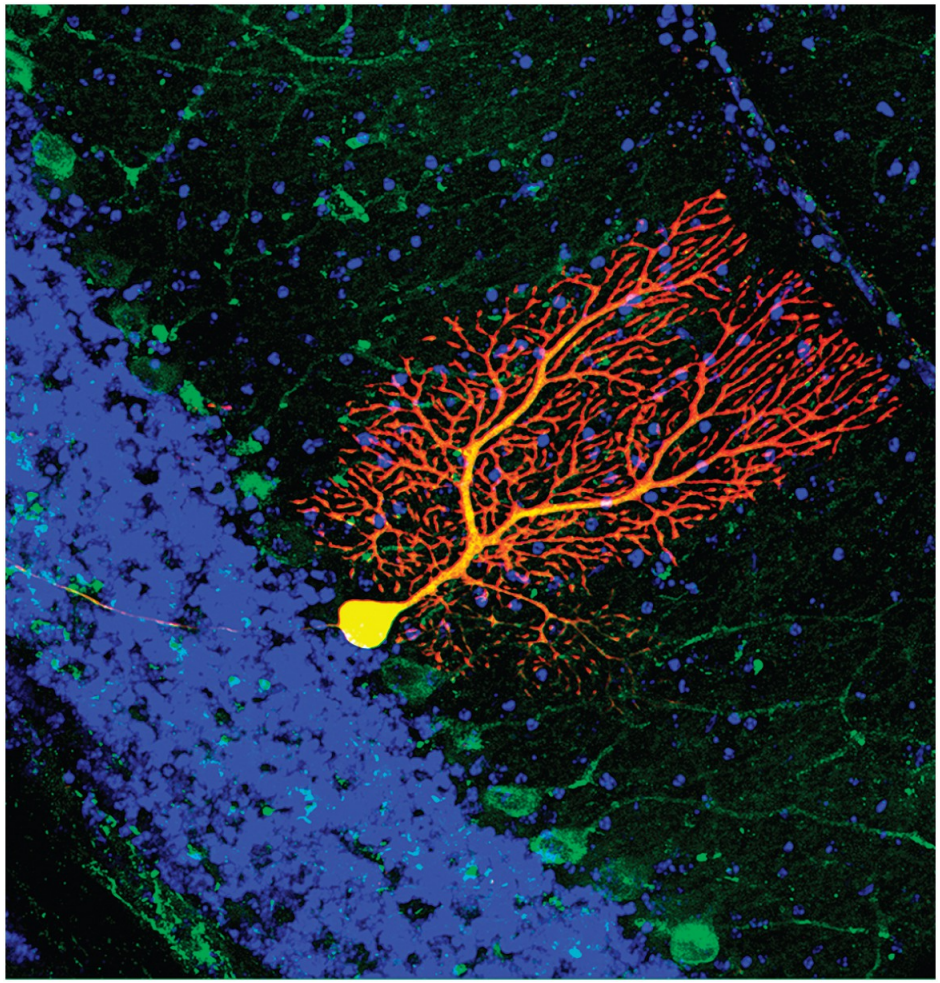
Chapter 12.1

Nervous Tissue



The Nervous System

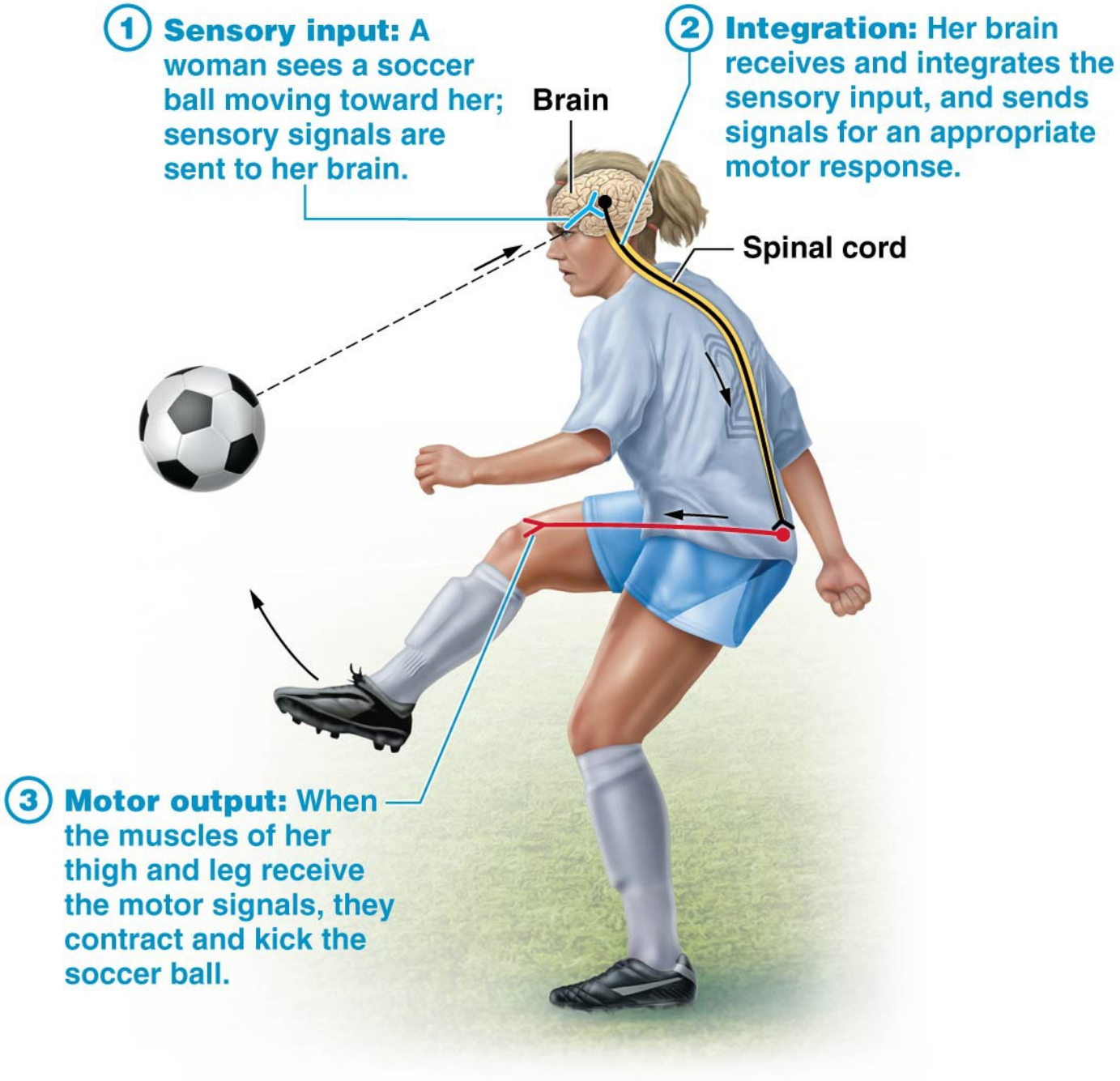
The Nervous System carries out its task in three steps:

- sense organs (receptors) receive information (sensory) about changes in the body and/or the external environment then transmits coded messages to the spinal cord and the brain

- brain and spinal cord processes this information (integration), relates it to past experiences, and determine what response is appropriate to the circumstances

- brain and spinal cord issue commands (motor command) to muscles and gland cells to carry out a response

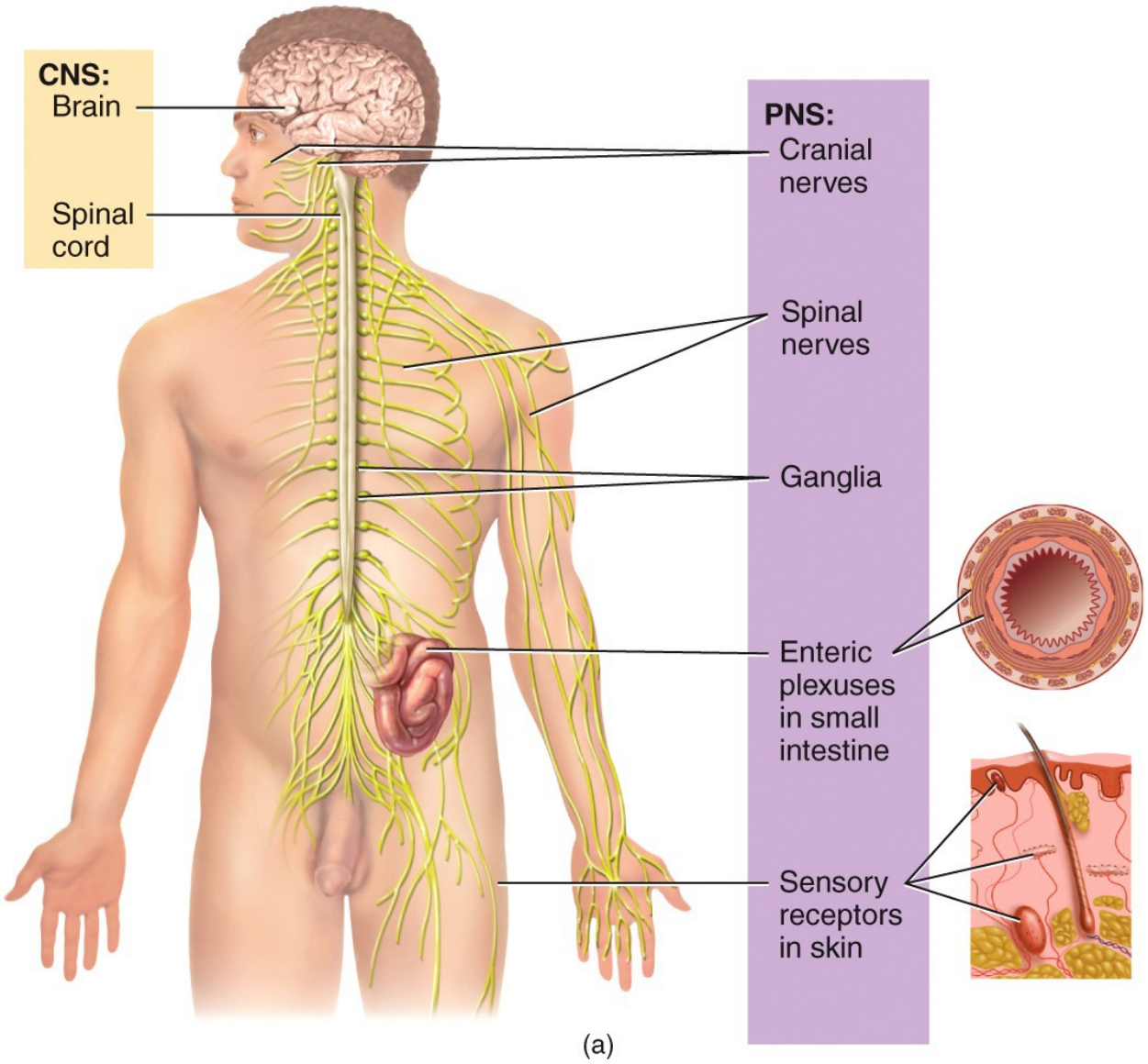
> What is the significance of a stimulus?


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.
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.

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

What are the two anatomical division of the nervous system?



The organization of the peripheral nervous system.

PNS Sensory (Afferent) Division

SOMATIC SENSORY DIVISION

Sensory neurons carry signals from muscles, bones, joints, and the skin, as well as special sensory signals.

Special sensory neuron

Eye

Skin

Sketelal muscle

General sensory neuron

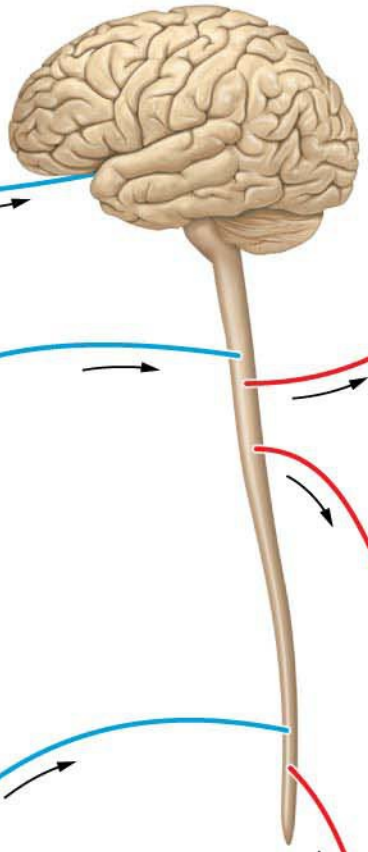
VISCERAL SENSORY DIVISION

Sensory neurons carry signals from viscera.

Urinary bladder

Visceral sensory neuron

Central Nervous System (CNS)

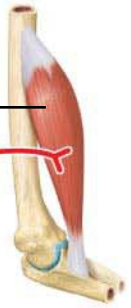


PNS Motor (Efferent) Division

SOMATIC MOTOR DIVISION

Motor neurons carry signals to skeletal muscles.

Sketelal muscle

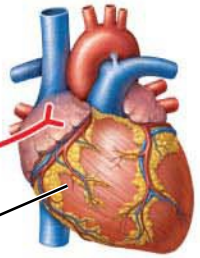


Lower motor neuron

VISCERAL MOTOR DIVISION: Autonomic Nervous System (ANS)

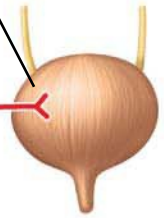
Sympathetic and parasympathetic neurons carry signals to viscera.

