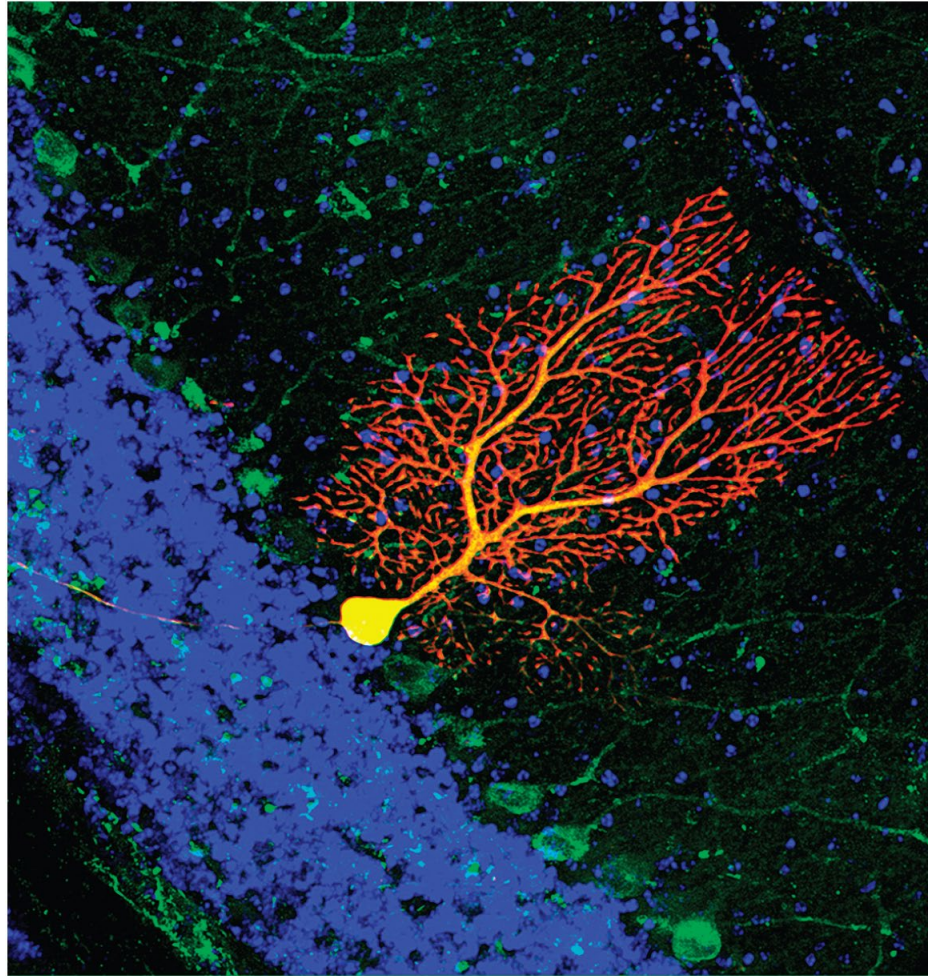


# Chapter 12.1

## Nervous Tissue



# The Nervous System

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*The Nervous System* carries out its task in **three steps**:

**receive information (sensory) ///** sensory organs (receptors) detect changes in the body or in the external environment // transmit sensory information to the spinal cord and the brain

**processes this information ///** brain and spinal cord process the information // called **integration of information** // brain able to relates sensory information to past experiences,

- determine what response is appropriate
- evaluates circumstances // salience

**issue commands (motor command)**

- brain and/or spinal cord send action potentials to muscles and gland cell

- > Similar to C1 the homeostasis reflex (receptor-integrator-effector model)
- > What is the significance of a stimulus to the receptor?

**1 Sensory input:** A woman sees a soccer ball moving toward her; sensory signals are sent to her brain.

**2 Integration:** Her brain receives and integrates the sensory input, and sends signals for an appropriate motor response.

Stimulus modality matched to sensory input transducer.



Brain

Spinal cord

**3 Motor output:** When the muscles of her thigh and leg receive the motor signals, they contract and kick the soccer ball.

What are the different types of sensory input transducers?

What is the difference between interoception and exteroception?

# Two Anatomical Divisions of the Nervous System

---

## Central nervous system (CNS)

- brain and spinal cord enclosed in bony coverings
- enclosed by cranium and vertebral column
- **nuclei** – isolated “islands” of gray matter within CNS

## Peripheral nervous system (PNS)

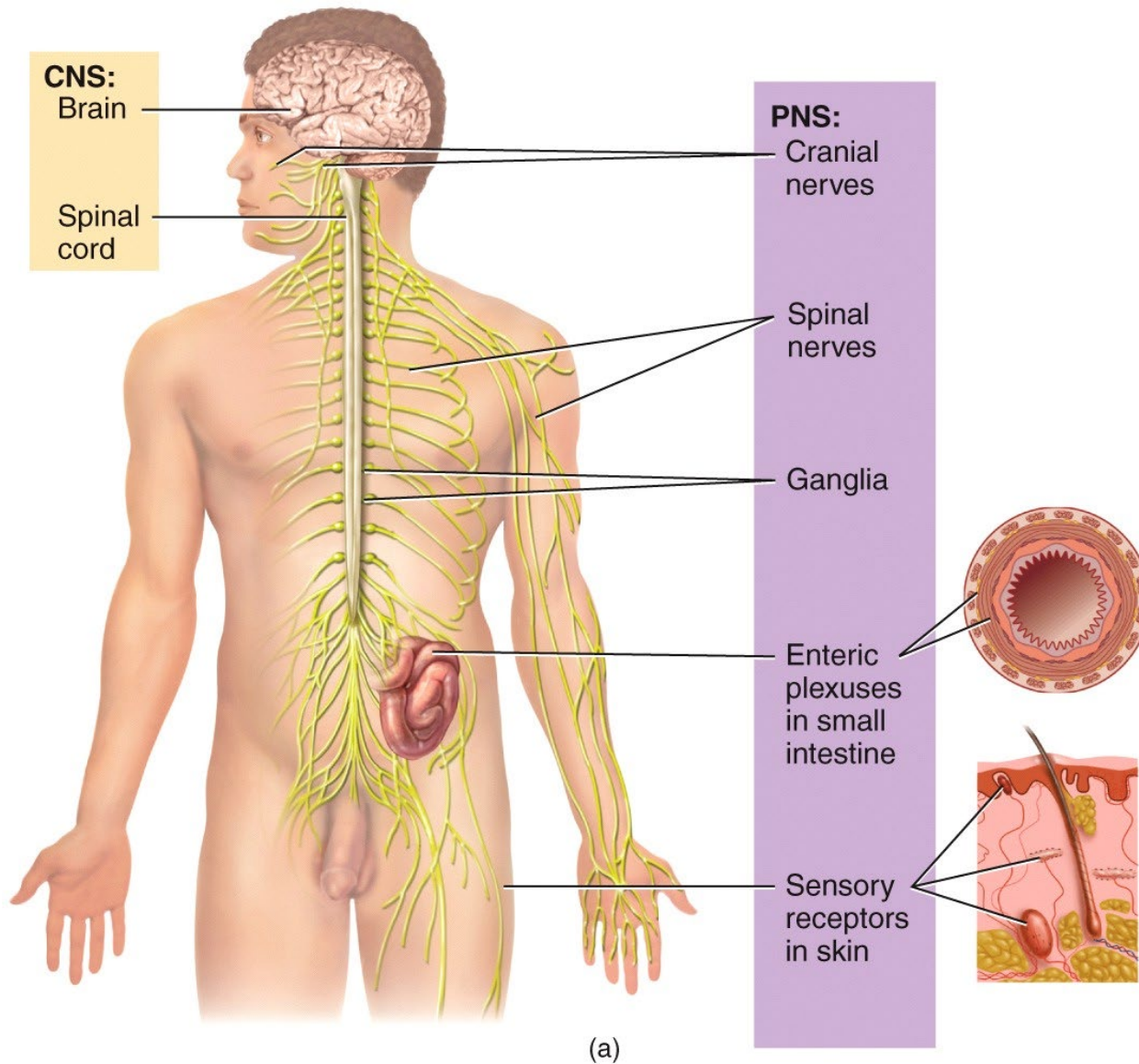
- all the nervous system except the brain and spinal cord
- composed of nerves and ganglia

**Nerve** – a bundle of nerve fibers (axons) wrapped in fibrous connective tissue

**Ganglion** – isolated “islands” of gray matter within PNS // soma outside CNS // a knot-like swelling in a nerve where neuron cell bodies are concentrated / info process

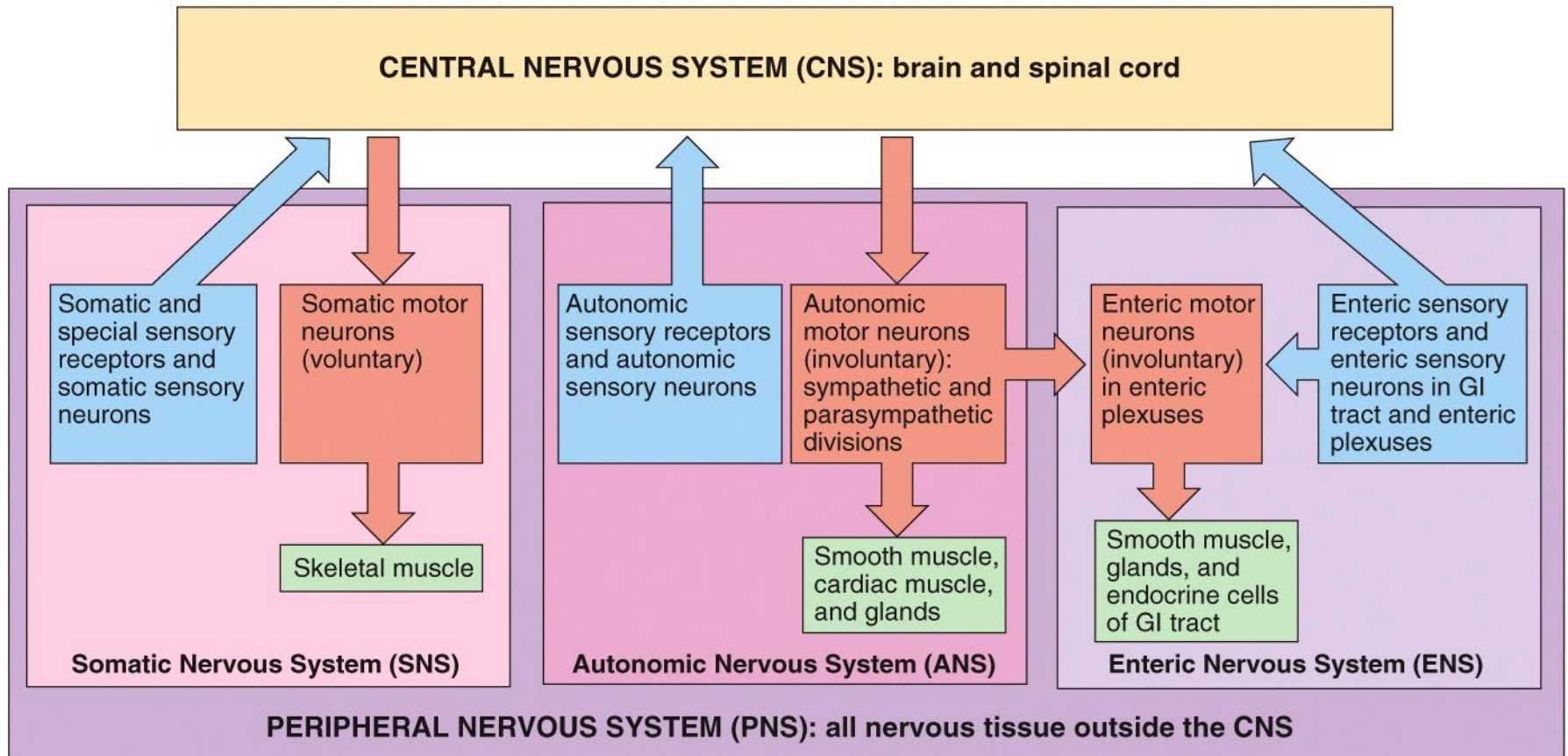
**Nuclei** – isolated “island” of gray matter in the CNS // info process

# What are the two anatomical divisions of the nervous system?



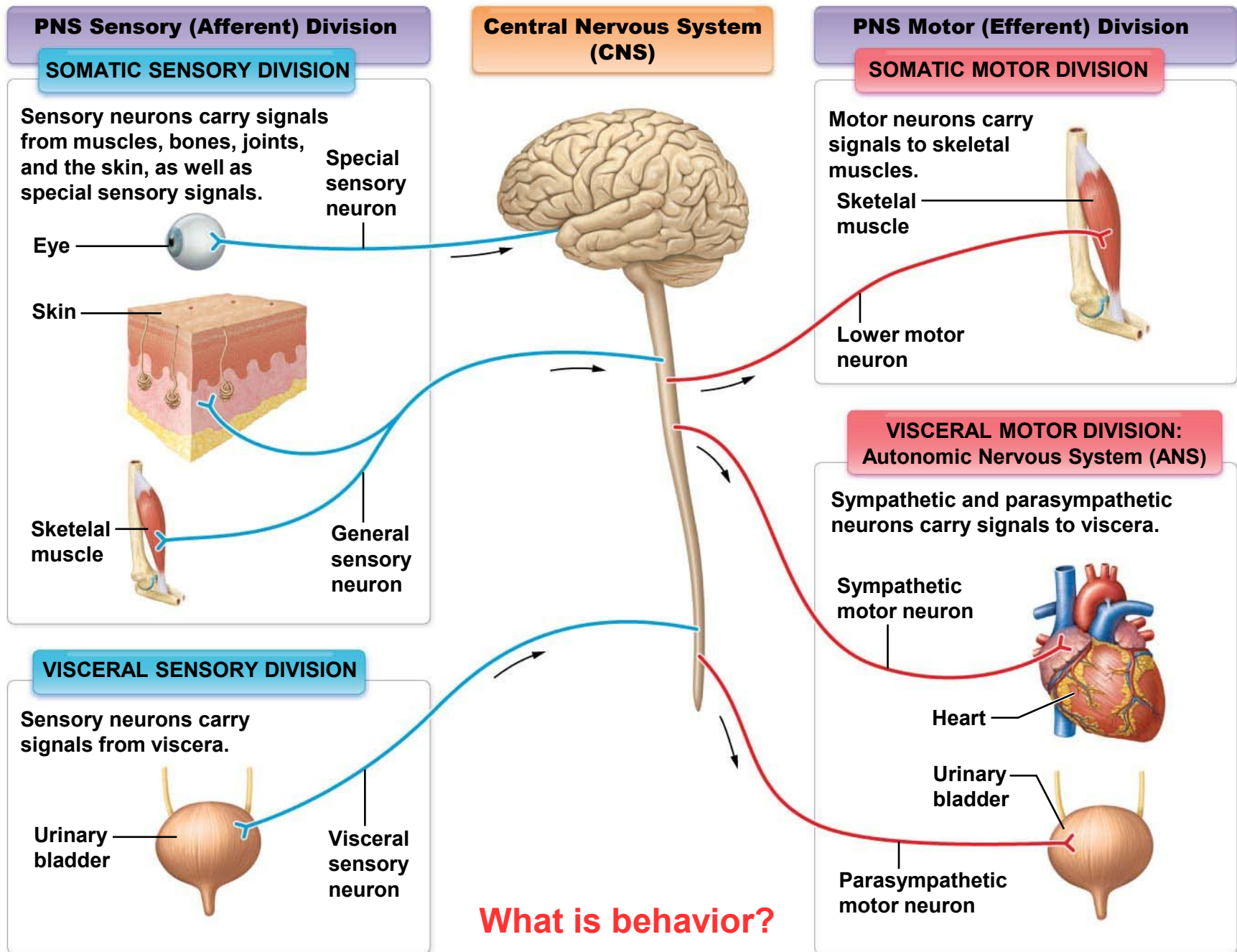
# Two Anatomical Divisions of the Nervous System

*(You maybe asked to label this on an exam!)*



- > What are the division of the peripheral nervous system?
- > What is the target tissue for each PNS division?
- > Note blue arrows sending information back to the CNS
- > What is unique about the enteric nervous system?

# The organization of the nervous system.



# How Do We Maintain Homeostasis?

---

The “internal environment” resist change around our cells by using organs to maintain a stable interstitial fluid by using these two systems:

**Endocrine system** - communicates **slowly** by means of chemical messengers (hormones) secreted into to the blood and change metabolism for cells with docking station (receptors) matched to the hormone

**Autonomic nervous system** - employs electrical current (action potentials) and chemicals (neuro-transmitters) to send **rapid** messages to cell

Two divisions

- Sympathetic Nervous System – prepares body for action
- Parasympathetic Nervous System – rest and restore system

- What is the boss of homeostasis? (What brain structure regulates homeostasis?)
- What brain structure regulates the endocrine system and autonomic nervous system?

