WARSAW UNIVERSITY OF TECHNOLOGY
FACULTY OF MATHEMATICS
AND INFORMATION SCIENCE

Neural Networks

Lecture 2

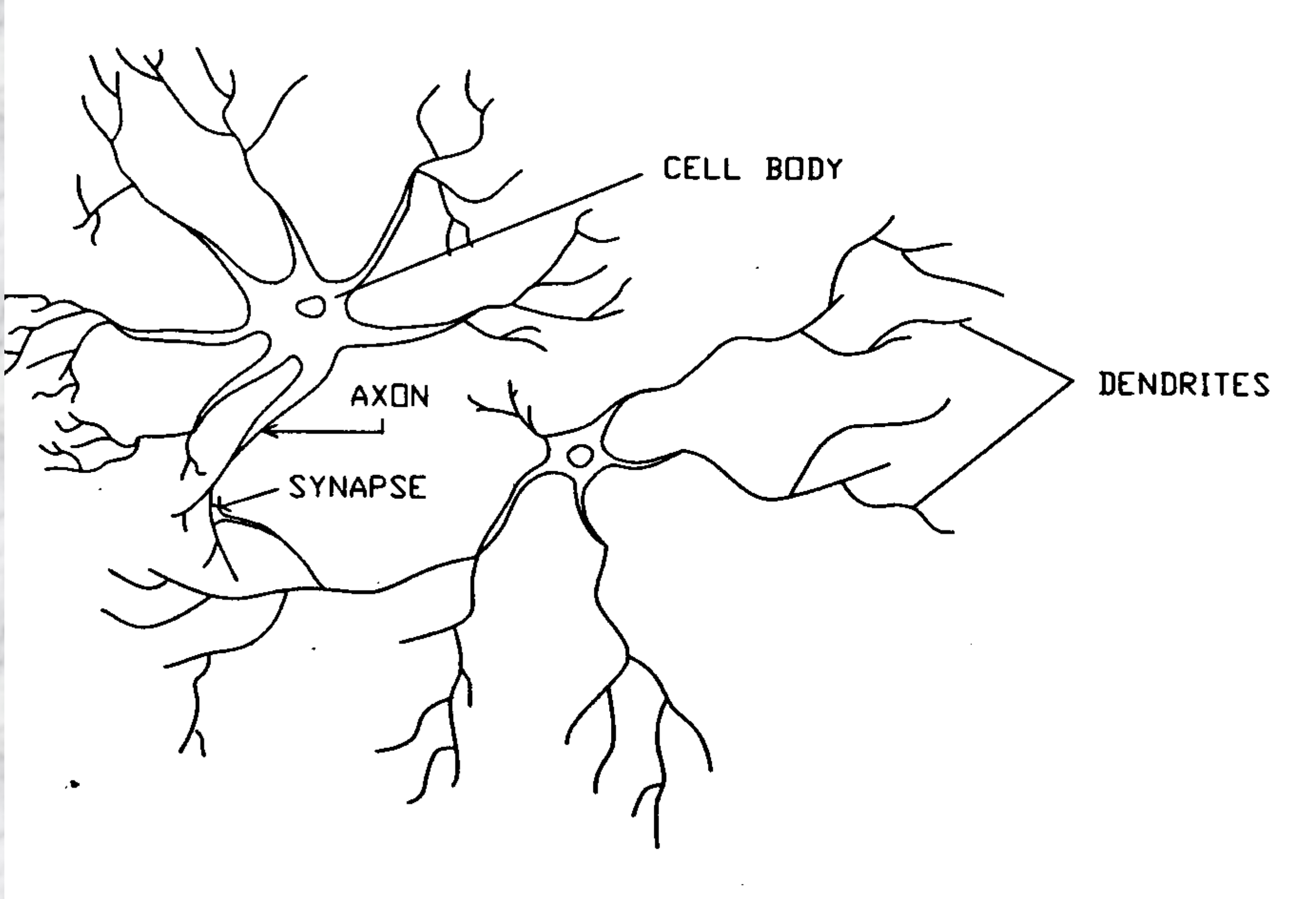
Human Nervous system

Biological and Neurological Background

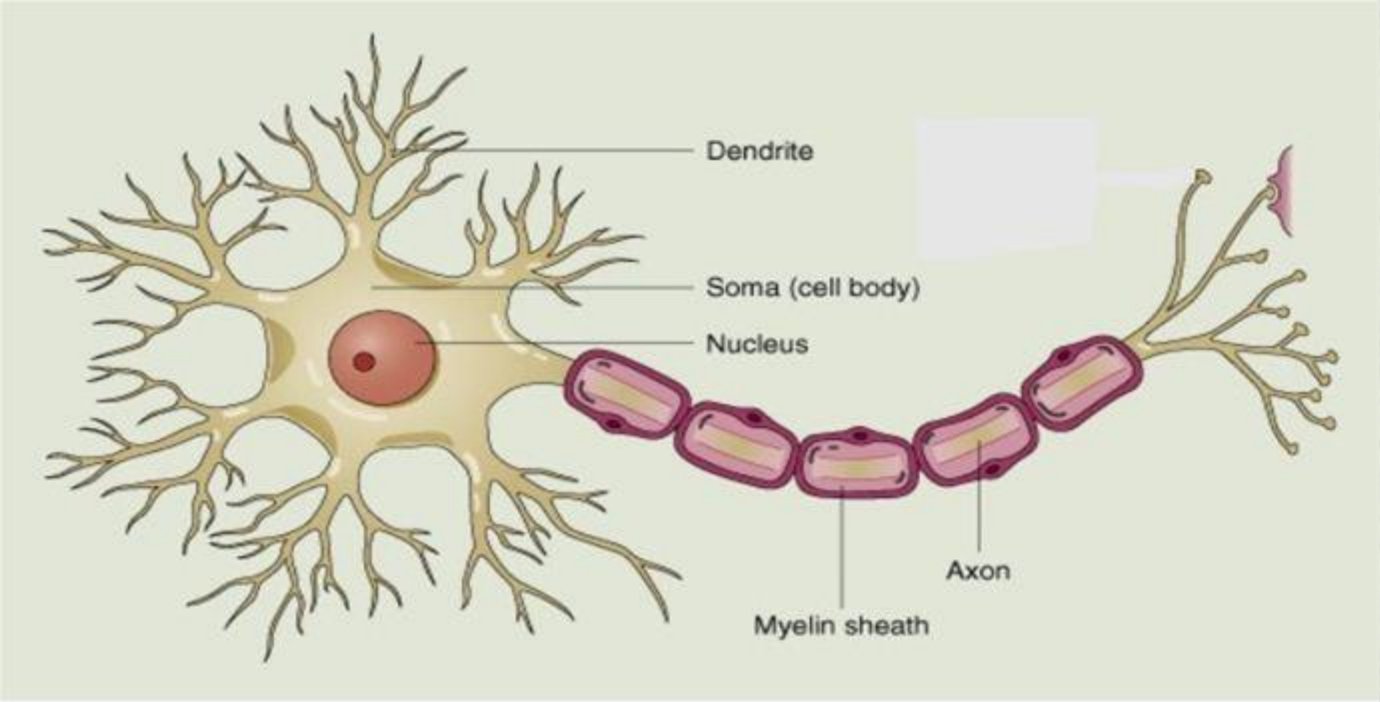
Neurons

- most specialized cells
- characterized by lack of abilities of reproduction and regeneration
- lifelong functioning, after 20 – every day about 10 000 neurons dies

