

Computation and the Brain: Lecture 1 Notes

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Questions: Is the brain a computer? Is the brain an algorithm? Is thinking about the brain in computational terms fun? Useful?

1 About the Course

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Course website: computationandbrain.github.io

Course content, including resources, homework and lecture notes, will be posted here!

Assignments:

- Readings (incl. research papers), talks to watch, 1-page responses, 1-2 discussion points per week.
- Final project: survey a topic in computational neuroscience, code up or do a math extension of something we talked about in class.
- Attend class and participate

2 Comparing Computers and Brains

Computer	Brain
Inorganic	Alive
Exact computation	Error prone
70-7,000,000 watts	20 watts
Chess, Go, Jeopardy	Survival, creativity, dreams
10^{18} operations/sec	50 operations/sec
Up to 40,000 processors	10^{11} components
Connects with others	Connects to others... if in the mood
Designed	Evolved
Cool and mechanical	Rather emotional
Deliberately programmed	Behavior emerges from complex system

3 Timeline of Computation

- Archimedes
- Al Khwarizmi
- Fibonacci
- Alan Turing
- John Von Neumann
- Internet

4 Timeline of Neuroscience

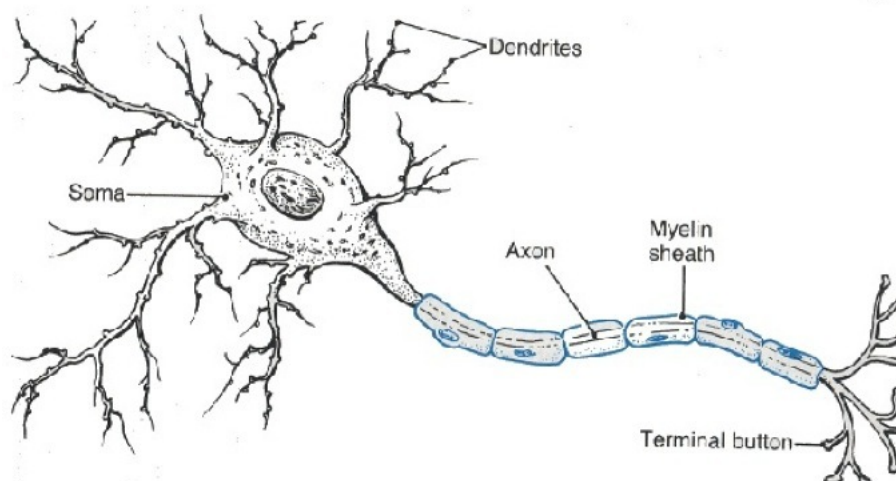
- Alcmaeon of Croton, 520 BCE: The brain is the seat of intelligence.
- Hippocrates, 400 BCE; Aristotle, 330 BC; Galen; 100AD.
- ...
- Luigi Galvani, 1760: There is electrical activity in the nerves of the brain.
- Broca and Wernicke, 1870: Two areas of the brain enable language.
- Camilo Golgi, 1872: We can stain a sparse set of neurons.
- S. Ramon y Cajal, 1880: Neuron drawings, axonal cone
- 1906: Reticulism (the nervous system is best viewed holistically) vs the neuron hypothesis (neurons are like other cells, just more complex.)

5 Nobel Prizes for Discoveries in Neuroscience

- 1906: Ramon y Cajal and Golgi, for discovery of the neuron.
- 1932: C. Sherrington, for discovery of the synapse.
- 1936: H. Dale and O. Loewi, for discovery of neurotransmitters by transfusing frog blood.
- 1963: Eccles, Hodgkin, Huxley, for discovery of the spike (models for neuron firing.)
- 1967, 1981: Granit, Hartline, and Wald; Sperry, Hubel, and Wiesel for vision
- 1970: Katz, von Euler, Axelrod, for discovery of synaptic vesicles (think balloons containing neurotransmitters.)
- 1991, 2000: Neher and Sakmann; Carlsson, Greengard, and Kandel for discovery of ion channels - mechanism behind neuron firing.
- 2006: R. Axel and L. Buck: olfaction
- 2014: O'Keefe, Moser, and Moser: place cells and grid cells.

