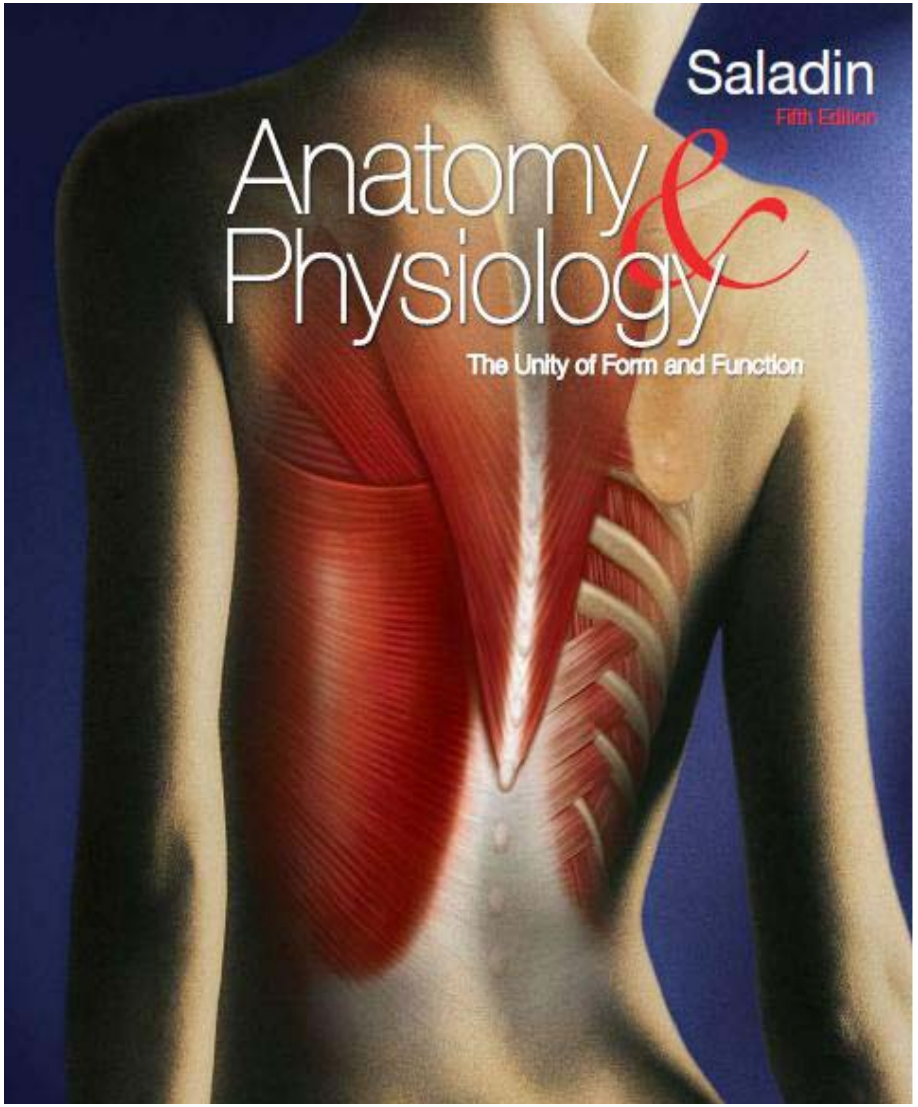
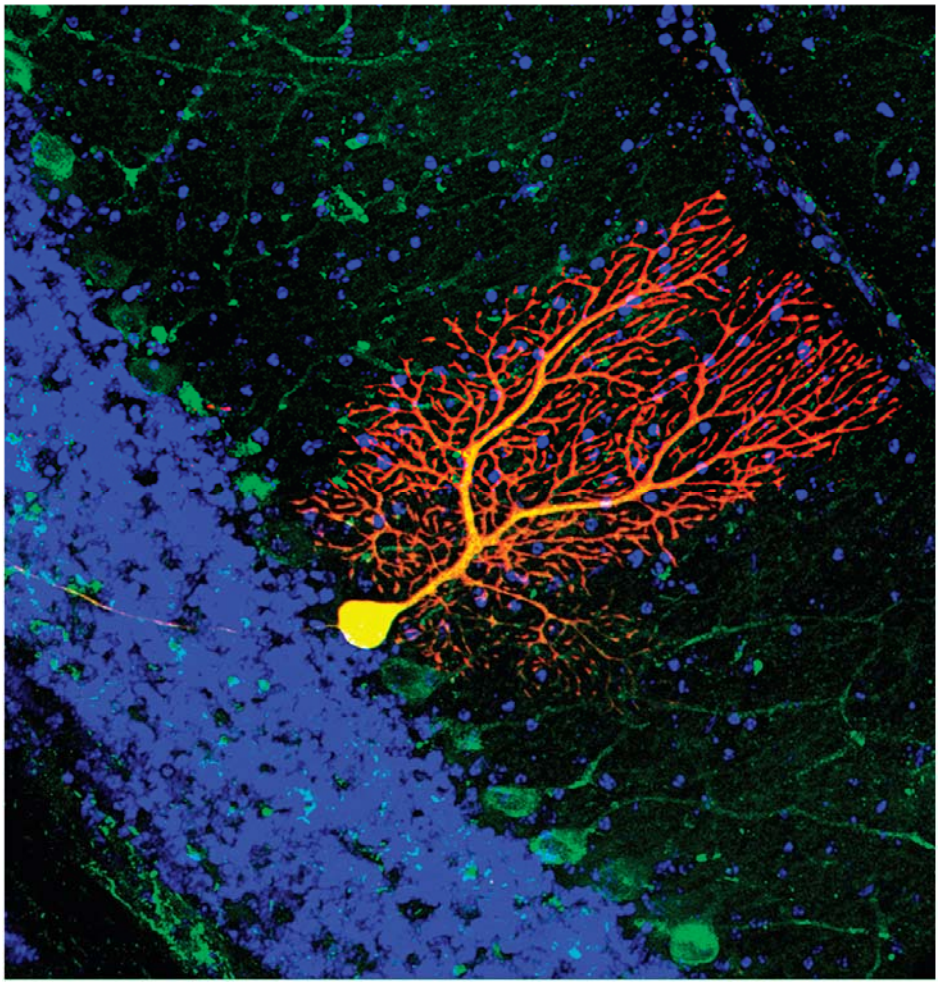


