The nervous system: anatomy and physiology

Part I: individuals cells

Cognition and Neuroscience

Academic year 2024/2025

Francesca Starita

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From individual cells to circuits to systems

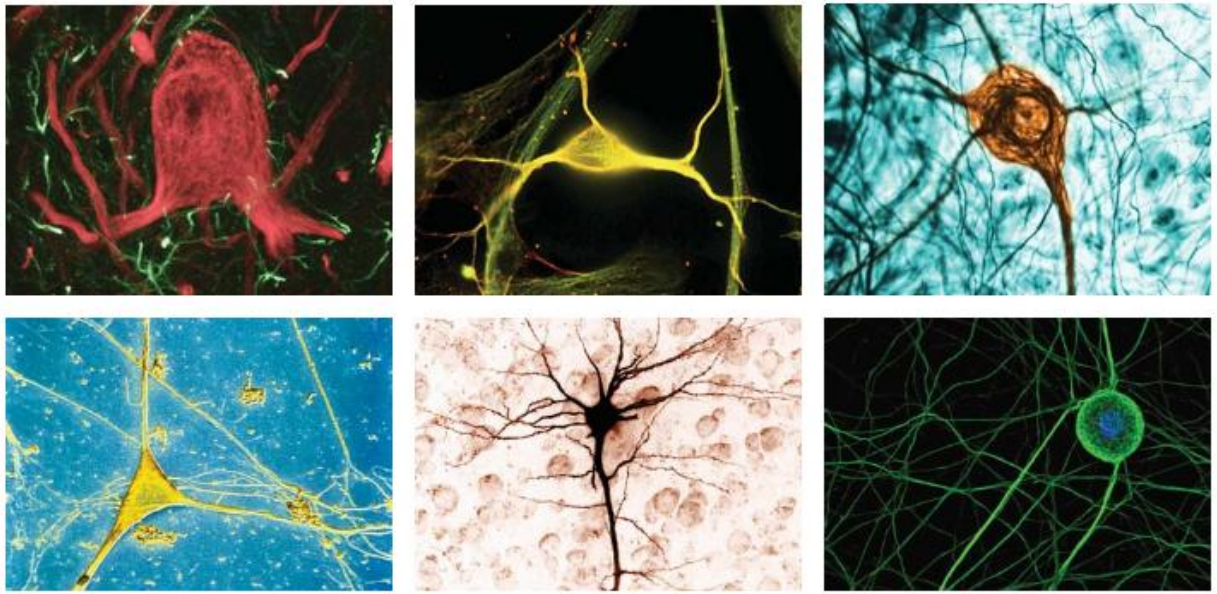
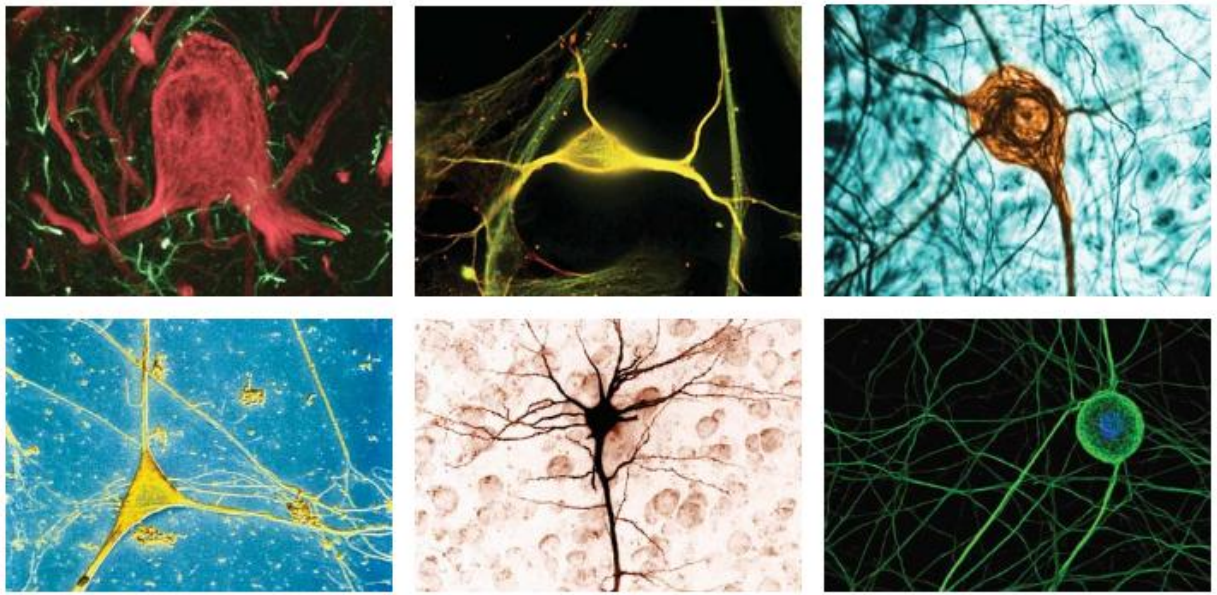


FIGURE 2.2 Mammalian neurons show enormous anatomical variety.

From individual cells to circuits to systems



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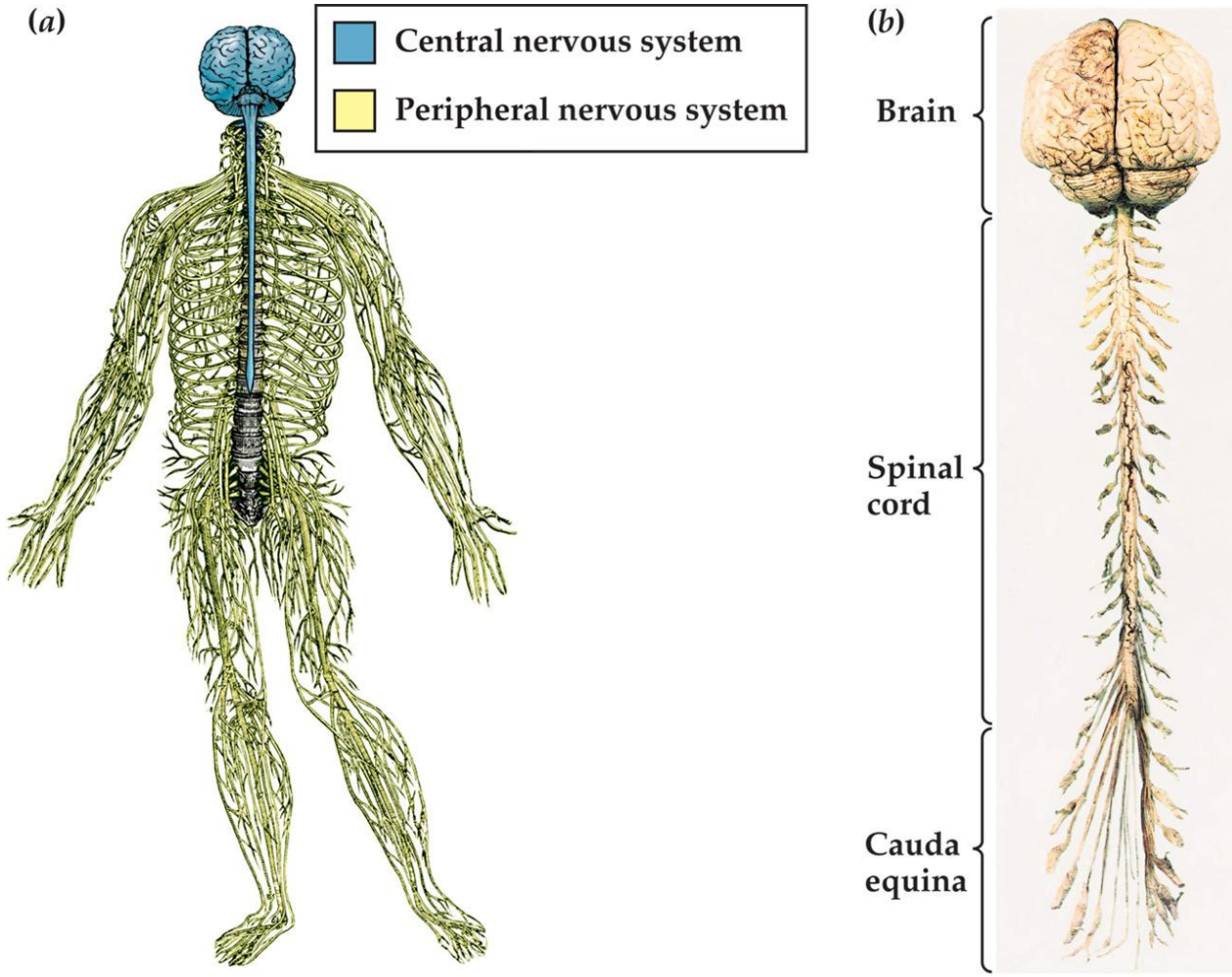

THE MIND'S MACHINE, Figure 2.6

Learning objectives

- Explain the roles of neurons and of the different types of glial cells.
    - Describe the structure and function of the different types of glial cells
    - Describe the structure of a neurons and the function of its three components
    - Discuss how neurons receive, evaluate, and transmit information
    - Describe the four regions of a neuron that generate signals

Learning objectives

- Describe how information is transferred within a single neuron.
    - Explain how the resting membrane potential is established and maintained.
    - Define postsynaptic potentials (PSPs) and explain how they contribute to the generation of action potentials.
    - Describe how spatial and temporal summation contribute to the generation of an action potential.
    - Explain the properties of action potentials and how they enable efficient neuronal signaling.
    - Describe the process of saltatory conduction and its role in the rapid propagation of action potentials.
    - Explain how the firing rate of action potentials encodes information about the strength of a stimulus.
    - Explain the role of myelin in the nervous system and the consequences of myelin damage.

Individual cells

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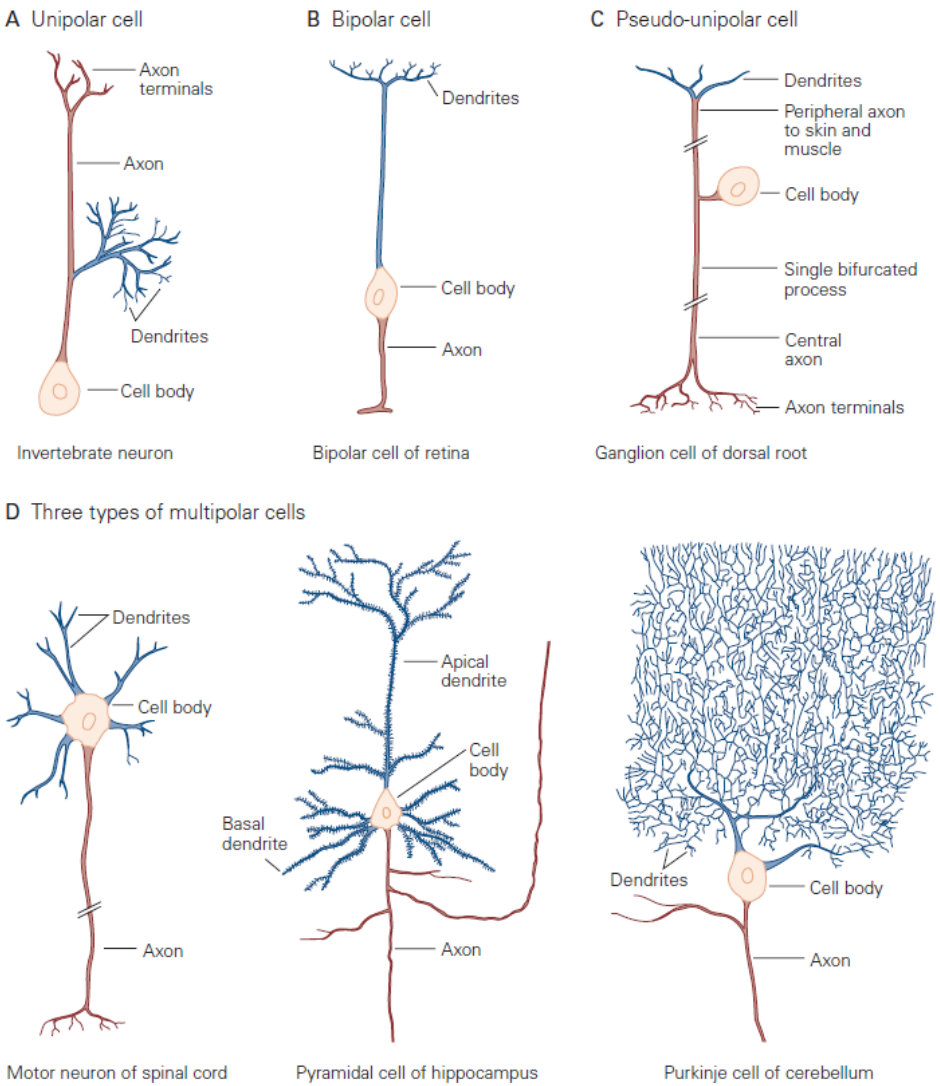
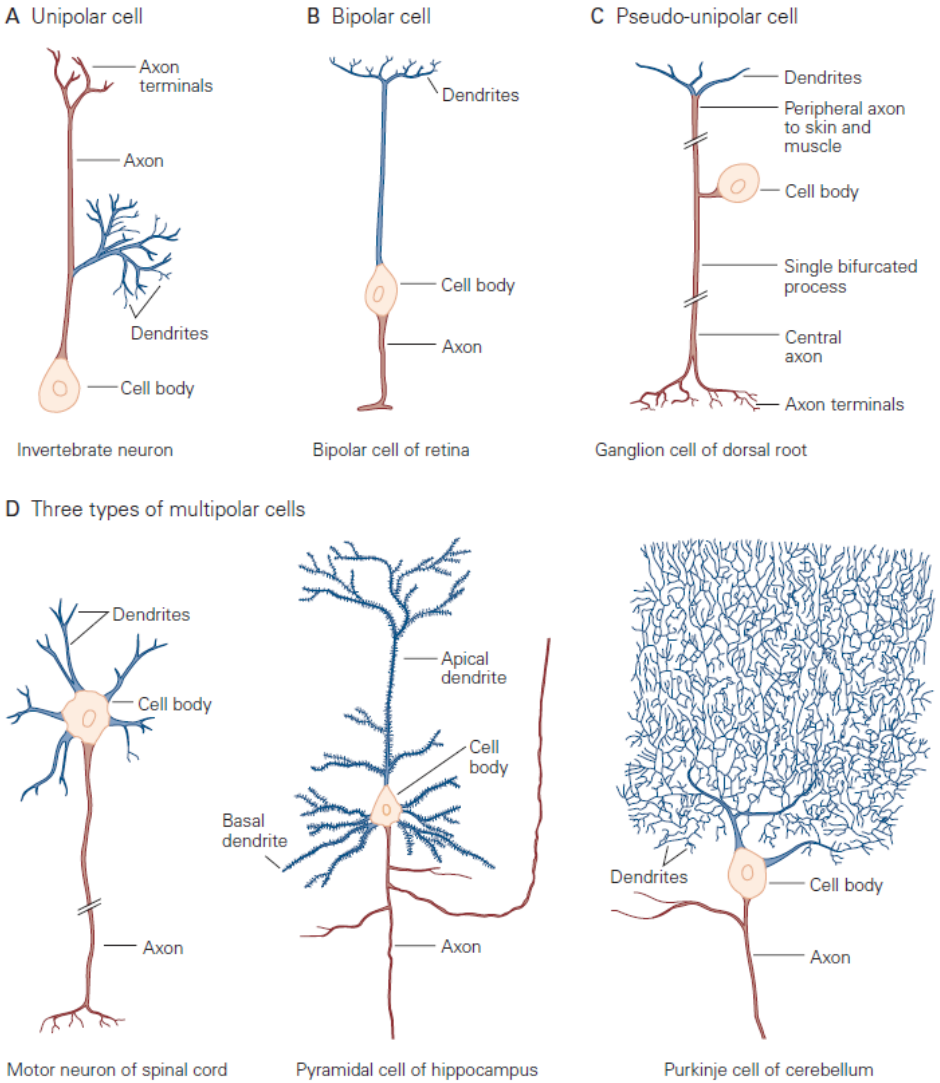
Nerve cells, or neurons



The Nervous System Has Two Classes of Cells

Nerve cells, or neurons



Glial cells, or neuroglia

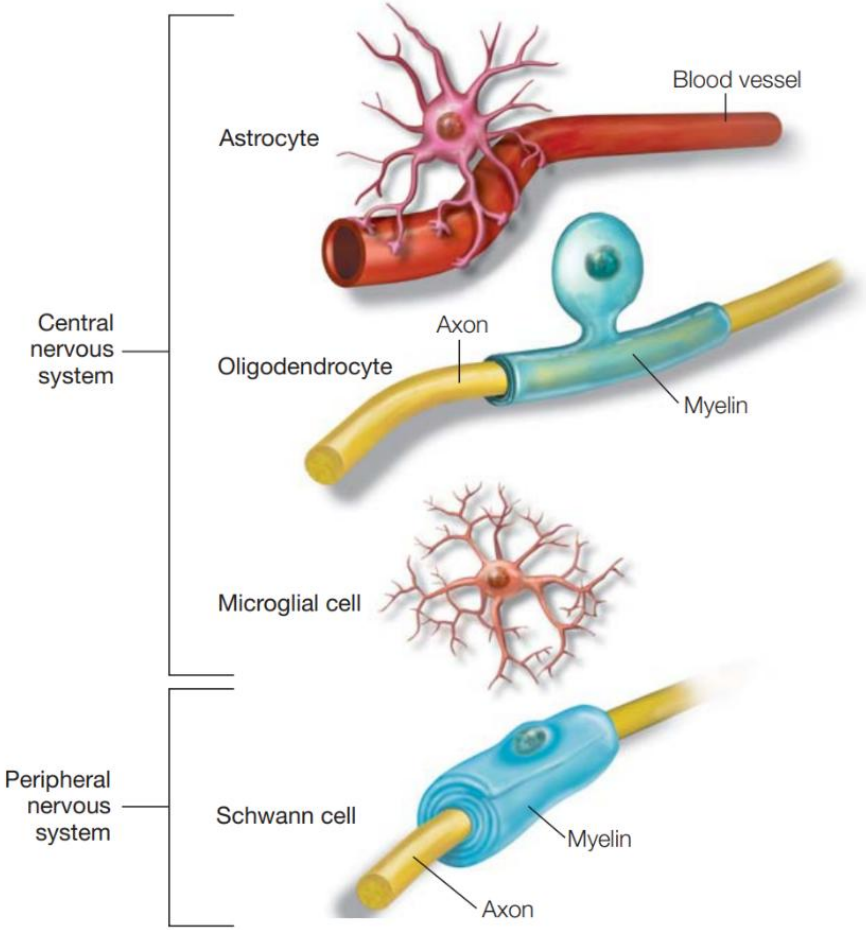


FIGURE 2.15 Various types of glial cells in the mammalian central and peripheral nervous systems.
An astrocyte is shown with end feet attached to a blood vessel. Oligodendrocytes and Schwann cells produce myelin around the axons of neurons—oligodendrocytes in the central nervous system, and Schwann cells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

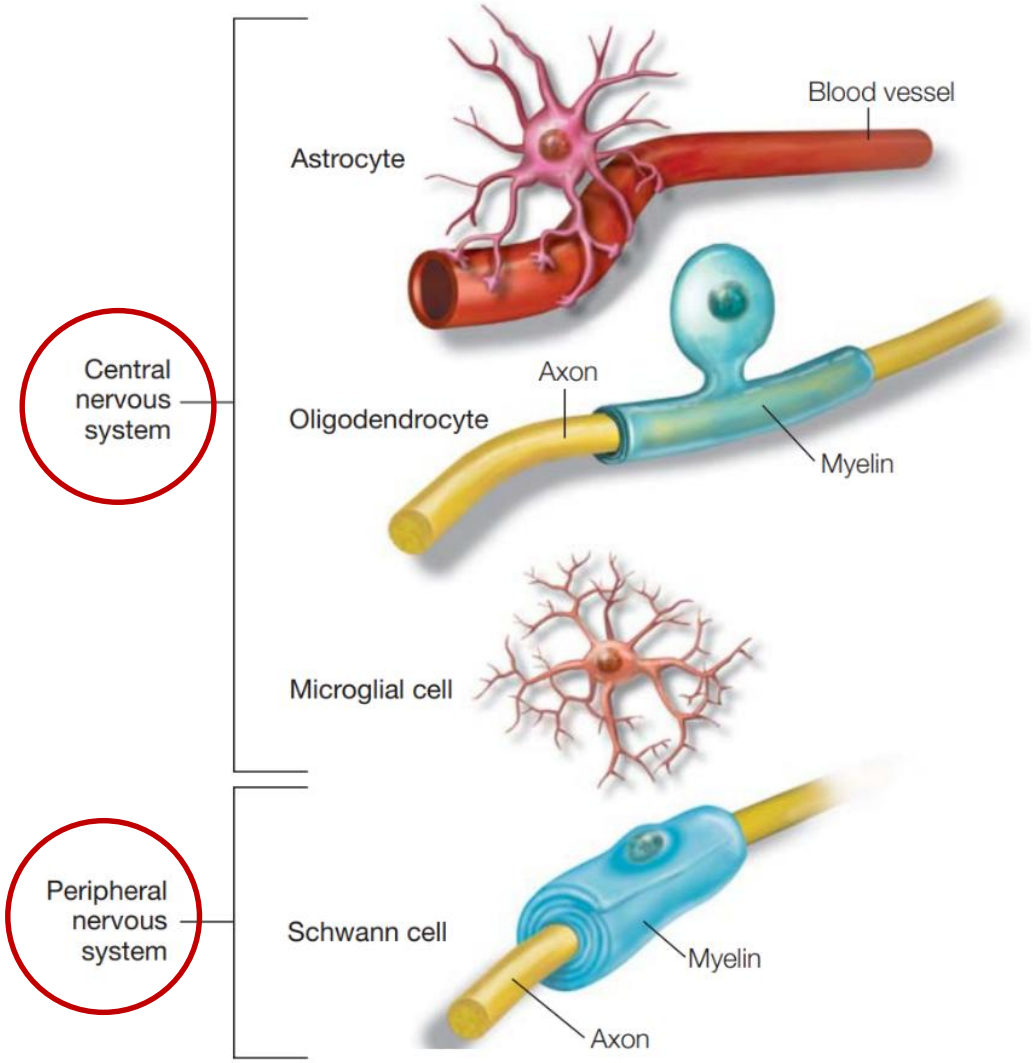
Neuroglia = "nerve glue"

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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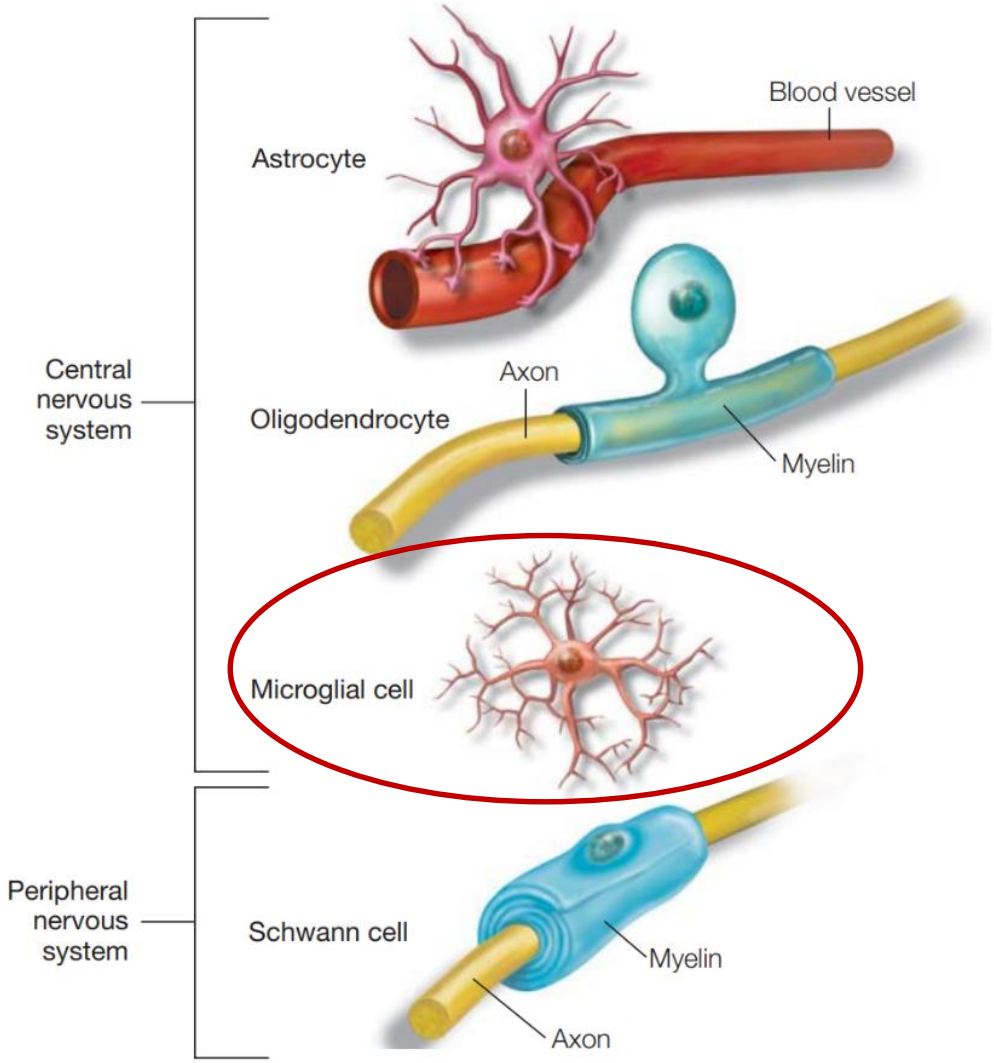
Immune support: microglia

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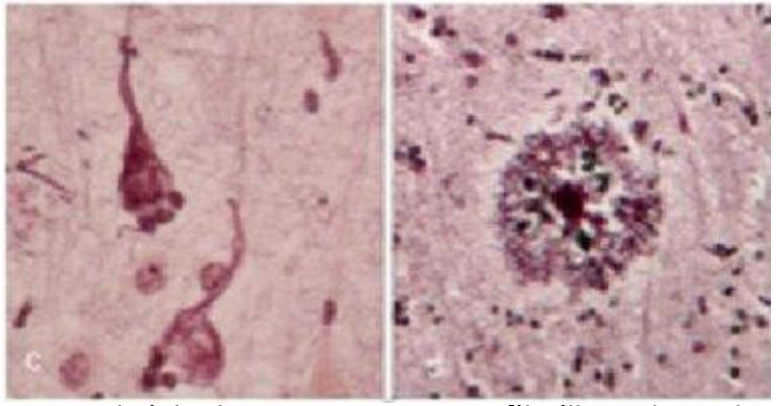
- In neurodegenerative disorders such as **Alzheimer's disease**, **microglia** may become **hyperactivated**, promoting neuroinflammation that can lead to the characteristic toxic protein deposits seen in Alzheimer's (amyloid plaques and neurofibrillary tangles)



amyloid plaques neurofibrillary tangles

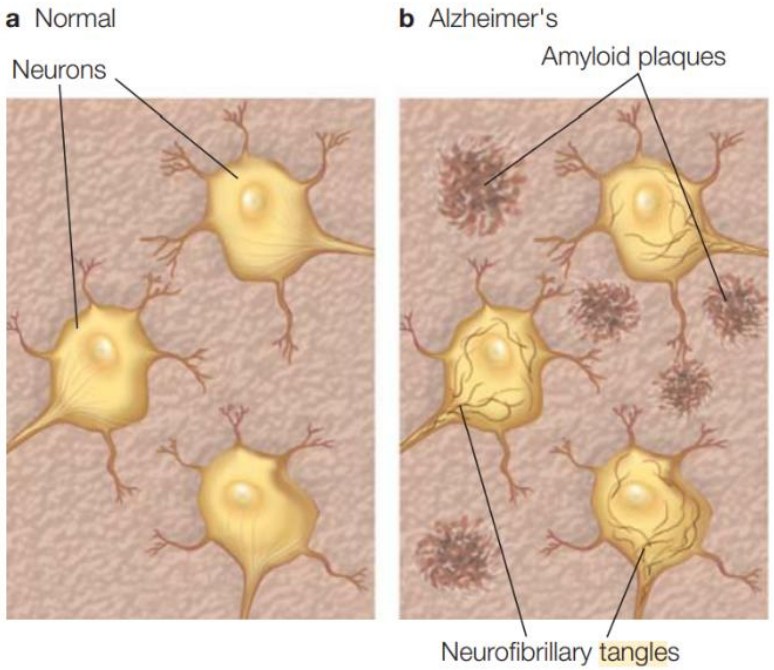


FIGURE 9.17 Comparison of cortex in Alzheimer's patients and normal participants.
These diagrams depict a normal section of cortex with cortical neurons **(a)** and a section of cortex in an Alzheimer's patient containing amyloid plaques between neurons and neurofibrillary tangles within neurons **(b)**.