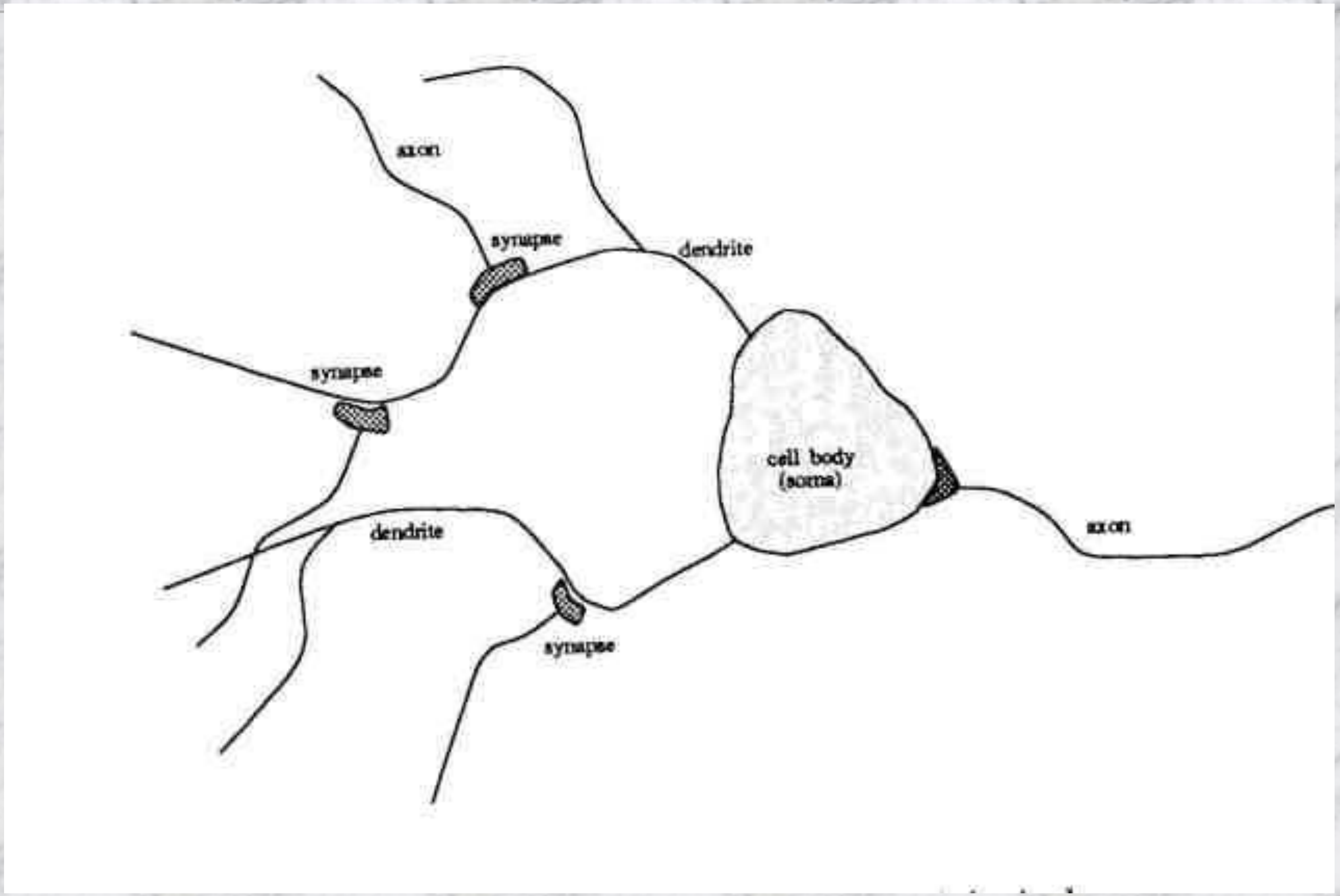
Structure and properties of a neuron



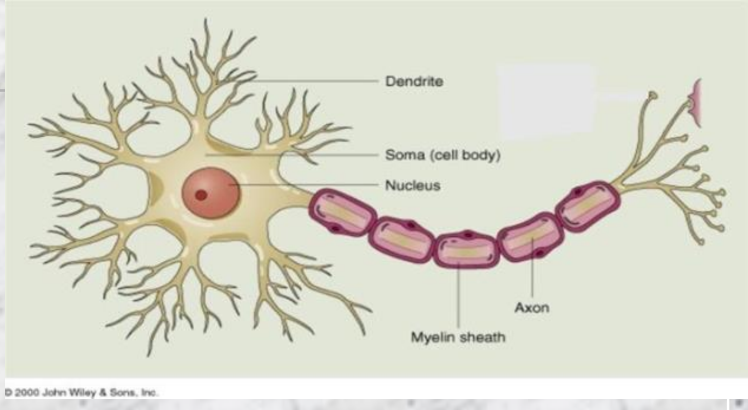
Structure and properties of a neuron



Structure and properties of a neuron



Structure and properties of a neuron



A *soma* is the body of the neuron.

Attached to the soma are long, irregularly shaped filaments, called *dendrites*. They are small in diameter, usually several microns or less, while their length may run to anything from the fraction of a millimeter to the order of a meter.

Short, and highly branched - constitute *dendritic trees*.

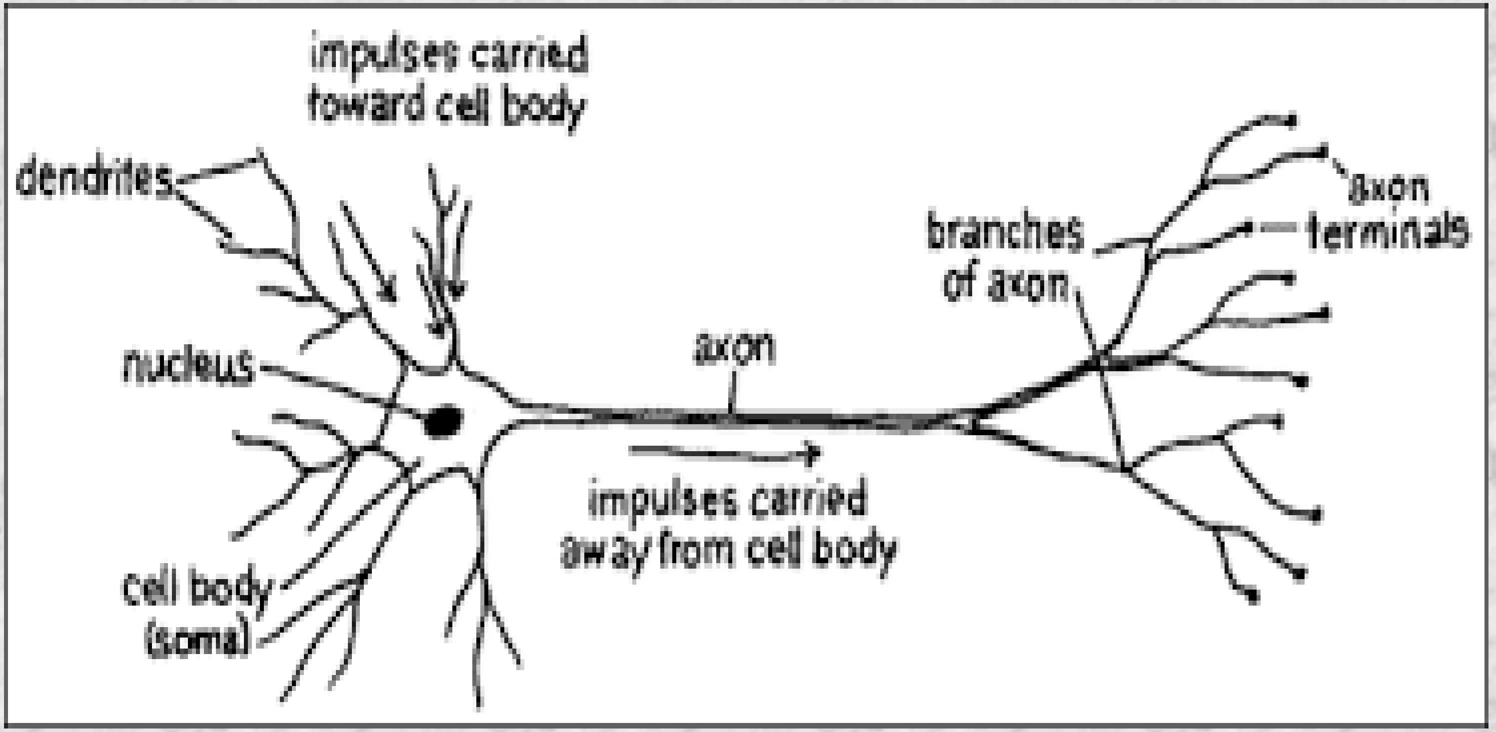
Another and long process attached to the soma of approximately uniform diameter is called a *neurite* or *axon*.

