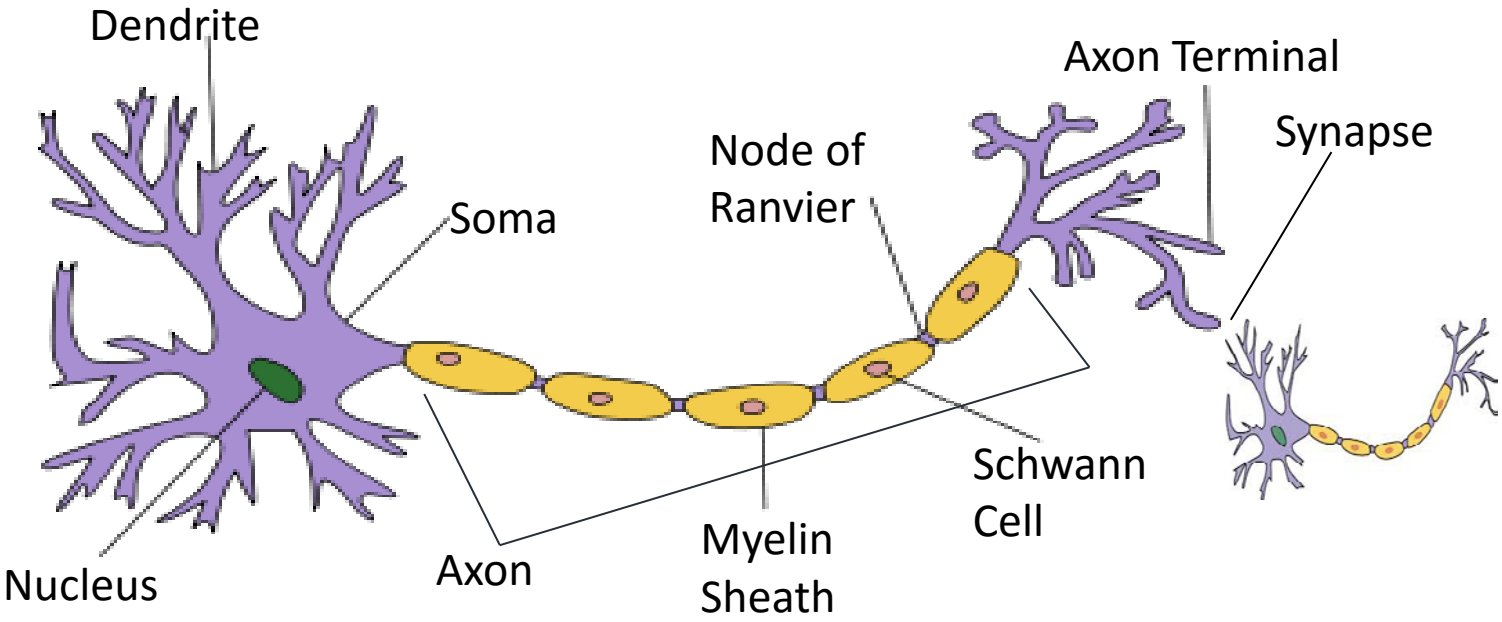
CISC452/CMPE452/COGS 400
Biological Neurons

Farhana Zulkernine

Neuron

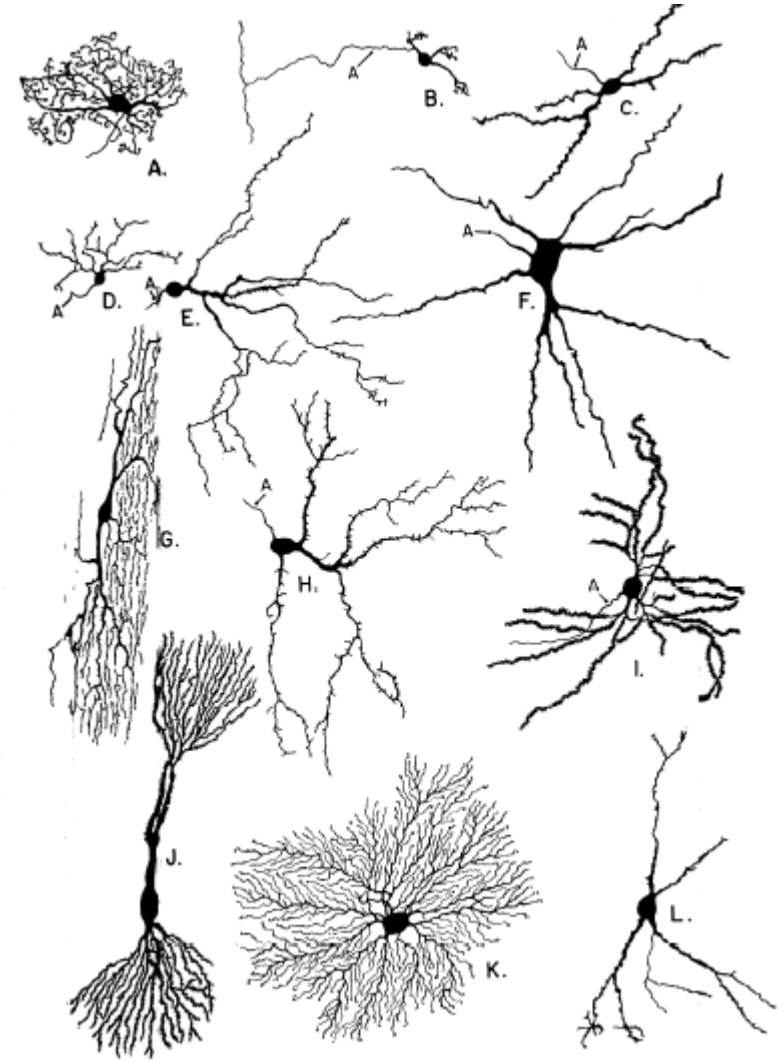


- The human brain has about 10^{11} very tiny neurons.
- Each neuron is connected to about 10^{4} other neurons.
- Each neuron only connects directly to a very small portion of other neurons < => as if you could only communicate directly with 3 other people in Canada.

