General Design of Nervous System:

**Analogy = Computer**

**Input =** Sensory System
- Receptors:
  - Tactile
  - Visual
  - Auditor
  - Olfactory

**Processing =** Integrative System
- 99% of sensory information discarded
- Synapses determine pathway of signals
- Information stored for future use

**Output =** Motor System
- Effectors:
  - Skeletal muscle
  - Smooth muscle
  - Glandular secretion

**Memory:**
- Highly facilitated synaptic pathways (sensory input not required to excite pathway)
Organization of Nervous System:

Nervous system

Central nervous system (CNS) → Brain → Spinal cord → Peripheral nervous system (PNS)

Motor output → Motor division (efferent) → Sensory division (afferent) → Sensory input

Autonomic nervous system (involuntary; smooth & cardiac muscle)

Somatic nervous system (voluntary; skeletal muscle)

Sympathetic division → Parasympathetic division

Histology of Nervous System:

A. Neuroglia (supporting cells – “nerve glue”)

Central Nervous System (CNS)

Astrocytes:
- anchor neurons to capillaries
- repair damaged neural tissue
- maintain “blood / brain barrier”

Microglia:
- macrophages; engulf invaders

Ependymal cells:
- line canals / ventricles of brain
- produce cerebrospinal fluid (CSF)

Peripheral Nervous System (PNS)

Schwann cells:
- Insulate neurons (myelin sheath)

Satellite cells:
- Function similar to astrocytes

Oligodendrocytes:
- Insulate neurons (myelin sheath)
Histology of Nervous System:

B. Neurons

- Specialized “excitable” cells
- Allow for communication throughout body (via electrical impulses)

Neuron Anatomy:

1) Dendrites: Receive information (environment / other neurons)
2) Cell body (soma): Integrates information / initiate response
3) Axon: Conducts action potential (AP – electrical impulse)
4) Synaptic terminals: Transmit signal (other neurons / effector organs)

Functional Classification of Neurons:

1) Sensory (Afferent) neurons:
   - Carry information from sensory receptors to CNS
2) Motor (Efferent) neurons:
   - Carry information from CNS to effector organs
3) Association neurons (Interneurons):
   - Interconnects neurons in brain / spinal cord
Histology of Nervous System:

B. Neurons

- Specialized “excitable” cells
- Allow for communication throughout body (via electrical impulses)

Structural Classification of Neurons (# of processes):

- **Multipolar** (≥ 3 processes)
  - Motor neurons
  - Interneurons

- **Bipolar** (2 processes)
  - Sensory neurons (e.g., special sense organs)

- **Unipolar** (1 process)
  - Sensory neurons (PNS)

Central Nervous System
Organization of Nervous System:

Nervous system

Integration

Central nervous system (CNS)

Peripheral nervous system (PNS)

Motor output

Sensory input

Motor division (efferent)

Sensory division (afferent)

Autonomic nervous system (involuntary; smooth & cardiac muscle)

Somatic nervous system (voluntary; skeletal muscle)

Sympathetic division

Parasympathetic division

Brain:

• ~ 3.5 lbs (35 billion neurons)
• ♂ brain ~ 10% larger than ♀ brain

Gross Anatomy:

Cerebrum (forebrain)

Diencephalon (midbrain)

Brainstem (hindbrain)

Cerebellum

No correlation exists between brain size and intelligence…
Embryonic Development of Brain:

**Step 1:**
Neural plate forms from surface ectoderm

**Step 2:**
Neural plate invaginates; forms neural groove
- Neural folds flank neural groove

**Step 3:**
Neural fold cells migrate; form neural crest
- Neural crest gives rise to PNS

**Step 4:**
Neural groove becomes neural tube; sinks deep
- Neural tube gives rise to CNS

---

Embryonic Development of Brain:

How we will consider brain anatomy

<table>
<thead>
<tr>
<th>Neural tube</th>
<th>Primary brain vesicles</th>
<th>Secondary brain vesicles</th>
<th>Adult brain structures</th>
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</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>Proencephalon (forebrain)</td>
<td>Telencephalon (endbrain)</td>
<td>Cerebrum</td>
</tr>
<tr>
<td></td>
<td>Mesencephalon (midbrain)</td>
<td>Diencephalon (interbrain)</td>
<td>Diencephalon</td>
</tr>
<tr>
<td>Posterior</td>
<td>Rhombencephalon (hindbrain)</td>
<td>Mesencephalon (midbrain)</td>
<td>Brain stem (midbrain)</td>
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<td>Metencephalon (afterbrain)</td>
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<td>Myelencephalon (spinalbrain)</td>
<td>Cerebellum</td>
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<tr>
<td></td>
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<td></td>
<td>Brain stem (medulla)</td>
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<td></td>
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<td>Spinal cord</td>
</tr>
</tbody>
</table>
Embryonic Development of Brain:

