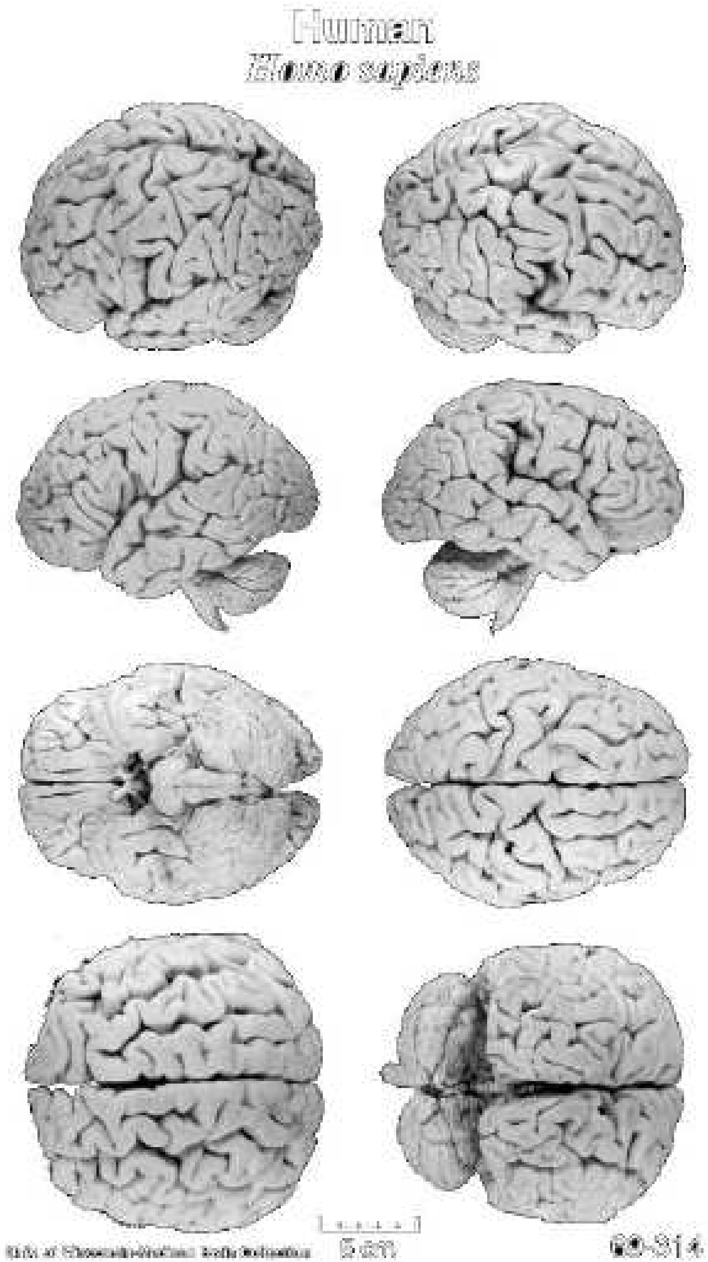
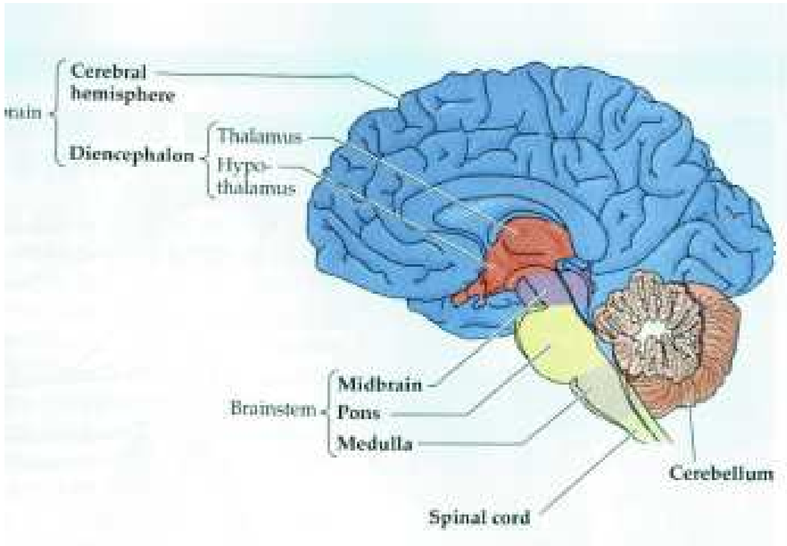
Goal:

- To understand the gross organization of the brain.
- To understand the basic computational units of the brain.

Views of the Human Brain



Structure of the Central Nervous System



Functional segregation

Spinal cord (Rückenmark) Gathers info from sensors (e.g., skin, muscles, joints). Distributes motor commands. Processes motor reflexes.

Brain stem (Hirnstamm) Controls autonomous functions, e.g., digestion, respiration, heart rythm. Visual and auditory reflexes.

Cerebellum (Kleinhirn) Fine motor skills, motor learning.

