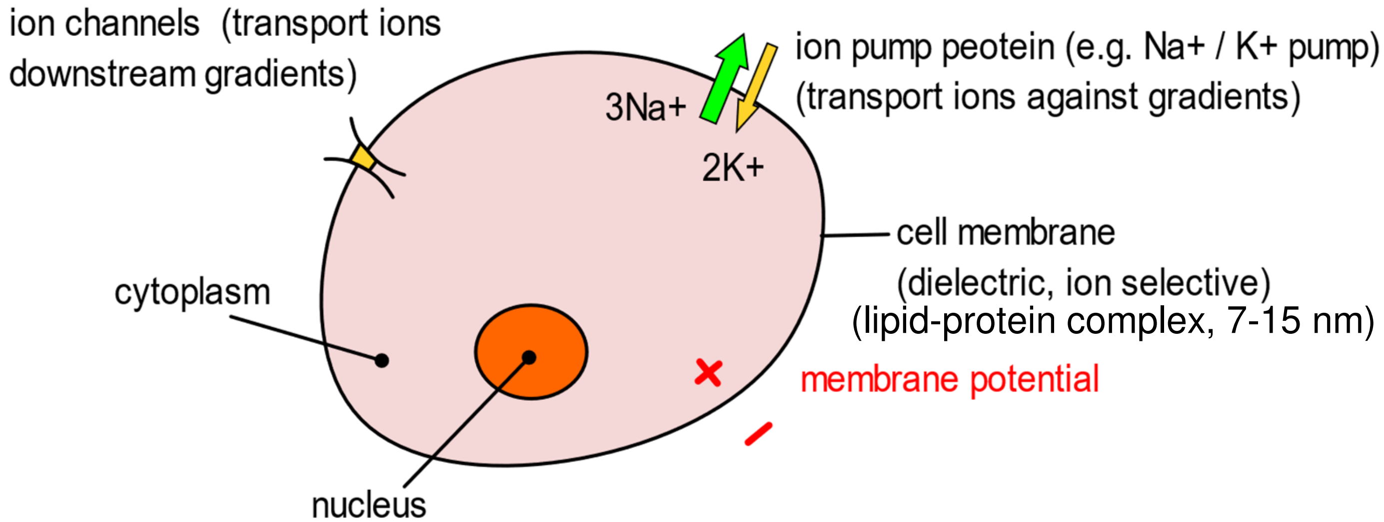
Biopotentials

Biopotential: An electric signal (voltage) that is:

- measured across distinct points of living cells or tissues
- generated by biochemical processes
  examples: transmission of neural stimuli, contraction of muscle cells

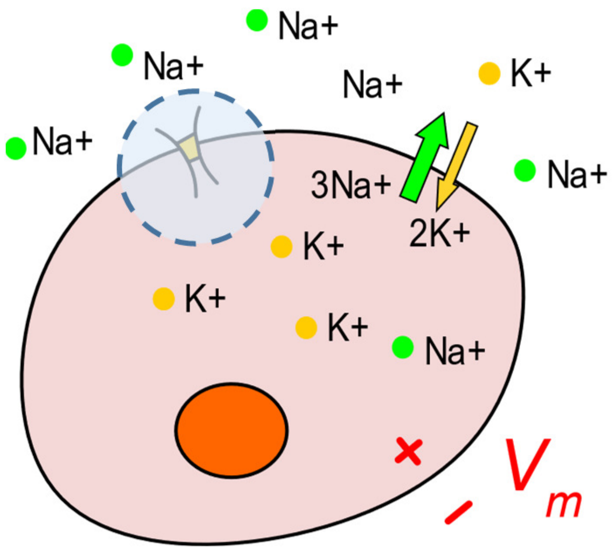
Generation of a biopotential in a cell (simplified view)



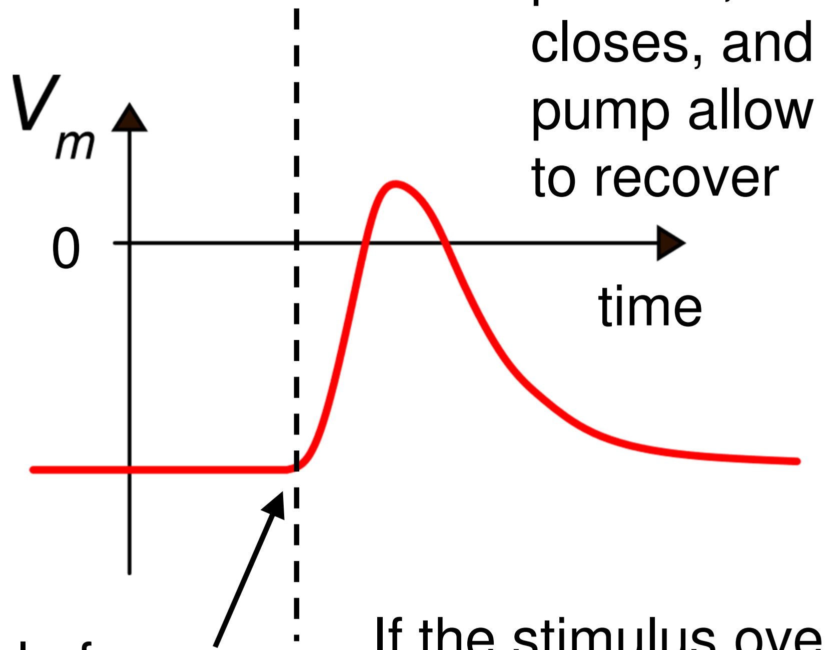
Due to protein pumps, Na+ concentration is much higher outside the cell.

The cell internal gets a negative potential:
from –100 mV to –50 mV.

Electrically excitable cells



Electrically excitable cells are marked by ion channels that are controlled by local potential:
(**voltage-gated** ion channels).

