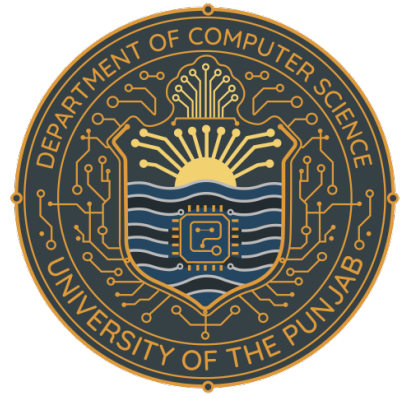
CS-563 Deep Learning

Neural Computation



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Neuroscience:
A short introduction to ourselves

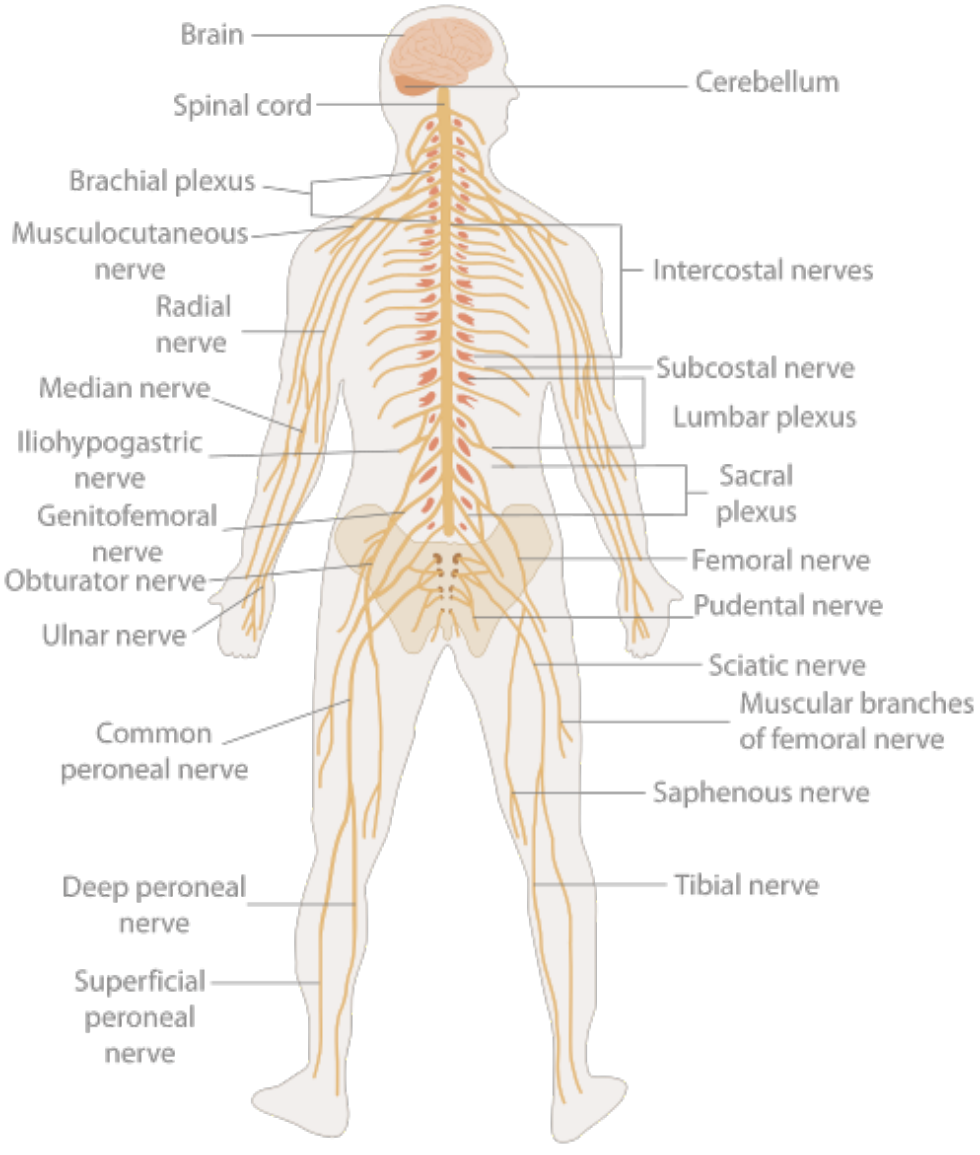
It's all in the brain!

