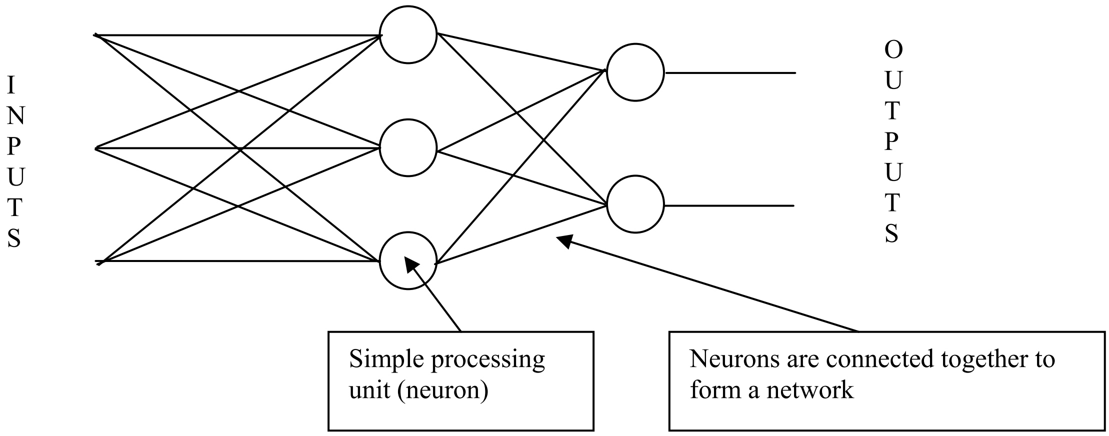
1. An introduction to Neural Networks

The Artificial Neural Network (*Neural Net* or just *ANN* for short) is a collection of simple processors connected together. Each processor can only perform a very straightforward mathematical task, but a large network of them has much greater capabilities and can do many things which one on its own can't. Figure 1.1, shows the basic idea.

Figure 1.1, a Neural Net consists of many simple processing units connected together.

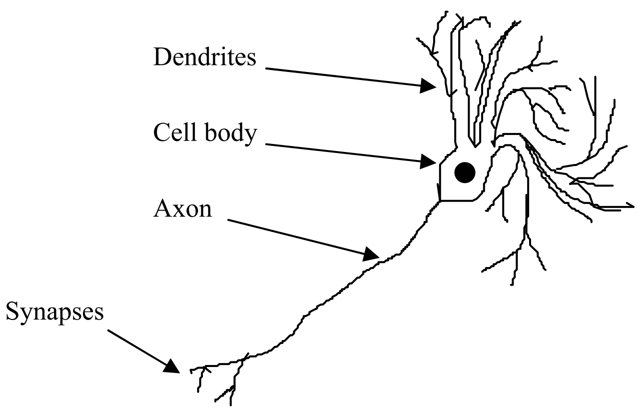


The inspiration behind the Neural Net is the brain. The human brain consists of about 100 billion processing units connected together in just such a network. These processing units are called "Brain Cells" or "Neurons" and each one is a living cell. Before proceeding to discuss the operation of the Artificial Neural Network, it will help us if we pause to understand something of how the real one works.

1.1 Real Brains

Looking at a real neuron under a microscope (it's much too small to see directly), it typically appears as shown in figure 1.2.

Figure 1.2, a Biological Neuron.

