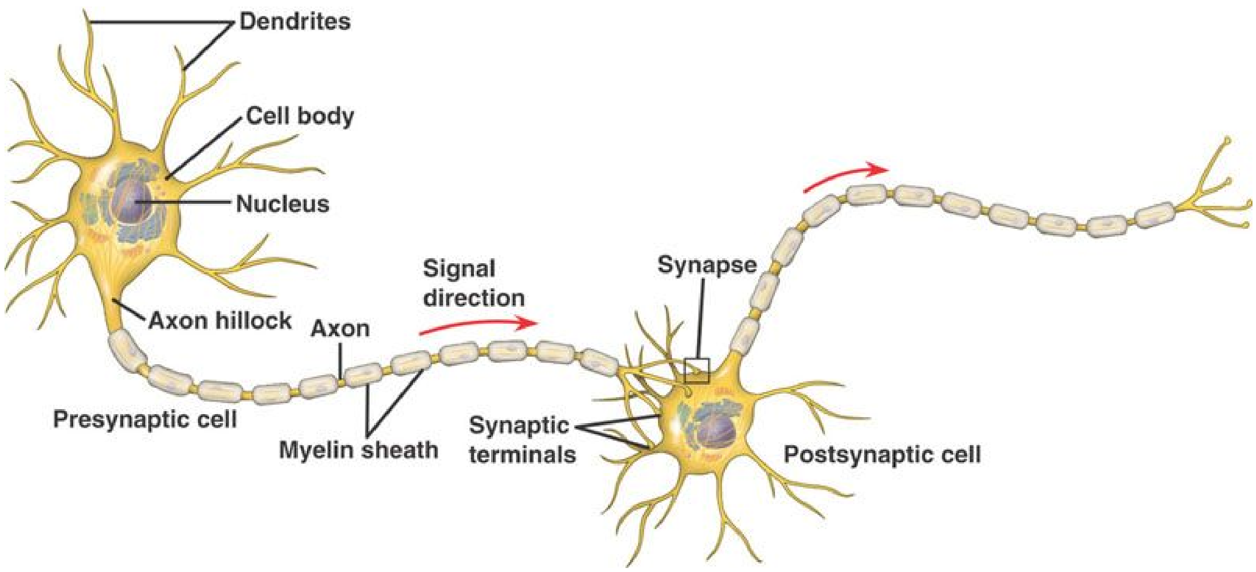
Neural Networks Learning Tool: Guided Problem Set
Renee Sajedian, Ai Li, and Sophia Wilhelmi

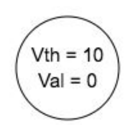


A neuron is a cell in the nervous system. It has many parts, such as the dendrites, soma, axon hillock, axon and terminal boutons. We will only be focusing on the soma (the body) and the axon of a neuron. In our simulator's design, it will look like the neuron has many axons, but technically this isn't true. It has one axon that synapses onto one or multiple neurons. Neurons communicate by receiving electrical signals from other (presynaptic) neurons, and sending signals down the axon to other neurons. Through this simple communication, neurons represent and transmit information, and perform computations. The components of a neuron's computation that we will be focusing on are the "activation" of the neuron, the "threshold" of the neuron, and the "weight" of the axon.

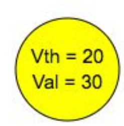
<u>Activation:</u> The "activation" of a neuron is its voltage. When a neuron receives electrical signals from other neurons, this increases or decreases its voltage. In our simulator, it is called "Val"

<u>Threshold:</u> This is the voltage that allows a neuron to fire. If the weights of active presynaptic neurons sum to a voltage equal or greater than the postsynaptic neuron, then the postsynaptic neuron will fire, and be active in the next time step.

<u>Weight:</u> Weight is how strongly the presynaptic neuron affects the postsynaptic neuron. Weight between neurons in the brain can be modulated. Positive weight (excitatory) will help the neuron it is connected to reach activation, but negative weight (inhibitory) will make it harder for the connected neuron to fire.



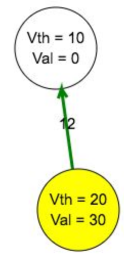
In our simulator, this is what two neurons look like -------------------------------->
It has an activation, and a threshold which can both be set by the user.



Problem 1)

Try: Open up the simulator. It will be in “add” mode. Click to add a neuron. Set its threshold to 5. Now click to add another neuron. Set its threshold to 6.

In our simulator, this is what an axon connecting two neurons looks like:



The “weight”, or the strength of the axon can be set by the user. Setting the weight to a negative value makes the weight inhibitory. It is depicted as a red arrow. Setting the weight to a positive value makes the weight excitatory. It is depicted as a green arrow.

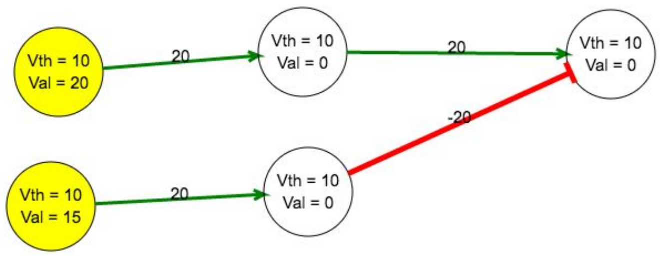
Try: Click and drag from the neuron on the left to the neuron on the right to create an axon. Set its weight to 7.