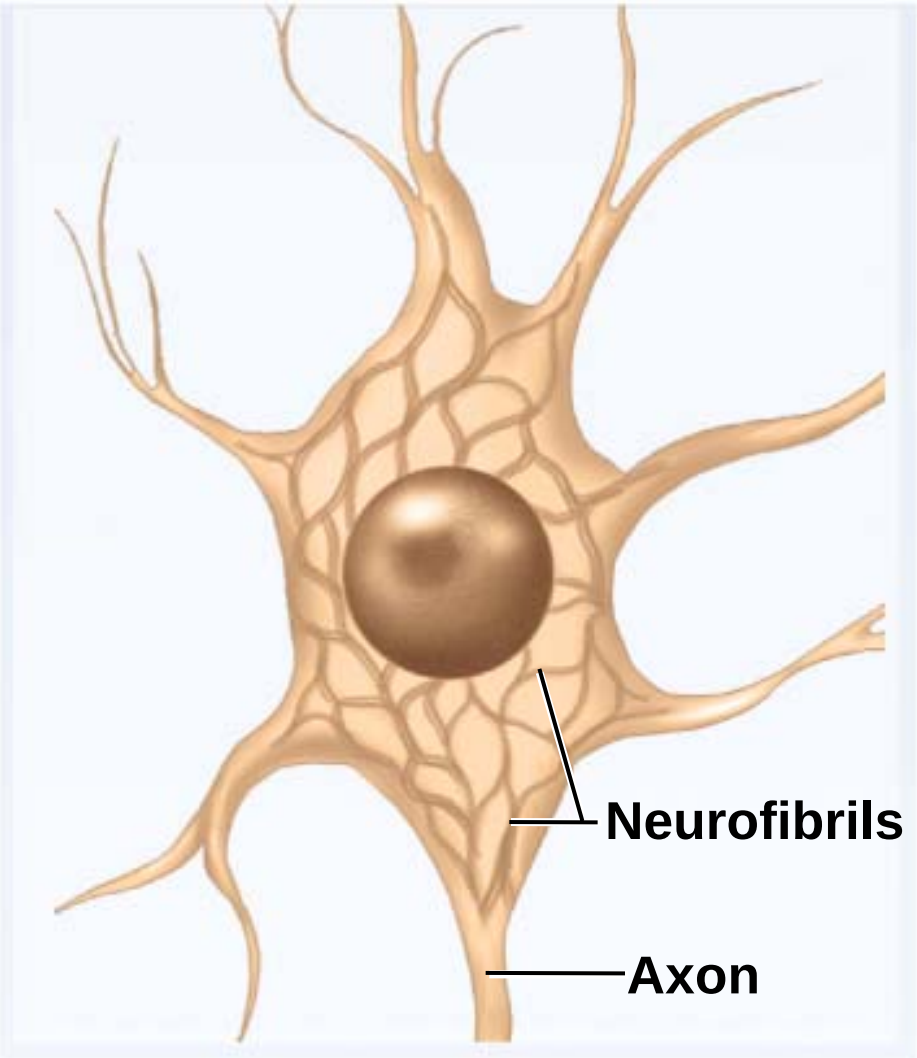
Chapter 12

Nervous Tissue



Nervous Tissue

- overview of the nervous system
- properties of neurons
- supportive cells (neuroglia)
- electrophysiology of neurons
- synapses



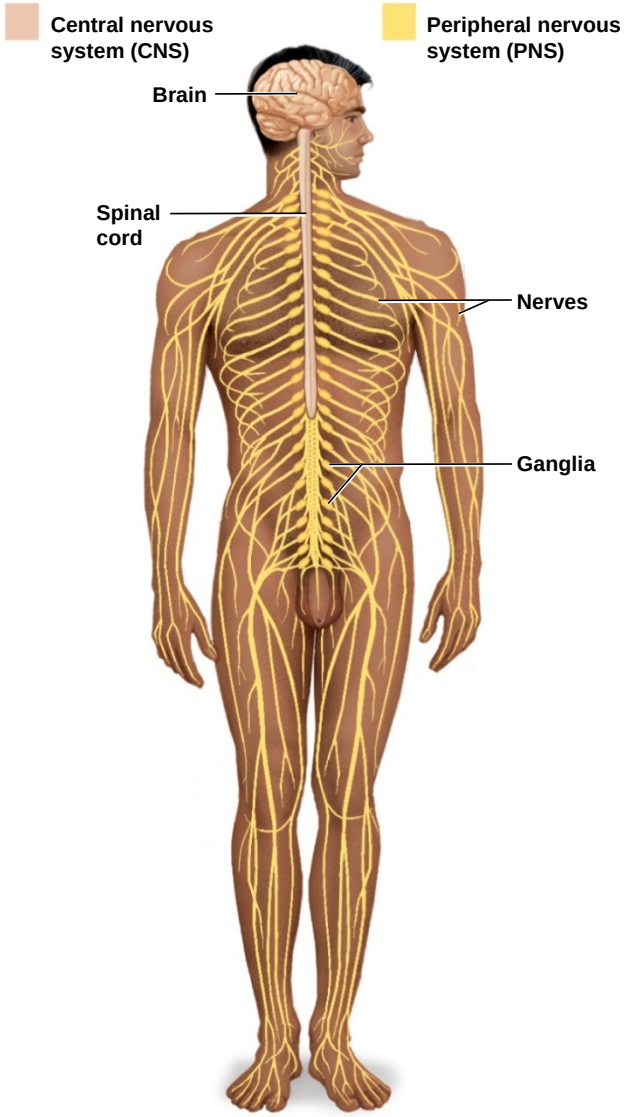
Overview of Nervous System

- **endocrine** and **nervous system** maintain internal coordination
  - **endocrine system** - communicates by means of chemical messengers (**hormones**) secreted into to the blood
  - **nervous system** - employs electrical and chemical means to send messages from cell to cell
    - *nervous system* carries out its task in **three basic steps**:
      - sense organs **receive information** about changes in the body and the external environment, and **transmits coded messages** to the spinal cord and the brain
      - brain and spinal cord **processes this information**, relates it to past experiences, and determine what response is appropriate to the circumstances
      - brain and spinal cord **issue commands** to muscles and gland cells to carry out such a response

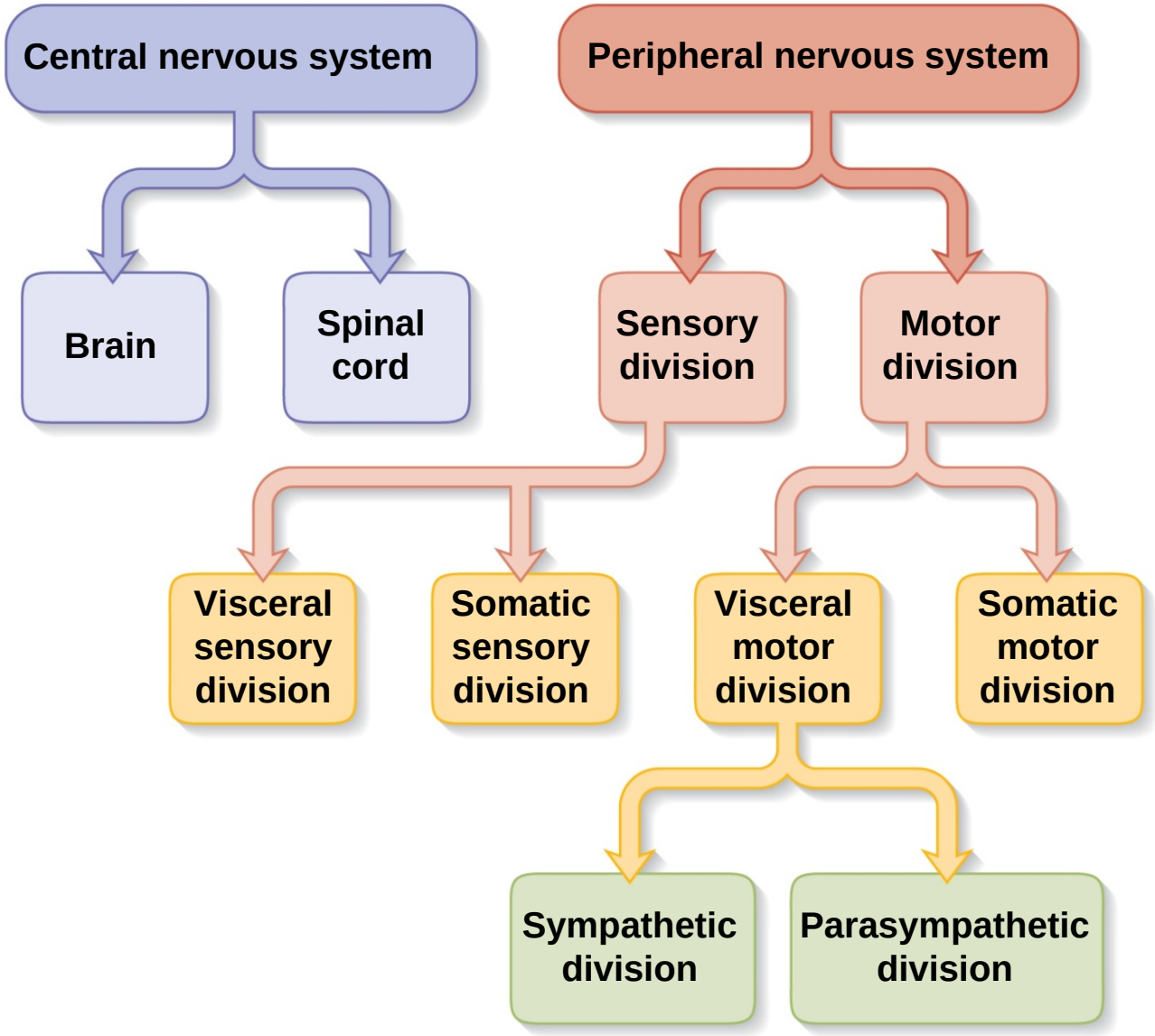
Two Major Anatomical Subdivisions of Nervous System