# Sensory Divisions to Brain

---

**Sensory division neurons** /// carries sensory signals from receptors located in skeletal muscles and other tissues to the CNS

informs the CNS of stimuli throughout the body

**Somatic sensory neurons (division)** - carries signals from receptors in the skin, muscles, bones, and joints

**Visceral sensory neurons (division)** - carries signals from the viscera of the thoracic and abdominal cavities /// heart, lungs, stomach, blood vessels, and urinary bladder

# Motor Divisions to Brain

---

Motor Division Neurons (2 types = somatic and visceral)

Somatic motor neurons = to skeletal muscles

Visceral motor neurons = by way of the Autonomic Nervous System = to glands, smooth muscle, and cardiac

These visceral motor signals originate in CNS and flow out to the effectors

**Effectors** = tissues that respond to commands from the CNS

# Peripheral Nervous Motor Divisions

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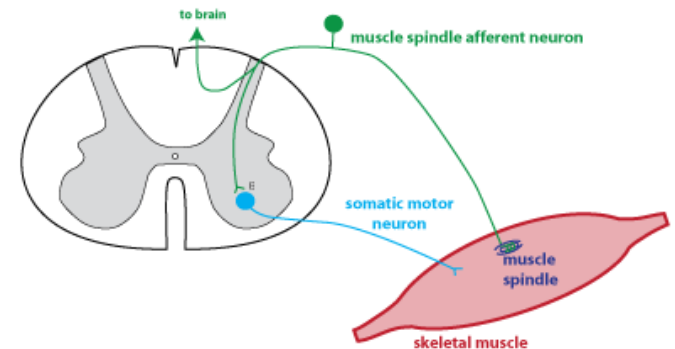
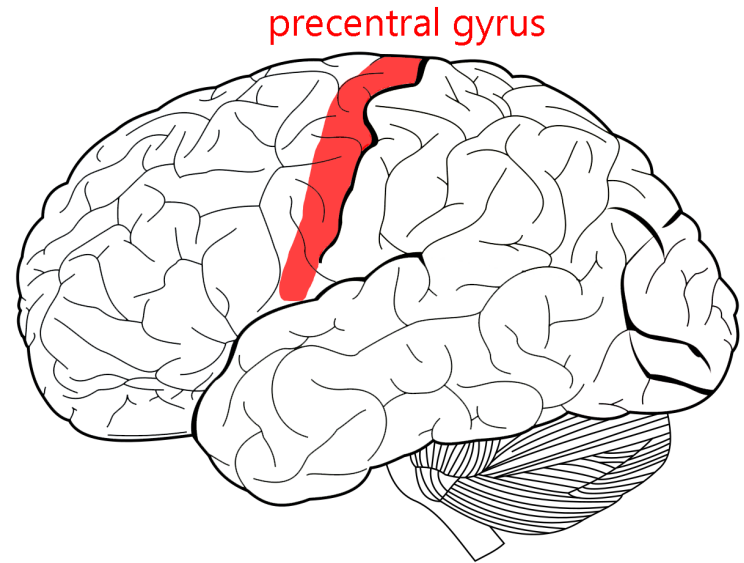
## Somatic Motor Division (efferent fibers)

carries signals to skeletal muscles

signal originates from brain's precentral gyrus // upper motor neuron and lower motor neuron

output produces skeletal muscular contraction /// voluntary

*spinal cord reflex* /// “somatic reflexes” - do not require precentral gyrus function (the motor strip) // a spinal cord reflex may cause an involuntary skeletal muscle contractions



# Peripheral Nervous Motor Divisions

---

**Visceral motor division** (this is the autonomic nervous system)

- carries signals to glands, cardiac muscle, and smooth muscle
- involuntary reflexes regulated by two division // also called **visceral reflexes** (e.g. salivation, voiding urinary bladder)

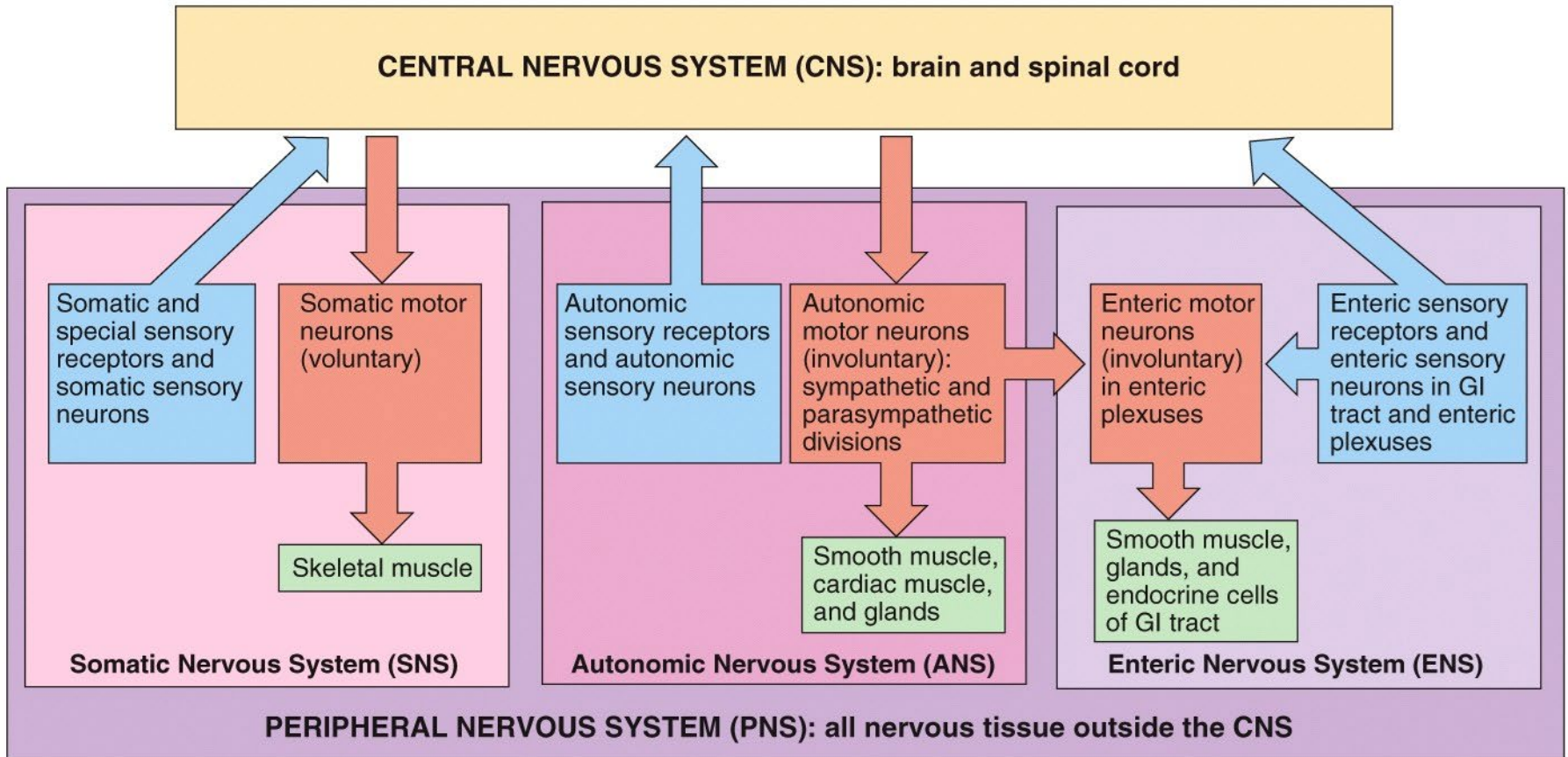
**sympathetic division**

- tends to arouse body for action
- accelerating heartbeat and respiration, while inhibiting digestive and urinary systems

**parasympathetic division**

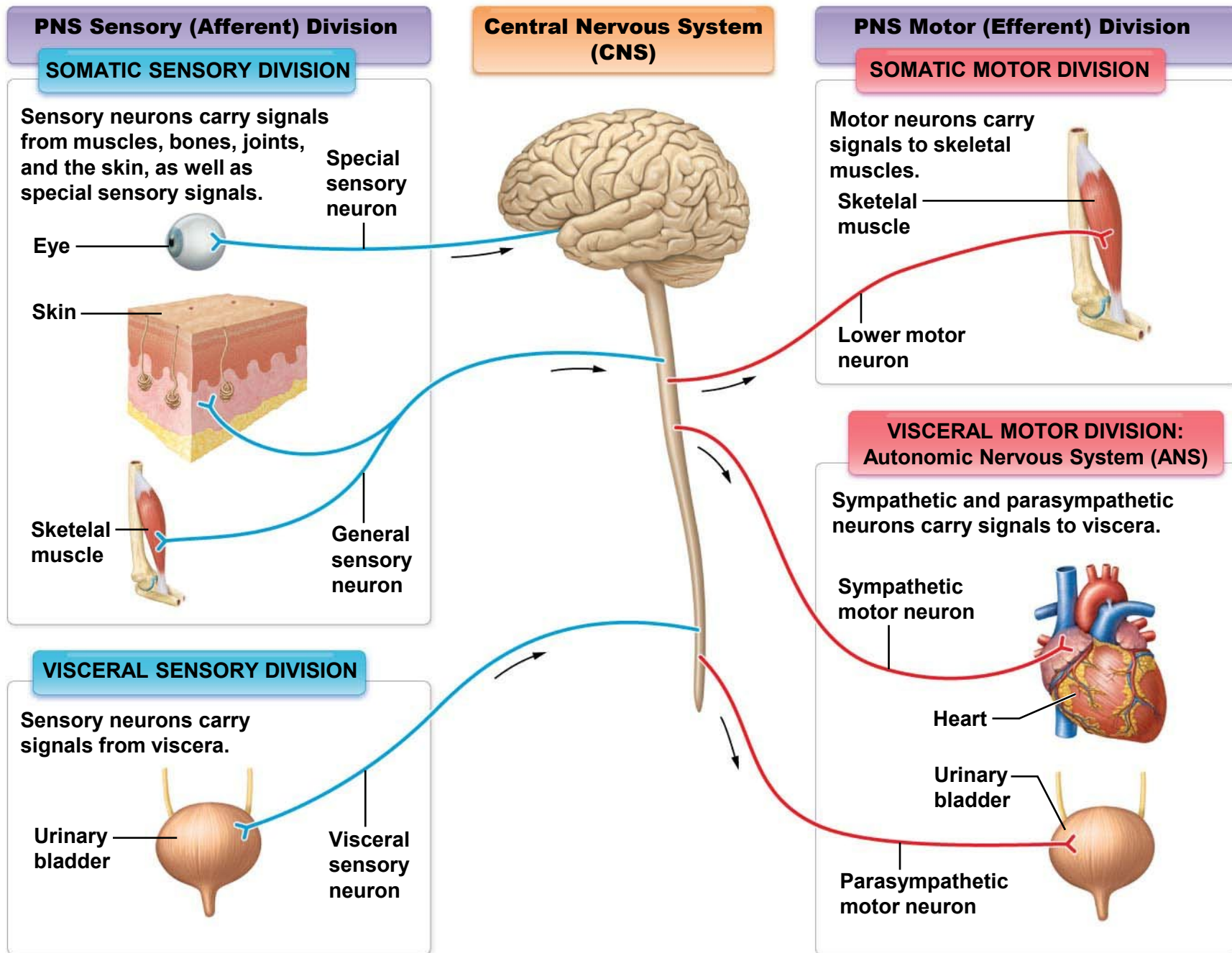
- tends to have calming effect
- slows heart rate and breathing
- stimulates digestive and urinary systems
- rest and restore division

# Nervous System Structure



(b)

# The organization of the peripheral nervous system.



# Universal Properties of a Neuron

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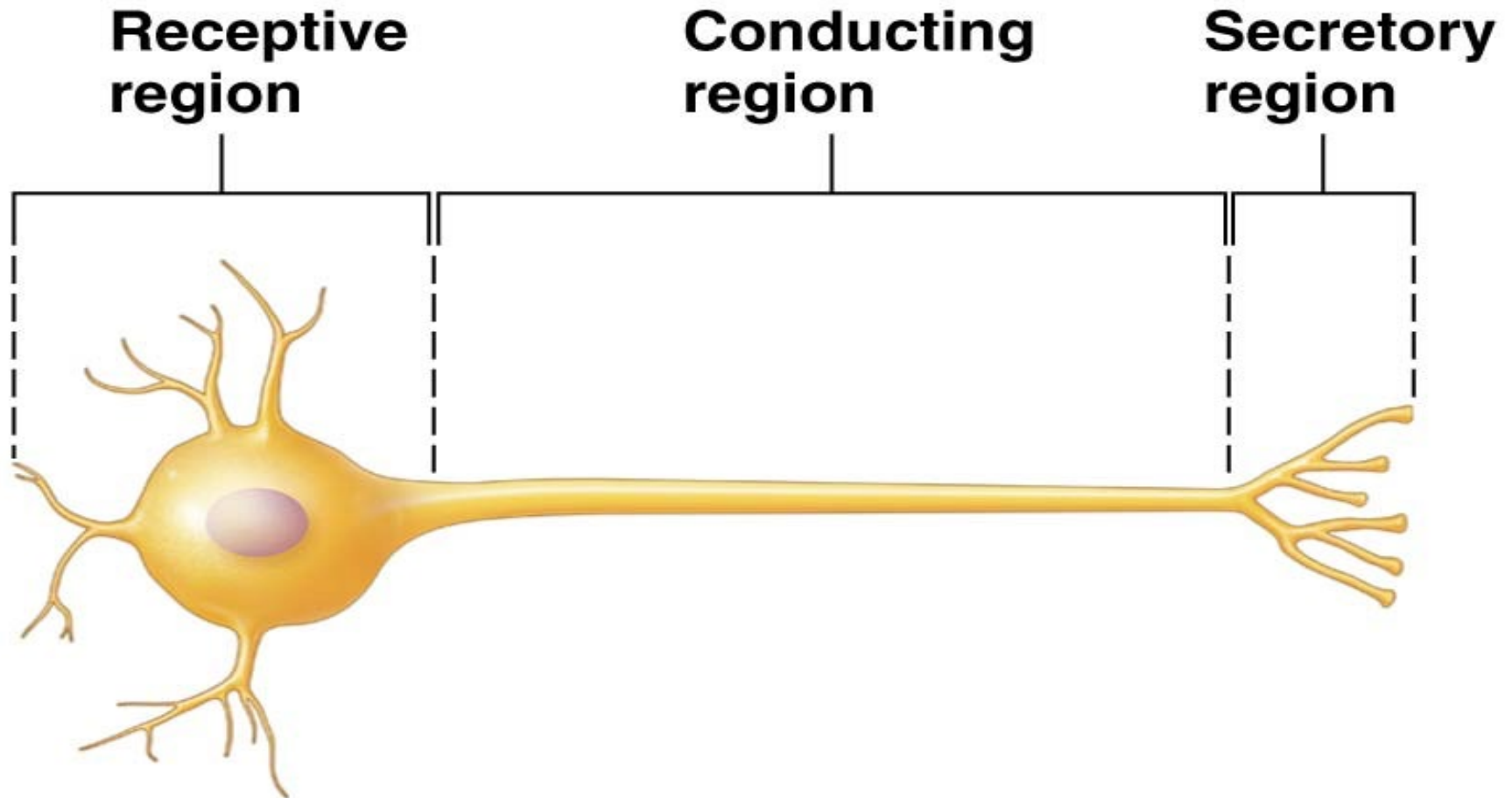
Neurons Are Excitable (irritability) /// respond to environmental changes called stimuli

Conductivity /// neurons respond to stimuli by producing **electrical signals** (action potentials = current) that are quickly conducted to other cells

Secretion /// when electrical signal reaches end synaptic knob, a chemical **neurotransmitter** is secreted /// crosses the synaptic gap and initiates a local potential on the post synaptic membrane

*Note: The neuron's function requires an electro-chemical form of communication! // its not just an electrical signal and not just a chemical signal but an electro-chemical signal which occurs across the synapse*

# Functional Regions of a Neuron



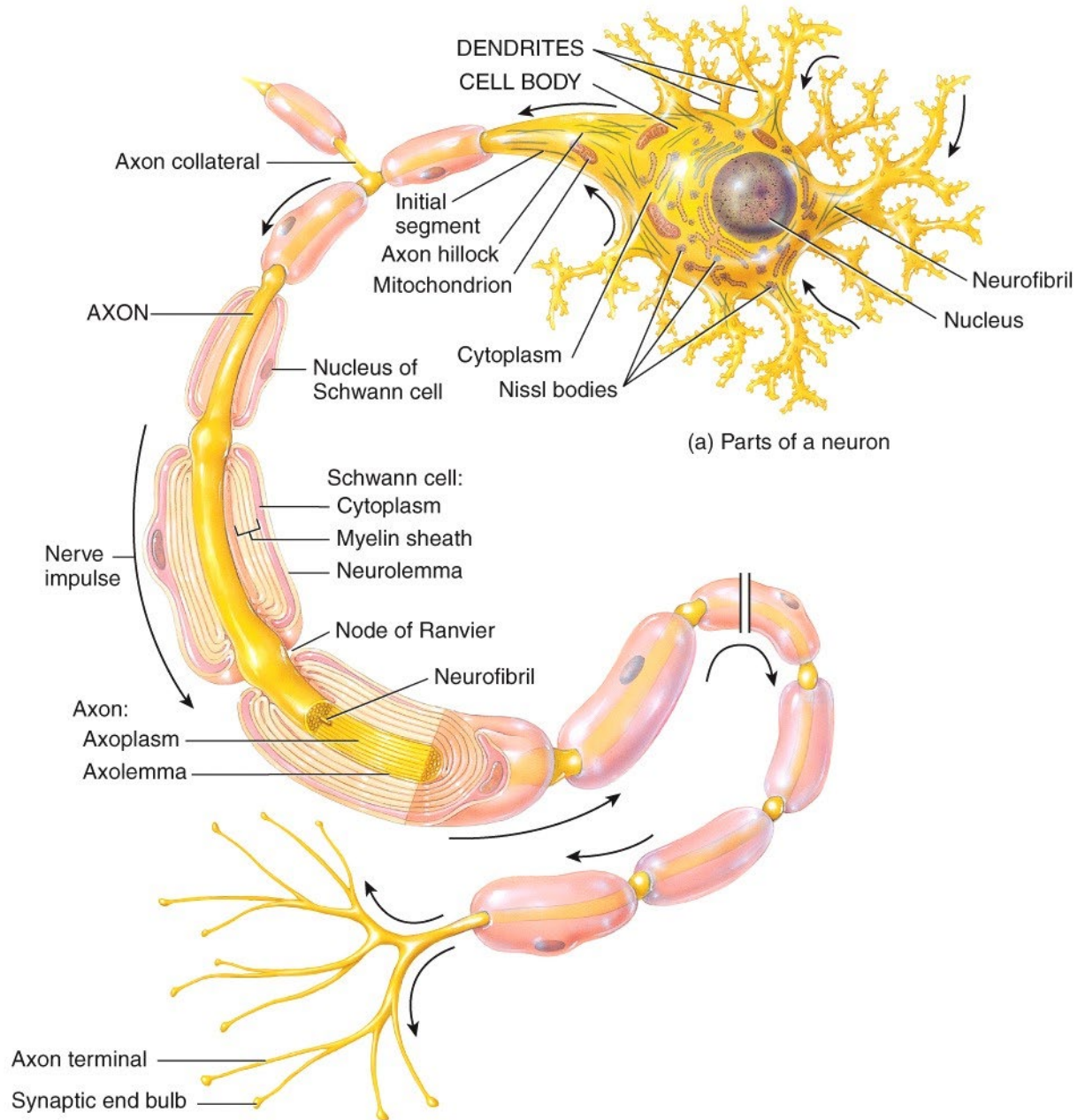
- > What is the direction of the electrical impulse?
- > What do we mean by unidirectional?

