CISC452/CMPE452/COGS400

Biological Neurons

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YouTube videos – Basic Neurons

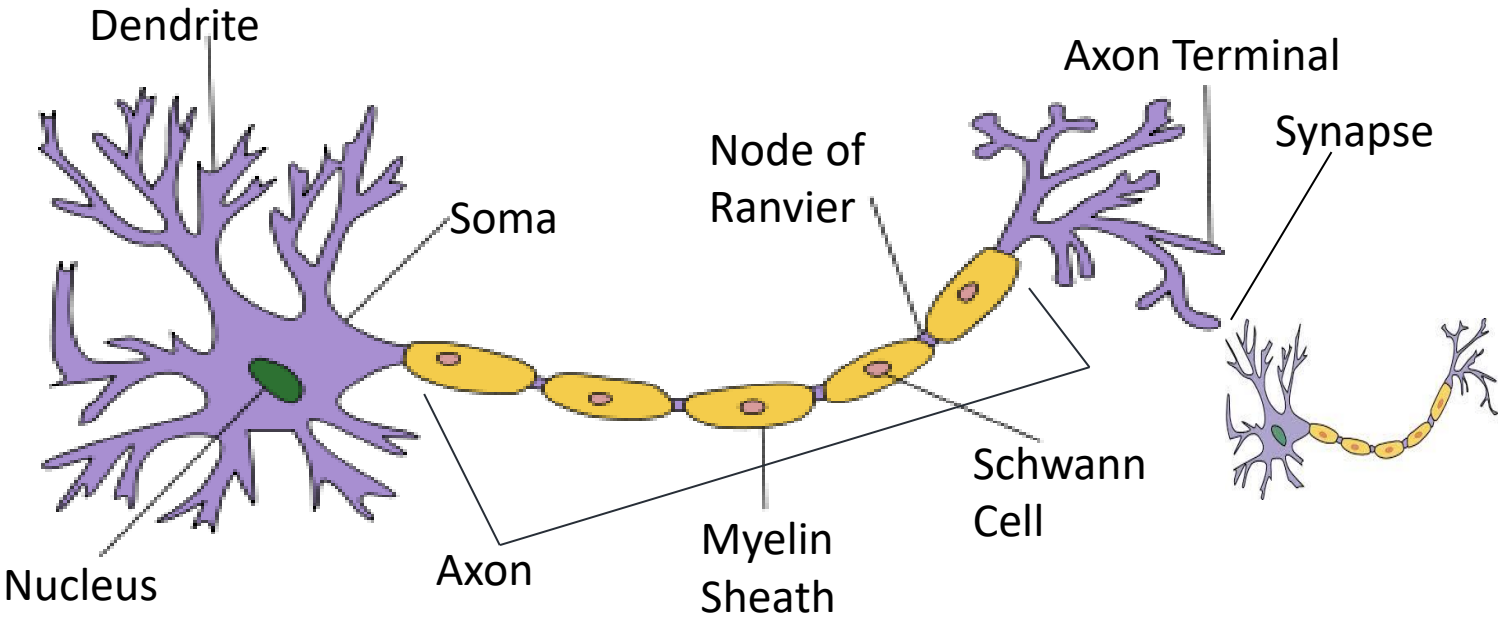
- Neurons:

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

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

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

Neuron

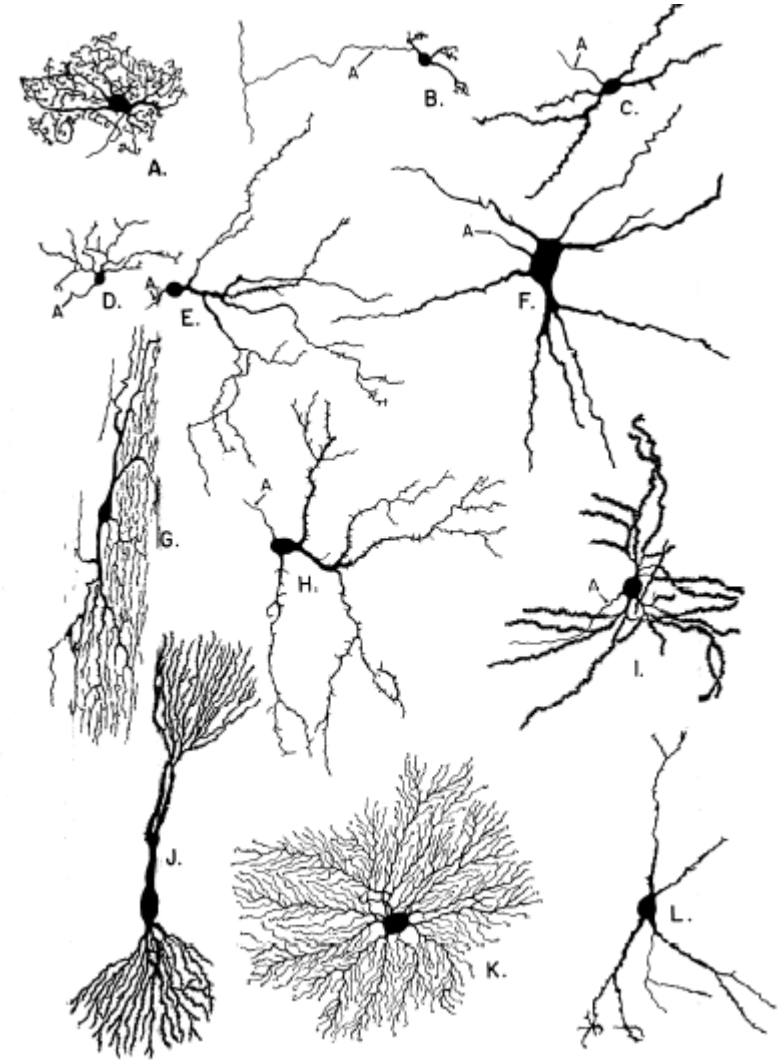


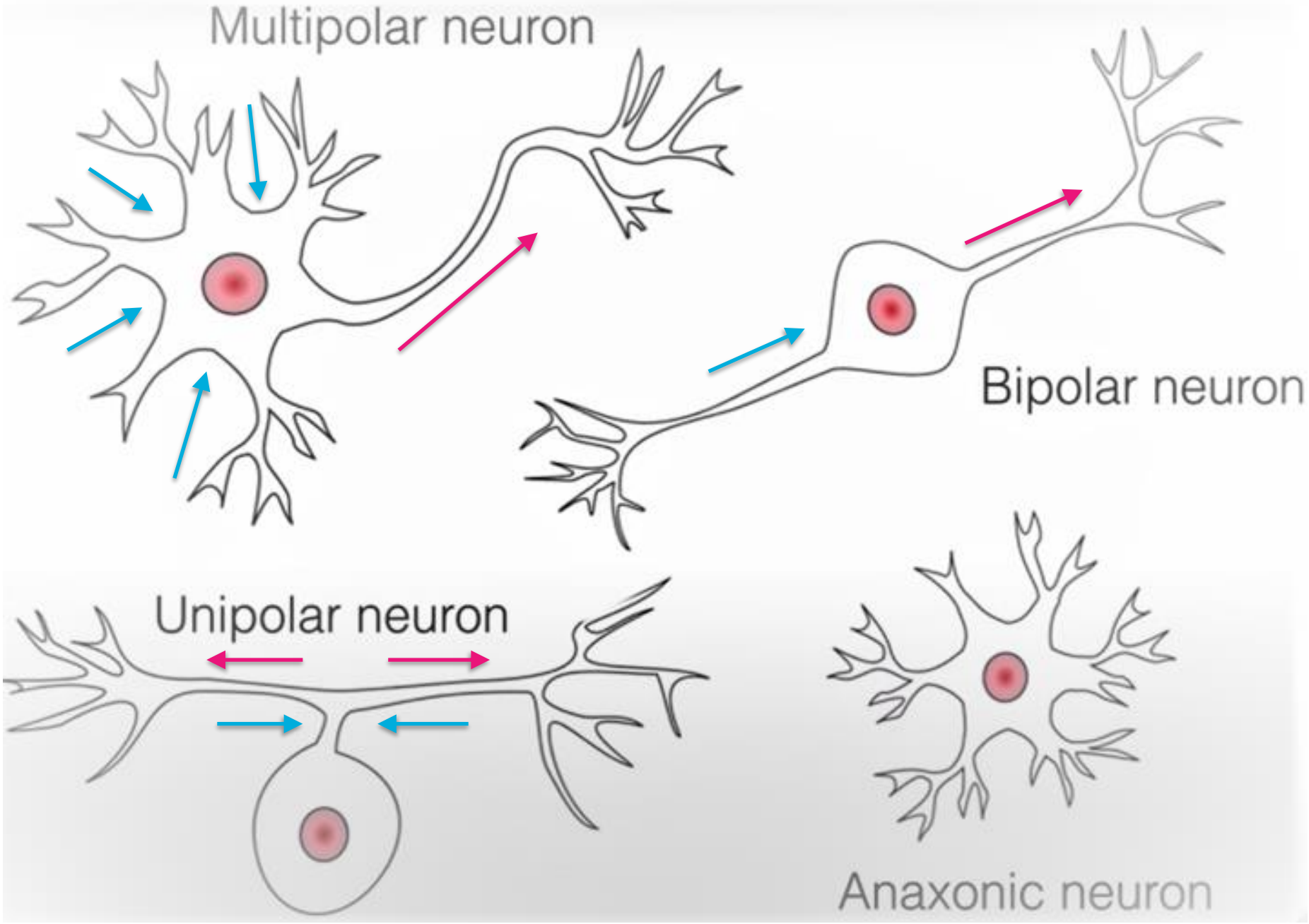
- The human brain has about 10^{11} very tiny neurons.
- Each neuron is connected to about 10^{4} other neurons.
- Each neuron only connects directly to a very small portion of other neurons < => as if you could only communicate directly with 3 other people in Canada.

Youtube Video

Neurons

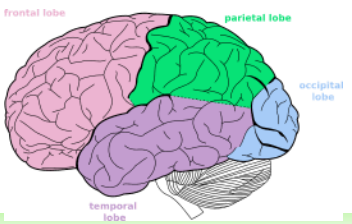
- Neurons appear in many different forms in different places in the brain.
- We will only be concerned with a simple model of the neuron.





