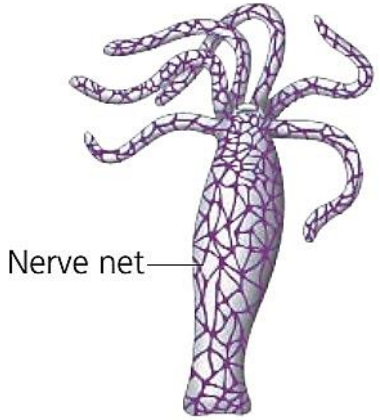
Nervous systems consist of circuits of neurons and supporting cells

By the time of the Cambrian explosion, more than 500 million years ago specialized nervous systems had appeared that enable animals to sense their surroundings and respond rapidly. **Hydras**, **jellies**, and other **cnidarians** are the simplest animals with nervous systems. In most cnidarians, interconnected neurons form a diffuse **nerve net** which controls the contraction and expansion of the gastrovascular cavity.

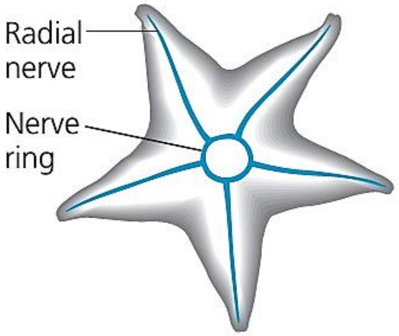
In more complex animals, the axons of multiple neurons are often bundled together, forming **nerves**. These fibrous structures channel information flow along specific routes through the nervous system. For example, **sea stars** have a set of radial nerves connecting to a central nerve ring. Within each arm of a sea star, the radial nerve is linked to a nerve net from which it receives input and to which it sends signals that control muscle contraction.

In many animals, neurons that carry out integration form a **central nervous system (CNS)**, and neurons that carry information into and out of the CNS form a **peripheral nervous system (PNS)**.

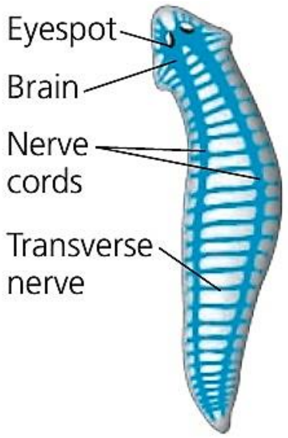
In nonsegmented worms, such as the planarian in a small brain and longitudinal nerve cords constitute the simplest clearly defined CNS. In certain nonsegmented worms, the entire nervous system is constructed from only a small number of cells, as in the case of the nematode Caenorhabditis elegans. In this species, an adult worm (hermaphrodite) has exactly 302 neurons, no more and no fewer.



(a) Hydra (cnidarian)



(b) Sea star (echinoderm)



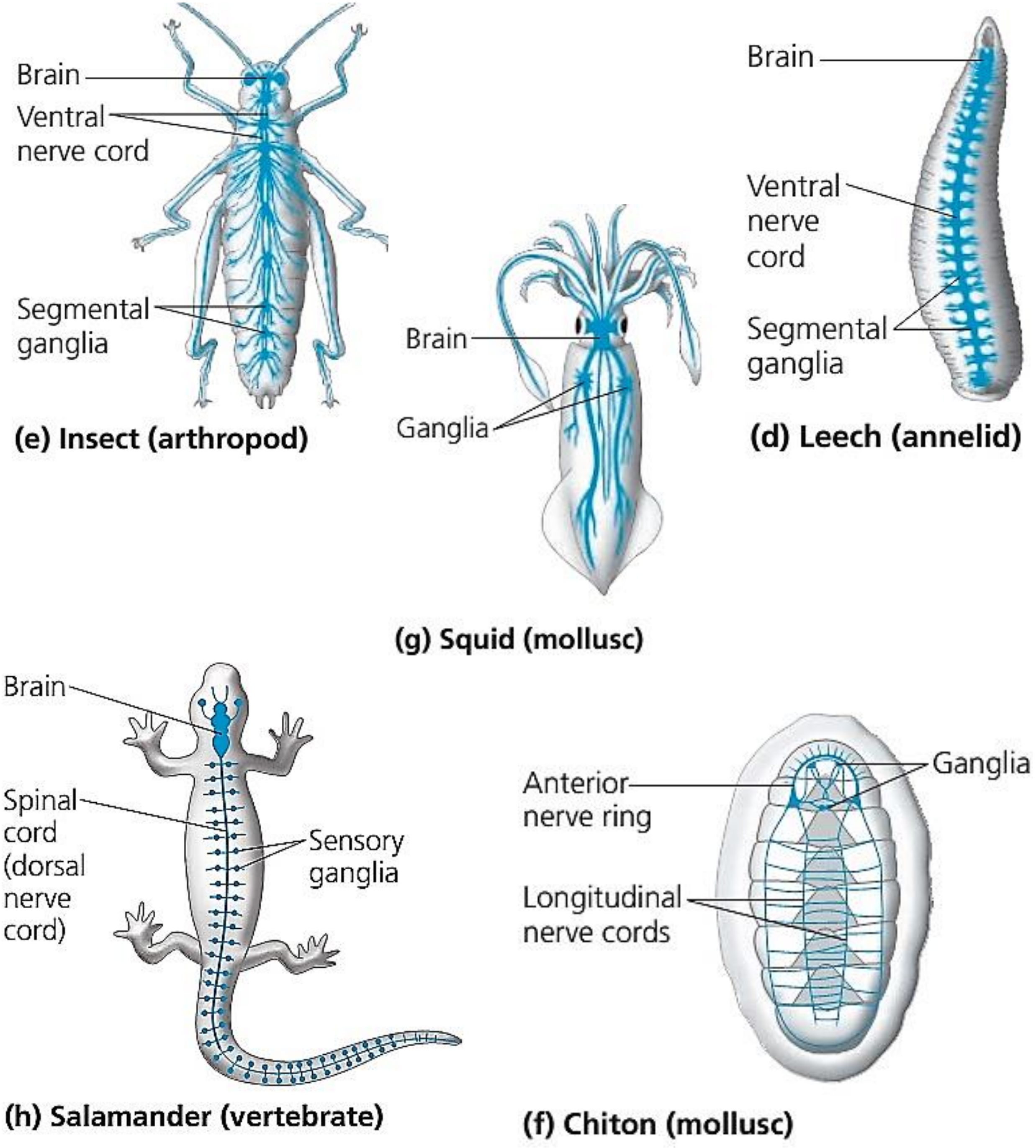
(c) Planarian (flatworm)