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.

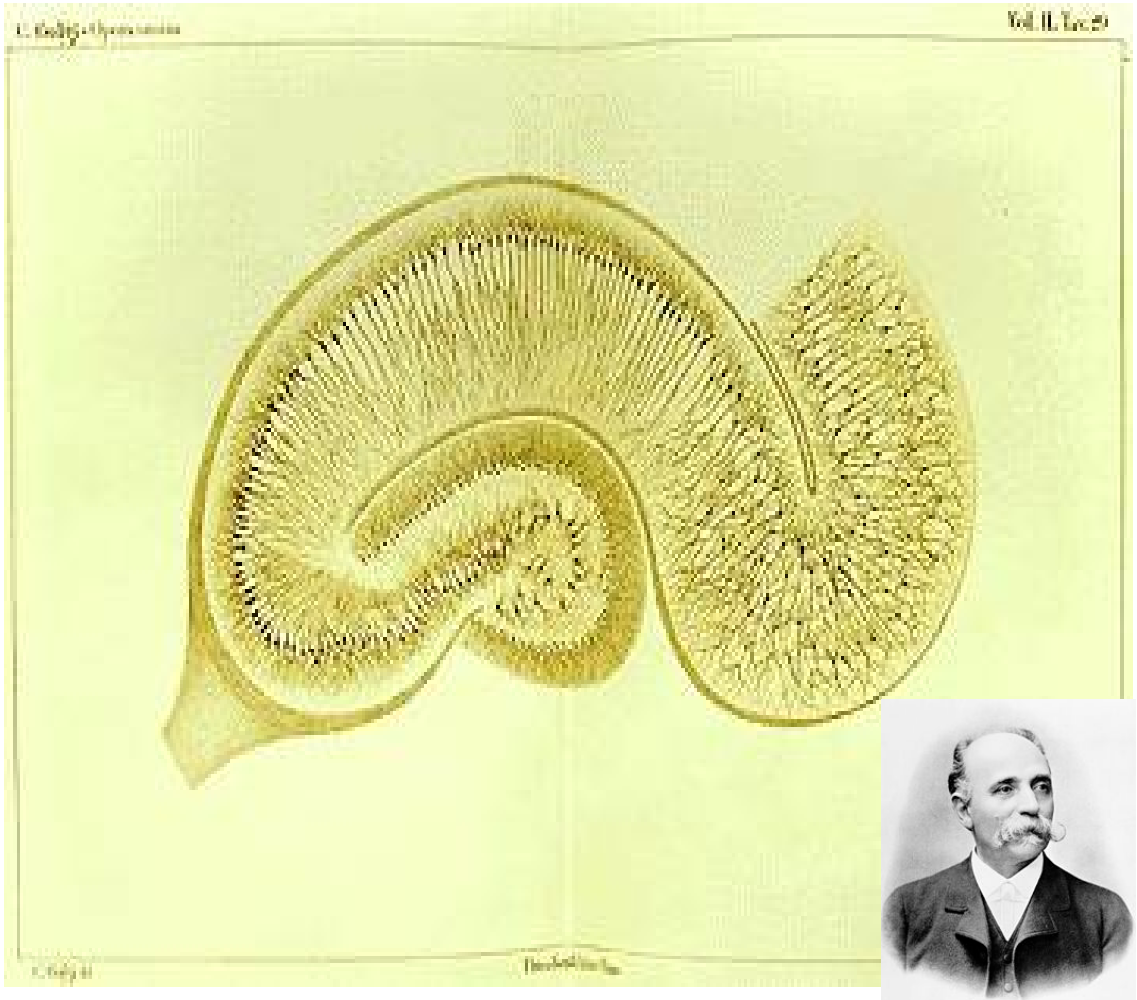


Layered Biological Neuron Architectures

- 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..

