ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

# The nervous system: anatomy and physiology

Cognition and Neuroscience
Academic year 2021/2022

**Francesca Starita**

francesca.starita2@unibo.it

# From individual cells to circuits to systems

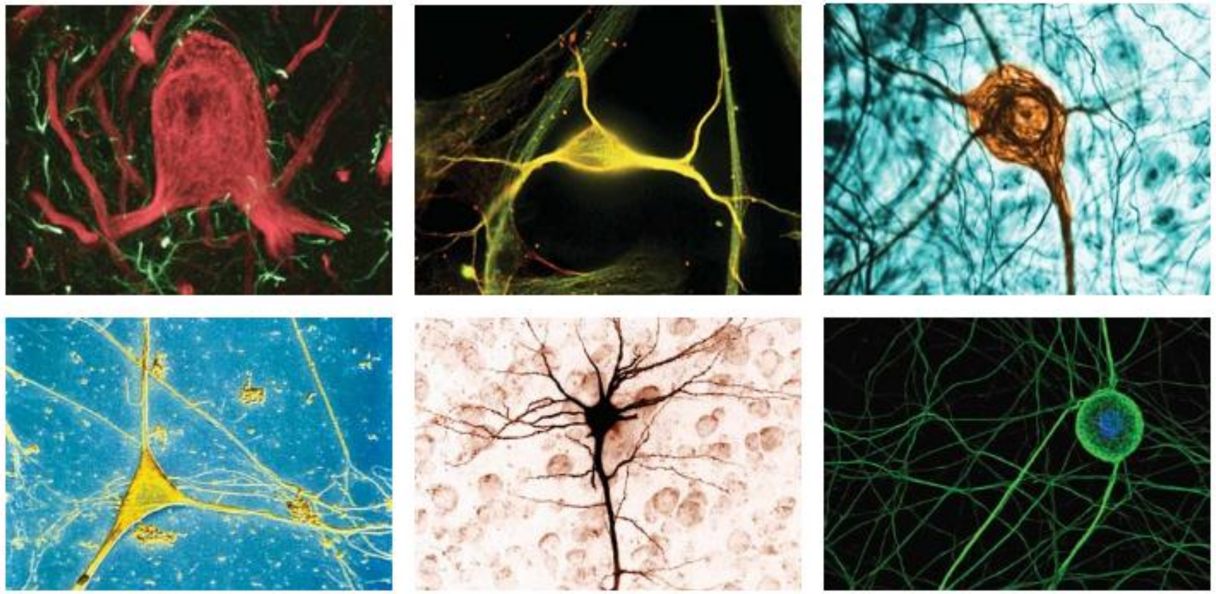


**FIGURE 2.2 Mammalian neurons show enormous anatomical variety.**

# From individual cells to circuits to systems

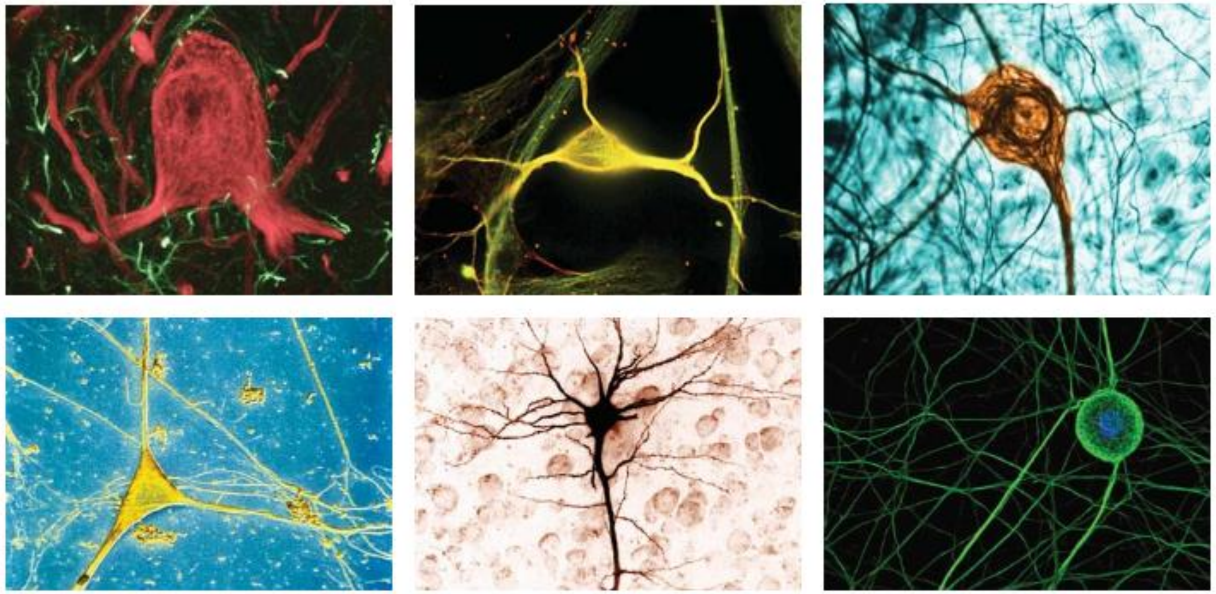
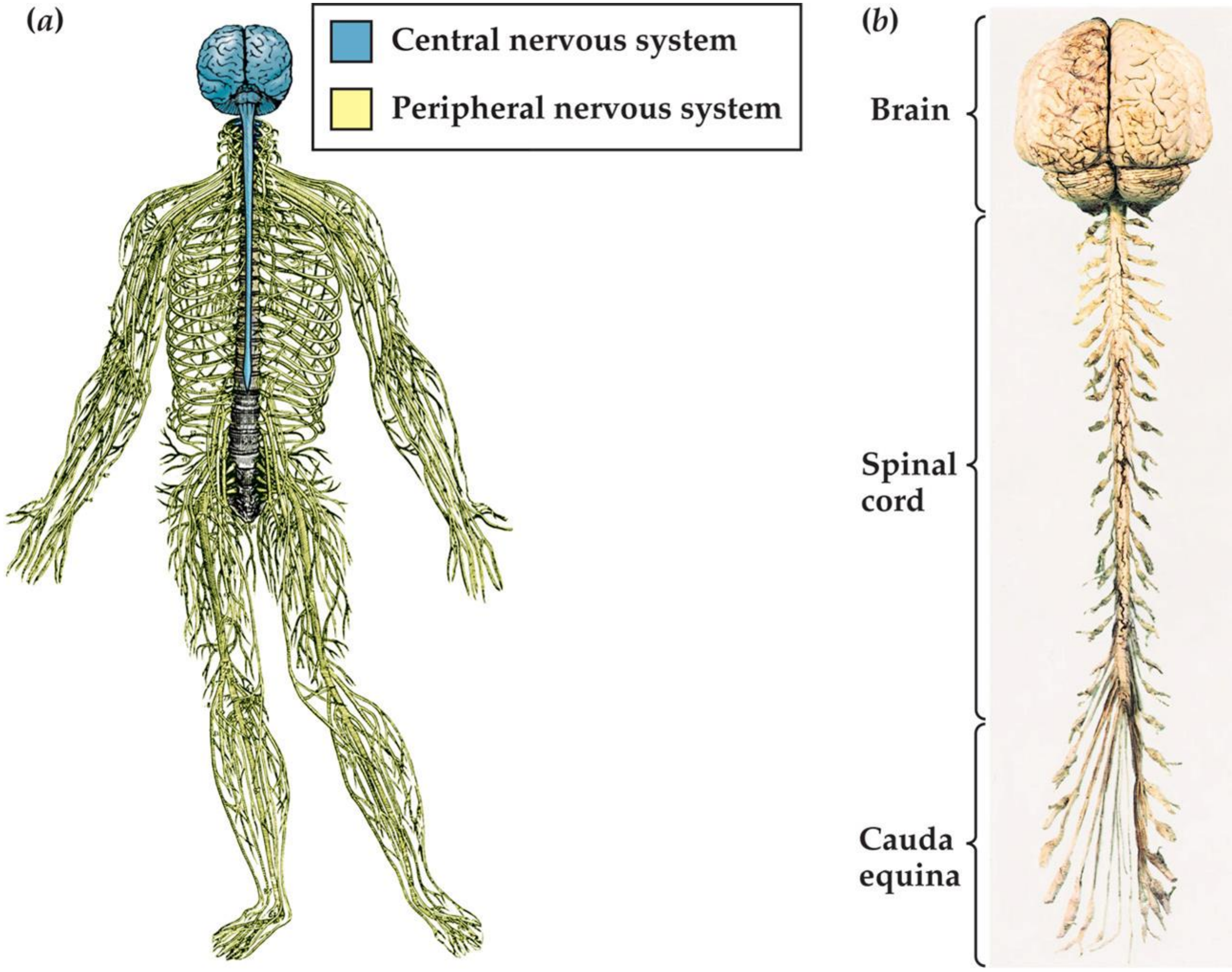


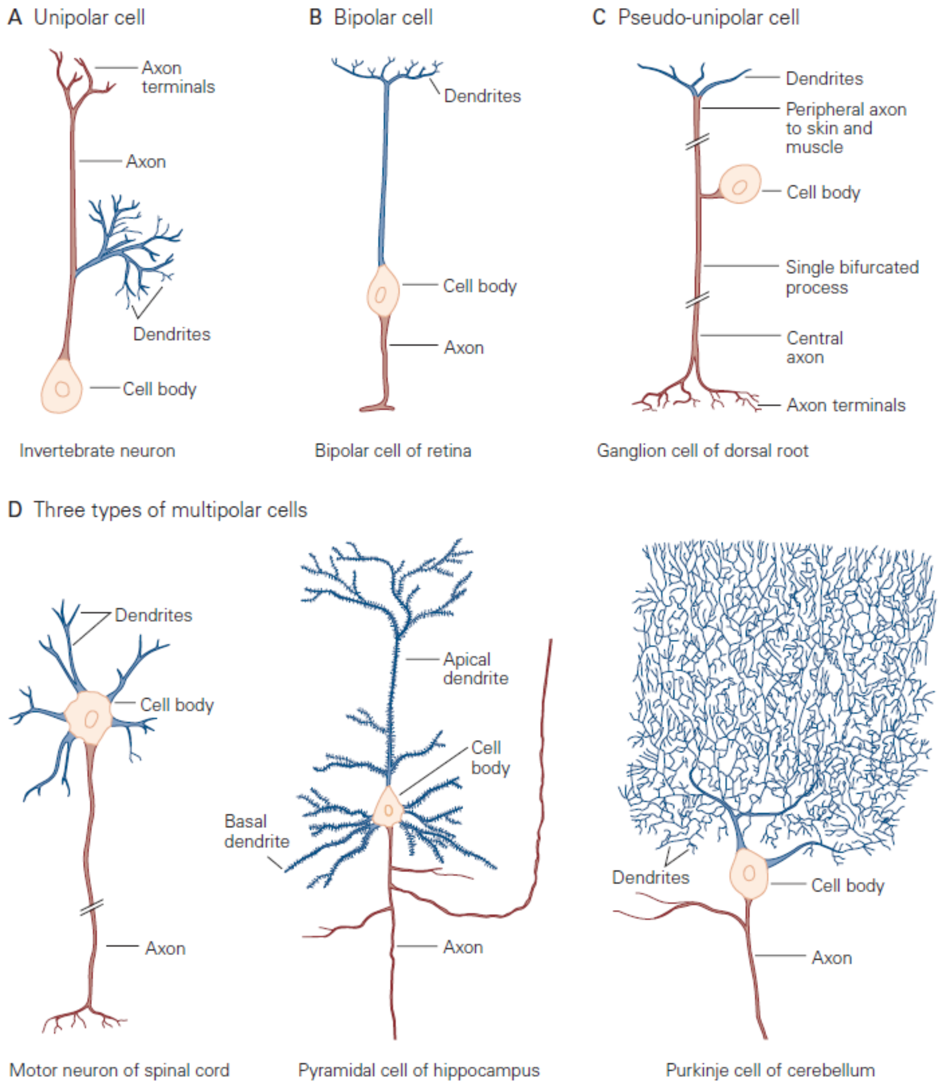
**FIGURE 2.2** Mammalian neurons show enormous anatomical variety.




*THE MIND'S MACHINE*, Figure 2.6

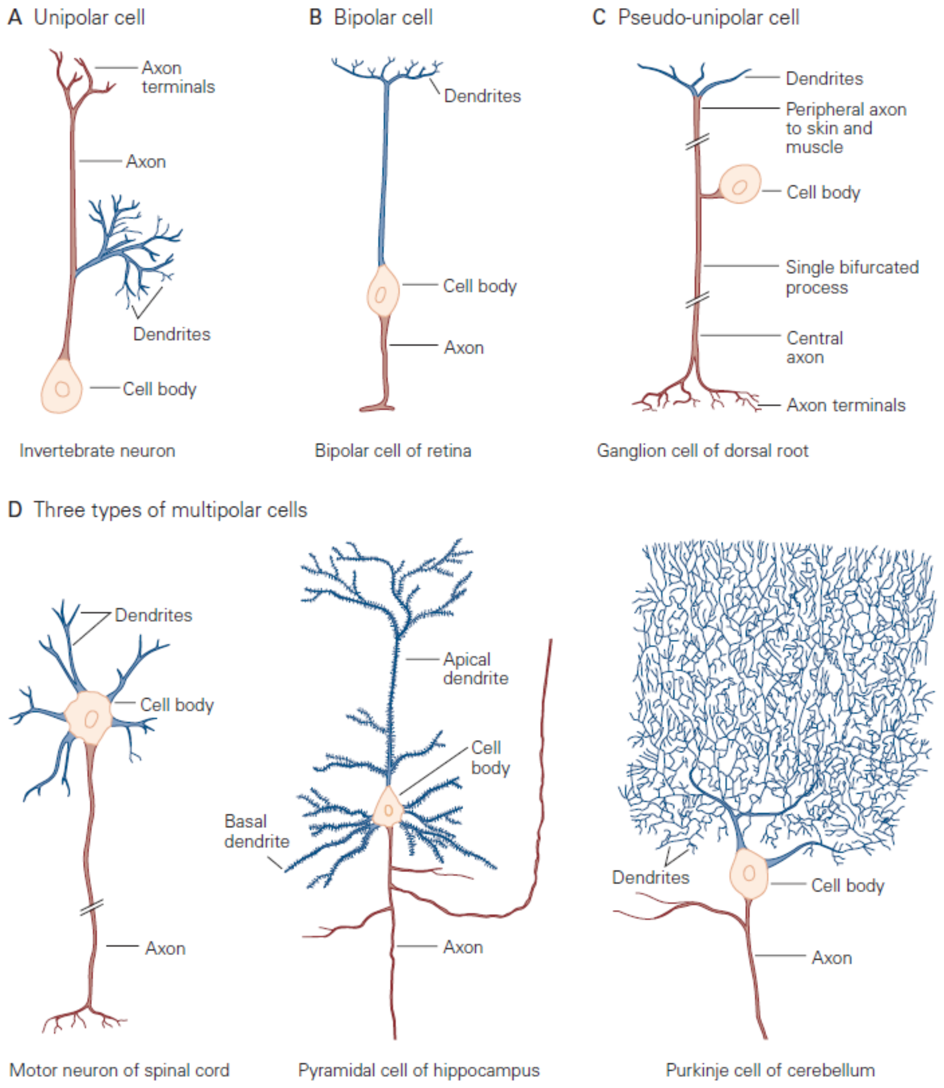
# Individual cells

# Nerve cells, or neurons



# The Nervous System Has Two Classes of Cells

## Nerve cells, or neurons




## Glial cells, or neuroglia

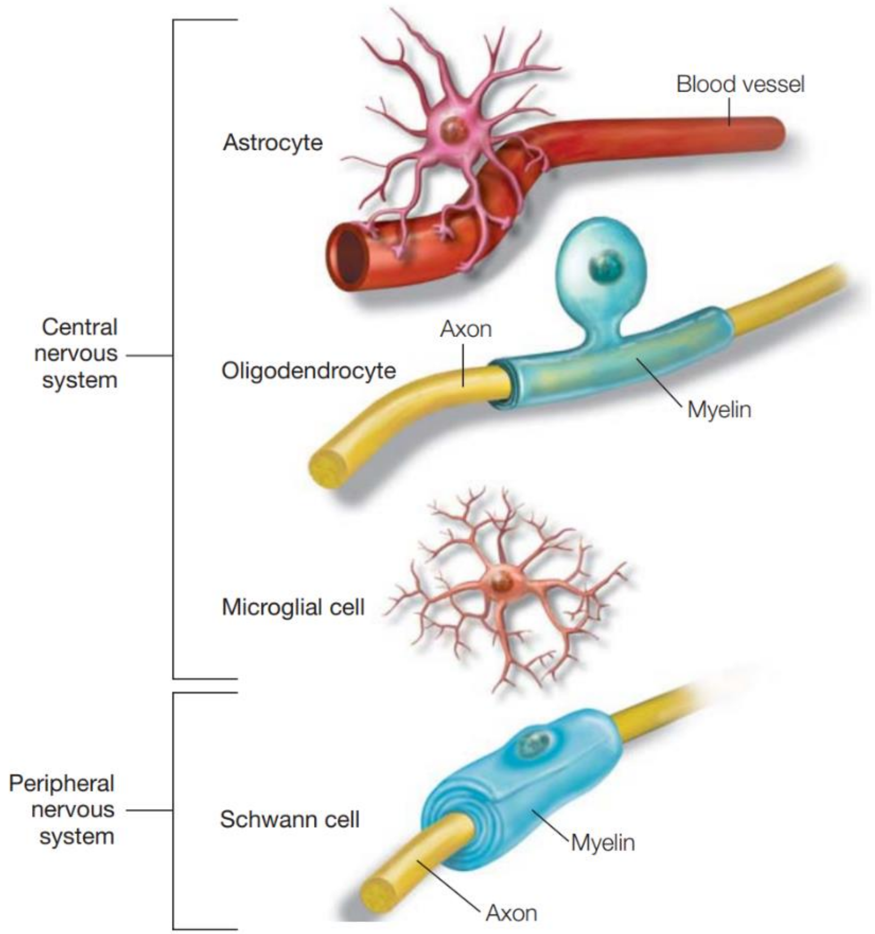



**FIGURE 2.15 Various types of glial cells in the mammalian central and peripheral nervous systems.**
An astrocyte is shown with end feet attached to a blood vessel. Oligodendrocytes and Schwann cells produce myelin around the axons of neurons—oligodendrocytes in the central nervous system, and Schwann cells in the peripheral nervous system. A microglial cell is also shown.

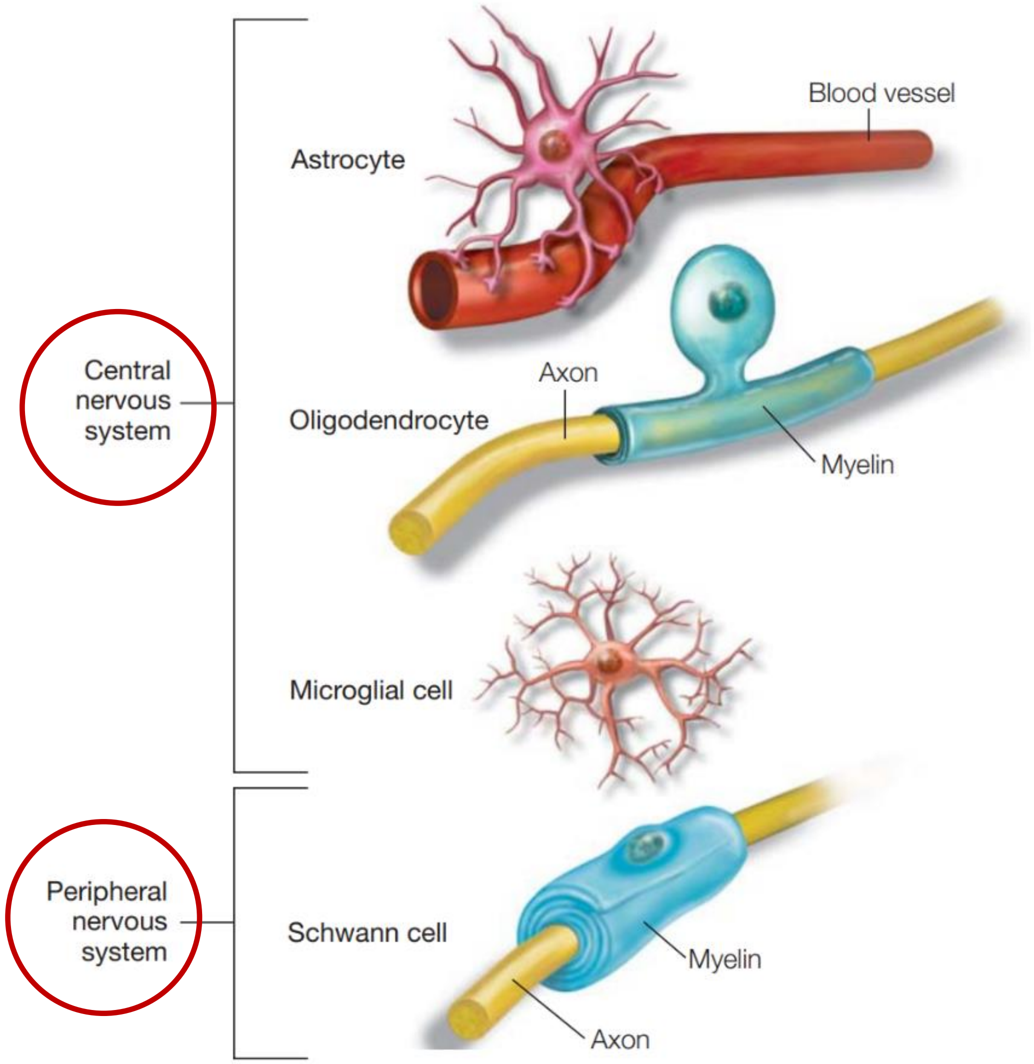
# Neuroglia = "nerve glue"

**Glial cells greatly outnumber neurons:**

- there are 2 to 10 times more glia than neurons in the vertebrate central nervous system.

**Glial Cells Support Nerve Cells:**

- Structural
- Immune
- Nourishment
- Signaling

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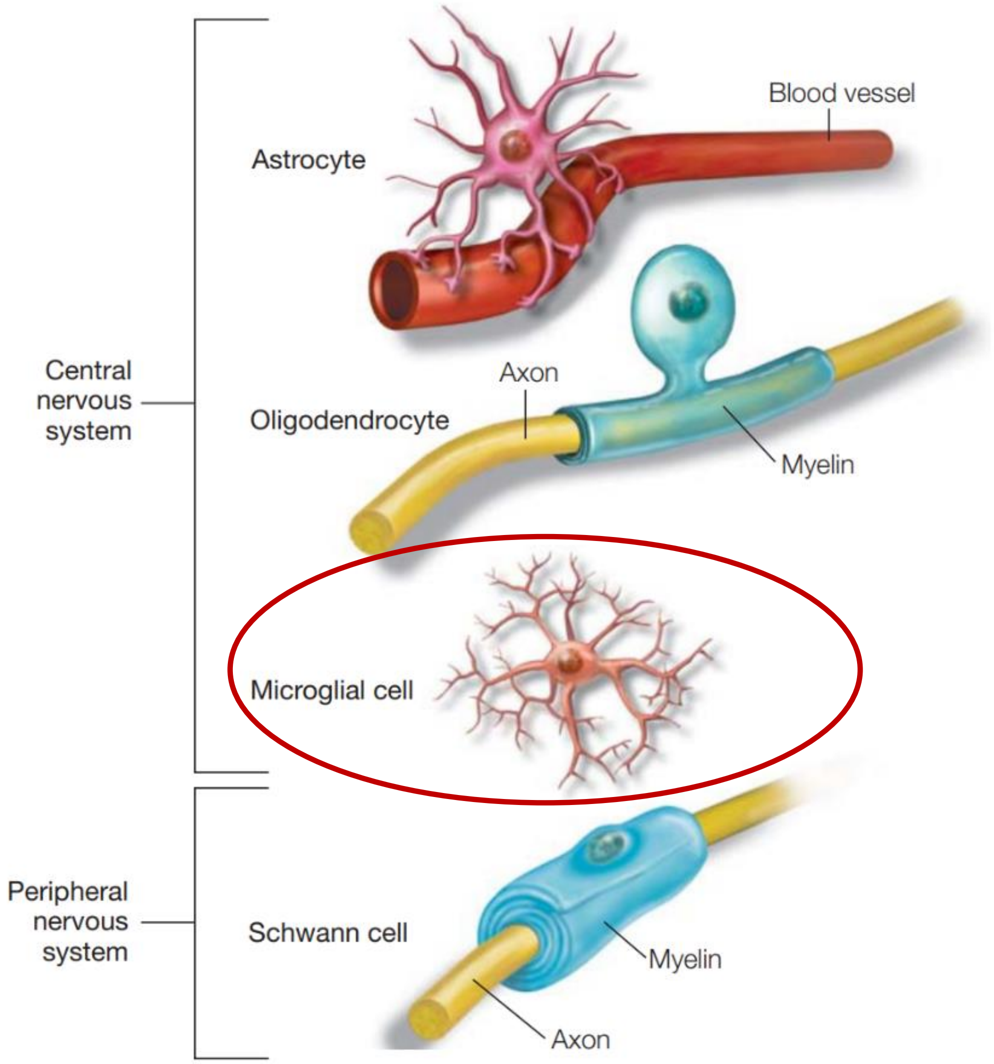
# Immune support: microglia

## Microglia are immune system cells

- brain's protectors: **identify when something has gone wrong and initiate a response that removes the toxic agent and/or clears away the dead cells**
- they are mobilized to present antigens and become phagocytes during injury, infection, or degenerative diseases

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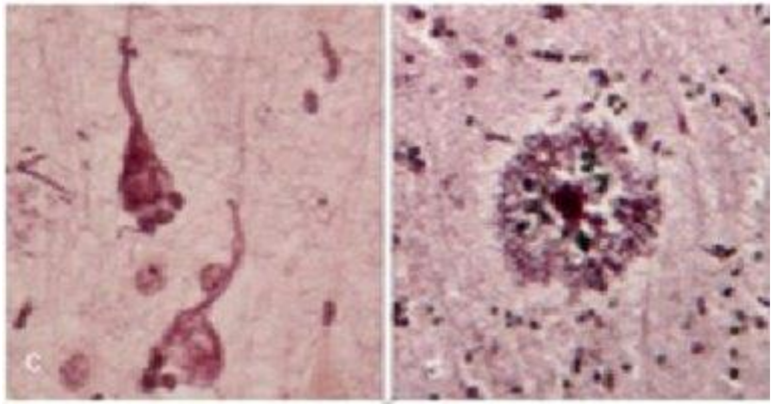
- In neurodegenerative disorders such as **Alzheimer's disease**, **microglia** may become **hyperactivated**, promoting neuroinflammation that can lead to the characteristic toxic protein deposits seen in Alzheimer's (amyloid plaques and neurofibrillary tangles)



amyloid plaques     neurofibrillary tangles

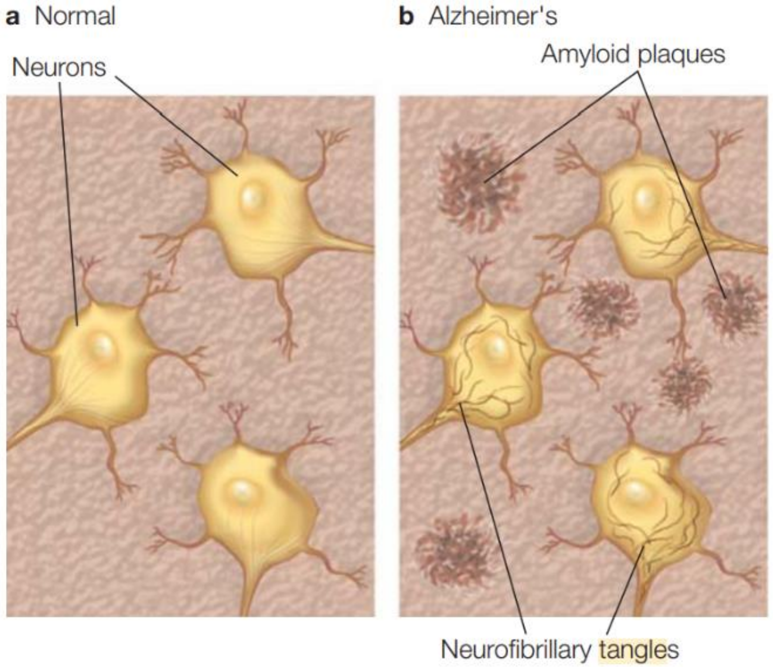



**FIGURE 9.17 Comparison of cortex in Alzheimer's patients and normal participants.**
These diagrams depict a normal section of cortex with cortical neurons (a) and a section of cortex in an Alzheimer's patient containing amyloid plaques between neurons and neurofibrillary tangles within neurons (b).

# Immune support: microglia

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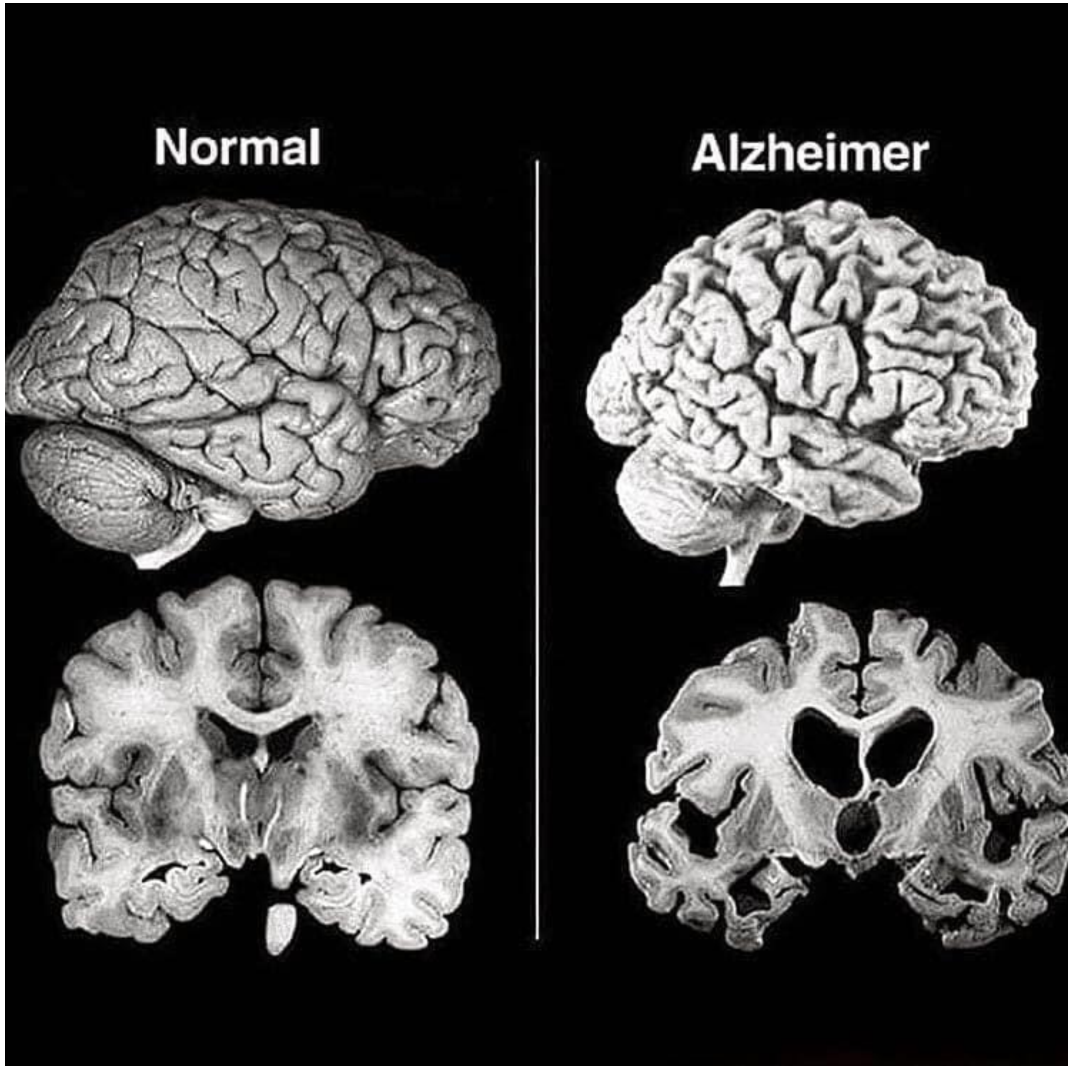
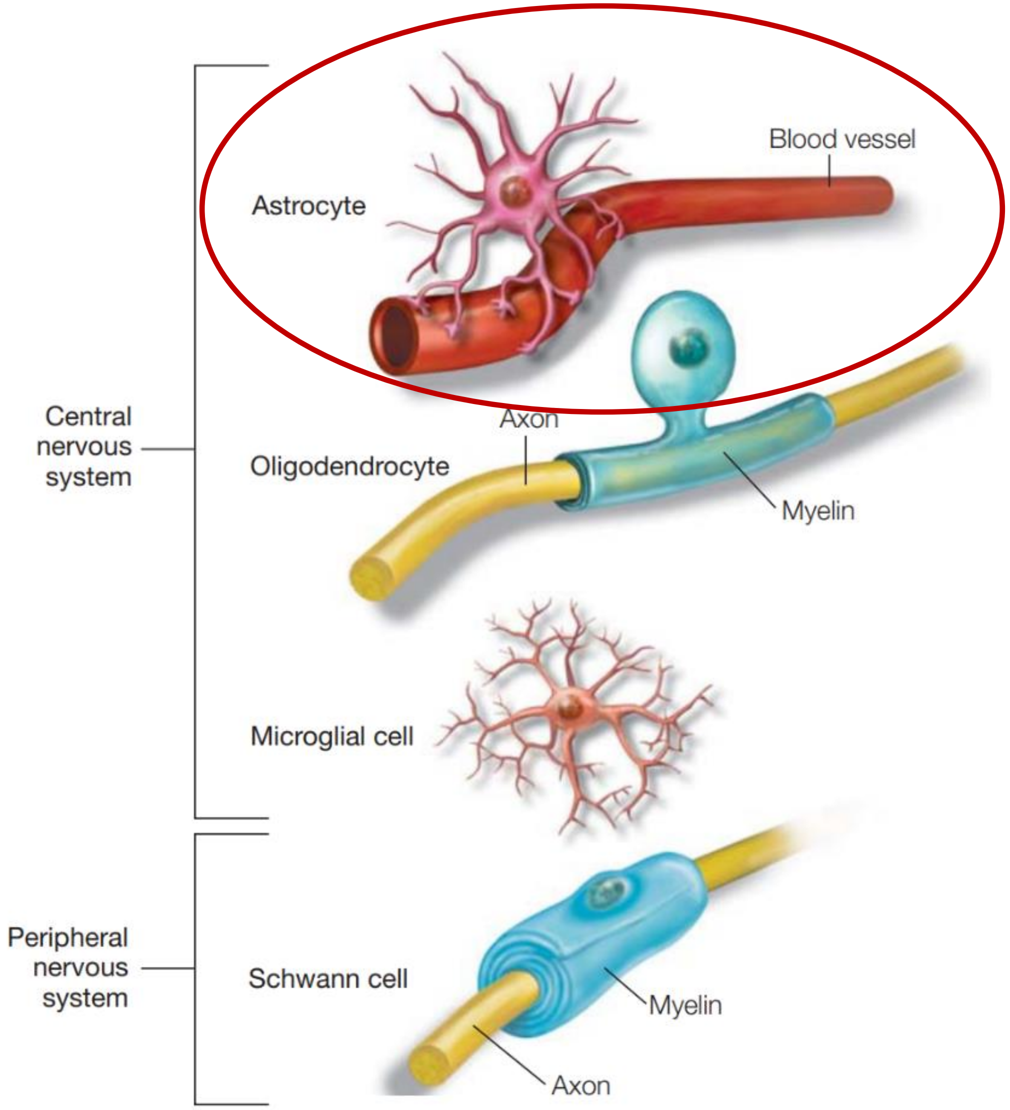


# Nourishing support: astrocytes

- constitute nearly **half the number of brain cells**
- star-shaped, round form
- **surround neurons and are in close contact with the brain's vasculature** → important roles in **nourishing neurons and in regulating the concentrations of ions and neurotransmitters** in the extracellular space
- astrocytes and neurons communicate with each other to modulate synaptic signaling
- **maintain the blood-brain barrier**, between the tissues of the central nervous system and the blood

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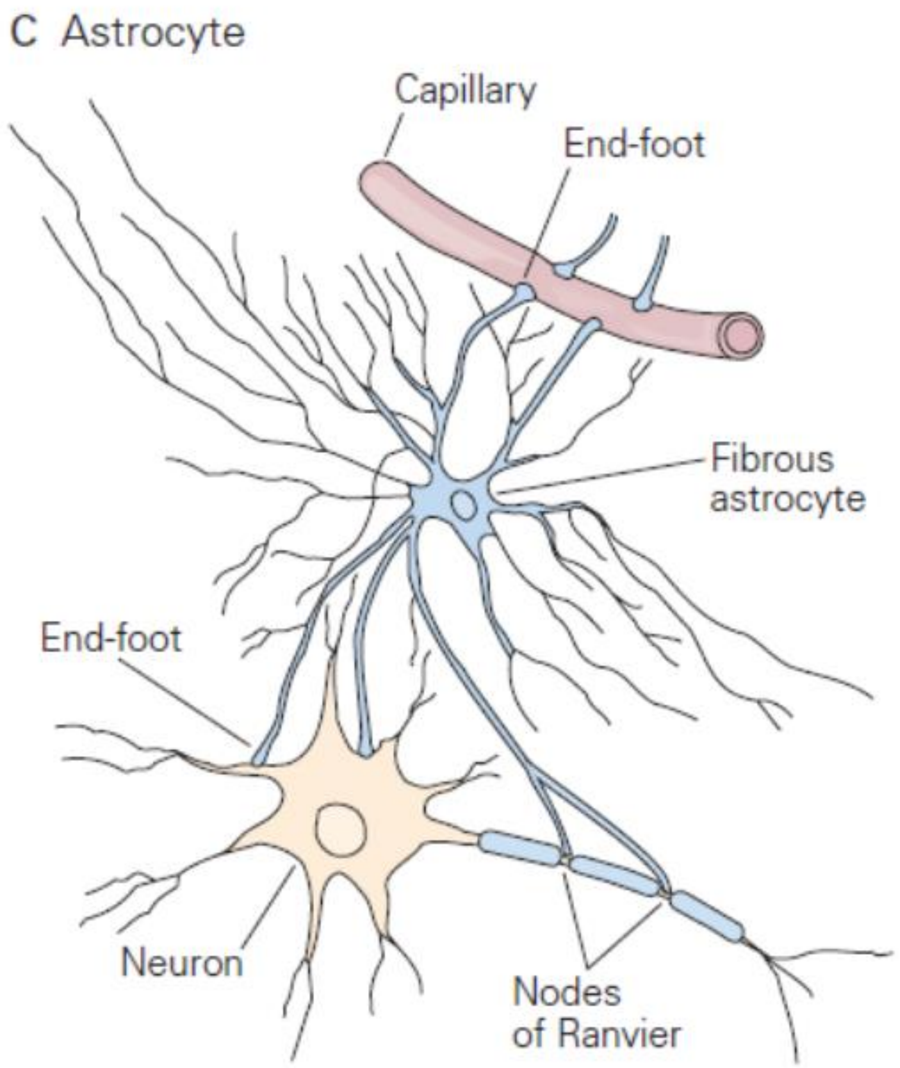
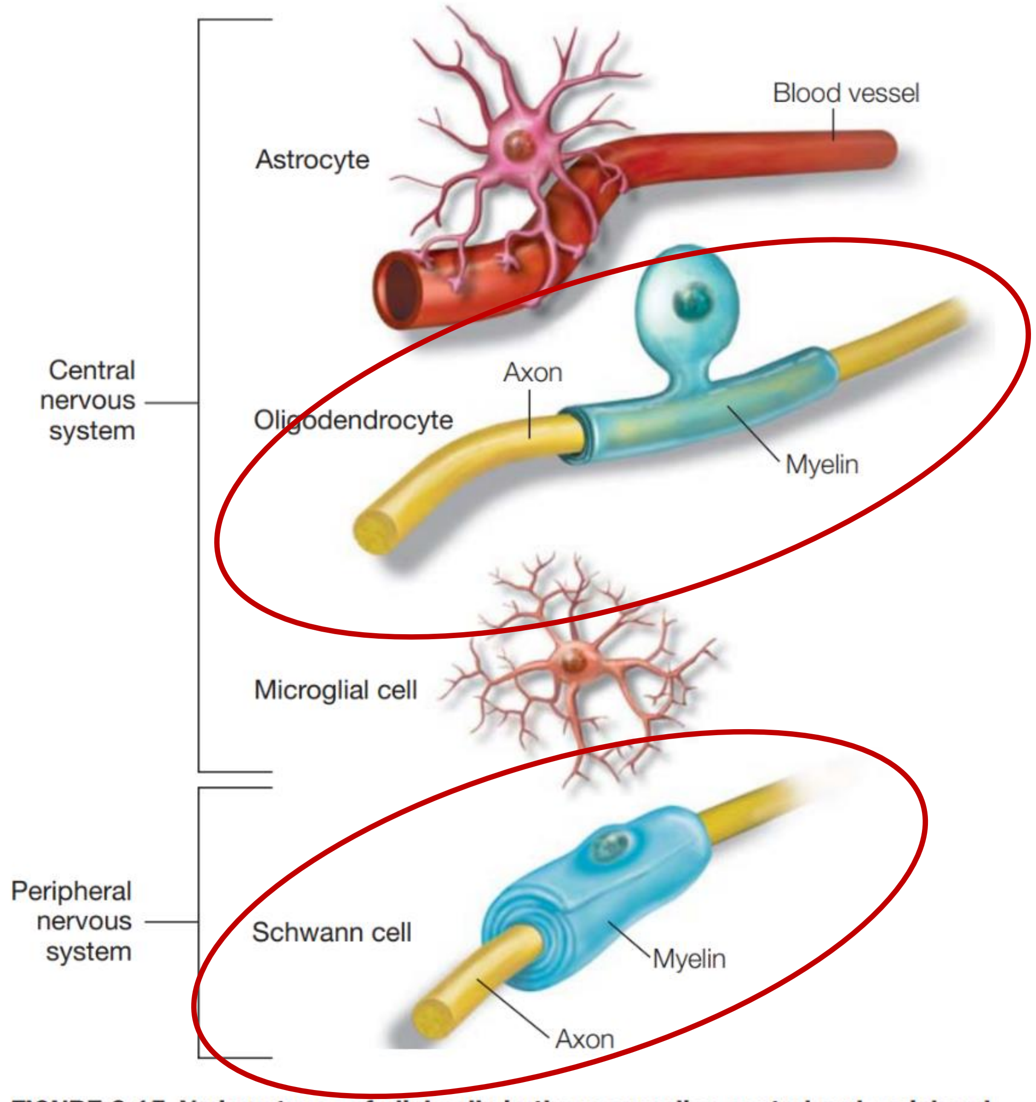


# Signaling support: oligodendrocytes and Schwann cells

- Oligodendrocytes are in the central nervous system (CNS)
- Schwann cells are in the peripheral nervous system (PNS)

- **provide the insulating material along the axon**
- produce thin sheets of **myelin** that wrap concentrically, many times, around the axon of neurons to allow rapid conduction of electrical signals along the axon
- Myelin is white, giving "white matter" its name

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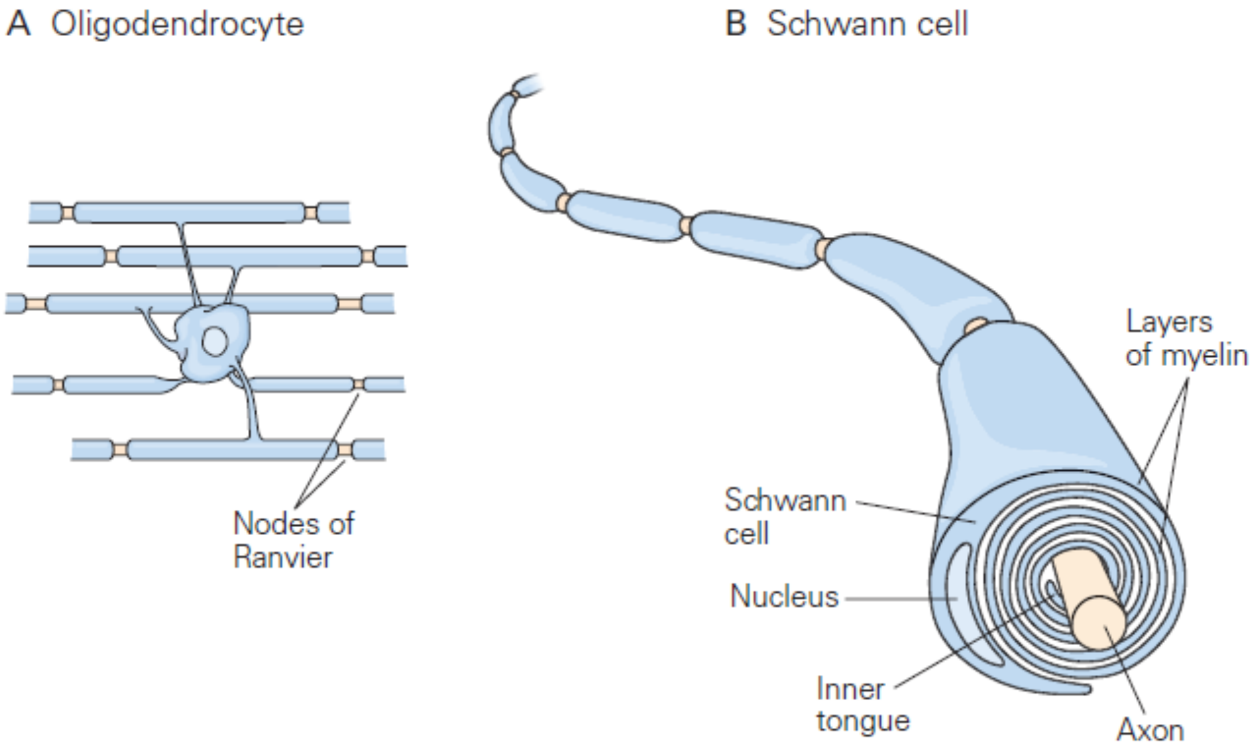
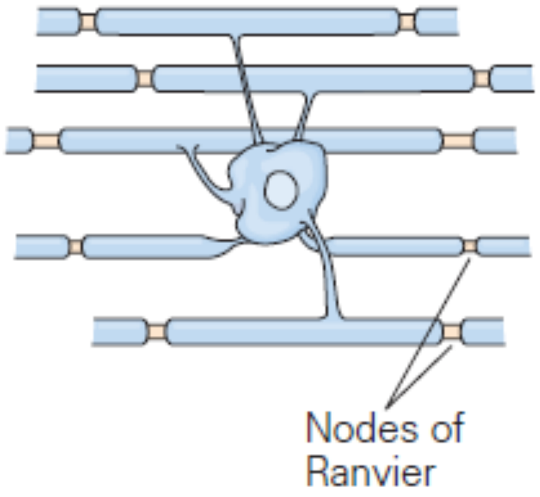
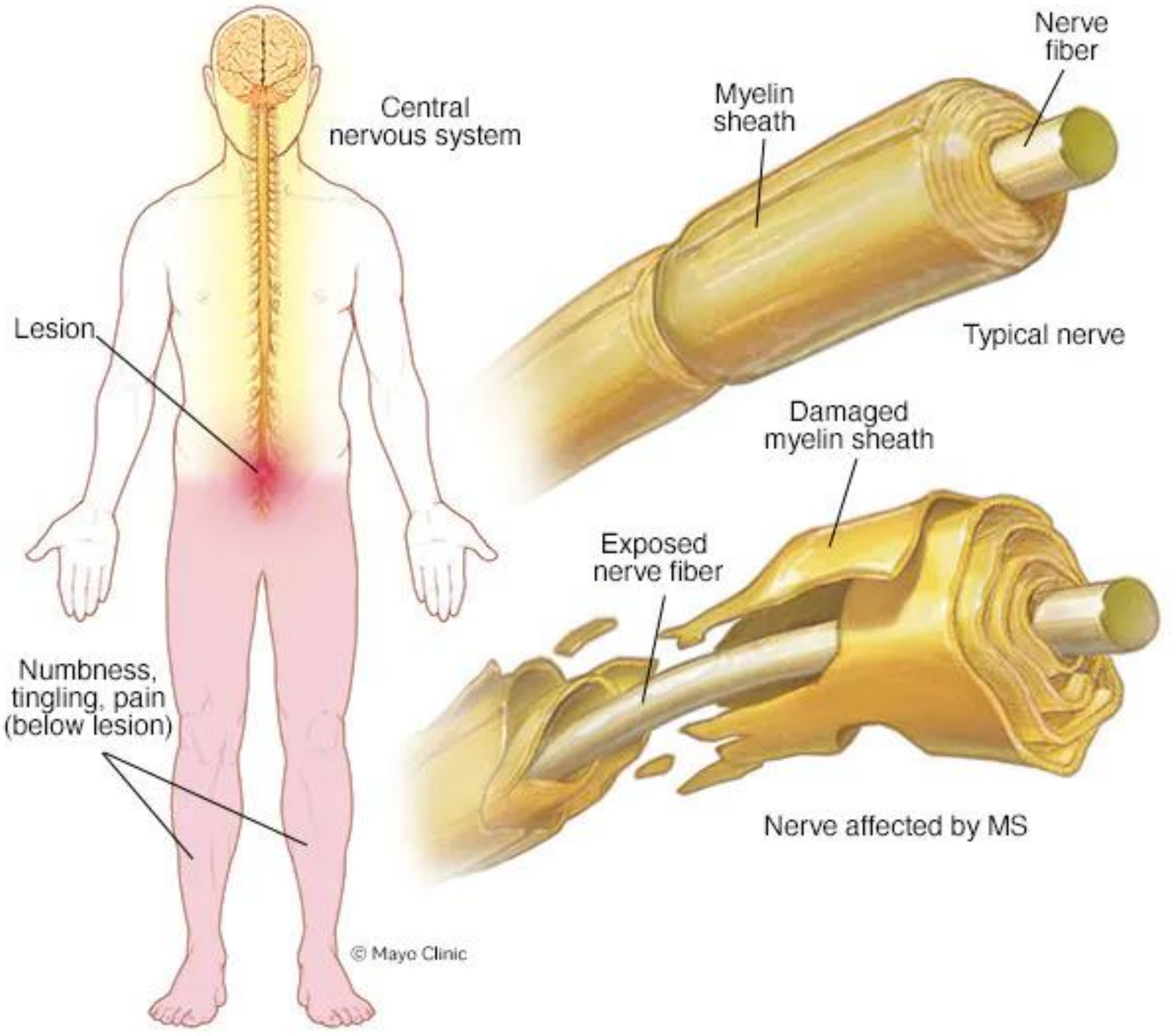


# Signaling support: oligodendrocytes (in the CNS)

- In **Multiple Sclerosis the immune system mistakenly attacks the oligodendrocytes** (autoimmune disease)
- This damages and scars the myelin sheath in the CNS, meaning that messages travelling along the nerves become slowed or disrupted



# Neurons are the signaling units of the nervous system

- 100 billion neurons in the nervous system
- 100 distinct types of neurons
    - Neurons vary in their form, location, and interconnectivity within the nervous system, and these variations in structure are closely related to their functions
- **Each neuron receives and gives rise to thousands of connections**
- Some of these connections are formed nearly a meter from the cell body of the neuron

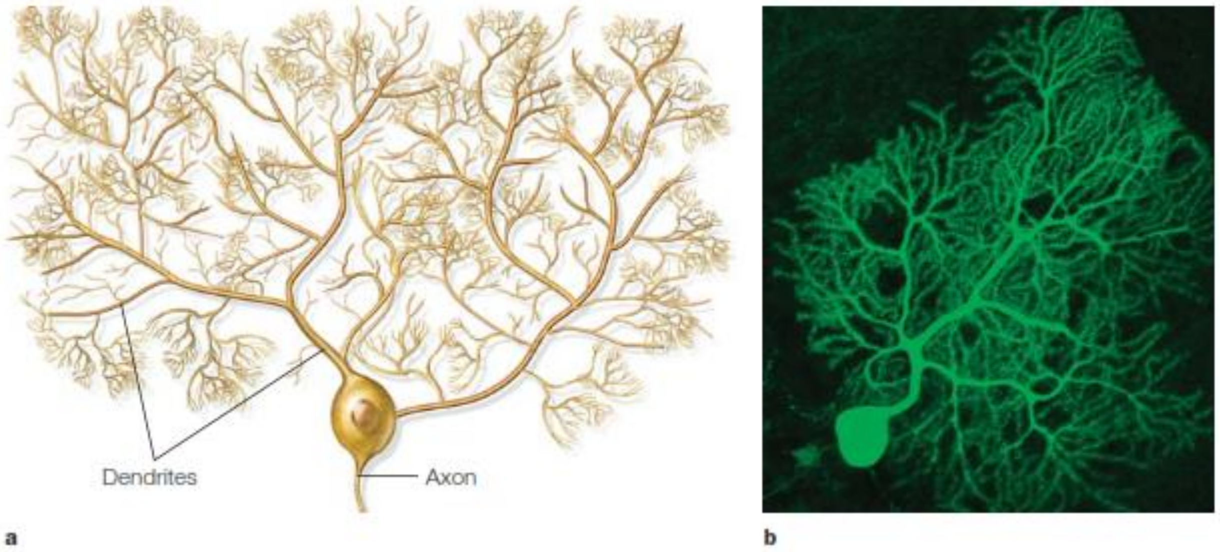



**FIGURE 2.4 Soma and dendritic tree of a Purkinje cell from the cerebellum.**

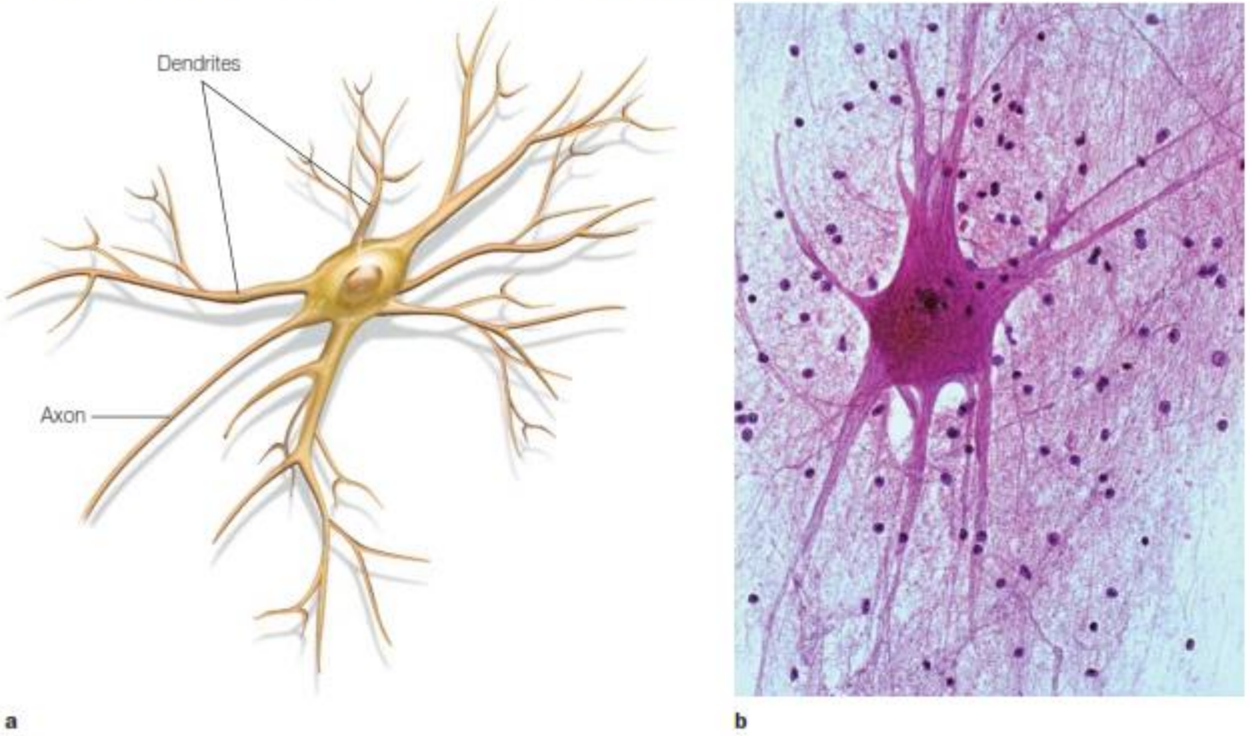
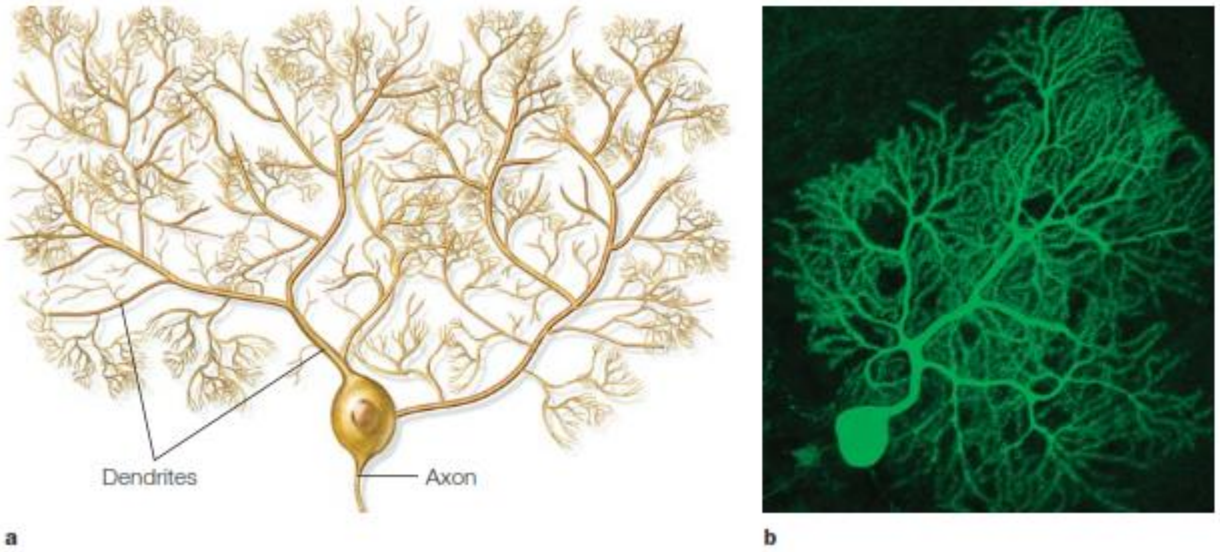



**FIGURE 2.5 Spinal motor neuron.**

## Neurons are the signaling units of the nervous system

1. take in information
2. make a " decision" about it, following some relatively simple rules
3. pass it along to other neurons, by changes in their activity levels

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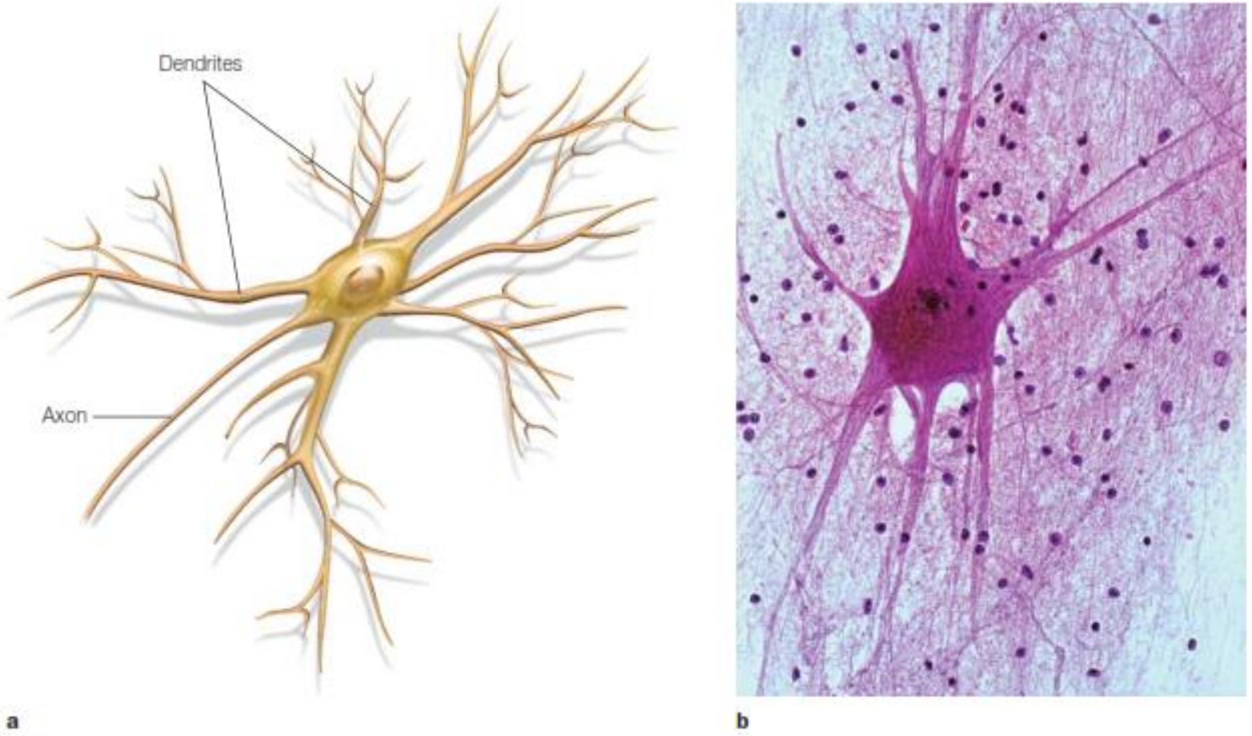
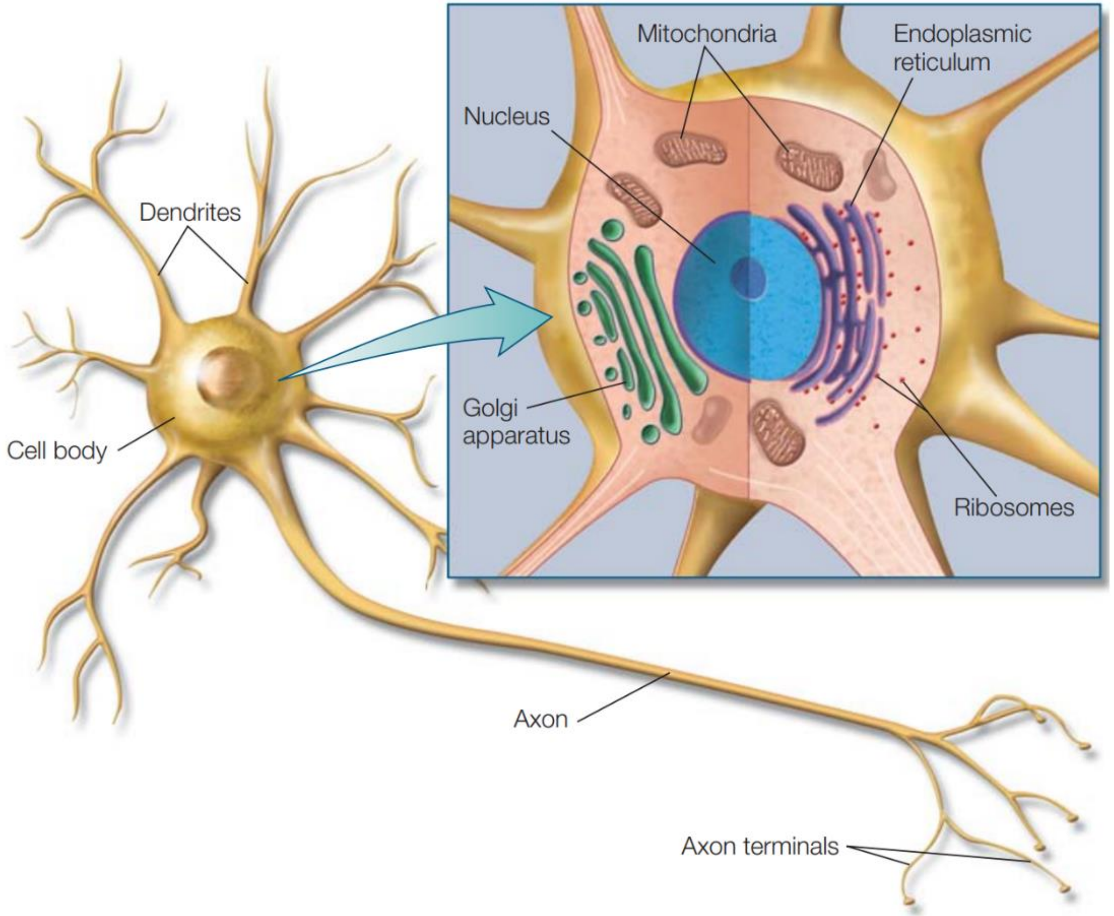



FIGURE 2.5 Spinal motor neuron.

