University of BRISTOL

Introduction to the brain

Part II: Brain Cells and Connectivity

A brief introduction to neurons, brain physiology and how cells communicate

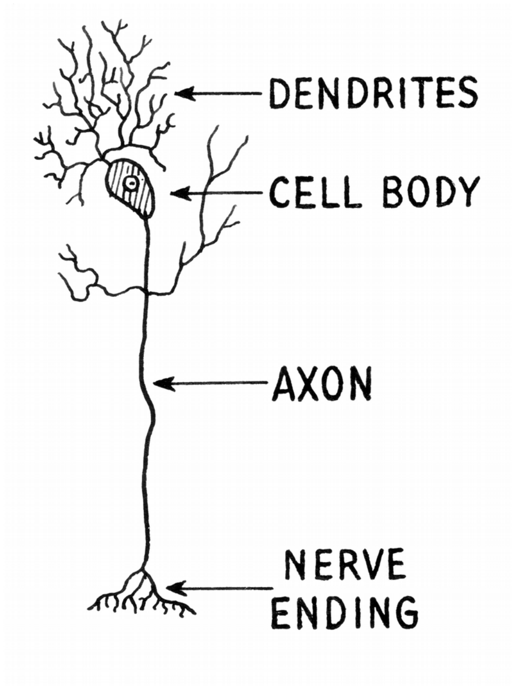
Learning Objectives

To gain an understanding of the basic anatomy of a typical neuron

To gain an understanding of the basic physiology of a typical neuron

To be introduced to the action potential and the synapse: these are the essential elements of neuronal communication

