

Digital vs Analog

Consider a simple $y = \sin(t)$ function. It can be thought of as a continuous or analog function as for any real number t we can input into the function $t + \delta$ where δ can be made arbitrarily small. Now consider a sampled $y = \sin(t)$ shown in figure 1 at every interval T . This is an example of a digital or discrete signal.

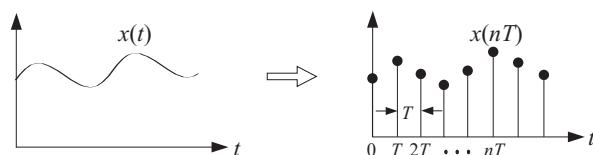


Figure 1: The conversion of a continuous signal to discrete involves sampling at time instances T

A digital signal can also have the output sampled at discrete values, so for $y = \sin(t)$, y could hypothetically take on only a 1 or -1 for input x . This will be a similar model for a neuron with regard to action potentials, for some input either the neuron fired or it didn't. However, as you'll read in Debanne, D. "What are the mechanisms for analogue and digital signalling in the brain?", this may not be the entire story.

The Basics

The neuron is the fundamental unit for the nervous system. It contains 3 main structures: the cell body, the dendrite for input electrical signals, and the axon for output electrical signals. The segment connecting the axon and cell body is called the **axonal initial segment** (a.k.a. axonal hillock) and is used to initialize action potentials due its large radius and high density of sodium channels. The axon terminates at the dendrite of another cell. At this junction the axon's membrane is often referred to as the pre-synaptic membrane and the dendrite as the post-synaptic membrane. In the pre-synaptic membrane (i.e. in the axon), near the membrane is a region called the **active zone** where neurotransmitter filled vesicles and the proteins for exocytosis of the vesicles reside. One of these proteins are **SNARE** proteins that are used to bind the vesicles to the membrane and then facilitate their fusion causing the release of the neurotransmitters.

When an action potential invades an axonal terminal, voltage-gated calcium channels open causing an increase in calcium in the cytoplasm. Higher concentration of calcium will cause the neurotransmitter filled vesicles to fuse to the membrane, allowing the neurotransmitters to diffuse to the post-synaptic membrane and bind ligand gated ion channels causing them to open.

The two most common neurotransmitter in the central nervous system is **glutamate** and **GABA**, which have opposite effects. Glutamate binds a sodium channel that will cause a depolarization allowing the action potential to continue propagating in the post-synaptic neuron (this is referred to as an excitatory post-synaptic potential (**EPSP**)). GABA causes chloride to enter the neuron causing a hyperpolarization and electrical inhibition of the neuron (this is referred to as an inhibitory post-synaptic potential (**IPSP**)).

There are two classes of receptors a neurotransmitter can bind: **ionotropic**, which is a channel that opens quickly when the neurotransmitter binds, and **metabotropic**, which interacts via a **G-protein coupled receptor (GPCR)** (figure 2). The GPCR, when bound by neurotransmitter, activates its associated G-protein which, through a signalling cascade, activates a channel to open or close. Metabotropic receptors are usually slower (response \approx 1 sec to 1 hour) and are typically associated with long term changes in the synapse for memory and learning. An example of a metabotropic receptor is the **muscarinic** receptor at the neuromuscular junction which binds acetylcholine from the nerve to cause contraction or relaxation of the muscle.

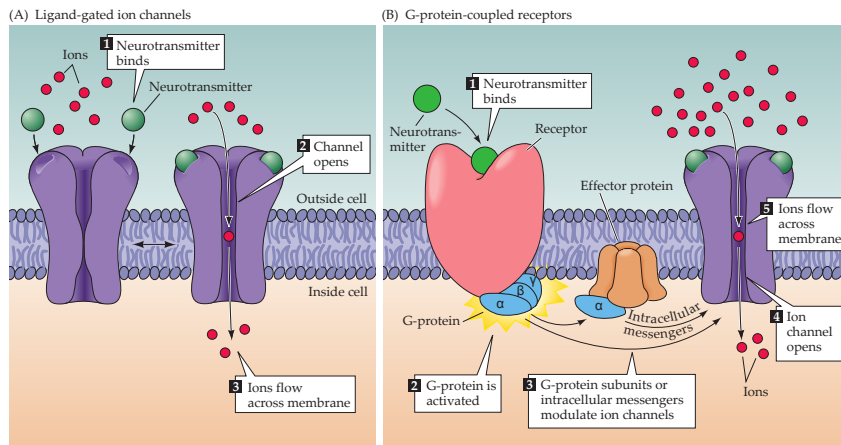


Figure 2: Ionotropic receptor is shown on the left and the metabotropic receptor on the right

Additional Terms

Pair-Pulsed ratio: When an action potential fires, it elevates the calcium in the axon terminal. If a second action potential occurs before the calcium is able to return to its steady-state, more calcium will enter causing an elevation in concentration greater than the previous action potential. As a result, more neurotransmitter is expected to be released with the second action potential which in turn should cause a greater change in the post-synaptic membrane's potential. The pair-pulsed ratio of the depolarizing potentials in the post-synaptic neuron from each action potential is defined as the pair-pulsed ratio.

Interneurons: Neurons that are neither sensory or motor, which form connections between different neurons and neural structures.

Tonic firing: When the frequency of the action potentials from a neuron are constant.