Sympathetic motor neuron



Heart

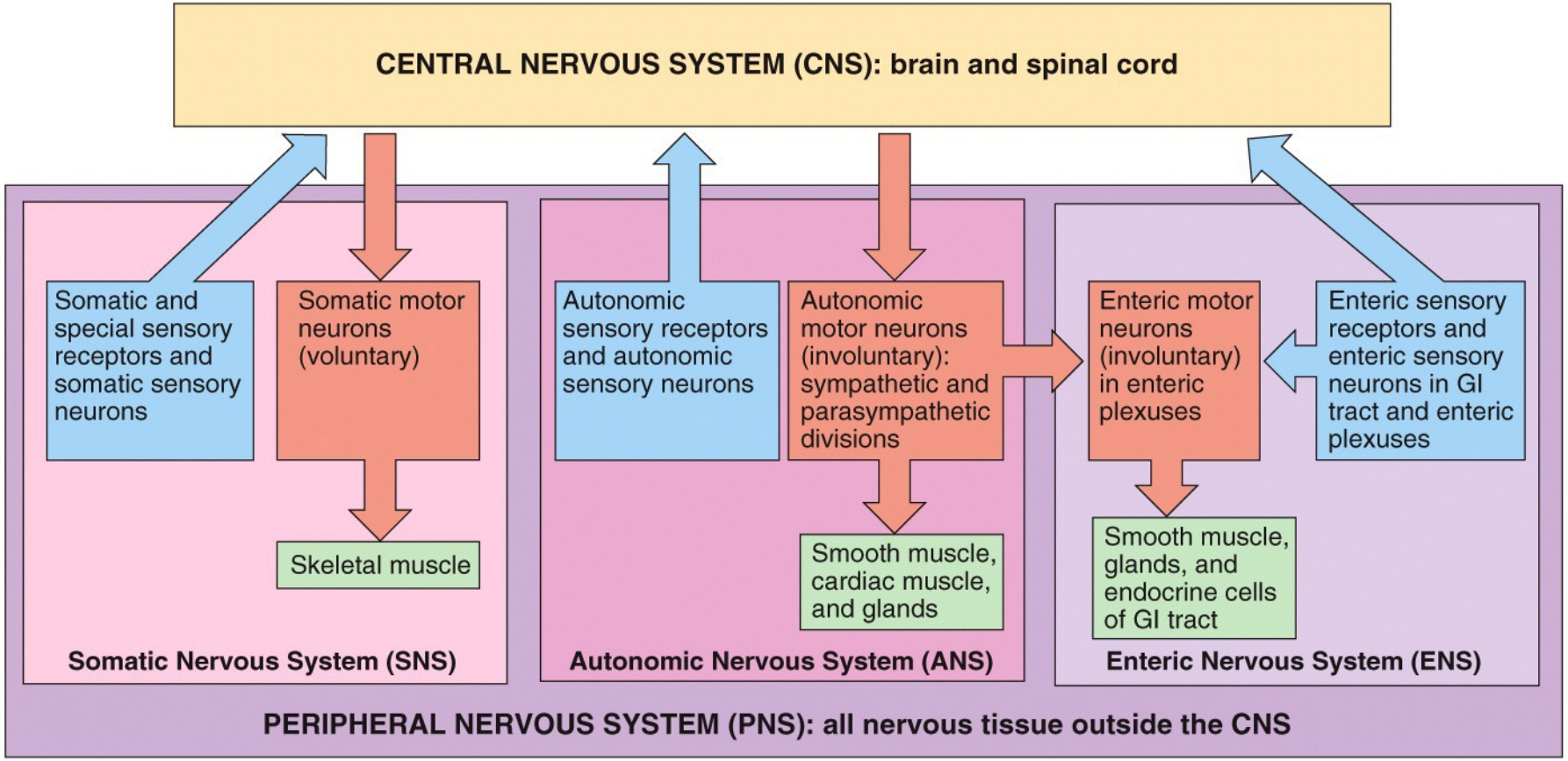
Urinary bladder



Parasympathetic motor neuron

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?

How Do We Maintain Homeostasis?

- The “internal environment” resist change and maintains 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 brain structure regulates the endocrine system and autonomic nervous system?
- What brain structure regulates homeostasis?

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 muslces
- 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

PNS Motor Divisions

Somatic Motor Division (efferent fibers)

carries signals to skeletal muscles

signal originates from brain's pre-central gyrus

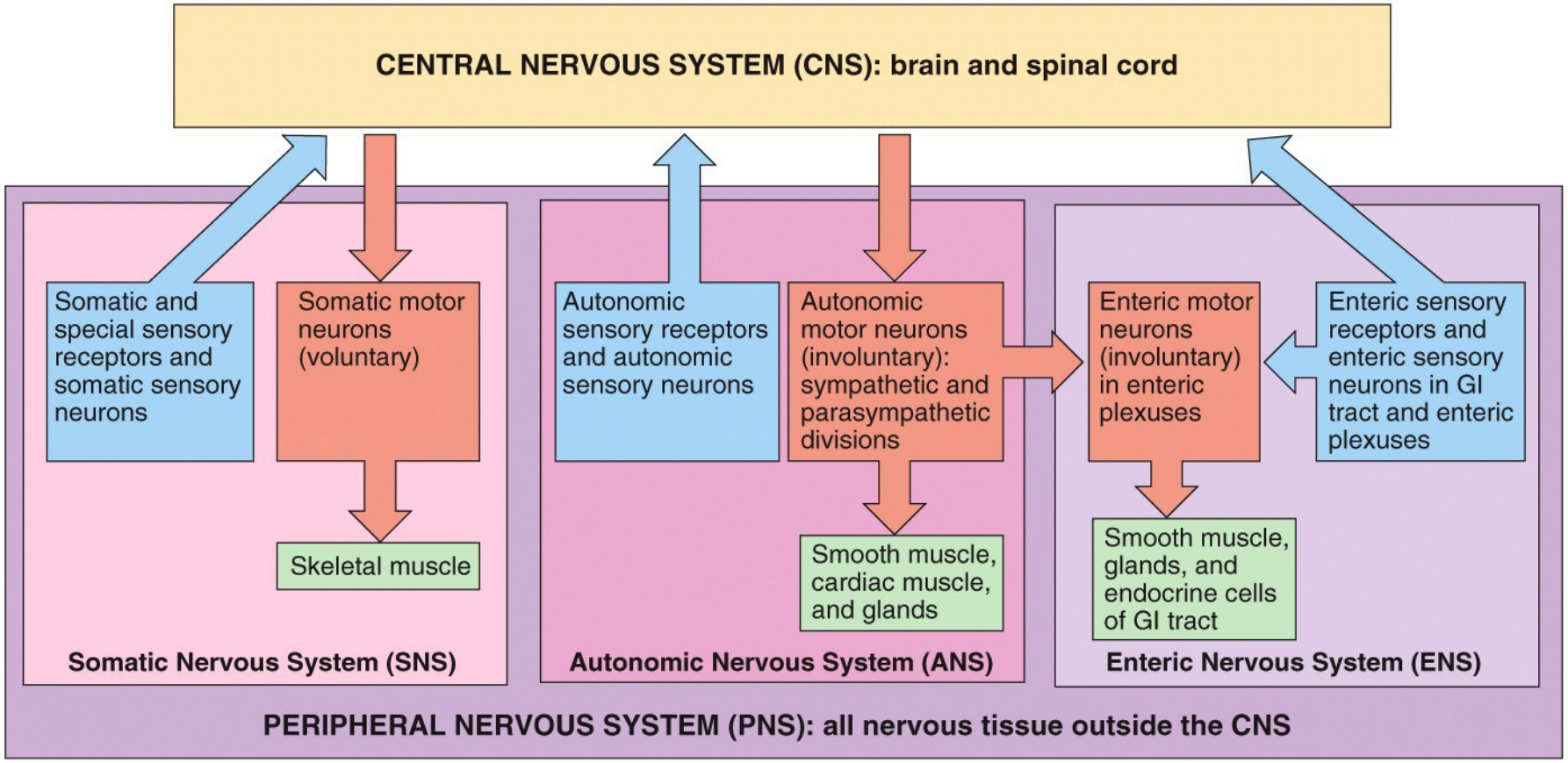
output produces skeletal muscular contraction /// voluntary

note: spinal cord reflex /// “somatic reflexes” - does not require pre-central gyrus function // these reflexes cause involuntary skeletal muscle contractions

PNS Motor Divisions

- Visceral motor division (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 heart beat 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

Subdivisions of Nervous System



(b)

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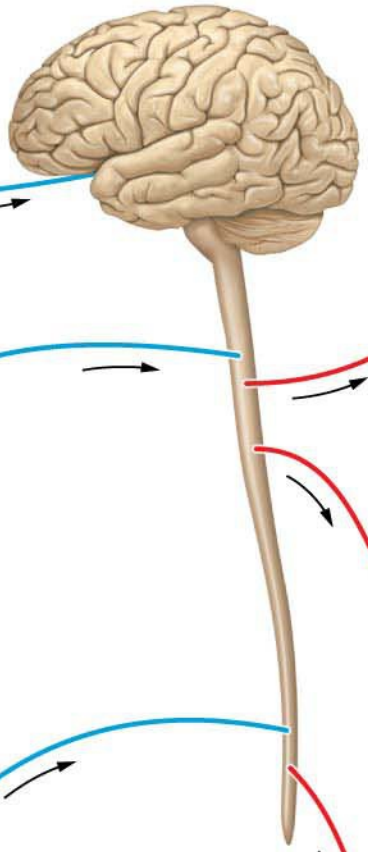

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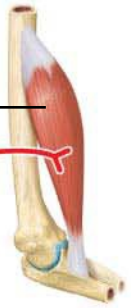

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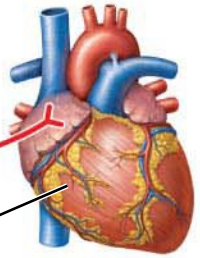
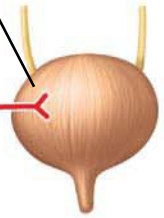


Heart

Urinary bladder



Parasympathetic motor neuron

Universal Properties of a Neuron

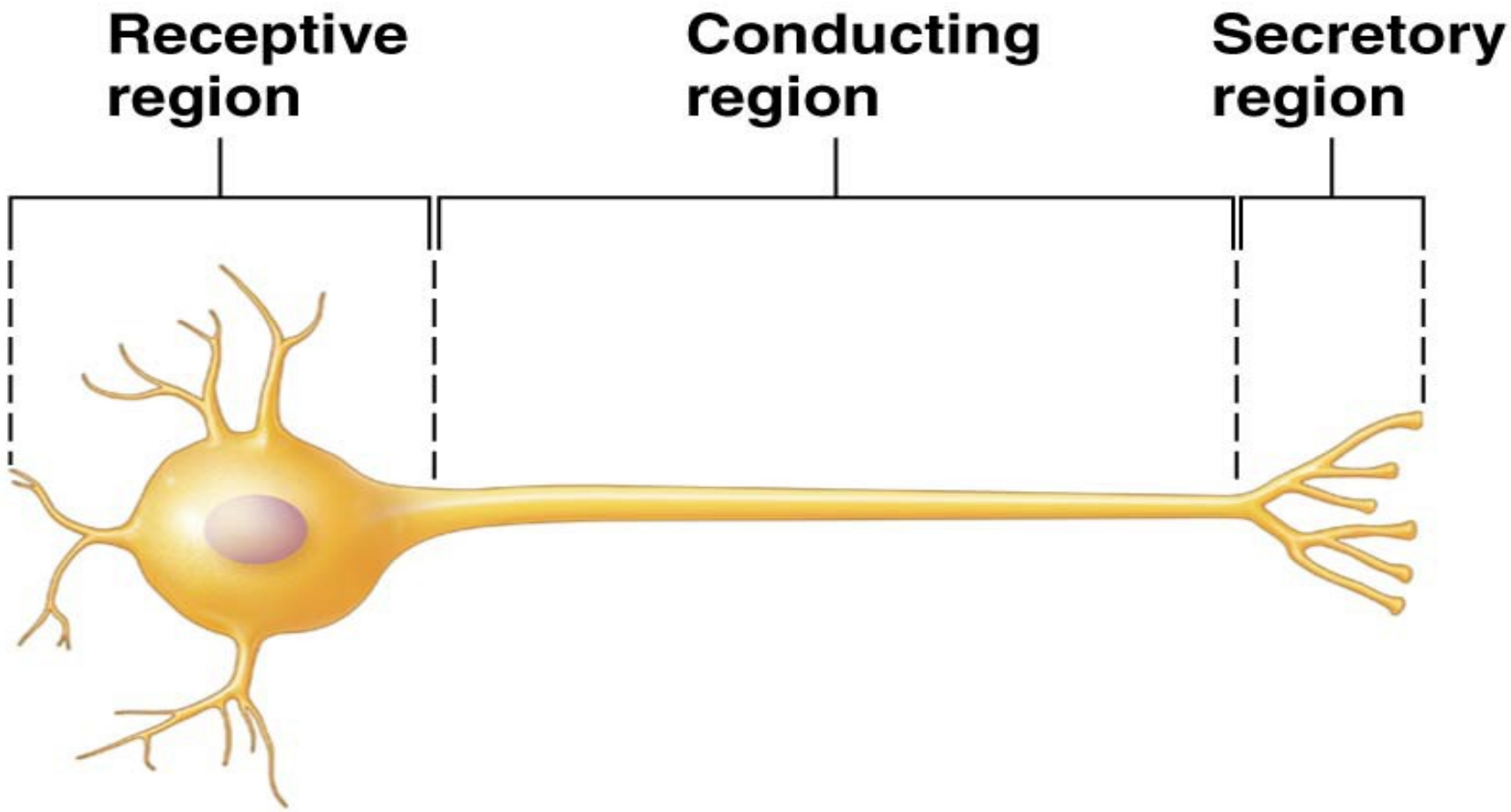
- Neurons Excitable (irritability) /// respond to environmental changes called stimuli

- Conductivity /// neurons respond to stimuli by producing electrical signals that are quickly conducted to other cells // action potentials

- Secretion /// when electrical signal reaches end of nerve fiber, a chemical neurotransmitter is secreted that crosses the gap and stimulates the next cell

- *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 both which occurs at the synapse*

