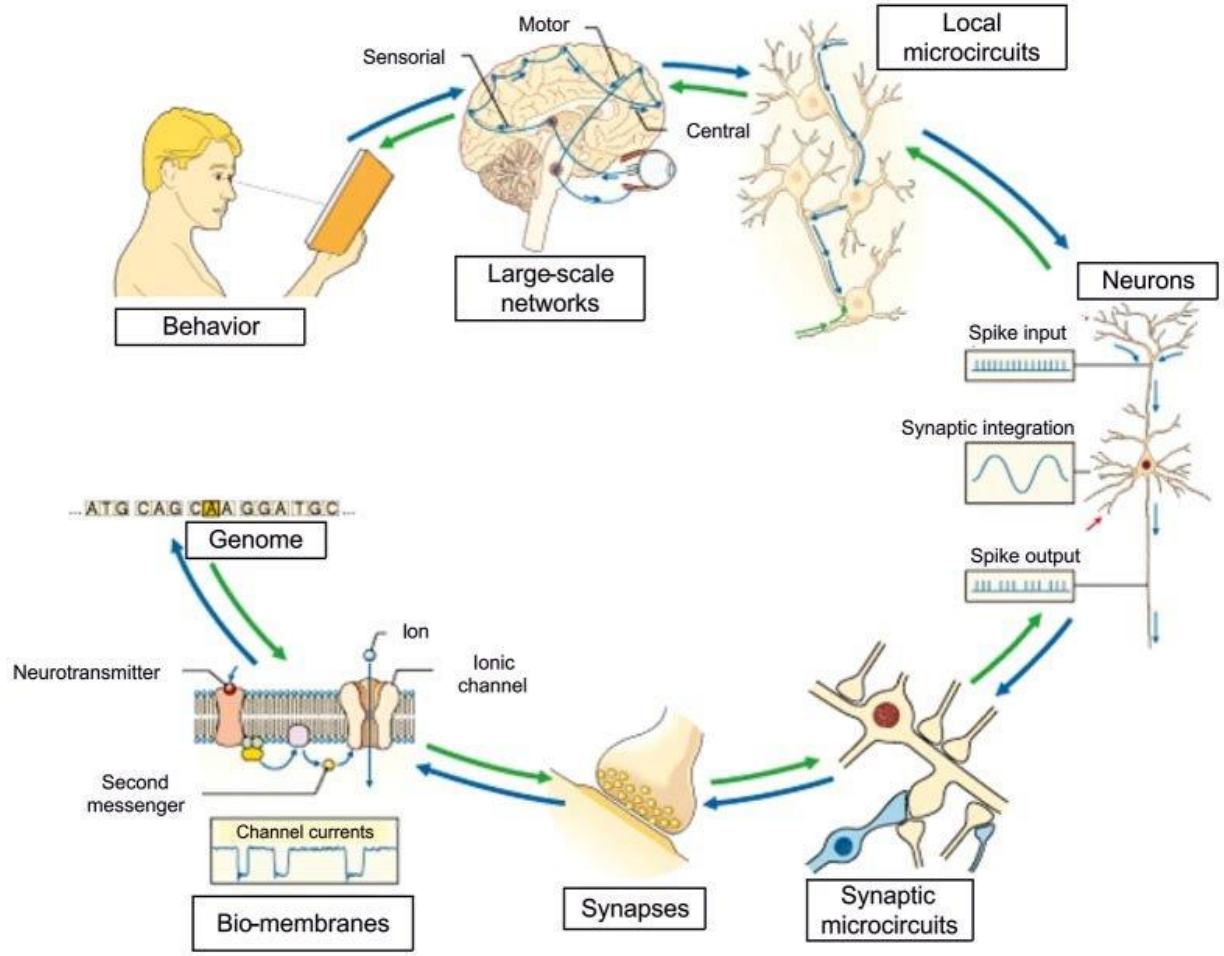
Neuron structure and function

Lecture 2

Outline

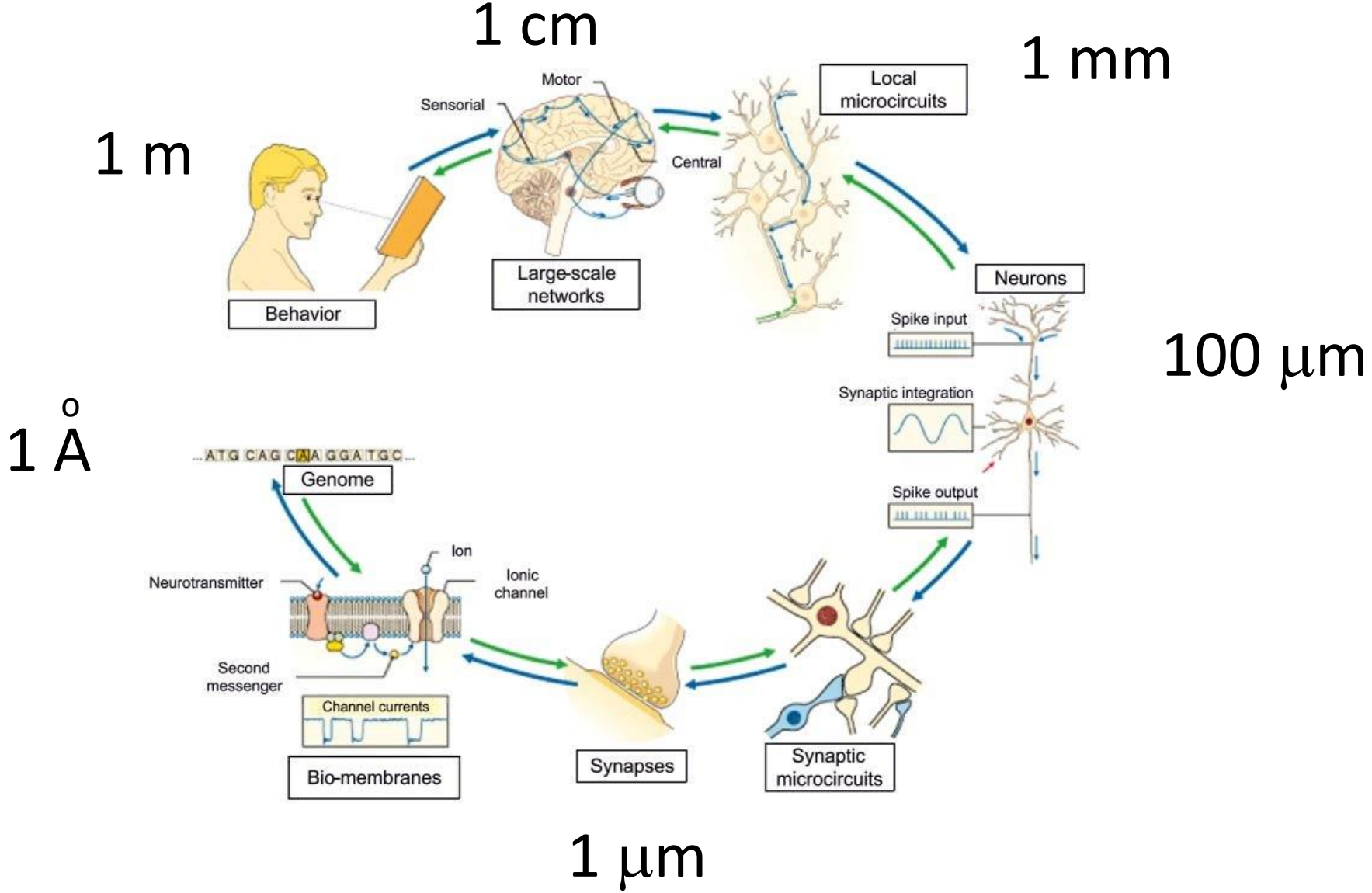
- General nervous system description
- Functional classes of neurons
- Basic function of neurons
- Structural classes of neurons
- Glial cells
- Neuron communications and action potential

Multiscale organization of the brain



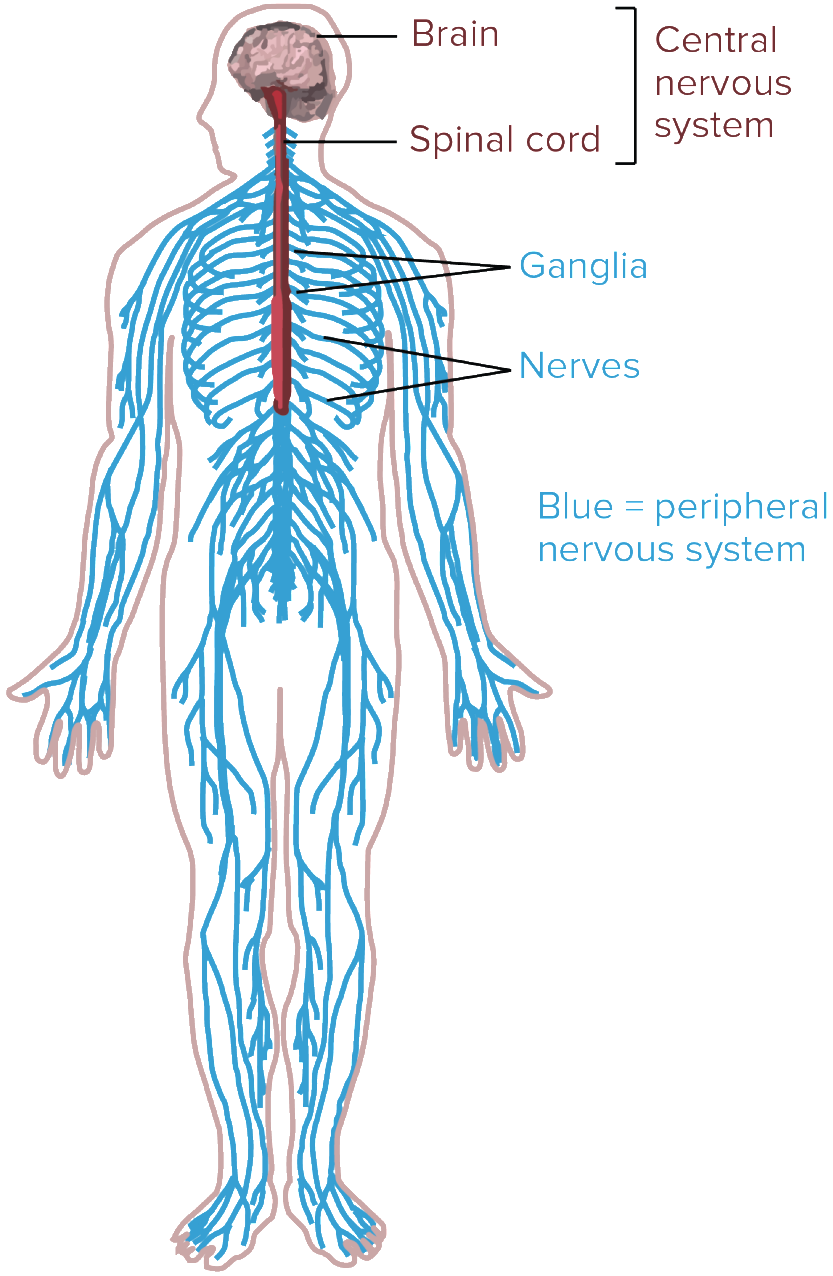
Panel illustrates the multiple levels characterizing brain organization, from molecules to cells, circuits and behaviour.

Multiscale organization of the brain



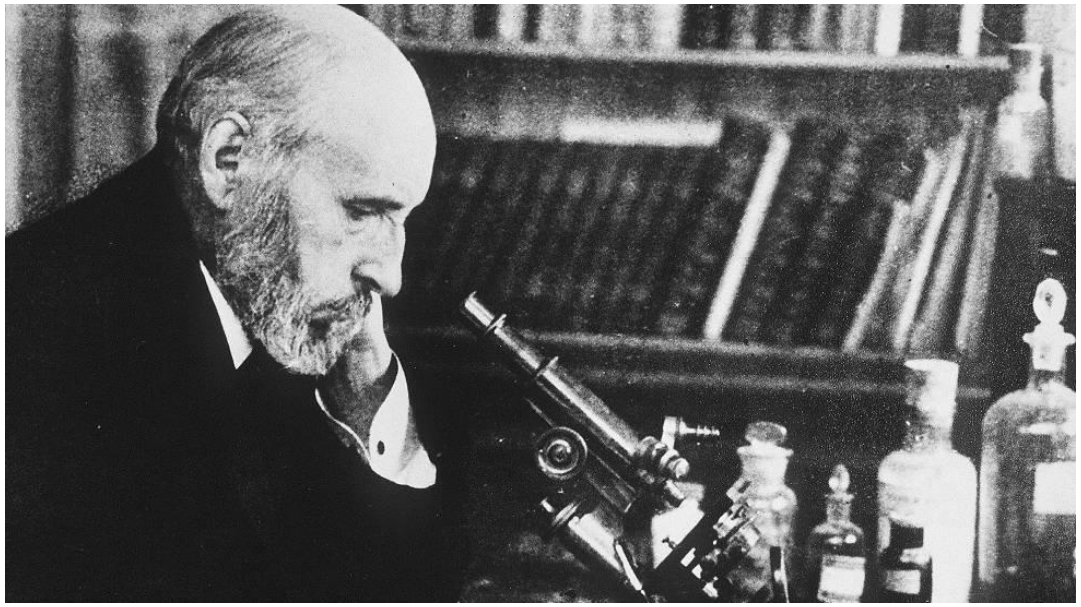
The human nervous system

- The **central nervous system** (**CNS**) consists of the brain and the spinal cord. It is in the CNS that all of the analysis of information takes place.
- The **peripheral nervous system** (**PNS**), which consists of the neurons and parts of neurons found outside of the CNS, includes sensory neurons and motor neurons. Sensory neurons bring signals into the CNS, and motor neurons carry signals out of the CNS.



