Each of the $10^{11}$ (one hundred billion) neurons has on average 7,000 synaptic connections to other neurons. It has been estimated that the brain of a three-year-old child has about $10^{15}$ synapses (1 quadrillion).
Cell body. The metabolic center of the neuron; also called the soma.

Dendrites. The short processes emanating from the cell body, which receive most of the synaptic contacts from other neurons.

Axon hillock. The cone-shaped region at the junction between the axon and the cell body.

Axon. The long, narrow process that projects from the cell body.

Cell membrane. The semipermeable membrane that encloses the neuron.

Myelin. The fatty insulation around many axons.

Nodes of Ranvier (pronounced RAHN vee yay). The gaps between sections of myelin.

Buttons. The buttonlike endings of the axon branches, which release chemicals into synapses.

Synapses. The gaps between adjacent neurons across which chemical signals are transmitted.
Myelination in the Central Nervous System

CNS

- Nucleus
- Axon
- Oligodendroglia

PNS

- Axon
- Nucleus
- Schwann cell
Figure 3.13 A color-enhanced scanning electron micrograph of a neuron cell body (green) studded with terminal buttons (orange). Each neuron receives numerous synaptic contacts.

(Courtesy of Jerold J. M. Chun, M. D., Ph.D.)
1963 Nobel Prize in Physiology or Medicine

Sir Alan Lloyd Hodgkin

Andrew Huxley
Neuron Membrane Potential

- semi-permeable membrane separating different quantities of ions
- Force due to concentration gradient
- Force due to electrostatic attraction/repulsion
  - Na+
  - Cl-
  - K+
  - others...
Concentration Gradient
Electrostatic Pressure
Nernst Equation

\[ V_{Eq} = \frac{RT}{zF} \ln \left( \frac{[X]_{out}}{[X]_{in}} \right) \]

V = voltage (at equilibrium)
R = ideal gas constant (expresses energy of concentration gradient per Kelvin per mole)
T = temperature (K)
z = valence of the ionic species (eg., +1 for Na+, -1 for Cl-)
F = Faraday constant (electric charge/mole of electrons)
[X] = concentration of ion inside/outside membrane
Two forces at work:
- electrostatic pressure
- concentration gradient

Cl−: negatively charged chloride ions
Na+: positively charged sodium ions
K+: positively charged potassium ions

Figure 4.4 The passive and active forces that influence the distribution of Na+, K+, and Cl− ions across the neural membrane. Passive forces continuously drive K+ ions out of the resting neuron and Na+ ions in; therefore, K+ ions must be actively pumped in and Na+ ions must be actively pumped out to maintain the resting equilibrium.
Membrane Potential

• The interior of the neuron is kept at approximately -70 mV with respect to the exterior
Figure 3.13 A color-enhanced scanning electron micrograph of a neuron cell body (green) studded with terminal buttons (orange). Each neuron receives numerous synaptic contacts.
(Courtesy of Jerold J. M. Chun, M. D., Ph.D.)
Synapse Location and Anatomy

- Axon branches of neuron 1
- Axon of neuron 2
- Axon bulbs
- Dendrites
- Cell body
- Mitochondrion
- Synaptic vesicles
- Axon bulb
- Dendrite
- Synaptic cleft
An Ionotropic Receptor

- Neurotransmitter
- Ion
- Ionotropic receptor
- Closed ion channel
Membrane potential (mV)

<table>
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<tr>
<td>1</td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
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</tbody>
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Na⁺ channels close

K⁺ channels open, K⁺ begins to leave cell

Na⁺ channels open, Na⁺ enters cell

Threshold of excitation

K⁺ leaves cell

K⁺ channels close

Excess K⁺ outside diffuses away

Depolarizing shock applied
Fig. 4.8 Propagation of the nerve impulse along the axon
Graded potential
Vs
Saltatory Conduction

Cell body. The metabolic center of the neuron; also called the soma.

Dendrites. The short processes emanating from the cell body, which receive most of the synaptic contacts from other neurons.

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Synapses. The gaps between adjacent neurons across which chemical signals are transmitted.
Seven Steps in Neurotransmitter Action

1. Neurotransmitter molecules are synthesized from precursors under the influence of enzymes.

2. Neurotransmitter molecules are stored in vesicles.

3. Neurotransmitter molecules that leak from their vesicles are destroyed by enzymes.

4. Action potentials cause vesicles to fuse with the presynaptic membrane and release their neurotransmitter molecules into the synapse.

5. Released neurotransmitter molecules bind with autoreceptors and inhibit subsequent neurotransmitter release.

6. Released neurotransmitter molecules bind to postsynaptic receptors.

7. Released neurotransmitter molecules are deactivated either by reuptake or enzymatic degradation.
Spinal Cord

• Many cortical neurons synapse with other cortical neurons
• Interaction with the environment (except for the eye) generally through the spinal cord
Bone notch at the base of the neck is C7.

C1 Cervical spinal nerve roots C1 - C7 correspond with upper aspects of vertebral bodies.

Sensation of C7 nerve is for the middle finger.

C8 and lower spinal nerve roots leave below the corresponding vertebral body.

T1 Sensation of T4 spinal nerve is approximately level with the nipple line.

T4 Sensation of T6 spinal nerve root is approximately level with the bottom of the sternum.

T6 Sensation of T10 spinal nerve root is approximately level with the abdomen.

T10 Sensation of T12 spinal nerve root is approximately level with the pubic bone.

The sensations of lumbar nerves are over the legs.

L1 The spinal cord ends approximately between L1 & L2.

Sacral cord segments (S1-S5 ‘Cauda Equina’) are level with T12-L1 Vertebrae.

The sacral vertebrae are fused to make up the sacrum.

The coccygeal vertebrae are fused to make the coccyx or “tail bone”.

L5 S1  

S3 S5  

Sensation of S3, S4 & S5 nerves is the Perineal (genital) area.
Reflex arc

This interneuron excites motor neuron; causes muscular contraction

Spinal cord

Dorsal

Ventral

Motor neuron

This muscle causes withdrawal from source of pain

Axon of sensory neuron (pain)
Synapses in the brain

Neuromuscular junction
Organization of Cortex
The Human Basal Ganglia

Near the base of the brain is a small area called the substantia nigra which contains cells that produce dopamine.

Dopamine acts as a transmitter between the nerve endings.
Parkinson’s Disease

• Degradation of substantia nigra (pars compacta)
  – Loss of dopamine
  – Puts a “break” on input to motor cortex
• muscle rigidity, tremor, a slowing of physical movement (bradykinesia)
• This can be alleviated using
  – Levodopa
  – Deep brain stimulation of the internal segment of the globus pallidus (GPi) or subthalamic nucleus (STN)
Penfield Map

- Knee
- Hip
- Trunk
- Shoulder
- Arm
- Elbow
- Wrist
- Hand
- Fingers
- Thumb
- Neck
- Brow
- Eye
- Face
- Lips
- Jaw
- Tongue
- Swallowing
- Toes
Retinotopic Maps

- Much of visual cortex is organized in reference to position on the retina
Saccade Maps – Superior Colliculus
Saccade Maps – Frontal Eye Field
• Many brain regions seem not to have any particular map (e.g., frontal cortex), but this may reflect our incomplete understanding of those areas.