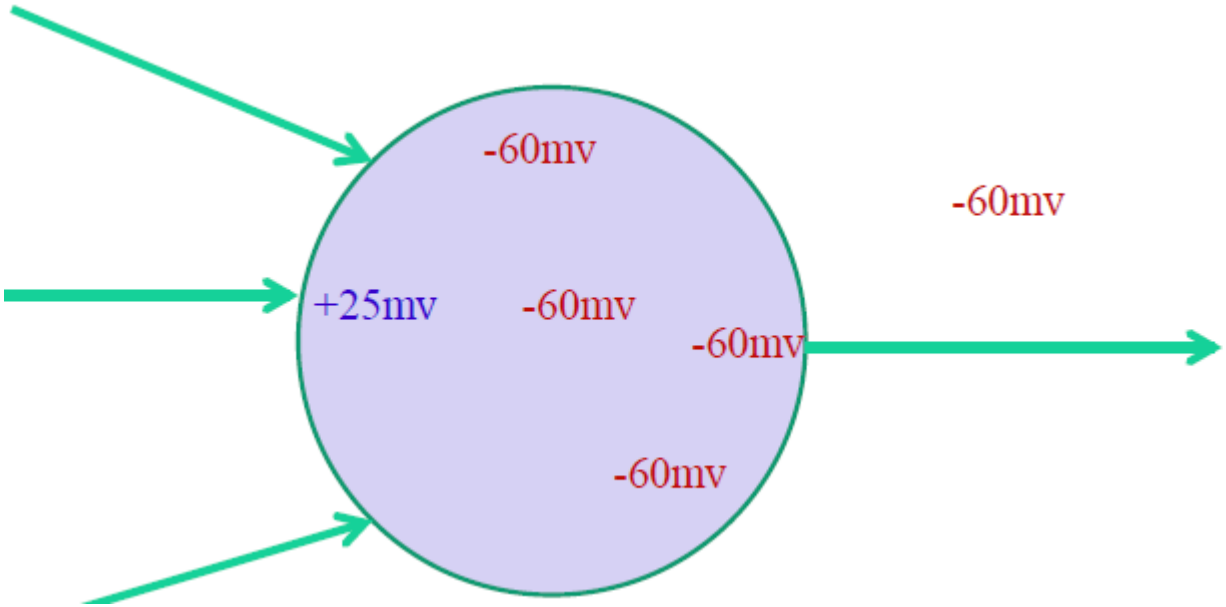


Youtube videos

- Neurons:
- https://www.youtube.com/watch?v=GIGqp6_PG6k
  https://www.youtube.com/watch?v=C4Gt322-XxI
  https://www.youtube.com/watch?v=vyNkAuX29OU
- Resting potential and Resting Membrane Potential:
  https://www.youtube.com/watch?v=YP_P6bYvEjE
- Action Potential:
  https://www.youtube.com/watch?v=ifD1YG07fB8
- Na^+ - K^+ pump and Refractory period:
- https://www.youtube.com/watch?v=Iiiz5CpFCQo
- https://www.youtube.com/watch?v=awz6lIss3hQ
- Neurotransmitters
  https://www.youtube.com/watch?v=p5zFgT4aofA

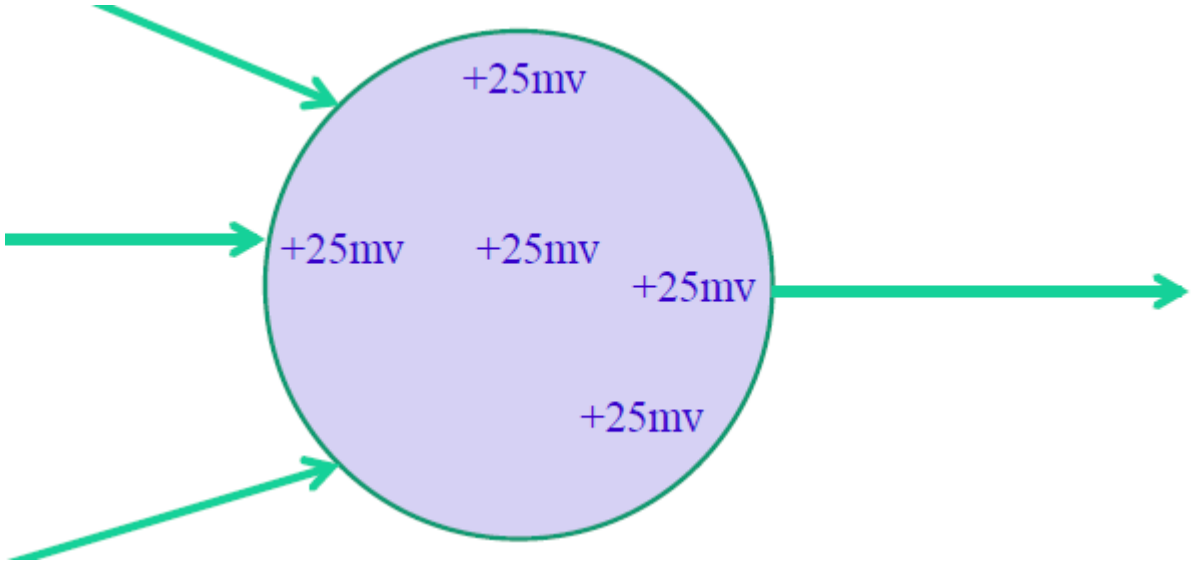
Potential in Neuron

- **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 have the effect of locally altering the potential at the dendrites where the signal arrives.