Neuron doctrine

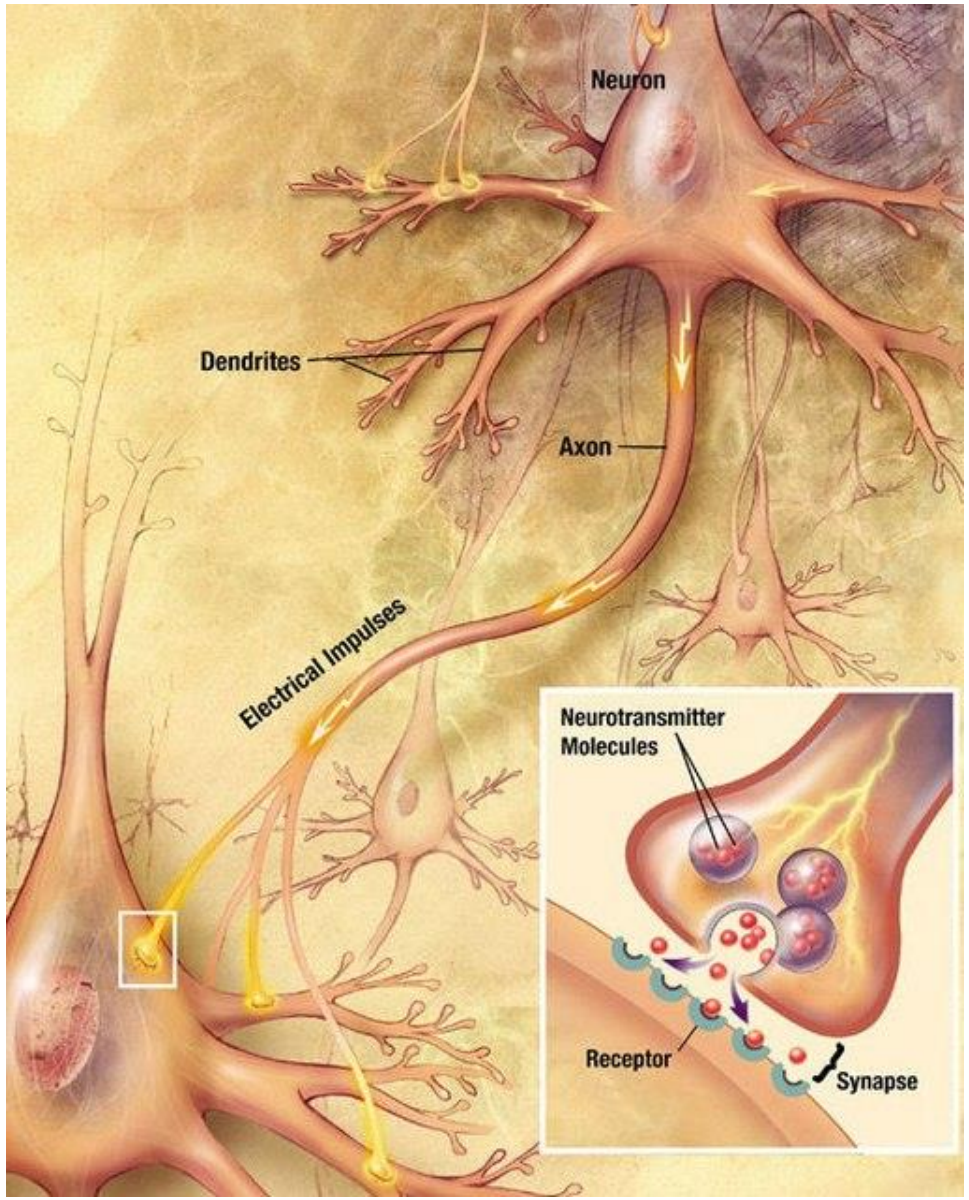
- The neuron doctrine is the fundamental idea that neurons are the basic structural and functional units of the nervous system.
- The theory was put forward by Santiago Ramón y Cajal in the late 19th century.



- He held that neurons are discrete cells (not connected in a meshwork), working as metabolically distinct units.

Law of Dynamic Polarization

- **A neuron receives signals at its dendrites and cell body and transmits them, as action potentials, along the axon in one direction: away from the cell body**
  - Most neurons have many short **dendrites** that receive signals, sending them inward towards the cell body as electrical impulses.
  - Neurons have a single **axon** that typically sends electrical impulses outwards away from the cell body. Axons can vary in length from extremely short to over 1 m to reach from the base of your spine to your ankle
- There are important exceptions: dendrites can serve as synaptic output sites of neurons and axons can receive synaptic inputs



Neuron

Neurons are similar to other cells in the body:

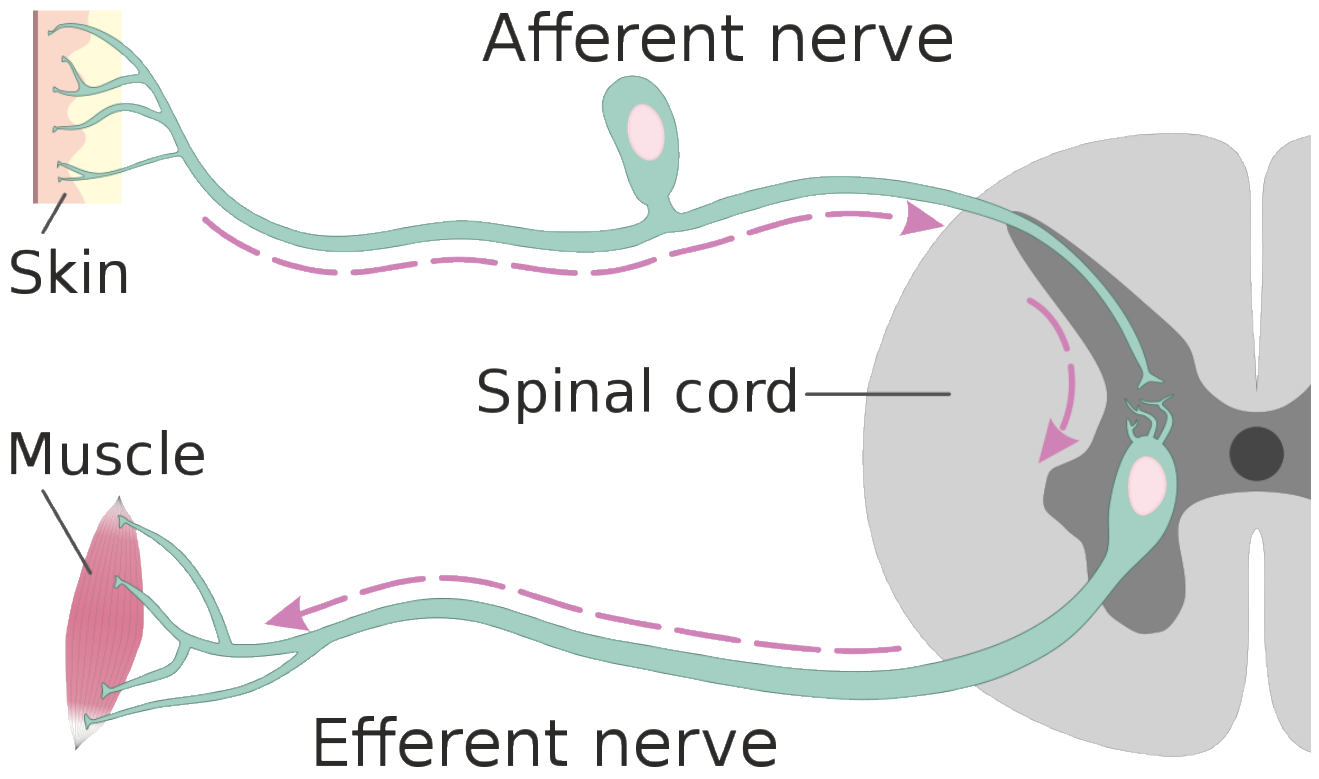
- Neurons are surrounded by a cell membrane.
- Neurons have a nucleus that contains genes.
- Neurons contain cytoplasm, mitochondria and other organelles.
- Neurons carry out basic cellular processes such as protein synthesis and energy production.

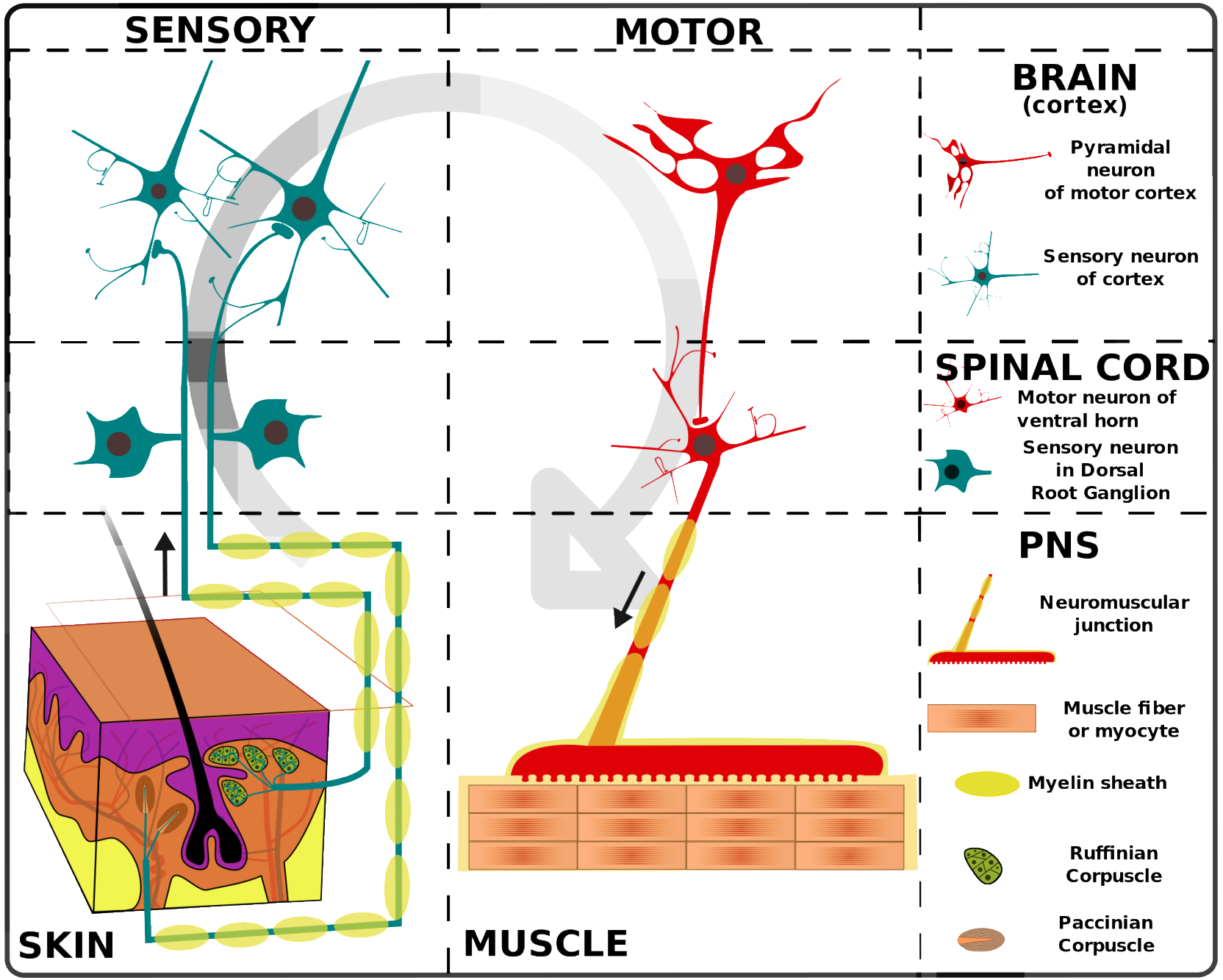
Neurons differ from other cells in the body:

- Neurons have specialize cell parts called **dendrites** and **axons**. Dendrites bring electrical signals to the cell body and axons take information away from the cell body.
- Neurons communicate with each other through an electrochemical process.
- Neurons contain some specialized structures (for example, synapses) and chemicals (for example, neurotransmitters).