Now, put the simulator in “Trigger” mode, by clicking ‘t’ on your keyboard. Click on the neuron to the left (where the arrow points from), and set the initial activation to 1. Notice that the neuron highlights yellow. This is because its activation is greater than its threshold. We will refer to this state as “activated.” Activation of the postsynaptic neuron (right) is calculated by adding all weights of presynaptic neurons (left), and determining if it is above threshold of the postsynaptic neuron. With inputted weight of 7 and threshold of 6, predict what will happen at the next time step.

Next, put the simulator in “Navigation” mode, by pressing the spacebar. This mode just makes sure a rogue click won’t add any features while you run your simulation. Press the “next” button to advance one time step. What do you notice changes in the simulation? What does this mean about the activation of each of the neurons?

Problem 2)

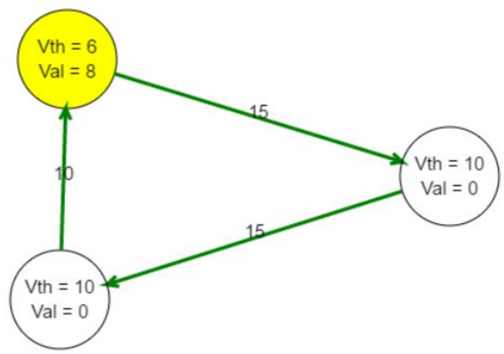
Clear the simulator, by pressing the “clear” button. Next, construct a network that looks like the diagram below:



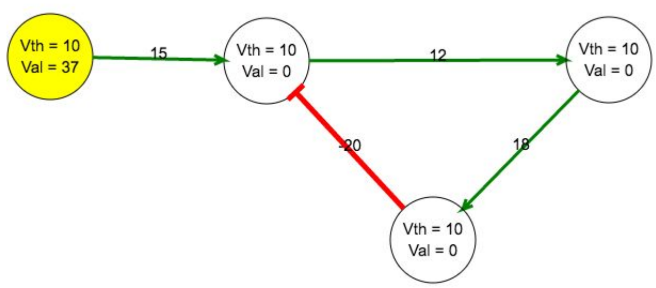
Now, enter trigger mode using “t”. Click on each of the leftmost neurons and set the initial activation to 10.
Press space to enter navigation mode. Now, click “next” once. The neurons in the second column should be activated. What will happen on the time step after this? Show your calculations of the predicted activation of the rightmost neuron.

Problem 3)

a) Excitatory loop:
   i) Create a circuit that looks like the one below. This is known as an excitatory feedback circuit. Trigger the upper neuron and set its initial activation value to 8.
   ii) Then, click next and watch the activation move through the circuit. What do you think will happen when the activation reaches the upper neuron again?

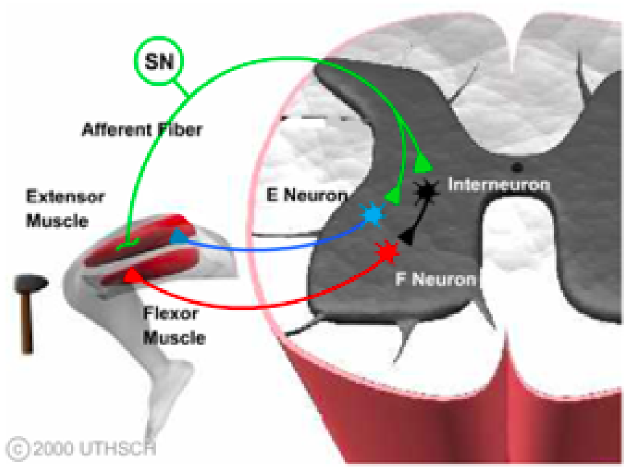


b) Inhibition loop:
   i) Create a circuit that looks like the one below. This is known as an inhibitory feedback circuit. Trigger all neurons this time by setting the initial activation to any number equal or greater than its threshold. Which neuron(s) will still be activated at time step two? Why?
   ii) What happens at the next timestep (timestep 3)? How could you change these values to have one more neuron activated at timestep 3?



Problem 4)

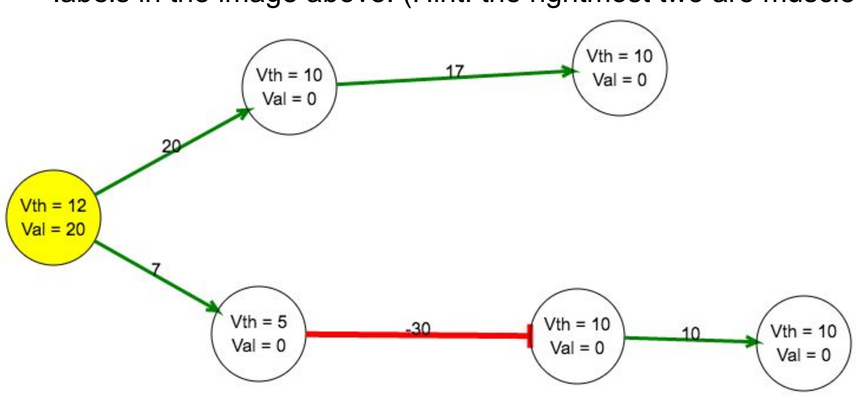
Biological example 1: A simple sensorimotor circuit.