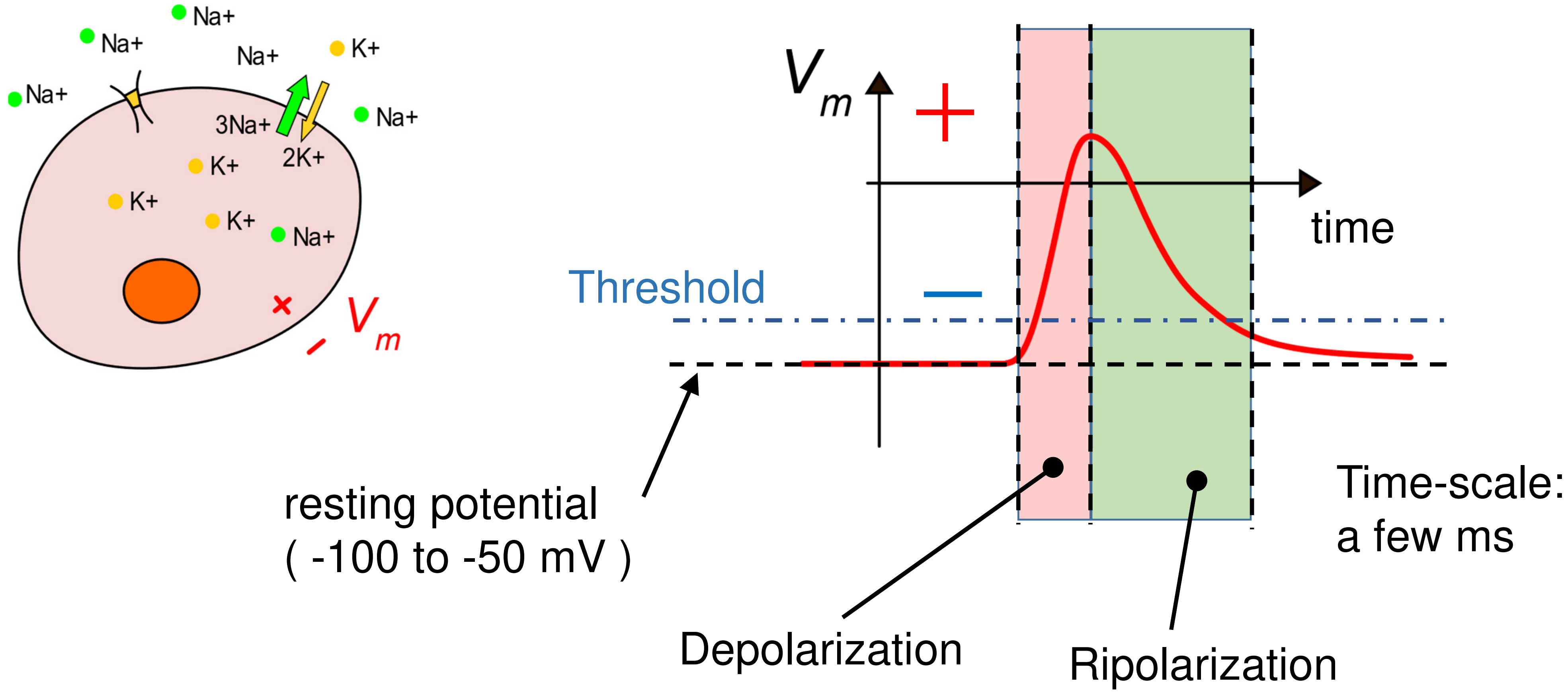


When potential gets positive, the ion-channel closes, and the ion pump allow the potential to recover

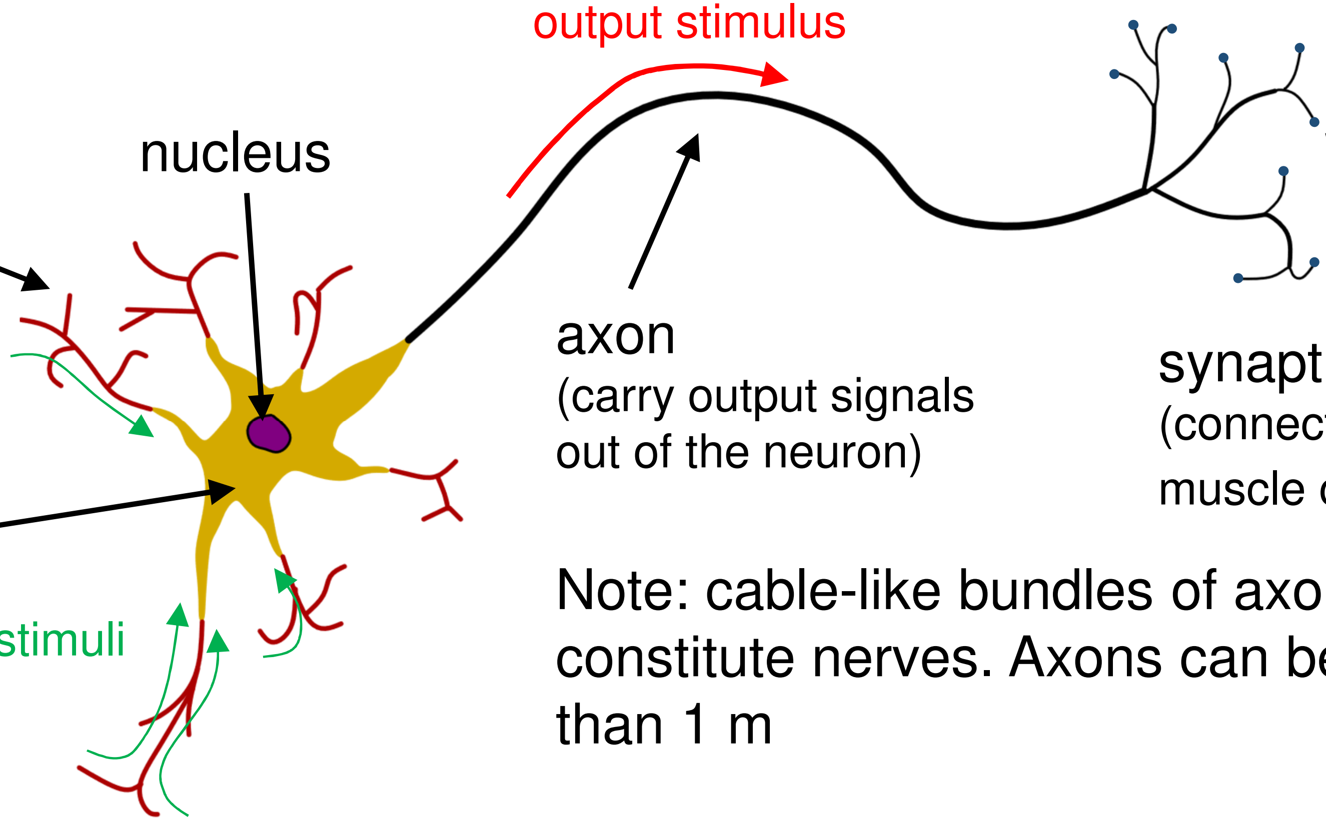
Arrival of an electrical stimulus

If the stimulus overcome a threshold, the ion-channel opens and let sodium (Na+) get into the cell increasing the membrane potential