Functional classes of neurons

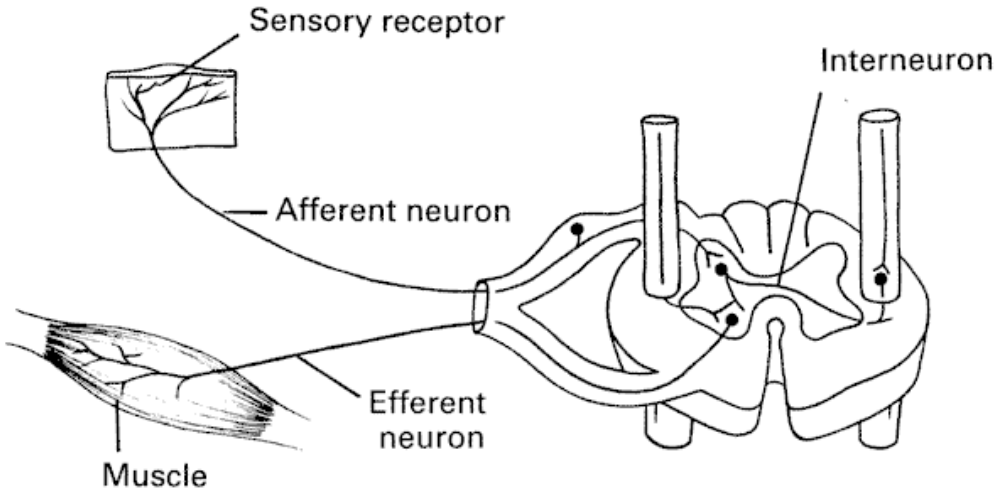
- **Sensory (or afferent) neurons** get information about what's going on inside and outside of the body and bring that information into the CNS so it can be processed. For instance, if you picked up a hot coal, sensory neurons with endings in your fingertips would convey the information to your CNS that it was really hot.
- **Motor (or efferent) neurons** get information from other neurons and convey commands to your muscles, organs and glands. For instance, if you picked up a hot coal, it motor neurons innervating the muscles in your fingers would cause your hand to let go.




SENSORY
MOTOR
BRAIN
(cortex)
Pyramidal neuron of motor cortex
Sensory neuron of cortex
SPINAL CORD
Motor neuron of ventral horn
Sensory neuron in Dorsal Root Ganglion
PNS
Neuromuscular junction
Muscle fiber or myocyte
Myelin sheath
Ruffinian Corpuscle
Paccinian Corpuscle
SKIN
MUSCLE

Classes of neurons

- **Interneurons**, which are found only in the CNS, connect one neuron to another. They receive information from one neurons (either sensory neurons or interneurons) and transmit information to other neurons (either motor neurons or interneurons).



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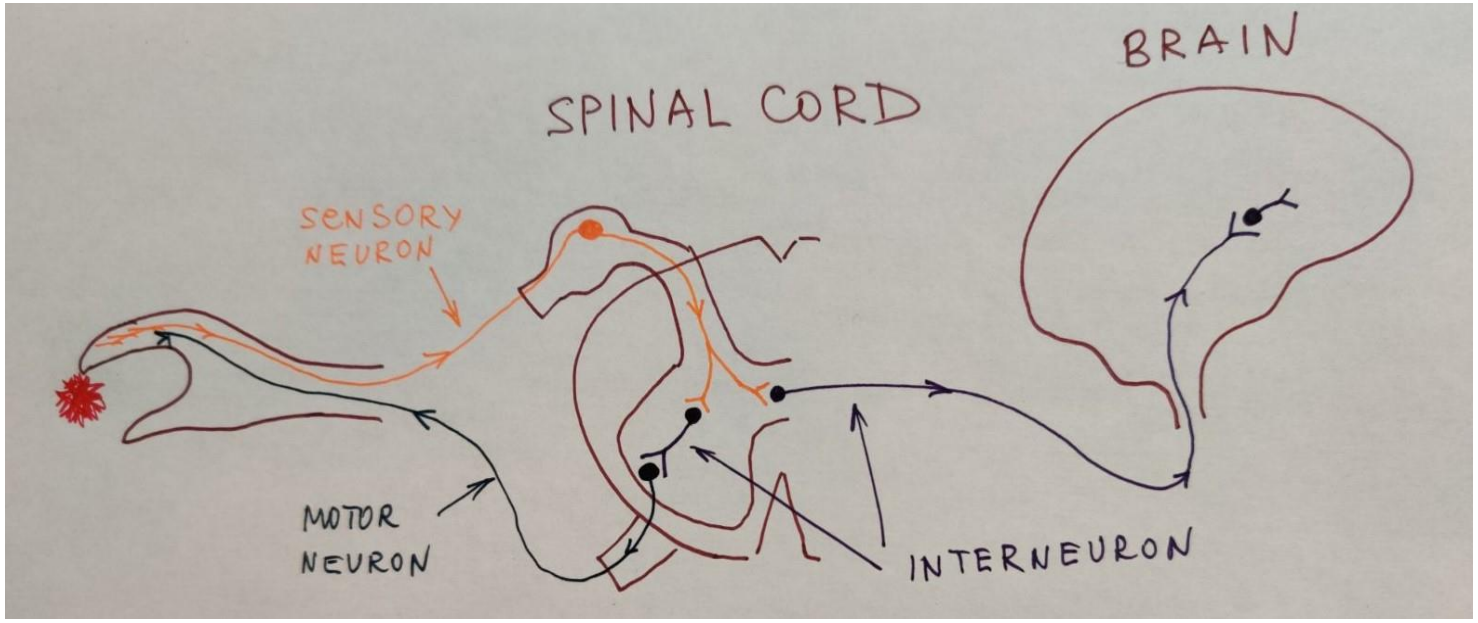


Classes of neurons

- **Interneurons** are the most numerous class of neurons and are involved in processing information, both in simple reflex circuits (like those triggered by hot objects) and in more complex circuits in the brain.
- It would be combinations of interneurons in your brain that would allow you to draw the conclusion that things that looked like hot coals weren't good to pick up, and, hopefully, retain that information for future reference.

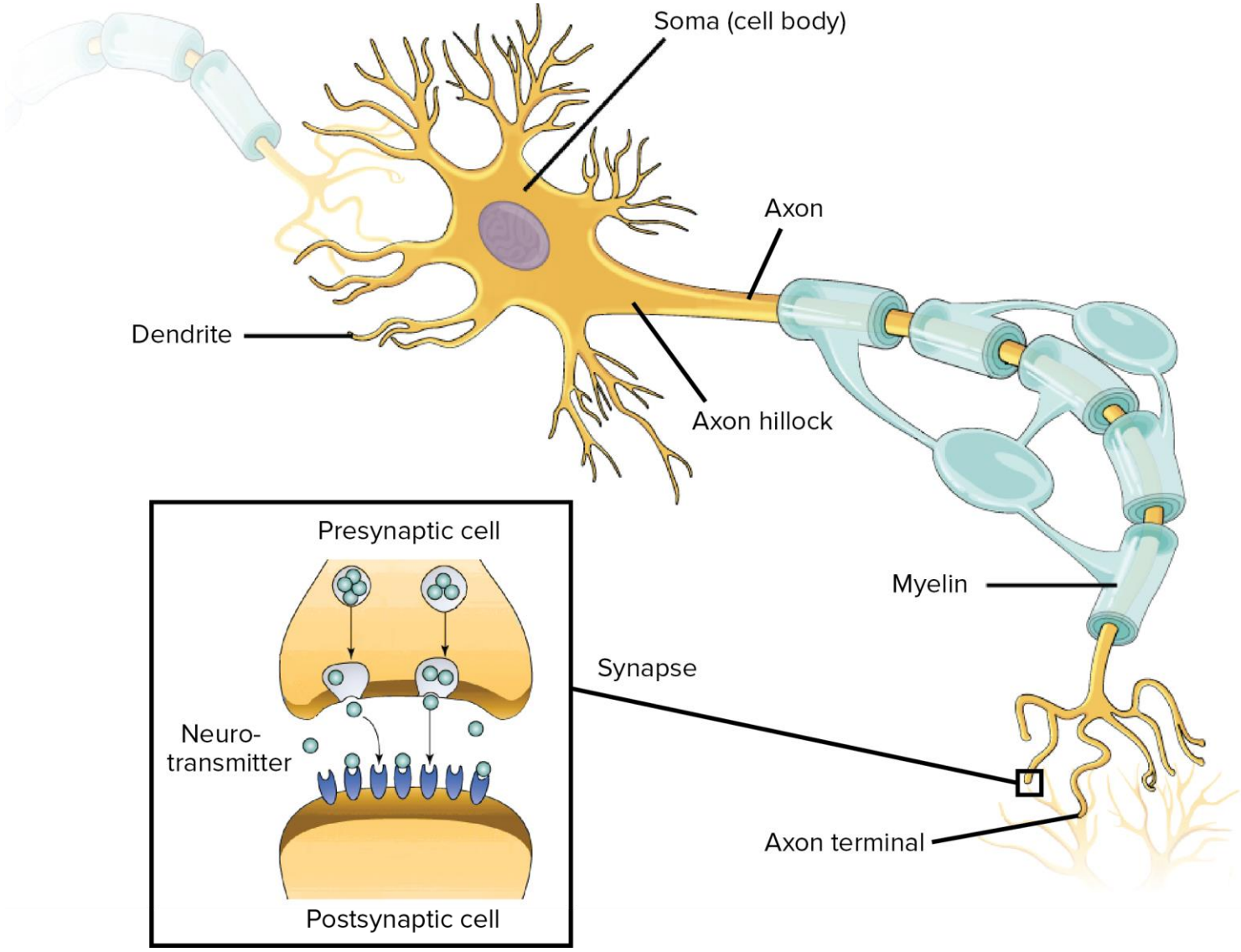
The basic functions of a neuron

- **Receive** signals (or information).
- **Integrate** incoming signals (to determine whether or not the information should be passed along).
- **Communicate** signals to target cells (other neurons or muscles or glands).

These neuronal functions are reflected in the anatomy of the neuron.

Anatomy and histology of neuron

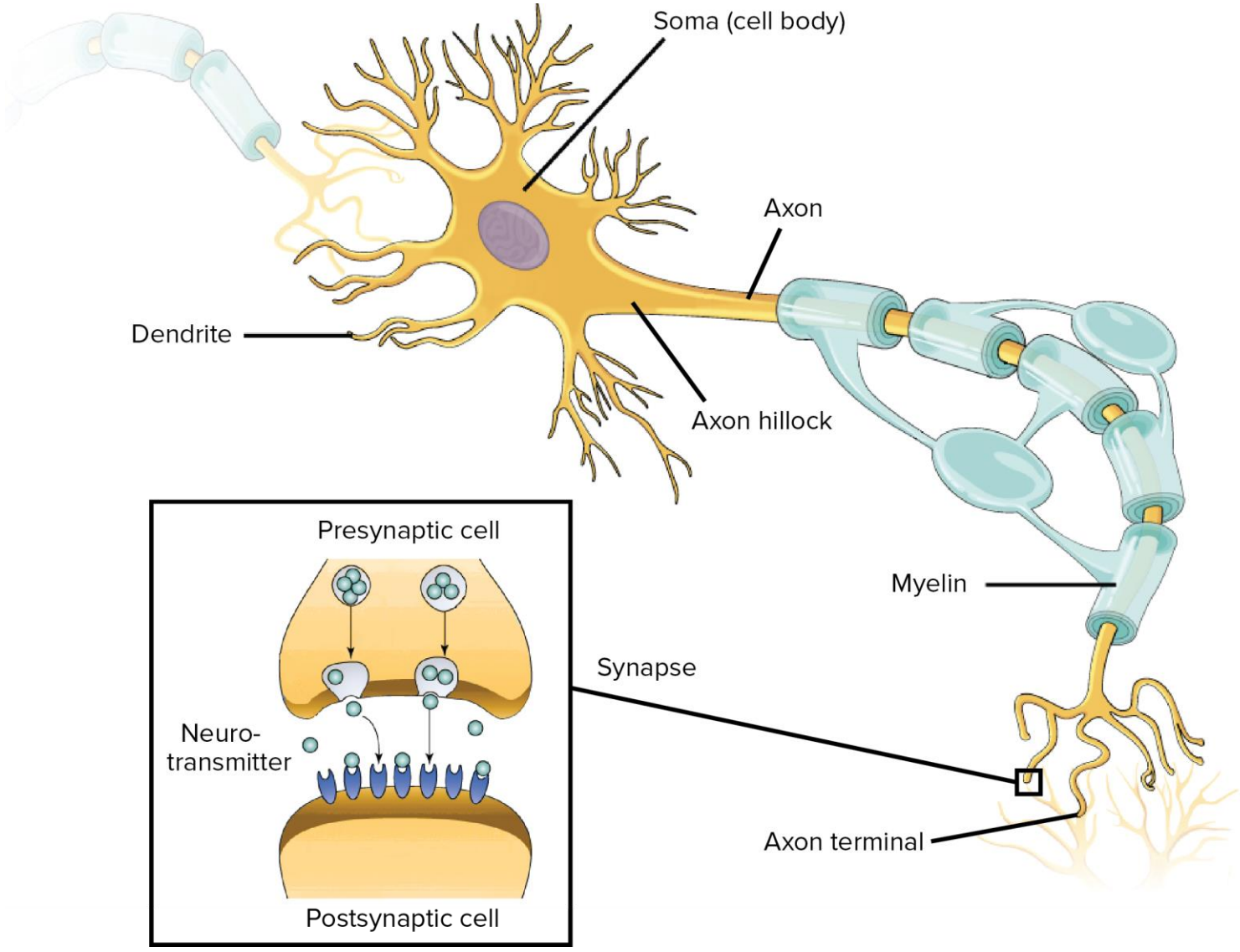
- **Soma**
- **Dendrites**
- **Axon**



Dendrites

The first two neuronal functions, receiving and processing incoming information, generally take place in the dendrites and cell body.