- Your whole existence, your experience of the universe, your happiness, your pain, your memories, your hopes – everything is essentially electrical signals between neurons.
- Sight, smell, sound – it's all in your brain.

Models of Human Cognition

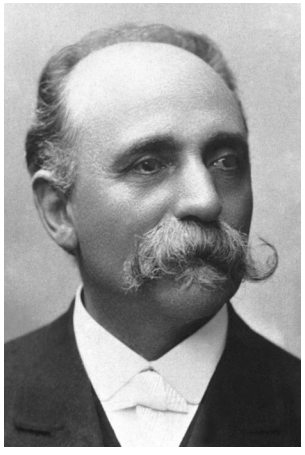
1. Associationism – from Aristotle till 19th century.
   - Humans learn by associating concepts.
   - Aristotle's 4 laws of association
     - **1.1** contiguity
     - **1.2** frequency
     - **1.3** similarity
     - **1.4** contrast
   - But where and what exactly is the physical mechanism behind associations?
2. Connectionism – last two centuries.
   - Animal systems work through extremely sophisticated networks of inter-connected neurons.

The Nervous System

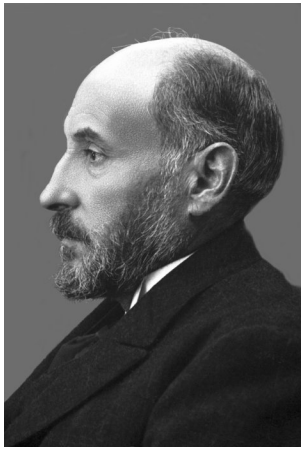


- Coordinates your actions and sensory information by transmitting signals to and from different parts of your body.
- Your brain and spinal cord constitute your *central nervous system*.