- **5 week old embryo**
  - Flexures develop to fit rapidly growing brain into membranous skull

- **13 week old embryo**
  - Cerebrum forced to grow posterior and lateral ('horseshoe')

- **26 week old embryo**
  - Convolutions develop to increase surface area of brain

Newborn

Basic Layout of Neurons:

**White matter**: Regions of myelinated axons in CNS

**Gray matter**: Regions of unmyelinated axons / cell bodies in CNS

Spinal cord

- Basic pattern observed in CNS

Cerebrum

- Cortex formed by migration of neurons
- Cerebellum similar to cerebrum in its external cortex
Brain Anatomy:

A. **Ventricles**: Hollow chambers enclosed within brain (continuous with each other…)

**Cerebrospinal fluid (CSF)**
- Provide constant, controlled environment for brain cells
- Protect brain from toxins
- Prevent escape of local neurotransmitters

**Choroid plexus**: Vascular network; produces CSF
- Similar ion composition to blood plasma
- ↓ protein content
- Gasses cross freely
- 0.5 L / day produced

Ventricles lined with *ependymal cells* (circulate CSF)

CSF Circulation:

1) CSF produced by choroid plexus in ventricles
2) CSF flows through ventricles and into subarachnoid space via lateral and median apertures
3) CSF exits subarachnoid space via arachnoid vili

Presence of CSF in subarachnoid space gives buoyancy to brain (97% weight reduction)

- Lumbar puncture (spinal tap)
- Hydrocephalus (‘water on the brain’)
Brain Anatomy:

B. **Cerebrum** (cerebral hemispheres):

- Central sulcus
- Parietal lobe
- Parieto-occipital sulcus
- Occipital lobe
- Temporal lobe
- Lateral sulcus
- Insula

~ 85% of brain mass
Brain Anatomy:

B. **Cerebrum (cerebral hemispheres):**

1) **Cerebral cortex** (gray matter)

2) **Cerebral white matter**

3) **Basal nuclei**

---

**Corpus callosum:**
White tract connecting cerebral hemispheres

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**Cerebrospinal Fluid (CSF):**

- **Ependymal cells**
- **Virchow-Robin spaces**
- **Cerebrospinal fluid (CSF)**
- **Leptomeninges**
- **Dura mater**
- **Arachnoid mater**
- **Pia mater**

---

**Neural cartography:**

- **Functional MRI scan** (measure blood flow)
- **Neural cartography** (electrostimulation)

---

**The cerebral cortex is the seat of conscious behavior**

- Only 2 - 4 mm thick but comprises 40% of the brain’s mass
- 2.5 ft² of surface area
Brain Anatomy:
B. Cerebrum (cerebral hemispheres):
1) Cerebral cortex:
   • Motor areas:

Somatotopic mapping:
The entire body is spatially represented in the cerebral cortex

Homunculus ("little man"):

Note:
One-to-one correspondence between cortical neurons and muscles misleading; map really "fuzzy"
Brain Anatomy:
B. Cerebrum (cerebral hemispheres):
1) Cerebral cortex:
   • Motor areas:
     Frontal eye field
     Controls voluntary movement of eyes
     Premotor cortex
     Controls learned motor skills of repetitious or patterned nature (e.g., typing)
     Broca’s area
     Controls muscles involved in speech production (often more pronounced in one hemisphere of brain)

Brain Anatomy:
B. Cerebrum (cerebral hemispheres):
1) Cerebral cortex:
   • Sensory areas:
     Primary somatosensory cortex
     Receives information from sensory receptors in skin & proprioceptors in joints
     Spatial discrimination
     Somatosensory association cortex
     Integrates / interprets somatosensory inputs (e.g., temp., pressure)
     Primary visual cortex
     Receives visual information (retinotopic mapping)
     Visual association area
     Integrates / interprets visual inputs (e.g., color, form)
     Primary auditory cortex
     Receives auditory information (tonotopic mapping)
     Gustatory cortex
     Receives / interprets sensations of taste
     Auditory Association area
     Integrates / interprets auditory inputs (e.g., music, thunder)
     Olfactory cortex
     Receives olfactory information
     Part of rhinencephalon (‘nose brain’)

Brain Anatomy:

B. Cerebrum (cerebral hemispheres):

1) Cerebral cortex:
   - Association areas (multimodal):
     - Anterior association area
       - (Prefrontal cortex)
       - Intelligence
       - Complex learning
       - Recall
       - Personality

Locations where sensations, thoughts, and emotions become conscious
(makes us who we are…)

Central Nervous System

Phineus Gage (1823 – 1860)

Phrenology:
The brain is the organ of the mind; contains localized, specific modules

Franz Gall
(1758 – 1828)

The American Crowbar Case

Introduction
Brain Anatomy:

B. Cerebrum (cerebral hemispheres):

1) Cerebral cortex:
   - Association areas (multimodal):
     - Anterior association area
     - Posterior association area
     - Limbic association area

   Processes emotions related to personal/social interactions

   - Location where sensations, thoughts, and emotions become conscious
     (makes us who we are...)