Phases of cell excitation

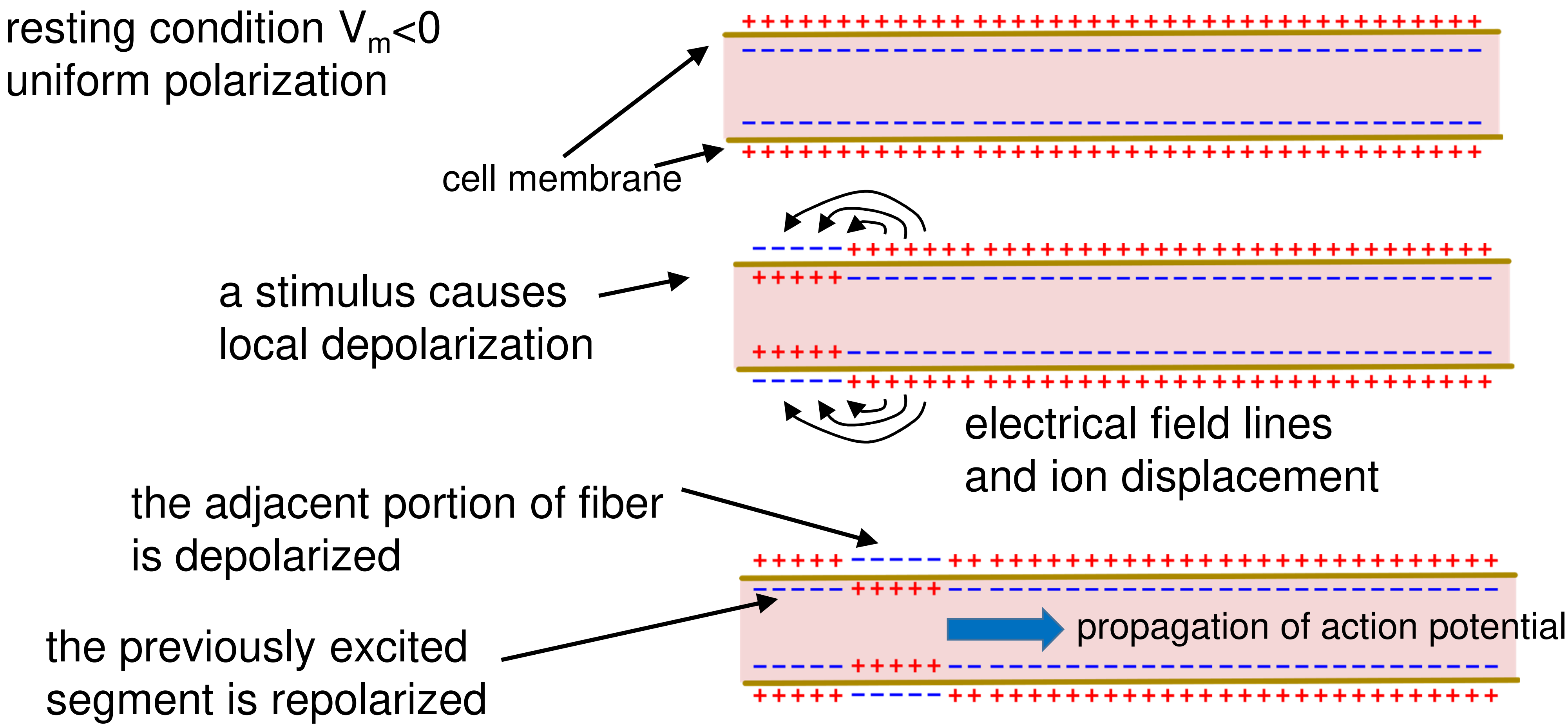


Nerve cells (neurons)

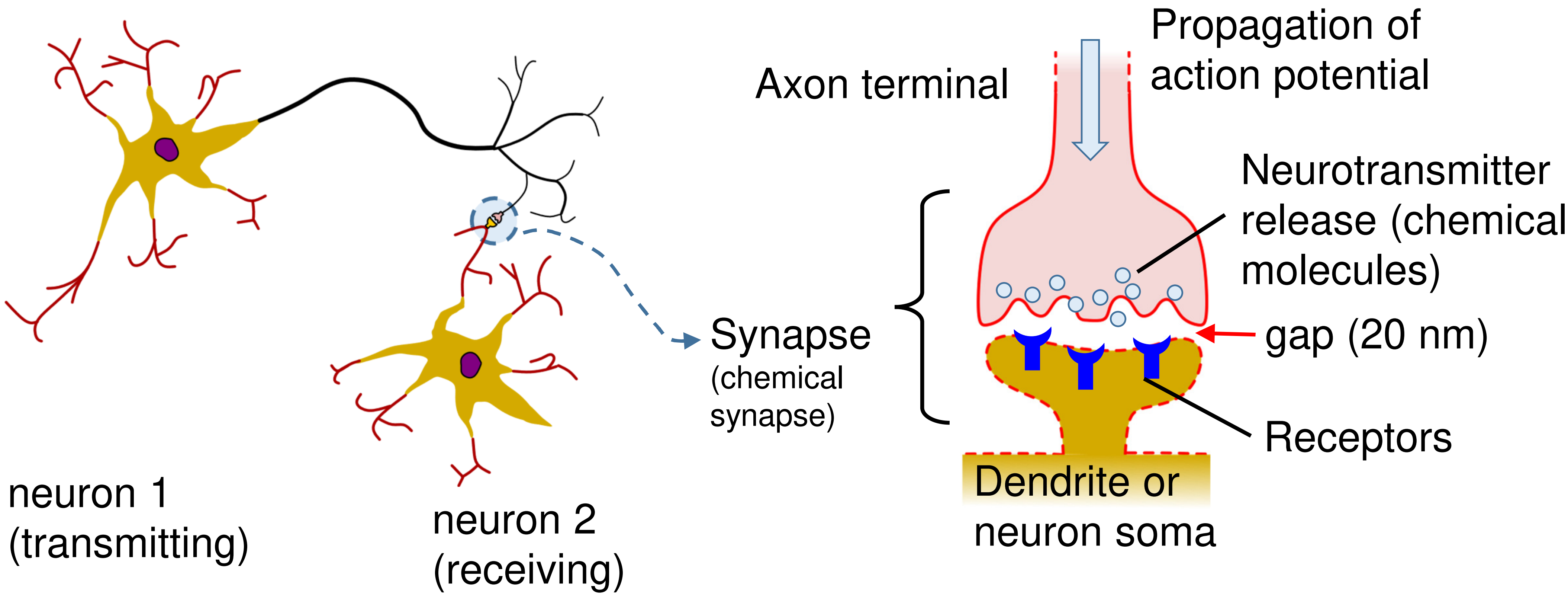


Note: cable-like bundles of axons constitute nerves. Axons can be longer than 1 m

Propagation of a stimulus along the axon or dendrites

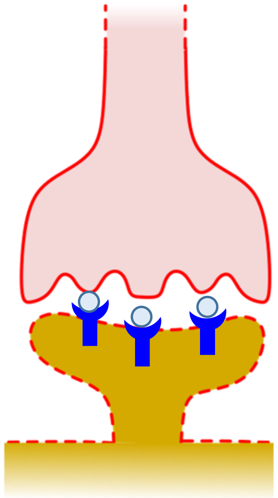


Propagation of stimuli between neurons (1)



Synapse "propagation time": 0.5-1 ms

Propagation of stimuli between neurons (2)