Functional Regions of a Neuron

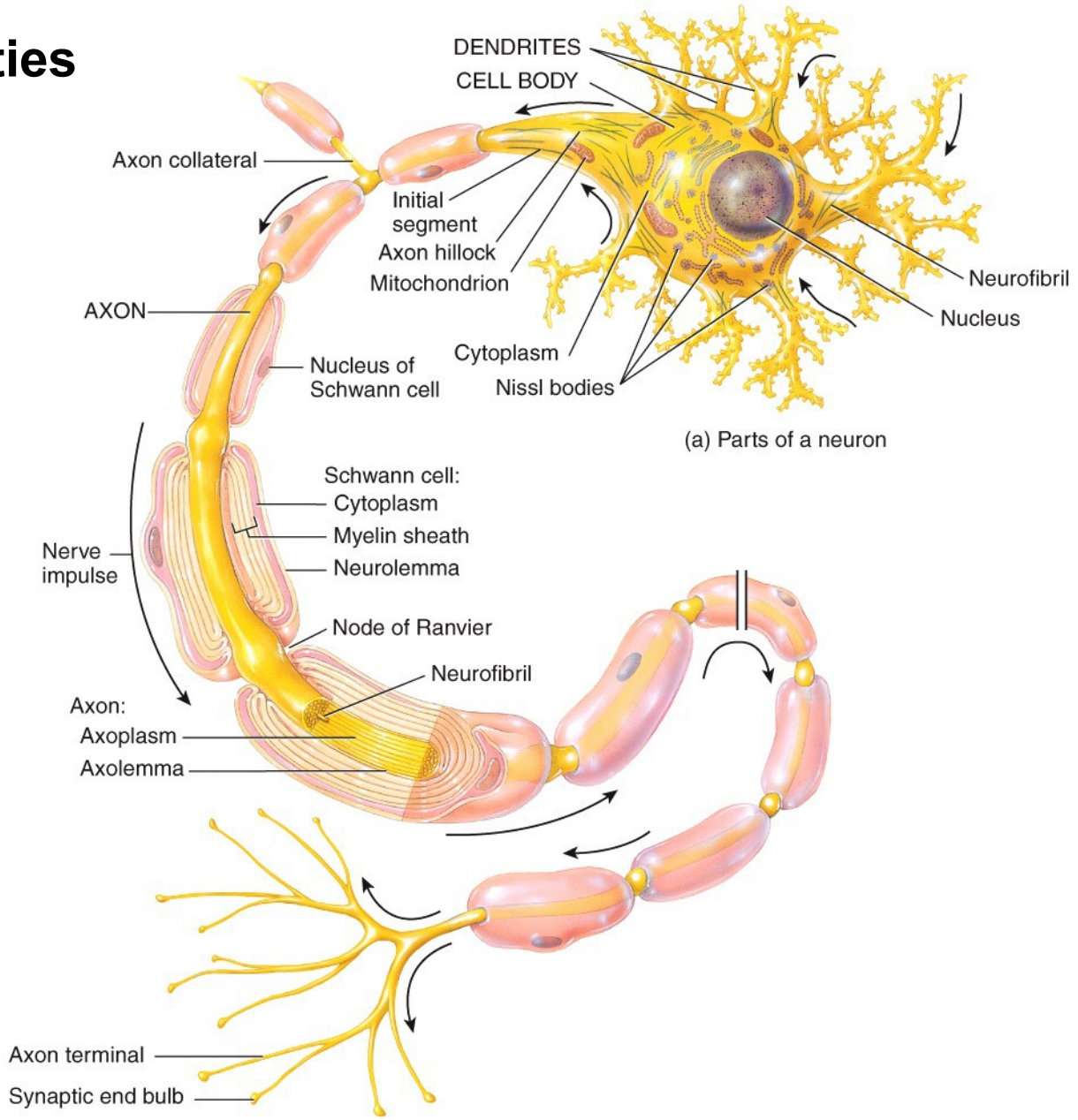


> What is the direction of the electrical impulse?
> What do we mean by unidirectional?

Universal Properties of a Neuron

Neurons are defined by either structural or functional criteria. Based on the structure, this is a “multi-polar neuron”.

A neuron will have all the common organelles associated with a typical cell.



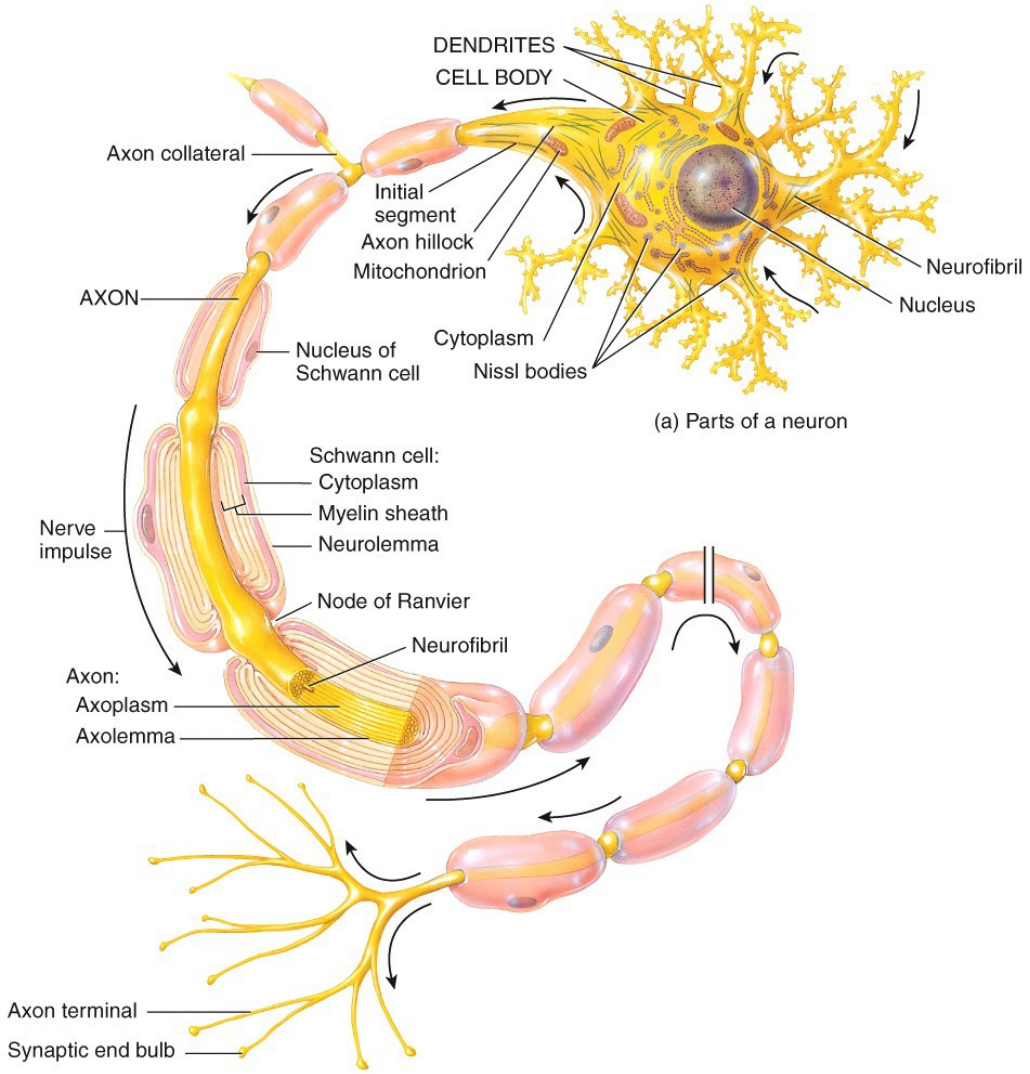
The Soma

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

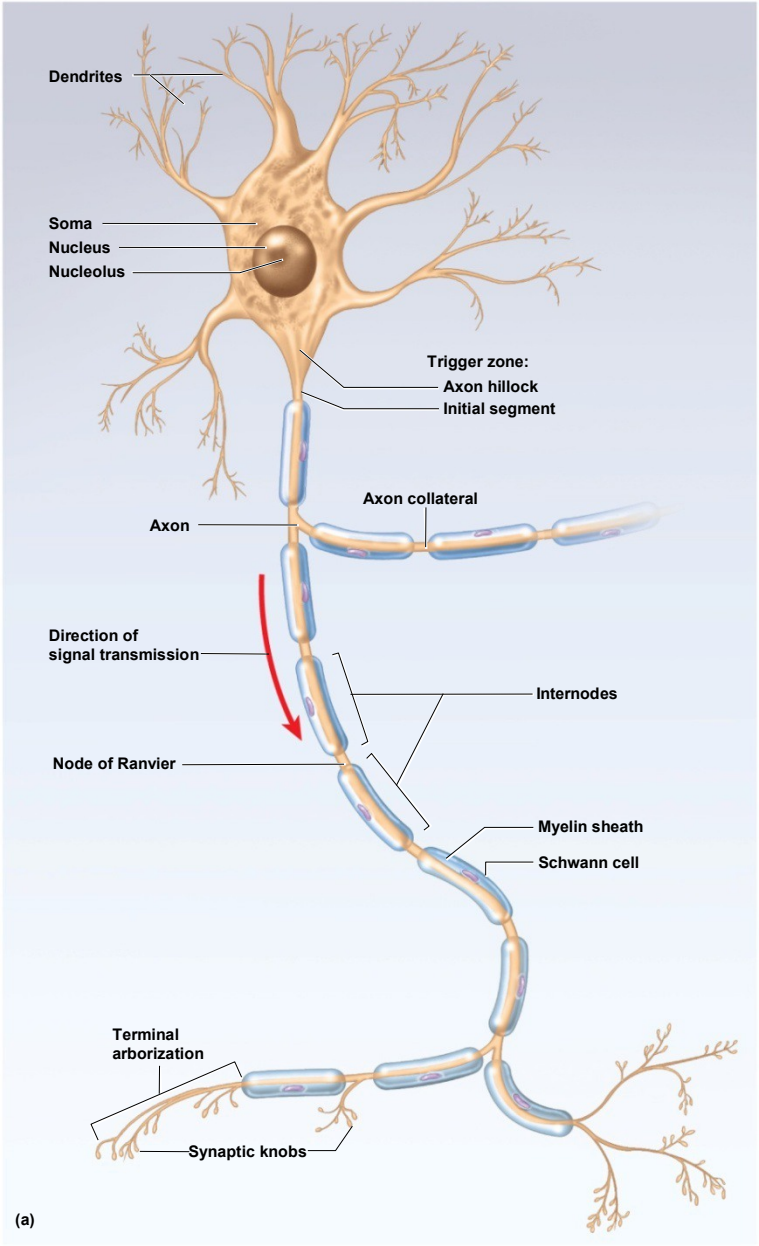


The Soma

- 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
- **Inclusions 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 receptors”
- Transducers = receptors
- Stumulus creates local potential /// graded potentials
- the more dendrites the neuron has, the more information it can receive and incorporate into decision making
- 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

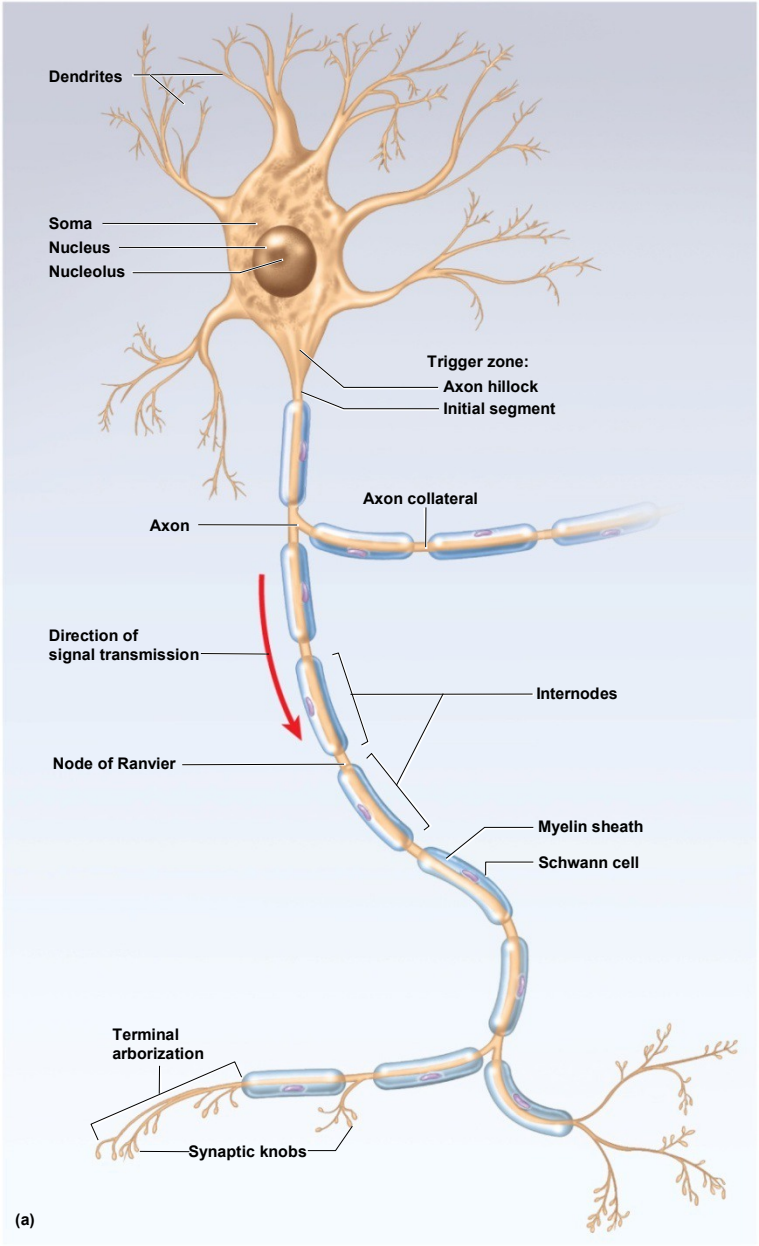
cylindrical, relatively unbranched for most of its length /// axon collaterals – branches of axon

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



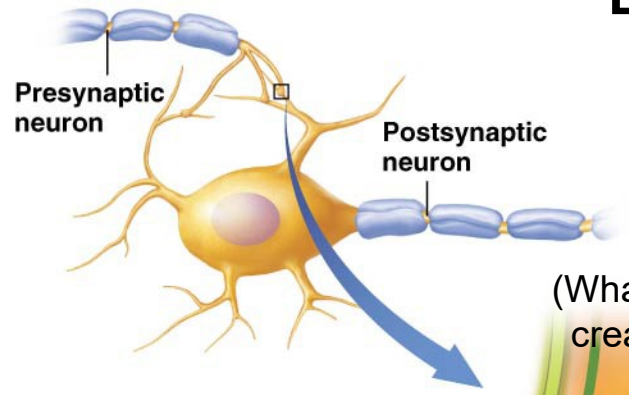
The Axon

- 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
  - contains synaptic vesicles full of neurotransmitter

