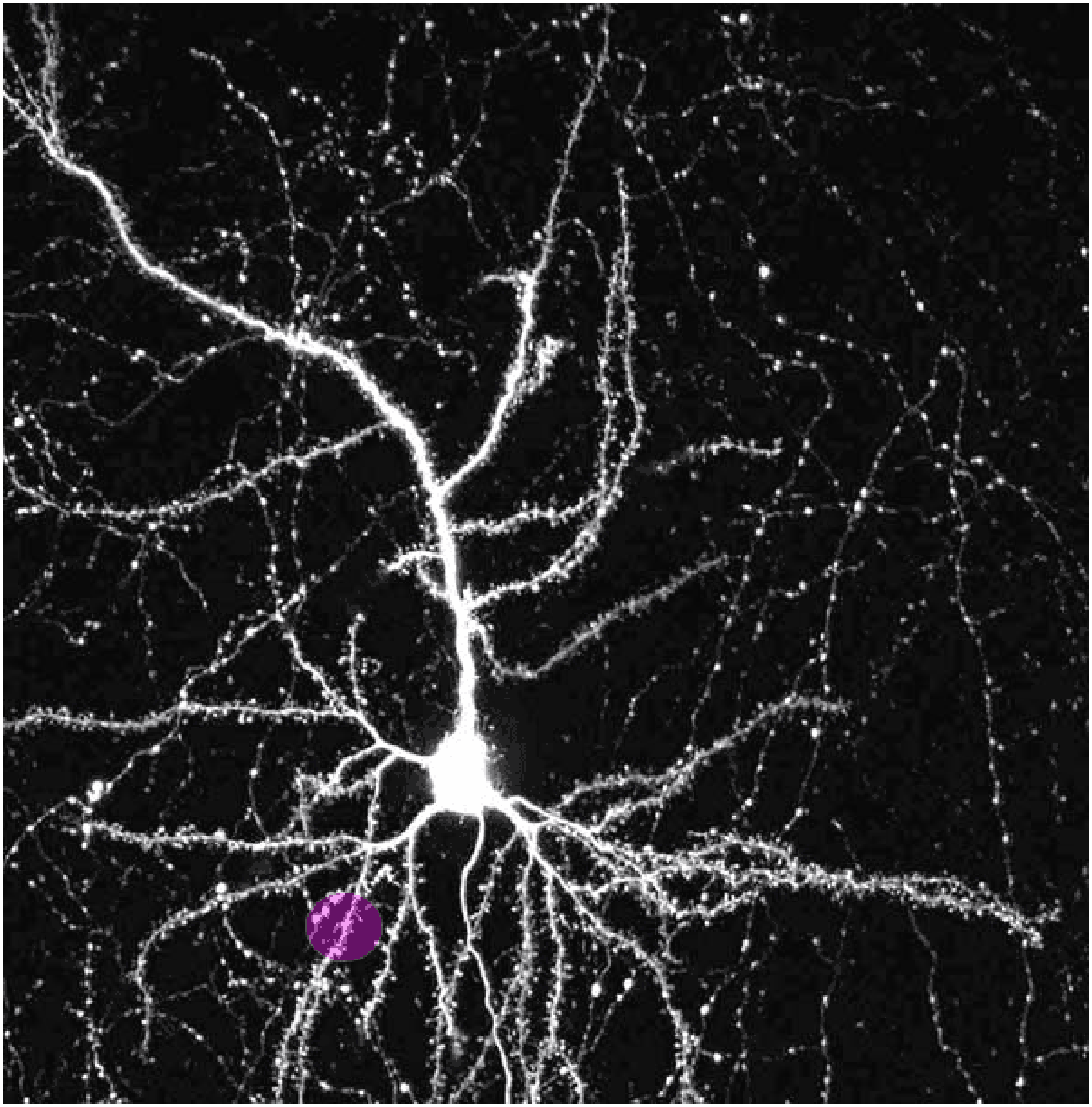
Mathematical Modeling of Neuronal Dynamics

