Biologically Inspired Computation

Dr Marta Vallejo

m.vallejo@hw.ac.uk

Complementary Material I

Introduction to Neurocomputing:

- Neural Computation and the Brain
- What is the Brain?
- The Nervous System
- Brain Organisation
- Biological Neural Network
- Neuron
- Neuron Connectivity
- Neuron: input signals
- Ionic Channels
- Spike Propagation
- The Synapse
- Long-term Potentiation
- Brain Organisation: cerebral cortex

Neural Computation and the Brain

"The human brain is a highly complex, non-linear and parallel computer (information processing system)"

What is the human brain good at?

- Speech recognition
- Facial identification
- Motor control
- Reading emotions
- Recognising images
- Driving a car...

If we can copy its design, perhaps we can solve these 'hard' problems

What is the Brain?

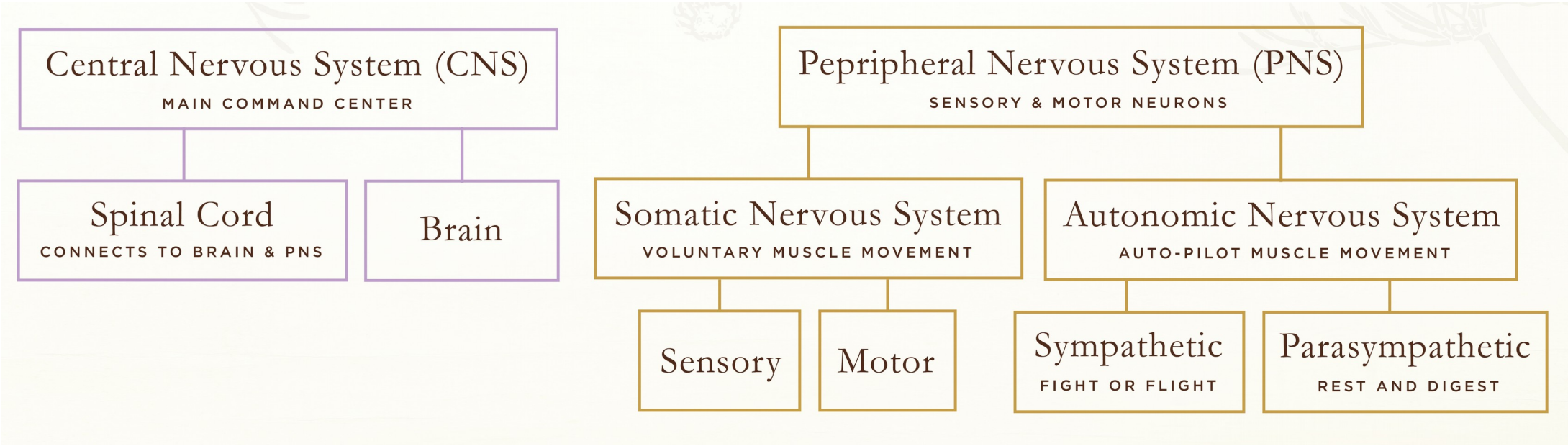
Brain: complex network of nerves and cells that coordinates actions by transmitting signals to the body.

- How is our brain organised?
- How does our brain process all the information it receives/perceives?
- What are the main mechanisms behind the cerebral functioning?

The Nervous System

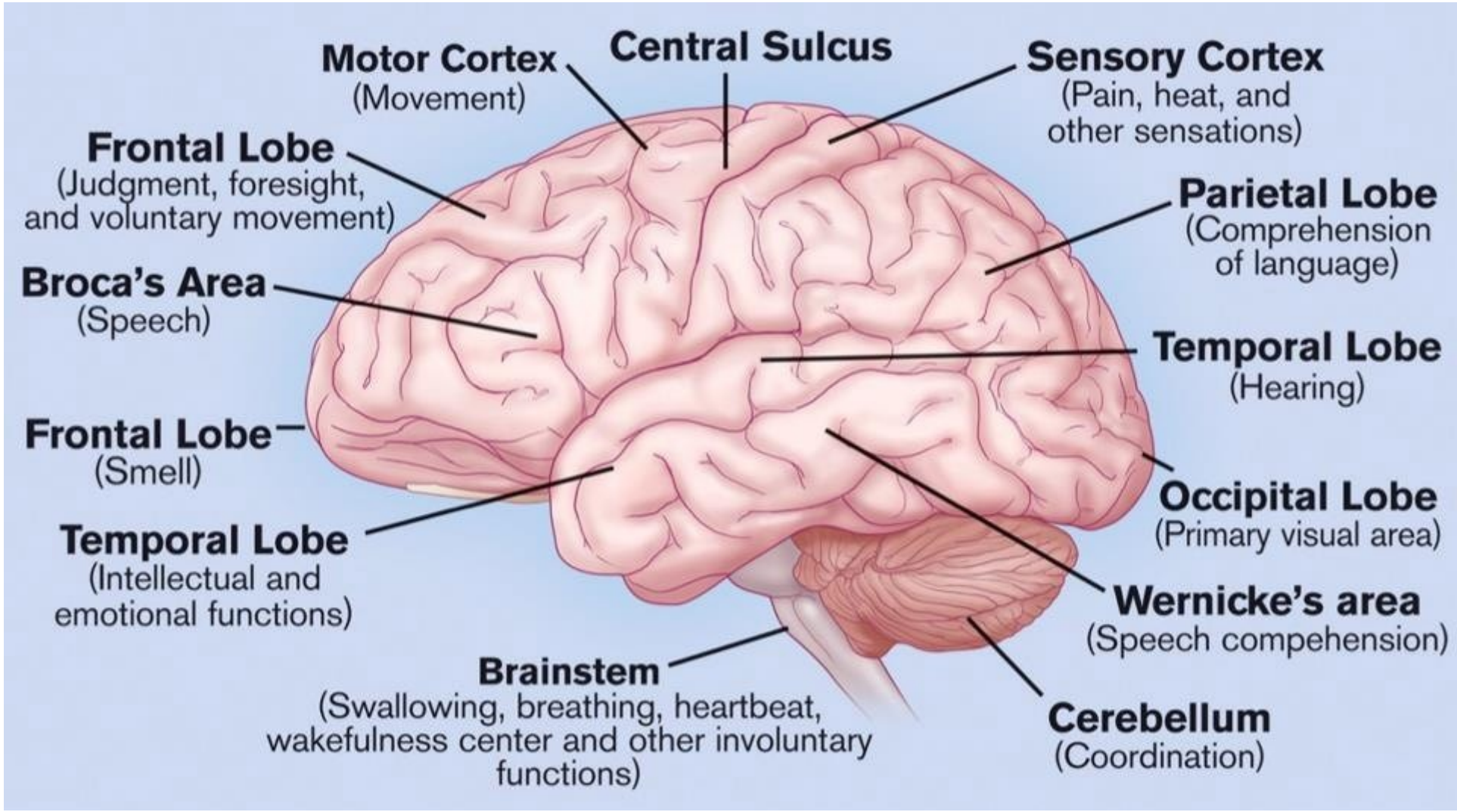
- The brain is part of the nervous system (NS).
- The main role of the NS is to process internal and external inputs (sensory stimuli).

