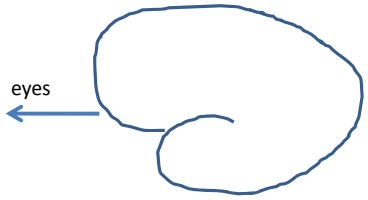
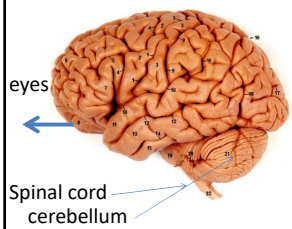
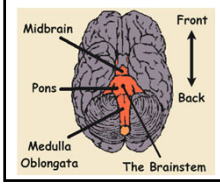
Neural Data Analysis
86-631/42-631

Instructor: Steven M. Chase
TAs: Jacob Rast, Alice Wu



10^{11} neurons, each making ~10^3 connections





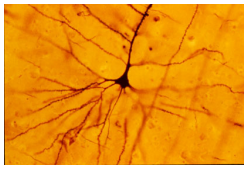
Parts of the brain

- Spinal cord: sends and receives information from the periphery (pretty much everything not on the skull),
- Brain stem: handles cranial nerves (special sensory input, muscles of the head), regulates awareness/arousal
- Medulla oblongata: core autonomic functions (digestion, breathing)
- Pons (regulates information into and out of cerebellum)
- Cerebellum: motor learning, motor control, possibly other functions.
- Midbrain: eye movement, coordination of visual/auditory reflexes
- Diencephalon: thalamus (information gateway), hypothalamus (endocrine)
- Cerebrum, deep: Deep lying structures (basal ganglia, motor control), hippocampus (memory formation, spatial navigation), amygdala (emotion)
- Cerebrum, surface: cerebral cortex (thinking!)

Santiago Ramon y Cajal (1852-1934)

In the 1800's, it was widely believed that the brain was glandular in nature: it caused action by secreting substances into muscles. Ramon y Cajal changed all that.

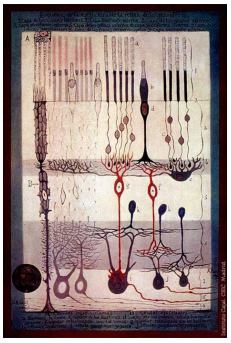
Ag Chromate turns black

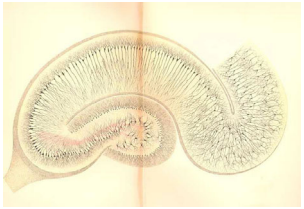


Golgi Staining

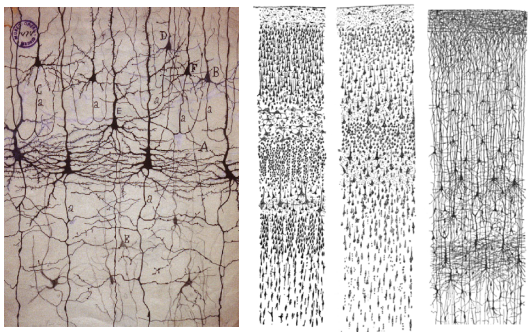
A histological method for looking at cells, in which you impregnate fixed nervous tissue with potassium dichromate and silver nitrate. Cells thus stained are filled by micro-crystallization of silver chromate. For reasons that still aren't clear, the stain is picked up at random by only about 1% of cells, but when it is picked up, it spreads throughout the entire cell, allowing it all to be visualized.

Drawings of Ramon y Cajal





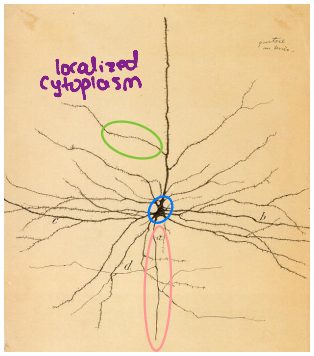
Drawings of Ramon y Cajal



In 1906, he and Golgi shared the Nobel Prize "in recognition for their work on the structure of the nervous system."

Doctrines of Ramon y Cajal

- **The neuron doctrine**: Neurons are the basic signaling units of the nervous system; each neuron is a discreetly bounded cell whose several processes arise from its cell body.
- **Principle of dynamic polarization**: Information flows in a predictable and consistent direction within the nerve cell.
- **Principle of connectional specificity**:
  - No cytoplasmic continuity between neurons, even at the synapse
  - Nerve cells do not connect indiscriminately to form random networks, rather
  - Each cell makes specific connections at precise and specialized points of contact, with some cells but not others.



3 core parts of a neuron

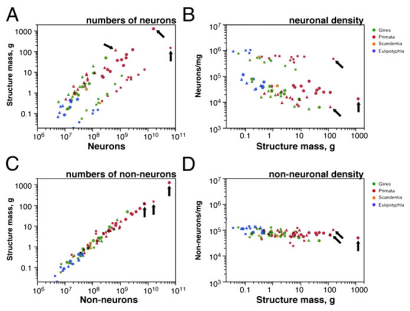
1. Dendrites (receive input through synapses, usually from ~1000 other cells)
2. Cell body (responsible for maintaining physiological homeostasis and integrating input).
3. Axon (transports the action potential, a voltage spike, down to synapses which release neurotransmitter).