# The structure of neurons

Components found in almost all eukaryotic cells:

- **Cell membrane**: membrane that separates the intracellular and extracellular space
- **The cytoplasm**: intracellular fluid that is made up of a combination of ions, predominantly ions of potassium, sodium, chloride, and calcium, as well as molecules such as proteins.
- **The extracellular fluid**: a bath where the neurons sit, made up of a mixture of the same types of ions found in the intracellular fluid
- **Cell body or soma**: metabolic center of the cell. It contains the nucleus, which contains the genes of the cell, and the endoplasmic reticulum, where proteins are synthesized.

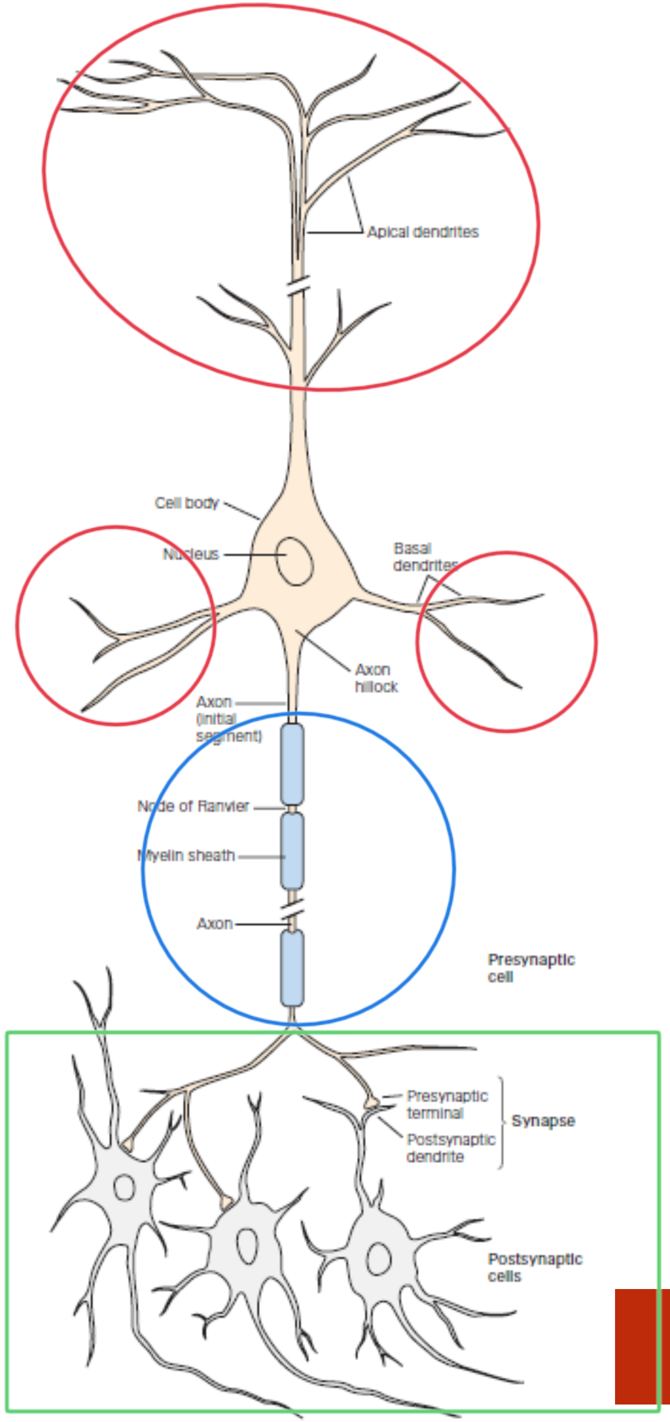


# The structure of neurons

Components unique to neuronal cells:

1. Dendrites
2. Axon
3. Synapses

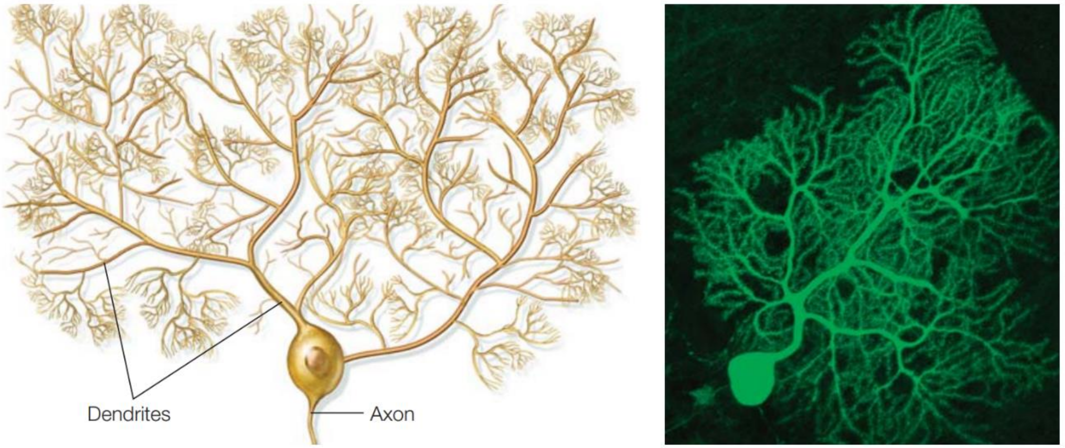
Each component has a distinct role in generating signals and communicating with other neurons.



# The structure of neurons

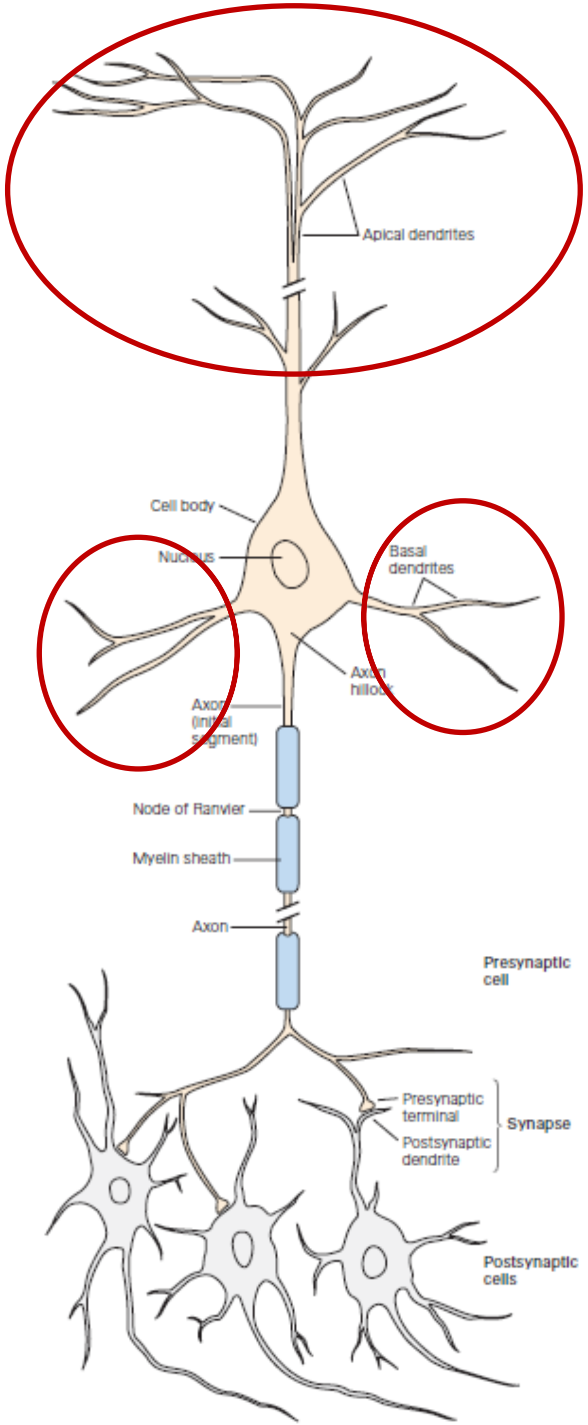
1. **Dendrites**

- **multiple processes**
- represents the **receiving zone** of the neuron: receives inputs from other neurons
- the main apparatus for receiving incoming signals from other nerve cells
- Can take many varied and complex forms, depending on the type and location of the neuron




a b

FIGURE 2.4 Soma and dendritic tree of a Purkinje cell from the cerebellum.

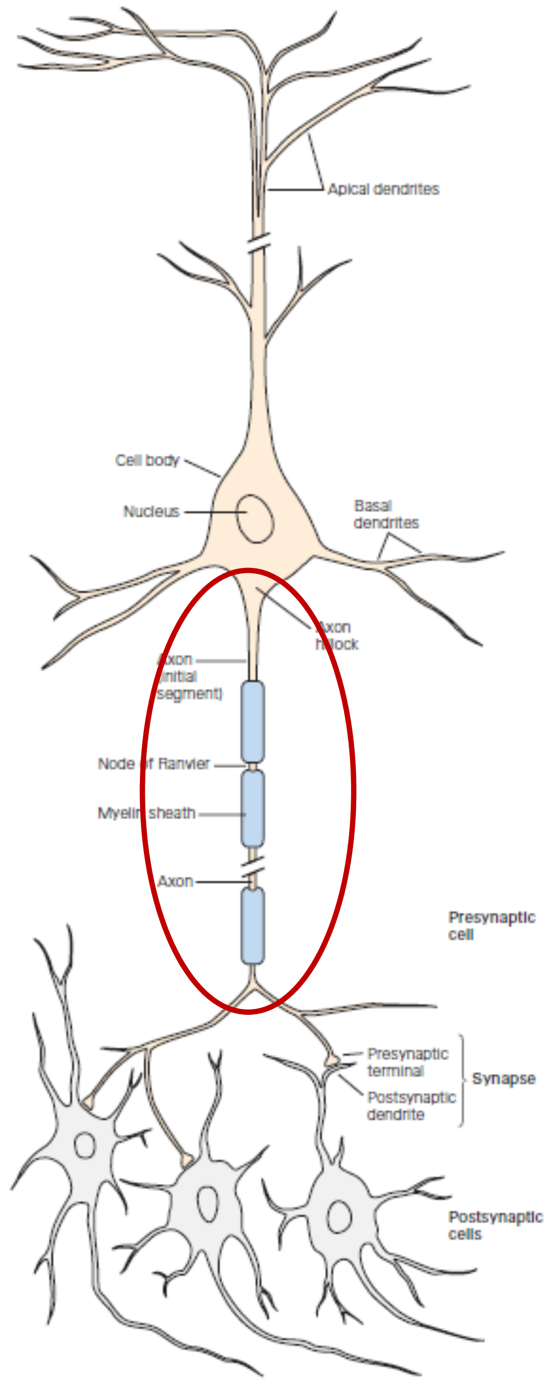


# The structure of neurons

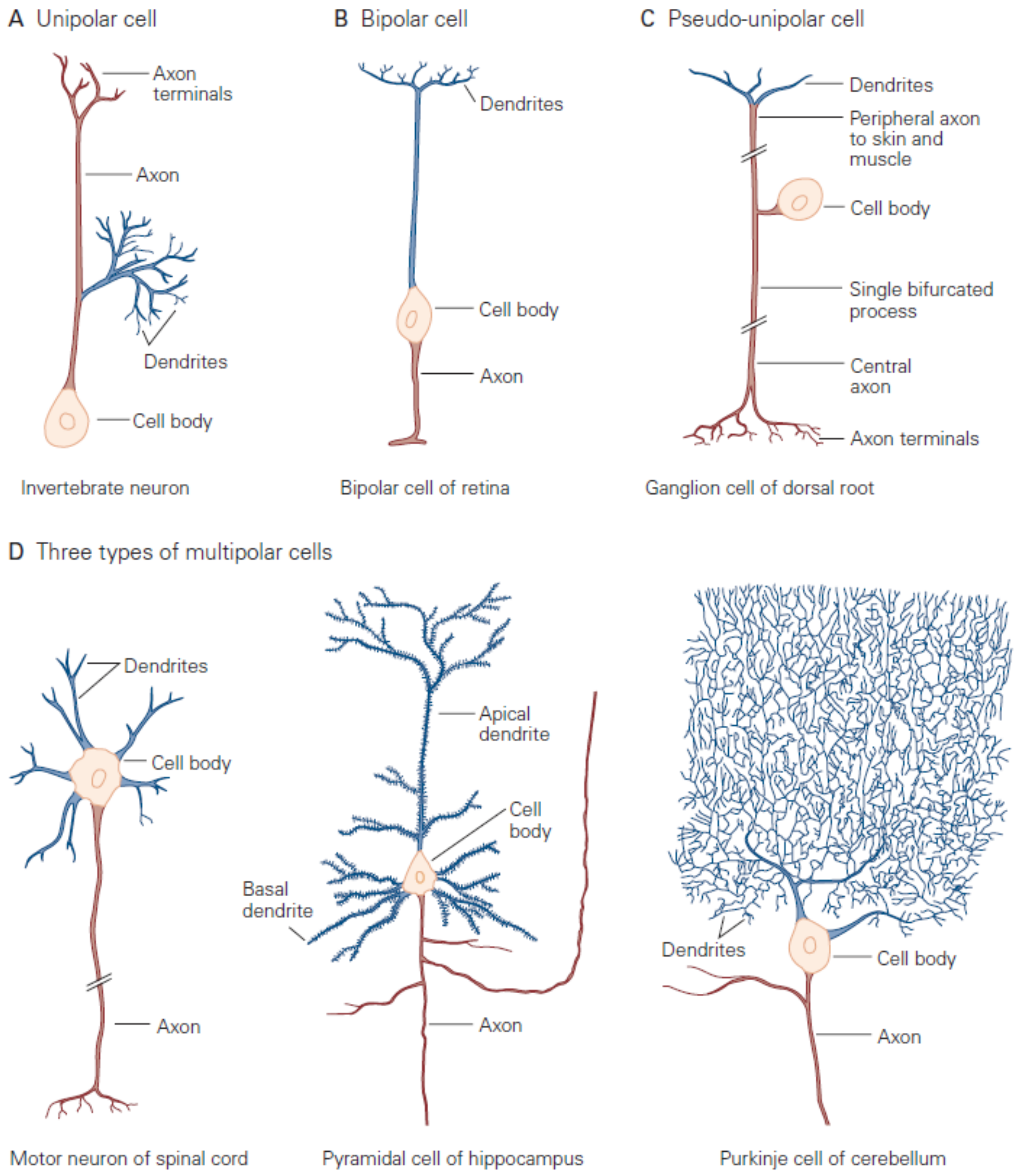
**2. Axon:**

- **single process**
- represents the **transmitting zone** of the neuron
- extends some distance from the cell body and carries signals from the input zone (dendrites) to the output zone (synapses)
- an axon can convey electrical signals over distances ranging from 0.1 mm to 2 m

ONLY ONE DIRECTION



# The structure of neurons



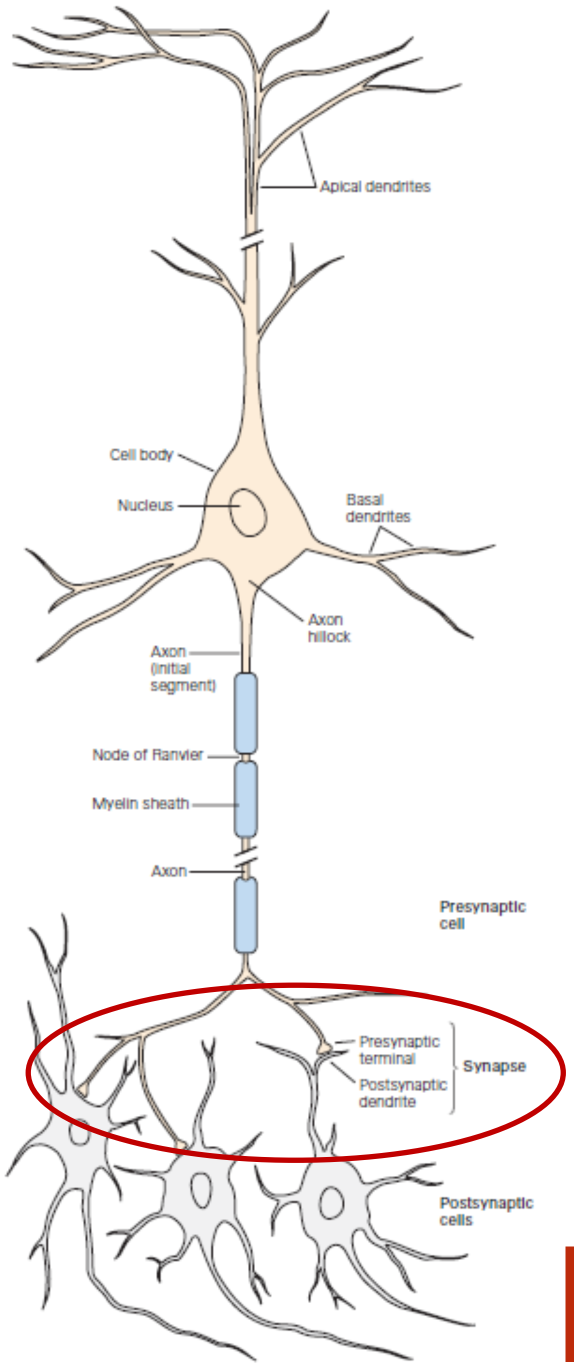
# The structure of neurons

**3. Synapse:**

- **multiple processes**
- represents the **output zone** of the neuron
- specialized structure at the end of the axon, where two neurons come into close contact so that chemical or electrical **signals can be passed from one cell to the next**
- enable communication between neurons

MULTIPLE DENDROIDS → RECEIVES ≠ INPUTS
+
ONE AXIOM → ELABORATES ALL INPUTS TOGETHER
+
MULTIPLE SYNAPSES → SENDS THE SAME MESSAGES TO ALL

ELABORATION OF ONE COHERENT MESSAGE STARTING FROM VARIOUS INPUTS



# Synapses enable communication between neurons

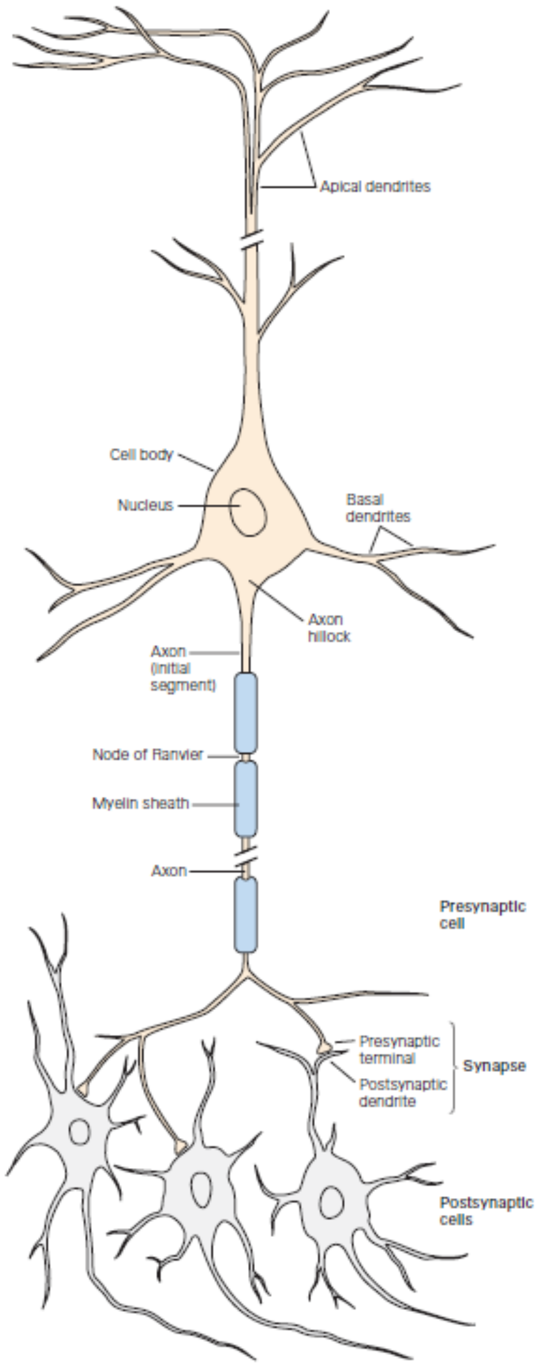
**Presynaptic cell**

- The nerve cell transmitting a signal
- From presynaptic terminals or nerve terminals, i.e. specialized enlarged regions of its axon's branches

**Postsynaptic cell**

- The cell receiving the signal

**Synaptic cleft**: the narrow space separating the presynaptic and postsynaptic cell



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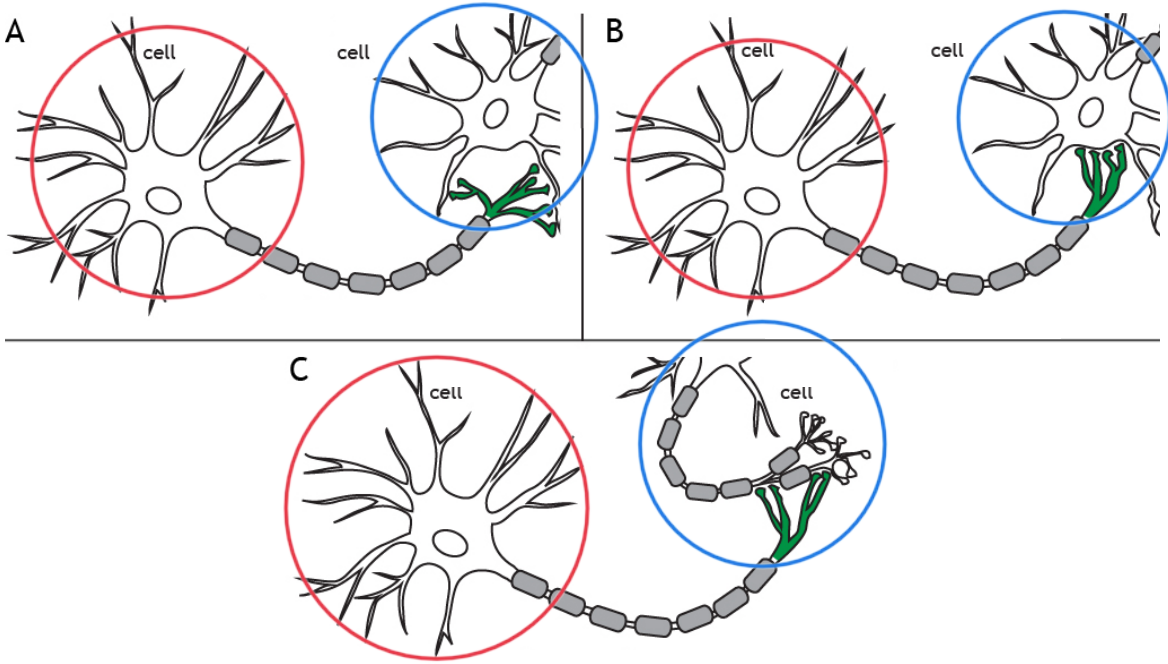
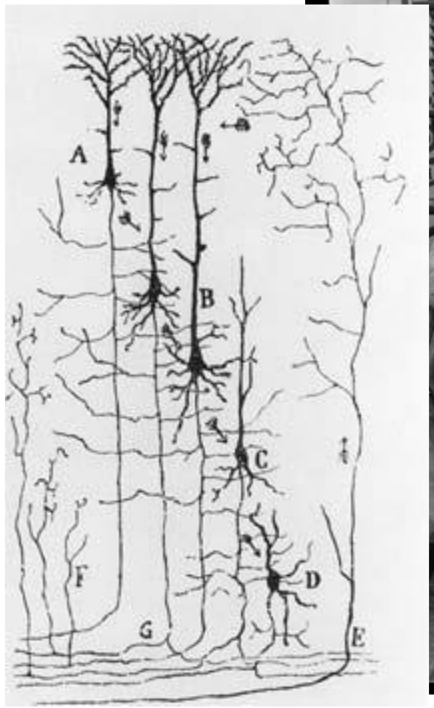
**Which one is the pre-synaptic and which one the post-synaptic cell?**

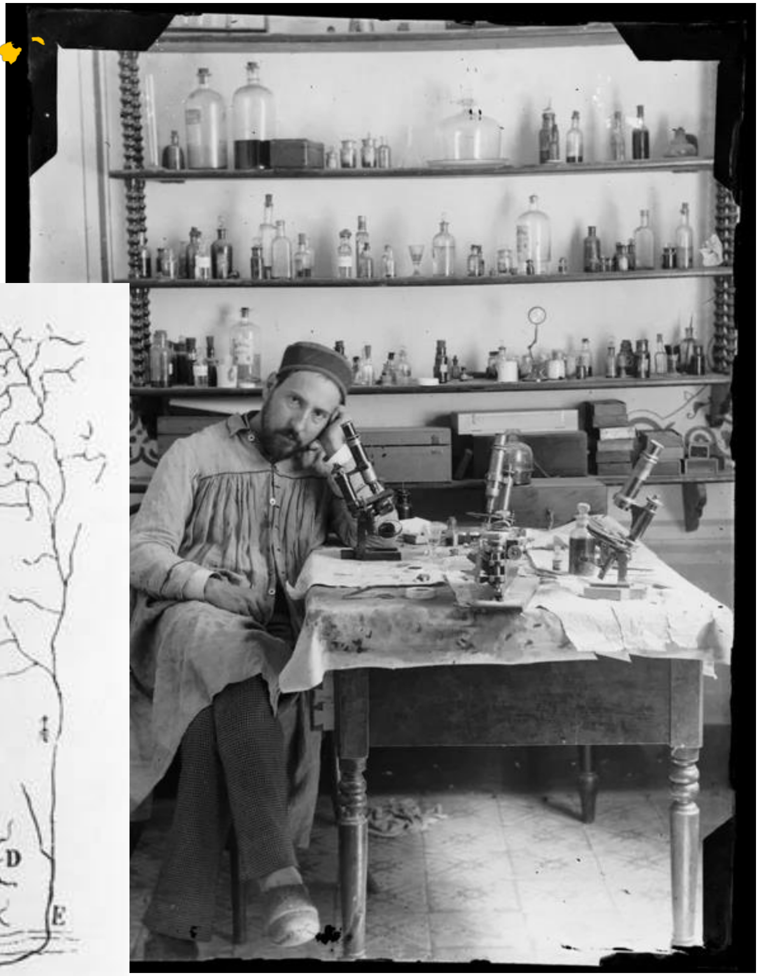


# Principle of connectional specificity

Nerve cells do not connect randomly with one another in the formation of networks. Rather, each cell makes **specific connections - at particular contact points -** with certain postsynaptic target cells but not with others.




Ramón y Cajal's drawing of the afferent inflow to the mammalian cortex



Santiago Ramón y Cajal (1852–1934)

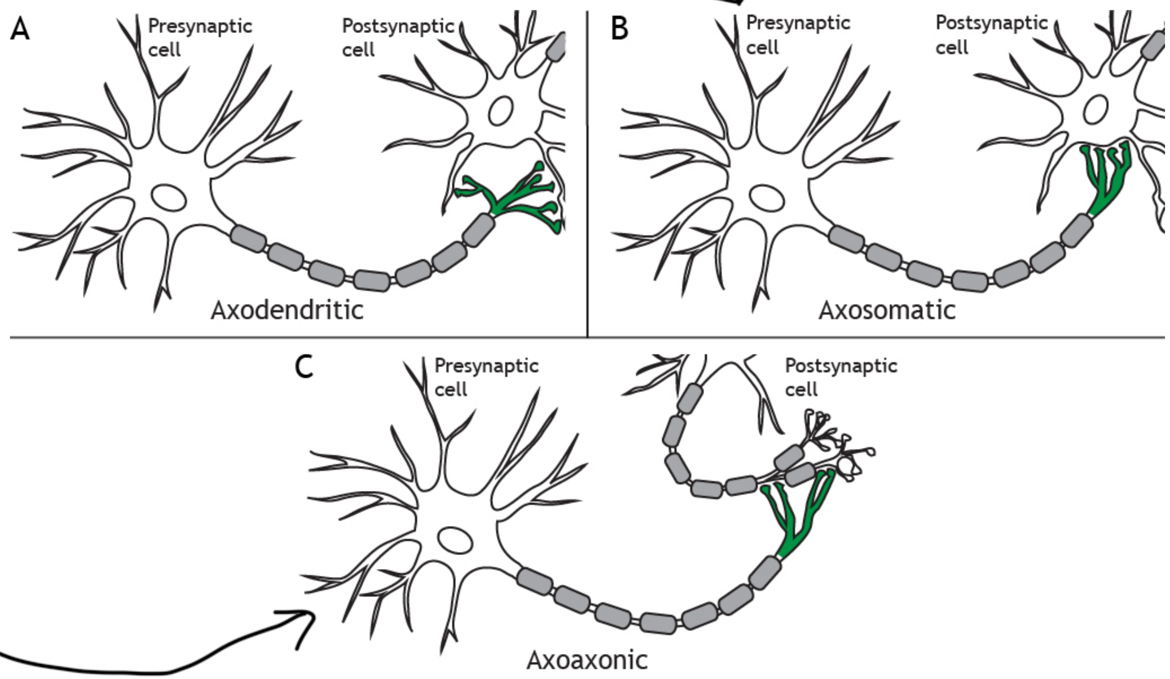
# Three types of synapses

**Axosomatic:** synapses that are made onto the soma or cell body of a neuron.

**Axodendritic:** synapses that one neuron makes onto the dendrite of another neuron. The most common type.

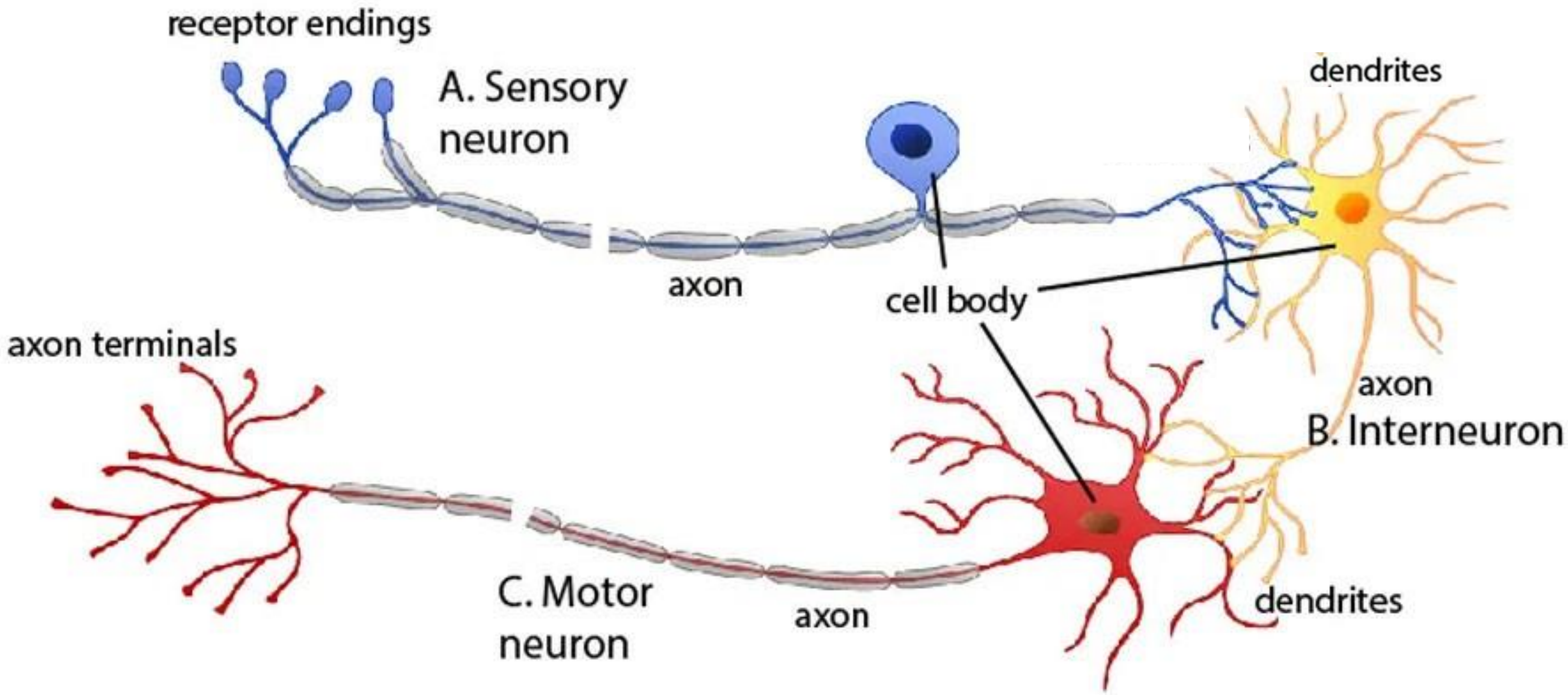
**Axoaxonic:** synapses made by one neuron onto the synapse of another neuron. Axoaxonic synapses mediate presynaptic inhibition and presynaptic facilitation.

**What kind of synapses are these?**



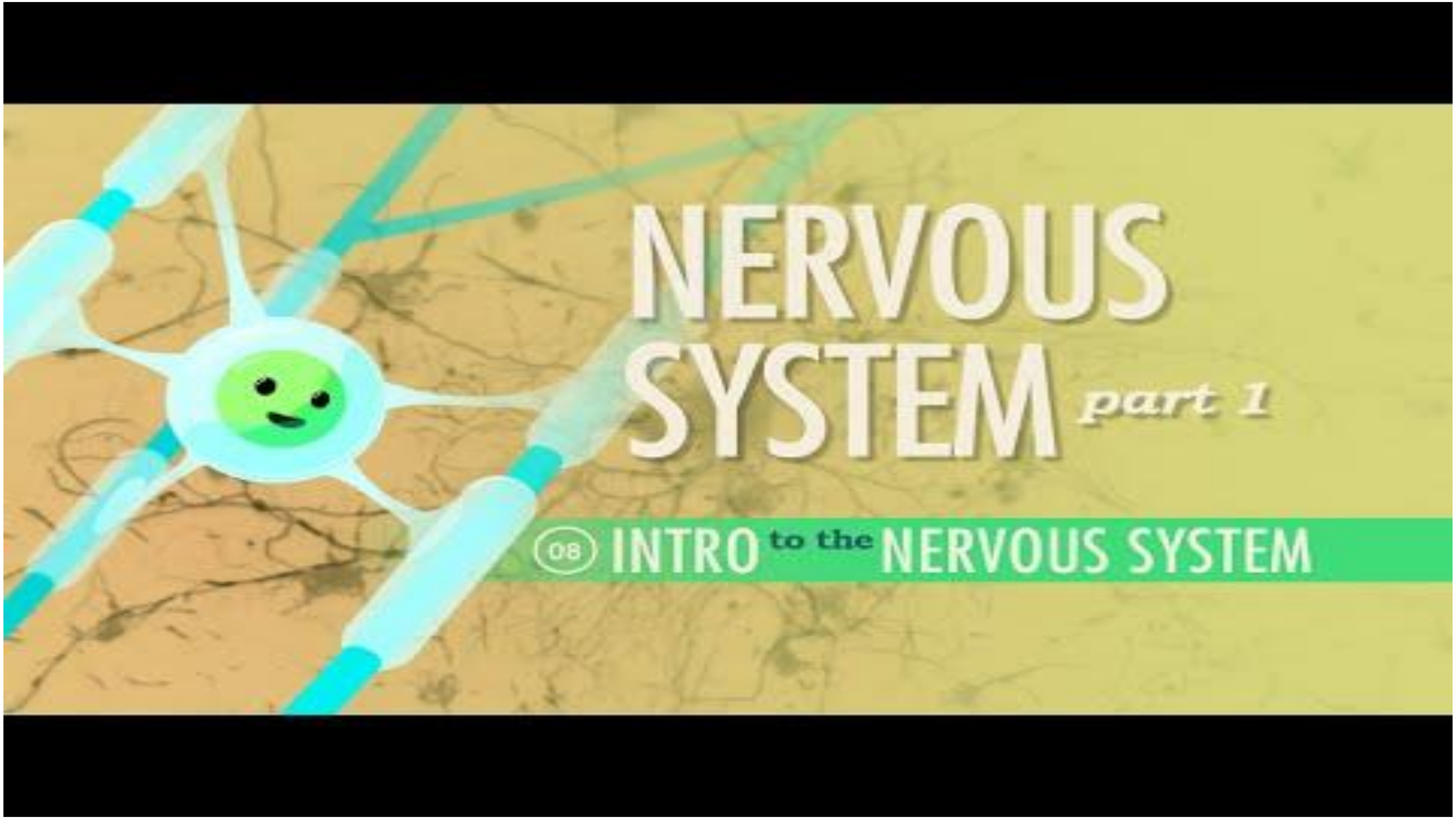
# Neurons are also classified into three major functional categories

1. **Sensory neurons** carry information from the body's peripheral sensors into the nervous system for the purpose of both perception and motor coordination.
2. **Motor neurons** carry commands from the brain or spinal cord to muscles and glands.
3. **Interneurons** mediate impulses between sensory and motor neurons.



wooclap

Questions 1-3

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# Information transfer within a single neuron

# Neurons receive, evaluate, and transmit information

IMPORTANTE PER CAPIRE

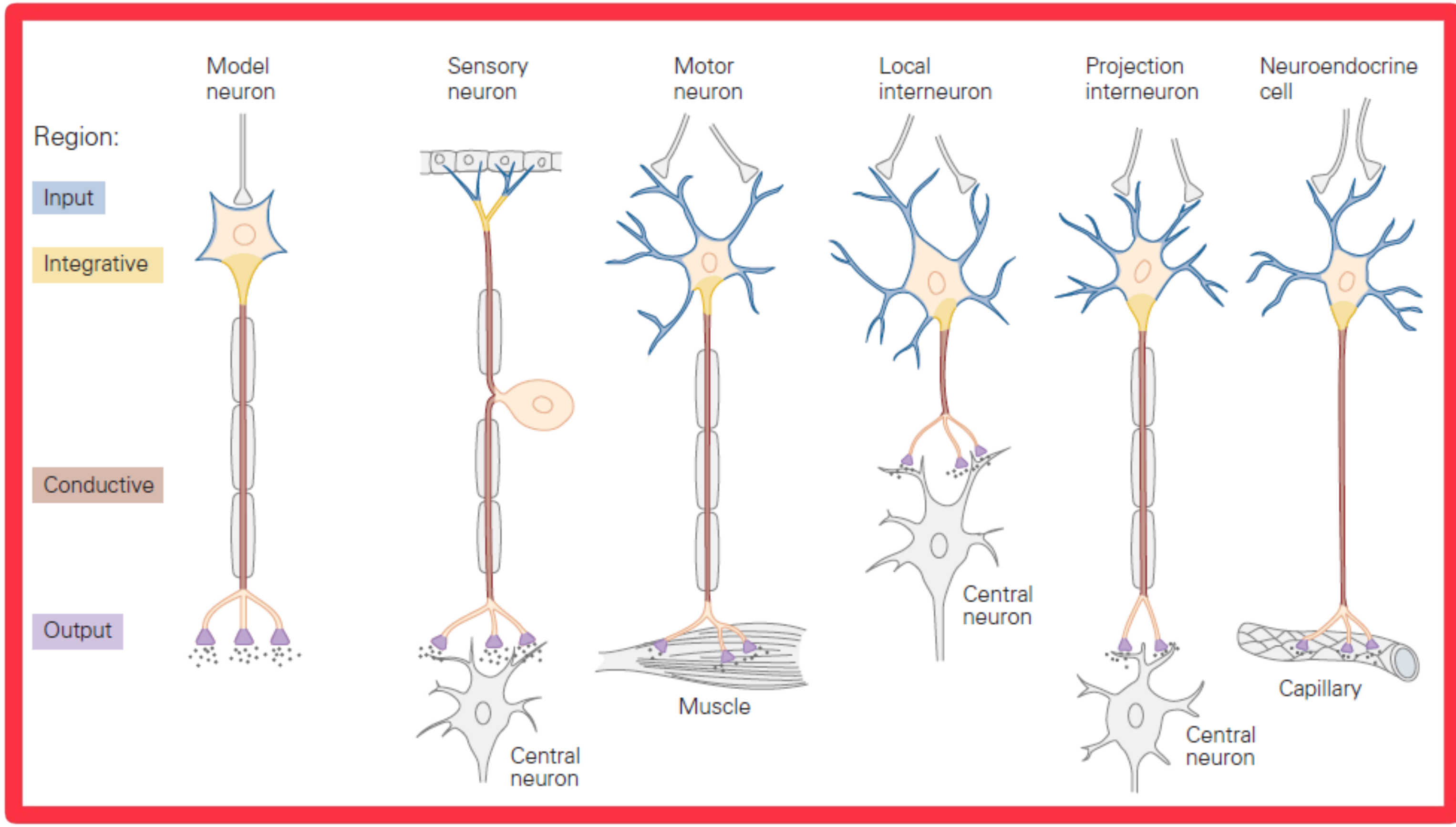
Information is transferred

1. **within a neuron**

- received at synapses on dendrites
- conducted within the neuron
- transmitted down the axon
- passed along at synapses on the axon terminals

2. **Between a neuron and**

- another neuron
- a non-neuronal cell: e.g. muscles or glands



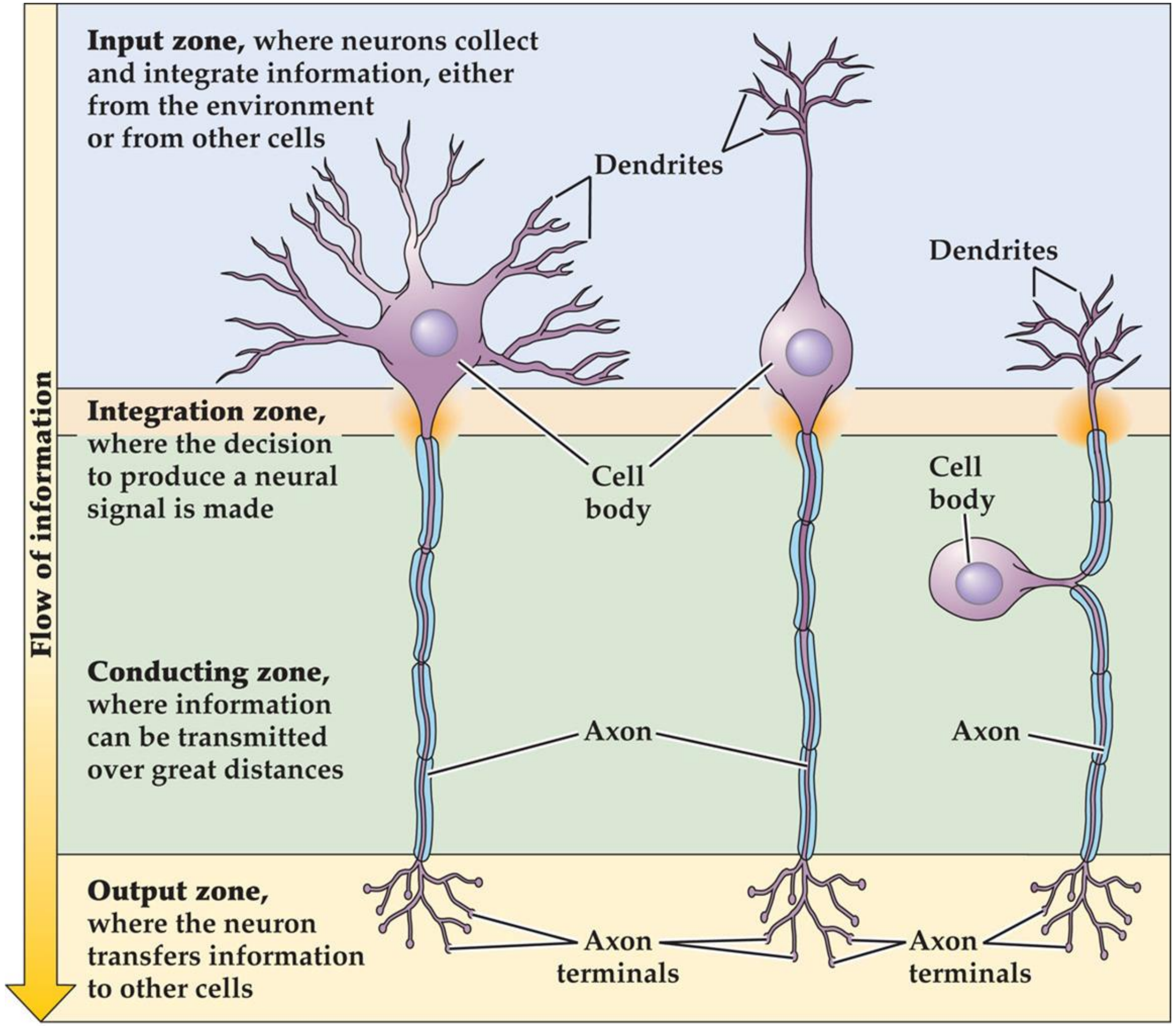
# Signaling is organized in the same way in all nerve cells

4 regions that generate 4 types of signal:

POST-SYNAPTIC POTENTIAL

1. Input signal: PSPs
2. Trigger signal: integration of all PSPs
3. Conductive signal: AP
4. Output signal: synaptic signal

Regardless of cell size and shape, transmitter biochemistry, or behavioral function




THE MIND'S MACHINE, Figure 2.3

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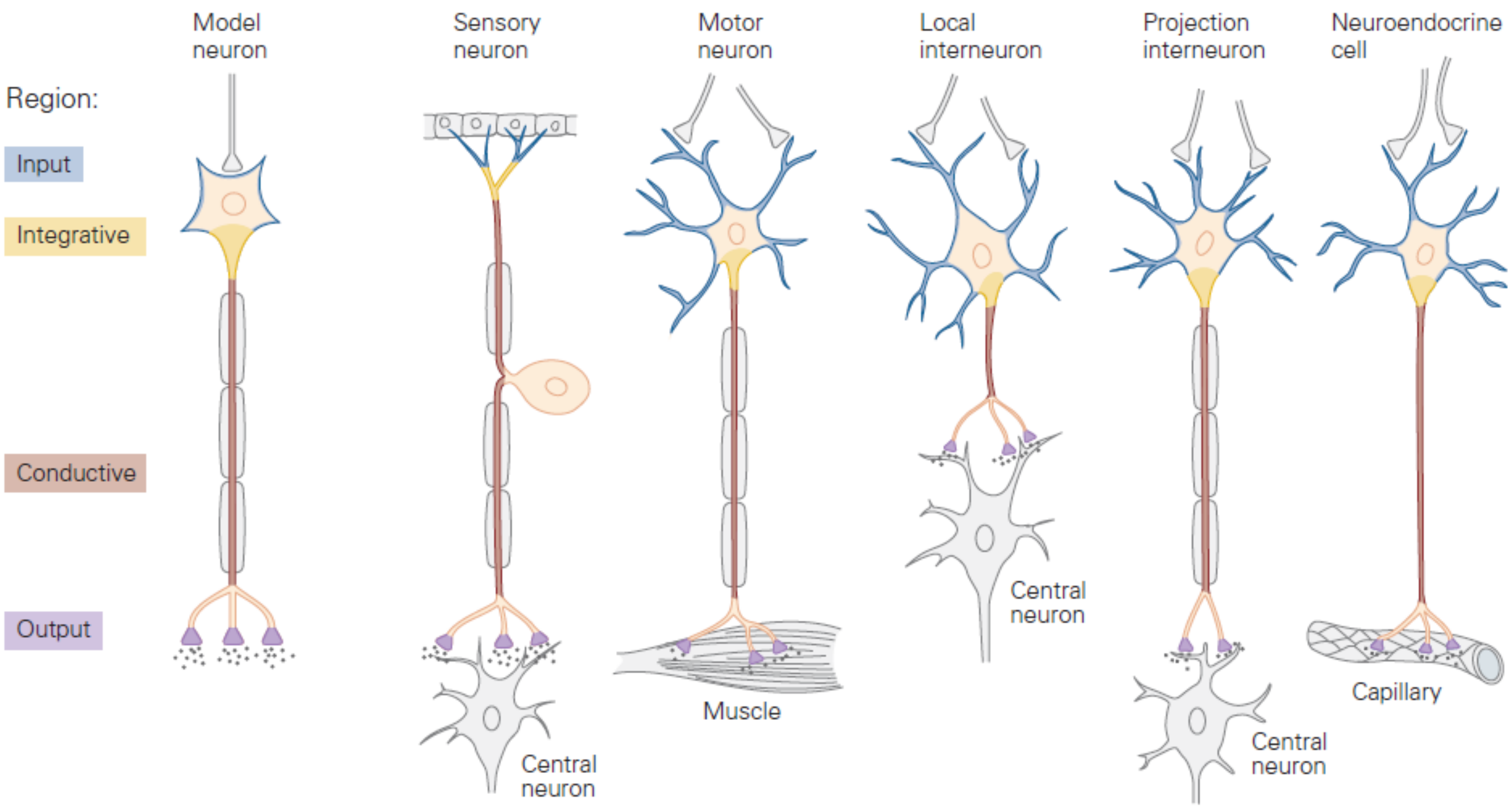
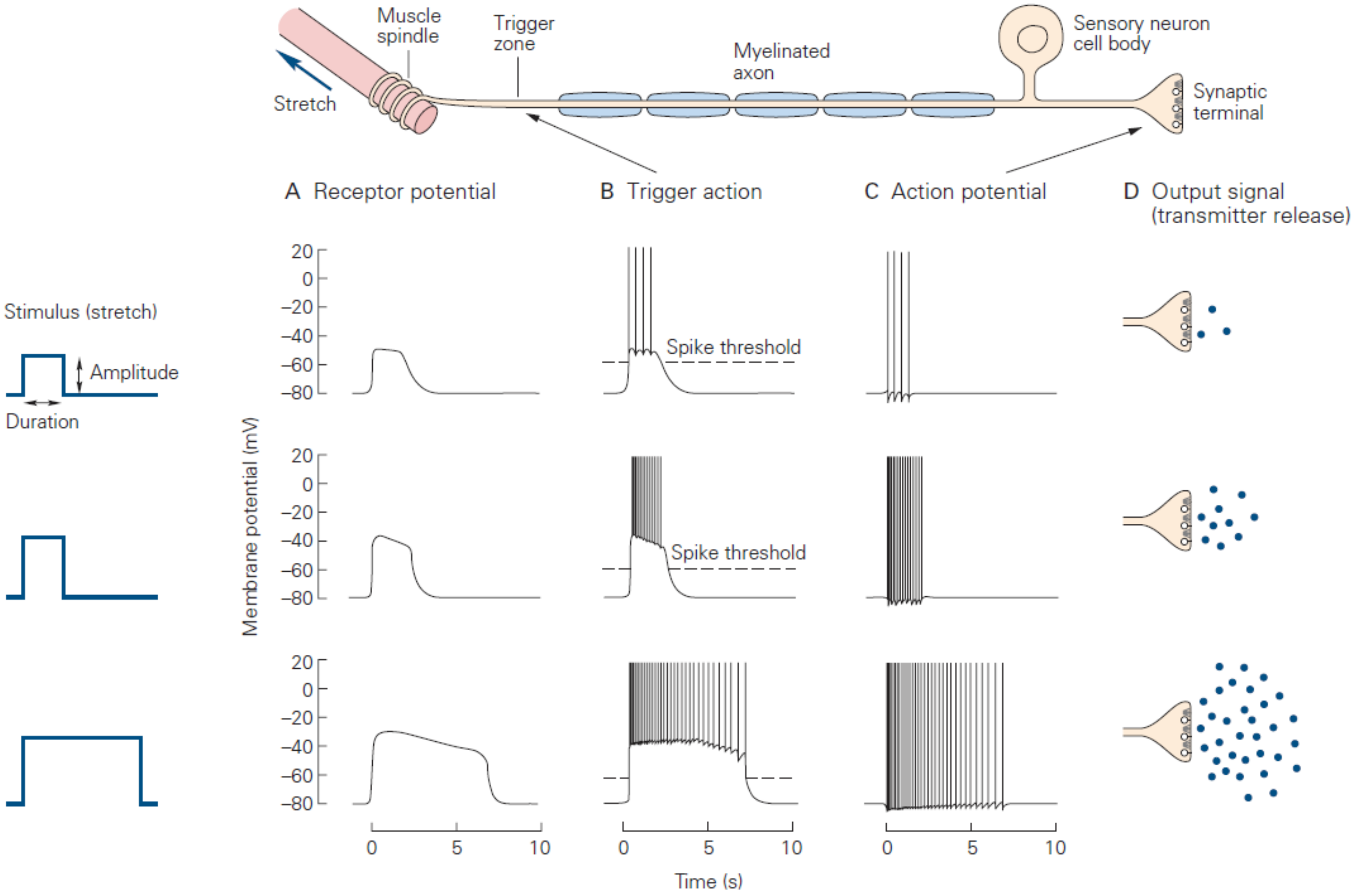