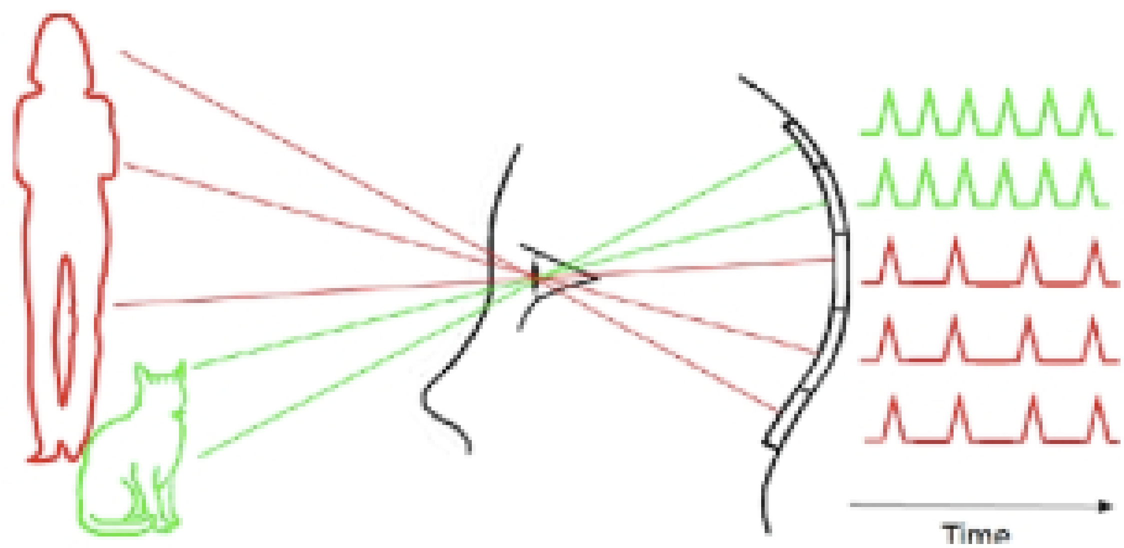
Neurons



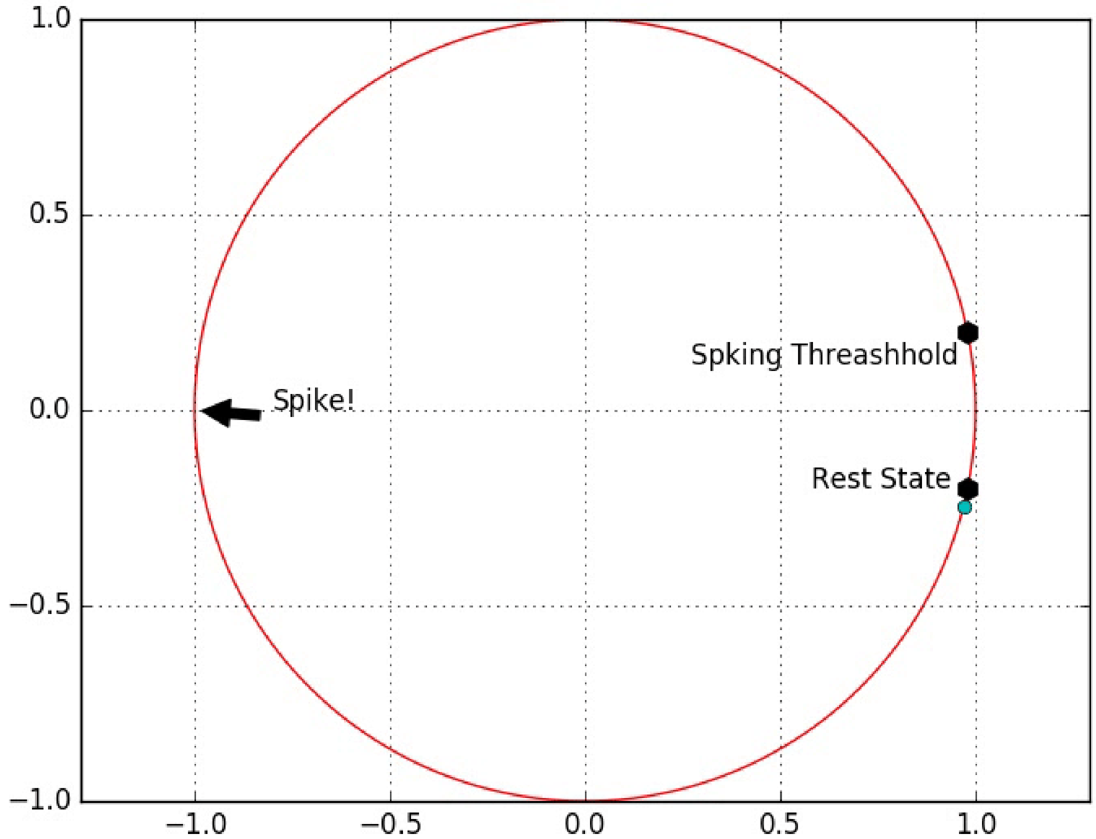
This is how a signal travels through a single neuron.