- **central nervous system** (CNS)
  - brain and spinal cord enclosed in bony coverings
    - enclosed by cranium and vertebral column
- **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** – a knot-like swelling in a nerve where neuron cell bodies are concentrated

Subdivisions of Nervous System



Subdivisions of Nervous System



Sensory Divisions of PNS

- **sensory division (afferent fibers)**
  - carries sensory signals from various receptors to the CNS
  - informs the CNS of stimuli within or around the body
    - somatic sensory division – carries signals from receptors in the skin, muscles, bones, and joints
    - visceral sensory division – carries signals from the viscera of the thoracic and abdominal cavities
      - heart, lungs, stomach, blood vessels, and urinary bladder

Motor Divisions of PNS

- **Motor division (efferent fibers)**
  - carries signals *from the CNS to gland and muscle cells* that carry out the body's response
  - **effectors** – cells and organs that respond to commands from the CNS

- **somatic motor division** – carries signals to skeletal muscles
  - output produces skeletal muscular contraction
  - as well as **somatic reflexes** – involuntary muscle contractions of skeletal muscles

- **visceral motor division** (**autonomic nervous system**)
  - carries signals to glands, cardiac muscle, and smooth muscle
  - involuntary, and responses of this system and its receptors are **visceral reflexes**
    - **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

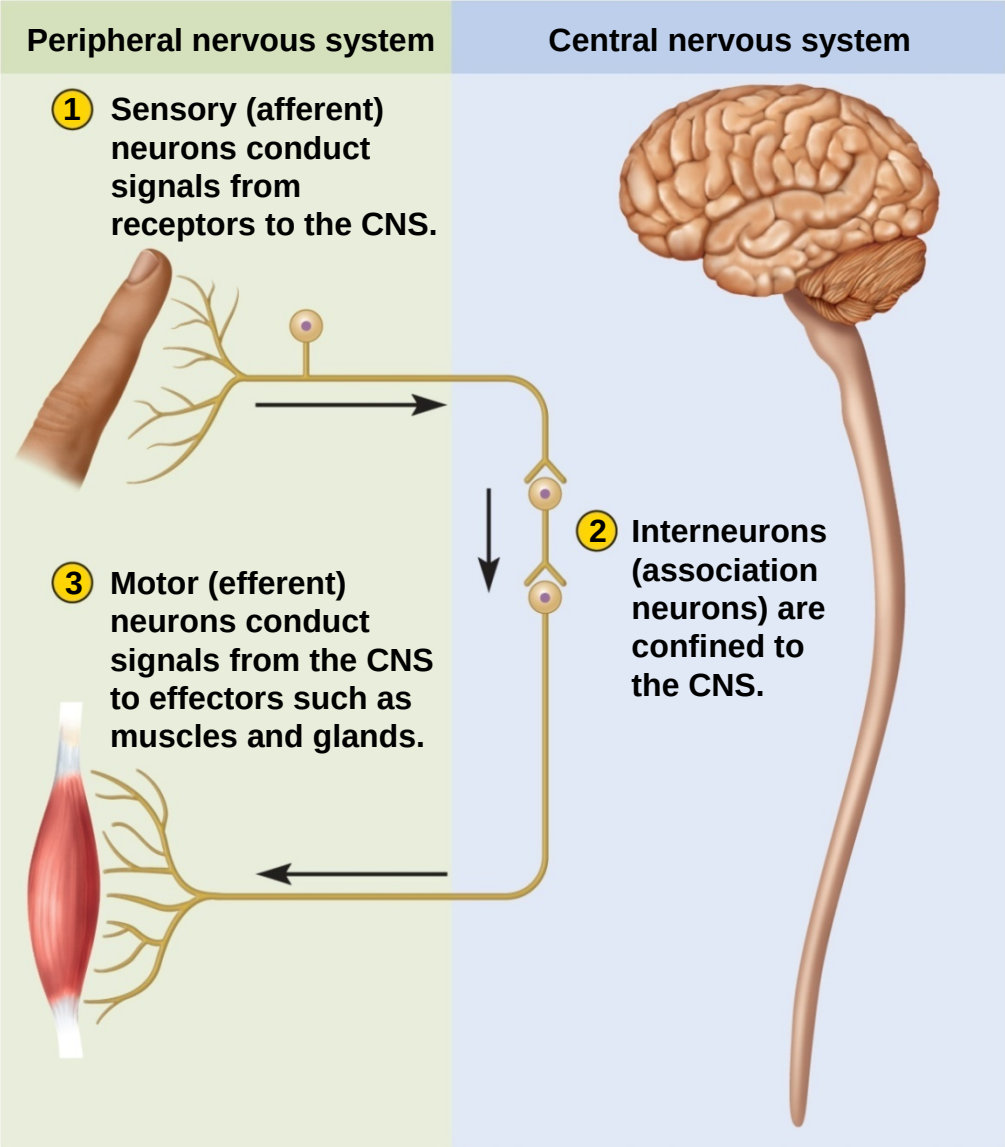
Universal Properties of Neurons

- **excitability (irritability)**
  - respond to environmental changes called stimuli
- **conductivity**
  - neurons respond to stimuli by producing electrical signals that are quickly conducted to other cells at distant locations
- **secretion**
  - when electrical signal reaches end of nerve fiber, a chemical neurotransmitter is secreted that crosses the gap and stimulates the next cell
- Note: electro-chemical communication!