# Each of the neuron’s four signaling regions produces a characteristic signal

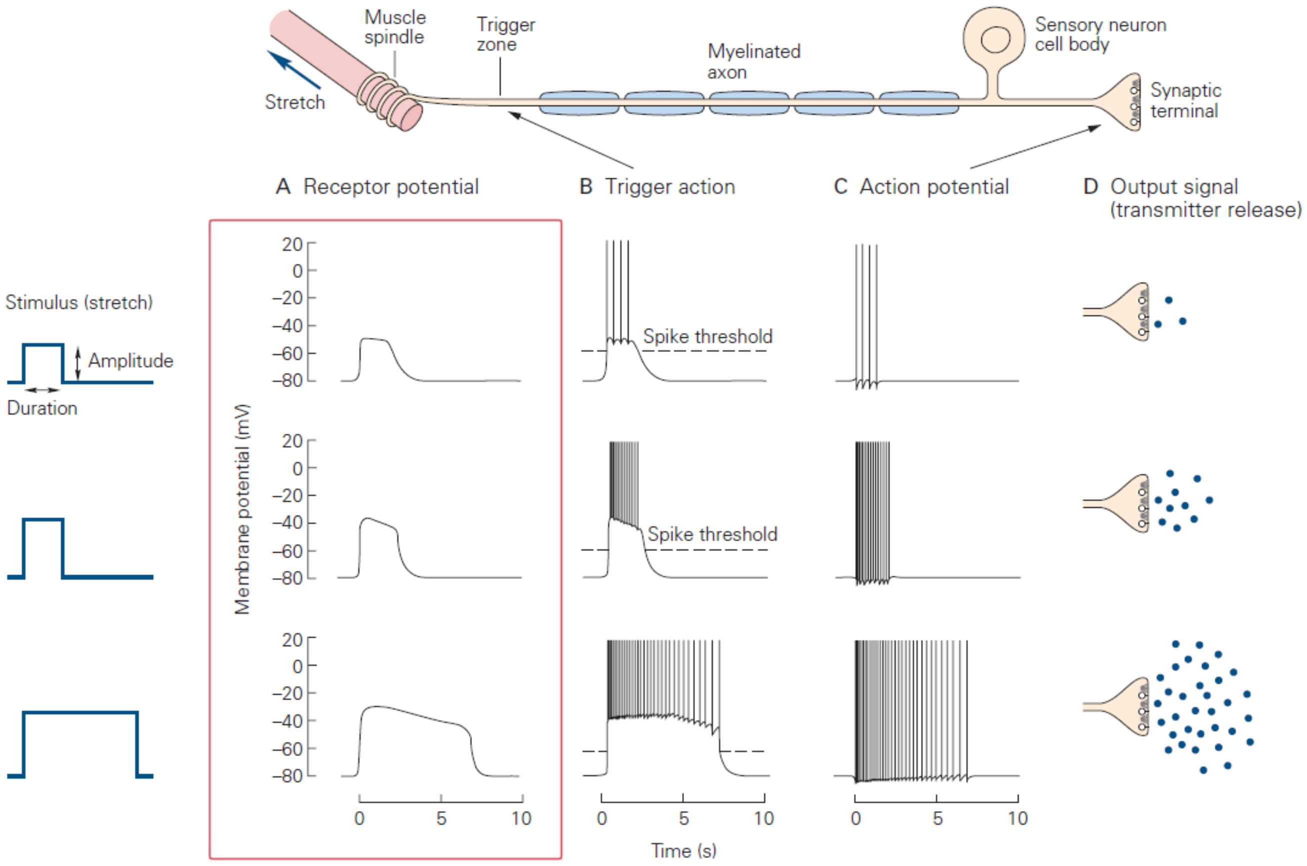


# Each of the neuron's four signaling regions produces a characteristic signal

(A) At the input region, the input signal (PSP) is graded in:

- Amplitude
- Duration

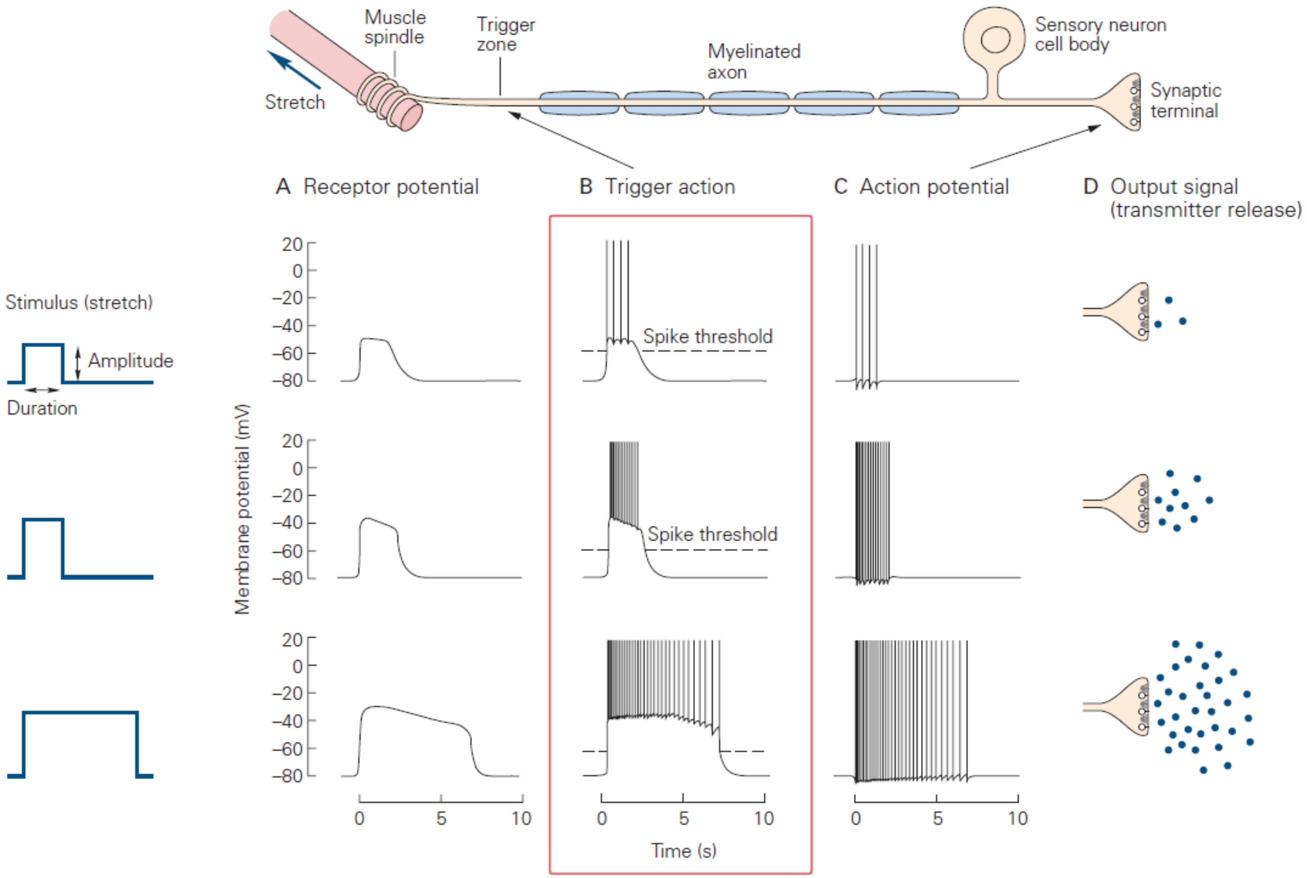
Proportional to the amplitude and duration of the stimulus



# Each of the neuron's four signaling regions produces a characteristic signal

(B) The trigger zone sums the PSPs and "decides" whether to generate and AP

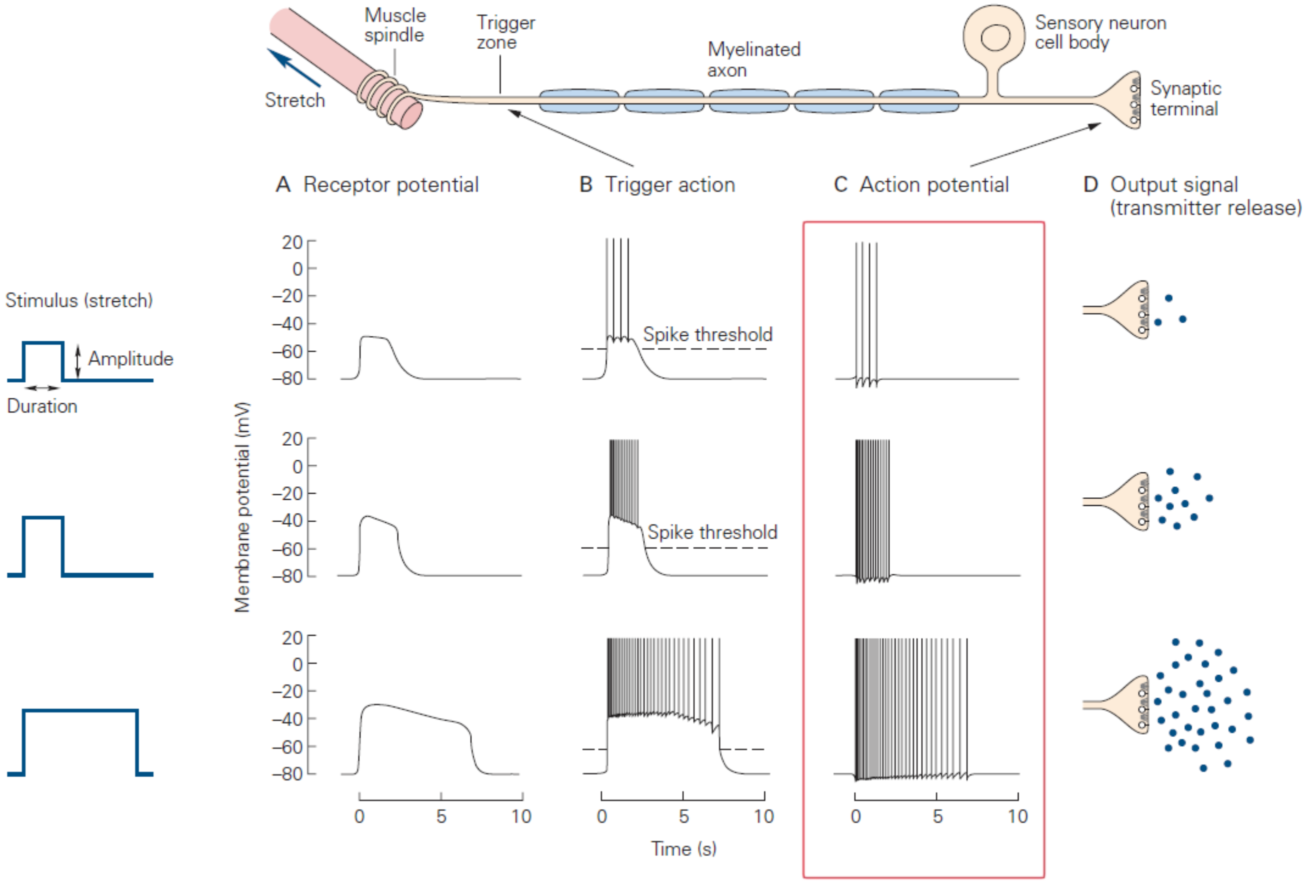
- An action potential is generated only if the input signal exceeds the voltage threshold for initiation (-55mV)
- Once the threshold is surpassed an action potential is generated
- Any further increase in amplitude of the input can only increase the **frequency of action potentials**
- The duration of the input determines the duration of the train of action potentials
- Thus, the graded amplitude and duration of PSPs is translated into a **frequency code** in the APs generated at the trigger zone. All APs produced are propagated along the axon.



# Each of the neuron's four signaling regions produces a characteristic signal

(C) Conductive region transmits action potentials

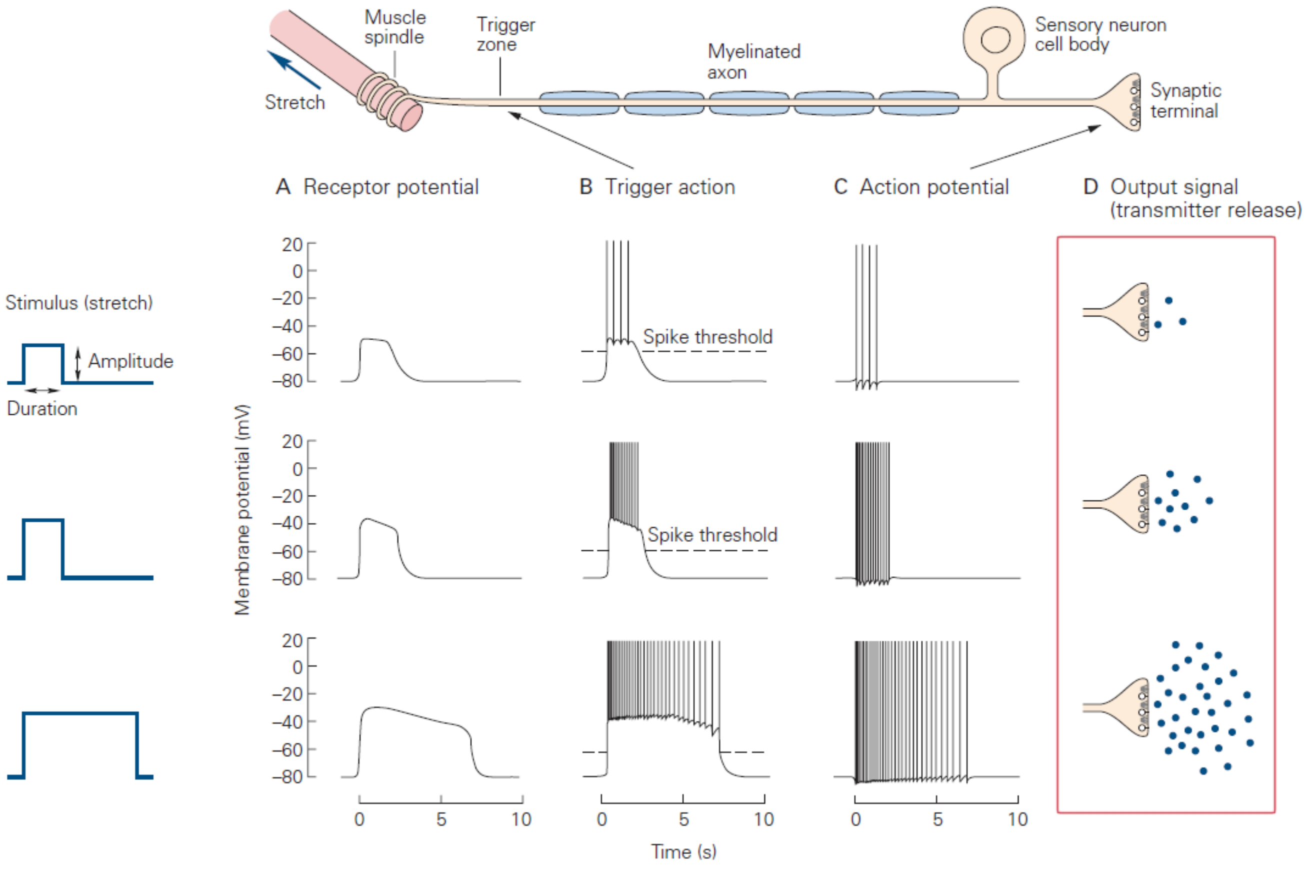
- Action potentials are all-or-none: they all have a similar amplitude and duration
- the frequency and duration of firing represents the information carried by the signal

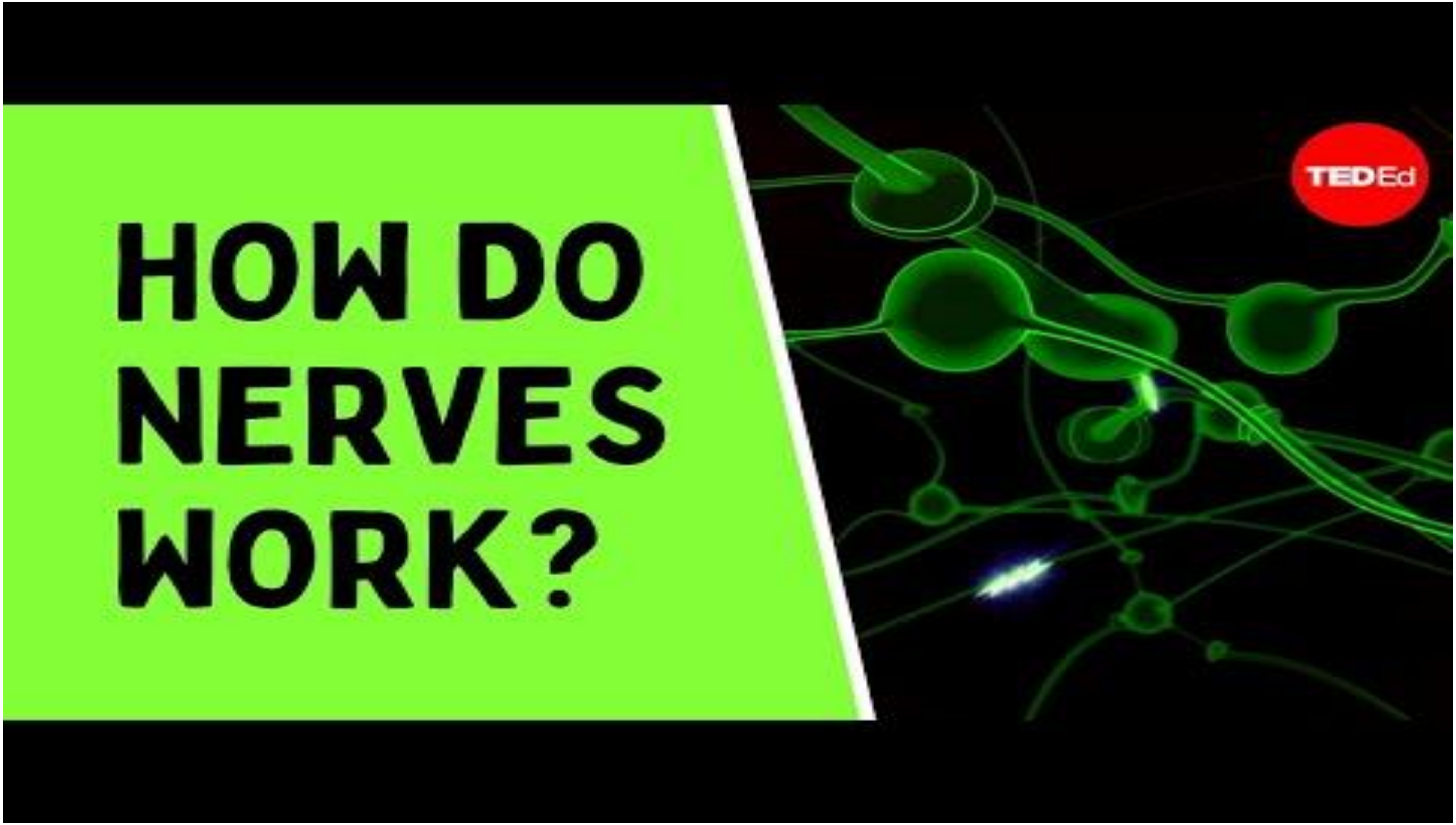


# Each of the neuron's four signaling regions produces a characteristic signal

(D) Output region produces the output signal responsible for synaptic communication

- At chemical synapses, the frequency of action potentials determines exactly how much neurotransmitter is released by the cell
- At electrical synapses, the signal is directly transmitted to the postsynaptic neuron





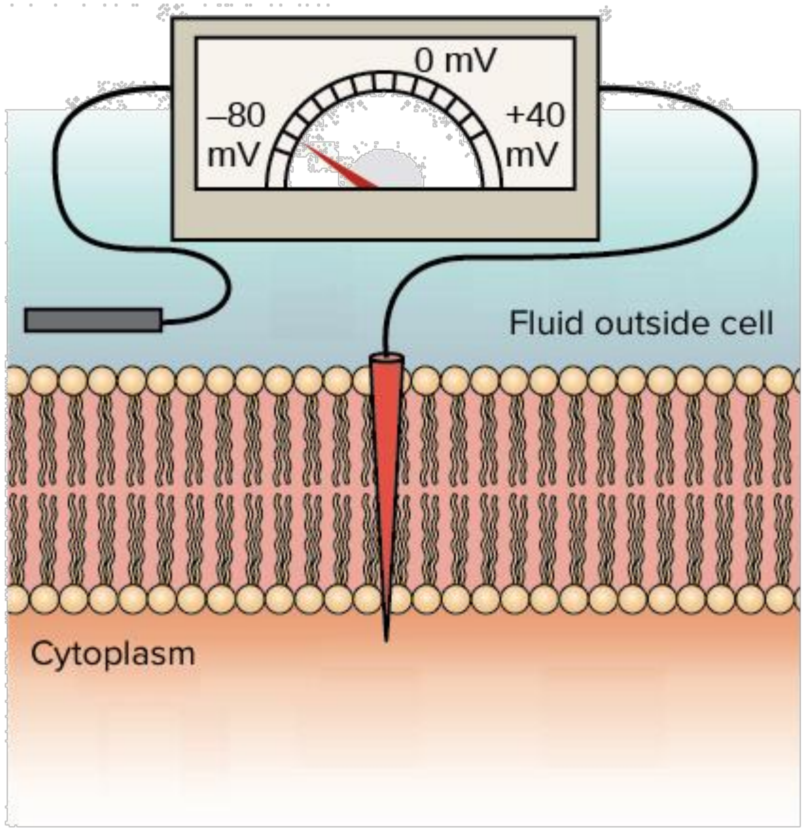

https://youtu.be/uU_4uA6-zcE

# Signaling within a neuron involves transient changes in the electrical state of the neuron

Produced by temporary changes in the electric current into and out of the cell

AND…

it all starts with the **resting membrane potential**



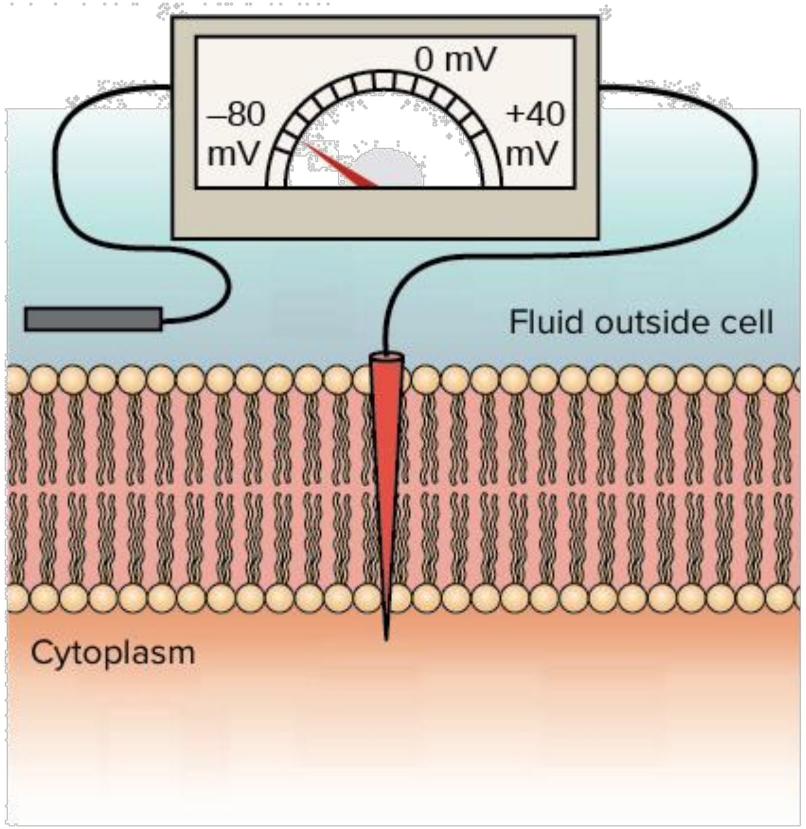
# Resting membrane potential

INSIDE VOLTAGE > OUTSIDE VOLTAGE

DUE TO IONS INSIDE THE NEURON

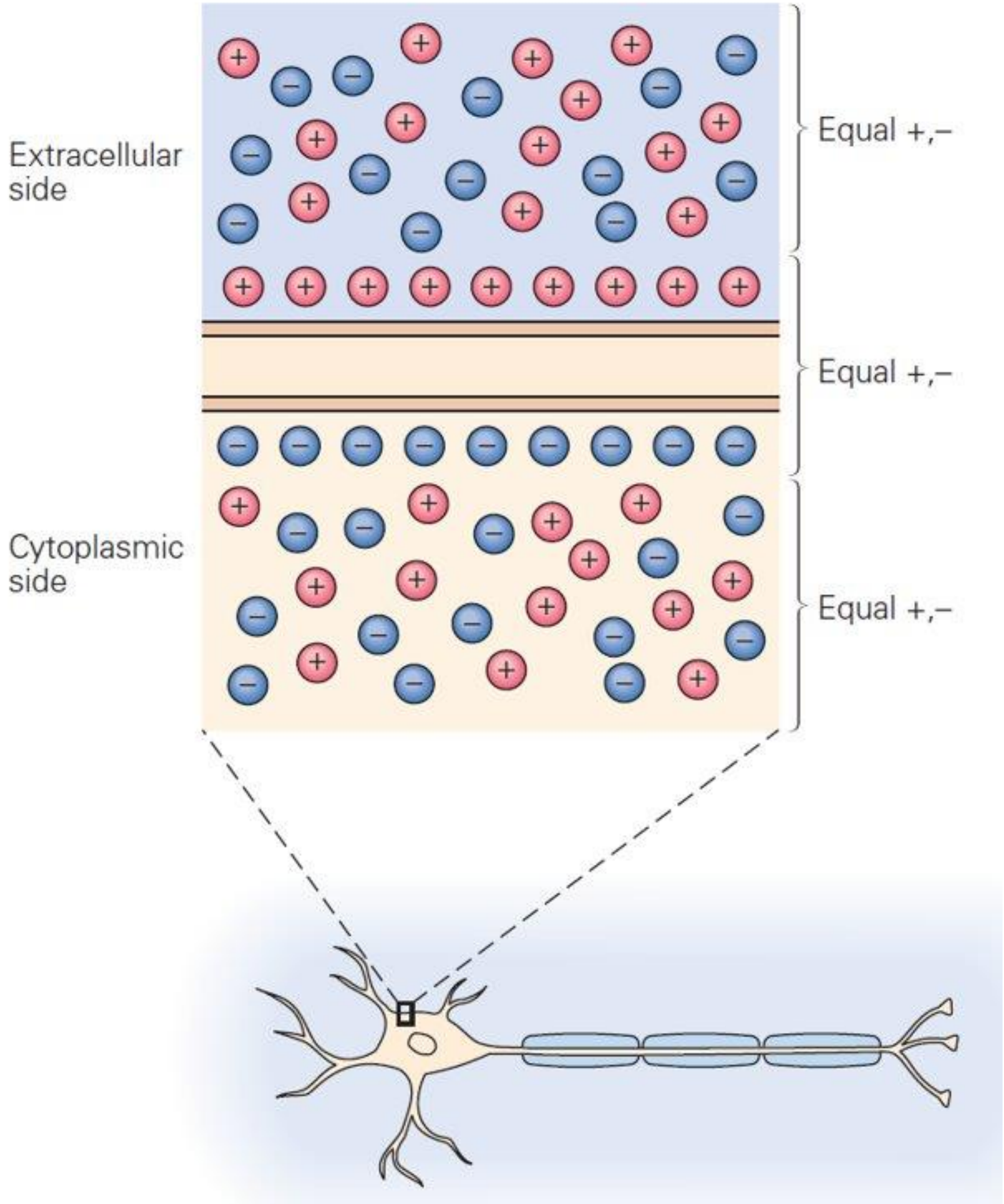
- In a resting neuron the voltage of the **inside** of the cell is about **70 mV more negative than** the voltage **outside** the cell

- This electrical potential difference means that the neuron has at its disposal a kind of battery
- like a battery, the stored energy can be used to do work, I.e. signaling work



# Resting membrane potential

- It **arises from the asymmetric distribution of ions across the neuron's cell membrane:**
    - Electrochemical forces cause the inside of cell to have a more negative potential than the outside: **-70 mV**
- It is the baseline on which all signaling occurs
- It **can be quickly and significantly altered, serving as a signaling mechanism**

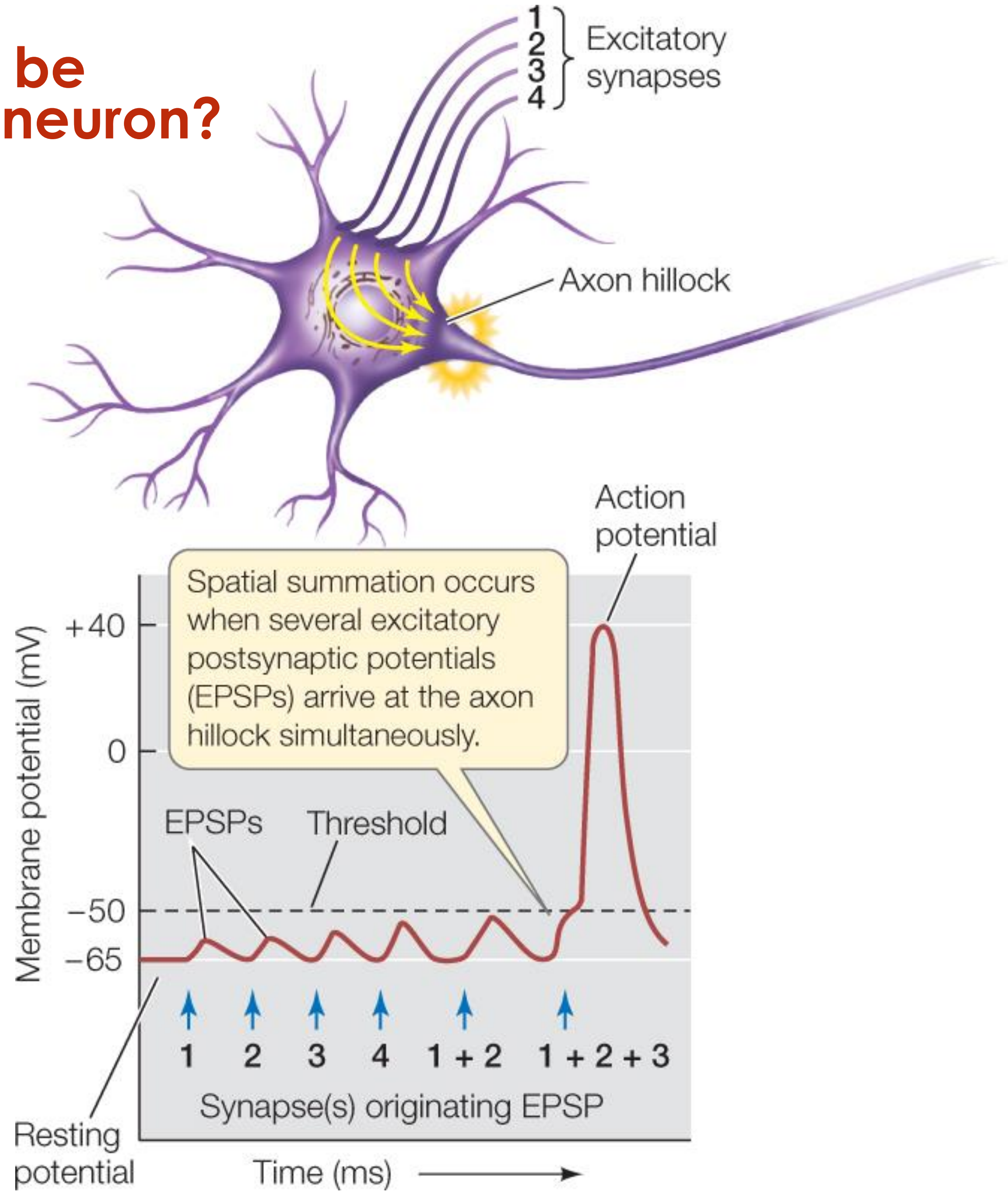


# How can the resting membrane potential be exploited to transmit information within a neuron?

**Postsynaptic potentials (PSPs)** are

- **small changes in membrane potential** that move the cell away from its resting membrane potential
- **graded potentials**
  - The amount of change in the membrane potential is determined by the size of the stimulus that causes it
- **They have to cause a strong enough change in membrane potential** that surpasses a certain threshold, **to trigger an action potential**, which then passes the signal along the axon

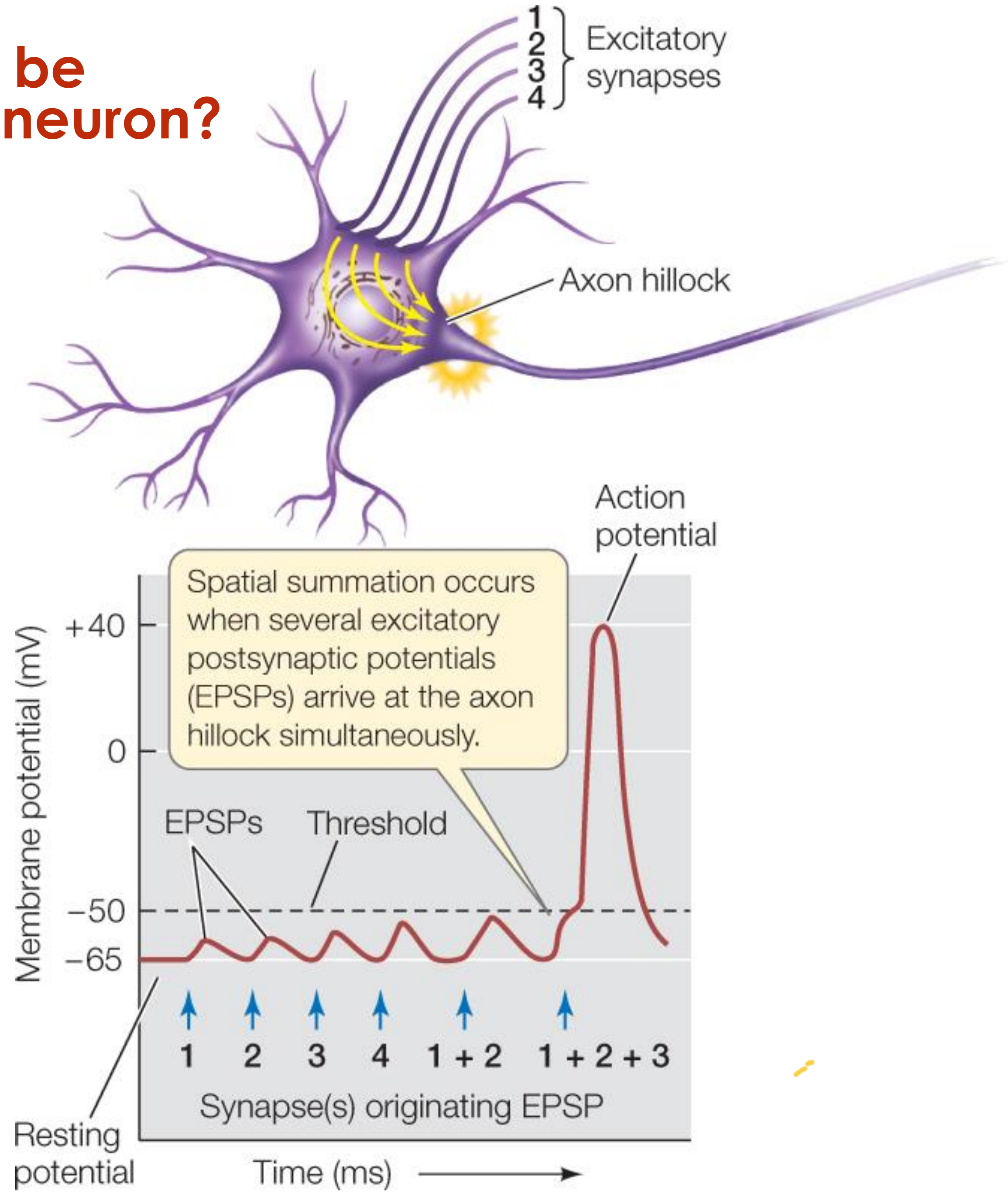
+ → HYPERPOLARIZING
− → DEPOLARIZING



## How can the resting membrane potential be exploited to transmit information within a neuron?

**Postsynaptic potentials (PSPs)** can be

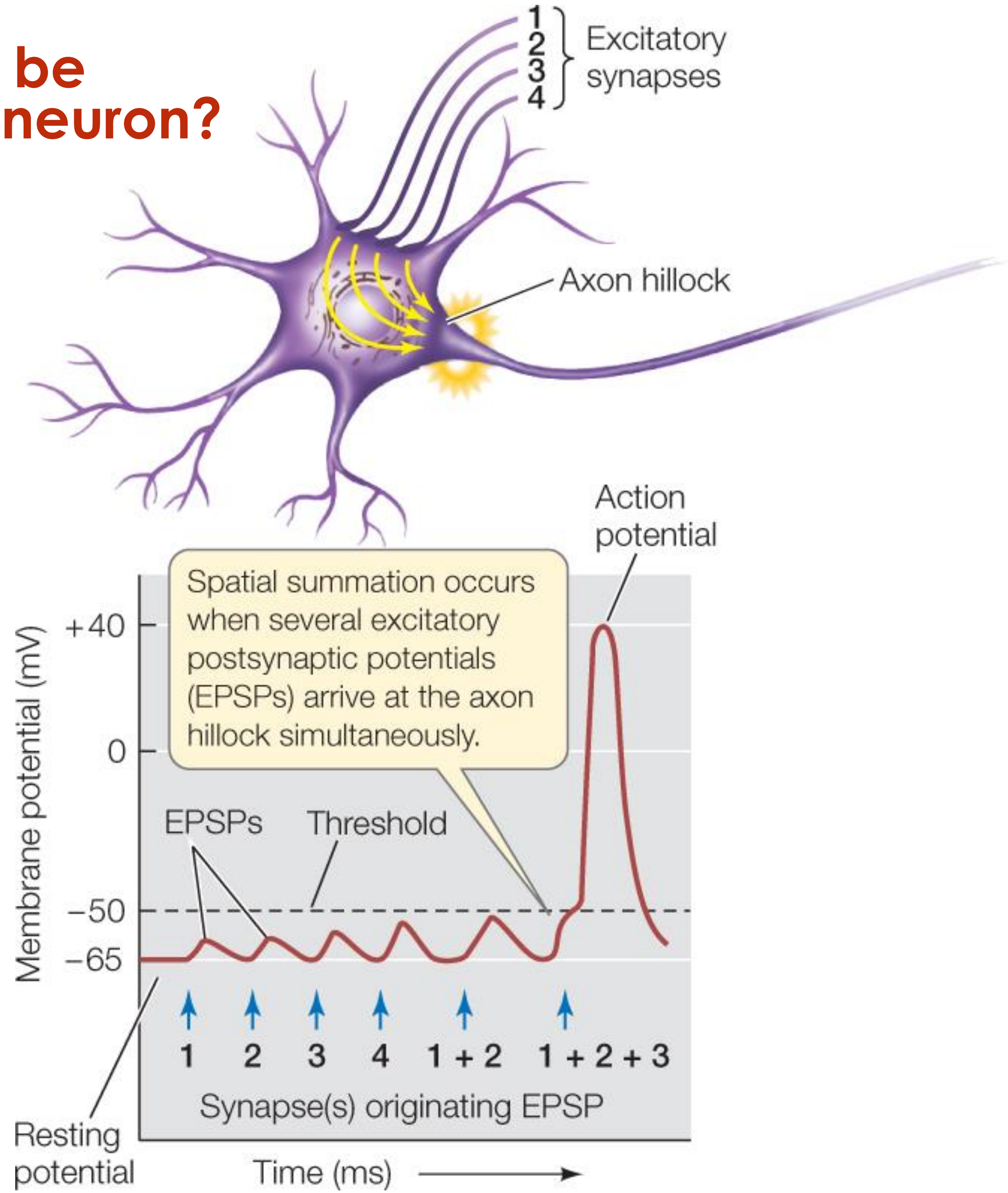
- **Depolarizing**
  - produce a **decrease in membrane potential**
  - Enhance the ability to generate action potential
  - **Excitatory** PSP
- **Hyperpolarizing**
  - produce an **increase in membrane potential**
  - Reduce the ability to generate action potential
  - **Inhibitory** PSP



# How can the resting membrane potential be exploited to transmit information within a neuron?

**Postsynaptic potentials (PSPs)** are

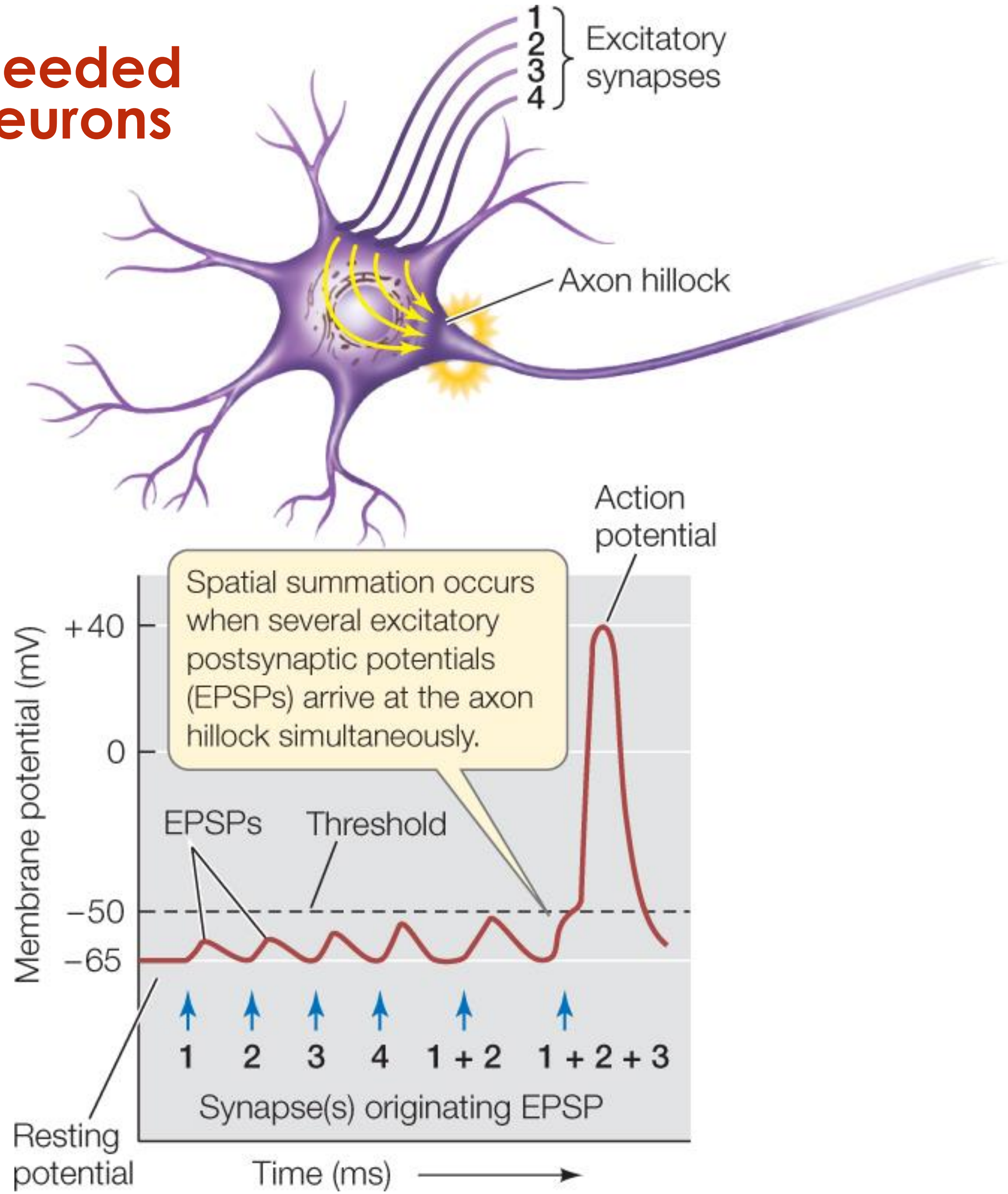
- **Small in amplitude**
- **passively conducted** through the cytoplasm of the dendrite and cell body
    - **decremental conduction**: it diminishes with distance from its origin (i.e. the synapse)
    - Will flow for maximum 1mm → too short to enable signal transmission down the entire the axon
    - **a single EPSP is not enough to trigger the firing of the neuron**



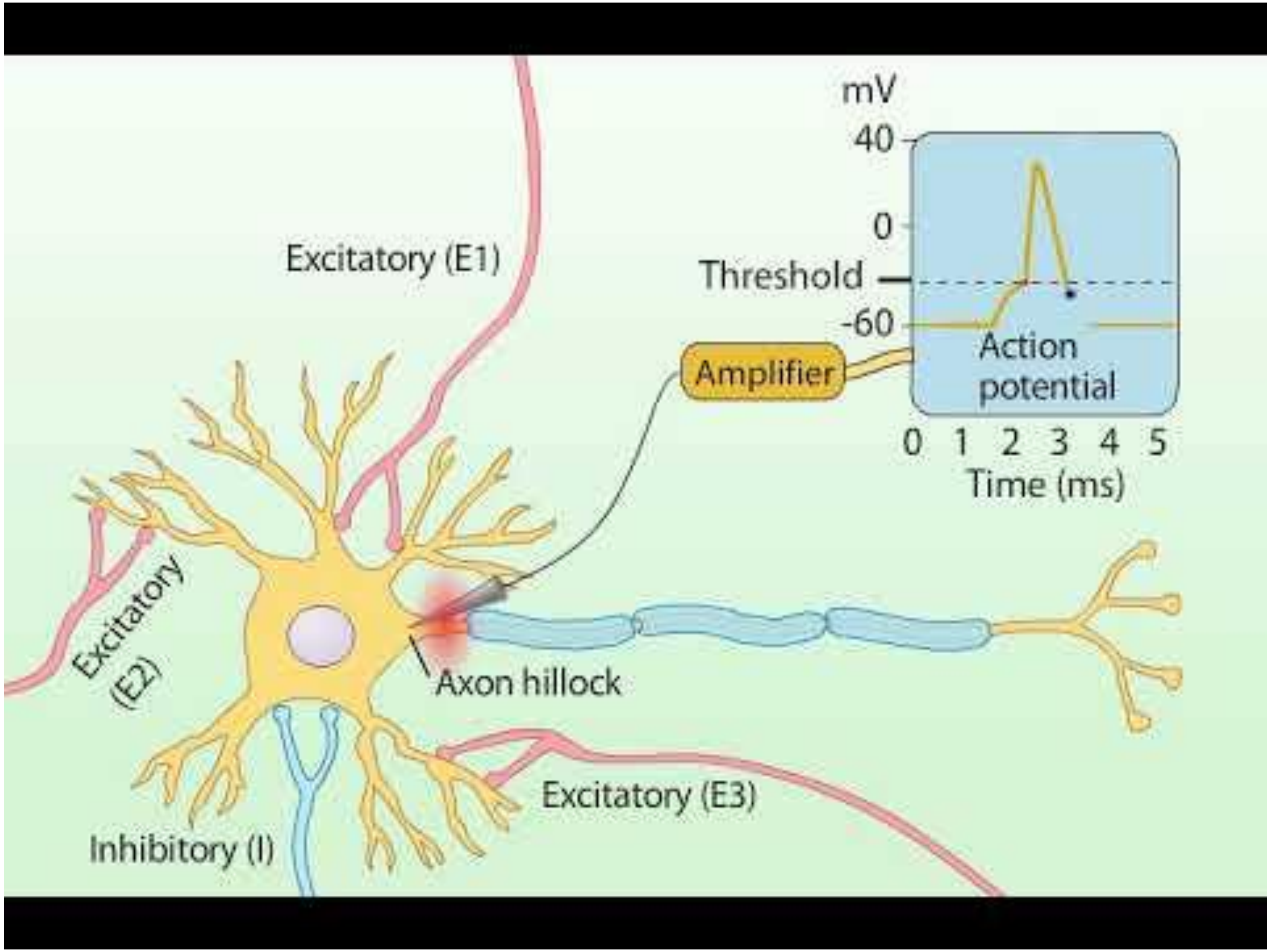
# Input from many presynaptic neurons is needed to generate an action potential in most neurons

Because a single EPSP is not enough to trigger the firing of the neuron

- The passive electrical currents that are generated following EPSPs on multiple distant dendrites **sum together** at the **axon hillock** (integrative region)
    - **Spatial summation**
        - Summation of excitatory and inhibitory PSPs received at spatially separate synapses
    - **Temporal summation**
        - Summation of excitatory and inhibitory PSPs received at different time points



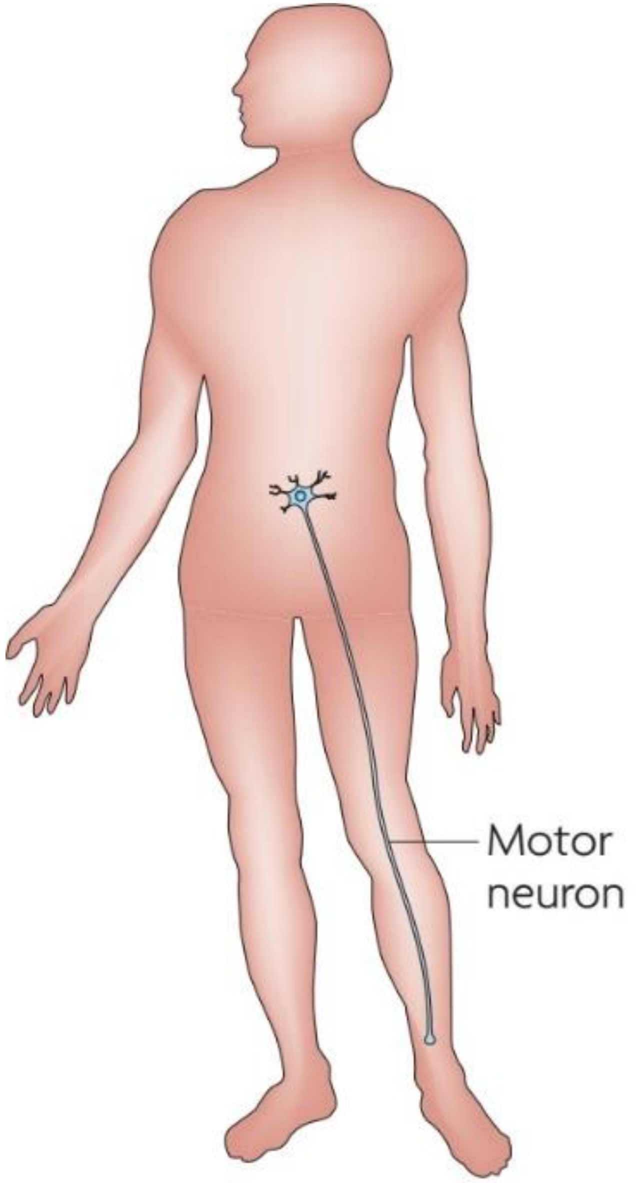
# Postsynaptic potentials (PSPs)




https://www.youtube.com/watch?v=B92rsa1is_k

# An evolutionary challenge...

- The maximum distance a passive current (e.g. EPSP) will flow is only about 1 millimeter.
- The longest axon of a human motor neuron can be over a meter long, reaching from the base of the spine to the toes. Sensory neurons can have axons that run from the toes to the posterior column of the spinal cord, over 1.5 meters in adults.
- To enable efficient communication, information must travel **far & fast**



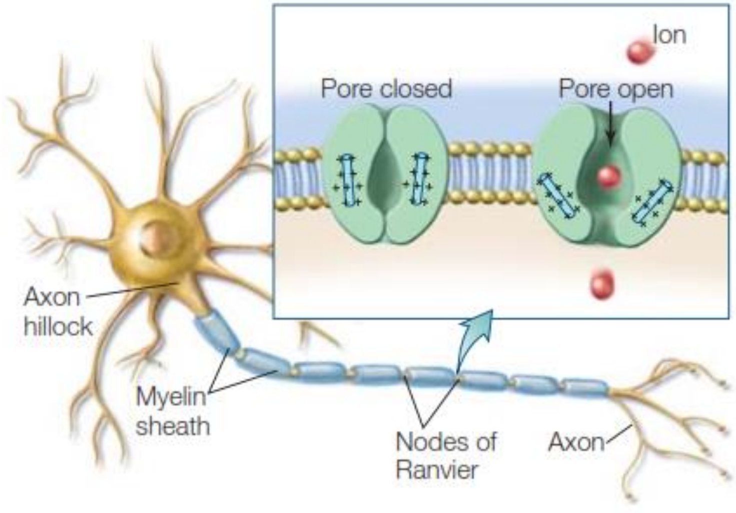
# Neurons evolved a clever mechanisms to overcome this challenge

1. Travelling **far**: the **Action Potential (AP)**

- That is a **rapid depolarization and repolarization of a small region of the cell membrane** caused by the opening and closing of ion channels

2. Travelling **fast**: **Saltatory conduction**

- APs are generated only at specific locations along the axon (i.e. Nodes of Ranvier)
- The AP “jumps” down the axon

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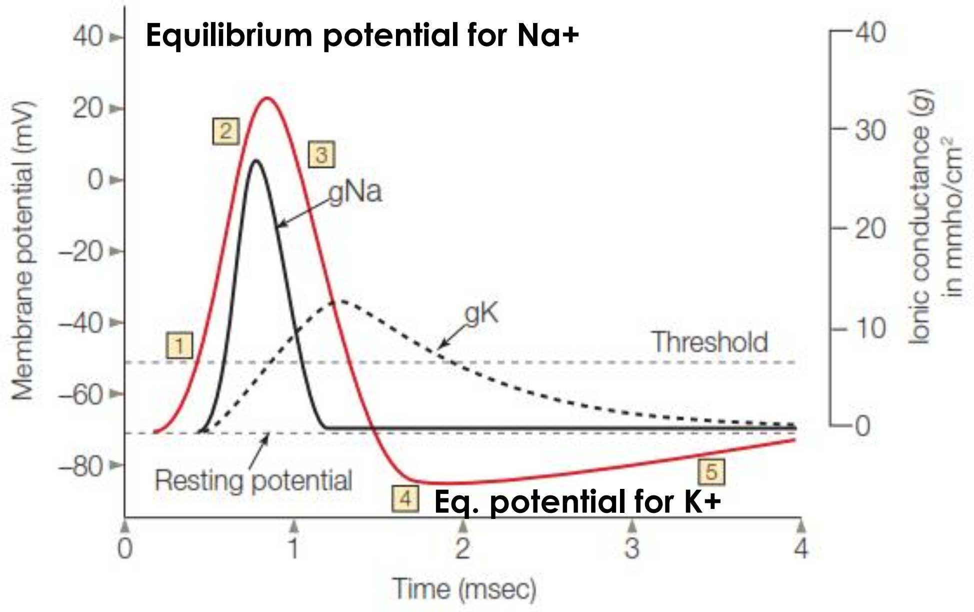
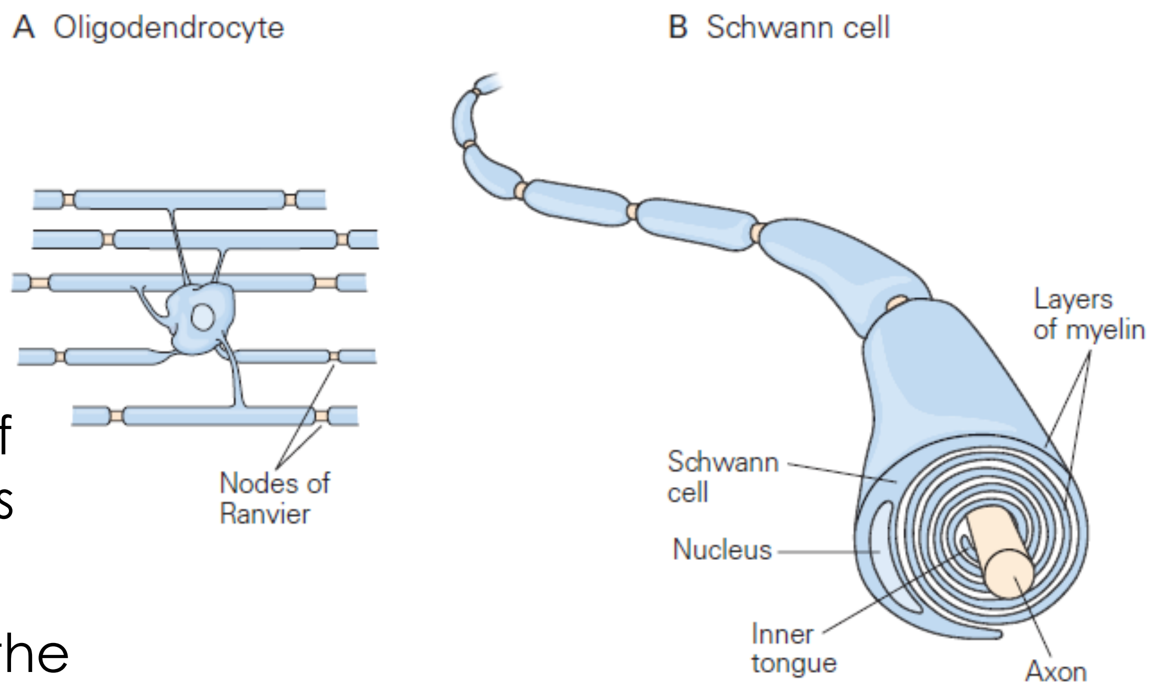
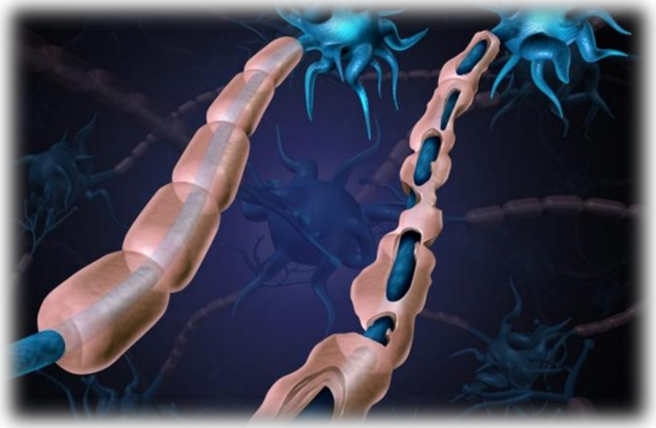



b

# Travelling fast: Saltatory conduction

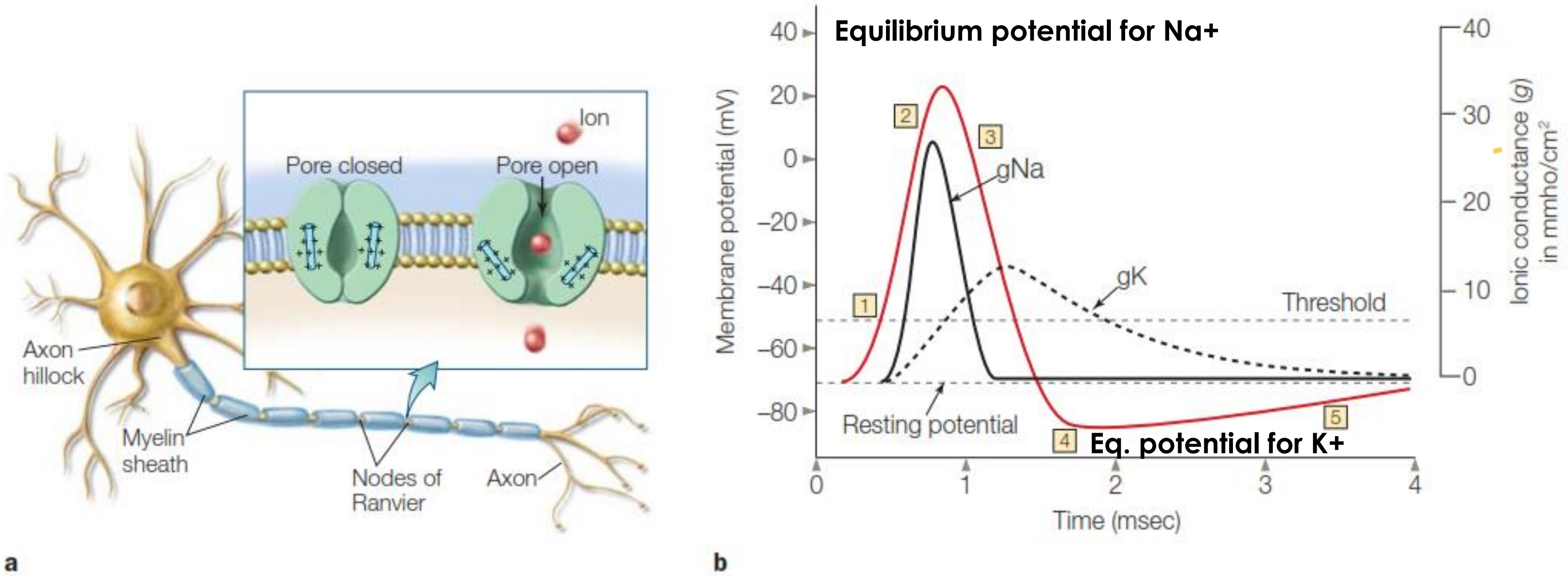
- Appearance that the AP "jumps" down the axon
- Oligodendrocytes (in CNS) and Schwann cells (in PNS) produce thin sheets of myelin that wrap around the axon of neurons
- Myelin
    - provides the insulating material along the axon → resistance to voltage loss
    - allows rapid conduction of APs along the axon
        - APs in myelinated axons can occur only at the Nodes of Ranvier, where myelination is interrupted and channels and pumps are actually located