   - Pattern recognition
   - Spatial recognition
   - Sensory grouping
   - Language centers (Wernicke’s area)

B. Cerebrum (cerebral hemispheres):

1) Cerebral cortex:
   - Contains 3 types of functional areas
   - Contralateral control (e.g., left hemisphere controls right body)
     Decussation:
     Location where neural pathways cross
     - Occur at different locations in CNS

   - Lateralization (i.e., hemisphere specialization)

The cerebral cortex is the seat of conscious behavior
Only 2 - 4 mm thick but comprises 40% of the brain’s mass
2.5 ft² of surface area

Central Nervous System
Brain Anatomy:

B. Cerebrum (cerebral hemispheres):

- **Basic regions:** (superficial to deep)
  1. Cerebral cortex (gray matter)
  2. Cerebral white matter
  3. Basal nuclei
Brain Anatomy:
B. Cerebrum (cerebral hemispheres):
2) Cerebral white matter:

Fiber tracts responsible for communication between cerebral areas and lower CNS

A) Commissural Fibers (form commissures):
• Interconnect cerebral hemispheres

B) Association Fibers:
• Interconnect areas of neural cortex within a single hemisphere

C) Projection Fibers:
• Interconnect cerebral hemispheres with other regions of the brain

Marieb & Hoehn – Figure 12.10

Brain Anatomy:
B. Cerebrum (cerebral hemispheres):

Basic regions:
(superficial to deep)
1) Cerebral cortex (gray matter)
2) Cerebral white matter
3) Basal nuclei
Brain Anatomy:
B. Cerebrum (cerebral hemispheres):
3) Basal nuclei:
   • Composed of gray matter (neuron cell bodies)
   • Function: 1) Subconscious control of skeletal muscle tone
               2) Control stereotypical motor movements (e.g., arm swing)
               • Regulate intensity / inhibit unnecessary movements
Brain Anatomy:

C. Diencephalon:

**Thalamus:**
- Composes 80% of diencephalon
- Relay station for all information entering / exiting the cerebral cortex

**Hypothalamus:**
- Autonomic control center
- Center for emotional response
- Body temperature regulation
- Regulation of food / water intake
- Regulation of sleep-wake cycles
- Control of endocrine system

**Epithalamus:**
- Houses pineal gland (melatonin) and choroid plexus (forms CSF)

------

Brain Anatomy:

**Limbic system (functional brain system):**

- Control emotional states (e.g., fear) / behavioral drives (e.g., sex drive)
- Link conscious (cerebral cortex) with unconscious function (brain stem)
  - Psychosomatic illnesses = emotion-induced illness
- Long-term memory storage / retrieval

**“Emotional brain”**

**Diencephalon structures:**
- Thalamus (anterior thalamic nuclei)
- Hypothalamus

**Cerebral cortex structures:**
- Cingulate gyrus
- Parahippocampal gyrus
- Hippocampus
- Amygdala

- Alzheimer’s Disease:
  Progressive degenerative disease of the brain
  - Memory loss
  - Disorientation
  - Moodiness / confusion
Brain Anatomy:

D. Brain stem:

- Deep gray matter; superficial white matter
- Produce rigidly programmed, autonomic behaviors necessary for survival
- Conduction pathways between higher and lower brain centers

  Midbrain:
  - Visual / auditory reflex centers

  Pons:
  - Regulate respiration rate / depth

  Medulla oblongata:
  - Location where fiber tracts from spinal cord cross over (decussation)
  - Autonomic reflex center
    - Heart rate / blood pressure
    - Respiratory rhythm
    - Vomiting / hiccupping / etc.
• Maintains cerebral cortical alertness (e.g., on / off switch)
• Filters out repetitive stimuli (~ 99% of stimuli filtered…)

Twisting of brain stem can lead to irreversible coma

Reticular Activating System (RAS - functional brain system):
- Raphe nuclei (midline)
- Medial (large cell) group
- Lateral (small cell) group

Aggregation of loosely clustered neurons:
Brain Anatomy:

E. Cerebellum:
- Gray matter superficial; white matter deep
- Precise timing of muscle coordination (balance, posture, repeated movements)
- All activity subconscious