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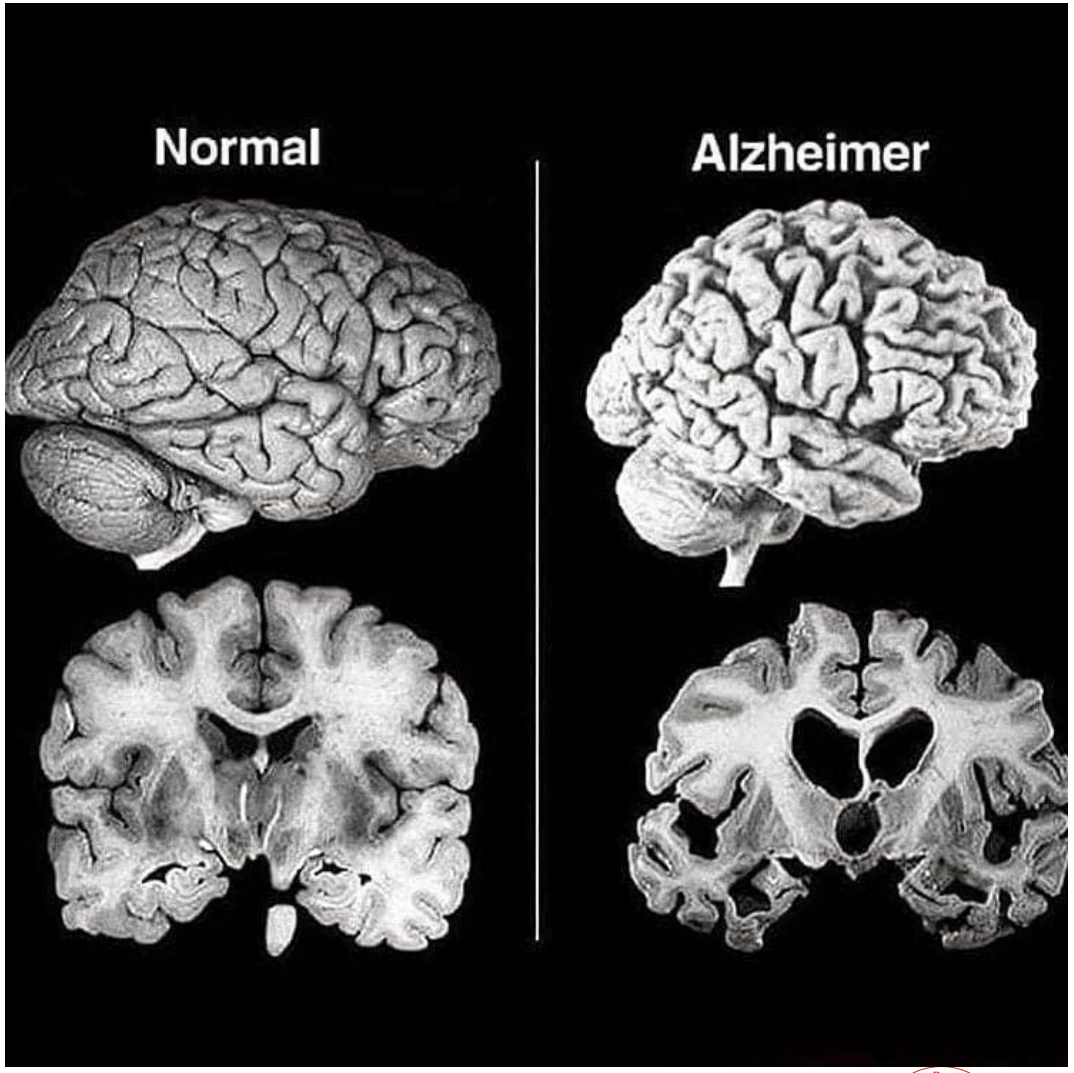
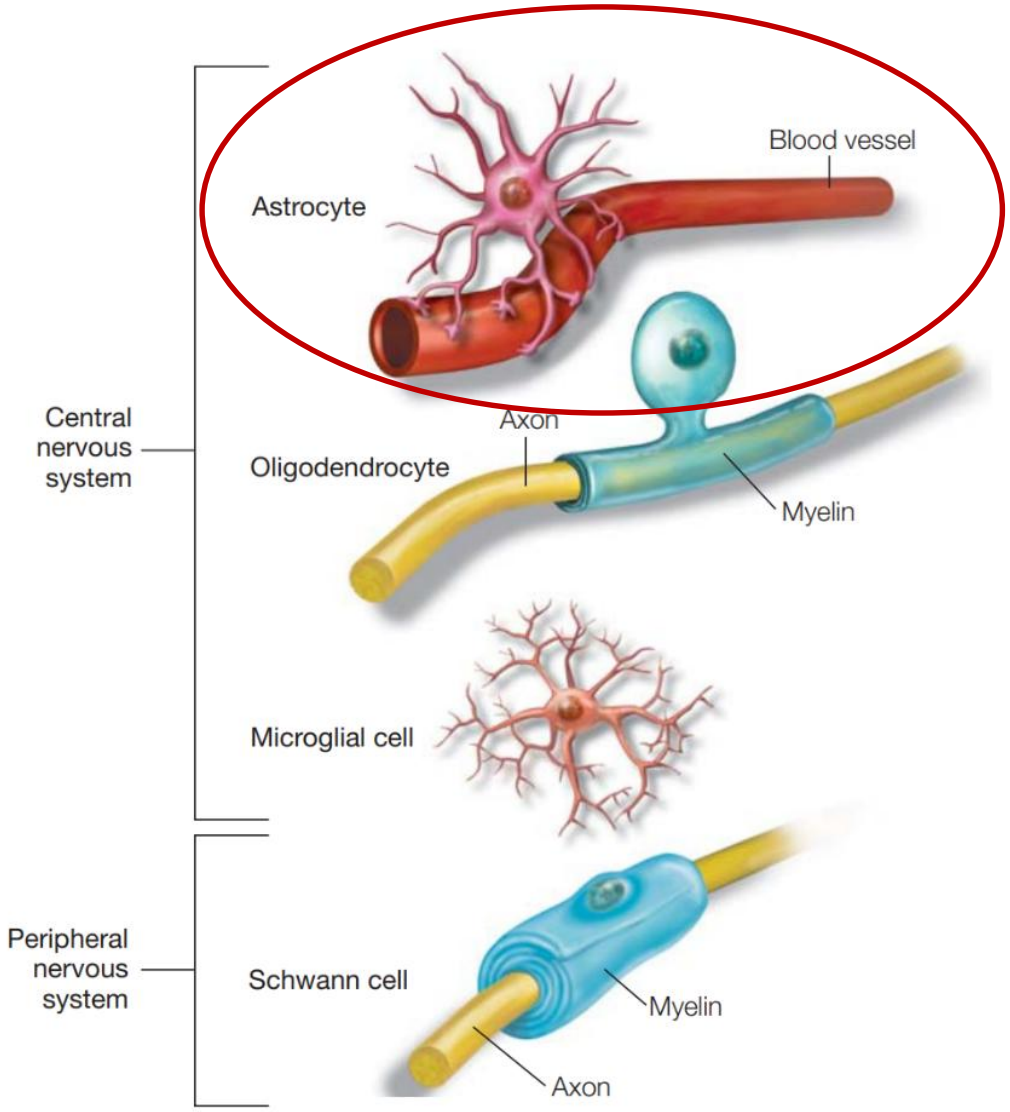


Nourishing support: astrocytes

- 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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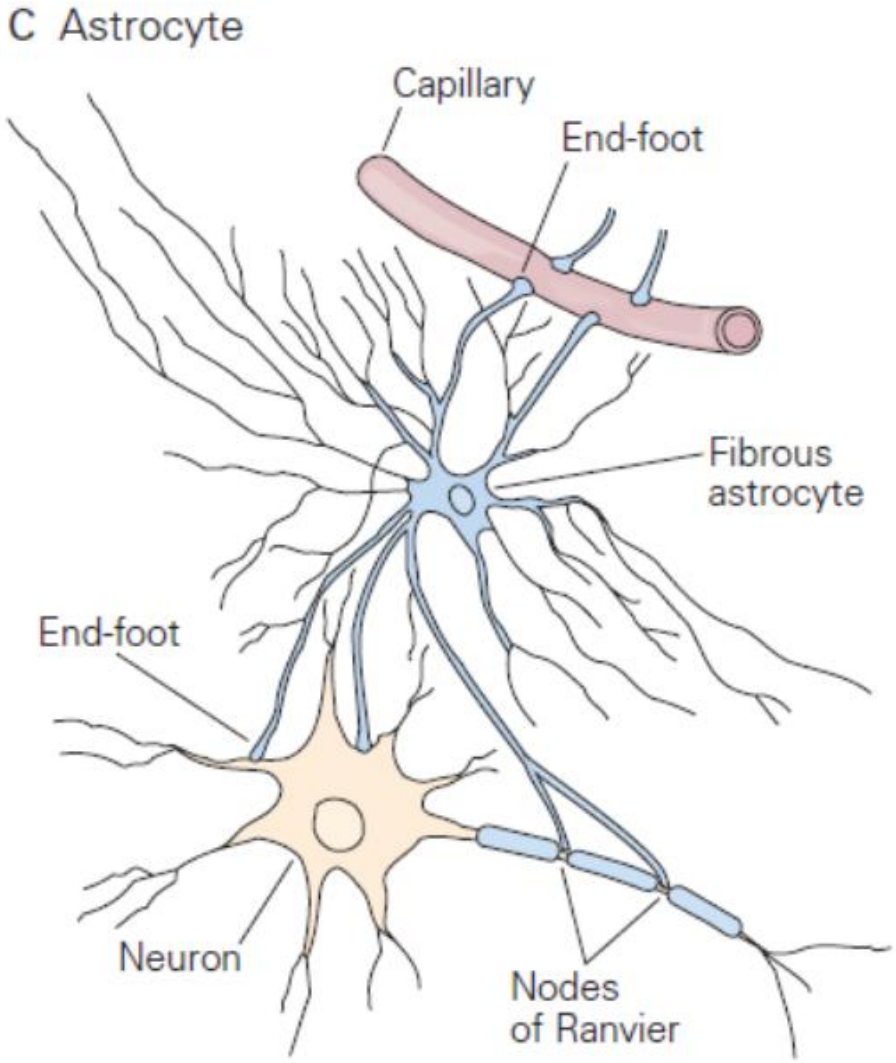
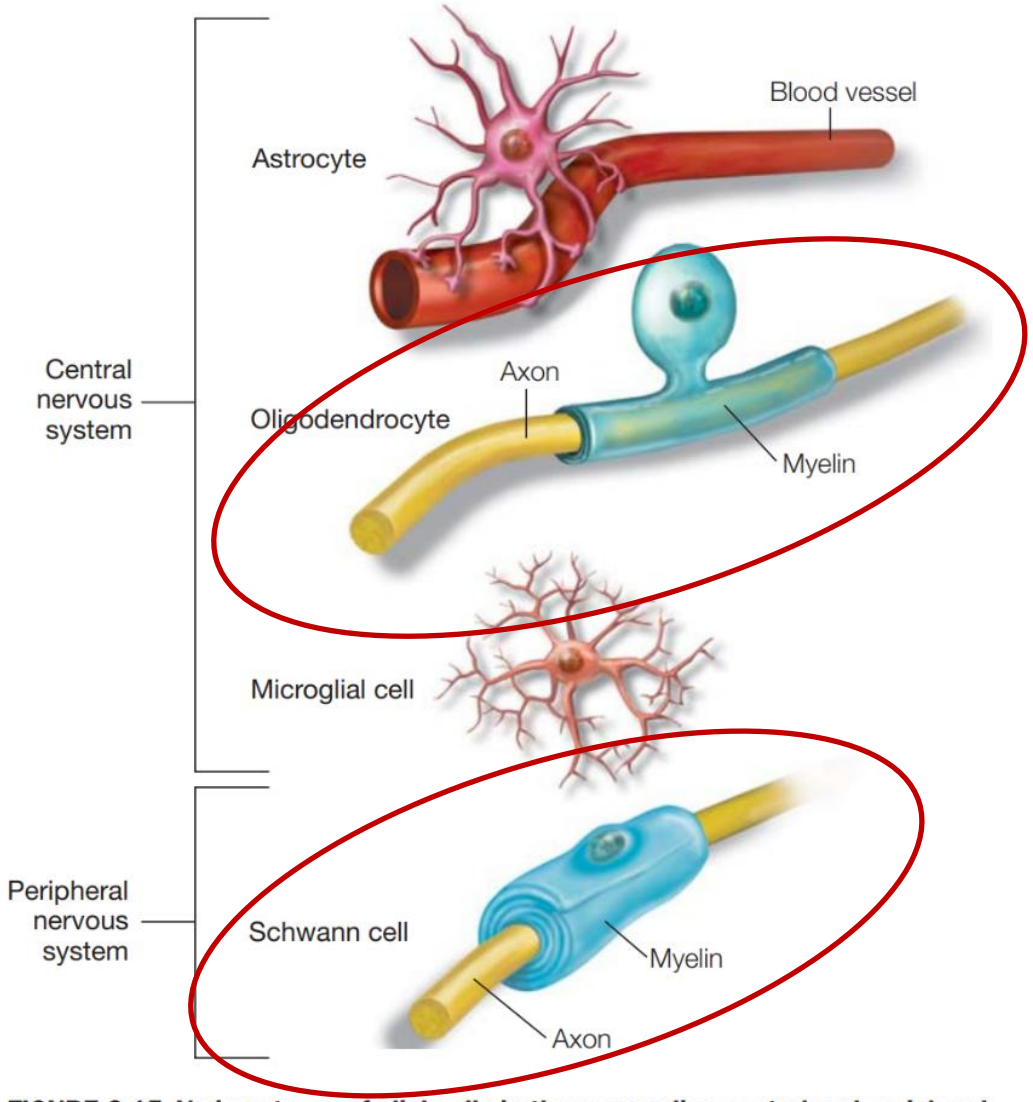


Signaling support: oligodendrocytes and Schwann cells

- 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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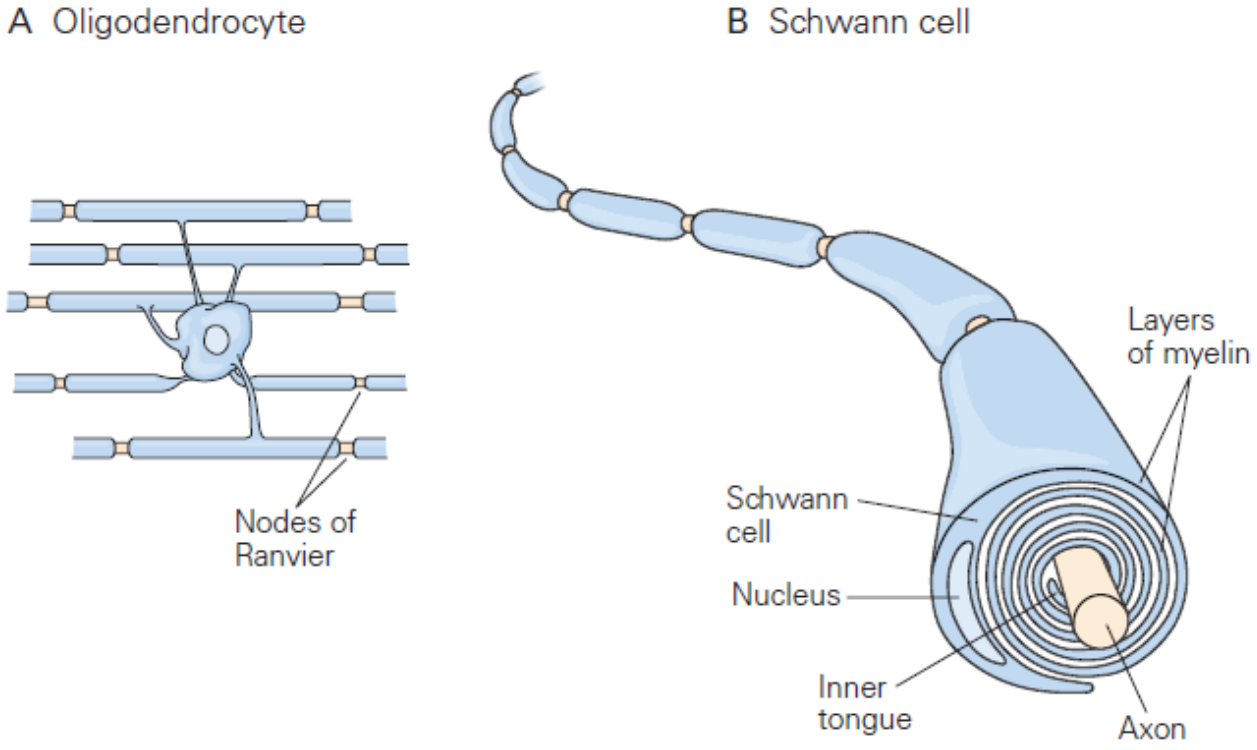
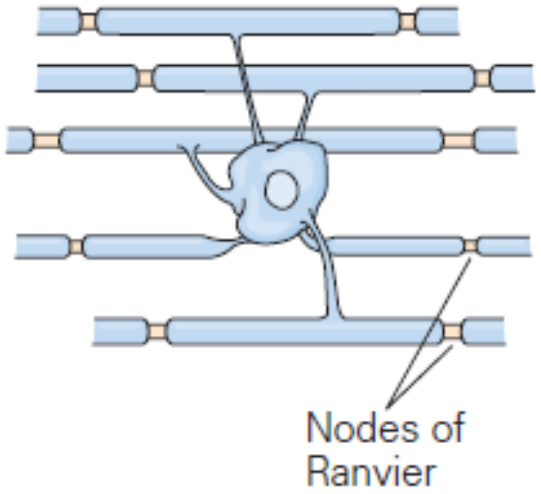
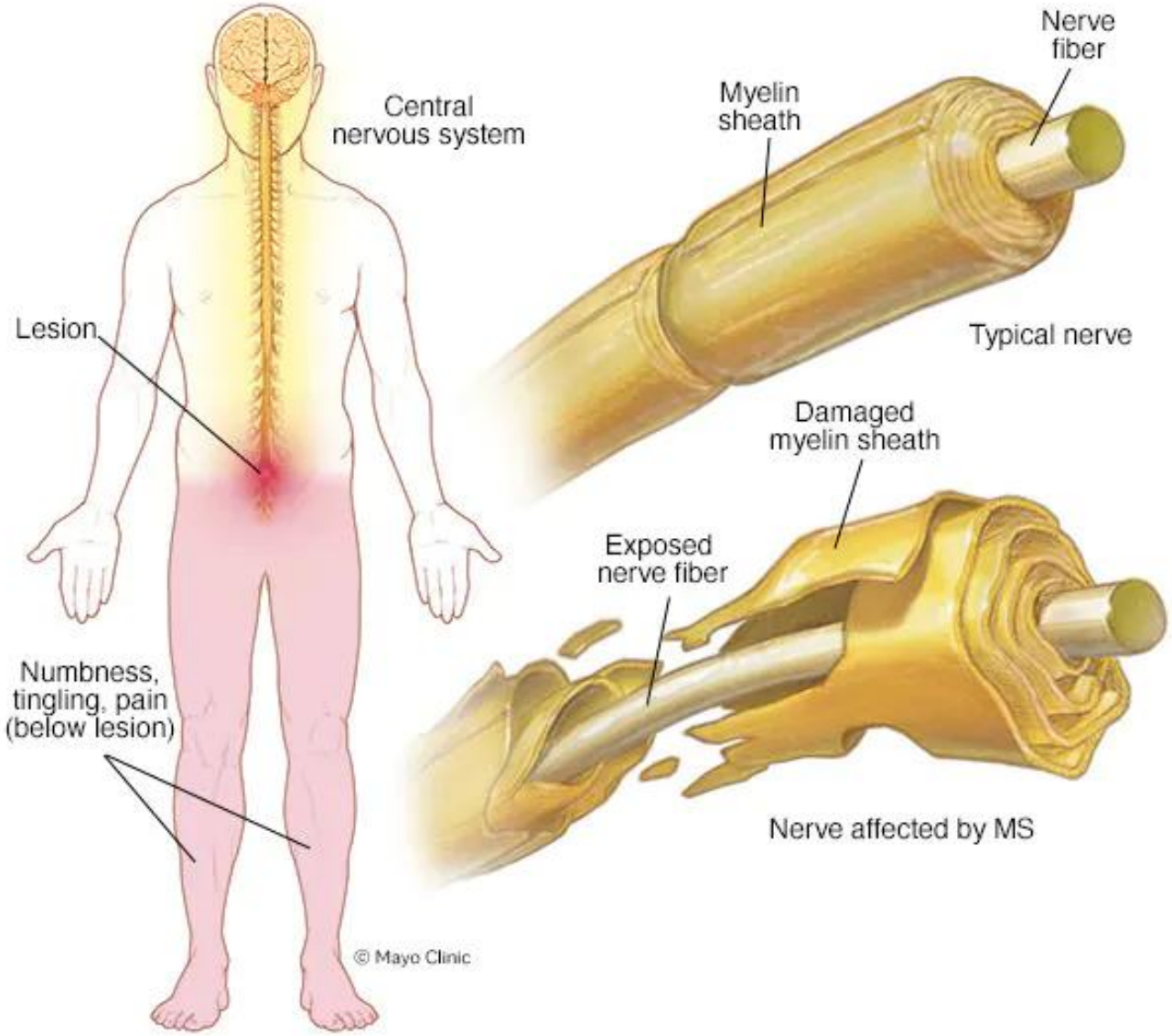


Signaling support: oligodendrocytes (in the CNS)

- 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

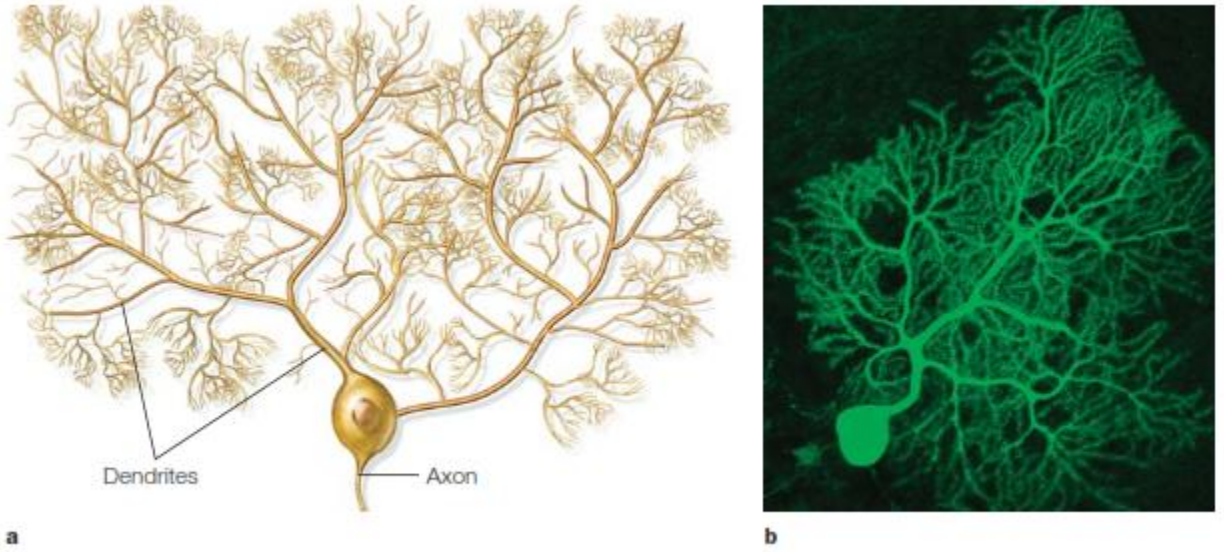


FIGURE 2.4 Soma and dendritic tree of a Purkinje cell from the cerebellum.

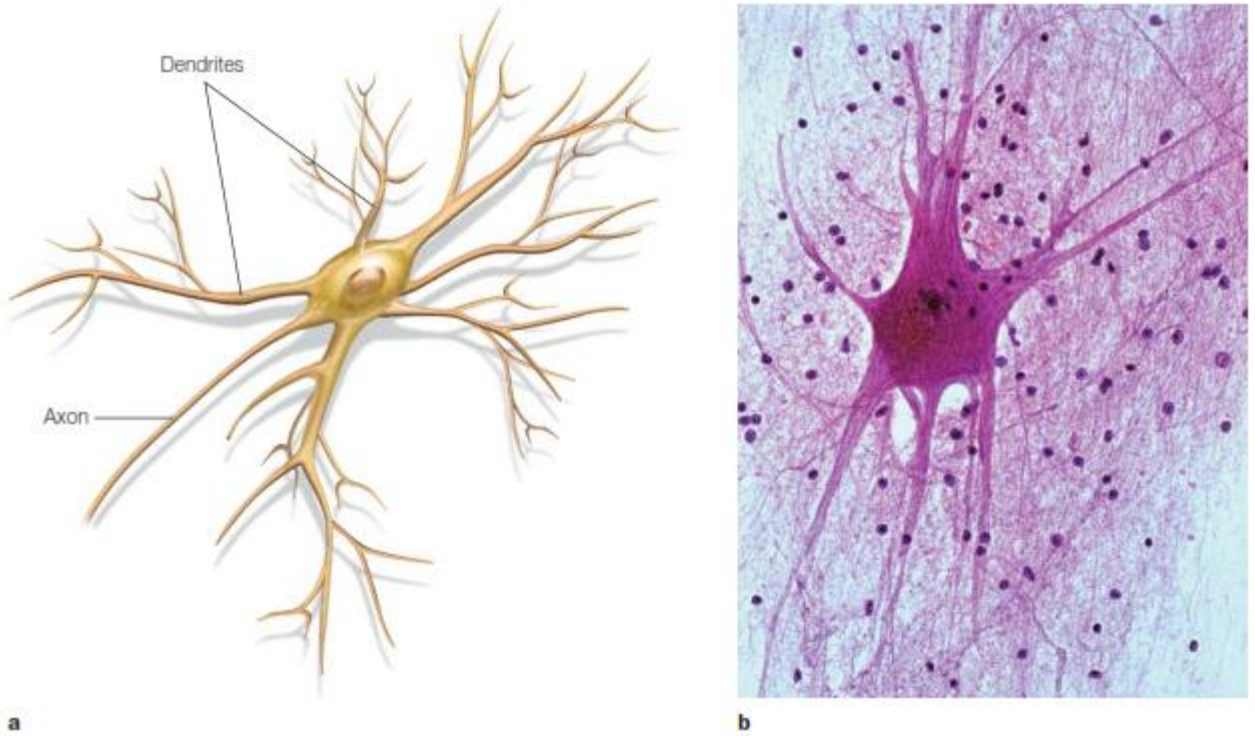
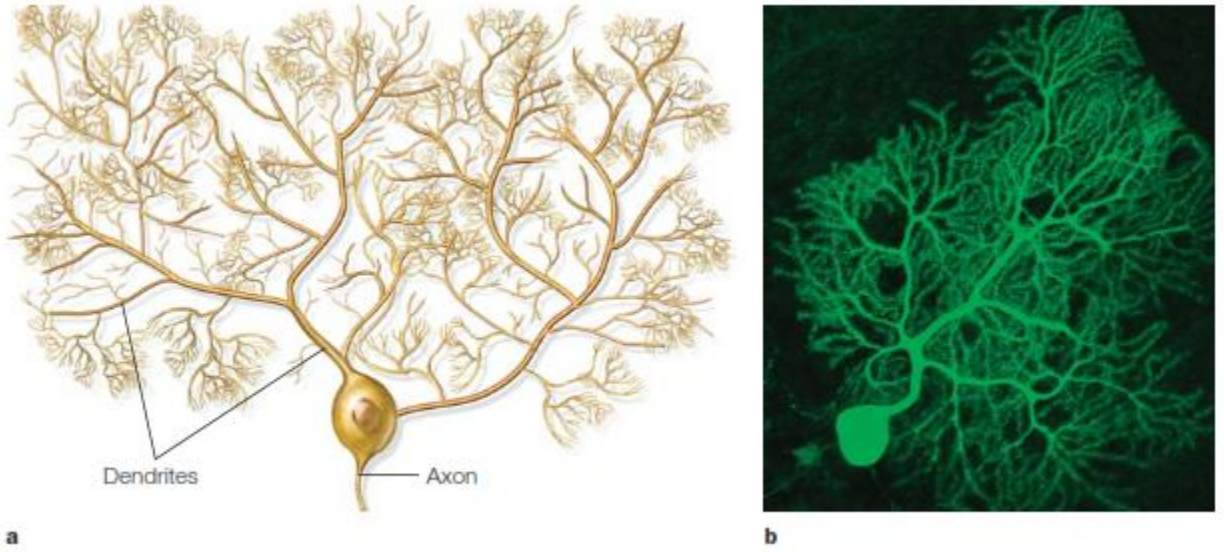


FIGURE 2.5 Spinal motor neuron.

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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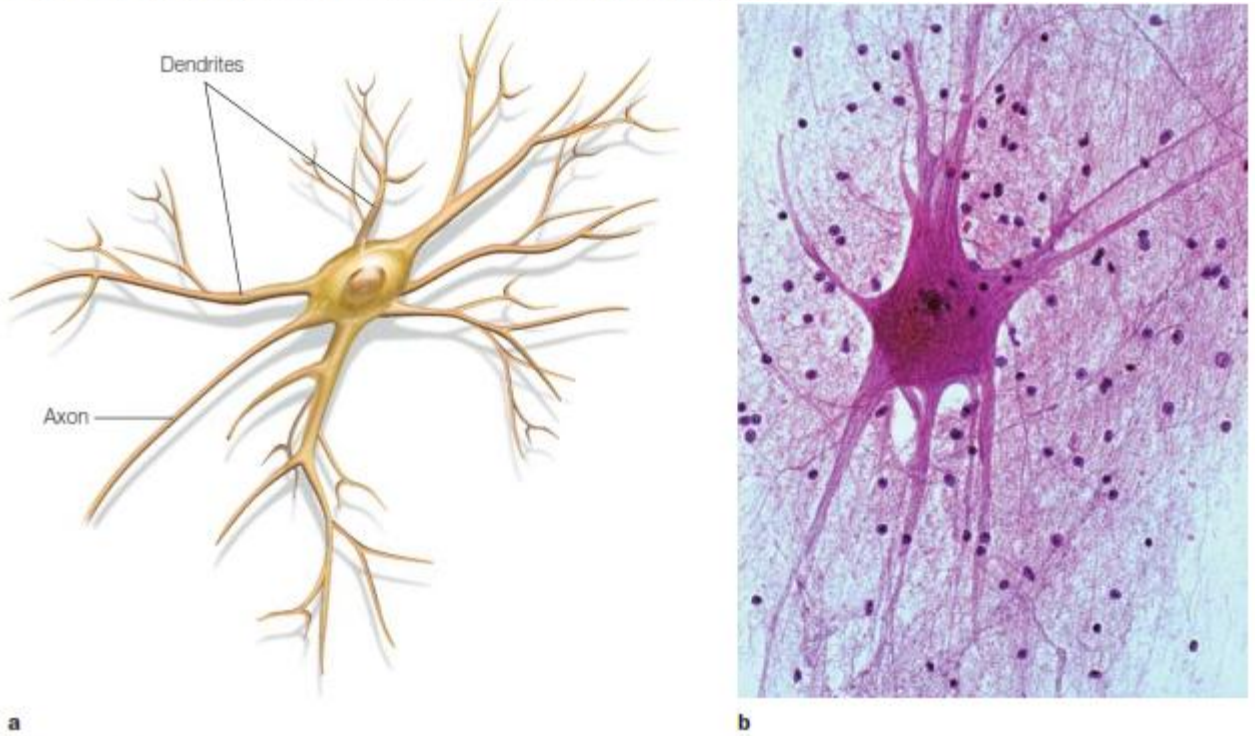
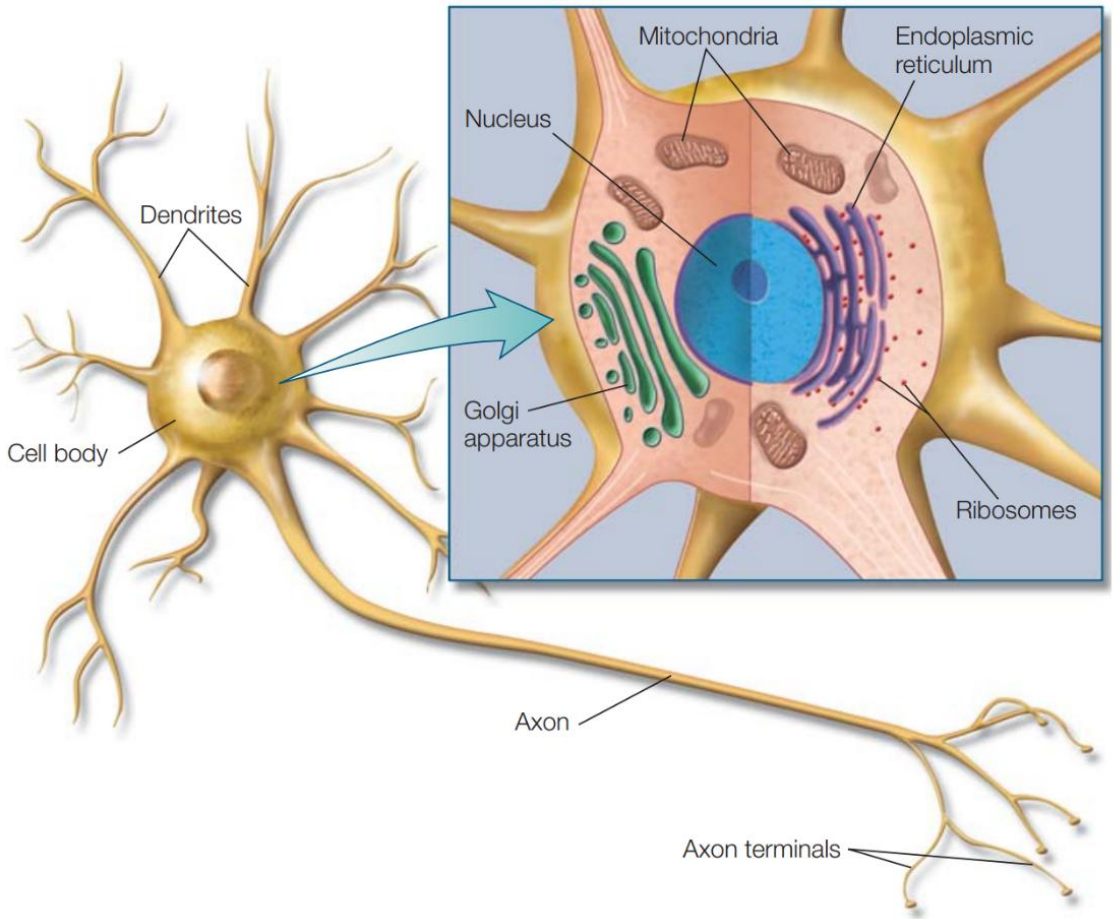


FIGURE 2.5 Spinal motor neuron.