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

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. 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.

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

Why we need to know this?

- Currently ANNs model only the multipolar neurons and use them to create human like intelligence.
- ANNs models were created to mimic the structure and function of biological neurons
- We may need to create novel ANN models to create human-like intelligence.

Signal Passing through Neurons

- Resting potential and Resting Membrane Potential:

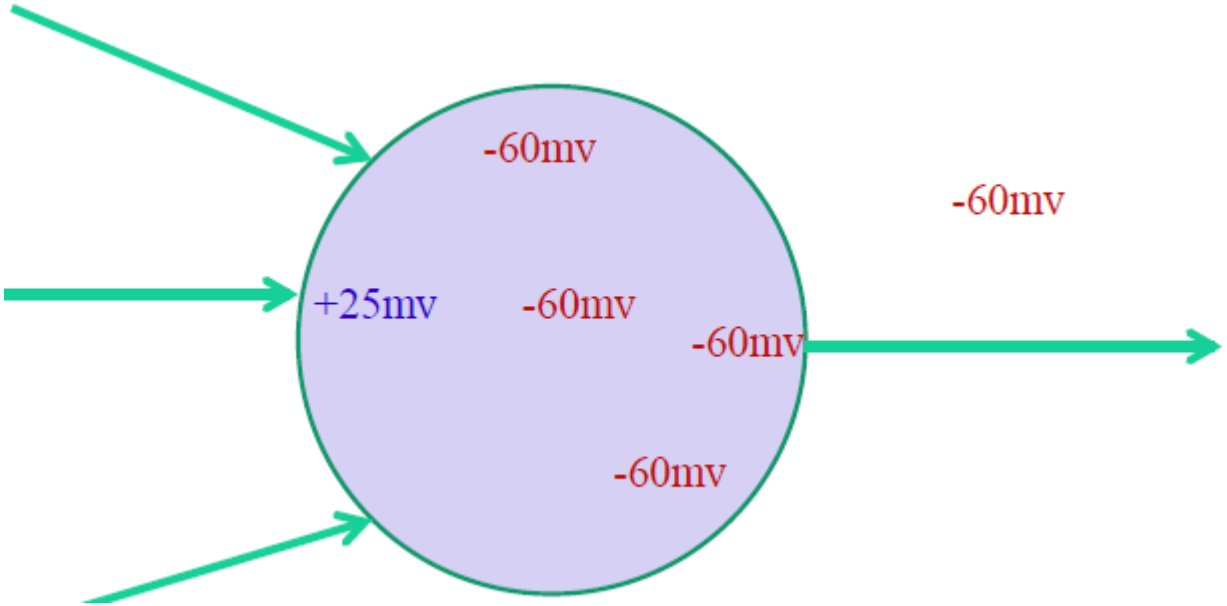
  https://www.youtube.com/watch?v=YP_P6bYvEjE
- Na^+ - K^+ pump and Refractory period:

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

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

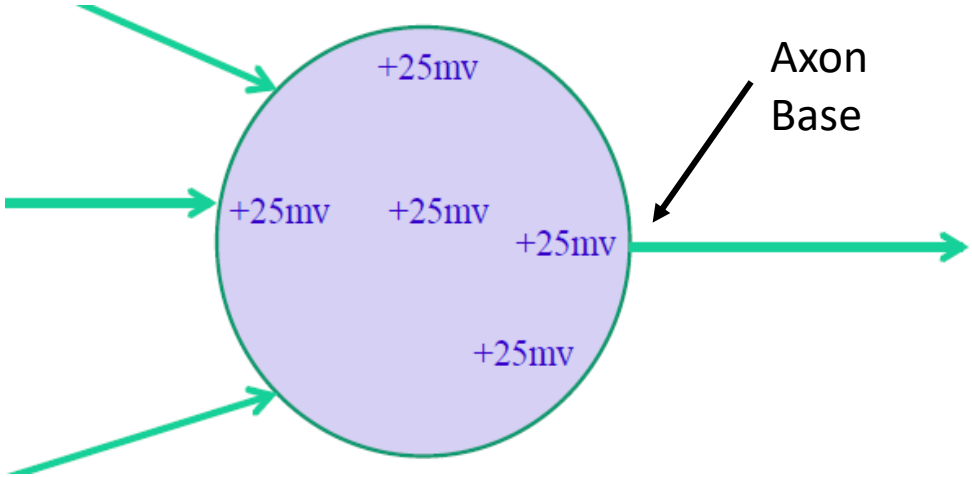
Potential in Neuron

- **Resting Potential (RP):** Electric potential or the difference between voltage inside and outside the neuron at a stable non-firing state
  - RP varies between 60~70 mv.



