CISC452/CMPE452/COGS400/CISC874

Biological Neurons

Farhana Zulkernine

Study Objective

- Understand the structure and functionality of biological neurons that make us intelligent
- Implement Artificial Neurons having similar functionality to create machine intelligence

Youtube videos – Basic Neurons

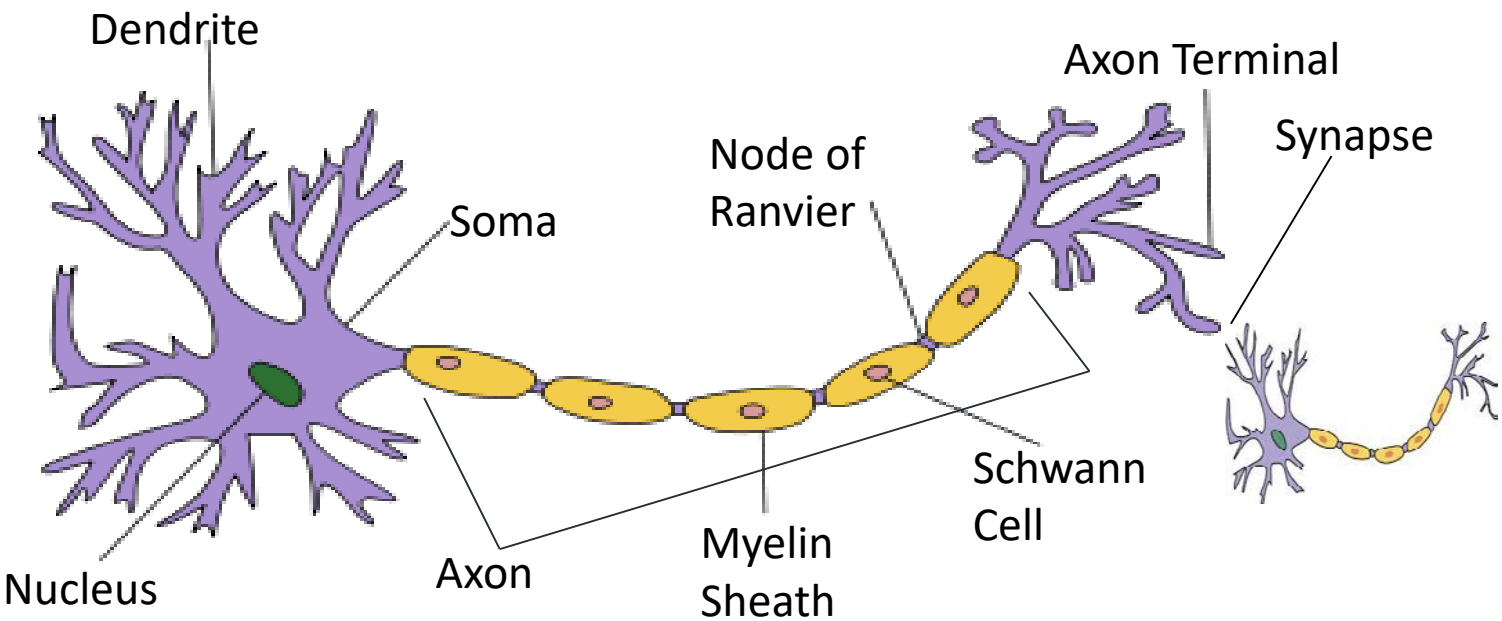
- Neurons:

  https://www.youtube.com/watch?v=GIGqp6_PG6k

  https://www.youtube.com/watch?v=C4Gt322-XxI

  https://www.youtube.com/watch?v=vyNkAuX29OU

Neuron

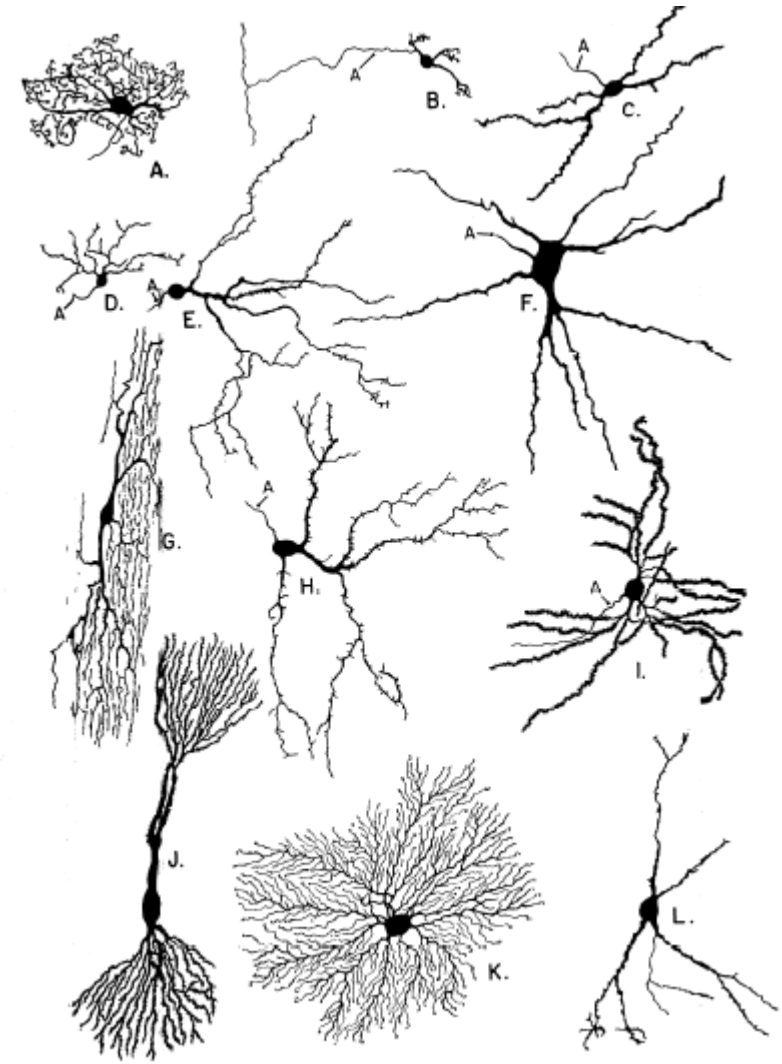


- The human brain has about 10^{11} very tiny neurons.
- Each neuron is connected to about 10^{4} other neurons.
- Each neuron only connects directly to a very small portion of other neurons < => as if you could only communicate directly with 3 other people in Canada.