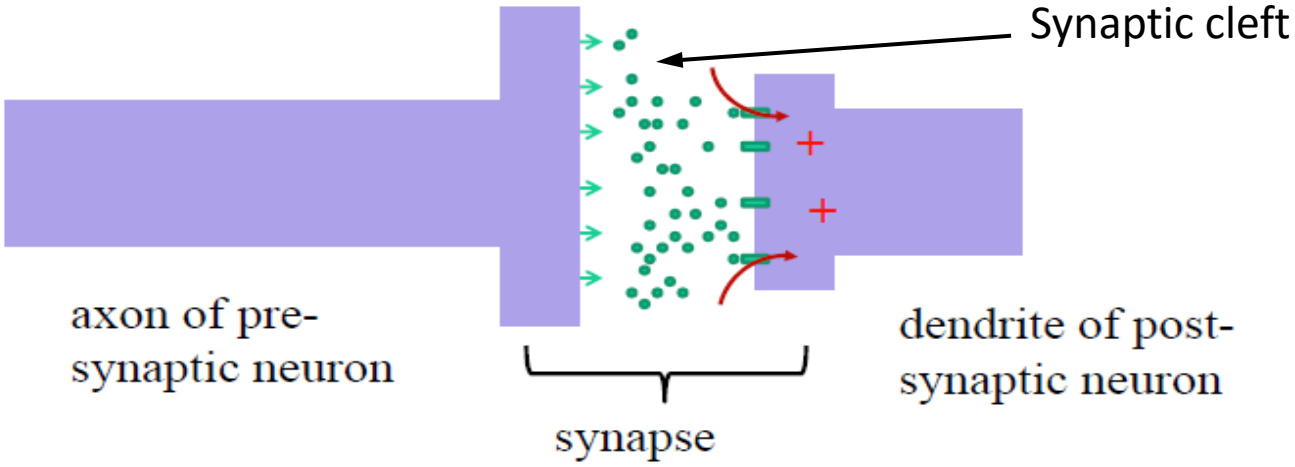
Potential (cont…)

- 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.



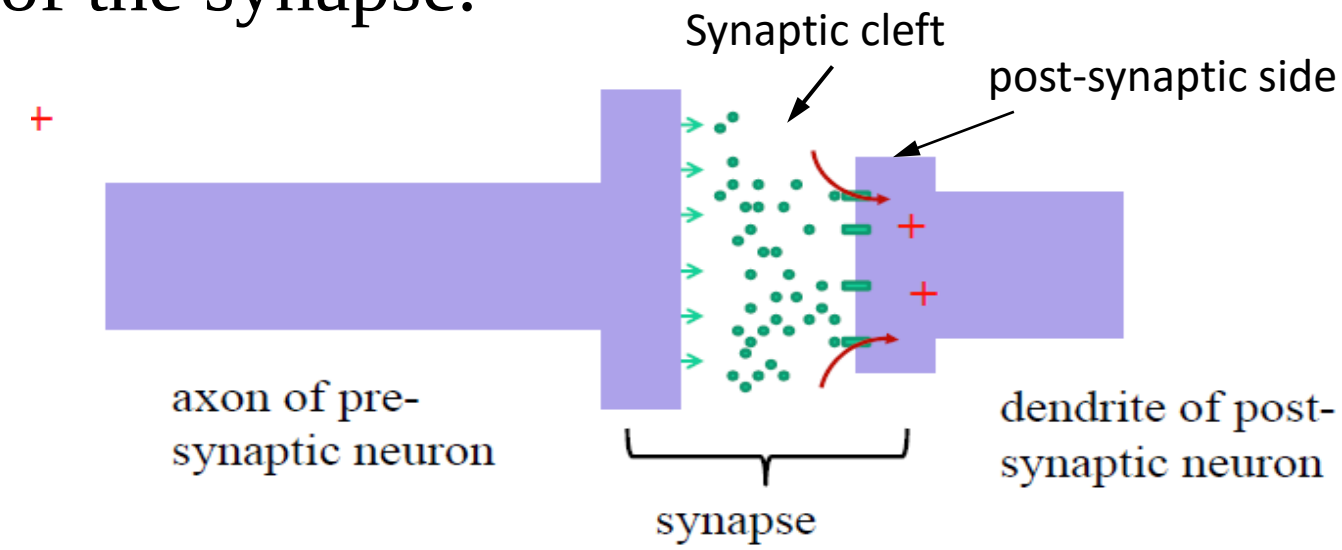
Transmission through Synapse

- 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.

