, distinguished in the diagrams by blue and yellow. The gastrovascular cavity has only one opening, which functions as both mouth and anus.



▼ Figure 17.11 Cnidocyte action. When a trigger on a tentacle is stimulated by touch, a fine thread shoots out from a capsule. Some cnidocyte threads entangle prey, while others puncture the prey and inject a poison.



Molluscs



Snails and slugs, oysters and clams, and octopuses and squids are all **molluscs** (phylum Mollusca). Molluscs are soft-bodied animals, but most are protected by a hard shell. Slugs, squids, and octopuses have reduced shells, most of which are internal, or they have lost their shells completely during their evolution. Many molluscs feed by using a file-like organ called a **radula** to scrape up food. Garden snails use their radulas like tiny saws to cut pieces out of leaves.

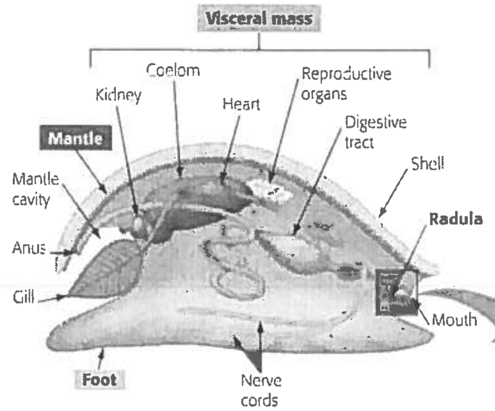
There are 93,000 known species of molluscs, with most being marine animals. All molluscs have a similar body plan **(Figure 17.12)**. The body has three main parts: a muscular foot, usually used for movement; a visceral mass containing most of the internal organs; and a fold of tissue called the mantle. The **mantle** drapes over the visceral mass and secretes the shell if one is present. The three major groups of molluscs are gastropods, bivalves, and cephalopods **(Figure 17.13)**.

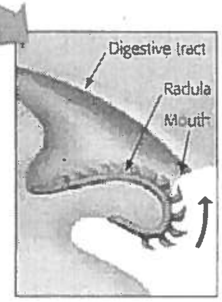
Most **gastropods**, including snails, are protected by a single spiraled shell into which the animal can retreat when threatened. Slugs and sea slugs lack shells. Many gastropods have a distinct head with eyes at the tips of tentacles (think of a garden snail). Marine, freshwater, and terrestrial gastropods make up about three-quarters of the living mollusc species.

The **bivalves**, including clams, oysters, mussels, and scallops, have shells divided into two halves hinged together. None of the bivalves have a radula. There are both marine and freshwater species, with most being sedentary, using their muscular foot for digging and anchoring in sand or mud.

What do you call a squid that's even larger than a giant squid?

Cephalopods are all marine animals and generally differ from gastropods and sedentary bivalves in that their bodies are fast and agile. A few have large, heavy shells, but in most the shell is small and internal (as in squids) or missing (as in octopuses). Cephalopods have large brains and sophisticated sense organs, which contribute to their success as mobile predators. They use beak-like jaws and a radula to crush or rip prey apart. The mouth is at the base of the foot, which is drawn out into several long tentacles for catching and holding prey. The giant squid, which averages about 10 m in length, was thought to be the largest living invertebrate until an even larger species was discovered in the ocean depths near Antarctica. Scientists estimate that this massive cephalopod, dubbed the colossal squid, grows to an average length of 13 m—as long as a school bus. A specimen caught in 2007 weighed almost half a ton. ☑





◄ **Figure 17.12 The general body plan of a mollusc.** Note the body cavity (a true coelom, though a small one) and the complete digestive tract, with both mouth and anus.

☑ CHECKPOINT

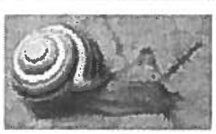
Classify these molluscs: A garden snail is an example of a ________; a clam is an example of a ________; a squid is an example of a ________.

Answer: gastropod; bivalve; cephalopod

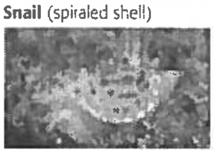
▼ **Figure 17.13 Mollusc diversity.**

MAJOR GROUPS OF MOLLUSCS

Gastropods

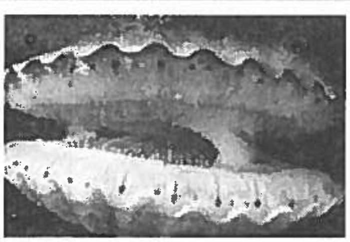


Snail (spiraled shell)



Sea slug (no shell)

Bivalves (hinged shell)



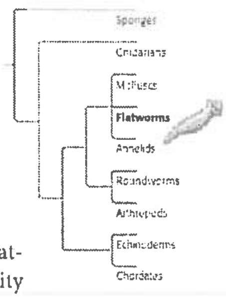
Scallop. This scallop has many eyes (small round structures) peering out between the two halves of the hinged shell

Cephalopods (large brain and tentacles)

Octopus. Octopuses live on the seafloor, where they search for crabs and other food. They have no shell. The brain of an octopus is larger and more complex, proportionate to body size, than that of any other invertebrate.

Nautilus. The shell of the nautilus is a coiled series of chambers. The animal inhabits only the outermost chamber; the others contain gas and fluid that enable the nautilus to regulate its buoyancy

Flatworms



Flatworms (phylum Platyhelminthes) are the simplest animals with bilateral symmetry. True to their name, these worms are ribbonlike and range from about 1 mm to about 20 m (about 65 feet) in length. Most flatworms have a gastrovascular cavity with a single opening. There are about 20,000 species of flatworms living in marine, freshwater, and damp terrestrial habitats (**Figure 17.14**).

The gastrovascular cavity of free-living flatworms called planarians is highly branched, providing an extensive surface area for the absorption of nutrients. When the animal feeds, a muscular tube projects through the mouth and sucks food in. Planarians live on the undersurfaces of rocks in freshwater ponds and streams.

A tapeworm doesn't have a mouth, so how does it eat?

Parasitic flatworms include blood flukes called schistosomes, which are a major health problem in the tropics. These worms have suckers that attach to the inside of the blood vessels near the human host's intestines. Infection by these flatworms causes a long-lasting disease called schistosomiasis or blood fluke disease, with such symptoms as severe abdominal pain, anemia, and dysentery. Although schistosomes are not found in the United States, more than 200 million people around the world are infected by these parasites each year.