Youtube Video

Neurons

- Neurons appear in many different forms in different places in the brain.
- We will only be concerned with a simple model of the neuron.

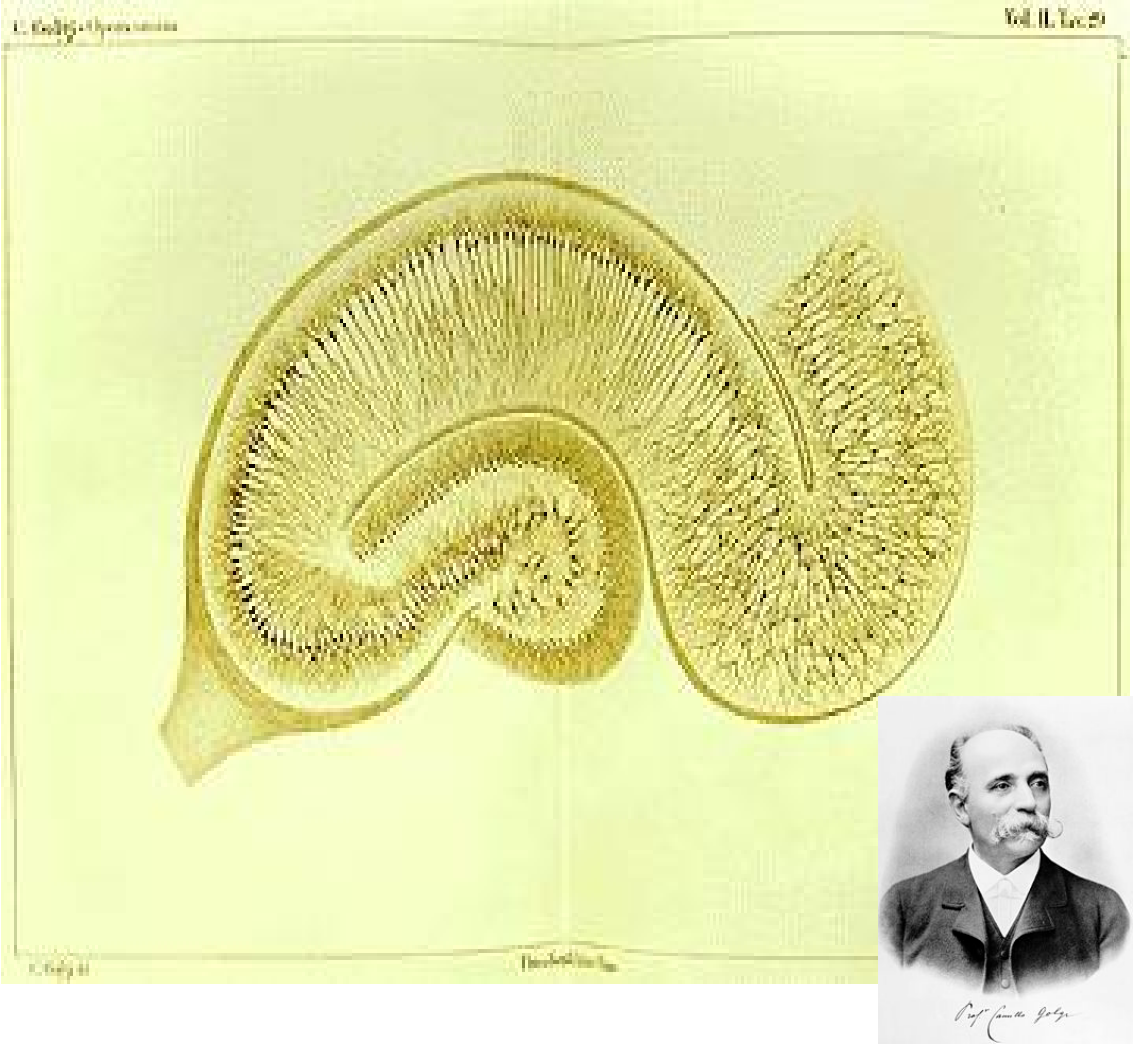


Layered Biological Neuron Architectures

- Different parts of the central nervous system are structured differently.
- The **cerebral cortex consists of many layers of neurons** with one layer feeding into the next. Layer boundaries are not rigid and some connections jump across layers.
- Each neuron is also connected with many, but not all of the other neighbouring neurons within the same layer.

Neuron

Camillo Golgi (1900) discovered a method of staining nervous tissue called ***black reaction*** which resulted in a stark black deposit on the soma as well as on the axon and all dendrites, providing an exceedingly clear and well-contrasted picture of neuron against a yellow background..



Interesting Facts

- The brain is metabolically very active. It consumes 25% of the body energy, while it only takes up about 1% of body weight.
- Almost the full set of neurons is in place before birth.
- Unlike most body cells, neurons in the brain are only able to divide to make new cells during fetal development and for a few months after birth. After that, no new brain cells are formed, although existing ones may increase in size until the age of about eighteen years. They are designed to last a lifetime.

Interesting Facts (cont…)

- During childhood, and particularly during adolescence, a process known as "synaptic pruning" occurs. Although the brain continues to grow and develop, the overall number of neurons and synapses are reduced by up to 50%, removing unnecessary neuronal structures and allowing them to be replaced by more complex and efficient structures, more suited to the demands of adulthood.

