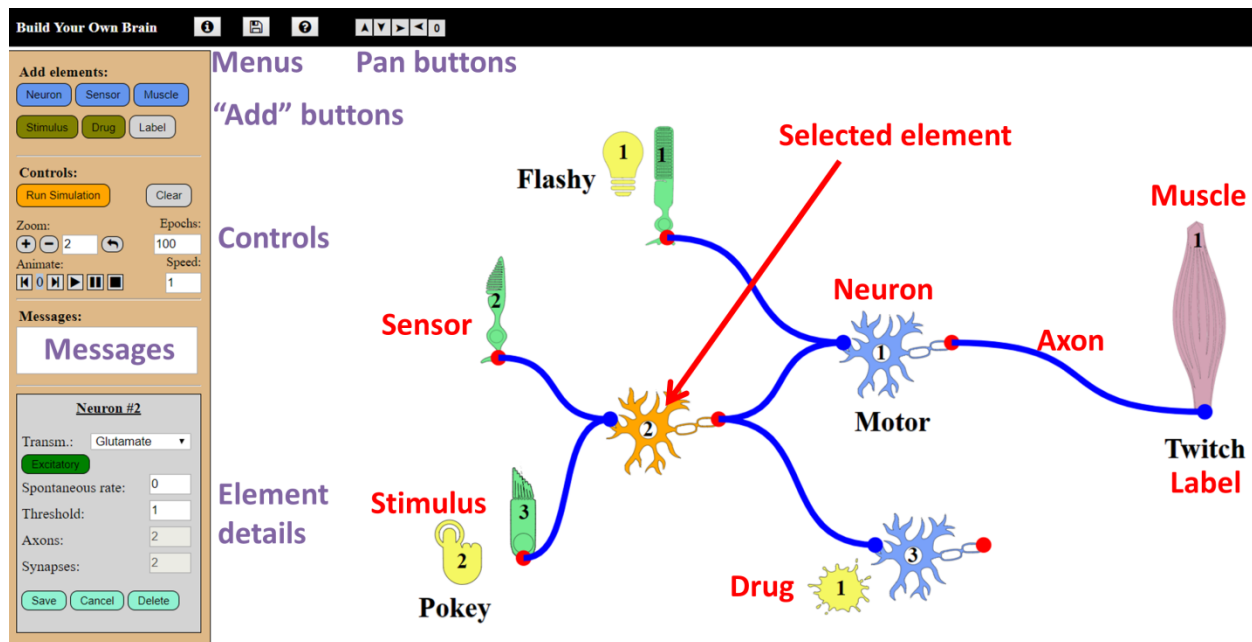


Build Your Own Brain


This document explains how to use the *Build Your Own Brain (BYOB)* website, which allows you to create a simple neural network and run it. It does not explain the neuroscience involved. The screenshot below shows the main parts of the screen.

The networks you build on *BYOB* are made of **neurons** and **muscles**. In addition, *BYOB* allows you to add external **stimuli** (like lights or sounds) and **drugs** that some neurons and muscles can react to. Neurons are connected to each other – and to muscles – using **axons**. All these elements have a range of properties that you can modify. When you have built a network, you can “run” the simulation to see how your network behaves. The simulation will run for a fixed number of time steps, which are called **epochs**.





The screen is divided into three main areas. At the top is a black menu bar that contains three drop-down menus and 5 pan buttons. On the left is an orange side bar that contains controls to construct and manage your network and a space to show details of specific elements. The rest of the screen is white and is the canvas on which you will create your network.

Menus

At the top left of the screen are three buttons that lead to drop-down menus. The left-most button, , allows you to view your network in three ways. The first option “*Show connections*” will open a new tab containing a table that summarizes the connections in your network. The second option “*Show simulation results*” will open a new tab containing a table displaying the behavior of the network. This option will only work if you have already run a simulation. More information on tables is given below. The third option “*Save snapshot*” will save an image of your canvas to a local file called “*Network.SVG*”.

The fourth option in this menu “*Show/Hide extra info*” will show or hide additional information on the network (see below).

The second menu, , allows you to save your current network or load an existing network from file. To save the current network, click the “*Save network*” option. You will be prompted – in the element details area – for a file name. Networks are saved as local files on your computer, which may mean that your browser will ask permission before you can save the file. Networks are saved as text files. To load a previously saved network, click the “*Load network*” option. You can either load a pre-made example network (click “*select example*”) or a local file (click “*select file*” to browse for one). Loaded networks will delete and replace any current network.

The third menu, , opens a help menu with a link to this document (under “*Instructions*”). It also has a link to more detailed documentation and to the “*Getting started*” guide.