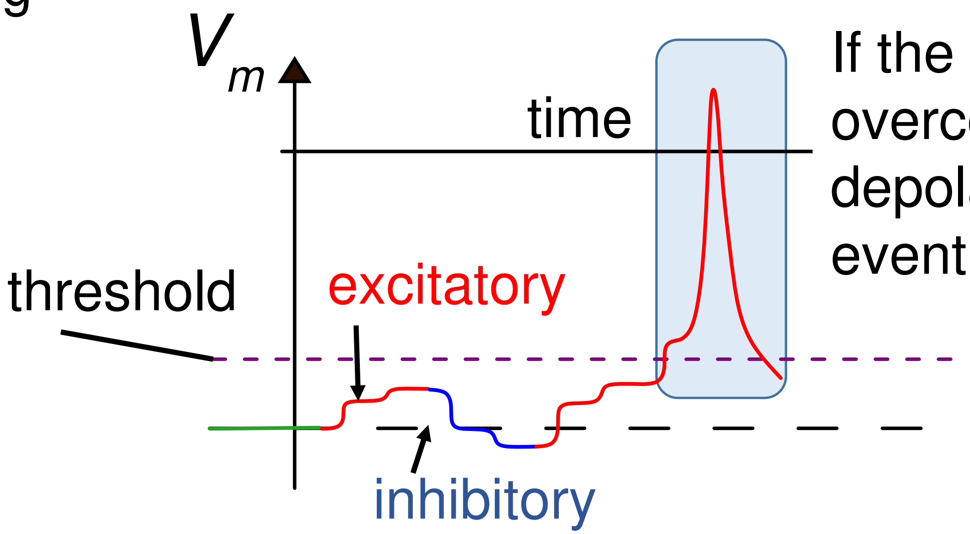


Receptors

Receptors are specialized ion channels that, once activated by the specific neurotransmitter, let ions get into the receiving neuron:

- Positive ions (e.g. Na+): excitatory
- Negative ions (e.g. Cl-): inhibitory

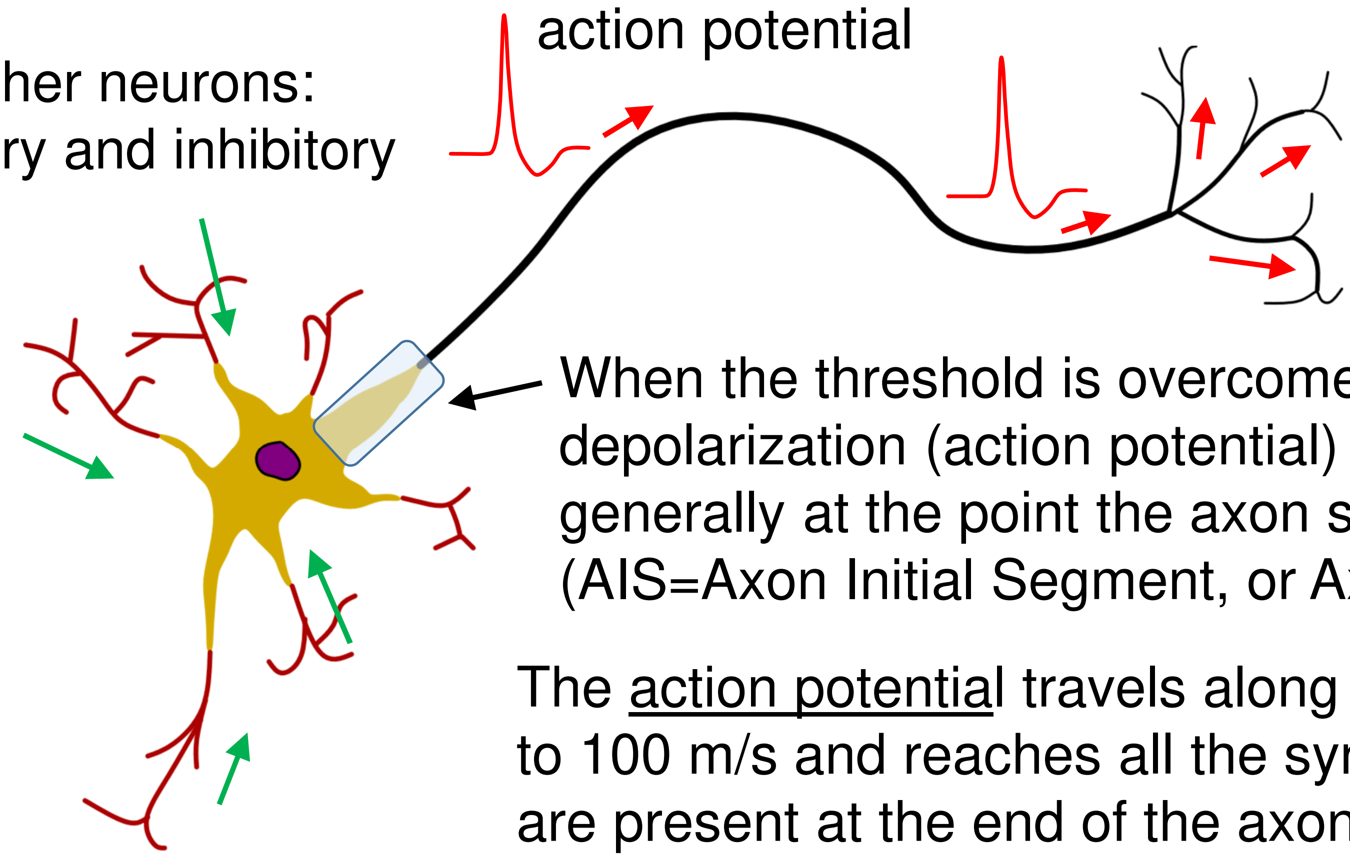
Neuron membrane potential (soma end dendrites). The evolution of the potential is the result of the action of multiple synapses



If the threshold is overcome, a depolarization event is triggered

Propagation of stimuli between neurons (3)