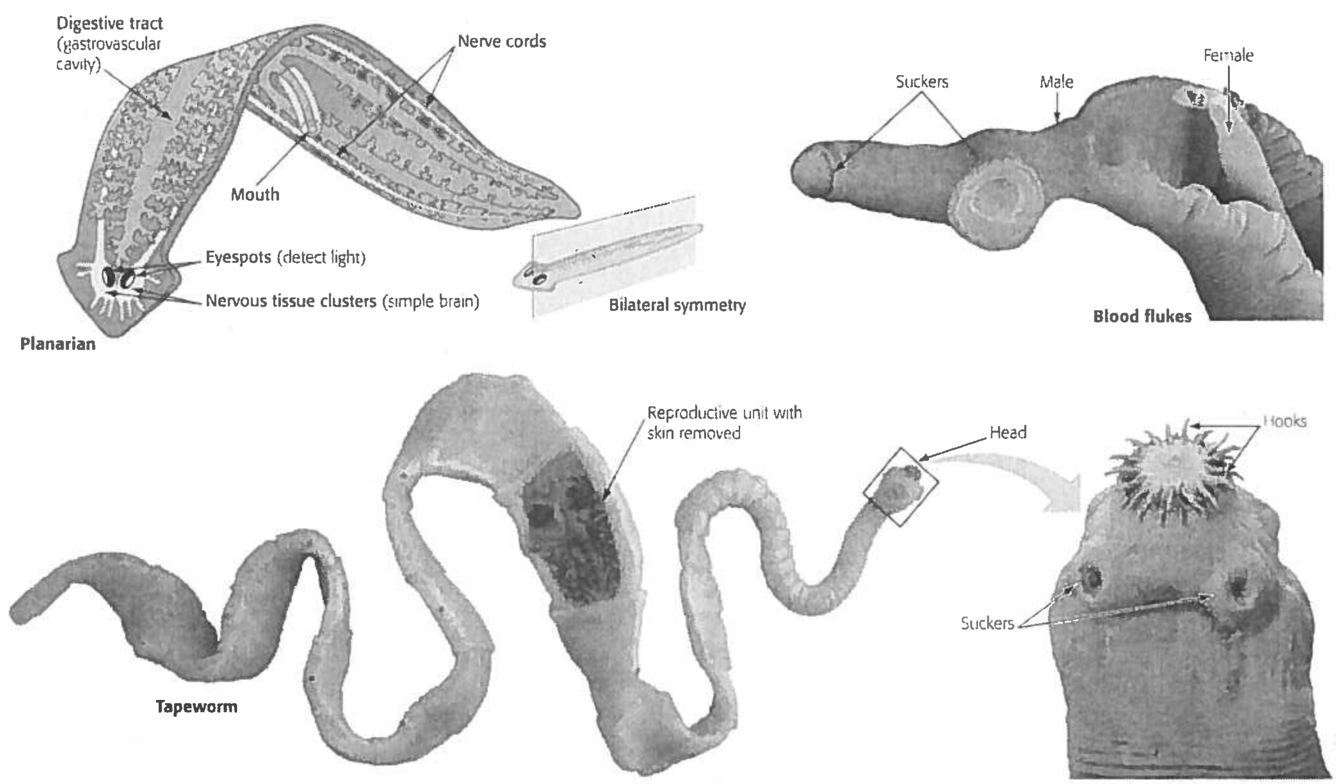
Tapeworms parasitize many vertebrates, including people. Most tapeworms have a very long, ribbonlike body with repeated parts. There is no mouth and no gastrovascular cavity. The head of a tapeworm is armed with suckers and hooks that lock the worm to the intestinal lining of the host. Bathed in partially digested food in the intestines of its host, the tapeworm simply absorbs nutrients across its body surface. Behind the head is a long ribbon of units that are little more than sacs of sex organs. At the back of the worm, mature units containing thousands of eggs break off and leave the host's body with the feces. People can become infected with tapeworms by eating undercooked beef, pork, or fish containing tapeworm larvae. The larvae are microscopic, but the adults can reach lengths of 2 m in the intestine. Such large tapeworms can cause intestinal blockage and rob enough nutrients from the host to cause nutritional deficiencies. Fortunately, an orally administered drug can kill the adult worms. ☑

☑ CHECKPOINT

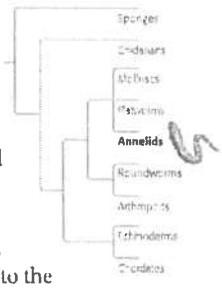
Flatworms are the simplest animals to display a body plan that is ________.

Answer: bilaterally symmetric

▼Figure 17.14 Flatworm diversity.



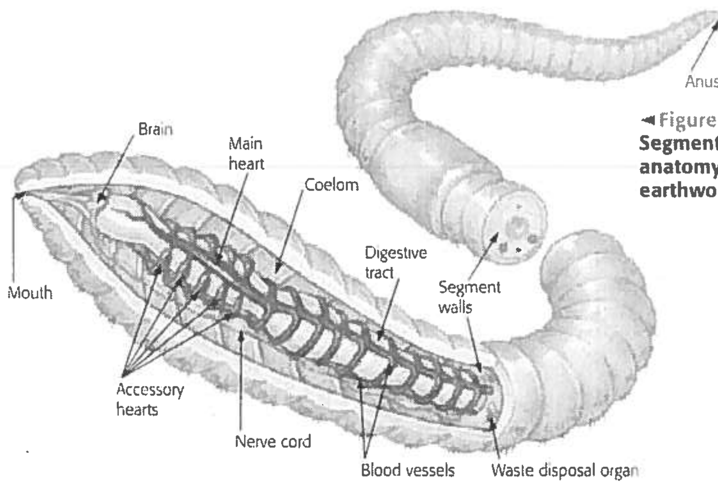
Annelids



Annelids (phylum Annelida) are worms that have **body segmentation,** which is the subdivision of the body along its length into a series of repeated parts called segments. In annelids, the segments look like a set of fused rings. There are about 16,000 annelid species, ranging in length from less than 1 mm to the 3-m giant Australian earthworm. Annelids live in damp soil, the sea, and most freshwater habitats. There are three main groups: earthworms, polychaetes, and leeches **(Figure 17.15)**.

Annelids exhibit two characteristics shared by all other bilateral animals except flatworms. One is a **complete digestive tract,** which is a digestive tube with two openings: a mouth and an anus. A complete digestive tract can process food and absorb nutrients as a meal moves in one direction from one specialized digestive organ to the next. In people, for example, the mouth, stomach, and intestines act as digestive organs. A second characteristic is a body cavity, which in this case is a coelom (a body cavity completely lined by mesoderm-derived tissue; see Figure 17.8c).