Functional Types of Neurons

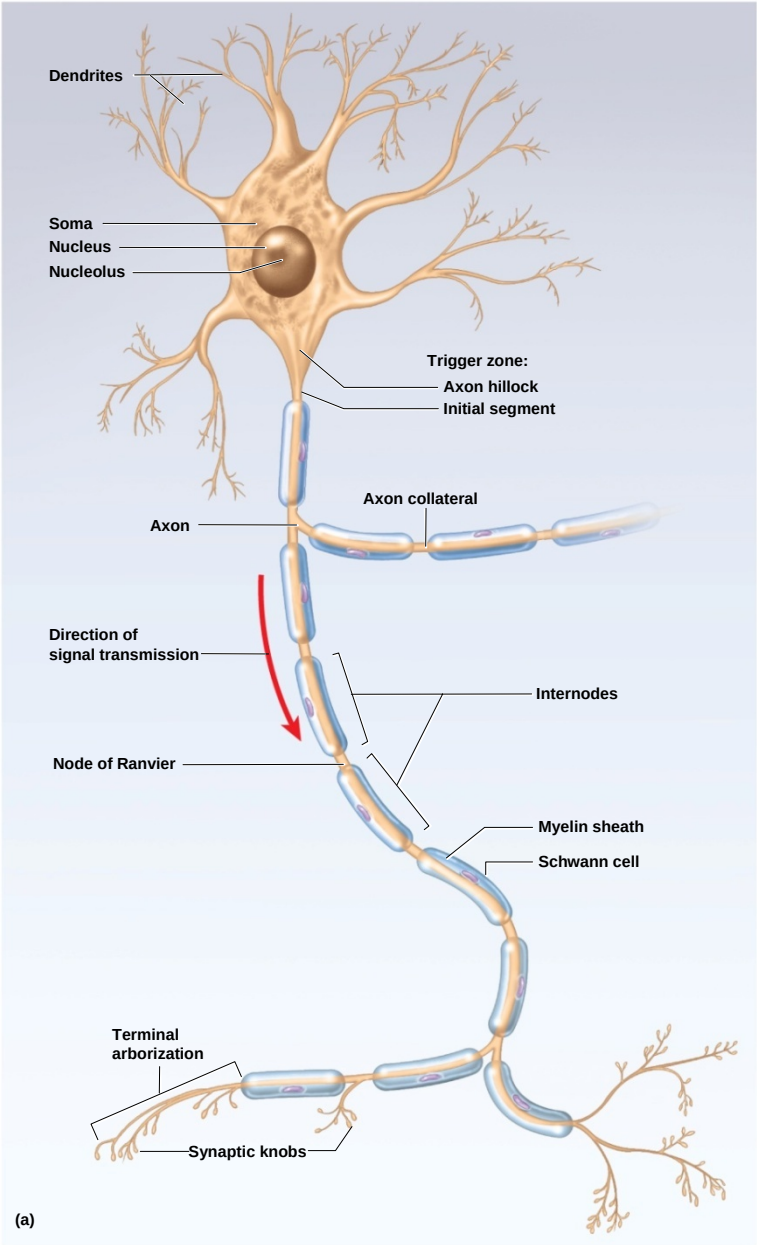
- **sensory (afferent) neurons**
  - specialized to detect stimuli
  - transmit information about them to the CNS
    - begin in almost every organ in the body and end in CNS
    - **afferent** – conducting signals toward CNS
- **interneurons (association) neurons**
  - lie entirely within the CNS
  - 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, and the outgoing motor pathways of the 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 Classes of Neurons



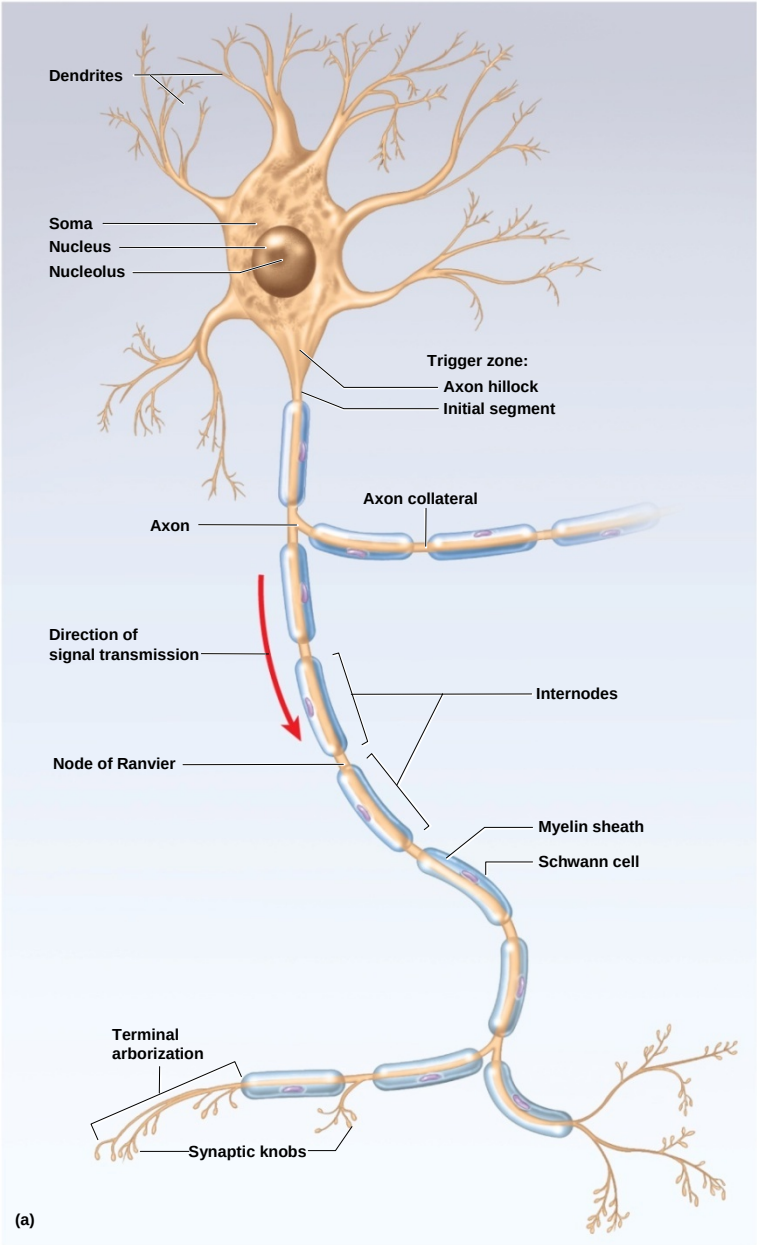
Structure of a Neuron – The Soma

- **soma** – 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
  - 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** – glycogen granules, lipid droplets, melanin, and **lipofuscin** (golden brown pigment produced when lysosomes digest worn-out organelles)
    - lipofuscin accumulates with age
    - wear-and-tear granules
    - most abundant in old neurons