To the right of the menus are the **pan buttons**. These arrow buttons allow you to move around in your view of the canvas. The right-most button re-centers the view. You can also move the view using the arrow keys on the keyboard.

Adding Elements

The main part of the screen is a blank canvas where you assemble your network. Networks are built up from elements. There are 6 kinds of elements: things that are part of the body (**Neurons**, **Sensors**, and **Muscles**), external **Stimuli**, **Drugs**, and **Labels**. To add an element, click the relevant button under “Add elements” at the left of the screen.

Newly created elements will appear at the top left of the canvas and you can drag-and-drop them anywhere. When an element is clicked, it becomes selected and turns orange. The properties of the selected element will be displayed, and can be edited, in the “*element details*” panel, on the left of the screen. If you change any properties of the element, click “*save*” to save your changes, or “*cancel*” to get rid of them. Click “*delete*” to remove that element from the network.

- **Neurons**: these are the basic building blocks of the network. Neurons have two connection points: a *dendrite* (blue dot) and an *axon hillock* (red dot). At each epoch of the simulation, a neuron can either fire (generate an action potential) or not fire. Firing takes one epoch. Action potentials will then move down that neuron’s axon(s), which also takes one epoch. Neurons have the following properties:
 - **Transmitter**: neurons emit neurotransmitters and the specific transmitter for each neuron can be selected from a drop-down list.
 - **Excitatory/Inhibitory**: neurons can be either excitatory or inhibitory. Clicking the button will toggle between those options. Note that the possible neurotransmitters the neuron can emit depend on whether it is excitatory or inhibitory. When not selected, excitatory neurons (and their axons) are light blue; inhibitory neurons (and their axons) are pink.
 - **Spontaneous rate**: neurons sometimes fire spontaneously, with no external stimulation. The number in this box determines the probability that the selected neuron will spontaneously

- fire in any epoch: if it is 0, the neuron will never spontaneously fire; if it is 1, it will fire in every epoch [spontaneous firing is the same as receiving threshold-level stimulation from outside, and can interact (sum) with other stimulation].
- **Threshold:** every neuron requires some minimal amount of stimulation to fire. This is called that neuron's *activation threshold*. You can set a neuron's threshold to any value larger than 0. The neuron will only fire in an epoch where the sum of all the stimulations it receives is at least equal to its threshold.
 - **Axons:** this box lists the number of axon branches this neuron has. It is not editable.
 - **Synapses:** this box lists the number of incoming synapses this neuron has. It is not editable.
- **Sensors:** sensors are special types of neurons that react to external stimulation rather than receiving inputs from other neurons. Sensors therefore have *axon hillocks* (red dot) but no dendrites. There are 6 kinds of sensors you can select from the drop-down list: **Rods** and **Cones** (retinal cells), **Hair** cells (auditory), **Olfactory** receptors (smell), **Taste**-buds, and **Touch** receptors. Like neurons, sensors can either fire or not in each epoch, but sensors can fire at different strengths, depending on the intensity of stimulation that they receive. Sensors do this by adjusting the strength of their axons (see below; with the exception of olfactory sensors, which act like normal neurons). Sensors do not fire spontaneously nor do they have thresholds.
 - **Type:** this box lists the type of the sensor. It is not editable.
 - **Transmitter:** sensors emit neurotransmitters and the specific transmitter for each sensor can be selected from a drop-down list.
 - **Excitatory/Inhibitory:** sensors can be either excitatory or inhibitory. Clicking the button will toggle between those options. Note that the possible neurotransmitters the sensor can emit depend on whether it is excitatory or inhibitory. When not selected, excitatory sensors are green, inhibitory sensors (and their axons) are pink.
 - **Subtype** (cones only): cone cells can be one of three types (Red, Green, or Blue), that react more or less to light, depending on its wavelength. Each subtype has a reaction function that it follows (see any textbook) that determines how strongly it will fire, based on the wavelength of the light it is stimulated with.
 - **Frequency** (hair cells only): hair cells have a specific frequency they are sensitive to, anywhere from 0 to 20,000 Hz. They will react to any sounds within 10 Hz of their value.
 - **Axons:** this box lists the number of axon branches this sensor has. It is not editable.
- **Muscles:** the main output of the brain is activating (and inhibiting) muscles. Muscles have *dendrites* (blue dot), but no axons, and they do not release neurotransmitters. Muscles can fire (flex) or not in each epoch.
 - **Threshold:** Like neurons, muscles have activation thresholds. The muscle will only flex in an epoch where the sum of all the stimulations it receives is at least equal to its threshold.
 - **Synapses:** this box notes how many incoming connections this muscle has. It is not editable.
- **Stimuli:** the sensor cells in the network react to external stimuli, like light or sound. *BYOB* therefore also allows you to add these things to the canvas. There are 5 kinds of stimuli you can add from the

drop-down menu: **light**, **sound**, **touch**, **odour**, and **taste**. Stimuli have no direct connections, since they are not part of the body. Stimuli can be on or off in each epoch and will affect all sensors of the right type (and frequency) that are within a certain distance of them. When a stimulus is selected (clicked) its properties will appear at the left of the screen and a circle showing the range of its effect will appear around it.