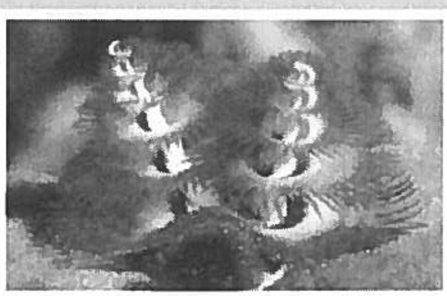
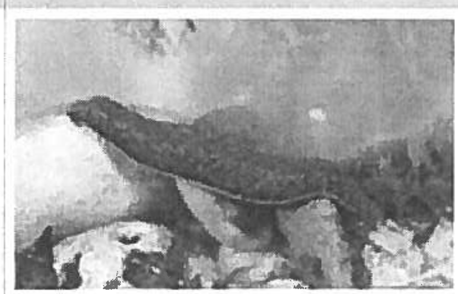
Earthworms, like all annelids, are segmented both externally and internally **(Figure 17.16)**. Many of the internal structures are repeated, segment by segment. The coelom (body cavity) is partitioned by walls (only two segment walls are fully shown here). The nervous system (yellow in the figure) and organs that dispose of fluid wastes (green) are repeated in each segment. The digestive tract, however, is not segmented; it passes through the segment walls from the mouth to the anus. Segmental blood vessels include one main heart and five pairs of accessory hearts.



◄ **Figure 17.16 Segmented anatomy of an earthworm.**

Earthworms eat their way through the soil, extracting nutrients as the soil passes through the digestive tract. Undigested material, mixed with mucus secreted into the digestive tract, is eliminated as castings through the anus. Farmers and gardeners value earthworms because the animals aerate the soil, and the castings improve the texture of the soil. Charles Darwin estimated that each acre of British farmland contained about 50,000 earthworms that produced 18 tons of castings per year.

▼ **Figure 17.15 Annelid diversity.**

MAJOR GROUPS OF ANNELIDS		
Earthworms	**Polychaetes**	**Leeches**
		
This giant Australian earthworm is bigger than many snakes. Perhaps you've slipped on slimy worms, but imagine actually tripping over one!	Polychaetes have segmental appendages that function in movement and as gills. This species is called a Christmas tree worm. The feathery, spiral structures are a pair of gills from a single worm.	The European freshwater leech *Hirudo medicinalis* can be used to repair tissue damage after reattachment surgery and other human trauma.

In contrast to earthworms, most **polychaetes** are marine, mainly crawling on or burrowing in the seafloor. Segmental appendages with hard bristles help the worm wriggle about in search of small invertebrates to eat. The appendages also increase the animal's surface area for taking up oxygen and disposing of metabolic wastes, including carbon dioxide.

The third group of annelids, **leeches**, are notorious for the bloodsucking habits of some species. However, most species are free-living carnivores that eat small invertebrates such as snails and insects. A few terrestrial species inhabit moist vegetation in the tropics, but the majority of leeches live in fresh water. A European freshwater species called *Hirudo medicinalis* is used for the treatment of circulatory complications. Most commonly, leeches are applied after reconstructive microsurgery in which limbs or digits are reattached. Because arteries (which transport blood into a reattached area) are easier to reconnect than veins (which transport blood out), blood can pool in the reattached area and stagnate, starving the healing tissue of oxygen. Medicinal leeches have razor-like jaws with hundreds of tiny teeth that cut through the skin. They secrete saliva containing an anesthetic and an anticoagulant into the wound. The anesthetic makes the bite virtually painless, and the anticoagulant prevents clotting as the leech drains excess blood from the wound. ☑

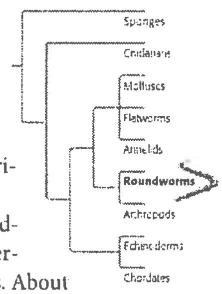
Medicinal leech

☑ CHECKPOINT

The body plan of an annelid displays ________, meaning that the body is divided into a series of repeated regions.

Answer: segmentation

Roundworms



Roundworms (also called **nematodes**, members of the phylum Nematoda) get their common name from their cylindrical body, which is usually tapered at both ends **(Figure 17.17)**. Roundworms are among the most numerous and widespread of all animals. About 25,000 species of roundworms are known, and perhaps ten times that number actually exist. Roundworms range in length from about 1 mm to 1 m. They are found in most aquatic habitats, in wet soil, and as parasites in the body fluids and tissues of plants and animals.

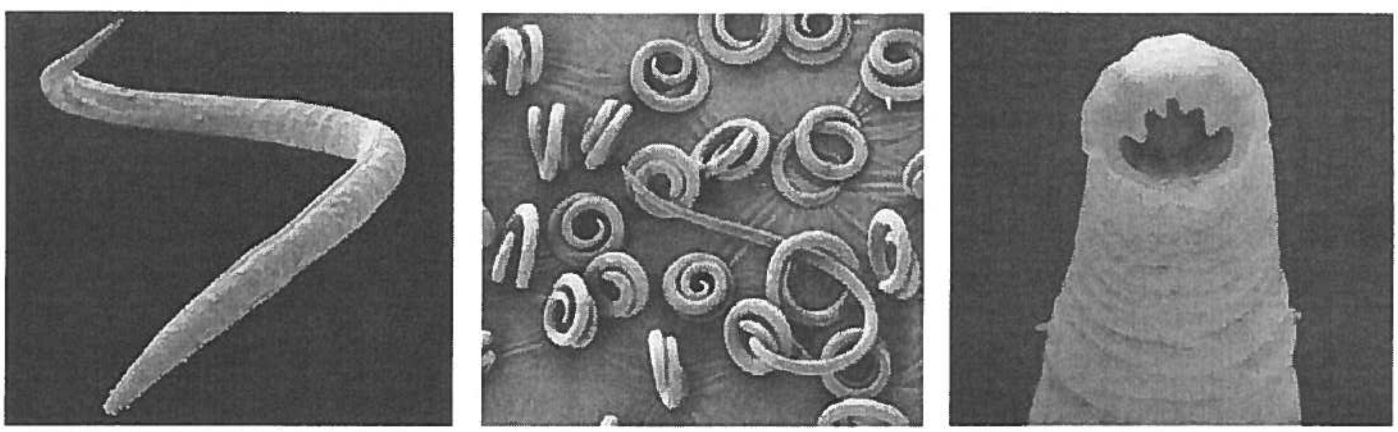
Free-living roundworms are important decomposers. They live virtually everywhere there is decaying organic matter, and their numbers are huge. Ninety thousand nematodes were found in a single rotting apple. In 2011, researchers even found nematodes living 2 miles underground, where they survive by grazing on microbes. Other species of nematodes thrive as parasites in plants and animals. Some are major agricultural pests that attack the roots of plants. At least 50 parasitic roundworm species infect people; they include pinworms, hookworms, and the parasite that causes trichinosis. ☑

☑ CHECKPOINT

Which phylum is most closely related to the roundworms? (*Hint*: Refer to the phylogenetic tree.)

Answer: arthropods

▼ **Figure 17.17 Roundworm diversity.**

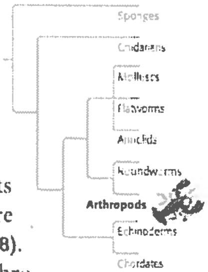


(a) A free-living roundworm. This species has the classic roundworm shape: cylindrical with tapered ends. The ridges indicate muscles that run the length of the body.