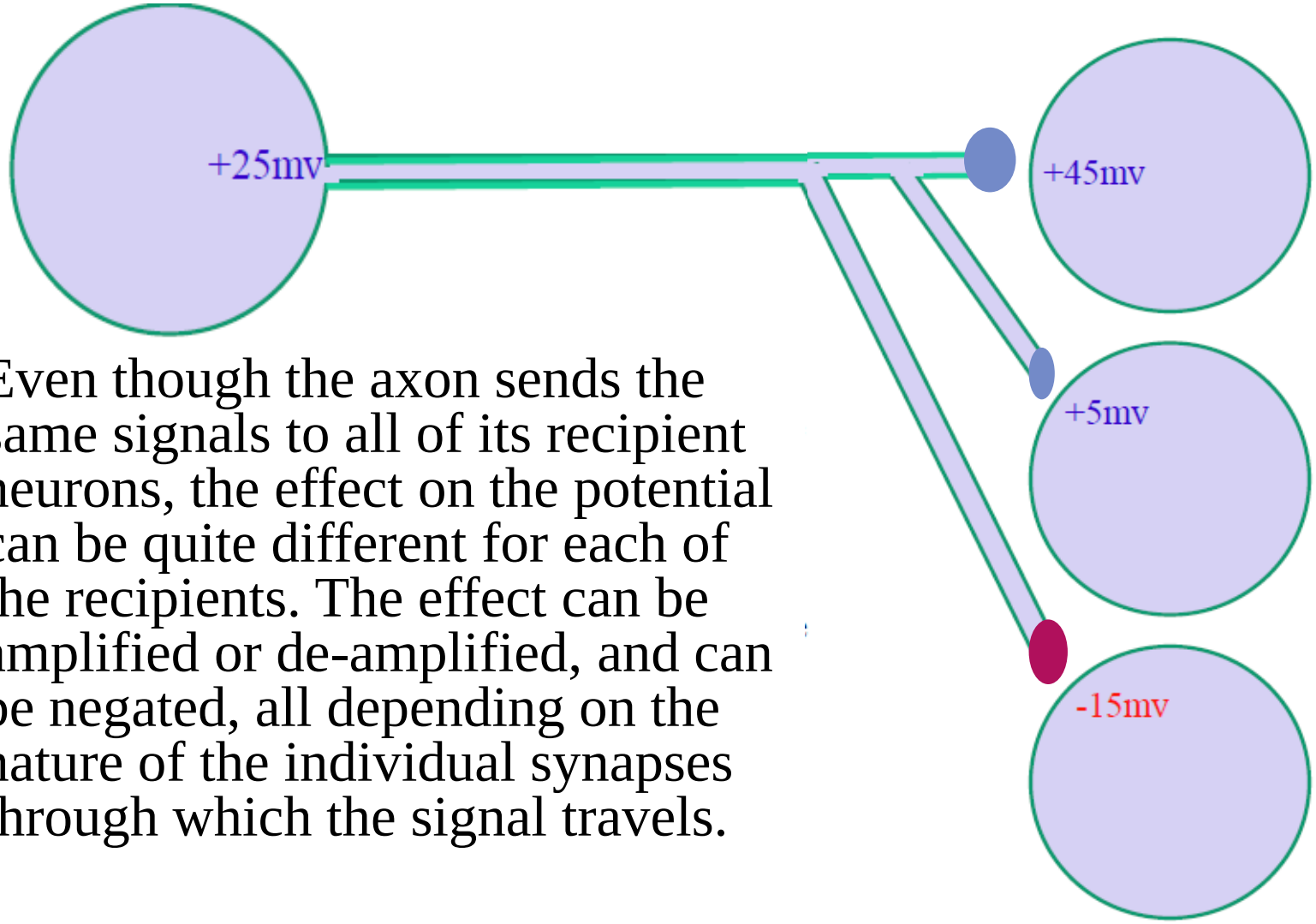


Transmission (cont…)

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



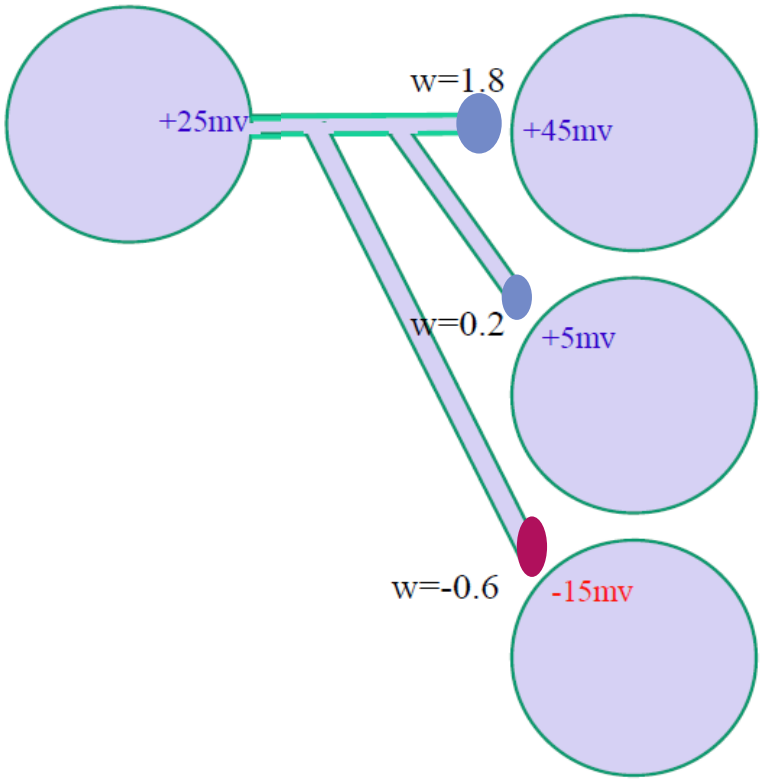
Varying Effects of Signals



- 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.