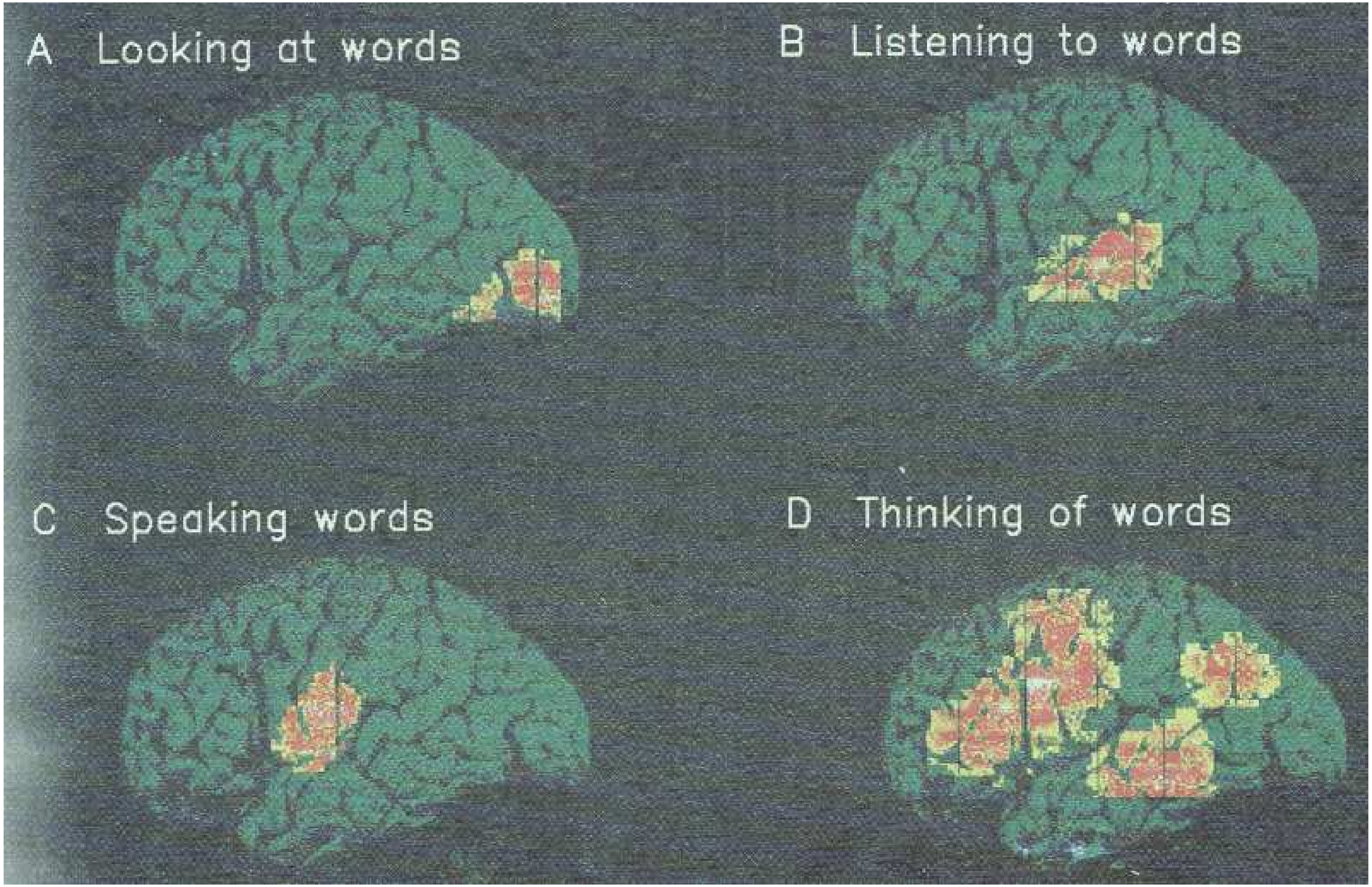
Diencephalon (Zwischenhirn)

- **Thalamus** Relay for all sensory input to the cortex
- **Hypo-Thalamus** Autonomous and hormonal functions, metabolic functions.

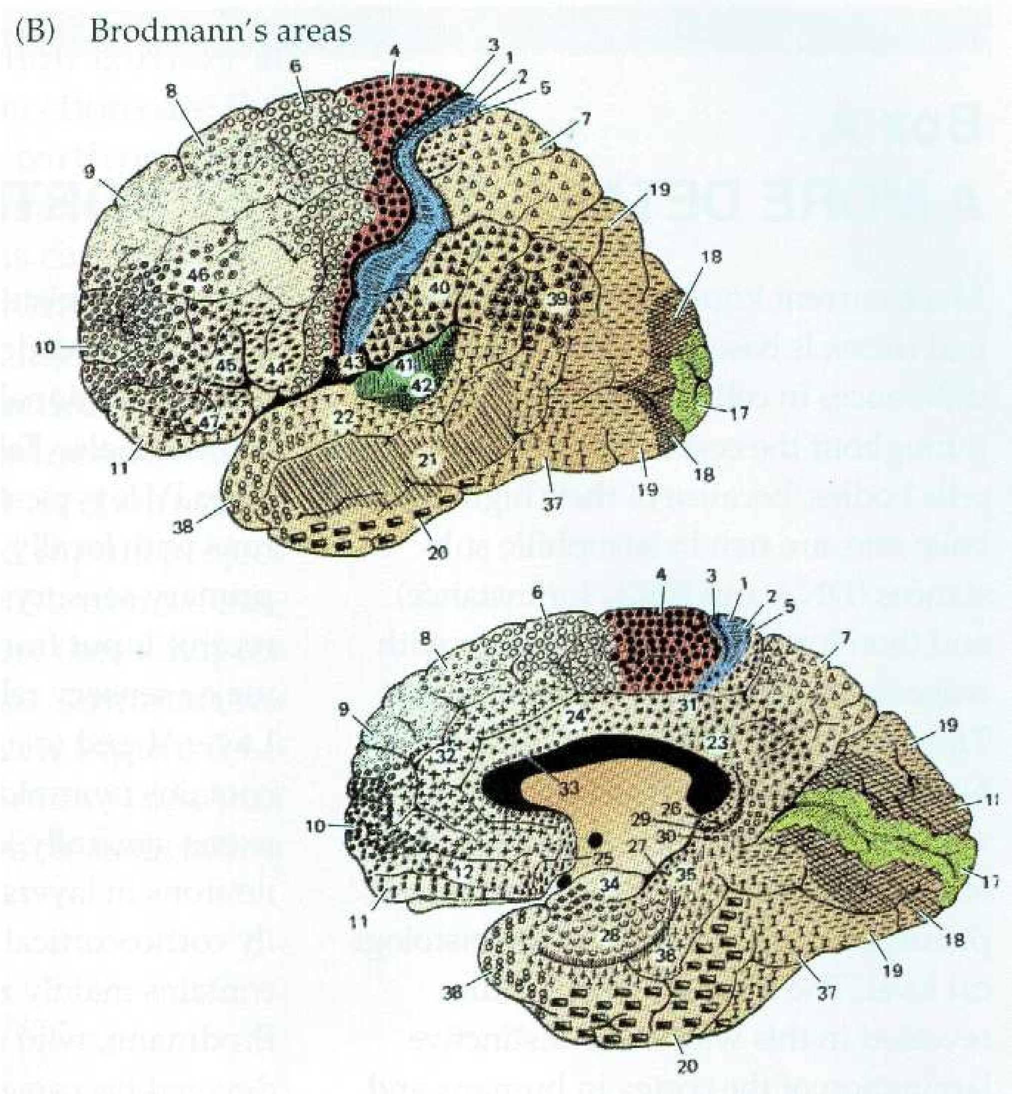
Prosencephalon (Vorderhirn)