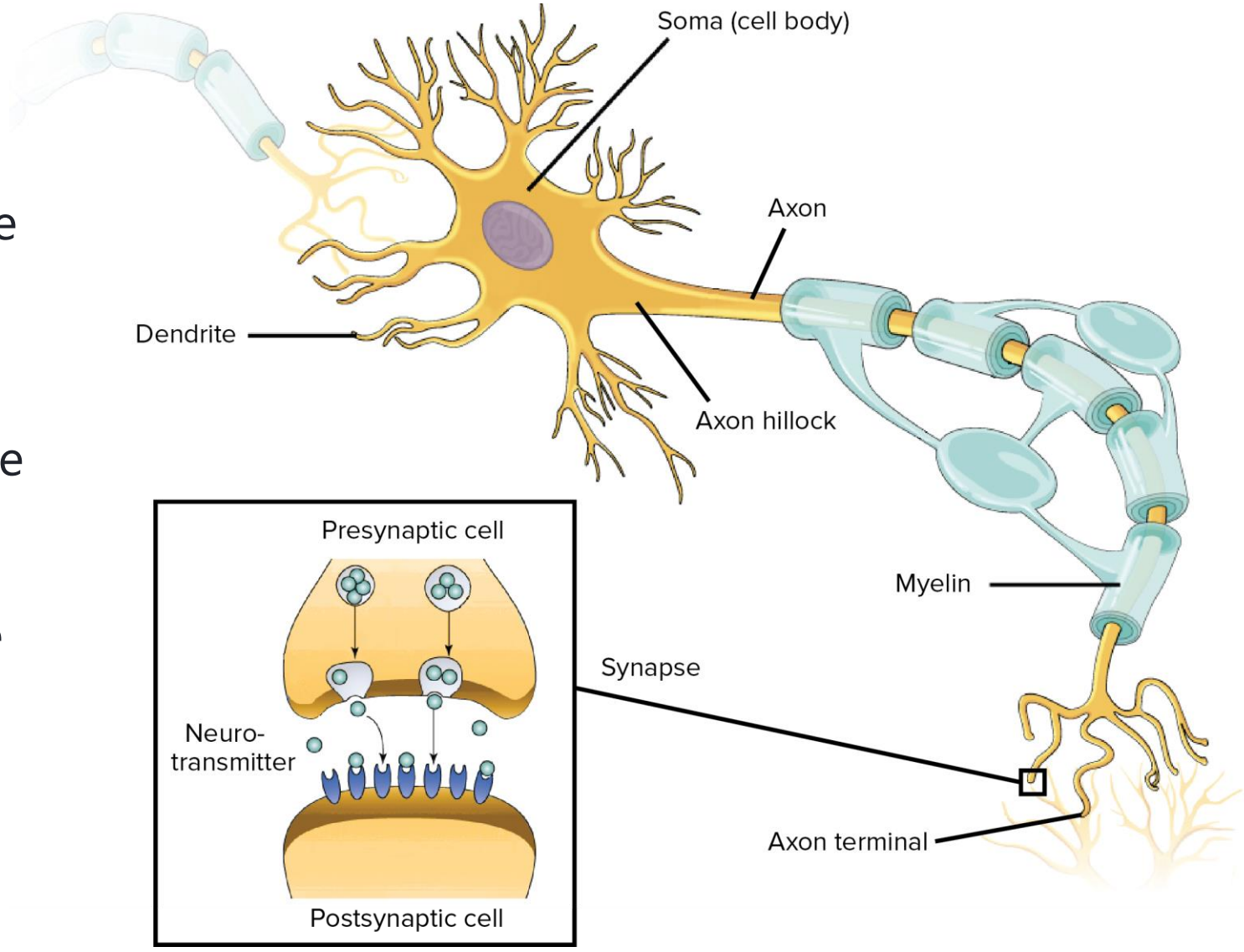
Incoming signals can be either **excitatory** – which means they tend to make the neuron fire (generate an electrical impulse) – or **inhibitory** – which means that they tend to keep the neuron from firing.



Dendrites

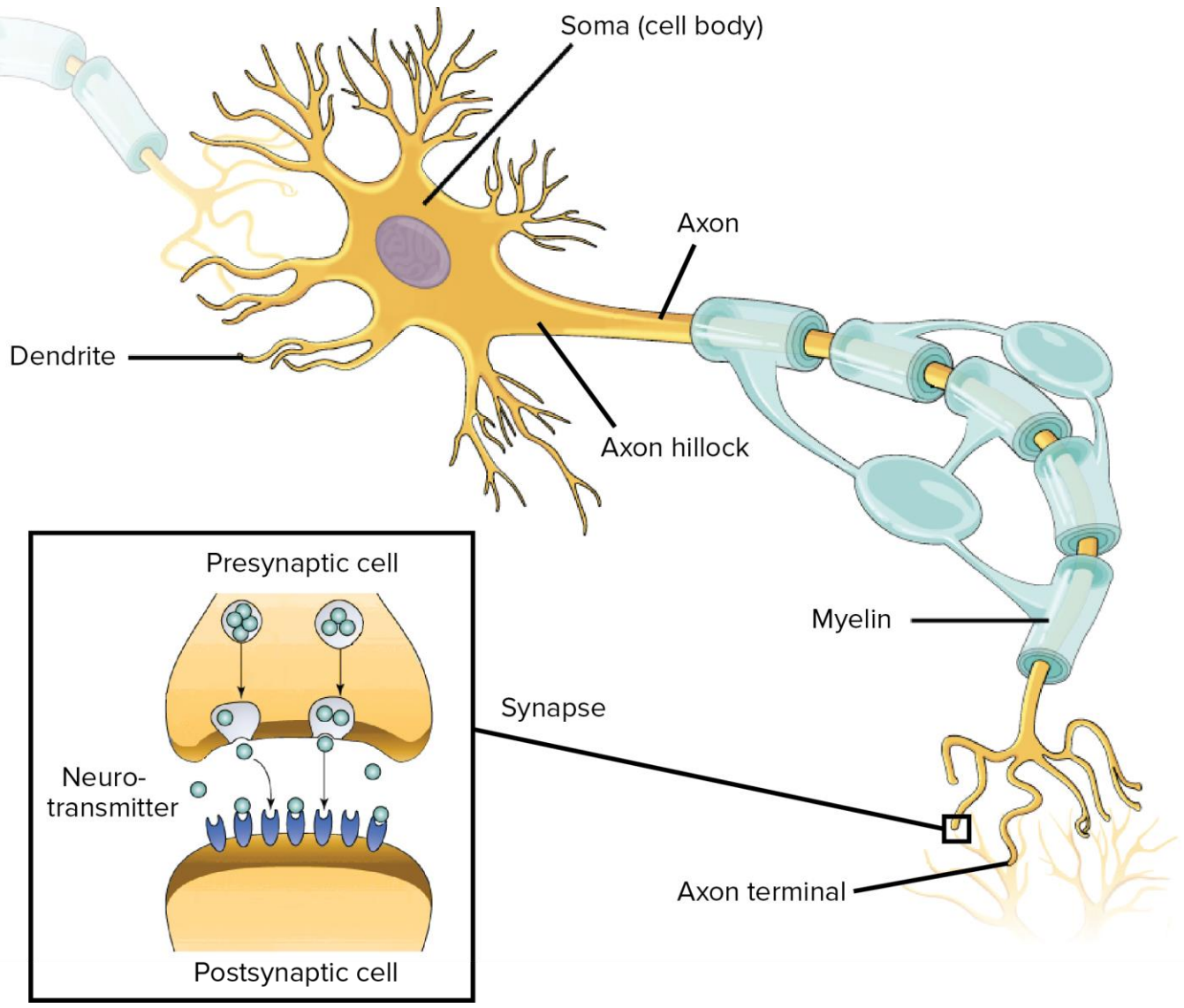
Neurons receive many input signals throughout their dendritic trees. A single neuron may have more than one set of dendrites, and may receive many thousands of input signals.

Whether or not a neuron is excited into firing an impulse depends on the sum of all of the excitatory and inhibitory signals it receives. If the neuron does end up firing, the nerve impulse, or **action potential**, is conducted down the axon.



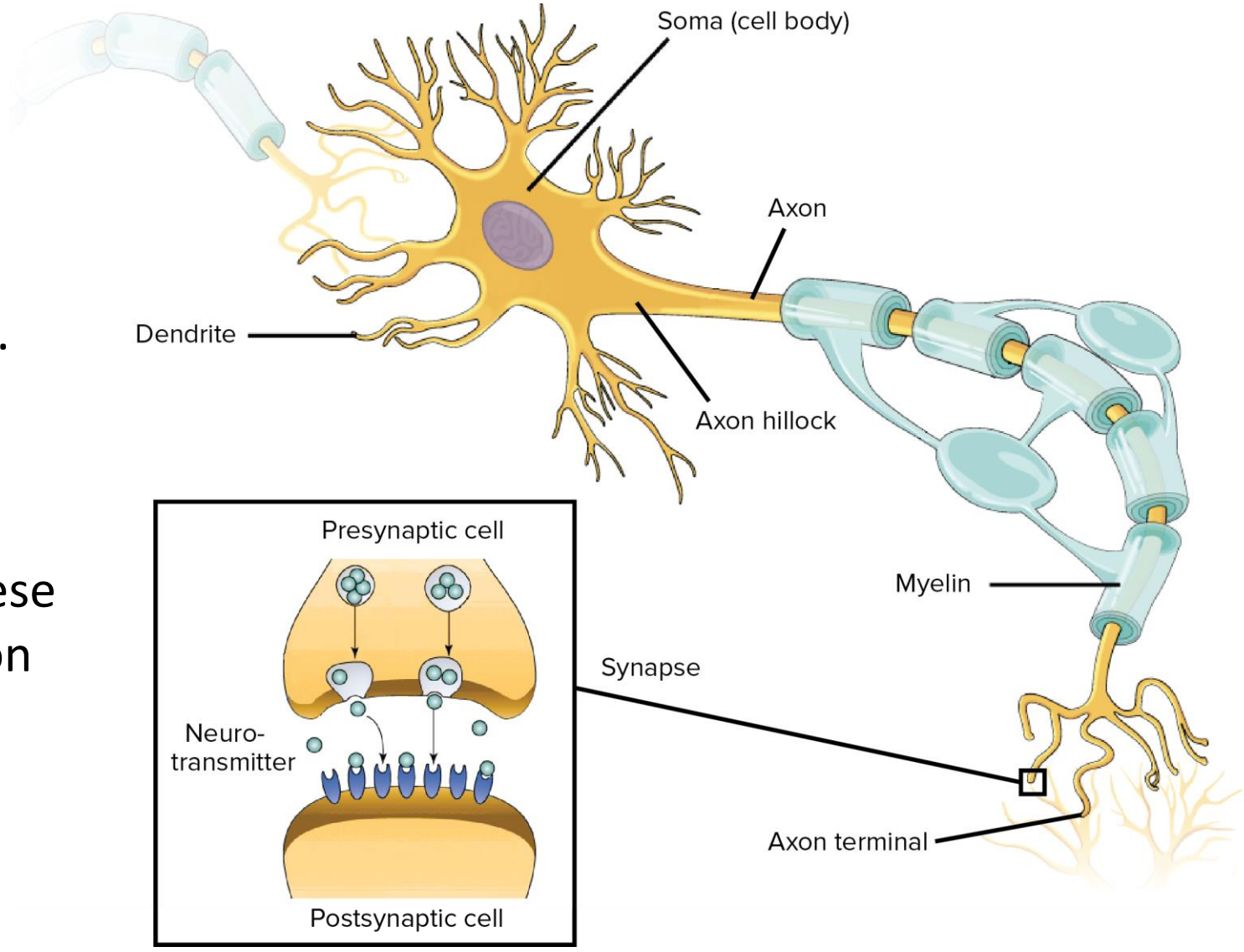
Axon

- The dendrites tend to taper and are often covered with little bumps called spines. In contrast, the axon tends to stay the same diameter for most of its length and doesn't have spines.
- The axon arises from the cell body at a specialized area called the **axon hillock**.