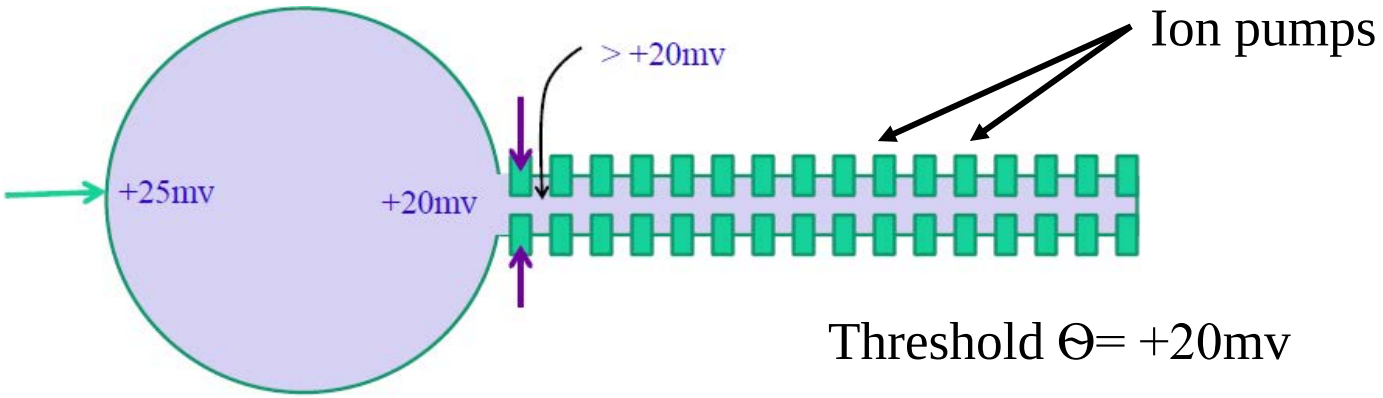
Synaptic Weights

- 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.



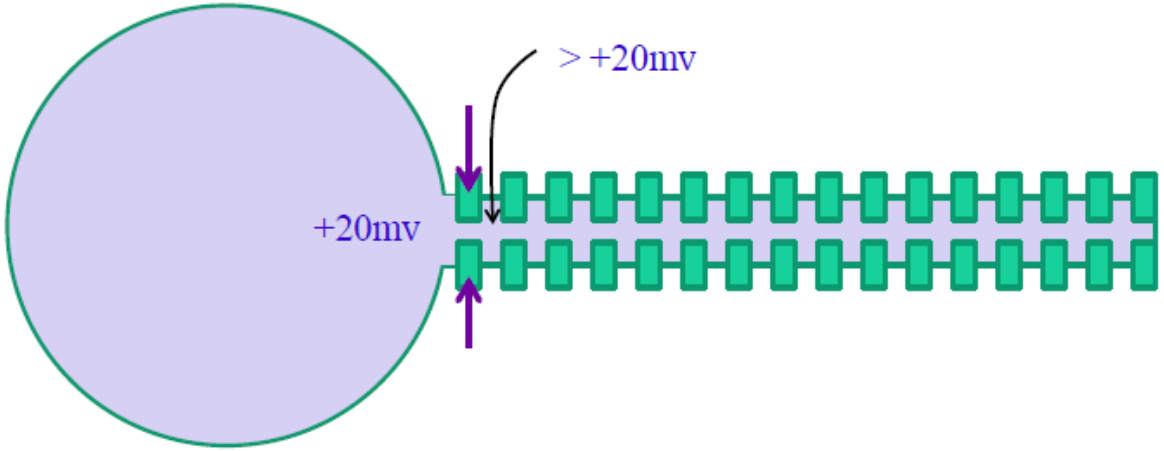
Thresholds for Transmission

- 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**.



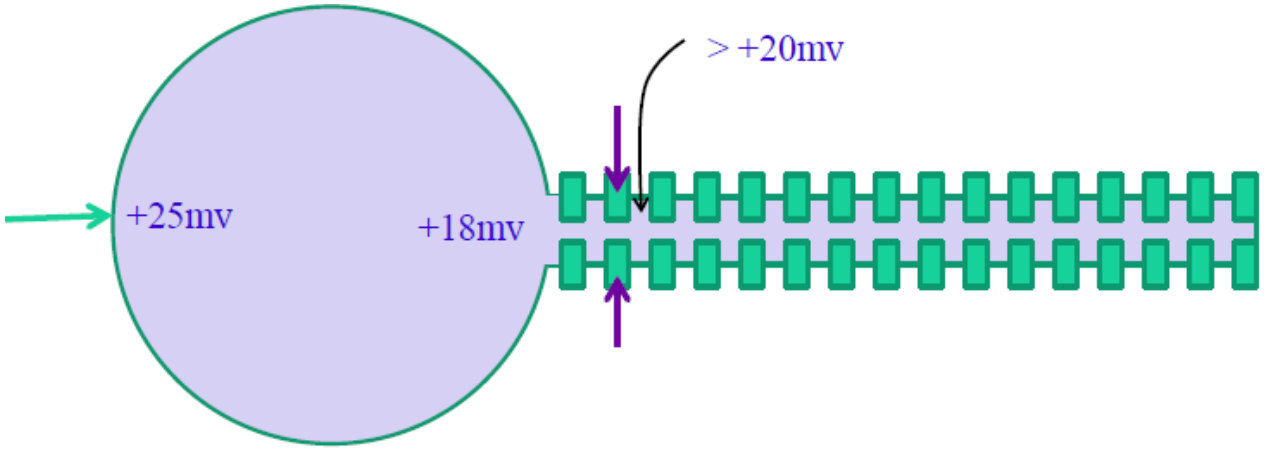
Thresholds (cont…)

- When the threshold is met at the axon base, the closest ion pumps operate, rushing ions into the axon, and raising the potential much higher. This, in turn triggers the ion pumps a little further along by bringing them over their threshold (through slow potential).