From other neurons: excitatory and inhibitory signals

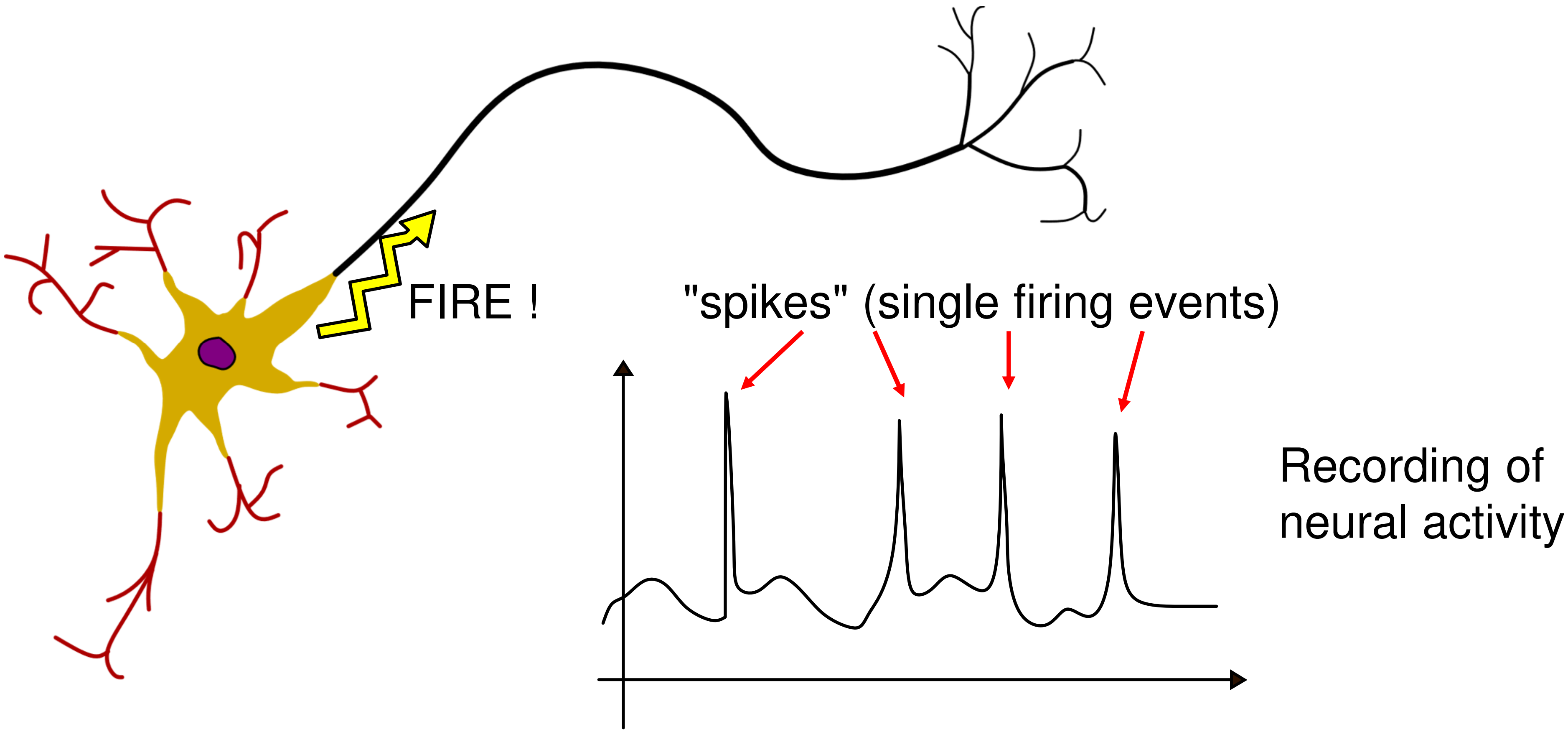


To other neurons: action can be excitatory or inhibitory, depending on the type of synapse

When the threshold is overcome, depolarization (action potential) begins generally at the point the axon starts (AIS=Axon Initial Segment, or Axon Hillock)

The action potential travels along the axon up to 100 m/s and reaches all the synapses that are present at the end of the axon, stimulating other neuros or other electrically excitable cells.

Neuron "firing"



Recap on the neuron function (highly simplified view)

- A neuron receives inputs through its dendrites and transmit it output (action potential) through the axon
- Connection between the axon and the dendrites is actuated by the synapses
- Reception of one input produces a variation of the cell potential: an inhibitory input reduces the cell potential, an excitatory input increases the cell potential
- The cell potential continuously varies up and down for the effect of a large number of successive or simultaneous stimuli from a large number of neurons. Then, the cell potential is the sum of different inputs that can be different in terms of magnitude and sign.
- When the potential overcome a certain threshold (that depends on the type of neuron) the neuron emits an action potential along the axon.

Types of Neurons

- **Motor neurons** : transmit signals from the central nervous system (brain and spinal cord) to muscles.
- **Sensory neurons** : generate action potentials from physical /chemical stimuli and transmit it to the brain / spinal cord)
- **Interneurons**: connect neurons to other neurons

Muscle Cells

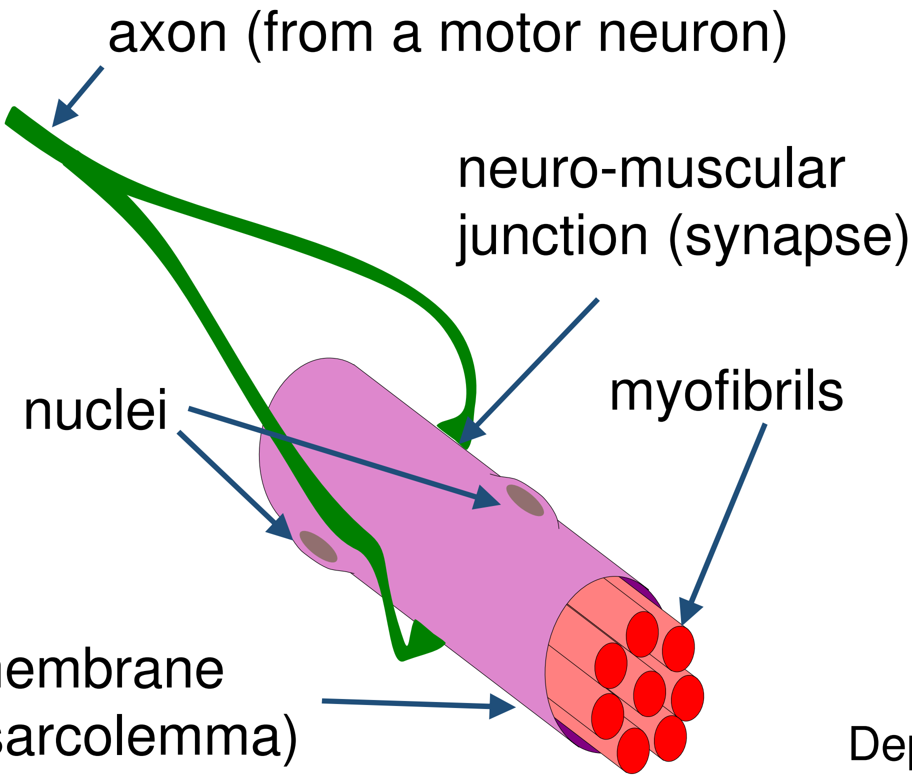
Muscle cells are another important type of electrically excitable cells

There are three main types of muscle cells:

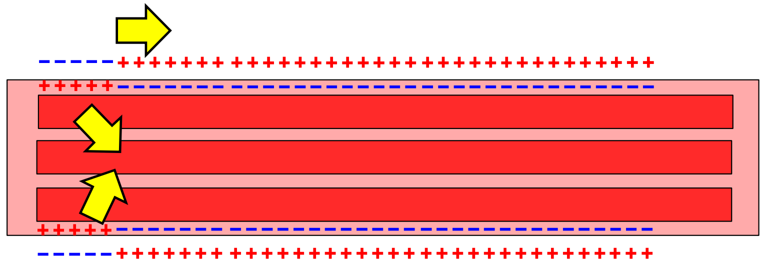
- Skeletal muscle cells, or muscle fibers (voluntary movements)
- Smooth muscle cells (involuntary movements, i.e. peristalsis)
- Cardiac muscle cells

Striated muscles

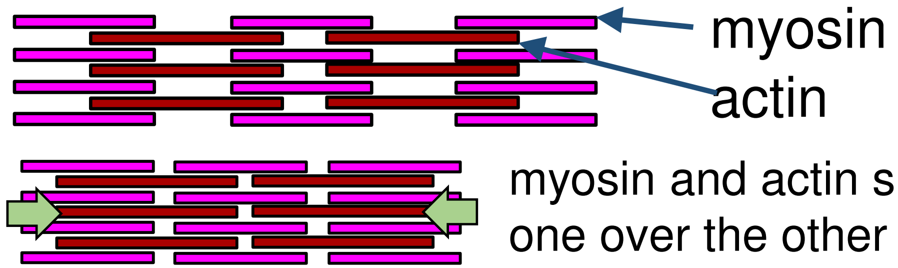
Skeletal muscle cells



Muscle cell (fiber). Can be several cm long a 100-200 μm wide.