Ref: http://www.human-memory.net/brain_neurons.html

Ion Pumps and Neurotransmitters

- Resting potential and Resting Membrane Potential:

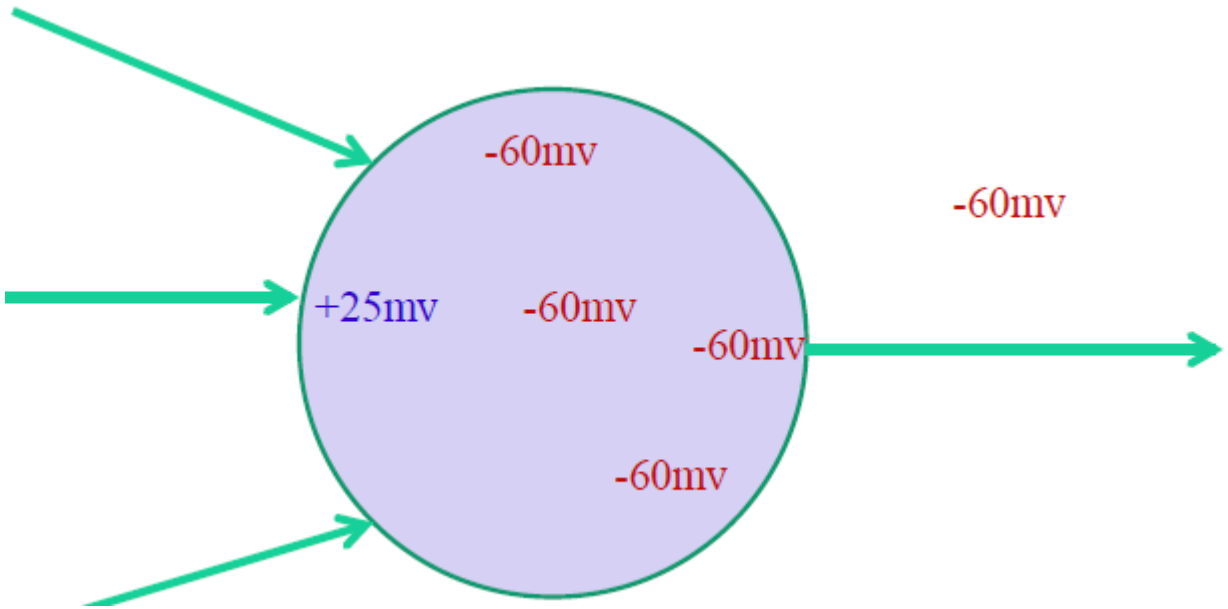
  https://www.youtube.com/watch?v=YP_P6bYvEjE
- Na^+ - K^+ pump and Refractory period:

  https://www.youtube.com/watch?v=Iiiz5CpFCQo
- Neurotransmitters

  https://www.youtube.com/watch?v=p5zFgT4aofA

Potential in Neuron

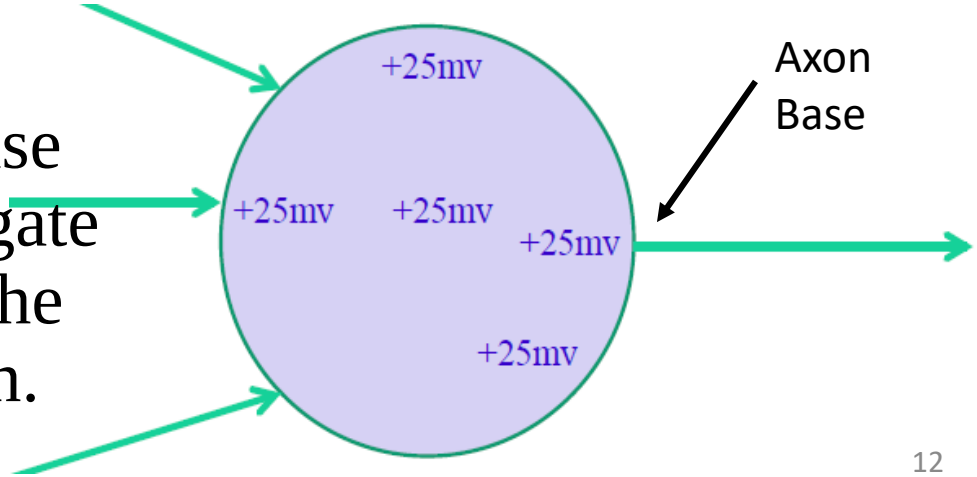
- **Resting Potential:** Refers to the difference between the voltage inside and outside the neuron at a stable non-firing state. The resting potential of the average neuron is around -60 millivolts, indicating more –ve charge inside the cell body than outside it.
- Incoming signals (+ve and –ve) have the effect of locally altering the potential at the dendrites where the signal arrives.



Potential (cont…)

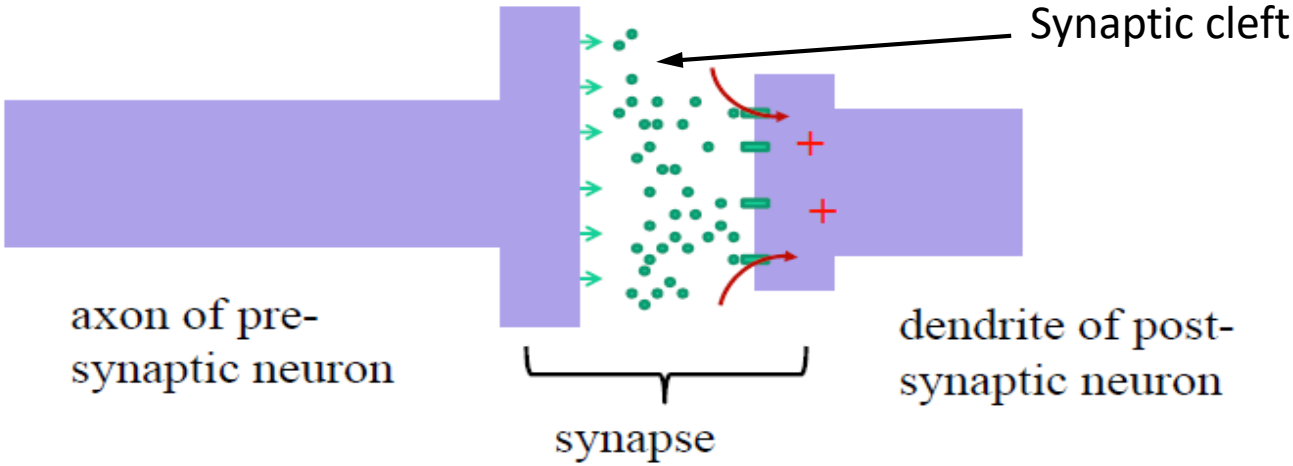
- If the incoming signal, and thus the locally altered potential is maintained, it will very quickly change the potential of the whole cell body. This is because the positive and negative ions attract each other, and will move to develop a uniform concentration. This transfer of potential is called slow potential. It actually takes place very quickly, but it is "slow" relative to other forms of conducting electric potential.