NEURON

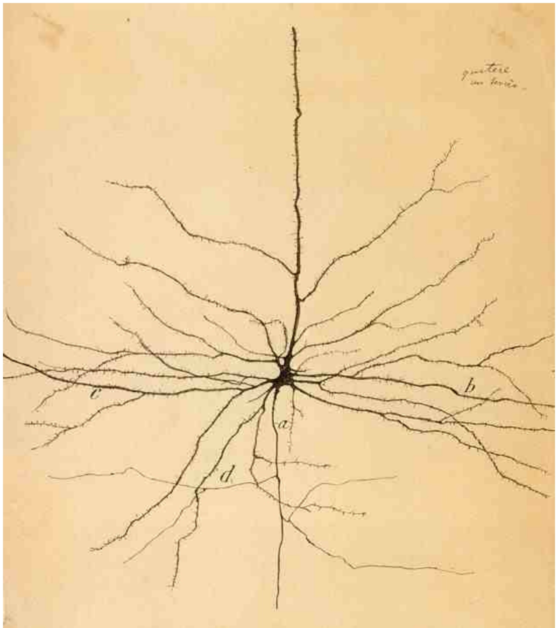


Information Received

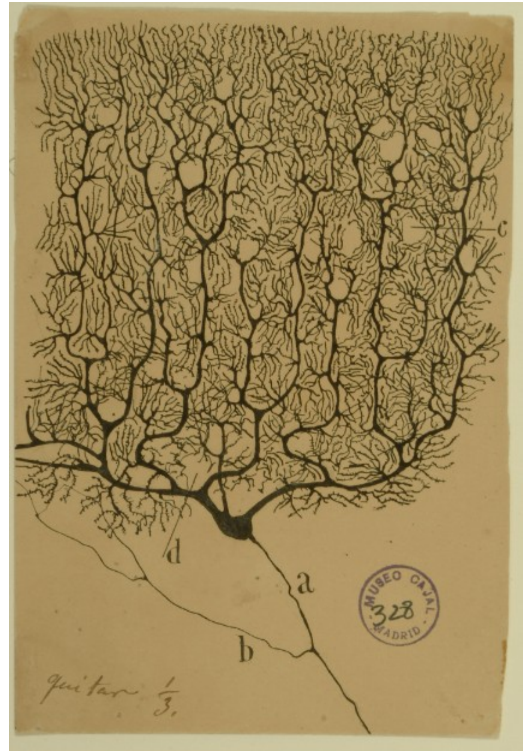
Information Sent out

wikimedia commons: http://commons.wikimedia.org/wiki/File:Dendrite_(PSF).png

Santiago Ramon y Cajal

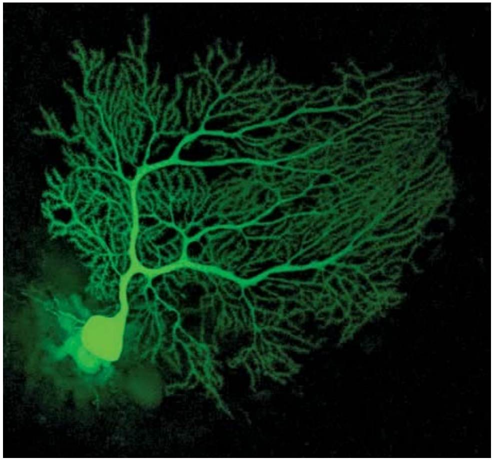


Pyramidal Neuron

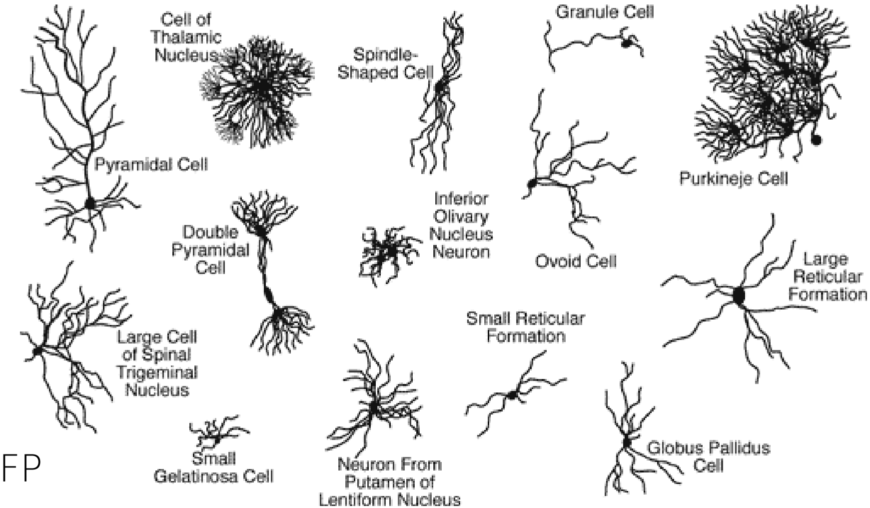


Purkinje Cell

Lots of different types of neuron



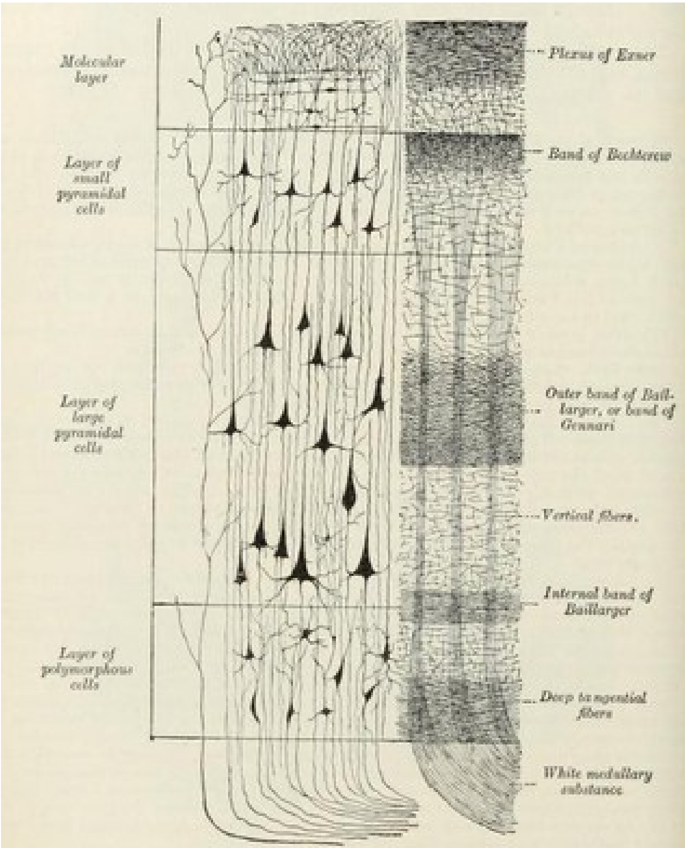
Purkinje cell labelled with GFP



We have around 90 billion neurons in our brain (Herculano Houzel, 2009, Frontiers in Human Neuroscience).