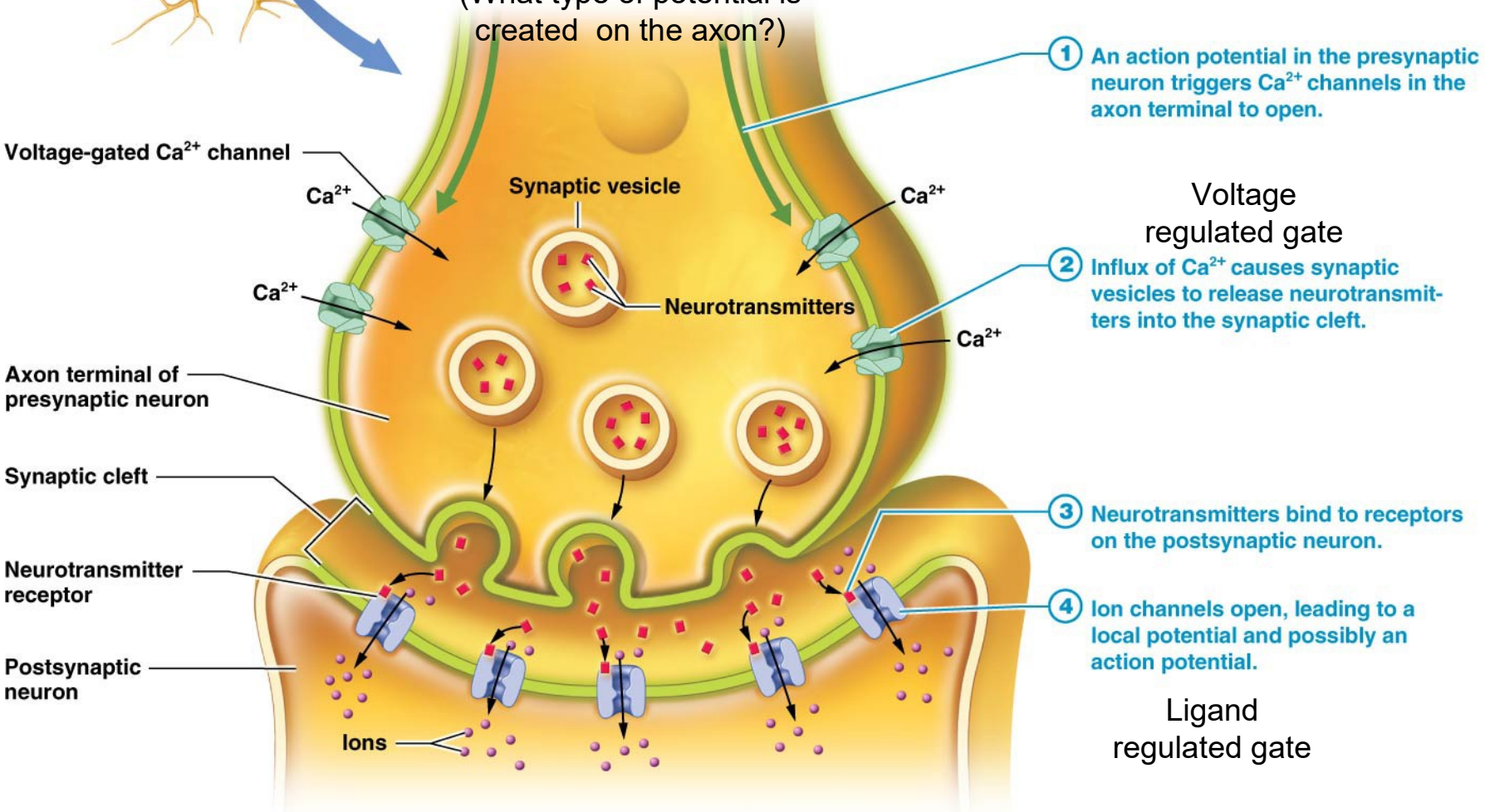
The Synaptic Knob

- 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 stimulatory others inhibitory
- Neurotransmitters made in soma and transported down axon in vesicles
- Neurotransmitters released from synaptic knob via exocytosis
- Synaptic knob forms part of the synapse // the presynaptic membrane
- Synapse three components: presynaptic membrane – synaptic cleft – post synaptic membrane)

Events at a chemical synapse: synaptic transmission.

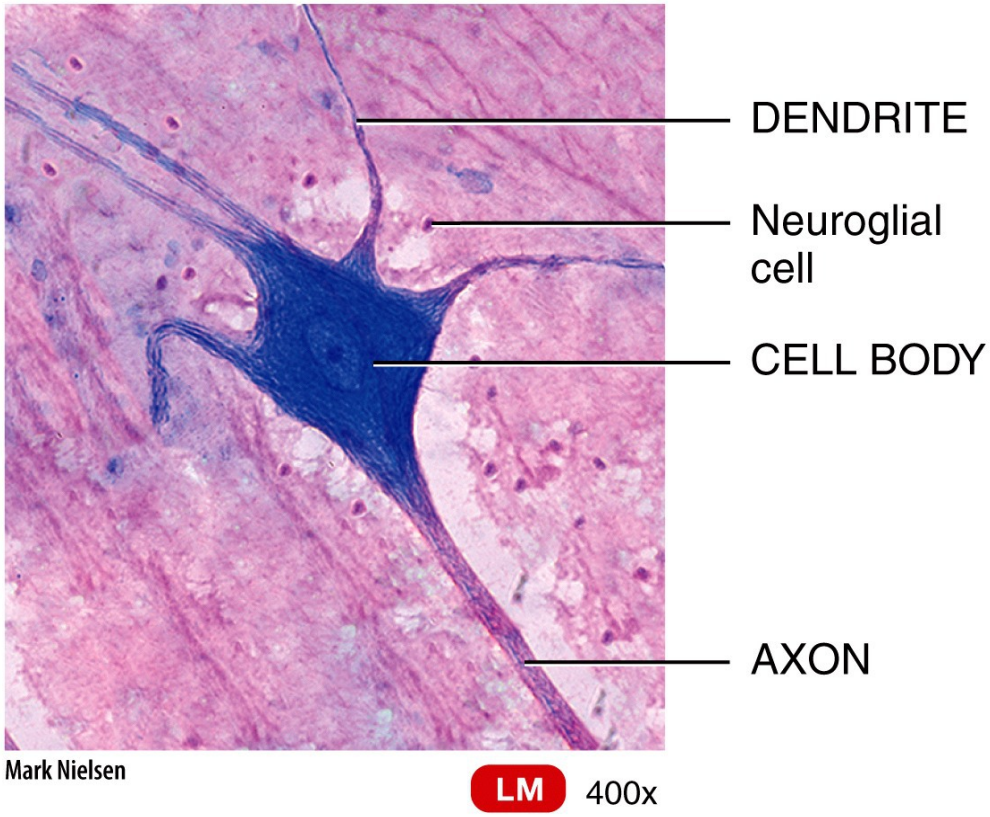


(What type of potential is created on the axon?)

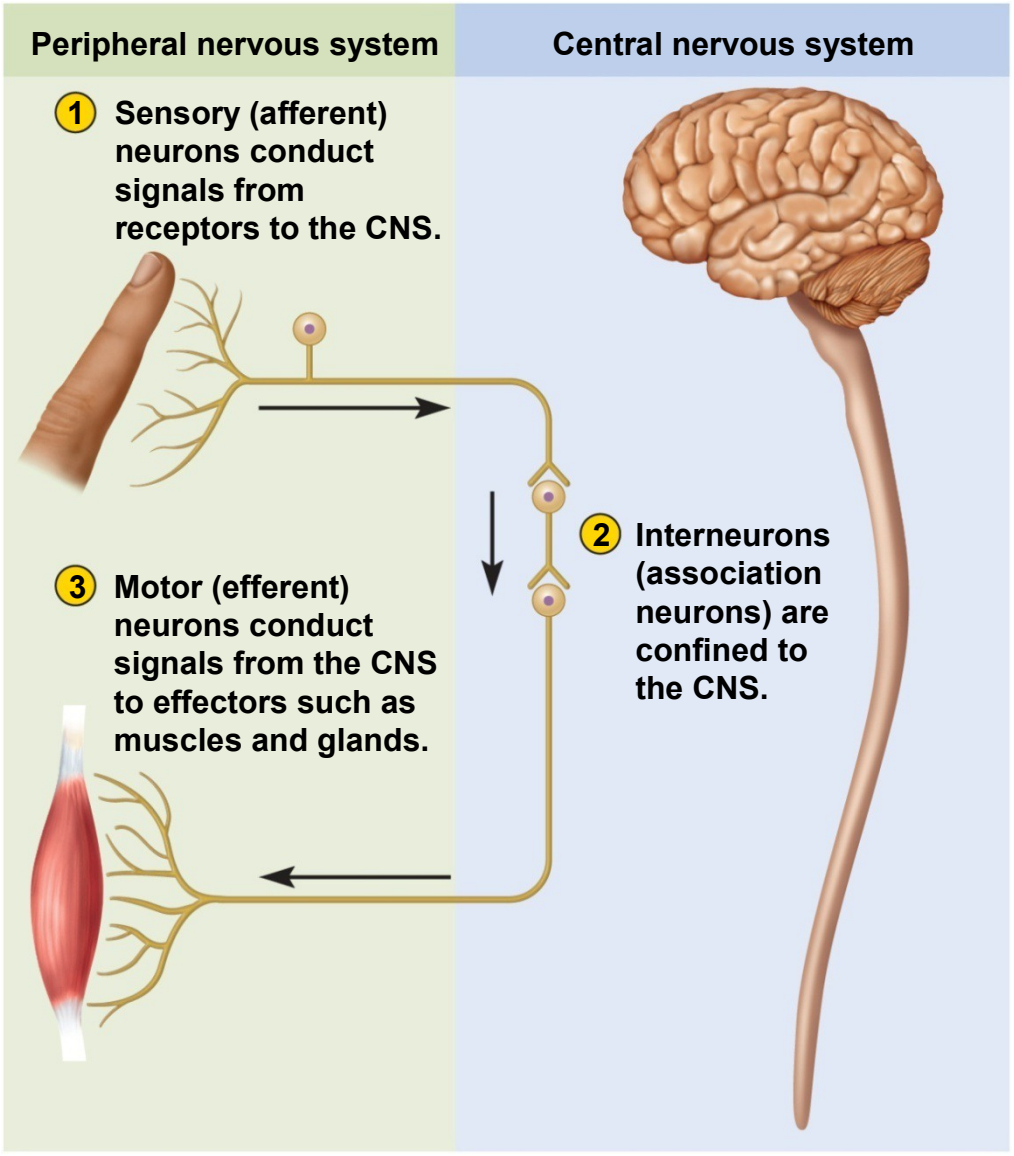


(What type of potential is created on the dentrite?)

Neurons Are Classified by Their Structure or Function



Functional Classes 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

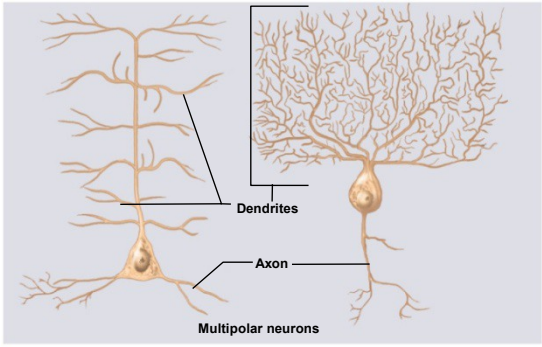
- Motor (efferent) neuron
  - send signals out to muscles and gland cells (the effectors)
    - motor because most of them lead to muscles
    - efferent neurons conduct signals away from the CNS

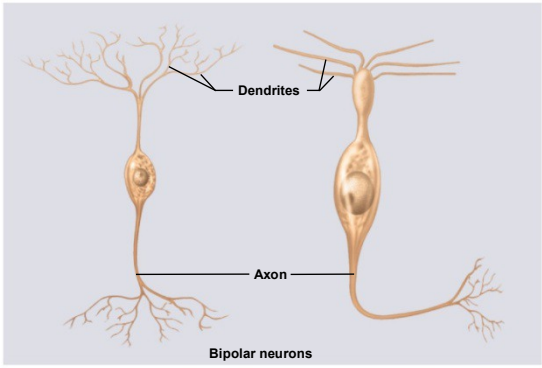
Functional Definition of Neurons
(sensory, motor, inter-neuron)

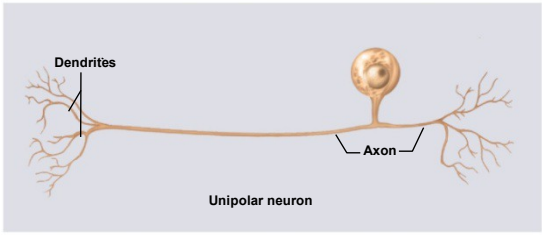
- Interneurons (association) neurons
  - lie entirely within the CNS
  - receive signals from many neurons and carry out the *integrative function*
    - process, store, and retrieve information and 'make decisions' that determine how the body will respond to stimuli
  - 90% of all neurons are interneurons
  - *lie between and interconnect the incoming sensory pathways to the outgoing motor pathways of the CNS*