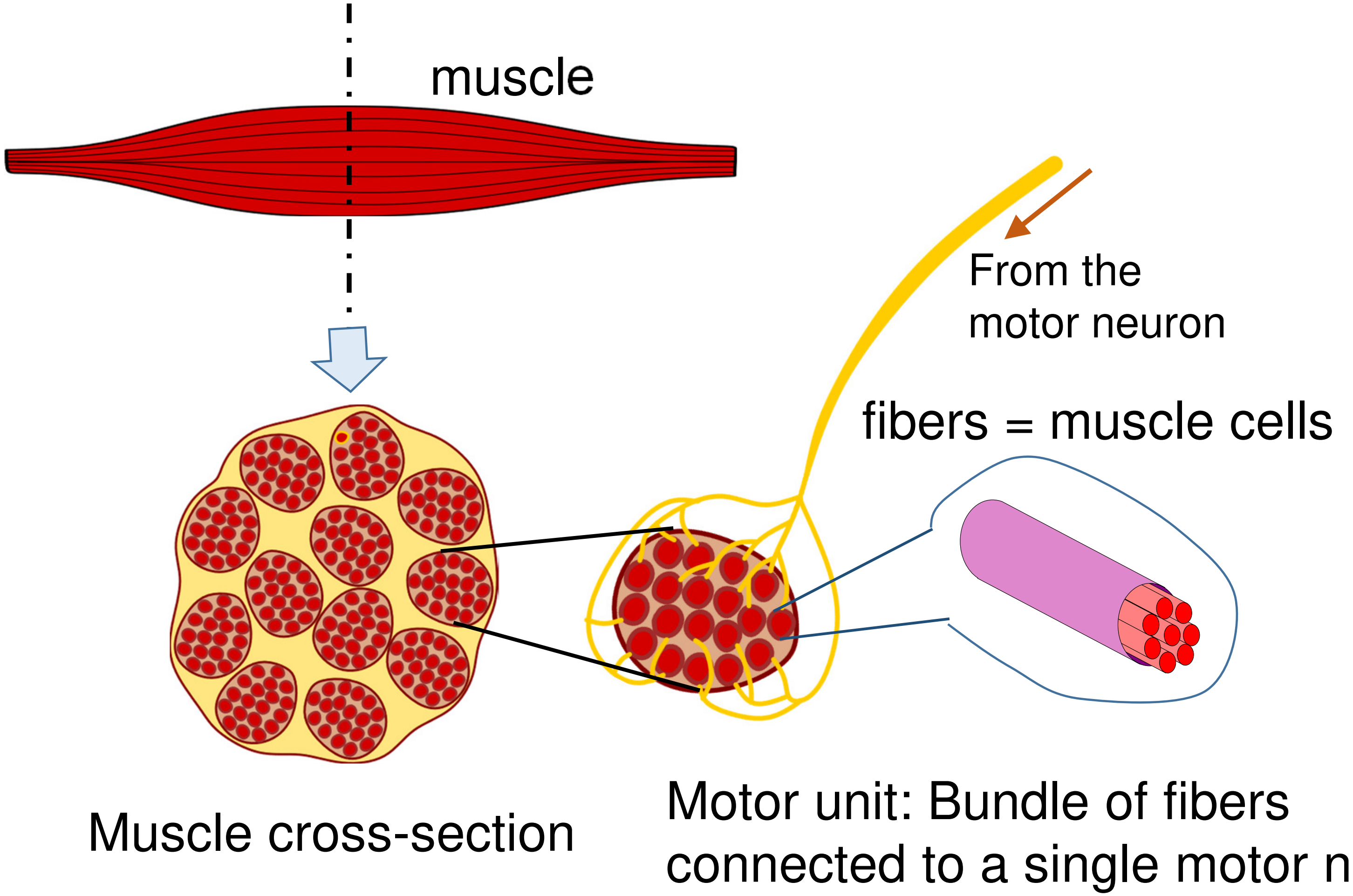
Depolarization proceeds along the fiber and towards the inner fibrils



myosin and actin slide one over the other

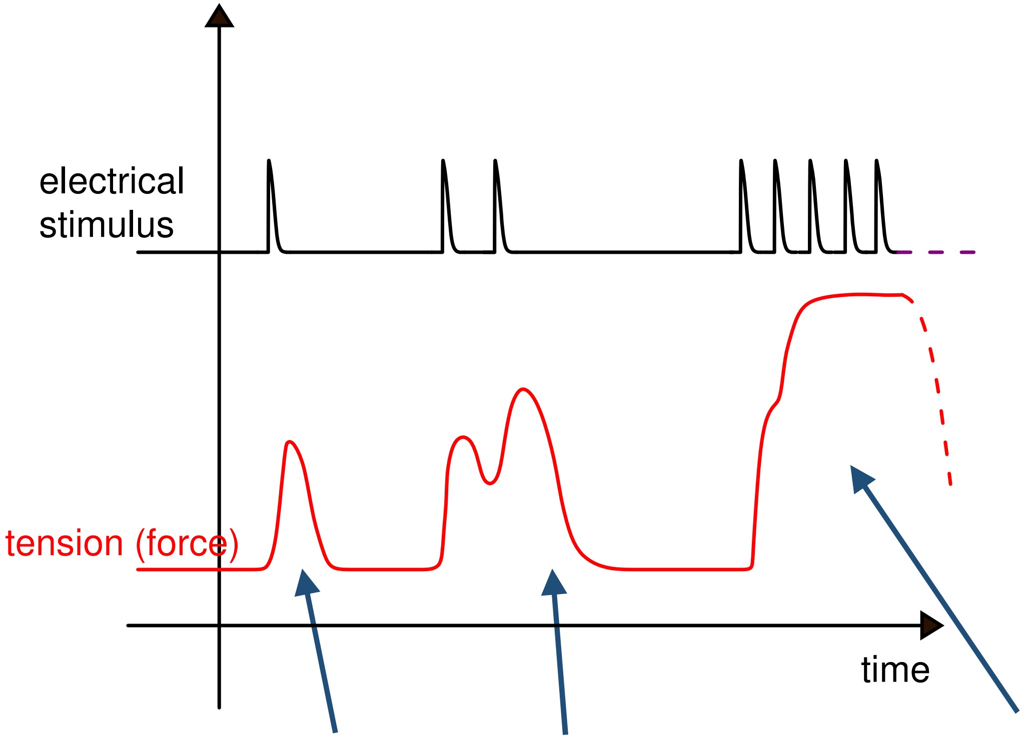
Depolarization triggers a chemical reaction chain that causes the fibrils to <u>contract</u>. This mechanism consumes ATP, which should be replaced by energy-consuming reactions

Muscle motor units



- The fibers forming a single motor unit contract all together
- Different motor units can contract independently form each other.
- The higher the number of motor units that are activated, the greater the strength produced by the muscle

Muscle stimulation



The strength of muscle contractions depends on the frequency of arriving action potentials and the number of motor neuros that are firing.