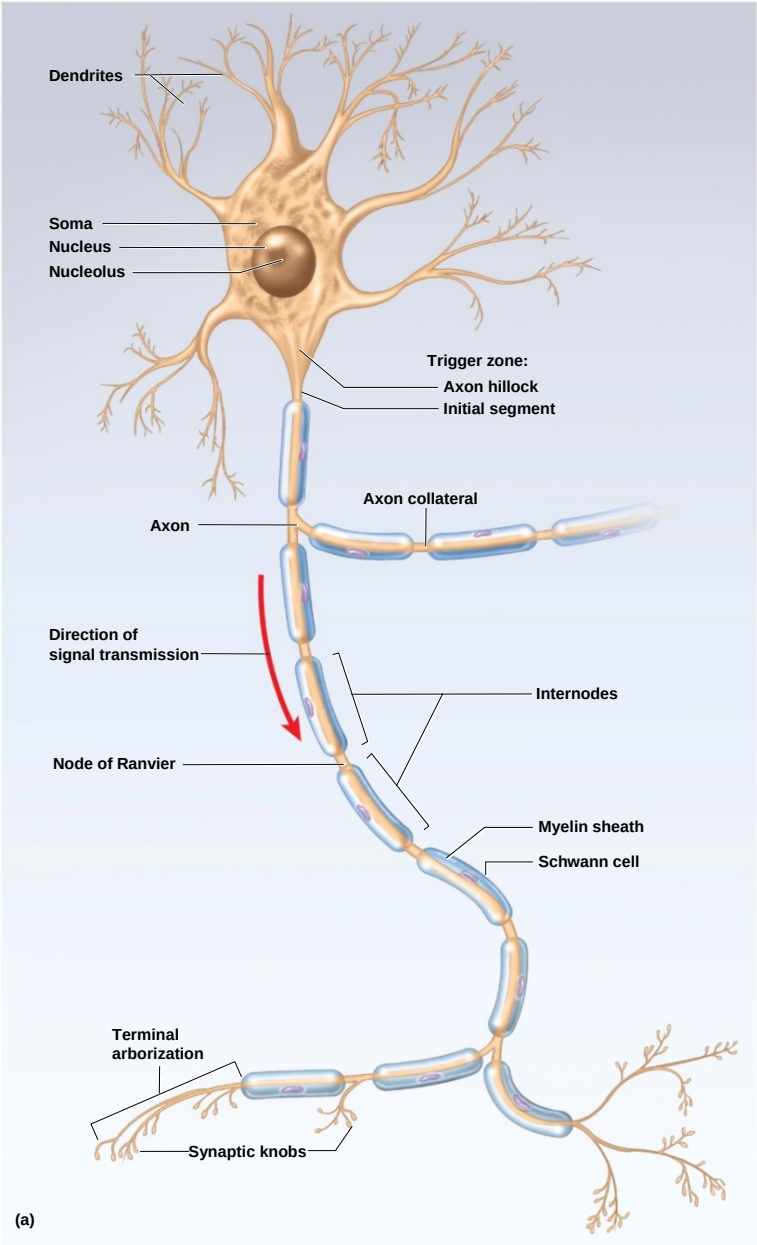
Structure of a Neuron – The Dendrites

- **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 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



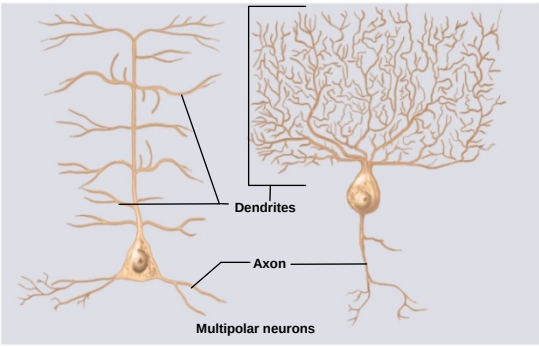
Structure of a Neuron – The Axon

- **axon** (**nerve fiber**) – originates from a mound on one side of the soma called the **axon hillock**
  - cylindrical, relatively unbranched for most of its length
    - **axon collaterals** – branches of axon
  - branch extensively on distal end
  - specialized for rapid conduction of nerve signals to points remote to the soma
  - **axoplasm** – cytoplasm of axon
  - **axolemma** – plasma membrane of axon
  - only **one axon per neuron**
  - **Schwann cells** and **myelin sheath** enclose axon
  - distal end, axon has **terminal arborization** – extensive complex of fine branches
    - **synaptic knob** (terminal button) – little swelling that forms a junction (synapse) with the next cell
    - contains **synaptic vesicles** full of neurotransmitter

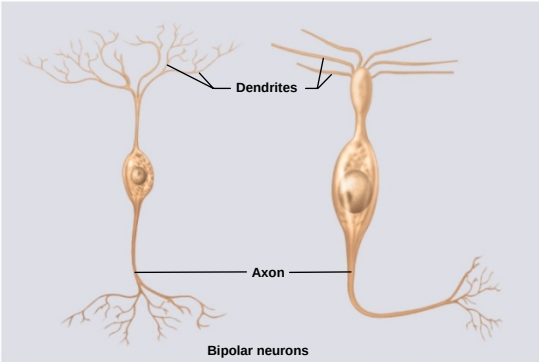


Variation in Neuron Structure

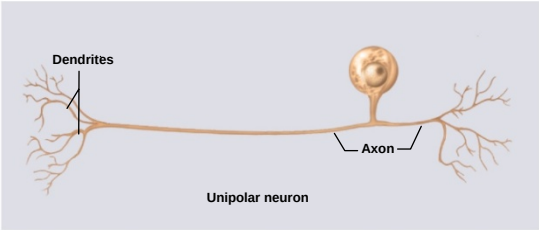
- **multipolar neuron**
  - one axon and multiple dendrites
  - most common
  - most neurons in the brain and spinal cord
- **bipolar neuron**
  - one axon and one dendrite
  - olfactory cells, retina, inner ear
- **unipolar neuron**
  - single process
  - sensory from skin and organs to spinal cord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



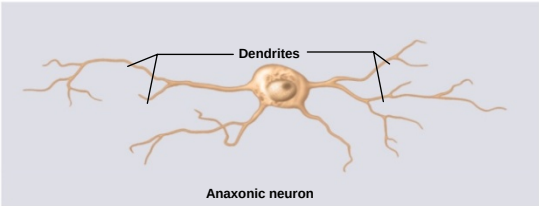
Multipolar neurons



Bipolar neurons



Unipolar neuron



Anaxonic neuron

Axonal Transport

- many proteins made in soma must be transported to axon and axon terminal
  - to repair axolemma, serve as gated ion channel proteins, as enzymes or neurotransmitters
- **axonal transport**
  - 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**
    - <u>for recycled materials and pathogens - rabies, herpes simplex, tetanus, polio viruses</u>
      - 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
  - <u>damaged nerve fibers regenerate at a speed governed by slow axonal transport</u>

Neuroglial Cells

- about **a trillion** (10^{12}) **neurons** in the nervous system (note: approximately 100 trillion in organism!)
- **neuroglia** outnumber the neurons by as much as **50 to 1**
- **neuroglia** or **glial cells**
  - support and protect the neurons
  - bind neurons together and form framework for nervous tissue
  - in fetus, guide migrating neurons to their destination
  - *if mature neuron is not in synaptic contact with another neuron then it is covered by glial cells*
    - prevents neurons from touching each other
    - gives precision to conduction pathways

Six Types of Neuroglial Cells (1 of 3)

- four types occur only in CNS
  - **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