# Universal Properties of a Neuron

Neurons are defined by using either structural or functional criteria.

Based on the structure, this is a “multi-polar neuron”.

Neurons have most of the common organelles of a typical cell.



# The Soma

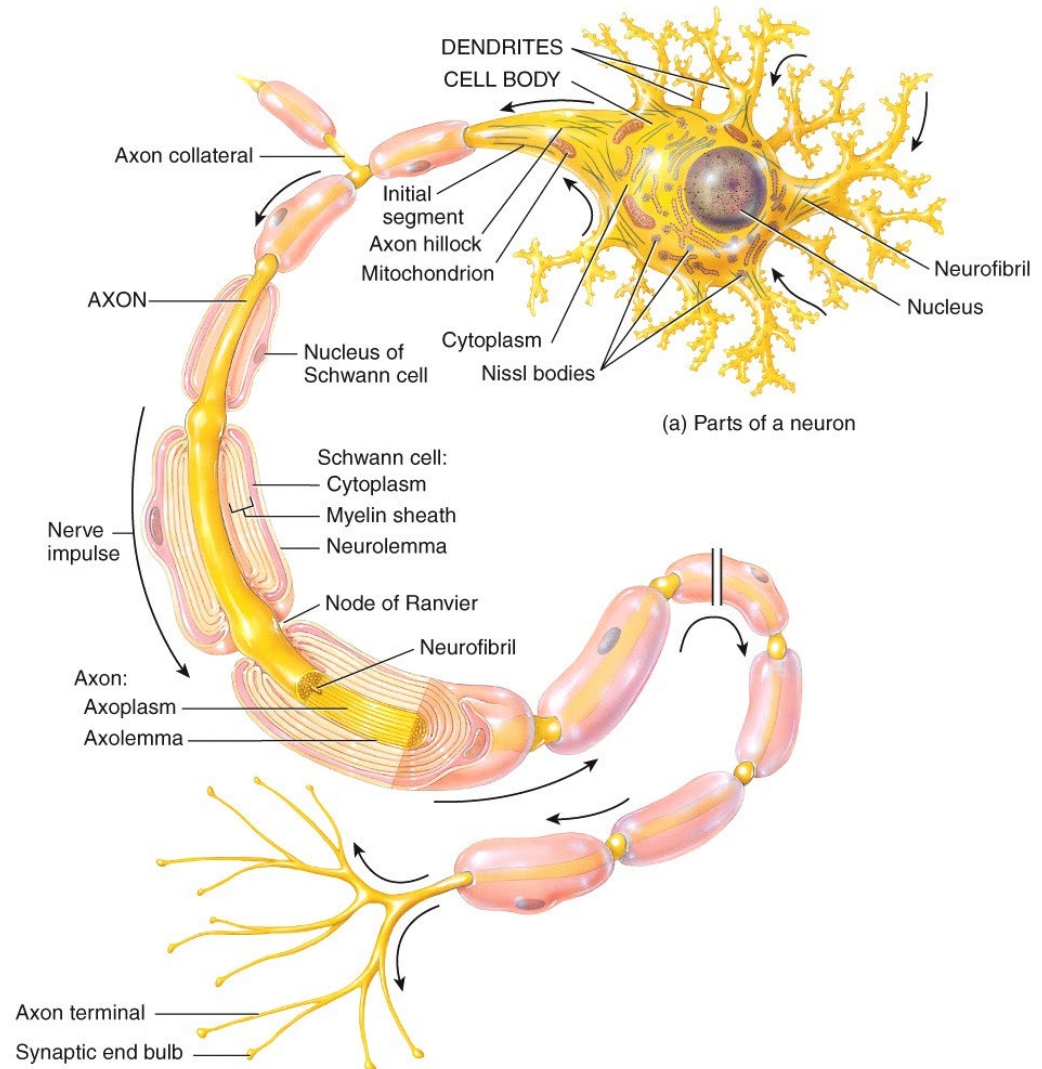
The soma is the control center of the neuron

also called **neurosoma**, **cell body**, or **perikaryon**

has a single, centrally located nucleus with large nucleolus

**cytoplasm** contains mitochondria, lysosomes, a Golgi complex, numerous inclusions, and extensive rough endoplasmic reticulum and cytoskeleton

Most neurons cannot divide by mitosis! (Some select regions within brain are believed to undergo mitosis. Olfactory bulb and hippocampus are two areas believed to support mitosis)



# The Soma

---

cytoskeleton consists of dense mesh of microtubules and **neurofibrils** (bundles of actin filaments)

compartmentalizes rough ER into dark staining **Nissl bodies**

**no centrioles** – no further cell division // there are exceptions to this understanding – with some mitosis in hippocampus and olfactory bulb

**inclusion bodies** – glycogen granules, lipid droplets, melanin

**Lipofuscin / inclusion bodies** (golden brown pigment produced when lysosomes digest worn-out organelles)

- lipofuscin accumulates with age
- wear-and-tear granules
- most abundant in old neurons

# The Dendrites

Vast number of branches coming from a few thick branches from the soma

Resemble bare branches of a tree in winter

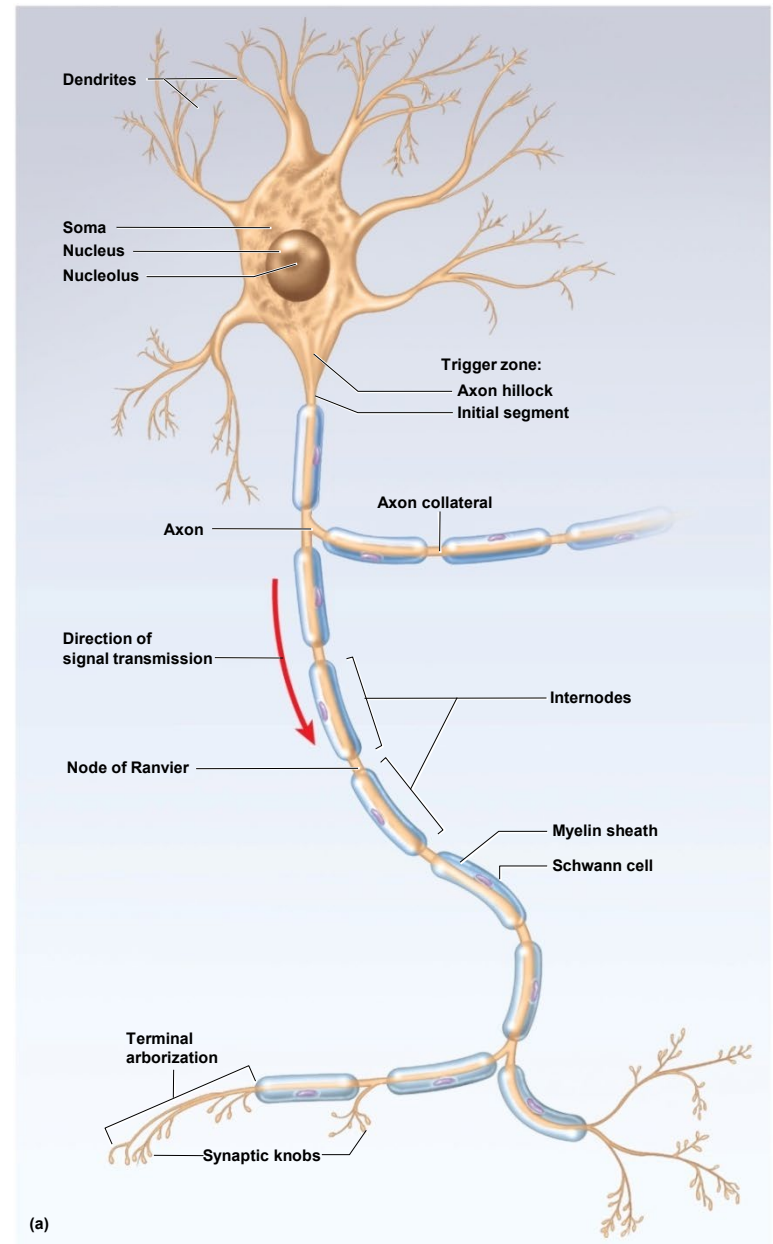
Primary site for receiving signals from other neurons = **“the dendrites are receptors”**

**Dendrites are transducers // convert a stimulus into an action potential**

Stimulus at dendrite creates a local potential  
/// graded potentials

The more dendrites the neuron has, the more information it can receive and incorporate into decision making

Dendrites provide precise pathway for the reception and processing of neural information



# The Axon

commonly called the nerve fiber

originates from a mound on one side of the soma called the **axon hillock** or **trigger zone**

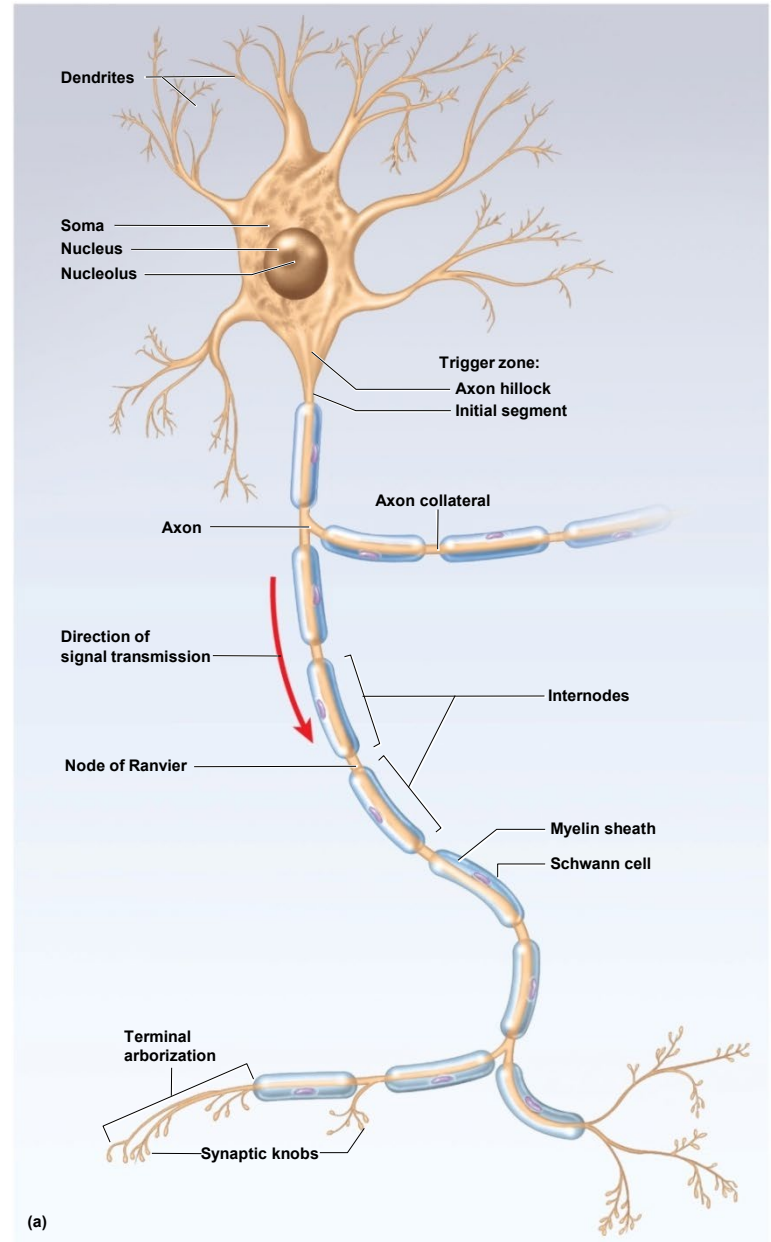
cylindrical, relatively unbranched for most of its length /// axon collaterals – branches of axon

branch extensively on distal end /// synaptic knobs

axoplasm – cytoplasm of axon

specialized for rapid conduction of nerve signals to points remote to the soma

transmits the **action potential** // **unidirectional transmission**



# The Axon

---

axolemma – plasma membrane of axon

only one axon per neuron

Schwann cells /// myelin sheath enclose axon

distal end of axon has terminal “arborization” – extensive complex of fine branches / like in a tree!

synaptic knob (terminal button) – little swelling that forms a junction (synapse) with the next cell

synaptic knob contain synaptic vesicles full of neurotransmitter

neurotransmitters made in the soma and transported in vesicles to the synaptic knob // released by exocytosis from synaptic knob

# The Synaptic Knob

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Terminal end of the neuron // forms junction between neuron to neuron - neuron to muscle or neuron to glandular tissue

One neuron may have hundreds of terminal knobs

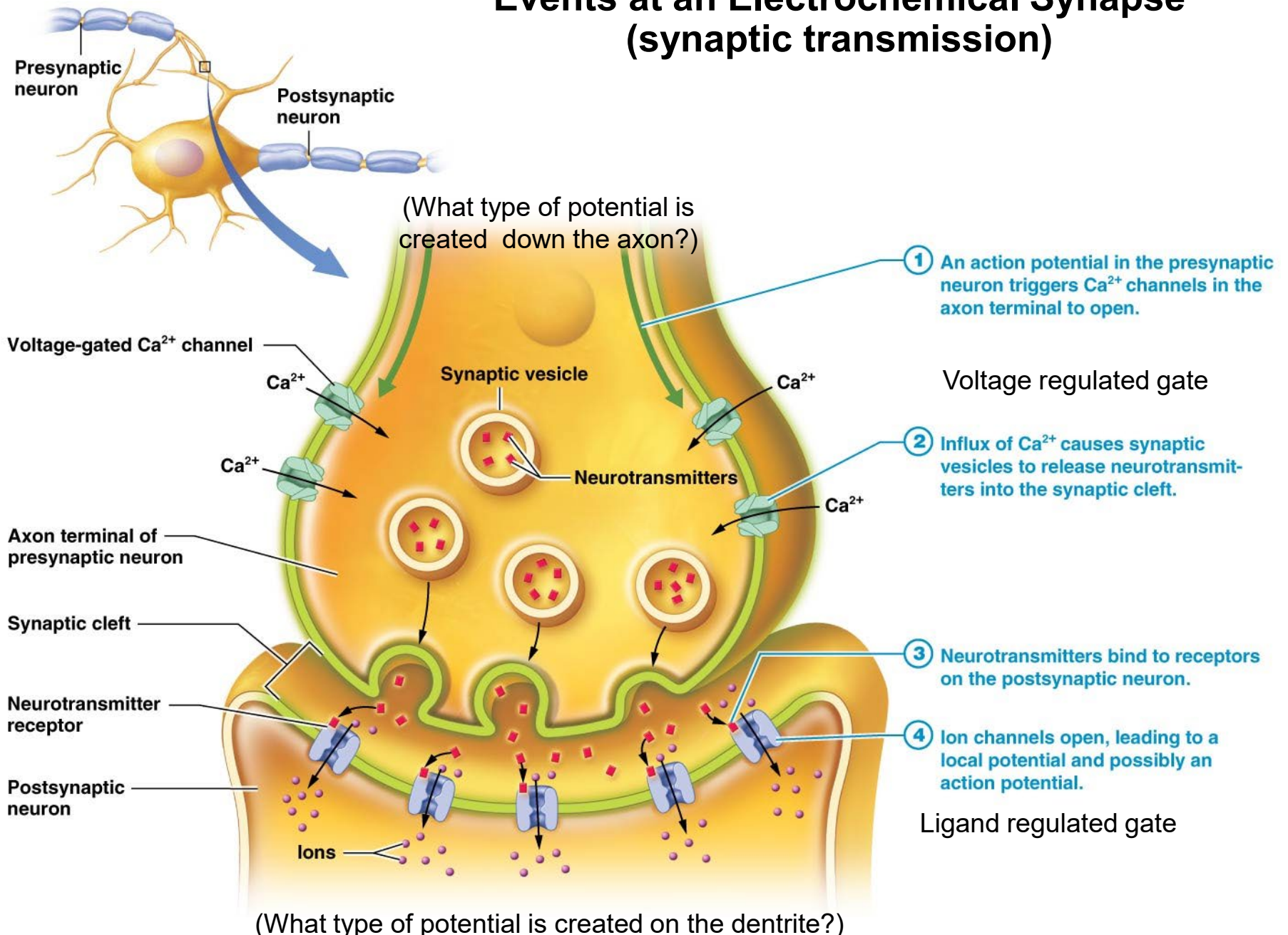
Stores neurotransmitters

Many different types of neurotransmitters /// some stimulate others inhibit post synaptic membrane