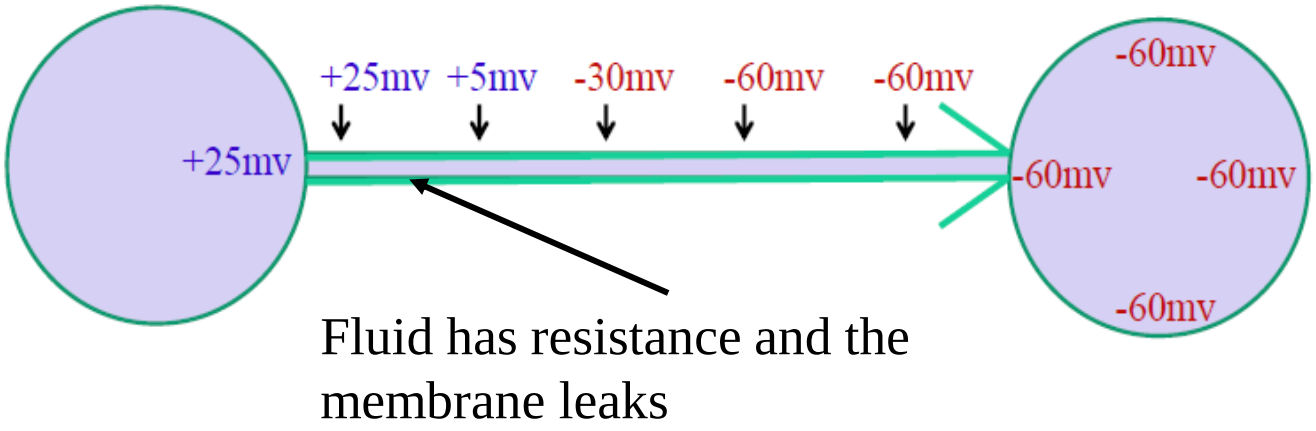
Transmission of Signal

- **Slow Potential:** Incoming voltage from dendrites (+ve and –ve) spreads inside the cell body and "slowly" alters the 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.



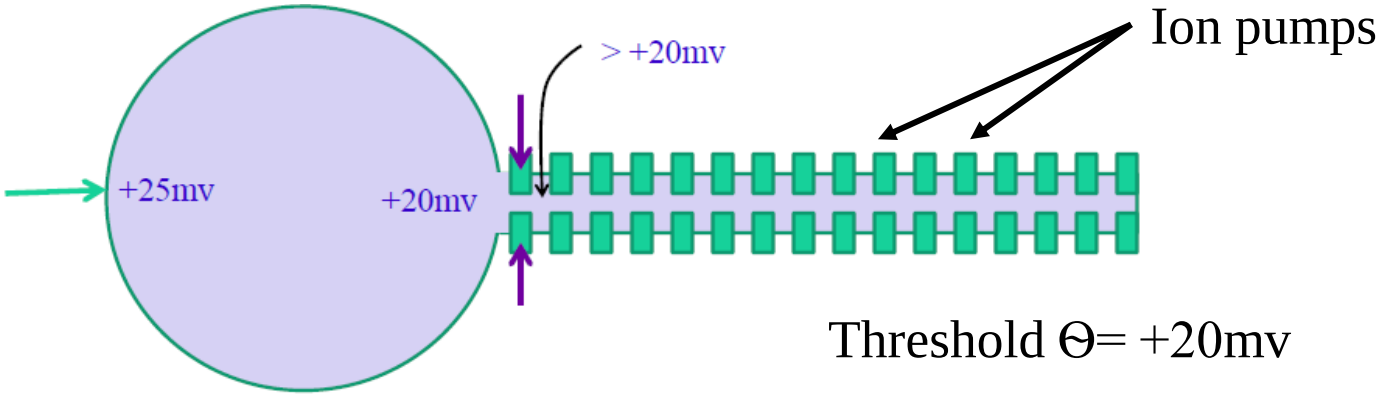
Boosting the Signal Strength

- The effect of the potential at the axon base would have little or no influence on the other end of the neuron without the mechanism of **ion pumps**.



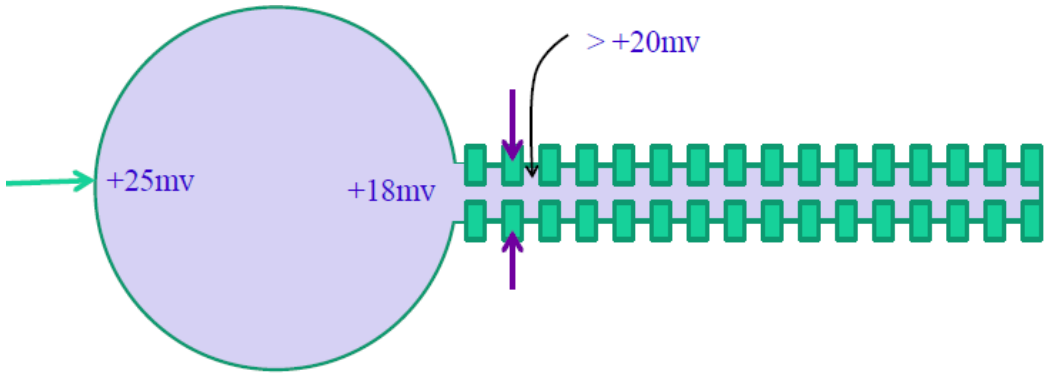
Ion Pumps and Action Potential

- **Action Potential:** If the potential at a point along the axon rises beyond a threshold, ion pumps at that point will operate, the gate would open and cause a sudden surge in +ve potential which is called an action potential.