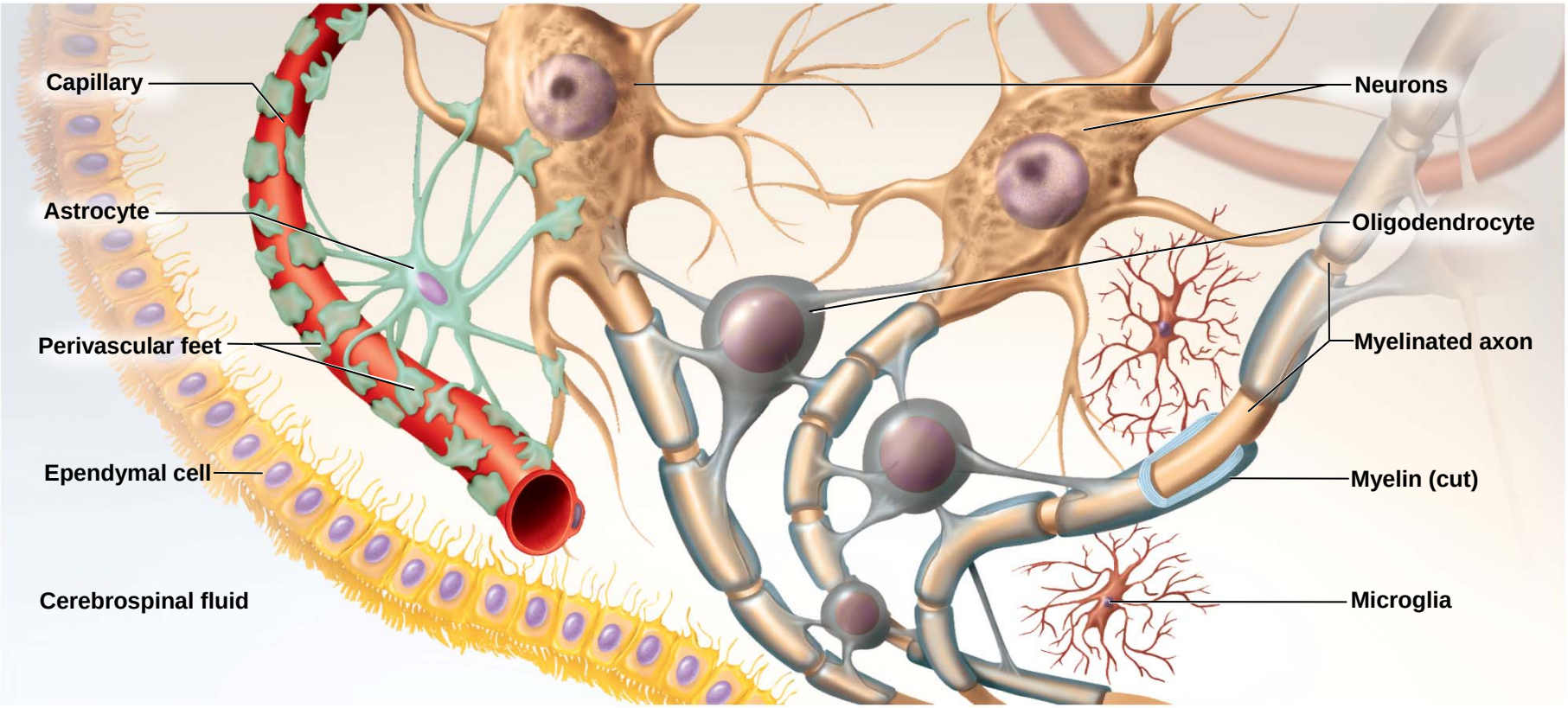
Six Types of Neuroglial Cells (2 of 3)

- **astrocytes**
  - most abundant glial cell in CNS
  - 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**
    - 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
    - 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

Six Types of Neuroglial Cells (3 of 3)

- 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

Neuroglial Cells of CNS



Glial Cells and Brain Tumors

- **tumors** - masses of rapidly dividing cells
  - mature neurons have little or no capacity for mitosis and seldom form tumors
- **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

Myelin

- **myelin sheath**
  - an insulating layer around a nerve fiber
  - formed by **oligodendrocytes in CNS** and **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
    - <u>completed in late adolescence</u>
    - 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

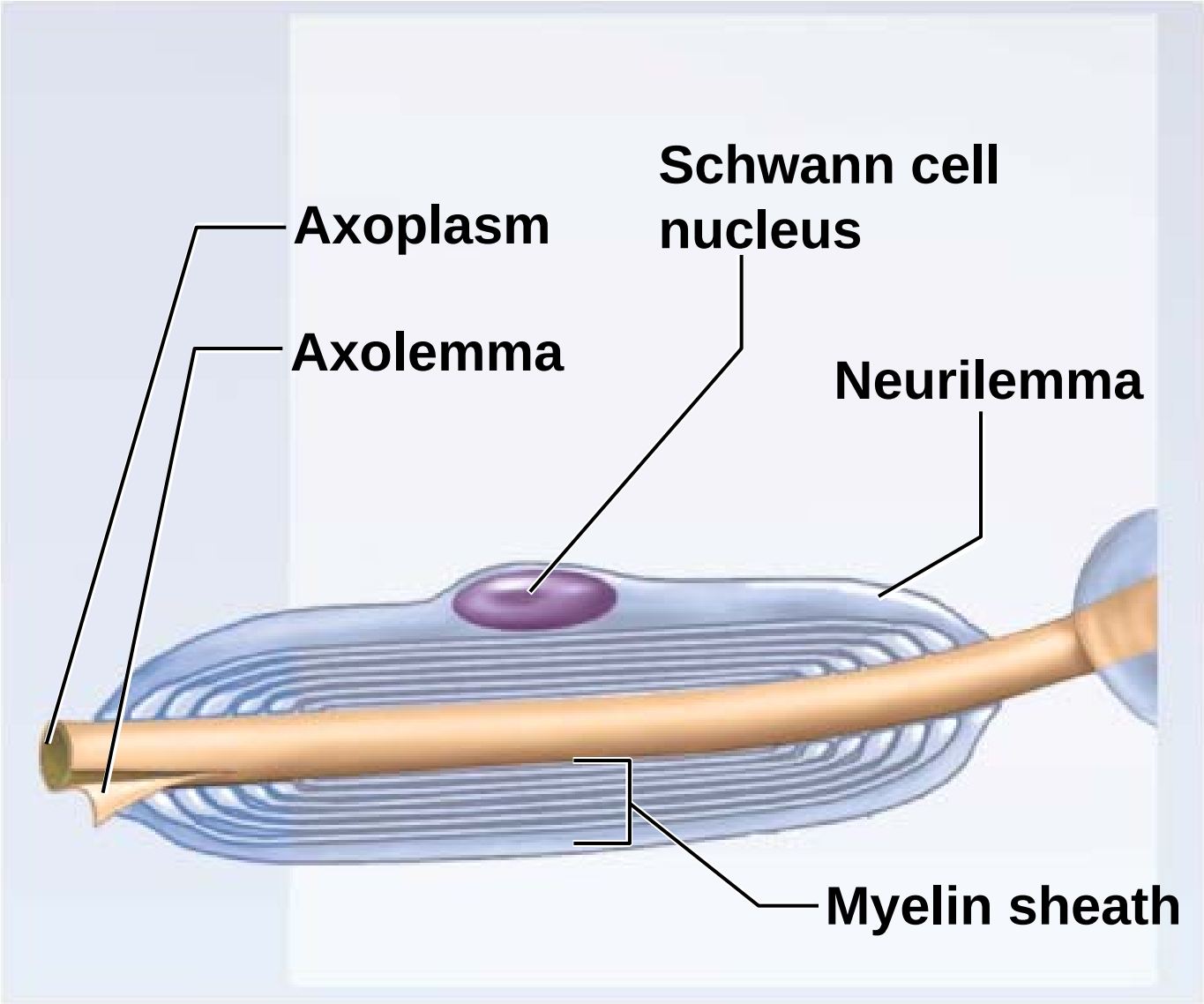
- In CNS
  - **oligodendrocytes** reaches out to myelinate several nerve fibers in its immediate vicinity
  - anchored to multiple nerve fibers
  - cannot migrate around any one of them like Schwann cells
  - must push newer layers of myelin under the older ones
    - so myelination spirals inward toward nerve fiber
  - nerve fibers in CNS have no neurilemma or endoneurium

Myelin

- Many Schwann cells or oligodendrocytes are needed to cover one nerve fiber
  - Schwann cells in PNS
  - Oligodendrocytes in CNS