We also have a lot of cells called glia. These do not send electrical impulses themselves but help support neurons and modulate their output.

Layers of the neocortex

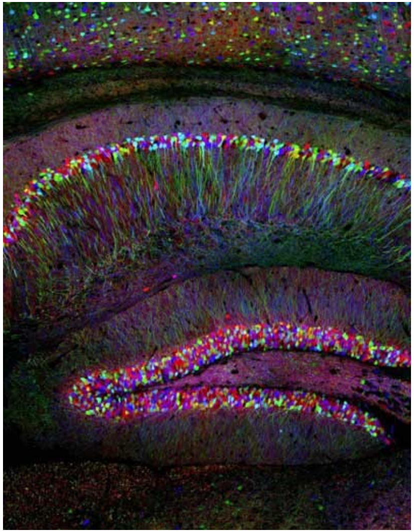


The neo cortex is made up of six cortical layers.

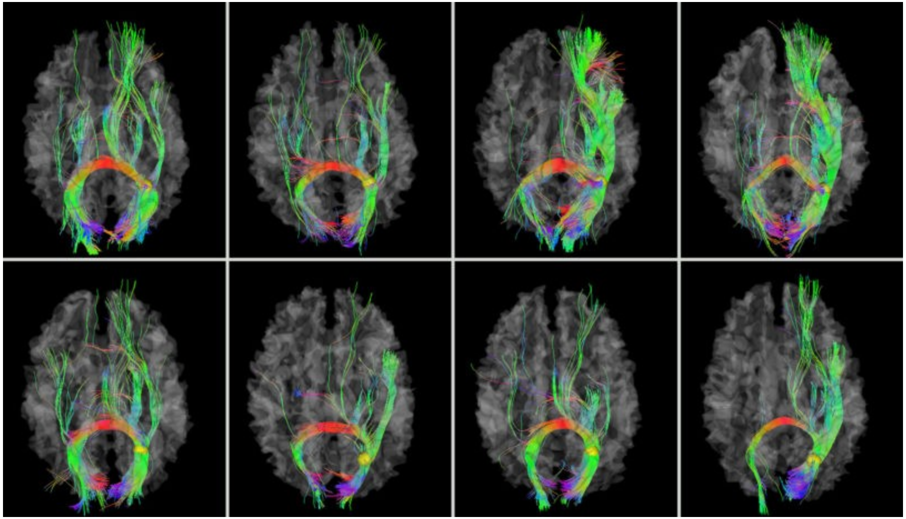
Cortical layers are characterised by cell type , cell distribution and cell connectivity with other cortical and subcortical areas.

Clear example is the visual cortex in the occipital lobe.

Long range connections



Centre for brain science, Harvard



DICCCOL: Dense Individualized and Common Connectivity-Based Cortical Landmarks, University of Georgia

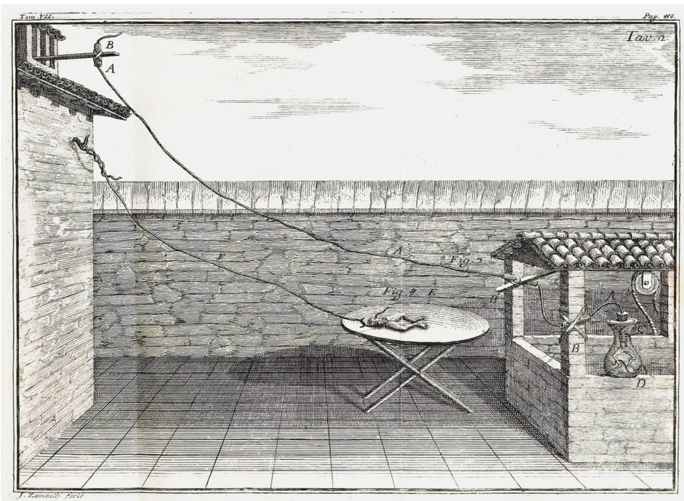
https://www.youtube.com/watch?v=ThO3FjxDx0Q