- When the cumulative potential at the axon base exceeds a threshold, a gate opens to the axon and the ions flows into the axon.



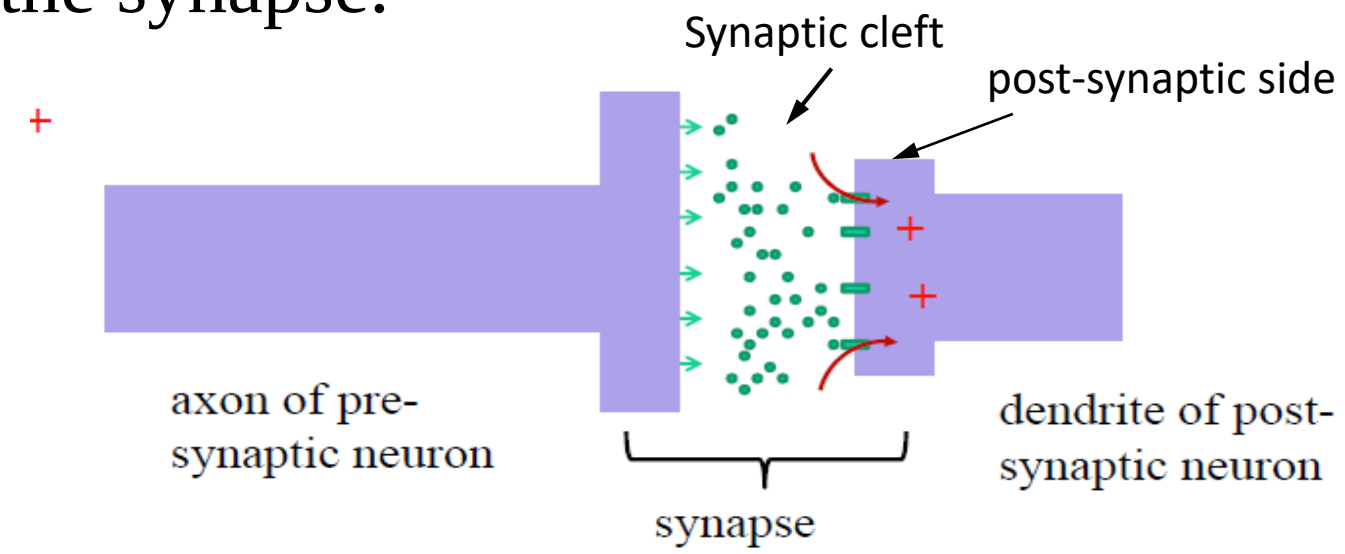
Transmission through Synapse

- The same signal transmitted to all of recipient neurons, can cause different effects on the recipient neurons depending on *type and ions at the synapses*.
- When an action potential arrives at the end of the axon, it causes the release of many tiny neurotransmitters. The neurotransmitters drift across the gap to the dendrite.