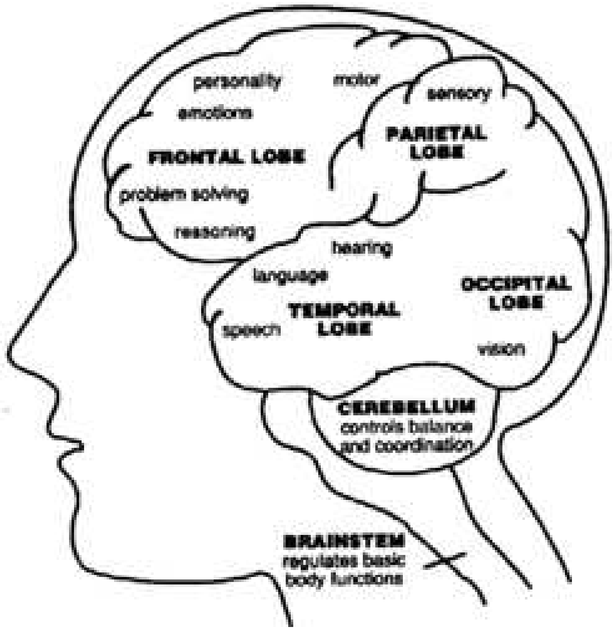
- **Hippocampus** Memory consolidation
- **Amygdala** Emotions
- **Cortex (Kortex)** Higher cognitive capabilites

