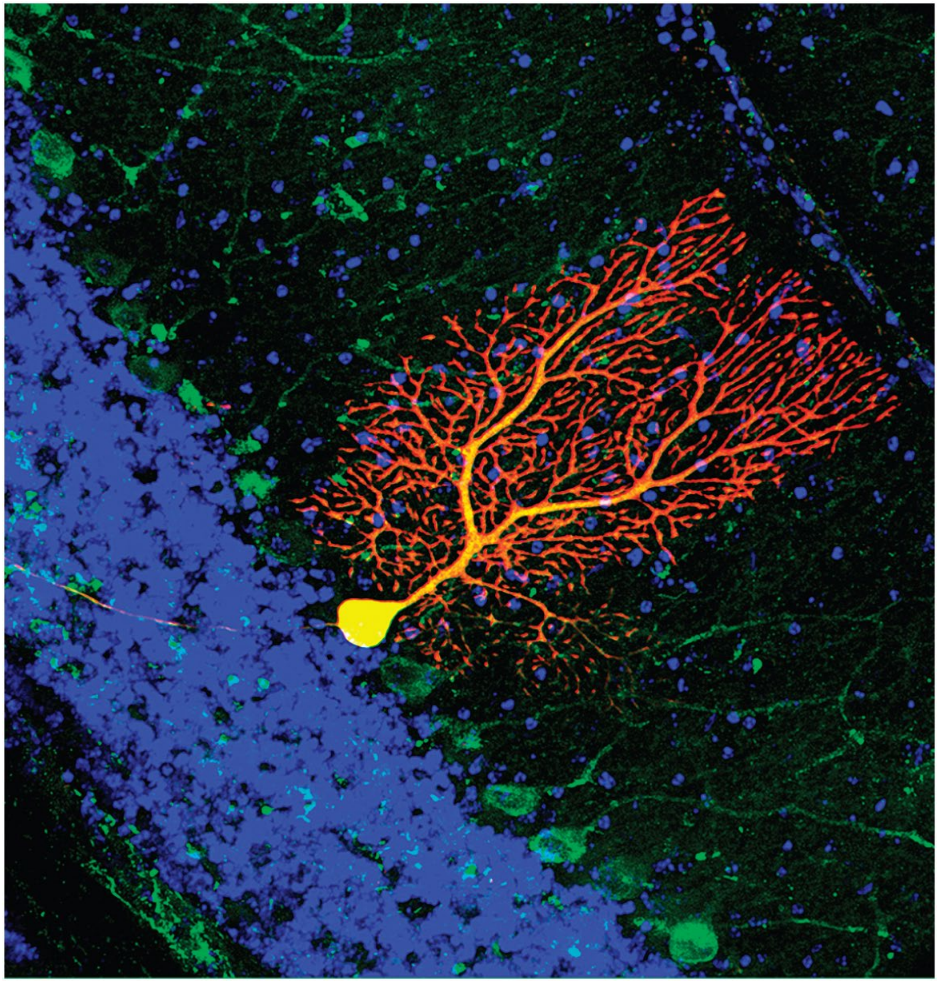
Chapter 12.1

Nervous Tissue



The Nervous System

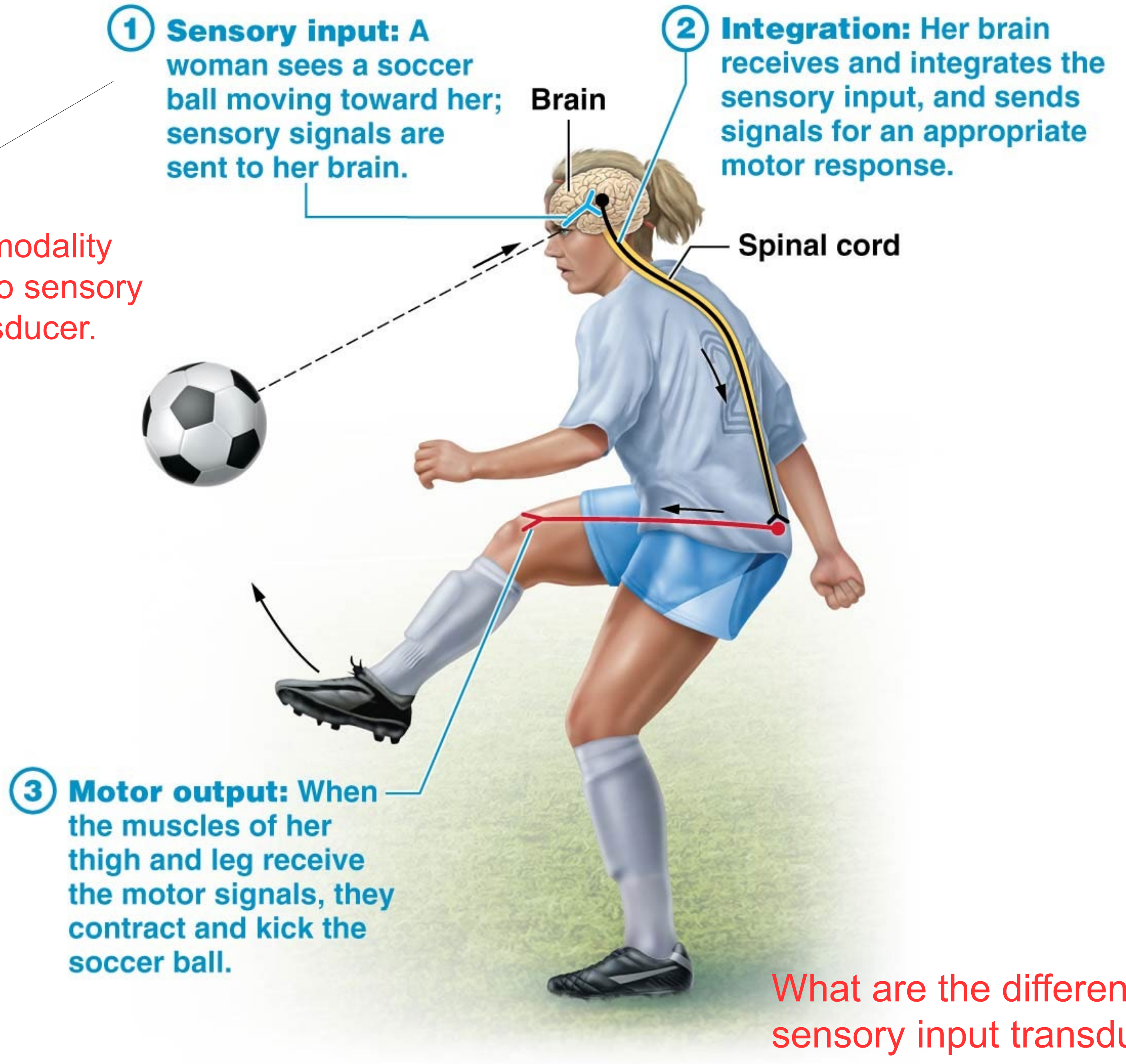
The Nervous System carries out its task in three steps:

- 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 homeostasis reflex “receptor-integrator-effector” model

> What is the significance of a stimulus to the receptor?

Stimulus modality matched to sensory input transducer.



What are the different types of sensory input transducers?

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

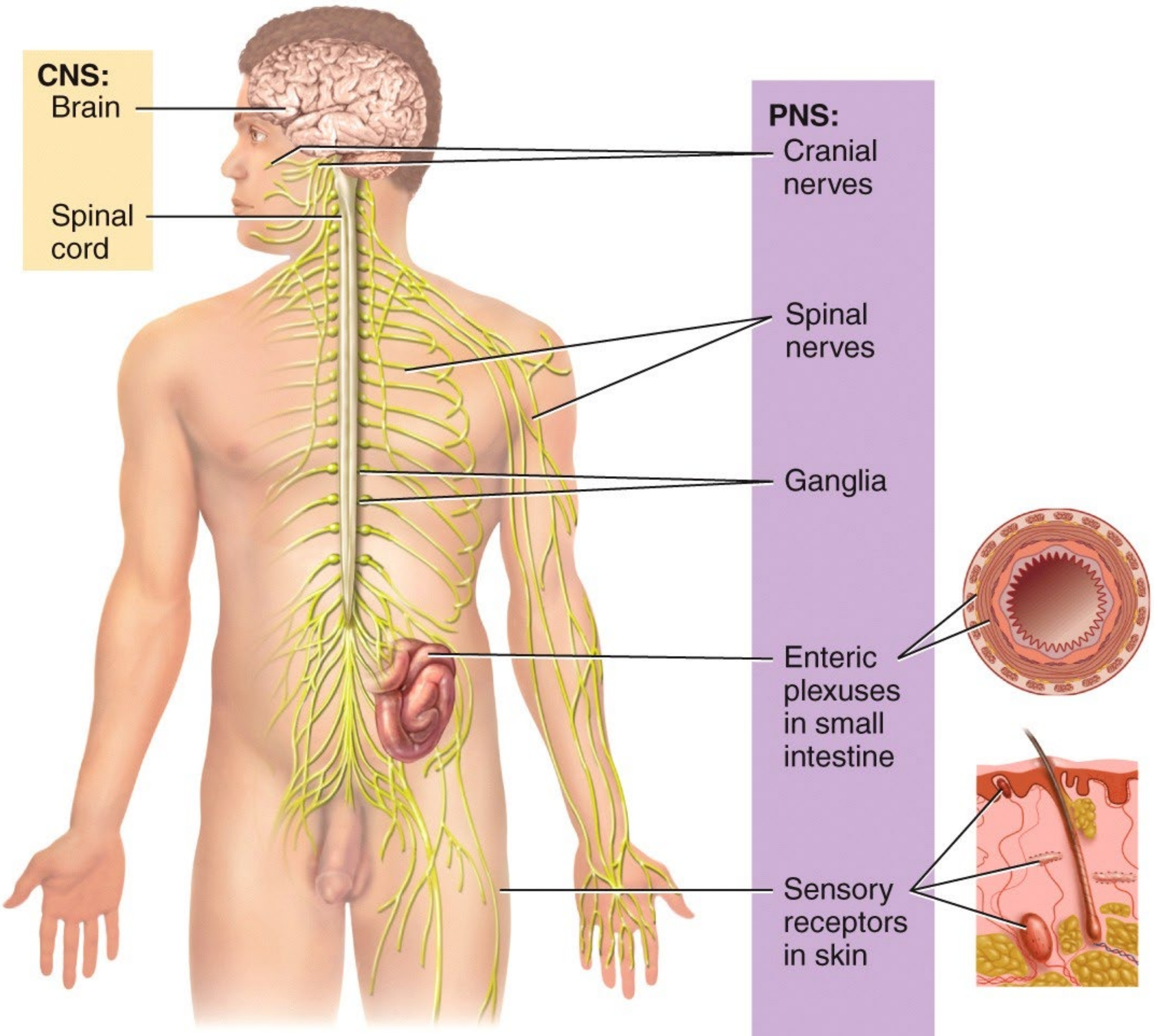
–composed of nerves and ganglia

•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

•nuclei – isolated “island” of gray matter in the CNS // info process

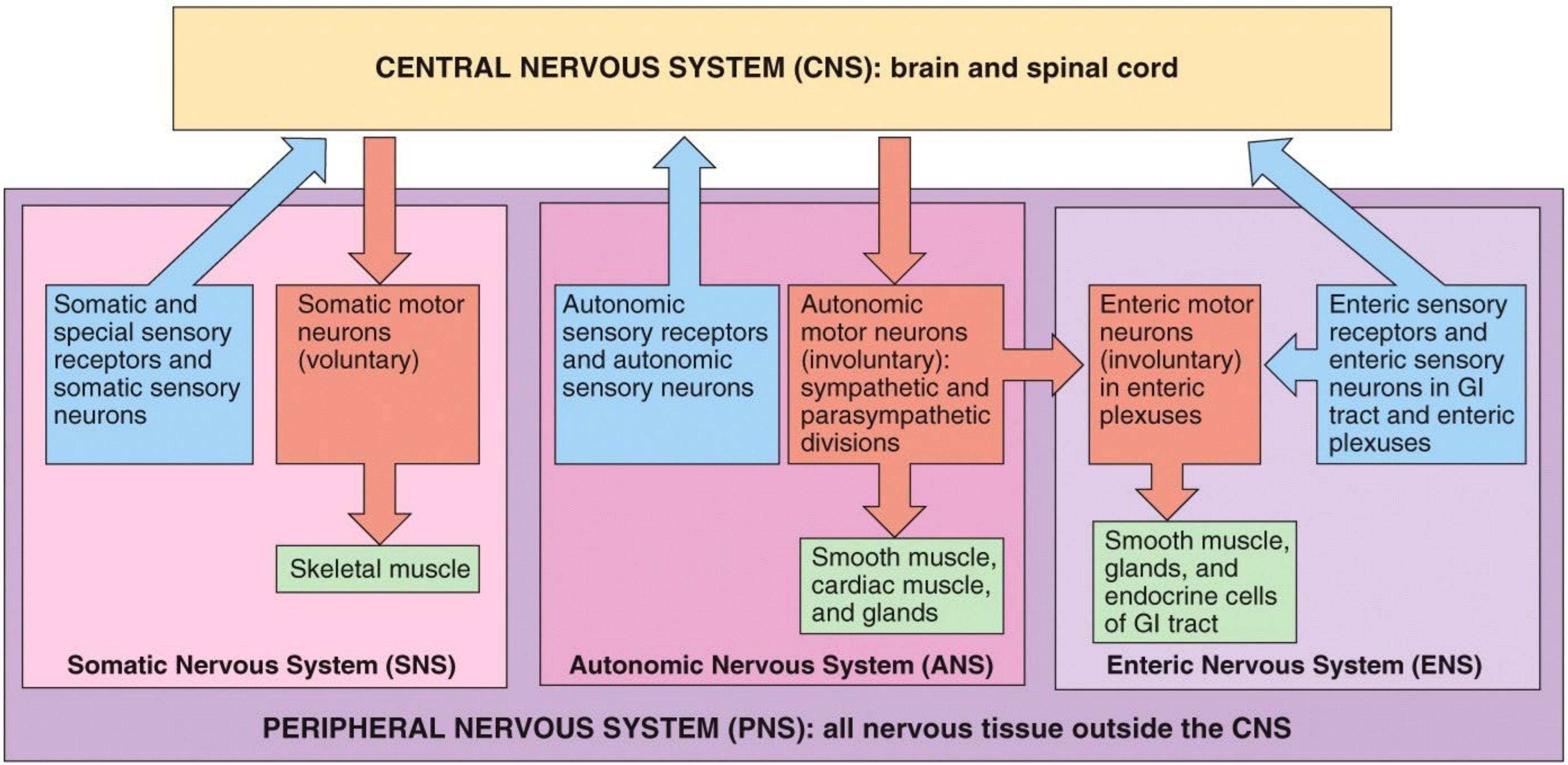
What are the two anatomical division of the nervous system?