6 A Rudimentary Neuroscience Vocabulary

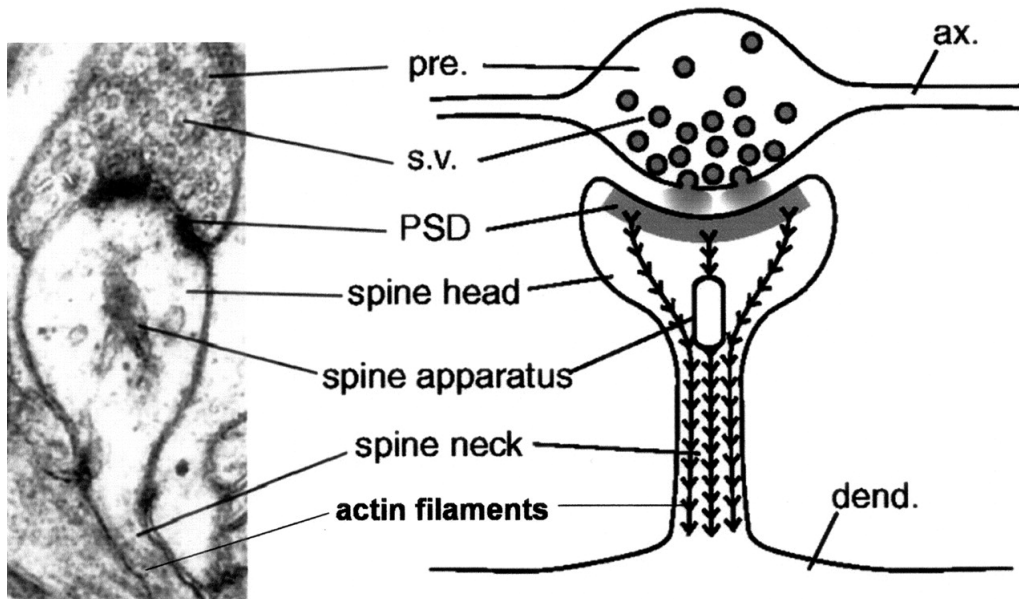
6.1 The Neuron



The neuron is composed of the soma (main body), dendrites (input system), and axon (output system). The axon is encased in myelin, a layer of insulating glial cells. At the end of the axon, the neuron branches out into terminal buttons attached to the dendrites of other neurons. The axon is about 4cm long on average, which is about a million times longer than the soma.

The neuron is surrounded by a membrane and stores about -70 mV in a steady state.
Neurons come in a wide variety of shapes and sizes.

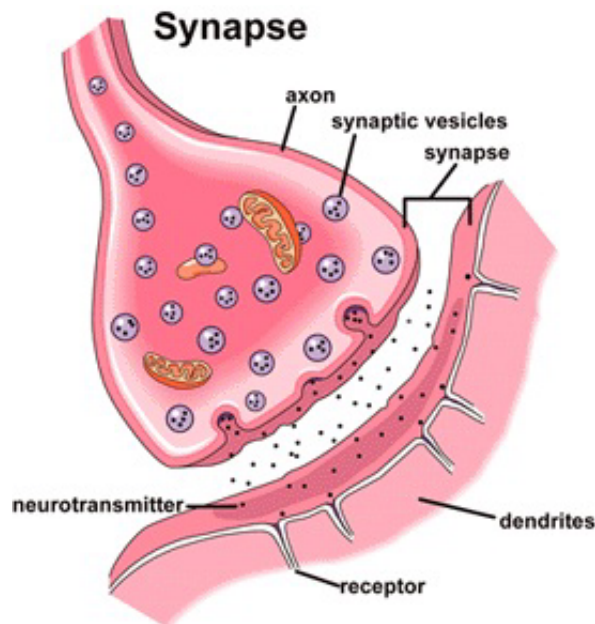
6.2 The Synapse



Small vesicles are located on the side of the axon, adjacent to the synapse at the tip of the dendrite of another neuron. There are 10,000 synapses per neuron. Each synapse has an effective weight, which determines how much its input is taken into account when a neuron fires. Synaptic weights can update, a property known as plasticity.

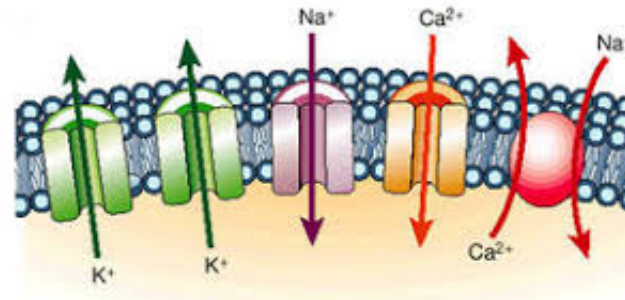
Your brain is currently the biggest it will ever be (if you're in your early 20s.)