More complex invertebrates, such as segmented worms (d) and arthropods (e), have many more neurons. Their behavior is regulated by more complicated brains and by ventral nerve cords containing **ganglia**, segmentally arranged clusters of neurons that act as relay points in transmitting information.

Within an animal group, nervous system organization often correlates with lifestyle. Among the molluscs, for example, sessile and slow-moving species, such as clams and chitons, have relatively simple sense organs and little or no cephalization, an evolutionary trend toward a clustering of sensory neurons and interneurons at the anterior (front) end of the body. Nerves that extend toward the posterior (rear) end enable these anterior neurons to communicate with cells elsewhere in the body. (f).

In contrast, active predatory molluscs, such as octopuses and squids have the most sophisticated nervous systems of any invertebrate. With their large, image-forming eyes and a brain containing millions of neurons, octopuses can learn to discriminate between visual patterns and to perform complex tasks, such as unscrewing a jar to feed on its contents (g).

In vertebrates such as a salamander (h) or human the brain and the spinal cord form the CNS; nerves and ganglia are the key elements of the PNS.



(e) Insect (arthropod)

(g) Squid (mollusc)

(d) Leech (annelid)

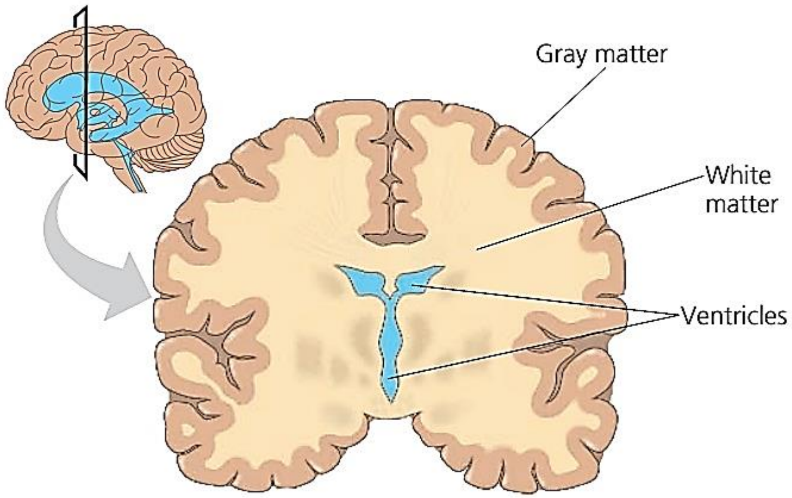
(h) Salamander (vertebrate)

(f) Chiton (mollusc)