(a)

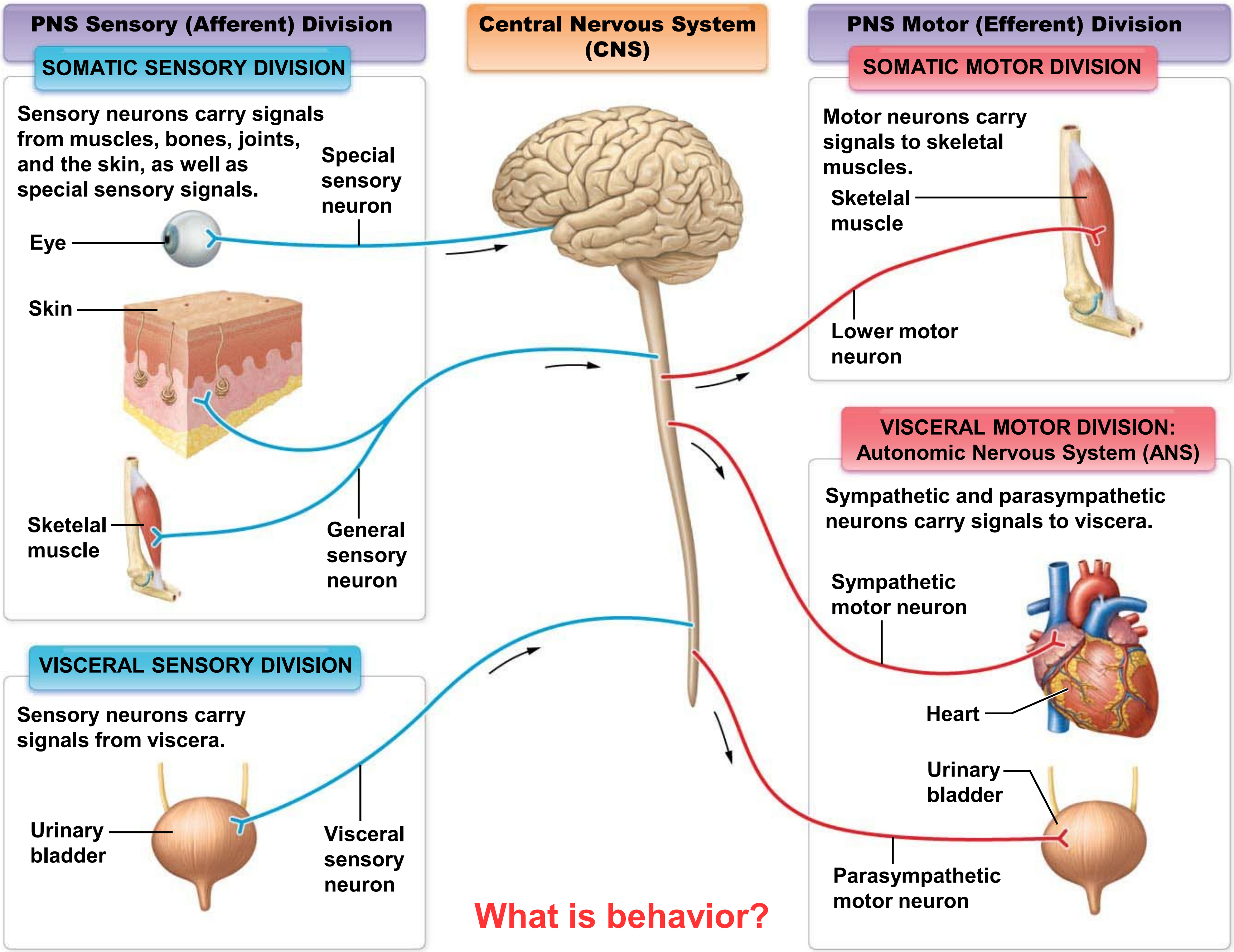
Two Anatomical Divisions of the Nervous System

(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.



What is behavior?

How Do We Maintain Homeostasis?

The “internal environment” resist change around our cells to maintain a stable condition 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 signals originate in *CNS and flow out to the effectors*

Effectors = tissues that respond to commands from the CNS

Peripheral Nervous Motor Divisions

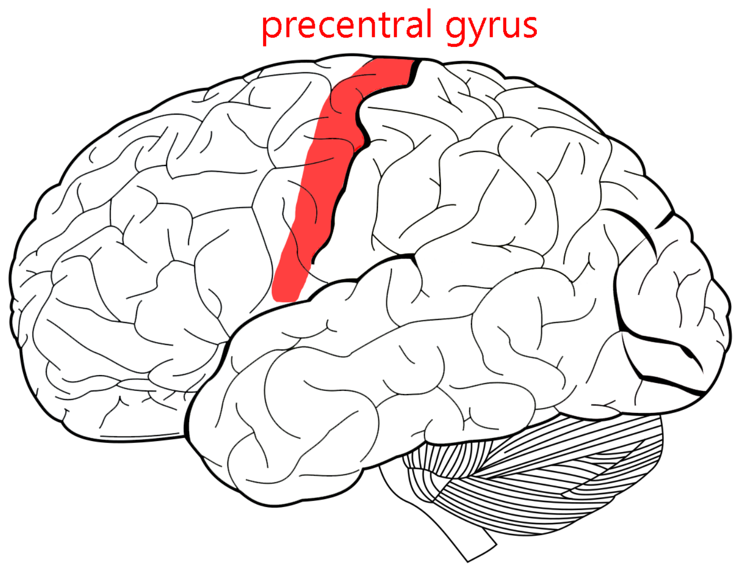
Somatic Motor Division (efferent fibers)

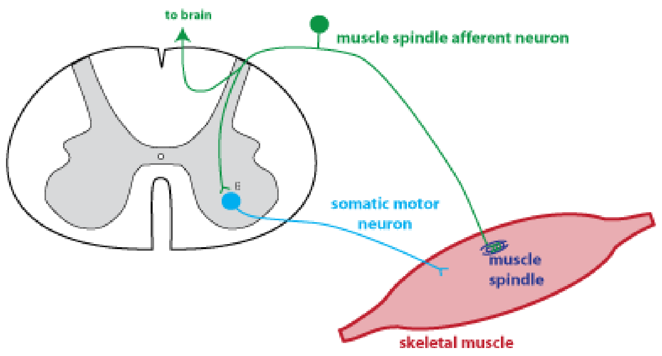
carries signals to skeletal muscles

signal originates from brain's precentral gyrus

output produces skeletal muscular contraction /// voluntary

spinal cord reflex /// "somatic reflexes" - do not require precentral gyrus function (i.e. the motor strip) // spinal cord reflexes <u>cause involuntary skeletal muscle contractions</u>





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

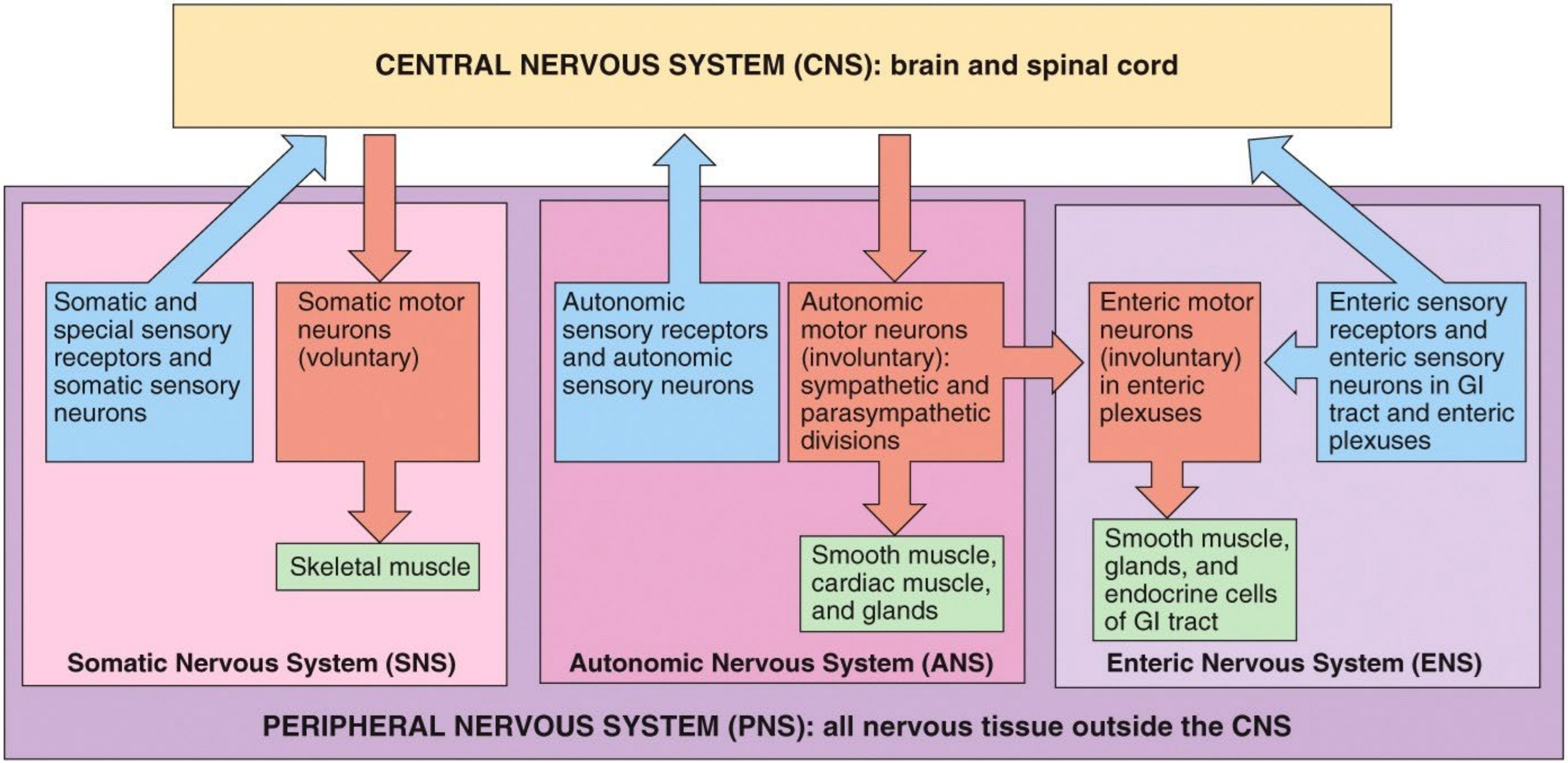
–tends to have calming effect

–slows heart rate and breathing

–stimulates digestive and urinary systems

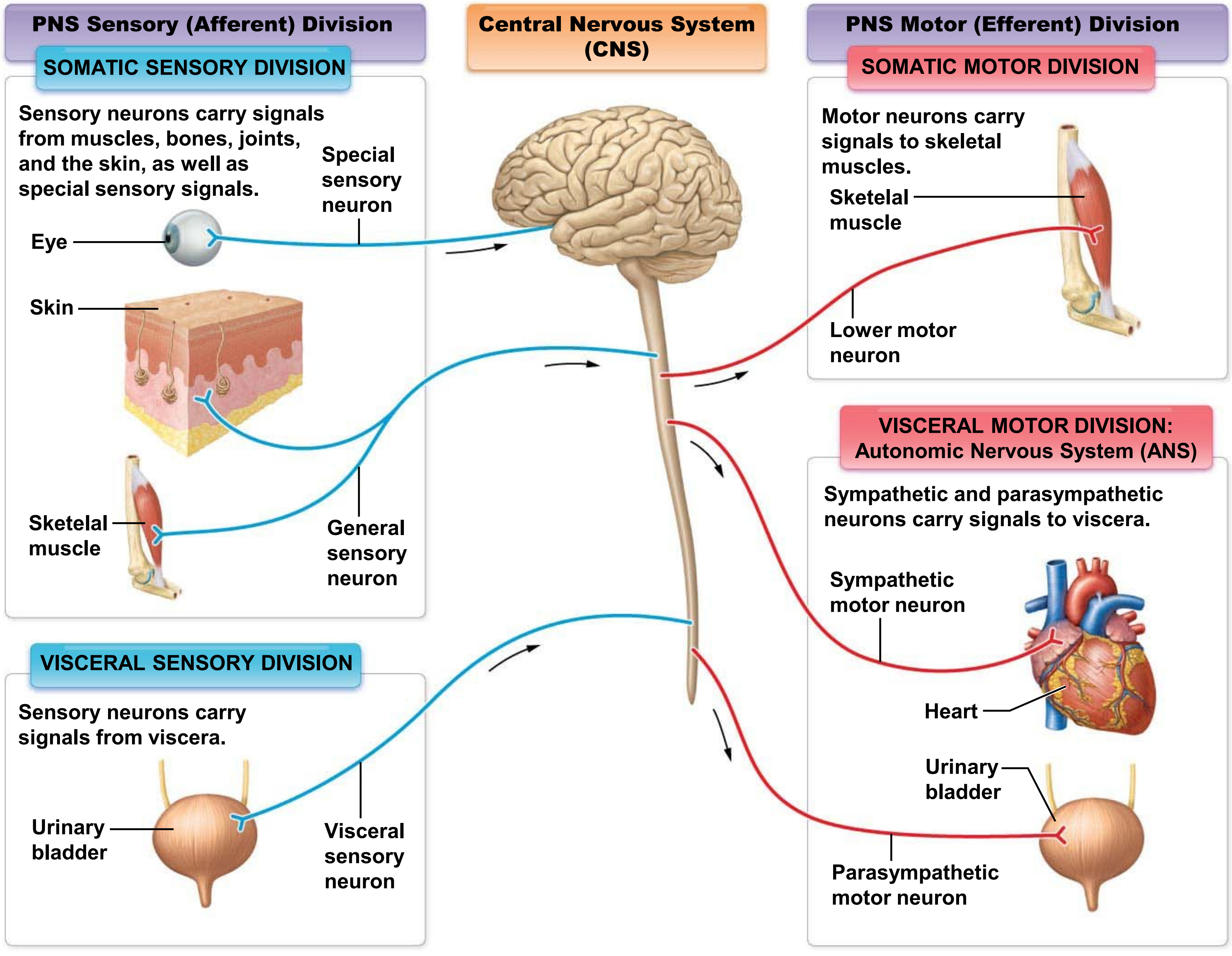
–rest and restore division

Nervous System Structure



(b)

The organization of the peripheral nervous system.



Universal Properties of a Neuron

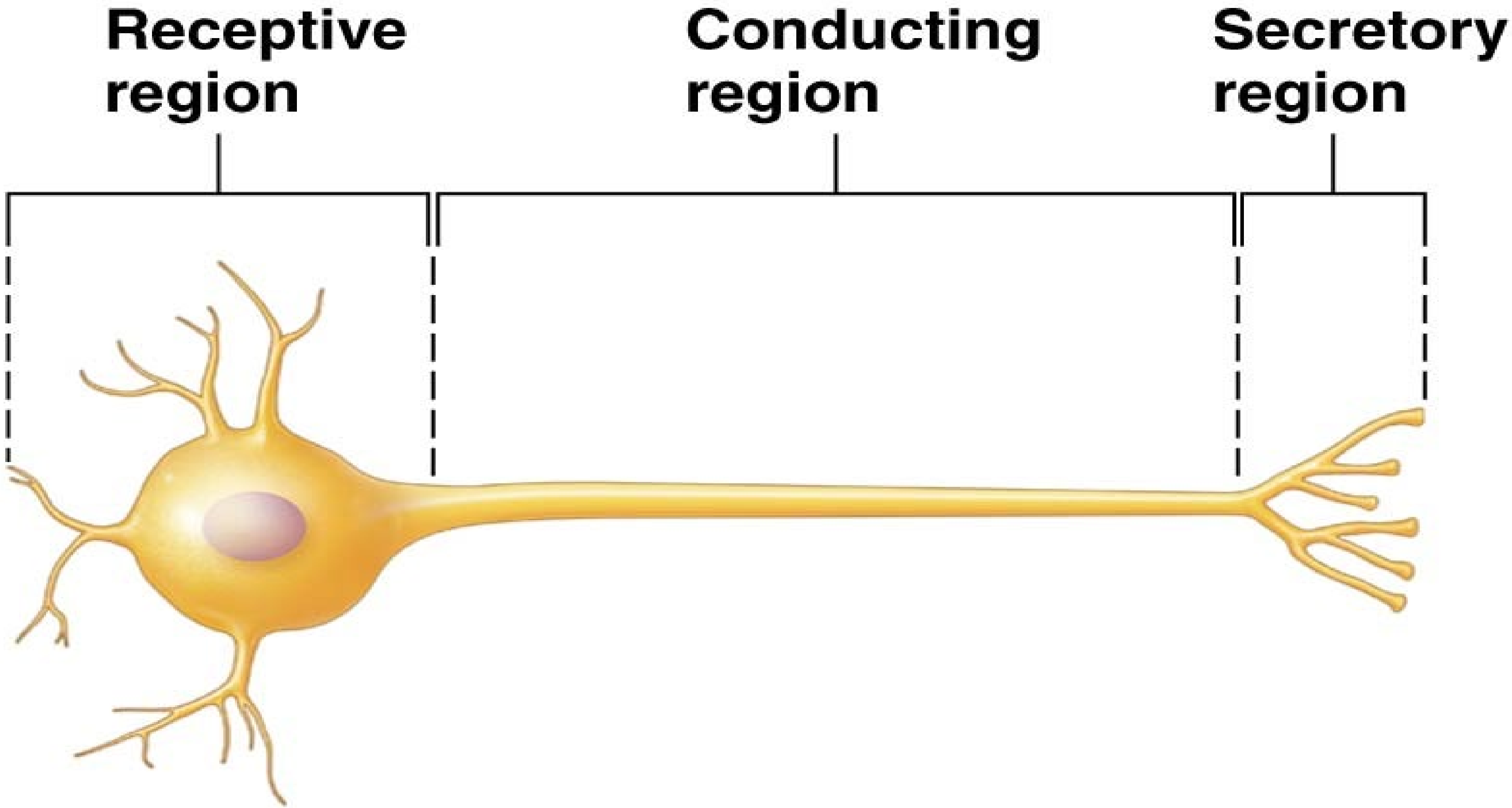
Neurons Are Excitable (irritability) /// respond to environmental changes called stimuli

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 synpatic 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