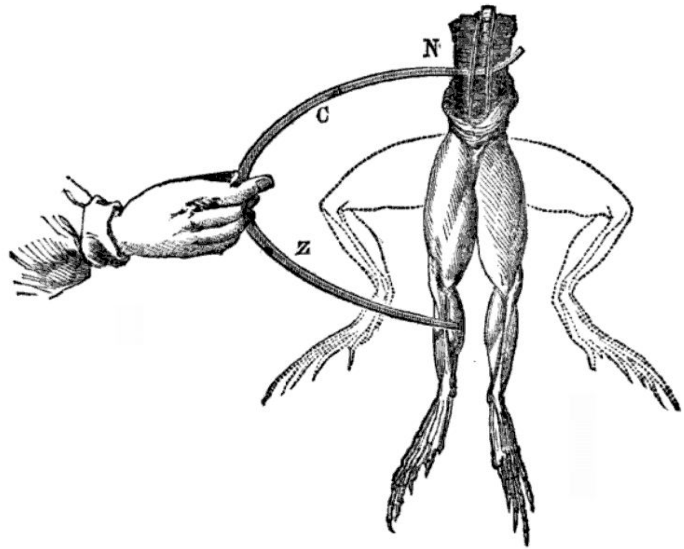
But how do neurons Communicate?

Neurons communicate with one another by changes in voltage.

A Brief History – Galvani, 1780s

"Animal Electricity"





https://en.wikipedia.org/wiki/Luigi_Galvani

Action Potential

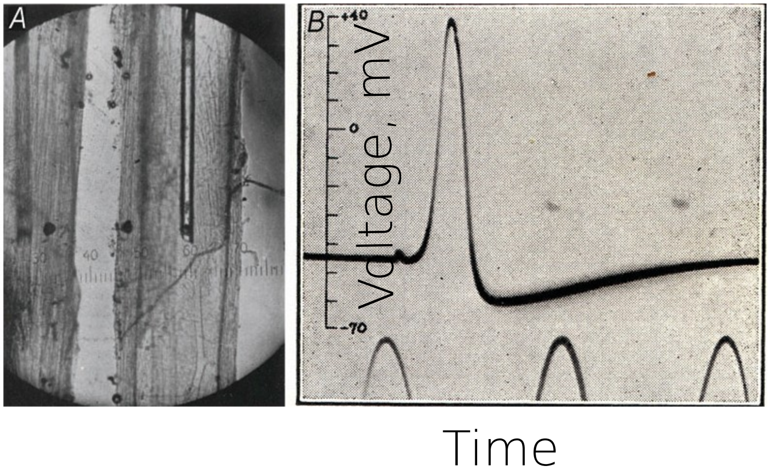


Fig. 6. Action potential and resting potential recorded between inside and outside of axon with capillary filled with sea water. Time marker 500 Hz. The vertical scale indicates the potential of the internal electrode in millivolts, the sea water outside being taken as at zero potential (from Hodgkin & Huxley, 1939; see also Hodgkin & Huxley, 1945; Curtis & Cole, 1940).

https://en.wikipedia.org/wiki/Squid

Hodgkin, A.L., and Huxley, A.F. (1939).
Action potentials recorded from inside a nerve fiber Nature, 144:710
Reprinted in the Journal of Physiology, 2012, A brief historical perspective: Hodgkin and Huxley

Neuron voltage dynamics

- The voltage inside a neuron is lower than outside. This is called the membrane potential and is between -70mV and -55mV.
- Inputs from other cells change the voltage, inhibitory cells decrease it, excitatory cells increase it.
- If the voltage exceeds a threshold of ~ -40mV the neuron sends out an action potential.
- Action potentials are also called spikes.