Fun brain facts

- What animal has the largest brain by weight?
  - Sperm whale! ~ 17 lbs. *Human: ~ 3.3 lbs.*
- Number of neurons?
  - Elephant? 257 billion. *Human: 87 billion*
  - *Elephant neurons are slightly larger than human neurons*
- Neurons in the cerebral cortex?
  - Killer whale* 43.1 billion. *Human: 20 billion*
- Largest brain relative to its body mass?
  - Ants! ~ 17%!! *Shrews: ~ 10%. Human: ~ 2%*

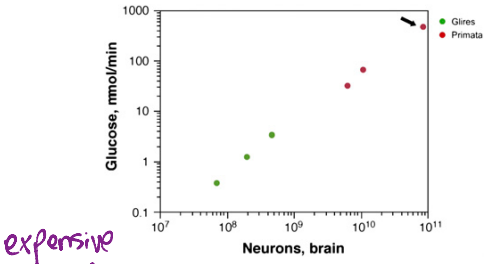
The big brain hypothesis

- At about 1.5 kg, the human brain is two- to threefold smaller than the elephant brain and four- to sixfold smaller than the brains of several cetaceans
- Humans also do not rank first, or even close to first, in relative brain size (expressed as a percentage of body mass), in absolute size of the cerebral cortex, or in gyrification (the amount of folds in the cortical surface).



Herculano-Houzel (2012) PNAS

The human brain costs ~516 kcal/day!



expensive organ

Herculano-Houzel (2012) PNAS

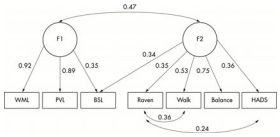
How do we start??

We build a model

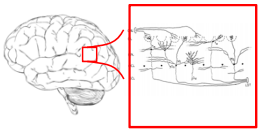
- *Model:* a representation containing the essential structure of some object or event in the real world.
- *Mathematical model* (ˌmath·əˈmad·ə·kəl ˈmäd·əl): A mathematical representation of a process, device, or concept by means of a number of variables which are defined to represent the inputs, outputs, and internal states of the device or process, and a set of equations and inequalities describing the interaction of these variables.

Levels of description…

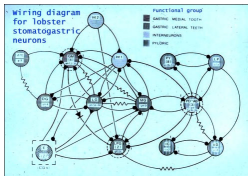
Whole-brain

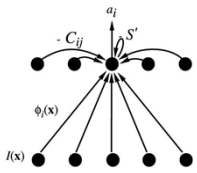


Levels of description…

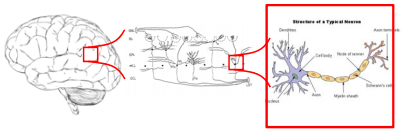


Cortical Circuit models

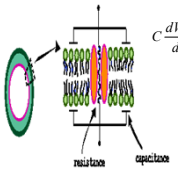




Levels of description…



Single neurons

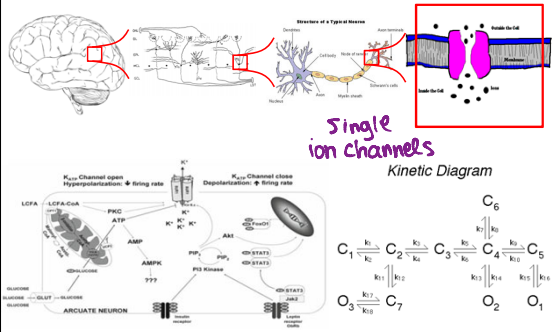


$$C\frac{dV_m}{dt} = I_{ext} - g_L(V_m - V_L) - g_{Na}m^3h(V_m - V_{Na}) - g_K n^4(V_m - V_K)$$

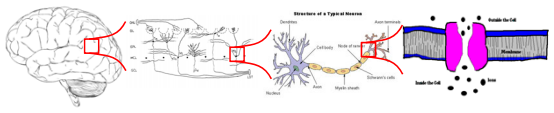
$$\frac{dn}{dt} = \frac{n - n_\infty}{\tau_n} \qquad \frac{dm}{dt} = \frac{m - m_\infty}{\tau_m}$$

$$\frac{dh}{dt} = \frac{h - h_\infty}{\tau_h}$$

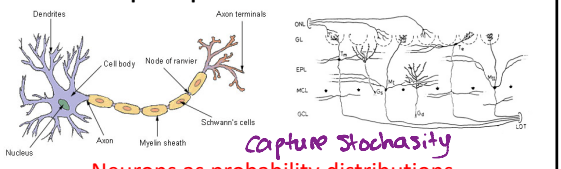
Levels of description…



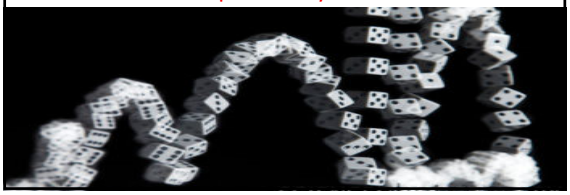
Levels of description…



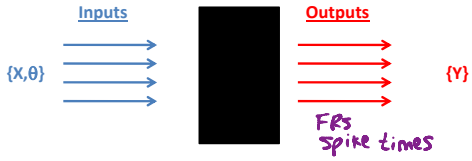
The perspective of this class…



Neurons as probability distributions



Neurons as probability distributions



A description of the stimuli and parameters that cause the neuron to respond.

P(Y|X)

P(Y;θ)

A description of the output responses that matter *(the neural code)*, and how they relate to the stimuli.

Tools we will use

- Probability theory (3 classes)
- Information theory - Neural codes
- Classification / Estimation - MLE, MAP, LDA
- Signal detection theory - d', ROC
- Decoding – PVA, OLE, Kalman
- Dimensionality reduction

7 problem sets → 49%
Probability Quiz → 10%
Midterm → 15%
Final → 15%
Participation → 11%