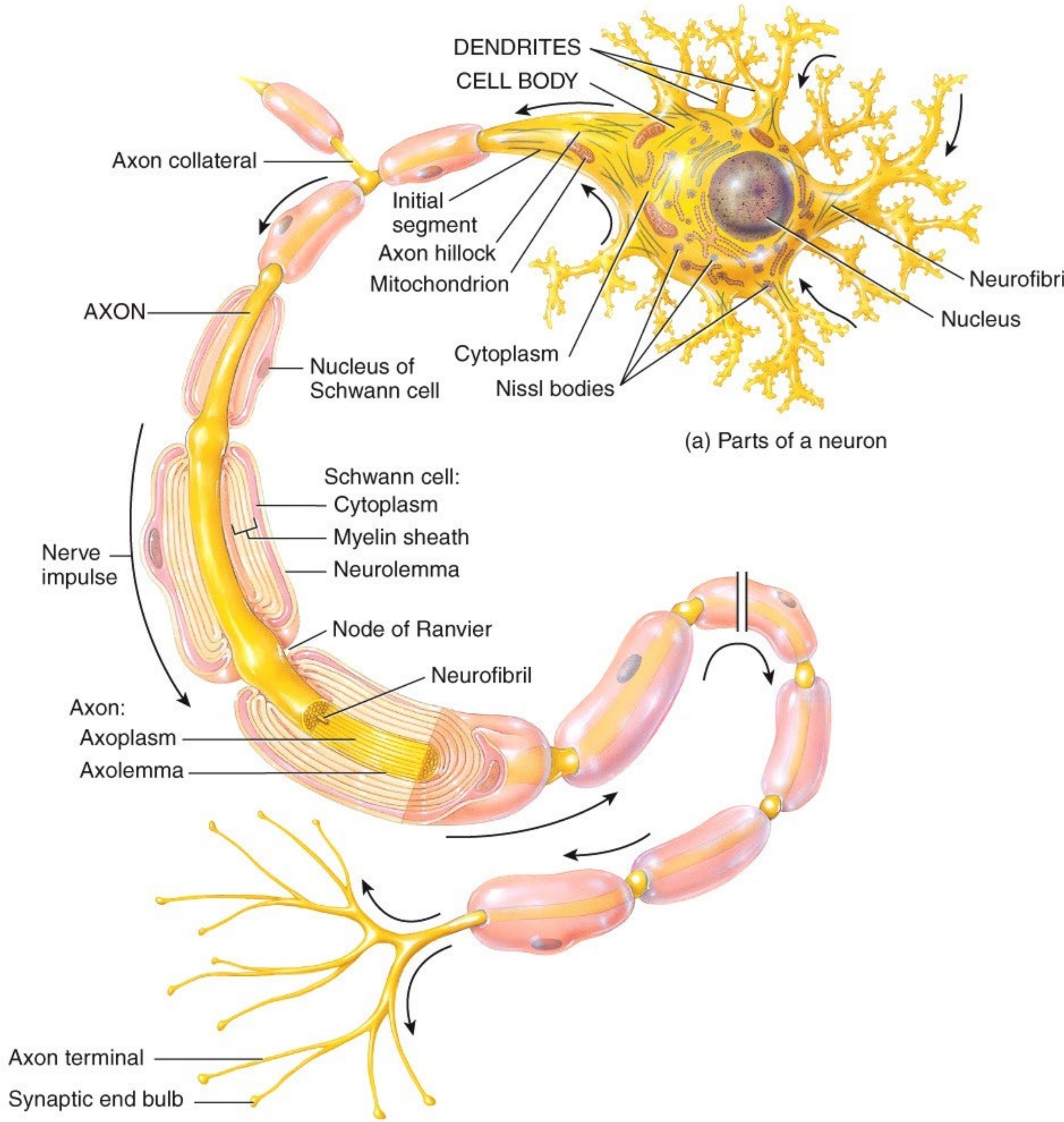
> What is the direction of the electrical impulse?
> What do we mean by unidirectional?

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”.

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



(a) Parts of a neuron

The Soma

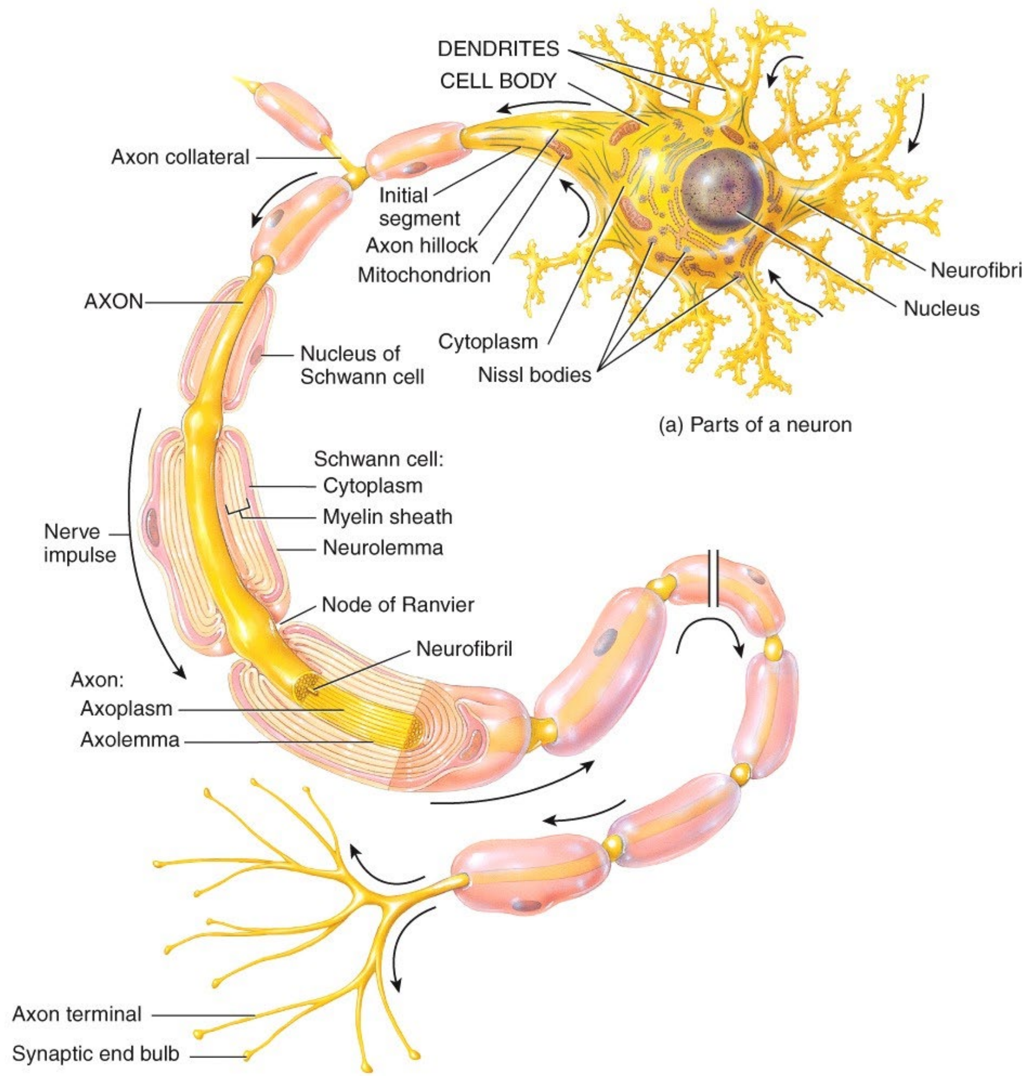
The soma is the control center of the neuron

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)



(a) Parts of a neuron

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

nclusions 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

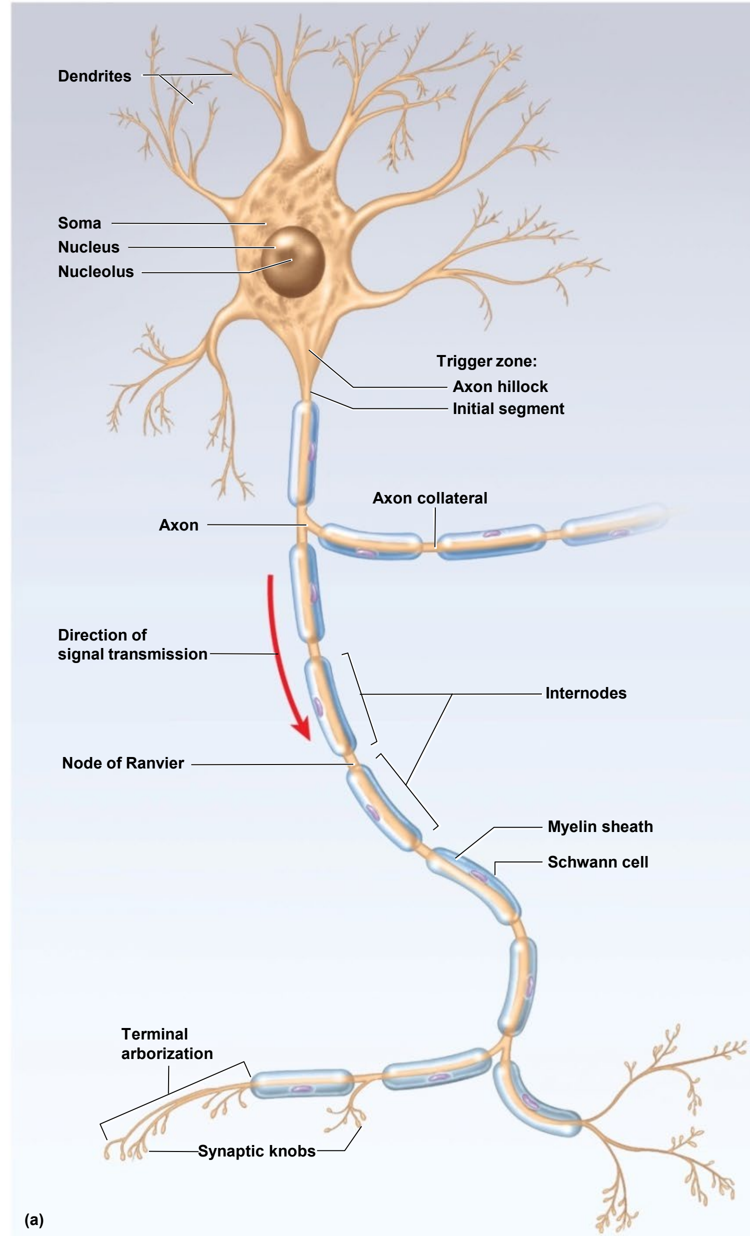
primary site for receiving signals from other neurons = "the dendrites are receptors"

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

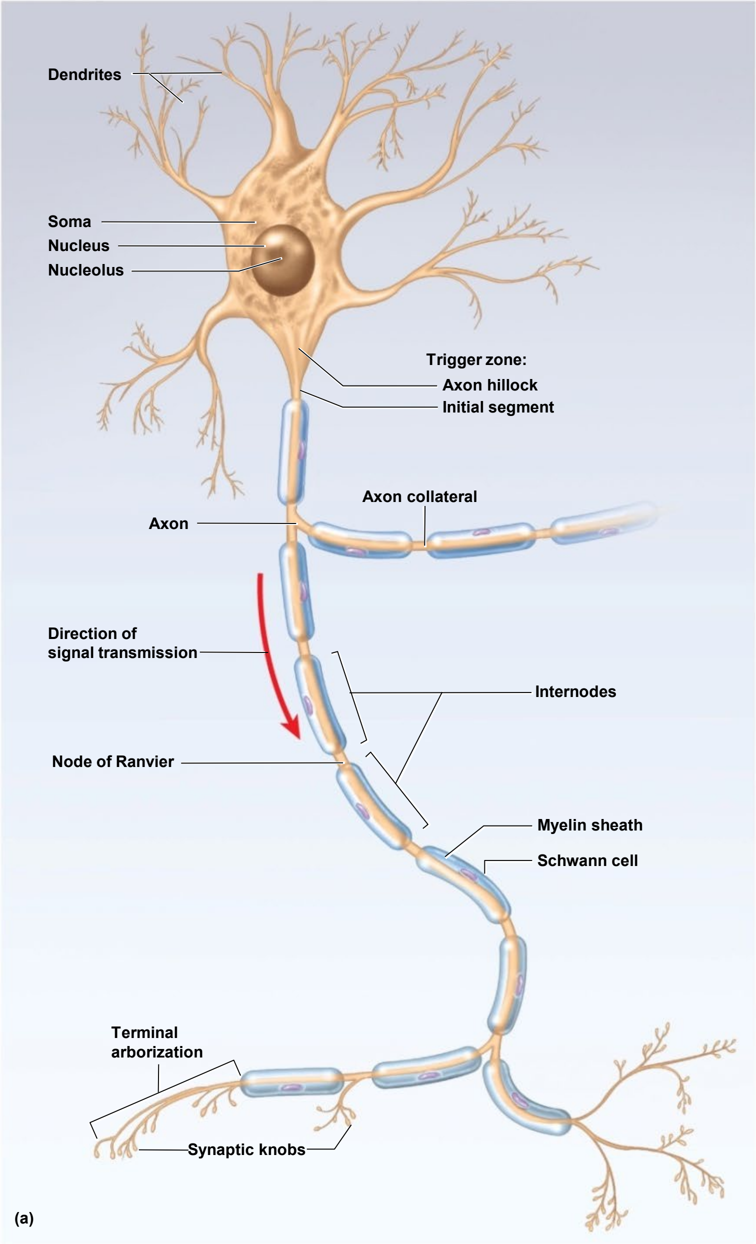
cylindrical, relatively unbranched for most of its length /// axon collaterals – branches of axon