6.3 Neurotransmitters



Neurotransmitters can be thought of as the chemical language of neurons. When a neuron fires, it releases neurotransmitters at from vesicles at the synaptic clefts (space between axon and dendrites.) Think of a vesicle as a bubble filled with neurotransmitter that reaches the boundary of the axon, merges with the boundary and bursts.

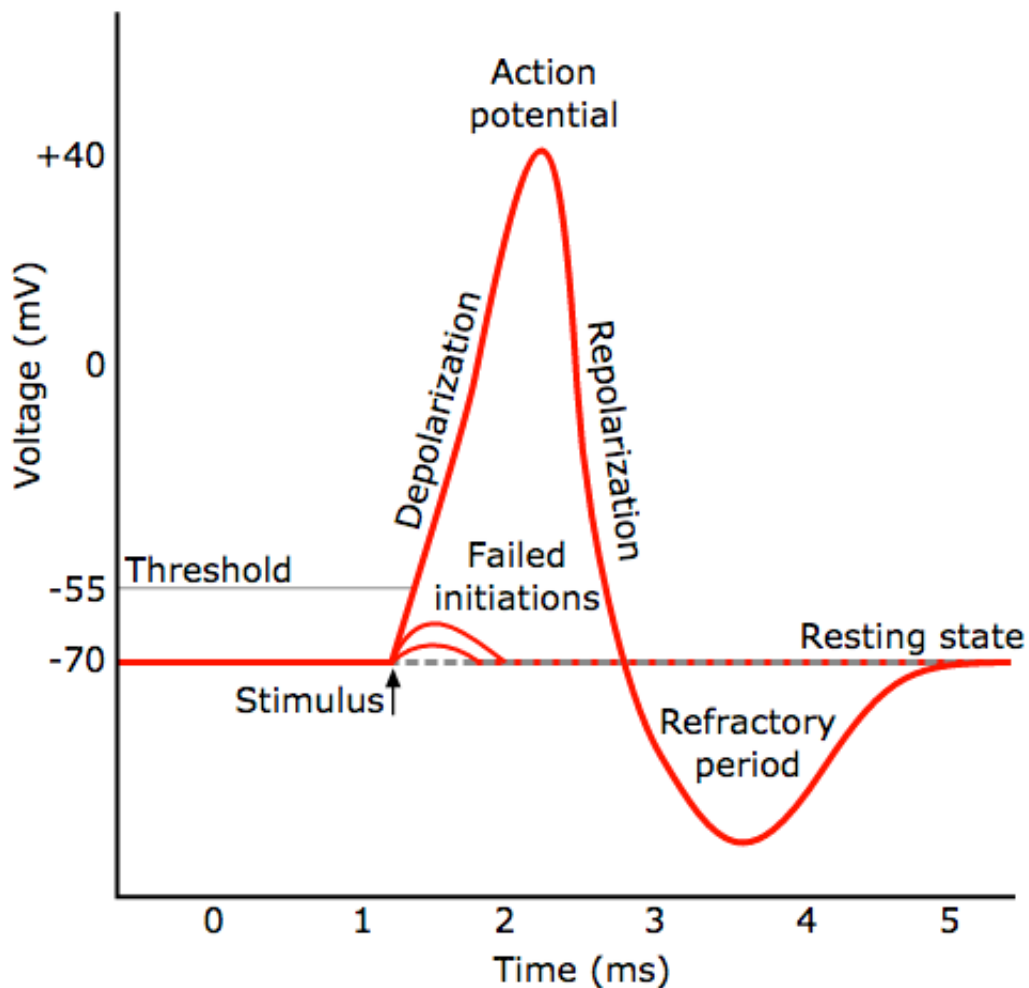
6.4 Ion Channels



Valves which allow ions of a specific type to enter and/or leave the neuron. They are either voltage gated (open when the neuron reaches a certain potential) or ligand gated (controlled by neurotransmitters).

For instance, the neurotransmitter Glu lets positive ions enter the neuron, increasing voltage (excitatory) and GABA lets negative ions enter the neurons, decreasing voltage (inhibitory).