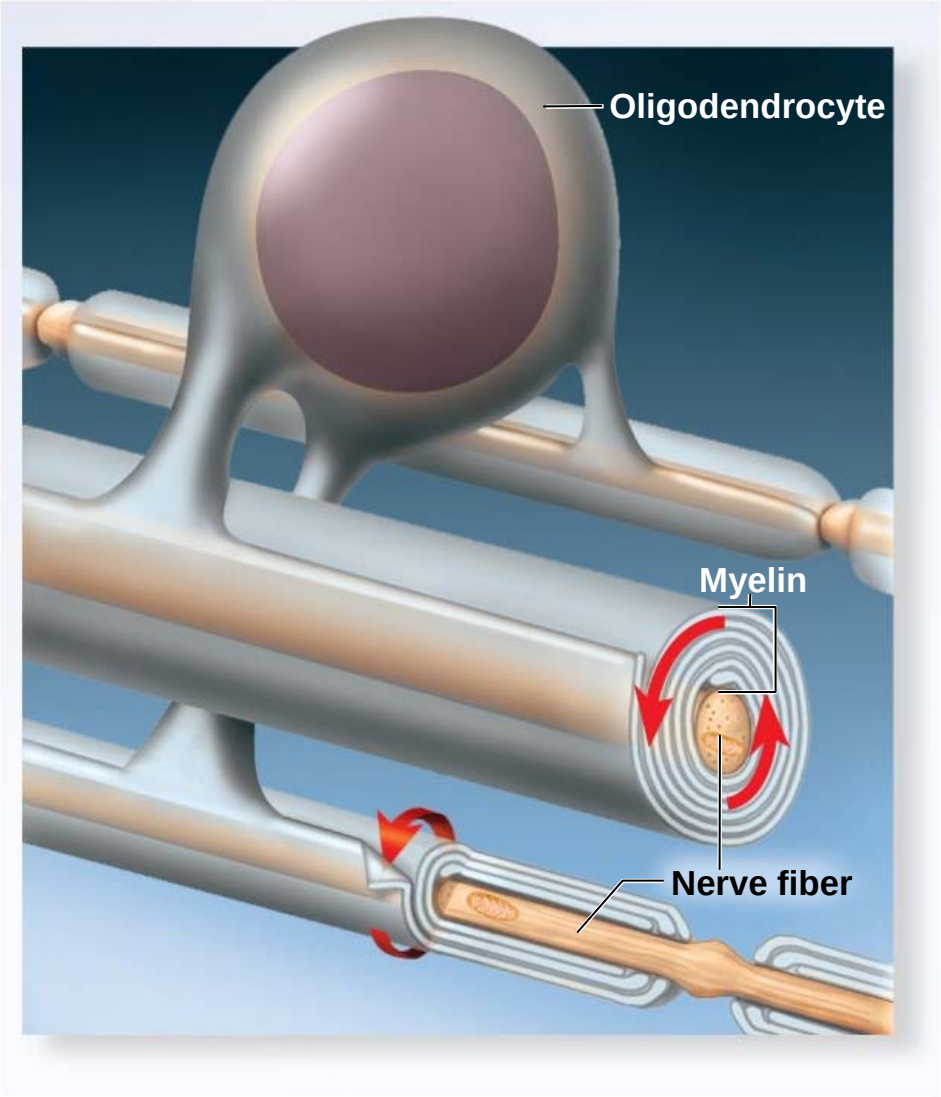
- **myelin sheath** is **segmented**
  - **nodes of Ranvier** – gap between segments
  - **internodes** – myelin covered segments from one gap to the next
  - **initial segment** – short section of nerve fiber between the axon hillock and the first glial cell
  - **trigger zone** – the axon hillock and the initial segment
    - play an important role in initiating a nerve signal