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

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

One neuron may have hundreds of terminal knobs

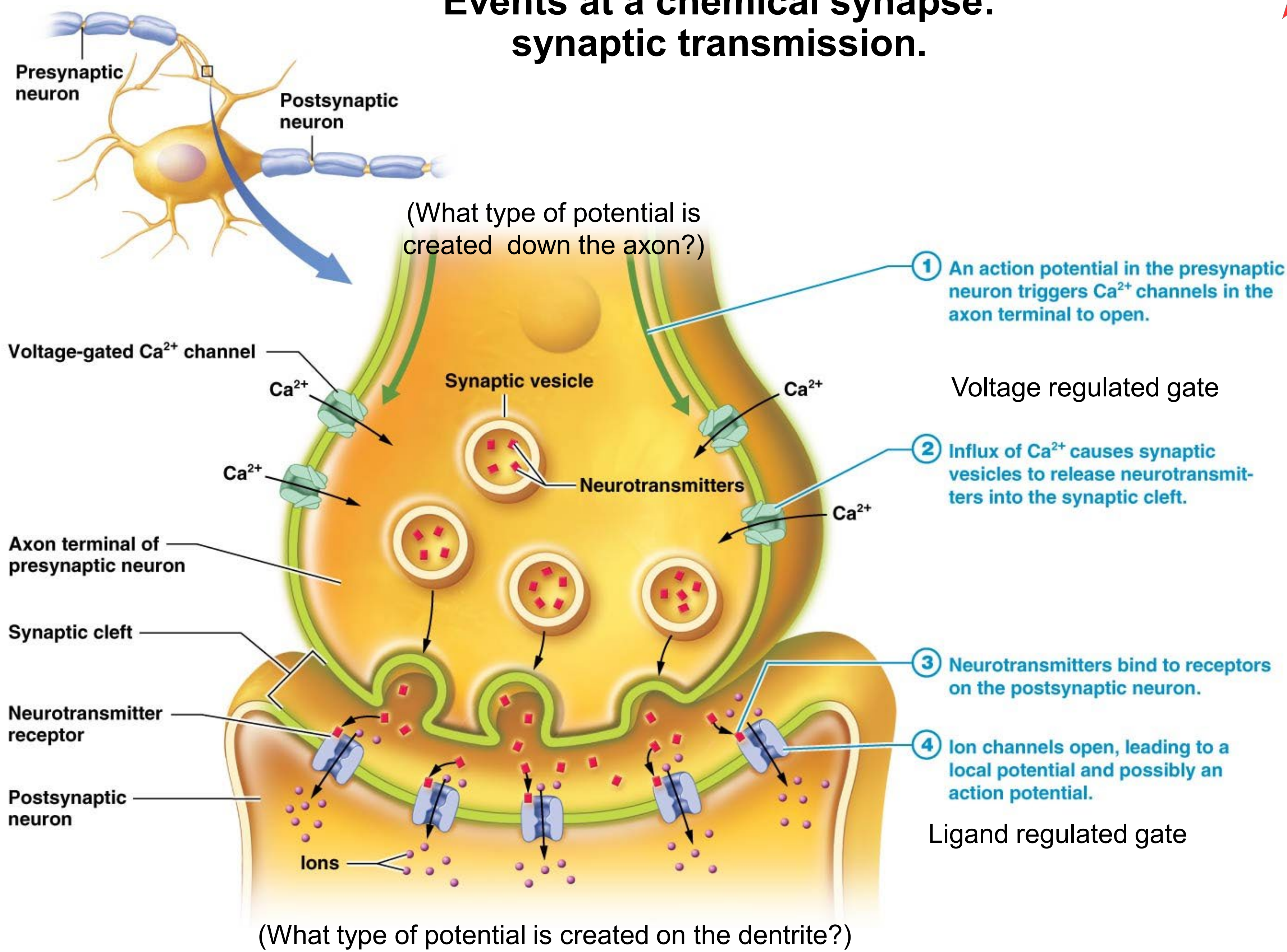
Stores neurotransmitters

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

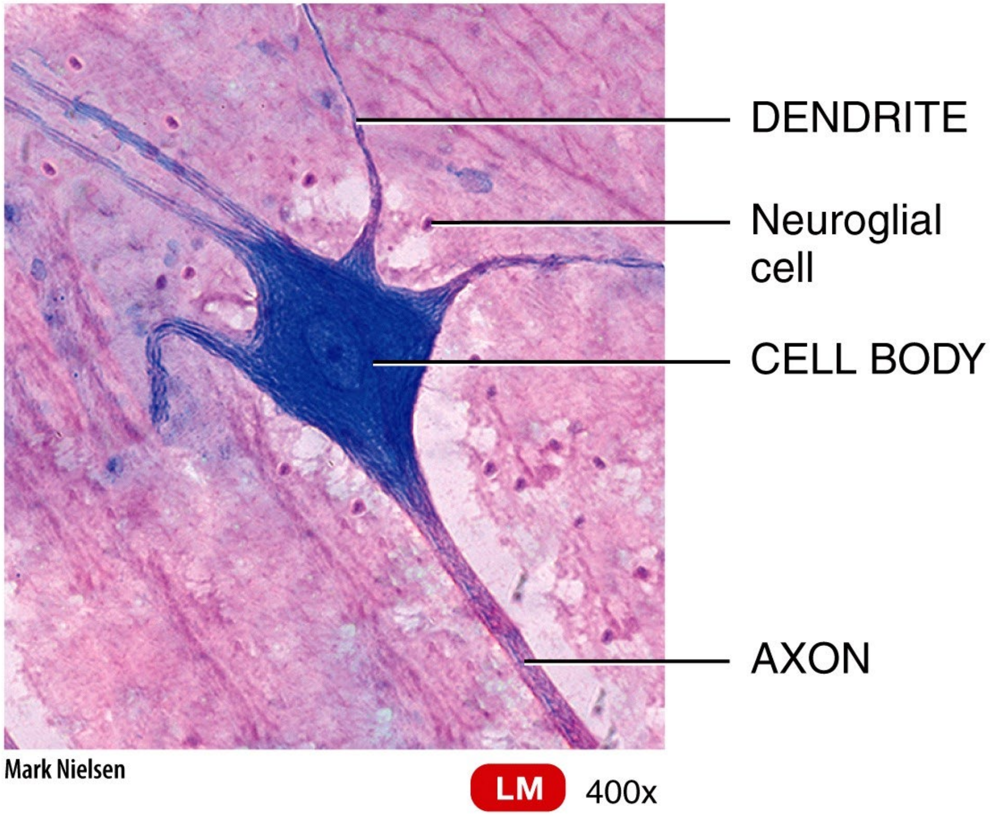
Synaptic knob is a part of the synapse // the presynaptic membrane

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

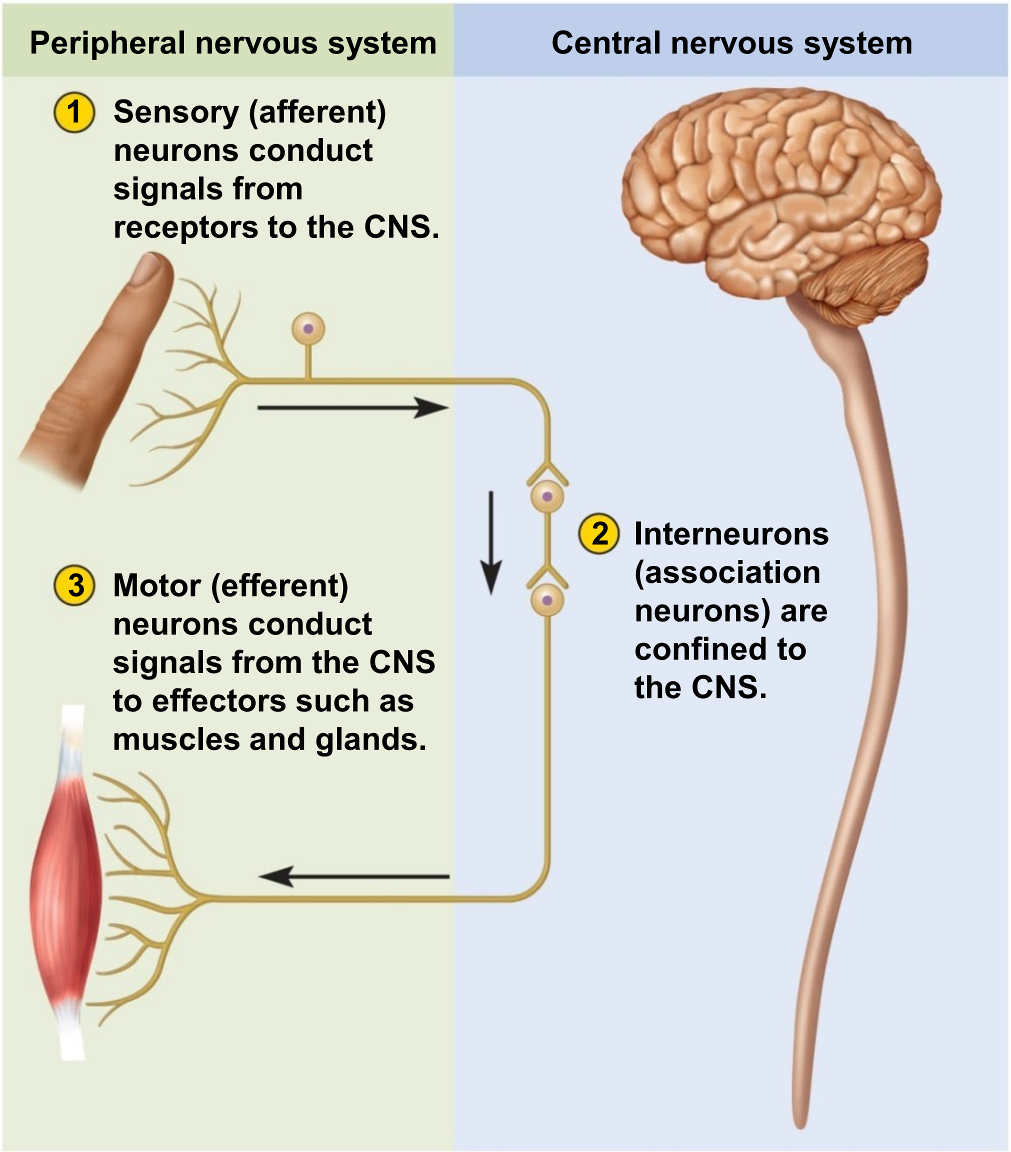
Events at a chemical synapse: synaptic transmission.

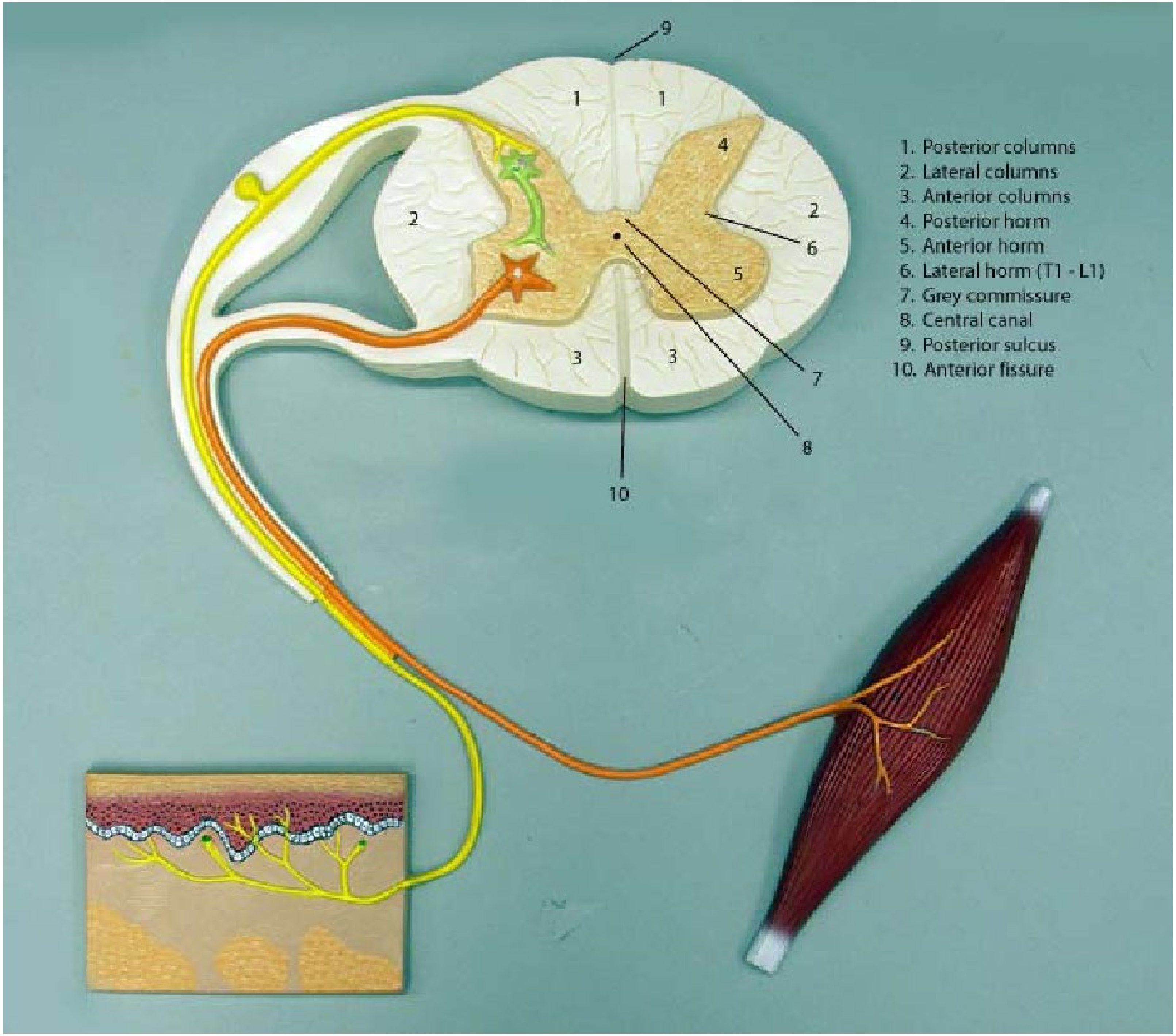


Neurons Are Classified by Their Structure or Function



Functional Classification of Neurons





9
1
1
4
2
2
6
5
7
8
3
3
10
1. Posterior columns
2. Lateral columns
3. Anterior columns
4. Posterior horm
5. Anterior horm
6. Lateral horm (T1 - L1)
7. Grey commissure
8. Central canal
9. Posterior sulcus
10. Anterior fissure

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

–lie entirely within the CNS

–receive signals from many neurons and 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

–*lie between and interconnect the incoming sensory pathways to the outgoing motor pathways of the CNS*