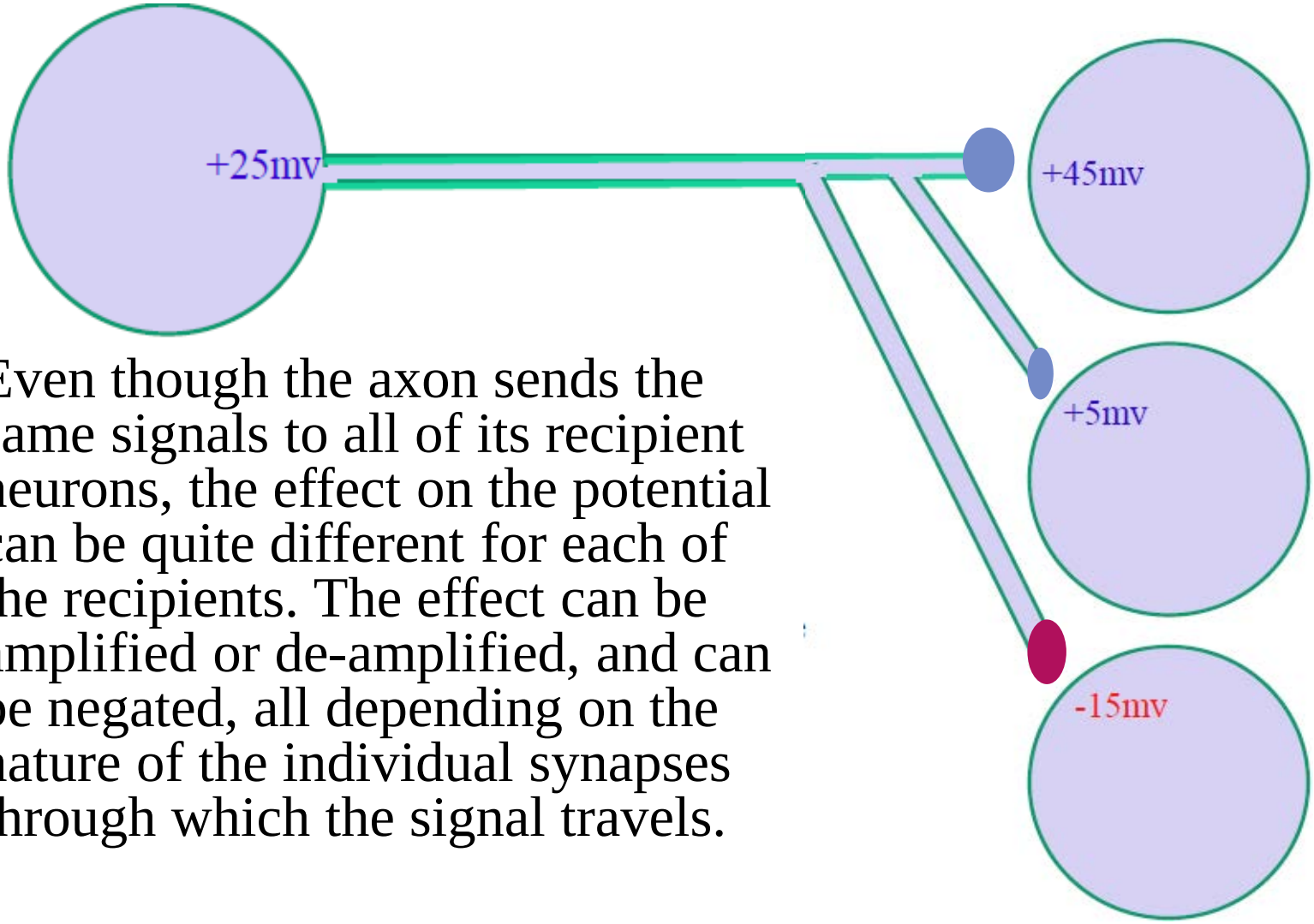


Transmission (cont…)

- On the post-synaptic side of the synapse, there are channels which are activated when contacted by a neurotransmitter and *"pump" ions into the dendrite*. Thus, the end result is a change in potential of the postsynaptic neuron at the site of the synapse.



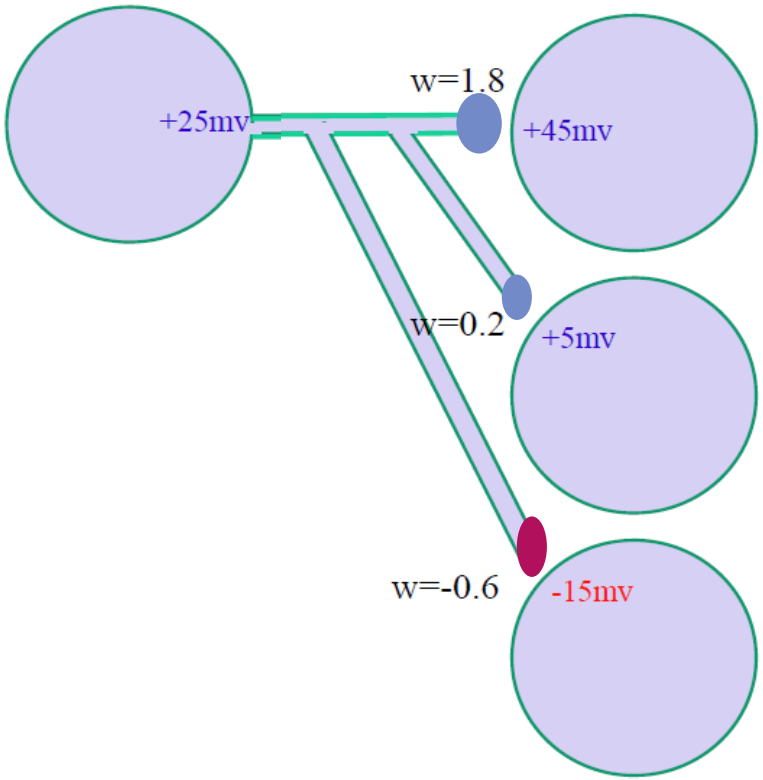
Varying Effects of Signals



- Even though the axon sends the same signals to all of its recipient neurons, the effect on the potential can be quite different for each of the recipients. The effect can be amplified or de-amplified, and can be negated, all depending on the nature of the individual synapses through which the signal travels.

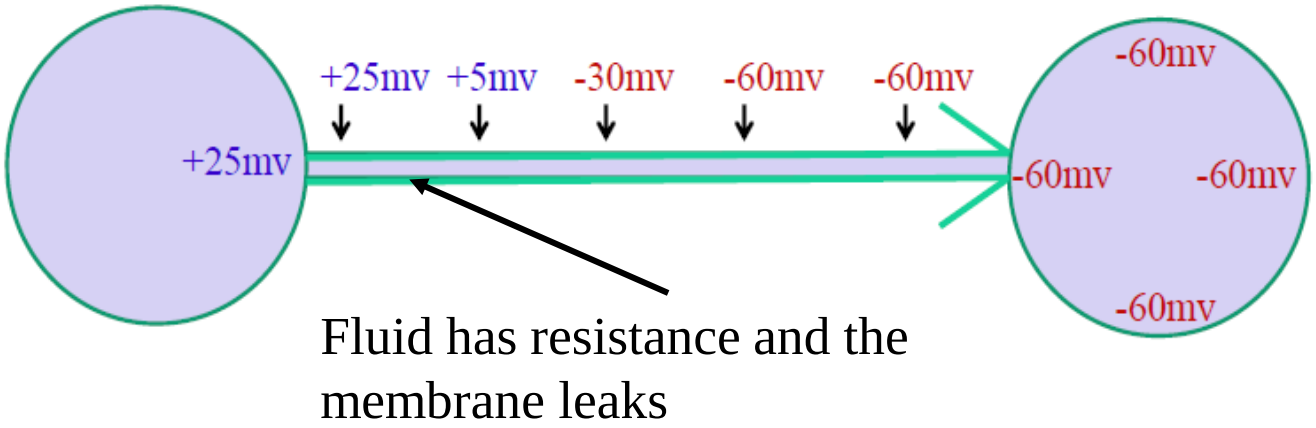
Synaptic Weights

- The variation in effect is modelled by assigning each synapse a number (called a **weight**, or synaptic strength) and *multiplying it by the signal* to determine the resulting local potential at the post-synaptic neuron.