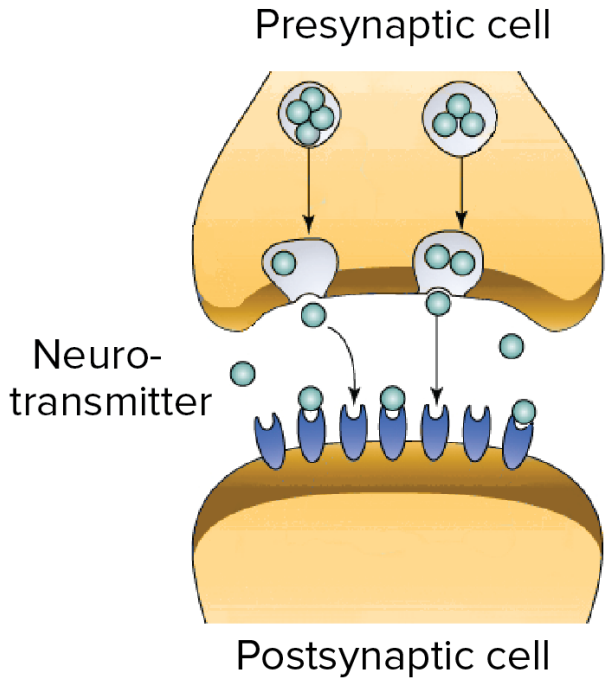
Axon

- Many axons are covered with a special insulating substance called **myelin**, which helps them convey the nerve impulse rapidly. Myelin is never found on dendrites.
- Towards its end, the axon splits up into many branches and develops bulbous swellings known as **axon terminals** (or **nerve terminals**). These axon terminals make connections on target cells.



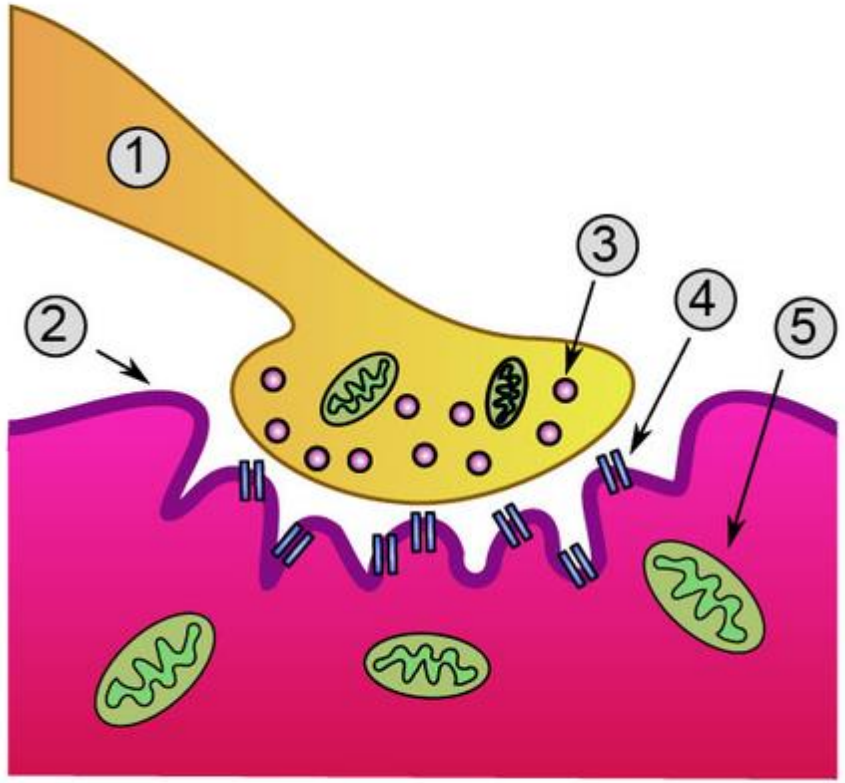
Synapses

Neuron-to-neuron connections are made onto the dendrites and cell bodies of other neurons. These connections, known as **synapses**, are the sites at which information is carried from the first neuron, the **presynaptic neuron**, to the target neuron (the **postsynaptic neuron**).



Neuromuscular junctions

- The synaptic connections between neuron (referred to as a motor neuron) and skeletal muscle cells are generally called neuromuscular junctions, and the connections between neurons and smooth muscle cells or glands are known as neuroeffector junctions.
- At a neuromuscular junction, the axon terminal of a neuron forms a synaptic connection not with another neuron, but instead with a muscle fiber.

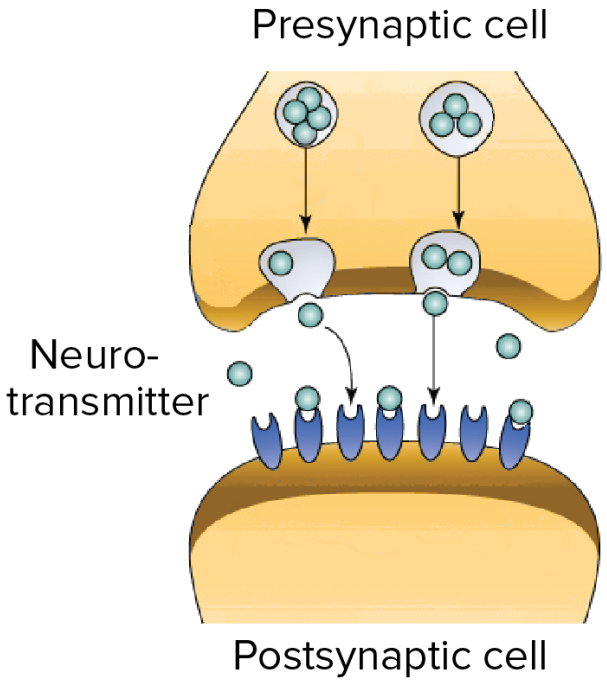


Synapses

At most synapses and junctions, information is transmitted in the form of chemical messengers called **neurotransmitters**.

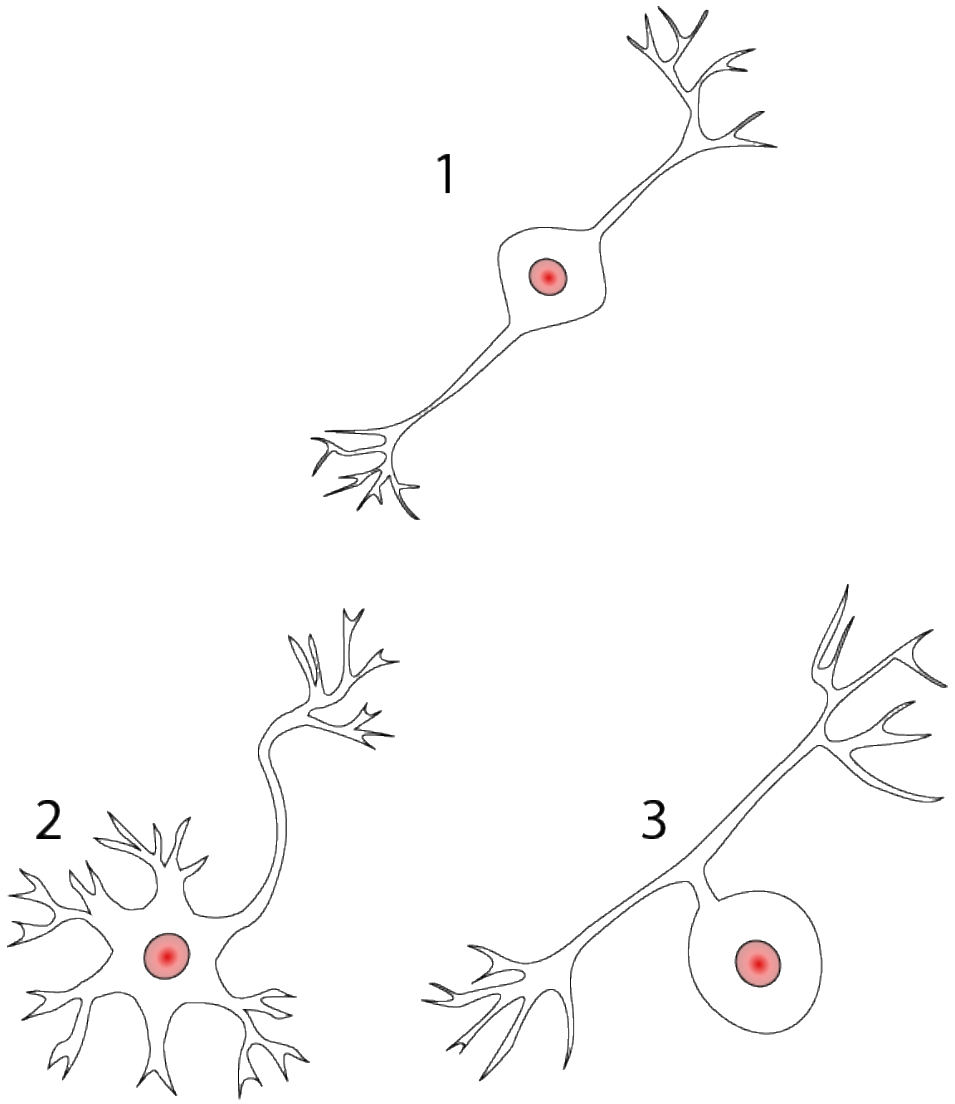
When an action potential travels down an axon and reaches the axon terminal, it triggers the release of neurotransmitter from the presynaptic cell.

Neurotransmitter molecules cross the synapse and bind to membrane receptors on the postsynaptic cell, conveying an excitatory or inhibitory signal.



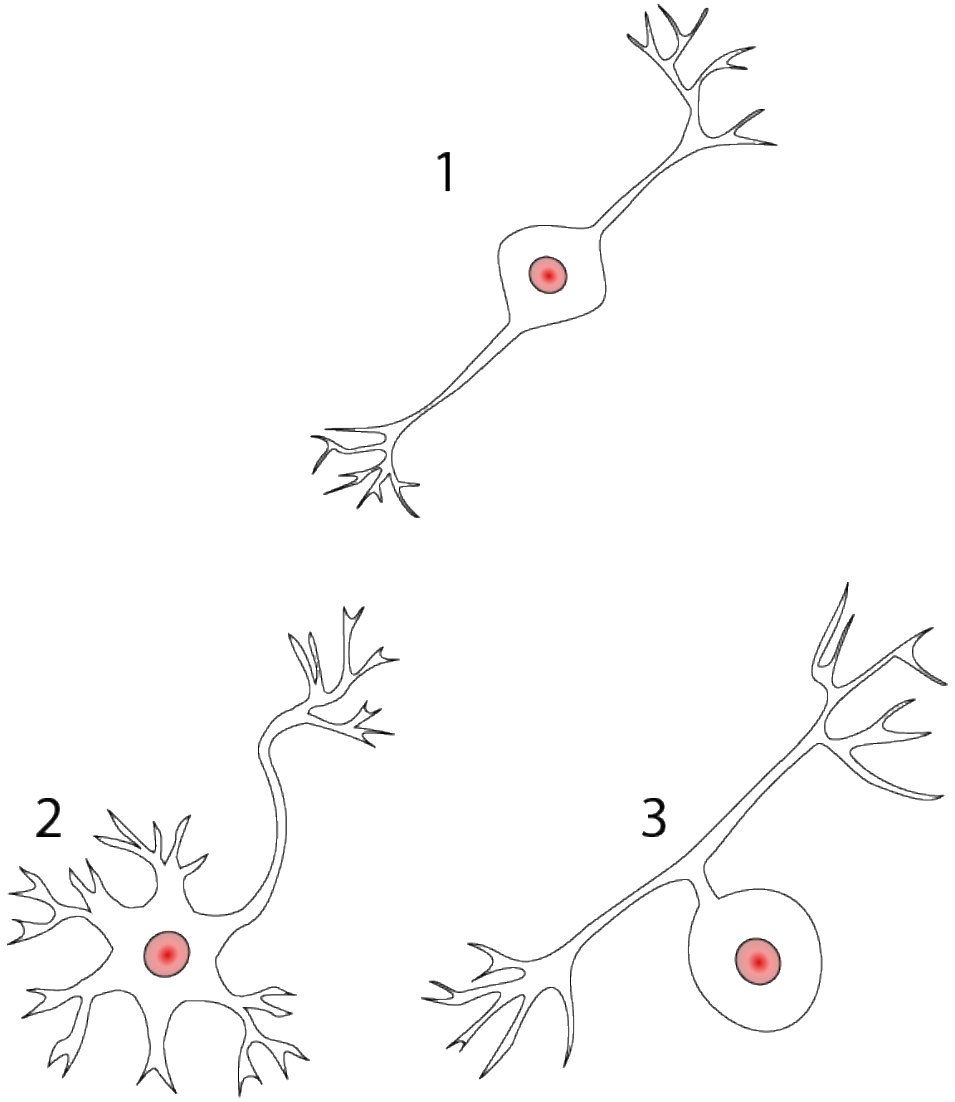
Structural classes of neurons

1. Bipolar neurons have only two processes that extend in opposite directions from the cell body. One process is called a dendrite, and another process – the axon. Although rare, these are found in the retina of the eye and the olfactory system.