Structural Definition of Neuron

•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

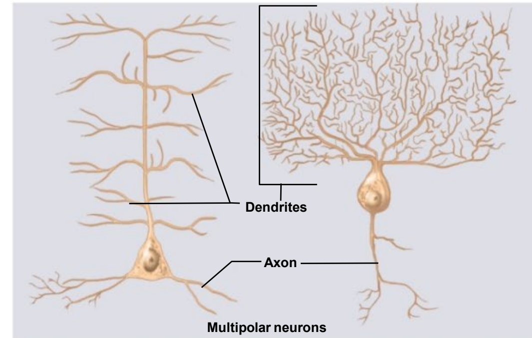
–single process

–sensory from skin and organs to spinal cord

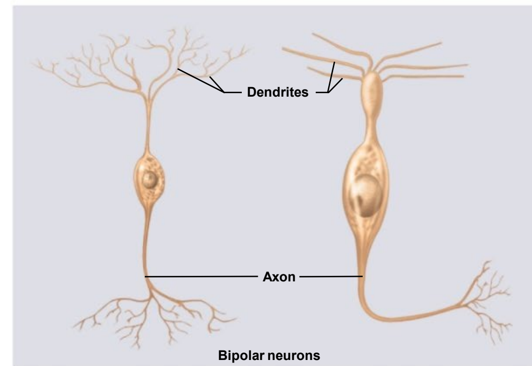
•anaxonic neuron

–many dendrites but no axon

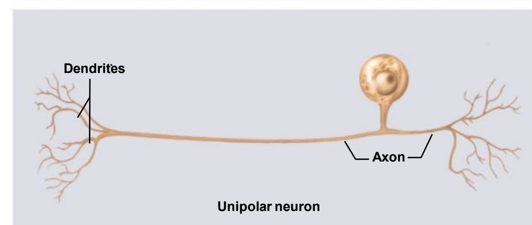
–help in visual processes



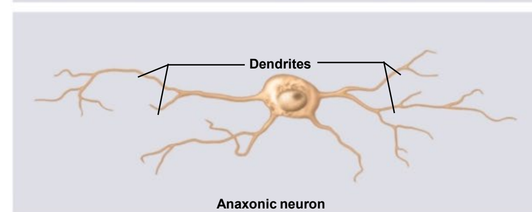
Multipolar neurons



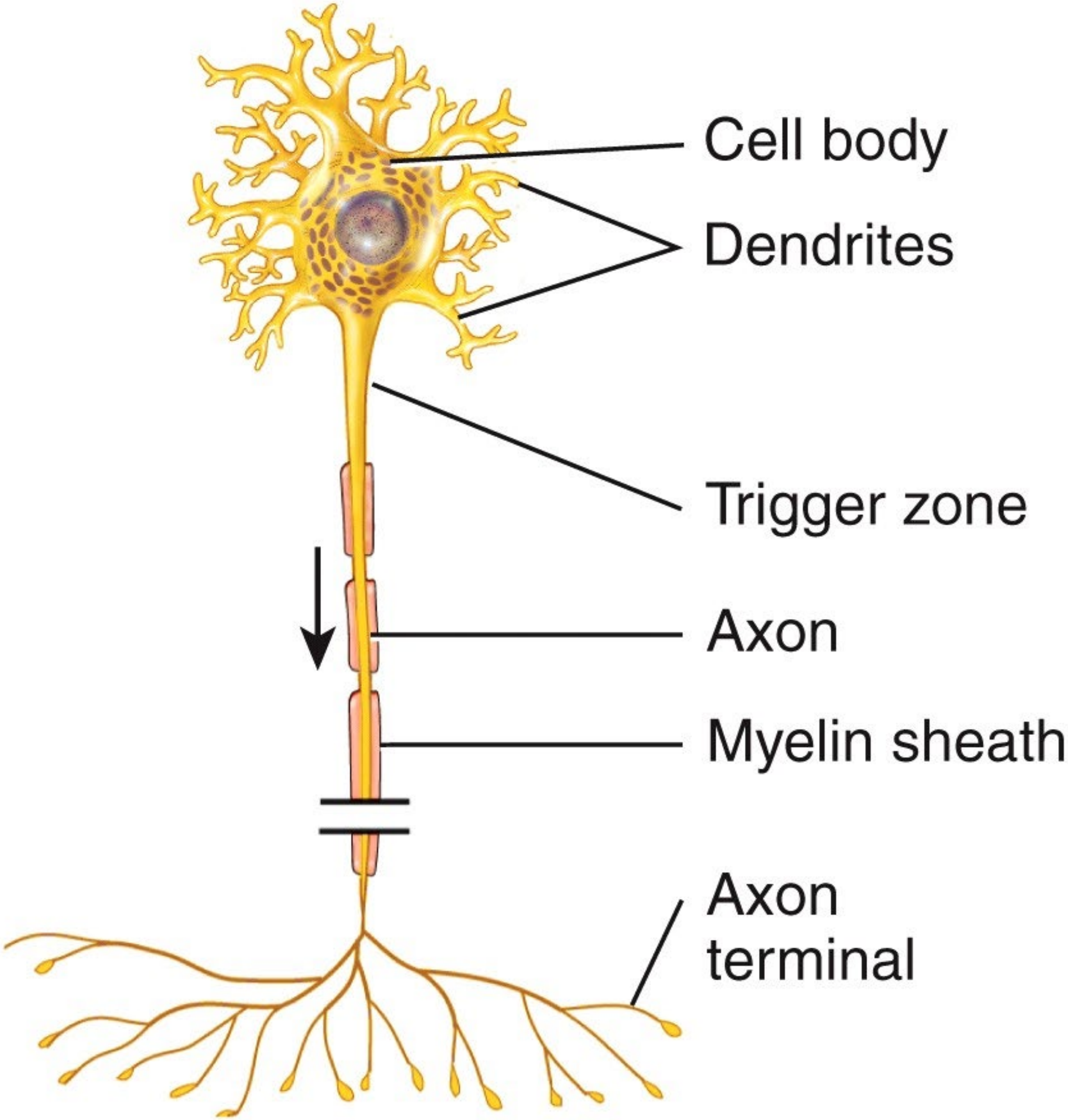
Bipolar neurons



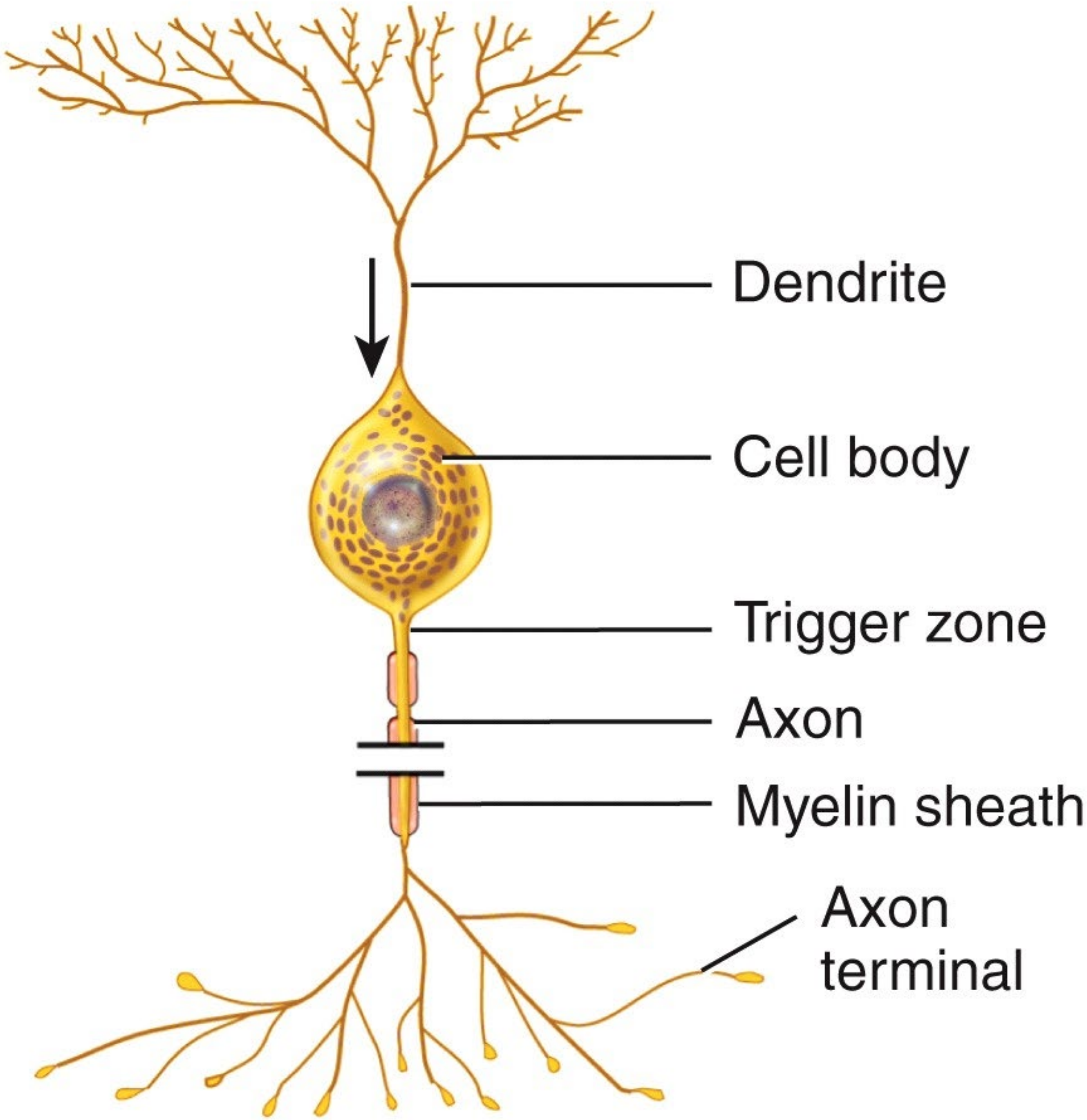
Unipolar neuron



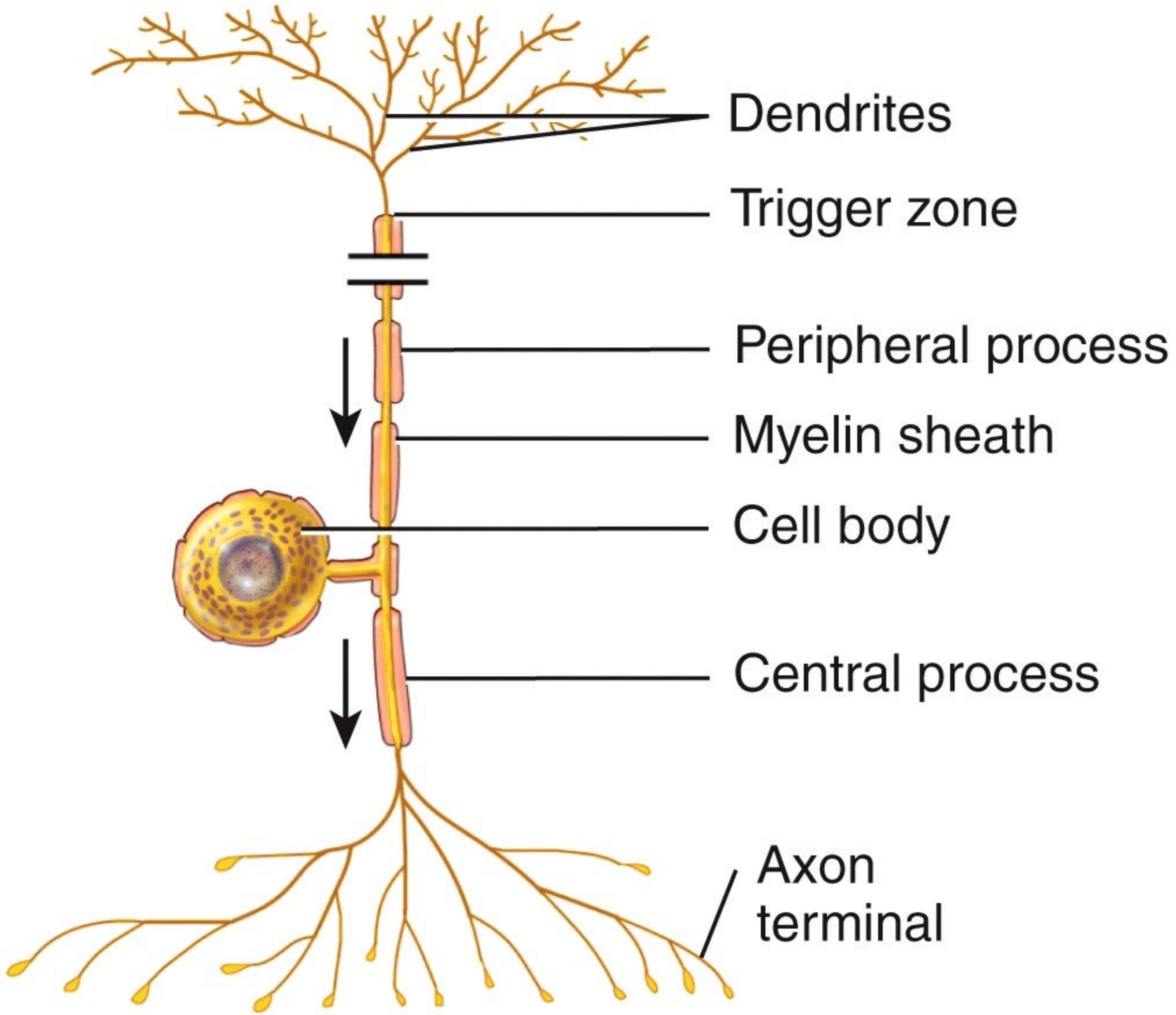
Anaxonic neuron



(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

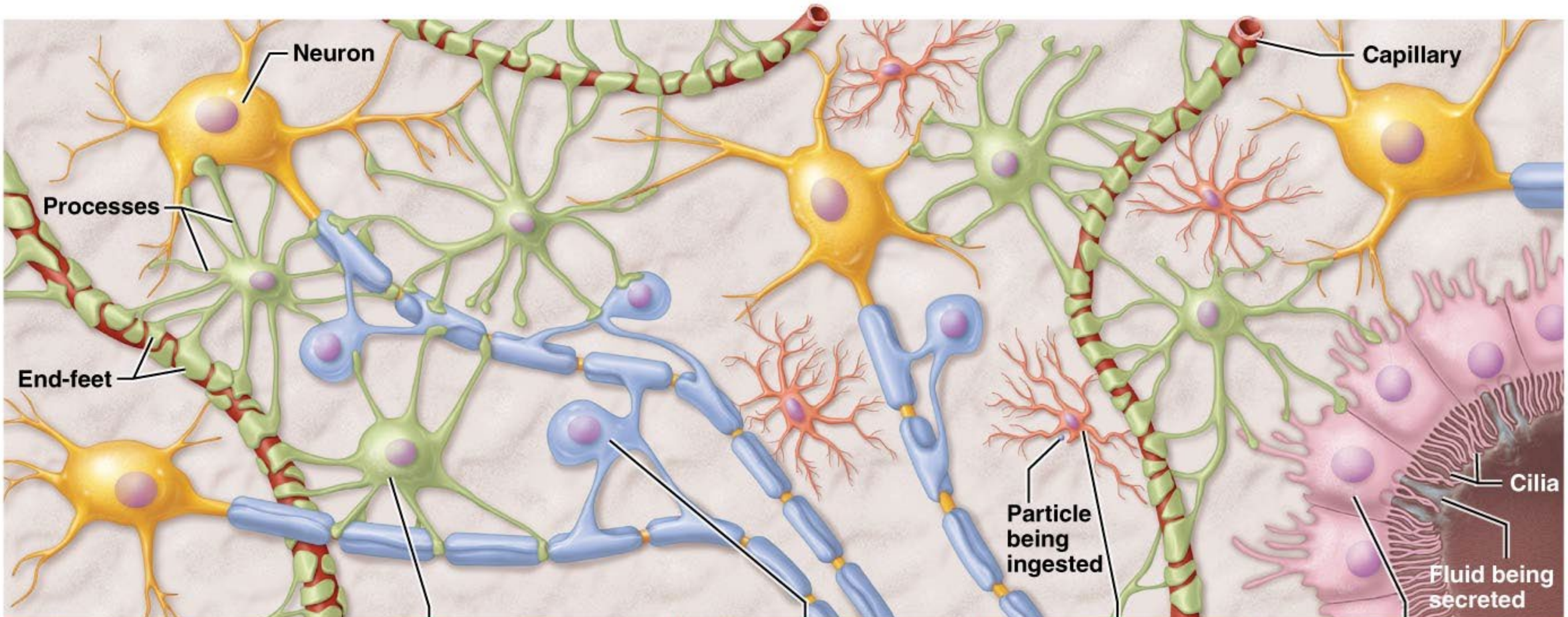
Bind neurons together and form framework for nervous tissue

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

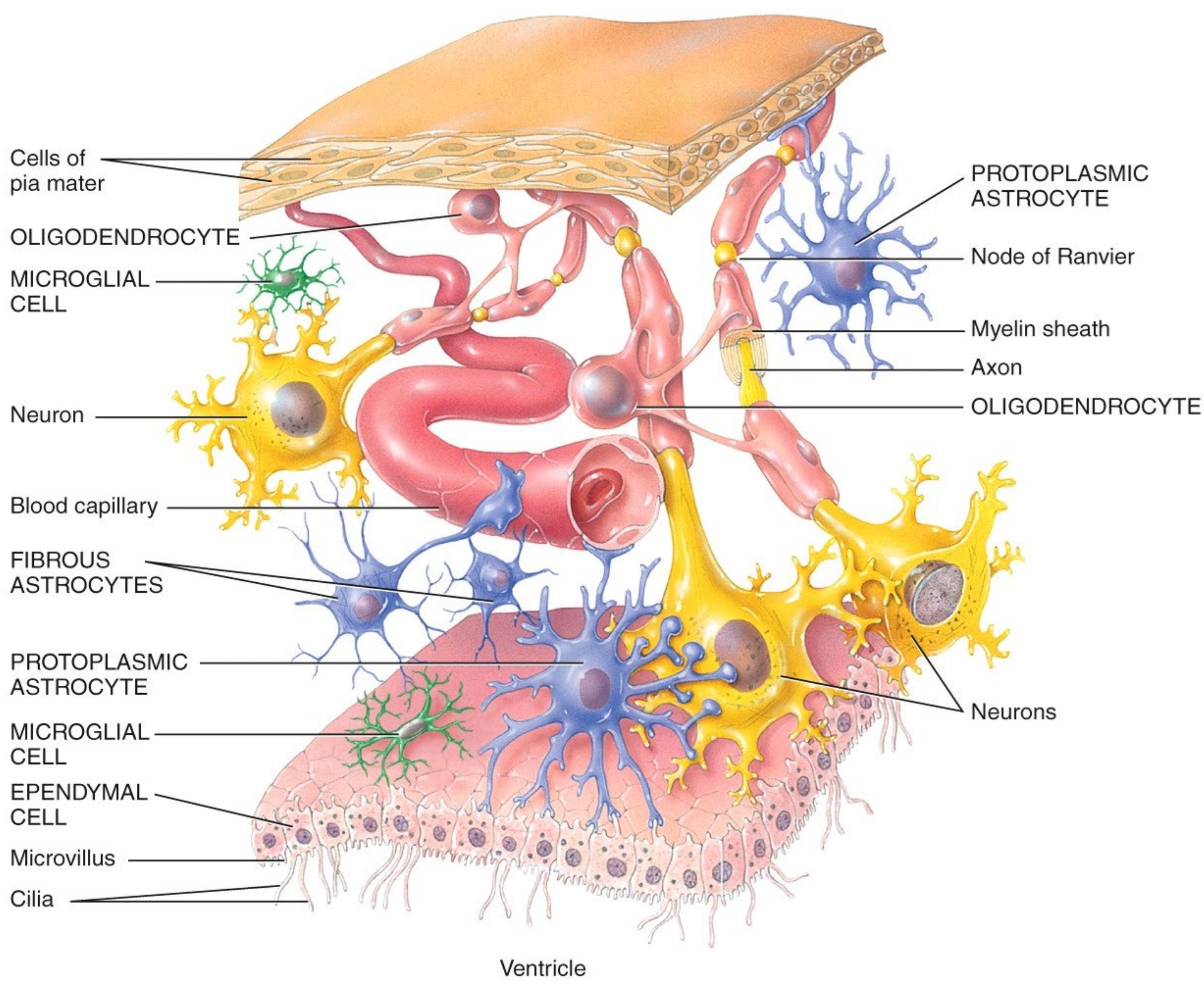
Glial cells prevents neurons from touching each other /// gives precision to conduction pathways

Neuroglial cells of the CNS.