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.

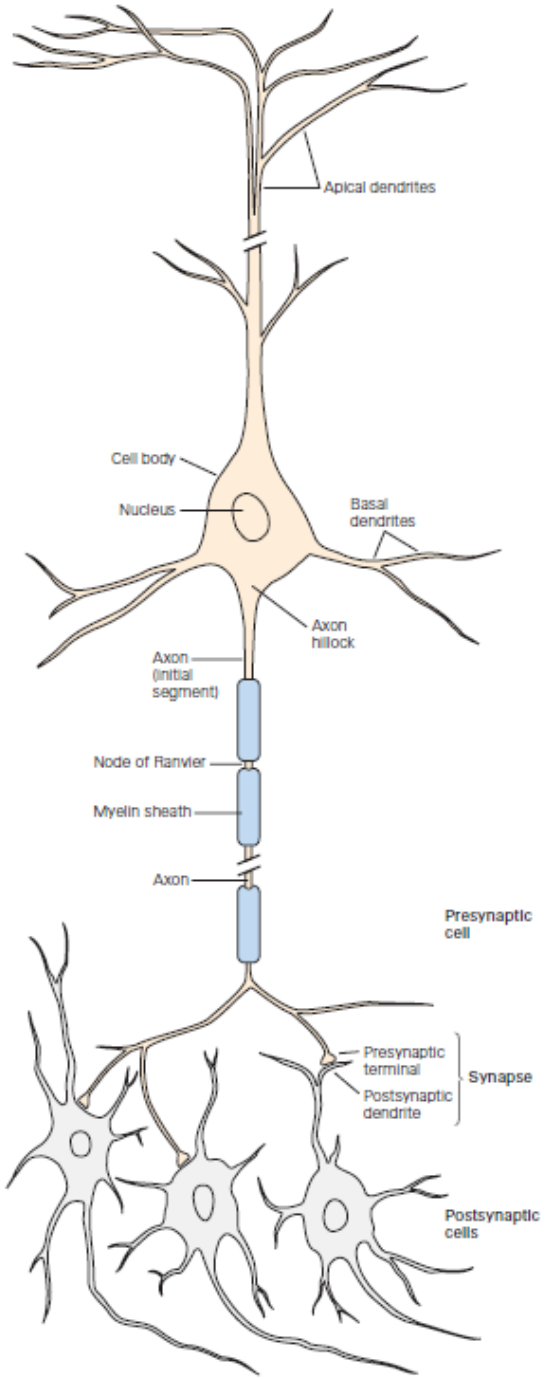


The structure of neurons

Components unique to neuronal cells:

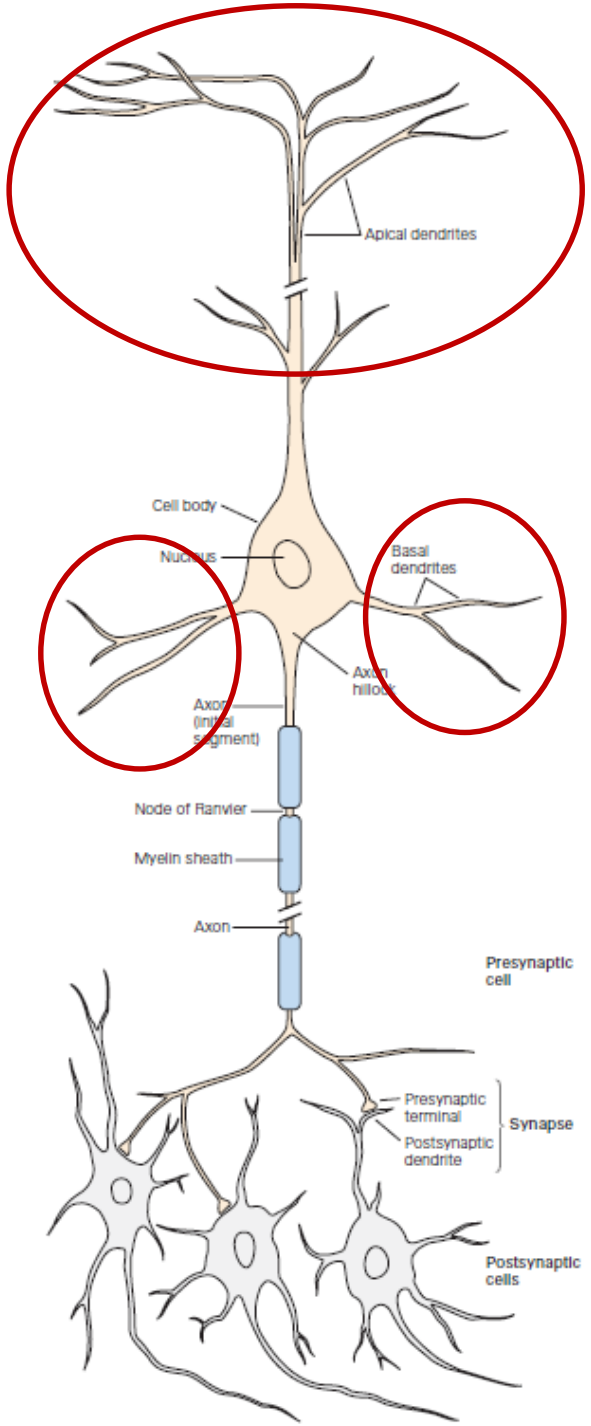
1. Dendrites
2. Axon
3. Synapses

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



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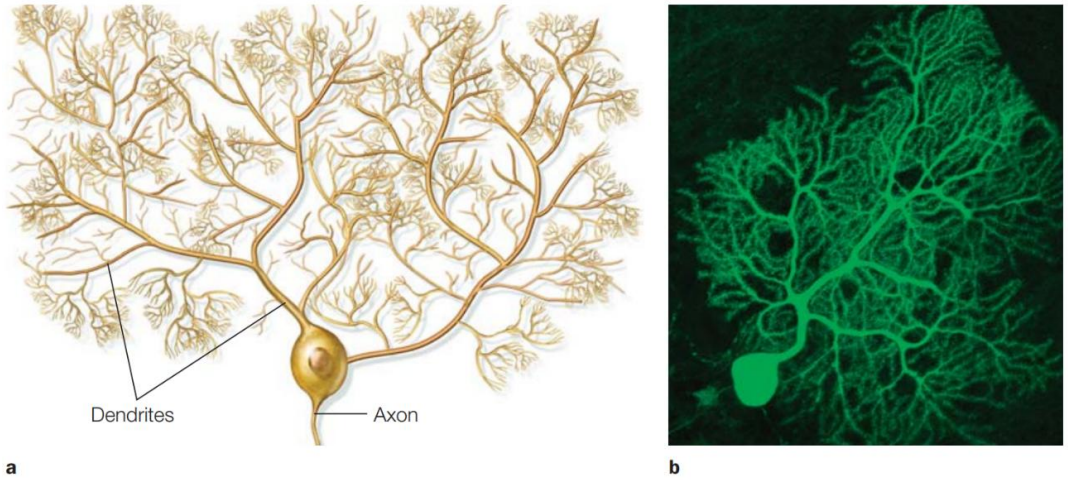

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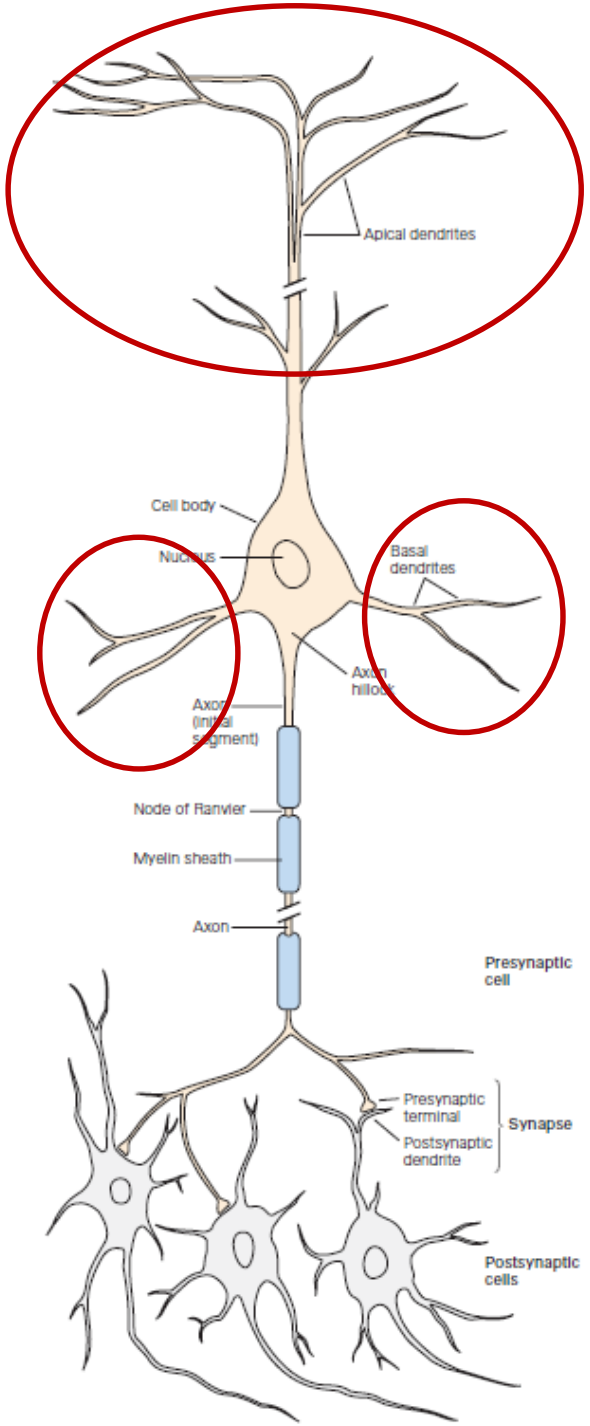
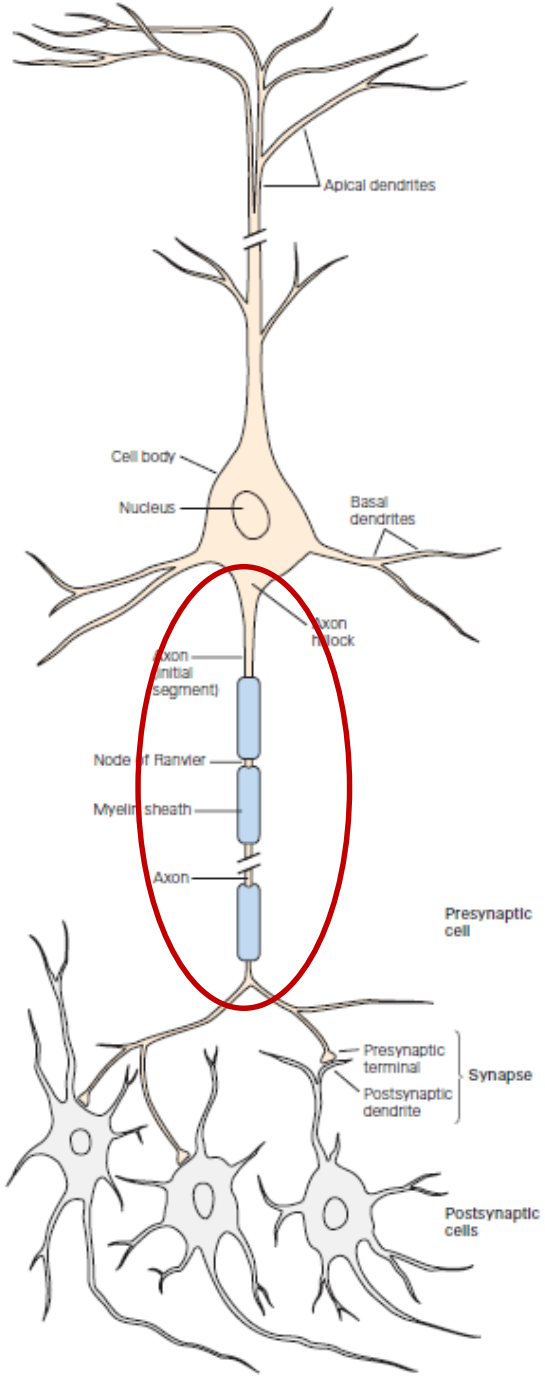


The structure of neurons

2. Axon:

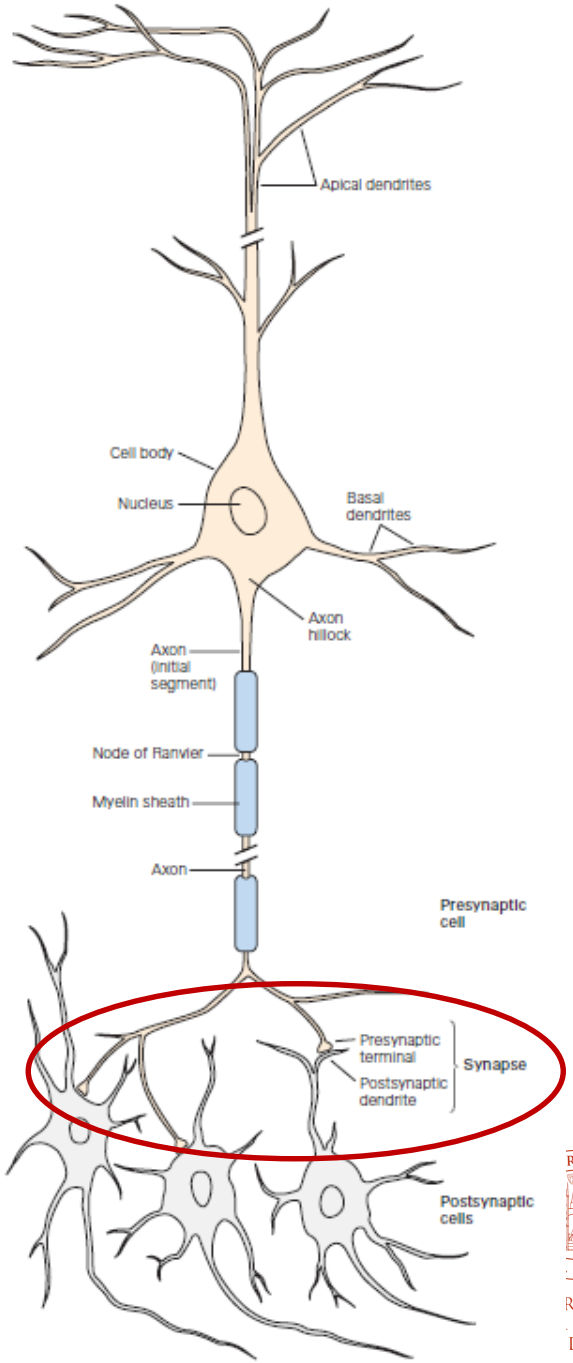
- **single process**
- represents the **transmitting zone** of the neuron
- extends some distance from the cell body and carries signals from the input zone (dendrites) to the output zone (synapses)
- an axon can convey electrical signals over distances ranging from 0.1 mm to 2 m



The structure of neurons

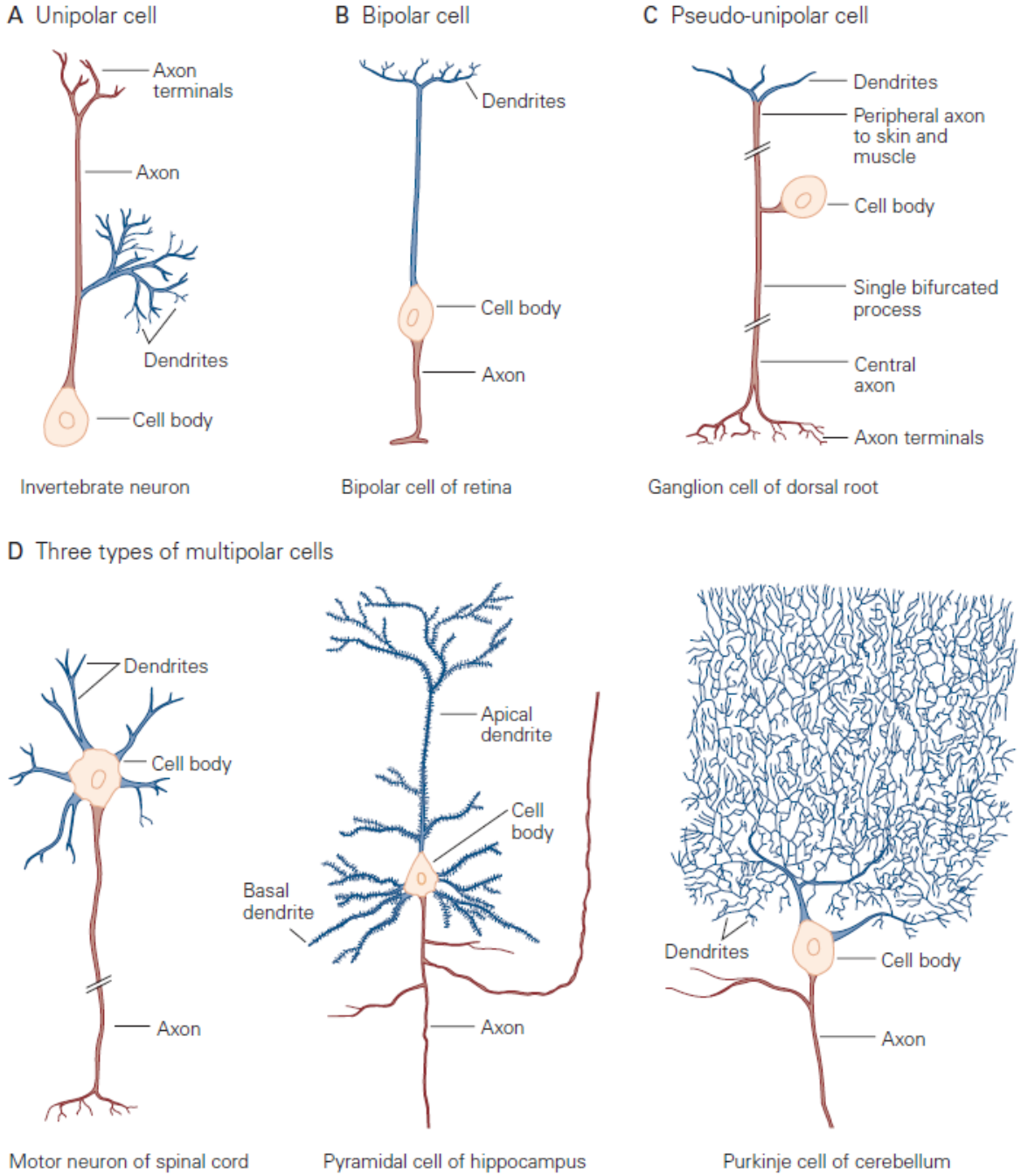
3. Synapse:

- **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



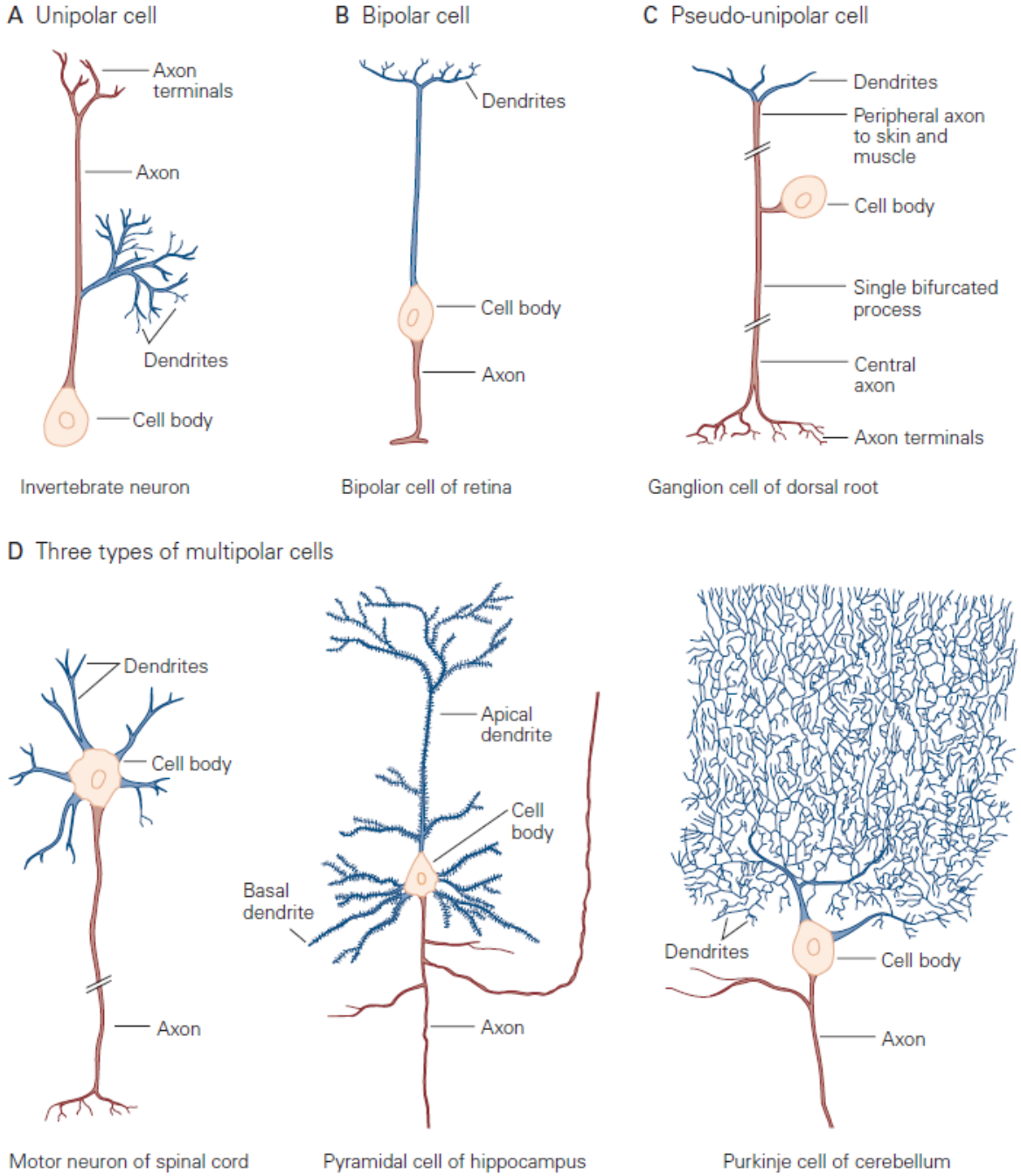
The structure of neurons

- Nerve cell shapes vary according to the number, branching and disposition of their projections or dendrites, collectively known as arborization.
- This determines their capacity for interacting with their environment and with other nerve cells or neurons, hence their computational ability and roles.
- Knowing how such shapes are determined is important for understanding nerve cell function.



The structure of neurons

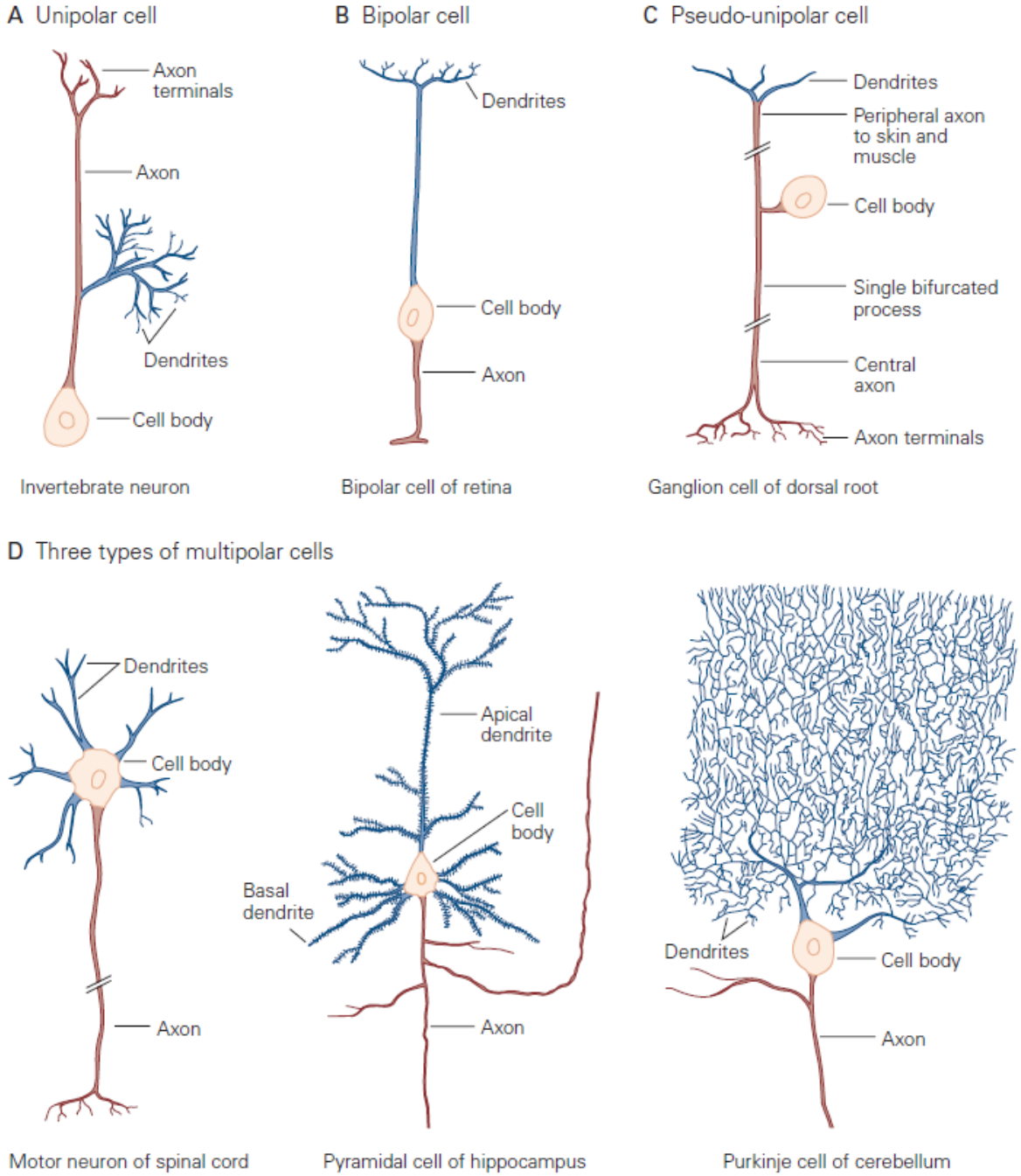
Unipolar Neurons – The simplest type, with a single process that branches into an axon and other receiving structures. They are common in invertebrates and found in the autonomic nervous system of vertebrates.



The structure of neurons

Bipolar Neurons – Have an oval cell body with two processes: one dendritic structure receiving signals and one axon sending information to the central nervous system. These neurons are found in sensory systems like the retina and olfactory epithelium.

