Nervous Systems:
Diversity & Functional Organization

(a) Cnidarian (jellyfish)
(b) Platyhelminth (planarian)
(c) Annelid (earthworm)
(d) Arthropod (crab)
(e) Mollusc (limpet)
(f) Cephalopod mollusc (squid)
(g) Echinoderm (sea star)
(h) Chordate (alligator)
Diversity of Neural Signaling

- The diversity of neuron structure and function allows neurons to play many roles.

- 3 basic function of all neurons:
  - Receive and integrate incoming signals
  - Conduct these signals through the cell
  - Transmit these signals to other cells
No clear correlation between complexity of an organism and complexity of its neurons
• Structure relates to the function of that particular neuron.
Functional Classifications

- Efferent neuron
- Interneuron
- Sensory neuron
Functional Classifications

- **Sensory (afferent) neurons:**
  Convey information from the body to the central nervous system (CNS).

- **Interneurons:**
  Located within the CNS and convey signals from one neuron to another.

- **Efferent Neurons:**
  Convey information from CNS to effector organs (ex. motor neurons).
Structural Classifications

- Multipolar neuron
- Bipolar neuron
- Unipolar neuron
Multipolar Neurons

- Many cellular extensions leading from the cell body:
  - only one is an axon.
  - All others are dendrites.

Most common type of neuron in vertebrates
Bipolar Neurons

- 2 main processes extend from the cell body:
  - One is highly branched and conveys signals to the cell body
  - One conveys signals away from the cell body.

- Least common type of neurons in vertebrates
Unipolar Neurons

- Has one single process away from the cell body which splits into 2 main branches:
  - One branch conveys signals to the cell body
  - One conveys signals away from the cell body.

- More common in invertebrates:
  - Invertebrate motor neurons are often unipolar rather than multipolar.
Polarity in Neurons

- Most neurons share the common property of polarity:
  - one end receives and the other transmits.

- Cnidarians provide exception to this rule: Some cnidarian neurons lack polarity and can send and receive signals at either end.
Giant Axons

- Increase in diameter, increases the conduction velocity of an action potential.

- No particular diameter qualifies an axon as giant.

- A giant axon is of exceptional diameter in comparison to other axons in the same animal.
1. The mantle cavity fills with water.

2. The brain sends a signal to the stellate ganglia, which send signals along axons of different diameters in the mantle.

3. Nerve impulses reach the muscle at many points in the mantle cavity.

4. The muscles of the mantle contract synchronously, rapidly closing the mantle, forcing water out the siphon, producing rapid jet propulsion.
Combining axons of varying diameters allows the giant squid to have near simultaneous contraction of its mantel, due to its ability to speed up transmission to its farthest parts from the CNS.
Nervous Systems

(a) Cnidarian (jellyfish) - Nerve net, Nerve ring
(b) Platyhelminth (planarian) - Brain, Nerve cords
(c) Annelid (earthworm) - Ventral nerve cord, Ganglion
(d) Arthropod (crab) - Brain, Thoracic ganglion

(e) Mollusc (limpet) - Ganglia, Nerve cord
(f) Cephalopod mollusc (squid) - Brain, Ganglion
(g) Echinoderm (sea star) - Radial nerve, Nerve ring, Ganglion
(h) Chordate (alligator) - Dorsal nerve cord (spinal cord), Ganglion

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The Nervous System

- **Homeostatic control system**: helping to regulate physiological processes and coordinate behavior.

- Complex behaviors and physiological control possible through the integration of information and multi-step neural pathways.
Neural Pathways

- Most nervous systems are organized into 3 functional divisions:
  - Afferent sensory division
  - Integrating centers
  - Efferent division
Functional Divisions

- Afferent sensory neurons carry signals from sensory receptors to one or more “Integrating centers”

- Integrating centers typically contain many interneurons – form synaptic connections among neurons.
Functional Divisions

- Integrating centers process information.
- Ultimately send an output signal through efferent neurons to effector organs.
Functional Divisions

Central nervous system

Peripheral nervous system

Sensory receptors (e.g., mechanoreceptors, photoreceptors)

Efferent neuron

Integrating center (e.g., brain, ganglia)

Interneuron

Effectors organs (e.g., muscles, glands)

Incoming stimulus

Output pathways

Sensors

Integrating centers

Output

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Bilateral Symmetry

- Anterior and posterior ends
- Right and left sides

- Sense organs concentrated at anterior end and have complex groupings of nerves = cephalization.