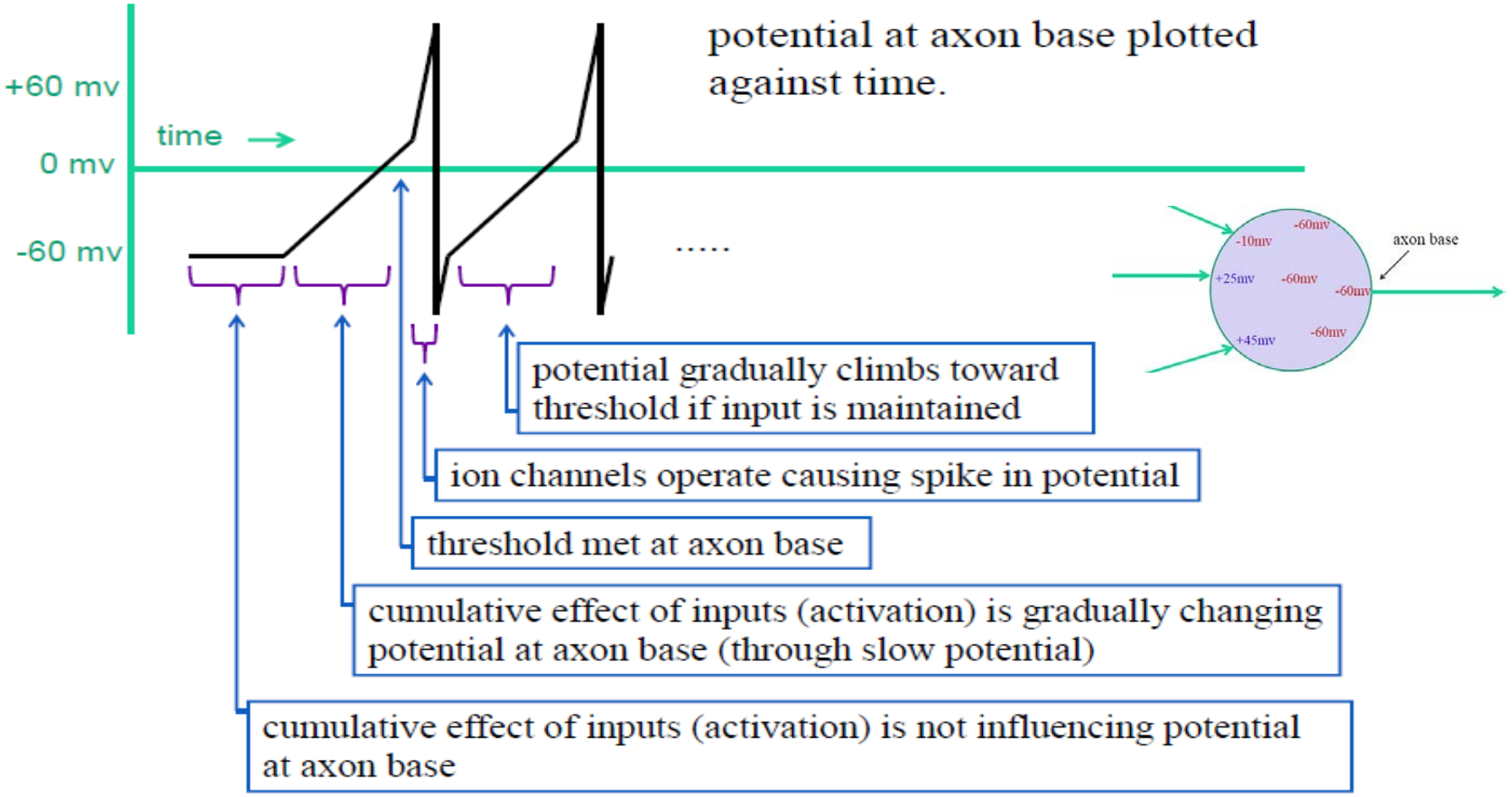


Thresholds (cont…)

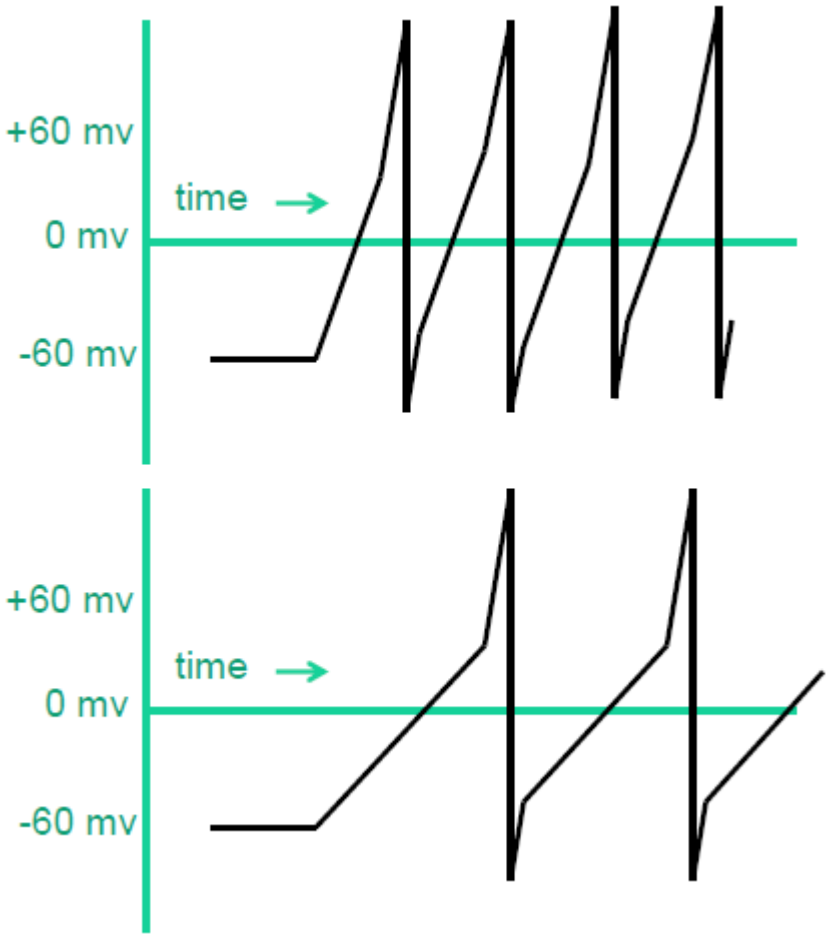
- Thus a spike in potential (the action potential) moves gradually down the axon. Note that after operating, the ion pumps need a short period to recover before they can operate again. This prevents the spike in potential from moving backwards on the axon. Also note that the potential at the axon base 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