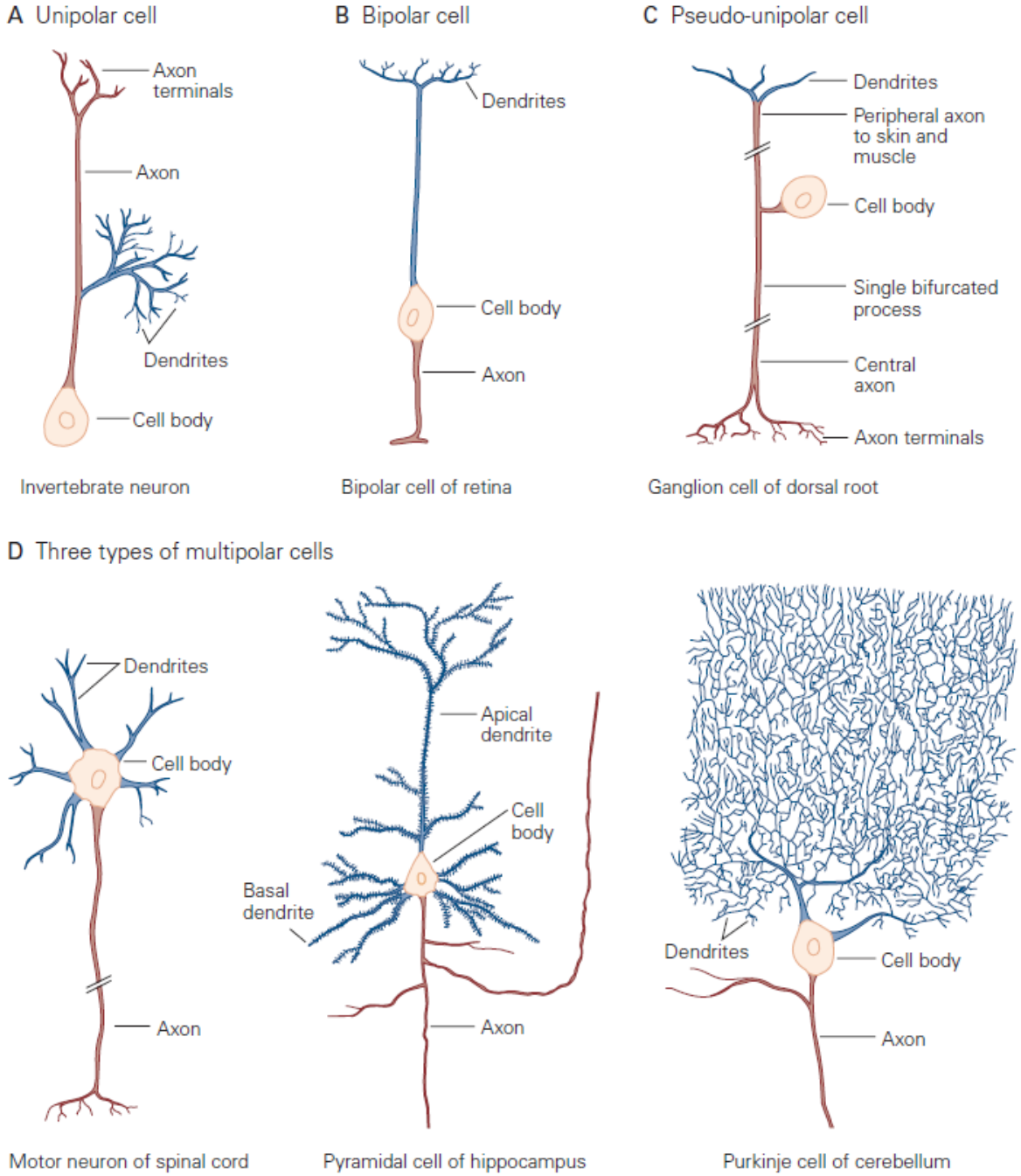
A variant, **pseudo-unipolar neurons**, initially develop as bipolar but fuse into a single process that splits into two branches—one to sensory receptors and the other to the spinal cord.



The structure of neurons

Multipolar Neurons – The most common type in vertebrates, with a single axon and multiple dendrites. Their shape and branching complexity vary, affecting the number of synaptic connections.

For example, spinal motor neurons receive about 10,000 contacts, while Purkinje cells in the cerebellum can receive up to a million connections.



Neurons receive, evaluate, and transmit information

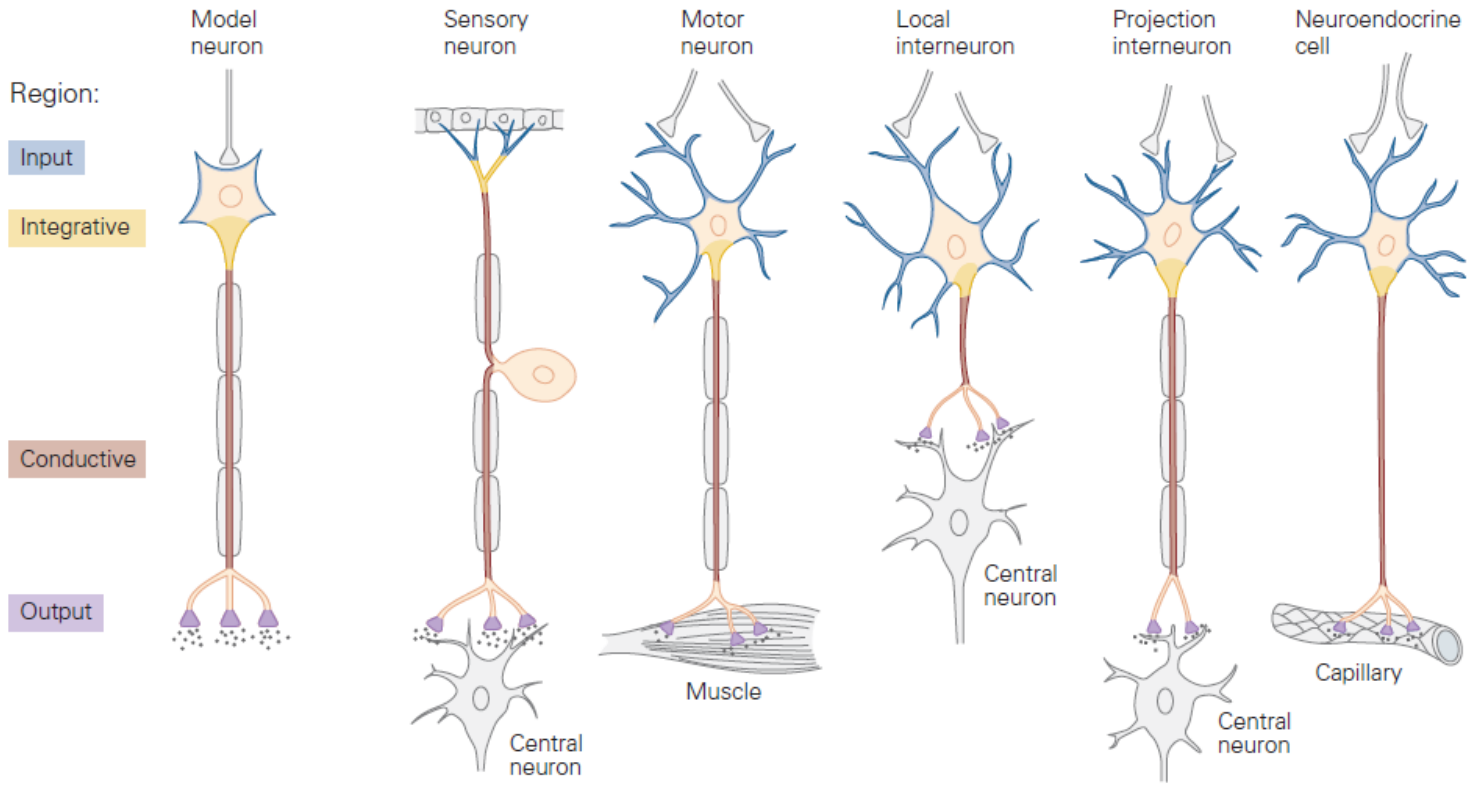
Information is transferred

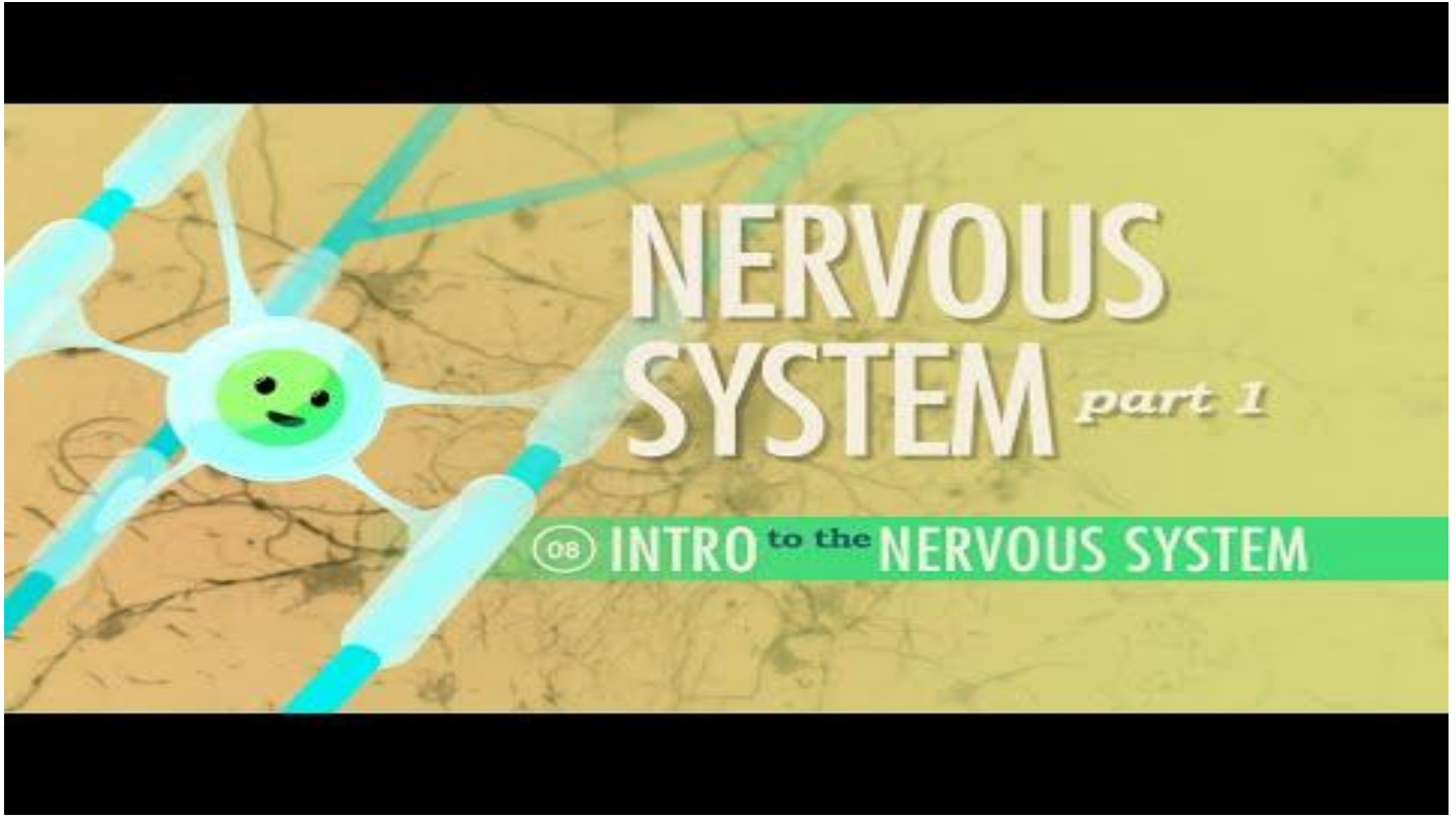
1. **within a neuron**

- 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





https://youtu.be/qPix_X-9t7E

From time 3:42 to 7:45

wooclap

Questions 1-3

Information transfer within a single neuron

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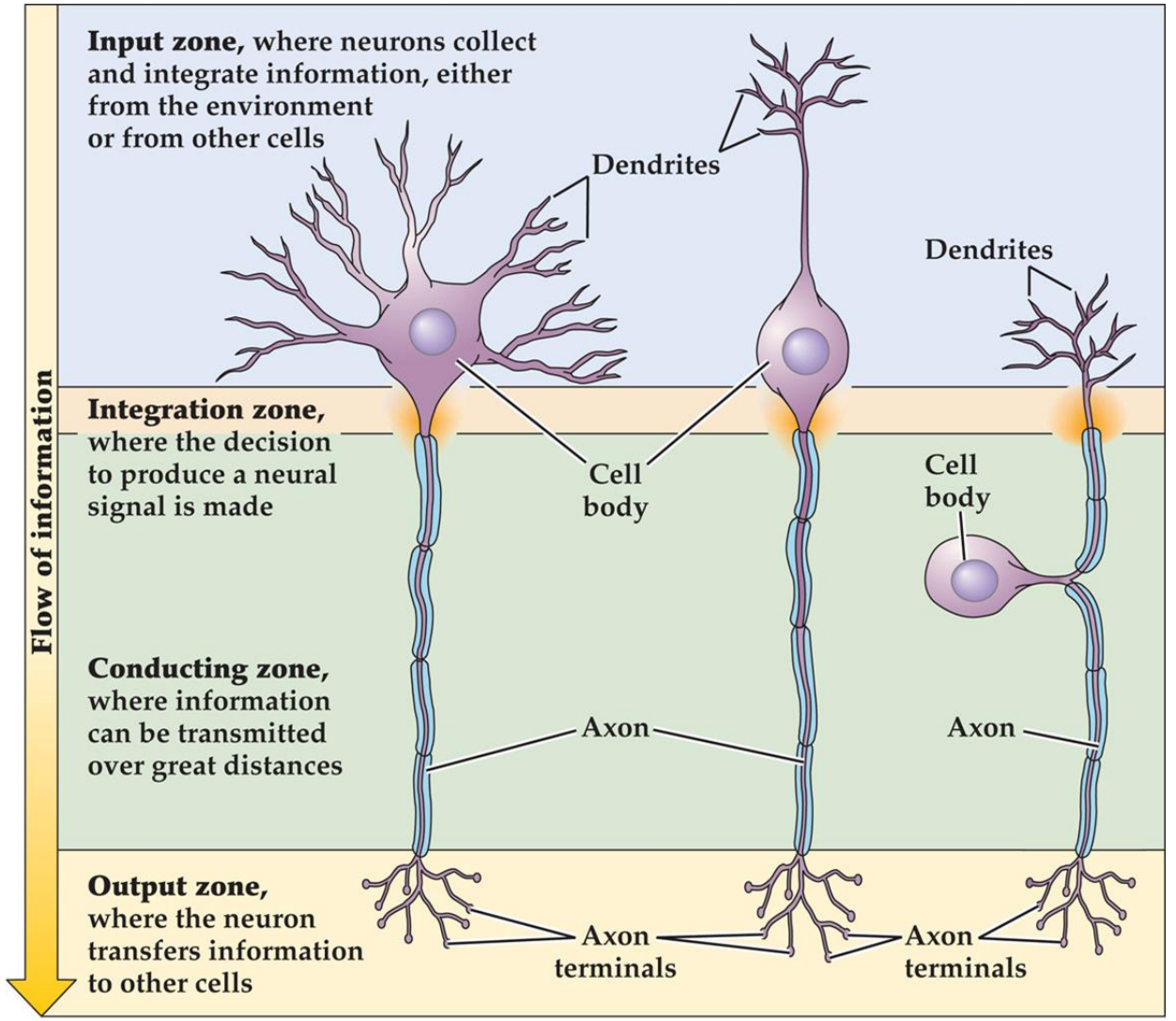
Signaling is organized in the same way in all nerve cells

4 regions that generate 4 types of signal:

A. Input signal: Postsynaptic Potentials (PSPs) or receptor potential
B. Trigger signal: integration of all PSPs or receptor potentials
C. Conductive signal: Action Potential (AP)
D. Output signal: synaptic signal

Regardless of cell size & shape, neurotransmitter biochemistry, or function



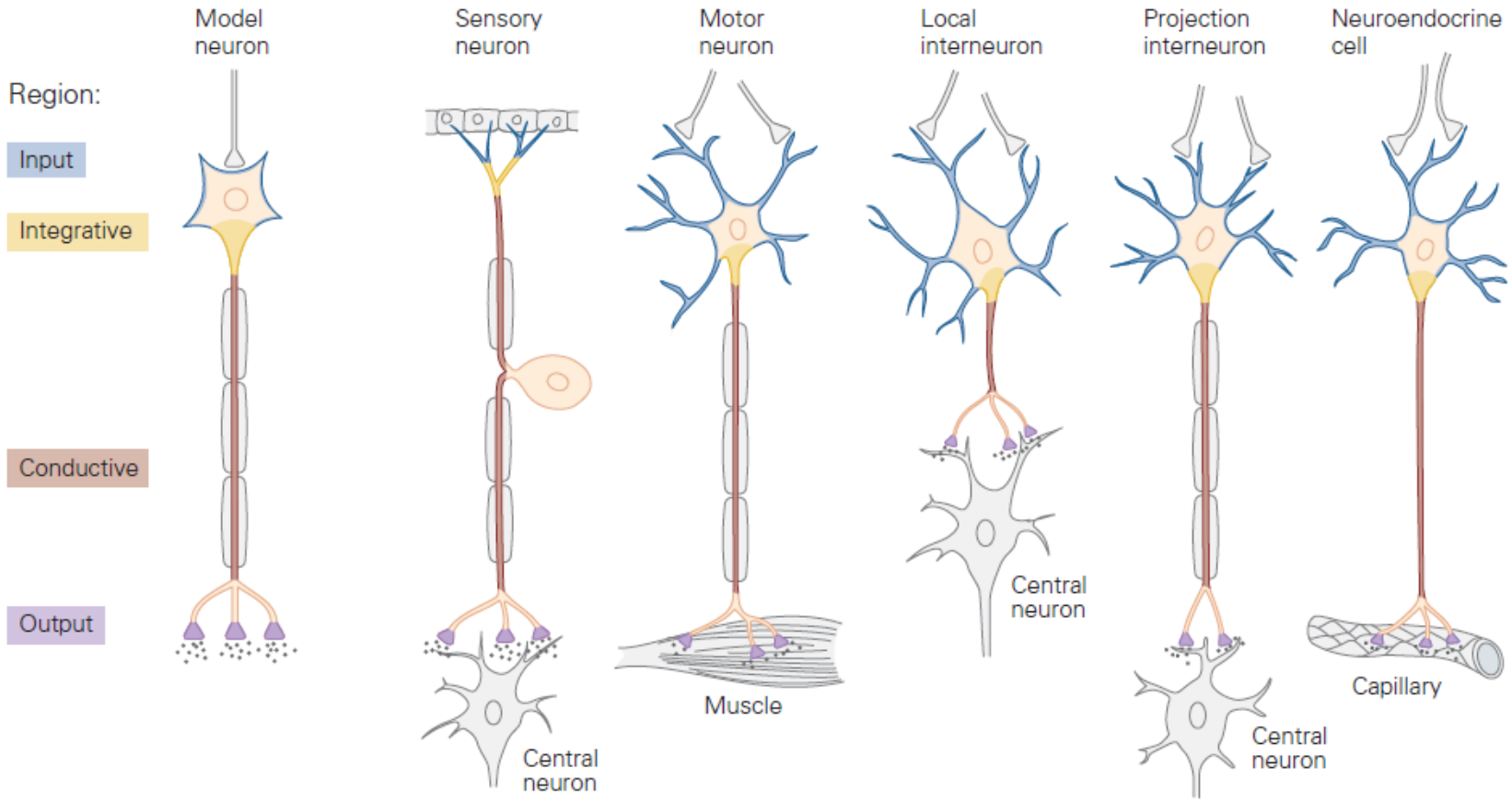
THE MIND'S MACHINE, Figure 2.3

Signaling is organized in the same way in all nerve cells

4 regions that generate 4 types of signal:

A. Input signal: Postsynaptic Potentials (PSPs) or receptor potential
B. Trigger signal: integration of all PSPs or receptor potentials
C. Conductive signal: Action Potential (AP)
D. Output signal: synaptic signal

Regardless of cell size & shape, neurotransmitter biochemistry, or function



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

4 regions that generate 4 types of signal:

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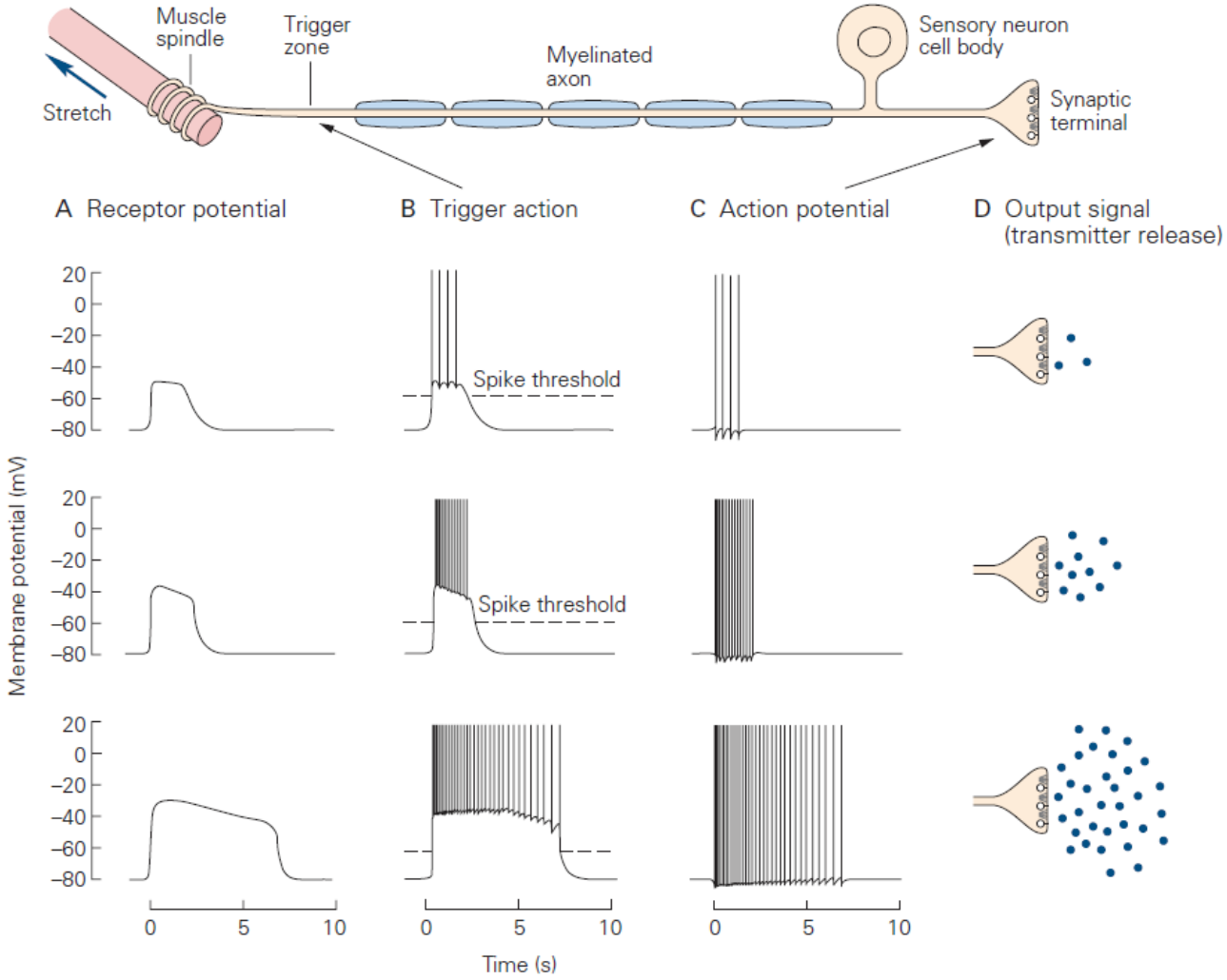
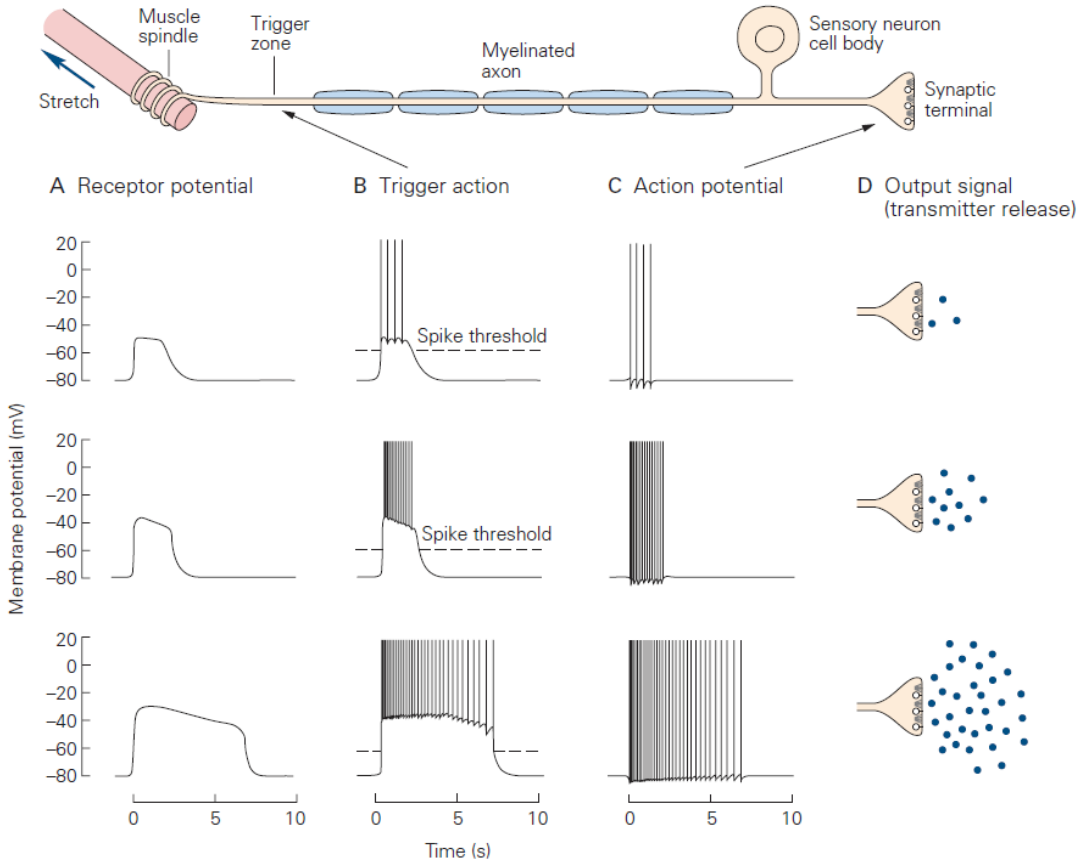


Each of the neuron's four signaling regions produces a characteristic signal

(A) At the input region, the input signal is the Postsynaptic Potential (PSP), or in this illustration, a receptor potential, that is graded in:

- Amplitude
- Duration

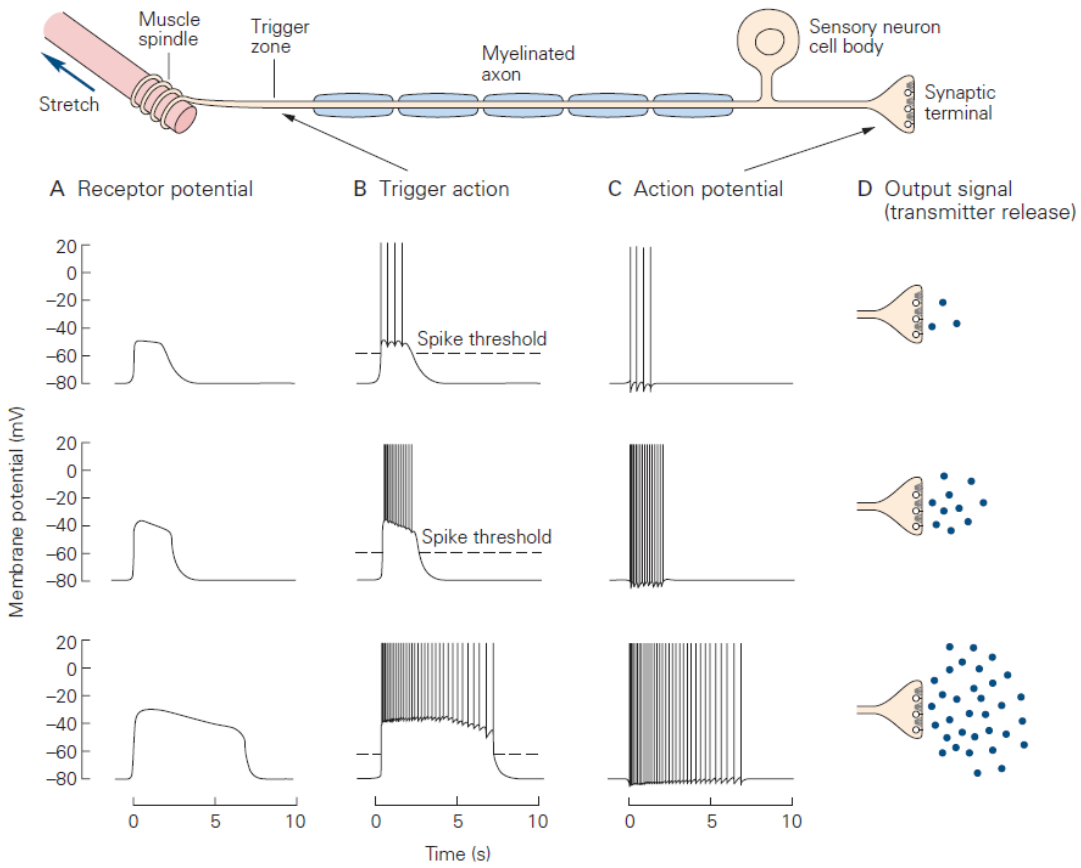
Proportional to the amplitude and duration of the input stimulus



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

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

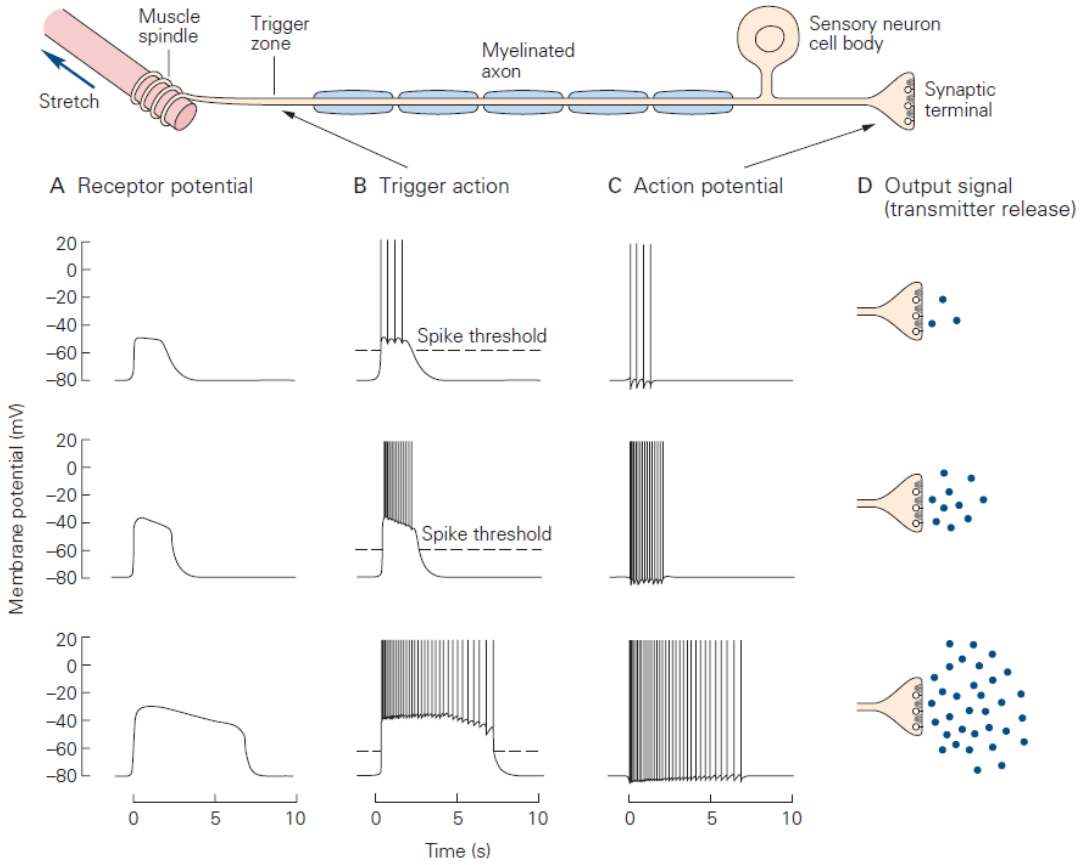
- An action potential is generated only if the input signal exceeds the voltage threshold for initiation (-55mV)
- Once the threshold is surpassed an action potential is generated
- Any further increase in amplitude of the input can only increase the **frequency of action potentials**
- The duration 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