NEUROGLIAL CELL TYPE	ASTROCYTE	OLIGODENDROCYTE	MICROGLIAL CELL	EPENDYMAL CELL
FUNCTION	• Anchor neurons and blood vessels • Regulate the extracellular environment • Facilitate the formation of the blood-brain barrier • Repair damaged tissue	• Myelinate certain axons in the CNS	• Act as phagocytes	• Line cavities • Cilia circulate fluid around brain and spinal cord • Some secrete this fluid

Note: two types of astrocytes - protoplasmic vs fibrous


Cells of
pia mater
OLIGODENDROCYTE
MICROGLIAL
CELL
Neuron
Blood capillary
FIBROUS
ASTROCYTES
PROTOPLASMIC
ASTROCYTE
MICROGLIAL
CELL
EPENDYMAL
CELL
Microvillus
Cilia
PROTOPLASMIC
ASTROCYTE
Node of Ranvier
Myelin sheath
Axon
OLIGODENDROCYTE
Neurons
Ventricle

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)

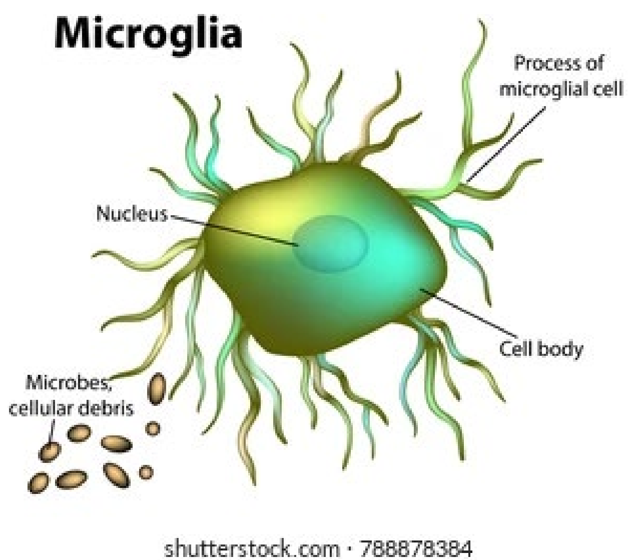
•clear liquid that bathes the CNS

•Ependymal cells with tight junctions form coroid plexus.

More About Neuroglial Cells

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

Astrocytes

•most abundant glial cell in CNS // some subdivide astrocytes into two types (protoplasmic vs fibrous)

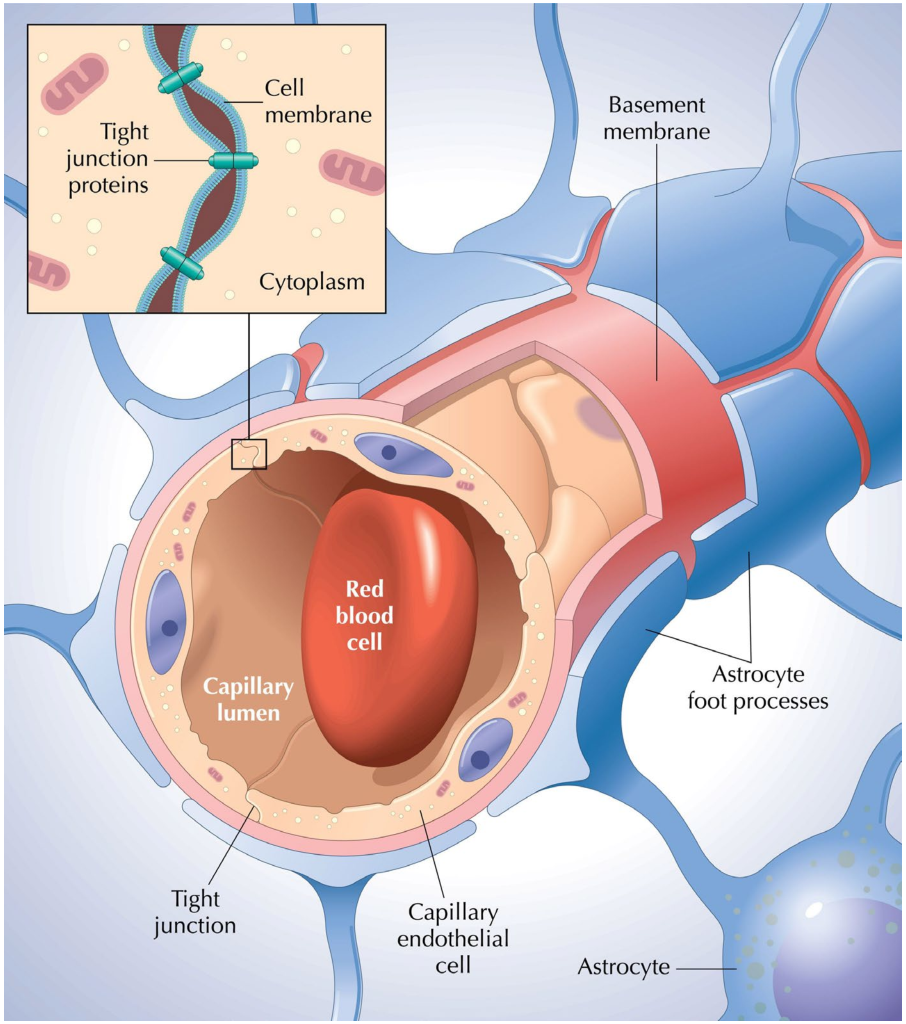
•cover entire brain surface and most nonsynaptic regions of the neurons in the gray matter of the CNS

•*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**

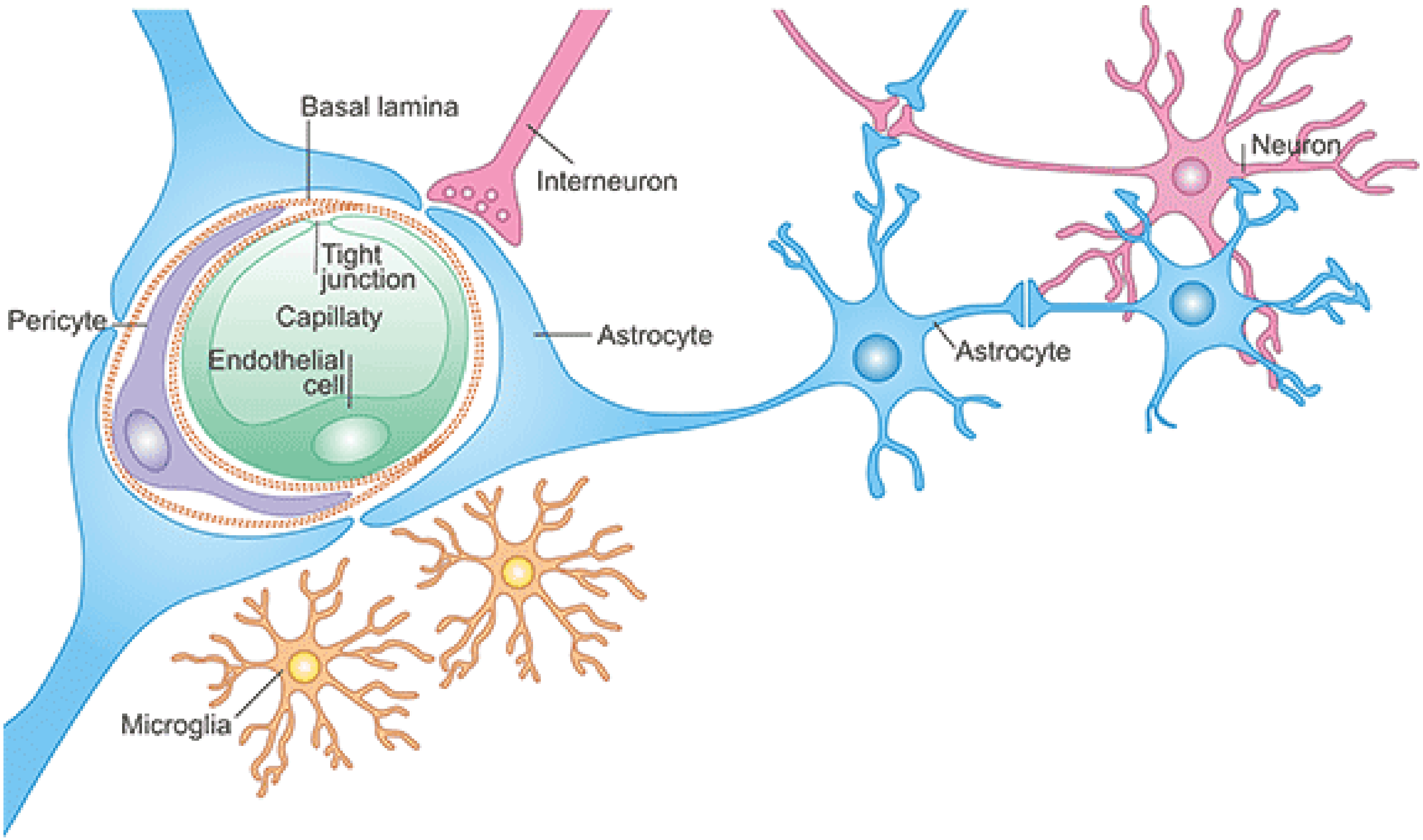
•(see next slide)

blood-brain barrier



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

blood-brain barrier



More About Neuroglial Cells

Astrocytes

–convert blood glucose to lactate and supply this to the neurons for nourishment

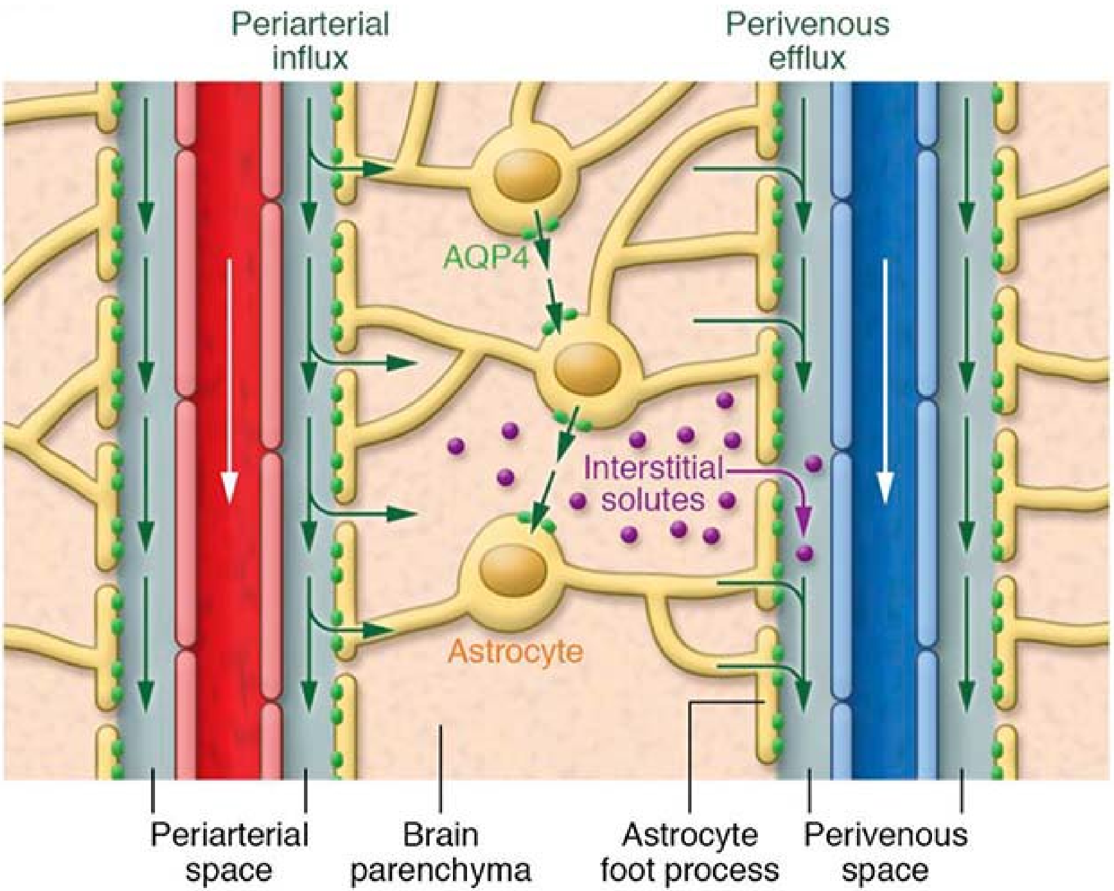
–nerve growth factors secreted by astrocytes promote neuron growth and synapse formation

–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

Two types of glial cells in PNS

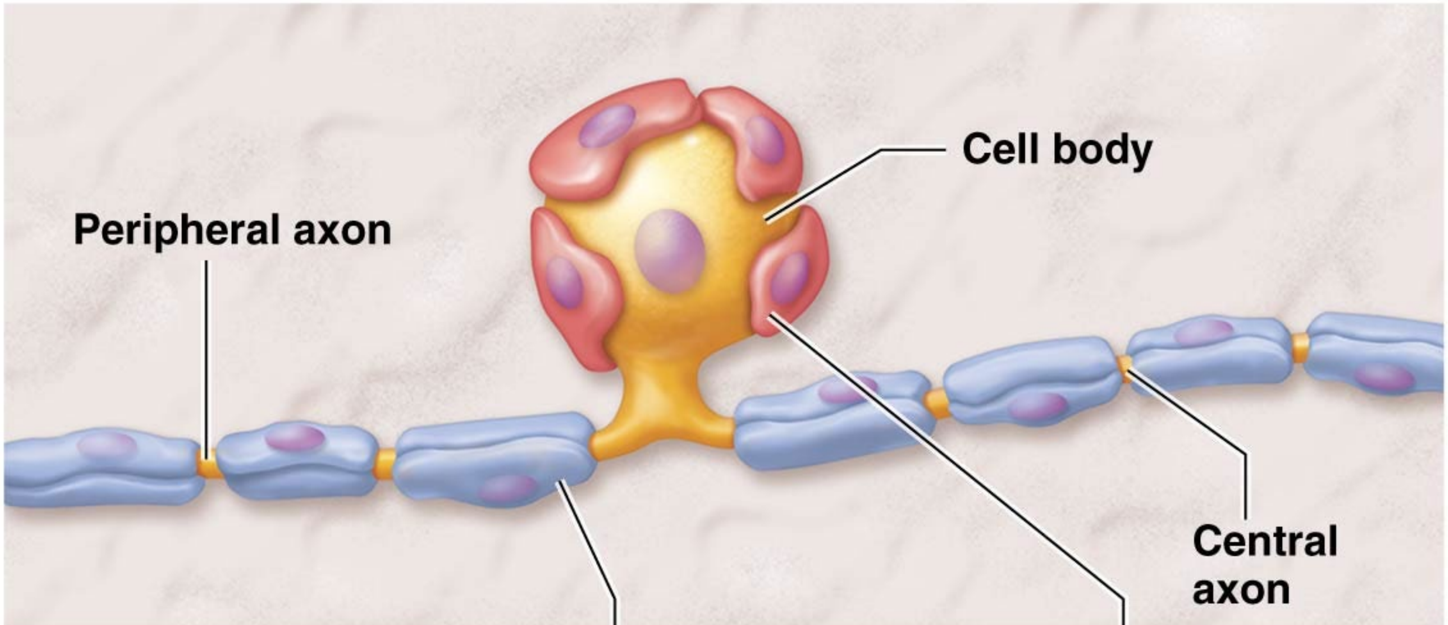
– **Schwann cells**

- 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.