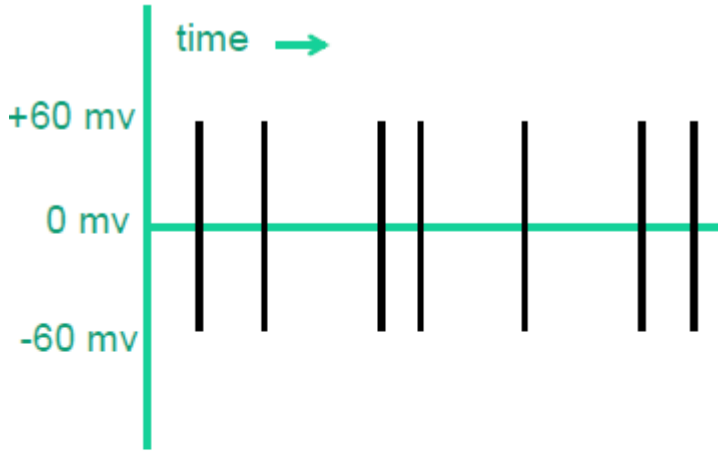


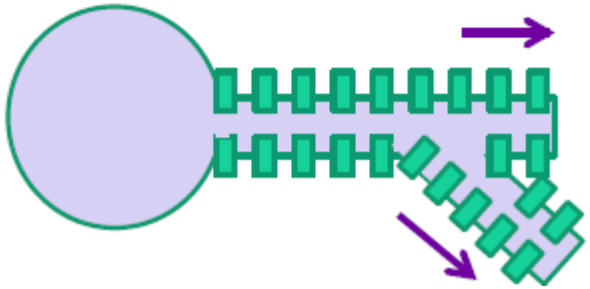
- The higher the activation, the faster the neuron will attain its threshold potential.
- The spacing in between action potentials is a direct measure of the activation of the neuron at the time.

Youtube video of Action Potential

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, so *all recipient neurons receive the same signal*.





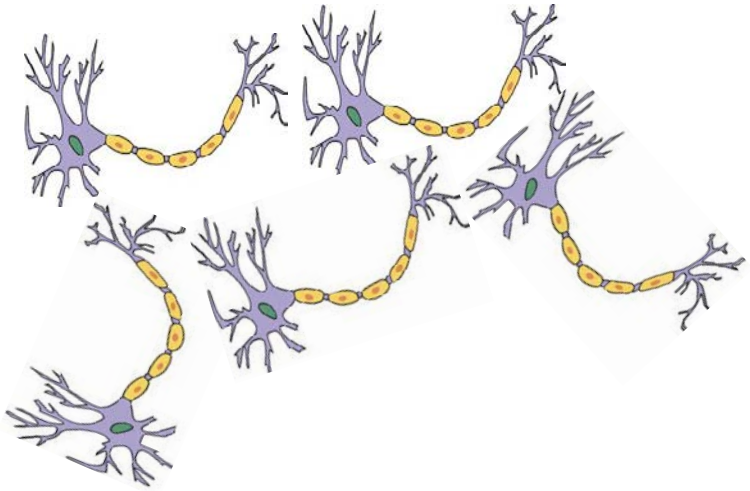
Youtube video: https://www.youtube.com/watch?v=ifD1YG07fB8

Inhibitory Connections

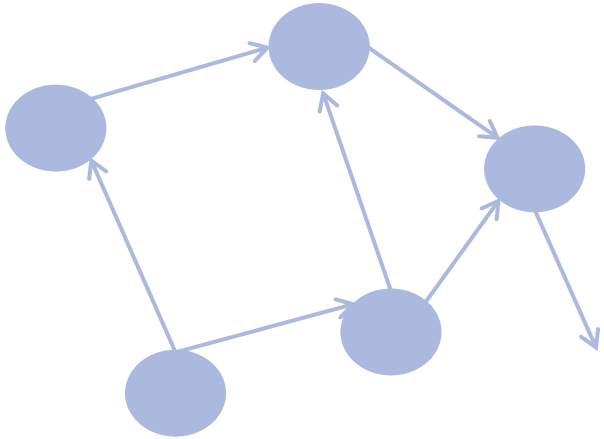
- Most of these connections are **excitatory**, but some are **inhibitory**.
- There are some **"veto" neurons** that have the overwhelming power of neutralizing the effect of a large number of excitatory inputs to a neuron.
- Some **indirect self-excitation** also occurs when one node's activation excites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

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.