# Action potentials have four properties that enable efficient neuronal signaling

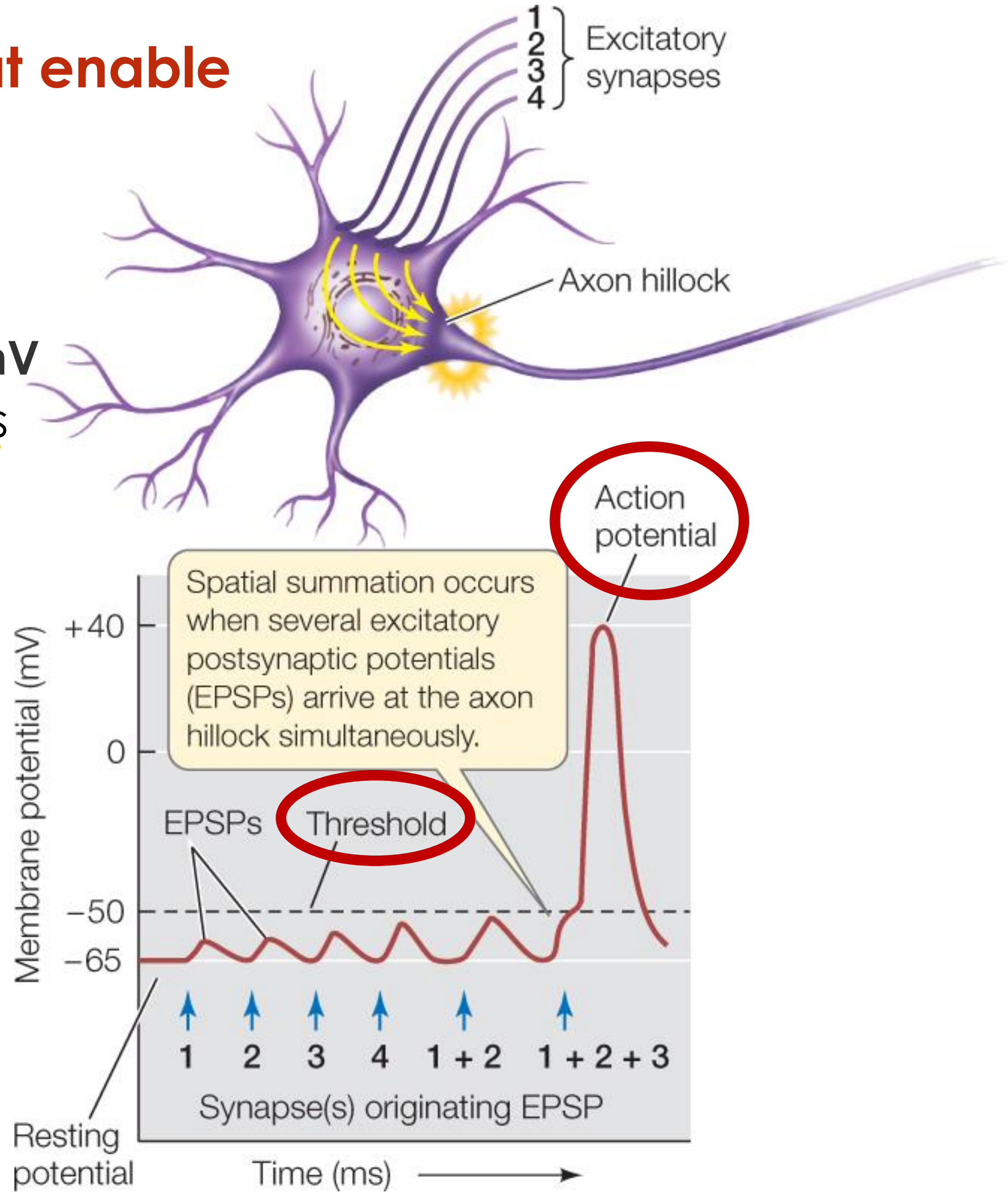
1. Threshold for initiation
2. Conducted without decrement
3. Refractory period
4. All-or-none nature



# Action potentials have four properties that enable efficient neuronal signaling

## 1. Threshold for initiation

- The AP is triggered only if summation of EPSPs depolarizes the cell membrane to at least **-55mV**
- Implication: only "meaningful" information leads to an AP



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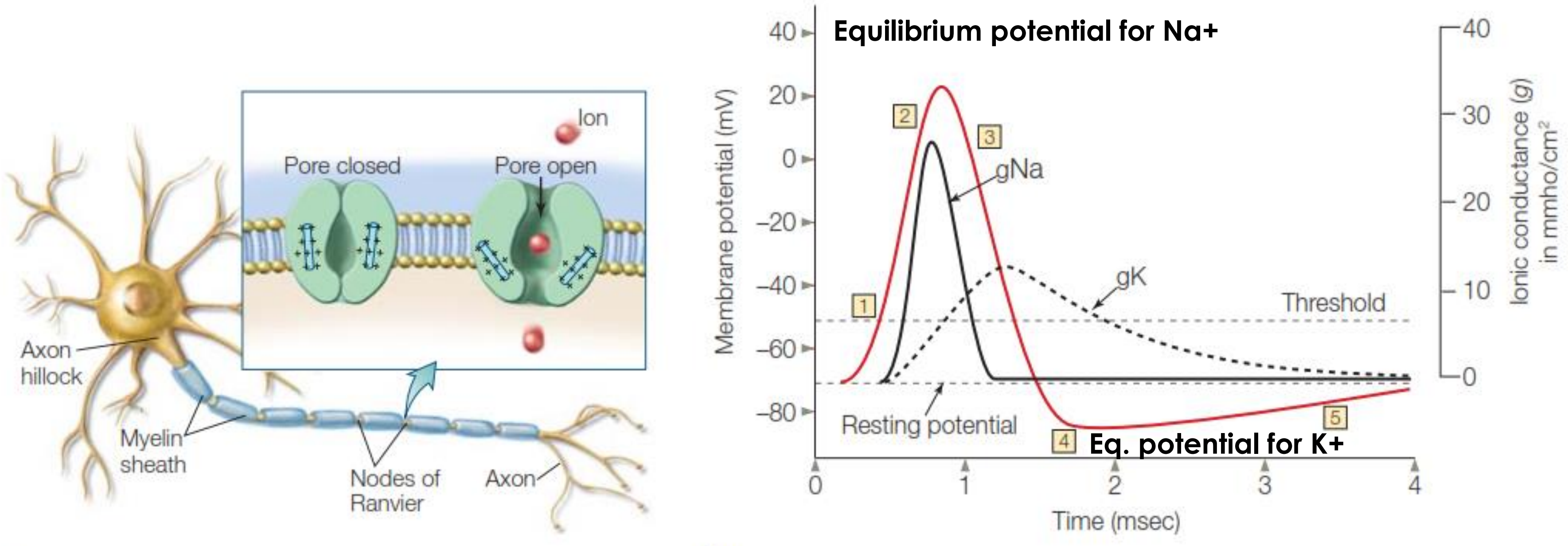


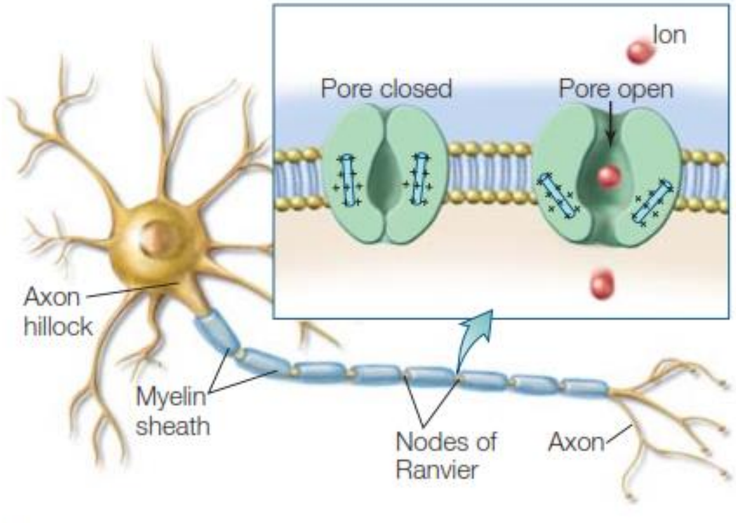

a

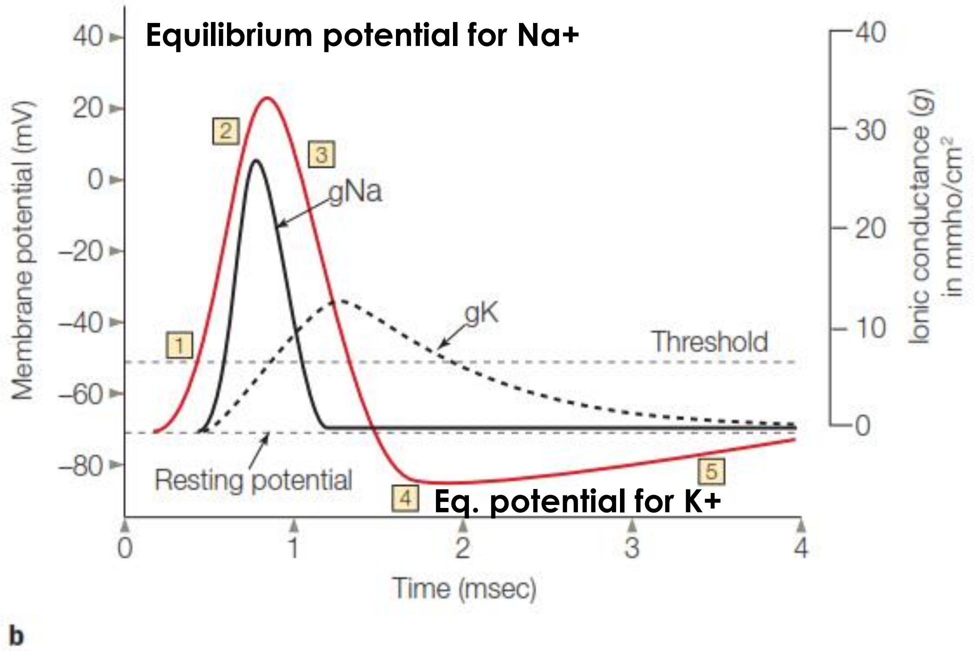
b

# Action potentials have four properties that enable efficient neuronal signaling

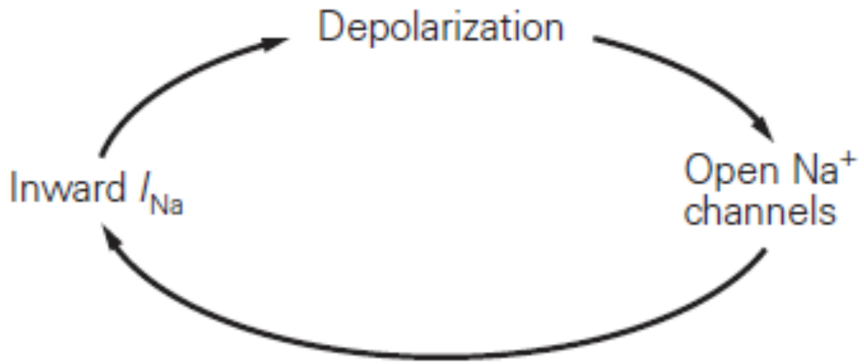
**2. Conducted without decrement**

- The AP is actively propagated & **self-regenerative**
- Depolarization causes **voltage-gated Na+ channels** to open → Na+ flows into the neuron



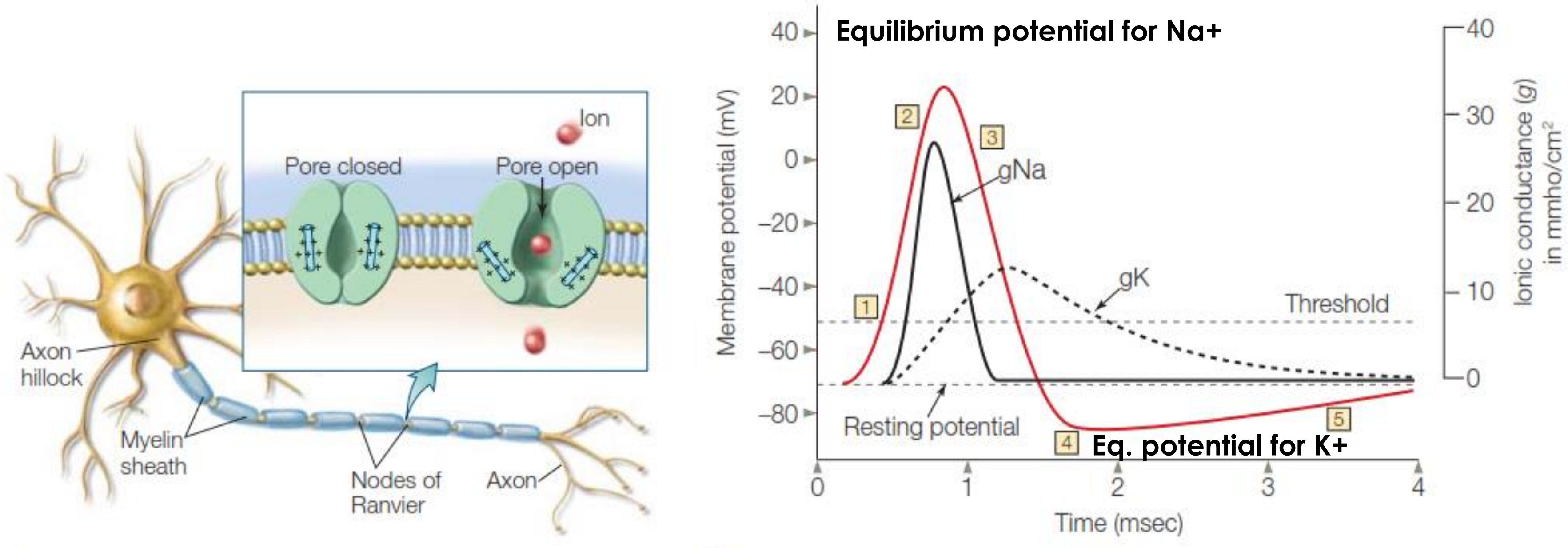



# Action potentials have four properties that enable efficient neuronal signaling




## 2. Conducted without decrement

- The influx of positively charged Na+ neutralizes the negative charge inside the neuron
- This starts a cycle, causing more voltage-gated Na+ channels to open & further depolarizing the neuron
- The cycle continues until it reaches the equilibrium potential for Na+ [2]



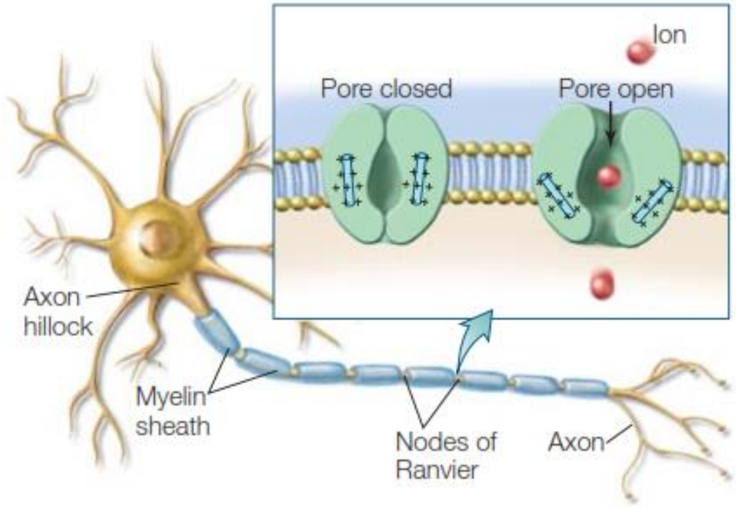

a

b

# Action potentials have four properties that enable efficient neuronal signaling

## 2. Conducted without decrement

- Then, **voltage-gated K+ channels open**, allowing K+ to flow out of the neuron down its concentration gradient [3]
- This shifts the membrane potential back toward
  - its resting potential and even slightly below it
  - to the K+ equilibrium potential [4], which is more negative than the resting potential, causing **hyperpolarization**

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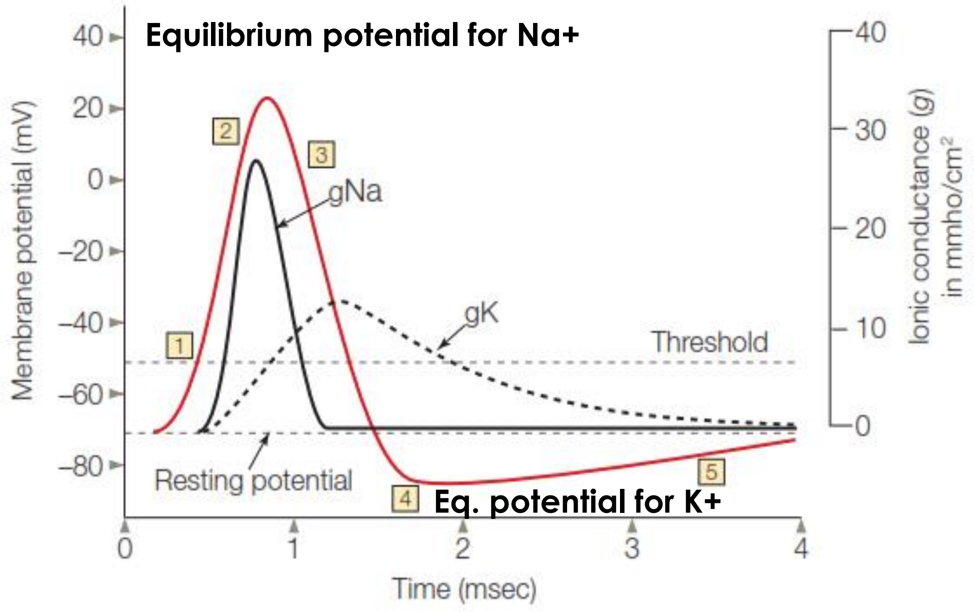
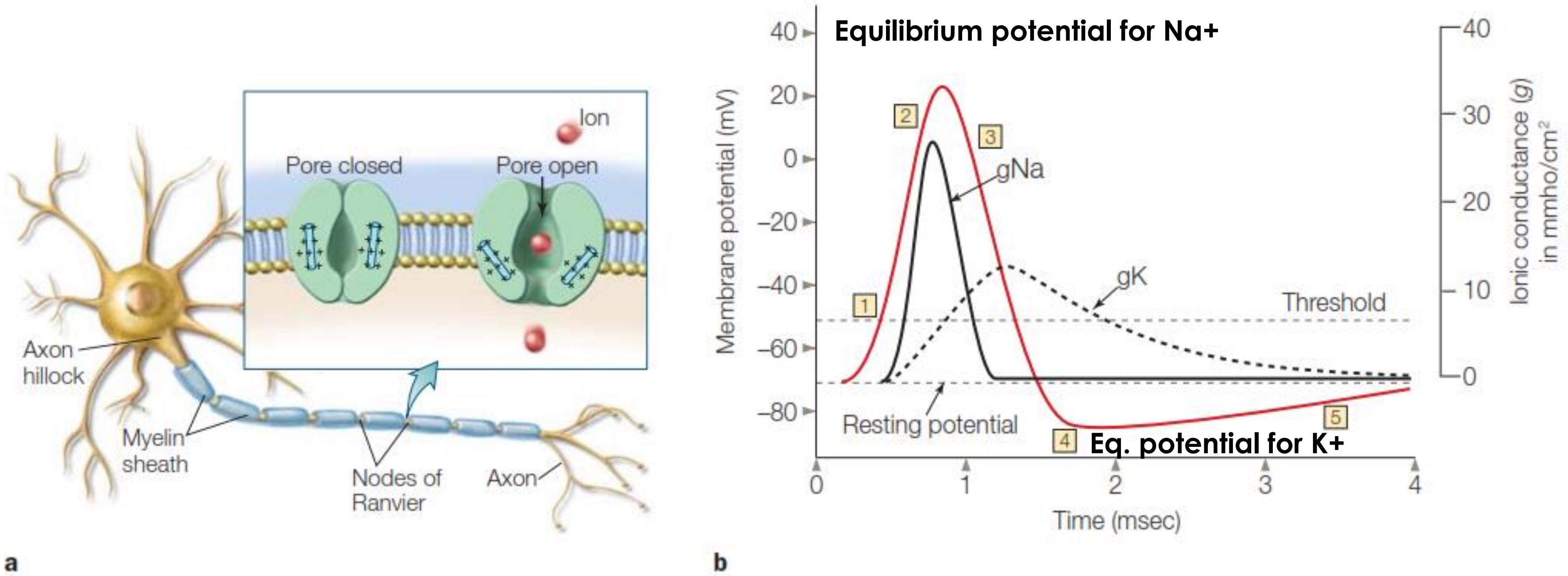



b

# Action potentials have four properties that enable efficient neuronal signaling

## 2. Conducted without decrement

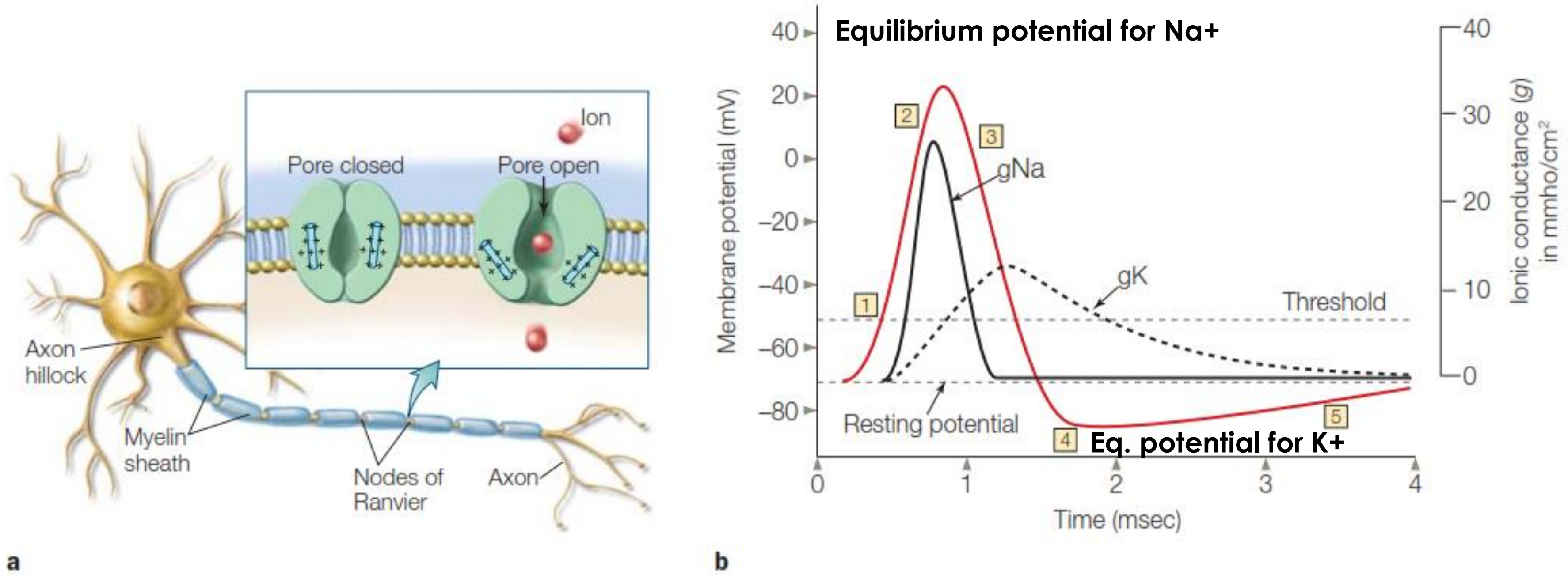
- K+ channels then close
- The membrane potential can return to its resting state [5]



# Action potentials have four properties that enable efficient neuronal signaling

## 2. Conducted without decrement

- Implication: the amplitude of the AP remains constant, even when it is conducted over great distances



# Action potentials have four properties that enable efficient neuronal signaling

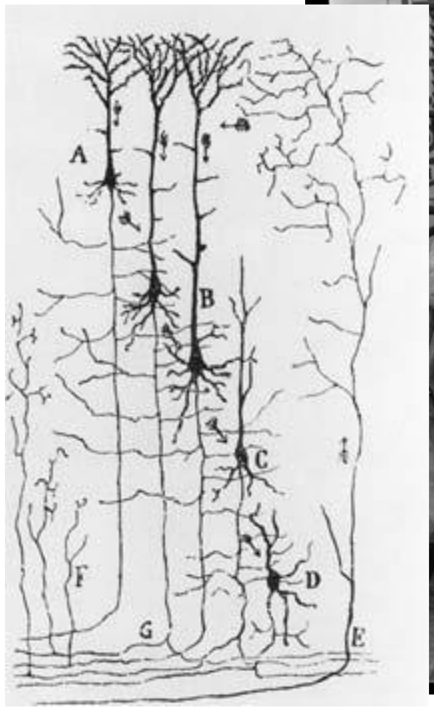
**3. Refractory period**

- During hyperpolarization the voltage-gated Na+ channels cannot open
- Implications:
    1. Limits the frequency of APs (i.e. # of APs that a neuron can generate in a given time)
    2. Unidirectional current flow: from the axon hillock toward the axon terminal.
        - The current cannot reopen the channels that generated it
        - It can depolarize the membrane a bit farther on, opening channels in the next portion of the membrane

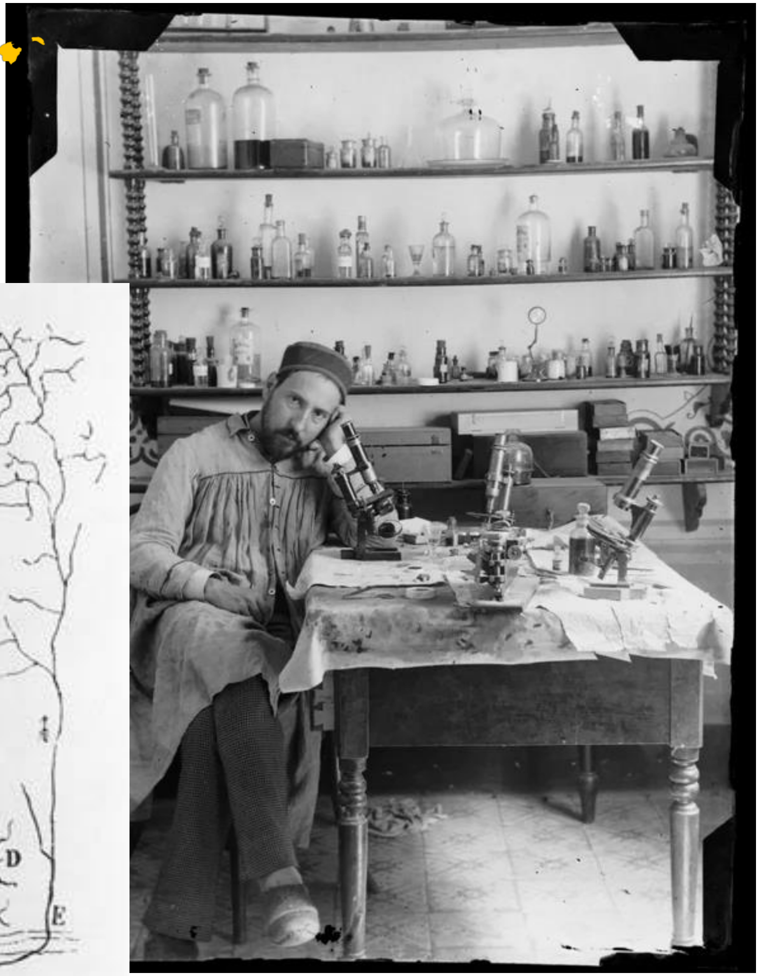
# Principle of dynamic polarization

Electrical signals within a nerve cell flow **only in one direction**:

- received at synapses on dendrites
- Transmitted down the axon
- Passed along at synapses on the axon terminals




Ramón y Cajal's drawing of the afferent inflow to the mammalian cortex

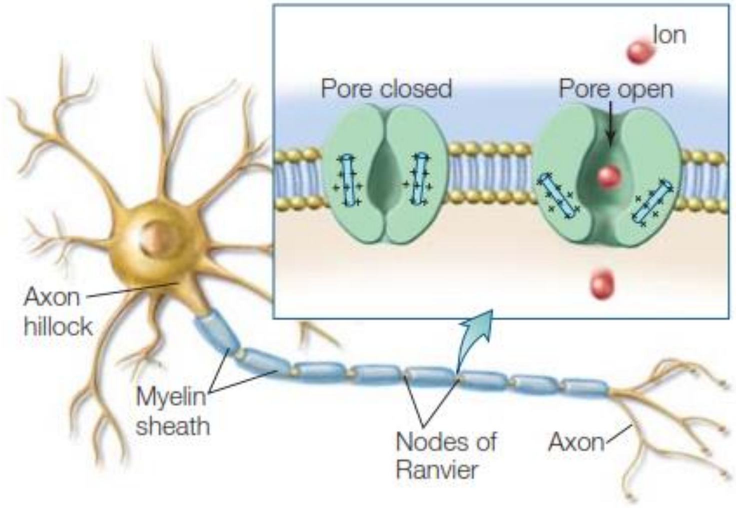


Santiago Ramón y Cajal (1852–1934)

# Action potentials have four properties that enable efficient neuronal signaling

## 4. All-or-none nature

- APs have always similar amplitude and duration, regardless of the size of the PSP that generated it
- The size and shape of an AP initiated by a large PSP is the same as that of an AP evoked by a current that just surpasses the threshold
- APs are binary signals
- Implication: the strength of the AP does not communicate anything about the strength of the input stimulus

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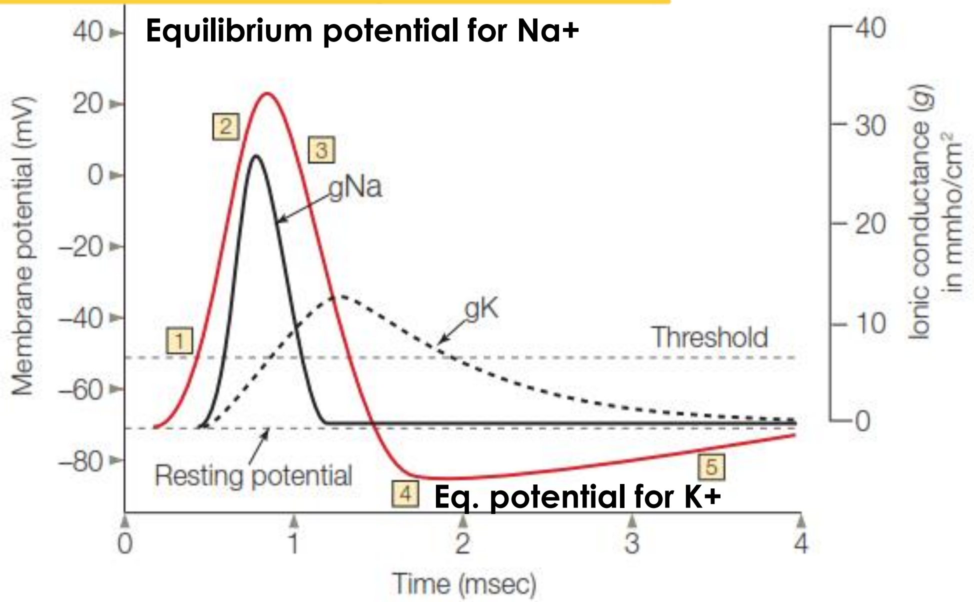


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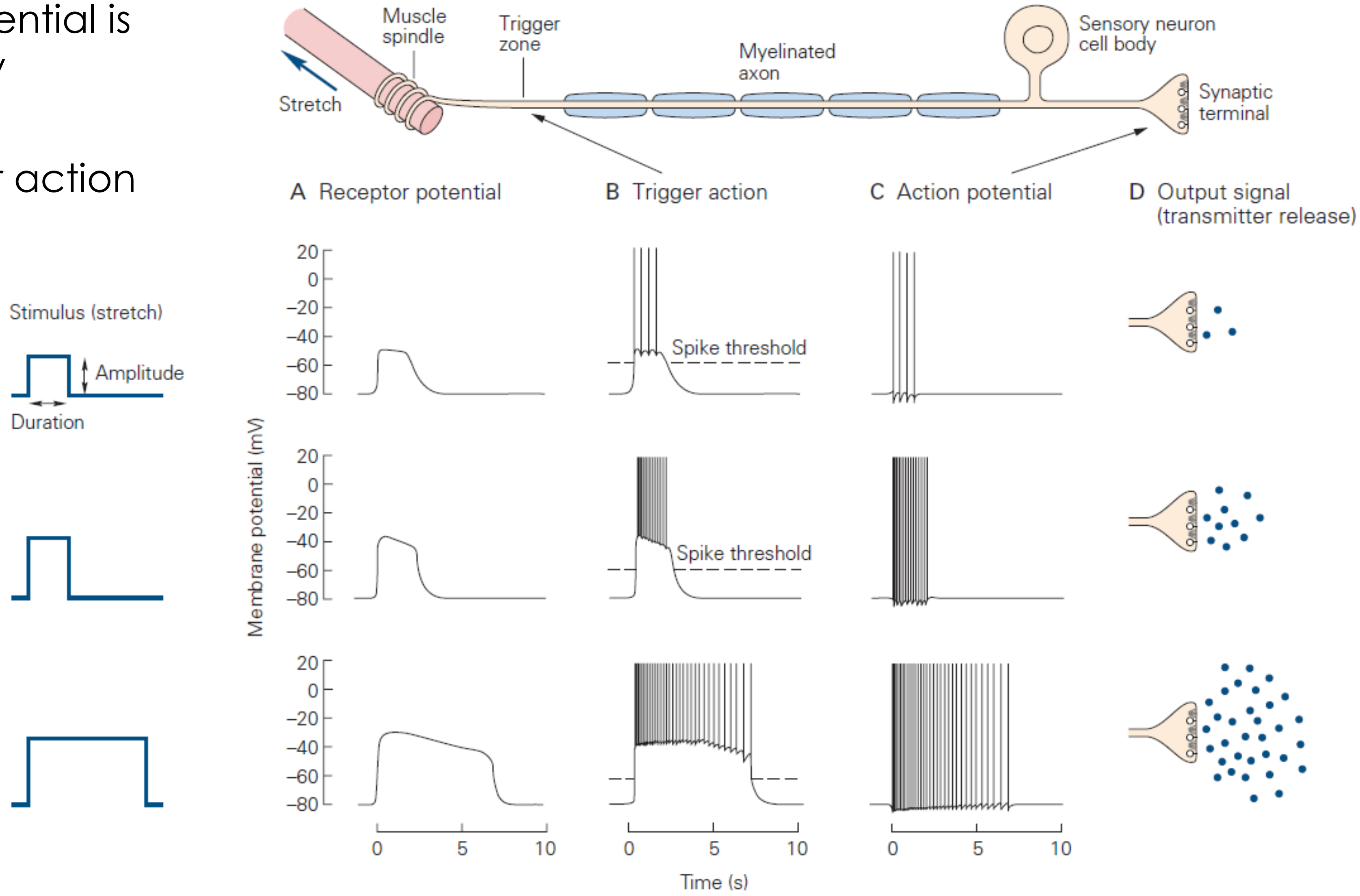
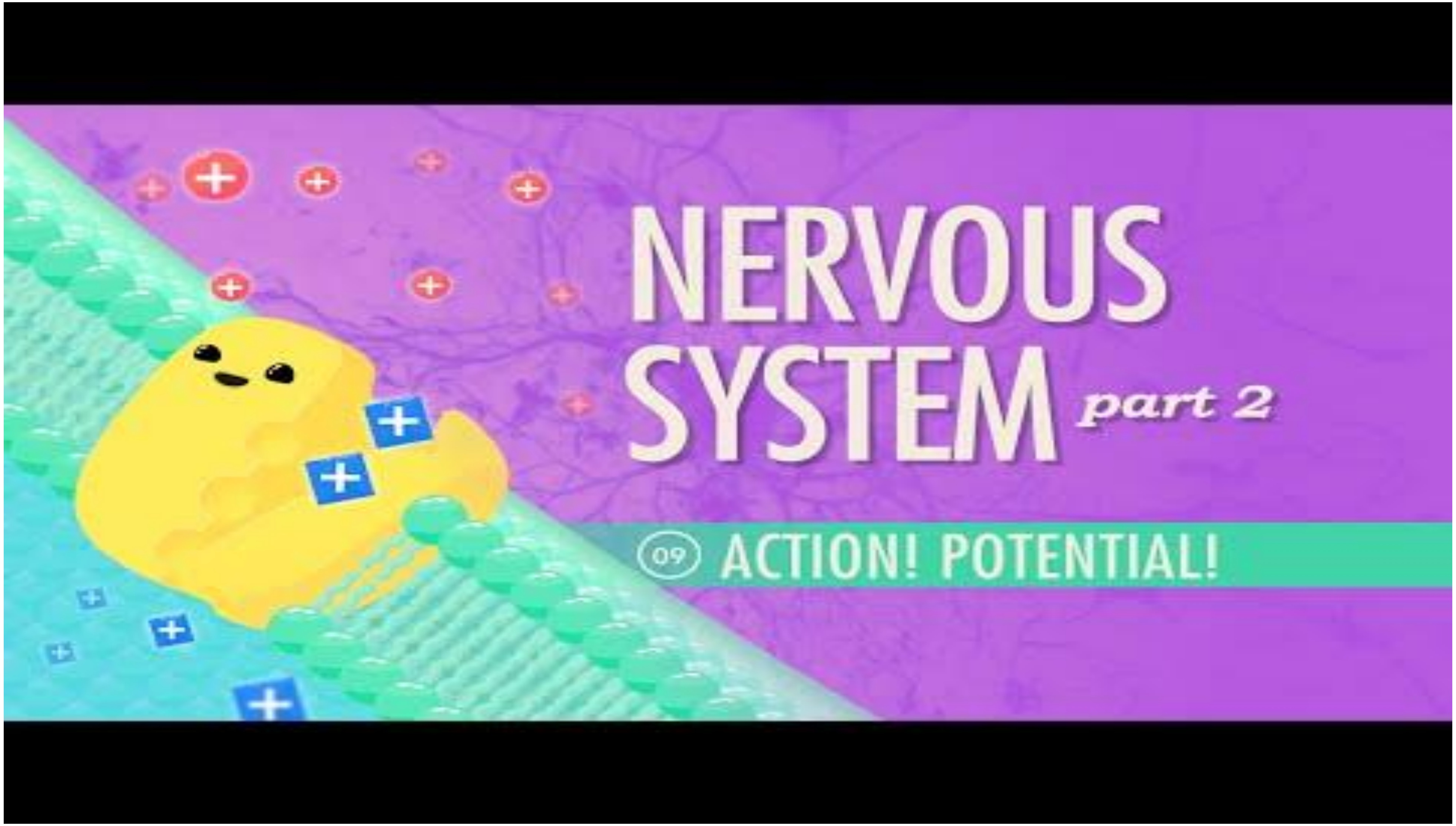
# So how does the neuron communicate information about the strength of the input stimulus?

The firing rate of the action potential is proportional to stimulus intensity

More intense stimuli elicit higher action potential firing rates.



Questions 5-7




https://youtu.be/OZG8M_IdA1M

# Correct firing is crucial for correct functioning...

https://youtu.be/LcO9YU-Pdws

## Correct firing is crucial for correct functioning...
## Seizures: the misfiring of neurons

ELIMINARE DA
QUI IN POI
!!!!

# From individual neurons to neural circuit

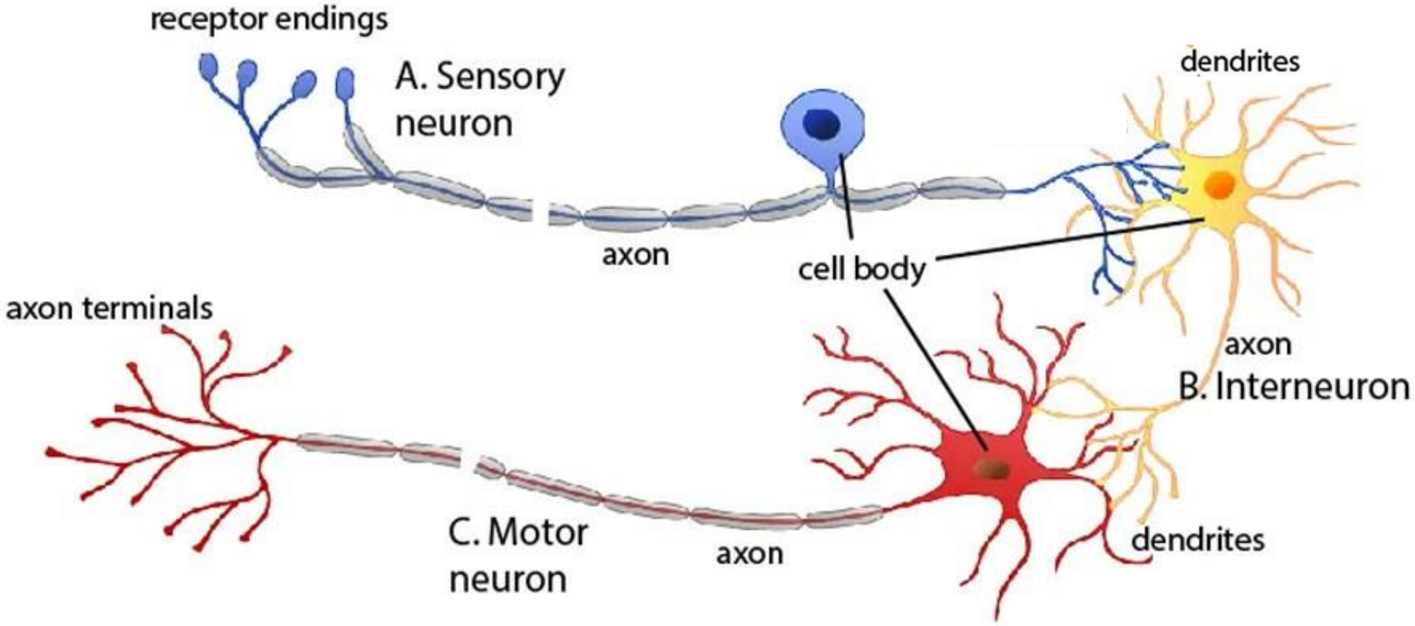
Combination of neurons create a neural circuit

# Each nerve cell is part of a circuit that has one or more specific behavioral functions

Neural circuit: Groups of interconnected neurons that process specific kinds of information.

1. take in information (input)
2. evaluate the input either at a synapse or within one or a group of neurons (process, integration)
3. convey the results to other neurons, muscles, or glands (output)

Every behavior is mediated by specific sets of interconnected neurons, and every neuron's behavioral function is determined by its connections with other neurons.



# Synapses enable communication between neurons

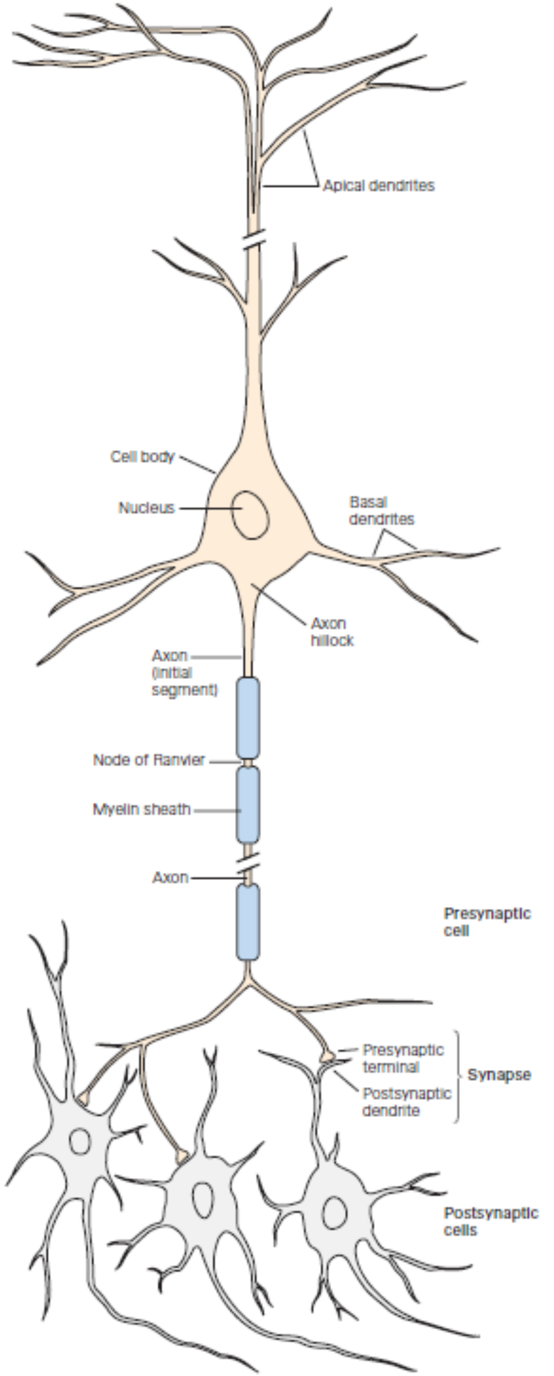
**Presynaptic cell**

- The nerve cell transmitting a signal
- From presynaptic terminals or nerve terminals, i.e. specialized enlarged regions of its axon's branches

**Postsynaptic cell**

- The cell receiving the signal

**Synaptic cleft**: the narrow space separating the presynaptic and postsynaptic cell



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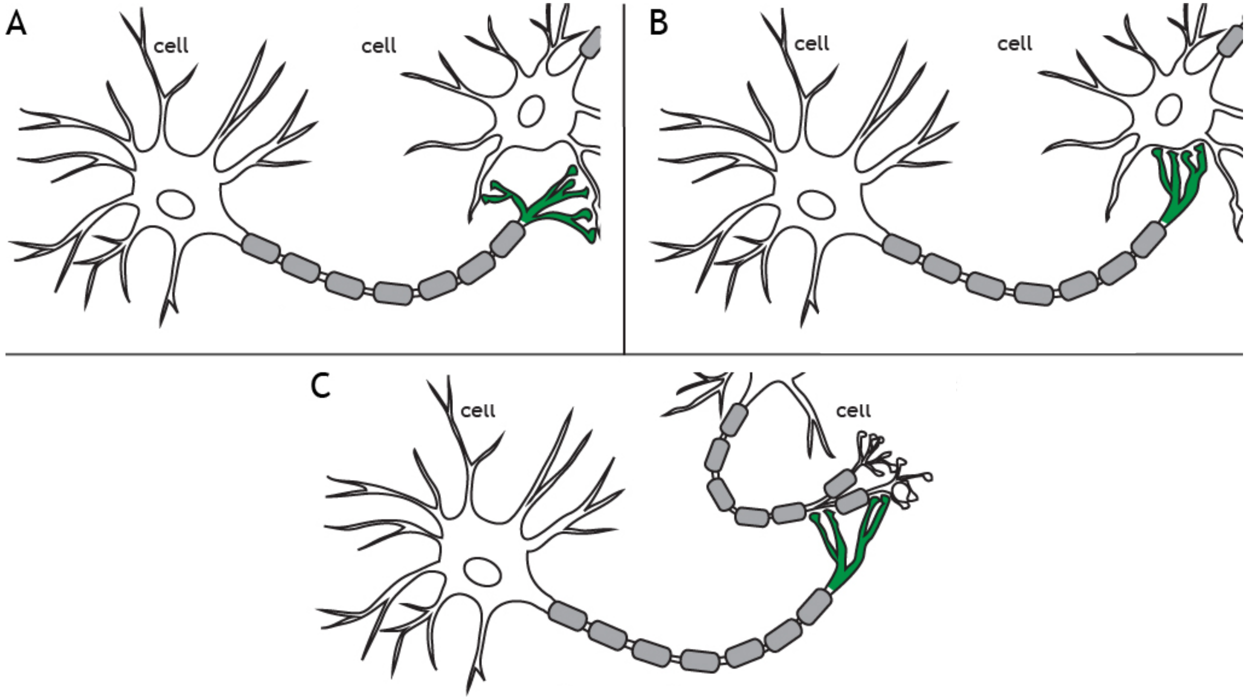
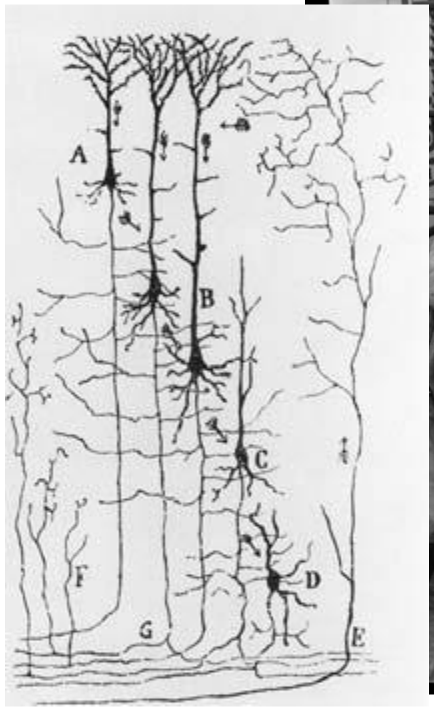
**Which one is the pre-synaptic and which one the post-synaptic cell?**



# Principle of connectional specificity

Nerve cells do not connect randomly with one another in the formation of networks. Rather each cell makes specific connections—at particular contact points—with certain postsynaptic target cells but not with others.

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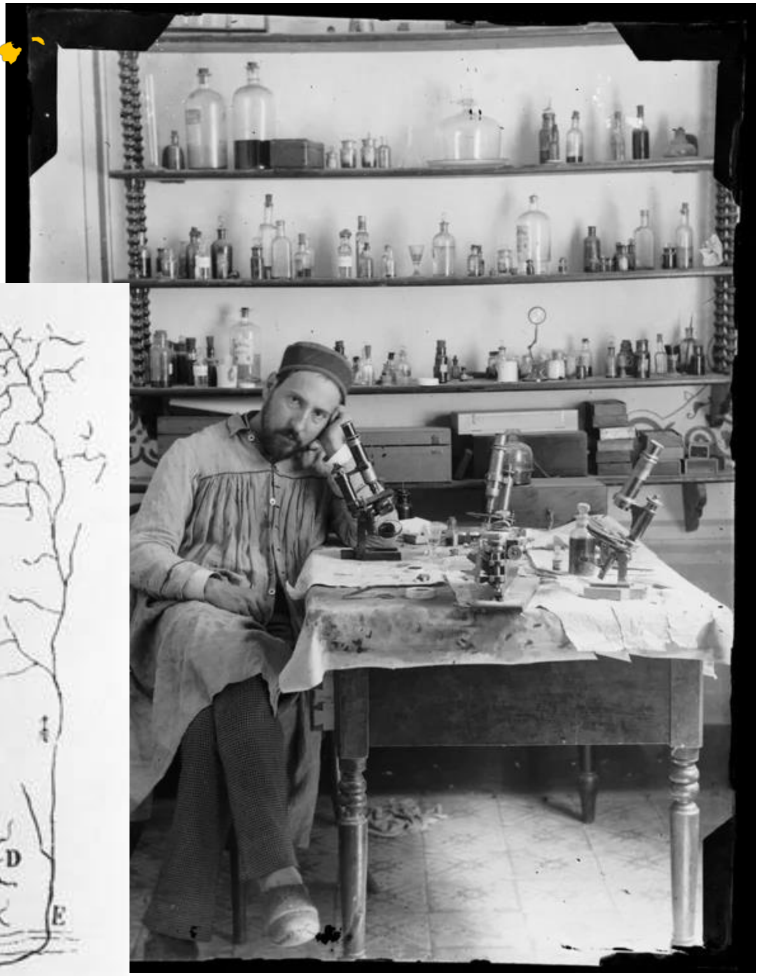


Santiago Ramón y Cajal (1852–1934)

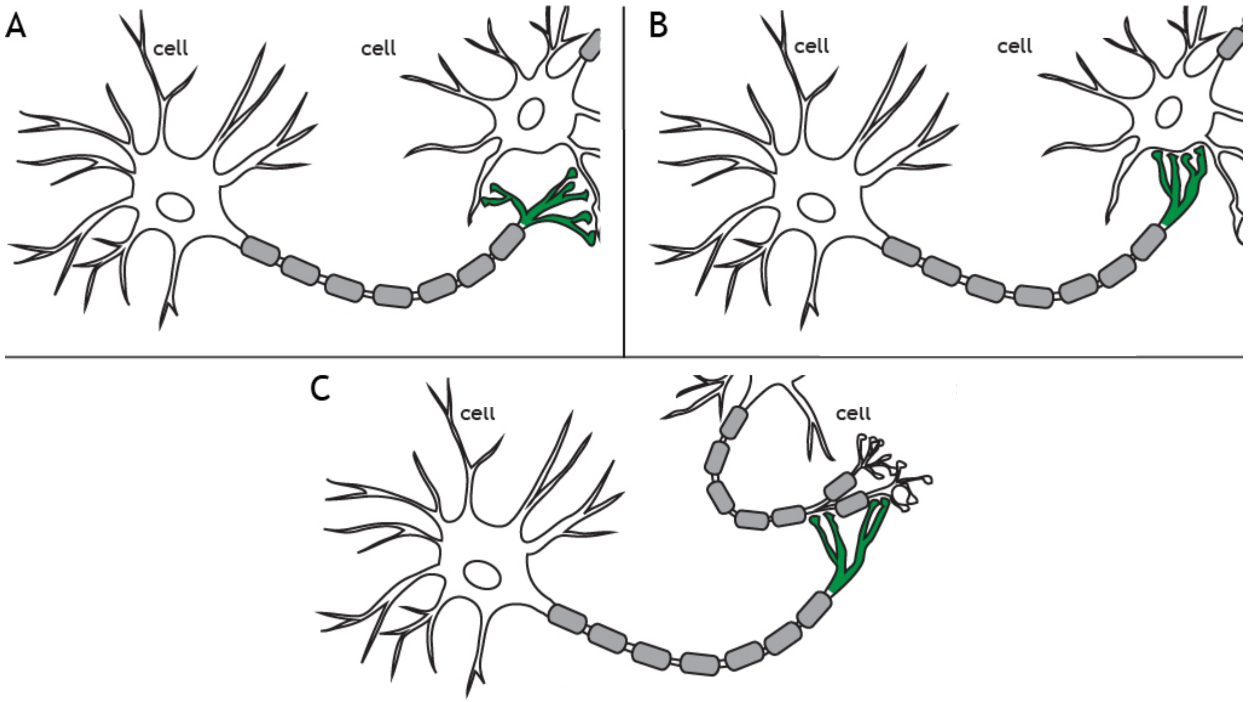
# Three types of synapses

**Axosomatic:** synapses that are made onto the soma or cell body of a neuron.

**Axodendritic:** synapses that one neuron makes onto the dendrite of another neuron. The most common type.

**Axoaxonic:** synapses made by one neuron onto the synapse of another neuron. Axoaxonic synapses mediate presynaptic inhibition and presynaptic facilitation.