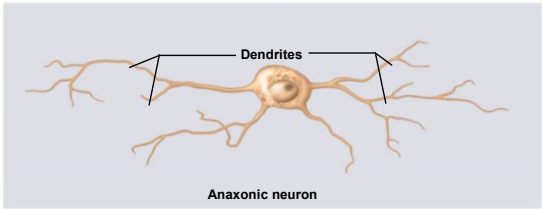
Structural Definition of Neuron

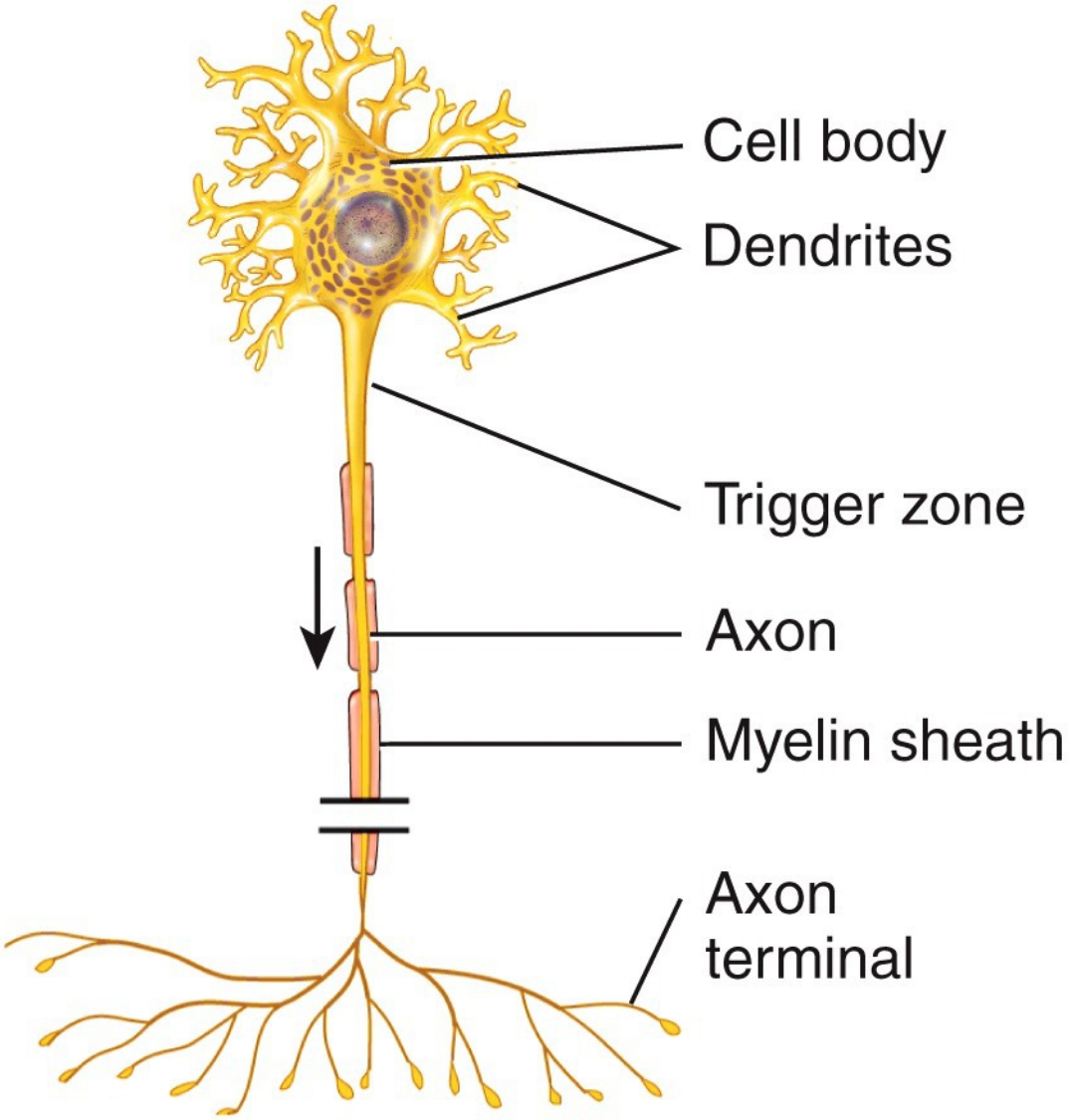
- multipolar neuron
  - one axon and multiple dendrites
  - most common
  - most neurons in the brain and spinal cord
- bipolar neuron
  - one axon and one dendrite
  - olfactory cells, retina, inner ear
- unipolar neuron
  - single process
  - sensory from skin and organs to spinal cord
- anaxonic neuron
  - many dendrites but no axon
  - help in visual processes



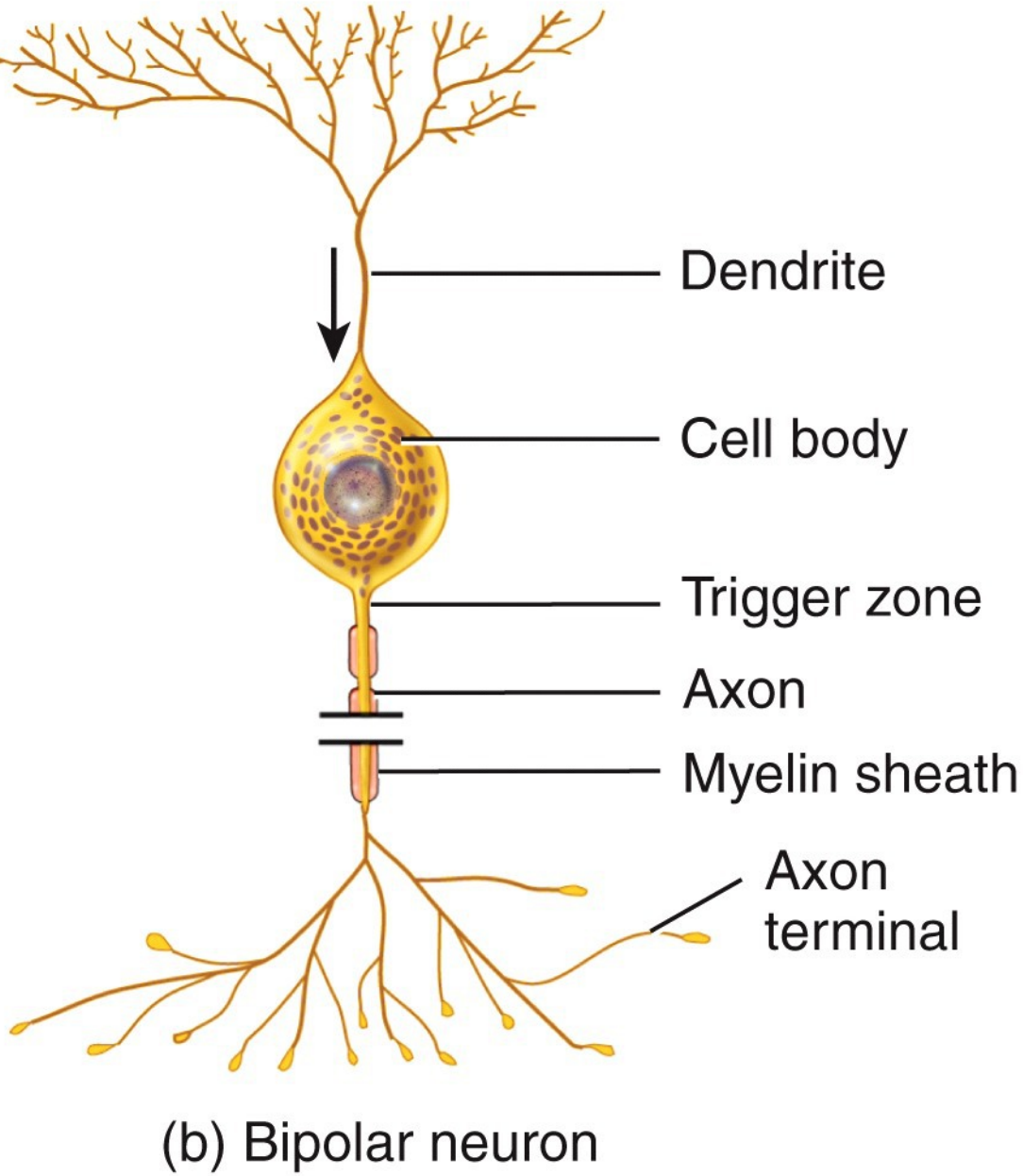




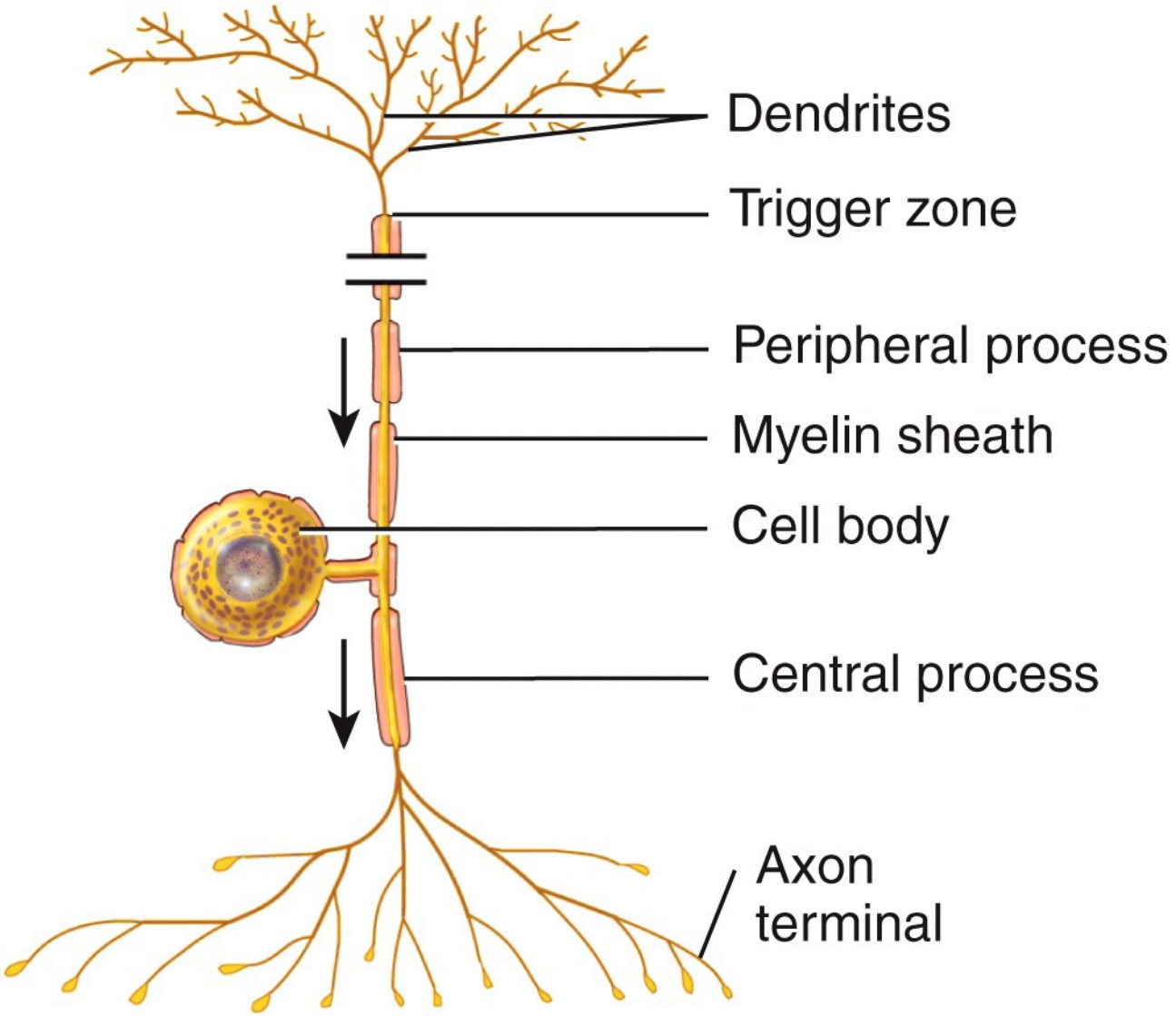




(a) Multipolar neuron



(b) Bipolar neuron



(c) Unipolar neuron

Neuroglial Cells

- Current studies suggest that the human brain contains about 170.68 billion cells, 86.1 billion of which are neurons and 84.6 billion of which are glial cells. Their study also suggests that the ratio of glia to neurons differs dramatically from one general brain region to the next

- How many cells are in the human body? 37.2 trillion cells.

- Neuroglia (also called glial cells)

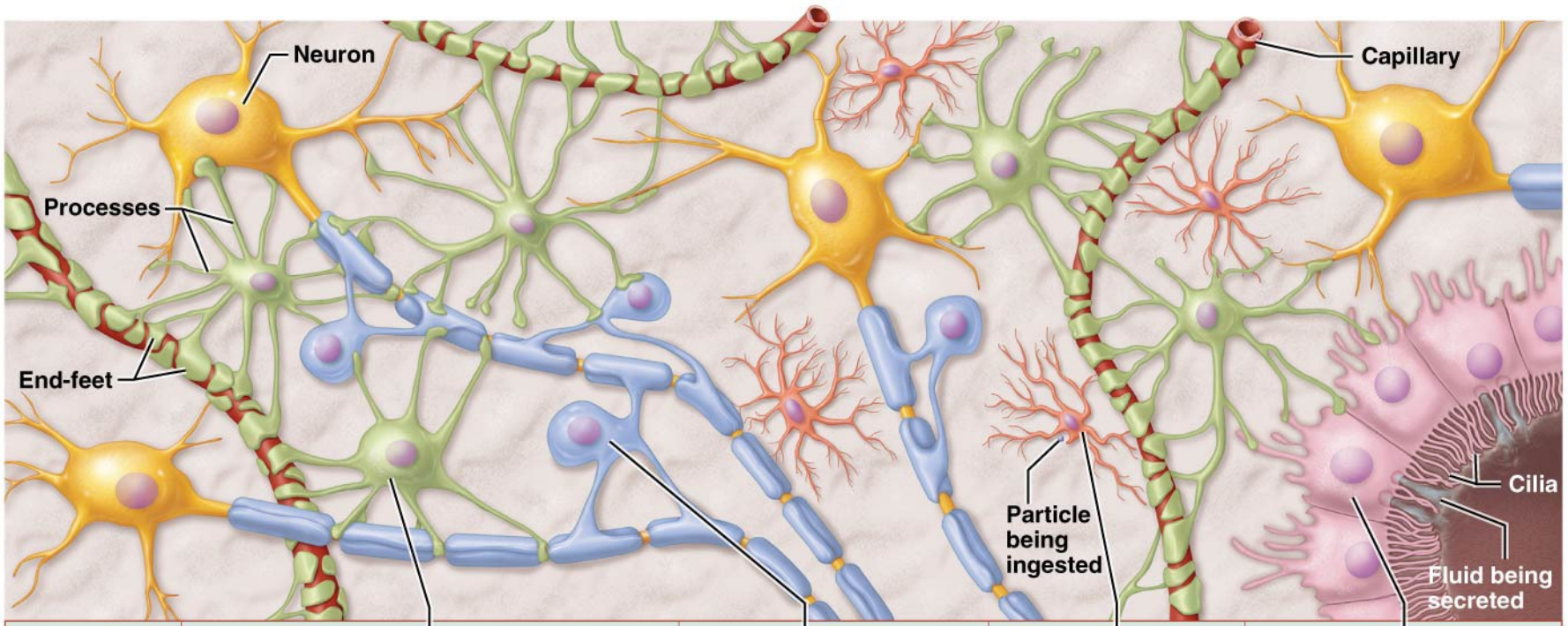
  - Support, protect, and enhance function of neurons