The Nervous System can be organised in different levels of complexity



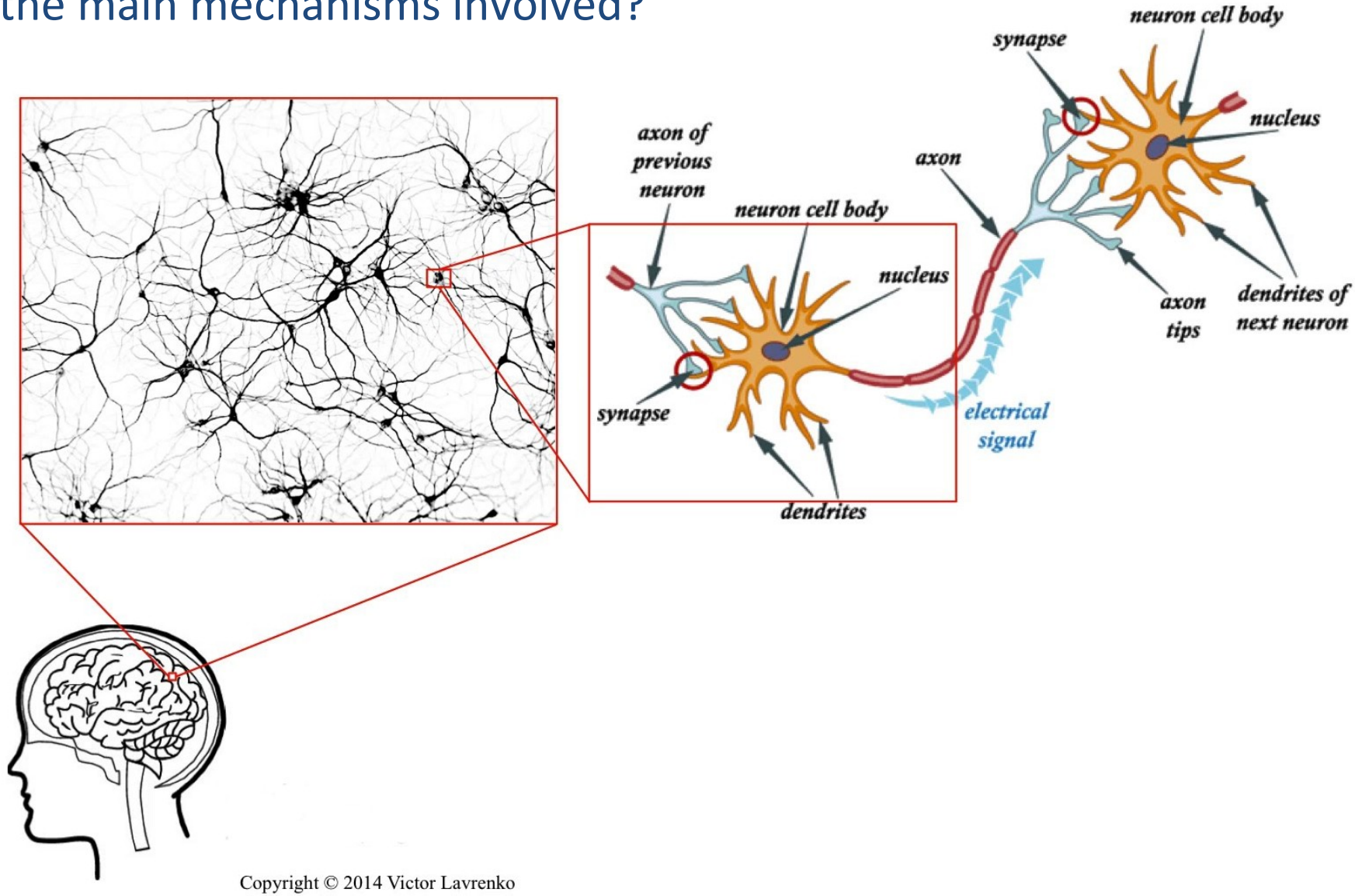
Brain Organisation

Organised in functional areas:



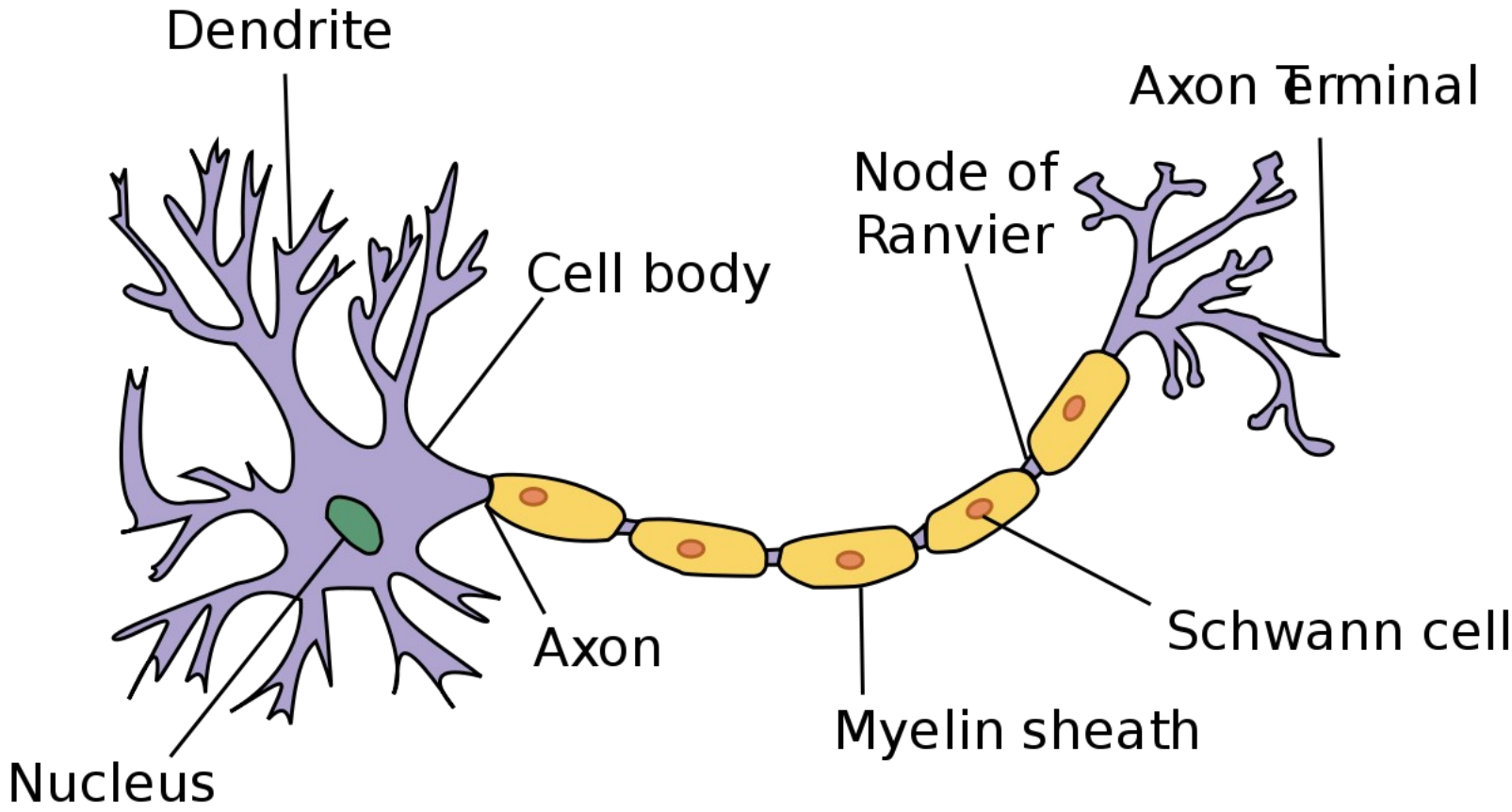
Biological Neural Network

How does our brain process all the information it receives/perceives and what are the main mechanisms involved?



Neuron

Neuron is the fundamental structural & functional unit of the brain.