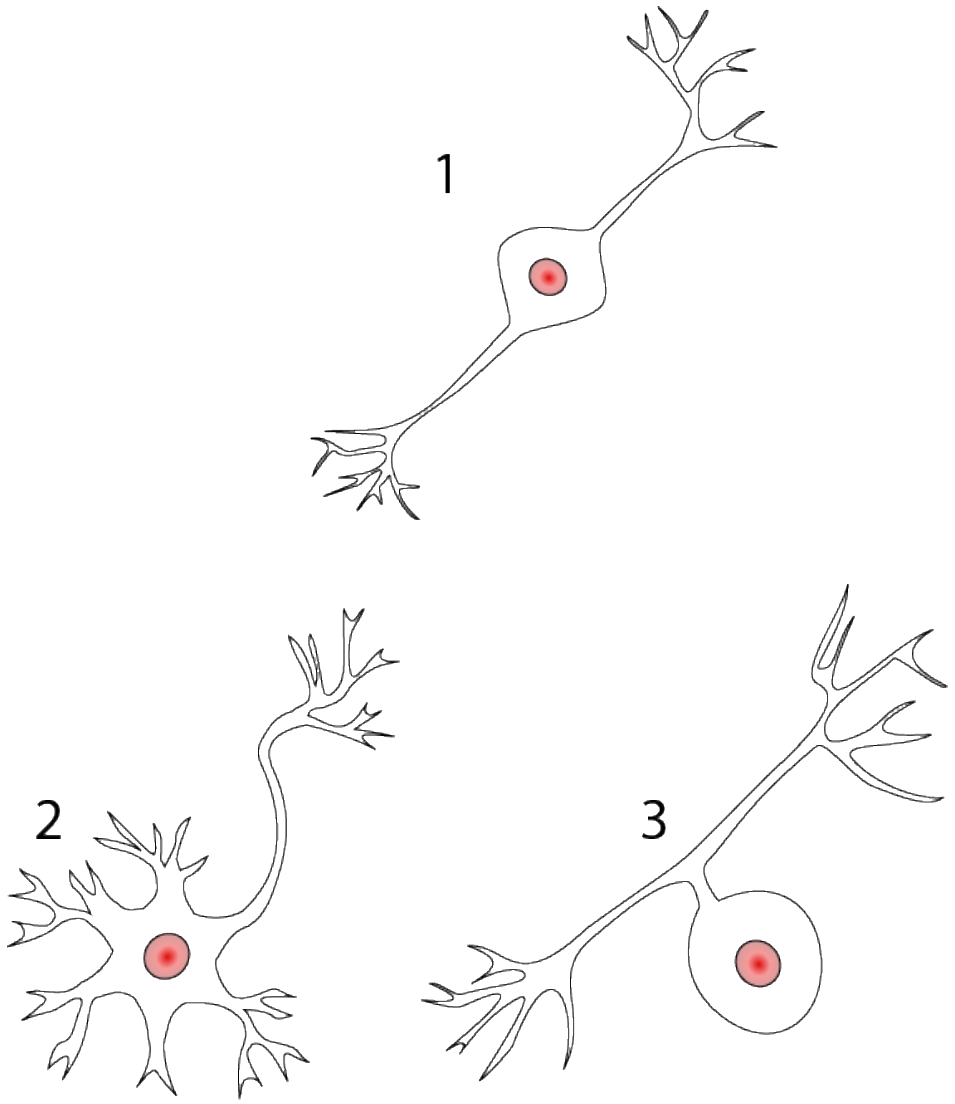
Structural classes of neurons

2. Multipolar neurons are defined as having three or more processes that extend out from the cell body.
   They comprise of more than 99% of the neurons in humans, and are the major neuron type found in the CNS and the efferent division of the PNS.



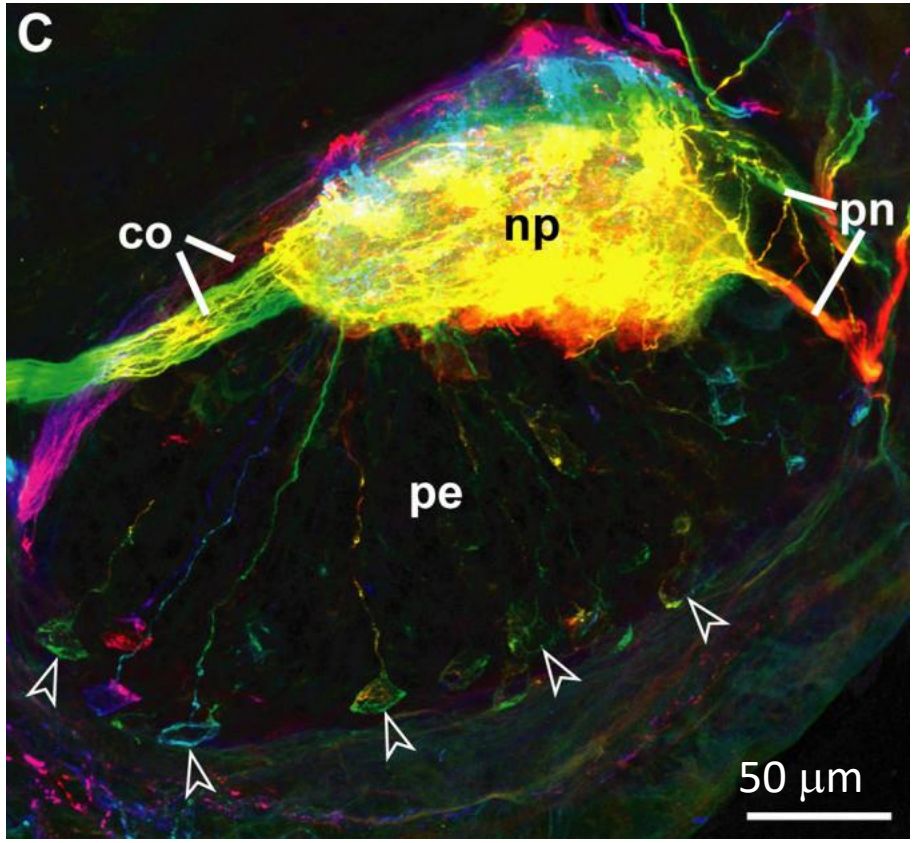
Structural classes of neurons

3. Pseudounipolar neurons have a single, short process that extends from the cell body and then branches into two more processes that extend in opposite directions. Unipolar neurons are found primarily in the afferent division of the PNS.



Structural classes of neurons

- Unipolar neurons is a type of neuron, found only in invertebrates, in which only one process called a neurite extends from the cell body.
- Unipolar neurons are common in insects, where the cell body is often located at the periphery of the brain and is electrically inactive.
- These cell bodies often send a single neurite into the brain; however, this neurite may ramify into many branches making a very complex set of connections with other neurites, in regions of neuropil.



Several unipolar neurons from a nerve ganglion of a velvet worm. Arrows mark the peripherally located cell bodies of several neurons, whose neurites extend into the central neuropil (np), where their complex ramifications are indiscernible

Onychophora is known as velvet worms (due to their velvety texture and somewhat wormlike appearance)

Structural classes of neurons

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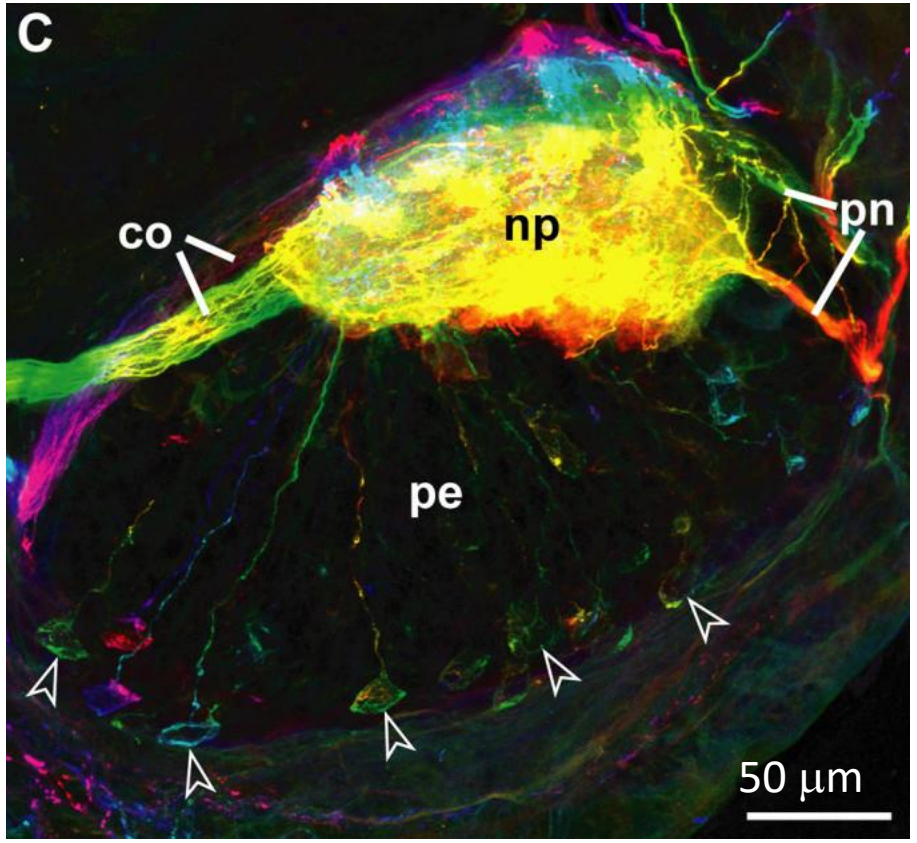

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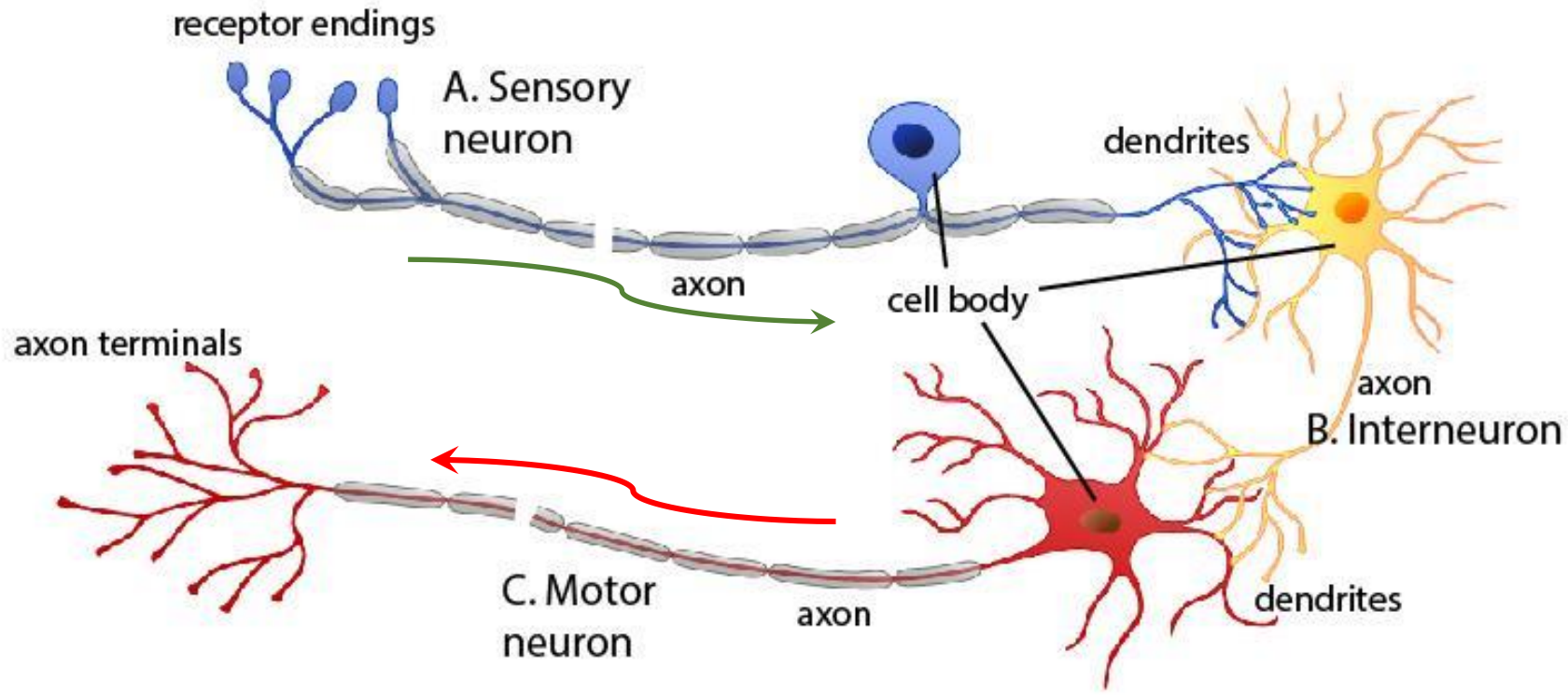
Sensory (afferent) vs. motor (efferent) neurons