The Neuron Doctrine



Camillo Golgi



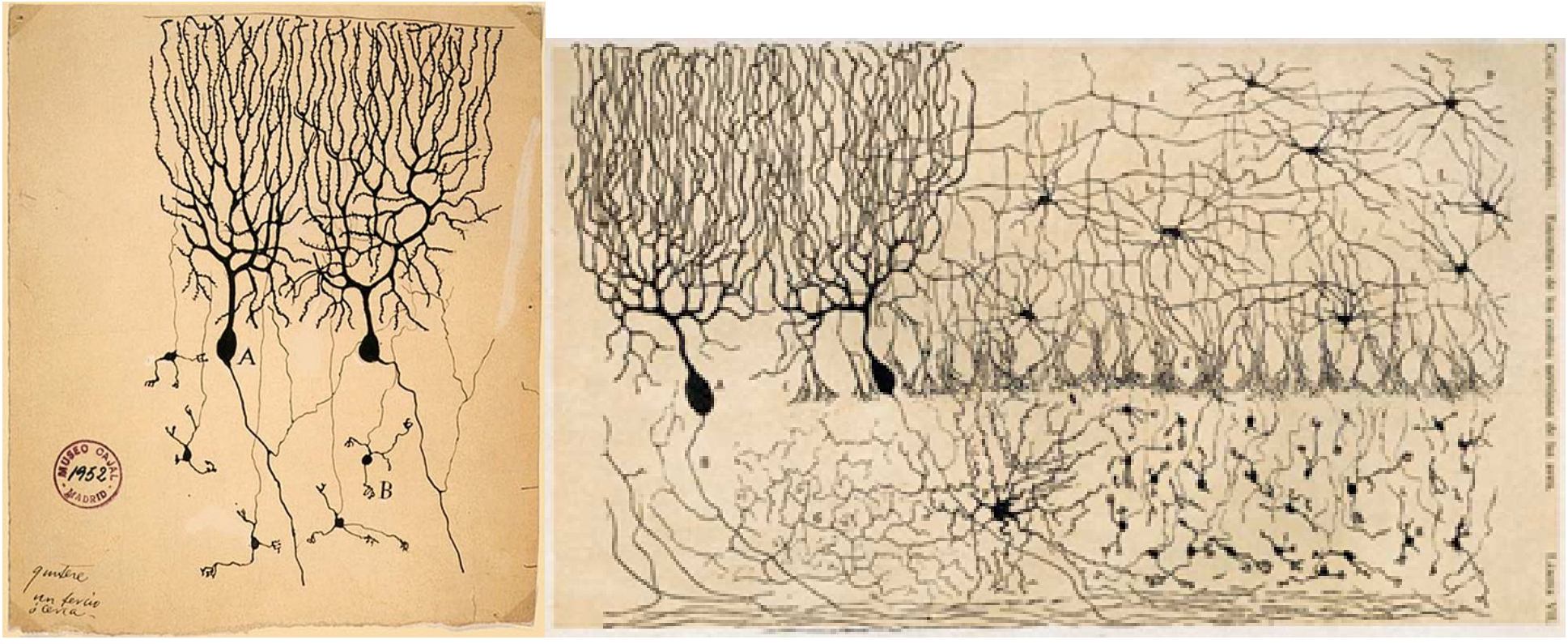
Santiago Ramón y Cajal

- 1906 Nobel Prize in Physiology or Medicine for studying how our bodies are controlled by the interaction between the brain and the nervous system.
- 1870s – Golgi discovered nerve cells could be coloured using silver nitrate.
- Cajal showed that *each nerve cell is an independent entity* and *nerve impulses travel from one cell to another*.

Source: https://www.nobelprize.org

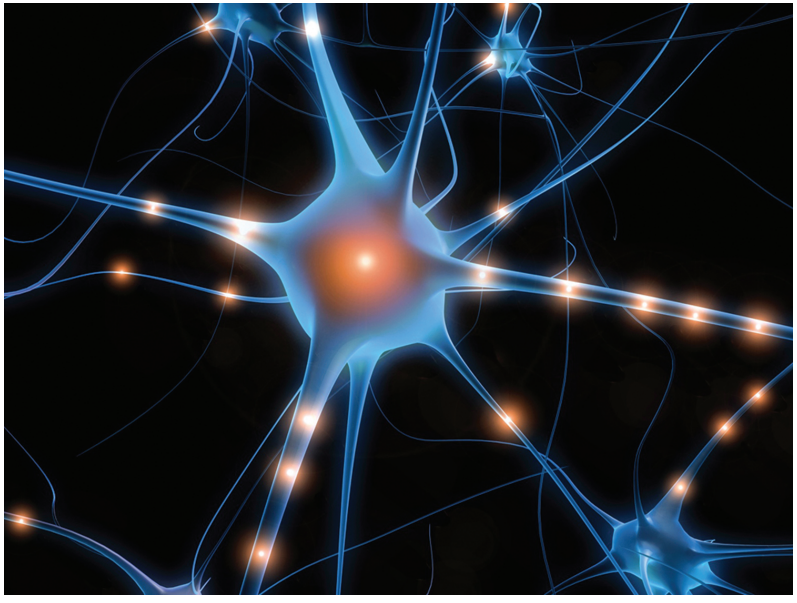
The nervous system is made up of discrete individual cells, called *neurons* and they form a *communication network*.

The Neuron Doctrine



Cajal's drawings showing branching and interconnectedness between nerve cells. Left: pigeon cerebellum from 1899. Right: Chick cerebellum from 1905.