Cortex and Behavior



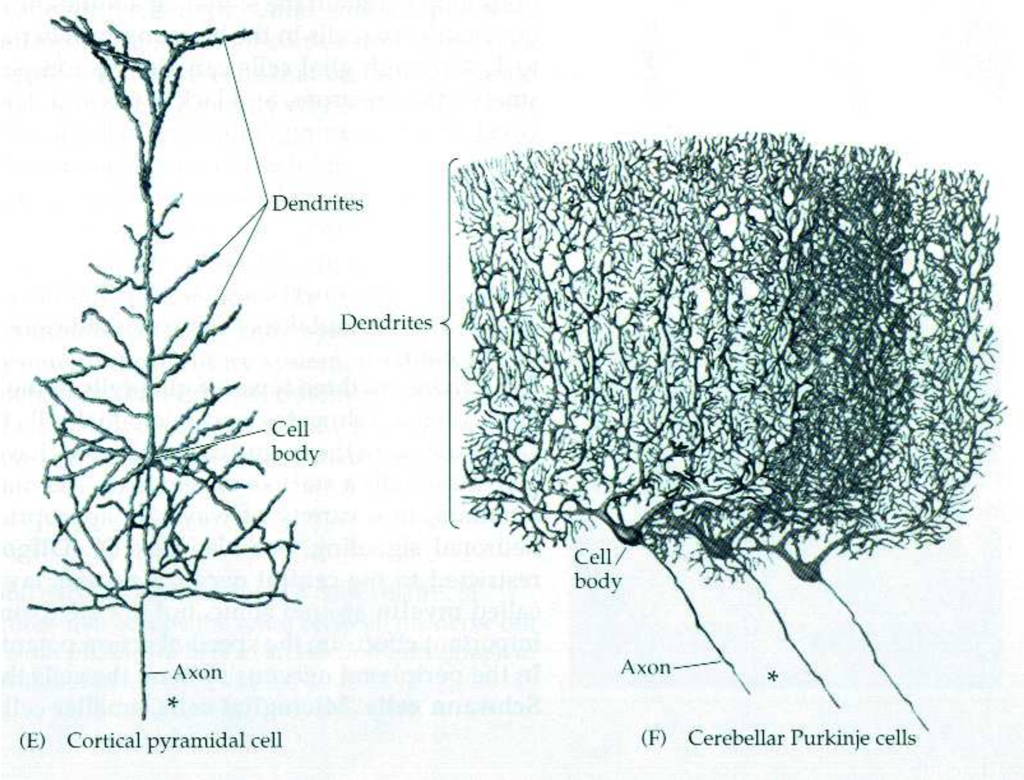
Brodmann Cortex Areas





Two Types of Cell Types in the Nervous System

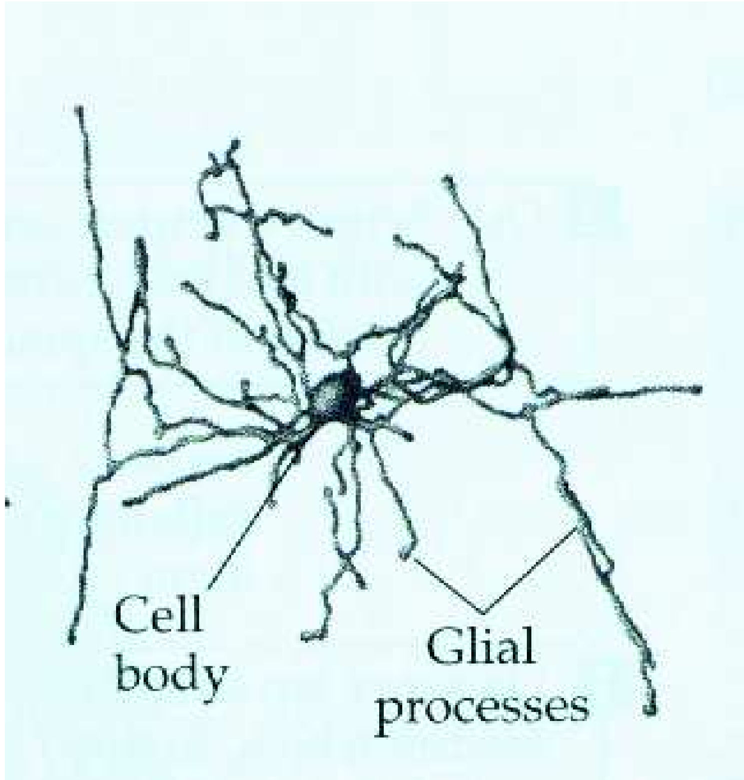
Nerve cells aka neurons



(E) Cortical pyramidal cell
(F) Cerebellar Purkinje cells

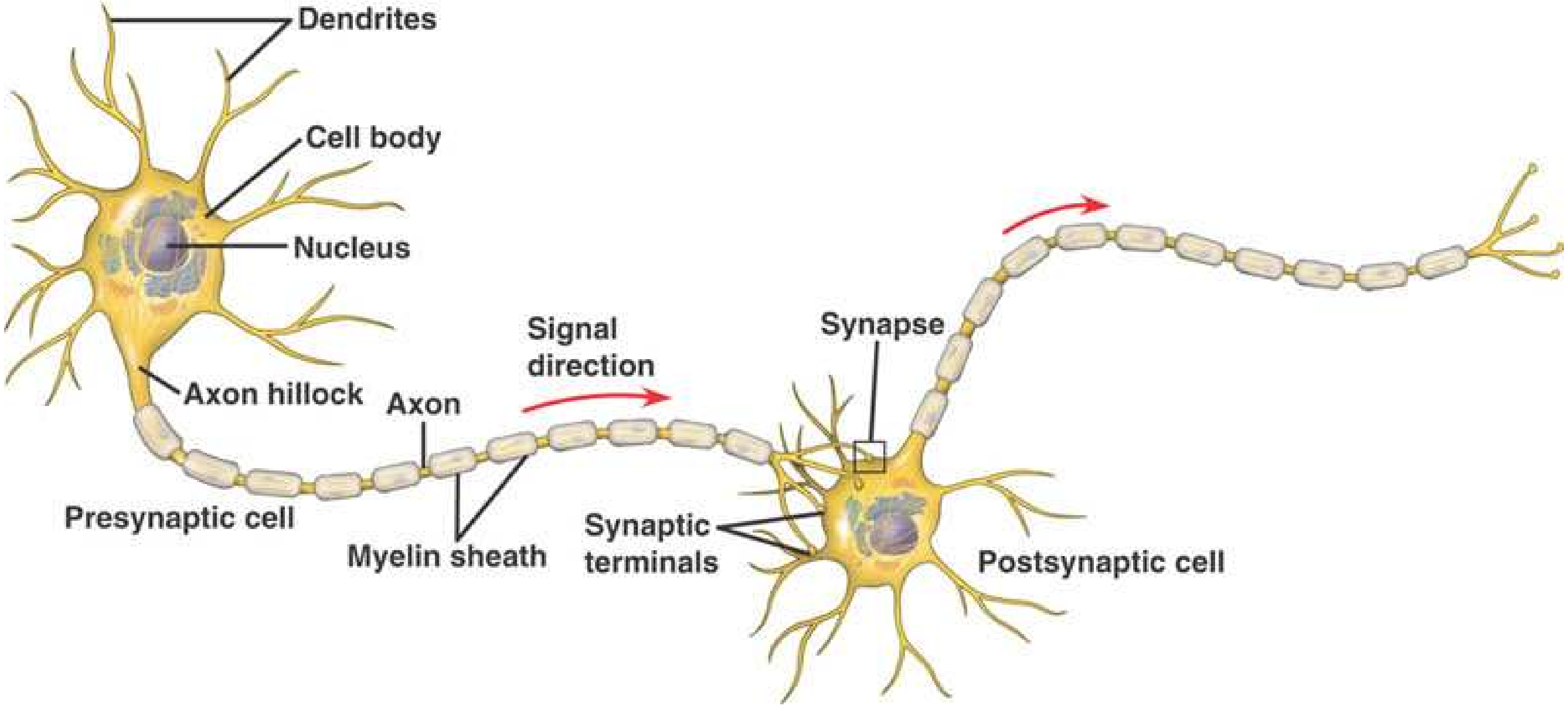
Information processing

Glial cells

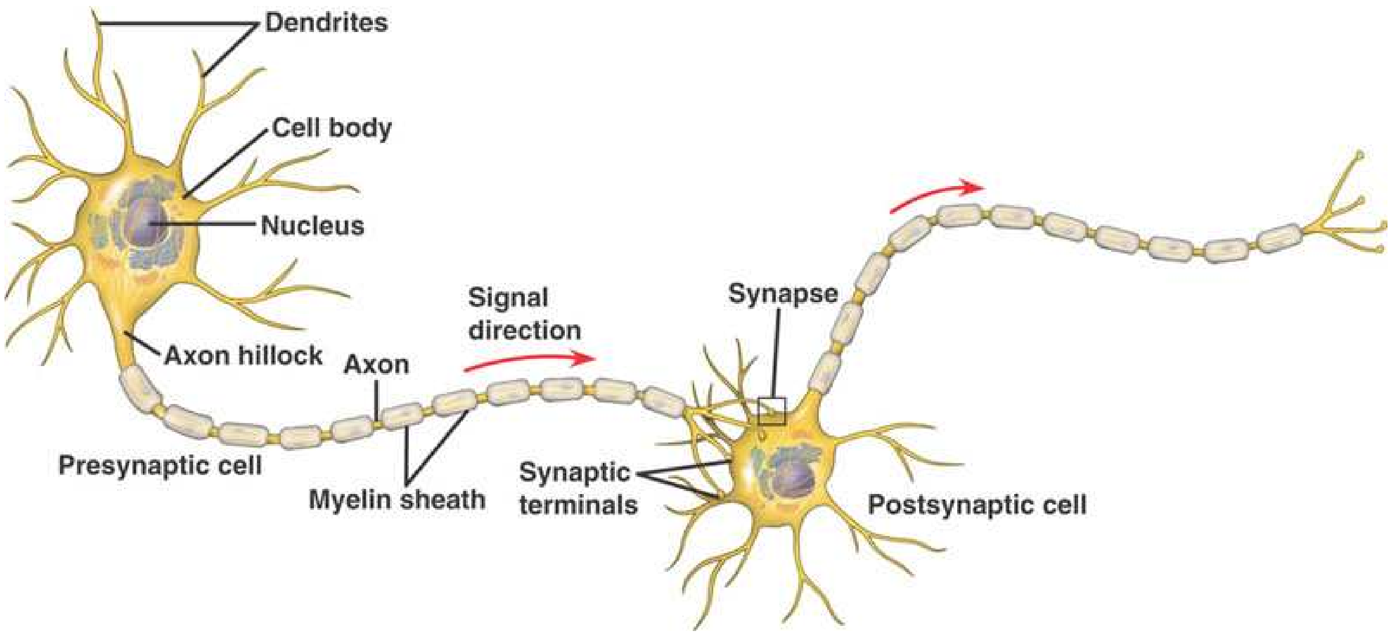


supporting cells

Neurons


Dendrites
Cell body
Nucleus
Axon hillock
Axon
Signal direction
Synapse
Presynaptic cell
Myelin sheath
Synaptic terminals
Postsynaptic cell

Neurons



Soma (Zellkörper) Contains the nucleus; metabolism

Dendrites (Dentriten) Input area of the cell. Gathers signals of *presynaptic* cells.

Axon Output area of the cell. The axon conducts the signals of the cell to the *postsynaptic* cells (length: 0.1mm to 2m; thickness: 0.0002mm to 0.02mm).

Axonhilloc Where the axon meets the soma.

Synapses (Synapsen) Signal transfer from the presynaptic cell to the postsynaptic cell.

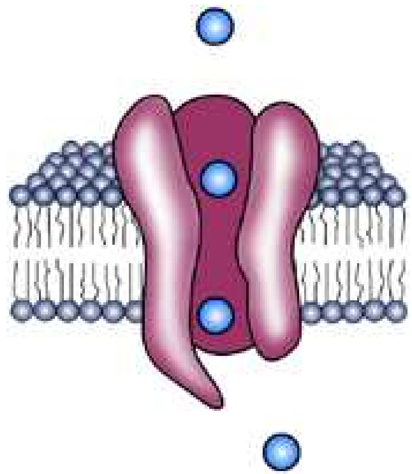