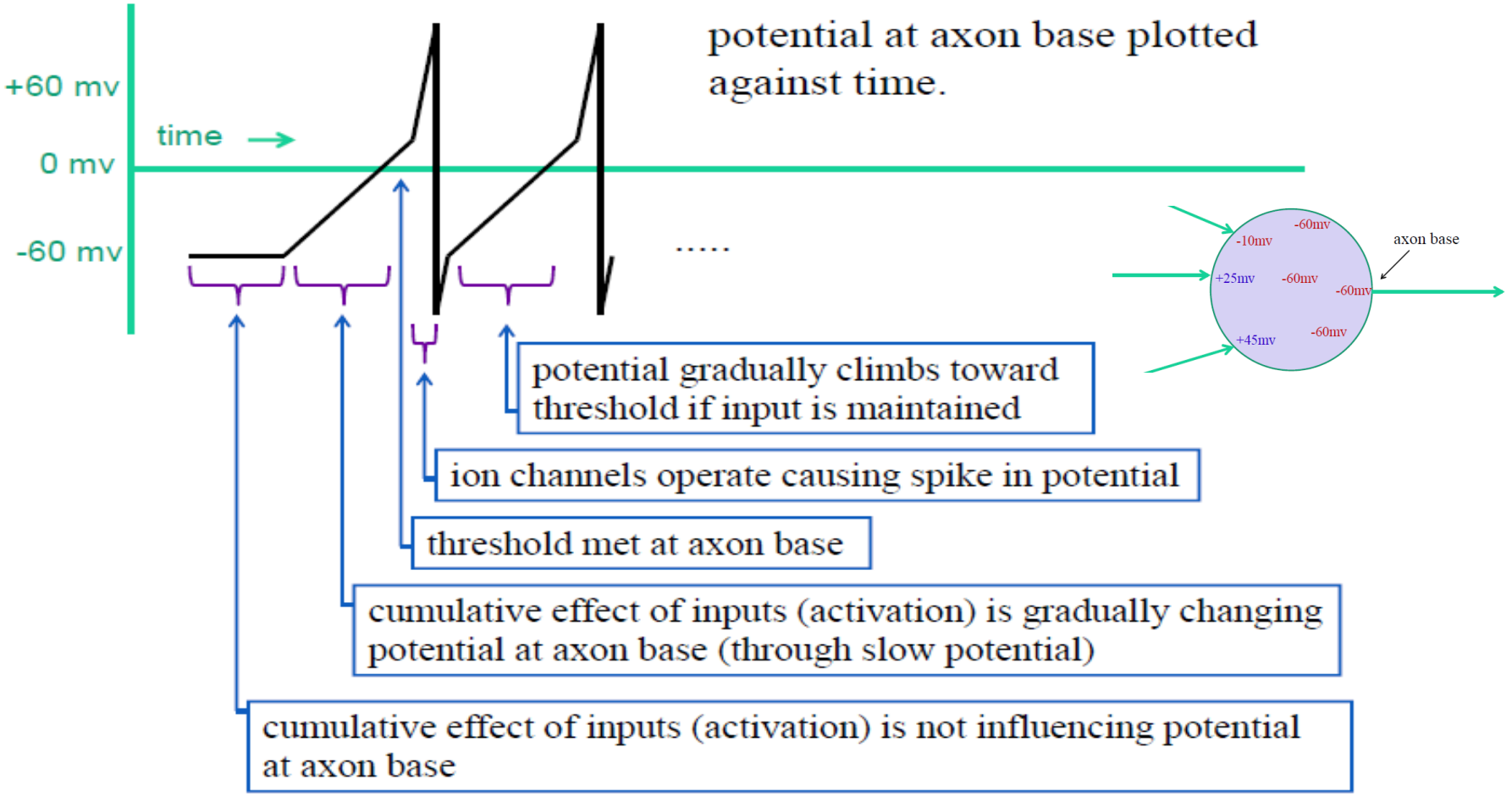


Maintaining Signal Strength

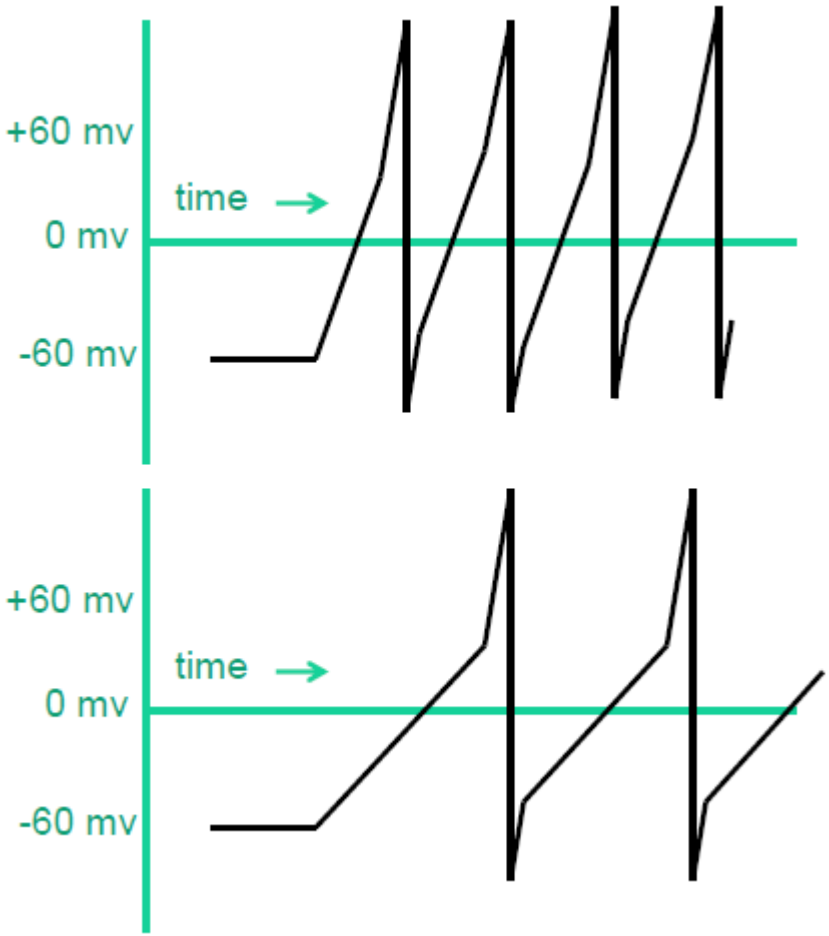
- Thus a spike in potential (the action potential) moves gradually down the axon. Note that after operating, the ion pumps need a short period to recover before they can operate again. This prevents the spike in potential from moving backwards on the axon. Also note that the potential at the axon base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