Organization of the Vertebrate Nervous System

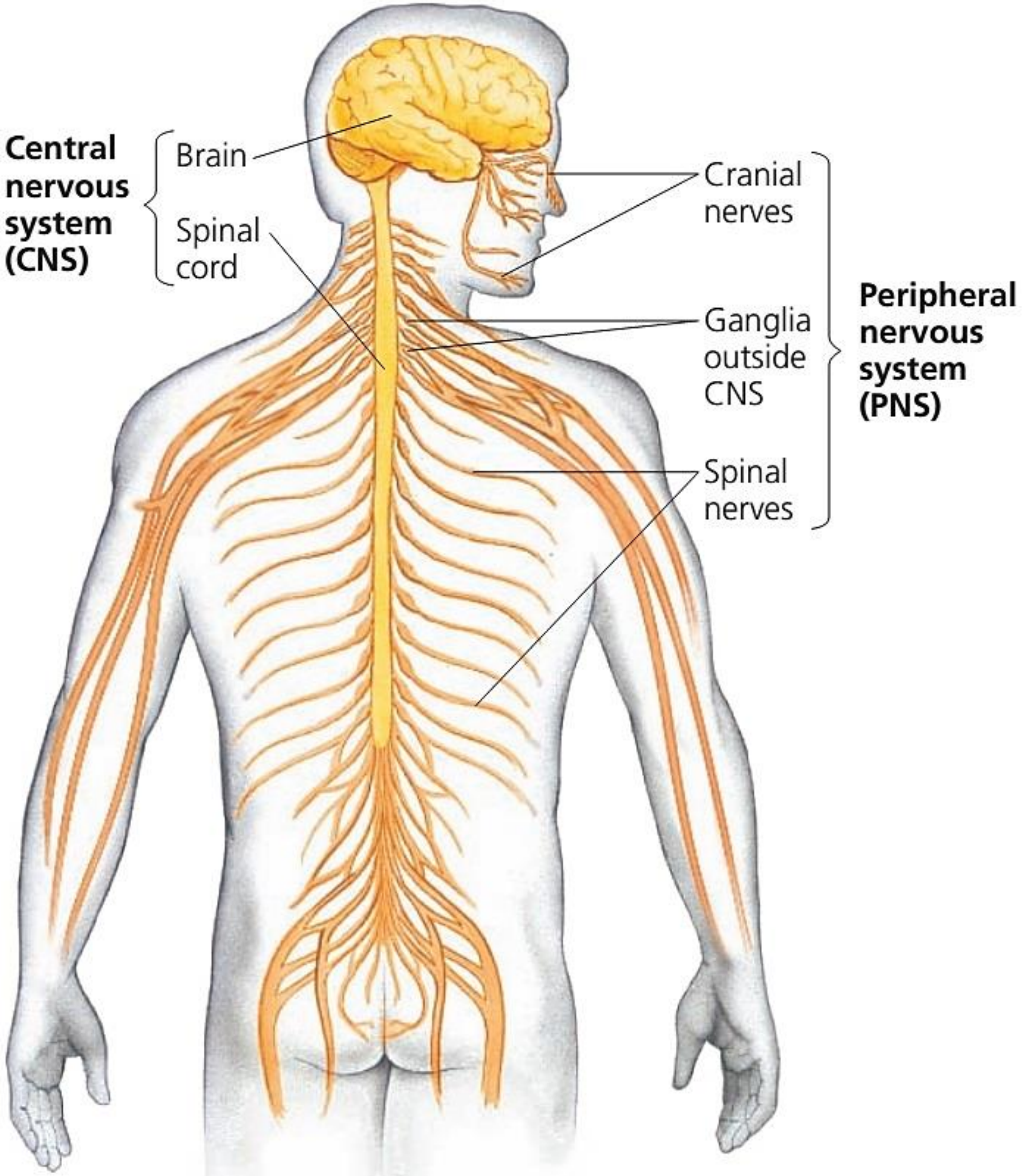
During embryonic development in vertebrates, the central nervous system develops from the hollow dorsal nerve cord. The cavity of the nerve cord gives rise to the narrow central canal of the spinal cord as well as the ventricles of the brain. Both the canal and ventricles fill with cerebrospinal fluid, which is formed in the brain by filtering arterial blood. The cerebrospinal fluid supplies the CNS with nutrients and hormones and carries away wastes, circulating through the ventricles and central canal before draining into the veins.

▼ **Figure 49.4 Ventricles, gray matter, and white matter.** Ventricles deep in the brain's interior contain cerebrospinal fluid. In the cerebrum, most of the gray matter is on the surface, surrounding the white matter.