A neuron is a cell that carries messages via spikes of electrical activity within the brain and to other parts of the body. It is the most basic unit of the nervous system. The brain is made up of ~100 billion neurons which respond to stimuli from the external environment and interact with one another. Neurons are connected to one another by axons, the long cable-like fibers branching off from the cell body. The relationships between neurons can be either excitatory (helping other neurons spike) or inhibitory (keeping other neurons from spiking). The collection of neurons within the body forms a network with neuron cells as nodes and the axons as connections. This interconnected network allows neurons to transmit signals to one another.

Through neuronal relationships, collections of neurons can come to fire in synchrony at the same time. This can help us to better understand the inner workings of the human brain. For example, it has been found that when a person looks at an object, neurons in the regions of their brain where the image maps to tend to fire in synchrony while other regions do not. A diagram of this is provided at the right.

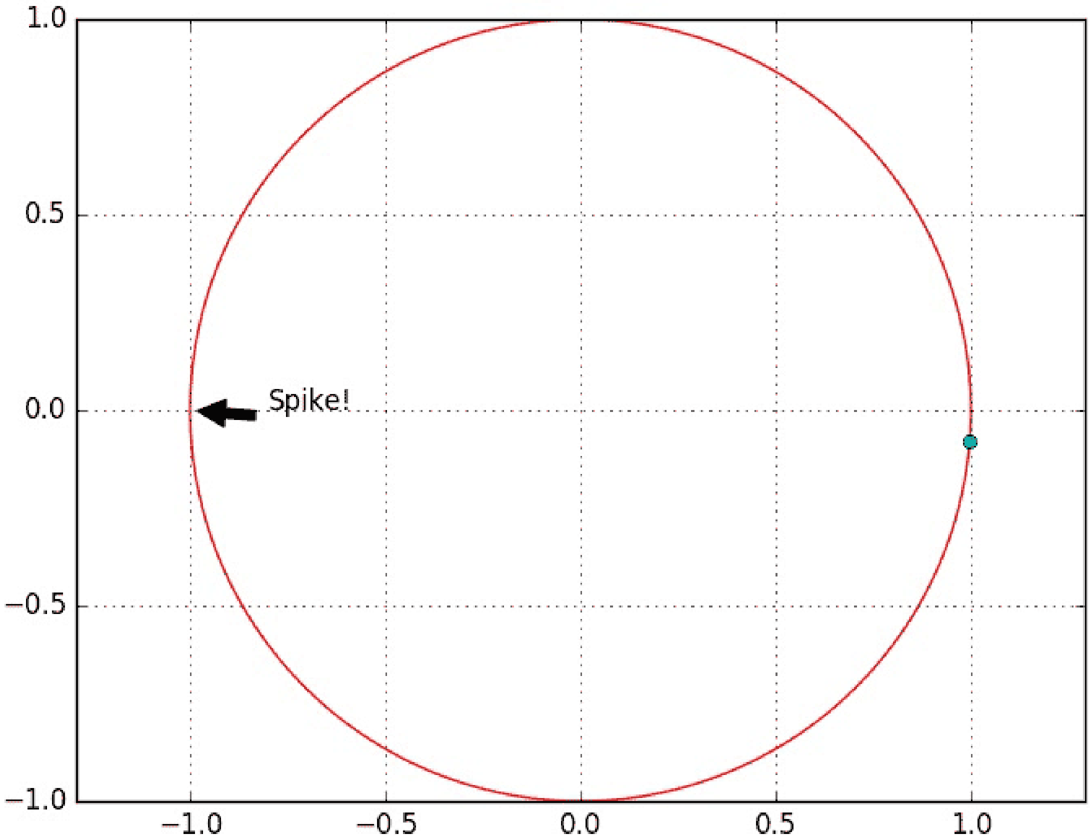


The Theta Neuron



This is an excitable theta neuron. The neuron ordinarily sits in a rest state and must be pushed past a threshold to spike.