Myelin Sheath in PNS

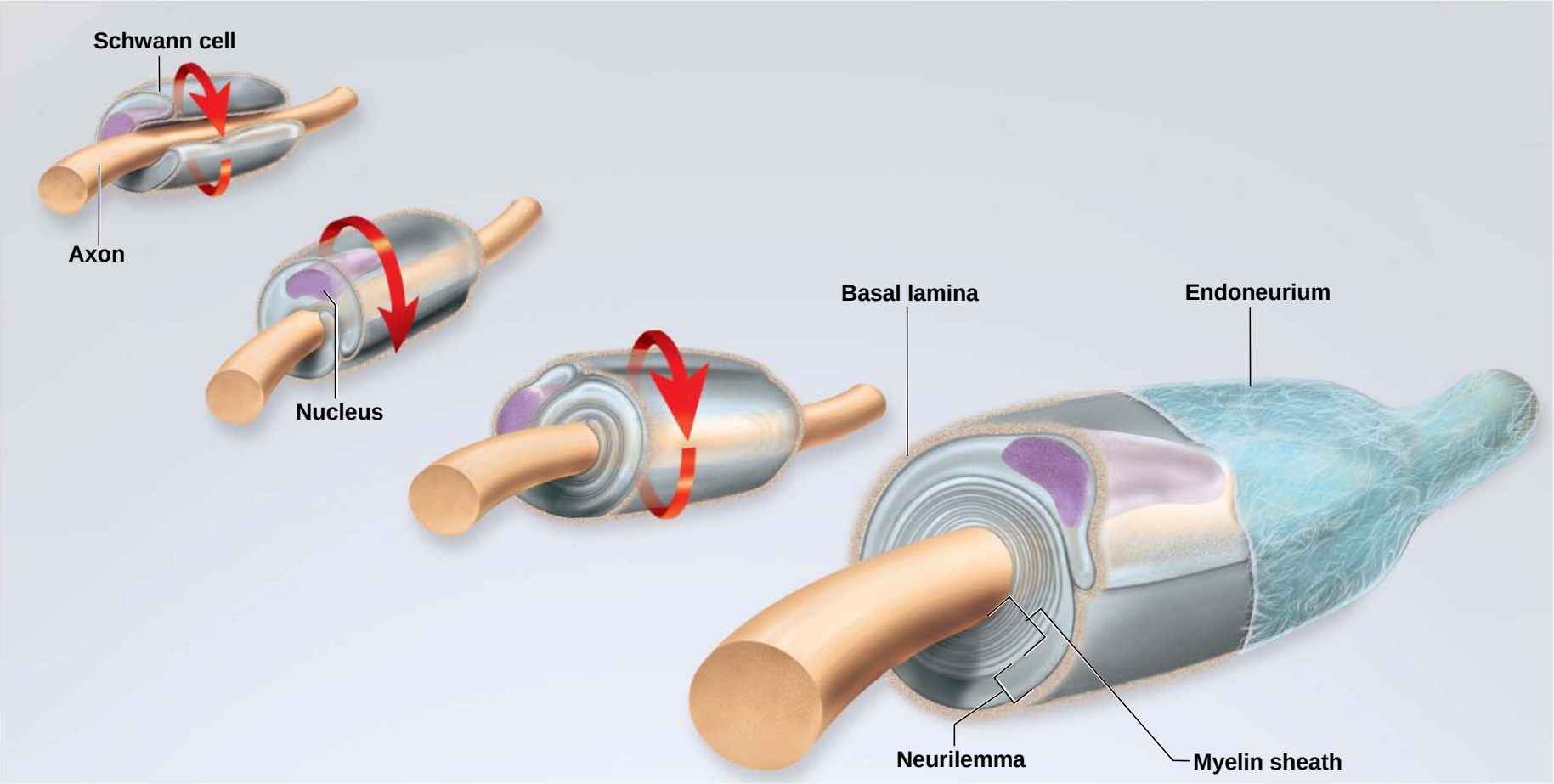


nodes of Ranvier and internodes

Myelination in CNS



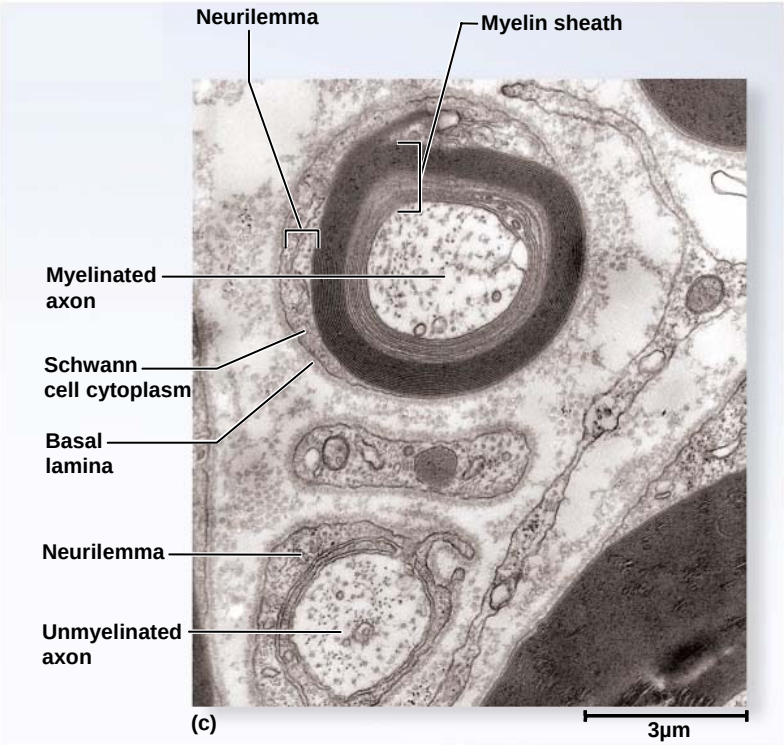
Myelination in PNS

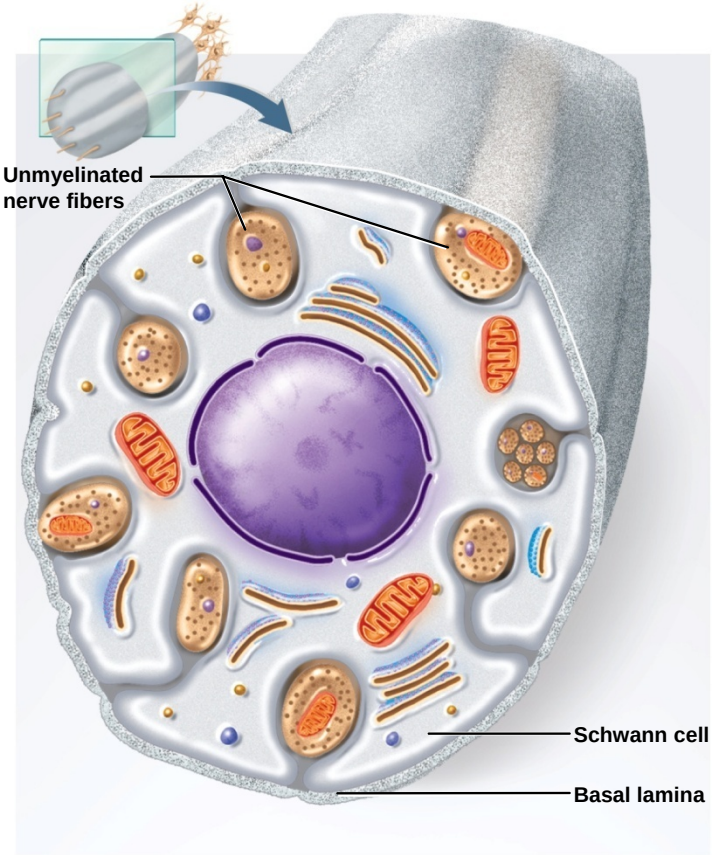


Diseases of Myelin Sheath

- 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 autoimmune triggered by virus
  - **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

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

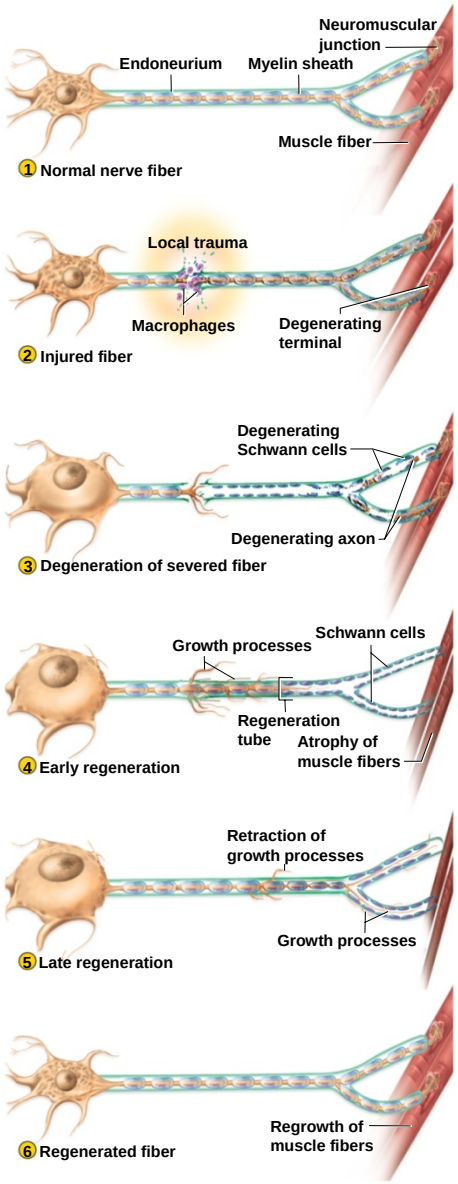
Conduction Speed of Nerve Fibers

- speed at which a nerve signal travels along a nerve fiber depends on two factors
  - **diameter of fiber**
  - **presence or absence of myelin**
- 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
- **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
  - <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 Nerves

- regeneration of a damaged peripheral nerve fiber can occur if:
  - its **soma is intact**
  - at least **some neurilemma remains**
- fiber distal to the injury cannot survive and it degenerates
  - macrophages clean up tissue debris at the point of injury and beyond
- soma swells, ER breaks up, and nucleus moves off center
  - due to loss of nerve growth factor from neuron's target cell
- 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 and reestablishes synaptic contact
- nucleus returns to normal shape
- Note: regeneration of damaged nerve fibers in the **CNS cannot occur at all**

Regeneration of Nerve Fiber



denervation atrophy

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

Electrophysiology of Neurons

- **Galen** thought that the brain pumped a vapor called *psychic pneuma* through hollow nerves and squirted in to the muscles to make them contract
- **Rene' Descartes** in the 17th century supported this theory
- **Luigi Galvani** discovered the role of electricity in muscle contraction in the 18th century
- **Camillo Golgi** developed important method for staining neurons with silver in the 19th century
- **Santiago Ramon y Cajal** set forth the **neuron doctrine** – nervous pathway is not a continuous 'wire' or tube, but a series of cells separated by gaps called synapses.
- neuron doctrine brought up two key questions:
  - how does a neuron generate a electrical signal?
  - how does it transmit a meaningful 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
  - <u>enables growing neurons to make contact with their target cells</u>
- 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