Neurons: Membrane and Ions

Membrane The cell membrane is the border between the inside of the cell (intracellular) and the outside of the cell (extracellular).

Ions Both, the intracellular as well as the extracellular fluid consist of water with dissolved ions (K, Na, Ca, Cl).

Membrane potential Because the concentrations of ions inside the cell are different than the concentrations outside, the cell is electrically charged. The Membrane potential is the potential of the intracellular fluid w.r.t the extracellular fluid. It is usualy around -65 mV.

Neurons: Channels and Pumps



The cell membrane itself is not permable to ions, however, in the membrane there are

Ion pumps which pump ions into and out of the cell, thereby keeping the membrane potential.

Ion channels

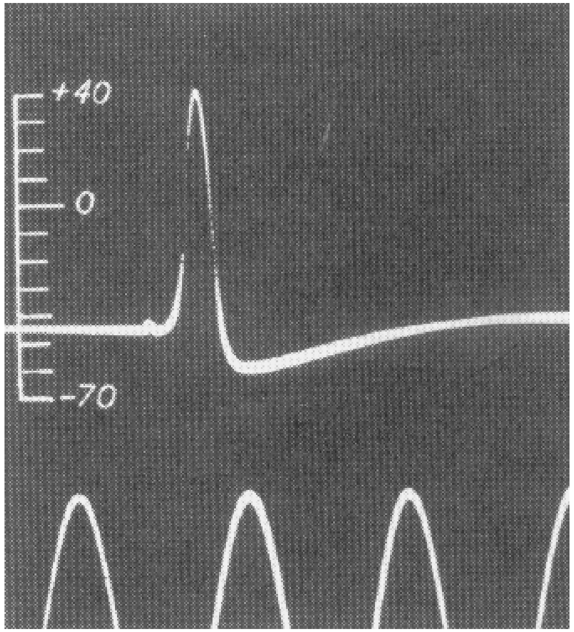
- They open under certain conditions.
- When open, they let certain ions traverse the membrane.
- Opening of channels therefore leads to local changes in the membrane potential.