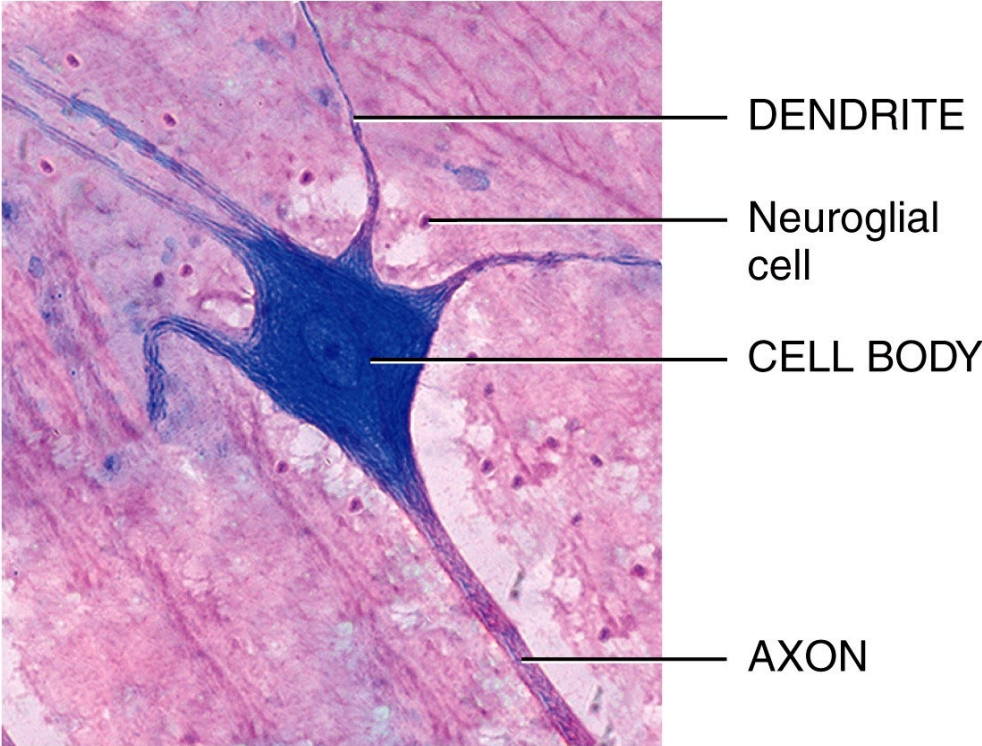
Synaptic knob is a part of the synapse // the presynaptic membrane

Synapse three components: presynaptic membrane – synaptic cleft – post synaptic membrane

# Events at an Electrochemical Synapse (synaptic transmission)



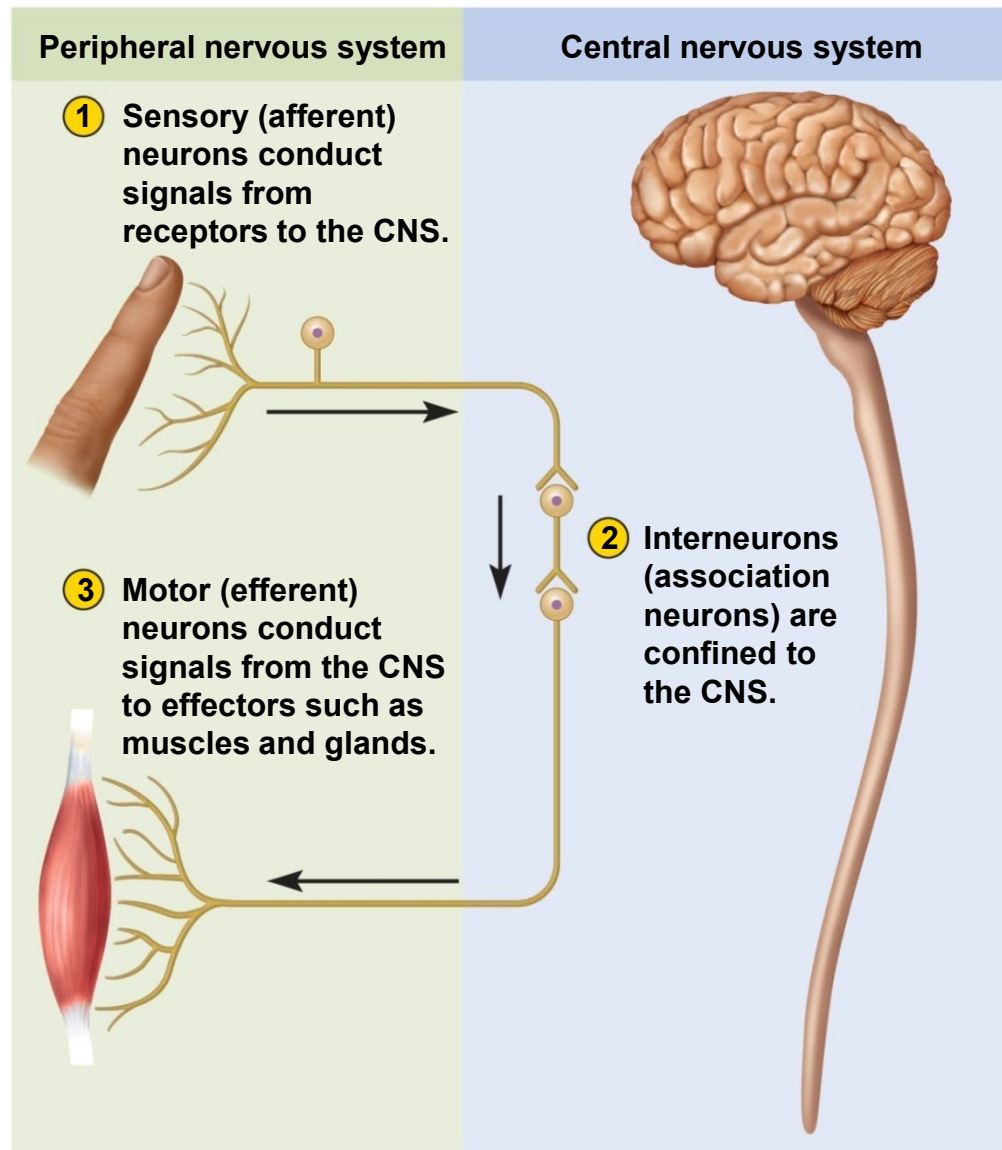
# Neurons Are Classified by Structure or Function

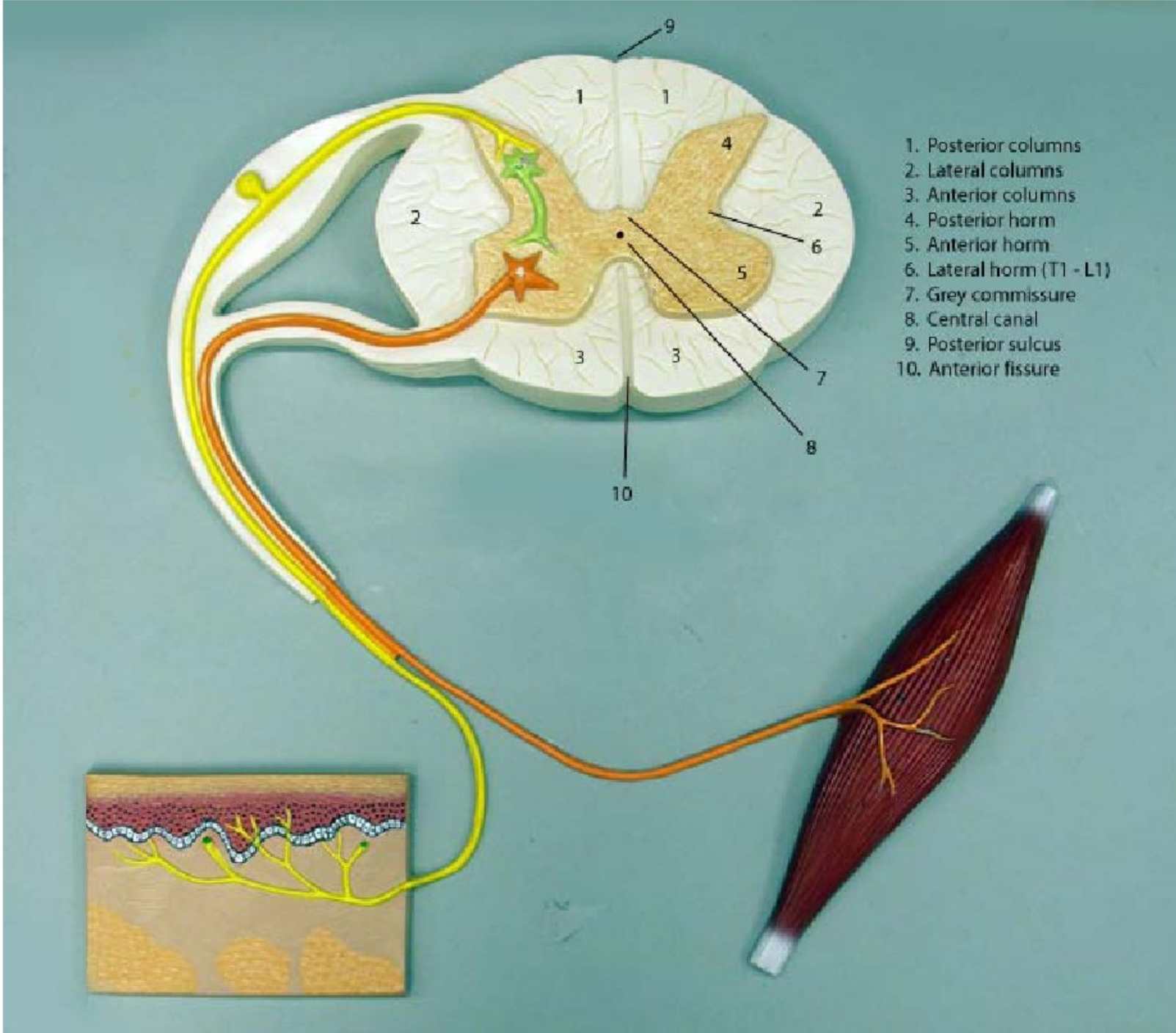


Mark Nielsen

LM 400x

# Functional Classification of Neurons





# Functional Definition of Neurons

## (sensory, motor, inter-neuron)

---

### Sensory (afferent) neurons

- specialized to detect stimuli
- transmit information about them to the CNS
- begin in almost every organ in the body and end in CNS
- afferent** – conducting signals toward CNS

### Motor (efferent) neuron

- send signals out to muscles and gland cells (the effectors)
- motor because most of them lead to muscles
- efferent** neurons conduct signals away from the CNS

# Functional Definition of Neurons

## (sensory, motor, inter-neuron)

---

### Interneurons (association) neurons

All parts of the neuron are entirely within the CNS

Receive signals from many neurons /// carry out the integrative function

Process, store, and retrieve information /// 'make decisions' that determine how the body will respond to stimuli

90% of all neurons are interneurons

*Between the sensory pathways to the outgoing motor pathways of the CNS*

# Structural Definition of Neuron

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## Multipolar neuron

- one axon and multiple dendrites
- most common
- most neurons in the brain and spinal cord

## Bipolar neuron

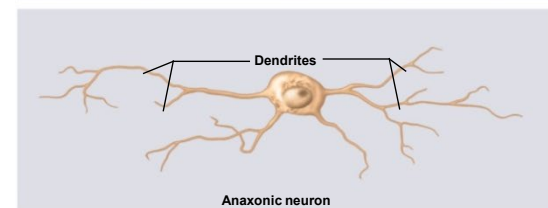
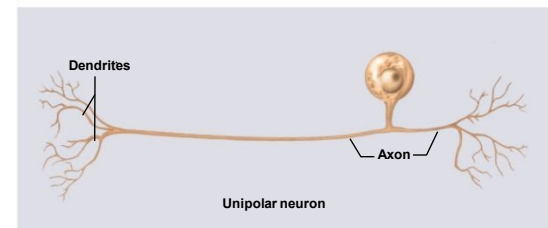
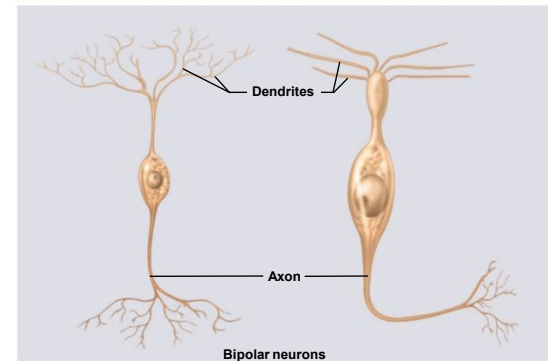
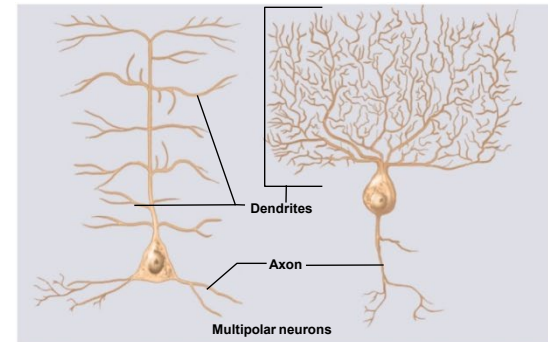
- one axon and one dendrite
- olfactory cells, retina, inner ear