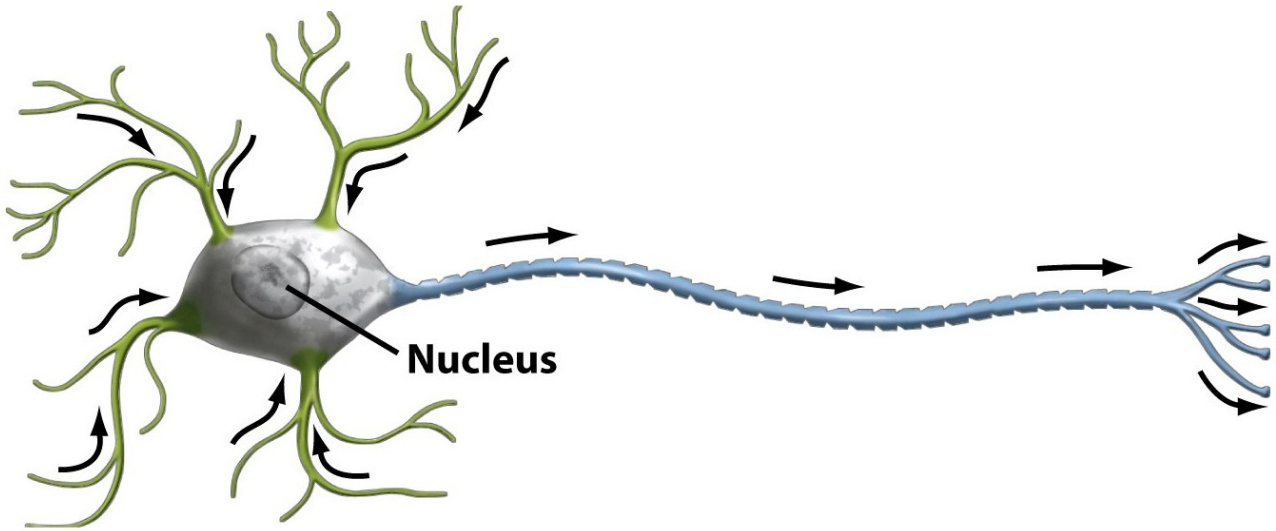
The human brain contains around 80 to 120 billion of neurons. They are discrete cells, not continuous with one another. They communicate by contact.

Neuron Connectivity

A neuron is capable of receiving input stimuli from 1,000 other neurons and propagate (or not) these signals to 1,000 other neurons.

Switching time of a few milliseconds (much slower than a logic gate), but connectivity hundreds of times higher

Information flows from dendrites to the axon via the cell body. This electrical information is called **spike** or **action potential**.

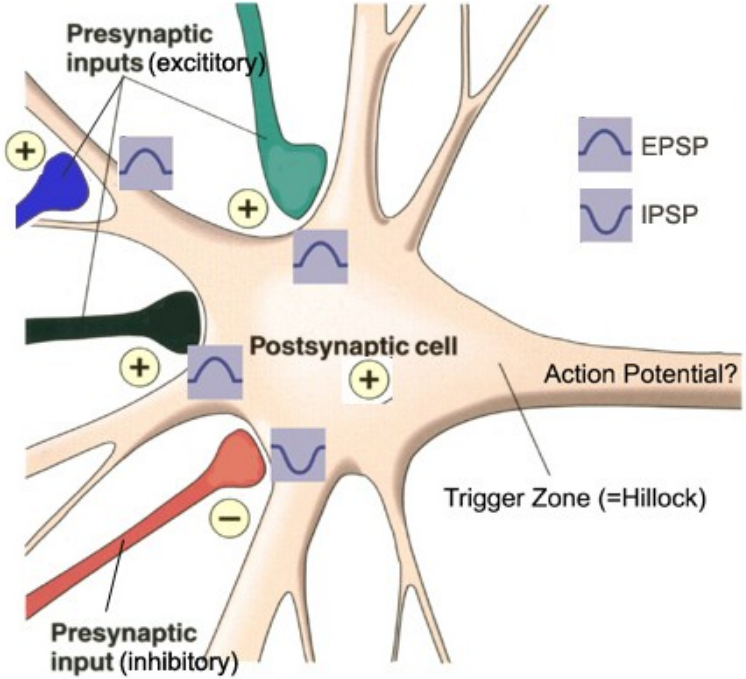


Neuron: input signals

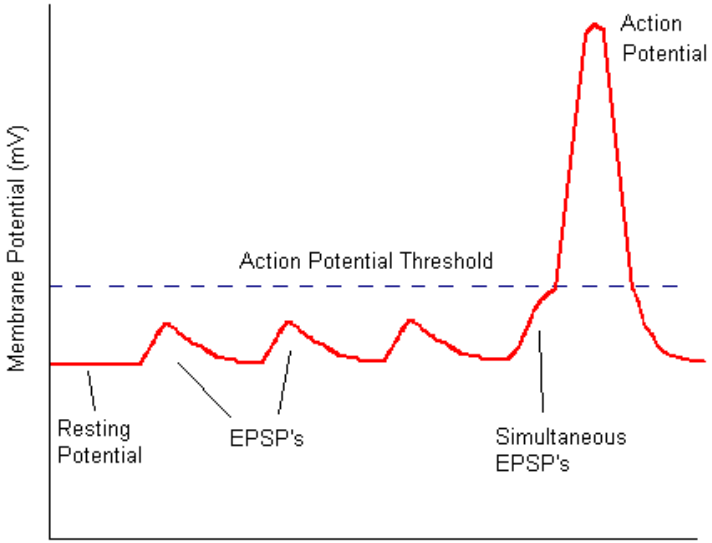
- A neuron receives input signals of various nature from the dendrites, which are **summed**;