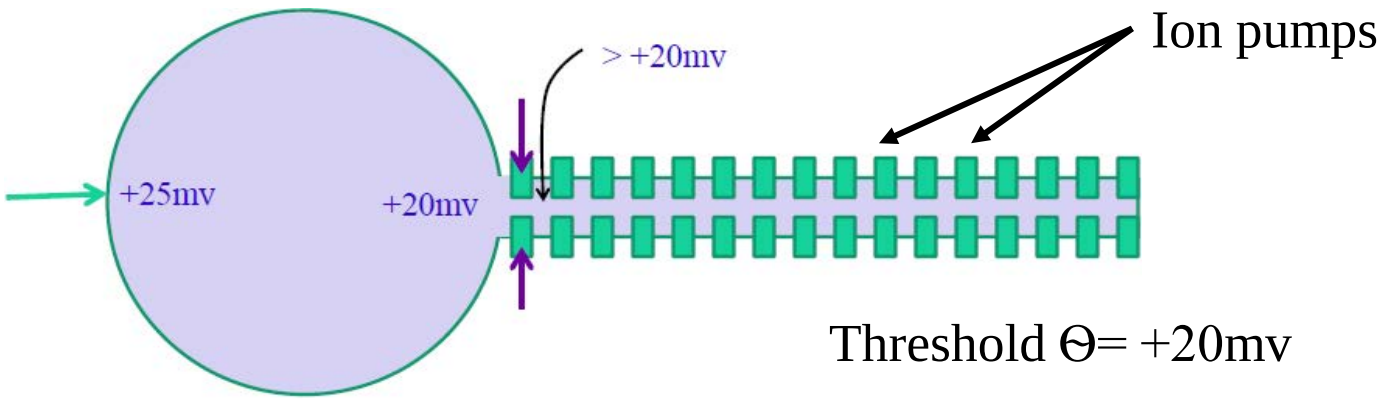
Thresholds for Transmission

- The effect of the potential at the axon base would have little or no influence on the potential at the site of “contact” without the mechanism of **ion pumps**.



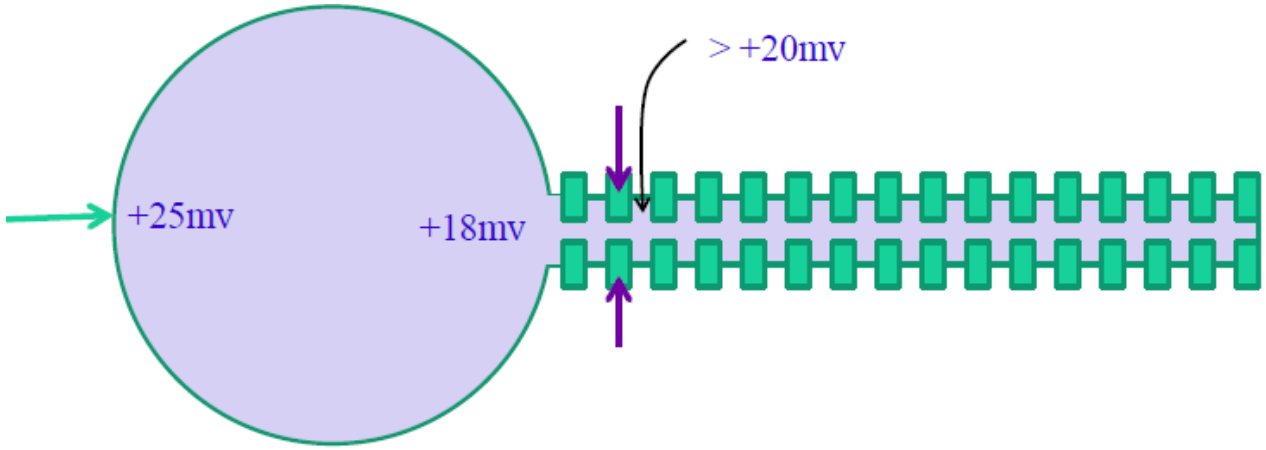
Thresholds for Transmission

- If the potential at a point along the axon rises beyond a threshold, ion pumps at that point will operate, and cause a sudden large local increase in potential called an **action potential**.