Structure and properties of a neuron

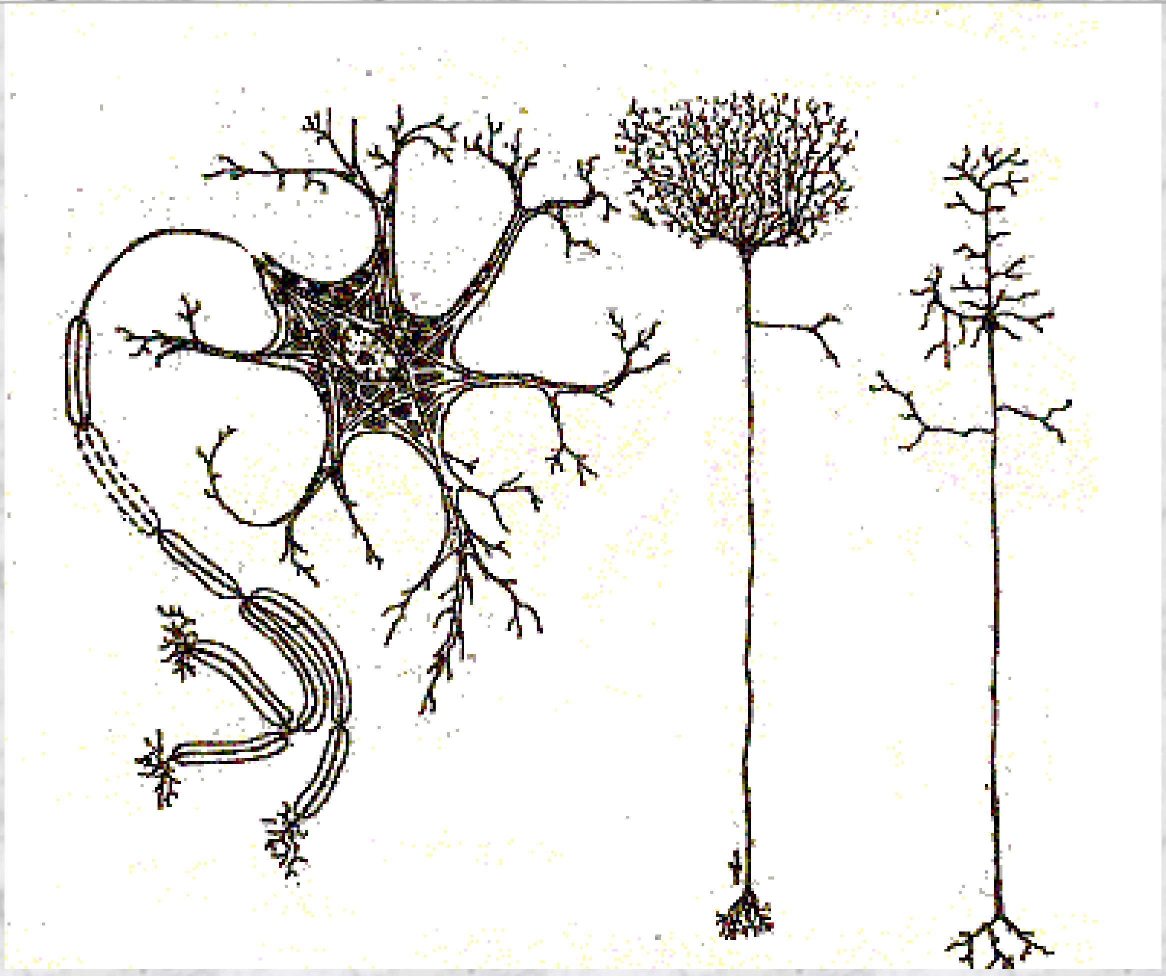
The neurons are not connected directly but, instead, by means of special nerve endings called *synapses* (0.5-2 μm).

There are synapses of various shapes making connections between the branching of an axon and a cell body, or branches of dendritic tree.

Structure and properties of a neuron



Structure and properties of a neuron



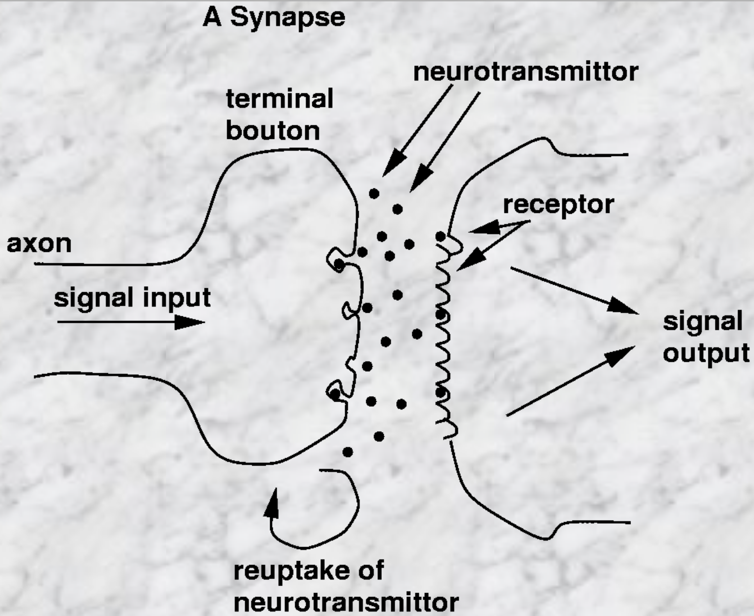
Structure and properties of a neuron

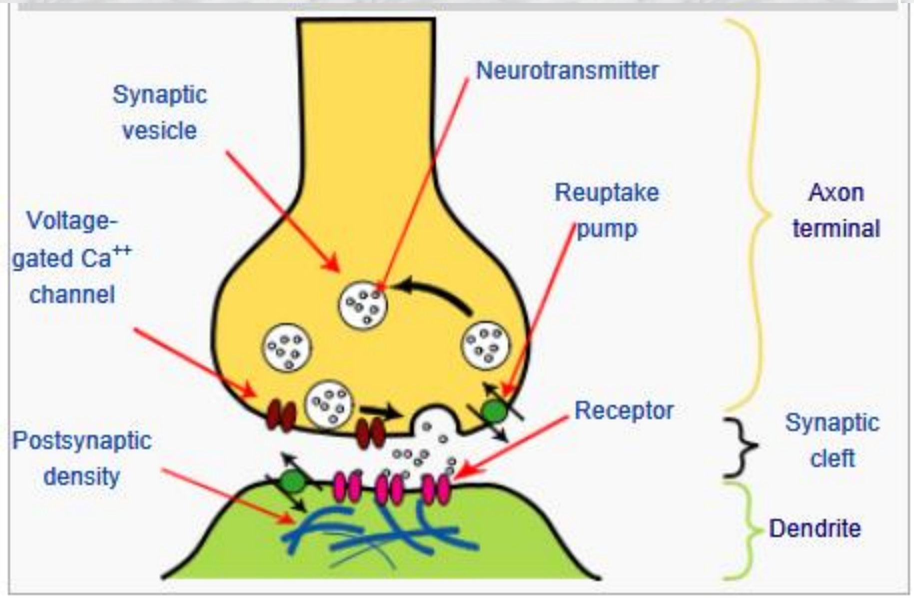
The neurons are not connected directly but, instead, by means of special nerve endings called *synapses*. There are synapses of various shapes making connections between the branching of an axon and a cell body, or branches of dendritic tree. There is no direct linkage across the junction; rather it is temporary chemical one.

Structure and properties of a neuron

The synapse releases chemical called *neurotransmitters* when its potential is raised sufficiently by the action potential. The neurotransmitters that are released by the synapse diffuse across the *gap*, and chemically activate gates on the dendrites (or soma, or axon), which, when open, allow charged ions to flow.

Structure and properties of a neuron





Structure and properties of a neuron

Neuron size and length of processes are very different.

The diameter of soma can vary from a few to several dozen of μm.