NEUROGLIAL CELL TYPE	SCHWANN CELL	SATELLITE CELL
FUNCTION	• Myelinate certain axons in the PNS	• Surround and support cell bodies

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 14th 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

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

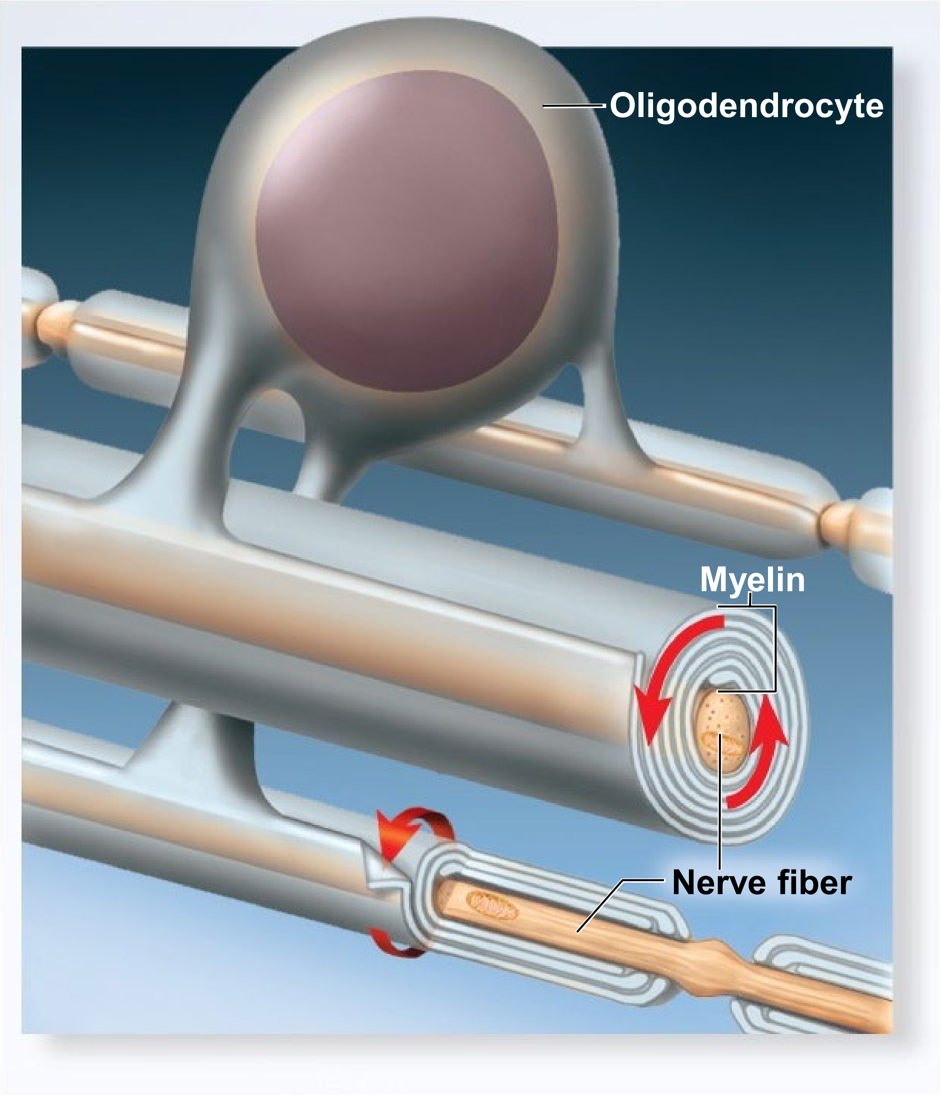
–anchored to multiple nerve fibers

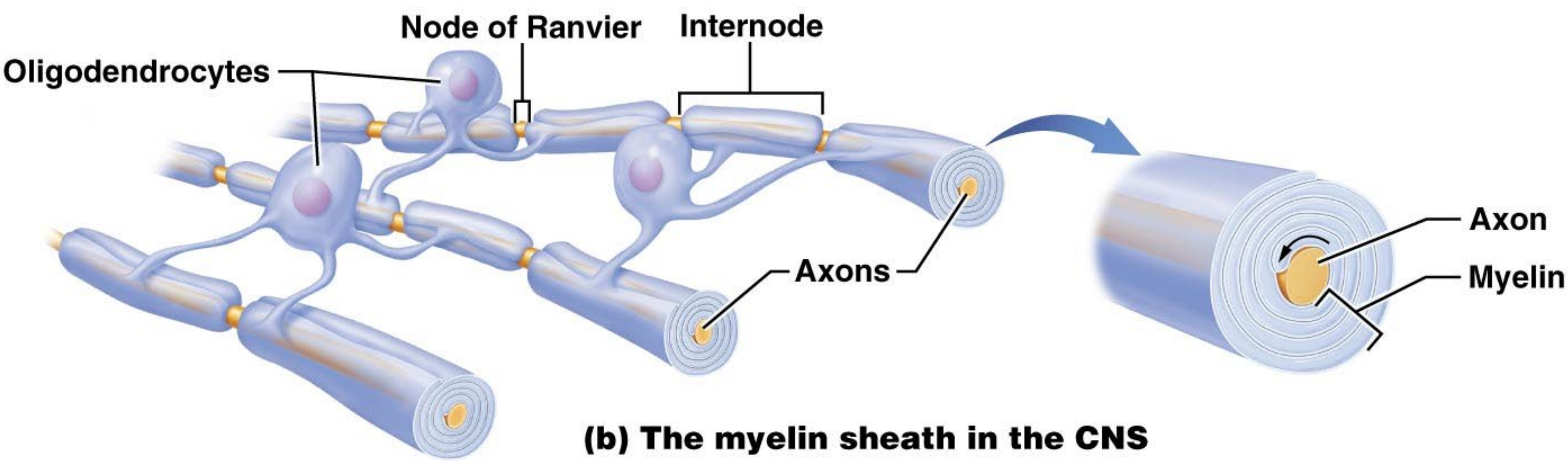
–cannot migrate around any one nerve fiber like Schwann cells

–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 Schawnn cell structure)

Myelination in CNS





(b) The myelin sheath in the CNS

Myelin in PNS

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

•**Myelin sheath** is **segmented**

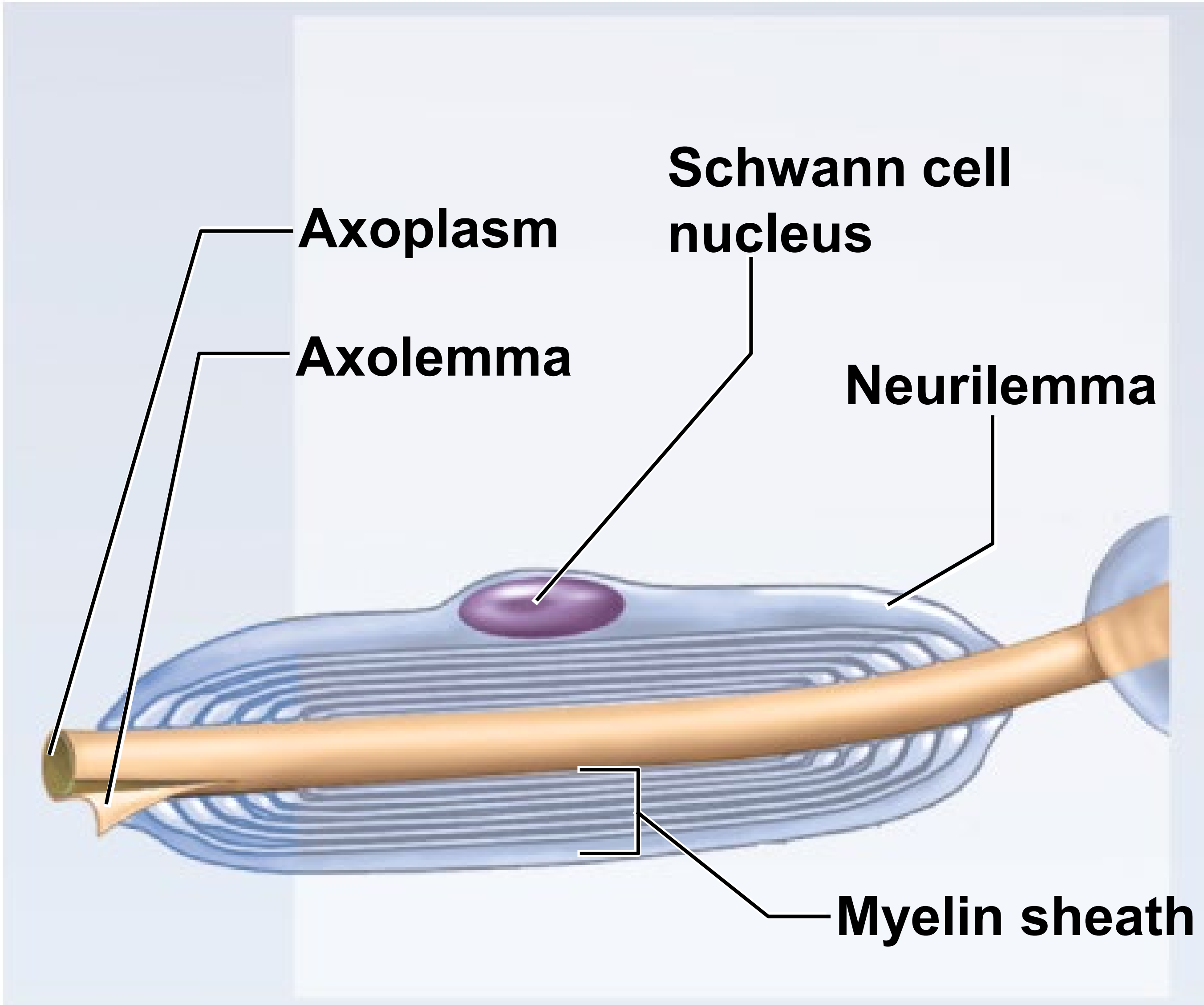
–**nodes of Ranvier** – gap between segments

–**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

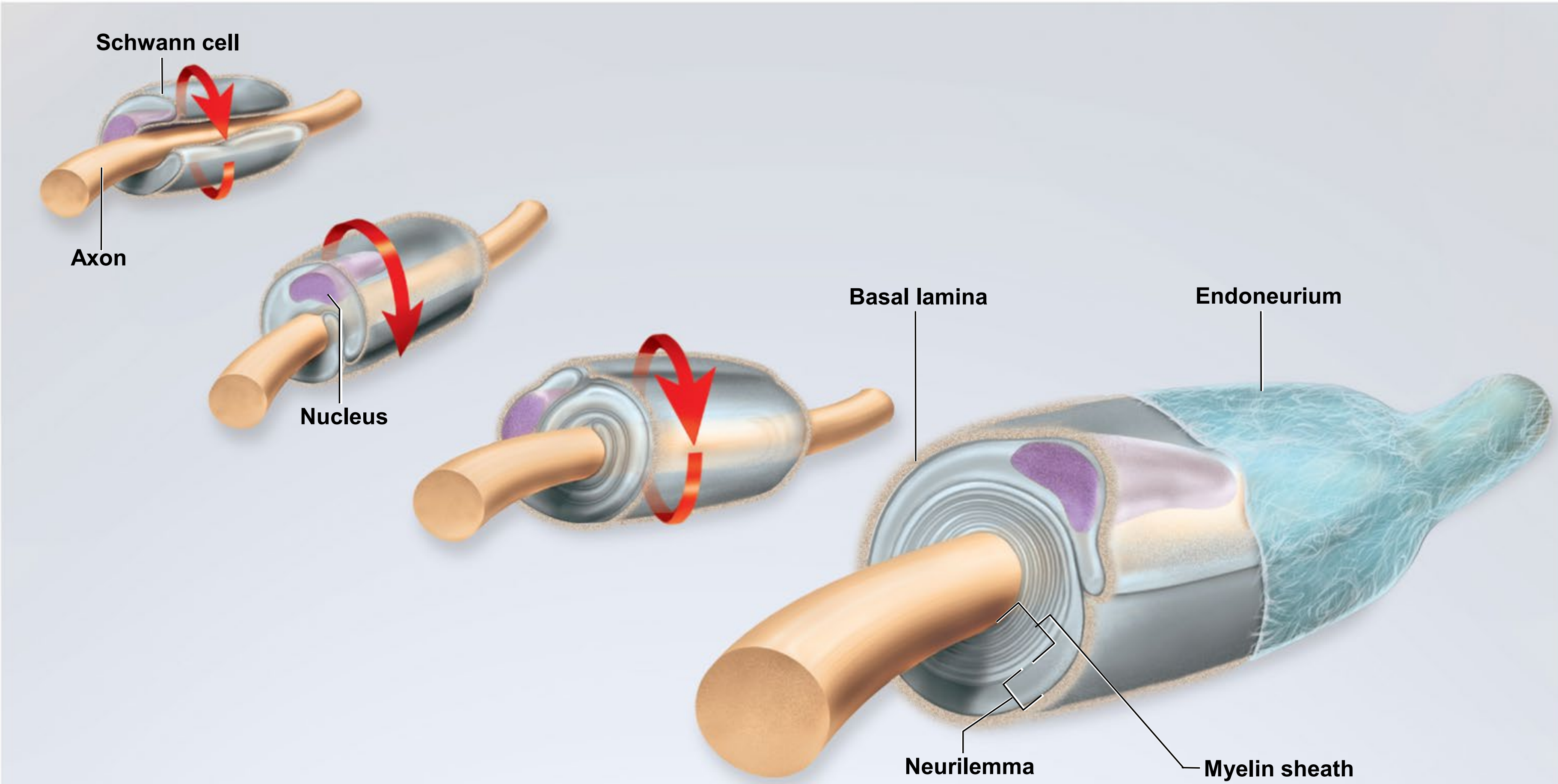
–**trigger zone** – the axon hillock and the first segment of neurolemma /// play an important role in initiating a nerve signal