**What kind of synapses are these?**



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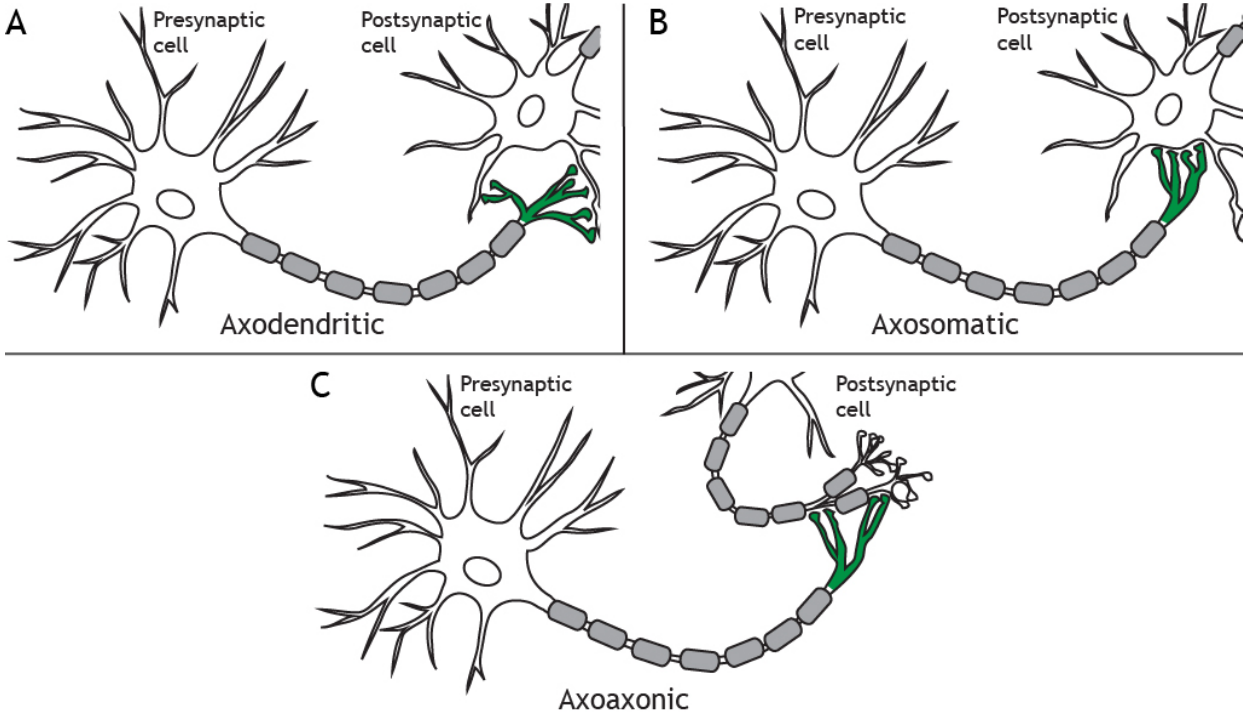
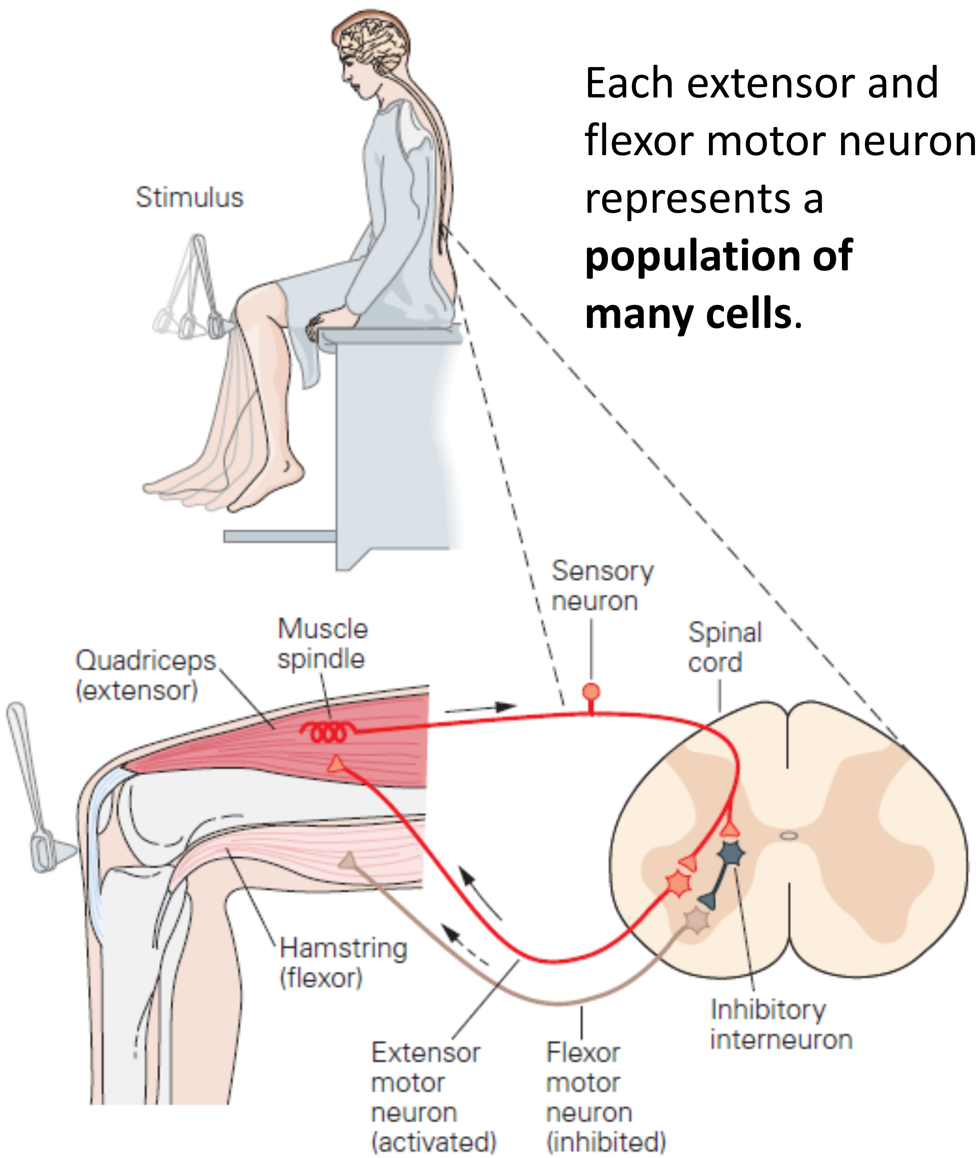


# A simple neural circuit: the knee-jerk reflex

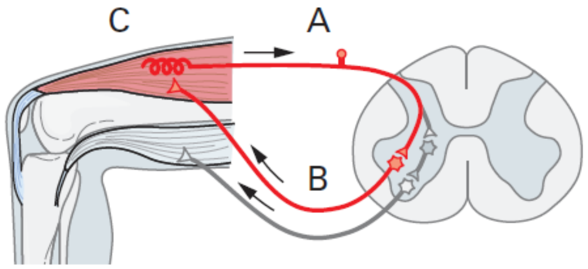
1. Sensory information is conveyed to the central nervous system (the spinal cord) from muscle.
2. Motor commands from the central nervous system are issued to the muscles that carry out the knee jerk.
3. Inhibitory commands are issued to motor neurons that innervate opposing (antagonist) muscles, providing coordination of muscle action.

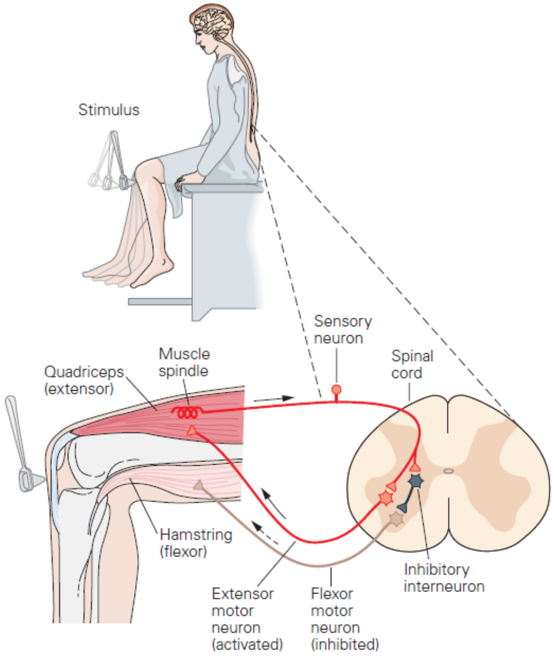
The combination of excitatory and inhibitory activity produces the reflex.

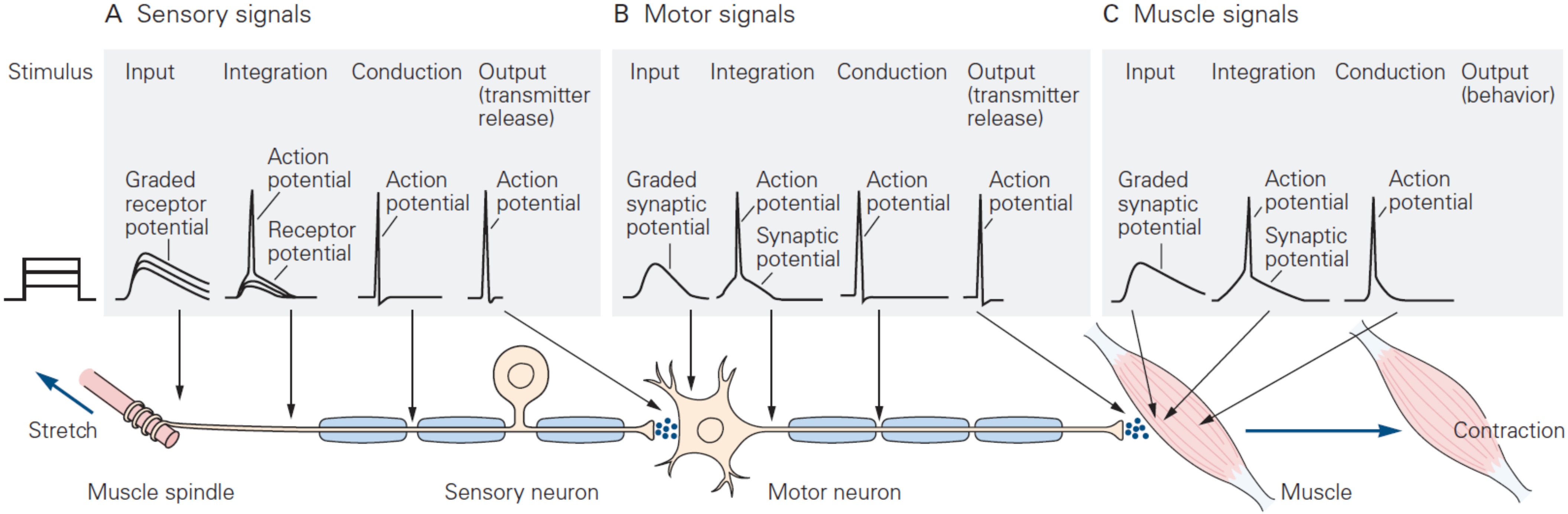



Each extensor and flexor motor neuron represents a **population of many cells**.

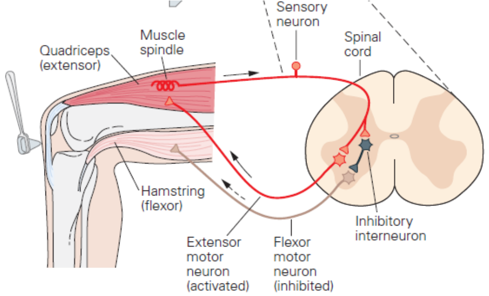
# A simple neural circuit: the knee-jerk reflex



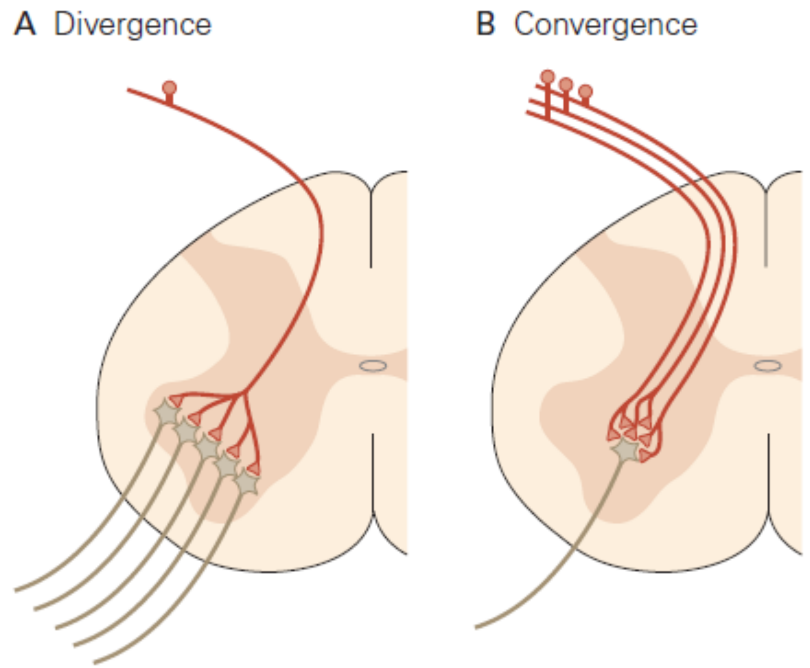



# Divergence and convergence




- The stretching of just one muscle activates several hundred sensory neurons, each of which makes direct contact with 45 to 50 motor neurons. --> divergence

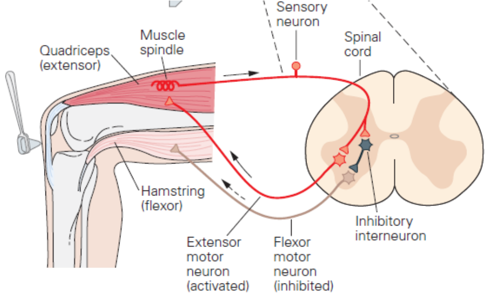
- A single motor cell in the knee jerk circuit receives 200 to 450 input contacts from approximately 130 sensory cells. --> convergence




**One** neuron activates **many** target cells

**Many** neurons activate a **single** target cells

# Divergence and convergence

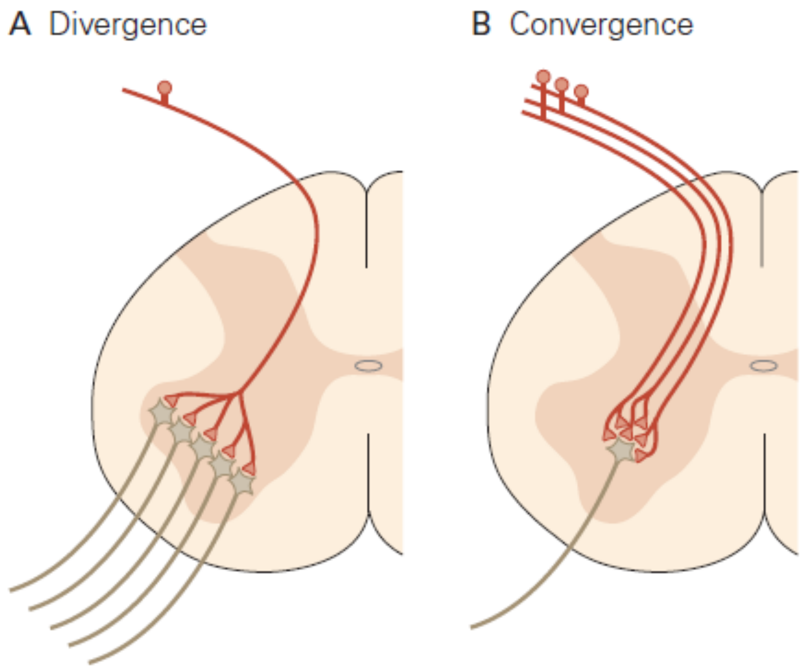



**Divergence:** observed in the input stages of the nervous system

- Functional utility: _______________

**Convergence:** observed at the output stages of the nervous system

- Functional utility: _______________

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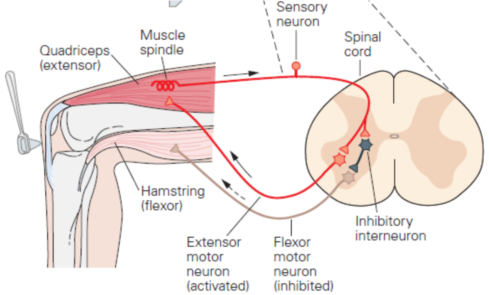
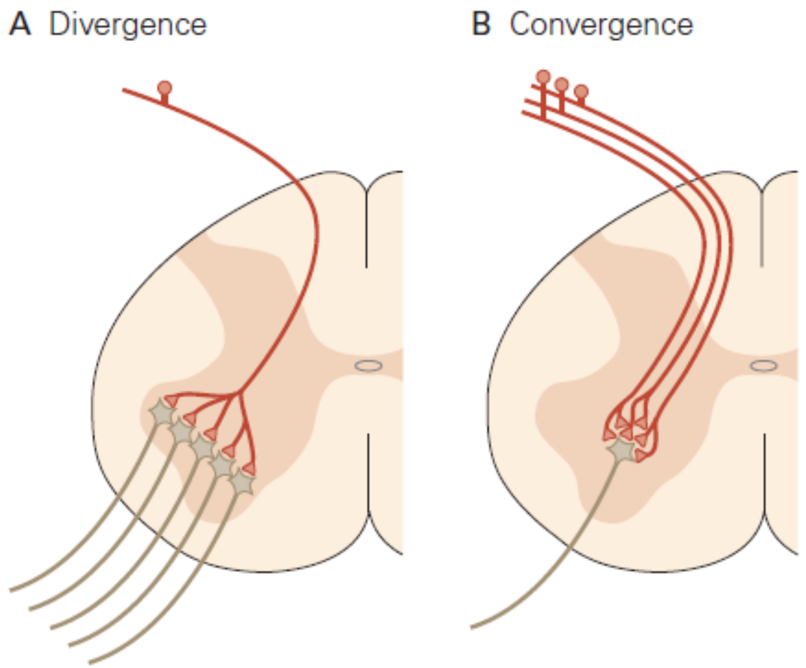



**Divergence:** observed in the input stages of the nervous system

- Functional utility: a single neuron can exert wide and diverse influence.

**Convergence:** observed at the output stages of the nervous system

- Functional utility: ensures that a motor neuron is activated only if a sufficient number of sensory neurons become activated together.

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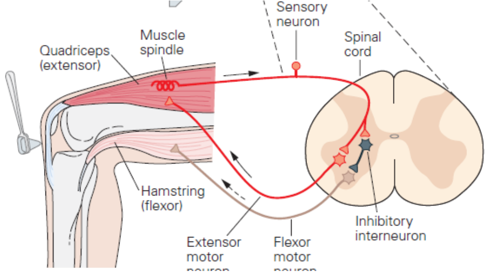
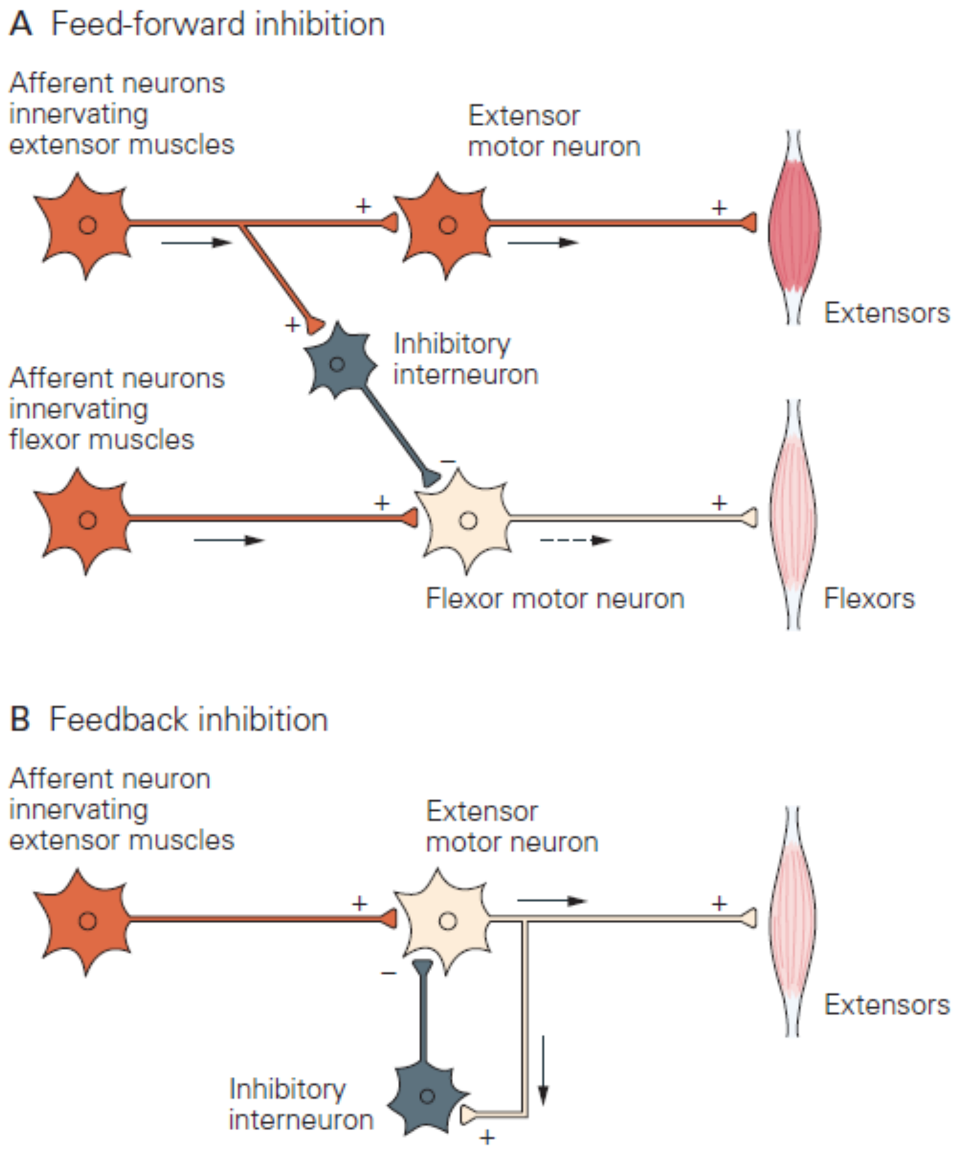
# Neurons are both excitatory and inhibitory



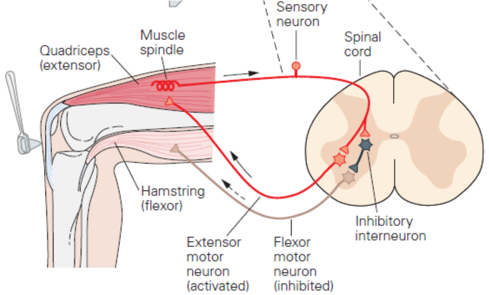

Excitatory neurons produce signals that increase the likelihood of firing of the postsynaptic neurons.

Not all important signals in the brain are excitatory.

Many neurons produce inhibitory signals that reduce the likelihood of firing.



# Feed-forward and feed-back inhibition

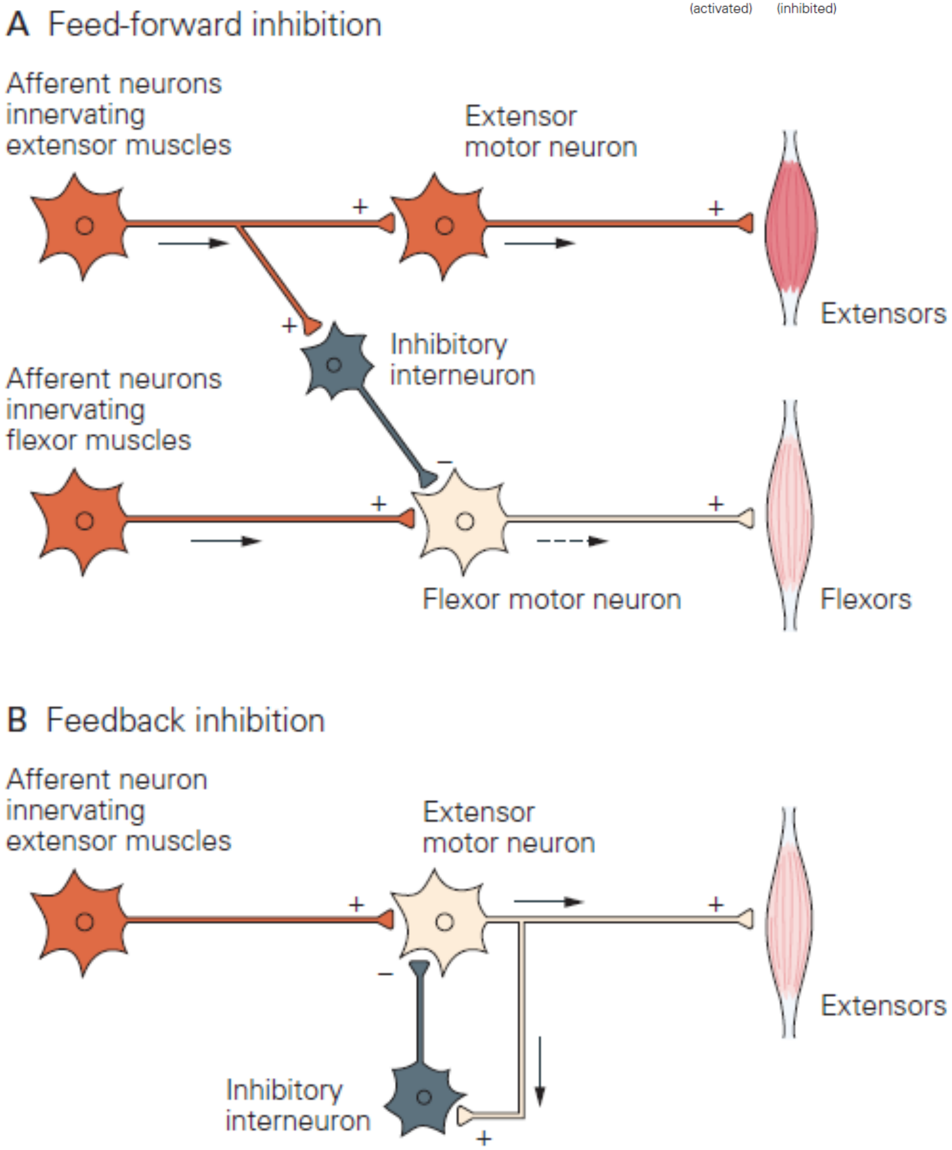



**Feed-forward inhibition**: excitatory neurons synapse onto inhibitory interneurons, inhibiting other downstream neurons

- Functional utility: _______________

**Feed-back inhibition:** excitatory neurons synapse onto inhibitory interneurons, which project back to the same neurons and inhibit them

- Functional utility: ____________________



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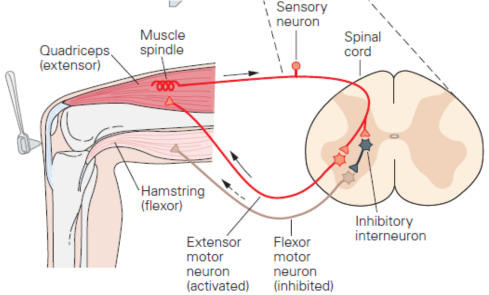
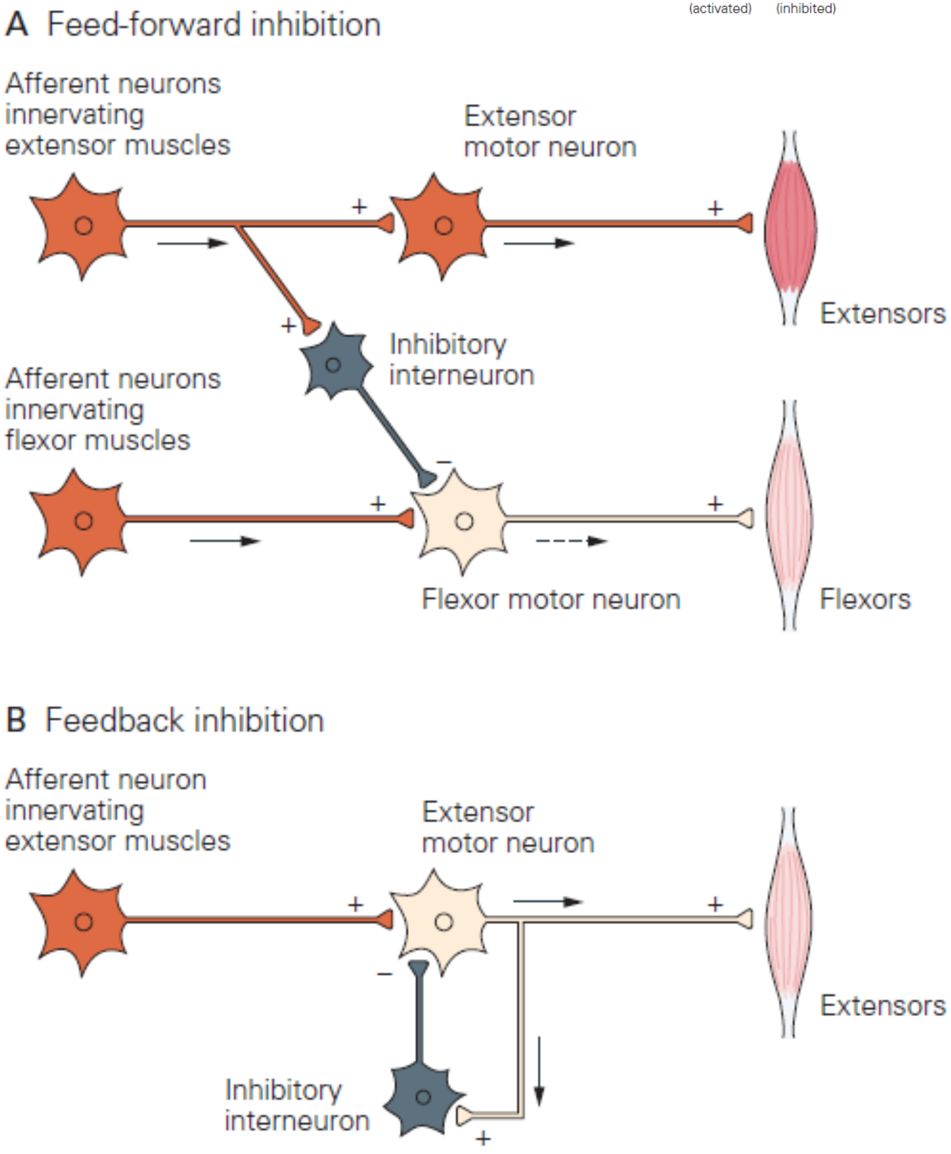



**Feed-forward inhibition**: excitatory neurons synapse onto inhibitory interneurons, inhibiting other downstream neurons

- Functional utility: enhances the effect of the active pathway by suppressing the activity of pathways mediating opposing actions.

**Feed-back inhibition:** excitatory neurons synapse onto inhibitory interneurons, which project back to the same neurons and inhibit them

- Functional utility: dampens activity within the stimulated pathway and prevent it from exceeding a certain critical level.



# No complex human behavior is initiated by a single neuron

- Each behavior is generated by the actions of many cells.
- Three components of the neural control of behavior:
    - sensory input
    - intermediate processing
    - motor output
- In vertebrates each component is
    - mediated by a single group or several distinct groups of neurons
    - **has multiple neural pathways that simultaneously provide the same or similar information --> ____________________________**

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- Evolutionary advantage: ________________________________________

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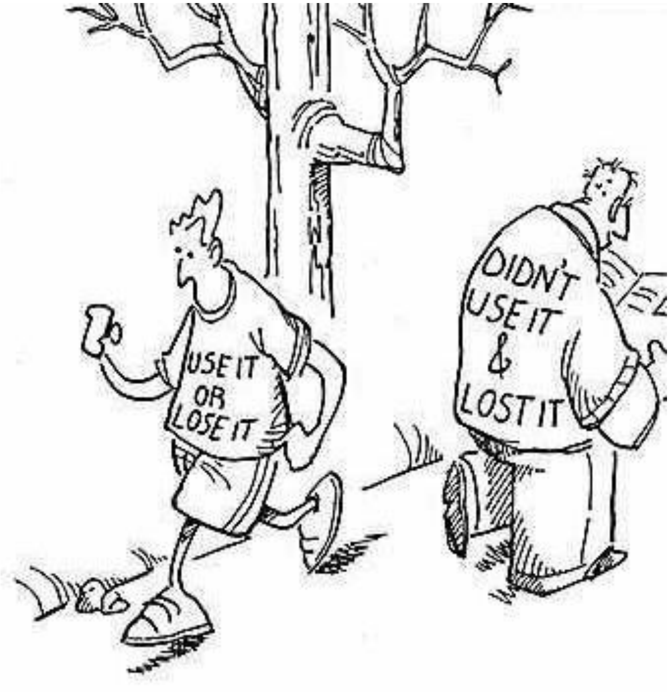
    - **has multiple neural pathways that simultaneously provide the same or similar information --> parallel processing _CAMBIARE PIU ACCURATAMENTE: aspetti diversi di stessa info analizzati in parallelo**
- Evolutionary advantage: it increases both the speed and reliability of function within the central nervous system

# Plasticity: Neural connections can be modified by experience & learning

- Chemical synapses are functionally and anatomically modified through experience and learning, throughout life.
- Short-term changes: functional physiological changes (lasting seconds to hours) that increase or decrease the effectiveness of existing synaptic connections.
- Long-term changes: structural changes (lasting days) that can give rise to further physiological changes that lead to anatomical alterations, including pruning of preexisting synapses or growth of new ones.



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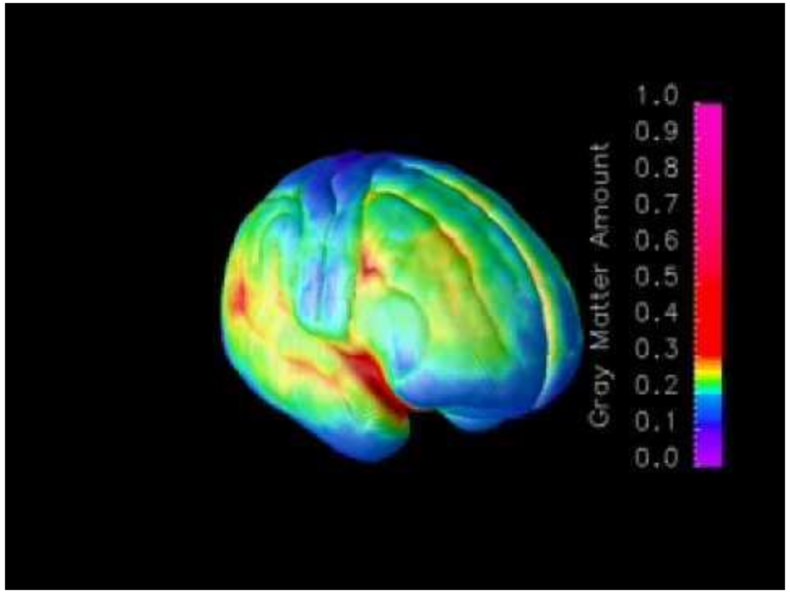
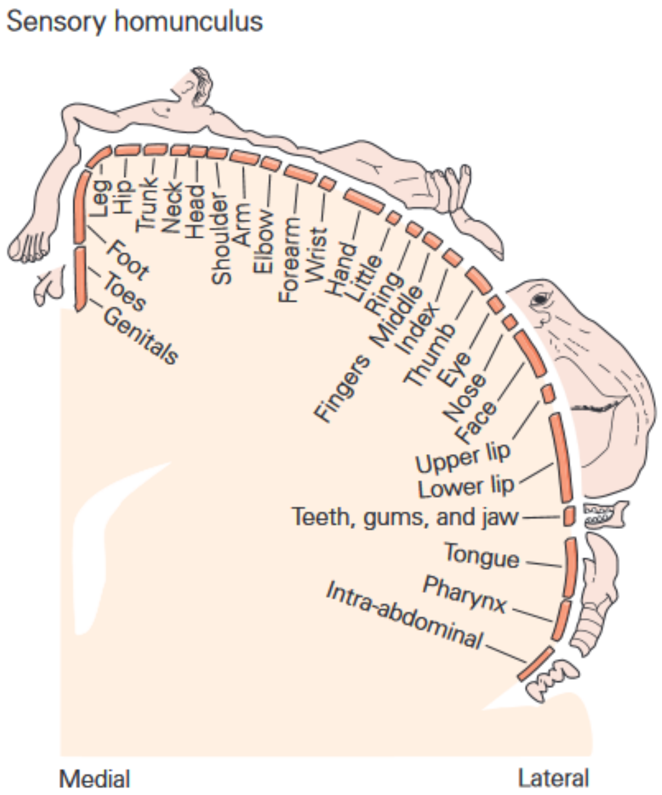



Right oblique view of gray matter maturation over the cortical surface between ages 4 and 21. The side bar shows a color representation in units of GM volume. Gogtay et al., 2004, PNAS https://doi.org/10.1073/pnas.0402680101

# A peculiar example of plasticity: phantom limb pain




https://www.youtube.com/watch?v=w6AfzCNDmbY&ab_channel=StarStuff

# Information transfer between two neurons

# Signaling within and between neurons is handled differently

Within a neuron:

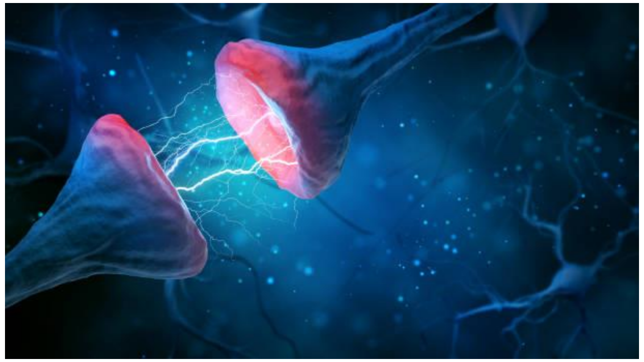
- transferring information involves changes in the **electrical state** of the neuron
- electrical currents flow through the volume of the neuron --> neuronal spikes

Between neurons:

- information transfer occurs at synapses

Chemical synapse

Electrical synapse

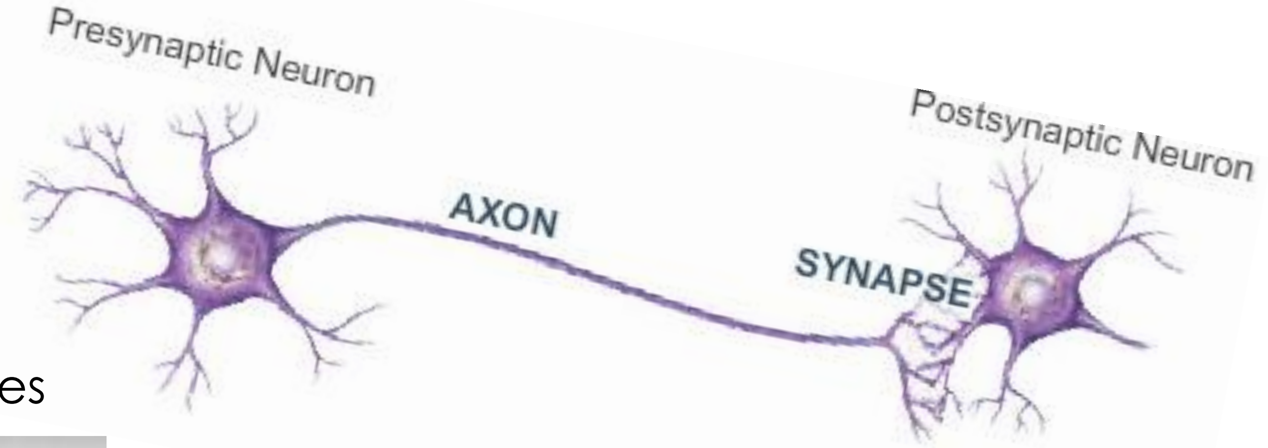


# The synapse enables neuronal communication

Chemical synapse

1930s synaptic transmission "fight"

Charles Sherrington realized that reflexes were not as fast as they should be if the nervous system was a continuous mass of tissue (syncytium)



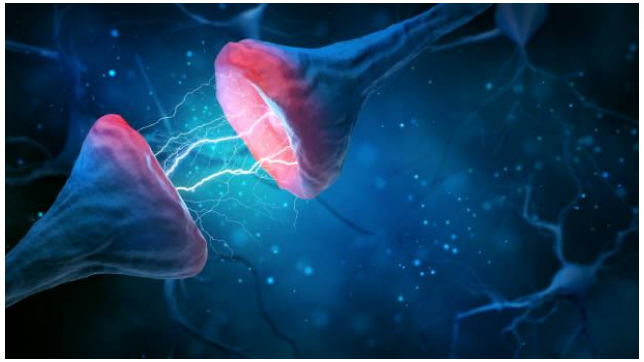

Henry Dale

Coined the term **synapse**

Charles Sherrington

Jhon Eccles

Electrical synapse



# Electrical and chemical synapses are structured differently

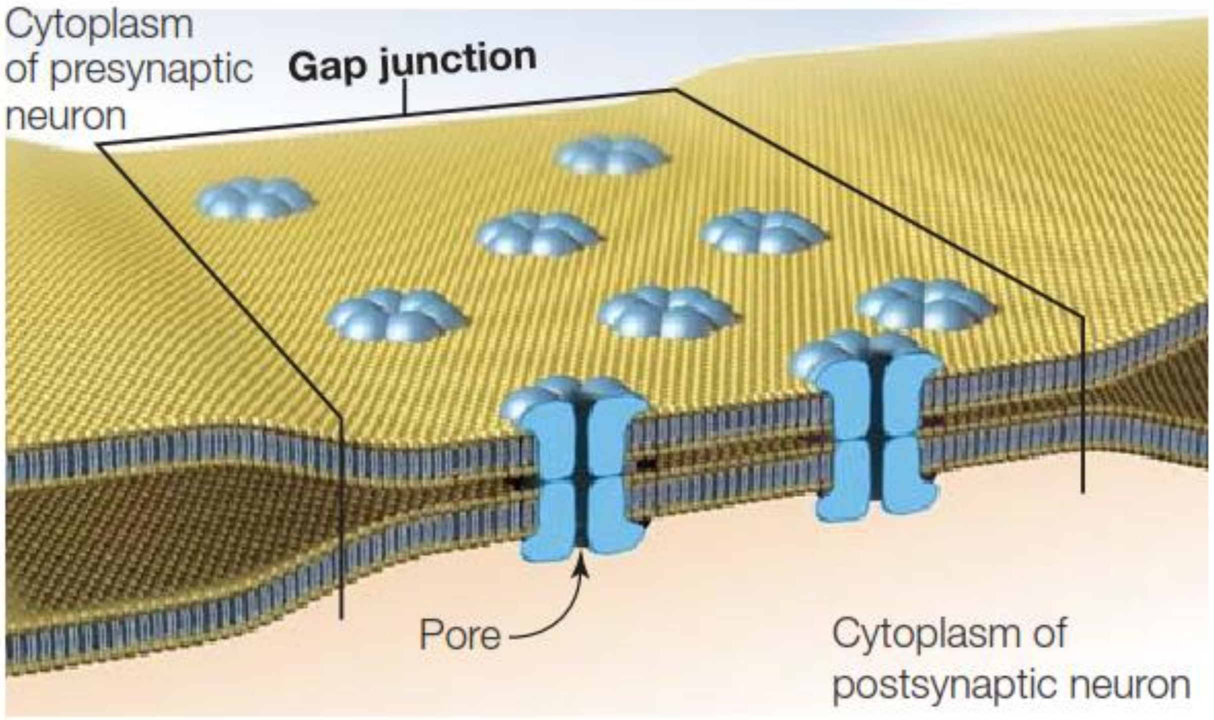



**FIGURE 2.14 Electrical synapse between two neurons.**

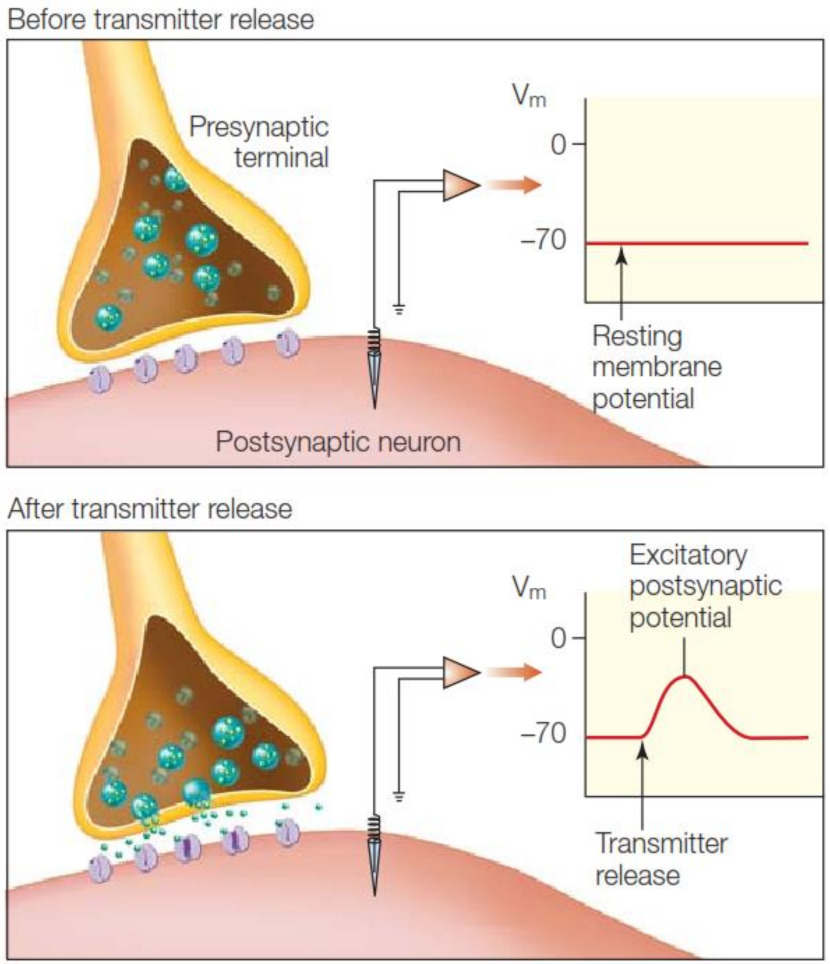



**FIGURE 2.13 Neurotransmitter leading to postsynaptic potential.**

# Electrical and chemical synapses are structured differently

**Electrical** synapses:

neuronal membranes are touching at gap junctions, and the cytoplasm of the two neurons are essentially continuous

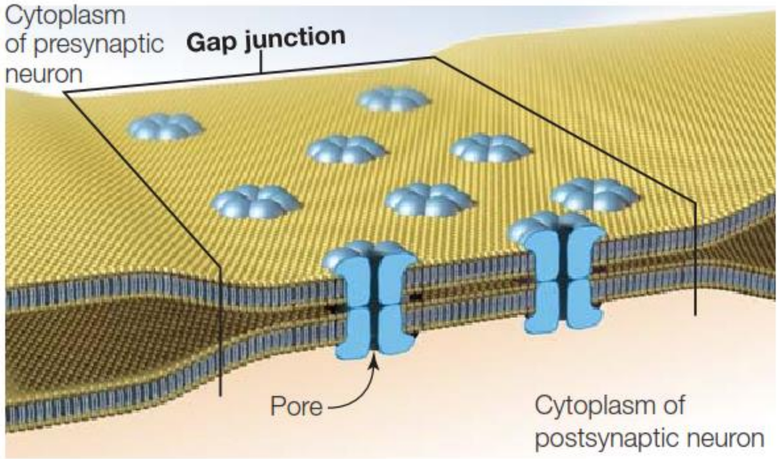
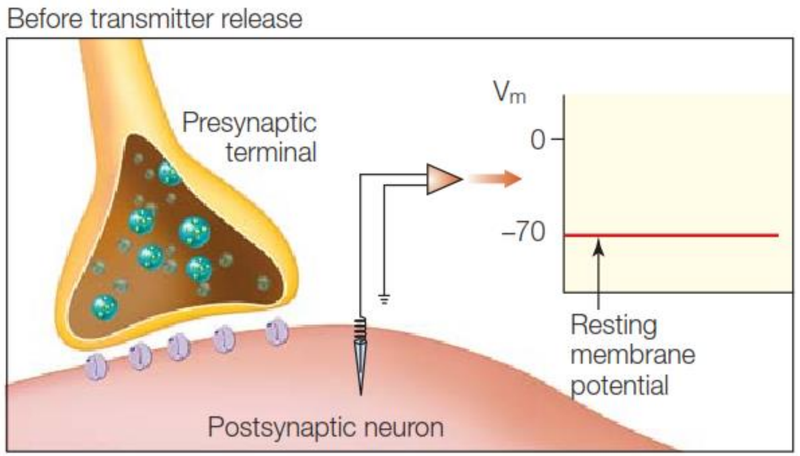



**FIGURE 2.14 Electrical synapse between two neurons.**

**Chemical** synapses:

no structural continuity between pre- and postsynaptic neurons, synaptic cleft separates the neurons



# Electrical and chemical synapses function differently

**Electrical** synapses:

Electrical synaptic transmission depends on the <u>instantaneous transmission of the flow of ions</u> from the pre- to the post-synaptic neuron

**Chemical** synapses:

Chemical synaptic transmission depends on the <u>diffusion of a neurotransmitter</u> across the synaptic cleft

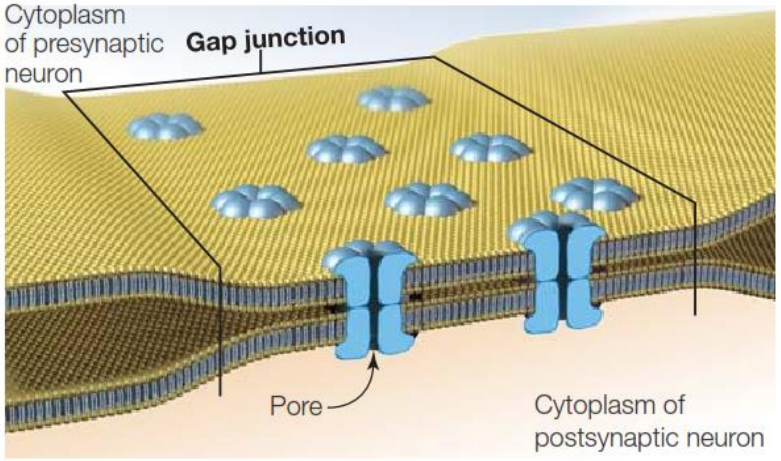
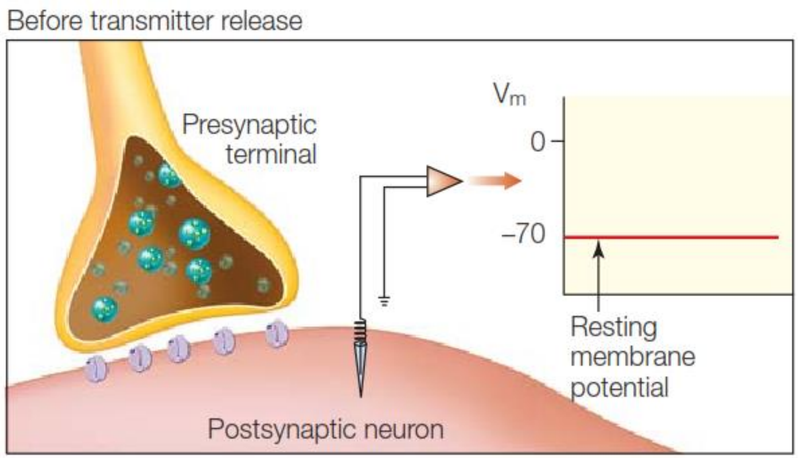



**FIGURE 2.14 Electrical synapse between two neurons.**



# Electrical Synapses Provide Instantaneous Signal Transmission

- Gap junction channels create pores connecting the cytoplasm of the two neurons
- The two neurons are **isopotential**
- Electrical changes in one neuron are reflected instantaneously in the other

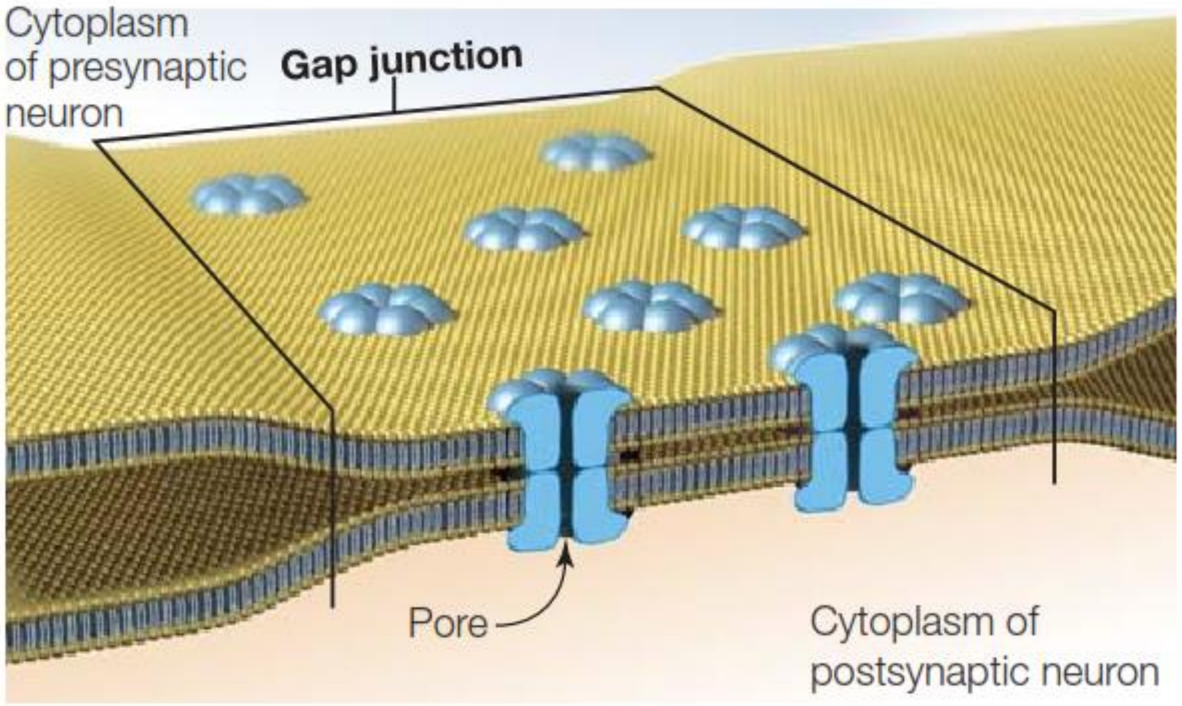



**FIGURE 2.14 Electrical synapse between two neurons.**

# Electrical Synapses

Advantages:

- __________________________
- __________________________

Limitations:

- _________________________________
- _________________________________
- _________________________________

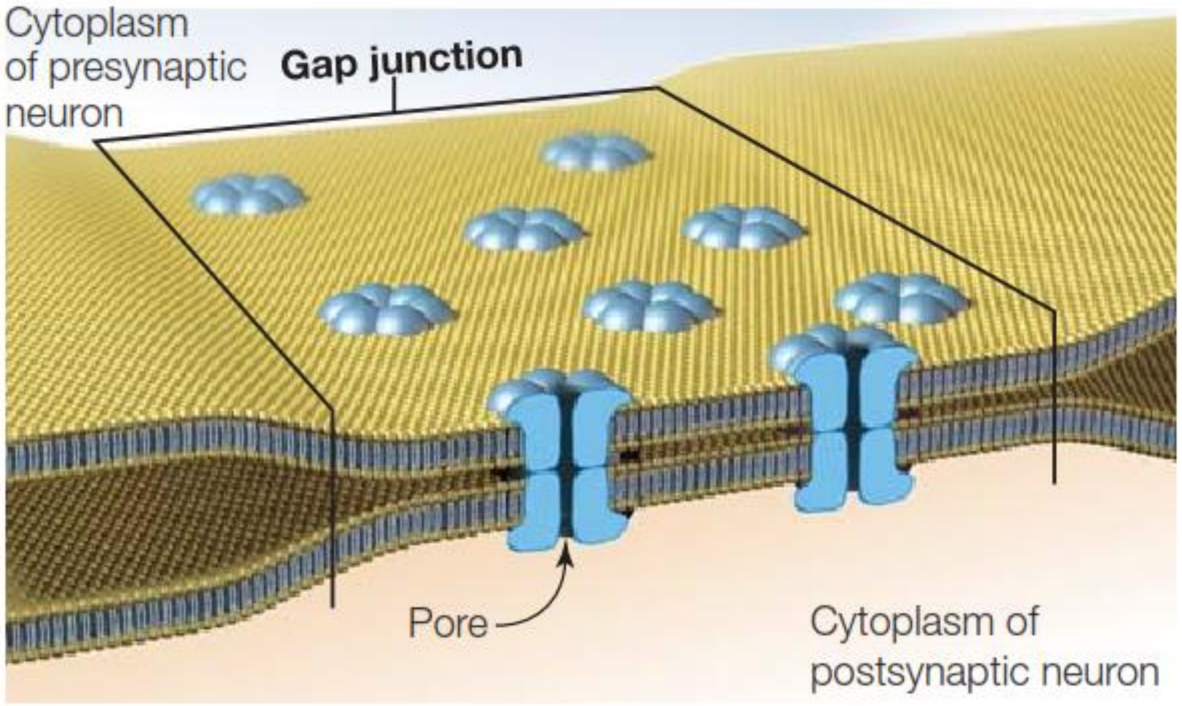



**FIGURE 2.14 Electrical synapse between two neurons.**

# Electrical Synapses

Advantages:

- Fast transmission (e.g. Invertebrate escape reflex)
- Synchronous operation of groups of neurons (e.g. hypothalamus)

Limitations:

- Less plastic than chemical synapses
- Cannot modulated signal from one neuron to the next
- Less specific

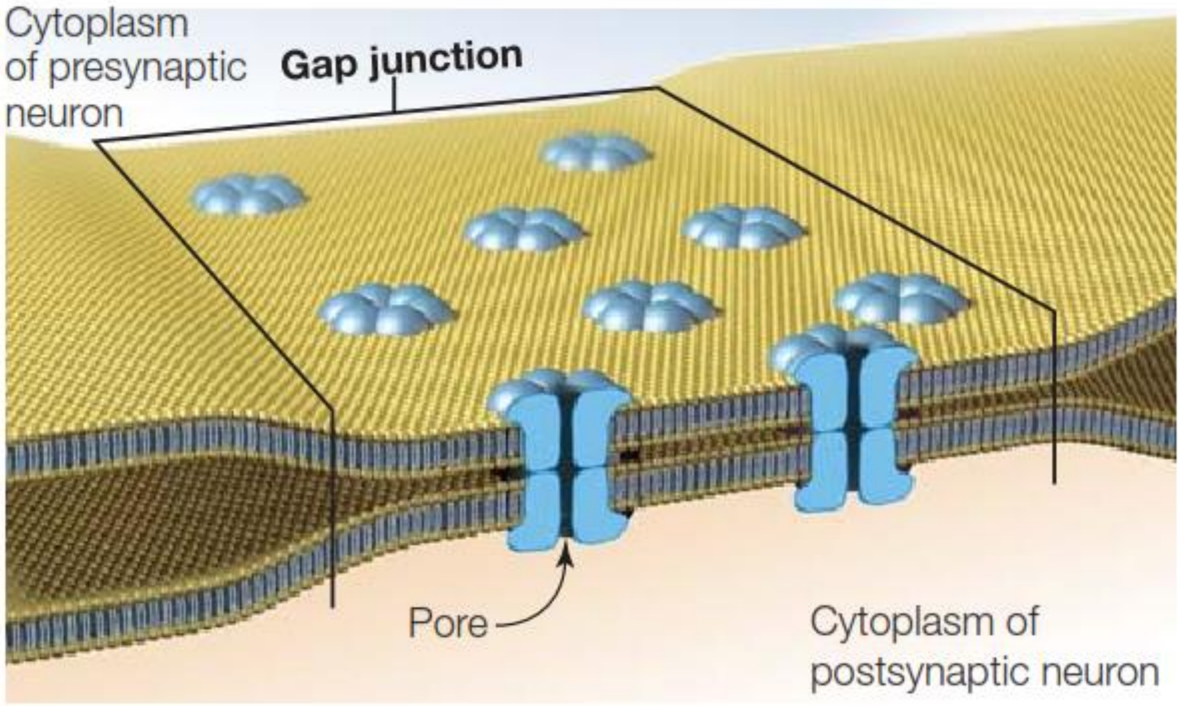



**FIGURE 2.14 Electrical synapse between two neurons.**

# Chemical synapses

Chemical synaptic transmission depends on the diffusion of a neurotransmitter across the synaptic cleft

**Neurotransmitter**: a chemical substance that binds receptors in the postsynaptic membrane of the target cell

**Presynaptic terminals**: specialized swellings of the axon, which typically contain synaptic vesicles

**Synaptic vesicles**: vesicles filled with several thousand molecules of the neurotransmitter

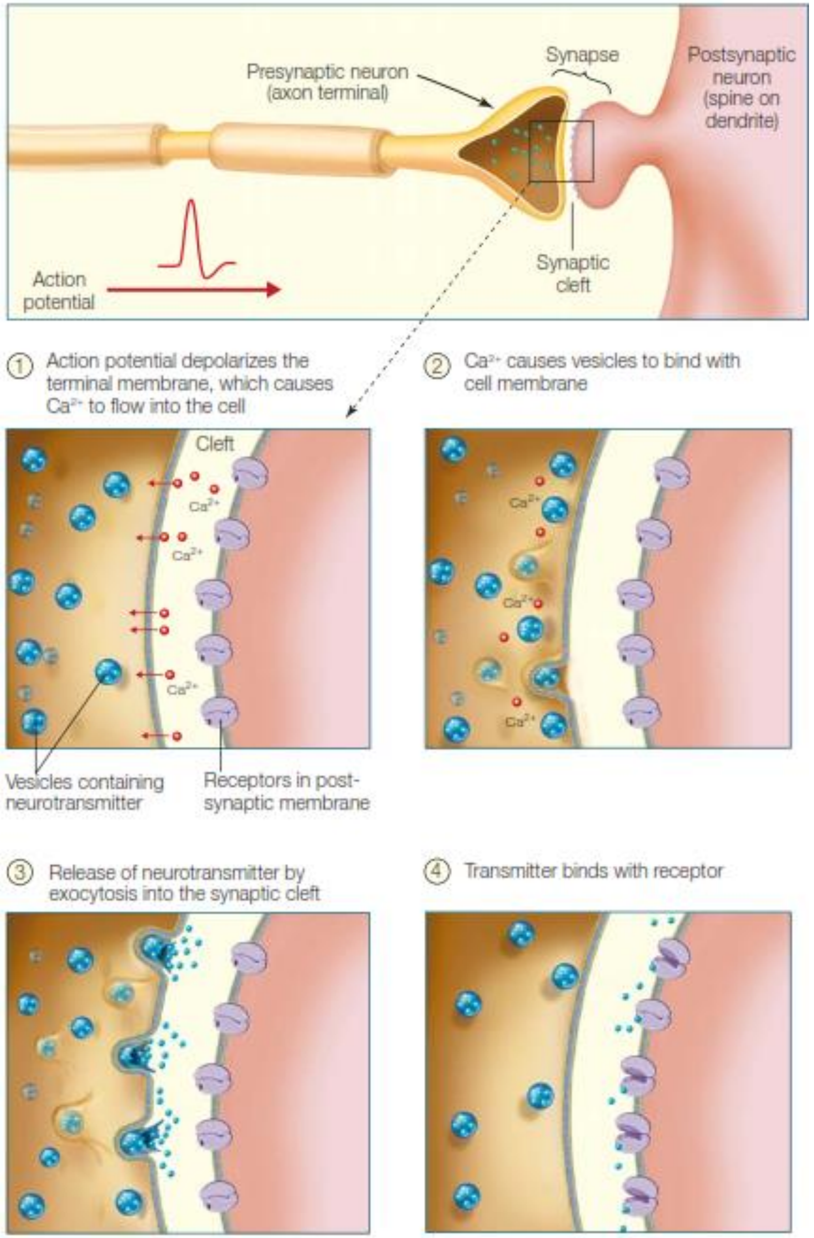



**FIGURE 2.12 Neurotransmitter release at the synapse, into synaptic cleft.** The synapse consists of various specializations where the presynaptic and postsynaptic membranes are in close apposition. When the action potential invades the axon terminals, it causes voltage-gated $Ca^{2+}$ channels to open (1), which triggers vesicles to bind to the presynaptic membrane (2). Neurotransmitter is released into the synaptic cleft by exocytosis and diffuses across the cleft (3). Binding of the neurotransmitter to receptor molecules in the postsynaptic

# Chemical synapses

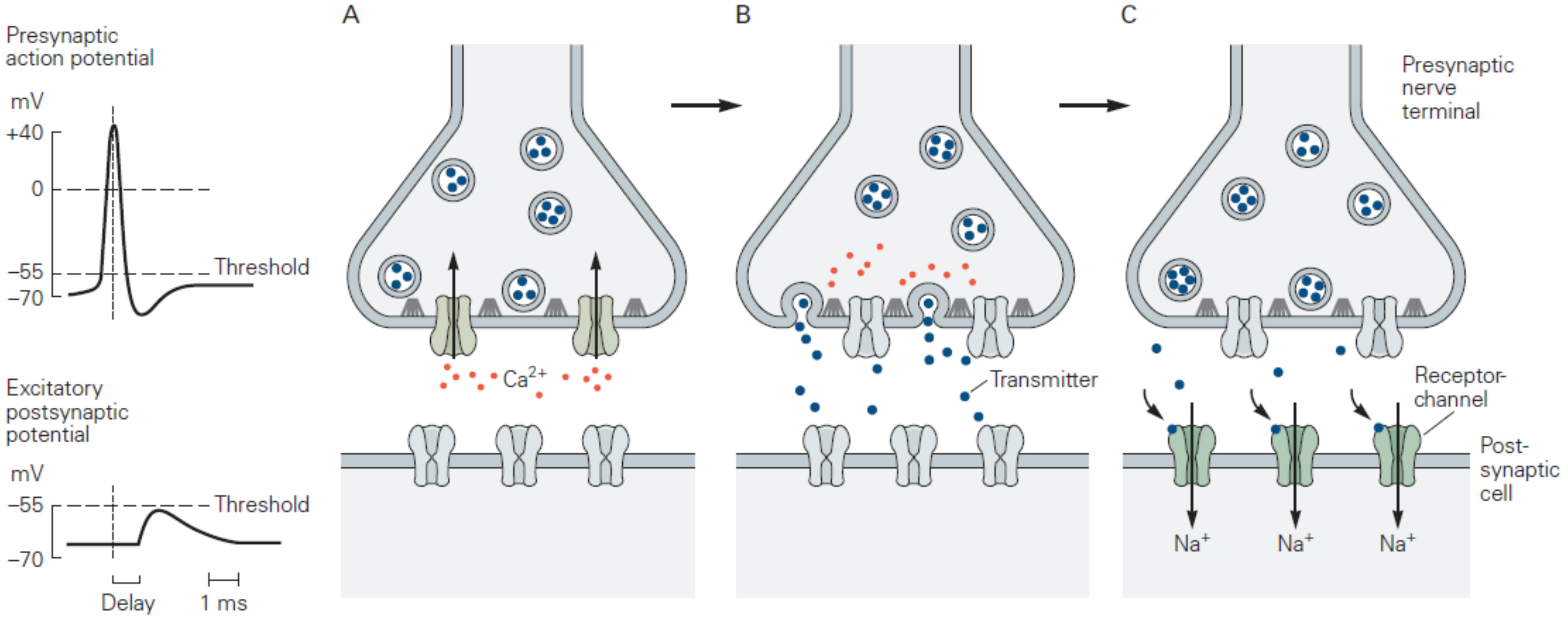



**Figure 8–8 Synaptic transmission at chemical synapses involves several steps.** The complex process of chemical synaptic transmission accounts for the delay between an action potential in the presynaptic cell and the synaptic potential in the postsynaptic cell compared with the virtually instantaneous transmission of signals at electrical synapses (see Figure 8–2B).