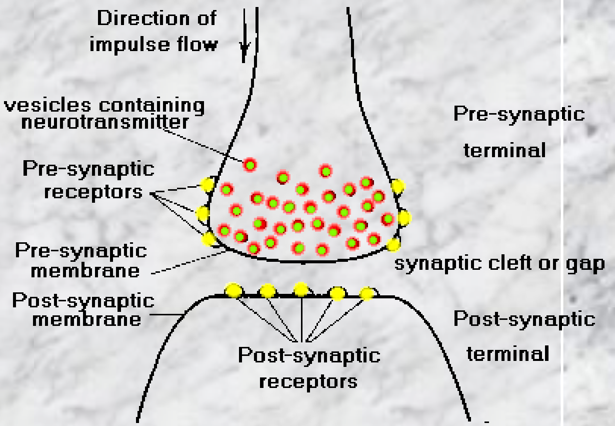
Diameter of processes is about 0.3 – 20 μm.

Length of processes can vary from the fraction of millimeter to the order of meter..

The nerve cell is sheathed in a membrane some 5-10 nm thick.

Structure and properties of a neuron

Inside synapse there are *synaptic vesicles*.



Two membranes can be distinguish: *presynaptic membrane*, which bounds the fibre of the preceding neuron, and *postsynaptic membrane* which constitutes the part of membrane receiving stimuli

Between there is *synaptic gap* of the order of 200Å.

Structure and properties of a neuron membrane

The active membrane has very particular properties:

1. A potential difference exist across the membrane; so called *membrane potential* (*resting potential*).

2. Complex, short-lived, electrochemical processes propagated on the membrane surface are initiated under the influence of particular stimuli (electrical and chemical).

3. The electrical responses during these processes are called *action potential*.

Structure and properties of a neuron membrane

Existence of four phenomena:

1. A difference in the concentration of various ions, causing these ions to move along their concentration gradients.
2. Membrane selectivity, whereas membrane has different permeabilities to different ions.
3. Ion motion under an electric field.
4. The active transport of sodium and potassium ions through the membrane in a direction opposite to the concentration gradient.

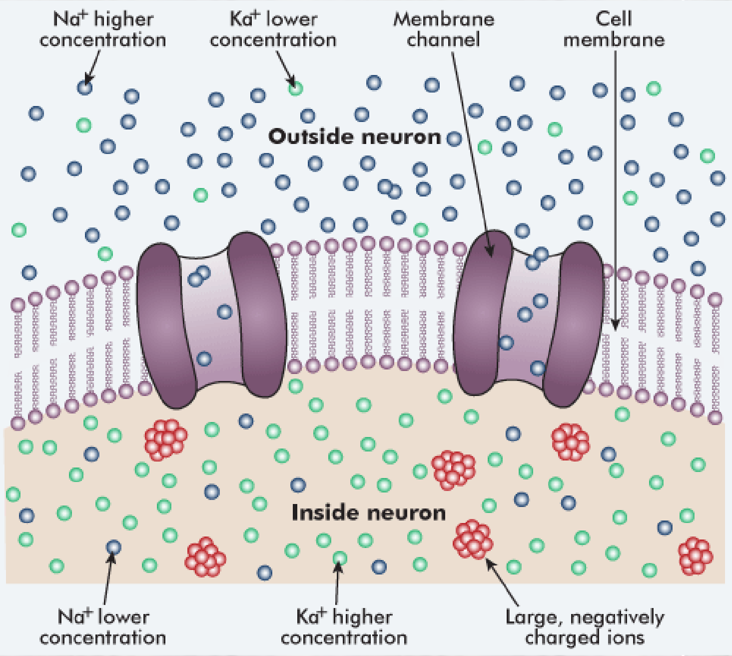
Structure and properties of a neuron membrane

Explanation :

<u>Inside</u>: high concentration of positively charged potassium ions K^+ and negatively charged organic ions Or $^-$.

<u>Outside</u>: positive sodium ions Na^+ and negatively charged chlorine ions Cl^-

Difference in concentration causes ionic flux proportional to the concentration gradient.



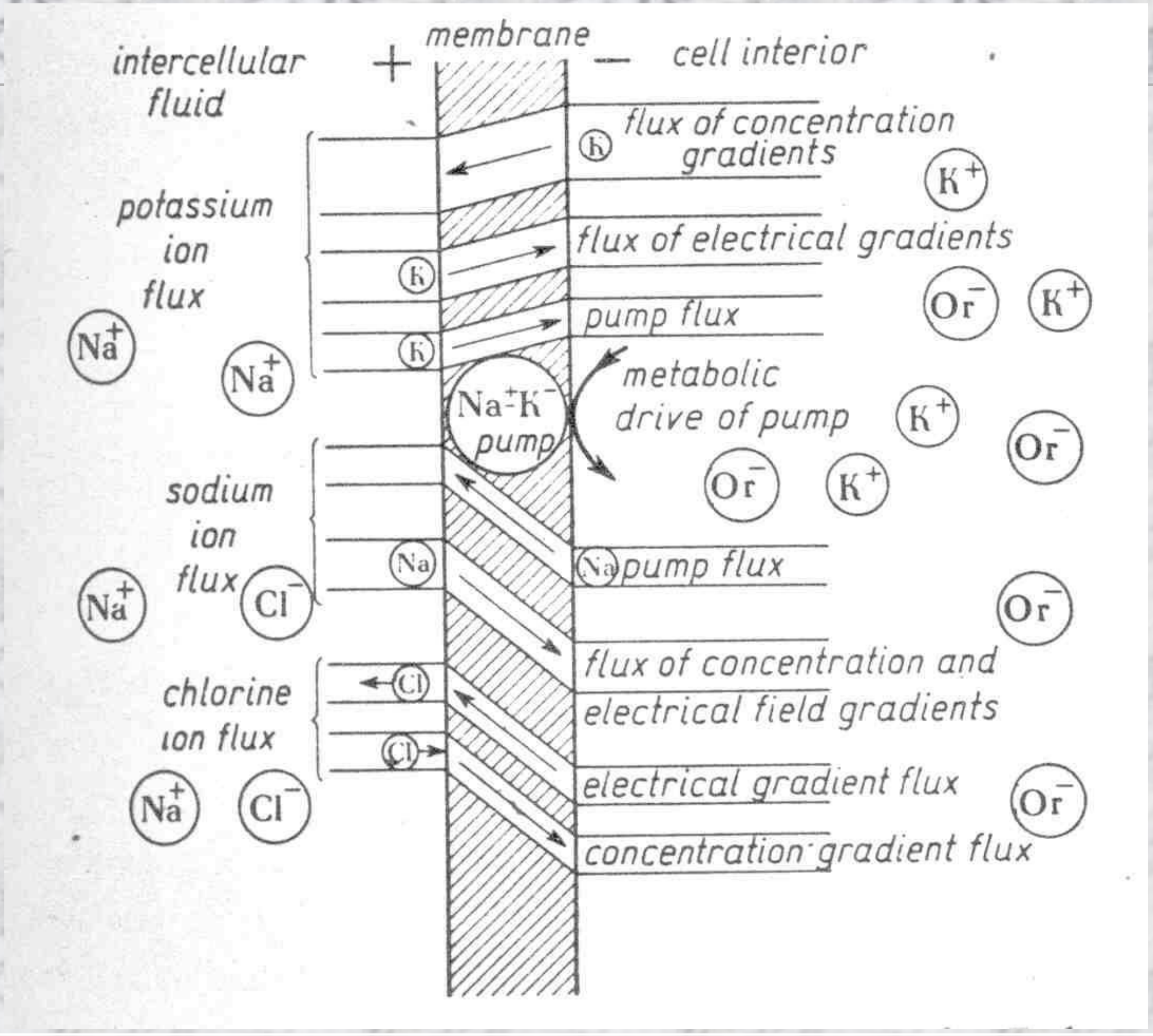
Structure and properties of a neuron membrane

Explanation :

In the steady state, the membrane permeability to potassium and chlorine ions is considerably higher than that of sodium ions, membrane is completely impermeable to the organic ions.

As a result of these differences in concentration and permeabilities, the K+ ion diffuse outward much more easily than the Na+ ions inward. The cell interior becomes negative with respect to intercellular region.

Structure and properties of a neuron membrane



Structure and properties of a neuron membrane

Explanation :

The net potential difference acts on K+ ions in a direction opposite to that in which the concentration gradient exerts in effect. After a time, a state of equilibrium is established.

It is so called *potassium membrane.*

The action potential across membrane is 60-90 mV.