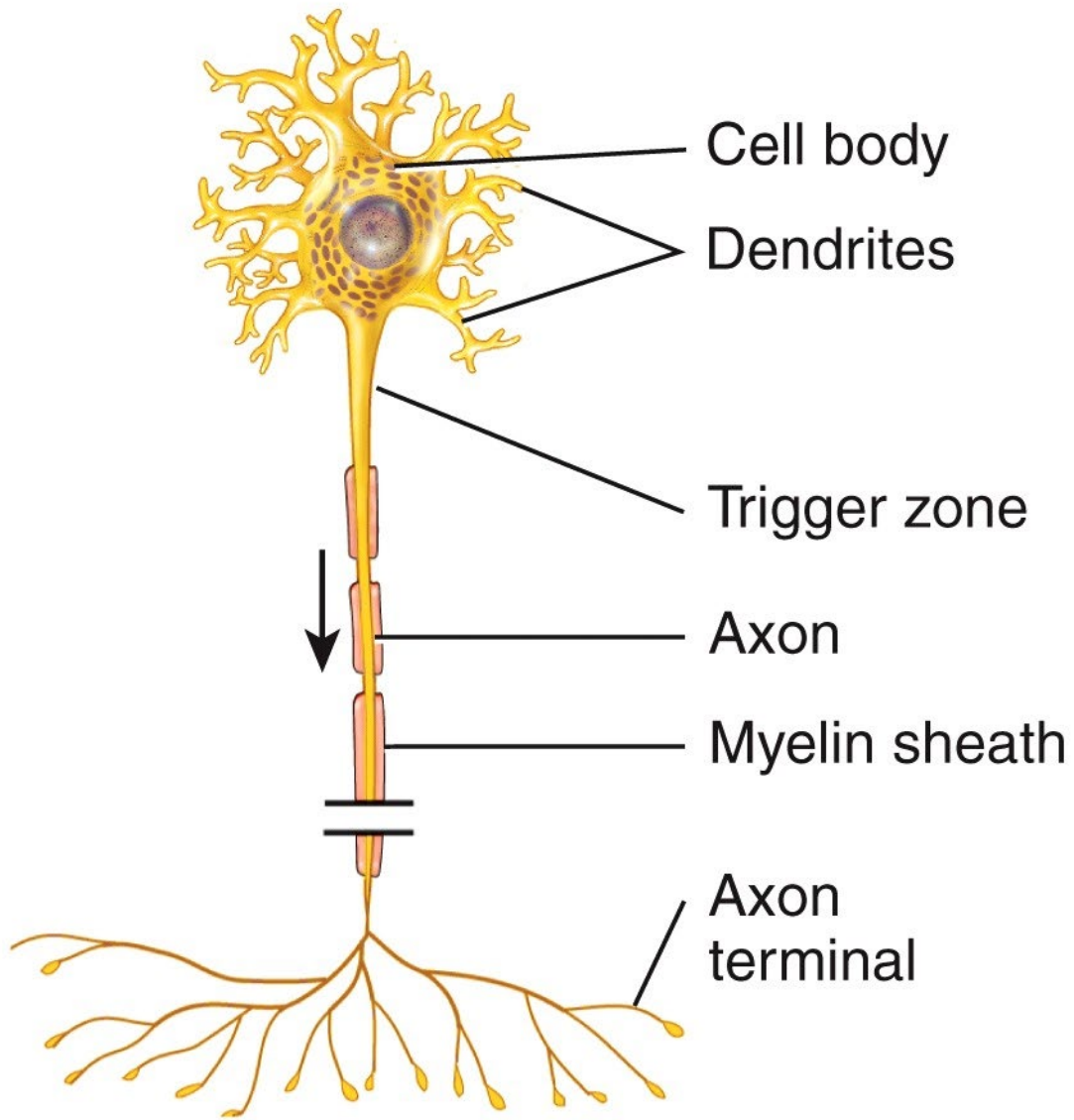
## Unipolar neuron

- single process
- sensory from skin and organs to spinal cord

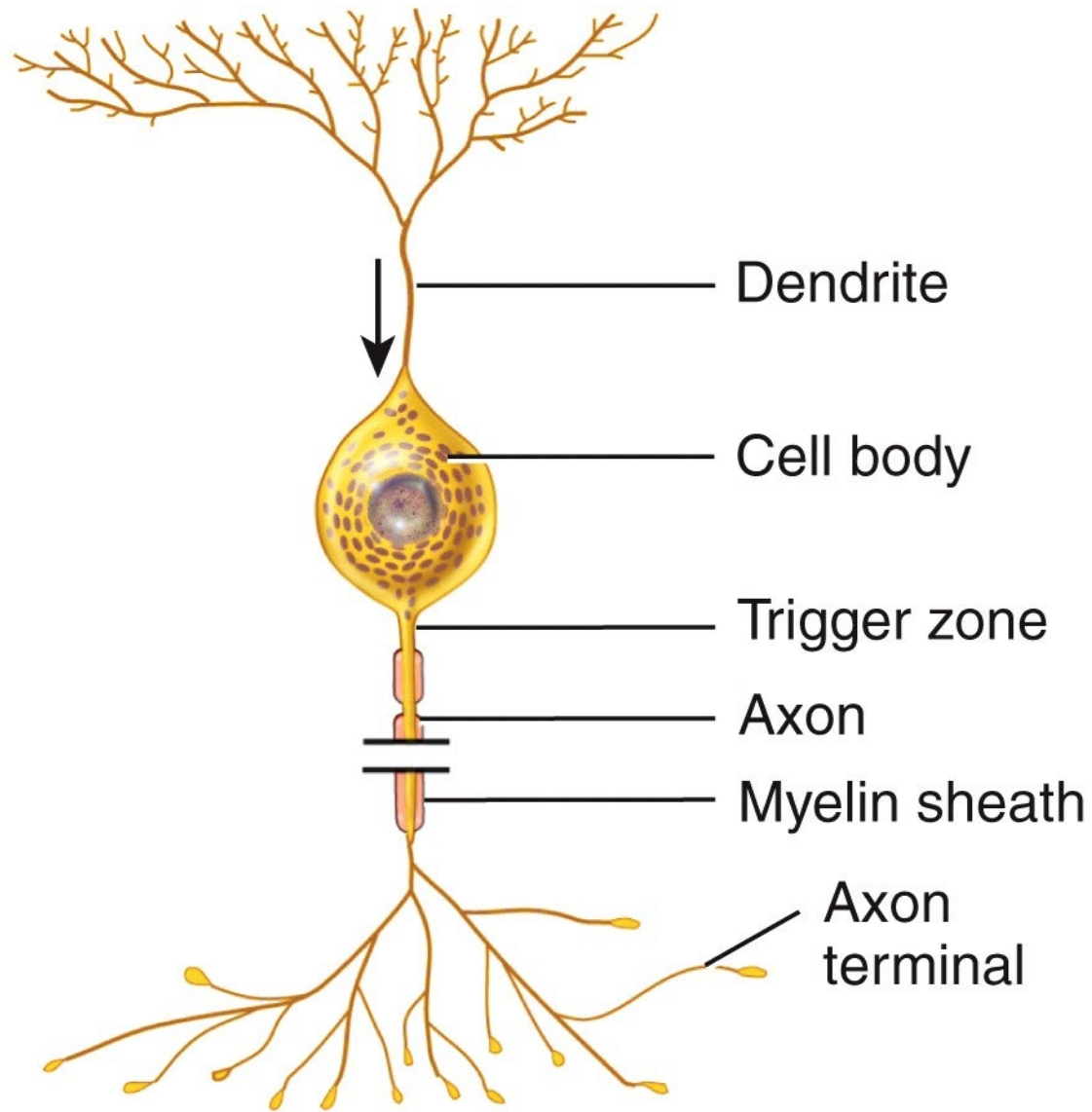
## Anaxonic neuron

- many dendrites but no axon
- help in visual processes

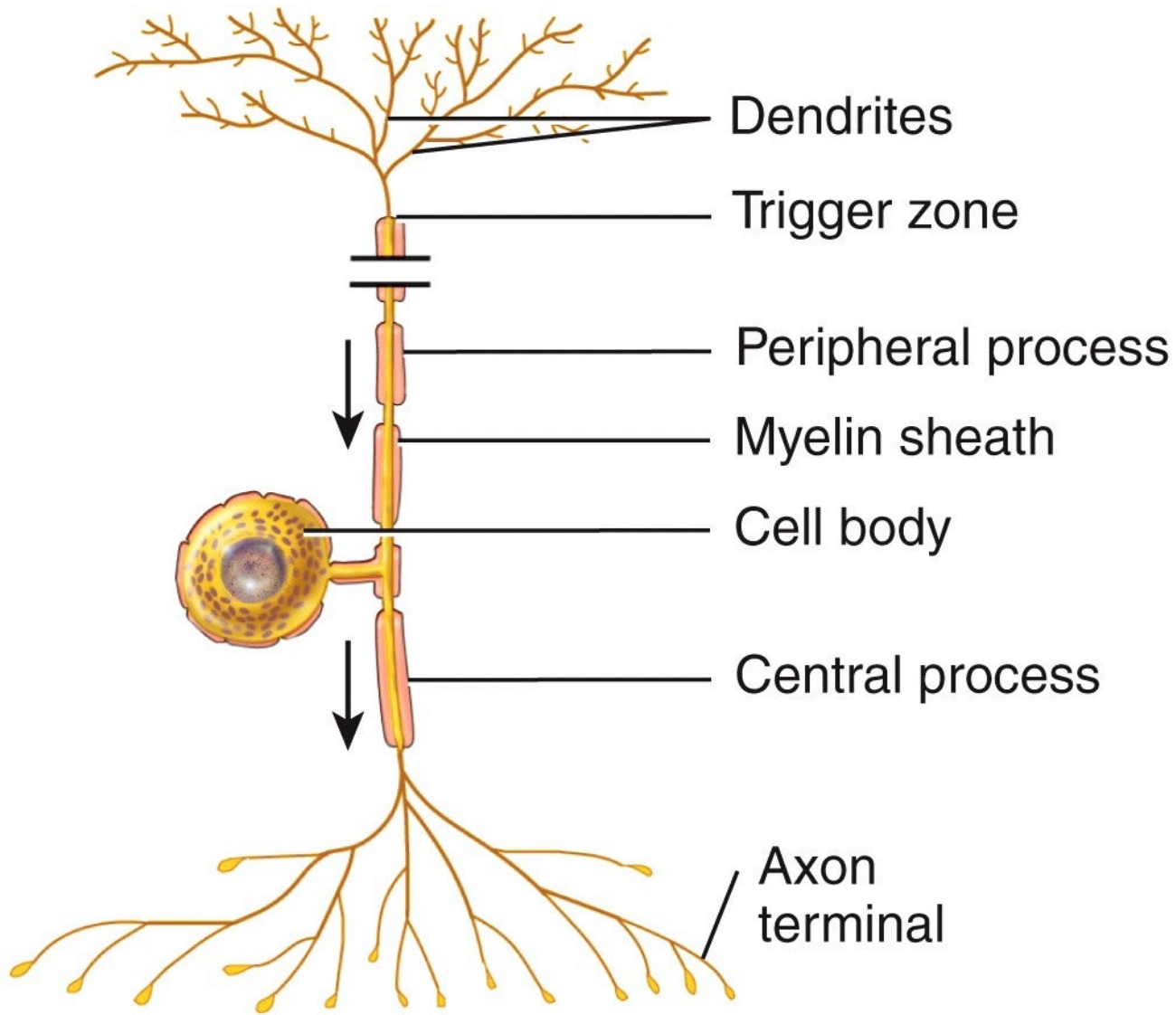




(a) Multipolar neuron



(b) Bipolar neuron



(c) Unipolar neuron

# Neuroglial Cells

---

How many cells are in the human body? 50 trillion cells (best estimate).

Estimate that the human brain contains about 170 billion cells, 86 billion of which are neurons and 86 billion of which are glial cells.

The ratio of glia to neurons differs dramatically from one general brain region to the next

Neuroglia are also called glial cells

Support, protect, and enhance function of neurons

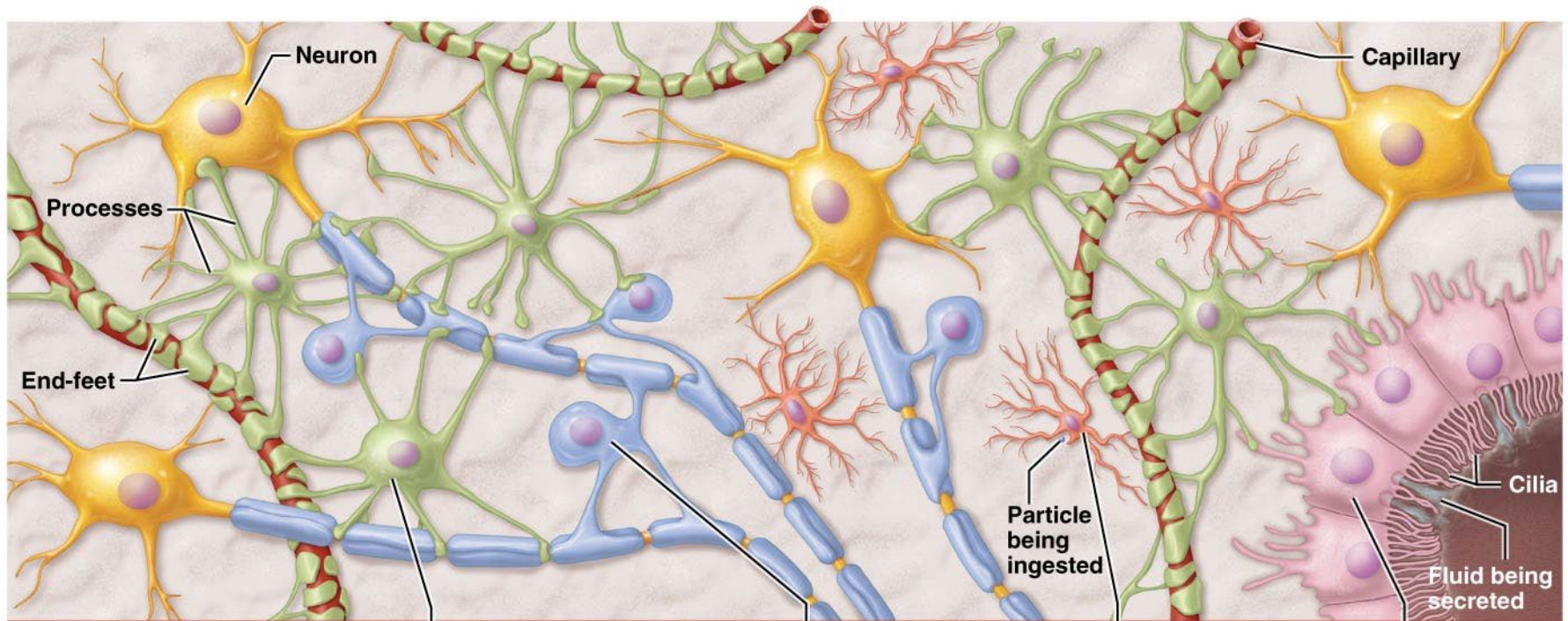
Bind neurons together and form framework for nervous tissue

In fetus, guide migrating neurons to their destination

*If the surface of a mature neuron is not in synaptic contact with another neuron, then non-synaptic surface is covered by glial cells*

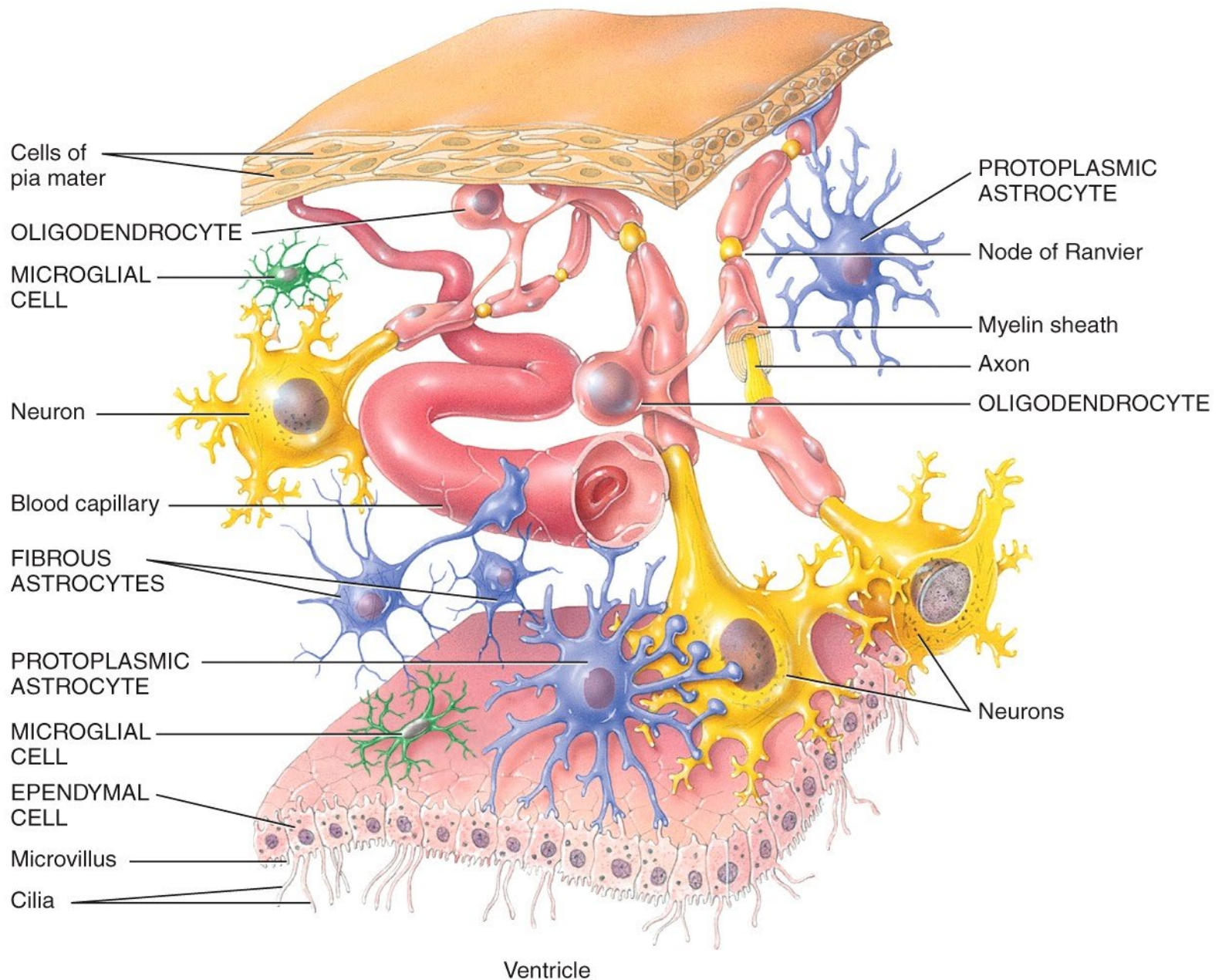
*Glial cells prevents neurons from touching each other /// gives precision to conduction pathways*

## Neuroglial cells of the CNS.



NEUROGLIAL CELL TYPE	ASTROCYTE	OLIGODENDROCYTE	MICROGLIAL CELL	EPENDYMAL CELL
FUNCTION	<ul style="list-style-type: none"> <li>• Anchor neurons and blood vessels</li> <li>• Regulate the extracellular environment</li> <li>• Facilitate the formation of the blood-brain barrier</li> <li>• Repair damaged tissue</li> </ul>	<ul style="list-style-type: none"> <li>• Myelinate certain axons in the CNS</li> </ul>	<ul style="list-style-type: none"> <li>• Act as phagocytes</li> </ul>	<ul style="list-style-type: none"> <li>• Line cavities</li> <li>• Cilia circulate fluid around brain and spinal cord</li> <li>• Some secrete this fluid</li> </ul>

Note: two types of astrocytes - protoplasmic vs fibrous



# More About Neuroglial Cells

---

Four only in CNS

Two only in PNS

## Oligodendrocytes

- form myelin sheaths in CNS
- each arm-like process wraps around a nerve fiber
- forms an insulating layer of myelin
- Increase speed of action potentials

## Ependymal cells

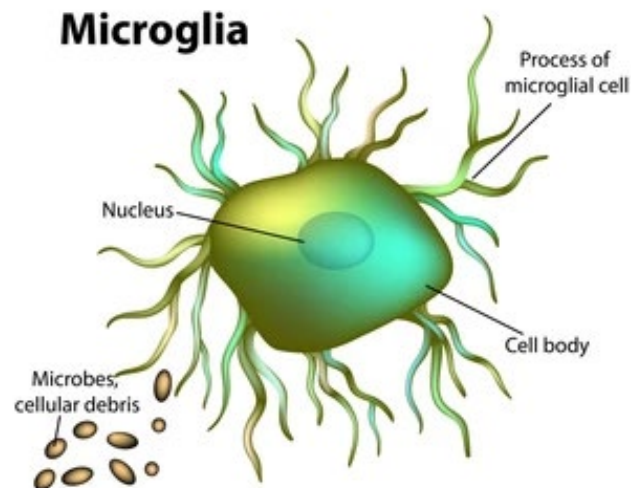
- lines internal cavities (ventricles) of the brain / no tight junctions
- cuboidal epithelium with cilia on apical surface
- secretes and circulates cerebrospinal fluid (CSF)
- clear liquid that bathes the CNS
- Ependymal cells with tight junctions form choroid plexus.