Continuing Transmission



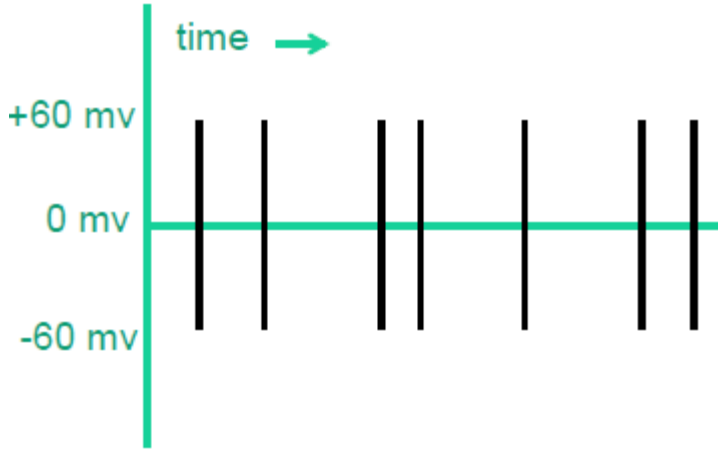
Measure of Activation

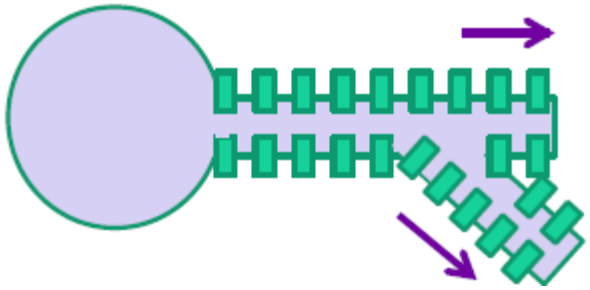


- The higher the activation, the faster the neuron will attain its threshold potential.
- The spacing in between action potentials is a direct measure of the activation of the neuron at the time.

Frequency of Action Potential

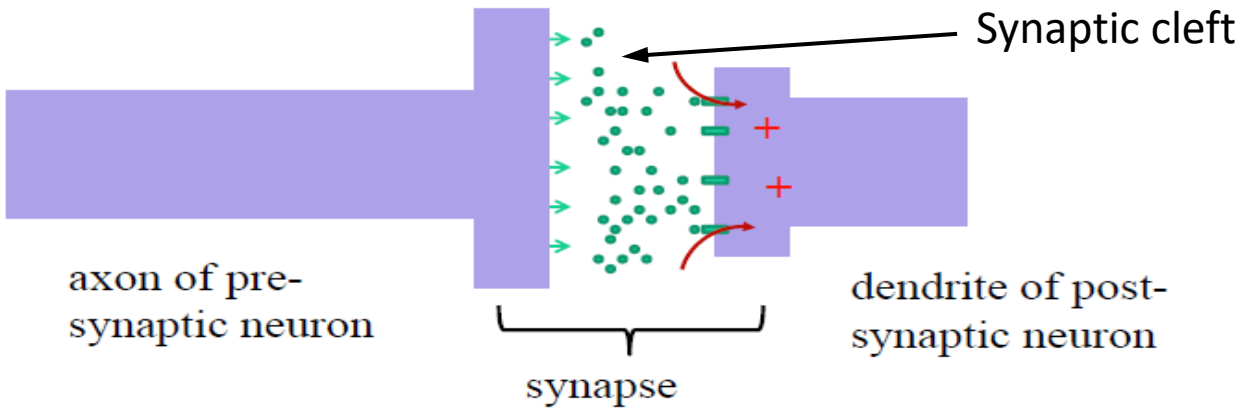
- Each of the action potentials generated by each neuron is exactly the same, so it is the **frequency of action potentials** that is encoding the signal from the neuron.
- Because of the *resting period* between action potentials, the **maximum firing rate can be about 200 per second**.
- When the axon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