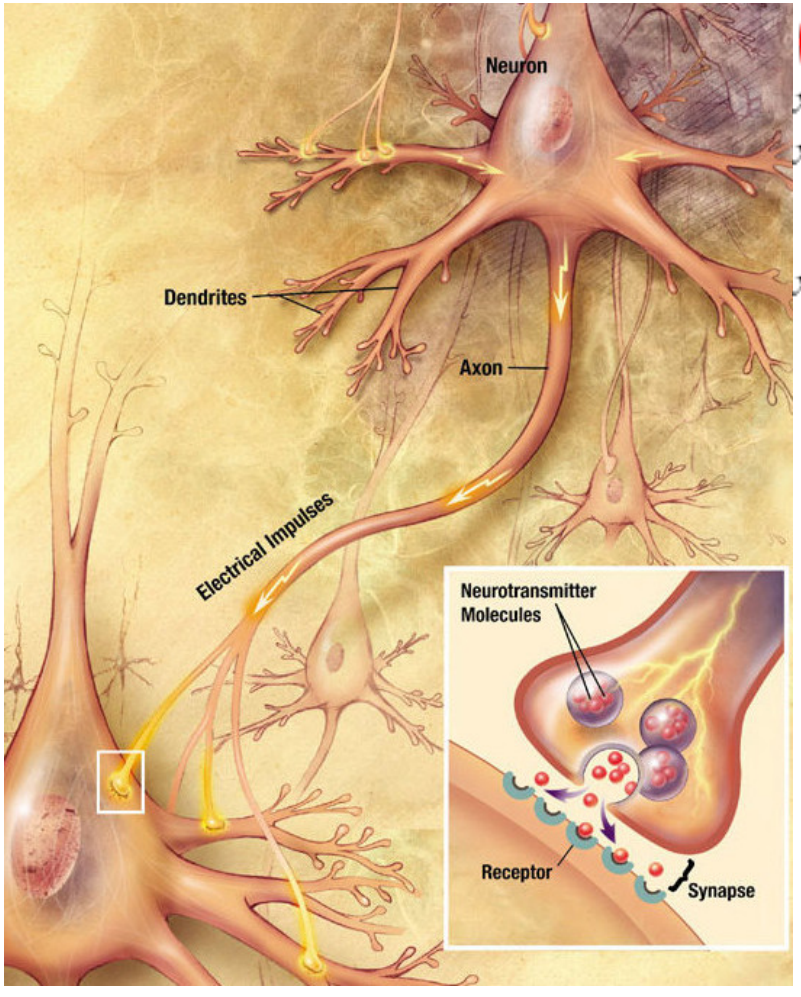
The Human Brain

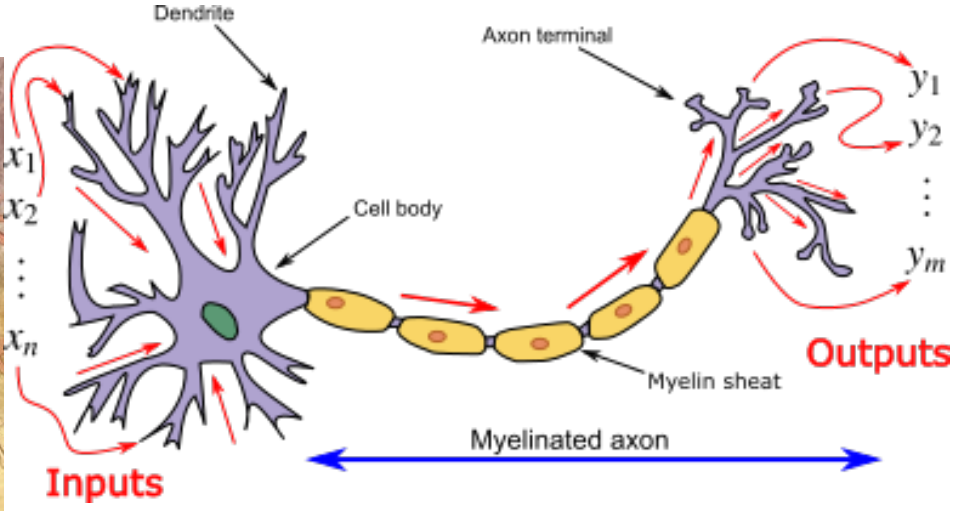


- Around 86 billion neurons[1].
- Each neuron has around 7,000 synaptic connections to other neurons on average.
- Around 1000 trillion connections in a 3 year old.
- Around 100 to 500 trillion in adults.

[1] Herculano-Houzel, 'The human brain in numbers: a linearly scaled-up primate brain'.