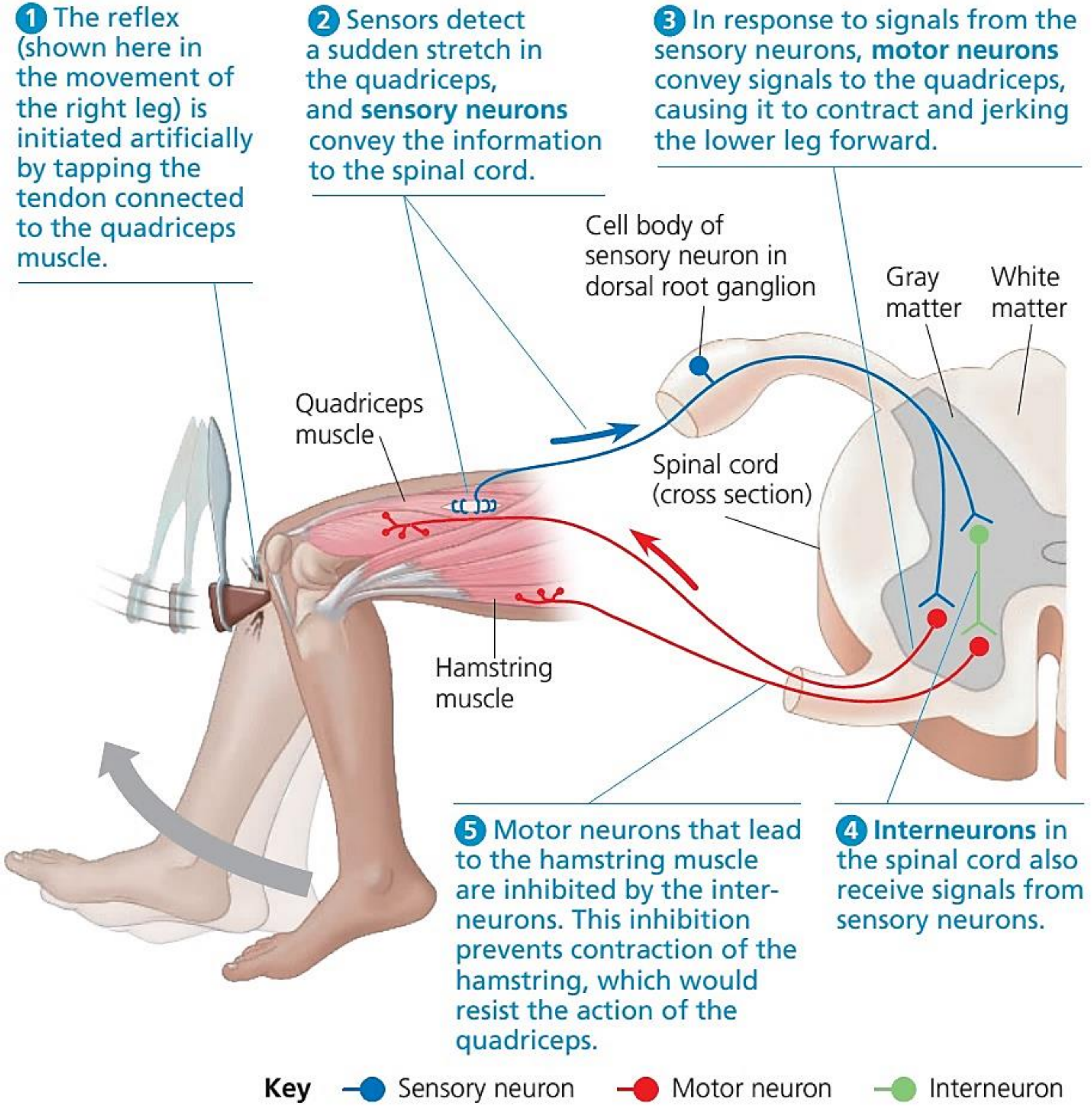
In addition to fluid-filled spaces, the brain and spinal cord have gray and white matter. **Gray matter** is primarily made up of neuron cell bodies. White matter consists of bundled axons. In the spinal cord, **white matter** forms the outer layer, reflecting its role in linking the CNS to sensory and motor neurons of the PNS. In the brain, white matter is predominantly in the interior, where signaling between neurons functions in learning, feeling emotions, processing sensory information, and generating commands.

▼ **Figure 49.3 The vertebrate nervous system.** The central nervous system consists of the brain and spinal cord (yellow). Left-right pairs of cranial nerves, spinal nerves, and ganglia make up most of the peripheral nervous system (dark gold).



In vertebrates, the spinal cord runs lengthwise inside the vertebral column, known as the spine. The spinal cord conveys information to and from the brain and generates basic patterns of locomotion. It also acts independently of the brain as part of the simple nerve circuits that produce **reflexes**, the body's automatic responses to certain stimuli.

Reflexes protect the body by providing rapid, involuntary responses to particular stimuli. Reflexes are rapid because sensory information is used to activate motor neurons without the information first having to travel from the spinal cord to the brain and back. If you accidentally put your hand on a hot burner, a reflex jerks your hand back even before your brain processes pain. Similarly, the knee-jerk reflex provides an immediate protective response when you pick up an unexpectedly heavy object.



▶ **Figure 49.5 The knee-jerk reflex.** Many neurons are involved in this reflex, but for simplicity only a few neurons are shown.