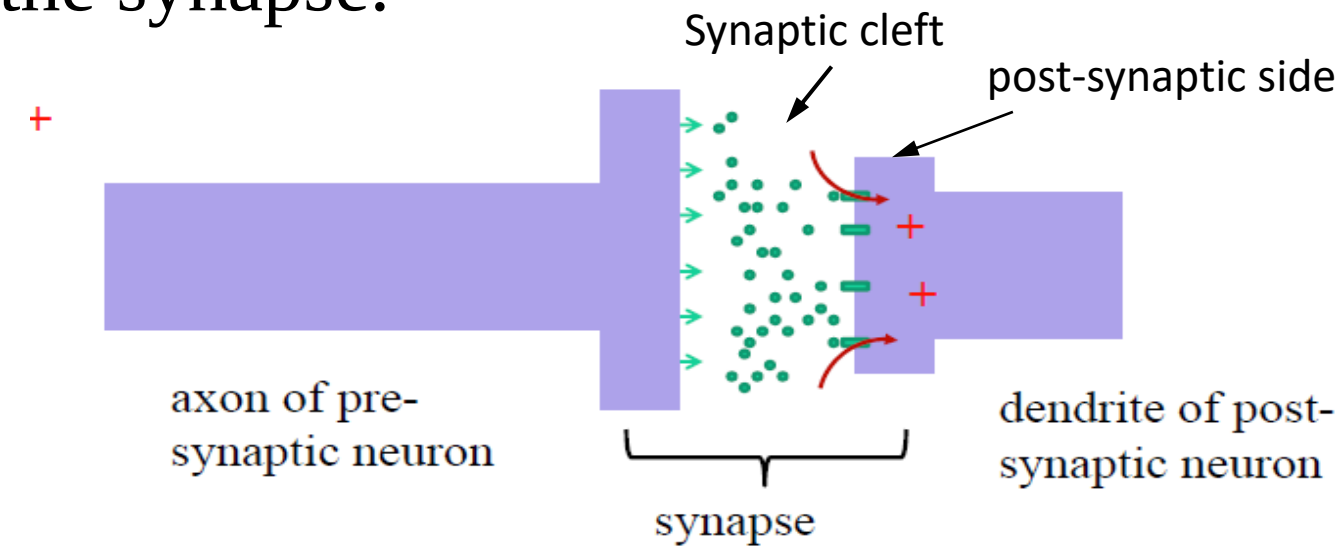
Synapse

- The same signal transmitted to all of recipient neurons, can cause different effects on the recipient neurons depending on *type of chemicals 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.