A. An action potential arriving at the terminal of a presynaptic axon causes voltage-gated $Ca^{2+}$ channels at the active zone to open. The **gray filaments** represent the docking and release sites of the active zone.

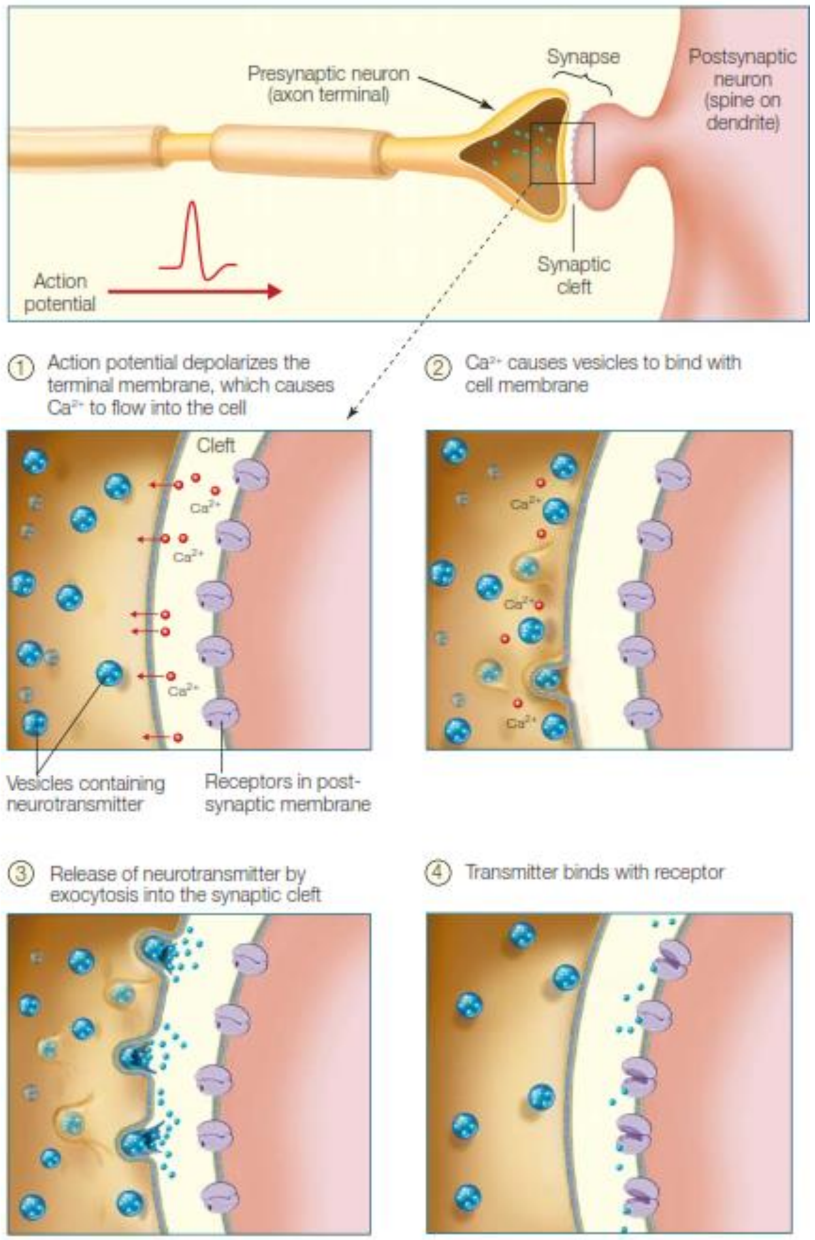
B. The $Ca^{2+}$ channel opening produces a high concentration of intracellular $Ca^{2+}$ near the active zone, causing vesicles containing neurotransmitter to fuse with the presynaptic cell membrane and release their contents into the synaptic cleft (a process termed *exocytosis*).

C. The released neurotransmitter molecules then diffuse across the synaptic cleft and bind specific receptors on the postsynaptic membrane. These receptors cause ion channels to open (or close), thereby changing the membrane conductance and membrane potential of the postsynaptic cell.

# Chemical synapses

**Inactivation of Neurotransmitters** can be accomplished by

1. Active reuptake of the substance back into the presynaptic terminal
2. Enzymatic breakdown or degradation of the transmitter in the synaptic cleft
3. Diffusion of the neurotransmitter away from the site of action (e.g., in the case of hormones that act on target cells distant from the synaptic terminals)

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# Neurotransmitter

- the effect of a neurotransmitter on the postsynaptic neuron is determined by the postsynaptic receptor rather than by the transmitter itself

- the same neurotransmitter released from the same presynaptic neuron onto two different postsynaptic cells might cause one to depolarize (excitation) and the other to hyperpolarize ( inhibition)

- Although most of the time neurotransmitters have a typical effect, either inhibitory or excitatory

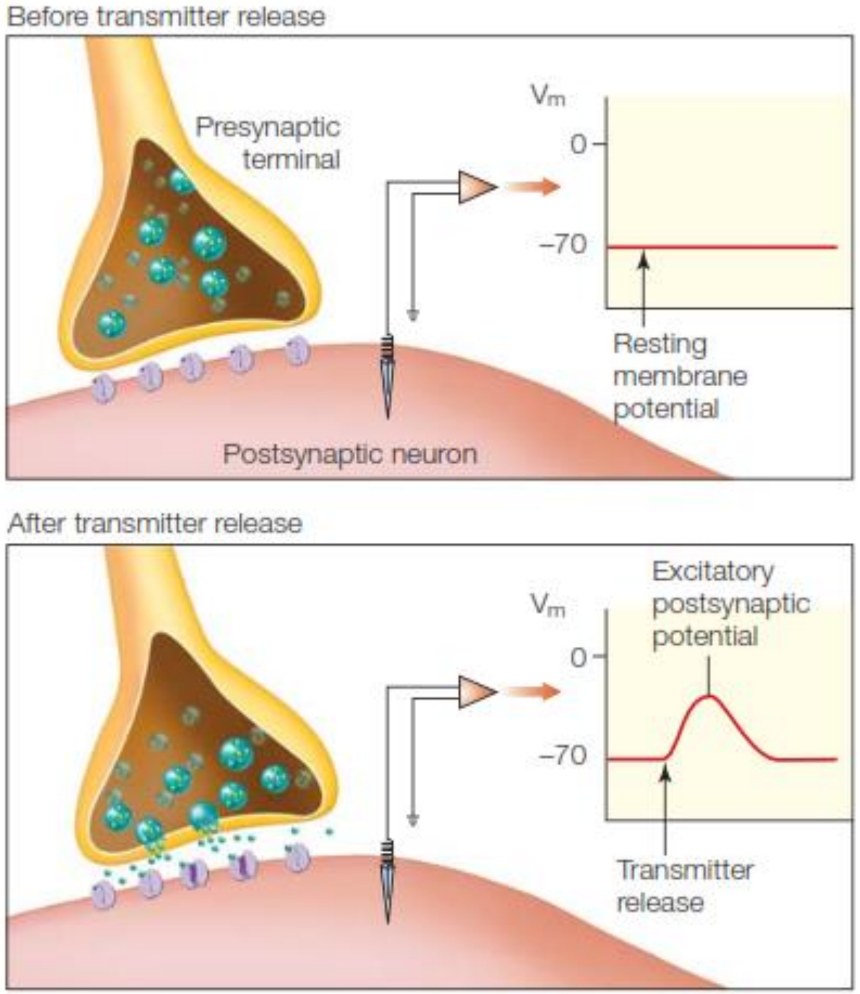



**FIGURE 2.13 Neurotransmitter leading to postsynaptic potential.** The binding of neurotransmitter to the postsynaptic membrane receptors changes the membrane potential ($V_m$). These postsynaptic potentials can be either excitatory (depolarizing the membrane), as shown here, or inhibitory (hyperpolarizing the membrane).

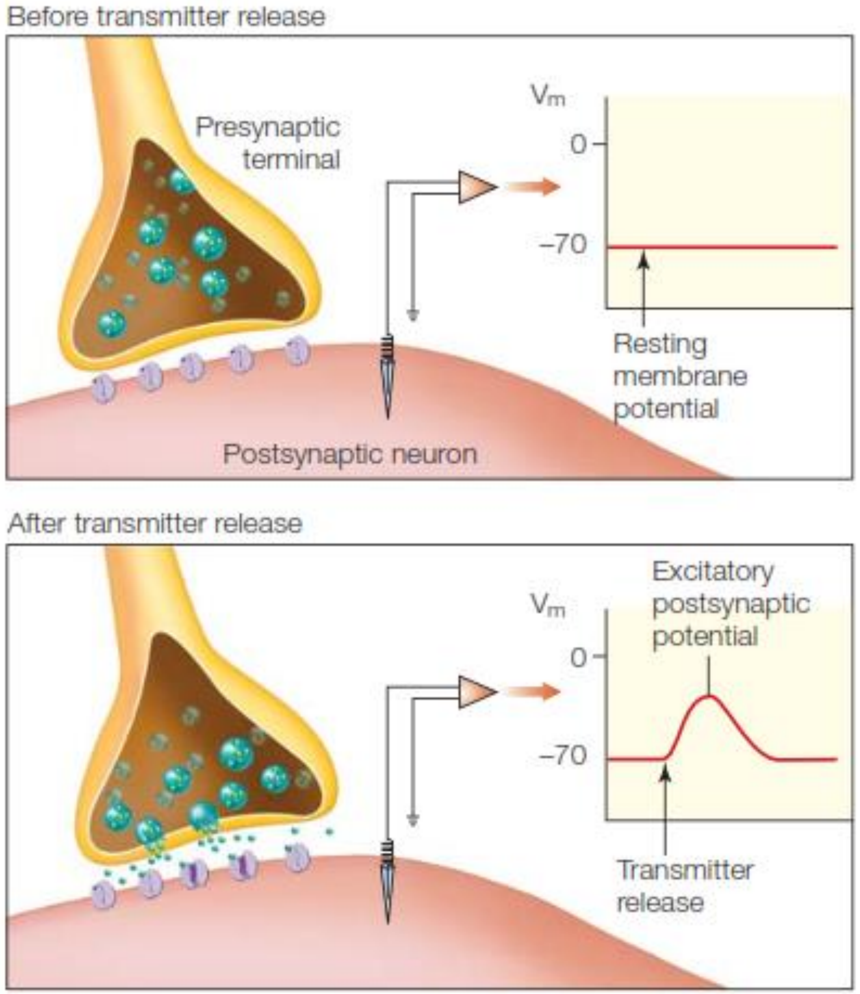
# Chemical Synapses

Advantages:

- ________________________
- ________________________
- ________________________

Limitations:

- ________________________

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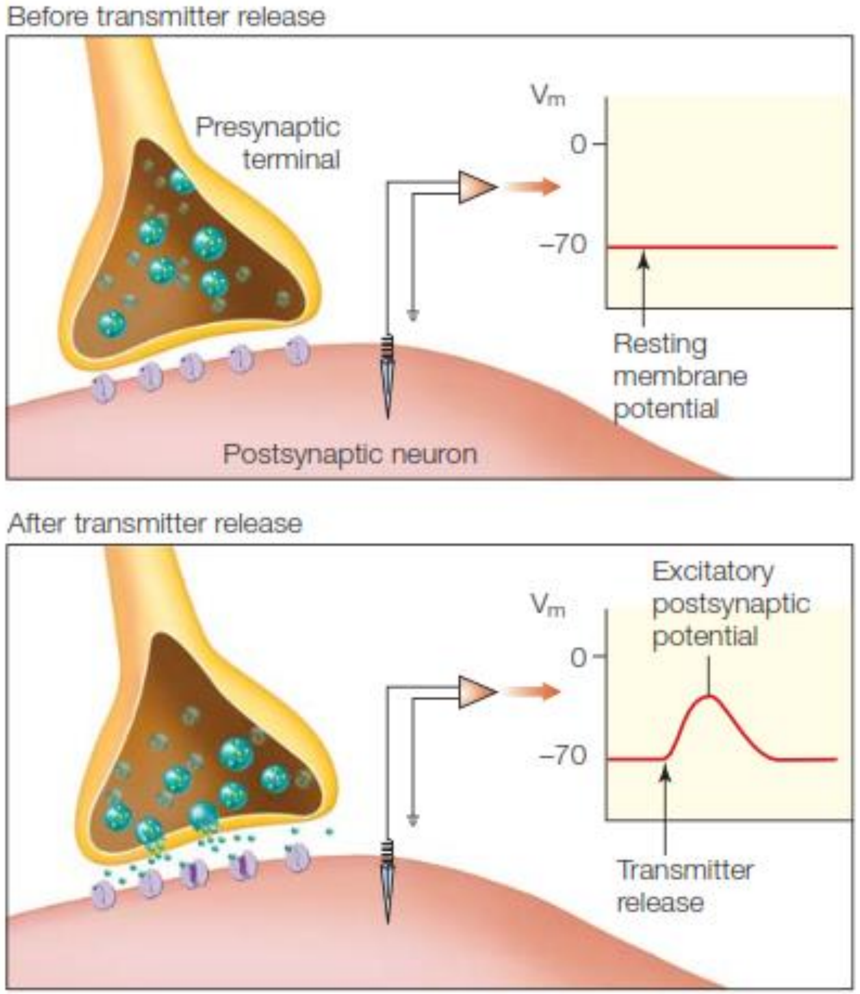
# Chemical Synapses

Advantages:

- More plastic than electrical synapses (functional and structural)
- Signal can be modulated from one neuron to the next: e.g. amplified, inhibited
- Highly specific depending on the presynaptic neurotransmitter and postsynaptic receptors

Limitations:

- Slower transmission

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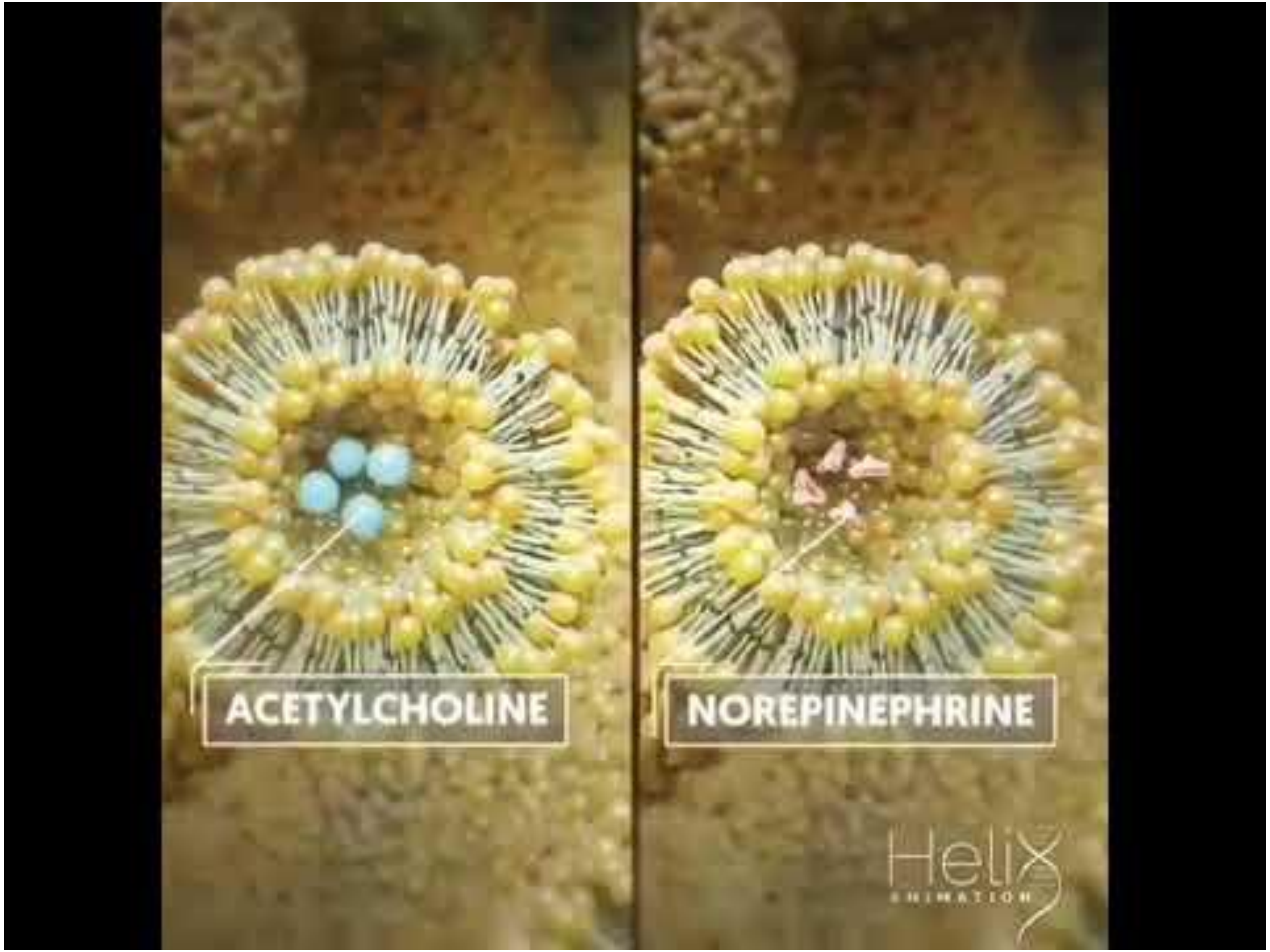

ACETYLCHOLINE
NOREPINEPHRINE
Helix
ANIMATION


https://youtu.be/VitFvNvRIIY

wooclap

Questions 8-11

# From neural circuits to neural systems

Combination of neural circuits create a neural system

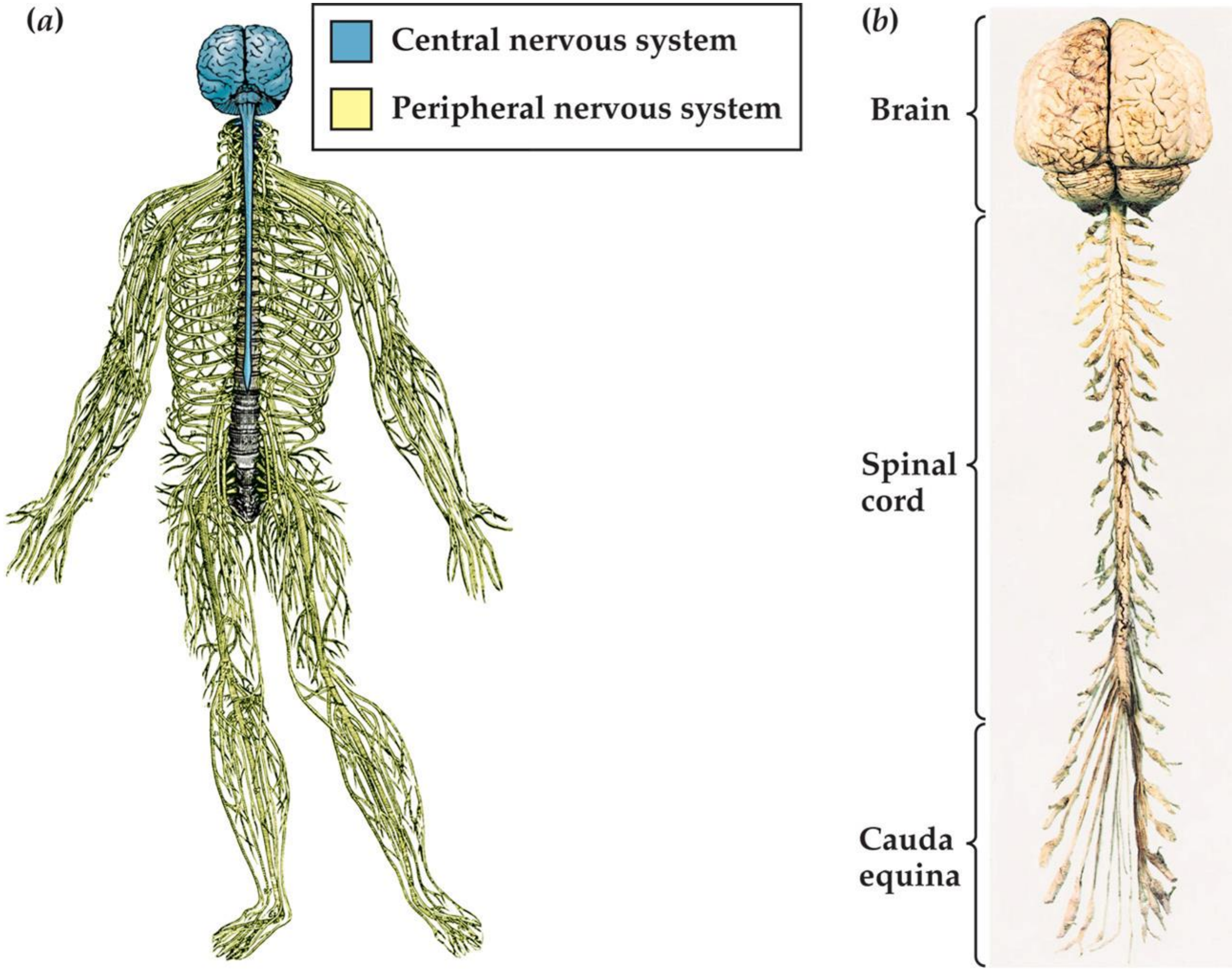
# The bigger picture: neural systems

**Peripheral nervous system (PNS)**:

- Nerves: bundles of axons and glia
- Ganglia: clumps of nerve cell bodies

outside of the CNS

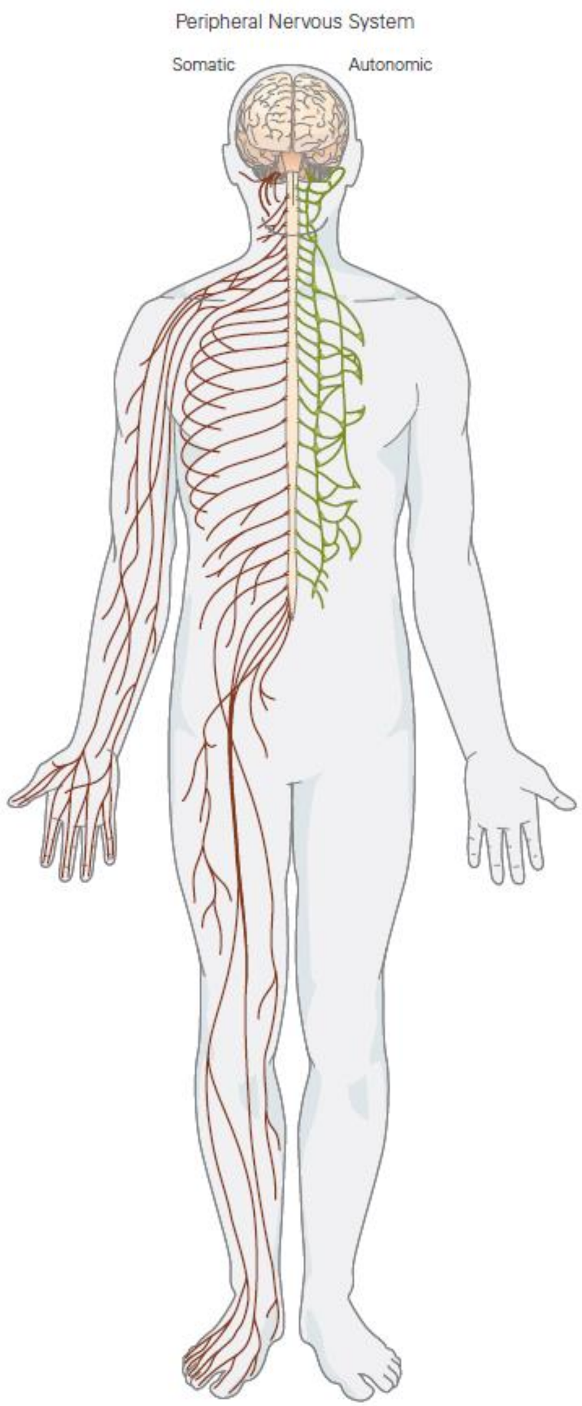
- delivers sensory information to the CNS
- carries the motor commands from the CNS to the muscles
- supplies the CNS with a continuous stream of information about both the external environment and the internal environment of the body
- has somatic and autonomic divisions




*THE MIND'S MACHINE*, Figure 2.6

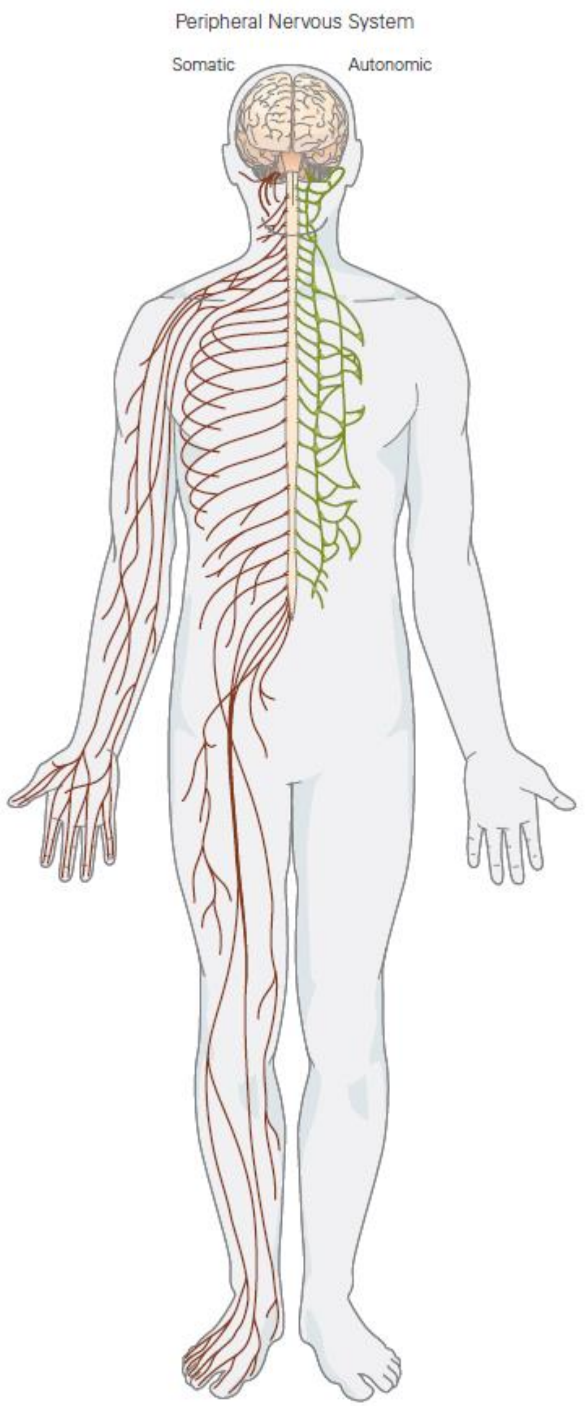
# PNS: the somatic nervous system

- sensory neurons that receive information from the skin, muscles, and joints.
- Receptors associated with these cells provide information about muscle and limb position and about touch and pressure at the body surface.
- Receptors are in transduce different types of physical energy (such as deep pressure or heat) into the electrical signals used by the nervous system.



# PNS: the autonomic nervous system

- mediates visceral sensation as well as motor control of the viscera, vascular system, and exocrine glands.
- sympathetic system: participates in the body's response to stress
- Parasympathetic system: acts to conserve body resources and restore homeostasis
- Enteric system: controls the function of smooth muscle of the gut



# The sympathetic and parasympathetic systems

They operate antagonistically:

- sympathetic system uses norepinephrine
- parasympathetic system uses acetylcholine

Example:

Sympathetic system

- prepares the body
  for action (fight or flight) by stimulating the adrenal glands to release adrenaline
- increases heart rate
- diverts blood from the digestive tract to the somatic musculature

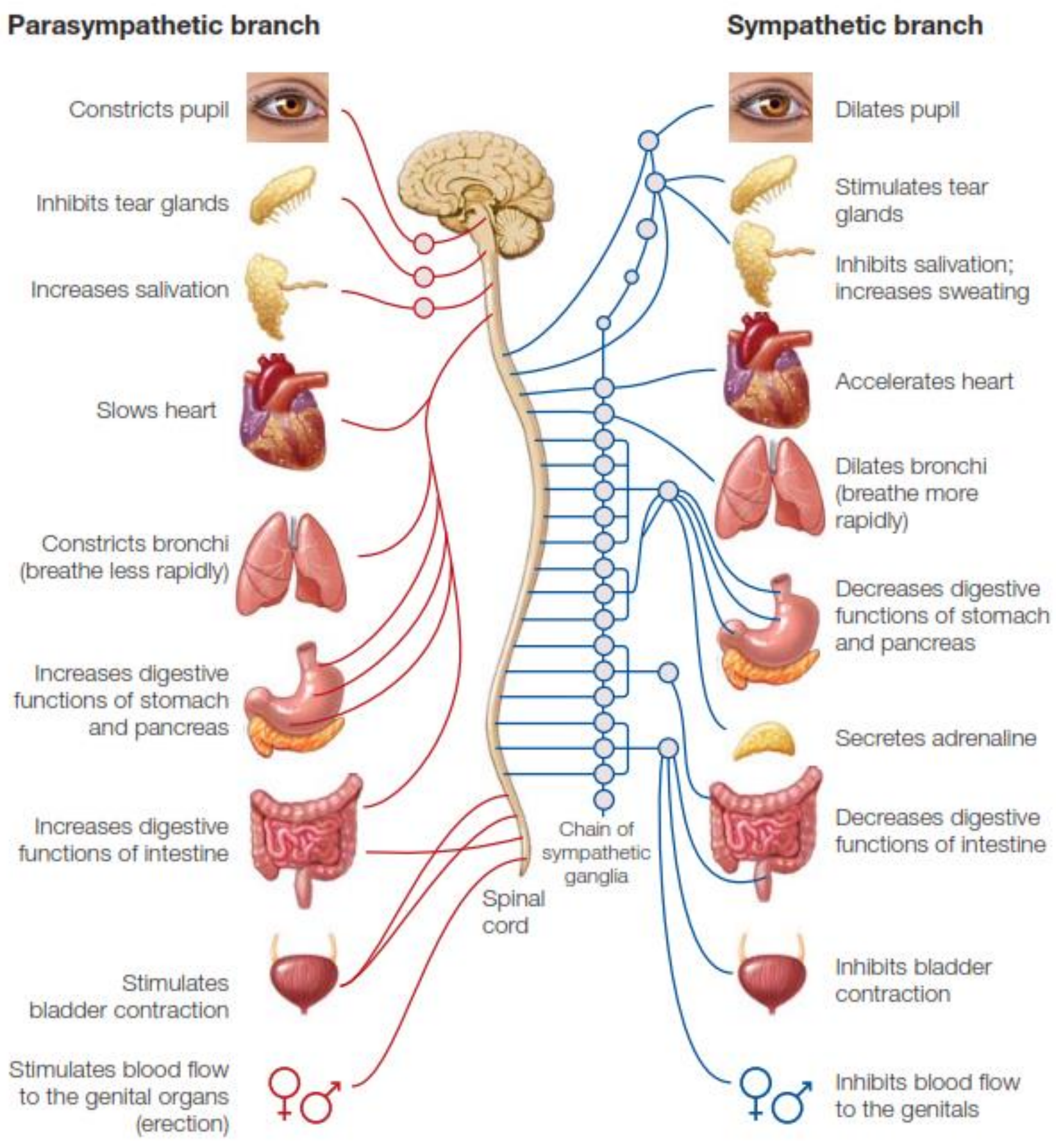



**FIGURE 2.17 Organization of the autonomic nervous system, showing sympathetic and parasympathetic branches.**

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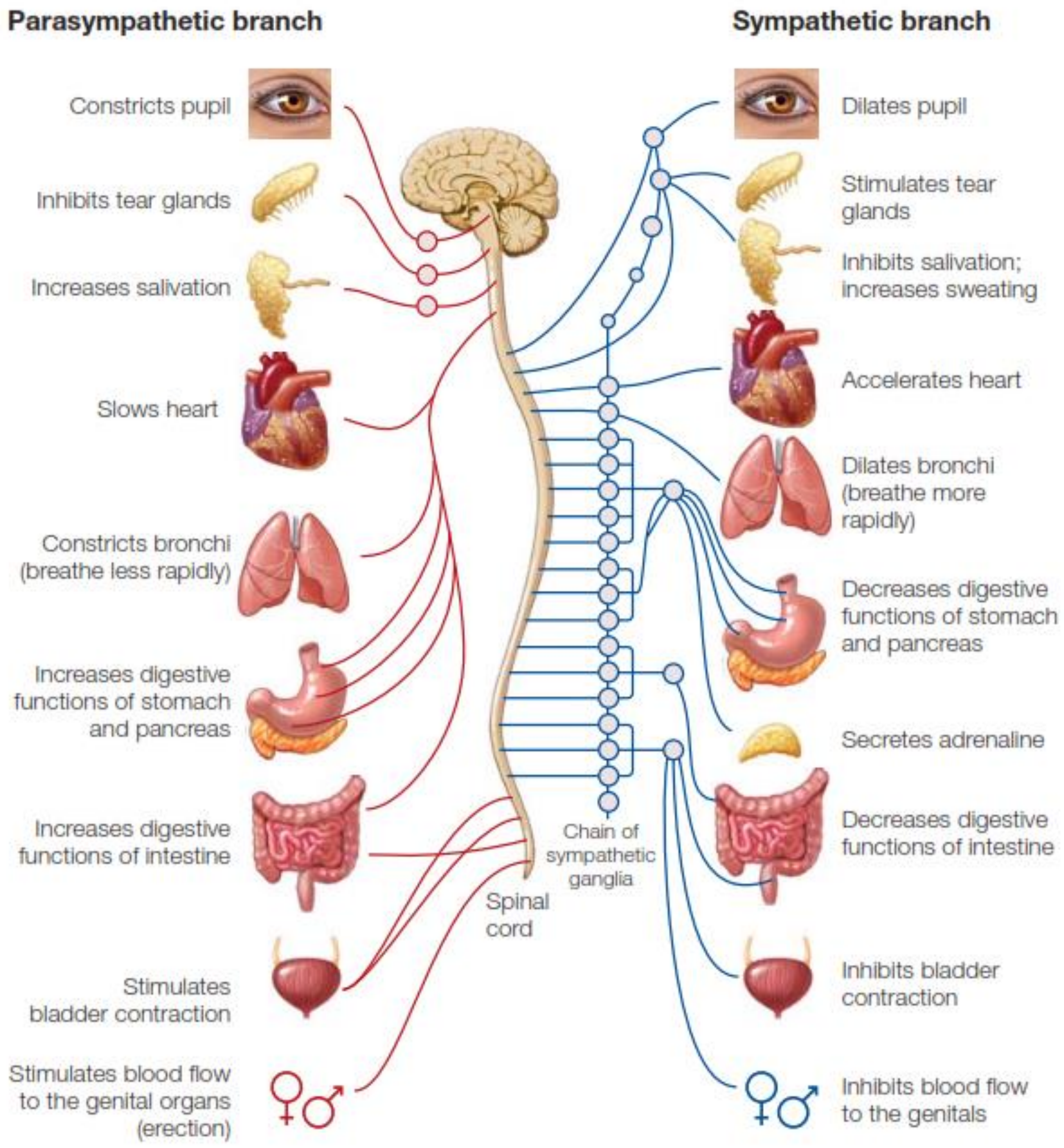
The parasympathetic system

- helps the body with functions germane to maintaining the body
- Slows heart rate
- stimulates digestion

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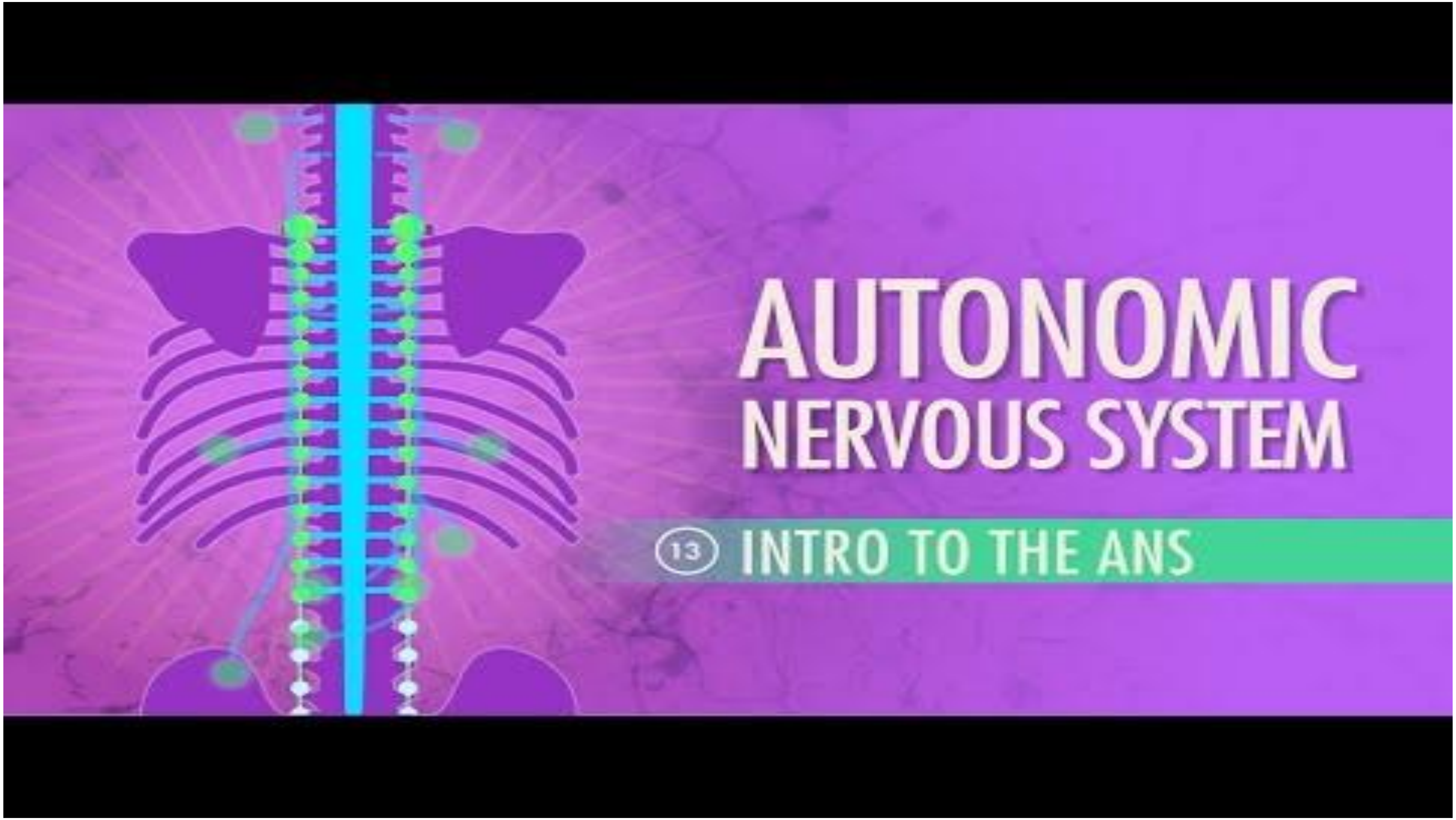
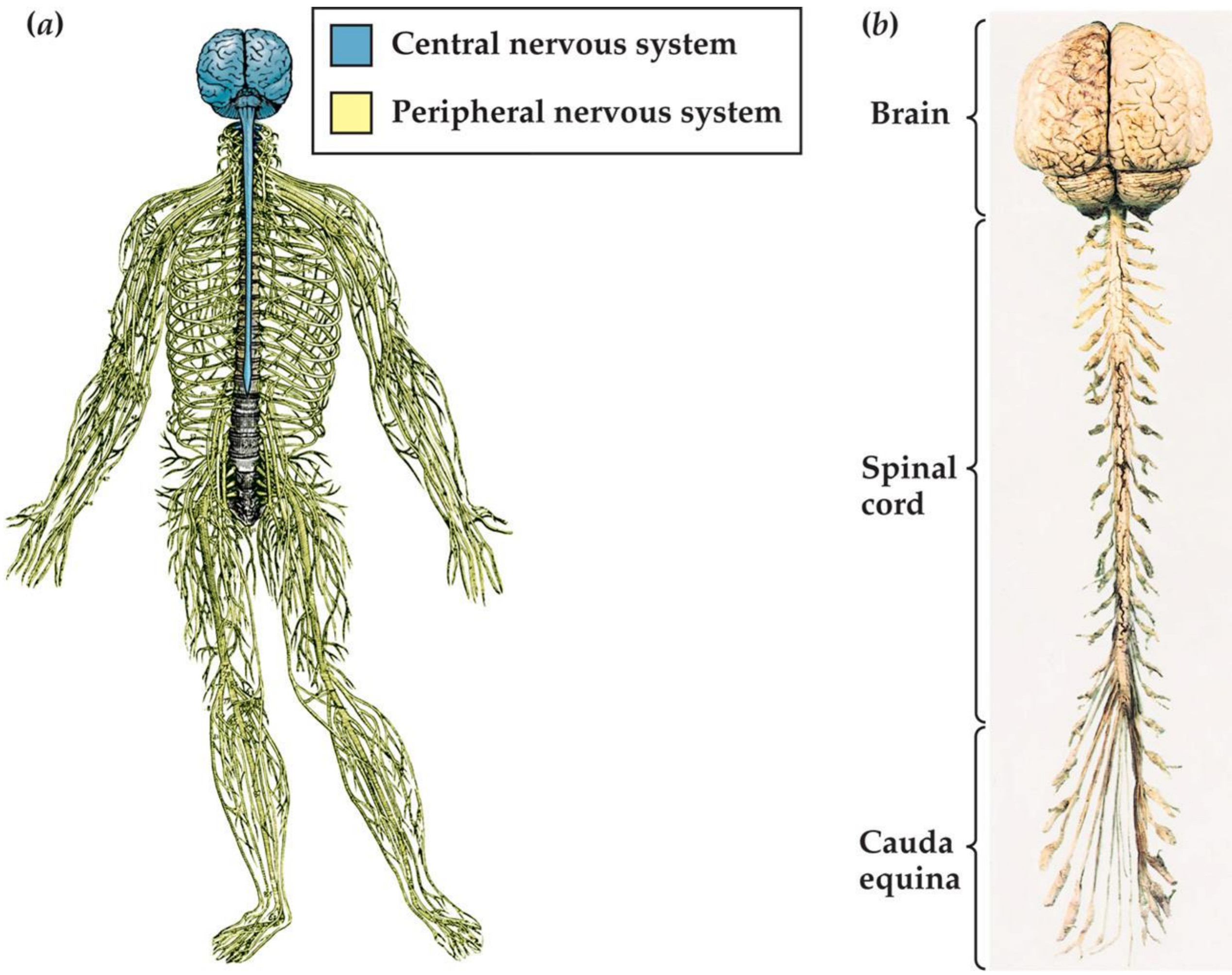



https://youtu.be/71pCilo8k4M

# The bigger picture: neural systems

**Central nervous system (CNS):**

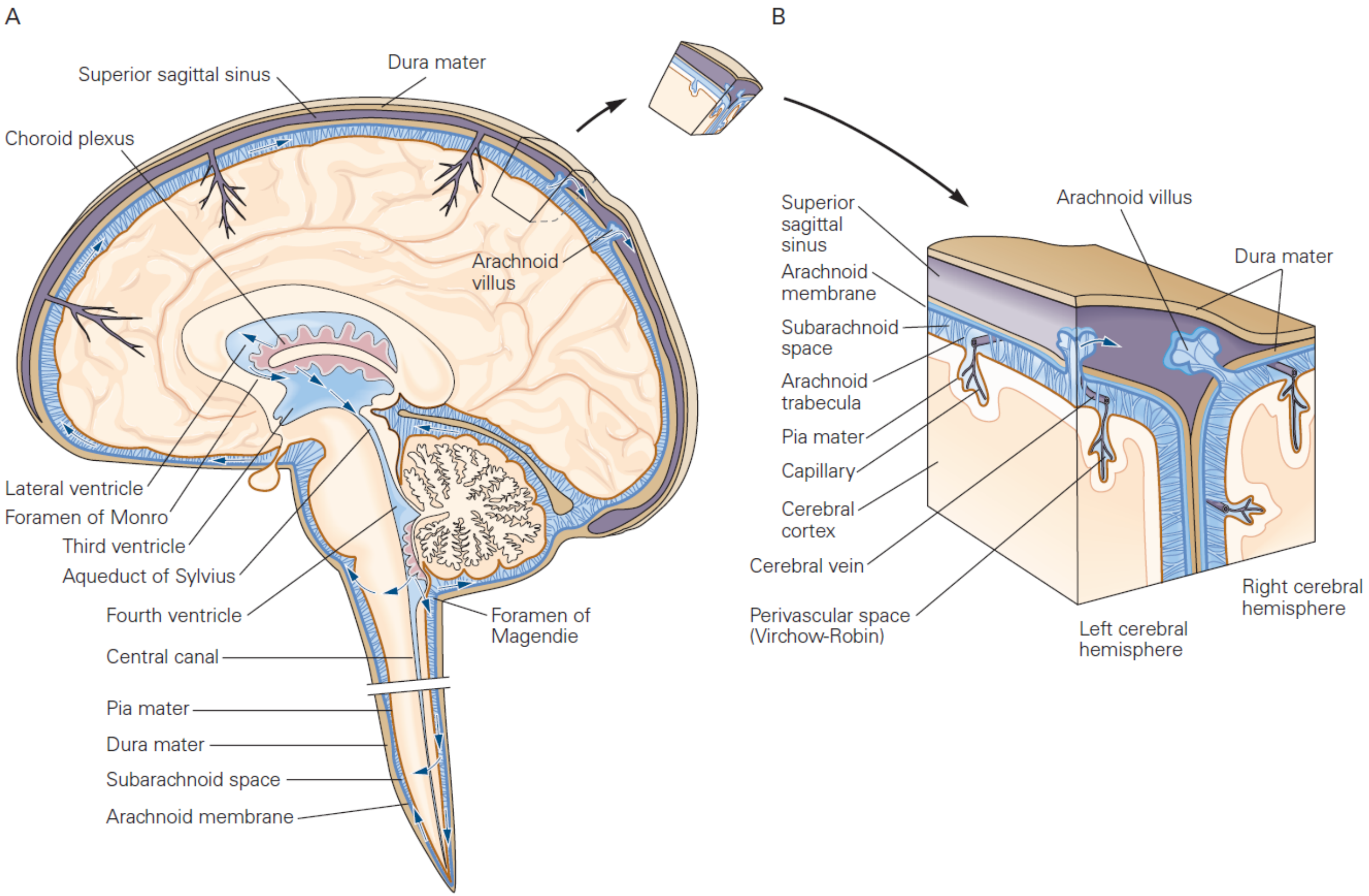
- brain
- spinal cord




*THE MIND'S MACHINE*, **Figure 2.6**

# CNS is protected by the meninges

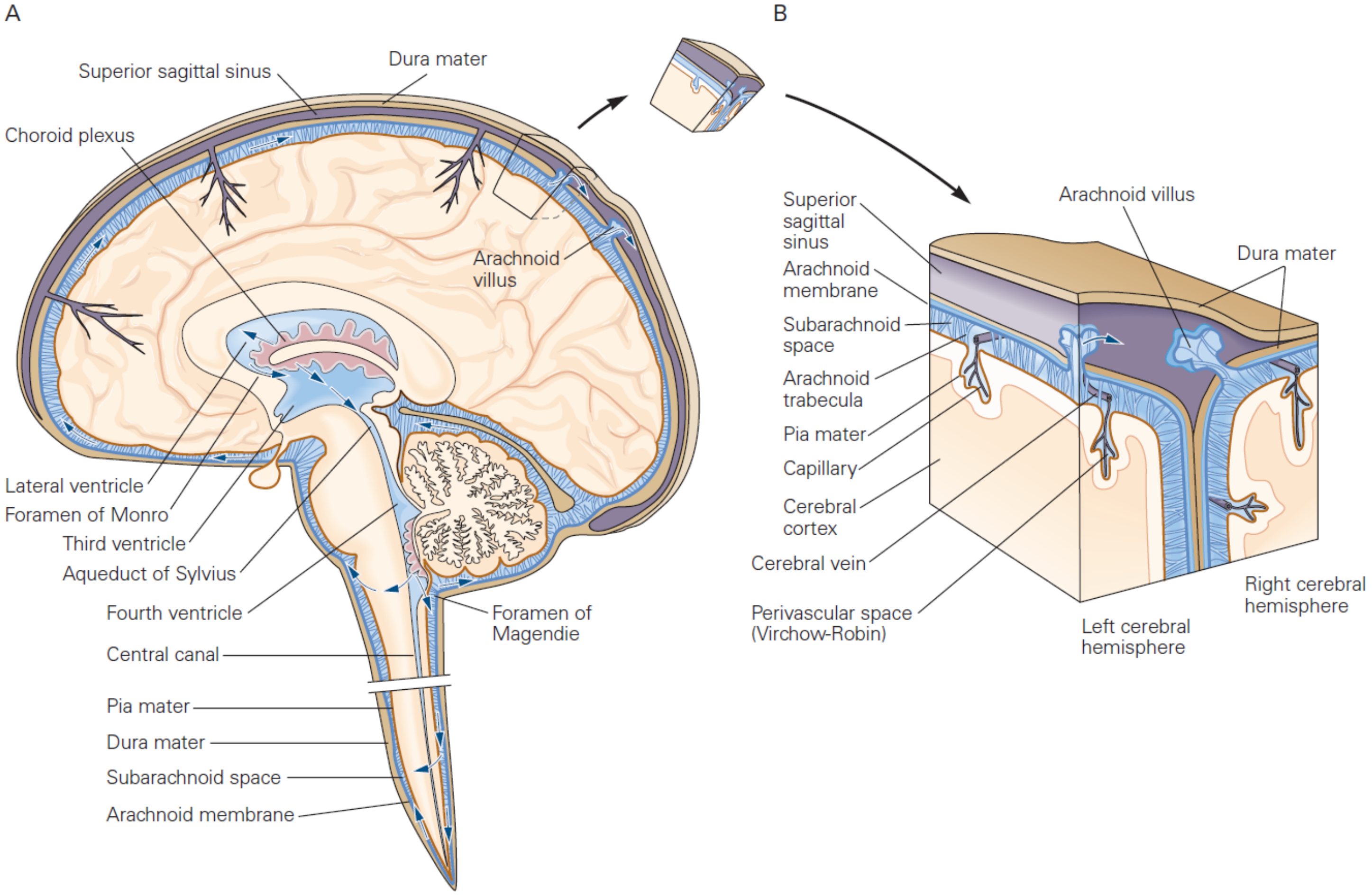
- 3 protective  membranes
- Dura mater
    - Most outer
    - thickest
- Arachnoid mater
    - middle
- Pia mater
    - Inner
    - Most delicate
    - Firmly adheres to the brain surface



# Brain & spinal cord float in the CSF

Cerebrospinal Fluid occupies:

- the space between the arachnoid membrane and the pia mater
- the brain ventricles
- cisterns and sulci
- central canal of the spinal cord



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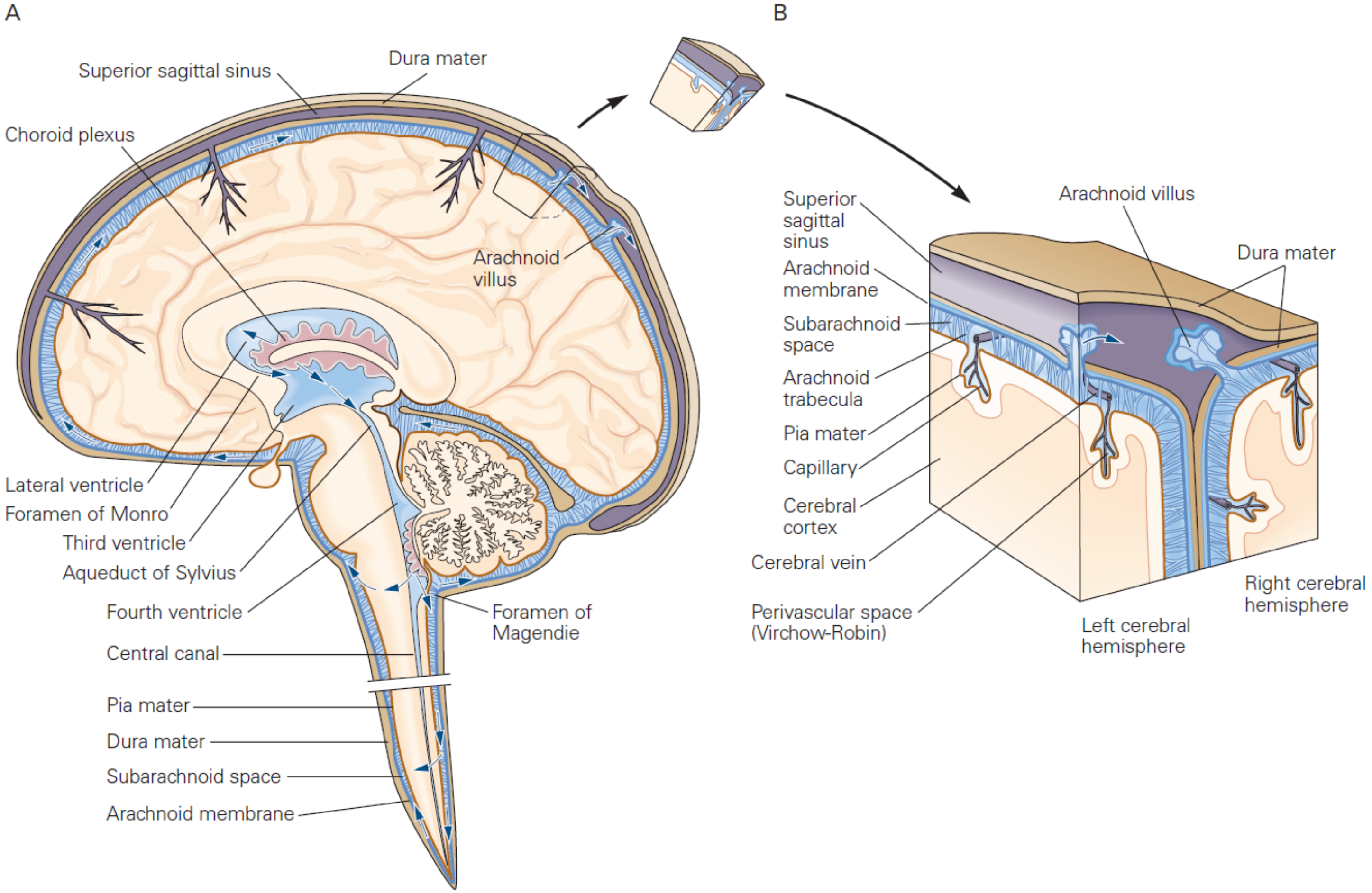
Cerebrospinal Fluid allows:

- the brain to float to help offset the pressure that would be present if the brain were merely sitting on the base of the skull
- reduces shock to the brain and spinal cord during rapid accelerations or decelerations, such as when we fall or are struck on the head



# Blood-brain barrier

- Barrier between the brain's blood vessels (capillaries) and the cells and other components that make up brain tissue.
- Whereas the skull, meninges and cerebrospinal fluid protect against physical damage, the blood–brain barrier provides a defense against disease-causing pathogens and toxins that may be present in our blood.

