Nervous System Structure and Function
Basic Functional Neuroanatomy

Functional Areas of the Cerebral Cortex

1. Visual Area:
   - Sight
   - Image recognition
   - Image perception

2. Association Area:
   - Short-term memory
   - Equilibrium
   - Emotion

3. Motor Function Area:
   - Initiation of voluntary muscles

4. Broca's Area:
   - Muscles of speech

5. Auditory Area:
   - Hearing

6. Emotional Area:
   - Pain
   - Hunger
   - "Fight or flight" response

7. Sensory Association Area

8. Olfactory Area:
   - Smelling

9. Sensory Area:
   - Sensation from muscles and skin

10. Somatosensory Association Area:
    - Evaluation of weight, texture, temperature, etc. for object recognition

11. Wernicke's Area:
    - Written and spoken language comprehension

12. Motor Function Area:
    - Eye movement and orientation

13. Higher Mental Functions:
    - Concentration
    - Planning
    - Judgment
    - Emotional expression
    - Creativity
    - Inhibition

14. Functional Areas of the Cerebellum

Motor Functions:
- Coordination of movement
- Balance and equilibrium
- Posture
Occipital Lobe Functions

- Vision
- Visual areas have retinotopic (mapping onto retina) representation of the outside world.

Damage can lead to cortical blindness
Parietal Lobe Functions

- Body awareness
- Spatial navigation
- Attention
- Damage leads to Attentional Neglect
Frontal Lobe Functions

- Motor Functions
- Speech
- Attention
- Appetitive Behaviors
- Social Interactions
- Emotion
- Executive Function
- Impulse Control
Phineas Gage

- Foreman of a railway construction crew.
- “A capable and efficient foreman, one with a well-balanced mind, and who was looked on as a shrewd smart business man.”
- On September 13th, 1848, an accidental explosion of a charge he had set blew his tamping iron through his head.
After the accident:

“Fitfull, irreverent, and grossly profane, showing little regard for his fellows.”

“Impatient and obstinate, yet capricious and vacillating, unable to settle on any of the plans he devised for future action.”

His friends said he was “No longer Gage.”
Temporal Lobe Functions

- Auditory Cortex
- Higher-level visual processing
  - Disruption of visual areas can lead to **agnosia** – e.g. prosopagnosia
- Language Comprehension
  - Disruption of language areas can lead to **aphasia**
Language areas of the brain

- **speech mouth movements**: Motor cortex
- **understanding words**: Wernicke’s area
- **producing words**: Broca’s area
- **hearing words**: Auditory cortex
When talking about the brain and body you have to know the meaning of terms that deal with directions. Note that for the brain dorsal indicates closer to the top of the head and ventral means closer to the jaw line. But for the body and the spinal cord dorsal means along your back and ventral means along your stomach.
Division into CNS and PNS is a matter of anatomy and development.

1) CNS is encased by the bones of the skull and vertebrae. PNS is outside those bones.

2) Neurons of CNS and PNS have separate embryological origins.
Peripheral Nervous System

Two parts to PNS -

**Somatic** - sensory input from skin, muscles and tendons. Motor output to skeletal muscles. This is why you feel and move.

**Autonomic** - sensory input from organs, motor output to organs and glands.

Neurons that line the walls of the gut form a part of the autonomic system called the **enteric nervous system**.
Central Nervous System

Everything enclosed in the bones of the cranium and vertebrae is central nervous system (CNS).

CNS is composed of brain and spinal cord. FYI, the word “spine” is used for the collection of vertebrae - they are bones. The nervous system part of it is the spinal cord.
Three connective tissue coverings exist between skull and brain (or vertebrae and spinal cord). The outer-most and thickest is the dura mater (literally, the tough mother). The inner-most and thinnest is the pia mater (soft mother). Between those two is the arachnoid mater (spidery mother). The meninges protect the brain from injury.
Meninges can also be vulnerable

Viral or bacterial infection of the meninges and the resulting inflammation is called **meningitis**.

An uncontrolled growth of cells in the meninges produces a surface tumor called a **meningioma**.
Cells of the brain are evenly divided between neurons and glia (about 30 billion of each in the human brain). This is a neuron. You need to appreciate for now it has parts - the two parts you should focus on are the cell body and the axon. The broken lines of the axon tell you it is generally much longer than what is illustrated here. The material around the axon is insulation called myelin.
Axons run in bundles called **tracts**. Because these tracts carry information from one region of the CNS to another, they run for long distances (as much as a meter). One example is the **corpus callosum**, the axons of which allow the two hemispheres to communicate with one another. Nuclei, by contrast, are discrete - they are seldom more than a few centimeters in any dimension.
The vertebrate brain is divided into two hemispheres. With very few exceptions what is found in one hemisphere is found in the other - almost all parts of the brain exist in pairs. A mid-sagittal section splits the two hemispheres cleanly down the middle - it affords us an excellent view of the parts of the human brain.
Microscopic view of the neuron

- Dendrites
- Microtubule Neurofibrils
- Neurotransmitter Receptor
- Synapse
- Synaptic vesicles
- Synapse (Axoaxonic)
- Synaptic cleft
- Axonal terminal
- Node of Ranvier
- Rough ER (Nissl body)
- Polyribosomes
- Ribosomes
- Golgi apparatus
- Nucleus
- Nucleolus
- Membrane
- Microtubule
- Mitochondrion
- Smooth ER
- Synapse (Axodendritic)
- Myelin Sheath (Schwann cell)
- Nucleus (Schwann cell)
- Microfilament
- Microtubule
- Axon
- Dendrites
- Axon hillock
The neuron’s structure

Three parts to a neuron:
- Cell body (soma)
- Dendrites
- Axon

All mammalian neurons have only one cell body and one axon but most have many dendrites.
The Law of Dynamic Polarization

These figures introduce the most important concept about neurons. They are compartmentalized so that separate functions are handled by distinct regions.

