

Similarities Between Neurons and Fiber Optics

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Rule-to-Build-By:

Rule 4 on the Living Architecture website states: "To achieve the best design, continuously tinker with the building plans."

What:

In living organisms, this rule-to-build-by is illustrated by nerve cells as they developed into a complex network in the body. A human-built structure that also upholds this principle is a network of fiber optics. Both of these are used to send signals to a certain destination.

How:

The nervous system in the human body is highly developed today, but it has evolved greatly over time since life began to form on earth. Communication between nerve cells occurs via chemical transmission of neurotransmitters (Sherwood, 2013). A single nerve cell, known as a neuron, is a structure consisting of a cell body, or soma, that contains dendrites and the nucleus, connected to the axon hillock, which leads to the axon, and ending with the synapse (Sherwood, 2013). They originated with the purpose of being specialized electrical signaling cells to relay messages to a destination in the body (Nerve, 2012). An adaptation of neurons was the ability to have an action potential occur in order to relay the signal electrically down the axon and to the next cell or to the destination (Nerve, 2012). Neurons can connect with each other and communicate via the synapse. In order to pass a signal on to the next neuron, the stimulus results in graded potentials on the cell body. The stimulus can be in the form of a neurotransmitter from another neuron, a neurotransmitter from a receptor cell, or stimuli straight from the environment (Ekstrom, 2012). Gated-channels respond to various stimuli and open to allow entry of either positive ions that cause depolarizations (EPSPs) or negative ions that cause hyperpolarizations (IPSPs) (Ekstrom, 2012). The buildup of depolarizations from graded potentials reaches a threshold and triggers action potentials, which is integrated at the axon hillock (Ekstrom, 2012). Action potentials happen because of the change in the membrane potential. Because of these voltage changes, action potentials start because the channels that are responsible for all of the ion movement are triggered by voltage and are known as voltage-gated channels (Sherwood, 2013). During the action potential, the extreme change in membrane potential starts to spread out further down the axon, and triggers other Na⁺ and K⁺ voltage-gated channels to respond, so another action potential gets triggered, resulting in a chain reaction all the way down the axon (Ekstrom, 2012). Due to the absolute refractory period that disables the ion channels for a short amount of time, the movement down the axon can only be forward towards the terminal end of the neuron (Ekstrom, 2012). Myelinated axons can make this process happen faster because it acts as a conductor so that the positive ions can flow through quickly to the next positions of Na⁺ and K⁺ channels located at the nodes of Ranvier (Ekstrom, 2012). When the action potentials reach the terminal end of the neuron, Ca⁺ channels are activated allowing the neurotransmitters to be exocytosed (Sherwood, 2013). Postsynaptic receptors respond to this stimulus and continue sending the signal to the next neuron until it reaches its destination. Simple nerve nets first evolved in cnidaria and then developed into more complex nerve cords in bilateral animals, which eventually led to the complex nerve network seen in mammals today (Evolution of nervous systems, 2012). Neurons can form neural networks from the connections that neurons form with other neurons. Neurons often start at the brainstem, traveling down the spinal cord as a nerve, which then branch out to be able to spread different parts of the body (Sherwood, 2013). A nerve is a bundle of axons of neurons that allow a signal to travel to its destination. They are surrounded by connective tissue to hold them together and have blood vessels within the nerve to account for the high energy requirements of the neurons (Nerve, 2012). Each bundle of axons within the nerve is

surrounded by a thin layer of cells called the perineurium that acts as a protective sleeve (Nerve, 2012). The evolution of the nervous system over time has allowed communication to occur between neurons through synapses and the development of bundles of neurons that relay a signal through a complex network of pathways (Evolution of nervous systems, 2012). This has been a result of tinkering with the building plans in order to achieve the best and most effective design. This principle is also seen when exploring the evolution of fiber optics.