# More About Neuroglial Cells

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## Microglia

- small, wandering macrophages
- formed by white blood cell called **monocytes**
- complete checkup on the brain tissue several times a day
- wander in search of cellular debris to phagocytize



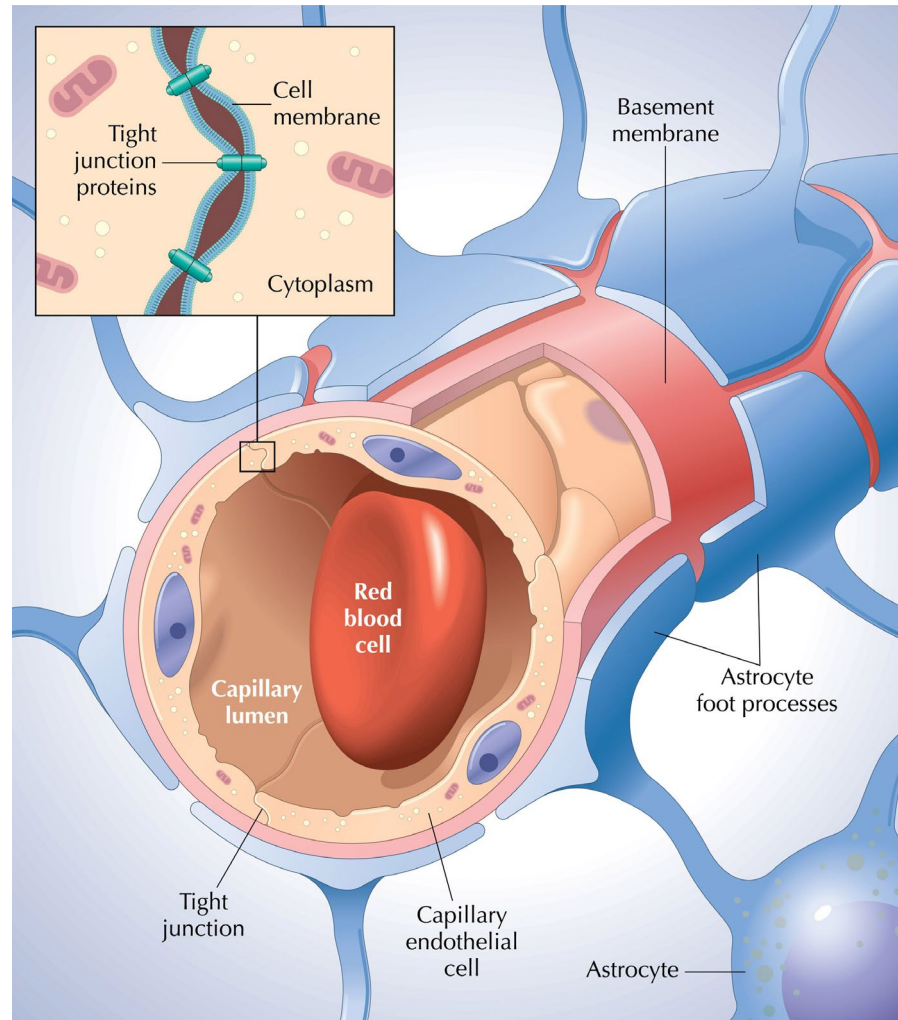
# More About Neuroglial Cells

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## Astrocytes

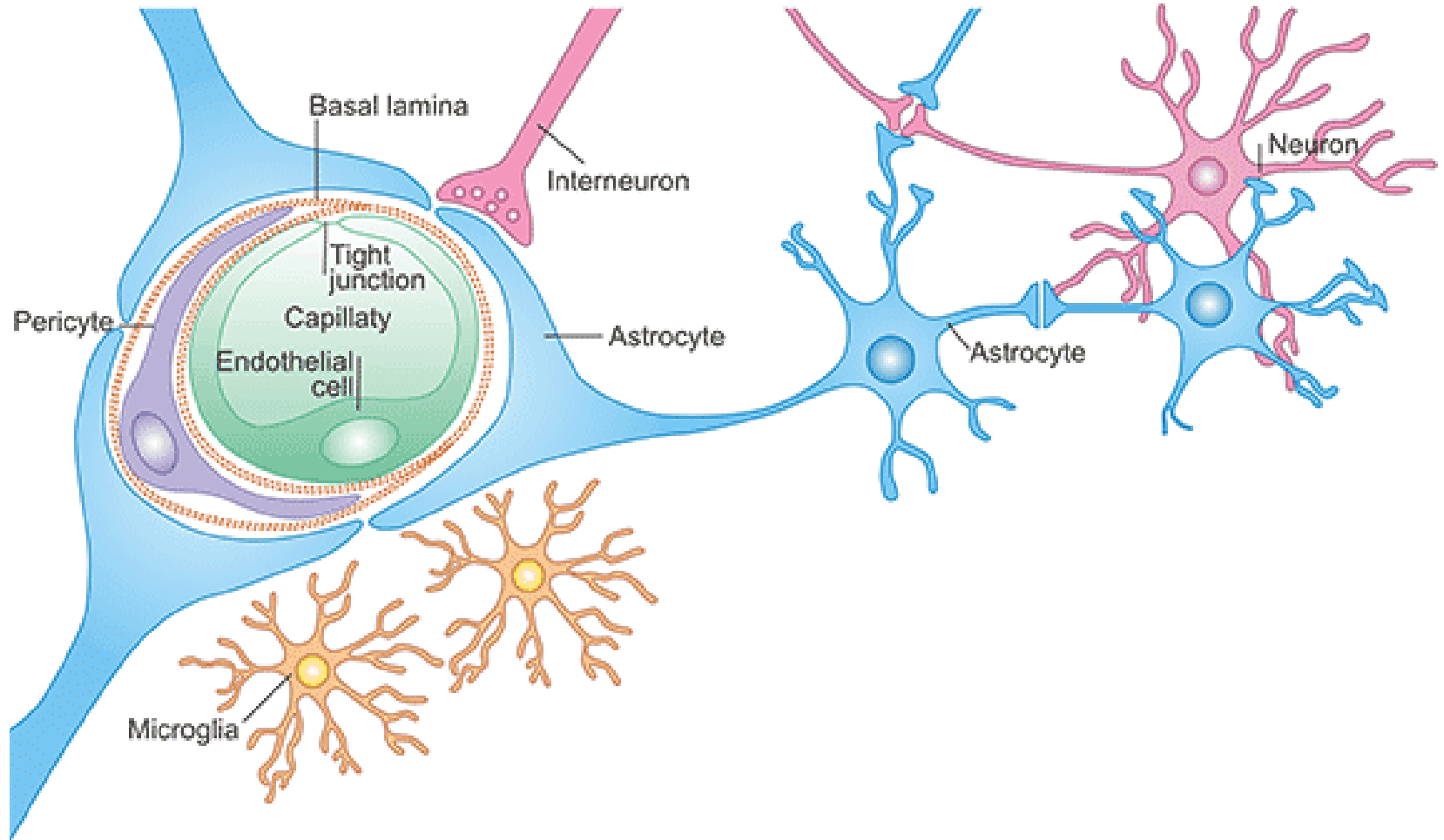
- most abundant glial cell in CNS // some subdivide astrocytes into two types (protoplasmic vs fibrous)
- cover entire brain surface and most nonsynaptic regions of the neurons in the gray matter of the CNS
- diverse functions // form a supportive framework of nervous tissue
- have extensions (**perivascular feet**) with tight junctions that contact blood capillaries to form the **blood-brain**
- (see next slide)

# blood-brain barrier



Nutrients in blood must pass through astrocyte's cytoplasm to reach a neuron.

# blood-brain barrier



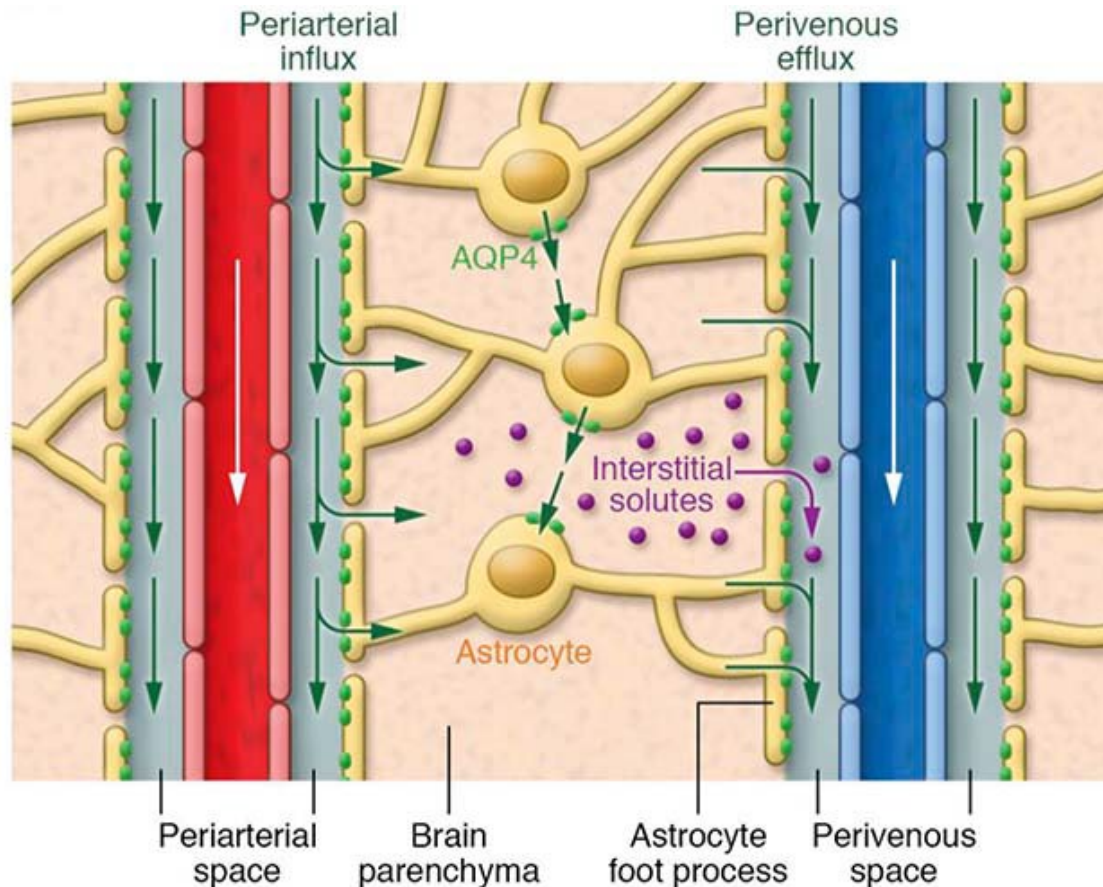
# More About Neuroglial Cells

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## Astrocytes

- convert blood glucose to lactate and supply this to the neurons for nourishment
- nerve growth factors secreted by astrocytes promote neuron growth and synapse formation
- communicate electrically with neurons and may influence synaptic signaling // role in memory not understood
- regulate chemical composition of tissue fluid by absorbing excess neurotransmitters and ions
- astrocytosis or sclerosis – when neuron is damaged, astrocytes form hardened scar tissue and fill space formerly occupied by the neuron

The **glymphatic system** is the central nervous system's (CNS) waste clearance system, analogous to the body's lymphatic system, and it is most active during sleep. It works by flushing **cerebrospinal fluid (CSF)** through the brain's interstitial spaces to carry away metabolic waste, such as proteins and metabolites, which are then absorbed into **perivenous spaces**. Proper glymphatic function, which is supported by glial cells called **astrocytes** and their **aquaporin-4 (AQP4) water channels**, is crucial for brain health and is disrupted in neurological conditions like Alzheimer's and Parkinson's diseases



# PNS Glial Cells

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Two types of glial cells in PNS

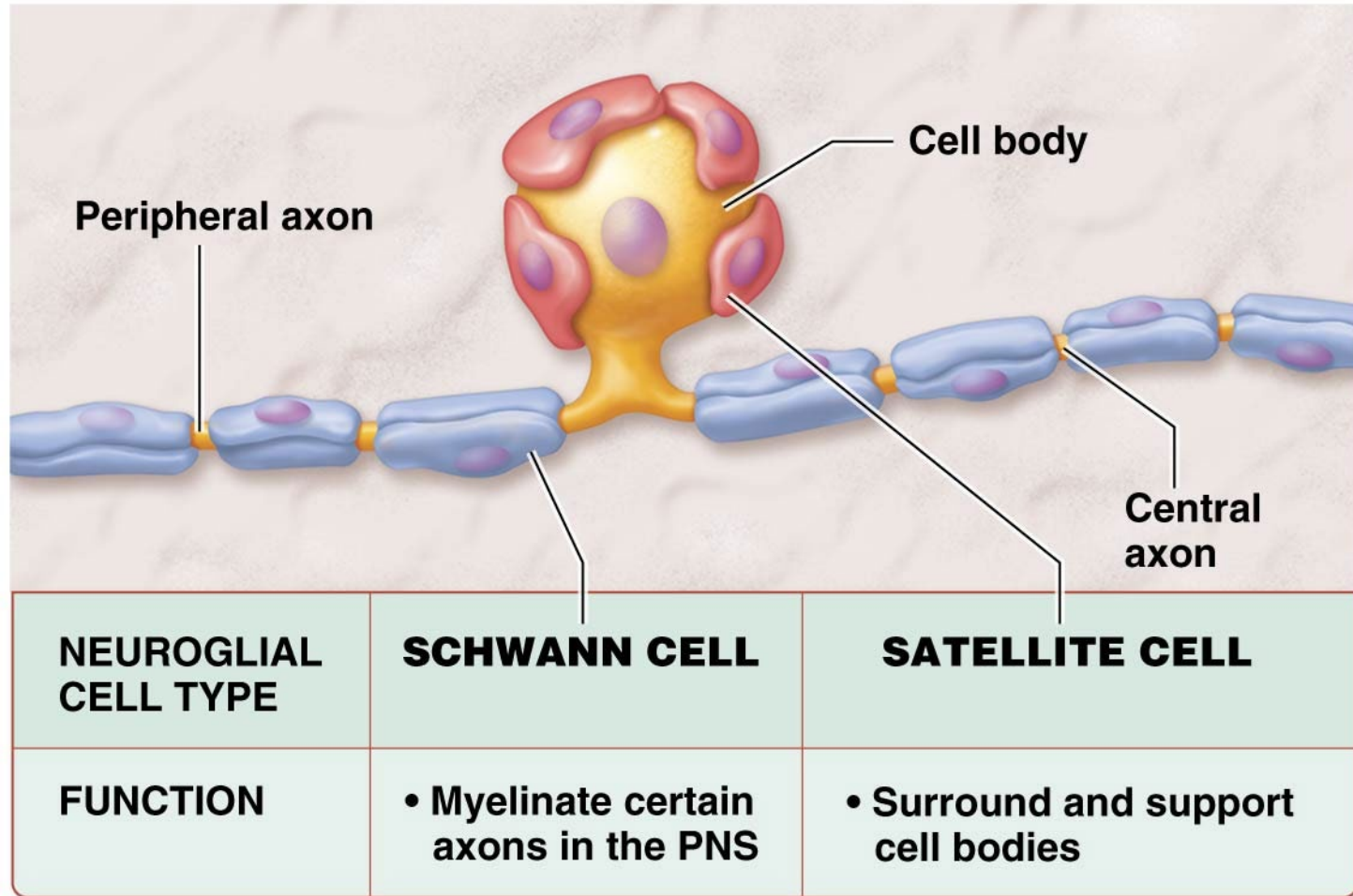
## Schwann cells

- envelope nerve fibers in PNS
- wind repeatedly around a nerve fiber
- produces a **myelin sheath** similar to the ones produced by oligodendrocytes in CNS
- assist in the regeneration of damaged fibers

## Satellite cells

- surround the neurosomas in ganglia of the PNS
- provide electrical insulation around the soma
- regulate the chemical environment of the neurons

# Neuroglial cells of the PNS.



# The Myelin Sheath

---

## Myelin sheath

- an insulating layer around a nerve fiber
- formed by **oligodendrocytes** in CNS
- formed by **Schwann cells** in PNS
- consists of the plasma membrane of glial cells (20% protein and 80 % lipid)

## Myelination = production of the myelin sheath

- begins the **14<sup>th</sup> week of fetal development**
- proceeds rapidly during infancy
- completed in late adolescence
- dietary fat is important to nervous system development (Danger! Trans Fat!)

# Myelin in PNS

**Schwann cell** spirals repeatedly around a single nerve fiber

lays down as many as a hundred layers of its own membrane

no cytoplasm between the membranes

**neurilemma** – thick outermost coil of myelin sheath /// contains nucleus and most of its cytoplasm

external to neurilemma is basal lamina and a thin layer of fibrous connective tissue – **endoneurium**

# Myelin in CNS

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**Oligodendrocytes** extend pseudopods (arm like structures) to reach out to myelinate several nerve fibers in immediate area

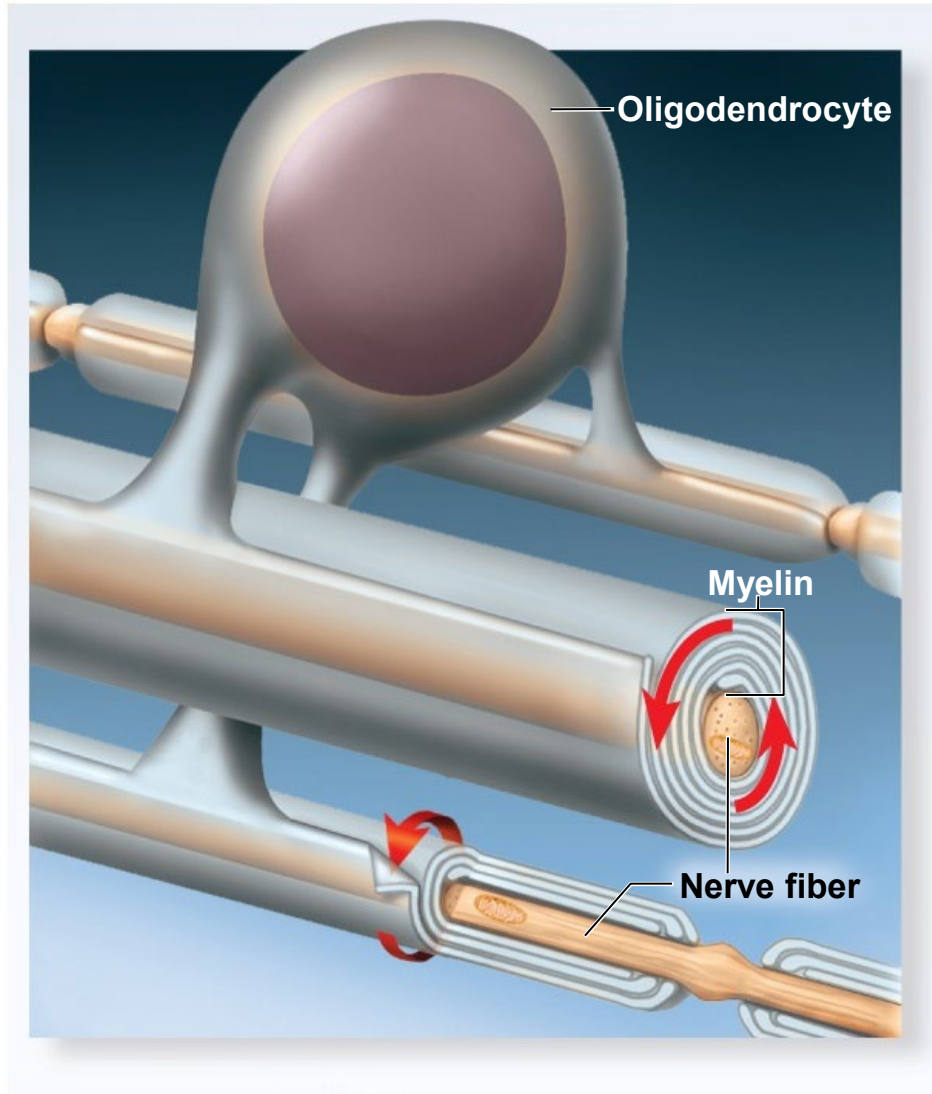
–anchored to multiple nerve fibers

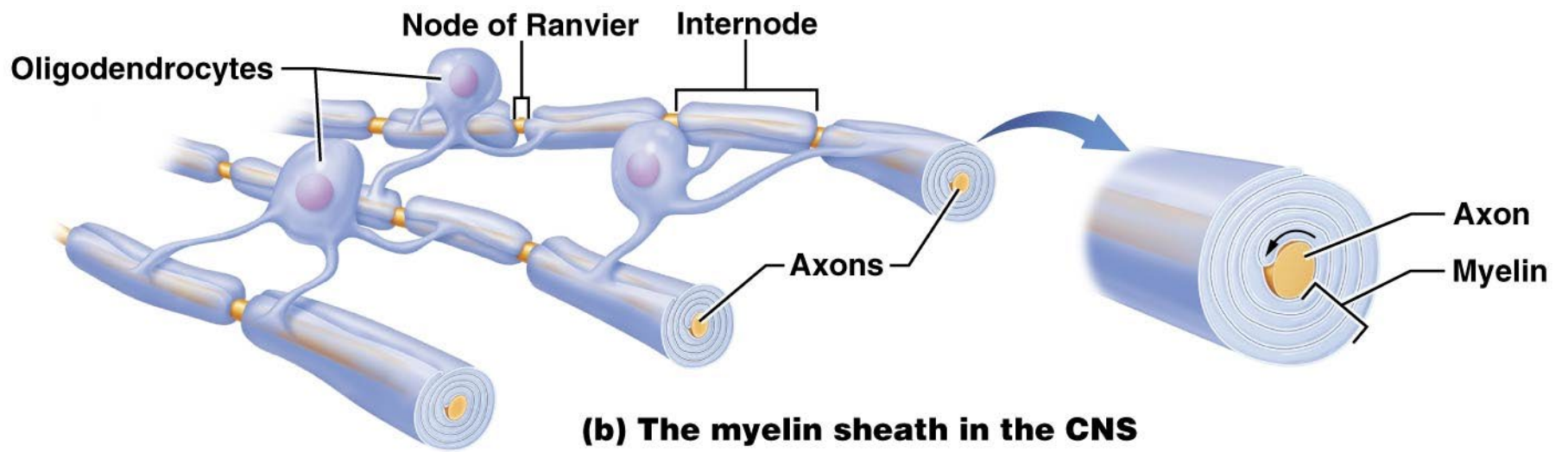
–cannot migrate around any one nerve fiber like Schwann cells