The action potential

Explanation :

- **Under the influence of impulses arriving at presynaptic knob, a special substance, called *mediator,* is released from the vesicles at the membrane (e.g. acetylcholine).**
- **The mediator into the synaptic gape induces the rise in the sodium conductance of postsynaptic membrane**

The action potential

Explanation :

- **This causes the transmembrane potential to decrease.**
- **The synaptic gap contains also a substance decomposing the mediator, and after a short time the mediator is decomposed and membrane potential returns to its previous value**
- **If the excitatory potential exceeds a threshold value an avalanche process begins, and the action potential associated with this process arises.**

The action potential

There are also synapses whose action is the reverse of that described – where the impulses arriving from a preceding neuron inhibit, rather than excite, the electrical activity of the given cell. The mediator enhances permeability of the postsynaptic membrane, thus causing hyper-polarisation.

Such a change of potential is induced by stimuli from many synapses on the cell body and dendrites.

This is referred to as ***spatial summation.***

The action potential

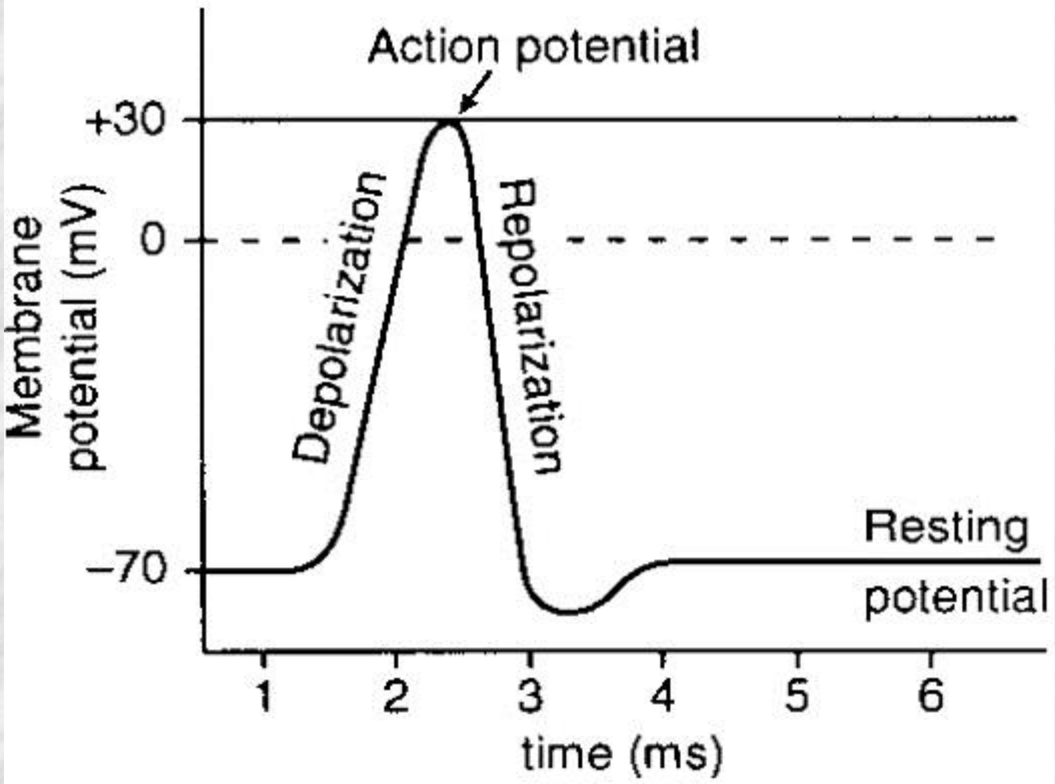
Since the mediator decomposes with a certain time constant, the net excitatory potential consist not only of impulses arriving at the given instant but also of signals transmitted in the brief period (several milliseconds) prior to a given instant. The impulses which arrive earlier have a smaller effect on the formation of a net excitatory potential. This phenomenon is called *temporal summation*.

The action potential

Excitability of nerve cell.

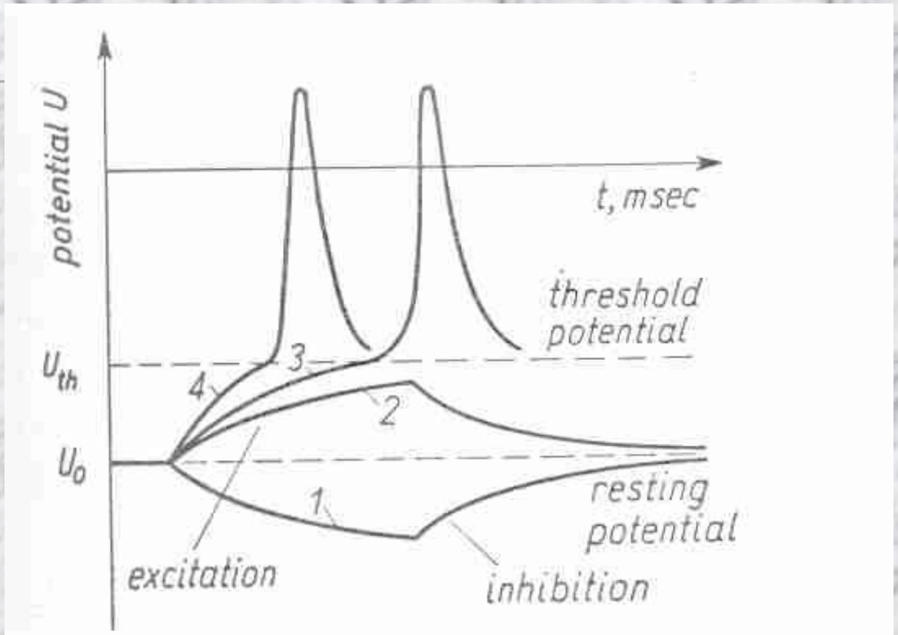
If the transmembrane potential is reduced to what is called the threshold value, this difference begins to fall off rapidly, even changing sign, only to return to its previuos value after. This process called *action potential*, is the form of an impulse with the duration of one millisecond.

The action potential



The action potential

Application of stimuli which are too small in amplitude (curve 2) causes transient process.



Stimuli of larger amplitudes , at certain point exceed a threshold value above which avalanche process begins – generation of action potential impulses (curves 3 and 4).

Curve 1 represents inhibitory process.

The action potential

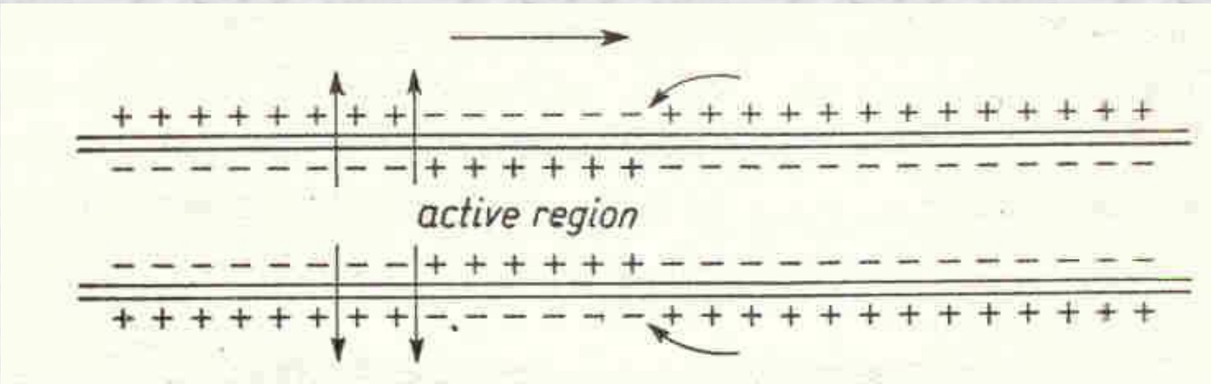
Excitability of nerve cell.