Fiber optics refers to transmitting light down thin layers of glass, or sometimes plastic, and is used in communication, lighting, and optical inspections, among many other things (Hayes, 2010). The fibers can be manufactured to be up to 45 kilometers long, but over longer distances, they must be spliced together (Hayes, 2010). The most common type of splice is called fusion splicing. This is the process of joining together two optical fibers at the ends of the fibers using heat (Hayes, 2010). By melting the two ends together, the goal is to prevent the light from being scattered or reflected at the splice. An alternative method to fusion splicing would be using optical fiber connectors (Hayes, 2010). These connectors can be beneficial to join optical fibers at points where the capability to connect or disconnect the fibers is required (Hayes, 2010). They are generally made to be spring-loaded so that when the fibers are connected, the signal loss due to an air gap would be eliminated (Hayes, 2010). The point of connection between two fibers is similar to the connection between neurons at the synapse. The fibers are used to transmit a signal through a complex network of fiber optics. The signal that a single optic fiber carries can be sent down a network of fibers that form a cable. Similar to how the nerve is formed from bundles of axons, fiber optic cables are formed this way. Small bundles of optic fibers are wrapped in a protective coating, similar to the perineurium in a nerve, which are then bundled again to form a cable with another coating, which is similar to the connective tissue surrounding the nerve. Outside plant cables typically have high fiber counts consisting of around 288 fibers (Hayes, 2010). The evolution of fiber optics communication arose from the demand for faster, inexpensive ways of transmitting signals over long distances (History of Fiber Optics, 2012). Dating back to Roman times, glass was being made into fibers (History of Fiber Optics, 2012). In the 1790s, the first optical telegraph was invented that was used to relay a message using light signals being transmitted from one tower to the next (History of Fiber Optics, 2012). Throughout the 1800s and 1900s, many advances were made with fiber optics communication. A major success happened in 1977 when the first live fiber optics telephone line was used in California (History of Fiber Optics, 2012). Soon after, fiber optics communication techniques were being used by many telephone companies in order to lower costs and to reassess their communication infrastructure (History of Fiber Optics, 2012). As complex fiber optic networks evolved in the telephone industry, this technology found its way into a variety of other industries including medical, military, data storage, networking, and broadcasting productions (History of Fiber Optics, 2012). Designs were tinkered with over time, which was necessary in order to achieve the best design.

Why:

The advantage to tinkering with the design of neural networks over evolutionary time is for more effective communication between neurons. Signals can be transmitted throughout the whole body quickly and efficiently because of the highly developed signaling network (Evolution of nervous systems, 2012). Nerve cells can serve a wider variety of functions if there are many of them capable of carrying signals to their destinations. The increased complexity that evolved in neuron connections led to the development of the brain and the many functions associated with it (Denes, et al, 2007). Looking at the nervous systems in simple organisms, it can be seen how they developed from evidence in their genes (Denes, et al, 2007). Studies have been conducted using sea sponges to look for clues about how neurons could have evolved in ancient animals (Denes, et al, 2007). The genome of the sea sponge, *Amphimedon queenslandica*, was explored and it was found that although they do not have nerve cells, they were able to synthesize some of the proteins required for cell-to-cell communication in the nervous system (Denes, et al, 2007). This study provided insight on the possible evolutionary pattern of nerve cells in more complex organisms. They also found that this sea sponge contained most of the necessary components to make post-synaptic density and was only lacking a few of the genes from the human postsynaptic density (Denes, et al, 2007). Evidence of evolution of nerve cells over time helped to explain why this biological structure upholds the principle that continuously tinkering with the design plan will enhance the final product.

By tinkering with the designs of the fiber optic cables, more effective means of sending signals over great lengths can be achieved. Trying out different bandwidths and finding the optimal optic fiber lengths will allow for the most efficient and cost-effective solution for communication demands (Hayes, 2010). Different attempts connecting two fibers will

determine how to reduce scattered light to produce a seamless light flow through the length of the fiber (History of Fiber Optics, 2012). As stated in Rule 4 on the Living Architecture website, "To achieve the best design, continuously tinker with the building plans."