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

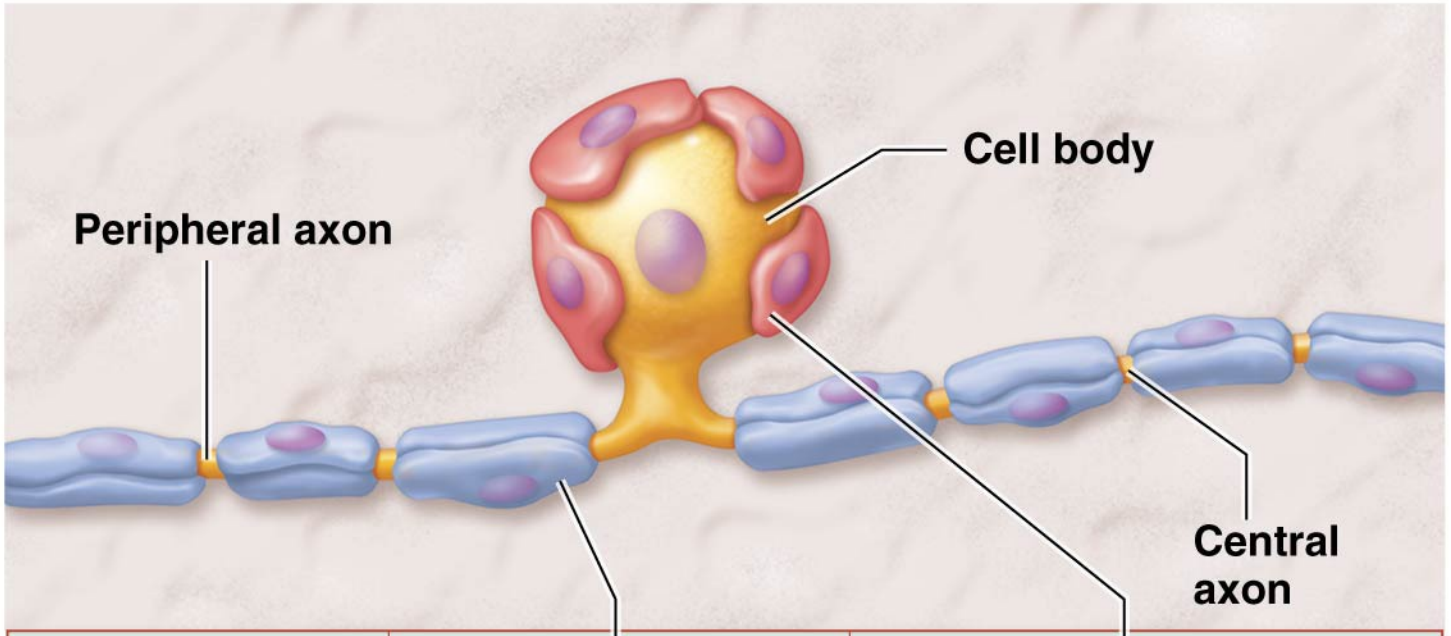
Neuroglial cells of the CNS.



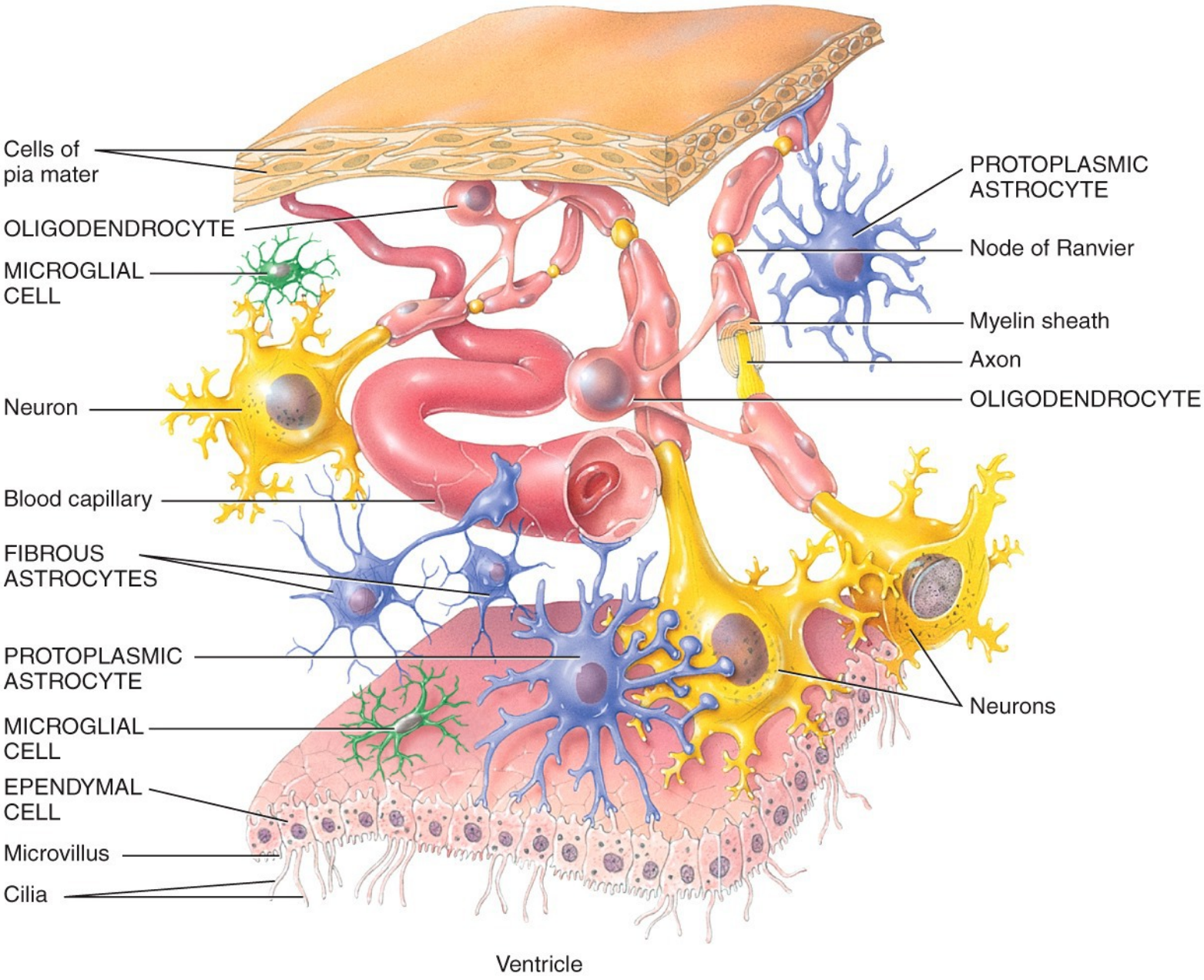
NEUROGLIAL CELL TYPE	ASTROCYTE	OLIGODENDROCYTE	MICROGLIAL CELL	EPENDYMAL CELL
FUNCTION	• Anchor neurons and blood vessels • Regulate the extracellular environment • Facilitate the formation of the blood-brain barrier • Repair damaged tissue	• Myelinate certain axons in the CNS	• Act as phagocytes	• Line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

Note: protoplasmic vs fibros astrocytes

Neuroglial cells of the PNS.



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


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 forming an insulating layer that speeds up signal conduction
  - **ependymal cells**
    - lines internal cavities of the brain
    - cuboidal epithelium with cilia on apical surface
    - secretes and circulates cerebrospinal fluid (CSF)
      - clear liquid that bathes the CNS
  - **microglia**
    - small, wandering macrophages
    - formed by white blood cell called **monocytes**
    - thought to perform a 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**) that contact blood capillaries that stimulate them to form a tight seal called the **blood-brain barrier**

More About Neuroglial Cells

- *Astrocyte / diverse functions (cont.)*
  - 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

More About Glial Cells

- Two types occur only 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

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** reaches out to myelinate several nerve fibers in its immediate vicinity
- anchored to multiple nerve fibers
- cannot migrate around any one of them 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

Myelin

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

- **Myelin sheath** is **segmented**

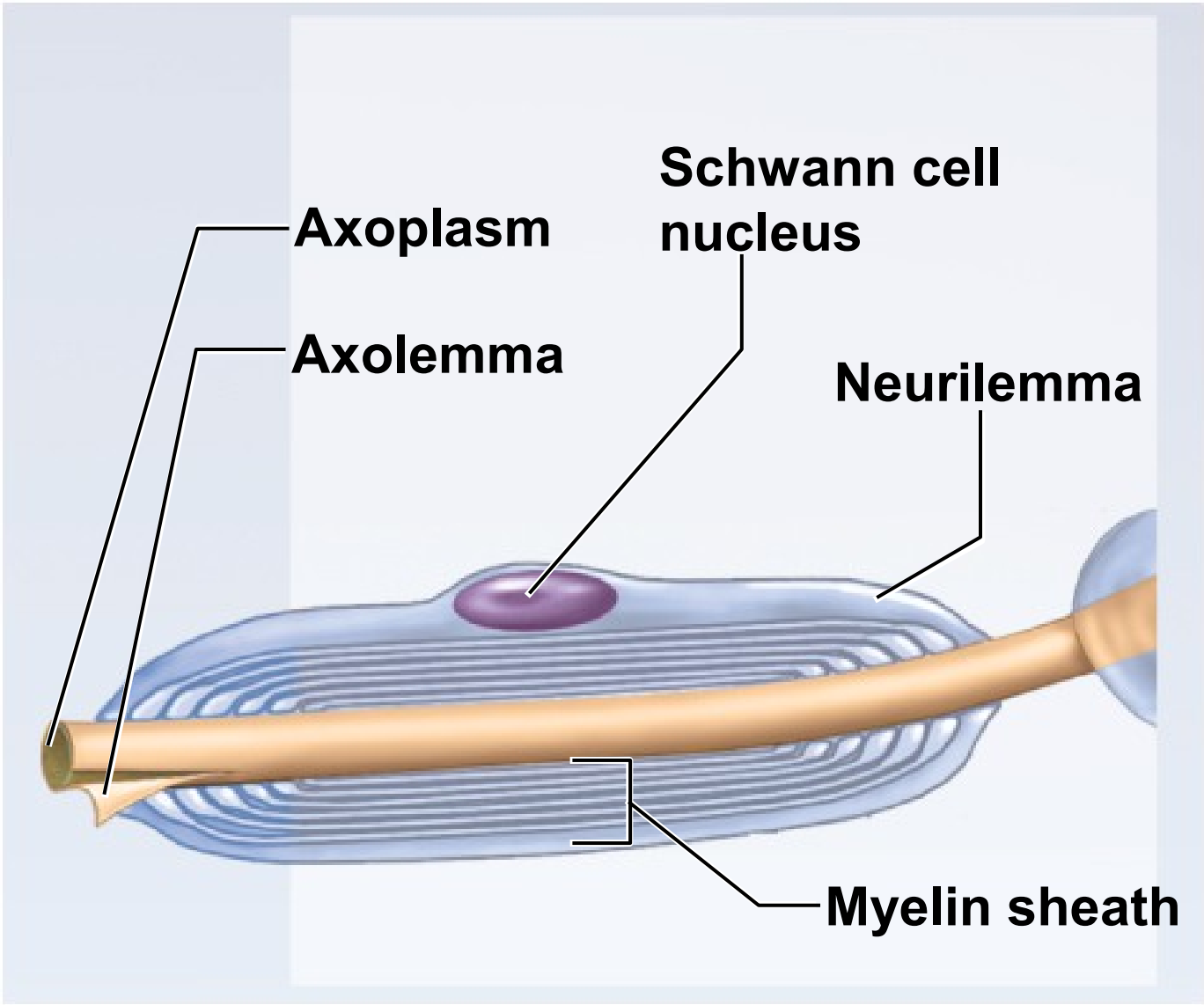
  - **nodes of Ranvier** – gap between segments

  - **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

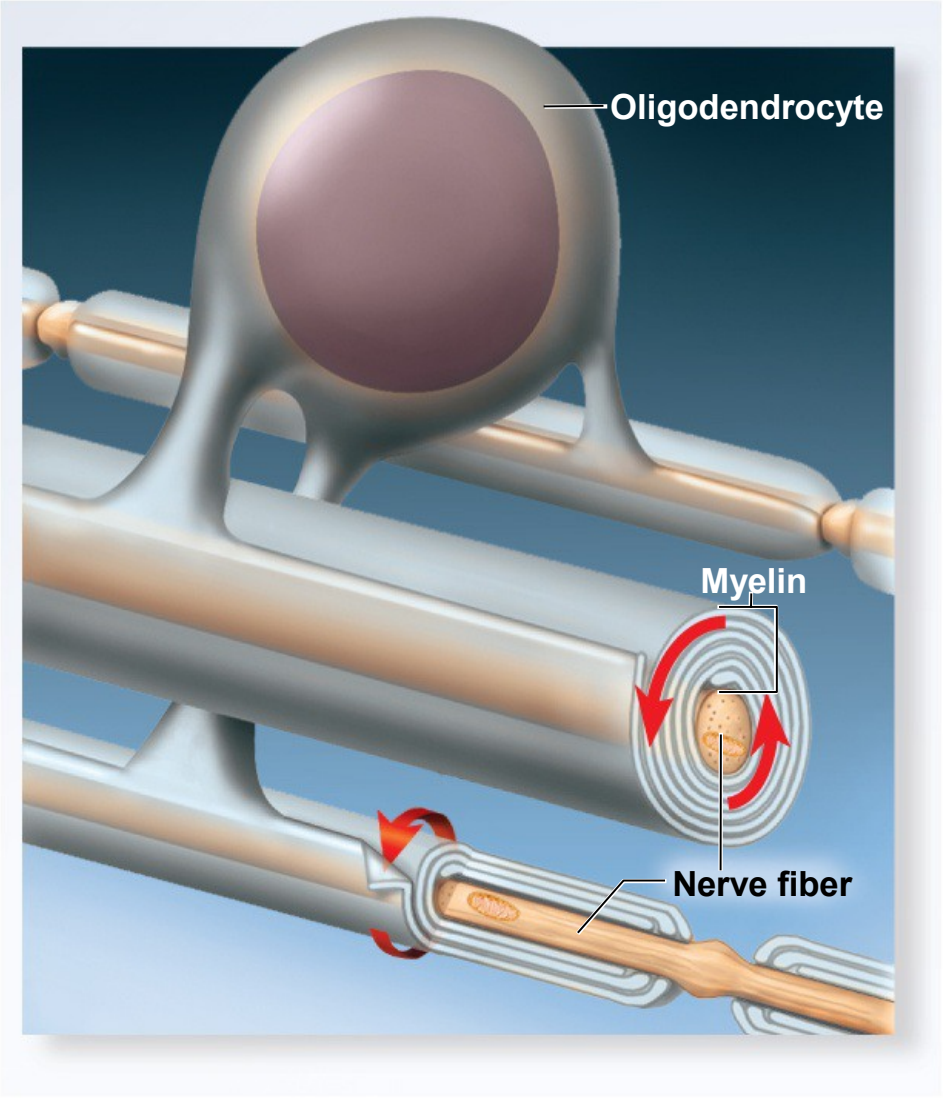
  - **trigger zone** – the axon hillock and the first segment of neurolemma /// play an important role in initiating a nerve signal