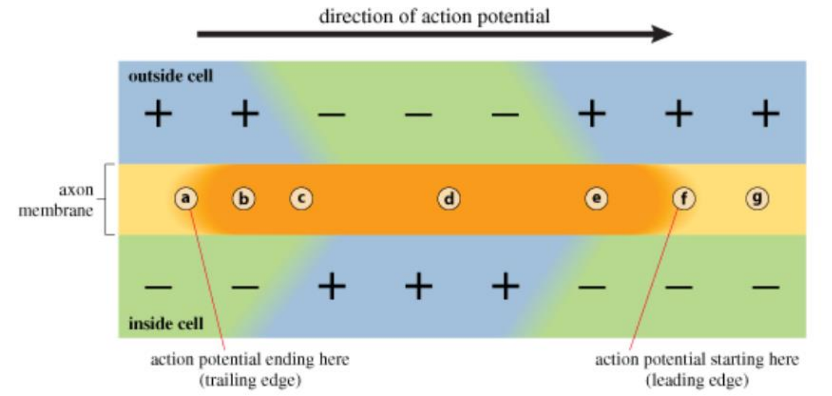
The sudden drop in the potential at some point of a membrane leads to the flow of surface currents and finally the action potential is propagated along the membrane.

The nerve fibre can be compared with an electric cable. Signals are propagated along, consisting process of a membrane discharging and the resting potential restored quickly.

The action potential

The propagation of excitation along an axon





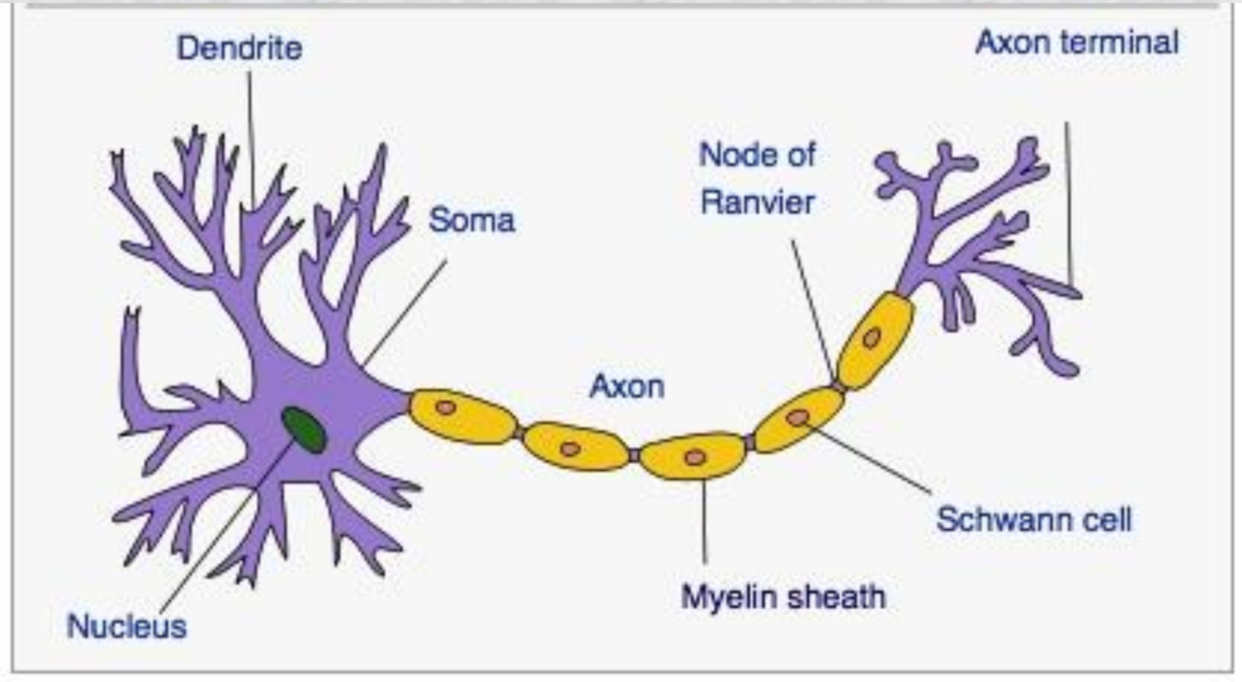
The action potential

Excitability of nerve cell.

Such stimuli propagated relatively slowly (1-2 m/s).

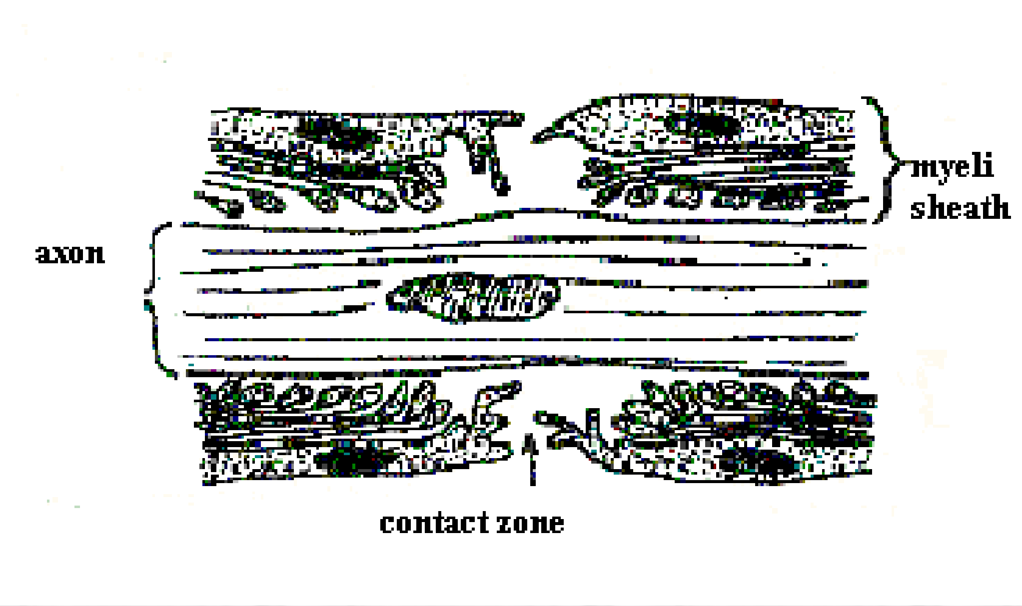
If the axons are coated by a myelin sheath the propagation speed rises up to 150 m/s.

Impulse propagation



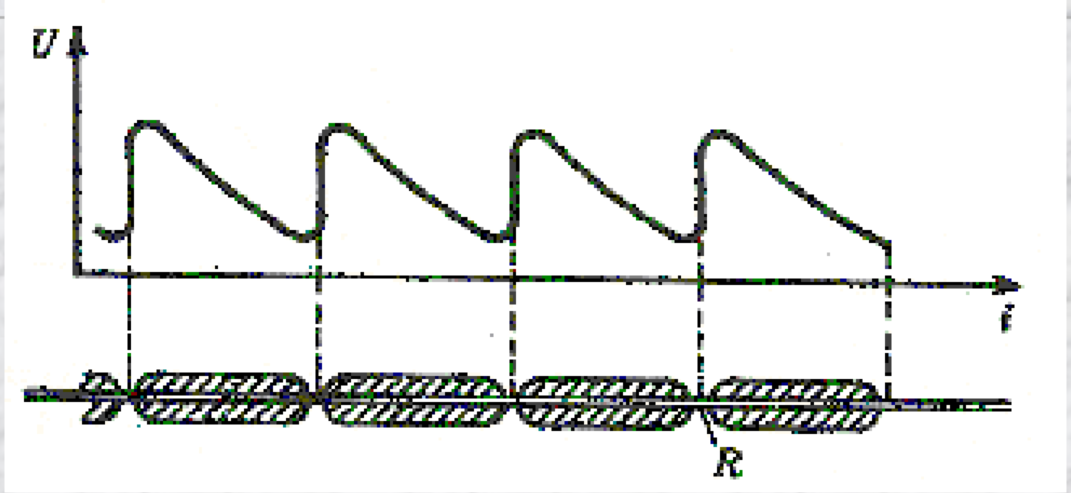
The schematic myelinated axon

Impulse propagation



The microscopic structure of the Renvier node. It is visible that in the contact zone the axons' membrane is in a direct contact with intercellular fluid. Apart of that is isolated by my sheath.