A Purkinje cell spiking

A retinal ganglion cell spiking

https://www.youtube.com/watch?v=KE952yueVLA

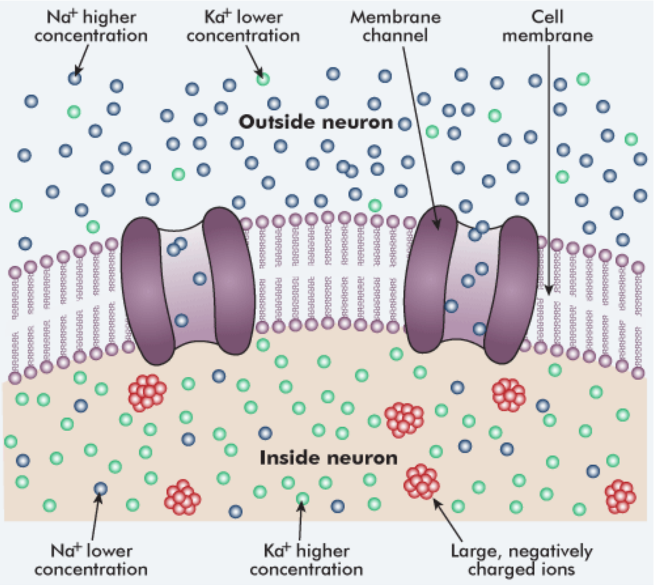
Axonal Membrane

The axonal membrane can let sodium and potassium ions into and out of the cell.

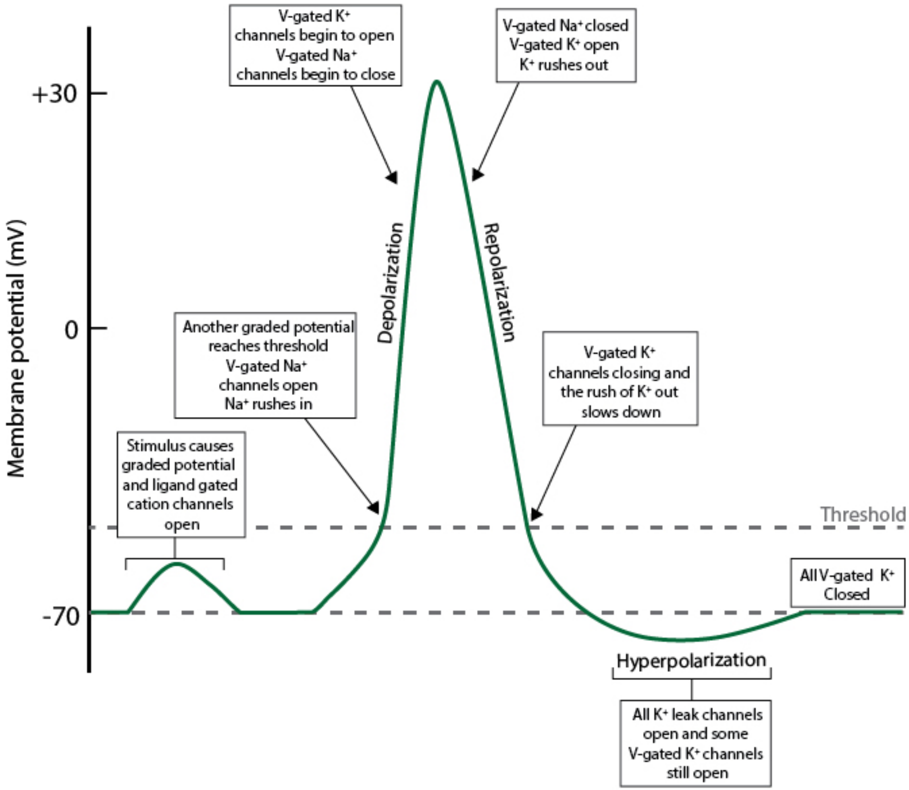
There are special channels in the membrane that allow sodium and potassium ions through.

Not all of these channels are open all of the time. They open and close depending on voltage and the flow of ions depends on the concentration of sodium and potassium inside and outside the cell and membrane voltage.

There will be more on this later on in the course.