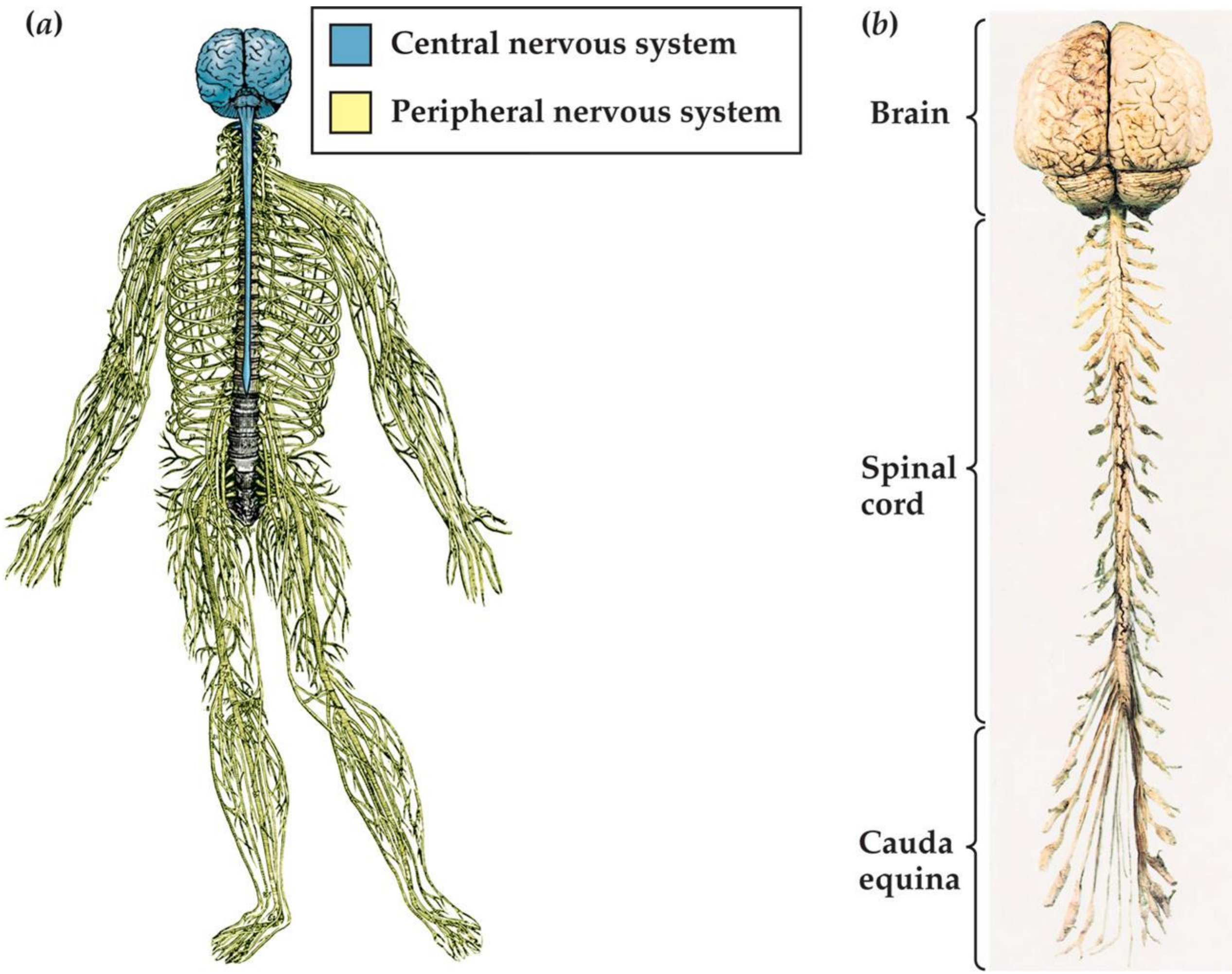
When do we need to get through it?

- Very effective at preventing unwanted substances from accessing the brain, which has a downside. The vast majority of potential drug treatments do not readily cross the barrier, posing a huge impediment to treating mental and neurological disorders.

# CNS: the spinal cord

- takes in sensory information from the body's peripheral sensory receptors
- relays it to the brain
- conducts the final motor signals from the brain to muscles

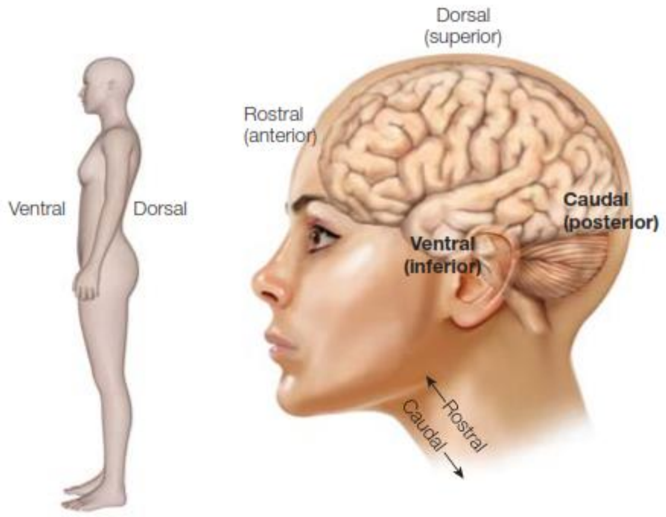
- enclosed in the *vertebral column*
  - *a stack* of separate bones, the *vertebrae*
  - extend from the base of the skull to the fused vertebrae at the coccyx (tailbone)

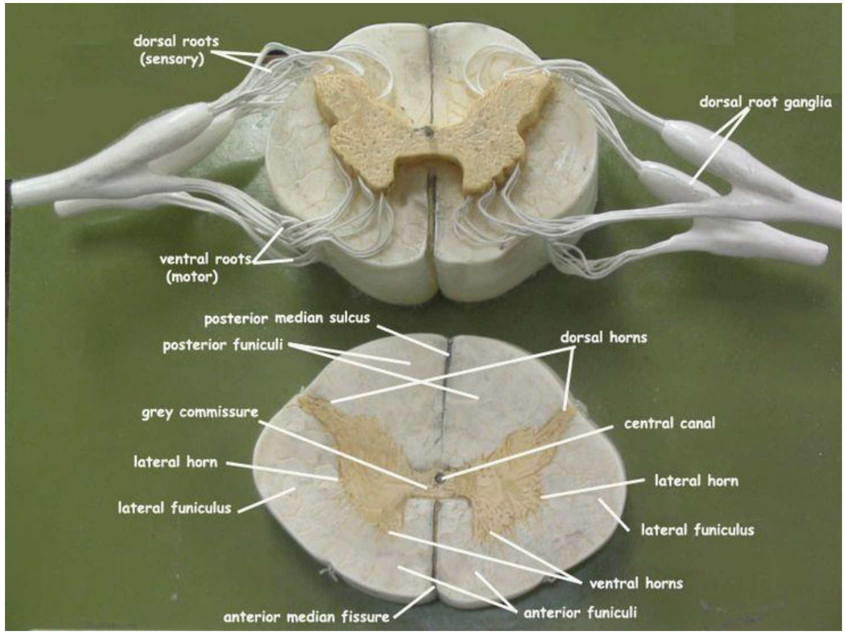


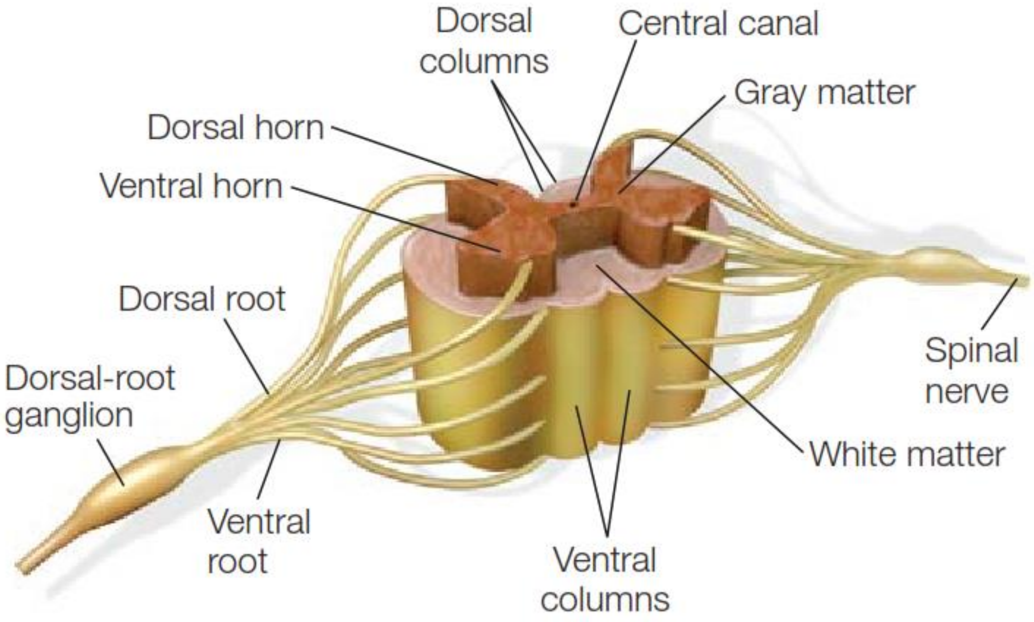

THE MIND'S MACHINE, Figure 2.6

# CNS: the spinal cord

- divided into 31 segments
- Each segment has a right and a left spinal nerve that enters and exits from the vertebral column
- Receives and sends info from below the neck (face from cranial nerves)



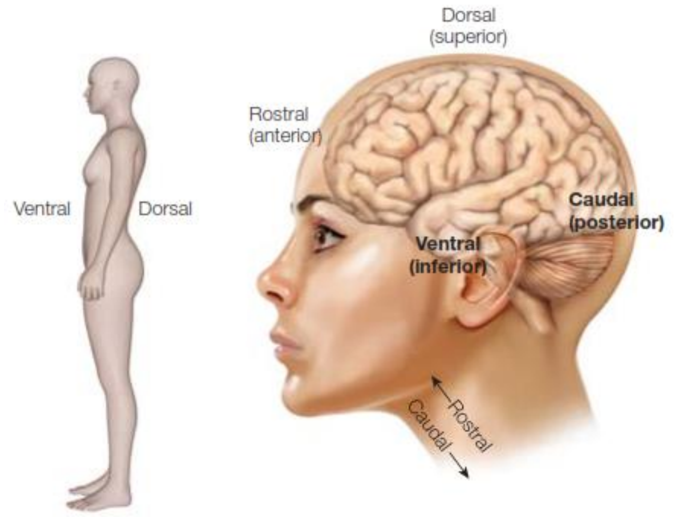



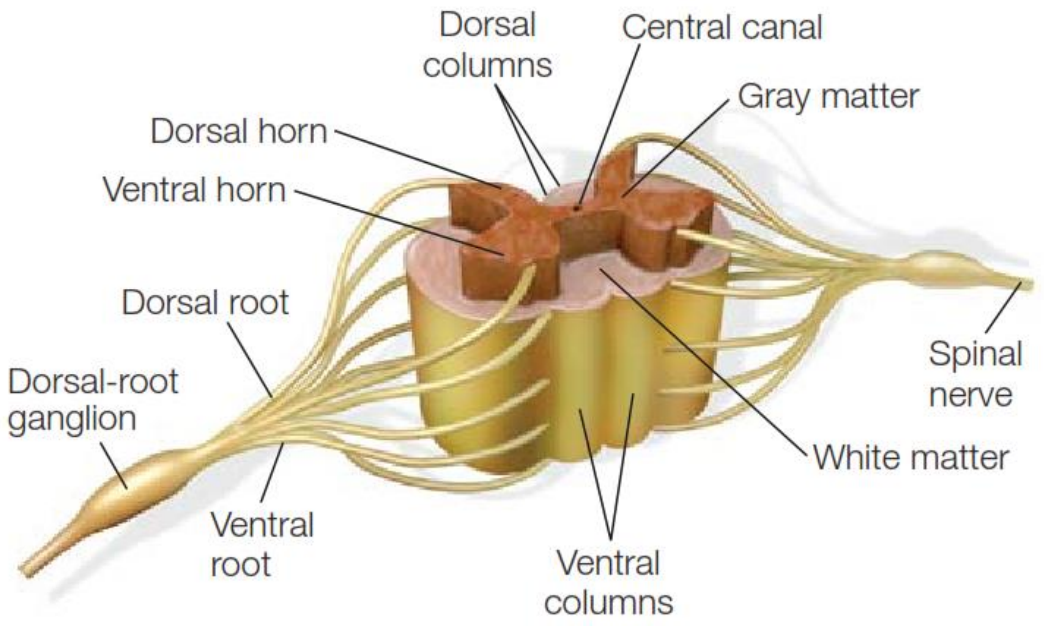



# CNS: the spinal cord

- divided into 31 segments
- Each segment has a right and a left spinal nerve that enters and exits from the vertebral column

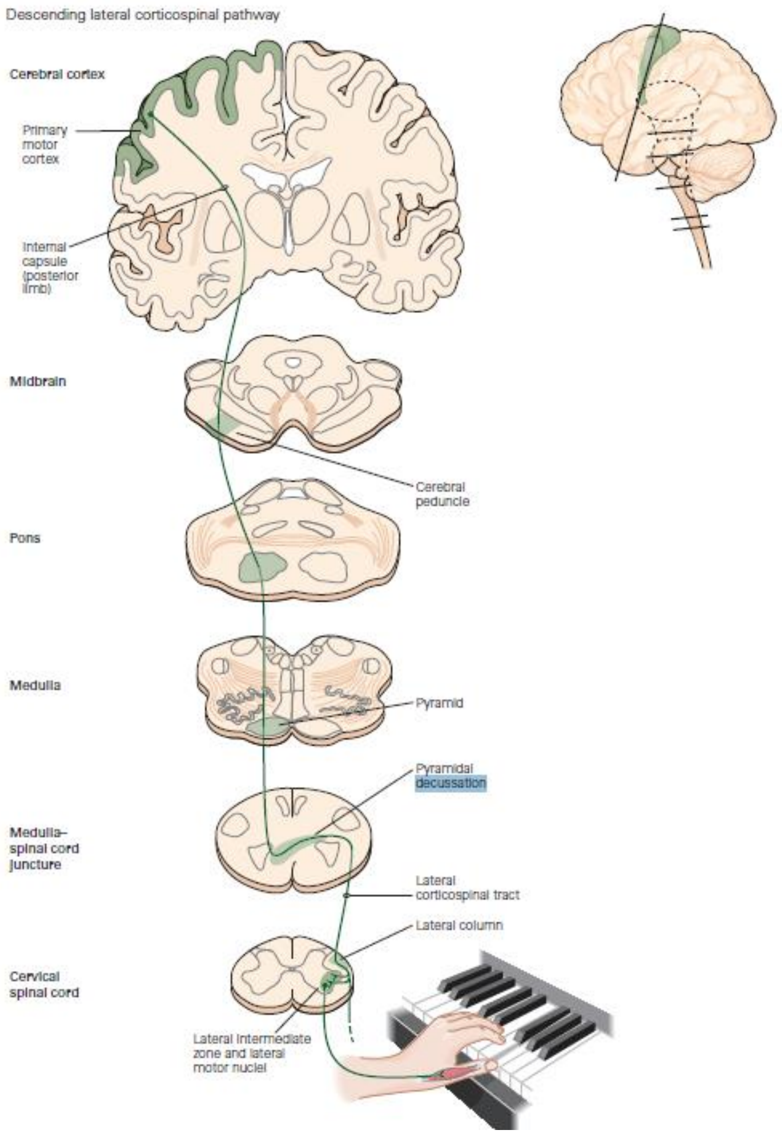
- Each spinal nerve has
  - sensory axon: afferent neuron, input through the dorsal root into the spinal cord
  - motor axons: efferent neuron carries motor output through the ventral root away from it
  - Bell-magendie law: dorsal sensory, ventral motor

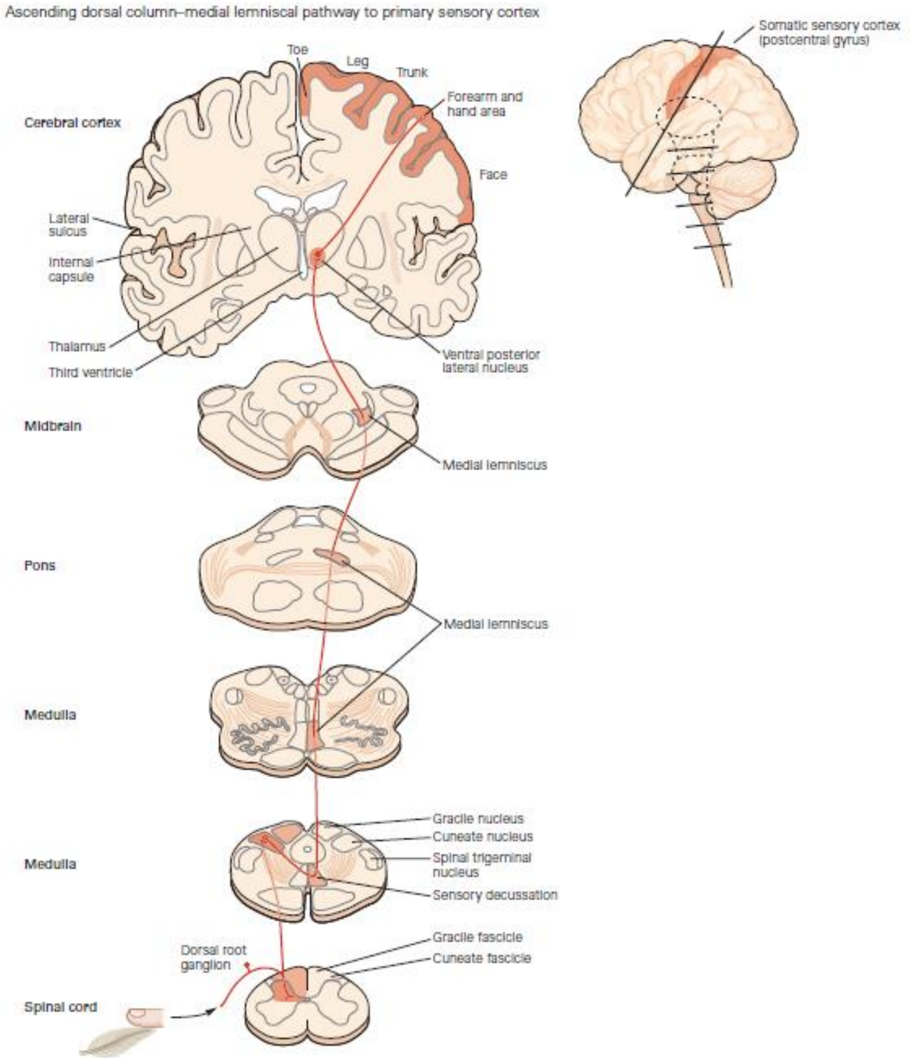


# Functional Systems on One Side of the Brain Control the Other Side of the Body

- Most pathways in the central nervous system are bilaterally symmetrical and cross over to the opposite (contralateral) side of the brain or spinal cord
- Sensory and motor activities on one side of the body are mediated by the cerebral hemisphere on the opposite side
- The pathways of different systems cross at different anatomical levels within the central nervous system



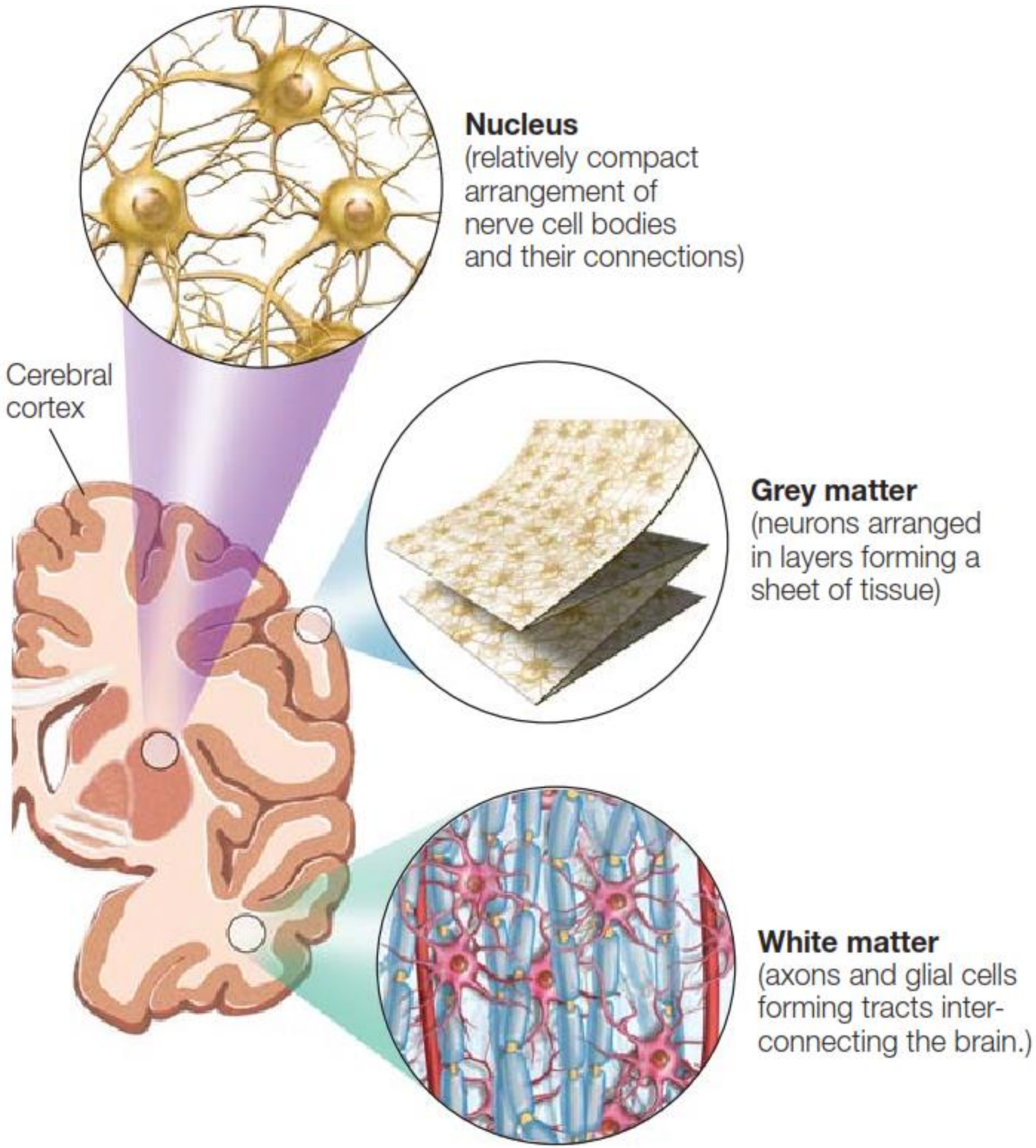
# In the CNS neurons are bunched together in various ways

**Nucleus:**

- compact arrangement of nerve cell bodies and their connections, ranging from hundreds to millions of neurons, with functionally similar inputs and outputs
- located throughout both the brain and the spinal cord

**Layer:**

- thin sheets, folded across the surfaces of the cerebral hemispheres like handkerchief
- found in the cerebral cortex



# The brain

https://www.brainfacts.org/3d-brain#intro=false&focus=Brain

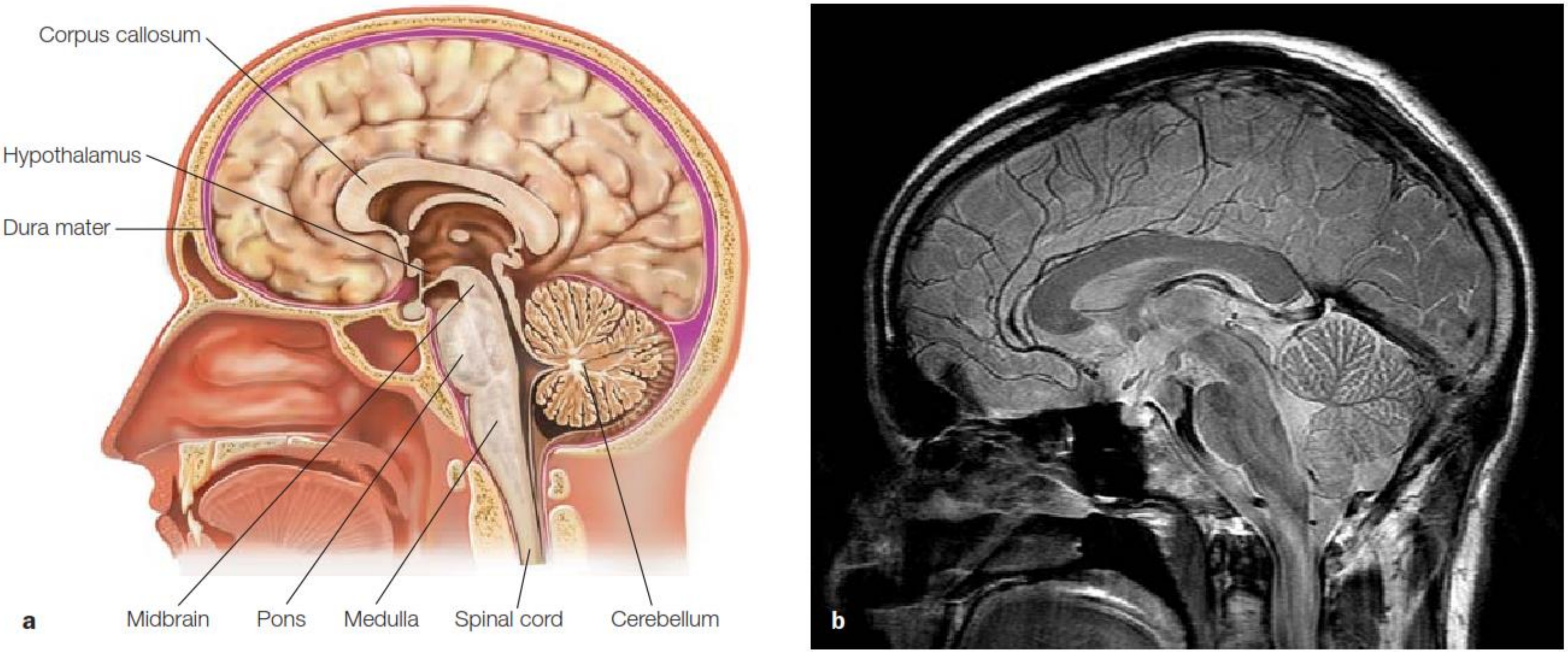


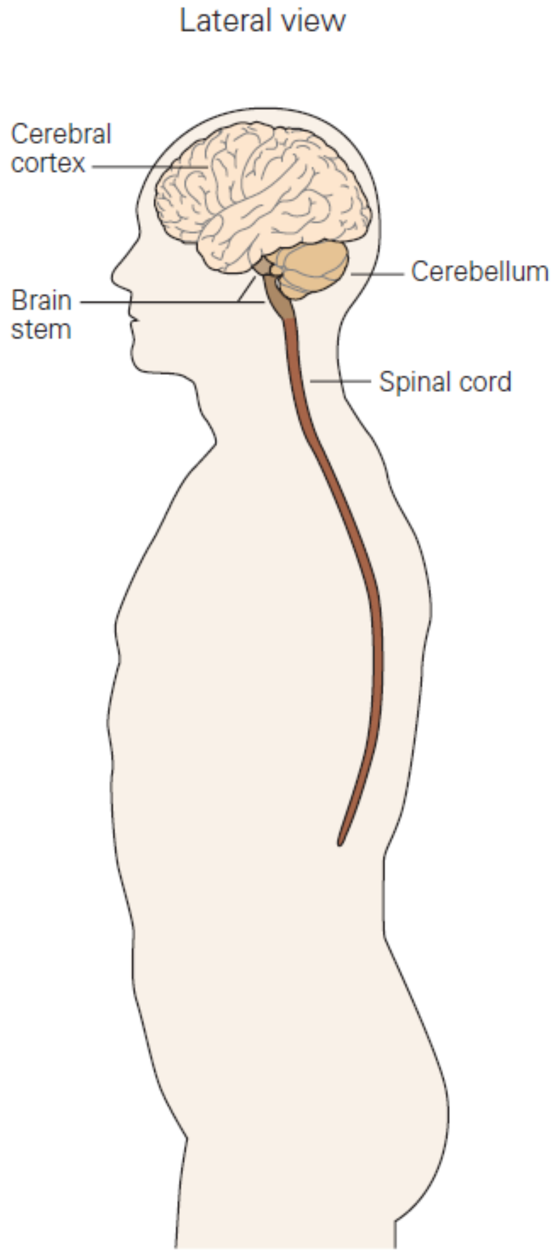

**FIGURE 2.20 Gross anatomy of a brain showing brain stem.**
**(a)** Midsagittal section through the head, showing the brainstem, cerebellum, and spinal cord. **(b)** High-resolution structural MRI obtained with a 4-tesla scanner, showing the same plane of section as in (a).

# The brain

Composed of 6 subdivisions

- Medulla
- Pons
- Midbrain
- Cerebellum
- Diencephalon
- Cerebral hemispheres or telencephalon

- It is mostly symmetrical along the midline:
    - each subdivision is found in both hemispheres of the brain with slight bilateral differences



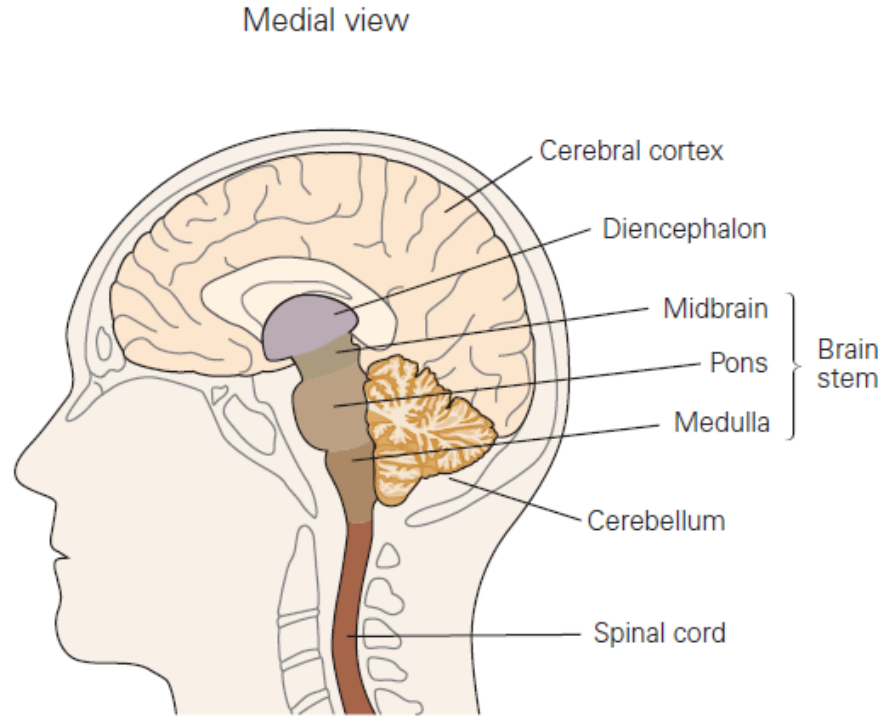



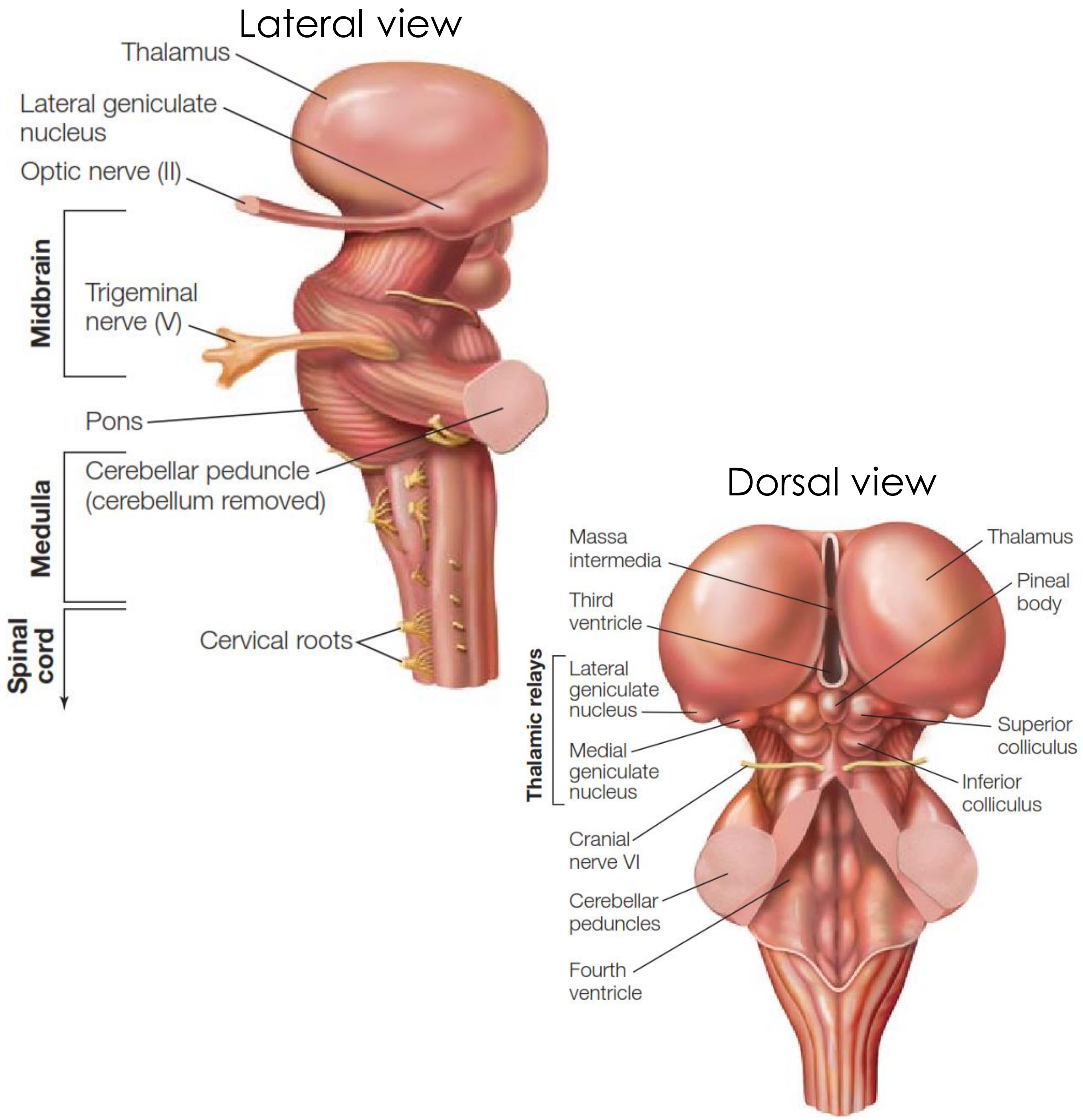

**Figure 15–3 The major divisions of the central nervous system.** Drawings show a lateral view of the left side of the brain and the medial surface of the right side of the brain. (Adapted, with permission, from Nieuwenhuys, Voogd, and van Huijzen 1988.)

# The brain stem

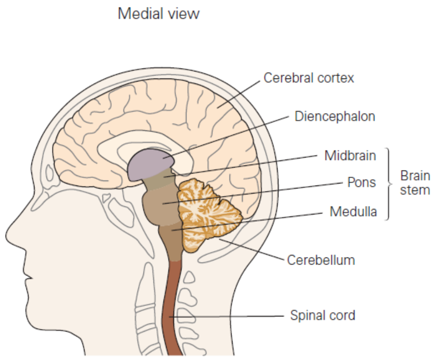
Regulates basic life functions:

- blood pressure
- Respiration
- Sleep/wakefulness

Damage to the brainstem is life threatening



# The cerebellum & pons are 1 functional unit (dalla elzione del pr




- Contains far more neurons than any other single subdivision of the brain, including the cerebral hemispheres
- Divided into several lobes
- Important for:
    - maintaining posture
    - coordinating head, eye, and arm movements
    - regulation of motor output
    - learning motor skills
- Considered a purely motor structure, new anatomical information about its interconnections with the cerebral cortex and functional imaging studies have shown that it is also involved in language and other cognitive functions

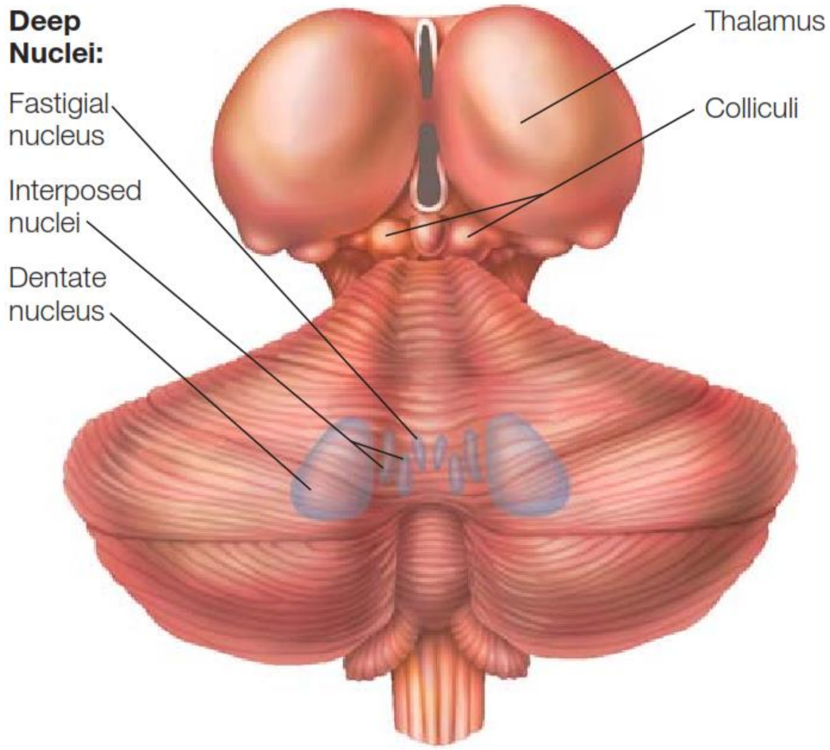



FIGURE 2.22 Gross anatomy of the cerebellum.

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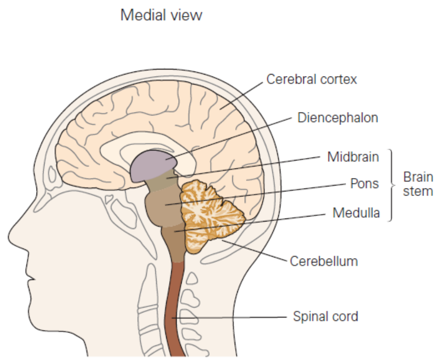
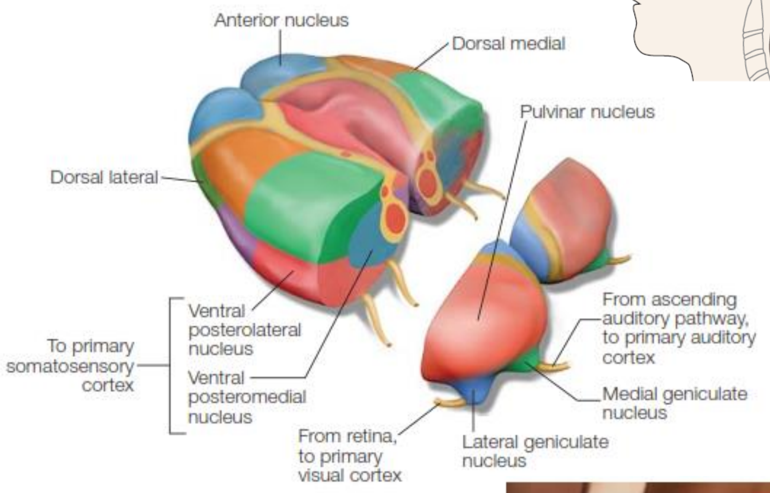
# The diencephalon: thalamus & hypothalamus

**Thalamus:** "gateway to the cortex"
- essential link in the pathway of sensory information from the periphery to sensory regions of the cerebral hemispheres
- determines which sensory information reaches the neocortex

**Hypothalamus:**
- ventral to the thalamus
- link between the nervous and the endocrine system
- Regulates body temperature, thirst and hunger, and the circadian rhythm
- essential component of the motivational systems of the brain, initiating and maintaining behaviors the organism finds aversive or rewarding



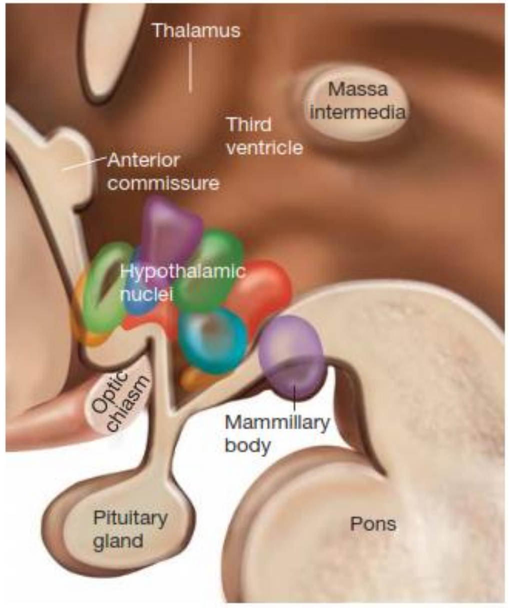
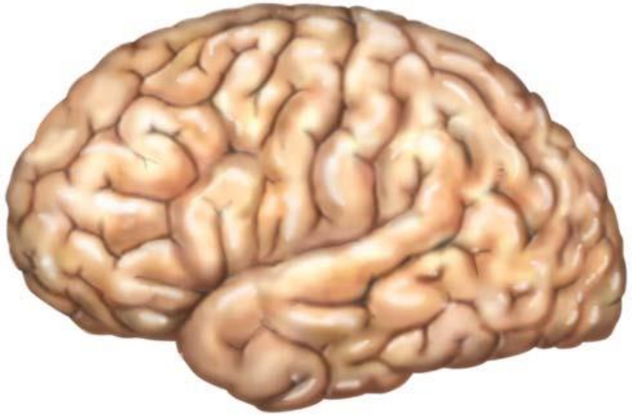




FIGURE 2.25 Midsagittal view of the hypothalamus.

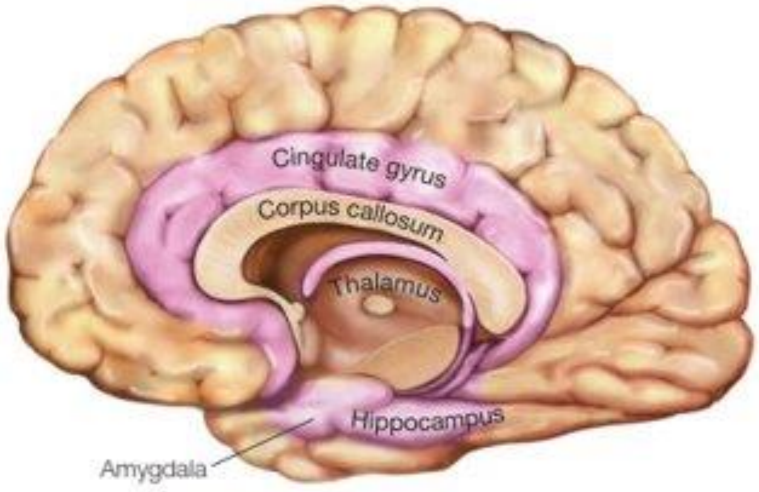
# The telencephalon or cerebral hemispheres



- The largest part of the human brain

Consists of:

- the cerebral cortex made of grey matter (i.e. neuronal cell bodies)
- the underlying white matter (i.e. axons and glial cells)
- three deep-lying structures that regulate cortical activity:
    - Basal ganglia
    - Amygdala
    - Hippocampal formation

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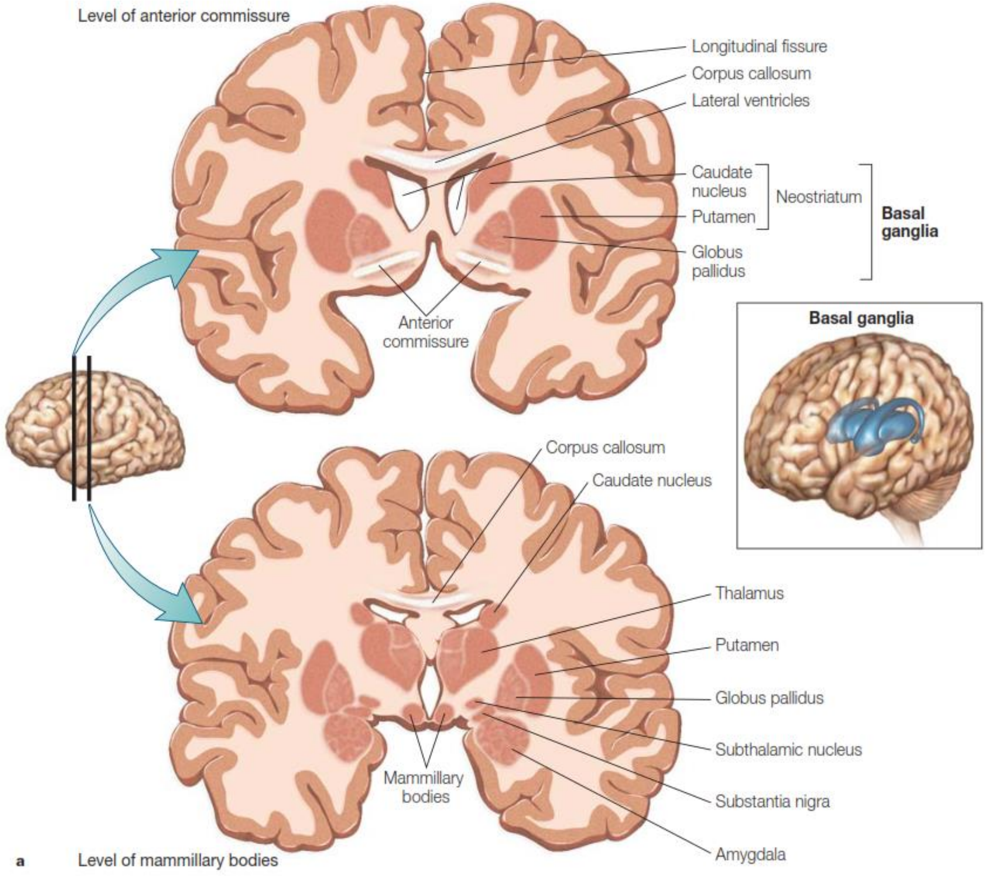
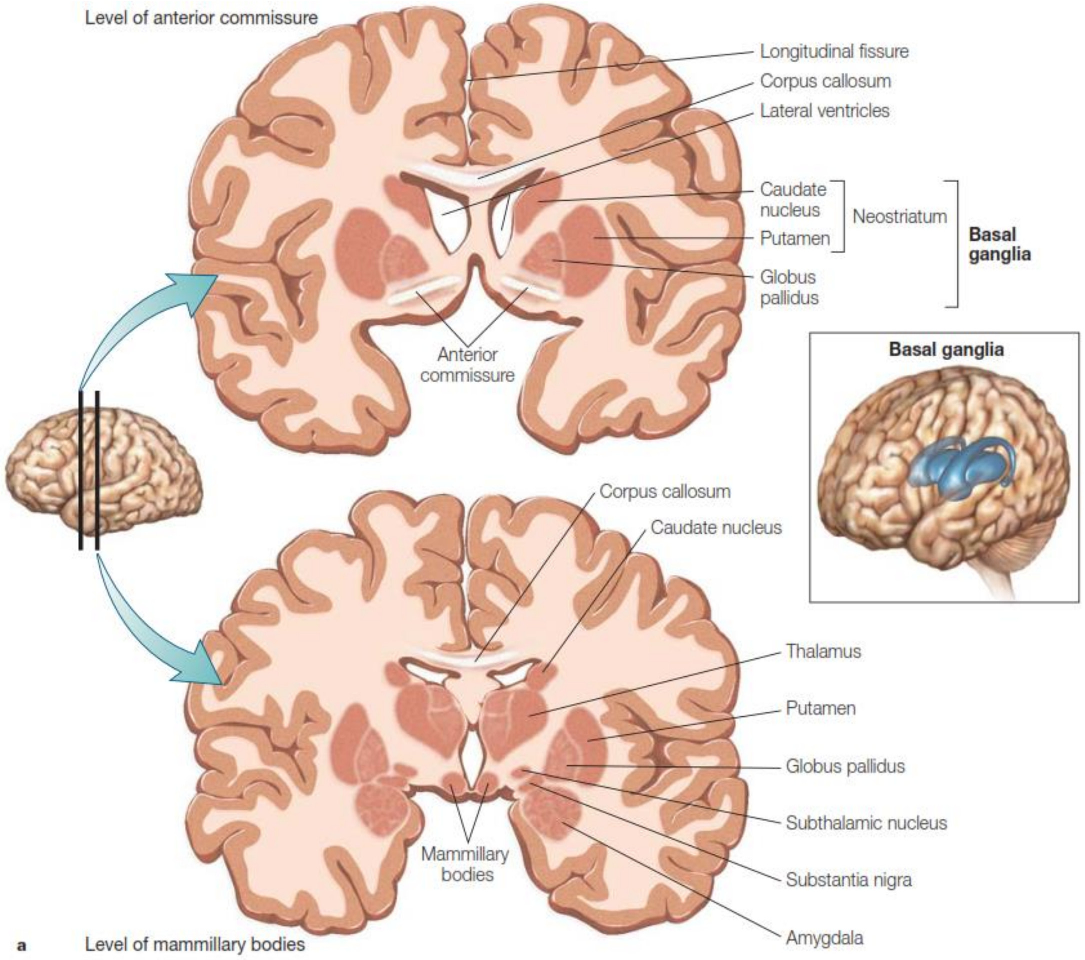


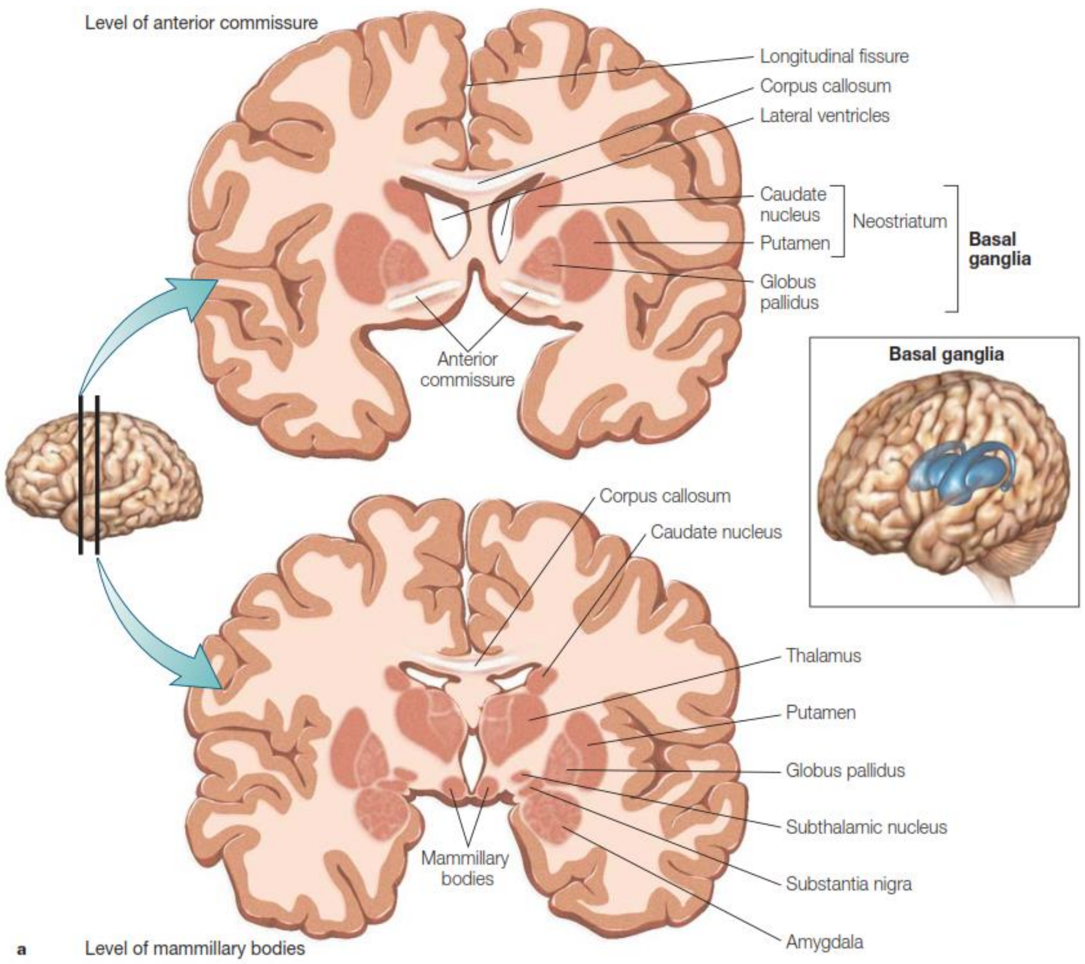
# Basal Ganglia

- Collection of subcortical nuclei
- Receive inputs from sensory and motor areas
- Send output largely through the thalamus to the frontal lobe
- Extensively interconnected



# Basal Ganglia have crucial role in motor control

- action selection
- action gating
- motor preparation
- Timing
- fatigue
- task switching



# Basal Ganglia have crucial role in motor control

Physiologically

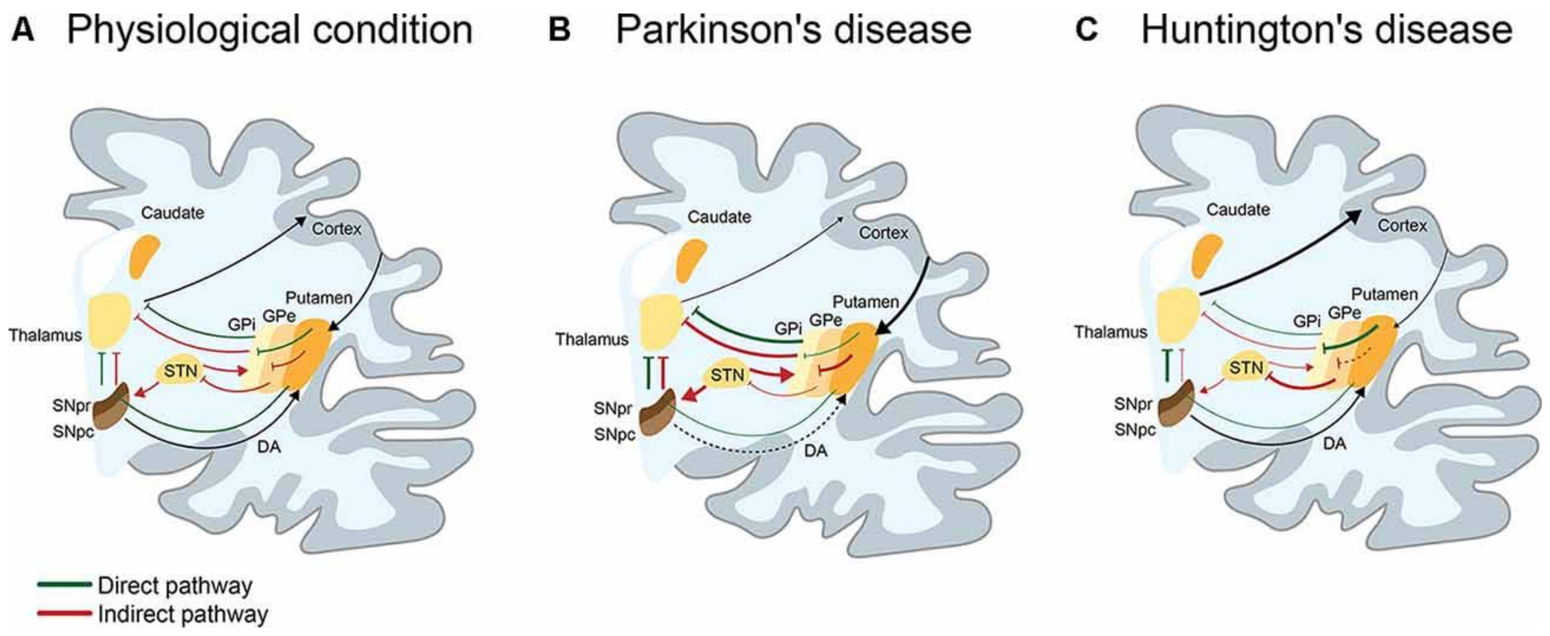
- the direct (green line) pathway participates in the activation of movement.
- the indirect pathway (red line) participates in the inhibition of movement.

**Parkinson's disease**

- the loss of dopaminergic neurons of the SNpc, induces an <u>overactivation of the indirect pathway</u> and decrease of movement (hypokinesia).

**Huntington's disease** (early stage)

- neurons of the <u>indirect</u> pathway appear to be <u>affected before</u> the neurons of the <u>direct</u> pathway.