Short axon, Receptor, Cell body at the side; no dendrites (or low number)



Long axon, No receptor, Cell body terminal and has many short dendrites

Neurons are the oldest cells in the body

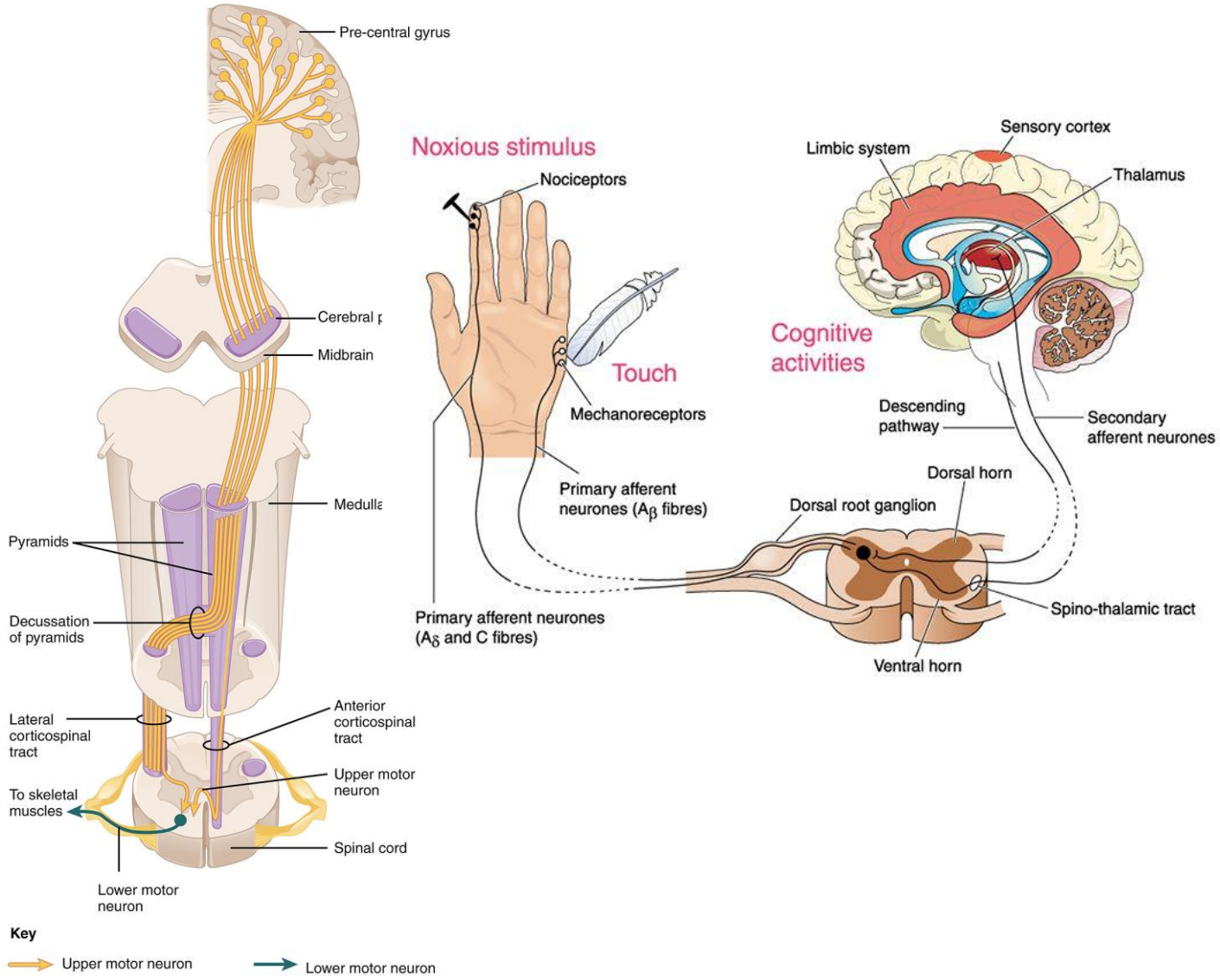
- Most neurons are amitotic, i.e. lose their ability to divide. Exceptions to this rule are found in olfactory neurons (those associated with smell) and hippocampal regions of the brain.
- Lifespans of amitotic neurons is near 100 years.
- If a neuron is damaged or lost, it is not easily replaced. For this reason, there is usually limited recovery from serious brain or spinal cord injuries.
- In fact, you have fewer neurons when you are old compared to when you are young.

Neurons metabolism

- Perhaps the slow recovery rate or lack of regeneration is to ensure that learned behavior and memories are preserved throughout life.
- Neurons also have exceptionally high metabolic rates and subsequently require high levels of glucose and oxygen.
- The body will go to great lengths to ensure that neurons are adequately fed;
- If for some reason the brain detects that it is not receiving adequate amounts of nutrition, the body will shut down immediately (i.e., faint).

Neurons are the longest cells in the body!

- Neurons can be quite large - in some neurons, such as corticospinal neurons (from motor cortex to spinal cord) or primary afferent neurons (neurons that extend from the skin into the spinal cord and up to the brain stem), size can be more than 1 meter!



Glial cells

There are four main types of glial cells in the adult vertebrate nervous system:

- astrocytes,
- oligodendrocytes,
- microglia.

} are found only in the central nervous system (CNS)

- Schwann cells

} are found only in the peripheral nervous system (PNS)

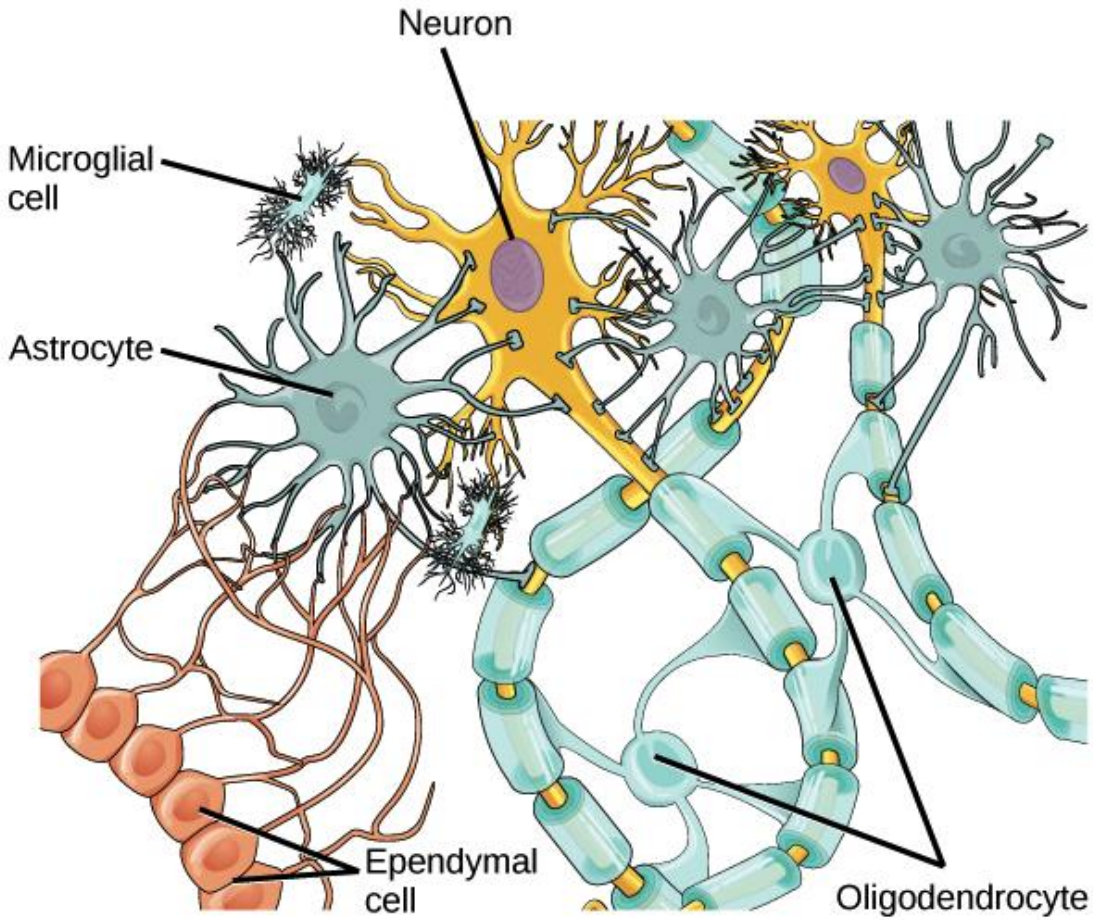
Types of glia and their functions

- **Astrocytes** are the most numerous type of glial cell. In fact, they are the most numerous cells in the brain.
- **Astrocytes** come in different types and have a variety of functions.
- **Astrocytes** help regulate blood flow in the brain, maintain the composition of the fluid that surrounds neurons, and regulate communication between neurons at the synapse. During development, astrocytes help neurons find their way to their destinations and contribute to the formation of the blood-brain barrier, which helps isolate the brain from potentially toxic substances in the blood.

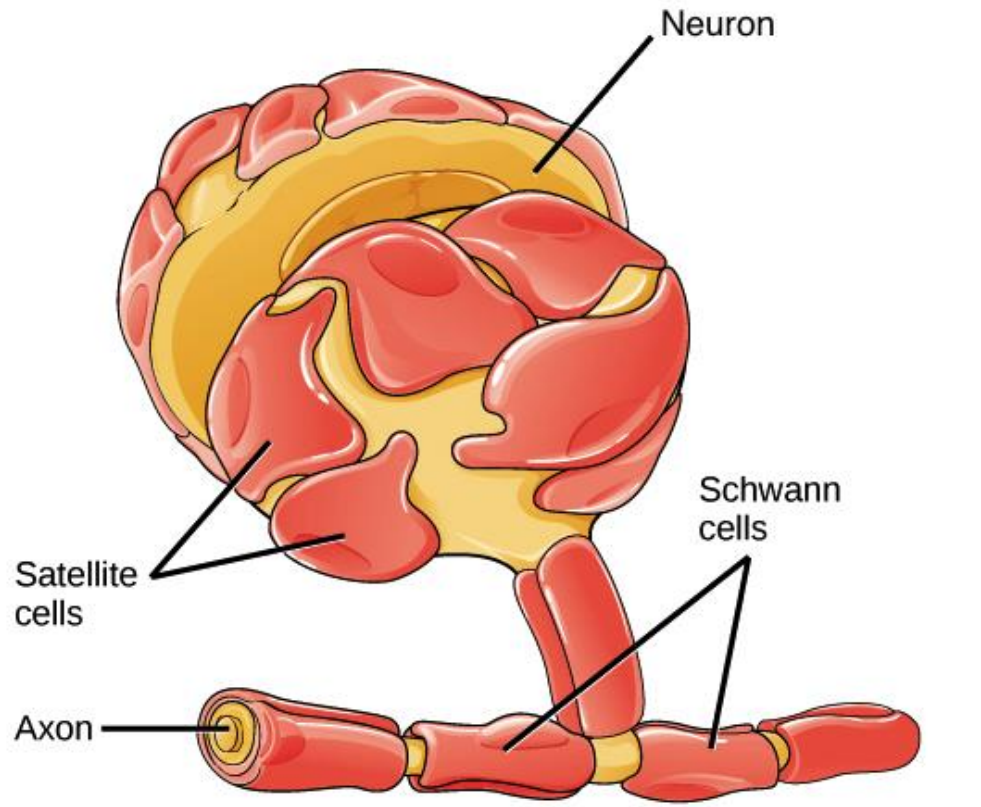
Types of glia and their functions

- **Microglia** are related to the macrophages of the immune system and act as scavengers to remove dead cells and other debris.
- The **oligodendrocytes** of the CNS and the **Schwann cells** of the PNS share a similar function. Both of these types of glial cells produce myelin, the insulating substance that forms a sheath around the axons of many neurons.
- Myelin dramatically increases the speed with which an action potential travels down the axon, and it plays a crucial role in nervous system function.