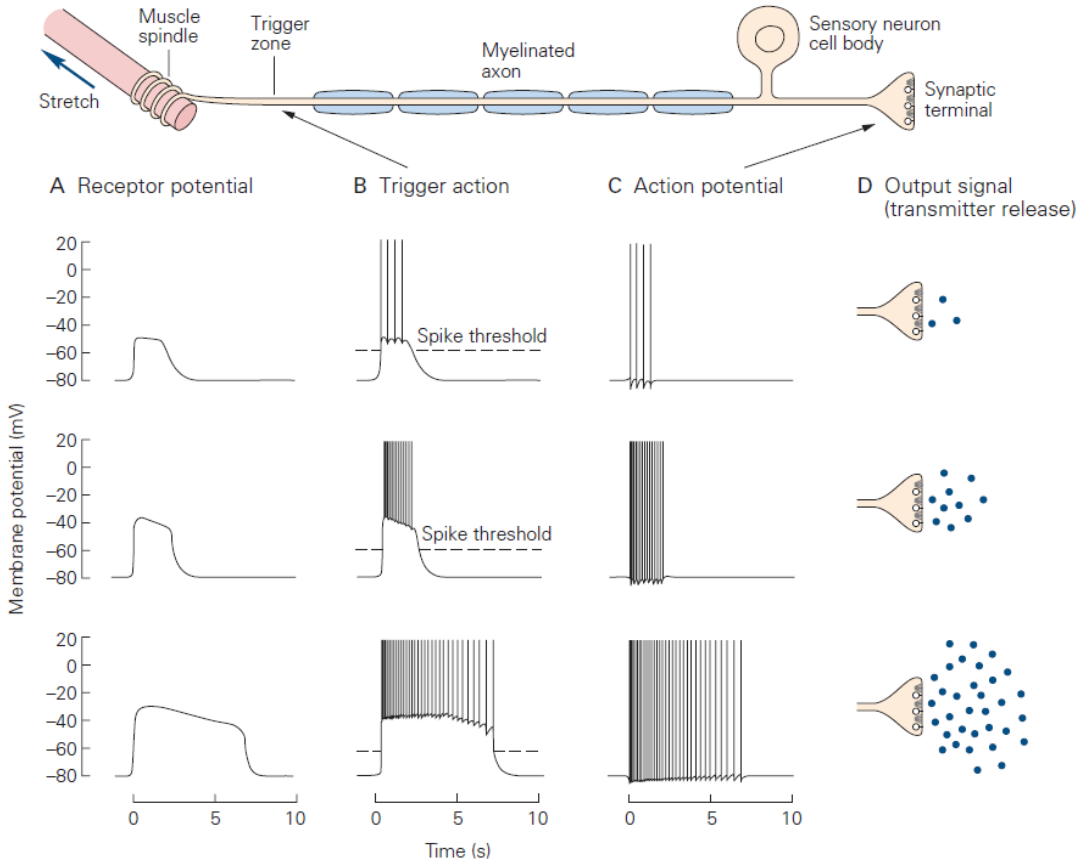
- Action potentials are all-or-none (binary): they all have a similar amplitude and duration
- the frequency and duration of firing represents the information carried by the signal

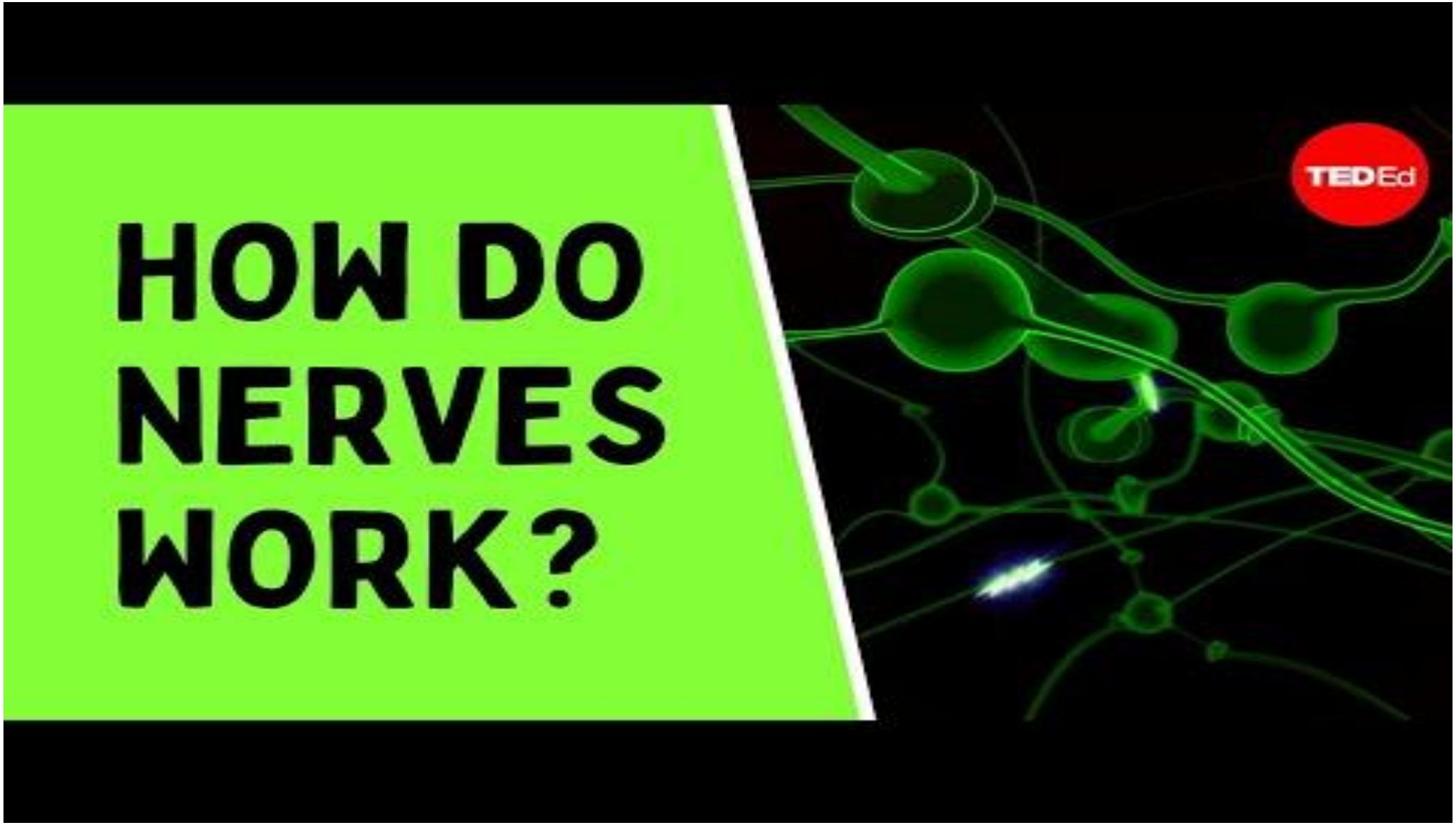


Each of the neuron's four signaling regions produces a characteristic signal

(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

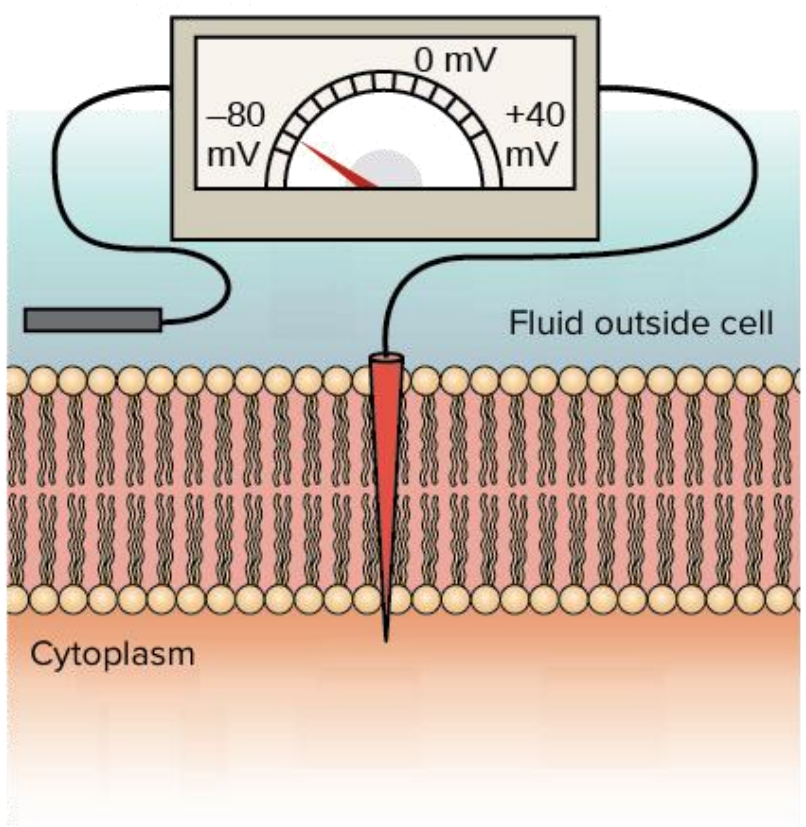
AND...

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...

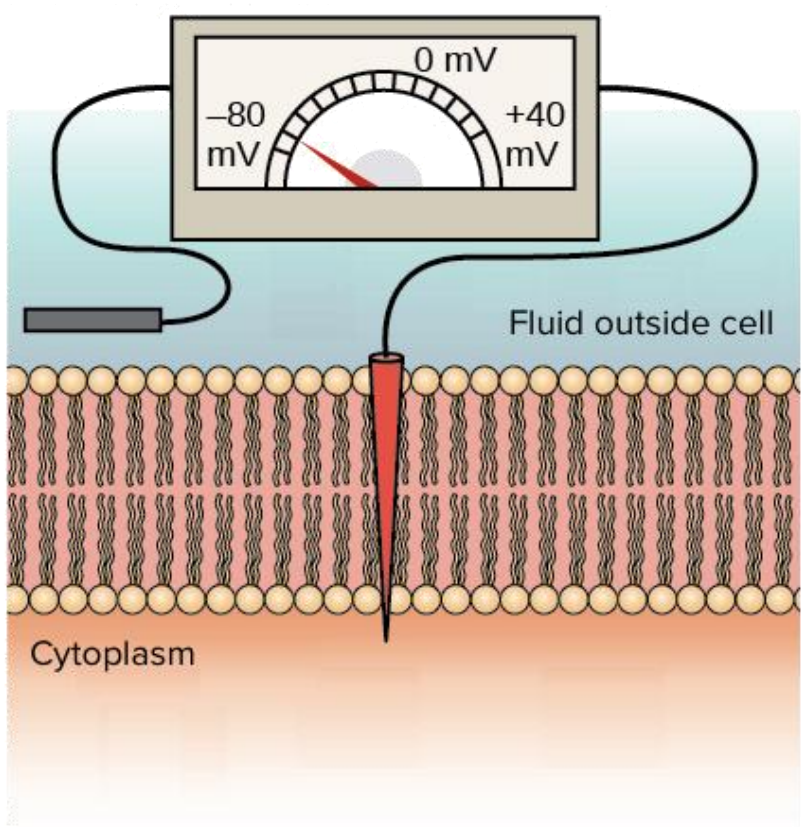
it all starts with the **resting membrane potential**



Resting membrane potential

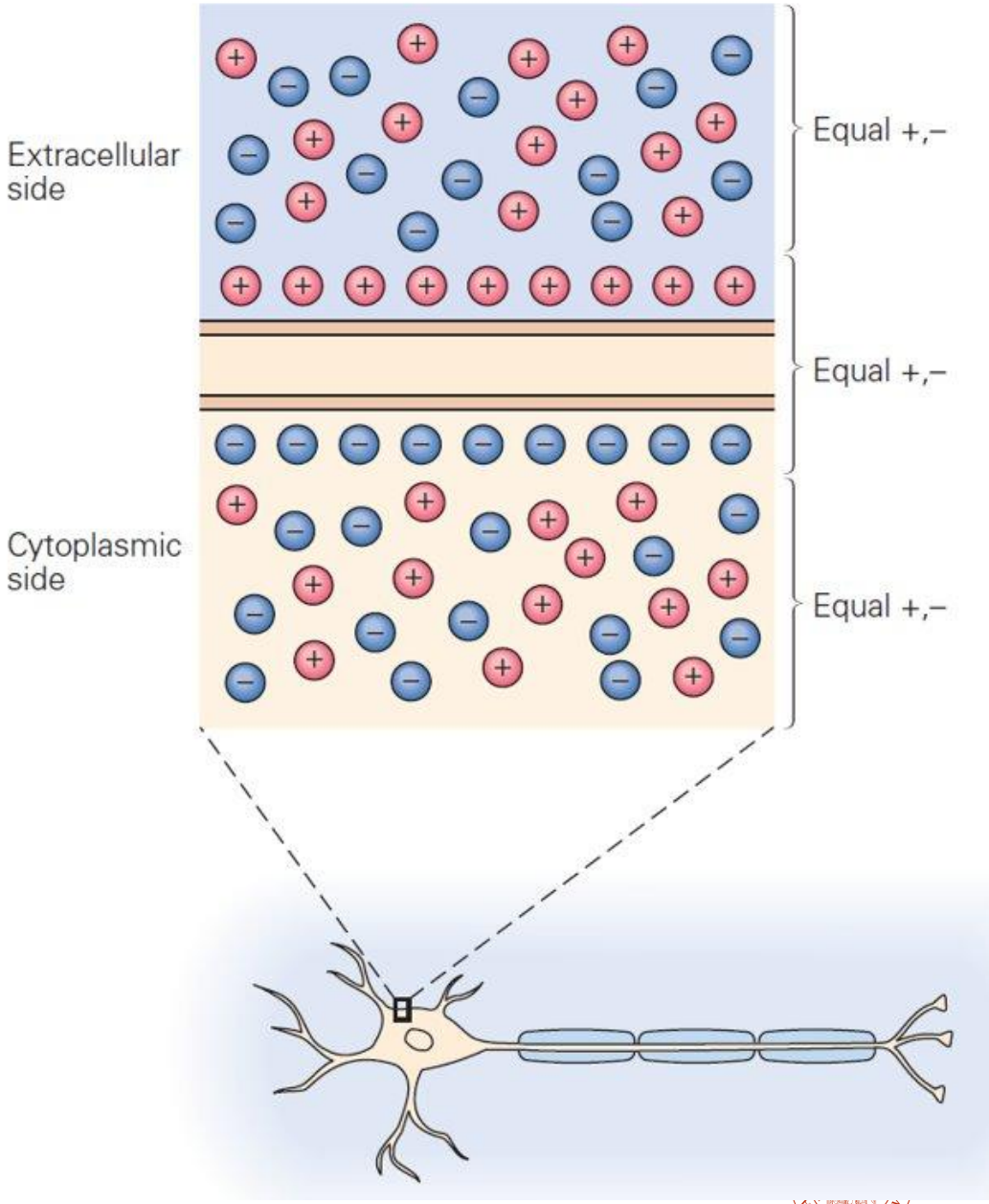
- In a resting neuron the voltage of the **inside** of the cell is about **70 mV more negative than** the voltage **outside** the cell

- 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

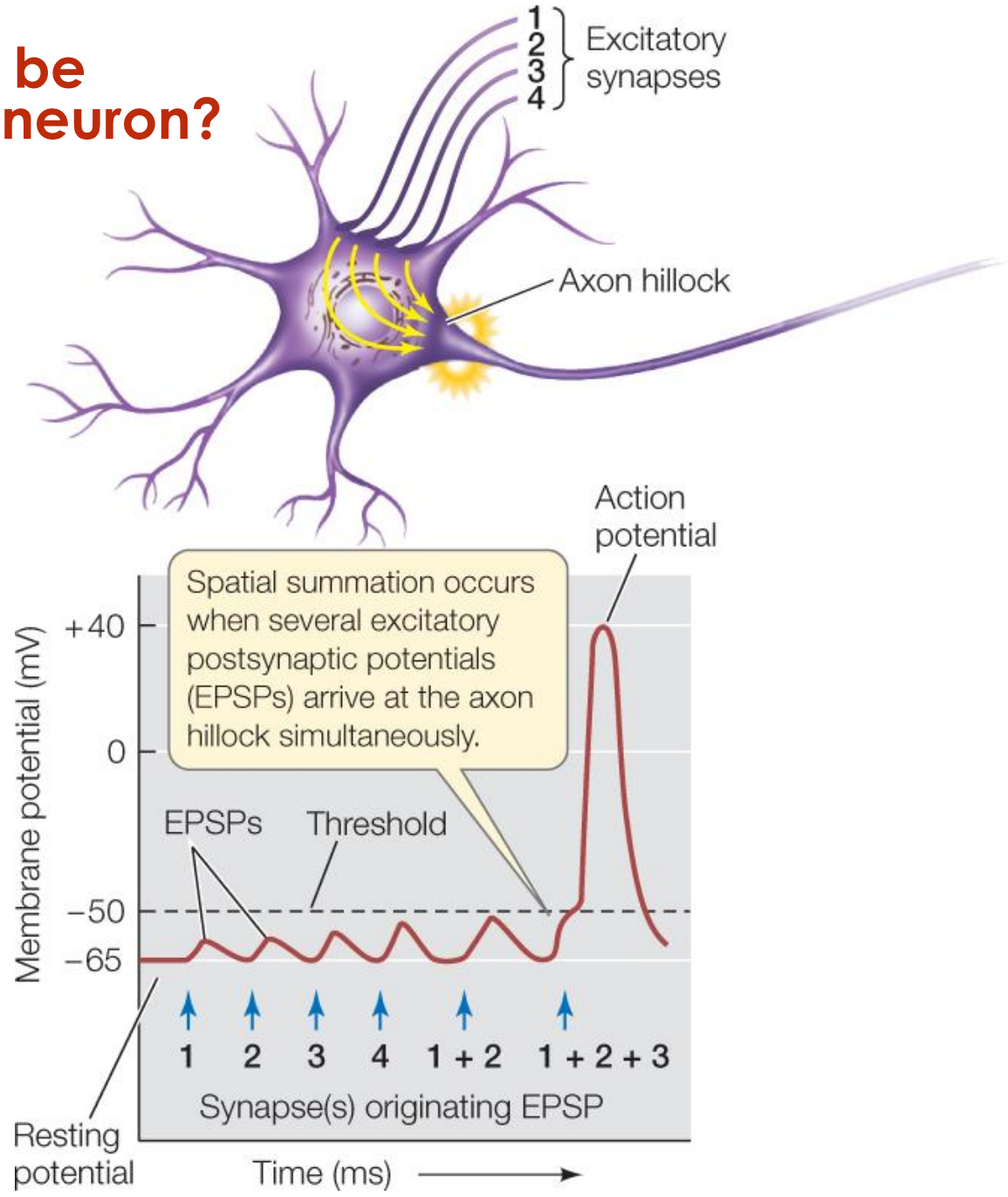
- It **arises from the asymmetric distribution of ions across the neuron's cell membrane:**
  - Electrochemical forces cause the inside of cell to have a more negative potential than the outside: **-70 mV**
- It is the baseline on which all signaling occurs
- It **can be quickly and significantly altered,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



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

Postsynaptic potentials (PSPs) are

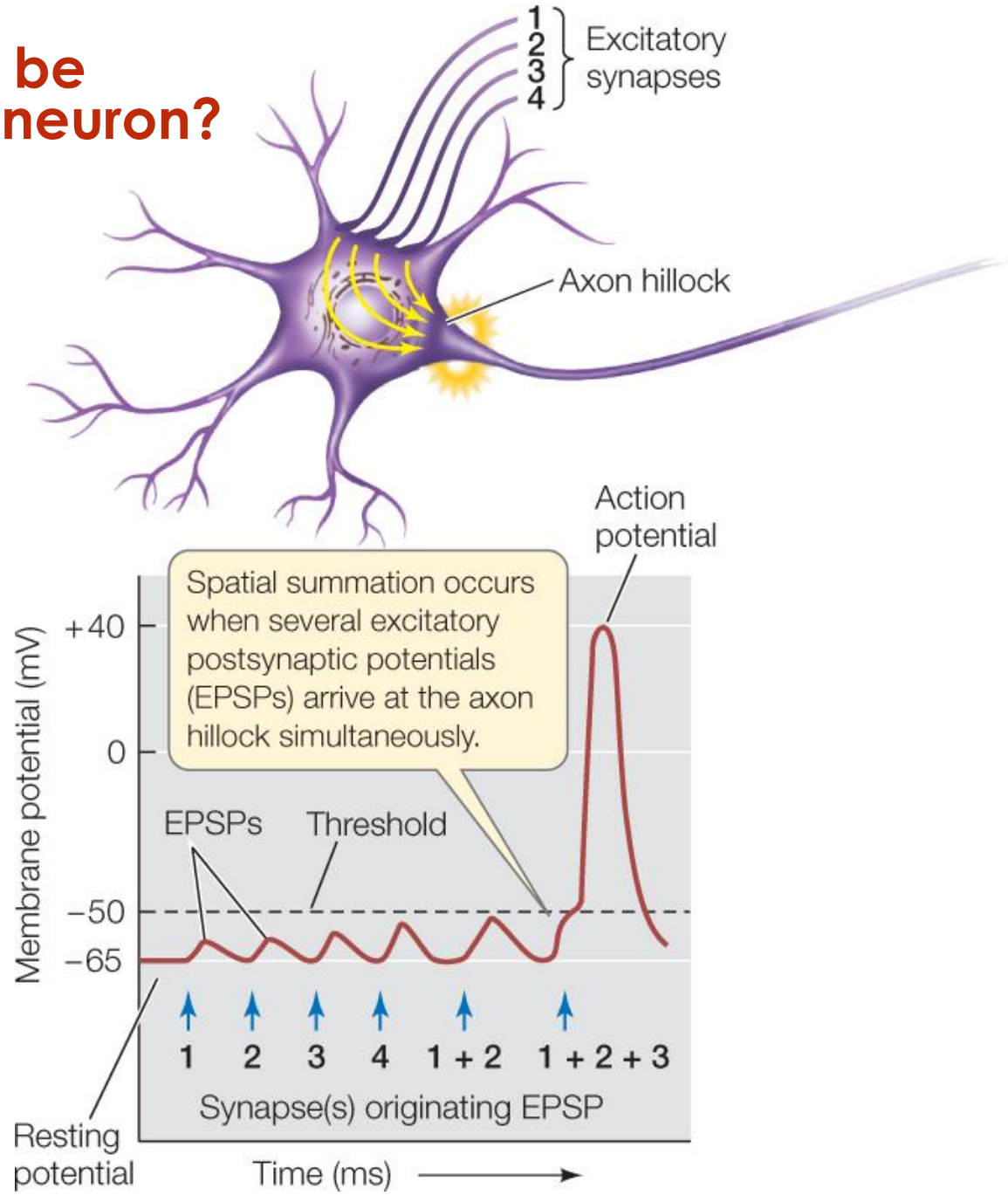
- **small changes in membrane potential** that move the cell away from its resting membrane potential
- **graded potentials**
    - The amount of change in the membrane potential is determined by the size of the stimulus that causes it
- **They have to cause a strong enough change in membrane potential**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



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

Postsynaptic potentials (PSPs) can be

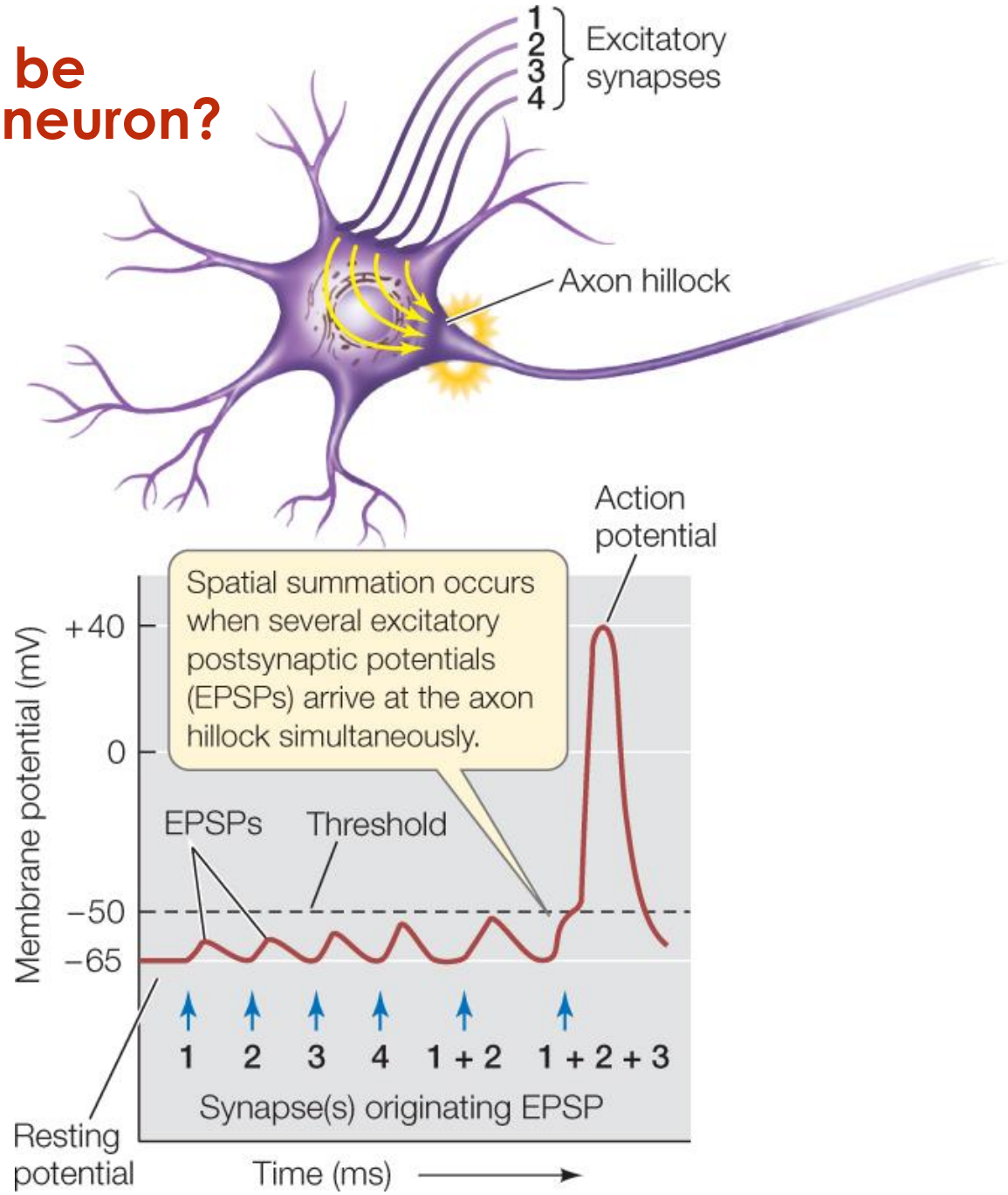
- **Depolarizing**
  - produce a **decrease in membrane potential**
  - Enhance the ability to generate action potential
  - **Excitatory** PSP



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

Postsynaptic potentials (PSPs) can be

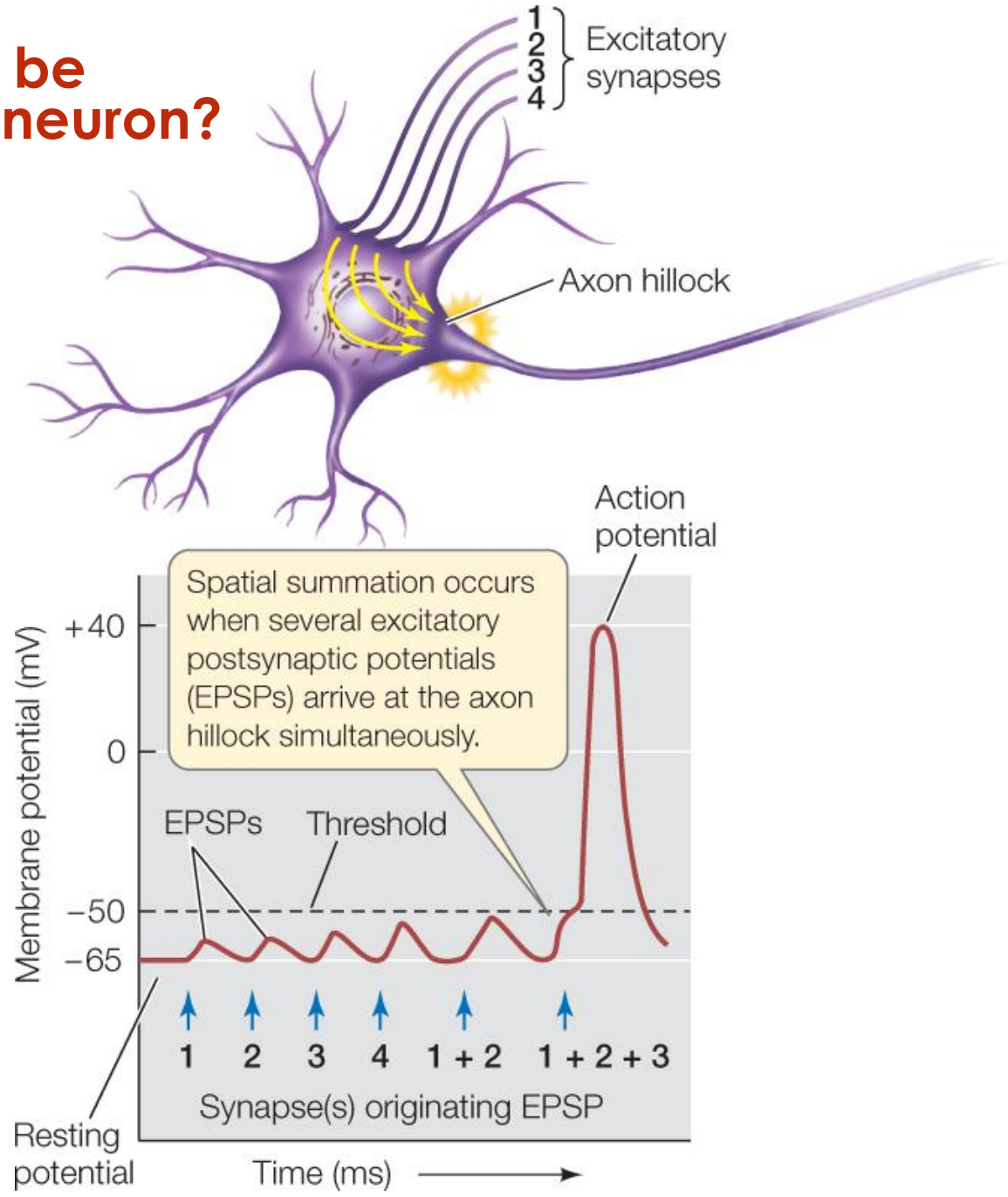
- **Depolarizing**
  - produce a **decrease in membrane potential**
  - Enhance the ability to generate action potential
  - **Excitatory** PSP
- **Hyperpolarizing**
  - produce an **increase in membrane potential**
  - Reduce the ability to generate action potential
  - **Inhibitory** PSP