- **Type:** this box lists the type of the stimulus. It is not editable.
 - **Effect radius:** this is the distance from the stimulus within which it can affect sensors. Note that only sensors of the correct type will be affected (e.g., a **light** stimulus will activate **rods** or **cones**, but not **hair** cells) and, for **cones** and **hair** cells, only if the frequencies match. You can set the radius to any value. The circle shown on the canvas will show which sensors fall within range.
 - **Intensity:** this will determine the strength of stimulation the sensor receives (see above).
 - **Frequency** (light and sound only): the determines the frequency or wavelength of the stimulus, and affects which sensors it can activate, and how strongly (for light).
 - **Schedule:** this will determine whether the stimulus is on or off in each epoch. The schedule should be a list of numbers separated by commas. Each number gives the probability that that stimulus will be on in that epoch: 0 means the stimulus will definitely be off; 1 that it will be on; intermediate values that it has that probability of being on. The simulation will cycle through the sequence and loop back to the beginning. So, for example, if you entered this sequence into the box: "0, 1, 0.5" and ran a simulation for 5 epochs, then the stimulus would be off for the first epoch, on for the second, then have a 50% chance of being on for the third, then off for the fourth, and then on for the fifth. Any appropriate sensor in range of a stimulus when it is on will receive the stimulation.
- **Drugs:** the interactions between neurons and muscles can be affected by psychoactive drugs. *BYOB* allows you to add drugs to the system to see how they affect the behavior. Drugs, like stimuli have no direct connections, since they are not part of the body. Drugs can be on or off in each epoch, like stimuli, and will affect any synapses (blue dots where an axon connects to a neuron or muscle) of the right type that are within a certain distance of them. When a drug is selected (clicked) its properties will appear at the left of the screen and a circle showing the range of its effect will appear around it.
 - **Class:** Different drugs affect the brain in different ways. The website allows you to add drugs of several different classes. At the moment, there are 2 classes of drugs:
 - **(Ant)agonist:** agonists and antagonists bind to post-synaptic receptors, often competing with endogenous ligands. They may also activate the receptor.
 - **Reuptake inhibitor:** these are drugs that block transporters on the pre-synaptic membrane, preventing them from reabsorbing neurotransmitter. They therefore cause the transmitter to remain in the synaptic cleft longer. Here, these drugs will cause the neuron to still be stimulated somewhat in the epoch following any endogenous stimulation.
 - **Target:** this drop-down list allows you to specify what the drug will bind to. For *(Ant)agonists*, this will be a list of receptor types. For *Reuptake inhibitors*, this will be a list of

neurotransmitter types. Drugs will only affect synapses that use the transmitter or receptor that they are specific to.

- **Affinity:** how well a drug binds to its target is called its *affinity* for the target. This value can be anything from 0 to 1 and will determine how strongly the drug will compete with any endogenous stimulation. For Reuptake inhibitors, this will determine what proportion of the previous stimulation is left over at the next epoch.
 - **Efficacy** (only for *(Ant)agonists*): this value sets how strongly the drug activates the receptor it binds to.
 - **Effect radius:** this is the distance from the drug within which it can affect synapses (blue dots where an axon connects to a neuron or muscle). You can set the radius to any value. The circle shown on the canvas will show which synapses fall within range.
 - **Schedule:** this will determine whether the drug is present or not in each epoch and functions exactly like the schedules of stimuli (above).
- **Labels:** to make your network easier to understand, you can attach labels to any point. Labels have a text, which can be set by typing in the “text” box (in the “*element details*” area) and clicking “save”. They have no effect on the simulation.

Connecting Elements

Axons, which connect elements to each other, are created by clicking on the *axon hillock* (red dot) of the relevant element. Only neurons and sensors have axons. Clicking the red dot of any element will create a short blue line extending from the dot, with a green dot at the end of it. Drag the green dot towards any other element’s *dendrite* (blue dot) and release it to connect those two elements. The green dot will snap to any nearby dendrite and connect. Sensors do not have dendrites.