- Typically have one or more ganglia
Bilateral Symmetry

- **Ganglia** = groupings of neuronal cell bodies interconnected by synapses.

- Ganglia function as integrating centers for nervous systems.

- In many species the ganglia in the anterior region are grouped in large clusters forming a **brain**.
Organization

- **Within the Brain:**
  - *Nuclei* = groupings of neuronal cell bodies
  - *Tracts* = groupings of neuronal axons

- **Outside the brain:**
  - Axons of different afferent and efferent neurons are usually organized into *nerves*
Nerve Organization

- Nerve = fascicles + blood vessels + connective tissue
- Most nerves contain both afferent and efferent neurons
Cephalization

- Becomes increasingly apparent in more complex nervous systems.

- Degree varies greatly among species, but most have a well developed brain, several ganglia, and one or more nerve chords.
Octopuses

- Brain much larger relative to its body size than fish or reptiles.
Octopuses

- Each arm has a large ganglion that controls arm movements and can function essentially independently of the brain.

- So integrating center is highly distributed and involves both the brain and ganglion.
Vertebrate Nervous System

- Vertebrates are among the most highly cephalized animals.

- Unique in possessing a hollow dorsal nerve cord not seen in invertebrates which possess a solid ventral nerve cord.
Vertebrate Nervous System

- **Central Nervous System (CNS):**
  - Encased in cartilaginous or bony covering
  - Composed of the brain and spinal cord

- **Peripheral Nervous System (PNS):**
  - Nerves and neurons throughout rest of body
Central Nervous System

- Cranial nerves: exit directly from brain case
- Spinal nerves: emerge from spinal cord at regular intervals
- Spinal nerves are named based on the region where they originate:
  - Cervical spinal nerves
  - Thoracic spinal nerves
  - Lumbar, sacral, & coccygeal nerves
Grey & White Matter

- Brain and spinal cord contain two types of tissue, called gray and white matter:
  - **White matter** = Bundles of axons and associated myelin sheaths
  - **Gray matter** = Neuronal cell bodies and dendrites.
Grey matter of the Spinal Cord

- Butterfly appearance
- “wings” termed dorsal and ventral horns

- Dorsal horns = Afferent sensory neurons terminate
- Ventral horns = Efferent neurons originate
Protecting the CNS

- **Meninges**: One (meninx) or more protective layers of connective tissue surrounding the brain and spinal cord.
Protecting the CNS

- Fish = single meninx

- Amphibians, birds, reptiles = 2 meningies

- Mammals have 3 meningies:
  1. Dura matter
  2. Arachnoid matter
  3. Pia matter
Protecting the CNS

- Skull (cranium)
- Dura mater
- Arachnoid mater
- Pia mater

Cranial meninges

- Dura mater
- Arachnoid mater
- Pia mater

Spinal meninges

- Vertebra
- Spinal cord
Protecting the CNS

- Within the meninges the brain and spinal cord float in a plasma-like fluid called cerebrospinal-fluid (CSF)
  - CSF acts as a shock absorber and cushions delicate tissues.

- CNS is physiologically separated from the rest of the body via the blood-brain barrier (BBB).
Blood-Brain Barrier

• Formed by tight junctions between endothelial cells lining brain capillaries.

• Prevents harmful materials from leaking out of the bloodstream and into the CNS.

• Allows useful molecules (i.e., glucose and amino acids) to enter via protein exchanger channel or pump.
Vertebrate Brain

- 3 main regions:
  - Hindbrain – reflex responses, involuntary behaviors
  - Midbrain – routing or integrating center
  - Forebrain – integration center, learning & memory, complex processing tasks
Brain Size in Vertebrates

- Brain size and structure vary among taxa.
- Much of the variation can be accounted for by body size.
- At a given body size, brain size can differ substantially among taxa.
Brain Size in Vertebrates

- Birds and mammals have unusually large brains for their body size:
  
  6-10x larger than similarly sized reptiles.