http://nba.uth.tmc.edu/neuroscience/s1/introduction.html

The image above depicts a well-understood sensorimotor circuit: the circuit that produces the knee-jerk reflex. When the extensor muscle is stimulated, the sensory nerve carries this signal to two excitatory interneurons in the spinal cord. The interneuron depicted in blue synapses with neurons in the extensor muscle, causing these neurons to fire and the muscle to contract. The interneuron depicted in black synapses with an inhibitory neuron which then synapses with neurons in the flexor muscle. When the red neuron fires, it inhibits neurons in the flexor muscle, ensuring that they won't inappropriately contract.

a) Below is our depiction of this circuit in our simulator. Label the neurons to match the labels in the image above. (Hint: the rightmost two are muscles, not neurons)

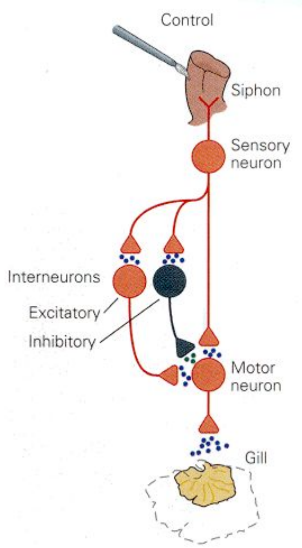


b) Which neuron should be triggered by the hammer hitting the knee?

c) Trigger this neuron and press "n" to move through the cascade. What is the function of the inhibitory connection between the two neurons? Apply this to how it may affect the muscle it synapses on.

Problem 5)

Biological example 2: Aplysia shock reflex circuit.



http://usdbiology.com/cliff/Courses/Behavioral%20Neuroscience/Aplysia/Apfigs/Apcirpics.html

An Aplysia is a type of sea slug, with a simple circuit to cause a contraction reflex in the gill due to a noxious stimulus (a shock) from the siphon, a different part of the sea slug's body. The shock excites the sensory neuron, which excites both the interneurons and the motor neuron. These added together has a direct affect on the gill, causing it to contract and close in fear of the shock. In a real Aplysia, this circuit would strengthen over repeated stimulation, and consequently it would take less stimulation to create the same gill response. However, our simulator assumes that it is the first time you're triggering the pathway each time you do.

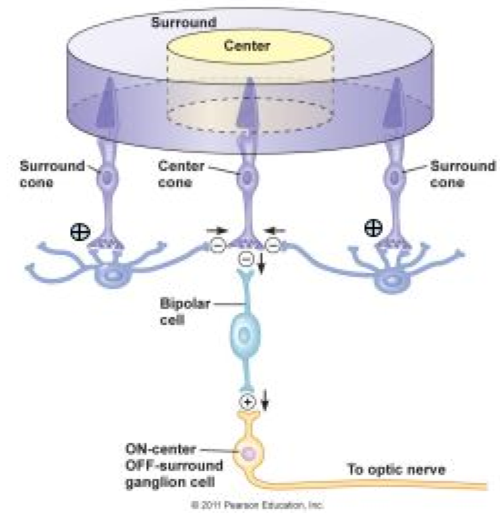
a) Create this one yourself! Draw your circuit below (Hint: the circuit starts at the top, and the output is the gill)
b) Try varying the weight of the axon between the inhibitory neuron and its postsynaptic motor neuron. How does this change the output of the network? Try to get different outputs each time.
c) What values of each neuron and each axon would not let the signal pass to the gill? Place these values on your drawing in part a. (Assume the sensory neuron has to be triggered successfully i.e. it the syphon was shocked)

Problem 6)

Create your own circuit! Make a circuit that does something interesting. What does it do?

Problem 7)

Challenge Problem:



The image above depicts the center-surround circuit, which is involved in transmitting information about luminance from the cones to the ganglion in the eye. Cones in the eye are unusual compared to other neurons in that they are usually strongly depolarized and firing at a high rate. This means that the neuron is firing strongly while no light is shone. Light causes the cone cells to hyperpolarize and decrease their firing rate. The center cones are inhibitory, so light causes weaker inhibition of the bipolar cell, and therefore stronger activation of the ganglion cell. The surround cones are excitatory, so when they are in darkness they excite the horizontal cells, which inhibit the center cone and hyperpolarize it further, strengthening the effect the central light has on the ganglion cell.

a) Create this circuit in our simulator. The negative symbols represent inhibition, while the positive represents excitation. This is tricky: now you want trigger the input neurons when there is no light. Therefore, since the light is only in the center, the two left and right neurons will be triggered.
b) Under what conditions does the ganglion cell fire? Under what conditions is its activation maximized?
c) Adjust the inhibitory strength of the horizontal cells. What happens when the weight of their axons is 0? What happens when the weight is strongly negative?