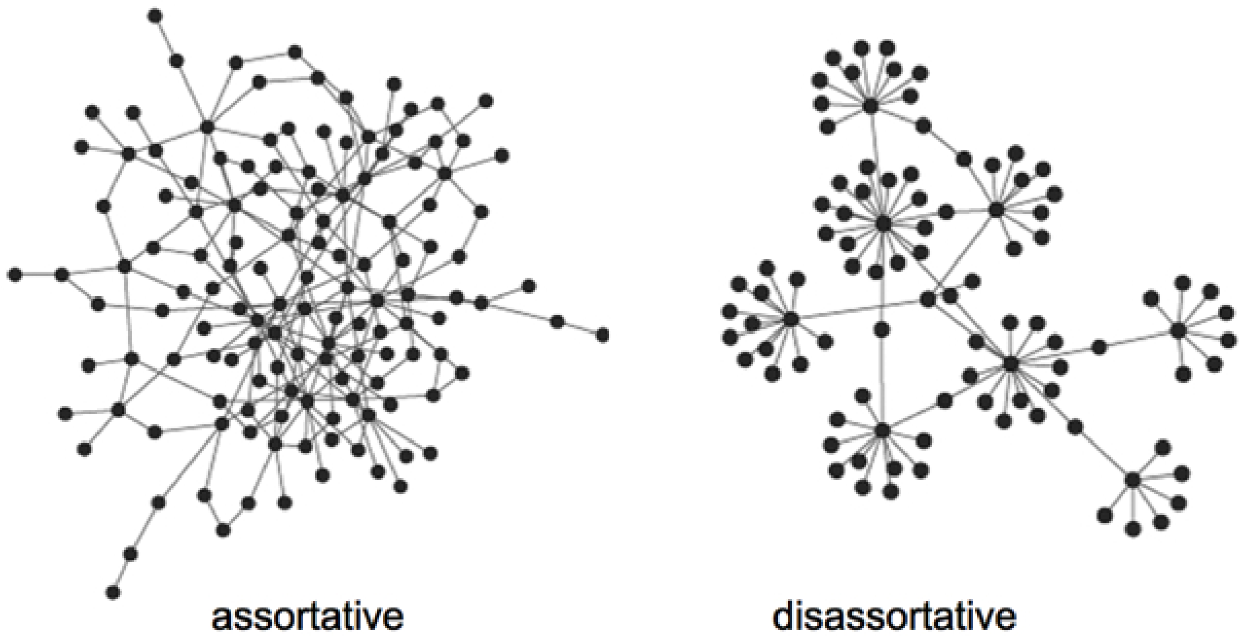
The theta neuron model is a simple mathematical model in which neuronal activity is represented by a point travelling around the unit circle. A neuronal spike is said to occur each time a neuron crosses the leftmost point of the circle. The theta neuron model allows for both excitable neurons, which must be pushed past a threshold to spike (see left), and regularly spiking neurons (see below). The excitable neurons settle into a rest state until an electrical signal (from external stimuli or other neurons spiking) pushes the neuron past the spiking threshold. The neuron will then spike once before returning to the rest state.
The regularly spiking neurons have no rest state or spiking threshold and continuously spike with a given rate. When a neuron spikes it sends a pulse-like electrical signal to those it is connected to. These signals can be transmitted in an inhibitory or excitatory manner. The combination of these dynamics can lead to cooperation or competition affecting the synchronization of the entire network.



The regularly spiking neuron has no rest state and continuously spikes.

Networks of Neurons: Open Questions

Neurons are the building blocks of the nervous system. By mathematically modeling their behavior using the theta neuron model we can learn important information about how they interact. For example, experiments have observed that synchrony in neuronal spikes occurs among neurons in different parts of the brain when they are assisting in the same processes. There are several open questions related to the synchronization of networks of connected neurons. We are investigating how the network structure effects synchronization. For example, does the number of connections each neuron is allowed to make influence synchronization? Can we form network connections in such a way that subgroups of neurons synchronize within the network? How is synchronization and spiking behavior effected by assortative mixing in the network?



Assortativity (mentioned in the last question) is a particularly interesting network property. Assortativity is the preference of nodes to be attached to similar nodes in a network. For example, networks can be assortative by degree (number of connections). In this case nodes of high degree attach to other nodes of high degree and those of low degree attach to others of low degree. A degree disassortative network is exactly the opposite; it has nodes of high degree attached to nodes of low degree.

Sources

- A Proposal by Michelle Girvan
- Choe, Yoonsuck. "Autonomous Acquisition of the Meaning of Sensory States Through Sensory-Invariance Driven Action." Biologically Inspired Approaches to Advanced Information Technology Lecture Notes in Computer Science (2004): 176-88. Web.
- Curiositry. "OpenBCI Brain Basics: Structure and Biology." The Autodidacts. N.p., n.d. Web.
- Merriam-Webster. Merriam-Webster, n.d. Web. 08 July 2016.
- "School of Life Sciences | Ask A Biologist." Neuron Diagram & Types. N.p., n.d. Web. 08 July 2016.
- Steps & Leaps." Steps Leaps. N.p., n.d. Web. 17 July 2016.

Made by Kim Crain and David Hathcock Source Code from Materialize