Troncoso-Escudero, Paulina et al. "On the Right Track to Treat Movement Disorders: Promising Therapeutic Approaches for Parkinson's and Huntington's Disease." *Frontiers in aging neuroscience* vol. 12 571185. 3 Sep. 2020, doi:10.3389/fnagi.2020.571185

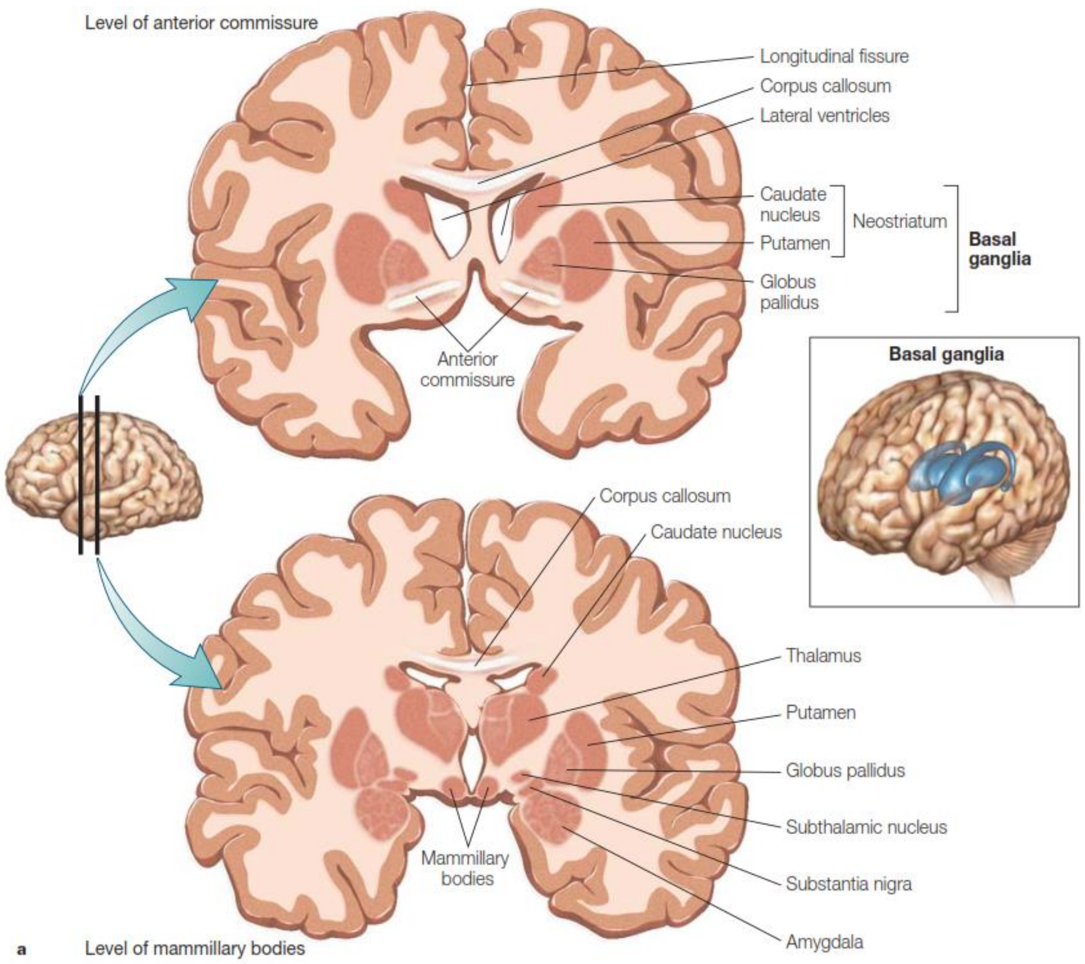
# Basal Ganglia have crucial role in reinforcement learning

Play a big role in reward-based learning and goal-oriented behavior

1. Combine an organism's sensory and motor context with reward information
2. Passes this integrated information to the motor and prefrontal cortex for a decision (Chakravarthy et al., 2009)

Have many **dopamine** receptors

- monitoring reinforcements and rewards
- Changes in dopamine represent the error between predicted future reward and actual reward (Shultz et al., 1997)

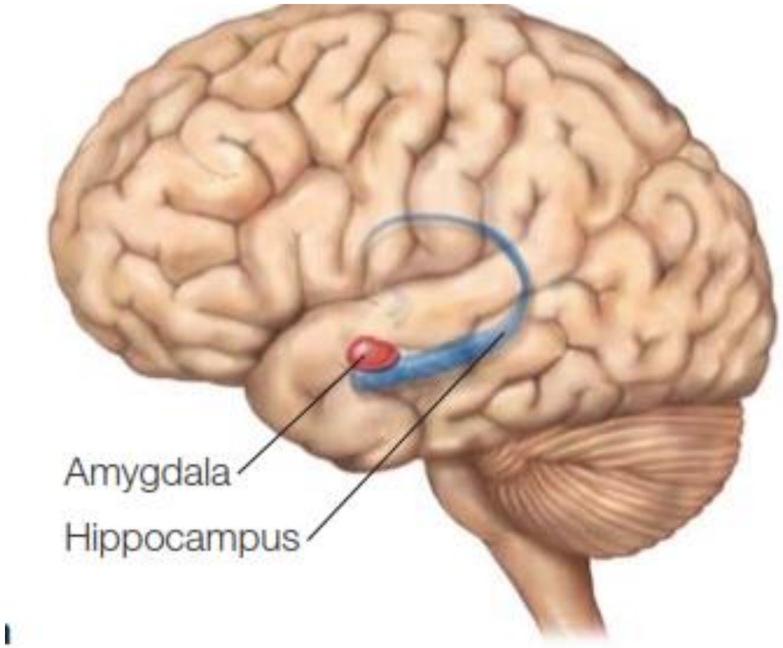


# The amygdala

- Small, almond shaped structures in the medial temporal lobe adjacent to the anterior portion of the hippocampus
- Collection of 13 nuclei
- Luiz Pessoa (2011) boils down the amygdala's job description by suggesting that it is involved in determining what a stimulus is and what is to be done about it

Involved in

- Attention
- Perception
- value representation
- decision making
- Learning
- memory

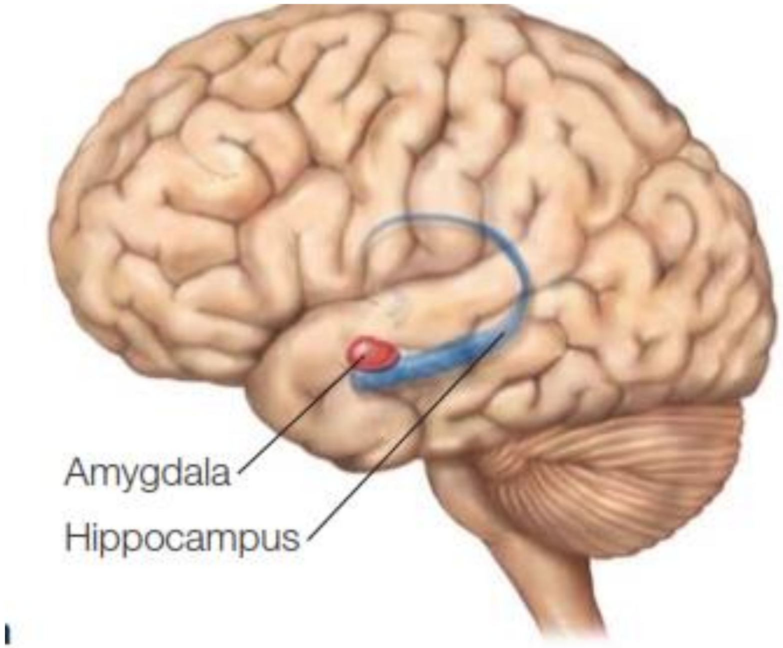


# The hippocampus

- Small, curved formation

Crucial for

- ____________________
- ____________________

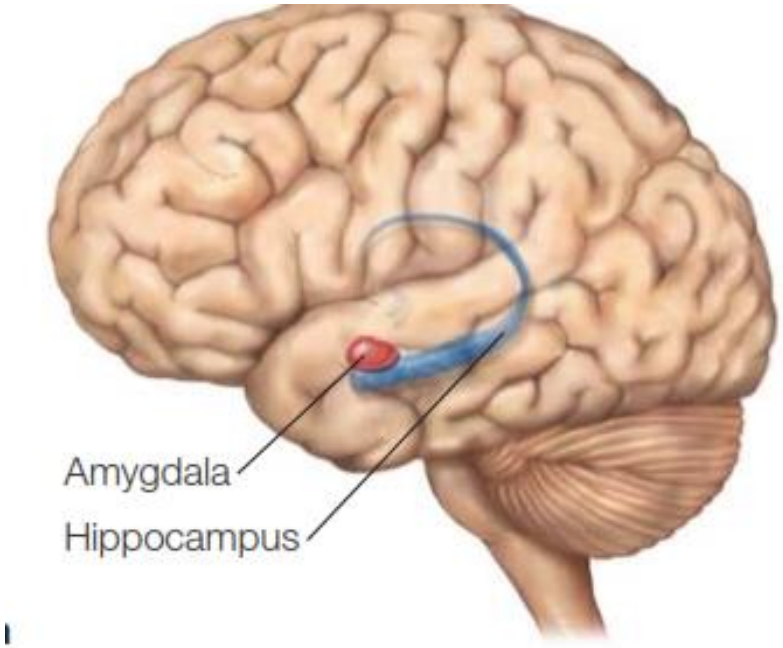


# The hippocampus

- Small, curved formation

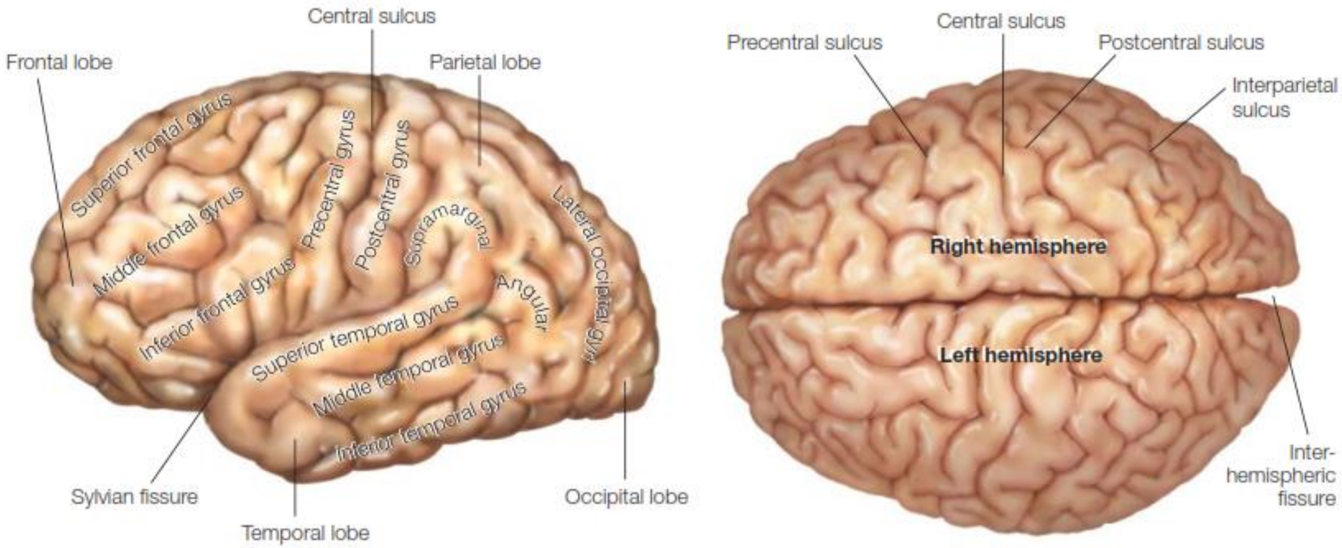
Crucial for

- Memory formation
- Spatial memory



# Cerebral Cortex

- Made up of large sheets of (mostly) layered neurons
- Two symmetrical hemispheres
- Connections between the cerebral hemispheres are via axons from cortical neurons that travel through the corpus callosum



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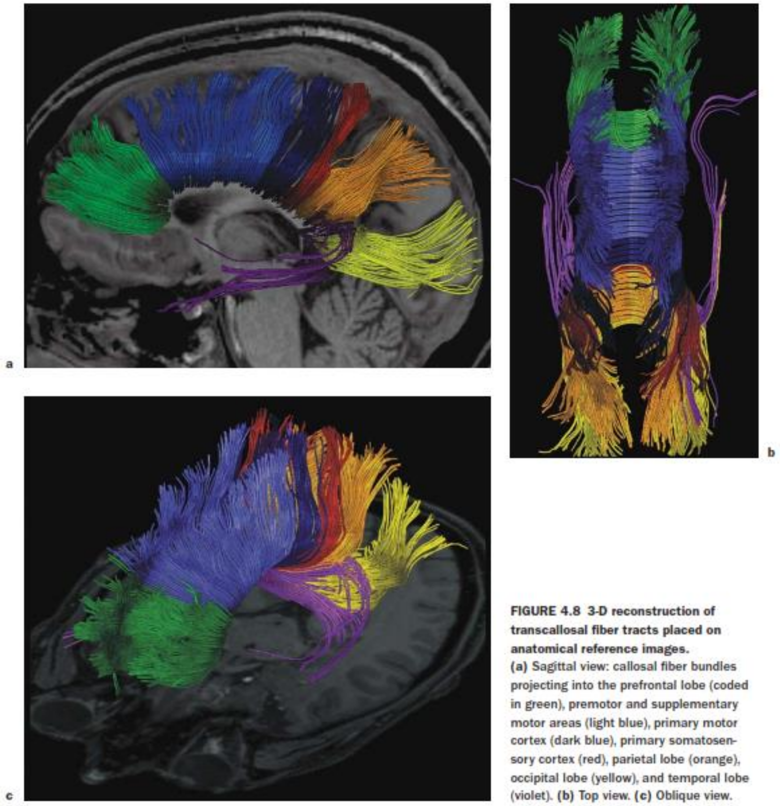
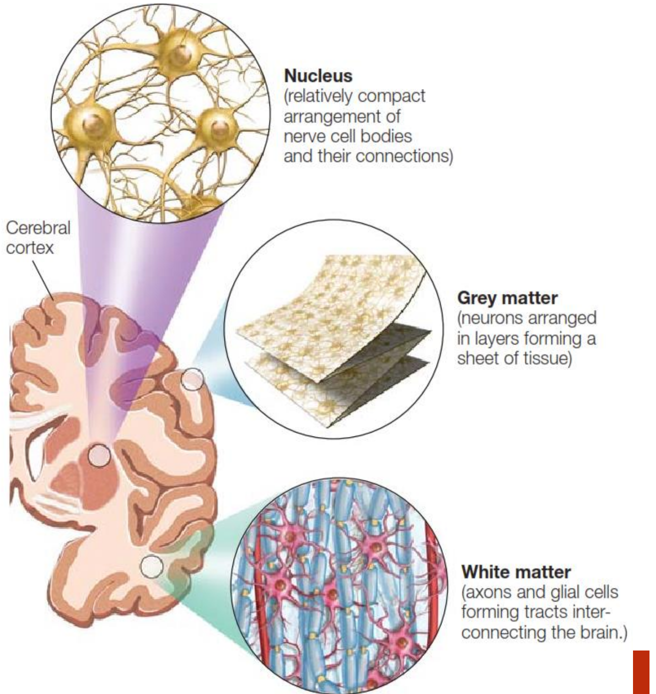
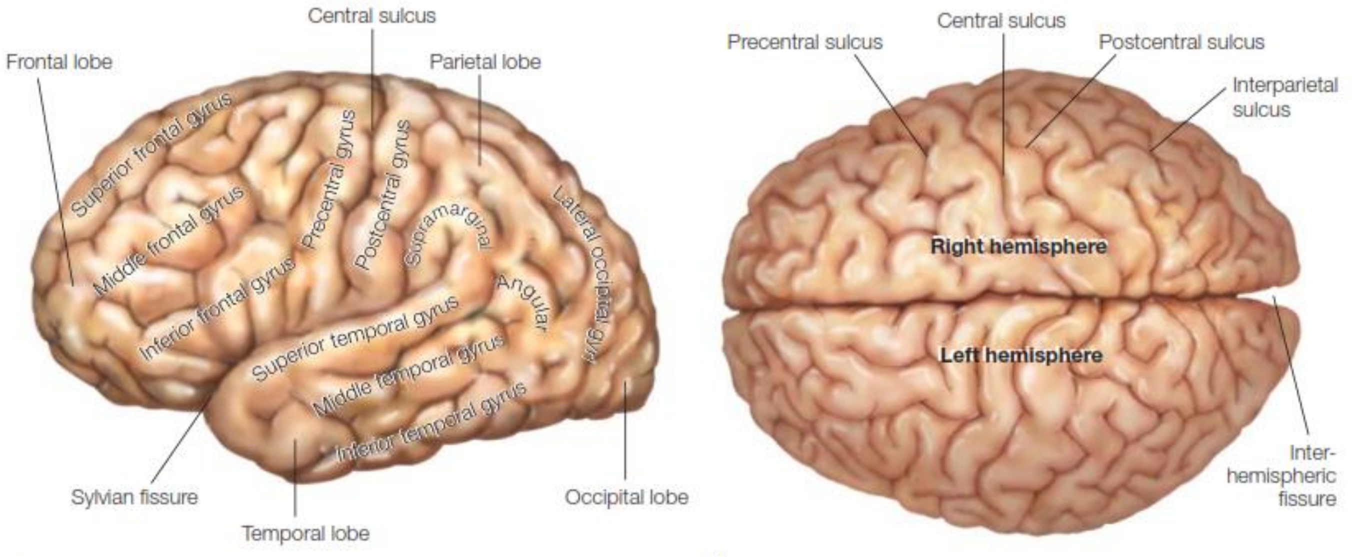



**FIGURE 4.8 3-D reconstruction of transcallosal fiber tracts placed on anatomical reference images.**
**(a)** Sagittal view: callosal fiber bundles projecting into the prefrontal lobe (coded in green), premotor and supplementary motor areas (light blue), primary motor cortex (dark blue), primary somatosensory cortex (red), parietal lobe (orange), occipital lobe (yellow), and temporal lobe (violet). **(b)** Top view. **(c)** Oblique view.



# Cerebral Cortex

- Contains many infoldings, or convolutions
    - Sulci: crevices
    - Gyri: crowns
- Total surface area of the human cerebral cortex is about 2.2 to 2.4$m^2$
- Highly folded cortex brings neurons into closer three-dimensional relationships to one another
- Reducing axonal distance and hence neuronal conduction time between different areas
- Possible because the axons that make long-distance corticocortical connections run under the cortex through the white matter and do not follow the foldings of the cortical surface

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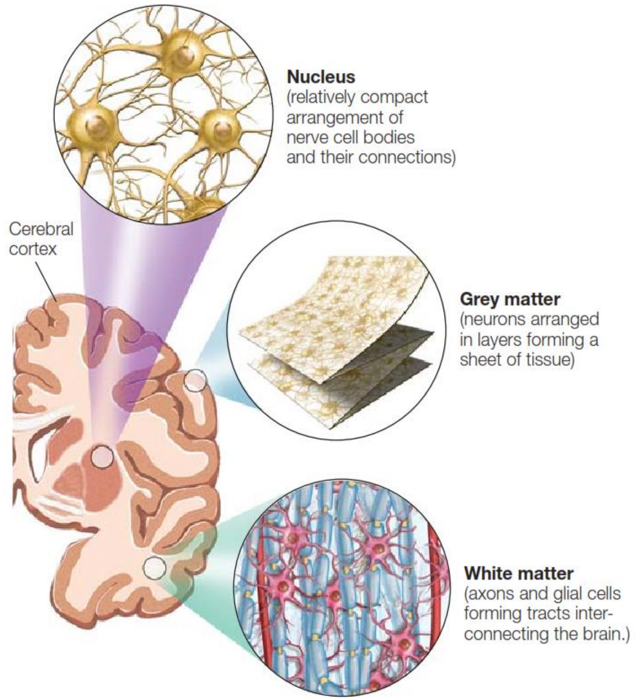
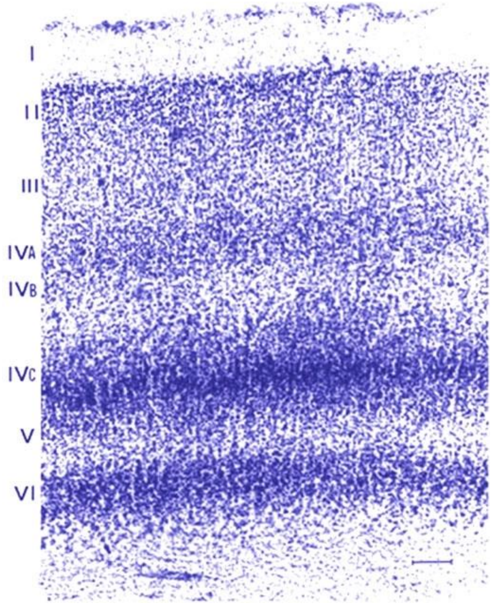


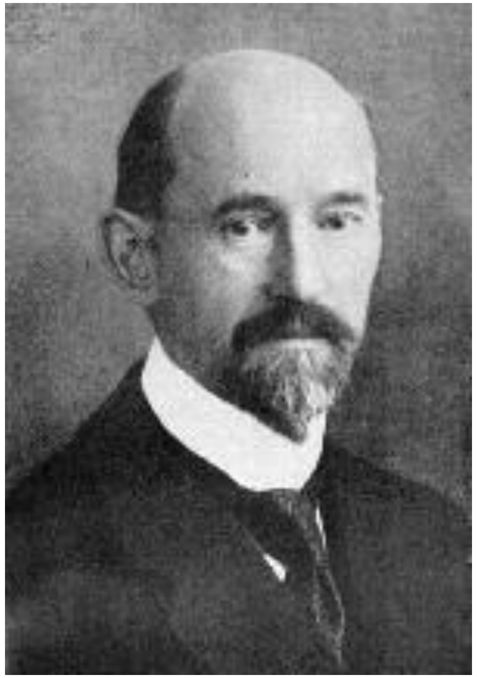
# Cerebral cortex: cytoarchitectonic division

Used tissue stains that permitted him to visualize the different cell types in different brain regions

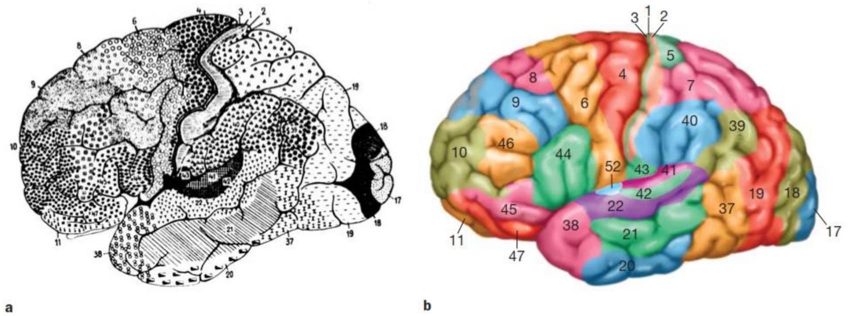
Characterized 52 distinct regions

**Cytoarchitectonics**: the study of cellular architecture or how cells differ between regions



Korbinian Brodmann



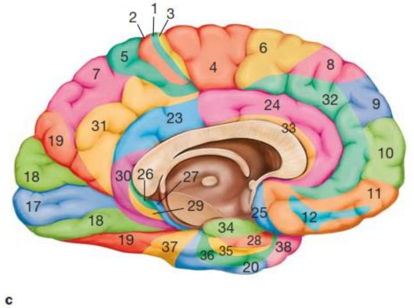




**FIGURE 2.31 Cytoarchitectonic subdivisions of the human cerebral cortex.**
**(a)** Brodmann's original cytoarchitectonic map from his work around the start of the 20th century. Different regions of cortex have been demarcated by histological examination of the cellular microanatomy. Brodmann divided the cortex into about 52 areas. **(b)** Lateral view of the right hemisphere showing Brodmann's areas color coded. Over the years, the map has been modified, and the standard version no longer includes some areas. **(c)** Medial view of the left hemisphere showing Brodmann's areas. Most of Brodmann's areas are symmetrical in the two hemispheres.

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# Cerebral cortex: cytoarchitectonic division

- Using different anatomical criteria, it is also possible to subdivide the cerebral cortex according to the general patterns of layering
- The neocortex (in red) includes areas like primary sensory and motor cortex and association cortex
- The neocortex contains six cortical layers, i.e. sheets of neurons neatly stacked on top of each other.
- The neurons of each layer are similar within a layer, but different between layers
- Deeper layers mature earlier than more superficial ones. The latter are thought to be involved in higher cognitive functions

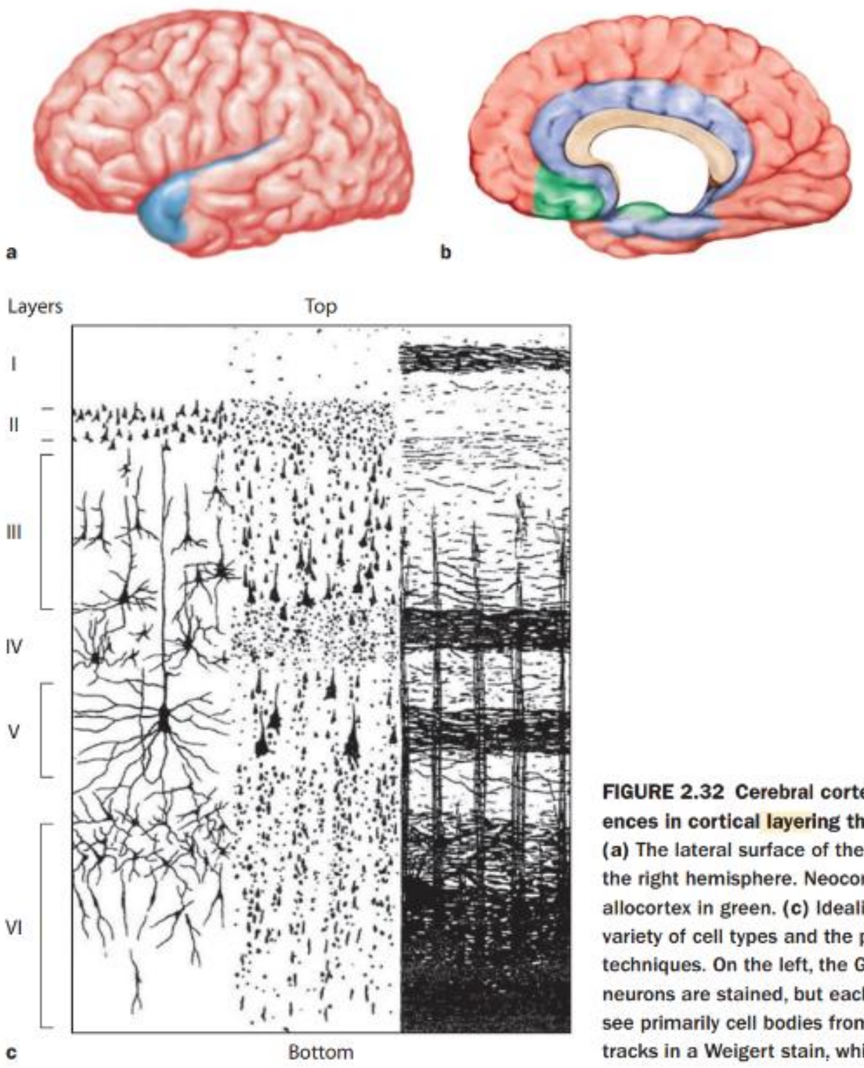
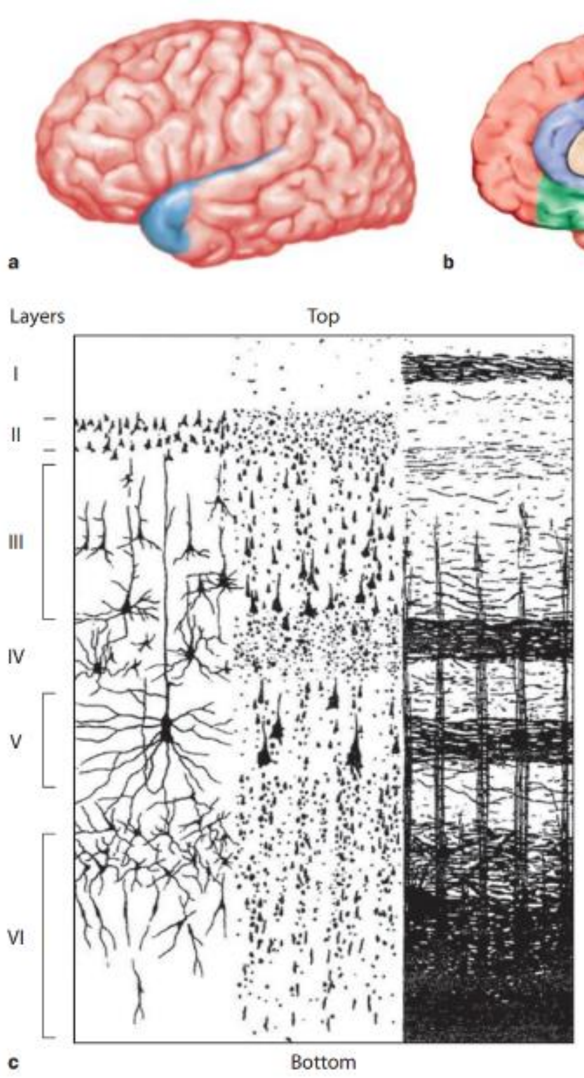



**FIGURE 2.32 Cerebral cortex, color-coded to show the regional differences in cortical layering that specify different types of cortex.** **(a)** The lateral surface of the left hemisphere. **(b)** The medial surface of the right hemisphere. Neocortex is shown in red, mesocortex in blue, and allocortex in green. **(c)** Idealized cross section of neocortex showing a variety of cell types and the patterns of three different types of staining techniques. On the left, the Golgi preparation is apparent: Only a few neurons are stained, but each is completely visualized. In the middle, we see primarily cell bodies from the Nissl stain. On the right, we see the fiber tracks in a Weigert stain, which selectively stains myelin.

# Cerebral cortex: cytoarchitectonic division

- The neurons in any one sheet, while interwoven with the other neurons in the same layer, are also lined up with the neurons in the sheets above and below it, forming columns of neurons running perpendicular to the sheets
- The neurons within a column synapse with those from the layers above and below them, forming an elemental circuit, and appear to function as a unit.

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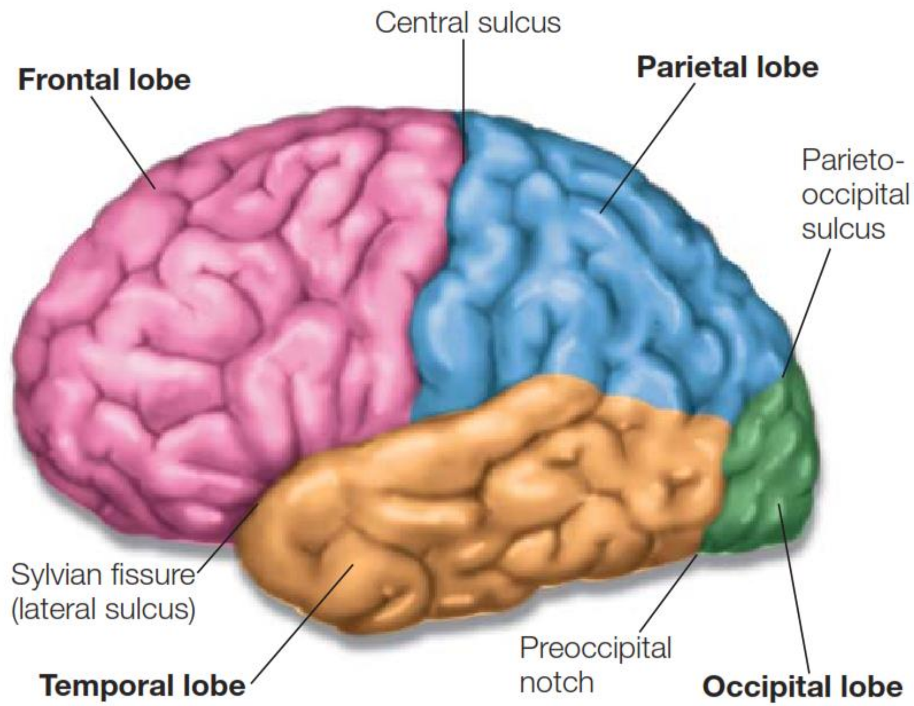
# Cerebral cortex: anatomical division

- Divided in 4 lobes distinguished from one another by pronounced sulci
- The lobes of the cerebral cortex have a variety of functional roles in neural processing
- Cognitive brain systems are often composed of networks whose component parts are located in different lobes of the cortex
- Each functional system is hierarchically organized:
    - areas of the cerebral cortex are designated as primary, secondary, or tertiary areas, depending on their functional sequence within the pathway



# **Cerebral cortex: functional division –** Frontal Lobe

- Motor cortex
  - planning and execution of movements
  - M1: contains neurons that directly activate somatic motor neurons in the spinal cord

- Prefrontal cortex
  - Long-term planning & organizing
  - executive functions
  - decision making
  - Motivation and value

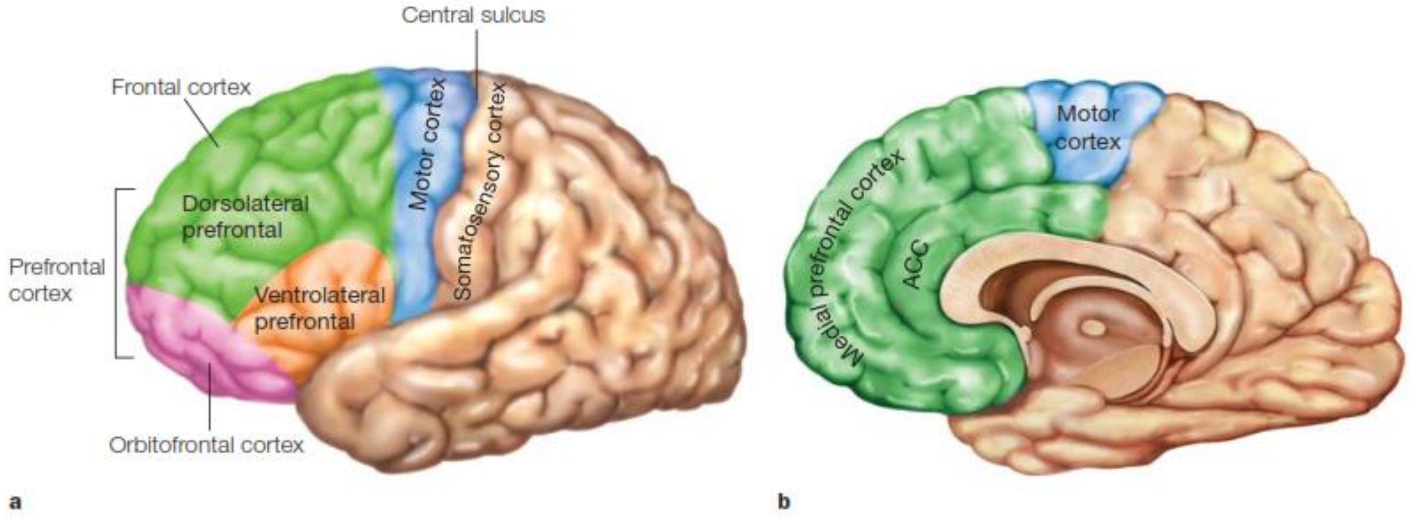


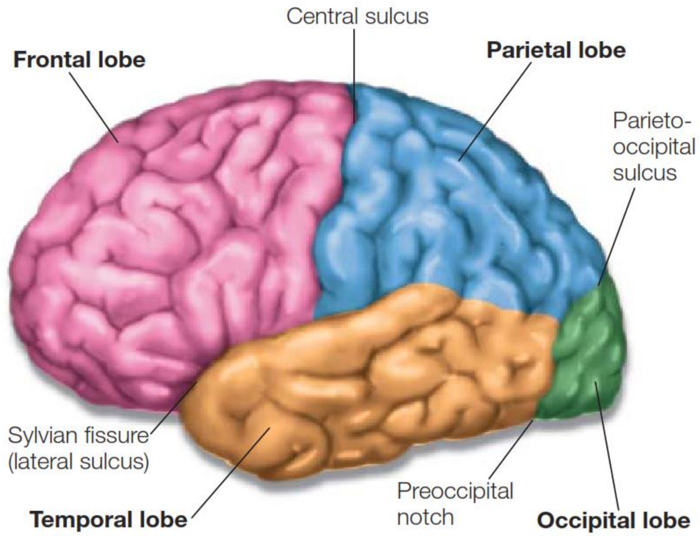

**FIGURE 2.33 The human frontal cortex.**
(a) Divisions of the frontal cortex. The frontal lobe contains both motor and higher order association areas. For example, the prefrontal cortex is involved in executive functions, memory, decision making, and other processes. (b) Midsagital section of the brain showing the medial prefrontal regions, which include the anterior cingulate cortex (ACC). Also visible is the supplementary motor area.

# **Cerebral cortex: functional division –** Parietal Lobe

Receives sensory information from:

- ______________
- ______________
- ______________

and integrates it



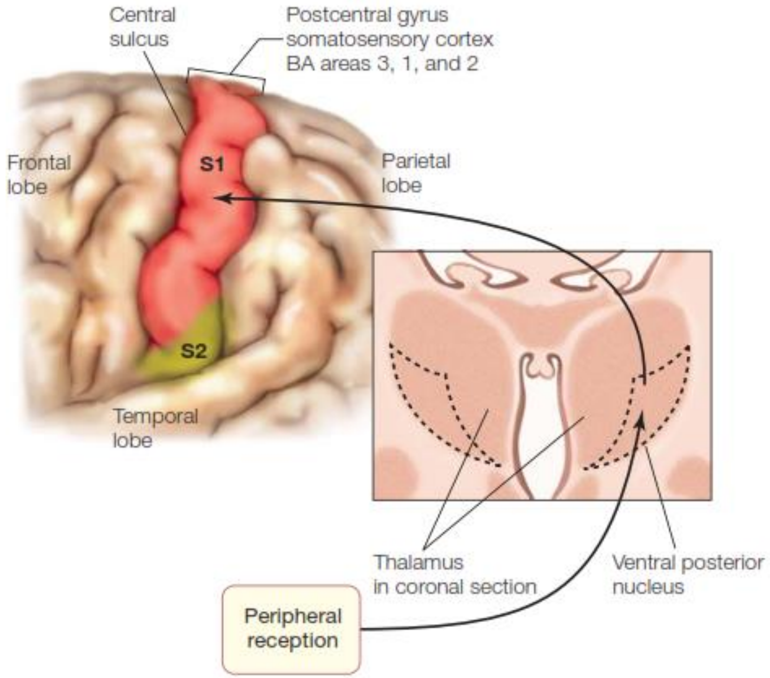



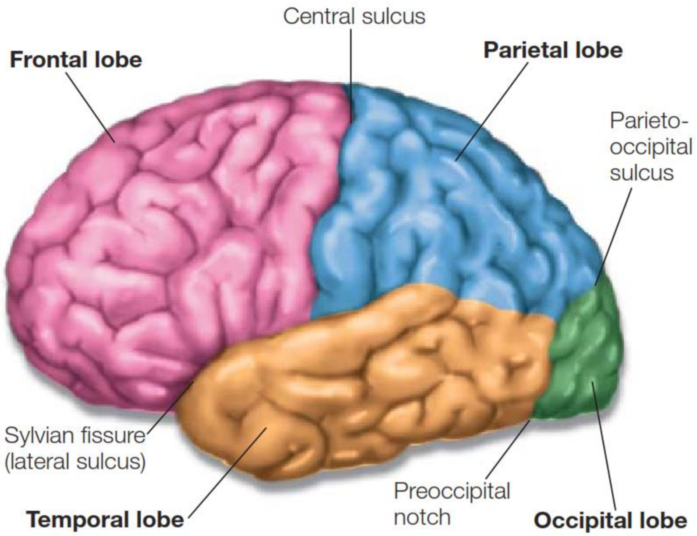

**FIGURE 2.34 The somatosensory cortex, which is located in the postcentral gyrus.**
Inputs from peripheral receptors project via the thalamus (shown in cross section) to the primary somatosensory cortex (S1). Secondary somatosensory cortex (S2) is also shown.

# Cerebral cortex: functional division – Parietal Lobe

Receives sensory information from:

- the outside world
- within the body
- memory

and integrates it




Includes the somatosensory cortex:

- S1: information about touch, pain, temperature sense, and limb proprioception (limb position) is received via receptor cells on the skin and converted to neuronal impulses that are conducted to the spinal cord and then to the somatosensory relays of the thalamus
- Higher-order sensory area: sends its outputs to multimodal association areas that integrate information from two or more sensory modalities

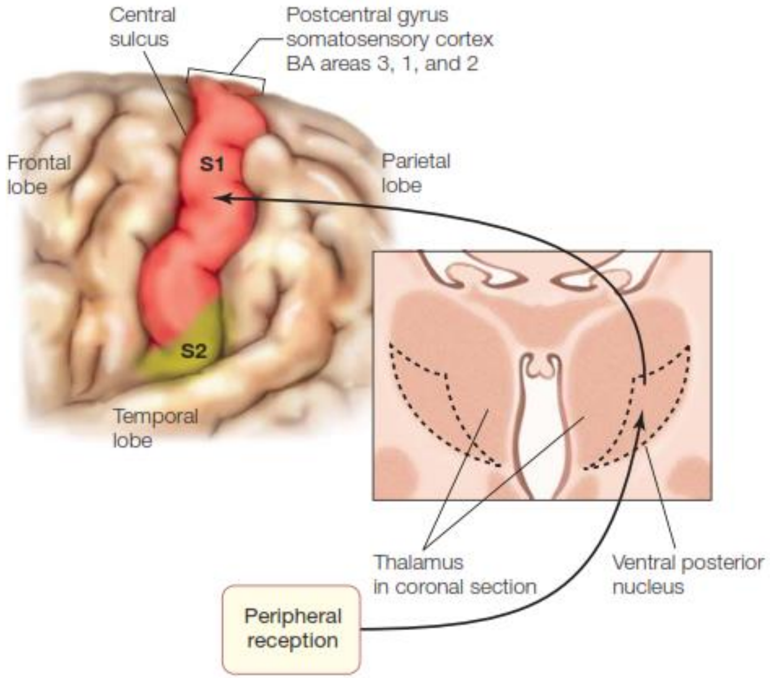
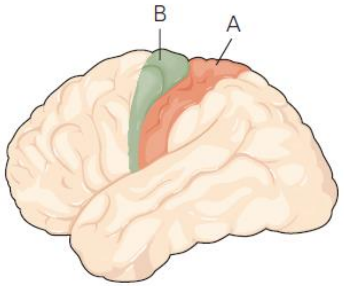
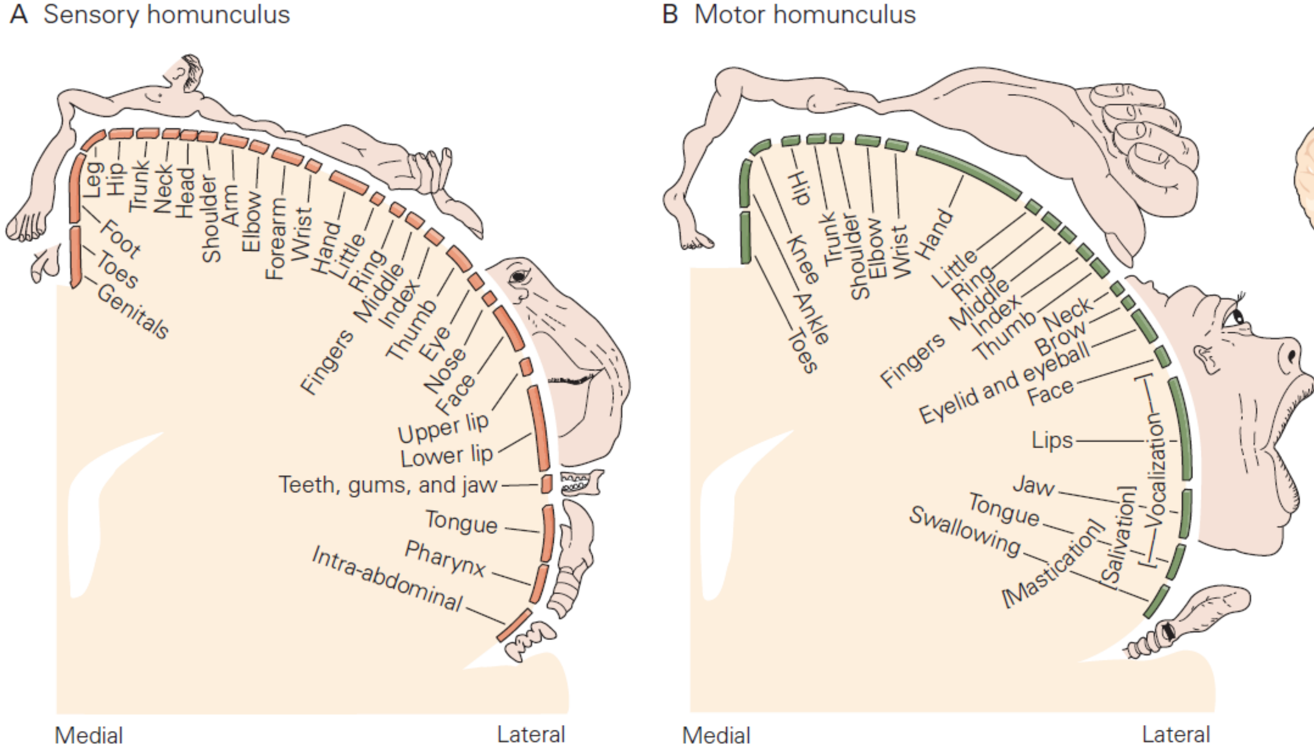



**FIGURE 2.34 The somatosensory cortex, which is located in the postcentral gyrus.**
Inputs from peripheral receptors project via the thalamus (shown in cross section) to the primary somatosensory cortex (S1). Secondary somatosensory cortex (S2) is also shown.

# Neurons are organized into a neural map of the body

- Topographic correspondence between cortical regions and body surface with respect to somatosensory and motor processes
- The neurons that regulate particular body parts are clustered together
- Somatotopy: mapping of specific parts of the body to areas of the  cortex
- Homunculus: map of the body surface on the cortex
- there is an indirect relation between the actual size of body parts and the cortical representation of the body’s parts
- The extent of the representation of a body part reflects the density of innervation of that part



# Cerebral cortex: functional division – Occipital Lobe

- Visual cortex
  - ______________________
- Primary visual cortex: begins the cortical coding of visual features like
  - Luminance
  - spatial frequency
  - Orientation
  - motion
- retinotopic maps:
  - the receptive fields of visual cells form an orderly mapping between spatial location and the neural representation of that dimension

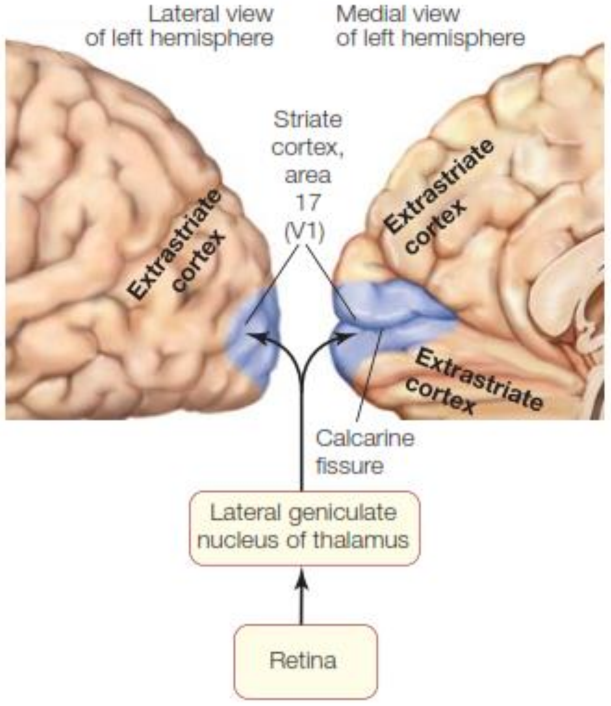
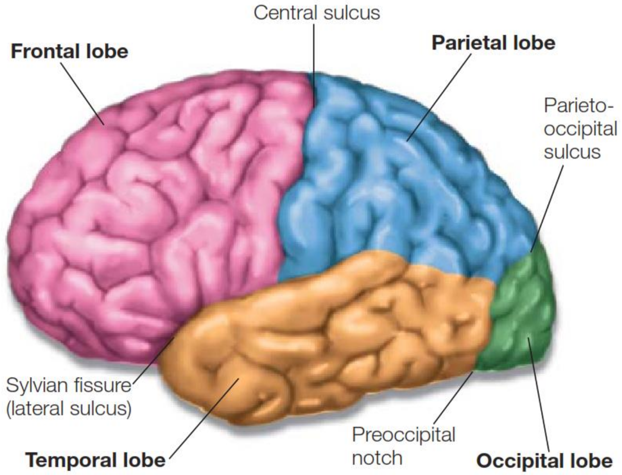



**FIGURE 2.35 The visual cortex, which is located in the occipital lobe.**
Brodmann area 17, also called the *primary visual cortex*, visual area 1 (V1), and striate cortex, is located at the occipital pole and extends onto the medial surface of the hemisphere, where it is largely buried within the calcarine fissure.



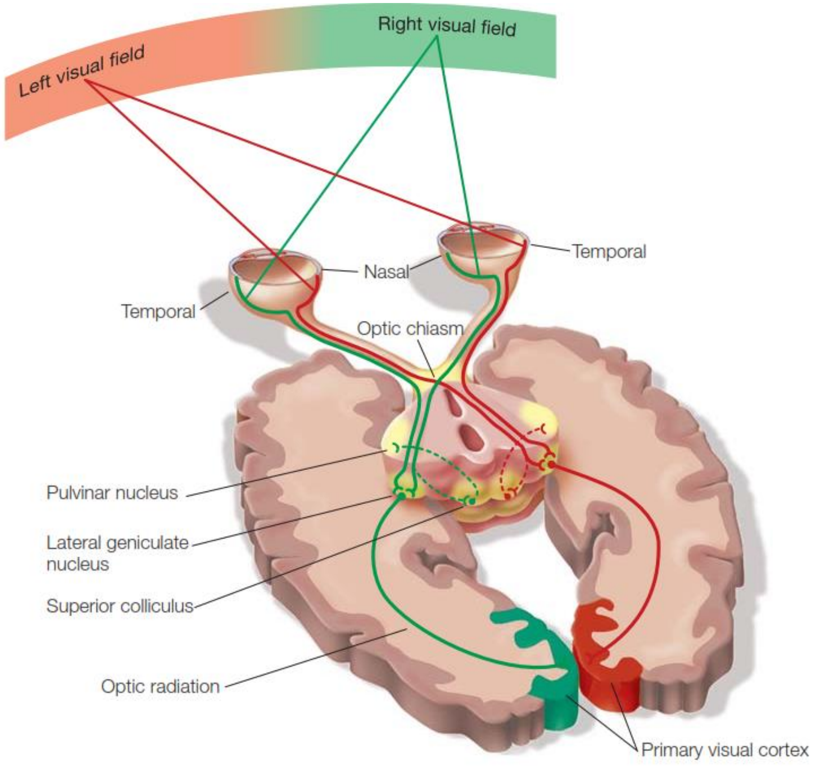
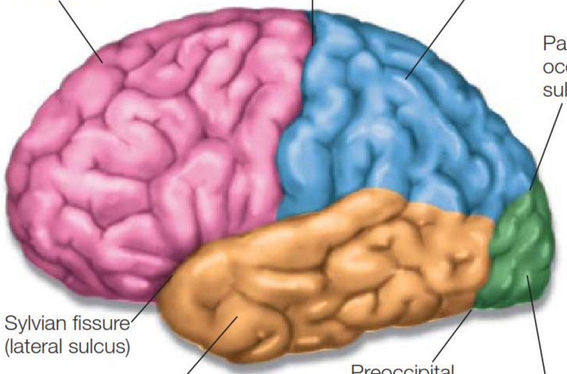




**FIGURE 5.23 The primary projection pathways of the visual system.**

# **Cerebral cortex: functional division –** Temporal Lobe




Includes the auditory cortex:

- ____________________

# Cerebral cortex: functional division – Temporal Lobe

Includes the auditory cortex:
  - Sound processing
- from the cochlea in the ear proceeds through the subcortical relays to the thalamus to reach primary auditory cortex
- Tonotopic organization:
  - layout of the neurons based on sound frequency

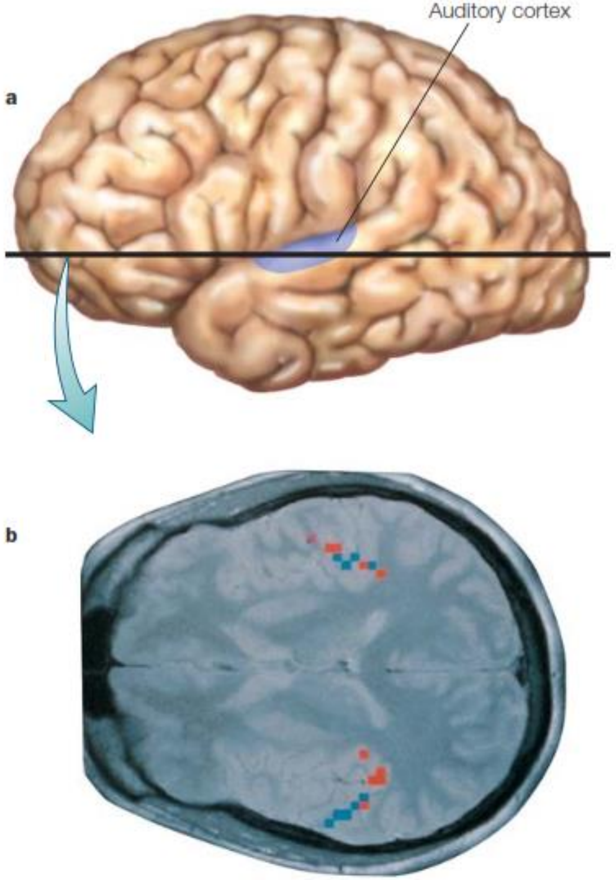
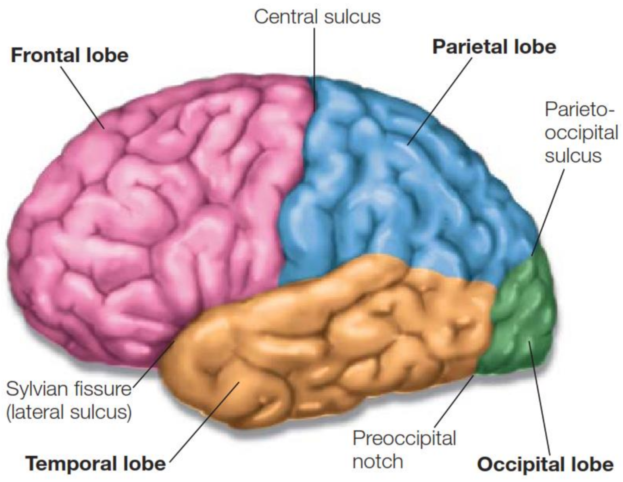



**FIGURE 2.36 The human auditory cortex.**
**(a)** Primary auditory cortex, which is located in the superior temporal lobe. The primary auditory cortex and surrounding association auditory areas contain representations of auditory stimuli and show a tonotopic organization. **(b)** This MRI shows areas of the superior temporal region in horizontal section that have been stimulated by tones of different frequencies (shown in red vs. blue) and show increased blood flow as a result of neuronal activity.



# Cerebral cortex: functional division – Association cortex

- Portion of the neocortex that is neither sensory nor motor
- contain cells that may be activated by more than one sensory modality
- receives and integrates inputs from many cortical areas to produce <u>integrated experience</u> of the world
- responsible for all our high-end human abilities, such as language, abstract thinking
- Each sense has a sensory association area:
    - visual association cortex: e.g. from individual features to a face
    - Auditory association cortex: e.g. ____________________

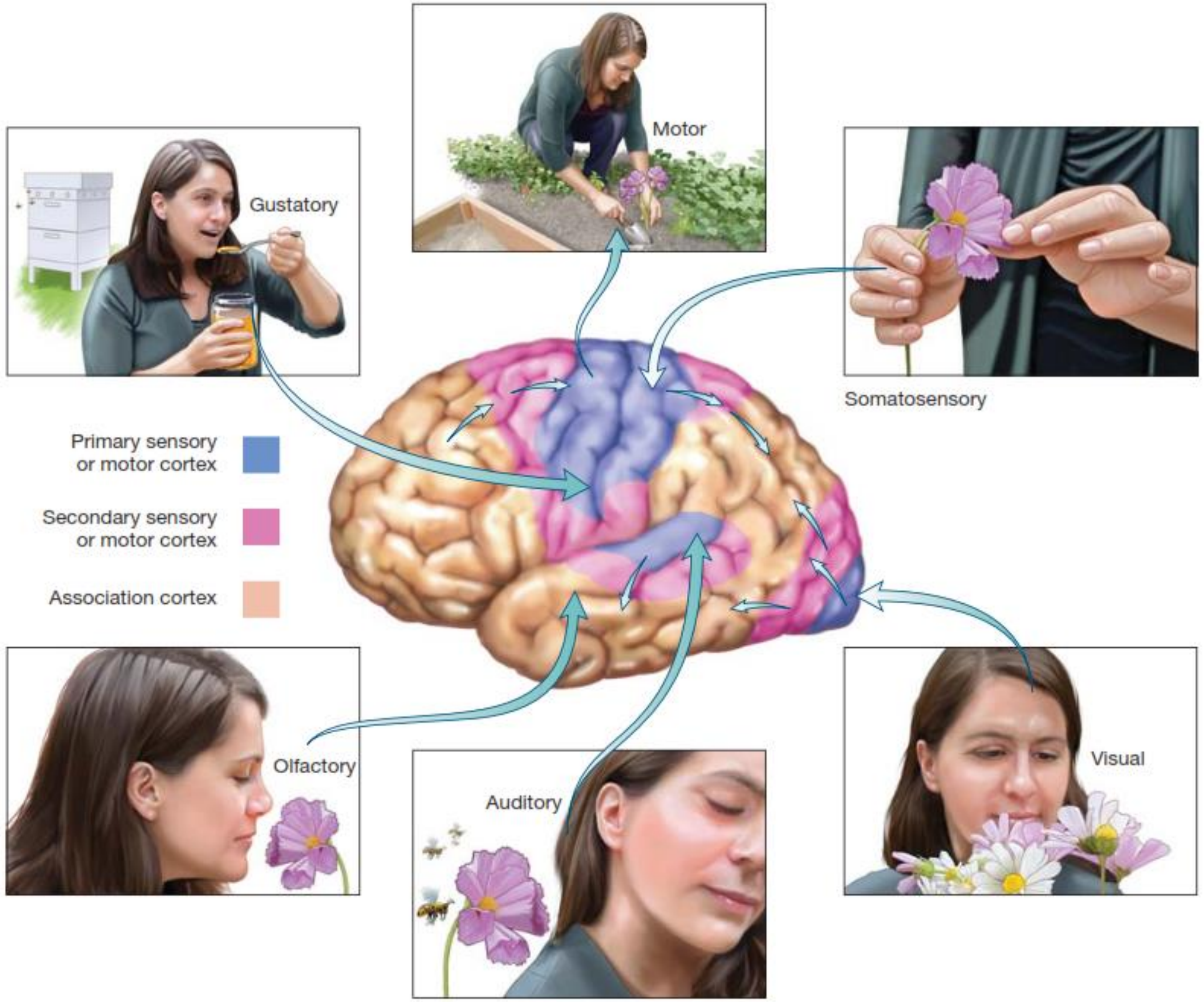



**FIGURE 2.37 Primary sensory and motor cortex and surrounding association cortex.** The blue regions show the primary cortical receiving areas of the ascending sensory pathways and the primary output region to the spinal cord. The secondary sensory and motor areas are colored pink. The remainder is considered association cortex.


https://youtu.be/q8NtmDrb_qo

# Recommended readings

- Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2014). Cognitive Neuroscience, The biology of the mind.
  - Chapter 2

- Kandel, E. R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S., Hudspeth, A. J., & Mack, S. (Eds.). (2000). Principles of neural science. New York: McGraw-hill.
  - Chapter 2, 4, 6, 7, 8, 15