Myelin Sheath in PNS

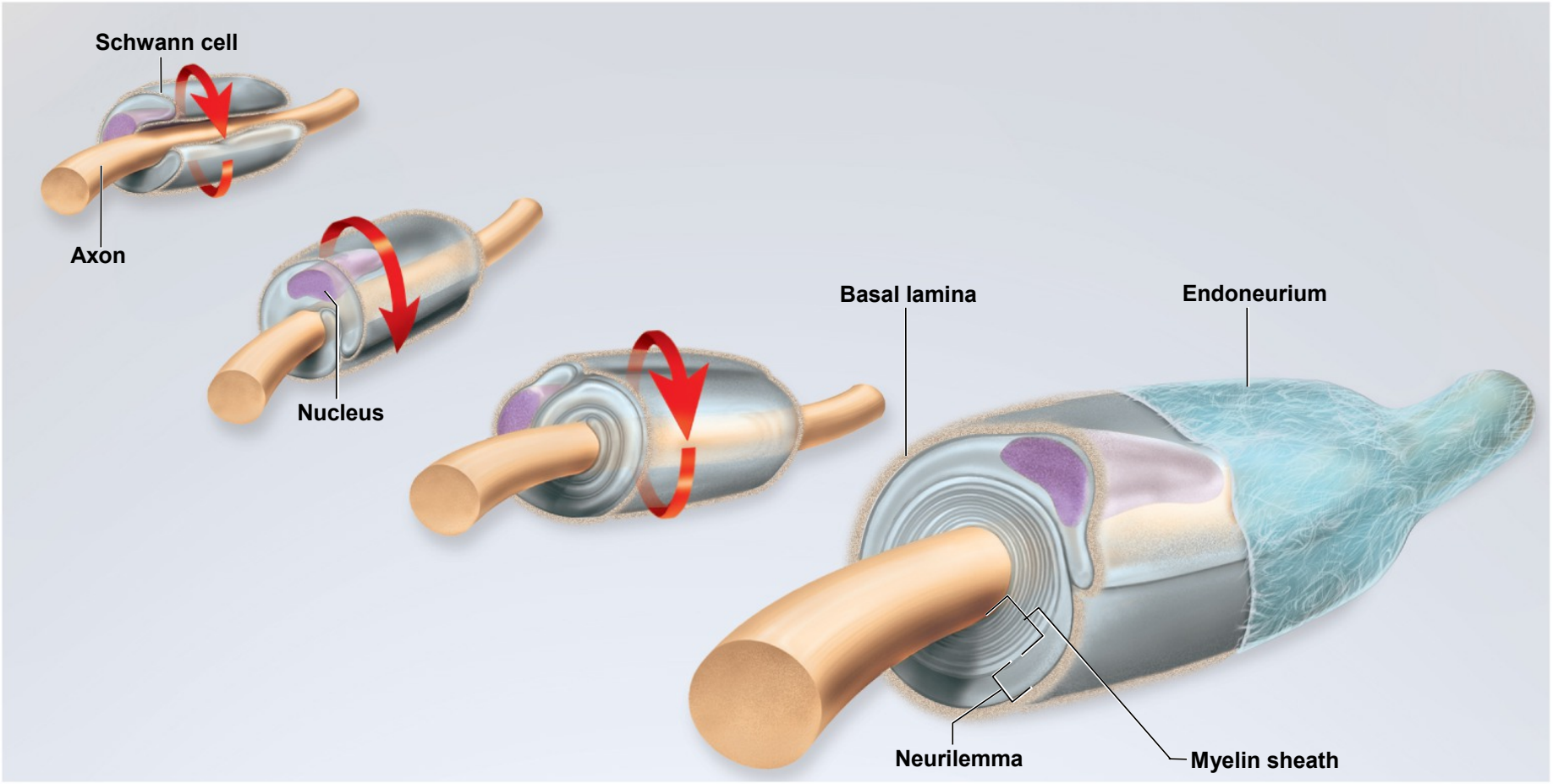


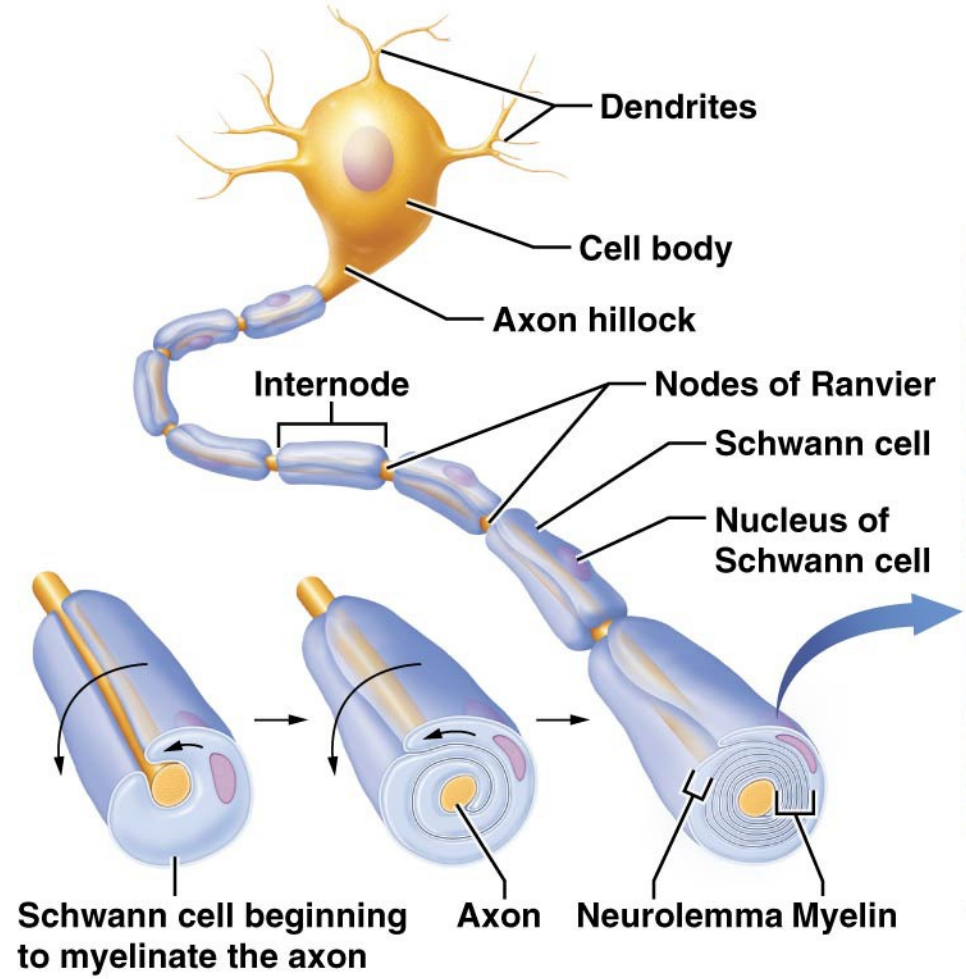
nodes of Ranvier and internodes

Myelination in CNS

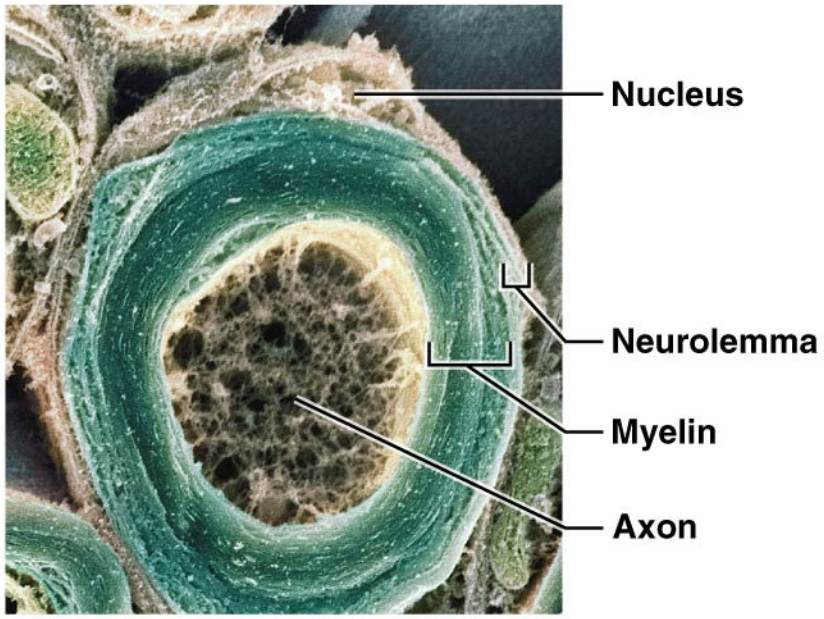


Myelination in PNS





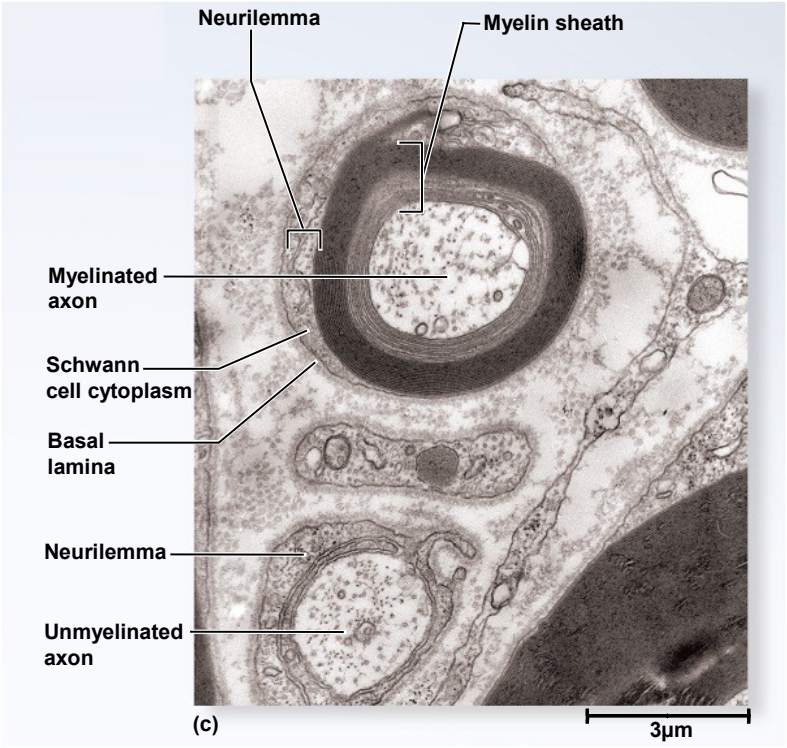
(a) The myelin sheath and myelination in the PNS

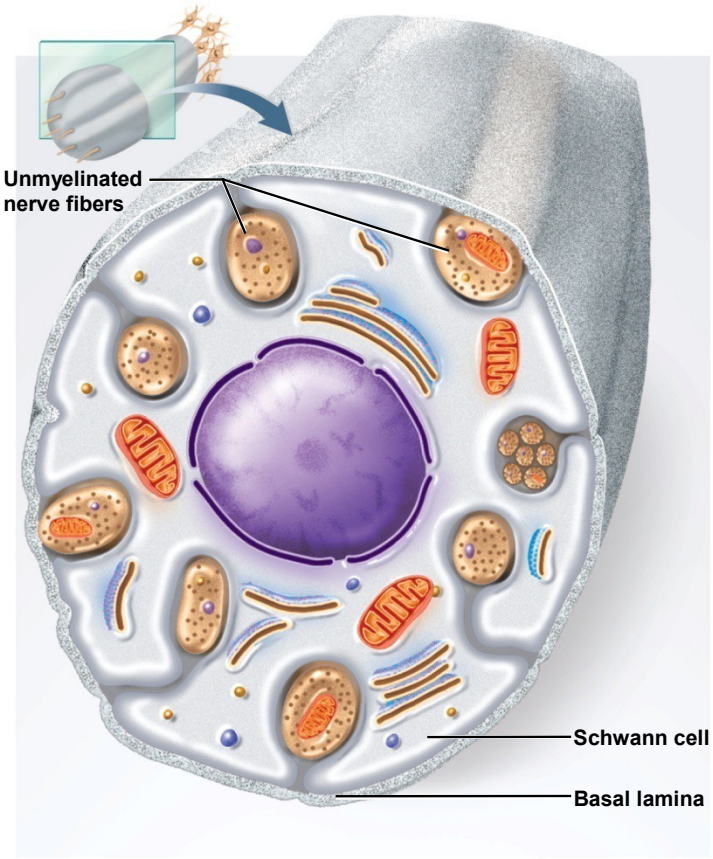


Cross-section of a myelin sheath

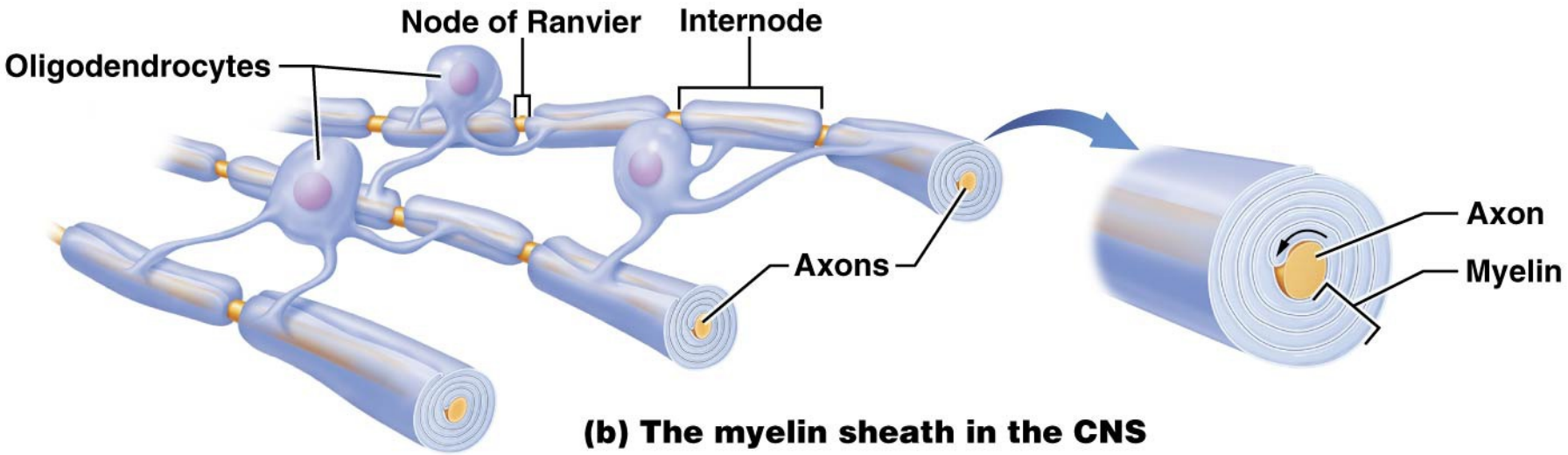
SEM (30,700×)