EPSP: excitation pre-synaptic potential

IPSP: inhibitory pre-synaptic potential

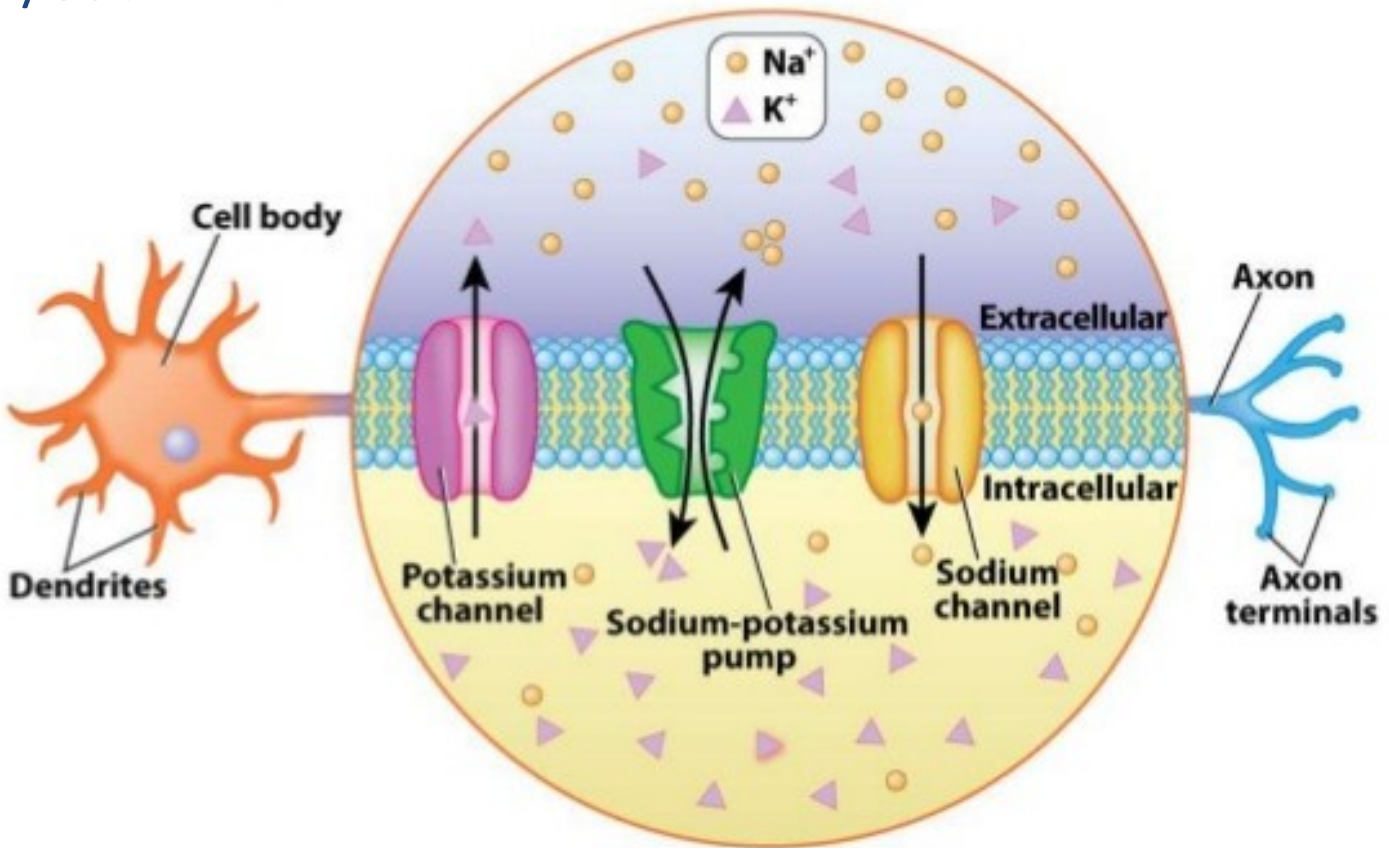


- If the excitatory influence is predominant (threshold), the neuron is activated and generates informational messages to the output synapses;



Ionic Channels

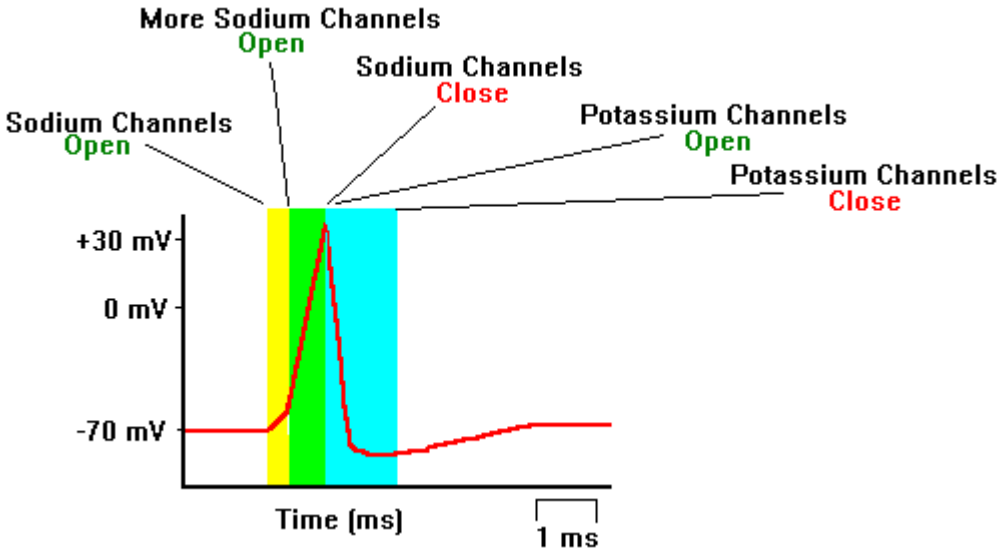
Cell membrane contains some gates called **ionic channels** that allow **specific** ions to flow in/out.