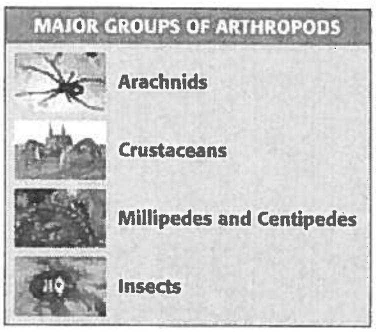
(b) Parasitic roundworms in pork. The potentially fatal disease trichinosis is caused by eating undercooked pork infected with *Trichinella* roundworms. The worms (shown here in pork tissue) burrow into a person's intestine and then invade muscle tissue.

(c) Head of hookworm. Hookworms sink their hooks into the wall of the host's small intestine and feed on blood. Although the worms are small (less than 1 cm), a severe infestation can cause serious anemia.

Arthropods



Arthropods (phylum Arthropoda) are named for their jointed appendages. Crustaceans (such as crabs and lobsters), arachnids (such as spiders and scorpions), and insects (such as grasshoppers and moths) are examples of arthropods **(Figure 17.18)**. Zoologists estimate that the total arthropod population numbers about a billion billion (10^{18}) individuals—that's about 150 million arthropods for each person! Researchers have identified over a million arthropod species, mostly insects. In fact, two out of every three species of life that have been scientifically described are arthropods. And arthropods are represented in nearly all habitats of the biosphere. In species diversity, distribution, and sheer numbers, arthropods must be regarded as the most successful animal phylum.



◄ **Figure 17.18 Arthropod diversity.**

General Characteristics of Arthropods

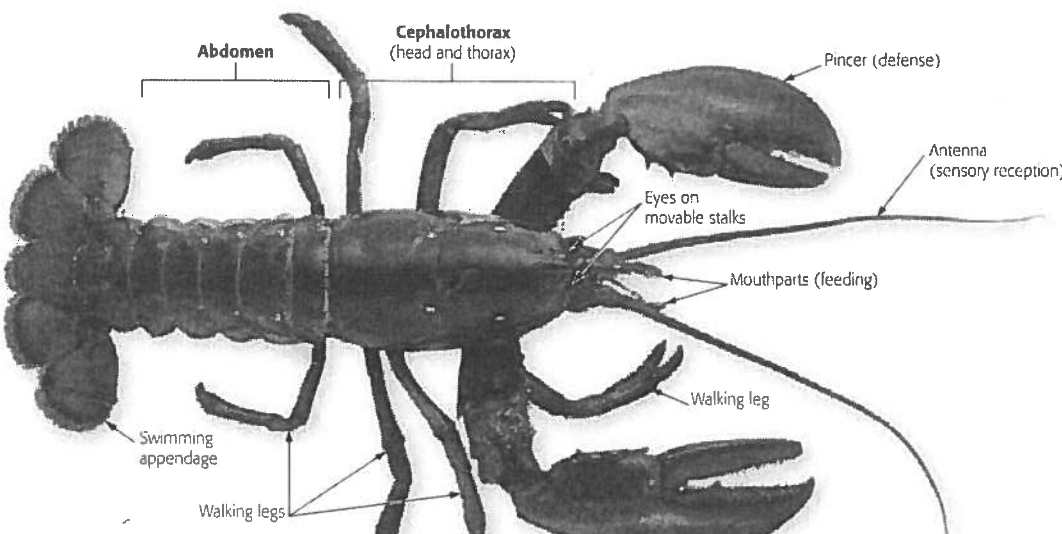
Arthropods are segmented animals. In contrast with the repeating similar segments of annelids, however, arthropod segments and their appendages have become specialized for a great variety of functions. This evolutionary flexibility contributed to the great diversification of arthropods. Specialization of segments (or of fused groups of segments) provides for an efficient division of labor among body regions. For example, the appendages of different segments may be adapted for walking, feeding, sensory reception, swimming, or defense **(Figure 17.19)**.

The body of an arthropod is completely covered by an **exoskeleton**, an external skeleton. This coat is constructed from layers of protein and a polysaccharide called chitin. The exoskeleton can be a thick, hard armor over some parts of the body (such as the head), yet be paper-thin and flexible in other locations (such as the joints). The exoskeleton protects the animal and provides points of attachment for the muscles that move the appendages. There are, of course, advantages to wearing hard parts on the outside. Our own skeleton is interior to most of our soft tissues, an arrangement that doesn't provide much protection from injury. But our skeleton does offer the advantage of being able to grow along with the rest of our body. In contrast, a growing arthropod must occasionally shed its old exoskeleton and secrete a larger one. This process, called molting, leaves the animal temporarily vulnerable to predators and other dangers. The next five pages explore the major groups of arthropods. ☑

☑ CHECKPOINT

What is the primary difference between your skeleton and a crab's skeleton?

Answer: Your skeleton is interior, whereas a crab has an exterior skeleton (an exoskeleton).



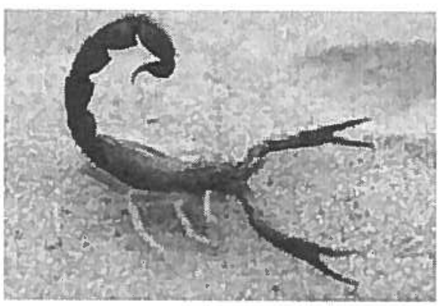
◄ **Figure 17.19 Anatomy of a lobster, a crustacean.** The whole body, including the appendages, is covered by an exoskeleton. The body is segmented, but this characteristic is obvious only in the abdomen.

Campbell Essential Biology with Physiology, Fourth Edition, by Eric J. Simon, Jean L. Dickey, and Jane B. Reece. Published by Benjamin Cummings.

Arachnids

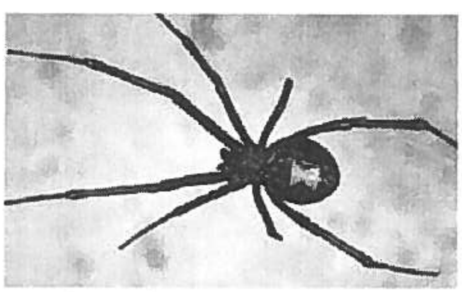
Most **arachnids** live on land. Scorpions, spiders, ticks, and mites are examples (**Figure 17.20**). Arachnids usually have four pairs of walking legs and a specialized pair of feeding appendages. In spiders, these feeding appendages are fang-like and equipped with poison glands. As a spider uses these appendages to immobilize and dismantle its prey, it spills digestive juices onto the torn tissues and sucks up its liquid meal.