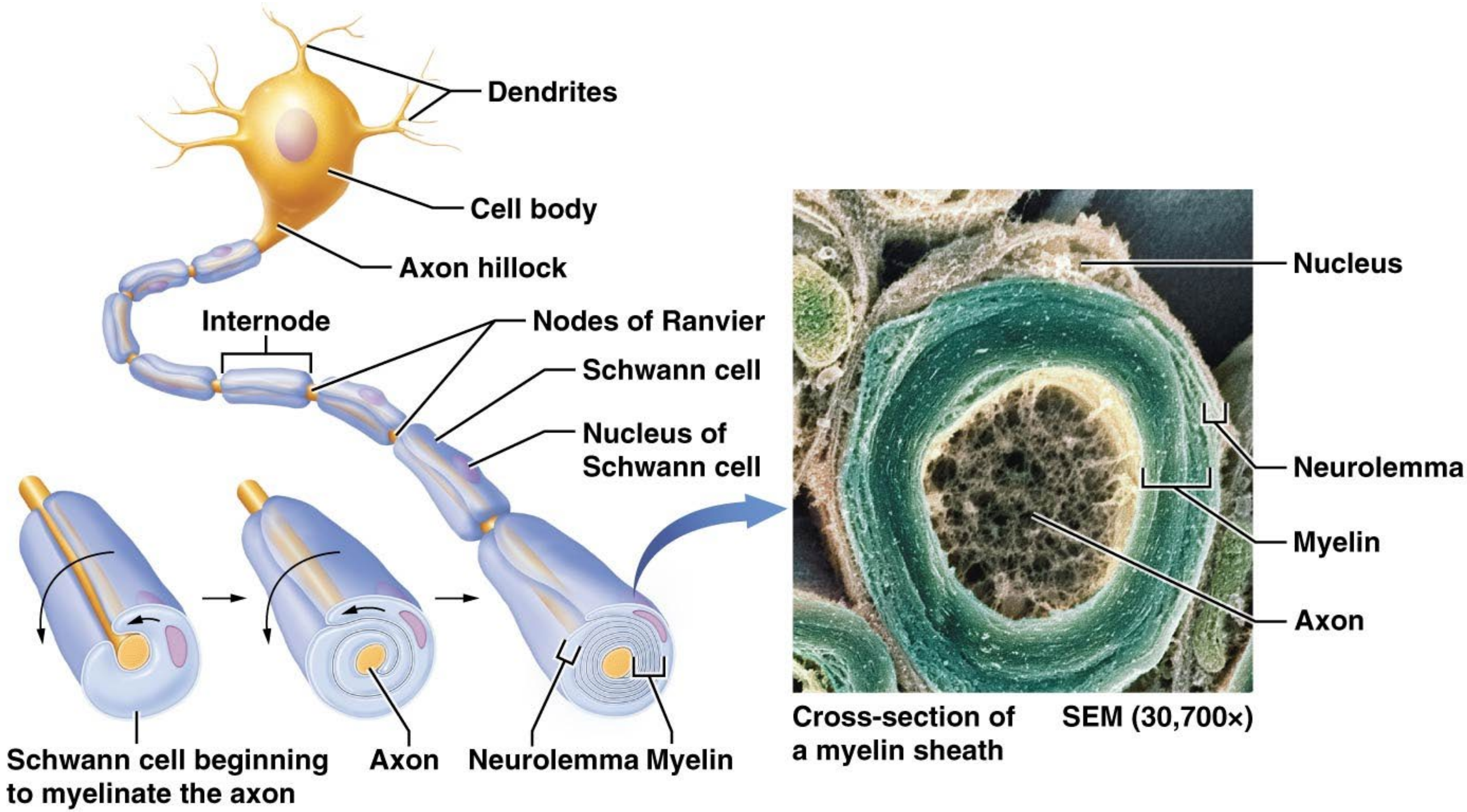
Myelin Sheath in PNS



nodes of Ranvier and internodes

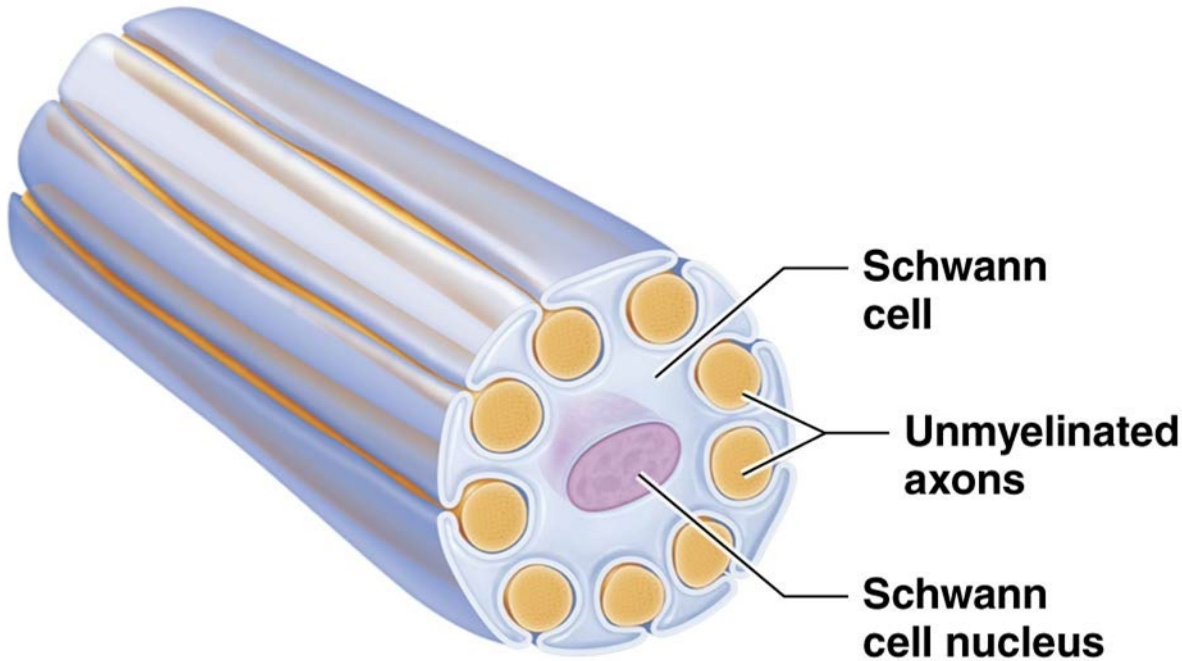
Myelination in PNS



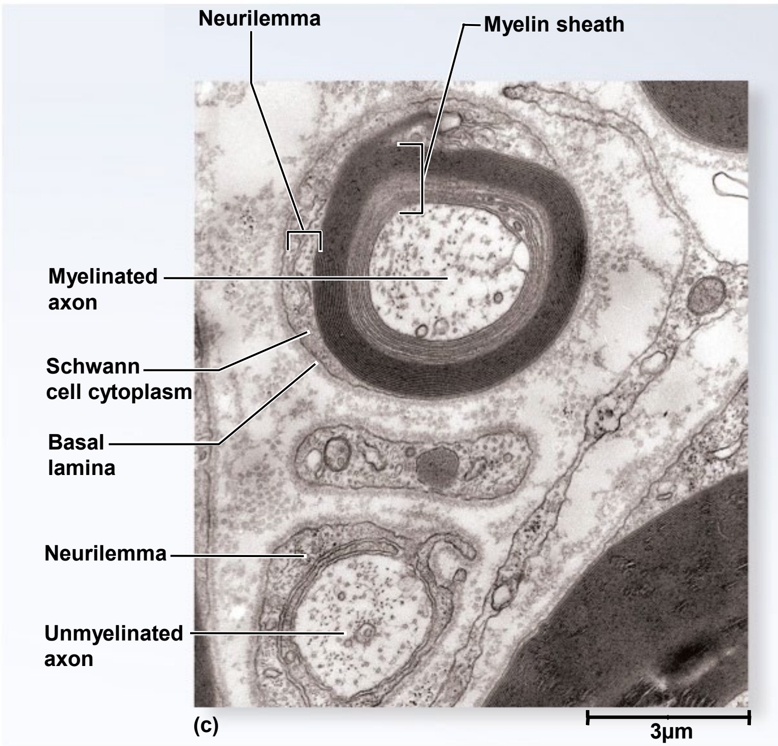


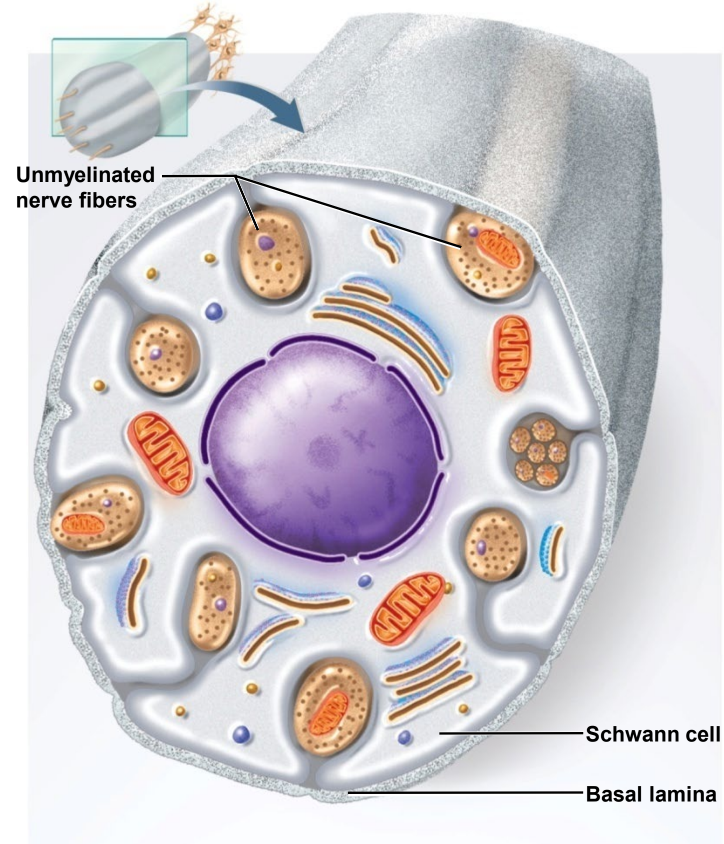
(a) The myelin sheath and myelination in the PNS

Unmyelinated peripheral axons and Schwann cells.



Unmyelinated Axons of PNS





- 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)

–<u>slow signals supply the stomach and dilate pupil where speed is less of an issue</u>

–<u>fast signals supply skeletal muscles and transport sensory signals for vision and balance</u>

Regeneration of Peripheral Motor Nerves

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 Schwan 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)

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

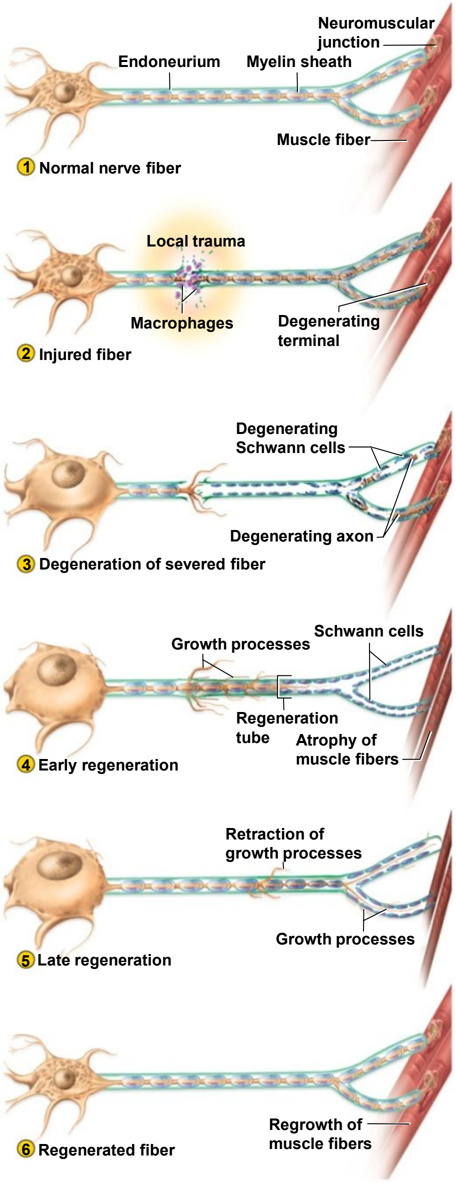
regeneration tube – formed by Schwann cells, basal lamina, and the neurilemma near the injury

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

nucleus returns to normal shape

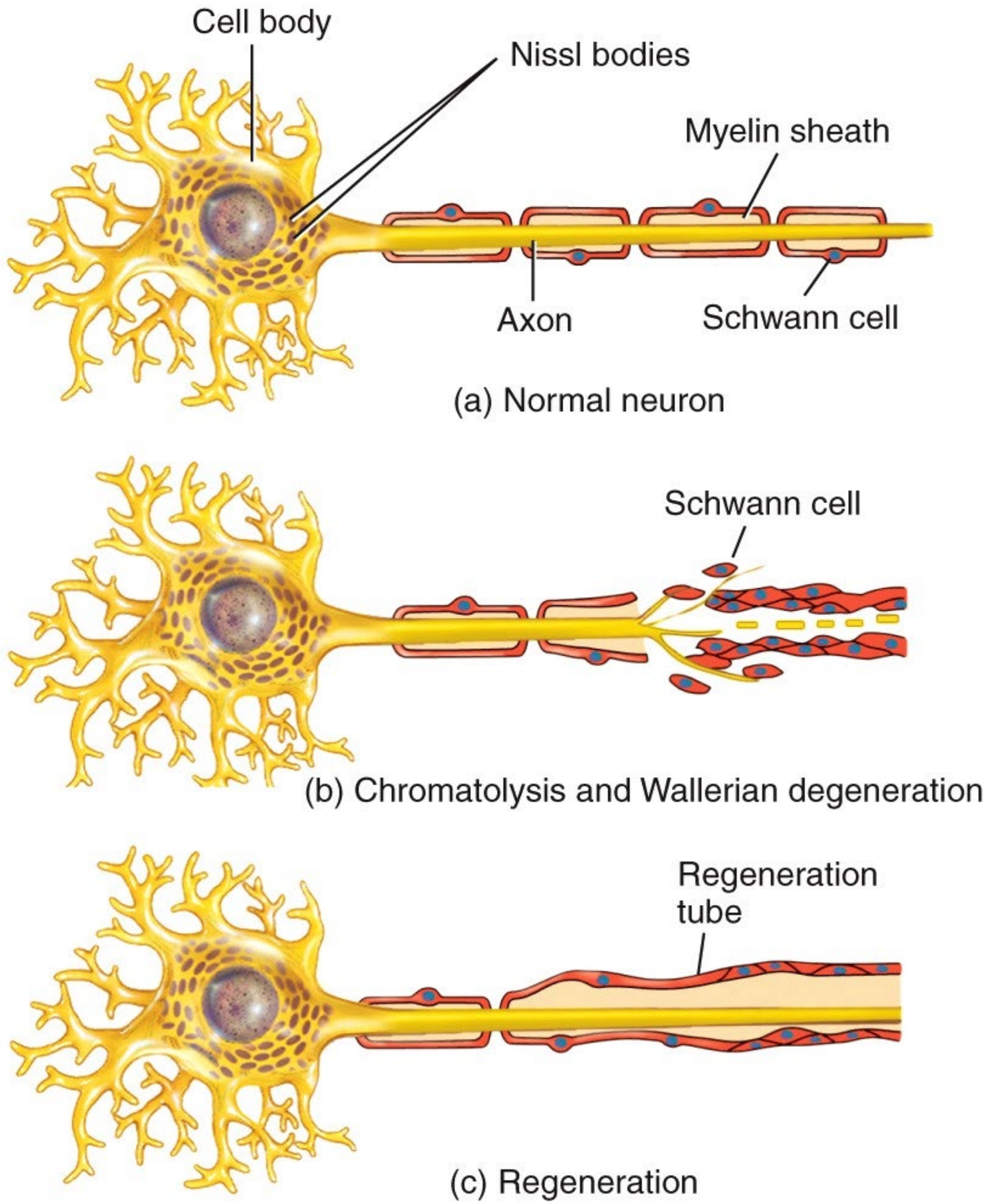
Regeneration of damaged nerve fibers in the CNS will not occur (Why?)

Regeneration of Nerve Fiber



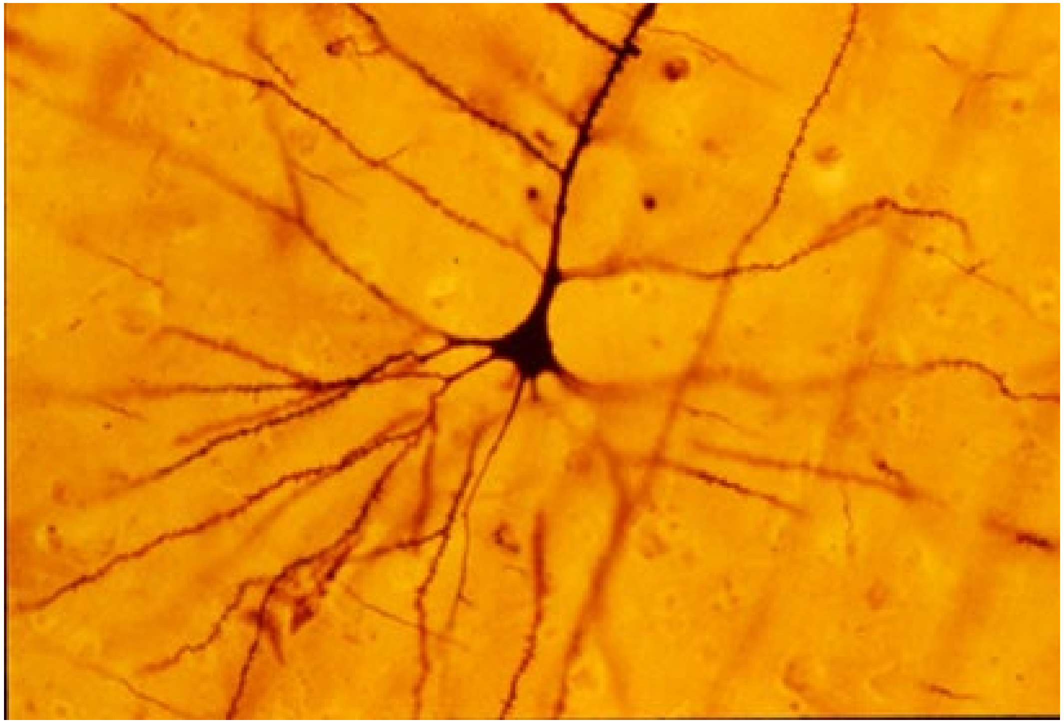
Denervation Atrophy

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


Cell body
Nissl bodies
Myelin sheath
Axon
Schwann cell
(a) Normal neuron
Schwann cell
(b) Chromatolysis and Wallerian degeneration
Regeneration tube
(c) Regeneration

Discover of Neuron's Structure

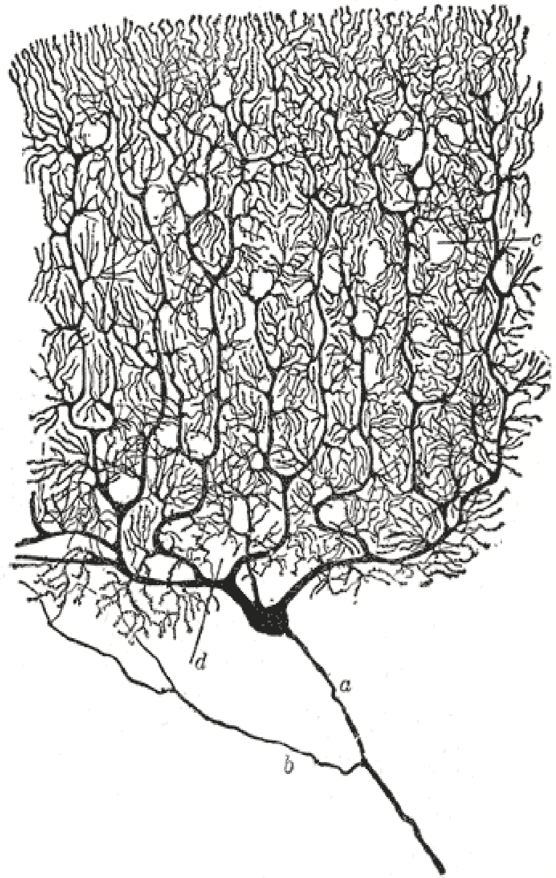
Golgi's silver staining technique is used to visualize nervous tissue under light microscopy. The method was discovered by Camillo Golgi, an Italian physician and scientist, who published the first picture made with the technique in 1873.



Discover of Neuron's Structure

Santiago Ramony 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

–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

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

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

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

Multiple sclerosis

oligodendrocytes and myelin sheaths in the CNS deteriorate

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

Tay-Sachs disease - a hereditary disorder of infants of Eastern European Jewish ancestry

- abnormal accumulation of glycolipid called **GM_2** in the myelin sheath

- normally decomposed by lysosomal enzyme /// enzyme missing in individuals homozygous for Tay-Sachs allele

- accumulation of **ganglioside** (GM_2) disrupts conduction of nerve signals

- blindness, loss of coordination, and dementia /// fatal before age 4