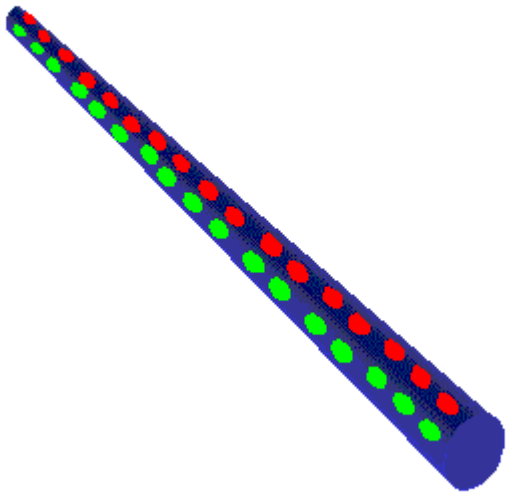


They can change the “open/close” property according to conditions in their environment allowing **neuronal signalling.** Opening causes changes in the local membrane potential: a **spike** or **action potential**

Spike Propagation

With the open and close of the ionic channels a spike is propagated along the axon.





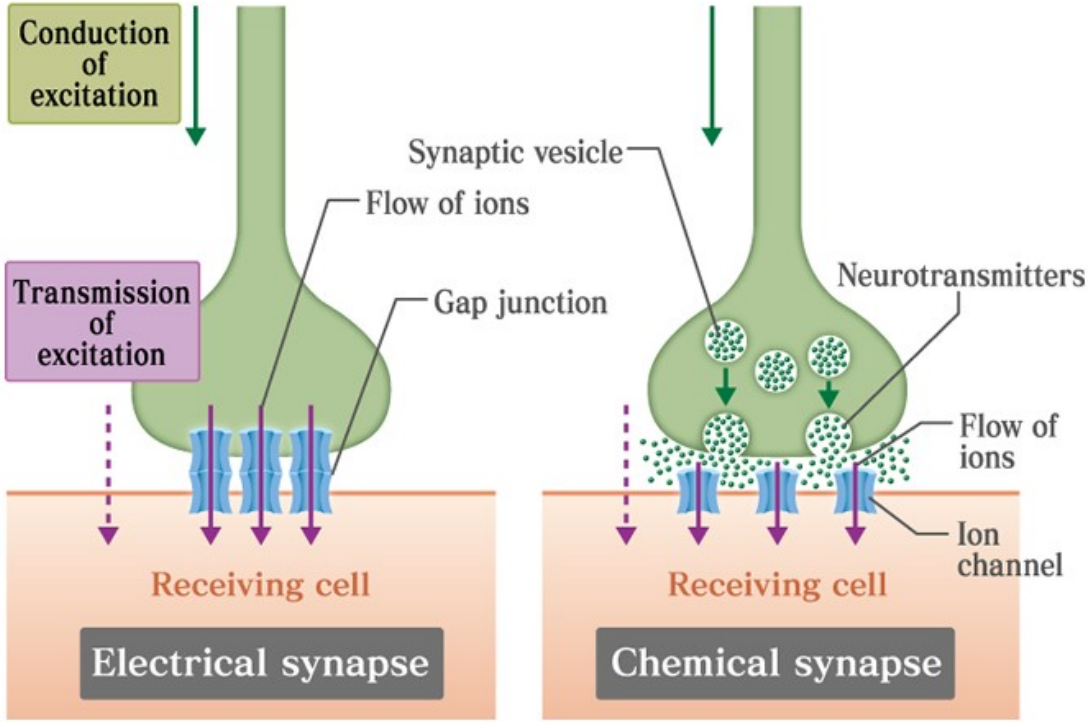
http://people.eku.edu/ritchisong/301notes2.htm

From https://psych.hanover.edu/Krantz/neural/actpotanim.html

The Synapse

The **axon** splits into thousands of branches. At the end of each branch, a structure called a **synapse** serve as a junction between two neurons

1. 2.