Cerebellar Processing:
- Cerebral cortex sends signal to move
- Sensory information from body
- Maintain body coordination
- Commands to motor neurons of spinal cord

Protection of the Brain:

1) Bone (Skull – cranium portion)
2) Meninges (specialized connective tissue membranes)

A) Dura mater (“tough mother”)
   - Fibrous outer coating (2 layers)
   - Protects CNS
B) Arachnoid mater (“spider mother”)
   - Delicate middle layer
   - Nourishes CNS
C) Pia mater (“gentle mother”)
   - Thin inner membrane
   - Contains blood vessels

Meningitis: Inflammation of the meninges
Protection of the Brain:
1) **Bone** (Skull – cranium portion)
2) **Meninges** (specialized connective tissue membranes)
3) **Blood-brain barrier**: Astrocyte-maintained barrier lining blood capillaries

Three layers of protection:
A. Capillary endothelium
B. Thick basal lamina
C. Bulbous ‘feet’ of astrocytes
  • Signal tight junction formation

Tightly regulate substances bathing brain:
- **In**: glucose, amino acids, selected electrolytes
- **Out**: metabolic waste (urea), proteins, toxins, drugs
  • Displays differentially permeable (e.g., vomit center → brain stem)

---

Homeostatic Imbalances of the Brain:
1) **Traumatic brain injury**
   - Concussion: Alteration in brain function following blow to head
   - Subdural hemorrhage: Bleeding into subarachnoid space via ruptured vessels
   - Cerebral edema: Swelling of the brain

2) **Cerebrovascular accident**
3) **Degenerative brain disorders**
   - Alzheimer’s disease
   - Parkinson’s disease
   - Huntington’s disease

---

Central Nervous System

**Leading cause of accidental death in North America**

**Ischemic stroke**
Blockage of blood supply to brain due to blood clot
- May be transient

---

Marieb & Hoehn – Figure 11.3
Organization of Nervous System:

- **Central nervous system (CNS)**: Includes the brain and spinal cord.
- **Peripheral nervous system (PNS)**: Composed of sensory and motor nerves.
  - **Motor division (efferent)**: Transmits motor signals from the CNS to the periphery.
  - **Sensory division (afferent)**: Transmits sensory signals from the periphery to the CNS.

Afferent (sensory division) inputs include:
- **Autonomic nervous system**: (involuntary; smooth & cardiac muscle)
- **Somatic nervous system**: (voluntary; skeletal muscle)

Efferent (motor division) outputs include:
- **Sympathetic division**
- **Parasympathetic division**

Spinal Cord:
- Provides conduction pathway to / from brain
- Contains major reflex centers
- Independently initiates patterns of motor activity (e.g., walking)

Gross Anatomy:
- ~ 18 inches long (via vertebral foramen)
- Two enlargements (cervical / lumbar)
  - Innervation of limbs
- Cord proper ends at L₁
  - **Cauda equina** ("horse’s tail")
- Spinal nerves (31 pairs)

Protected by vertebral column / meninges
Spinal Cord:
Cross-sectional Anatomy:

**Characteristics:**
1) Decussation present
2) Multi-neuron pathways
3) Somatotopy exhibited
4) Symmetrical arrangement

**Ascending tracts:**
Carry information to brain

**Descending tracts:**
Carry information from brain

**Transverse tracts:**
Carry information across cord
Cross-sectional Anatomy:

- **Central canal**
- **Posterior median sulcus**
- **Posterior horn (interneurons)**
- **Lateral horn (visceral motor neurons)**
- **Anterior horn (somatic motor neurons)**
- **White matter**
- **Gray matter**
- **Gray commissure**
- **Posterior funiculus**
- **Lateral funiculus**
- **Anterior funiculus**
- **Anterior median fissure**

Cross-sectional Anatomy:

- **Dorsal Root**
- **Dorsal root ganglion**
- **Sensory neuron**
- **Interneuron**
- **Motor neuron**
- **Spinal nerve**
- **Ventral Root**
Spinal Cord:
Organization of Gray Matter:

Homeostatic Imbalances of the Spinal Cord:
1) **Spinal cord trauma**

- **Paralysis / Paresthesias**
  Damage to spinal cord leading to functional / sensory loss

- **Paraplegia**
  Transection of spinal cord between T₁ and L₁

- **Quadriplegia**
  Transection of spinal cord between C₄ and C₇

2) **Poliomyelitis**

- Destruction of ventral horn motor neurons by poliovirus

3) **Amyotrophic lateral sclerosis (ALS)**

- Progressive destruction of ventral horn motor neurons (autoimmune?)

- Lou Gehrig's disease