▼ **Figure 17.20 Arachnid characteristics and diversity.**



Scorpion. Scorpions have a pair of large pincers that function in defense and food capture. The tip of the tail bears a poisonous stinger. Scorpions sting people only when prodded or stepped on

Dust mite. This microscopic house dust mite is a ubiquitous scavenger in our homes. Dust mites are harmless except to people who are allergic to the mites' feces.



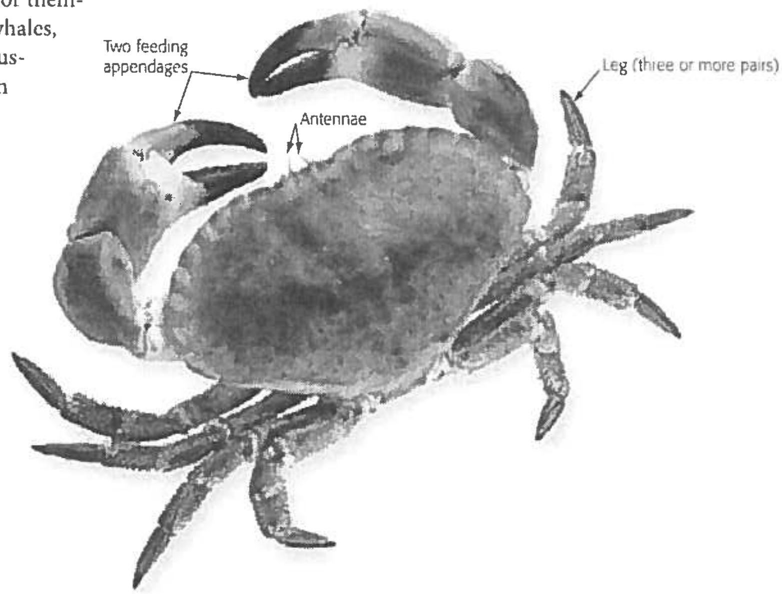
Spider. Like most spiders, including the tarantula in the large photo, this black widow spins a web of liquid silk, which solidifies as it comes out of specialized glands. A black widow's venom can kill small prey but is rarely fatal to humans.

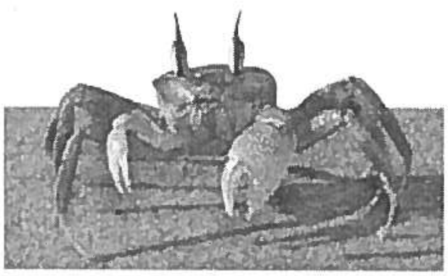
Wood tick. Wood ticks and other species carry bacteria that cause Rocky Mountain spotted fever. Lyme disease is carried by several different species of ticks.

Crustaceans

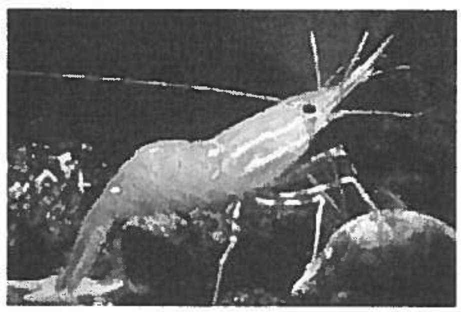
Crustaceans are nearly all aquatic, including delectable species of crabs, lobsters, crayfish, and shrimps (**Figure 17.21**). Barnacles, which anchor themselves to rocks, boat hulls, and even whales, are also crustaceans. One group of crustaceans, the isopods, is represented on land by pill bugs. All of these animals exhibit the arthropod characteristic of multiple pairs of specialized appendages.

▼ **Figure 17.21 Crustacean characteristics and diversity.**

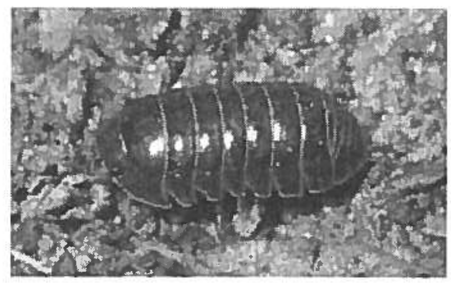




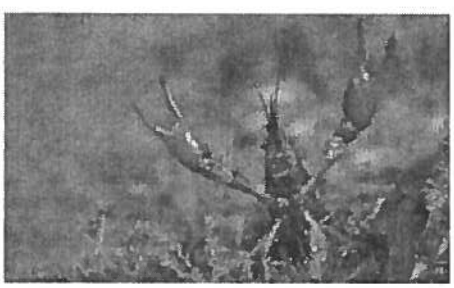
Crab. Ghost crabs are common along shorelines throughout the world. They scurry along the surf's edge and then quickly bury themselves in sand.



Shrimp. Naturally found in Pacific waters from Africa to Asia, giant prawns are widely cultivated as food.



Pill bug. Commonly found in moist locations with decaying leaves, such as under logs, pill bugs get their name from their tendency to roll up into a tight ball when they sense danger.



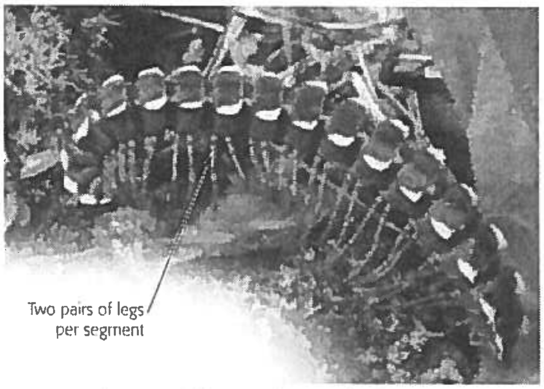
Crayfish. The red swamp crayfish, cultivated worldwide for food, becomes a pest when released outside of its native range in the southeastern United States.

Barnacles. Barnacles are stationary crustaceans with exoskeletons hardened into shells by calcium carbonate (lime). The jointed appendages projecting from the shell capture small plankton.

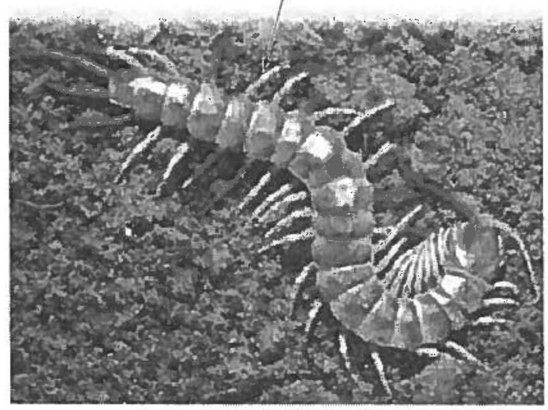
Millipedes and Centipedes

Millipedes and **centipedes** have similar segments over most of the body and superficially resemble annelids, but their jointed legs reveal they are arthropods (**Figure 17.22**). Millipedes are landlubbers that eat decaying plant matter. They have two pairs of short legs per body segment. Centipedes are terrestrial carnivores, with a pair of poison claws used in defense and to paralyze prey, such as cockroaches and flies. Each of their body segments bears a single pair of legs.