Axons are also elements of the network and have their own properties. Clicking an axon will select it (it will turn orange) and bring up its properties in the “*element details*” area. Axons have the following properties:

- **Connected elements:** the top of the details box shows the two elements connected by this axon. This is not editable.
- **Transmitter:** this is the neurotransmitter that this axon emits at the synapse. This box is not editable. The neurotransmitter is determined by the neuron or sensor that the axon belongs to.
- **Strength:** this is the strength of the synapse, which is how much stimulation it will provide to the element it connects to, when it fires. The thickness of the axon shows its strength.
- **Receptor:** this is the type of receptor on the post-synaptic membrane of this synapse. The list of receptors you can select from depends on the transmitter that the axon is releasing.

Neurons and muscles in the network only fire when they are stimulated via axons or by drugs (except for spontaneous firing). Both neurons and muscles have thresholds – a minimum amount of stimulation that they have to receive in order to fire. Note that stimulations die out immediately in the next epoch so the activation applied to any cell only depends on the stimulation it receives in a single epoch.

Assume, for example, that there is a neuron **A**, with a threshold of 1.5. Neuron **A** receives two axons from other neurons, each with a strength of 0.8. If both axons happen to be active in the same epoch, they will provide a total of 1.6 units of stimulation to neuron **A**, which will therefore fire in the next epoch. However, if only one of the axons is active in some epoch, neuron **A** will receive less stimulation than its threshold and will not fire.

Controls

Under the “add” buttons are a set of controls for the network. After you have built your network, you can run it by clicking the orange “*Run Simulation*” button. A successful run will result in a message (in the “*messages*” box) confirming completion of the simulation. The “*Clear*” button will delete your entire network and let you start over. You can zoom the canvas in and out, using the “+” and “-” zoom buttons, using *Shift+* or *Shift-*, or entering a magnification level in the text box and clicking .

BYOB runs a discrete-time model. This means that time, in the simulation, moves in fixed steps. These steps are called **epochs**. You can set the number of epochs that will be run using the “*epochs*” box. After you have run the simulation, you can show an animation of the network running (see below). The speed of the animation is set using the “*speed*” box, in number of frames per second. Animations are controlled using the “*Animate*” buttons. You can move forwards or backwards by one frame or play, pause, or stop the animation. The current frame number will be shown in blue between the buttons.

Learning

Some synapses are “plastic”, meaning that they can change over time. *BYOB* simulates one kind of plasticity, Long-Term Potentiation (or Depression; *LTP*, *LTD*) in one type of receptor, *NMDA*. Only synapses onto neurons can be plastic. To create a changeable synapse, make sure the presynaptic cell emits *glutamate* and that the axon has receptors set to *NMDA/AMPA*. This synapse will change in strength (starting from whatever you set it to) as follows:

- *LTP*: If the synapse (i.e., the axon) is activated in an epoch where its target neuron is already firing (in other words, both the axon and the postsynaptic neuron are active at the same time), then the strength of the synapse will increase by 0.1. It does not matter whether the current strength of the synapse is more or less than the target’s threshold.
- *LTD*: If the synapse (i.e., the axon) is activated in an epoch where its target neuron is NOT already active, and the strength of the synapse is less than the target’s threshold, then the strength of that synapse will decrease by 0.1.

Axons will appear thicker or thinner to represent their strength.

Tables of the Network

Network connections table:

This table will open in a new window or tab. The table shows all the elements in the network (neurons, sensors, and muscles). In each cell, the strength of the connection between those elements (the strength of the axon connecting them) will appear. Unconnected elements will have empty cells. Rows

of the table represent outgoing connections, columns incoming connections. Each element is labeled. Neurons are "N#", where # is the number of the cell, muscles are "M#", and sensors are labeled by their type: "R#" for rods, "C#" for cones, "H#" for hair cells, "O#" for olfactory cells, "T#" for touch, and "S#" for taste receptors. Labels, drugs, and stimuli don't appear in the table.

Simulation results table:

This table also opens in a new tab. Again, each element is listed along the top, as in the connections table. Rows now give the epochs of the simulation. In each cell of the table, a "1" will appear whenever the corresponding element was active.

Show/Hide extra information:

This option, in the information menu, will display, in red text beside each element in the network, some additional information about that element. For neurons, their threshold, spontaneous firing rate, and neurotransmitter will be shown; for muscles, their threshold; for sensors, their neurotransmitter and, if relevant, their sensitive frequency or subtype; for axons, their strength; for stimuli, their intensity and frequency; and for drugs, their class, target, and affinity and efficacy.

Contact

This website is still changing and I welcome feature suggestions and bug reports. Please contact me at nmiller@wlu.ca with any comments or suggestions for improvement.