–must push newer layers of myelin under the older ones (so myelination spirals inward toward nerve fiber)

–nerve fibers in CNS have no neurilemma or endoneurium (see Schwann cell structure)

# Myelination in CNS





# Myelin in PNS

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Many Schwann cells and oligodendrocytes are needed to cover one nerve fiber

• **Myelin sheath is segmented**

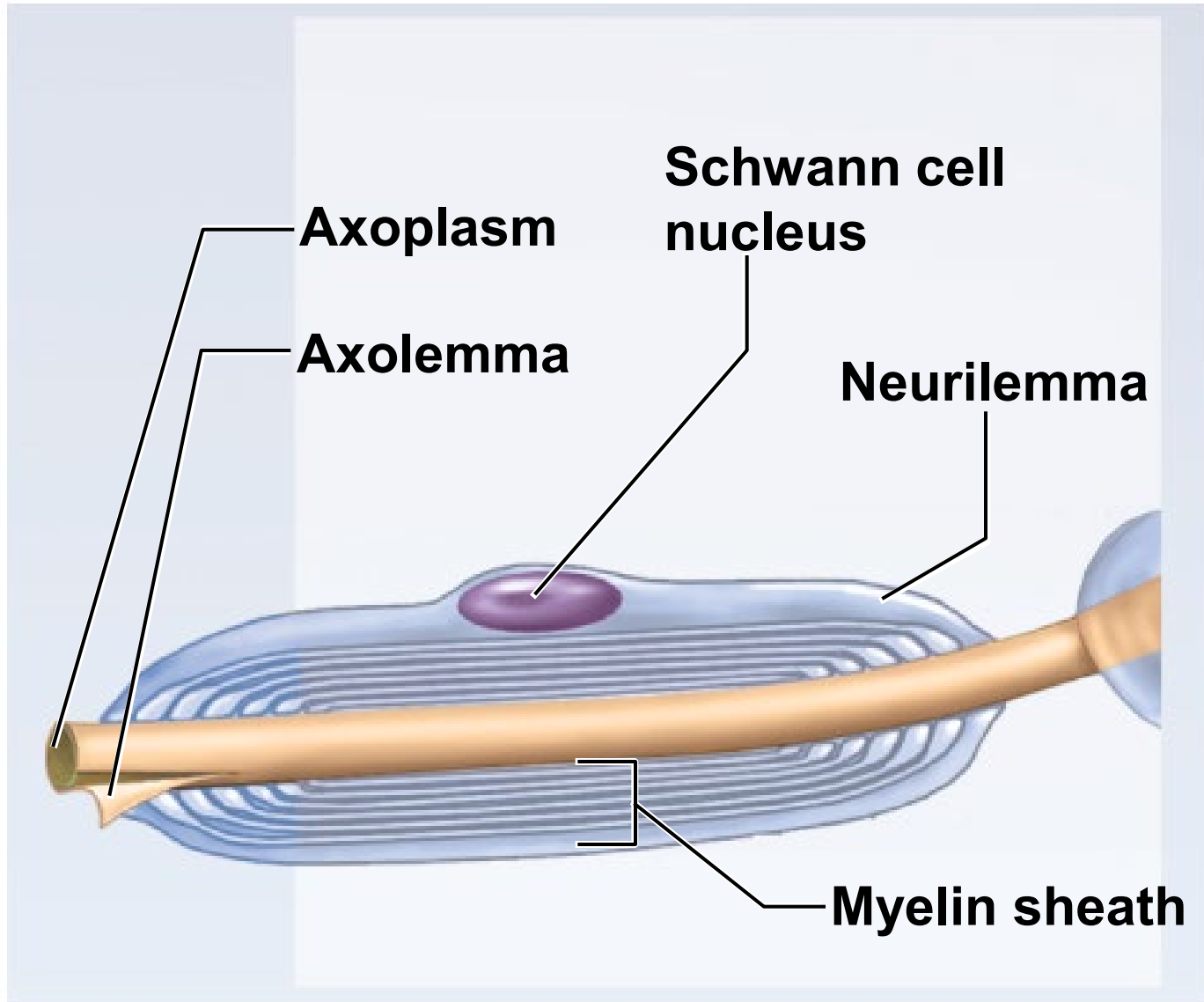
– **nodes of Ranvier** – gap between segments

– **internodes** – myelin covered segments from one gap to the next

– **initial segment** – short section of nerve fiber between the axon hillock and the first glial cell

– **trigger zone** – the axon hillock and the first segment of neurolemma /// play an important role in initiating a nerve signal

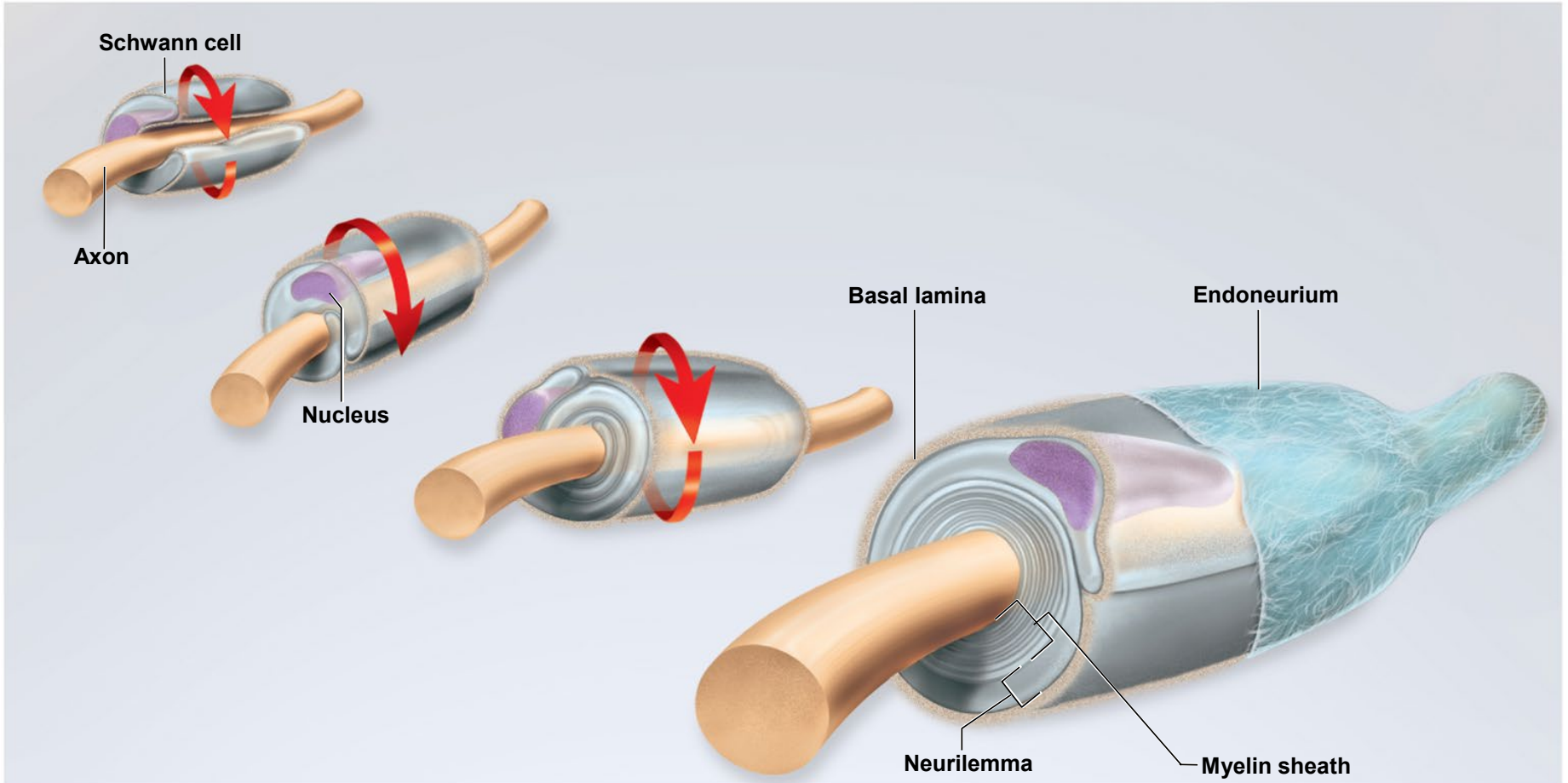
# Myelin Sheath in PNS

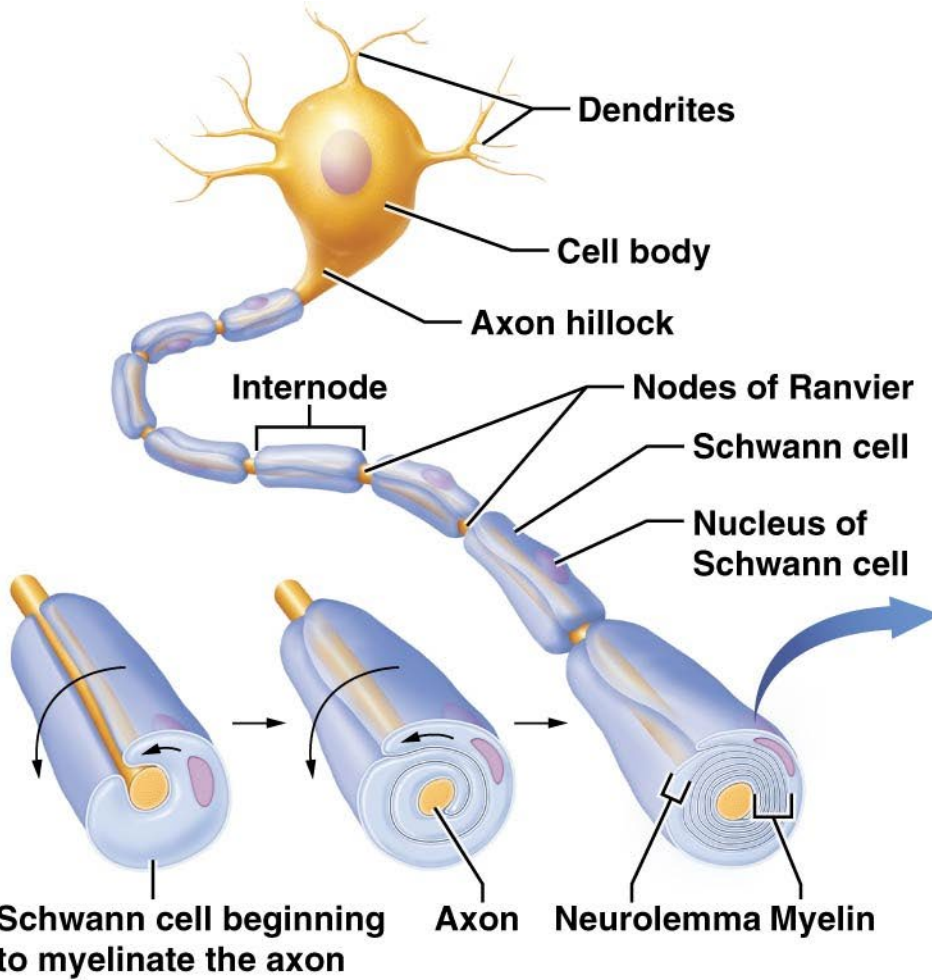


nodes of Ranvier and internodes

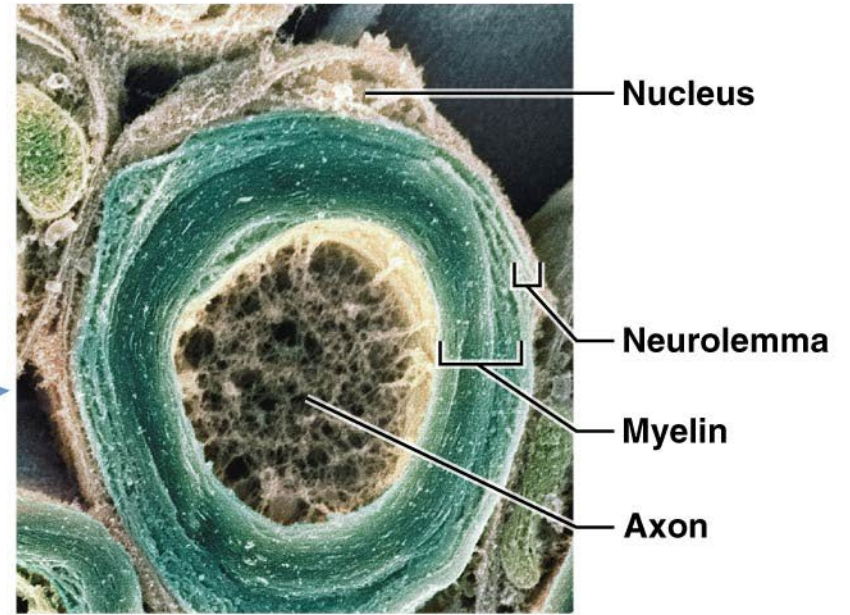
# Myelination in PNS

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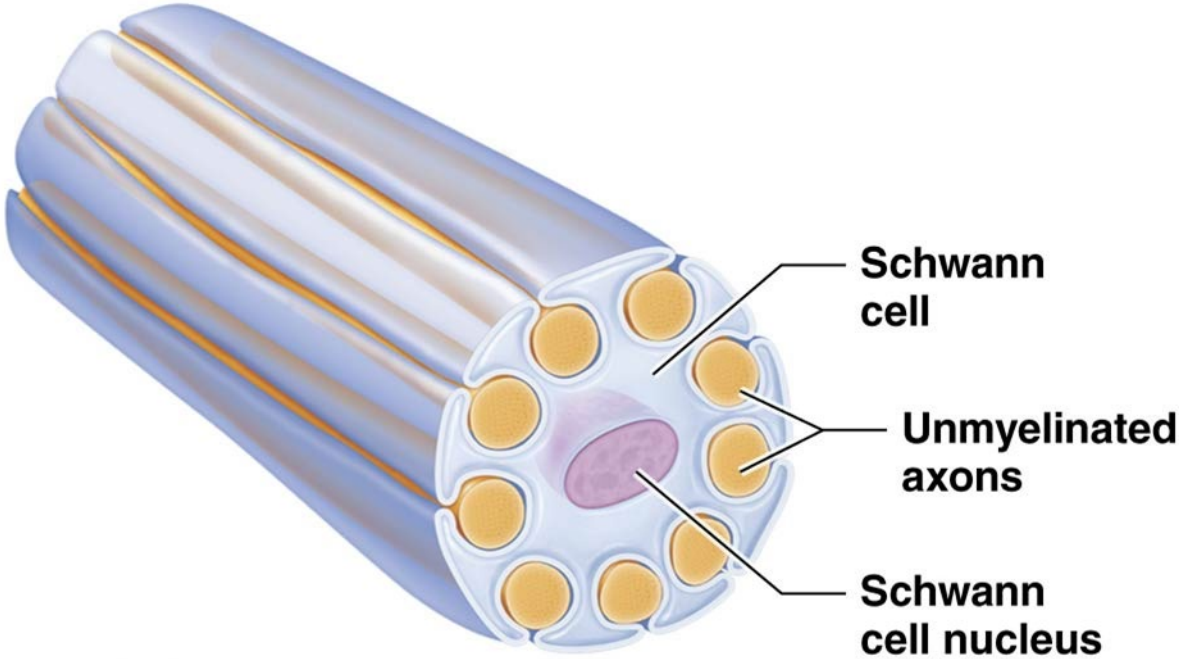