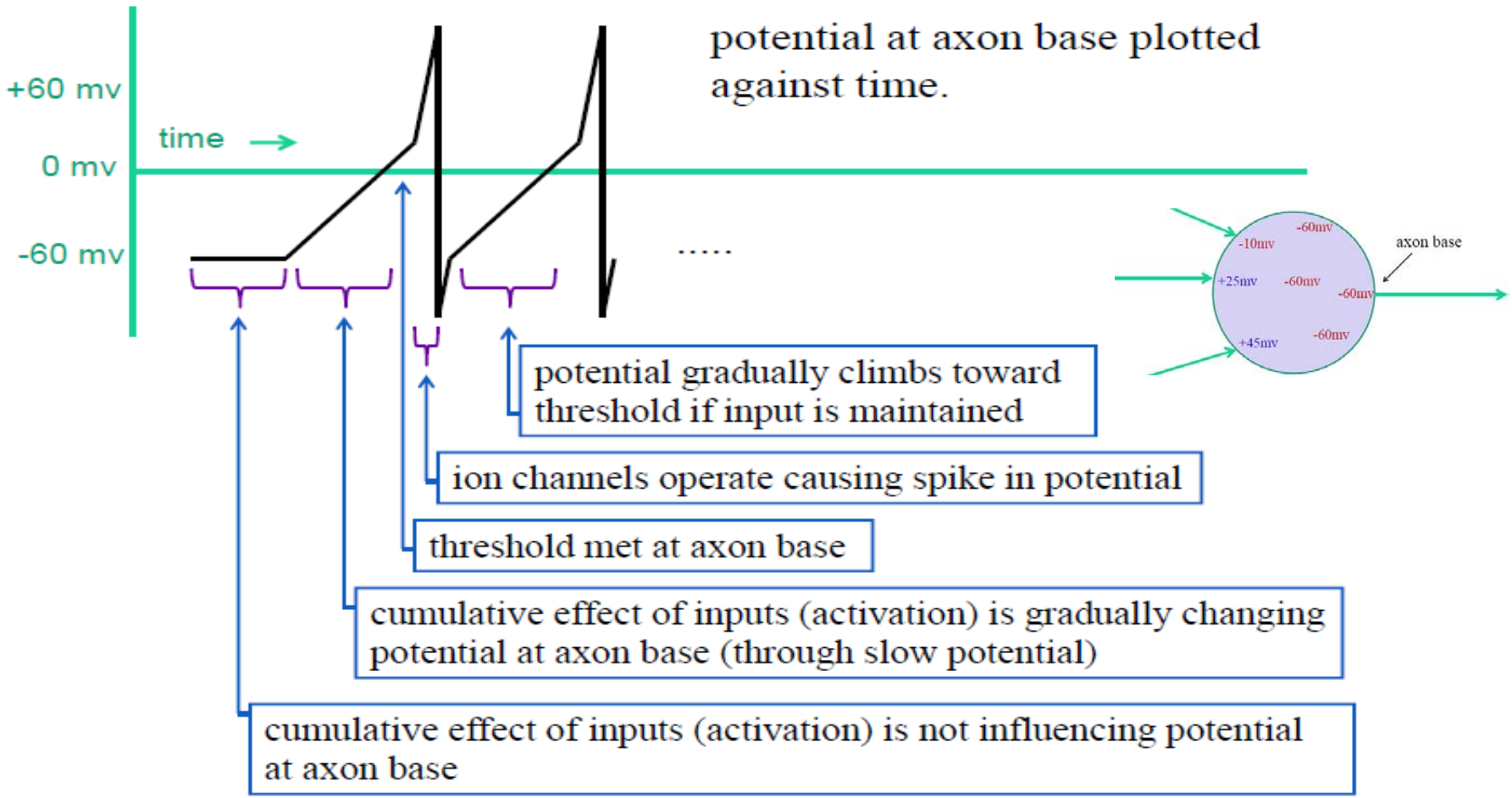


Thresholds (cont…)

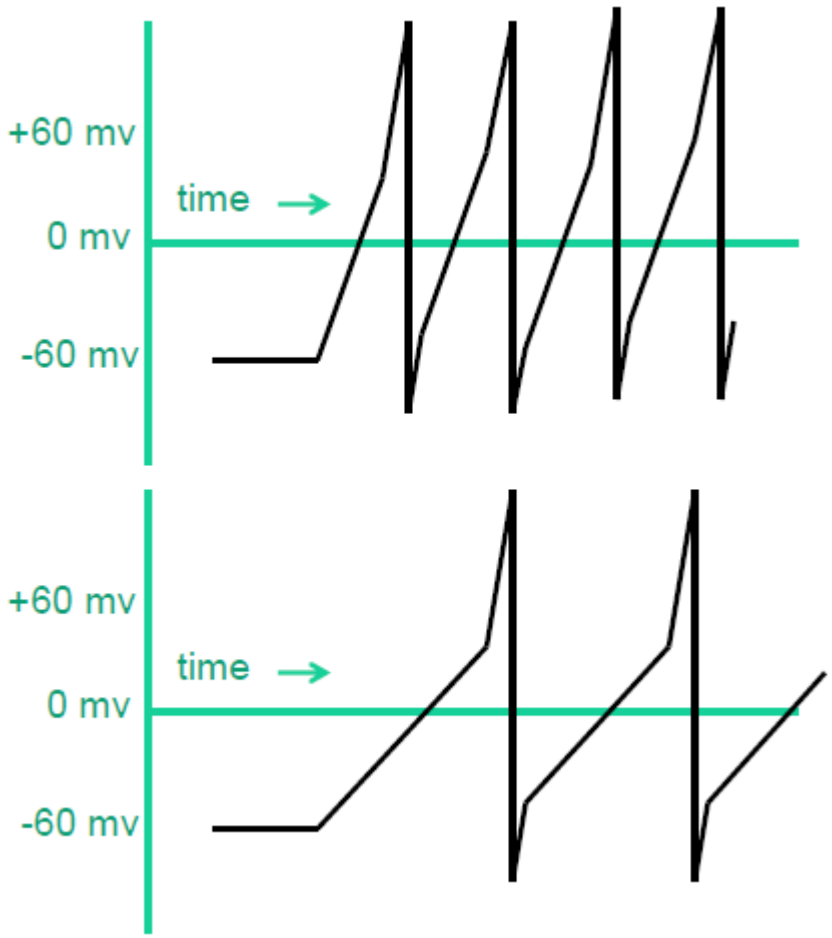
- Thus a spike in potential (the action potential) moves gradually down the axon. Note that after operating, the ion pumps need a short period to recover before they can operate again. This prevents the spike in potential from moving backwards on the axon. Also note that the potential at the axon base falls slightly when the spike is being generated. If the neuron returns to the threshold value, another spike of activity will start on the axon.