- Largely resulting from changes in the relative sizes of different parts of the brain
Bony Fishes & Birds
Mammals
Peripheral Nervous System

- **Afferent neurons** carry information to integrating centers (CNS) to be processed.

- Integrating centers (CNS) send out signals via **efferent pathways**.

- Afferent and efferent neurons make up the **peripheral nervous system (PNS)**.
Efferent Branch

- Autonomic Division
  - Homeostatic regulation
  - “involuntary nervous system”

- Somatic Motor Division
  - Control skeletal muscles
  - “voluntary nervous system”
Autonomic Division

• Sympathetic Nervous System
  ◦ Most active during stress & physical activity
  ◦ “fight-or-flight system”

• Parasympathetic Nervous System
  ◦ Most active during periods of rest
  ◦ “rest & digest system”

• Enteric Branch
  ◦ Digestion:
    • innervates GI tract, pancreas, & gallbladder
Peripheral nervous system

Efferent branch

Afferent (sensory) branch

Autonomic division

Sympathetic

Enteric

Parasympathetic

Motor division
Sympathetic & Parasympathetic

- Act together to maintain homeostasis

- Most internal organs receive input from both systems.
  - Dual innervation allows for regulation

- Effects of systems are usually antagonistic
Structural Differences

- **Sympathetic Pathways:**
  - Originate from thoracic and lumbar regions of spinal column

- **Parasympathetic Pathways:**
  - Originate from hindbrain or sacral region of spinal column
Basal Tone

- Even under resting conditions autonomic neurons of both systems are still producing action potentials = **basal tone**

- Increases or decreases in action potential frequency from this basal tone will have an affect on target organs.
Shared Structural Features: Sympathetic and Parasympathetic

- 2 neurons in series:
  - Cell body of *preganglionic* neurons located in the CNS
  - Preganglionic neurons synapses with *postganglionic* neuron.
  - These 2 neurons synapse within an autonomic ganglia.
Shared Structural Features: Sympathetic and Parasympathetic

- A single preganglionic neuron generally synapses with several postganglionic neurons.

- Postganglionic neurons release neurotransmitters at effector organs.
Structural Differences

- **Parasympathetic Nervous System:**
  - Parasympathetic ganglia located close to effector organ.
  - Long preganglionic neuron & short postganglionic neuron.

- **Sympathetic Nervous System:**
  - Sympathetic ganglia in chain running close to spinal column.
  - Short preganglionic neuron & long postganglionic neuron.
(a) Parasympathetic nervous system

(b) Sympathetic nervous system
Structural Differences

- **Parasympathetic Nervous System:**
  - Preganglionic neuron releases acetylcholine (ACh) to nicotinic ACh receptors
  - Postganglionic neuron releases acetylcholine (ACh) to Muscarinic ACh receptors

- **Sympathetic Nervous System:**
  - Preganglionic neuron releases acetylcholine (ACh) to nicotinic ACh receptors
  - Postganglionic neuron releases norepinephrine (NE) to Beta adrenergic receptors
(a) Parasympathetic nervous system

(b) Sympathetic nervous system

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Structural Differences

- **Parasympathetic nervous system:**
  - Preganglionic neuron forms synapses with 3 or fewer postganglionic neurons.
    - localized effects

- **Sympathetic nervous system:**
  - Preganglionic neuron forms synapses with 10+ postganglionic neurons.
    - widespread effects
Somatic Motor Pathways

- Control skeletal muscles and are usually under conscious control.

- “voluntary nervous system”

- Exception = reflex responses/arcs
  - Rapid involuntary movements in response to a stimulus.
Characteristics of Efferent Motor Pathways

- Efferent motor neurons **only** control skeletal muscle.

- Cell bodies of motor neurons located within CNS in vertebrates, never outside

- Only a single synapse between the CNS and effector organ.
Characteristics of Efferent Motor Pathways

- At neuromuscular junction, a motor neuron splits into a cluster of axon terminals over the motor end plate.

- Synaptic cleft much narrower:
  - Neurotransmitters diffuse more rapidly
Characteristics of Efferent Motor Pathways

- All vertebrae motor neurons release acetylcholine.

- The effect of acetylcholine on skeletal muscle is always excitatory.
  - as opposed to the effect of ACh in the autonomic neurons which may be excitatory or inhibitory