6.5 The Spike



Excitatory stimulus causes the voltage of the neuron to rapidly spike from -70 mV to 40 mV. The spike lasts for about 2 ms, and is followed by a refractory period of about 2 ms during which the neuron cannot fire. Firing rate varies slightly between different types of neurons.

As excitatory neurotransmitters enter the neuron through ion channels, its potential increases. When a certain voltage threshold is exceeded, voltage gates for Na^+ ions open, causing the voltage to spike.

6.6 Olfaction

Odorants in the air come into contact with cilia, small hairs attached to neurons embedded in the epithelium of the nose. Signal travels to the piriform cortex, which consists of input, excitatory, and inhibitory layers.

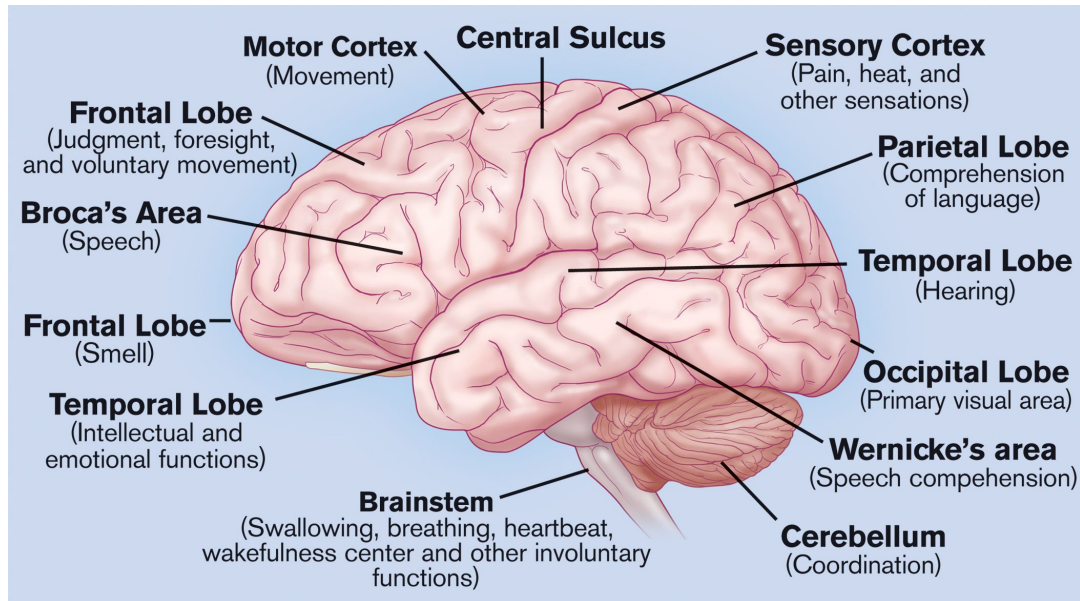
6.7 Place Cells and Grid Cells

A place cell is a neuron in the hippocampus that fires when the animal is in a particular location.

A grid cell is a neuron in the entorhinal cortex that fires when the animal is in any one of the nodes of a triangular grid.

Whoa.

6.8 Parts of the Brain



The cerebrum is divided into lobes, or "big chunks of brain." The cerebellum and brainstem are situated beneath the cerebrum.

The cerebral cortex is the "engine" of the brain. 1.5mm thick, 2500 cm² across, containing six layers and 20 billion neurons.

7 Early Advances in Computational Neuroscience

- 1944: McCulloch-Pitts neuron
- 1957: Rosenblatt perceptron
- 1960s: The first "AI Winter" (pessimism and stalling in AI research), followed by the Minsky-Papert perceptron and the first deep nets. "Neuroscience" and "neuron" coined.
- 1970s: David Marr puts computational neuroscience on a firm foundation. Proposed a three-step program: in order to understand a system in the brain, we need to know its *specifications* (input/output behavior), its *hardware* (what physical components make it up, and its *algorithm* (how the physical pieces interact to produce observed behavior).

8 Recording the Brain

- EEG: Net of neurons wrapped around the head. 1cm resolution, rapid time steps.
- fMRI: Head placed in scanner. 1mm resolution, 1s time steps.
- ECoG (electrocorticography): Network of probes, each with dozens of electrodes, embedded in the brain itself.