Impulse propagation

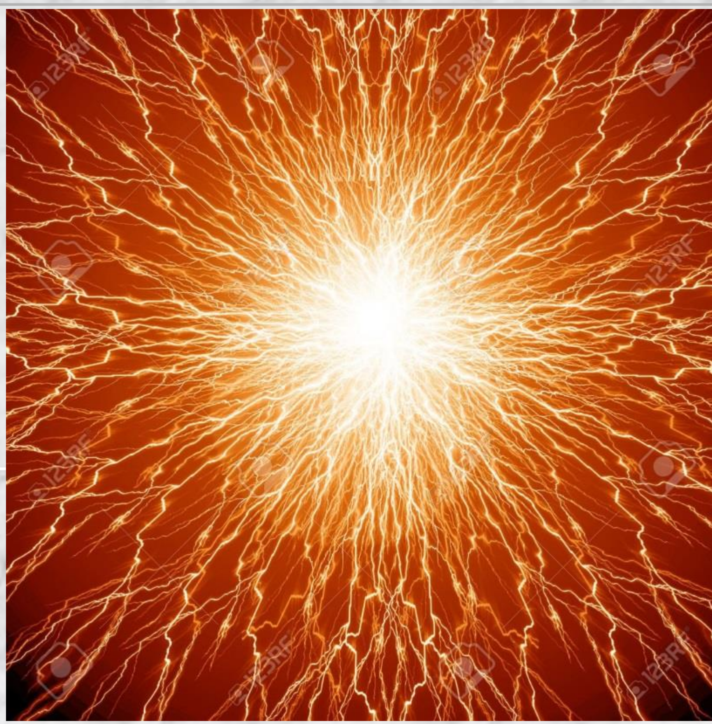


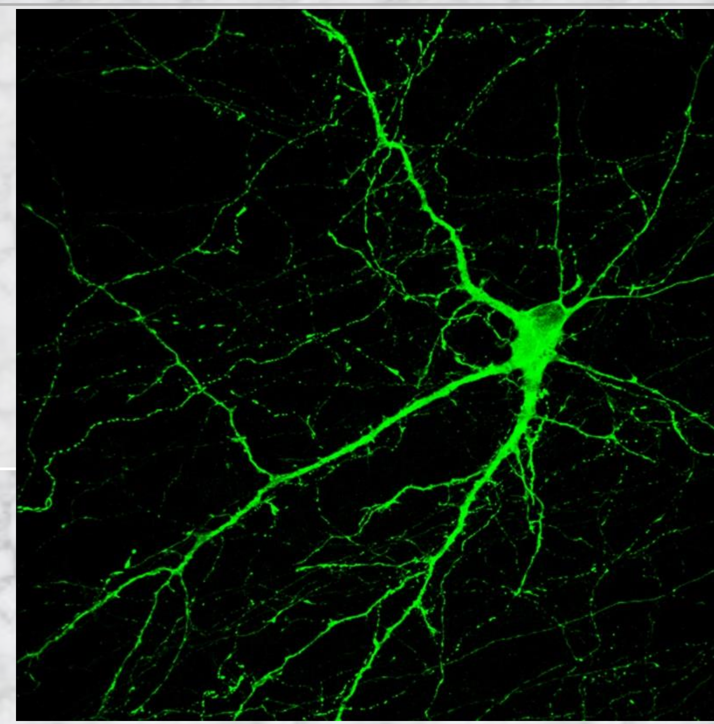
In the myelinated fibre the amplitude of the impulse is reduced several-fold in the interval between nodes, but is large enough to cause membrane at the next Renvier node to be excited – and original amplitude of the impulse – restored.