Action Potential

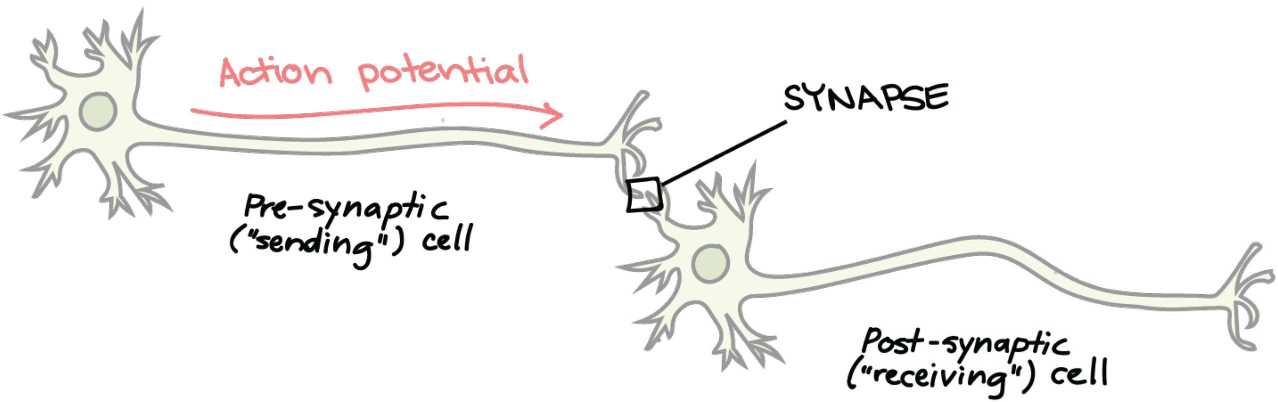


A refractory period occurs after each action potential. During the refractory period the neuron is unable to initiate another action potential.

https://content.byui.edu/file/a236934c-3c60-4fe9-90aad343b3e3a640/1/module5/readings/action_potential.html

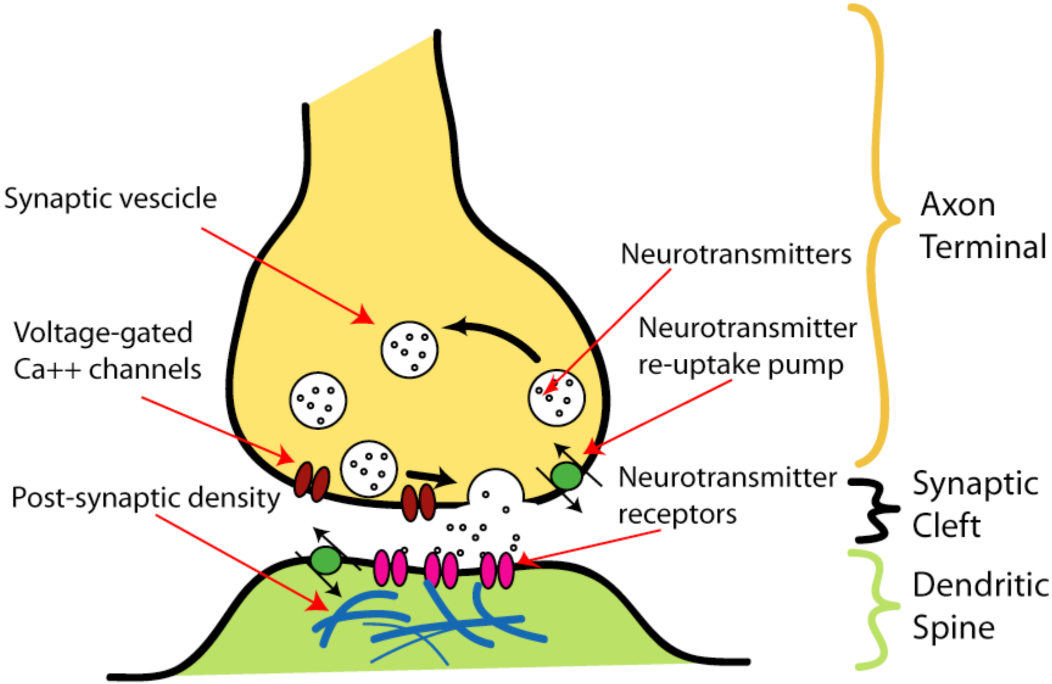
Chemical Synapse

Synapses are junctions between neurons that allow them to communicate. Synapses tend to occur between axon terminals in one cell and the dendrites of another cell. They permit the flow of information from one neuron to the next. Action potentials trigger chemicals to be released from the pre-synaptic bouton, which then have an affect on the post-synaptic bouton of another cell.