▸ **Figure 17.22 Millipedes and centipedes.**



Millipede. Like most millipedes, this blue millipede has an elongated body with two pairs of legs per trunk segment.



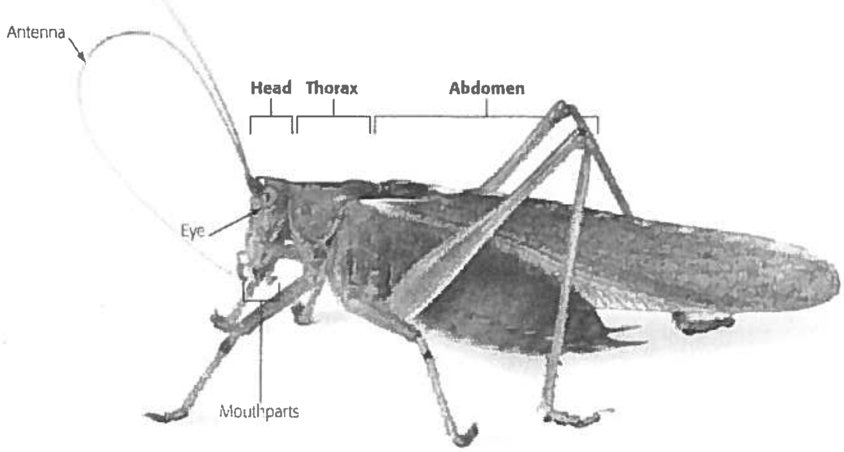
Centipede. Centipedes can be found in dirt and leaf litter. Their venomous claws can harm cockroaches and spiders, but not people.

Insect Anatomy

Like the grasshopper in **Figure 17.23**, most **insects** have a three-part body: head, thorax, and abdomen. The head usually bears a pair of sensory antennae and a pair of eyes. The mouthparts of insects are adapted for particular kinds of eating—for example, for biting and chewing plant material in grasshoppers; for lapping up fluids in houseflies; and for piercing skin and sucking blood in mosquitoes. Most adult insects have three pairs of legs and one or two pairs of wings, all extending from the thorax.

Flight is obviously one key to the great success of insects. An animal that can fly can escape many predators, find food and mates, and disperse to new habitats much faster than an animal that must crawl on the ground. Because their wings are extensions of the exoskeleton and not true appendages, insects can fly without sacrificing legs. By contrast, the flying vertebrates—birds and bats—have one of their two pairs of legs modified for wings, which explains why these vertebrates are generally not very swift on the ground.

▾ **Figure 17.23 Anatomy of a grasshopper.**

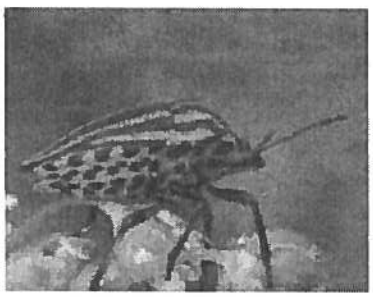


Insect Diversity

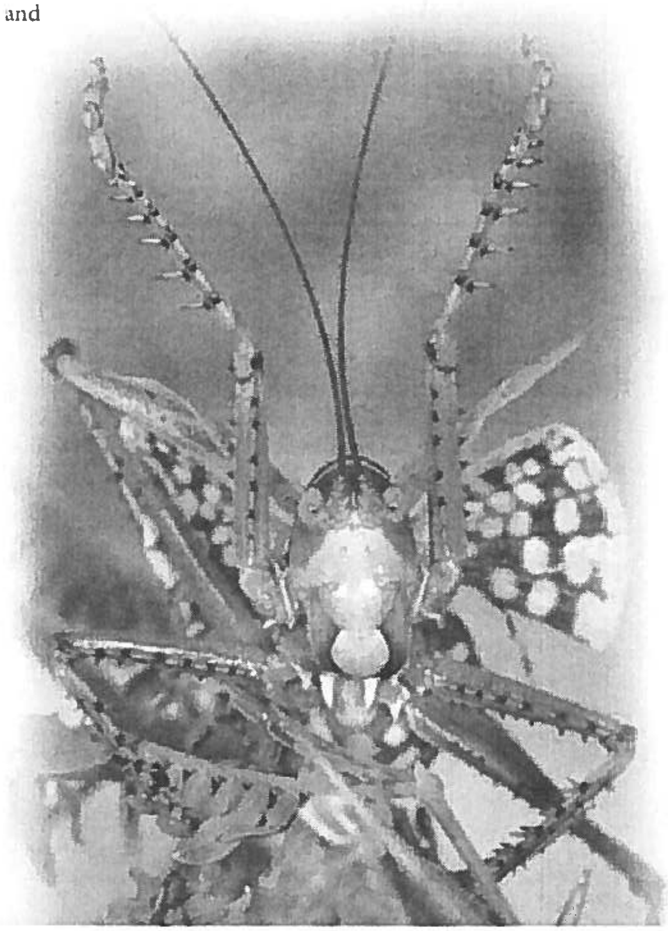
In species diversity, insects outnumber all other forms of life combined **(Figure 17.24)**. They live in almost every terrestrial habitat and in fresh water, and flying insects fill the air. Insects are rare in the seas, where crustaceans are the dominant arthropods. The oldest insect fossils date back to about 400 million years ago. Later, the evolution of flight sparked an explosion in insect variety.

▼ Figure 17.24 Insect diversity.

Rhinoceros beetle. Only males have a "horn," which is used for fighting other males and for digging.



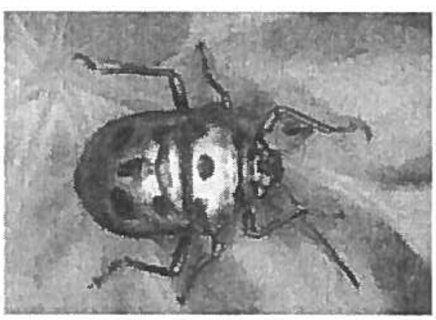
Red-and-black-striped stink bug. Members of this large insect family give off a foul-smelling liquid when disturbed.



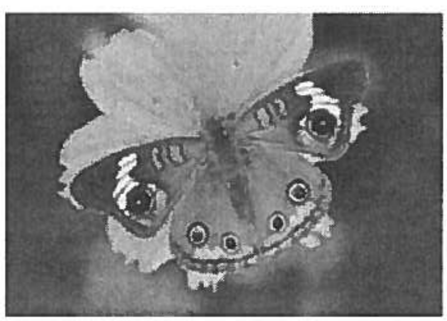
Greater arid-land katydid. Often called the red-eyed devil, this scary-looking predator displays its wings and spiny legs when threatened.