Electrical
↓
Chemical
↓
Electrical

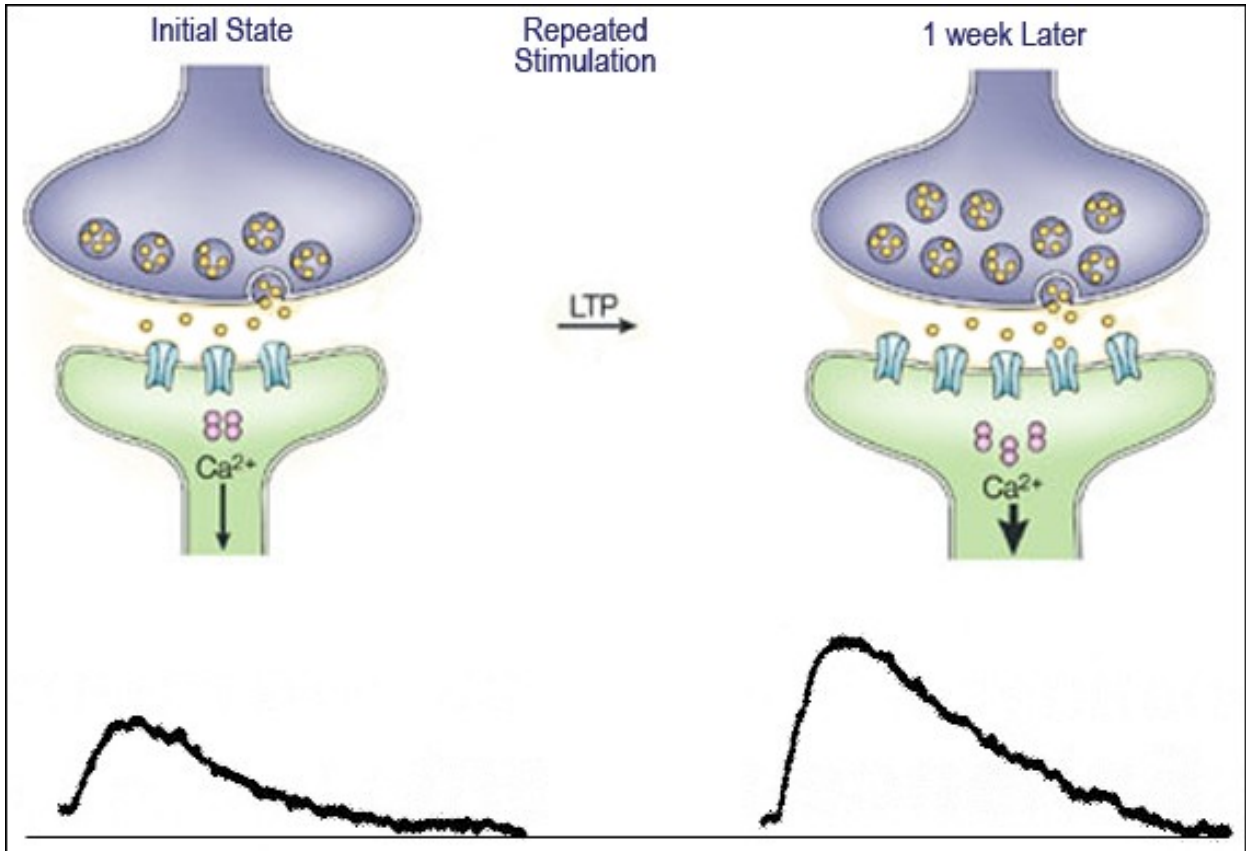
Number of receptors can change

Fast connections:
for synchronisation

Long-term Potentiation

Synaptic strength between two neurons results from repeatedly stimulating them synchronously.

Increasing the numbers of receptors at the synapse, then more neurotransmitters can be released from the presynaptic neuron, allowing for a stronger signal.



