Heather is going to be talking to you about simulations of the brain and mind. In order for you to appreciate these models, you first must know some basics about how the brain works. I’m going to tell you about how cells in the brain can communicate with one another, so then you can begin to appreciate how cells can form a dynamic network that can store memories and process information.

1. The central nervous system is made up of the brain and spinal cord. The brain is a heterogeneous structure, and different areas have different specializations.

2. For example, the occipital lobe is particularly important in processing visual information. The cerebellum is very important for balance. You’ll appreciate this when you get old enough to drink alcohol, this is an area that is affected by ETOH to impair your balance. It is important to know that the brain is a highly specialized structure with a great deal of heterogeneity.

3. The cells in the brain are similar to all other cells in that they have a cytoplasmic center that is separated from the outside environment by a semi-permeable membrane. The cells that make up the brain come in two different flavors. There are neurons and glia. Glia, which is Latin for glue, are the cells that serve a number of functions such as the removal of toxins and scavenging of debris. The neurons are the cells in the brain that communicate with one another. Neurons and glia come in many shapes and sizes. For example, this is a stain for neurons in an area of the brain known as the hippocampus, a structure that has been implicated in learning and memory.

4. Just to show you how varied neurons and glia can appear, I’ll show you a few examples. This is an example of a neuron in the cortex, and this is a glial cell.

5. These are neurons grown in culture, and this green cell is a glial cell.

6. My goal today is to explain how neurons are highly specialized structures that communicate with another across a specialized chemical connection known as a synapse. So, what gives a neuron the ability to send a signal from one end to the other?

7. Well, it turns out that every neuron is a miniature battery. If you were to record from the inside of a neuron, you would see that it has a negative potential of about –65 mV. So, this is a lot smaller than the 9V batteries that you’re used to using in your portable cd players, but nevertheless, this is enough to allow a neuron to have an electrical response to a stimulus. Let’s take a closer look at what allows the uneven spread of charge across a cell membrane, such that negative ions line up along the inside of the cell whereas positive ions line up along the outside of the cell membrane.

8. First, you have to know that cells are primarily made up of salts and water. An important trait of water is that it dissolves salts. For example, table salt thrown into
water separates into two separate ions, a positive sodium ion and a negative chloride ion.

9. You also have to know that cells are surrounded by a specialized membrane that has selective permeabilities. Within the cell membrane, there are channels that are selective to only certain types of ions.

10. If you look at the membrane that surrounds a neuron, you’d notice that the membrane is full of various types of pores that allow certain ions to flow through. Which direction the ions flow depends on the diffusion of ions as well as their electrical charge.

11. Diffusion is a simple property. If you were to pour some salt in water and just let it sit there for a few days, eventually the ions would diffuse until they become evenly distributed throughout the water. In a cell, you can imagine the inside and outside of the cell separated by a membrane. If salt is present on one side across a barrier, then it will stay there. However, if the membrane is permeable to salt ions, then they will eventually reach a chemical equilibrium such that the ions are distributed evenly across the membrane.

12. The other factor that alters the movement of ions across the membrane is electricity. Remember that each ion has a charge. Just think of a magnet—like poles repel each other while opposite poles attract one another. If a battery is set up, negative ions move toward the positive pole whereas positive ions move towards the negative pole.

13. Once again, the permeable membrane that surrounds neurons will permit the flow of ions from the inside of the cell to the outside of the cell.

14. These two forces, the chemical and electrical gradients, both contribute to the flow of ions across the membrane. There will be a net movement of ions across the membrane until an equilibrium is reached, such that the chemical and electrical gradients are in balance. Imagine a membrane that contains positive and negative ions. If the membrane is permeable only to the positive ions, then a negative charge will build up along the inside of the membrane. This is similar to what occurs in real neurons.

15. In a real neuron, the major ions are K, Na, Ca, and Cl. The membrane of the neuron is differentially permeable to these ions.