Types of glia and their functions



Central nervous system



Peripheral nervous system

Other types of glia

- **Satellite glial cells** cover the cell bodies of neurons in PNS ganglia. Satellite glial cells are thought to support the function of the neurons and might act as a protective barrier, but their role is still not well-understood.
- **Ependymal cells**, which line the ventricles of the brain and the central canal of the spinal cord, have hair-like cilia that beat to promote circulation of the cerebrospinal fluid found inside the ventricles and spinal canal.

How do neurons communicate?

- **Neurons communicate electrochemically.**
- An electrical signal from one neuron's axon will trigger a release of neurotransmitters which bind to channels on another neuron's dendrite.
- This causes the channels to open and receive positively-charged ions from the synapse.
- If this increases the charge enough, can trigger an action potential, causing that neuron to send an electrical signal (positive charge) down its own axon.

Electrochemical signal

Electrical

Once a neuron has been stimulated by some sort of stimulus, it generates an electric potential that travels down the length of the cell.

Chemical

Once the electric current reaches the axon terminal at the end of the cell, it triggers the release of certain chemical messengers.

Electrochemical signal

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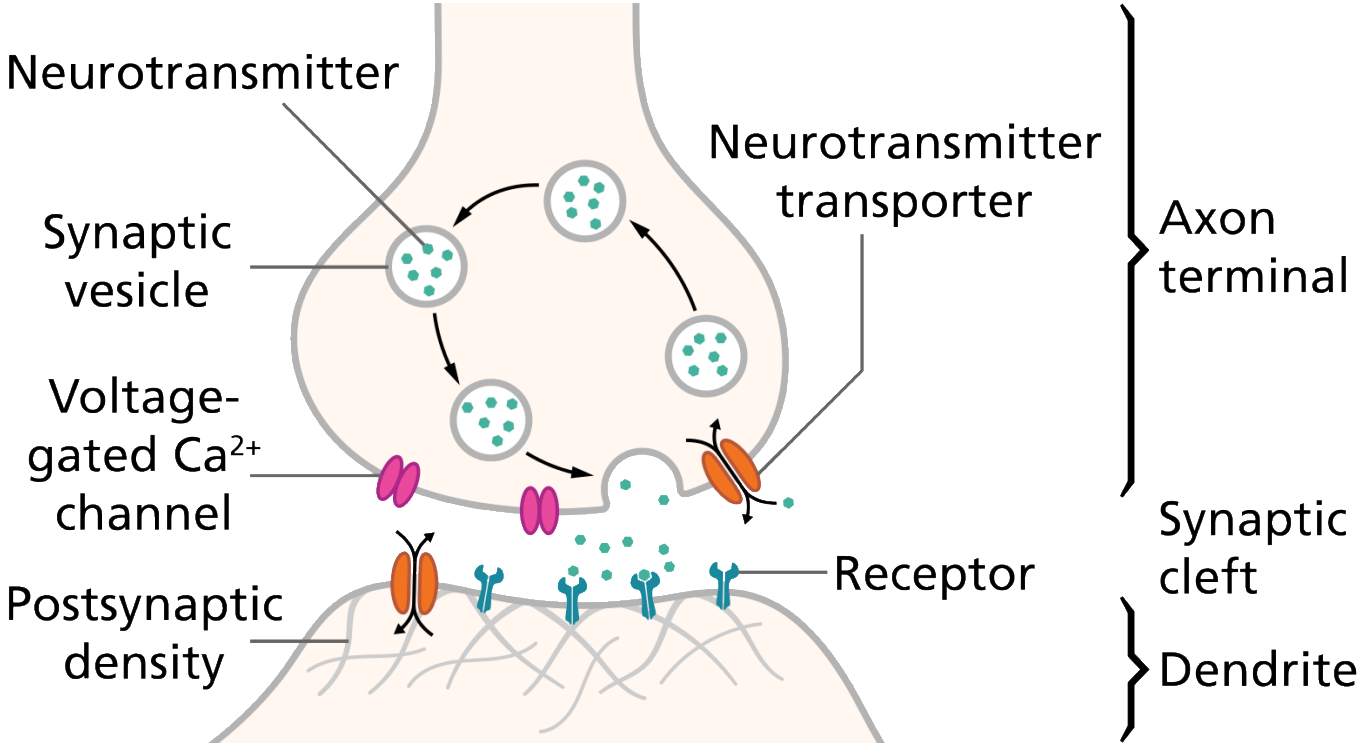
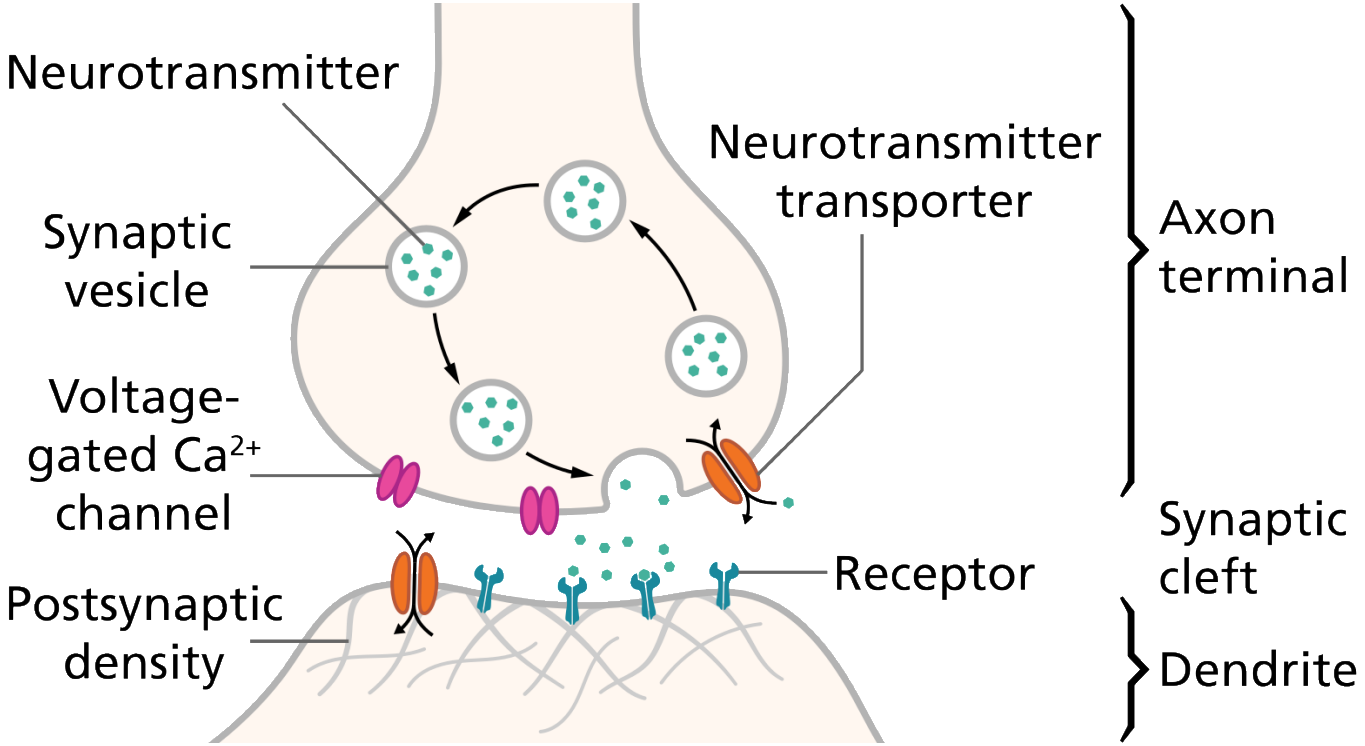


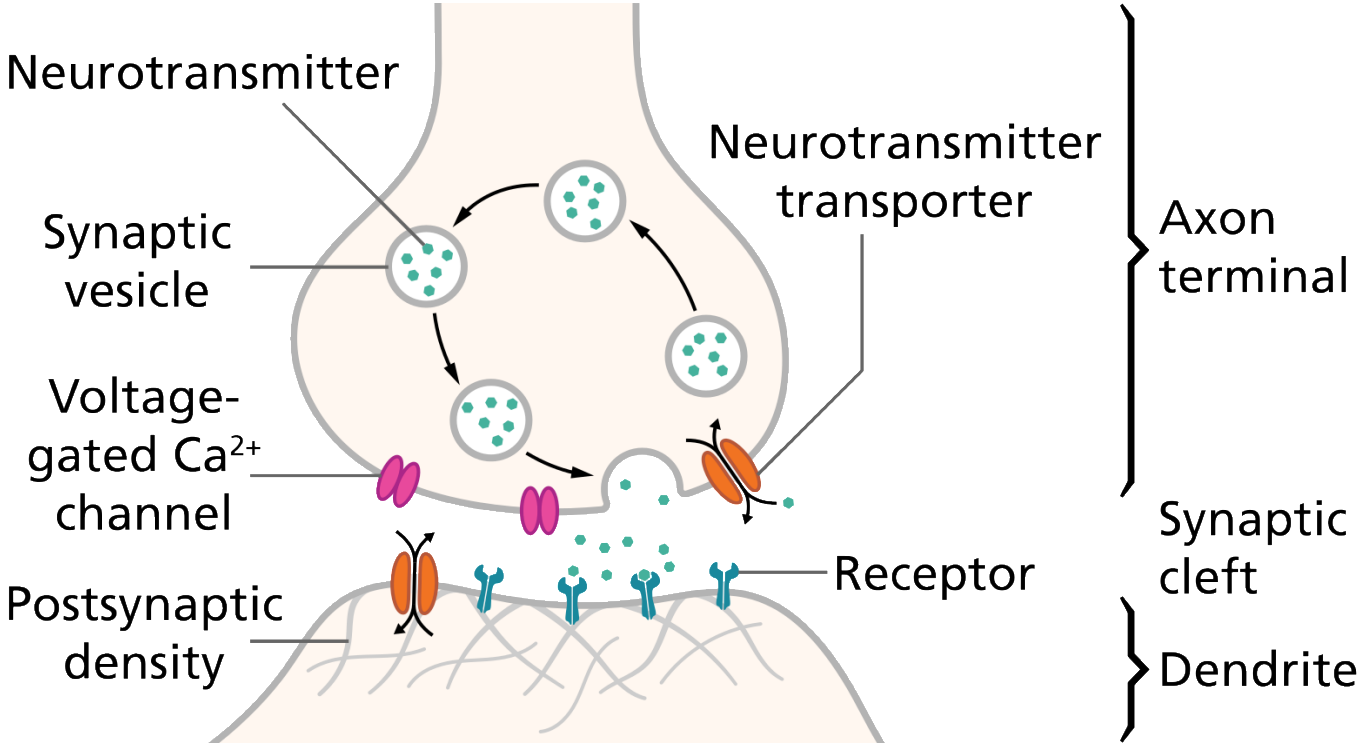
Neurotransmitters

- The primary class of signaling molecules are called **neurotransmitters**.
- These chemical messengers allow one neuron to communicate to another, and the response these messages generate depend on factors such as what specific type of messenger was sent, how much of it was sent, how long the message lasted, etc.



Neurotransmitters

- Released neurotransmitters must cross this synapse in order to reach their specific receptors on the other side, and then are recycled or broken down after achieving their desired effects.



Neurotransmitters

- A single neuron will produce several different neurotransmitters.
- A cascade of specific chemical reactions occurs after a synapse; these specific chemical reactions depend on the presence, absence, or combination of specific receptor types.
- These reactions affect the neuron with either excitation potential (depolarization) or inhibition potential (hyper-polarization). **Excitation makes it more likely that an action potential will fire; inhibition makes it less likely that an action potential will fire.**
- Neurotransmitters and their receptors influence behavior, learning, emotions, and sleep.

Neurotransmitters

Neurotransmitter	Role
Acetylcholine	Acetylcholine is a very widely distributed excitatory neurotransmitter that triggers voluntary muscle contraction and stimulates the excretion of certain hormones. It is involved in wakefulness, attentiveness, learning, memory, sleep, anger, aggression, sexuality, and thirst.
Dopamine	Dopamine correlates with movement, attention, and learning. Dopamine is involved in controlling movement and posture. It also modulates mood and plays a central role in positive reinforcement and dependency.
Norepinephrine	Norepinephrine is associated with alertness. neurotransmitter that is important for attentiveness, emotions, sleeping, dreaming, and learning. Norepinephrine is also associated with the “fight or flight” response.
Serotonin	Serotonin plays a role in mood, sleep, appetite, and impulsive and aggressive behavior.
GABA (Gamma-Amino Butyric Acid)	GABA is the major inhibitory neurotransmitter in the CNS, contributing to motor control, anxiety regulation, vision, and many other cortical functions.
Endorphins	Involved in pain relief and feelings of pleasure and contentedness.

Hormones

Hormones may have profound interactions with the nervous system.

Examples include:

- **adrenaline**, which controls responses to acute environmental stress
- **melatonin** which establishes biological rhythms and sleep patterns

Action potential

To be continued…