Spikes: The entity of information transfer

Electrical signals which are transmitted via the axons are called *action potentials*.

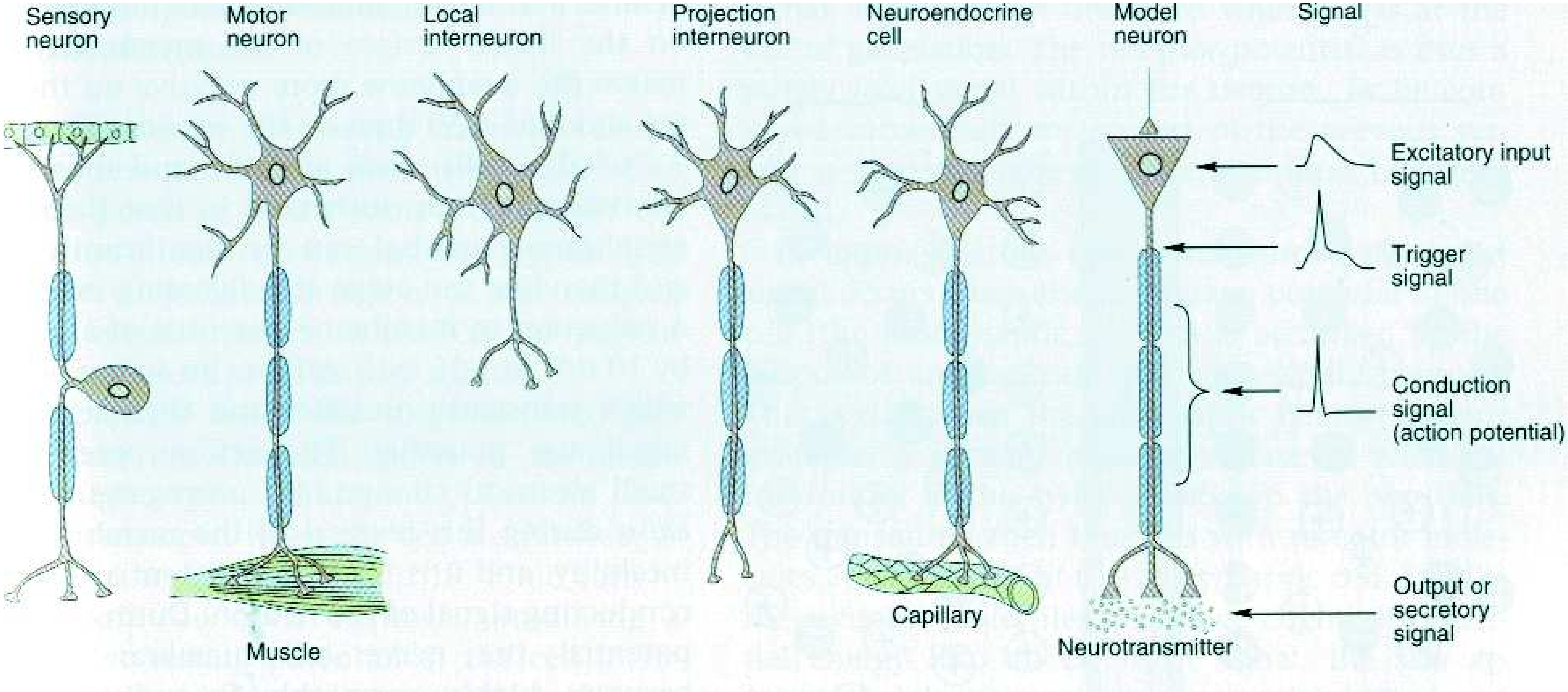
Action potentials are fast (1ms width) and stereotypical voltage pulses of about 100mV amplitude.

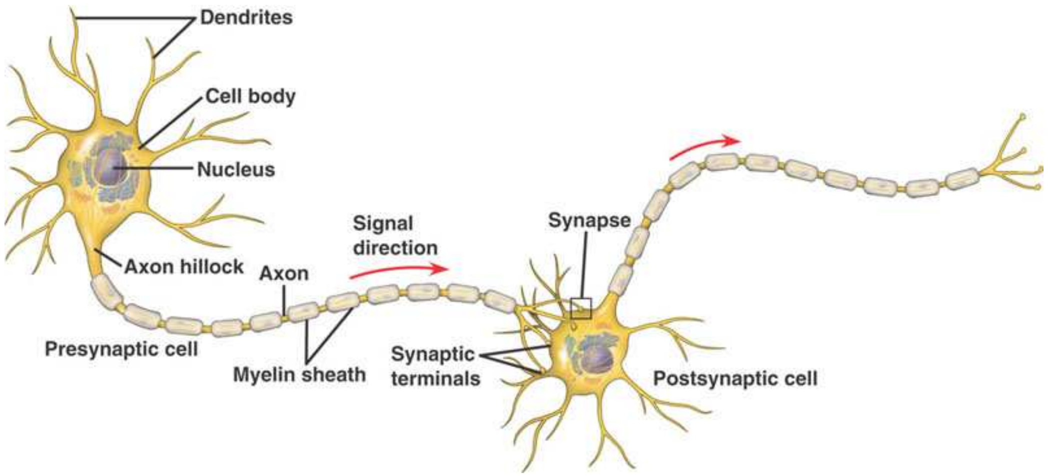
The information content of a spike is not given by its shape but by its occurence and probably the time of occurence.



First measurement of an action potential by Hodgkin and Huxley, 1939.