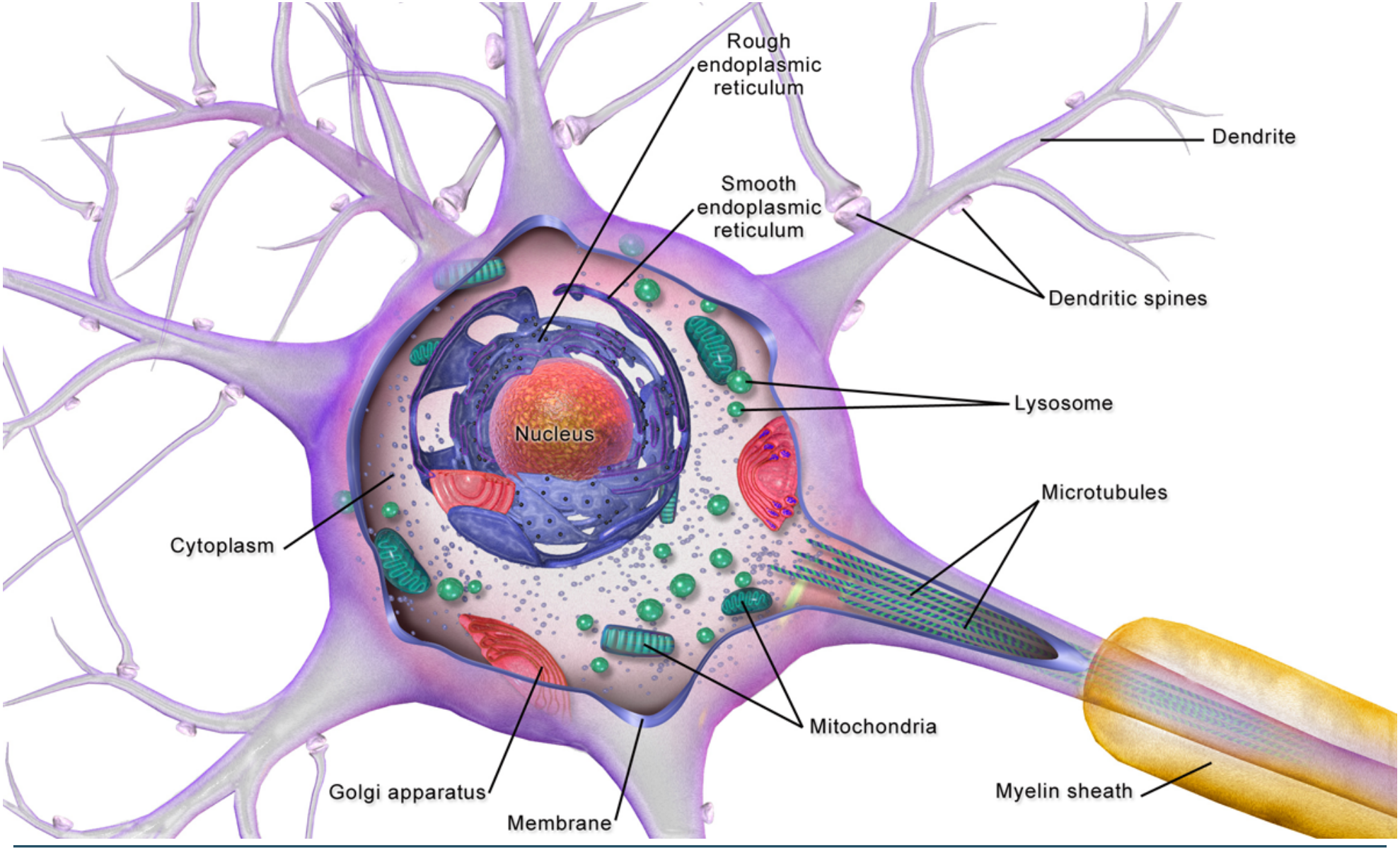
The Neuron
A Simplified View



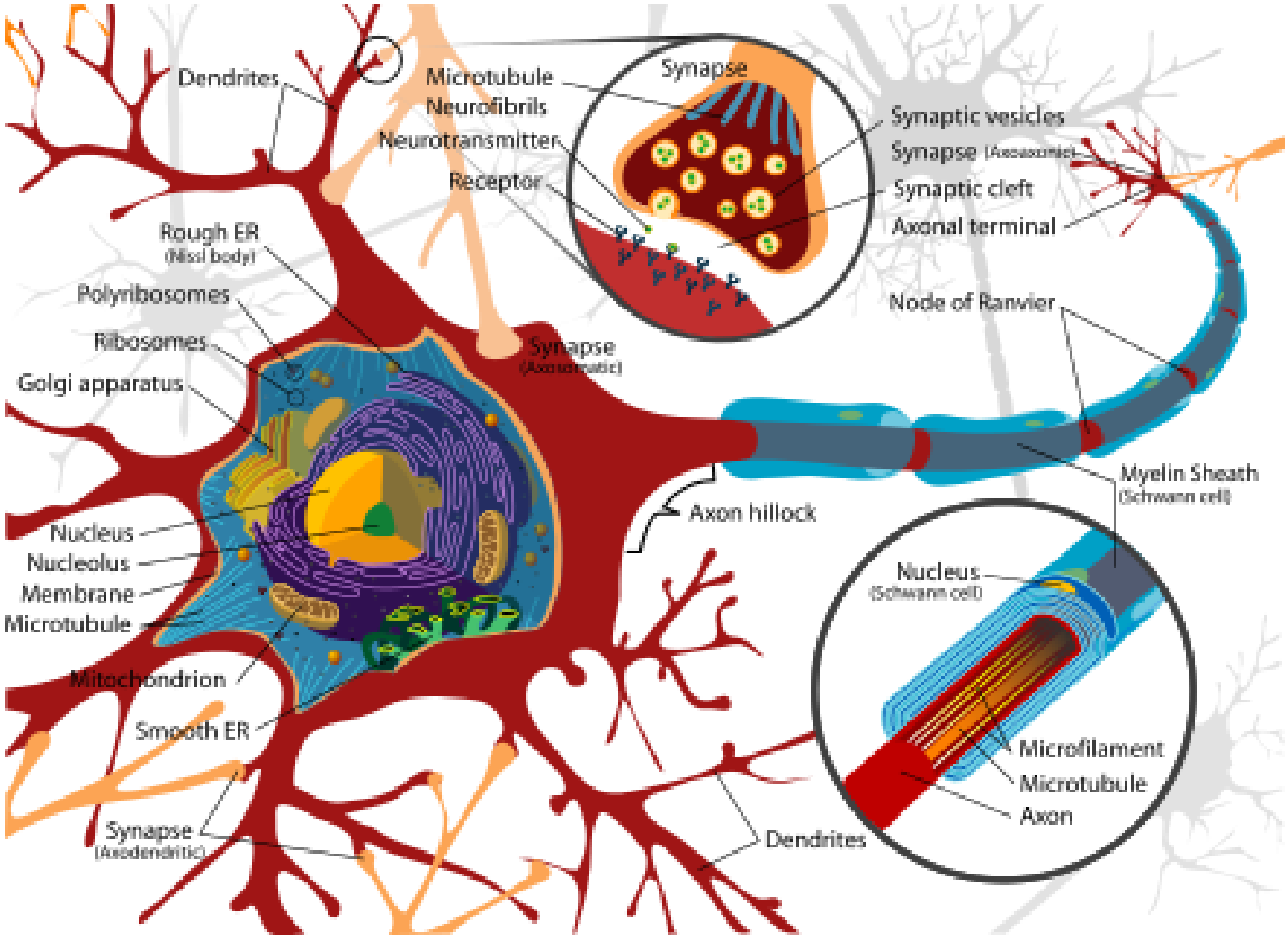


- An electrically excitable cell.
- Cell body called *soma* receives input via filaments called *dendrites*.
- Outputs to other cells via *axon*.
- Axon terminals and dendrites connect via *synapses* where neurotransmitters from one neuron transfer into the next neuron.