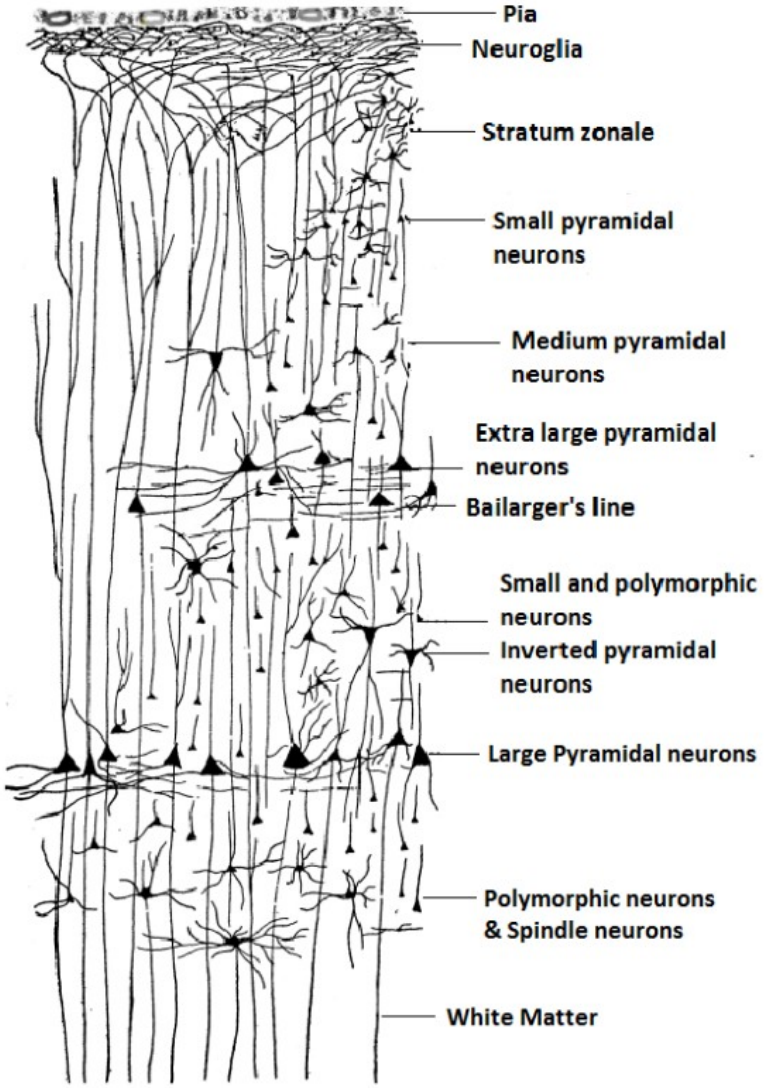
Synaptic Plasticity

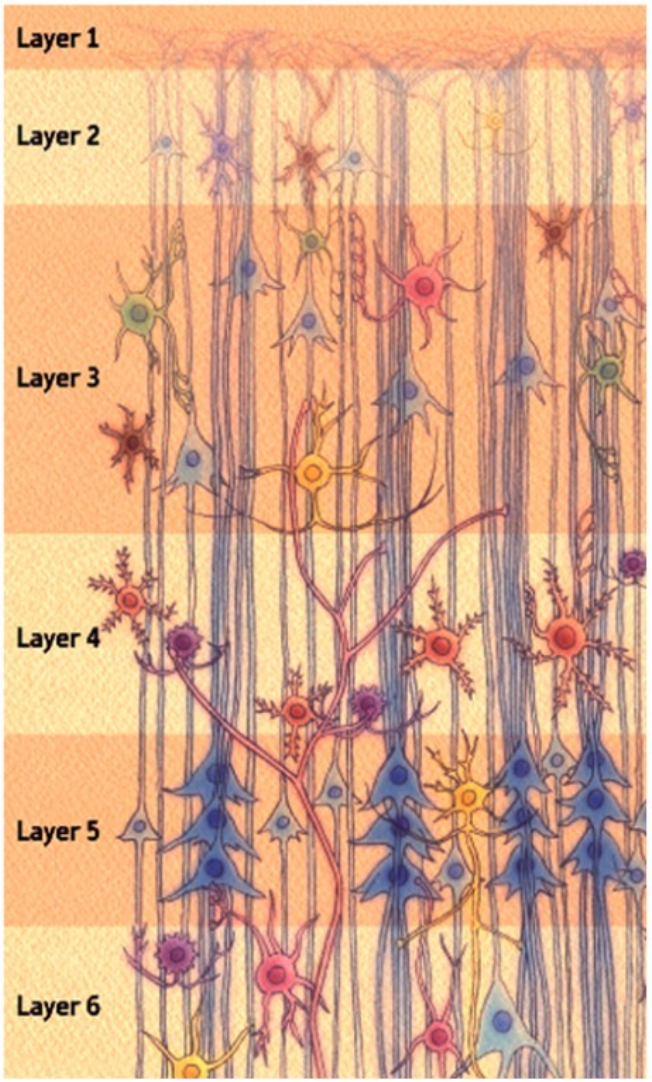
Crucial mechanism in learning and memory.

Opposite behaviour is called **Long-term depression**

Brain organisation and information processing in network of neurons

Cerebral Cortex: A layered sheet of Neurons





≈ 30 million of neurons

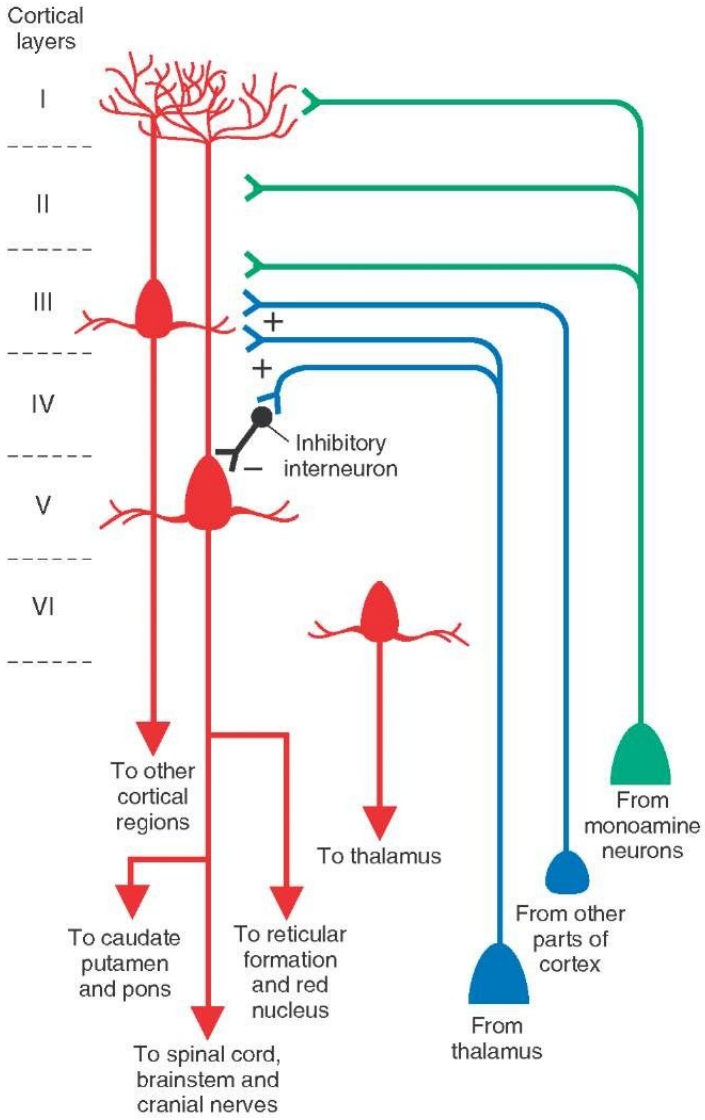
Each neuron ≈ 10,000 synapses

≈ 300 trillions of connections in total

Connections are represented as scalar values that measure '**strength**'

Cerebral Cortex

6 layers of neurons: relatively uniform in structure.



Each neuron grouping might have complex behaviours and functions which can not be observed by analysing single neurons.

Massively parallel computation & adaptive connectivity

Brain is very good at solving ill-posed problems (speech, vision)

To know more about brain connectivity:

http://fdeligianni.site/basics.html