Trilobite beetle. This beetle is found in the tropical rain forests of India and Southeast Asia.

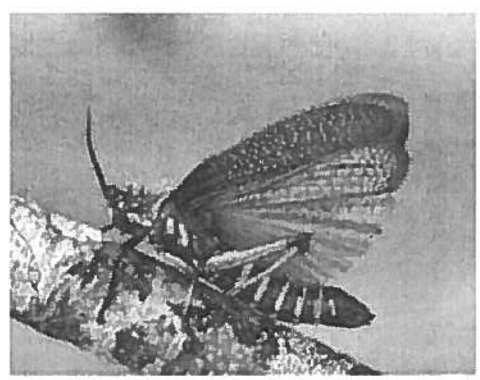
Praying mantis. There are over 2,000 species of praying mantises throughout the world.



Jeweled beetle. Light reflected from varying thicknesses of chitin produces the brilliant colors of this beetle.



Buckeye butterfly. The eyespots on the wings of this butterfly may startle predators.



Rainbow bush locust. This colorful relative of grasshoppers is found in Madagascar.

Many insects undergo metamorphosis in their development. In the case of grasshoppers and some other insect groups, the young resemble adults but are smaller and have different body proportions. The animal goes through a series of molts, each time looking more like an adult, until it reaches full size. In other cases, insects have distinctive larval stages specialized for eating and growing that are known by such names as maggots (fly larvae), grubs (beetle larvae), or caterpillars (larvae of moths and butterflies). The larval stage looks entirely different from the adult stage, which is specialized for dispersal and reproduction. Metamorphosis from the larva to the adult occurs during a pupal stage (**Figure 17.25**).

Forensic entomologists (forensic scientists who study insects) use their knowledge of insect life cycles to help solve criminal cases. For example, blowfly maggots feed on decaying flesh. Female blowflies, which can smell a dead body from up to a mile away, typically arrive and lay their eggs in a fresh corpse within minutes. By knowing the length of each stage in the life cycle of a blowfly, an entomologist can determine how much time has passed since death occurred.

When a killer dumps a body outdoors, who (or what) is first to arrive on the scene?

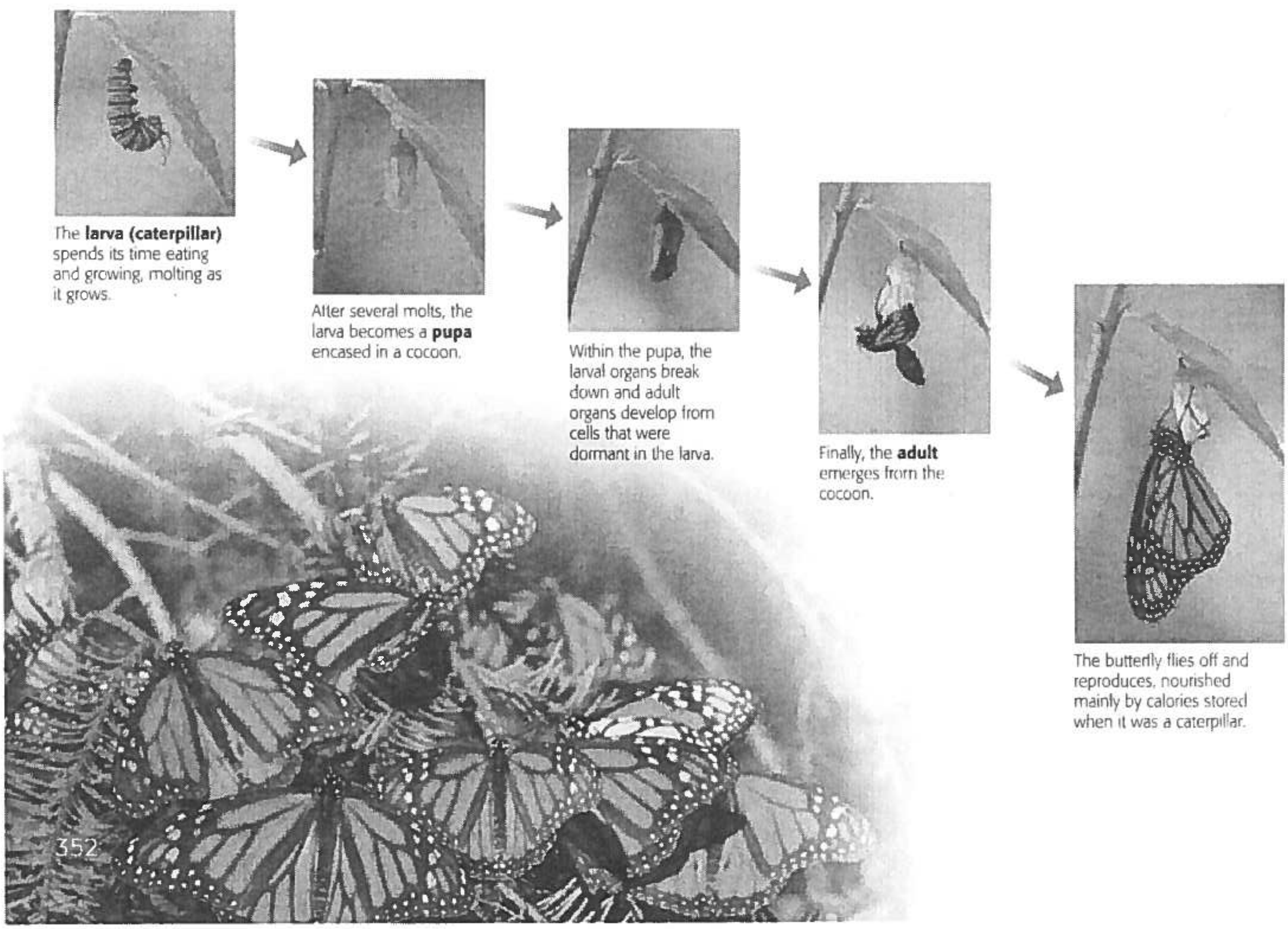
Animals so numerous, diverse, and widespread as insects are bound to affect the lives of all other terrestrial organisms, including people, in many ways. On the one hand, we depend on bees, flies, and other insects to pollinate our crops and orchards. On the other hand, insects are carriers of the microbes that cause many human diseases, such as malaria and West Nile disease. Insects also compete with people for food by eating our field crops. Trying to minimize their losses, farmers in the United States spend billions of dollars each year on pesticides, spraying crops with massive doses of insecticide poisons. But try as they might, not even humans have significantly challenged the preeminence of insects and their arthropod kin. As renowned entomologist Thomas Eisner put it: "Bugs are not going to inherit the Earth. They own it now. So we might as well make peace with the landlord." ☑

☑ CHECKPOINT

Which major arthropod group is mainly aquatic? Which is the most numerous?