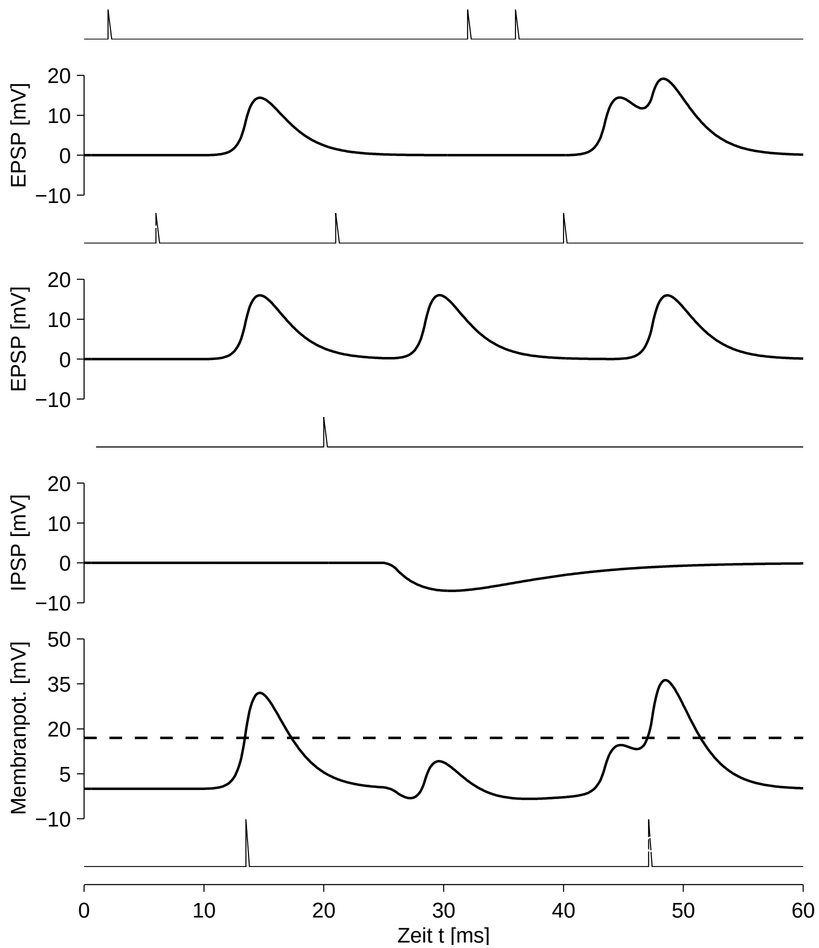
General Function of Nerve Cells



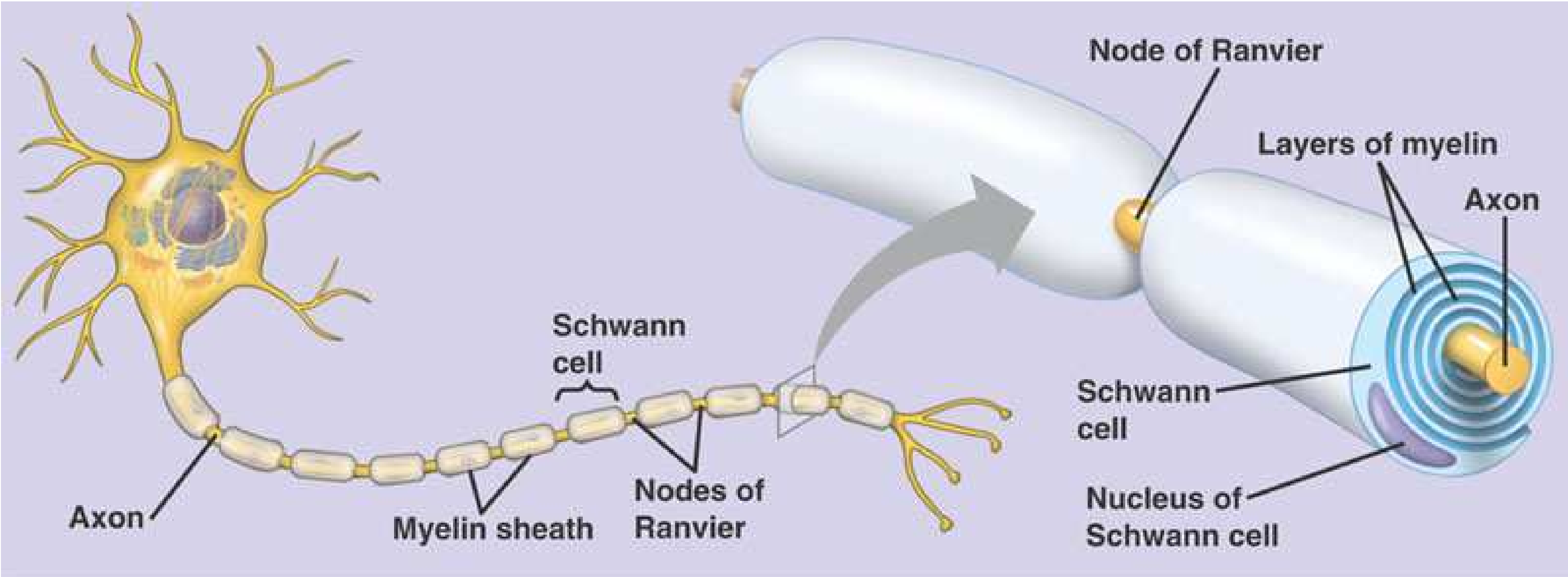


1. Analog signals (voltage changes) are produced at the input region.
2. As those voltages are conducted towards the soma, they are integrated (nonlinearly summed up).
3. It is decided at the Axonhilloc whether an action potential is generated.
4. The action potential is conducted to the synaptic terminals via the axon.
5. The synaptic terminals release neurotransmitters.
6. Those neurotransmitters cause a local voltage change in the postsynaptic neuron.