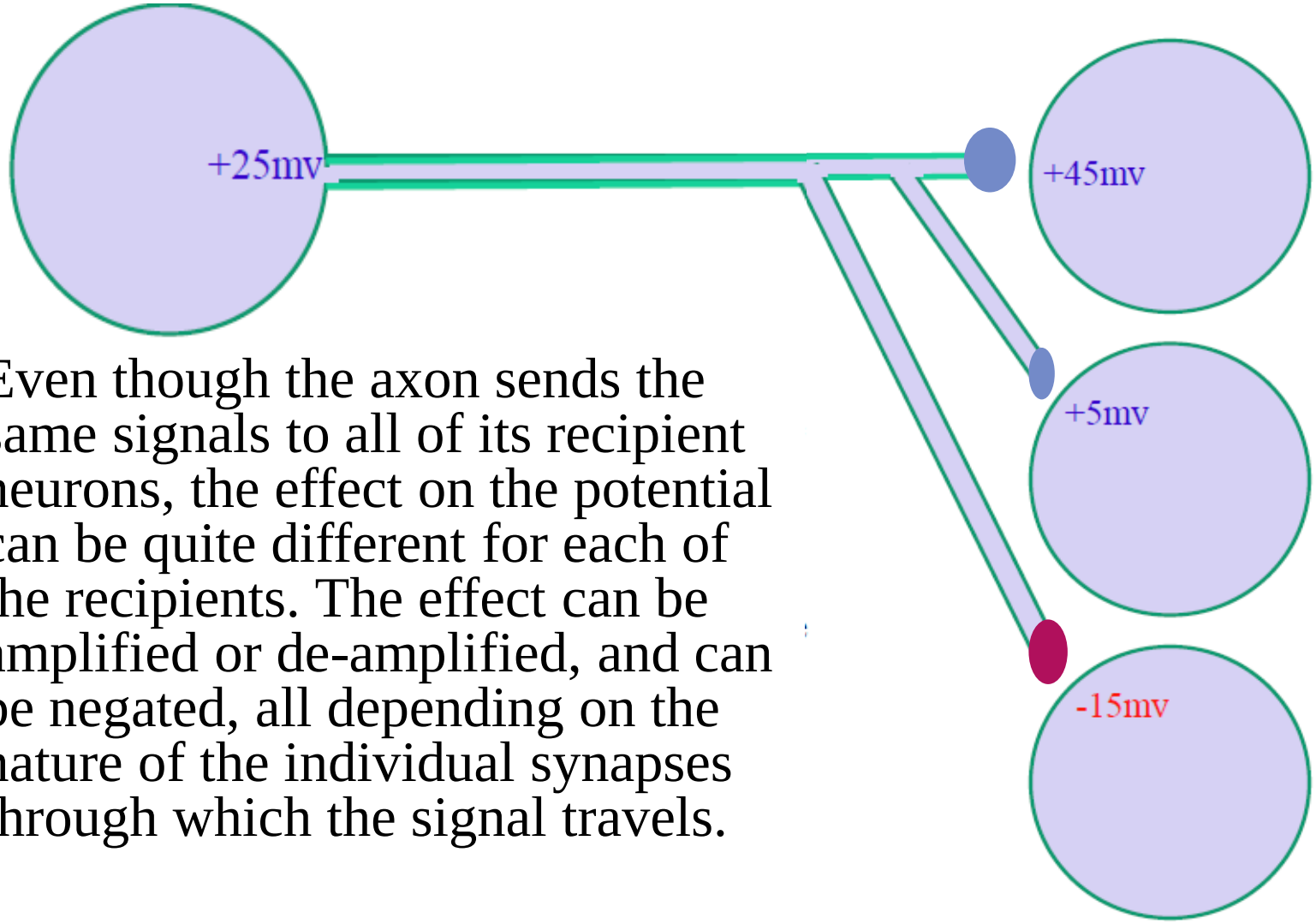


Signal Transmission through Synaptic Cleft

- 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.

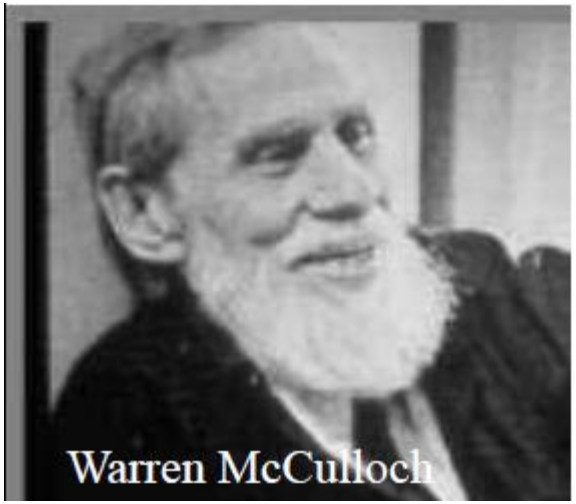


Change of Signals at Synapse



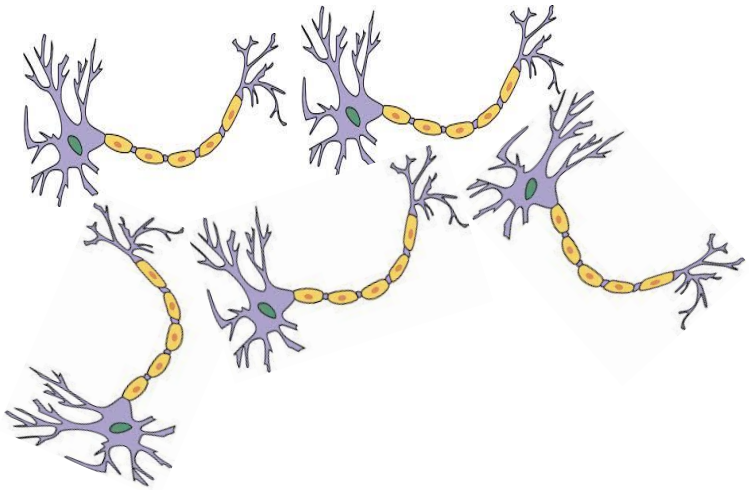
- Even though the axon sends the same signals to all of its recipient neurons, the effect on the potential can be quite different for each of the recipients. The effect can be amplified or de-amplified, and can be negated, all depending on the nature of the individual synapses through which the signal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

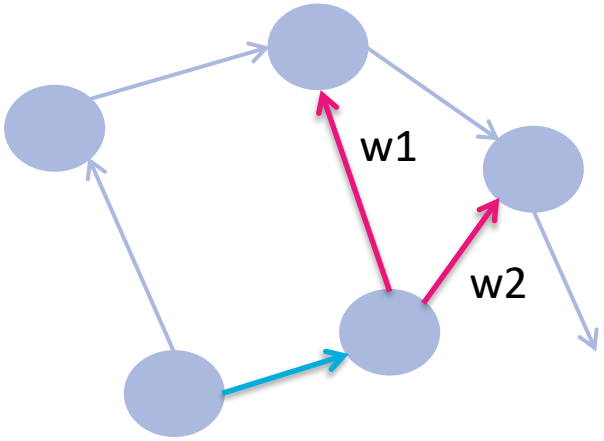
The First ANN Model



- Warren McCulloch (1899-1969) was an army psychiatrist who turned into neuropsychologist
- Assembled research group with Walter Pitts, Jerry Lettvin and pursued cybernetic model of the brain at MIT
- In 1943, they proposed the first ANN model to explain information flow through interconnected brain neurons.

Networks – Neuron vs ANN





Biological Neural Network

Representation in Artificial Neural Network

- Assigned a weight to each connection to model behaviour of synapse
- *An axon's output signal is multiplied by the weight* to determine the potential passed onto the post-synaptic neuron.

Inhibitory Connections

- Most of these connections are **excitatory** (+ve weight value), but some are **inhibitory** (-ve weight value).
- 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.

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.