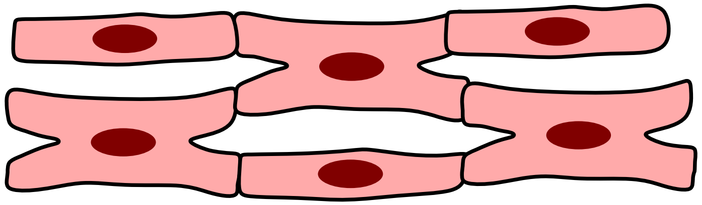
Single contraction "twitch"

Effect of two action potentials (summation)

Effect of a train of many action potentials occurring at high frequency: constant maximum tension or "complete tetanus".

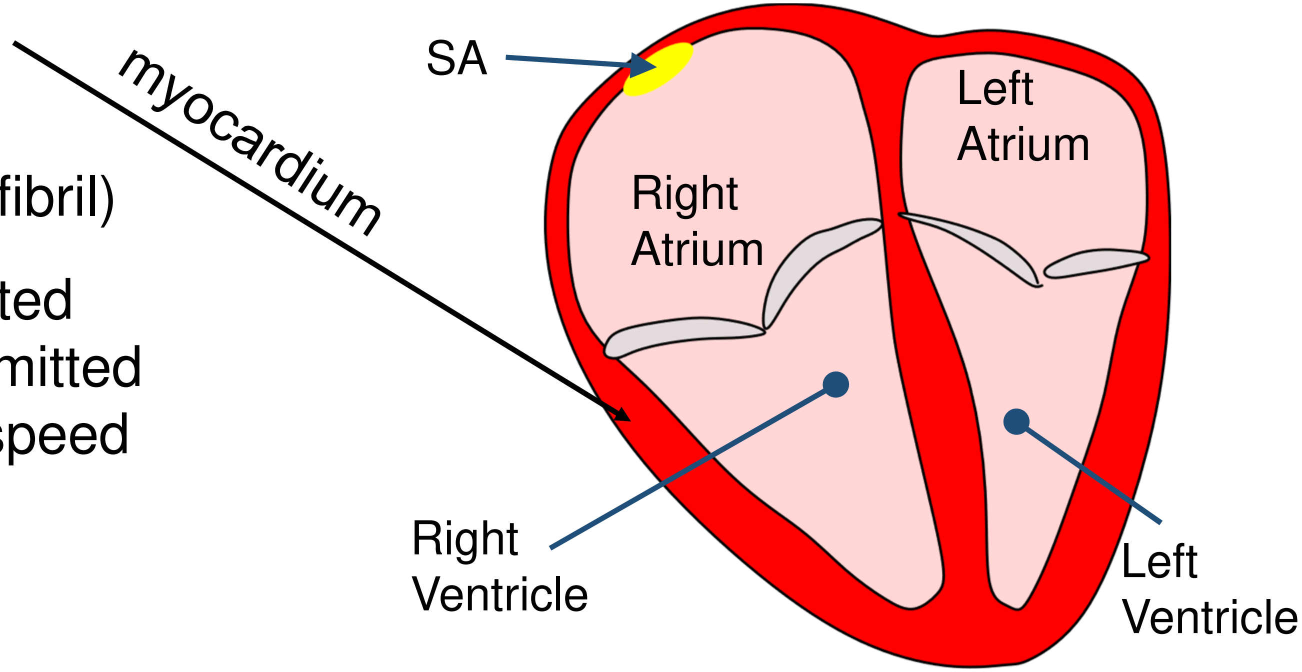
Cardiac muscle

Myocardium contraction is initiated by an <u>action potential</u> generated by specialized cardiac cells forming the sinoatrial (SA) node



Cells (striated: formed by myofibril)

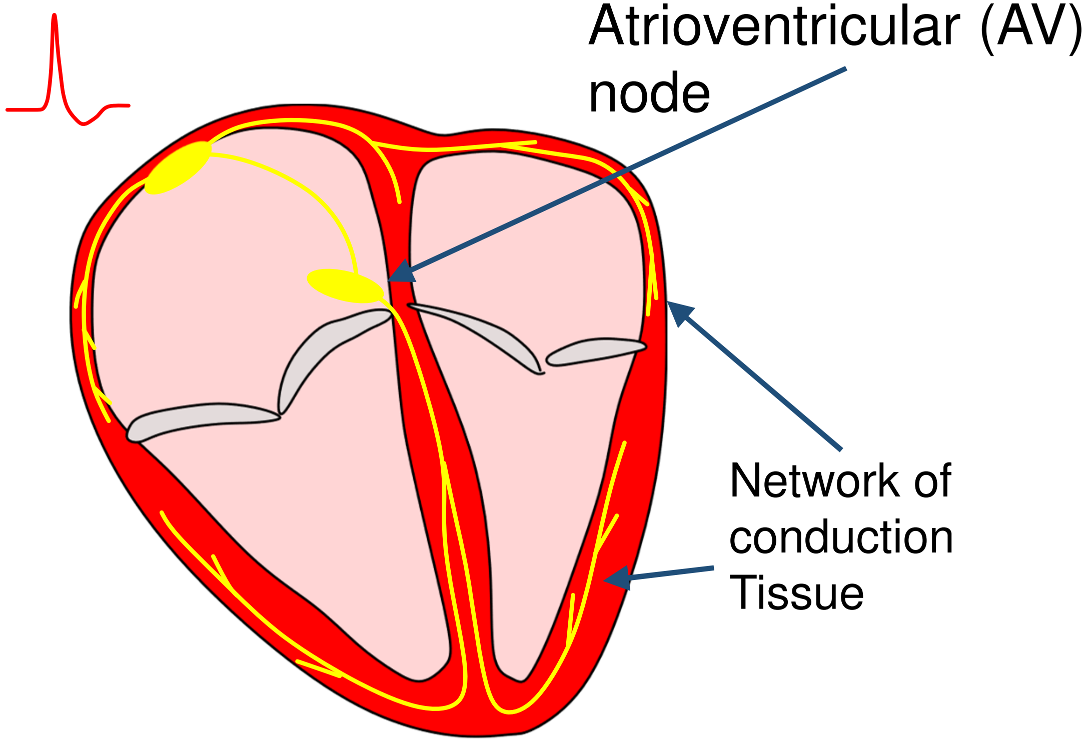
Short cells, highly interconnected
Action potential is easily transmitted from a cell to another at high speed