Continuing Transmission



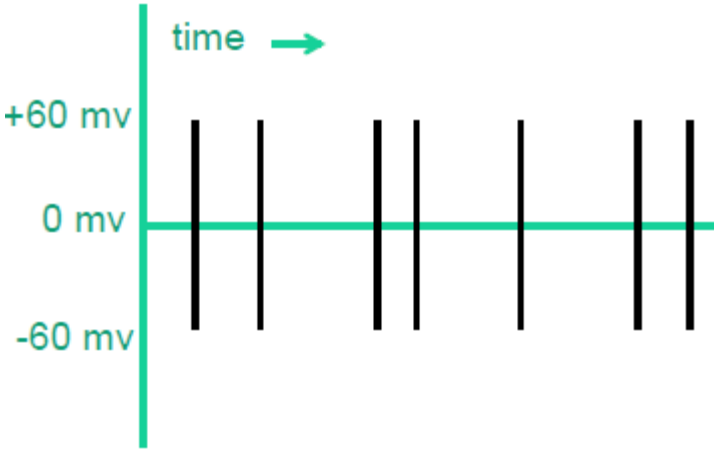
Measure of Activation

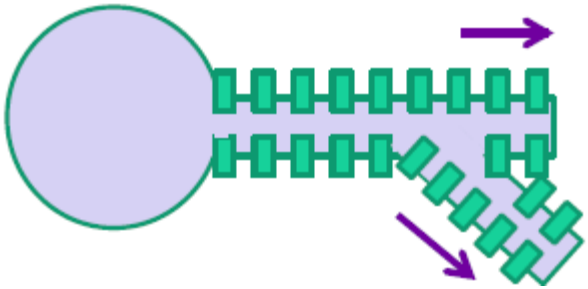


- The higher the activation, the faster the neuron will attain its threshold potential.
- The spacing in between action potentials is a direct measure of the activation of the neuron at the time.

Frequency of Action Potential

- Each of the action potentials generated by each neuron is exactly the same, so it is the **frequency of action potentials** that is encoding the signal from the neuron.
- Because of the *resting period* between action potentials, the **maximum firing rate is about 200 per second**.
- When the axon branches the same action potentials are propagated identically down all branches.



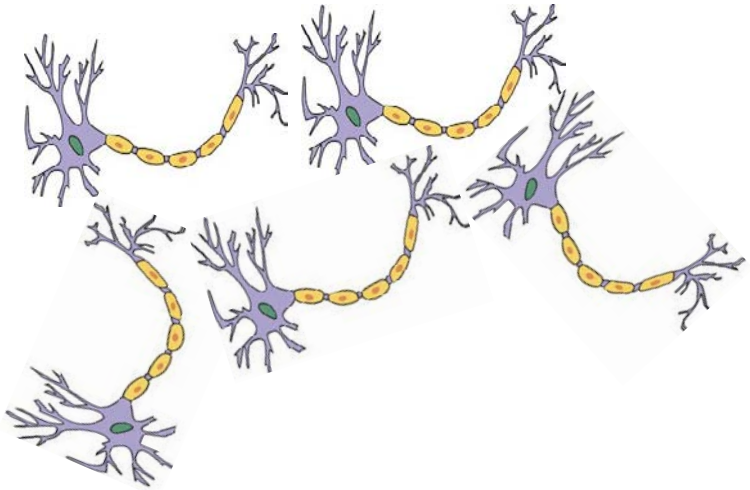


Inhibitory Connections

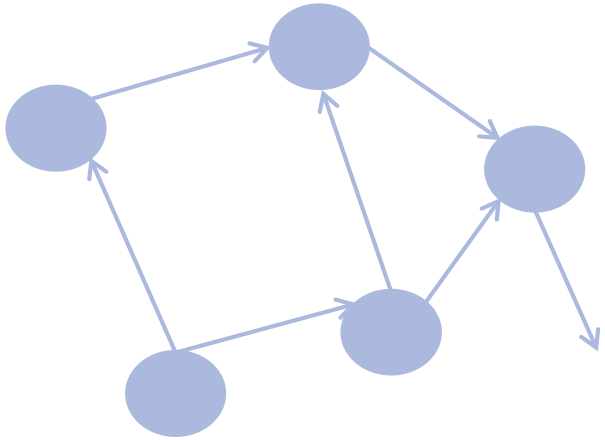
- Most of these connections are **excitatory**, but some are **inhibitory**.
- There are some **"veto" neurons** that have the overwhelming power of neutralizing the effect of a large number of excitatory inputs to a neuron.
- Some **indirect self-excitation** also occurs when one node's activation excites its neighbour, which excites the first node again.

Networks – Neuron vs ANN

- In 1943, McCullogh & Pitts proposed that information was being conveyed through the interconnected neurons in the brain.

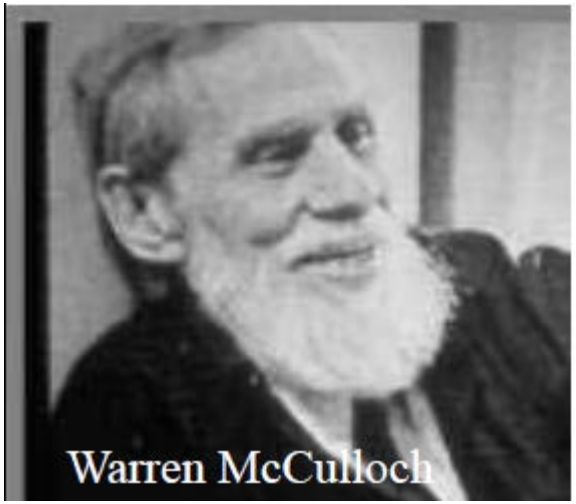


Biological Neural Network



Representation in Artificial Neural Network

The First ANN Model



- Warren McCulloch (1899-1969) was an army psychiatrist who turned into neuropsychologist
- Assembled research group with Walter Pitts, Jerry Lettvin
- Pursued cybernetic model of the brain at MIT – proposed the first ANN model

Summary

1. Incoming signals create potentials at the synapse sites of a neuron.
2. Each of these potentials influences (through slow potential) the potential at the base of the axon. The sum of all these influences is called the **activation**.
3. When activation exceeds some **threshold, action potentials** are generated, and propagate down the axon.
4. The same signal transmitted to all of recipient neurons, can cause different effects on the recipient neurons depending on type and ions at the synapses and the neurotransmitters.