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

Postsynaptic potentials (PSPs) are

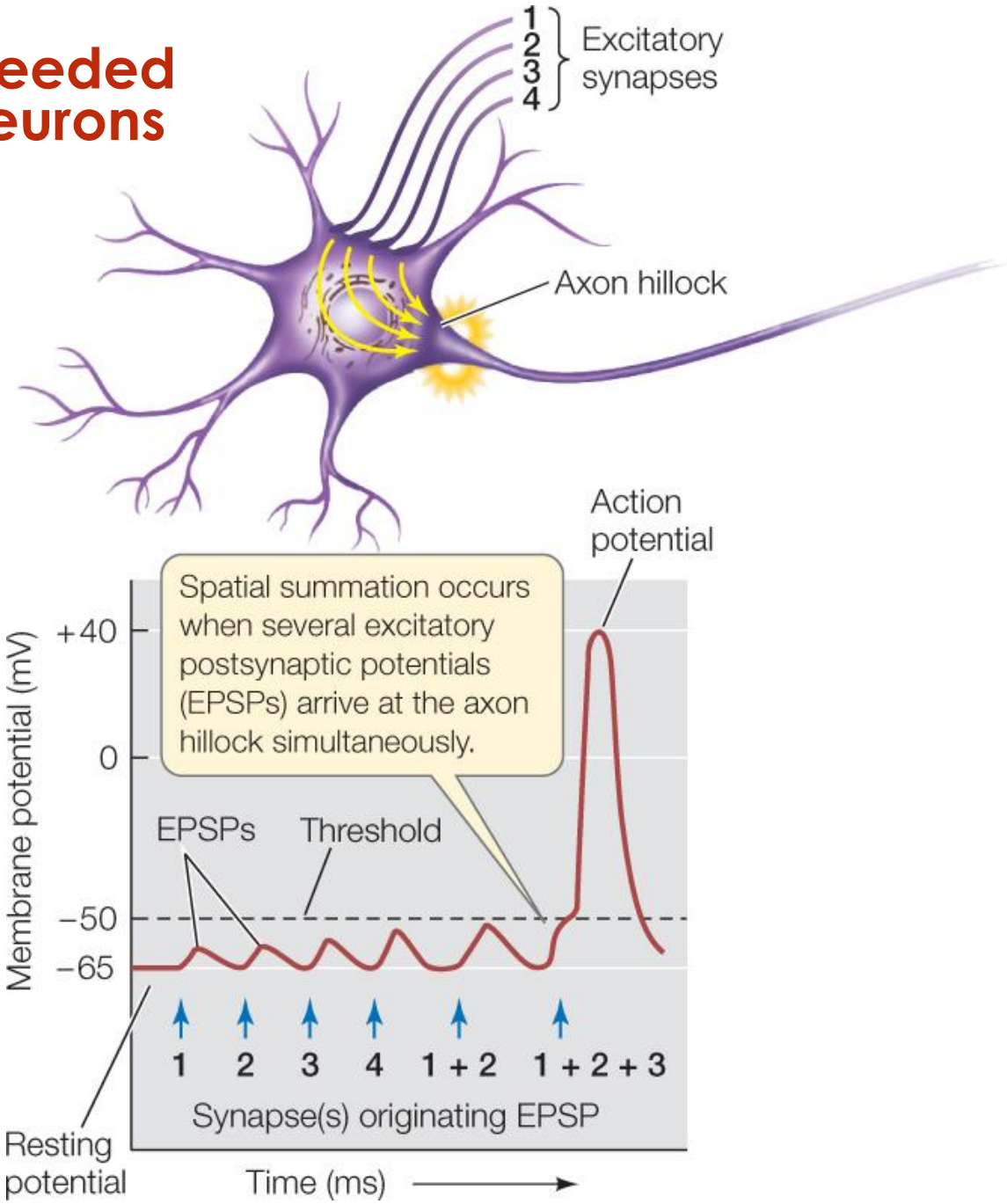
- **Small in amplitude**
- **Passively conducted** through the cytoplasm of the dendrite and cell body
  - **decremental conduction**: it diminishes with distance from its origin (i.e. the synapse)
  - Will flow for maximum 1mm → too short to enable signal transmission down the entire the axon
  - **a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



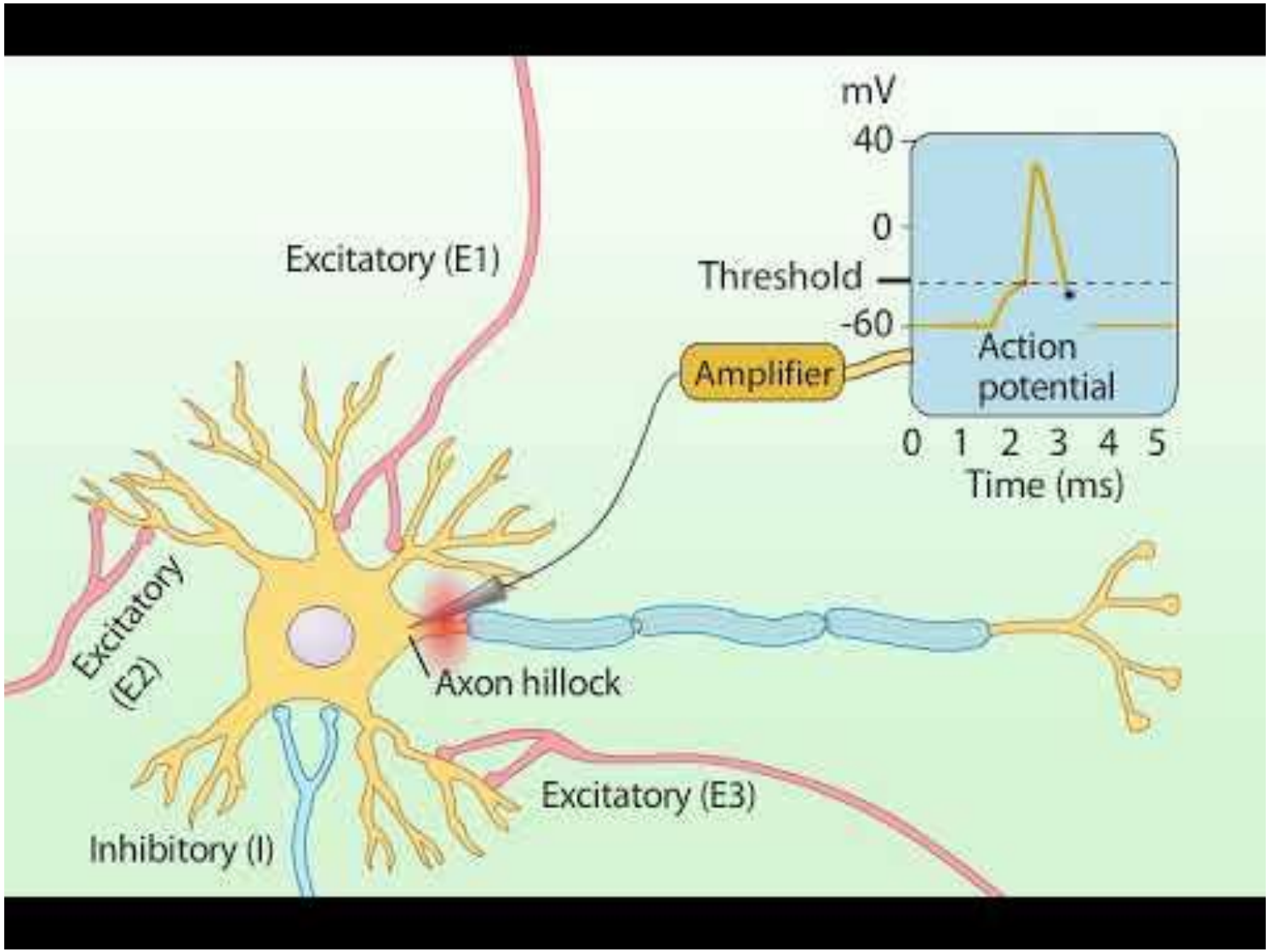
Input from many presynaptic neurons is needed to generate an action potential in most neurons

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)



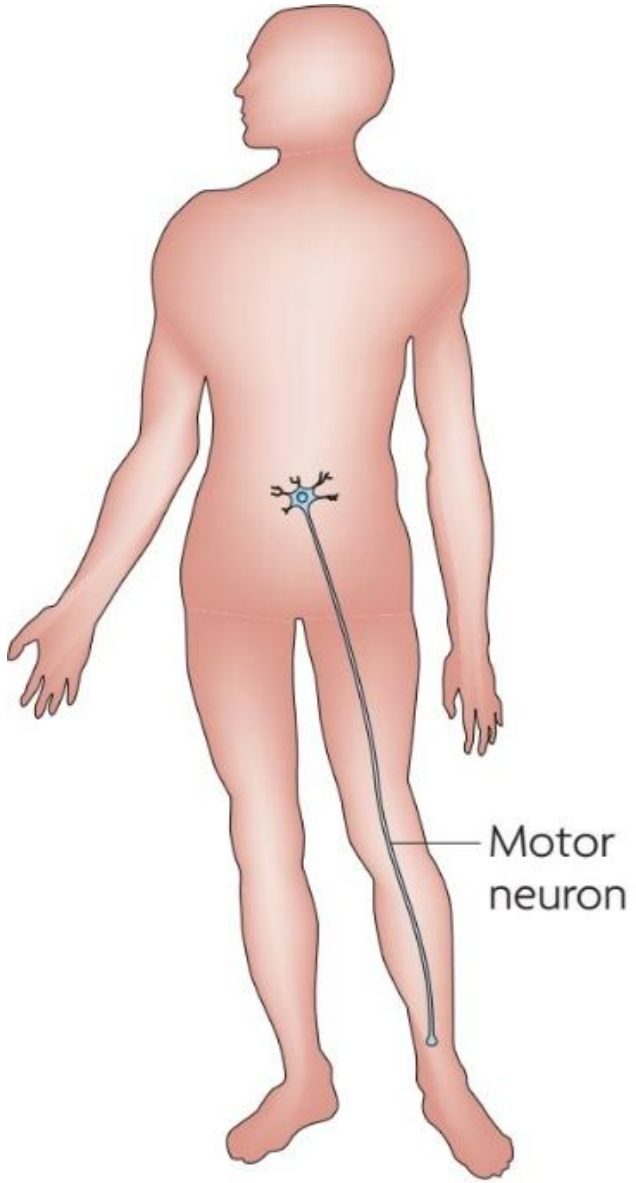
https://www.youtube.com/watch?v=B92rsa1is_k

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 and fast**



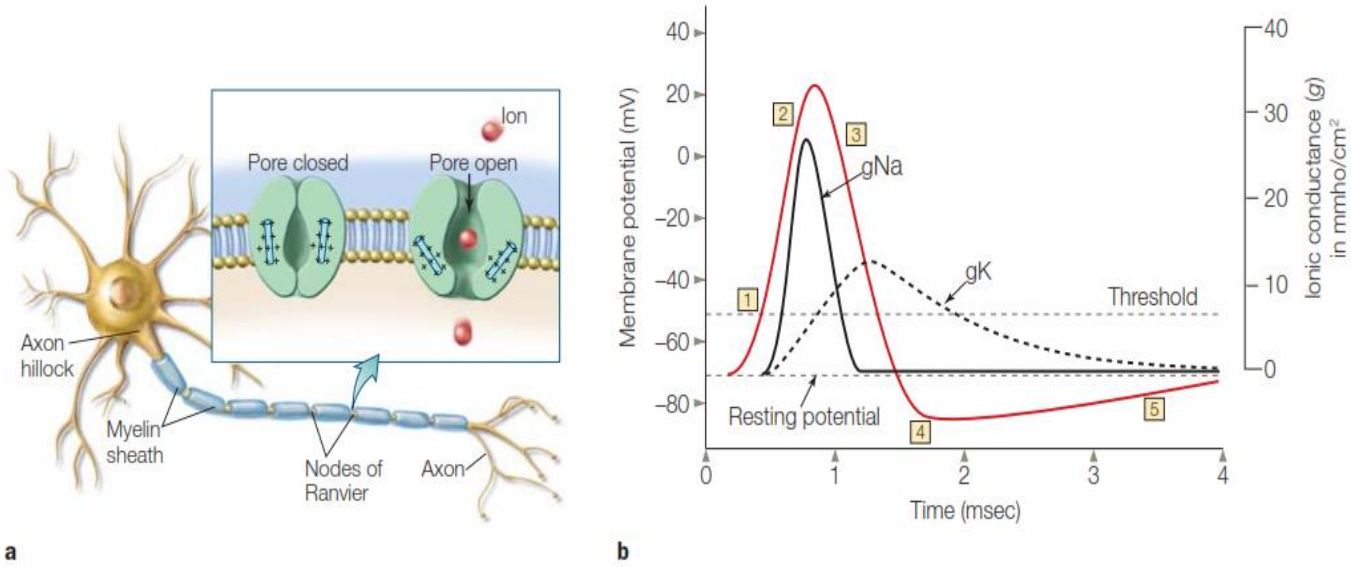
Neurons evolved a clever mechanisms to overcome this challenge

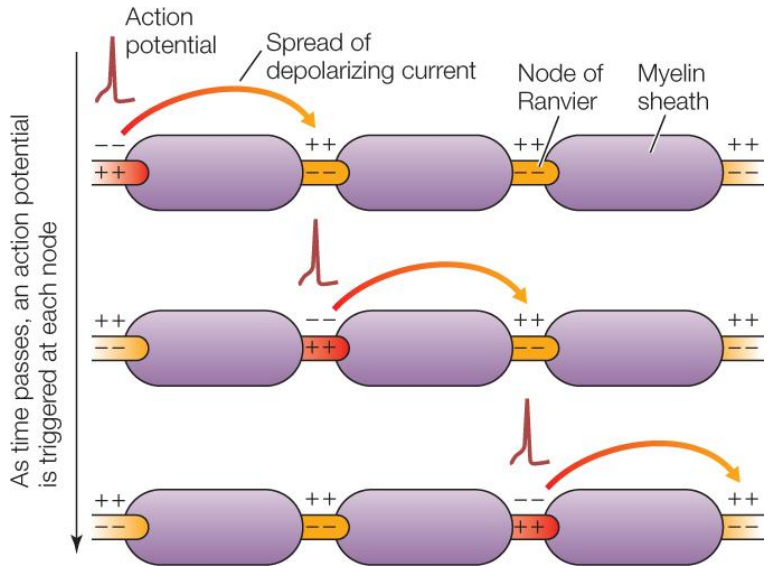
1. Travelling **far**: the **Action Potential (AP)**

- 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**

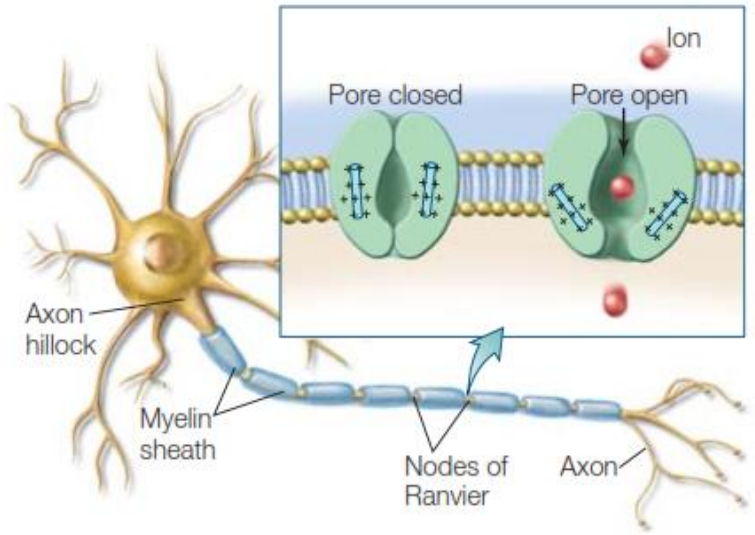
- APs are generated only at specific locations along the axon (i.e. Nodes of Ranvier)
- The AP "jumps" down the axon





Travelling far: 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 (binary) nature



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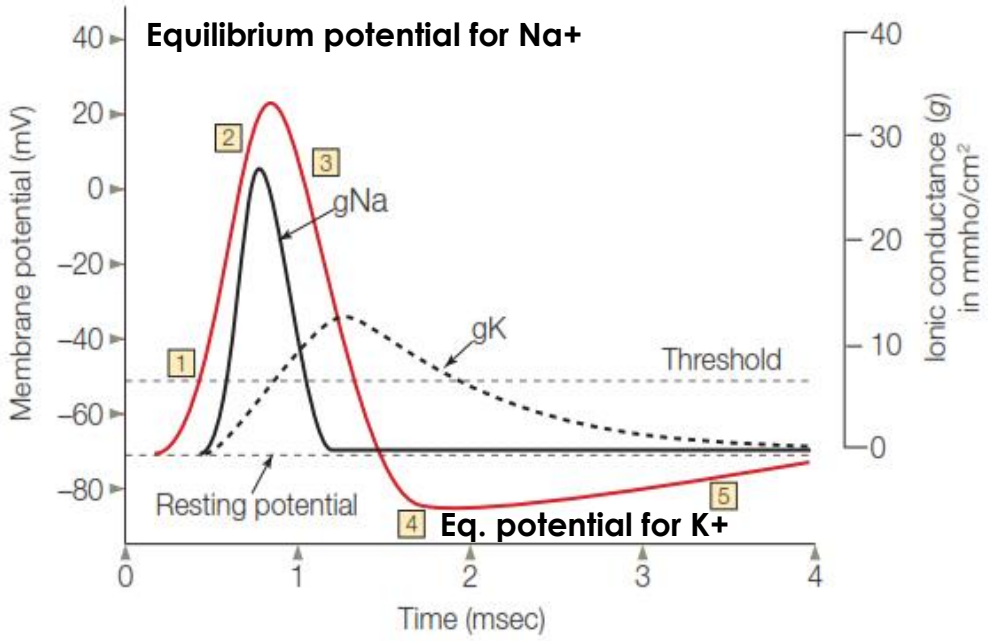


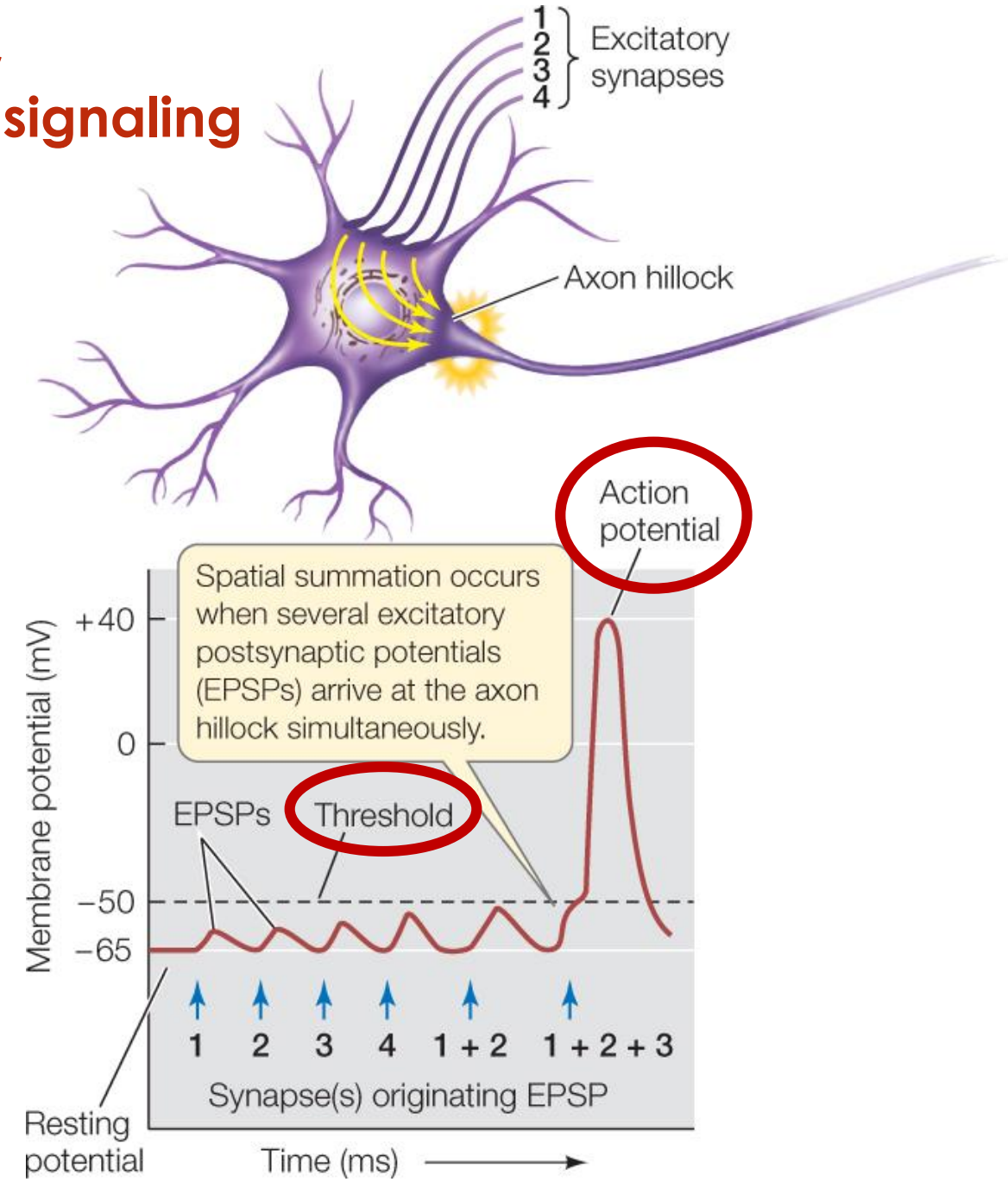
b

Travelling far: Action potentials have four properties that enable efficient neuronal signaling

1. Threshold for initiation

- The AP is triggered only if summation of PSPs depolarizes the cell membrane to at least -55mV
- Functional implication:

_____

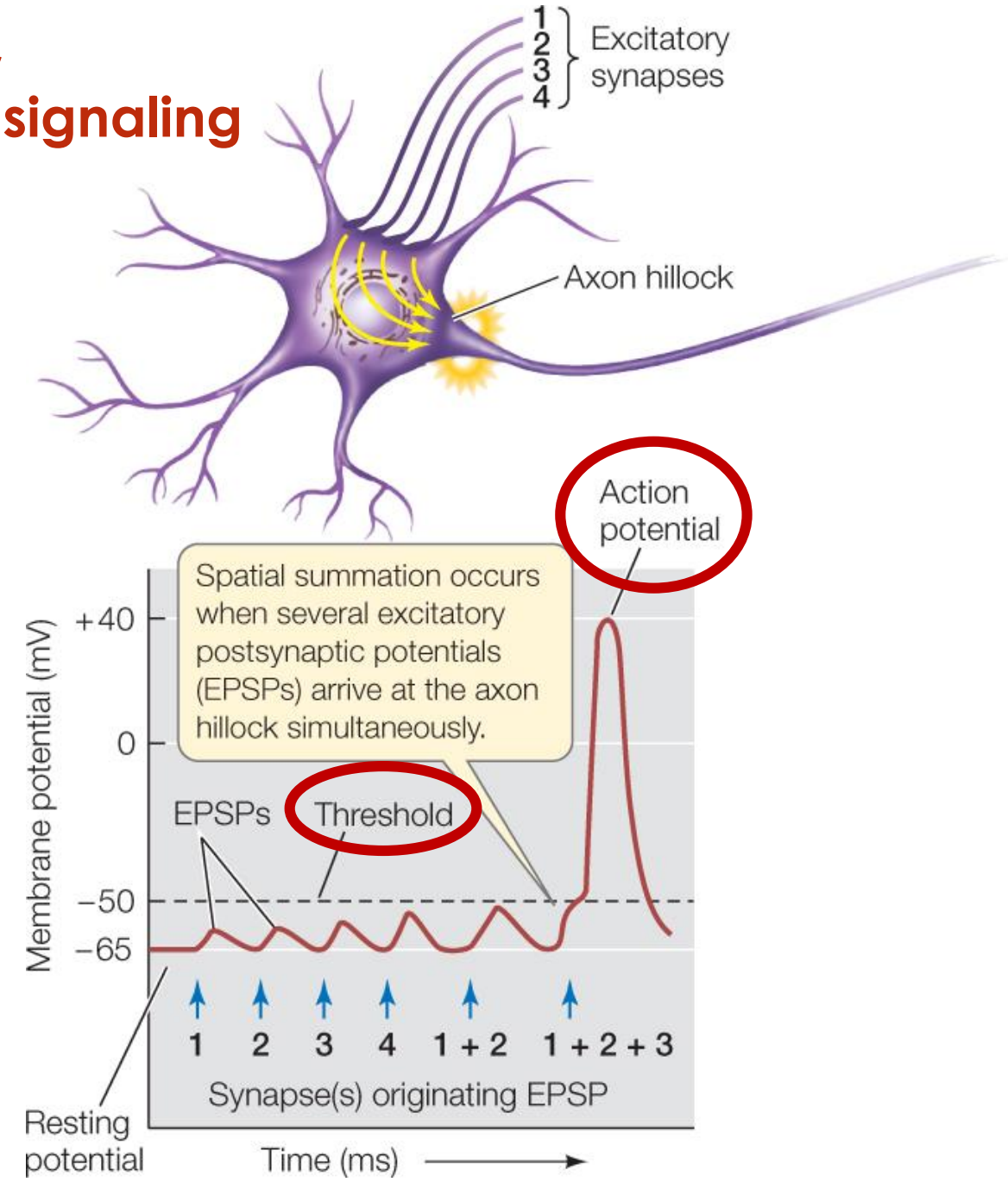


Travelling far: Action potentials have four properties that enable efficient neuronal signaling

1. Threshold for initiation

- The AP is triggered only if summation of PSPs depolarizes the cell membrane to at least -55mV
- Functional implication:

only "meaningful" information leads to an AP

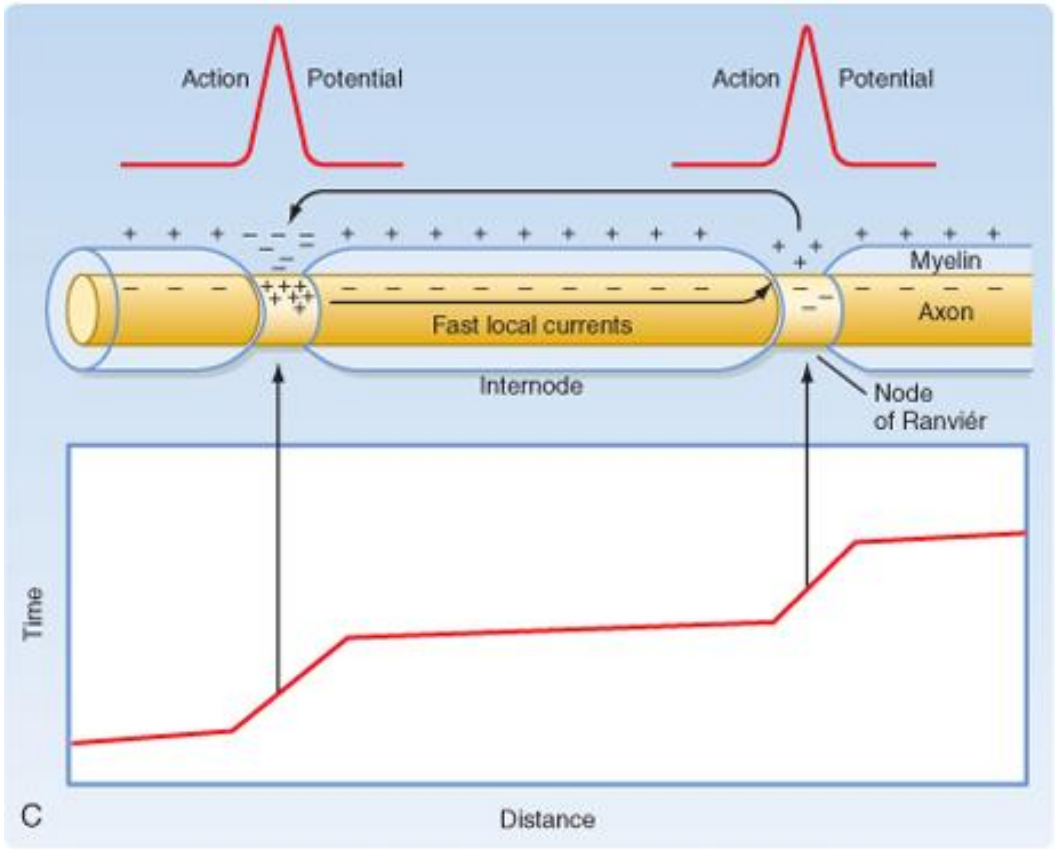


Travelling far: Action potentials have four properties that enable efficient neuronal signaling

2. Conducted without decrement

- The AP is actively propagated & **self-regenerative**
- Functional implication:

_____

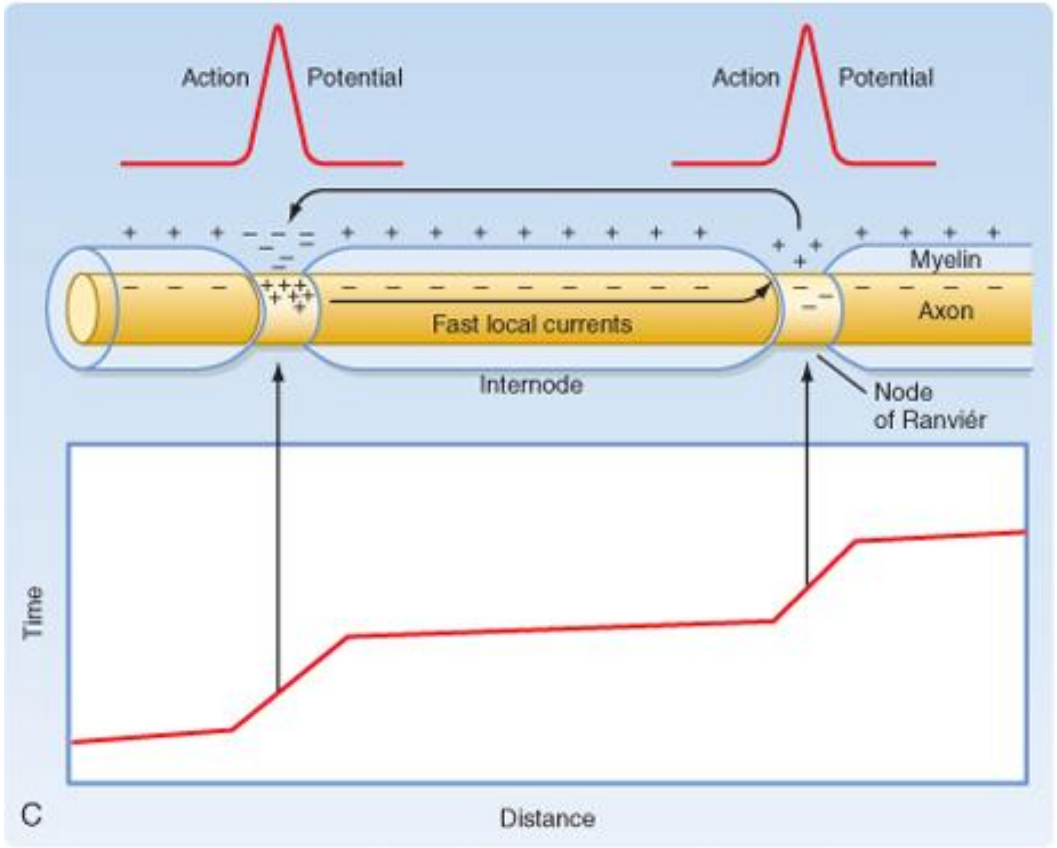


Travelling far: Action potentials have four properties that enable efficient neuronal signaling

2. Conducted without decrement

- The AP is actively propagated & **self-regenerative**
- Functional implication:

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

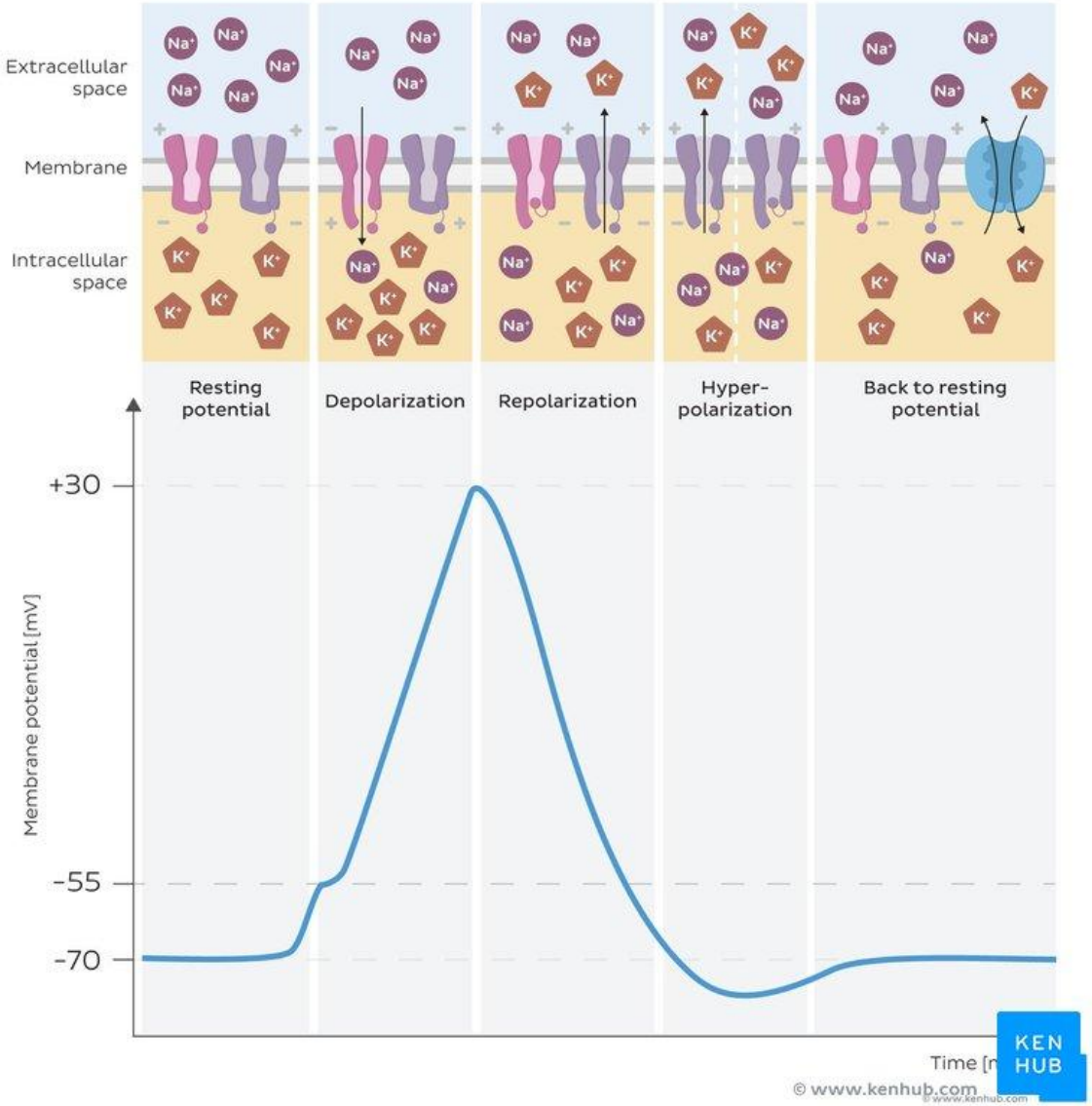


Travelling far: Action potentials have four properties that enable efficient neuronal signaling

2. Conducted without decrement

- The AP is actively propagated & **self-regenerative**

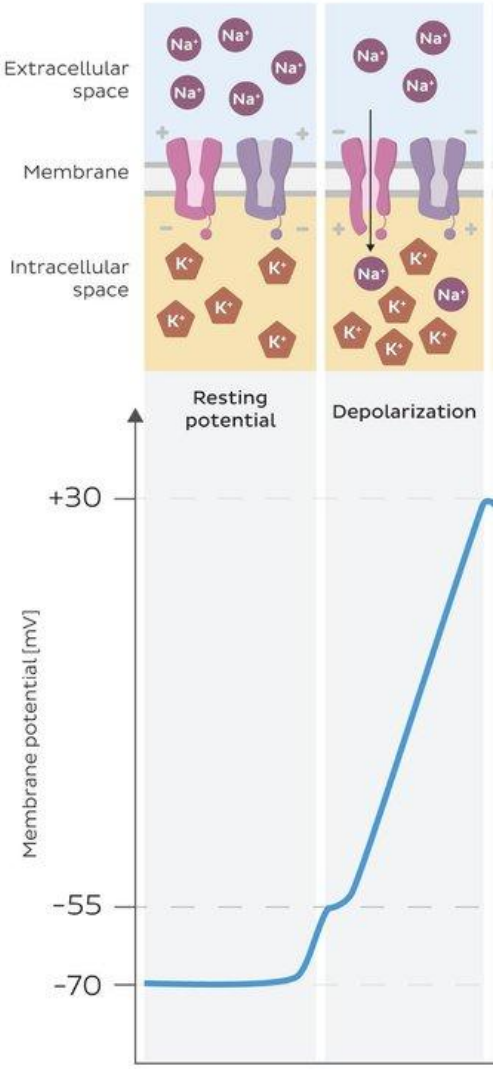
HOW DOES THIS HAPPEN?



Travelling far: Action potentials have four properties that enable efficient neuronal signaling

2. Conducted without decrement

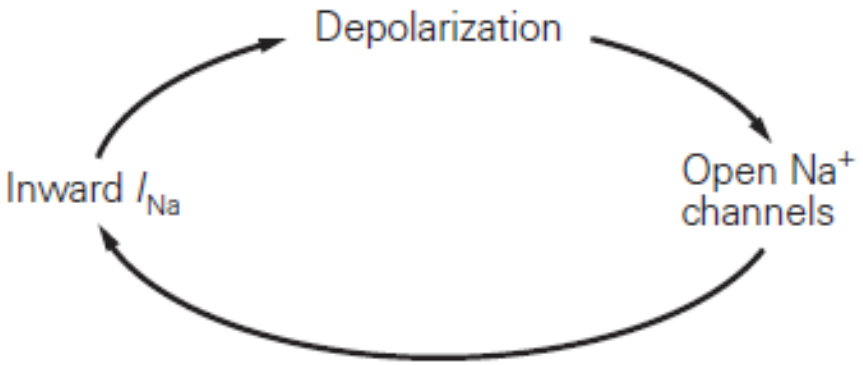
- Depolarization causes **voltage-gated Na+ channels** to open → Na+ flows into the neuron down its concentration gradient

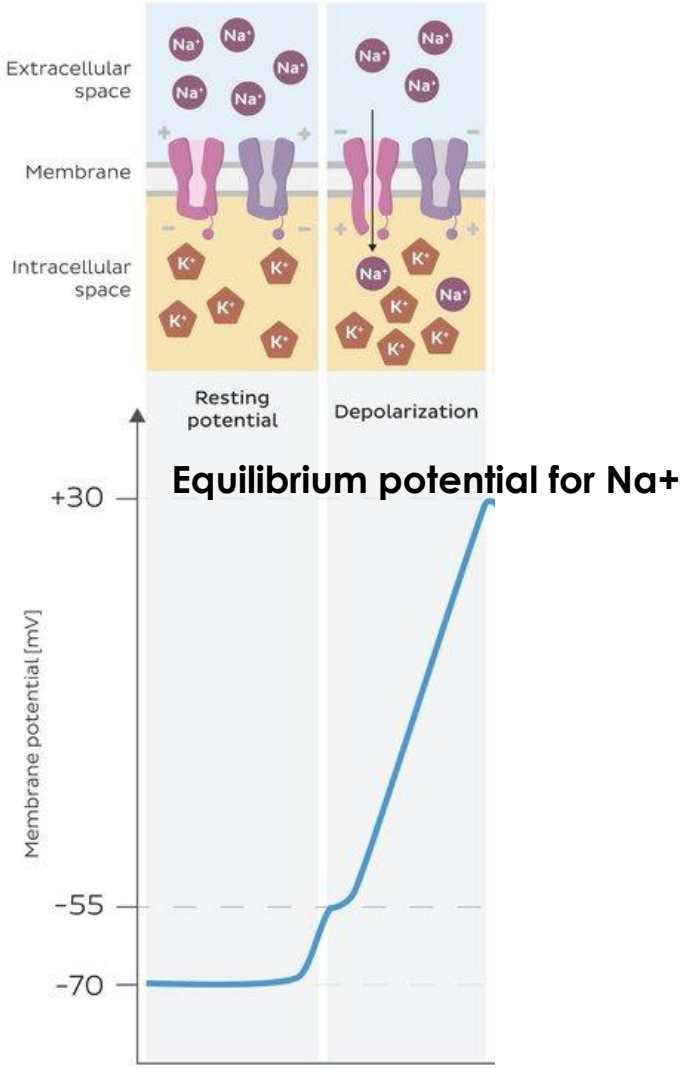


Travelling far: Action potentials have four properties that enable efficient neuronal signaling

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+

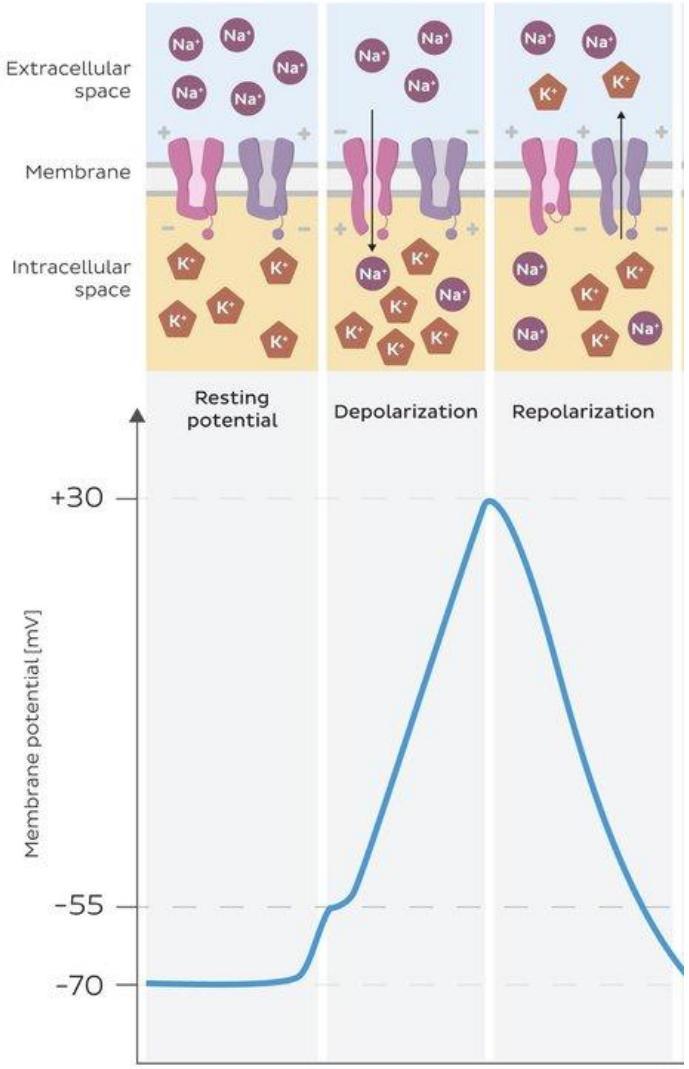




Travelling far: Action potentials have four properties that enable efficient neuronal signaling

2. Conducted without decrement

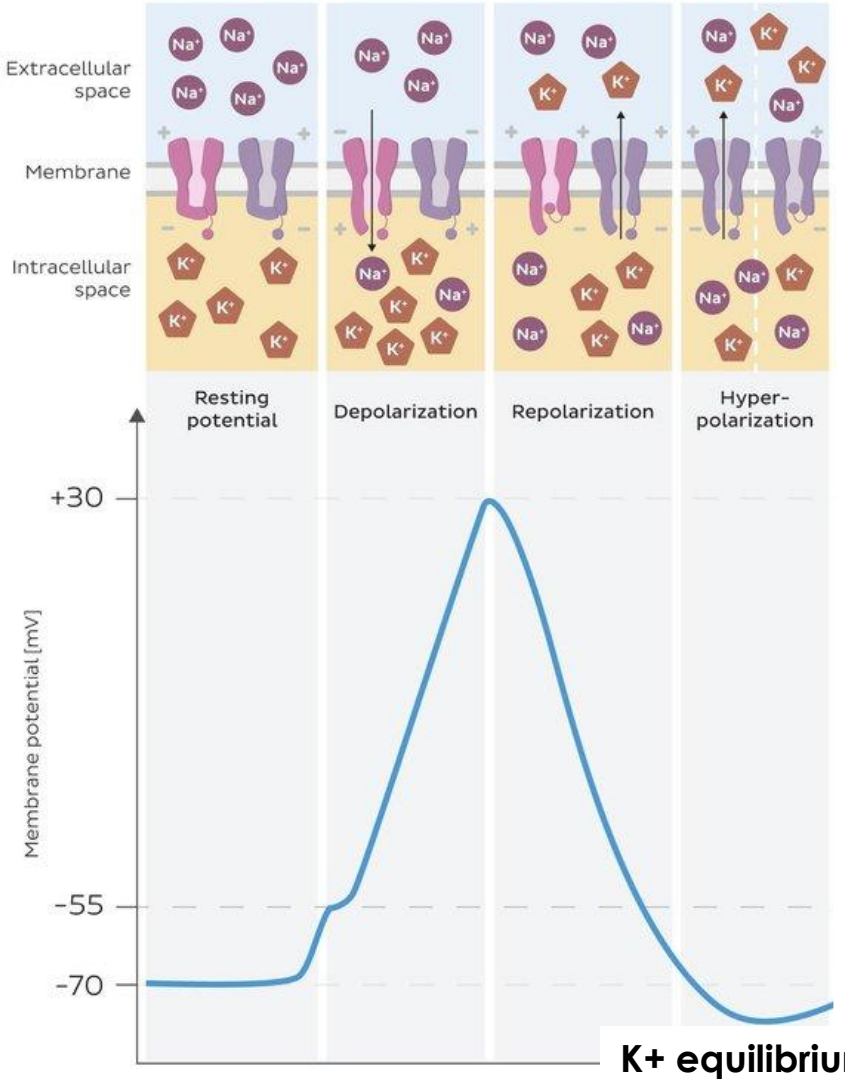
- Then, **voltage-gated K+ channels open**, allowing K+ to flow out of the neuron down its concentration gradient
- This shifts the membrane potential back toward
    - its resting potential



Travelling far: 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
- This shifts the membrane potential back toward
    - its resting potential and even slightly below it
    - to the K+ equilibrium potential, which is more negative than the resting potential, causing **hyperpolarization**

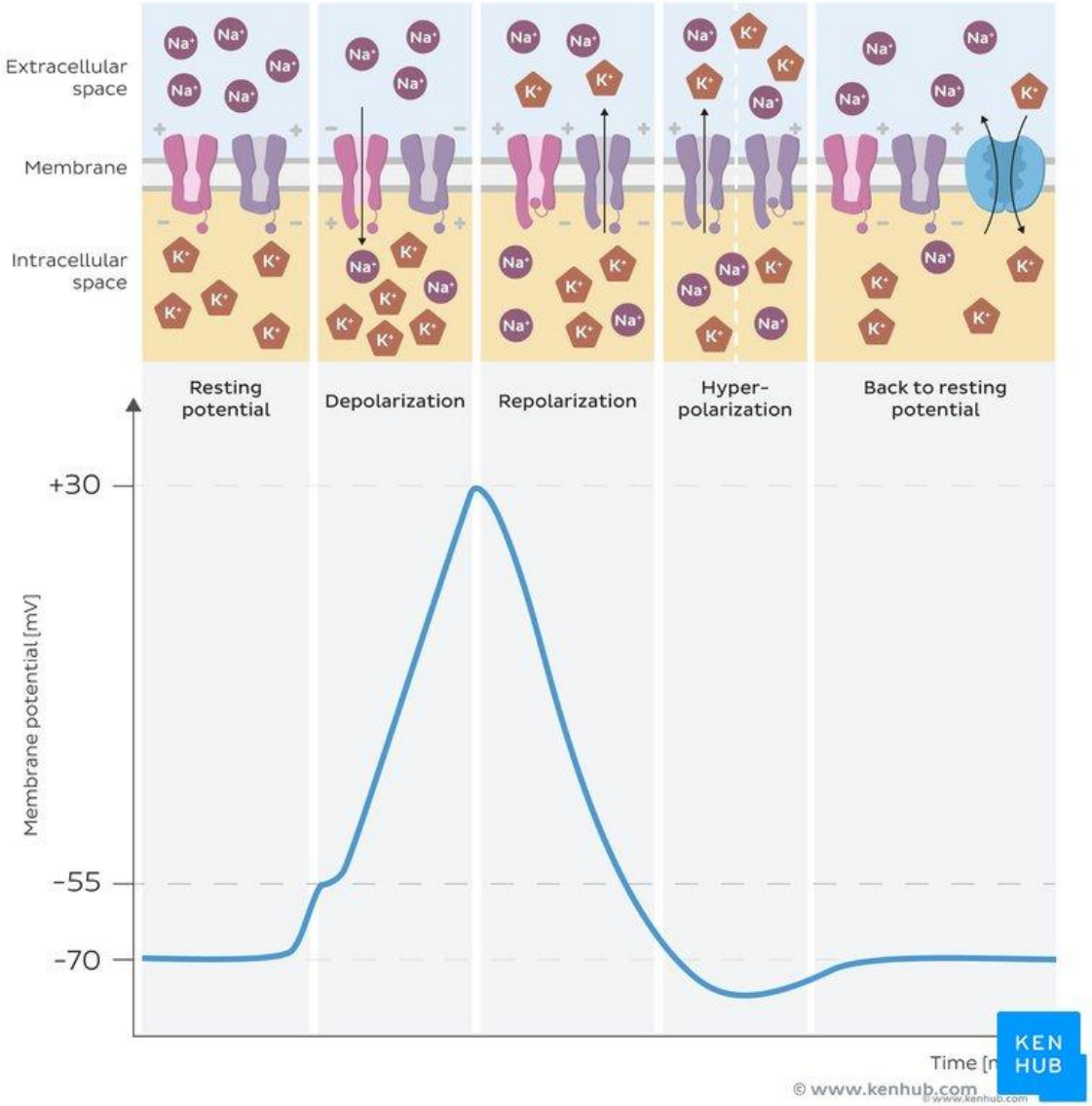


K+ equilibrium potential

Travelling far: Action potentials have four properties that enable efficient neuronal signaling

2. Conducted without decrement

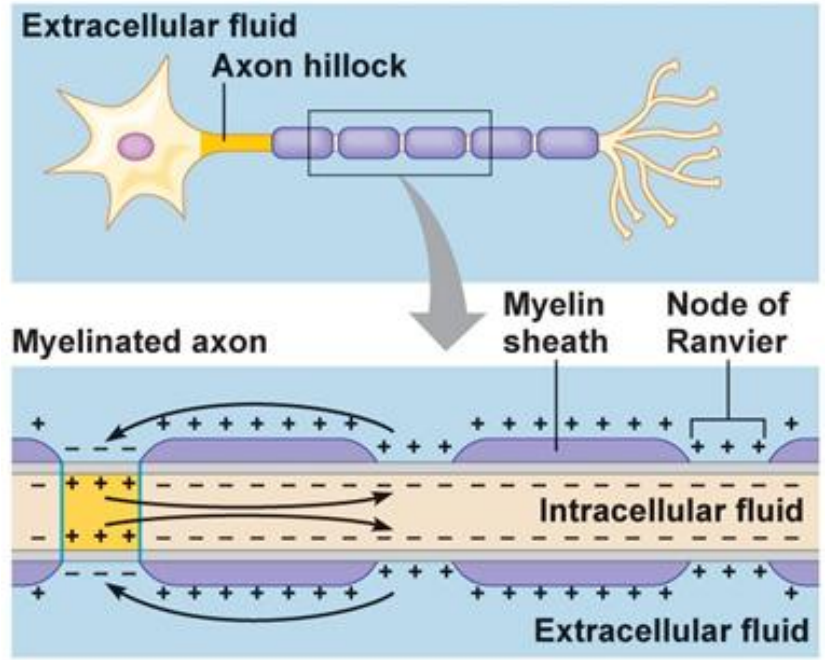
- K+ channels then close
- The membrane potential can return to its resting state

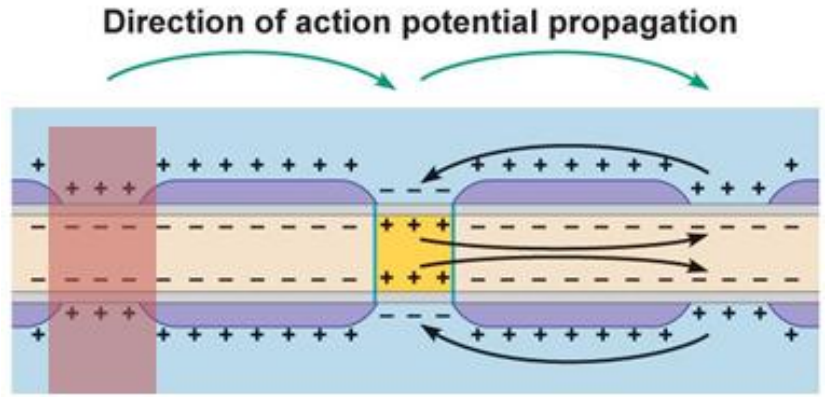


Travelling far: Action potentials have four properties that enable efficient neuronal signaling

3. Refractory period

- During hyperpolarization the voltage-gated Na+ channels cannot open
- Functional implications:
    1. _____
    2. _____



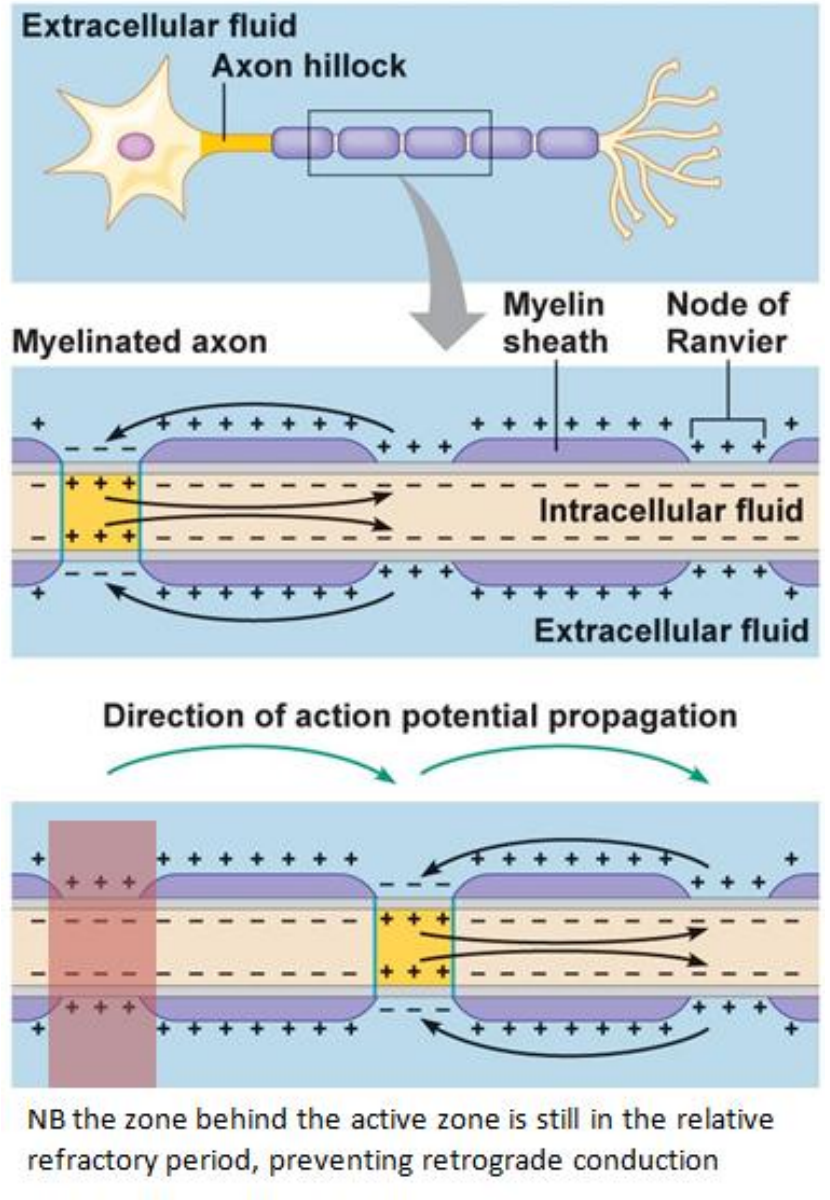


NB the zone behind the active zone is still in the relative refractory period, preventing retrograde conduction

Travelling far: Action potentials have four properties that enable efficient neuronal signaling

3. Refractory period

- During hyperpolarization the voltage-gated Na+ channels cannot open
- Functional implications:
    1. Limits the frequency of APs (i.e. # of APs that a neuron can generate in a given time), preventing overstimulation
    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

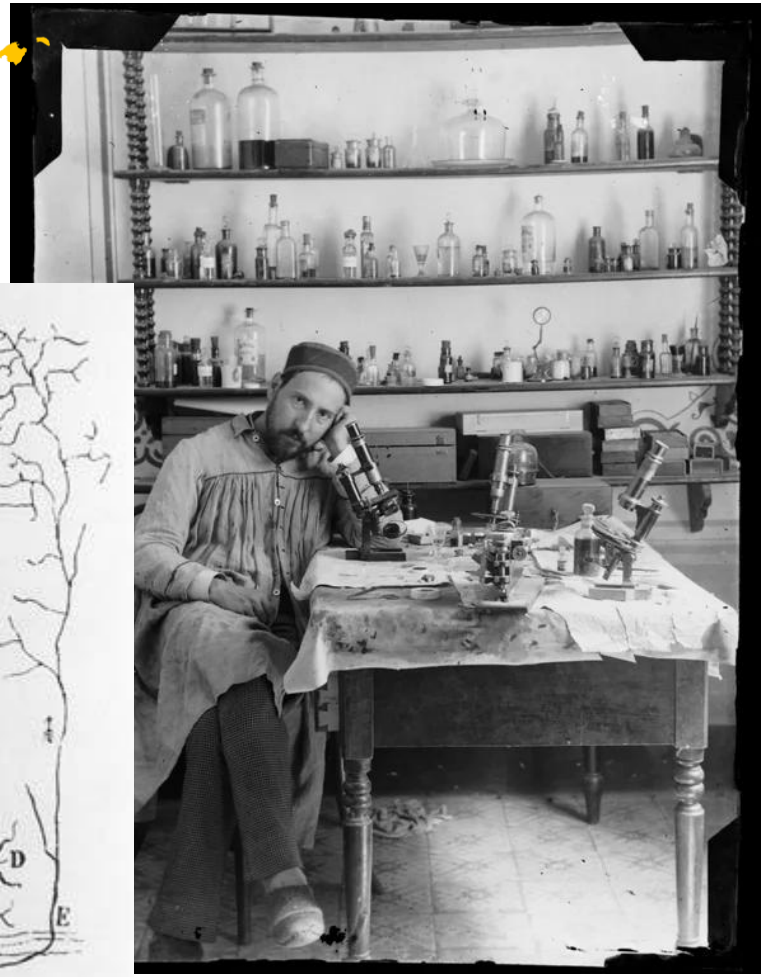


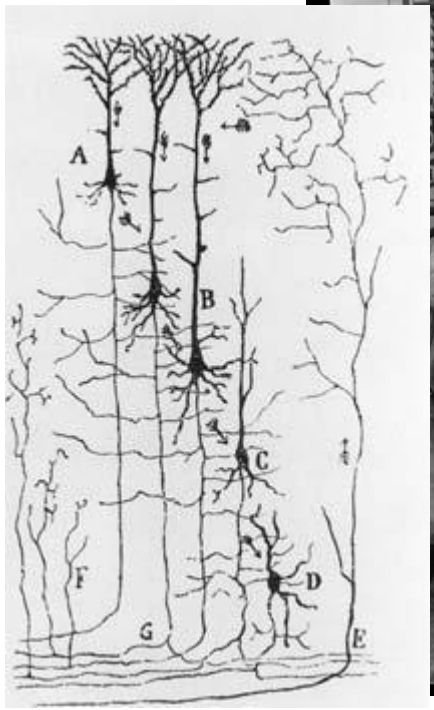
NB the zone behind the active zone is still in the relative refractory period, preventing retrograde conduction