Electrical events during a cardiac cycle

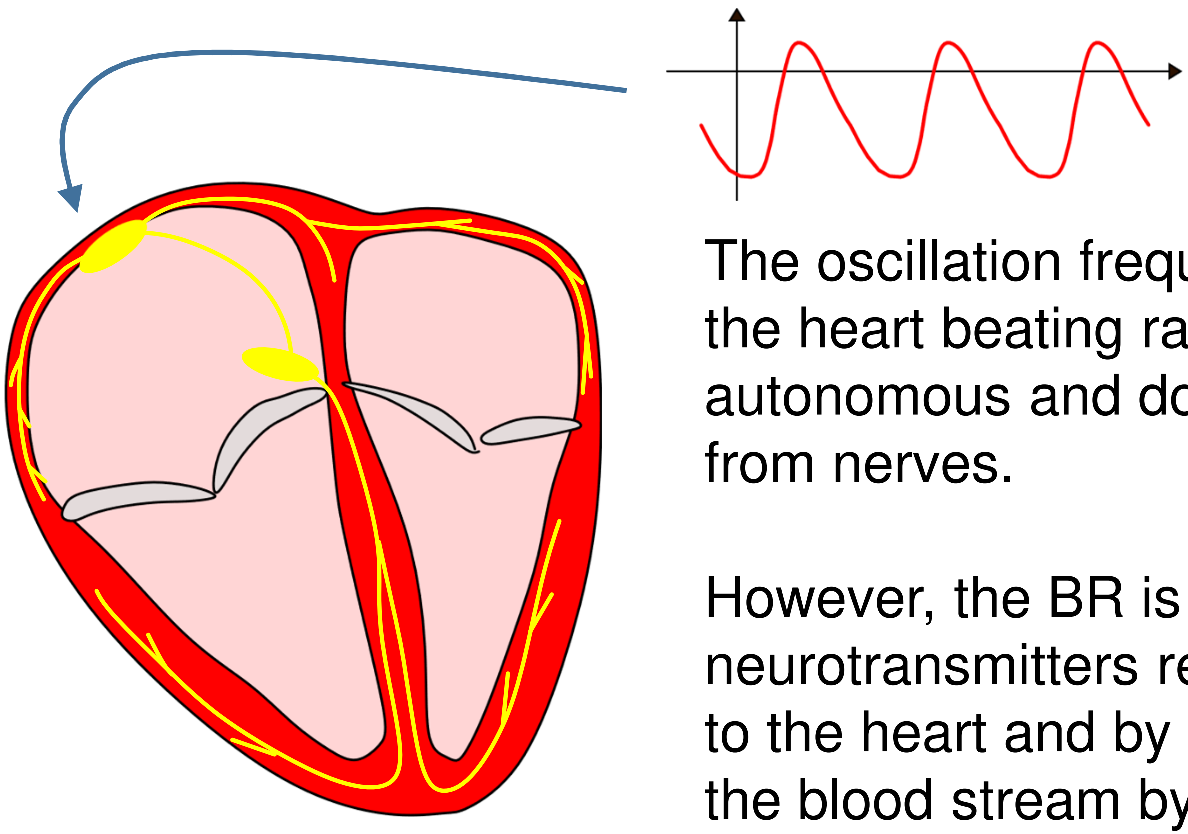
The SA node is a muscle cell that has not a stable resting potential: it continuously goes through depolarization and repolarization, operating like an oscillator

The action potential generated by the SA, rapidly spread across the atrii, through specialized conduction tissues (same type as the SA) causing contraction of the atrii



The stimulus is received by an intermediate node (AV) that introduces a delay of nearly 100 ms, and then propagate it to the ventricles, causing their strong and fast contraction

Neurostimulation of the heart

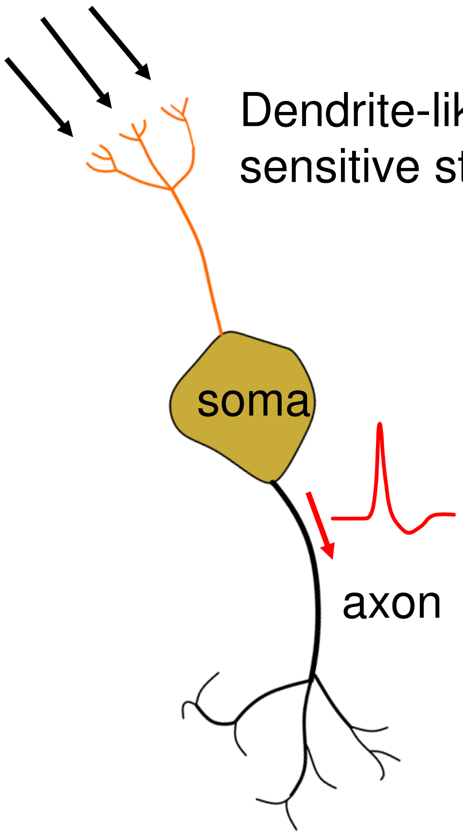


The oscillation frequency of the SA node sets the heart beating rate (BR). The SA is perfectly autonomous and does not require stimulations from nerves.

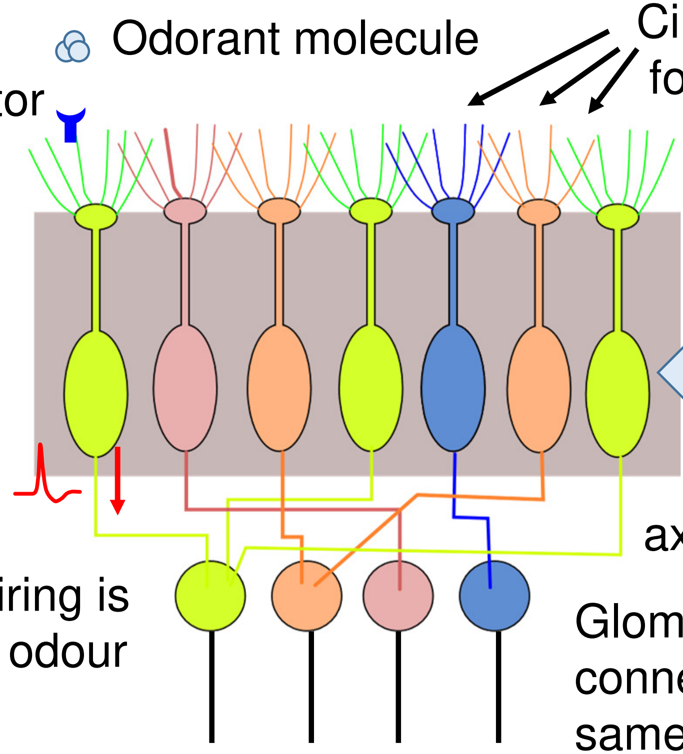
However, the BR is affected by neurotransmitters released by nerves connected to the heart and by other molecules released in the blood stream by endocrine glands

Sensory neurons

Quantity to be sensed
(light, temperature, molecules)



Example: Olfactory Sensory Neurons (OSN)



The frequency of firing is proportional to the odour intensity

Natural photoreceptors: the retina