Answer: crustaceans; insects

▼ **Figure 17.25 Metamorphosis of a monarch butterfly.**



The **larva (caterpillar)** spends its time eating and growing, molting as it grows.

After several molts, the larva becomes a **pupa** encased in a cocoon.

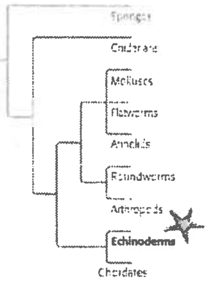
Within the pupa, the larval organs break down and adult organs develop from cells that were dormant in the larva.

Finally, the **adult** emerges from the cocoon.

The butterfly flies off and reproduces, nourished mainly by calories stored when it was a caterpillar.

MAJOR INVERTEBRATE PHYLA

Echinoderms



The **echinoderms** (phylum Echinodermata) are named for their spiny surfaces (*echin* is Greek for "spiny"). Among the echinoderms are sea stars, sea urchins, sea cucumbers, and sand dollars **(Figure 17.26)**.

Echinoderms include about 7,000 species, all of them marine. Most move slowly, if at all. Echinoderms lack body segments, and most have radial symmetry as adults. Both the external and the internal parts of a sea star, for instance, radiate from the center like the spokes of a wheel. In contrast to the adult, the larval stage of echinoderms is bilaterally symmetric. This supports other evidence that echinoderms are not closely related to other radial animals, such as cnidarians, that never show bilateral symmetry. Most echinoderms have an **endoskeleton** (interior skeleton) constructed from hard plates just beneath the skin. Bumps and spines of this endoskeleton account for the animal's rough or prickly surface. Unique to echinoderms is the **water vascular system**, a network of water-filled canals that circulate water throughout the echinoderm's body, facilitating gas exchange (the entry of O_2 and the removal of CO_2) and waste disposal. The water vascular system also branches into extensions called tube feet. A sea star or sea urchin pulls itself slowly over the seafloor using its suction-cup-like tube feet. Sea stars also use their tube feet to grip prey during feeding.

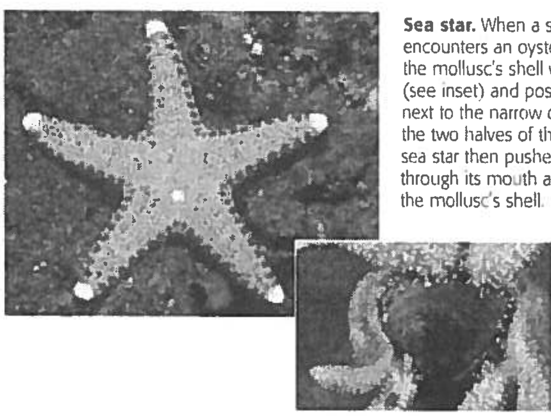
Looking at sea stars and other adult echinoderms, you may think they have little in common with humans and other vertebrates. But as shown by the phylogenetic tree at the left, echinoderms share an evolutionary branch with chordates, the phylum that includes vertebrates. Analysis of embryonic development can differentiate the echinoderms and chordates from the evolutionary branch that includes molluscs, flatworms, annelids, roundworms, and arthropods. With this context in mind, we're now ready to make the transition from invertebrates to vertebrates. ☑

☑ CHECKPOINT

Contrast the skeleton of an echinoderm with that of an arthropod.

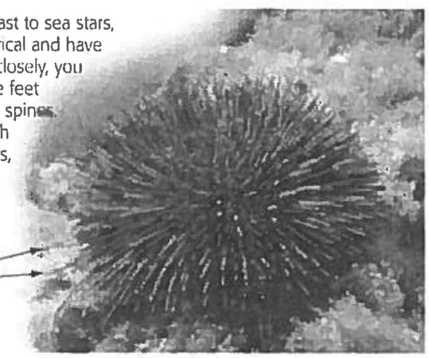
Answer: An echinoderm has an endoskeleton; an arthropod has an exoskeleton.

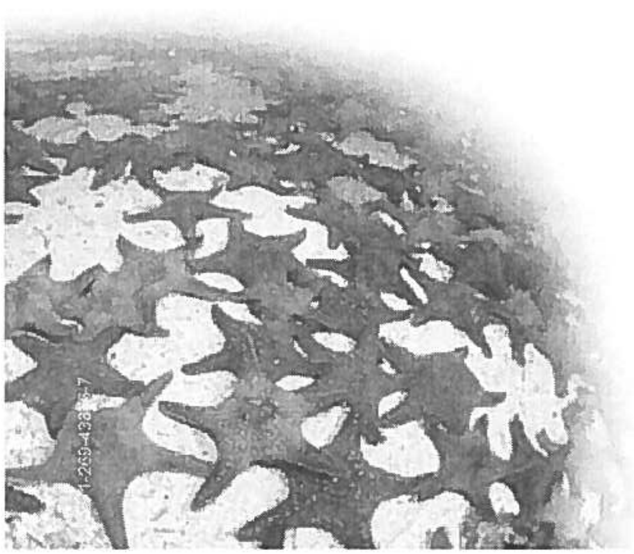
▼ Figure 17.26 Echinoderm diversity.

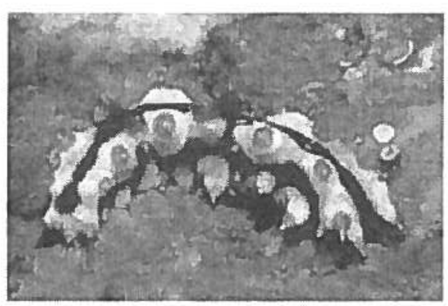


Sea star. When a sea star encounters an oyster or clam, it grips the mollusc's shell with its tube feet (see inset) and positions its mouth next to the narrow opening between the two halves of the prey's shell. The sea star then pushes its stomach out through its mouth and the crack in the mollusc's shell.

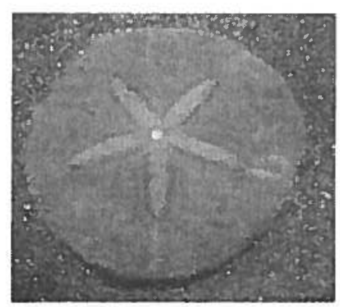
Sea urchin. In contrast to sea stars, sea urchins are spherical and have no arms. If you look closely, you can see the long tube feet projecting among the spines. Unlike sea stars, which are mostly carnivorous, sea urchins mainly graze on seaweed and other algae.







Sea cucumber. On casual inspection, this sea cucumber does not look much like other echinoderms. However, a closer look would reveal many echinoderm traits, including five rows of tube feet.



Sand dollar. Live sand dollars have a skin of movable spines covering a rigid skeleton. A set of five pores (arranged in a star pattern) allows seawater to be drawn into the sand dollar's body.