At least that is the case for 95% of neurons, 95% of the time.
Variations in dendritic morphology

**FIGURE 3.1** Typical morphology of projection neurons. *(Left)* A Purkinje cell of the cerebellar cortex and *(right)* a pyramidal neuron of the neocortex. These neurons are highly polarized. Each has an extensively branched, spiny apical dendrite, shorter basal dendrites, and a single axon emerging from the basal pole of the cell.
Variations in dendritic morphology

Motor neuron from spinal cord

Mitral cell from olfactory bulb

Pyramidal cell from cortex

Purkinje cell

Ganglion cell
Dendrites of neurons in the cerebral cortex of rats become progressively more complex over the first 3 weeks of postnatal life. For humans the same events would take years.
Serial imaging of the same neurons over a series of weeks demonstrates that even in adults, dendrites grow, branch and retract. As a result the pattern of the dendritic tree can change rather dramatically.

These three neurons from the rat superior cervical ganglion displayed progressive changes in length and complexity of individual branches in a matter of weeks.
Dendritic spines are the sites at which the majority of excitatory synapses are formed in the central nervous system. Some spines have long, skinny necks and a small head whereas (these can change very quickly) others have short necks and big heads (these are more stable.. called mushroom spines).
Comparison of neurons from young (A) and old (B) animals demonstrates a remarkable difference in the density of dendritic spines. Normal in C is to the left, and pathological cases are the three examples to the right (e.g. mental retardation, neurodegeneration).
Cell body (soma) as a factory

- **Dendrite**: Cell extension that collects information from other cells
- **Dendritic spine**: Small protrusion on dendrites that increases surface area
- **Nucleus**: Structure containing the chromosomes and genes
- **Nuclear membrane**: Membrane surrounding the nucleus
- **Mitochondrion**: Structure that gathers, stores, and releases energy
- **Endoplasmic reticulum**: Folded layers of membrane where proteins are assembled
- **Intracellular fluid**: Fluid in which the cell's internal structures are suspended
- **Tubule**: Tiny tube that transports molecules and helps give the cell its shape
- **Cell membrane**: Membrane surrounding the cell
- **Axon**: Extension that transmits information from cell body to other cells
Phospholipids are the major constituents of the plasma membrane - each is composed of two fatty acid tails that love fat (lipophilic) and hate water (hydrophobic) and a polar head that loves water (hydrophilic).
The 5 nm-thick plasma membrane of a neuron consists of proteins floating in a sea of **phospholipids**. To dissolve in the membrane these transmembrane proteins must have lipophilic (hydrophobic) regions as they mingle with fatty acid tails and hydrophilic regions where they come into contact with water.
Ion channels are one type of protein that spans the plasma membrane. Most channels are gated - that means they can open and close in response to some signal. This gating can be used for maintaining the membrane potential as well as signaling across and within neurons.

Two major classes of channels exist in neurons - those gated by changes in membrane potential (voltage-gated channels) and those gated by specific chemicals (ligand-gated channels).
Pumps are a special class of membrane proteins that requires energy to operate against the ionic concentration gradient. For example, the sodium/potassium pump is an **ATPase**. It requires energy (ATP) in order to operate.
Ionotropic receptors

We call receptors that form ion channels **ionotropic receptors**.

Binding of neurotransmitter produces a change in the shape of the proteins that make up the channel. That change in shape - called a **conformational change** - briefly opens a pore through the membrane.

Channels are always selective for **anions** (negatively charged) or **cations** (positively charged). Many cation channels are selective for the specific cation e.g. K\(^+\) or Na\(^+\).
Metabotropic receptors

Many receptors work not by opening ion channels but by activating a protein called a GDP-binding protein or just simply a G protein. For that reason they are called G-protein-coupled receptors (GPCRs).

Binding of neurotransmitter to a GPCR sets up a molecular cascade that can lead to anything from opening an ion to changes in gene transcription.
Ionotropic vs. metabotropic

- Rapid action
- Short-term effect
- Signaling

- Slow onset
- Longer effect
- Modulating
Three kinds of elements make up the neuronal cytoskeleton: microtubules, neurofilaments (neuronal intermediate filaments) and actin microfilaments. Neurofilaments and actin microfilaments are the major structural elements of a neuron - they establish and maintain a neuron’s complex shape.
Neurons use microtubules as highways to transport vesicles and other organelles. Transport can go from cell body to axon terminal (anterograde transport) or from terminal to cell body (retrograde transport). The two are driven by different molecular motors: kinesins (antero- and retrograde) and dyneins (retrograde).
One class of glial cell is the oligodendrocyte.

An electron micrograph (left) and a schematic diagram (right) document the function of oligodendrocytes--**myelination** of axons.
Schwann cells make PNS myelin

SCs are capable of responding rapidly to injury and can phagocytose damaged myelin and produce new myelin within a short period of time.

The presence of SCs can chaperone axonal regeneration following damage.
Astrocytes actively pump nutrients from the vasculature to neurons and provide support for endothelial cells.

Play a role in calcium-dependent signaling via gliotransmitters.
Microglia are macrophages

These resident **immune cells** of the nervous system survey the brain for damage and infection, engulfing dead cells and debris. Also involved in synaptic “pruning” during development.

Moreover, they are activated in many **neurodegenerative diseases**, but whether they are helpful or harmful in these conditions is a matter of debate.
Ependymal cells make CSF

Epithelial cells that produce, secrete and circulate cerebrospinal fluid (CSF) in the brain’s ventricles and make up the blood-CSF barrier by virtue of their tight junctions.