**(a) The myelin sheath and myelination in the PNS**



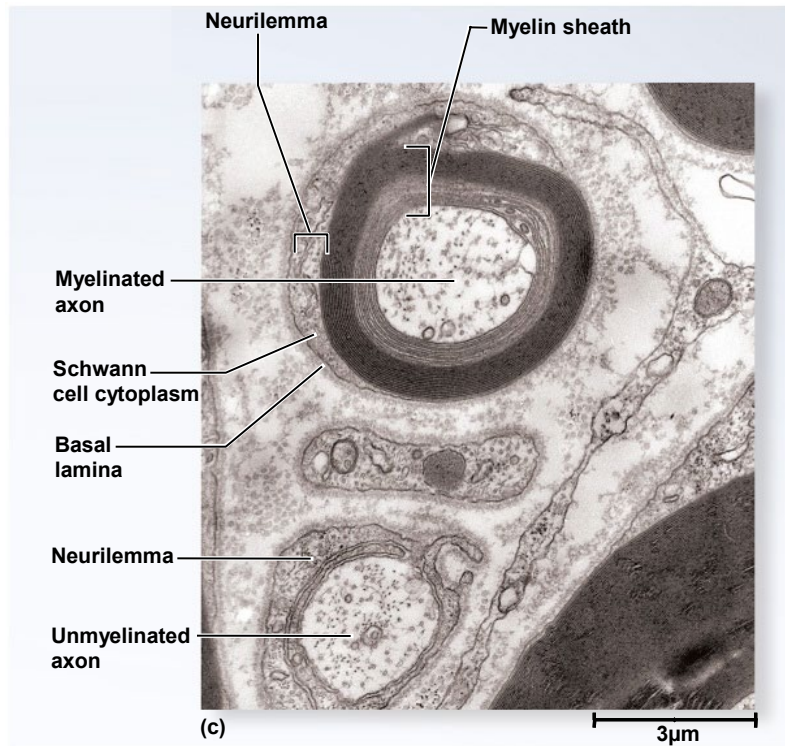
Cross-section of a myelin sheath SEM (30,700x)

# Unmyelinated peripheral axons and Schwann cells.

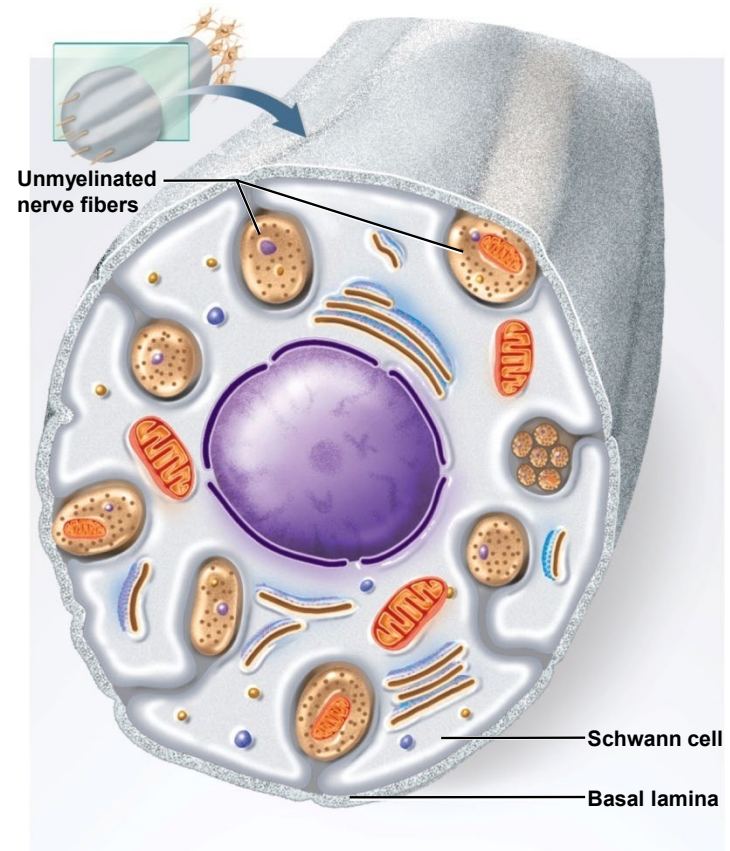


# Unmyelinated Axons of PNS

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- Schwann cells hold 1 – 12 small nerve fibers in grooves on its surface
- membrane folds once around each fiber overlapping itself along the edges
- **mesaxon** – neurilemma wrapping of unmyelinated nerve fibers

# Conduction Speed of Nerve Fibers

---

Speed at which a nerve signal travels along a nerve fiber depends on two factors

- diameter of fiber
- presence or absence of myelin / amount of myelination
- temperature (lower speed when cooled)

Signal conduction occurs along the surface of a fiber

–larger fibers have more surface area and conduct signals more rapidly

–myelin further speeds signal conduction

–Speeds ranging from 0.5 to 130 meters per second (1 to 300 miles per hour)

# Conduction Speed of Nerve Fibers

---

## Conduction speed

- small, unmyelinated fibers - 0.5 - 2.0 m/sec
- small, myelinated fibers - 3 - 15.0 m/sec
- large, myelinated fibers - up to 120 m/sec (300 miles per hour)
- slow signals supply the stomach and dilate pupil where speed is less of an issue
- fast signals supply skeletal muscles and transport sensory signals for vision and balance

# Regeneration of Peripheral Motor Nerves

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Regeneration of a damaged peripheral nerve fiber can occur only if ....

–The soma is not damaged but intact

–Neurilemma must be intact

axon distal to the injury cannot survive and this tissue degenerates

macrophages engulf necrotic tissue debris inside tubular Schwann cells  
distal to point of injury

during this process the soma swells, ER breaks up, and nucleus moves  
off center /// due to loss of nerve growth factor from neuron's target cell

# Regeneration of Peripheral Motor Nerve Axons *(not able to regenerate their cell bodies)*

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Axon stump sprouts multiple growth processes // severed distal end continues to degenerate

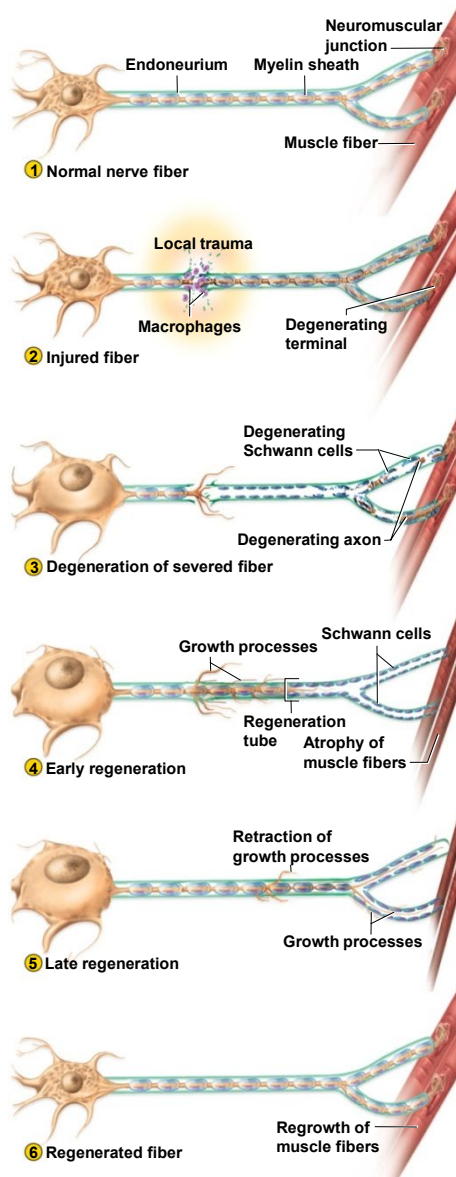
**Regeneration tube** – formed by Schwann cells, basal lamina, and the neurilemma near the injury

**Regeneration tube guides the growing sprout back to the original target cells /// re-establishes synaptic contact**

Nucleus returns to normal shape

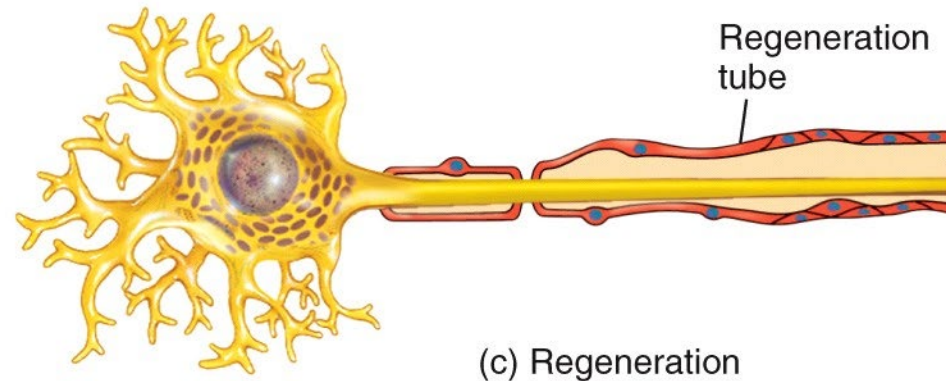
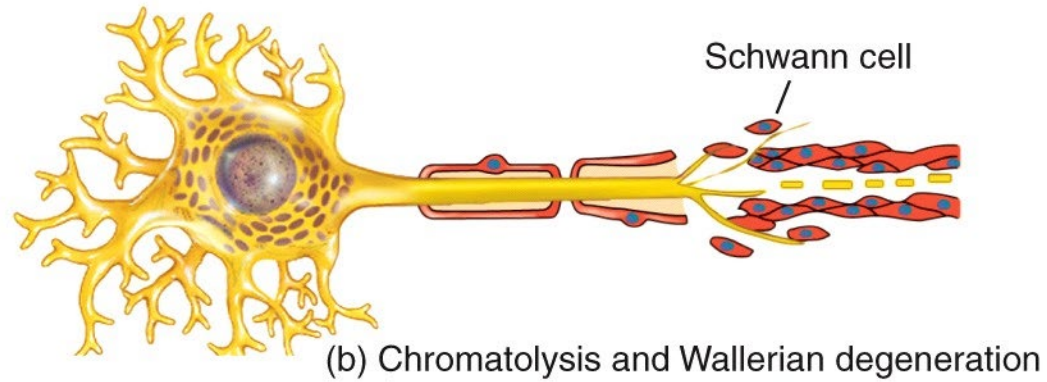
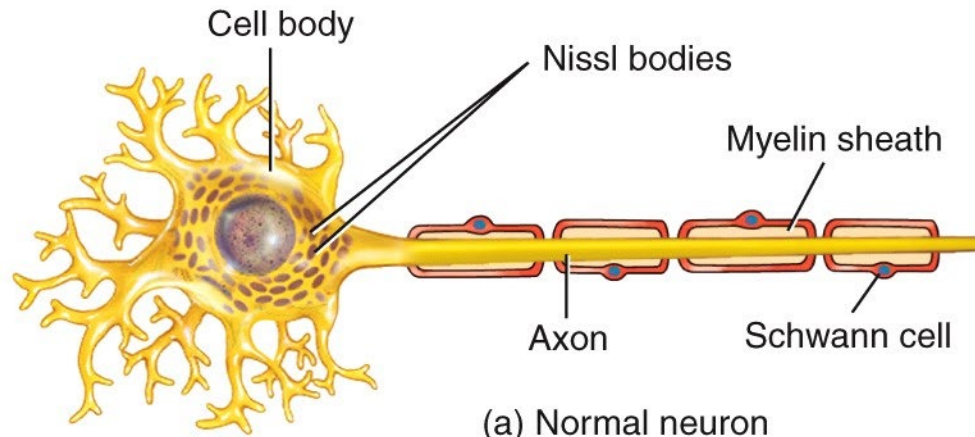
Regeneration of damaged nerve fibers in the CNS will not occur (Why?)

# Regeneration of Nerve Fiber



## Denervation Atrophy

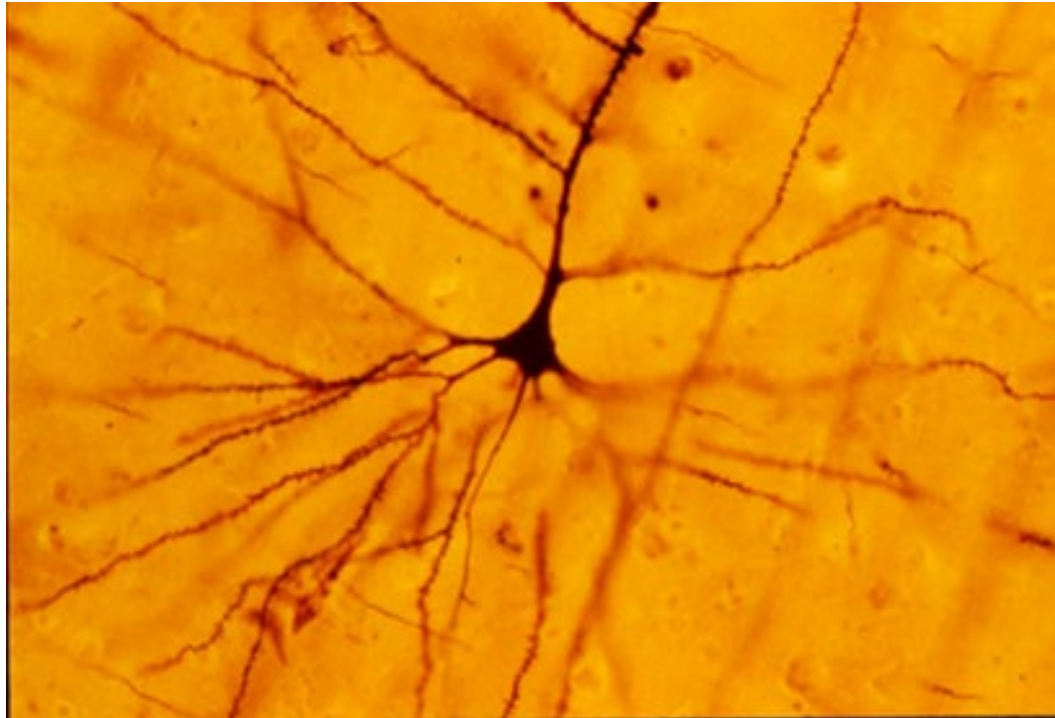
Atrophy of muscle due to loss of nerve contact by damaged nerve



# Discover of Neuron's Structure

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Golgi's silver staining technique is used to visualize nervous tissue under light microscopy. The method was discovered by Camillo Golgi, an Italian physician and scientist, who published the first picture made with the technique in 1873.



# Discover of Neuron's Structure

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Santiago Ramon y Cajal // Father of the Neuron Doctrine

Golgi staining was used by Spanish neuroanatomist Santiago Ramón y Cajal (1852–1934) to discover a number of novel facts about the organization of the nervous system.....

established the neuron doctrine

nervous pathway is not a continuous 'wire' or tube

nervous pathway a series of cells separated by gaps called synapses.

Neuron doctrine created two key questions:

- > How do neurons generate a electrical signal?
- > How do neurons transmit a message to the next cell?



# Nerve Growth Factor

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A **protein secreted by a gland, muscle, and glial cells** and picked up by the axon terminals of the neurons.

**Prevents apoptosis** (programmed cell death) in growing neurons

Enables growing neurons to make contact with their target cells

Isolated by Rita Levi-Montalcini in 1950s

Won Nobel Prize in 1986 with Stanley Cohen

Use of growth factors is now a vibrant field of research

# Axonal Transport

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Proteins are made in soma but must be transported to axon terminal /// e.g. to repair axolemma, serve as gated ion channel proteins, as enzymes or as neurotransmitters

Axonal transport is two-way passage of proteins, organelles, and other material along an axon

Anterograde transport – movement down the axon away from soma

Retrograde transport – movement up the axon toward the soma

Microtubules guide materials along axon /// motor proteins (kinesin and dynein) carry materials “on their backs” while they “crawl” along microtubules

Kinesin – motor proteins in anterograde transport

Dynein – motor proteins in retrograde transport

## Two Types of Axonal Transport - Fast and Slow

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**Fast axonal transport** // occurs at a rate of 20 – 400 mm/day

fast anterograde transport (up to 400 mm/day) /// organelles, enzymes, synaptic vesicles and small molecules

fast retrograde transport /// for recycled materials and pathogens - rabies, herpes simplex, tetanus, polio viruses // delay between infection and symptoms is time needed for transport up the axon

**Slow axonal transport** or axoplasmic flow // 0.5 to 10 mm/day

always anterograde // moves enzymes, cytoskeletal components, and new axoplasm down the axon during repair and regeneration of damaged axons

damaged nerve fibers regenerate at a speed governed by slow axonal transport

# Glial Cells and Brain Tumors

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Tumors - mass of rapidly dividing cells by mitosis

Mature neurons have little or no capacity for mitosis and do not form tumors

*Note: current science tells us certain neurons do have the capacity to undergo mitosis however... most neurons are in G zero*

Brain tumors arise from:

- meninges (protective membranes of CNS)
- by metastasis from non-neuronal tumors in other organs
- most come from glial cells that are mitotically active throughout life

Gliomas grow rapidly and are highly malignant

- blood-brain barrier decreases effectiveness of chemotherapy
- treatment consists of radiation or surgery

# Degenerative disorders of the myelin sheath

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## Multiple sclerosis

**oligodendrocytes** problem results in myelin sheaths in the CNS deterioration

myelin replaced by hardened scar tissue

nerve conduction disrupted (double vision, tremors, numbness, speech defects)

onset between 20 and 40 and fatal from 25 to 30 years after diagnosis

cause may be auto-immune triggered by virus

# Degenerative disorders of the myelin sheath

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**Tay-Sachs Disease** - a hereditary disorder of infants of Eastern European Jewish ancestry // Tay-Sachs disease is a rare genetic disorder caused by mutations in the **HEXA gene**. This prevents the body from producing the enzyme **beta-hexosaminidase A**, leading to toxic accumulations of a fatty substance called GM2 ganglioside in the brain and spinal cord.

abnormal accumulation of glycolipid called **GM<sub>2</sub>** in the myelin sheath // normally decomposed by lysosomal enzyme /// enzyme missing in individuals homozygous for Tay-Sachs allele

accumulation of **ganglioside** (GM<sub>2</sub>) disrupts conduction of nerve signals // blindness, loss of coordination, and dementia /// fatal before age 4

The condition is inherited in an **autosomal recessive** pattern. This means the following: **The Carrier Requirement:** Both biological parents must carry the mutated *HEXA* gene. Carriers do not have the disease themselves