A Simple Neuron Model



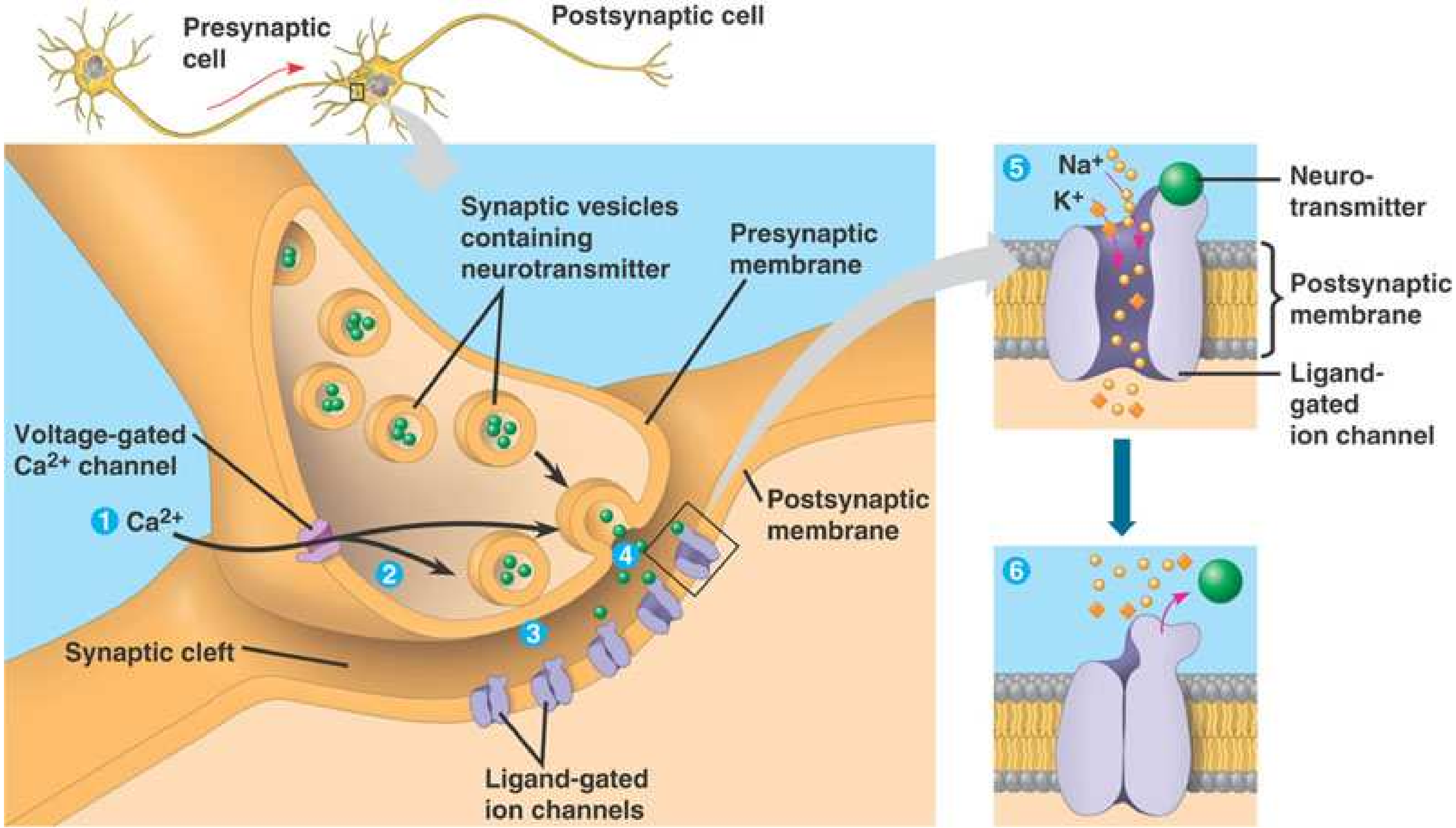
Myelinated Axons



Long-range axonal connections are myelinated for the sake of faster signal propagation.

A newer hypothesis is that myelination *controls* signal propagation speed.

Synapses


Presynaptic cell
Postsynaptic cell
Synaptic vesicles containing neurotransmitter
Presynaptic membrane
Voltage-gated Ca2+ channel
1 Ca2+
2
3
4
Postsynaptic membrane
Synaptic cleft
Ligand-gated ion channels
5 Na+
K+
Neuro-transmitter
Postsynaptic membrane
Ligand-gated ion channel
6

Two Types of Neurons

A neuron is either excitatory or inhibitory.

Excitatory cells

- They excite their postsynaptic targets (i.e., bring them closer to firing).
- Defined by the neurotransmitter which is used for synaptic transmission: e.g. Glutamate, Ach.
- A potential evoked is called “excitatory postsynaptic potential”, EPSP.

Inhibitory cells

- They inhibit their postsynaptic targets (i.e., tend to keep them from firing).
- Defined by the neurotransmitter which is used for synaptic transmission: e.g. GABA (gamma amino butter acid).
- A potential evoked is called “inhibitory postsynaptic potential”, IPSP.

Networks of Neurons

Neurons are strongly interconnected, each receiving input from approx. 10000 other neurons (in cortex). Neuronal connectivity shows highly structured randomness.

Drawing of Ramon y Cajal showing neurons in cortex.

Some numbers

In the human brain, there are

- $\approx 10^{12}$ neurons
- $\approx 10^{15}$ synapses
- $\approx 10^{5}$ neurons per 1 mm^3
- $\approx 10^{9}$ synapses pro 1 mm^3
- ≈ 4km axons per 1 mm^3
- ≈ 500m dendrites per 1 mm^3
- $\approx 10^{4}$ inputsynapses per neuron (in cortex)
- $\approx 10^{13}$ glial cells.