Inside the Neuron

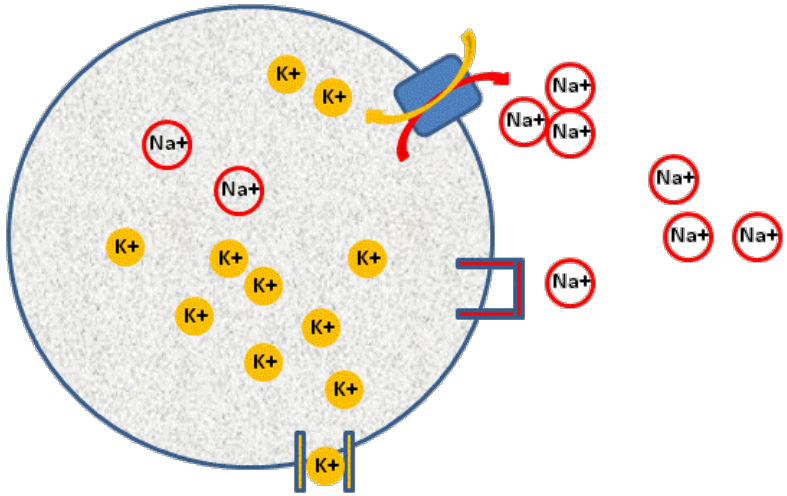


Inside the Neuron

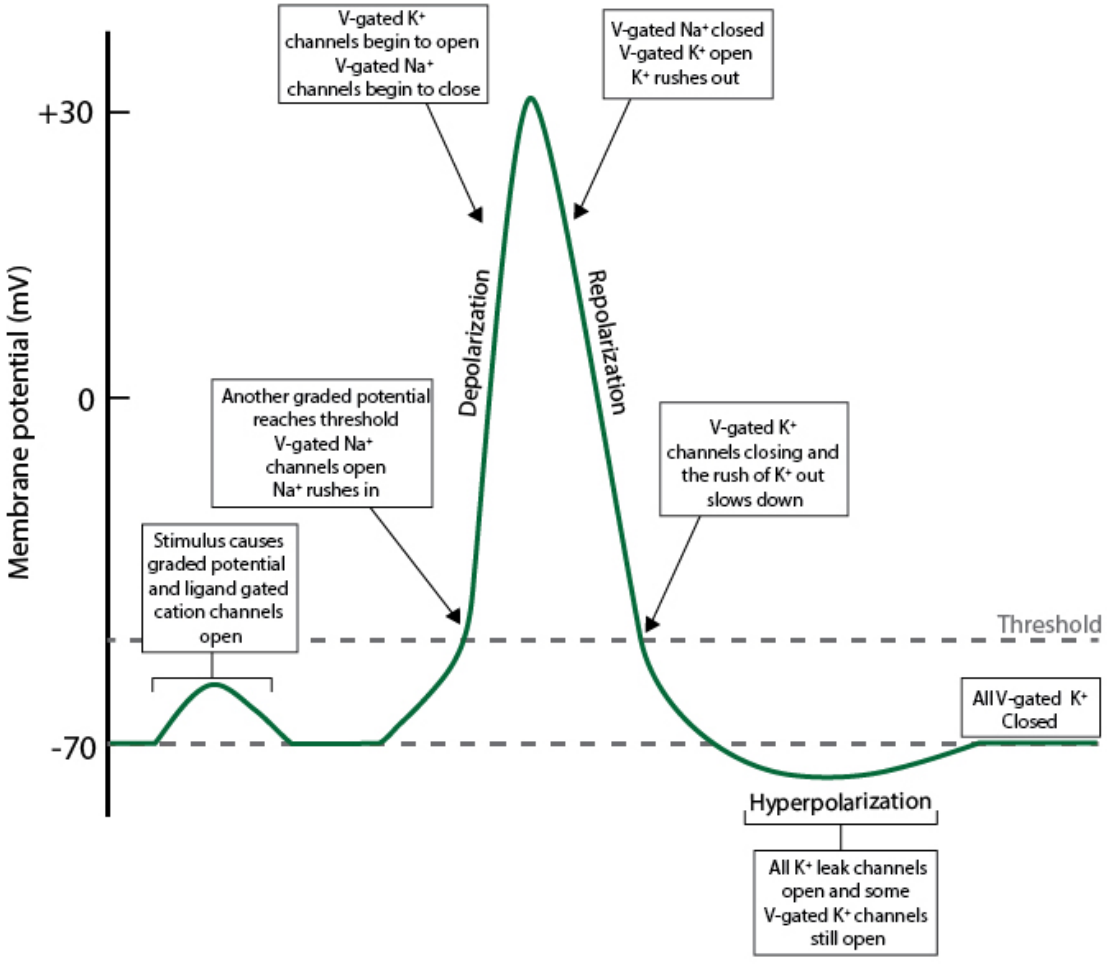


Neuron Spiking

- Neurons maintain voltage gradients across their cell membranes through sodium, potassium, chloride, and calcium ions.
- Sharp voltage changes cause the neuron to emit an electrochemical pulse or spike called an *action potential*.
- This pulse travels rapidly along the axon and activates synaptic connections.
- Synaptic signals may be excitatory or inhibitory, increasing or reducing the net voltage that reaches the soma (cell body).



How does a neuron fire?



- Action potential: a rapid change in voltage across the cell membrane.
- Due to influx of sodium ions, followed by a rapid return via efflux of potassium ions.
- This is the basis of transmitting signals in nerve cells, causing all movement and perception.

A convenient abstraction: a neuron fires when net charge across its membrane exceeds some threshold.

Summary

- Very little is known about the precise workings of our brains.
- Abstractly, neurons communicate via electrical impulses.
- What little is known is hard to model efficiently.
- Next lecture: history of neural computation modeling.