https://www.khanacademy.org/science/biology/human-biology/neuron-nervous-system/a/the-synapse

Chemical Synapse

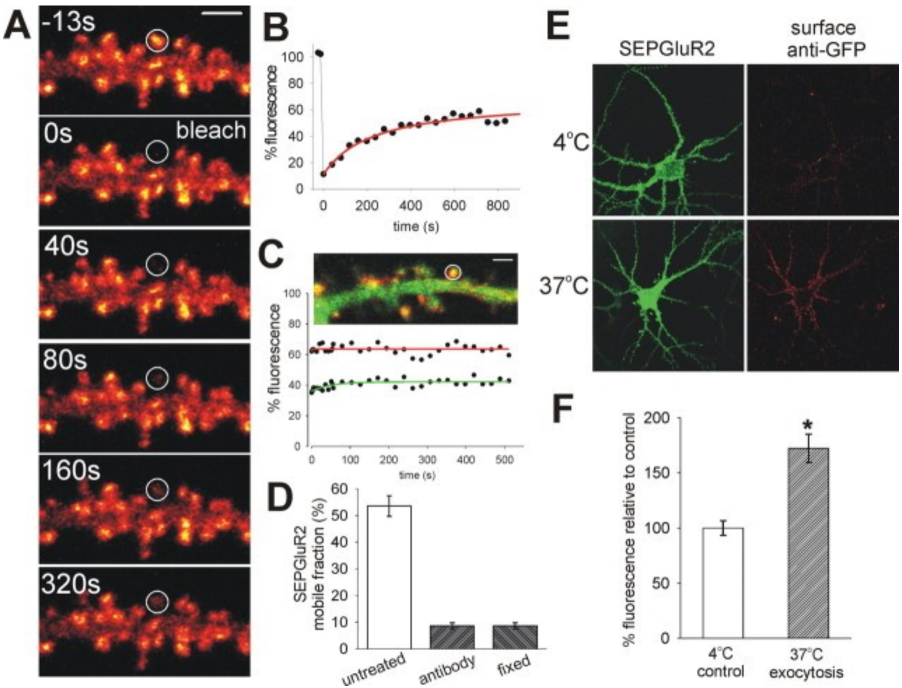


Pre-
synaptic
bouton

Post-
synaptic
bouton

http://upload.wikimedia.org/wikipedia/commons/b/b2/SynapseIllustration2.png

Dendritic Spines

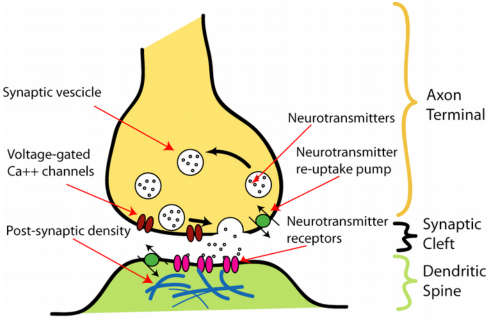


Neuronal dendrites are covered in tiny protusions, called dendritic spines, which are most likely to receive synaptic boutons.

Spines are dynamic, changing shape and number with need.

Dr Michael Ashby et al., J Neurosci. 2006 Jun 28; 26(26): 7046–7055.

Inhibitory and excitatory cells



Whether a cell is excitatory or inhibitory depends on the neurotransmitter that it releases.

Inhibitory cells cause a decrease in the voltage of the post-synaptic cell
- this decreases the likelihood that the post-synaptic cell will reach action potential threshold

Excitatory neurons cause an increase in the voltage of the post-synaptic cell
- this increases the likelihood of the post-synaptic cell reaching action potential threshold

Conclusions

Neurons are composed of a cell body, dendrites and an axon

Dendrites receive information from other cells (often on dendritic spines) and axons send out information to other cells

Information is sent down axons to the axon terminal in the form of voltage changes (electrical signals)

The synapse converts this electrical signal (the action potential) to a chemical signal (neurotransmitters) which gets received by nearby cells

Neurons can either excite or inhibit their target cells

Neuroscientists are able to record these voltage changes and computational neuroscientists are able to model these changes to gain a better insight into how the brain works