16. At rest, a neuron has large negative ions on the inside that can’t cross the cell membrane, but the membrane is very permeable to positive potassium ions. Thus, a negative potential occurs due to an uneven distribution of electric charge across the membrane. Now you basically can understand how cells have a potential, like a battery, to create an electrical charge.
17. Now you need to understand the anatomy of a neuron. The neuron has specialized structures. The heart of the neuron is the cell body, and this contains the genetic material of the cell. The neuron has dendrites, which act as antennas to receive information. The neuron also has the ability to send a message down an extension known as an axon, and this can in turn send a signal to the dendrites of another neuron. How can this occur?

18. The basic form of communication in neurons is the action potential. If you take a neuron, and inject a little current into it, you will notice that the cells potential can rapidly flip from being negative (-65 mV) to being positive (+40 mV). This rapid change in potential, or depolarization, is known as an action potential.

19. The neuron at rest is quite negative, as I mentioned. But, if the permeability of the cell membrane is altered, then positive ions can rush into the cell causing it to depolarize. The normal membrane permeabilities will be restored, and the cell will return to a negative resting membrane potential.

20. How many action potential a cell fires is determined by the level of depolarization. A small depolarization will lead to a few action potentials, whereas a large depolarization will lead to many action potentials being fired.

21. How is the action potential generated. At rest, the cell is largely permeable to potassium ions. If the cell becomes depolarized, special sodium channels are opened and this allows positive ions into the cell, depolarizing the cell. These channels turn off, and then the flow of potassium ions can repolarize the cell.

22. The action potential can be propagated down the axon because the entry of positive charge during the action potential causes the membrane just ahead to be depolarized… regenerating the action potential.

23. It is important to know that neurons are capable of firing different patterns and rates of action potentials, and these can be varied within individual neurons as well.

24. Now we can send a signal from one end of a cell to another in the form of an action potential. But, how is the signal communicated to another neuron?

25. When an action potential reaches the end of its terminal, it causes the release of a chemical neurotransmitter that is sent to a neighboring neuron.

26. Neurons have the ability to release a chemical, known as a neurotransmitter, and the neighboring neuron can receive the signal through specialized receptors.

27. Looking at a blow up of an axon terminal, you can see that it is filled with a chemical neurotransmitter (dopamine, in this example). The neighboring neuron has receptors that respond to the neurotransmitter. So, a chemical passes the gap between neurons, known as a synapse, to bind to receptors on a neighboring neuron. The binding of the
neurotransmitter can have a variety of effects, such as depolarizing the neuron, perhaps causing it to fire.

28. It is important to realize how complex communication between neurons can be. For example, there are multiple types of receptors. For example, the same neurotransmitter can act on different types of receptors.

29. For example, a neurotransmitter called acetylcholine can act on two different types of receptors, nicotine and muscarine receptors. Nicotinic receptors are present primarily in skeletal muscle whereas muscarine receptors are prevalent in the heart. Different drugs can act on different types of receptors. For example, for the smokers out in the group, nicotine in cigarettes binds to nicotinic receptors. This can disrupt the function of skeletal receptors. Thus, many smokers have tremors in their hands and many other minor motor dysfunctions.

30. As another example, a prominent neurotransmitter known as glutamate has at least three different types of receptors that it can act upon.

31. Now we can transmit an action potential down the axon of a neuron, cause the release of neurotransmitter across a synapse, and cause a response in a target neuron. So, a neuron basically acts as a receiver, in the dendrites, and a transmitter, down the axon and across the synapse.

32. It is important to realize that dendrites receive multiple inputs from many neurons, and it is the combined input that determines whether a neuron fires an action potential.

33. The integrated synaptic input determines whether or not an action potential is fired.

34. Also, it is important to realize that the number and strength of synaptic connections can change by experience. For example, a particularly salient event might cause the strengthening of a set of inputs, and this can help store a memory of that event.

35. Drugs can alter the synaptic communication between neurons.

36. Consider dopamine. When dopamine is released it binds to receptors on the neighboring neuron.

37. Dopamine is removed from the synapse by transporters that put dopamine back into the axon terminal.

38. Drugs such as cocaine disrupt the function of dopamine.

39. Cocaine blocks the transporters that remove dopamine from the synapse.
40. Thus, dopamine remains in the synapse for a long time, and can increase neural function in certain areas of the brain.

41. Cocaine can thus greatly alter brain activity. This is an example of an imaged brain showing activity before and after the use of cocaine. You can see changes in activity levels after cocaine use.