Unmyelinated Axons of PNS



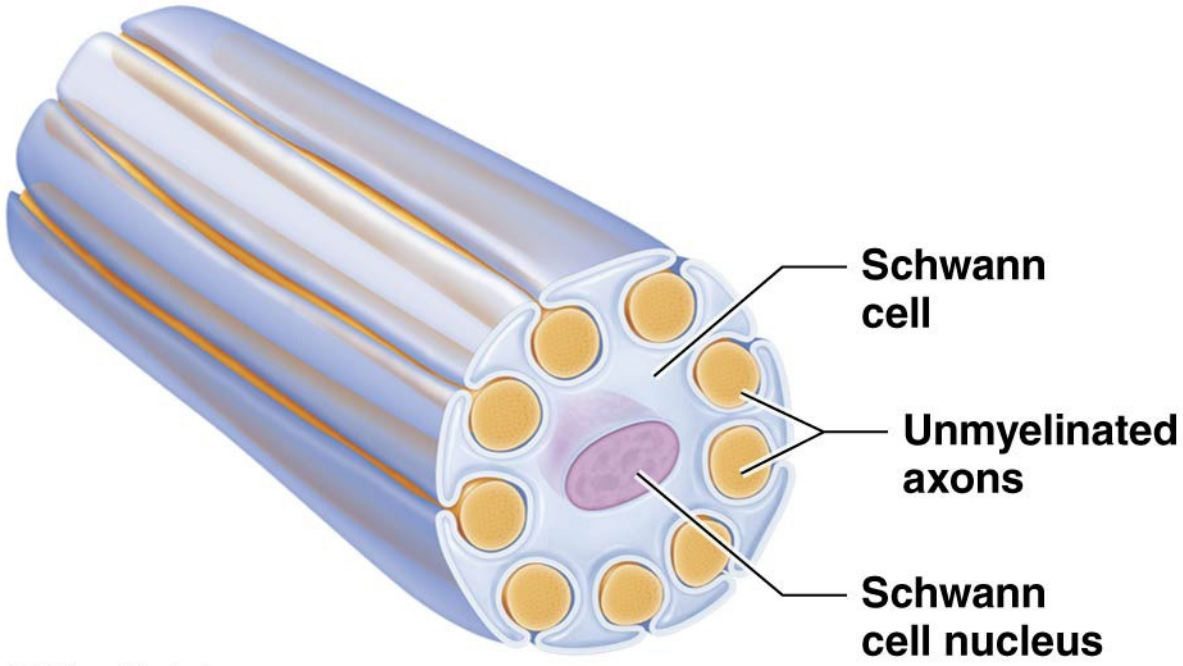


- Schwann cells hold 1 – 12 small nerve fibers in grooves on its surface
- membrane folds once around each fiber overlapping itself along the edges
- **mesaxon –** neurilemma wrapping of unmyelinated nerve fibers



(b) The myelin sheath in the CNS

Unmyelinated peripheral axons and Schwann cells.



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

- 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 they degenerate
  - macrophages engulf tissue debris inside tubular Schwan cells distal to point of damageat
- 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

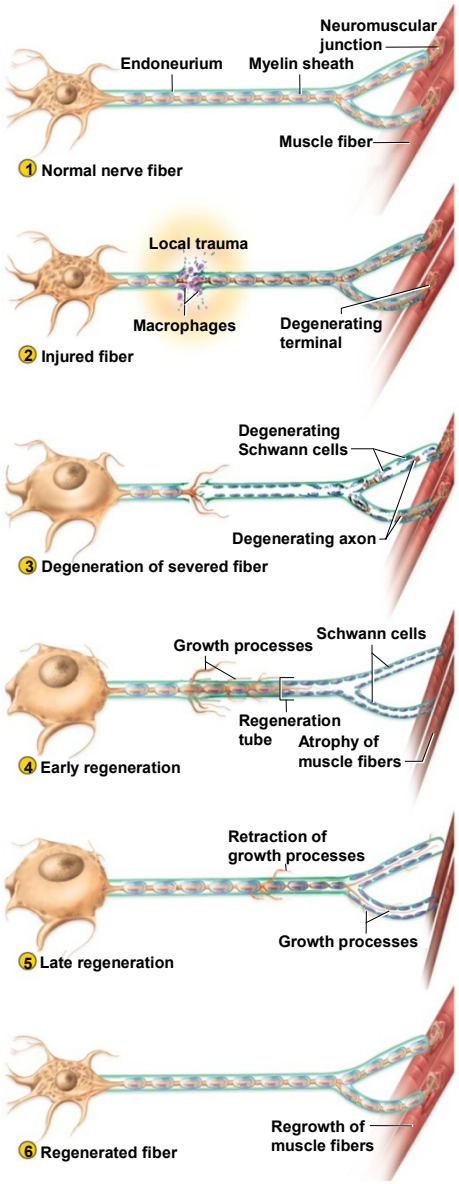
- regeneration tube – formed by Schwann cells, basal lamina, and the neurilemma near the injury

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

- nucleus returns to normal shape

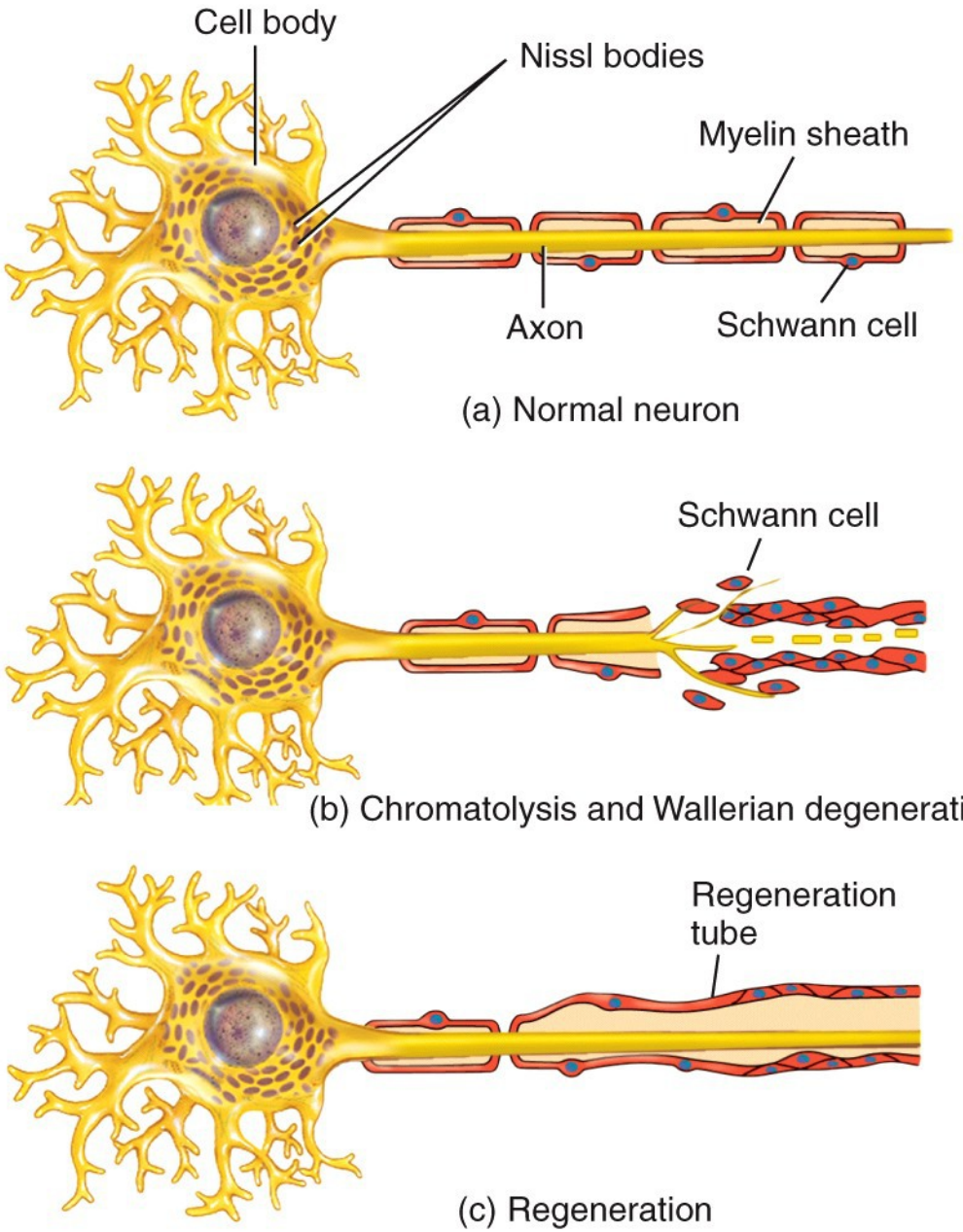
- Note: regeneration of damaged nerve fibers in the CNS may not occur

Regeneration of Nerve Fiber



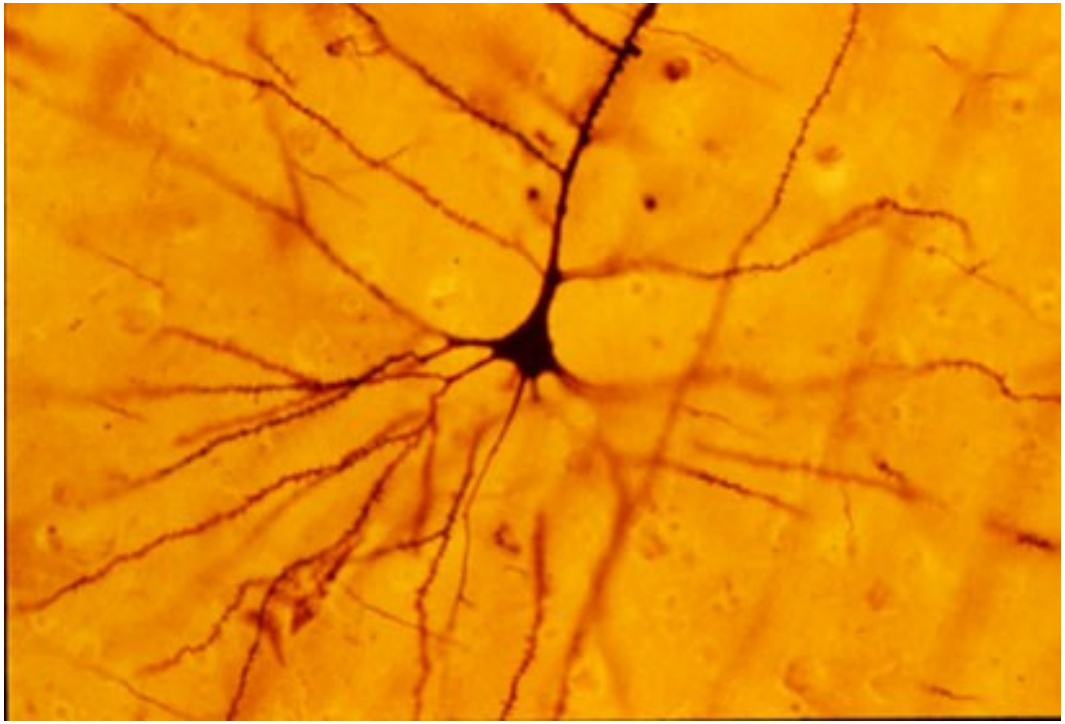
Denervation Atrophy

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.



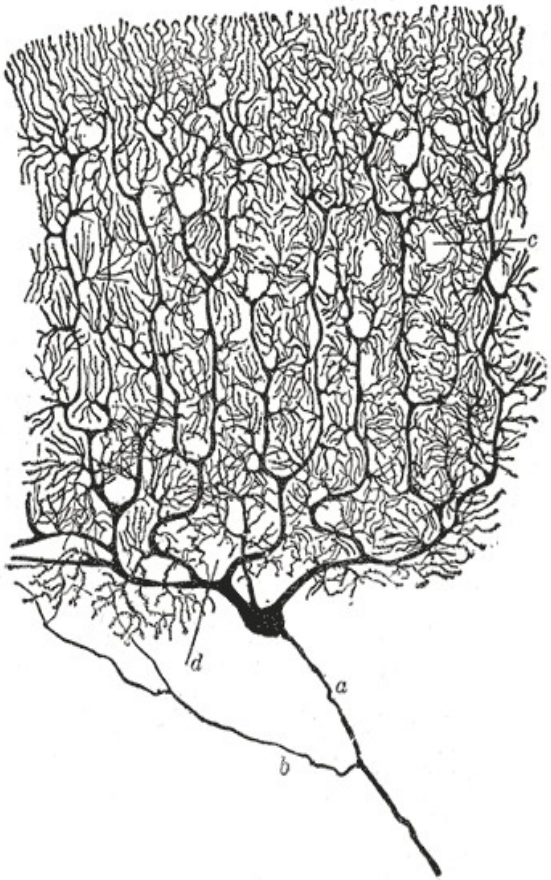
Discover of Neuron's Structure

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

- nerve growth factor (NGF)
  - 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 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 - masses of rapidly dividing cells /// mature neurons have little or no capacity for mitosis and seldom form tumors

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

- <u>brain tumors arise from:</u>
  - 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