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





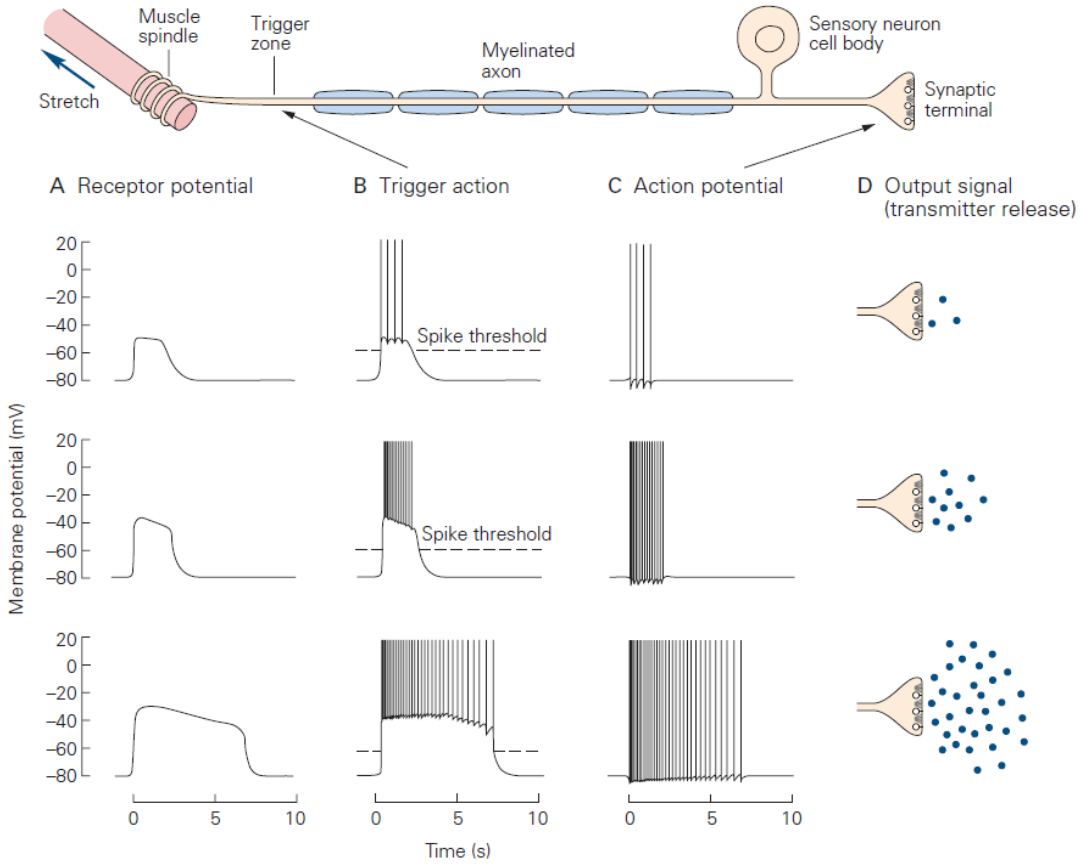
Ramón y Cajal's drawing of the afferent inflow to the mammalian cortex

Santiago Ramón y Cajal (1852–1934)

Travelling far: Action potentials have four properties that enable efficient neuronal signaling

4. All-or-none (binary) 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:



Travelling far: Action potentials have four properties that enable efficient neuronal signaling

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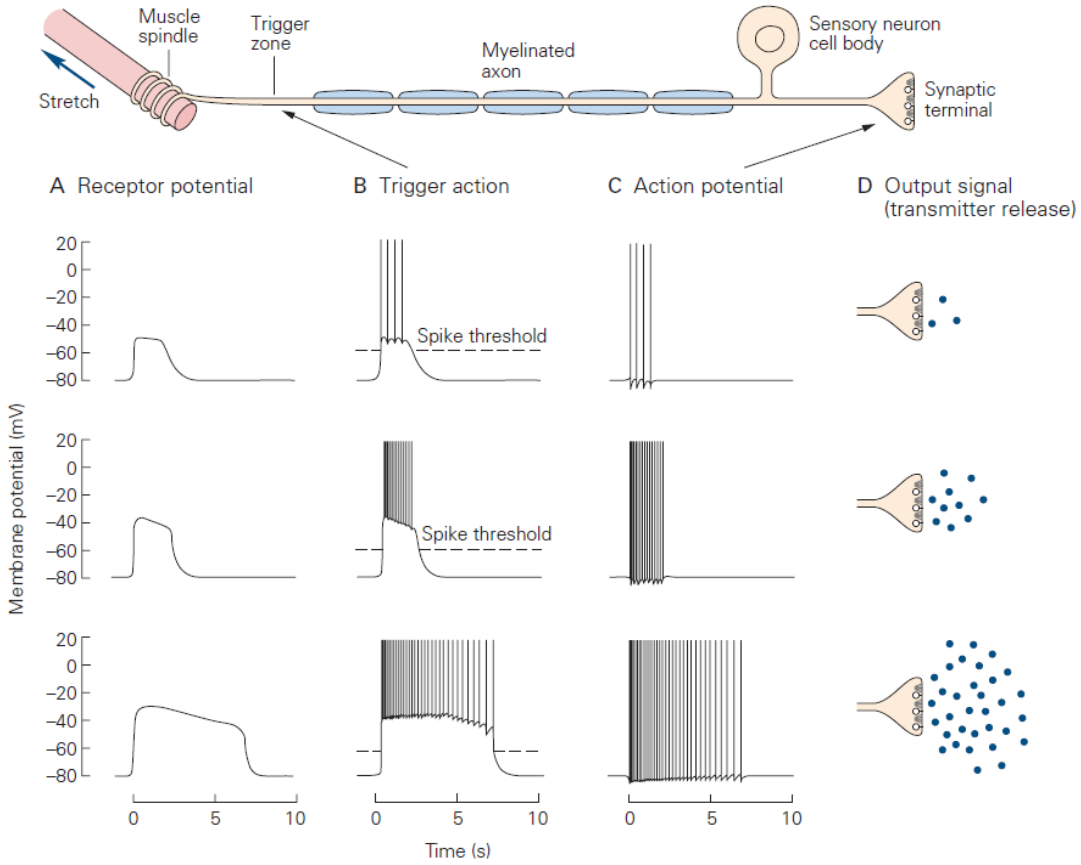
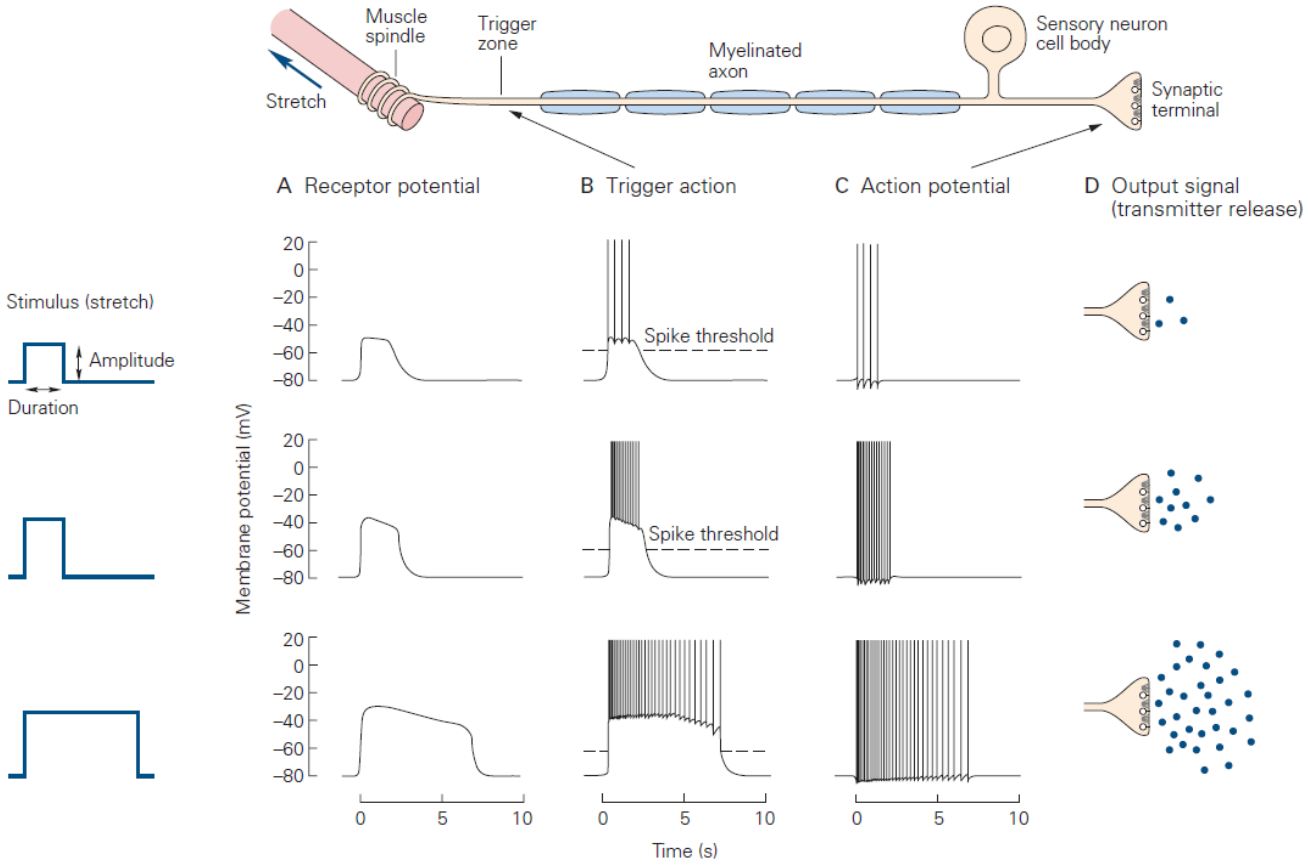
the amplitude of the AP does not communicate anything about the strength of the input stimulus

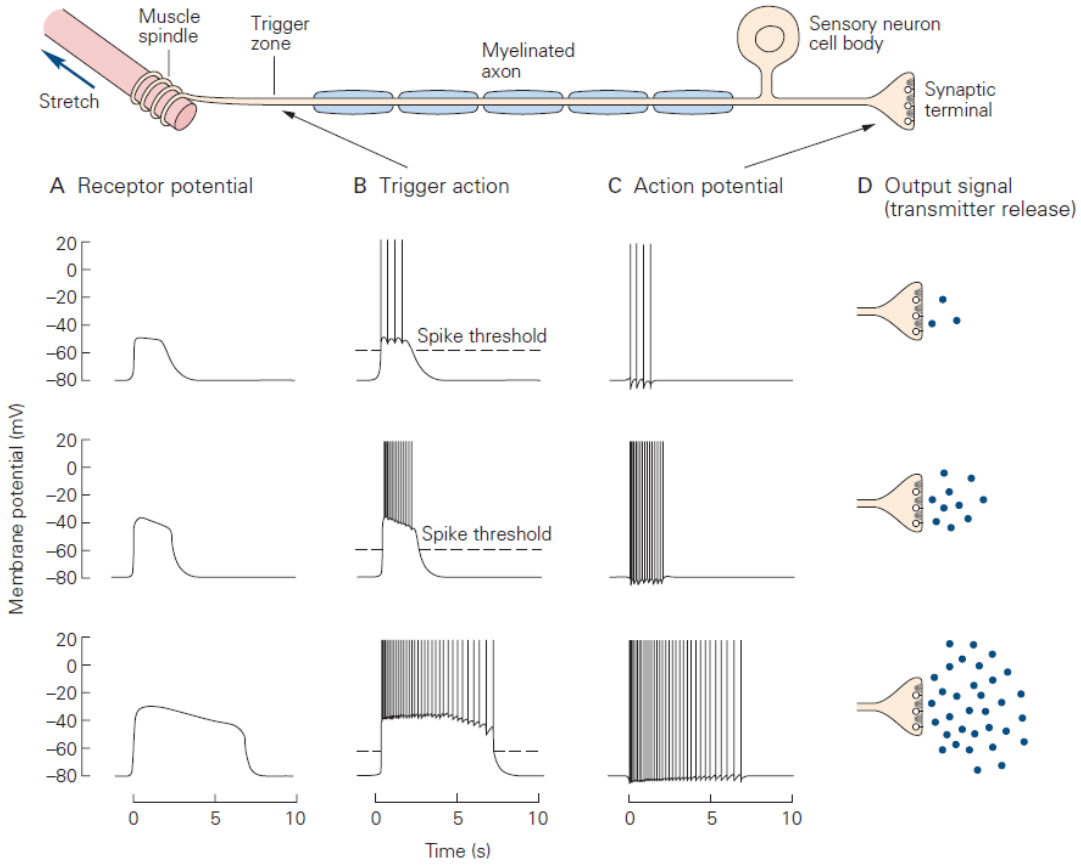


So how does the neuron communicate information about the strength of the input stimulus?



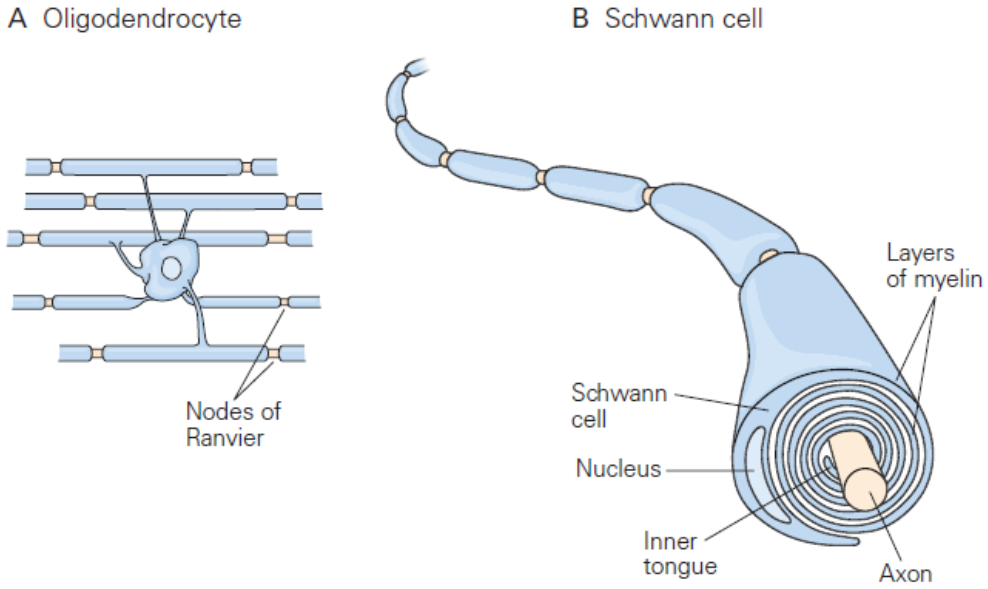
So how does the neuron communicate information about the strength of the input stimulus?

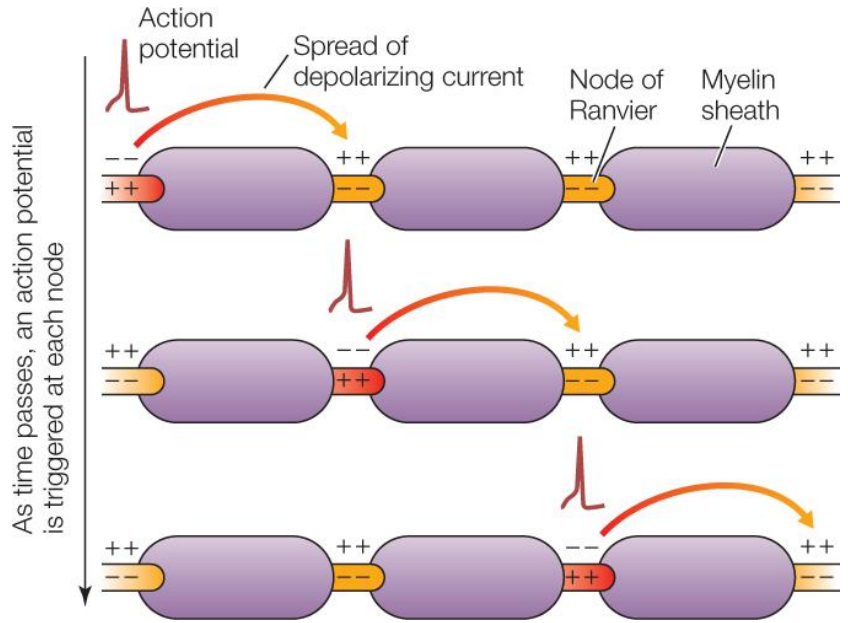
- Once the threshold is surpassed an action potential is generated
- Action potentials are all-or-none (binary): they all have a similar amplitude and duration
- Any further increase in amplitude of the input can only increase the **frequency of action potentials**
- The duration of the input determines 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.
- More intense stimuli elicit higher rates of action potentials.



Travelling fast: Saltatory conduction

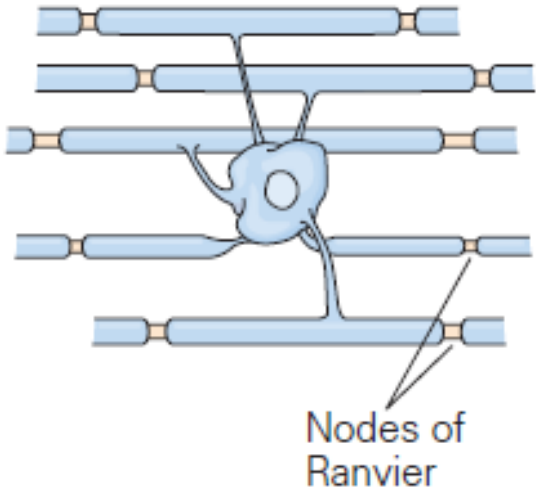
- Appearance that the AP "jumps" down the axon
- Oligodendrocytes (in CNS) and Schwann cells (in PNS) produce thin sheets of myelin that wrap around the axon of neurons
- Myelin
  - provides the insulating material along the axon → resistance to voltage loss
  - allows rapid conduction of APs along the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

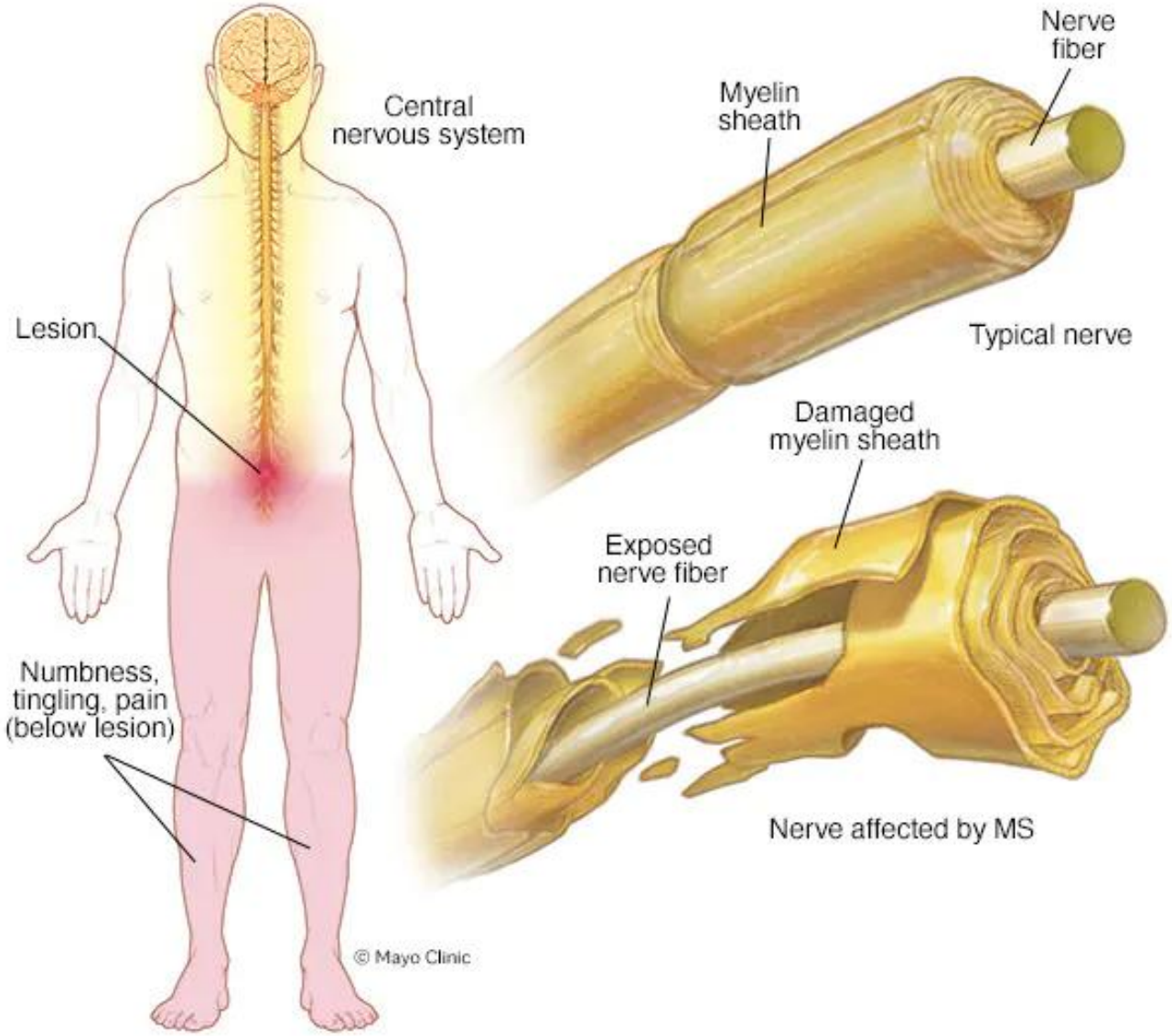




Signaling support: oligodendrocytes (in the CNS)

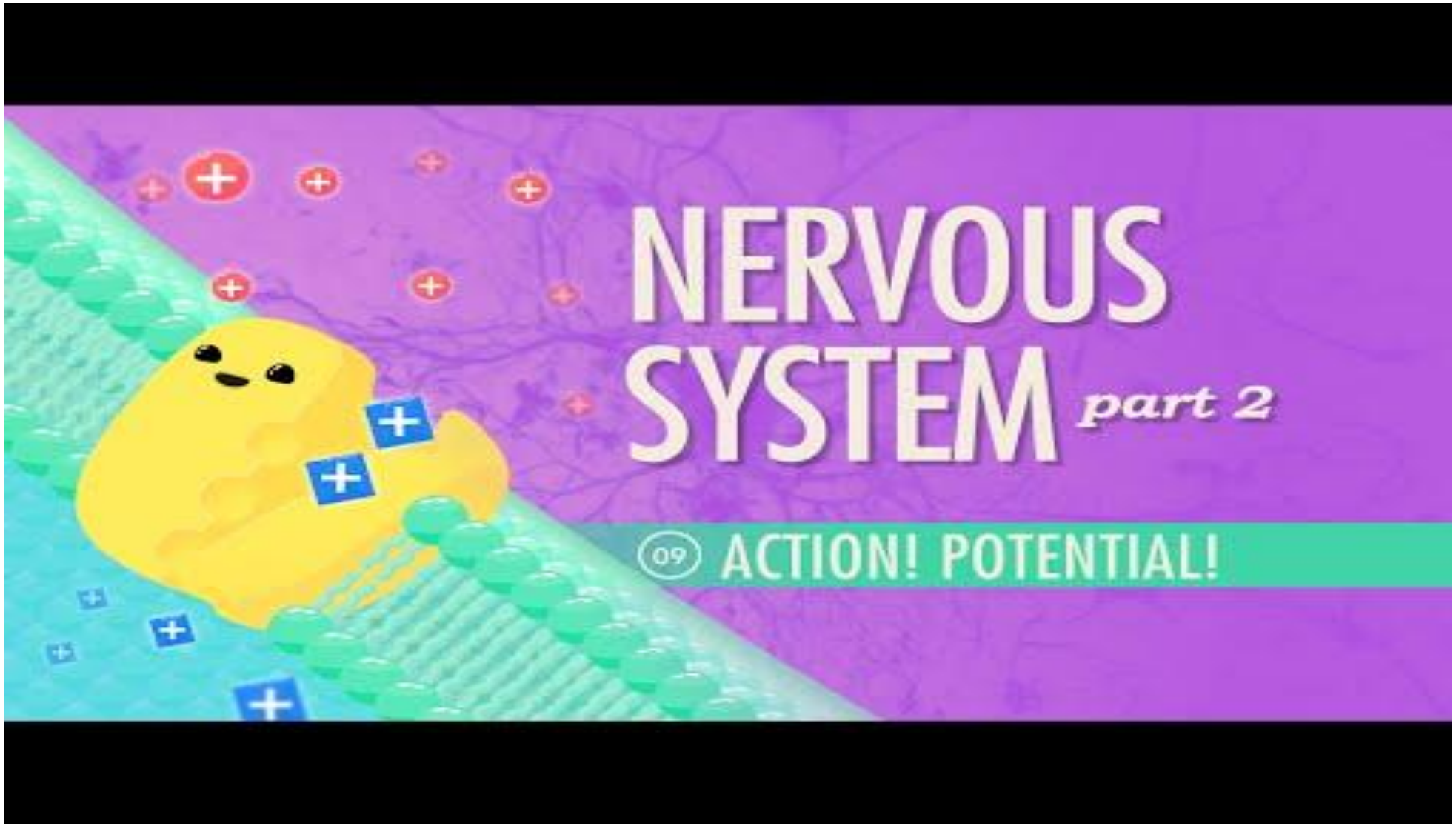
- In **Multiple Sclerosis the immune system mistakenly attacks the oligodendrocytes** (autoimmune disease)
- This damages and scars the myelin sheath in the CNS, meaning that messages travelling along the nerves become slowed or disrupted





wooclap

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

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

Revision questions

- Discuss the roles of glial cells in supporting neuronal function, including structural support, immune support, nourishment, and signaling. Provide specific examples of how different types of glial cells contribute to each of these functions.
- Describe the structure of a neuron and explain how each component contributes to the neuron's ability to receive, process, and transmit information.
- Explain the process of signal transduction within a neuron, from the reception of input signals at the dendrites to the transmission of output signals at the synapses.
- Compare and contrast the characteristics and functions of postsynaptic potentials (PSPs) and action potentials (APs). Explain how PSPs contribute to the generation of action potentials and how action potentials enable long-distance communication within the nervous system.
- Explain the significance of the "all-or-none" nature of action potentials. How do neurons communicate information about the strength or intensity of a stimulus given this limitation?
- Discuss the significance of myelin in neuronal signaling. Explain how myelin is formed, how it contributes to the speed and efficiency of action potential propagation, and what happens when myelin is damaged in diseases like Multiple Sclerosis.

Glossary of Key Terms

Action Potential (AP): A rapid, self-regenerating electrical signal that travels along the axon of a neuron, enabling long-distance communication.

Amyloid Plaques: Extracellular deposits of the protein amyloid-beta, found in the brains of individuals with Alzheimer's disease.

Astrocytes: A type of glial cell that supports neurons by providing nourishment, regulating the chemical environment, and maintaining the blood-brain barrier.

Axon: A single, elongated projection from a neuron that transmits electrical signals (action potentials) to other neurons or target cells.

Axon Hillock: The region where the axon originates from the cell body, and where action potentials are typically initiated.

Blood-Brain Barrier: A protective barrier formed by astrocytes and tight junctions between blood vessels in the brain, restricting the passage of substances from the bloodstream into the brain tissue.

Central Nervous System (CNS): The brain and spinal cord.

Glossary of Key Terms

Cytoplasm: The 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.

Dendrites: Branch-like extensions of a neuron that receive incoming signals from other neurons.

Depolarization: A decrease in the negative membrane potential of a neuron, making it more likely to fire an action potential (excitatory).

Equilibrium Potential: The membrane potential at which the electrical and chemical forces acting on an ion are equal, resulting in no net movement of the ion across the cell membrane.

Extracellular fluid: A bath where the neurons sit, made up of a mixture of the same types of ions found in the intracellular fluid.

Glial Cells (Neuroglia): Non-neuronal cells in the nervous system that provide support, nourishment, and protection to neurons.

Hyperpolarization: An increase in the negative membrane potential of a neuron, making it less likely to fire an action potential (inhibitory).

Microglia: A type of glial cell that acts as the immune cells of the central nervous system, removing debris and pathogens.

Glossary of Key Terms

Myelin: A fatty substance that insulates axons, increasing the speed and efficiency of action potential propagation.

Neurofibrillary Tangles: Intracellular aggregates of the protein tau, found in the brains of individuals with Alzheimer's disease.

Neurons: Nerve cells that transmit electrical and chemical signals, forming the basis of the nervous system.

Nodes of Ranvier: Gaps in the myelin sheath along the axon, where action potentials are regenerated during saltatory conduction.

Oligodendrocytes: A type of glial cell in the central nervous system that forms myelin sheaths around axons.

Peripheral Nervous System (PNS): The part of the nervous system outside the brain and spinal cord, including nerves and ganglia.

Postsynaptic Potential (PSP): A change in the membrane potential of a postsynaptic neuron in response to the binding of neurotransmitters.

Refractory Period: A period of time after an action potential during which the neuron is less likely or unable to fire another action potential.

Glossary of Key Terms

Resting Membrane Potential: The electrical potential difference across the neuron's cell membrane when it is at rest, typically around -70mV.

Saltatory Conduction: The "jumping" of action potentials from one Node of Ranvier to the next in myelinated axons, greatly increasing the speed of conduction.

Schwann Cells: A type of glial cell in the peripheral nervous system that forms myelin sheaths around axons.

Spatial Summation: The summation of PSPs arriving at different locations on the neuron at the same time.

Synapse: A specialized structure where two neurons come into close contact, allowing for the transmission of chemical or electrical signals.

Temporal Summation: The summation of PSPs arriving at the same location on the neuron at slightly different times.

Threshold: The level of depolarization that must be reached for an action potential to be initiated.