Some biology

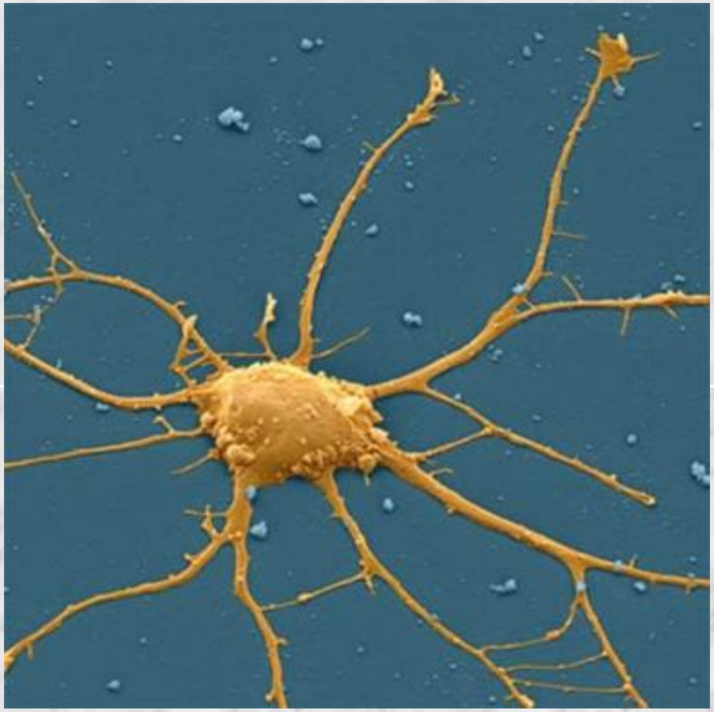
Different Nerve Cells

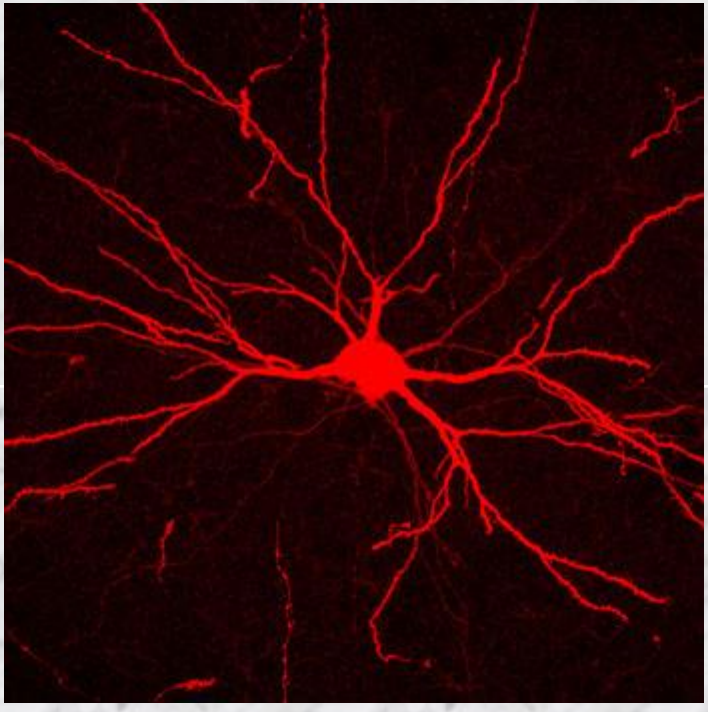
Example of a nerve cell



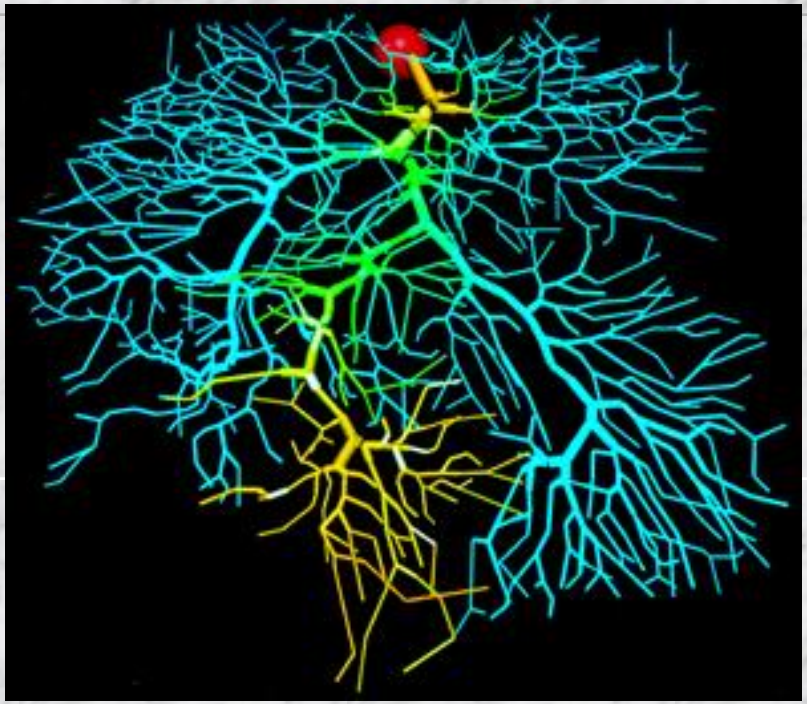


Example of a nerve cell

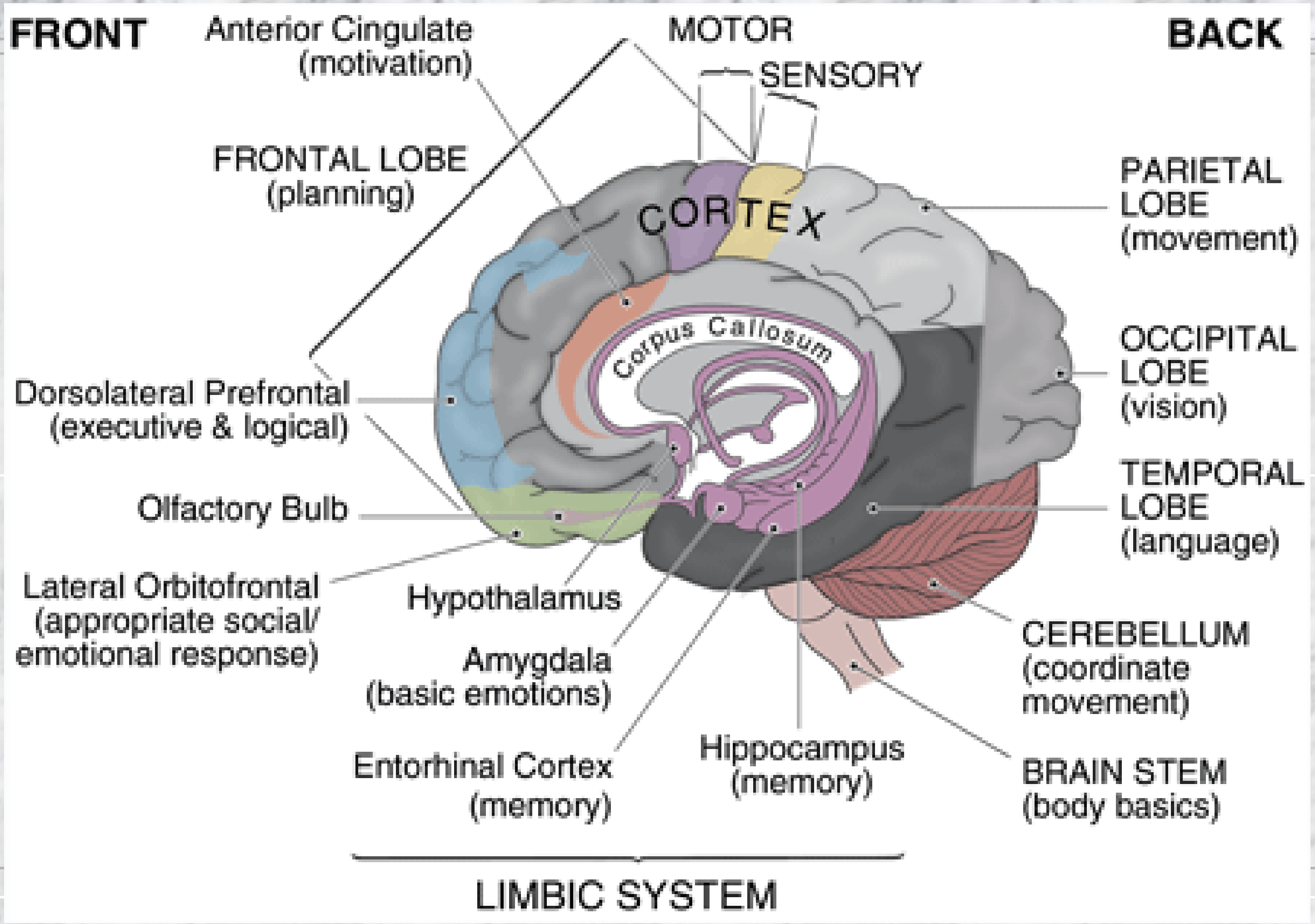




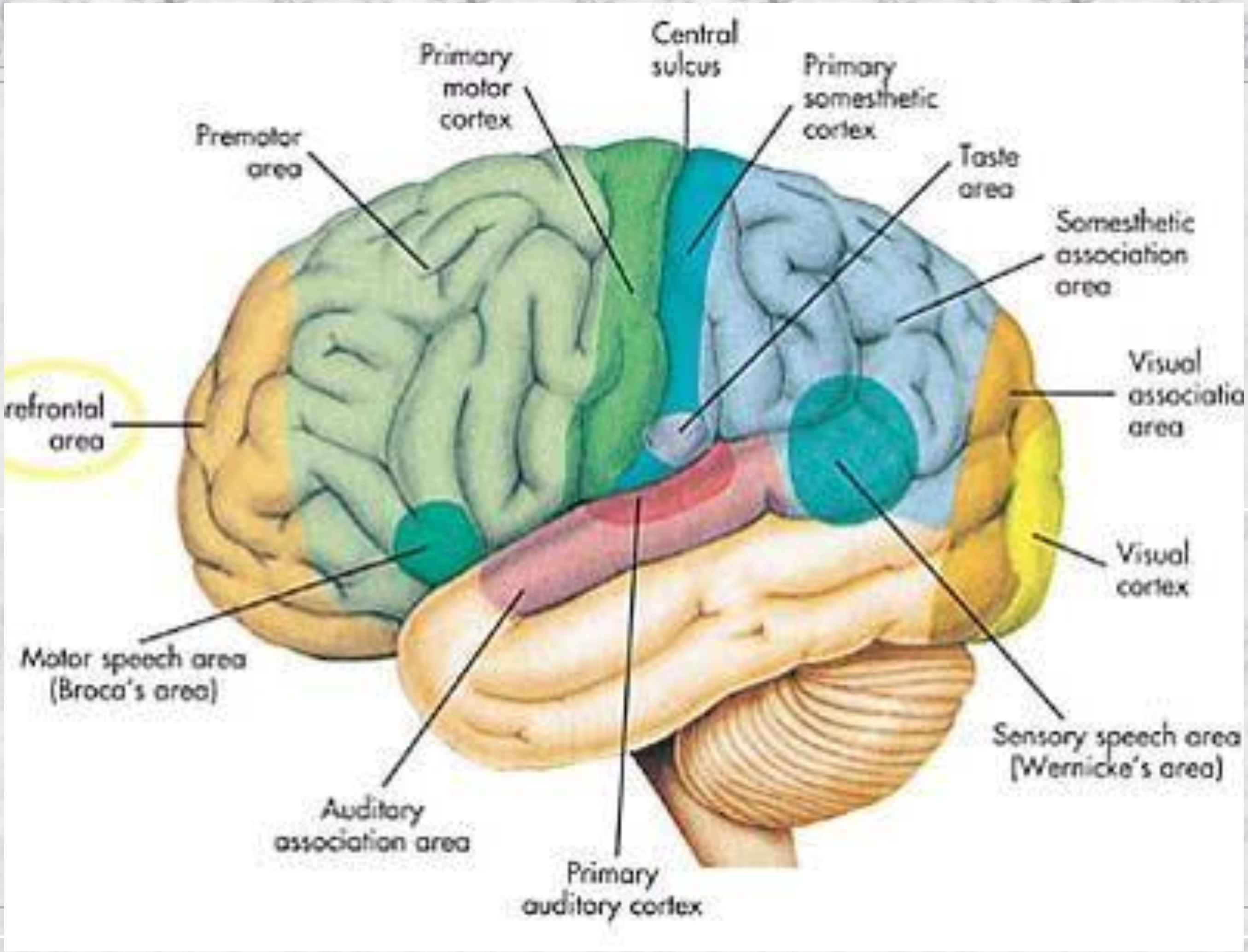
Example of a nerve cell



Important areas in the human brain



Important areas in the human brain



Important areas in the human brain