Figures:

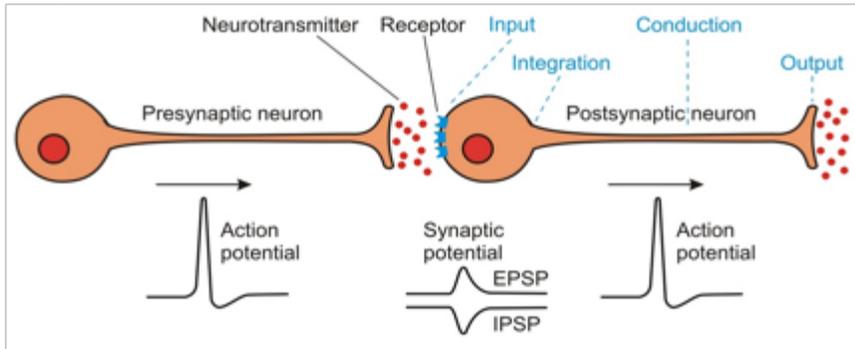


Figure 1. This figure shows how the neurons communicate with each other. The signal flows down the axon of the presynaptic neuron, neurotransmitters are released and picked up by the receptors of the postsynaptic neuron, and the signal continues to travel down the axon due to action potentials, repeating this process until it reaches its destination. (Gensch, 2009)

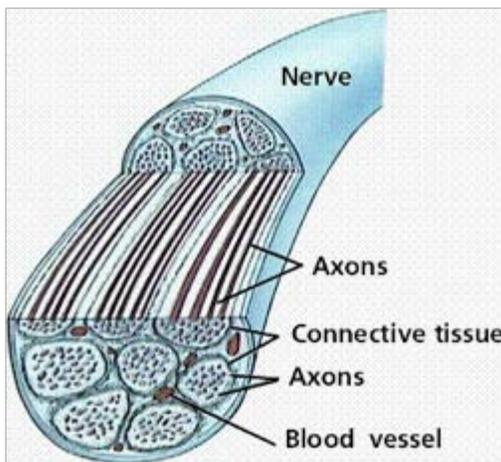


Figure 2. This figure shows how the axons of the neurons are bundled together to form a nerve. The axons are in bundles surrounded by connective tissue and blood vessels, which are then bundled together again to form the nerve. (Farabee, 2010)

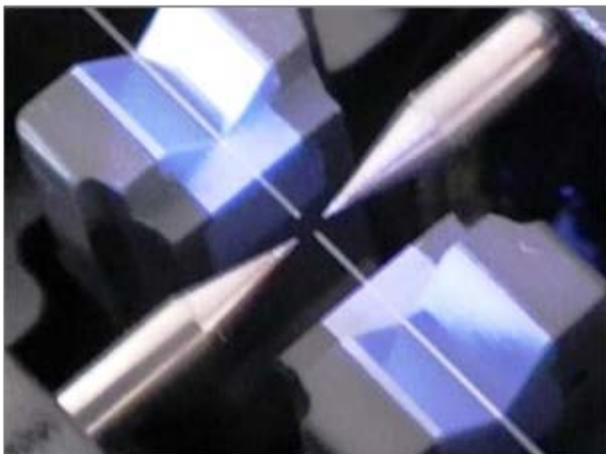


Figure 3. This picture shows the process of fusion splicing to form a seamless connection between two optic fibers so the light signal can pass through without scattering and reflecting the light. (ISI: Case Studies in Network Cabling & Data Installation, 2012)



Figure 4. This is a bundle of optic fibers that contains many individual fibers that come together to form a cable, similar to the bundle of axons that form a nerve. Each colored tube in the photo has smaller bundles of optic fibers surrounded by a protective coating. They are all joined together to make one cable that is capable of transmitting a signal. (Berrett, 2000)

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