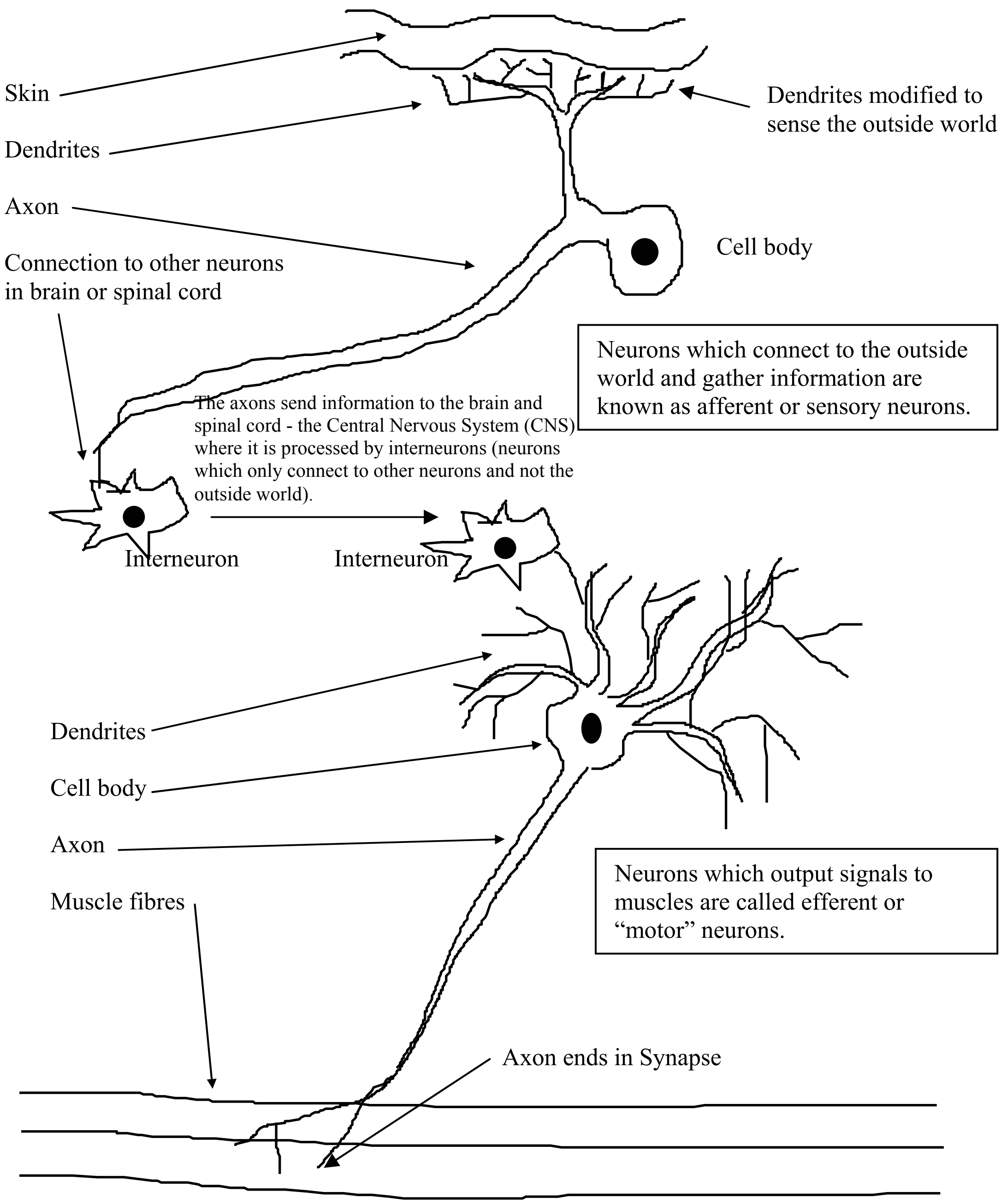


The dendrites are the receiving end of the neuron; they pick up signals from other neurons, or from the outside world if the neuron is a sensory one. The cell body contains the mechanisms that keep the cell alive, for example the nucleus. Finally, the

Axon transmits signals to other neurons, or to muscles or glands if the neuron is a motor one (it's bundles of these axons that the layman would call "nerves").

All inputs to the body are processed by neurons. The light sensors in our eyes, which are called rods and cones, are neurons in which the dendrites have become modified to be stimulated by light. Under our skin are pressure sensing neurons - as well as heat sensors, pain sensors and a myriad of other neurons modified to detect what's around us. Likewise, our muscles are stimulated to move by motor neurons. Figure 1.3 shows how the system works.

Figure 1.3, how neurons control the functions of the body.



The input information is passed along the long axons of the sensory neurons into the spinal cord and brain. There they are connected to other neurons (called interneurons).

Finally, the result of the processing is passed to the output neurons which stimulate muscles or glands to affect the outside world. This mechanism is responsible for all our actions from simple reflexes to consciousness itself.

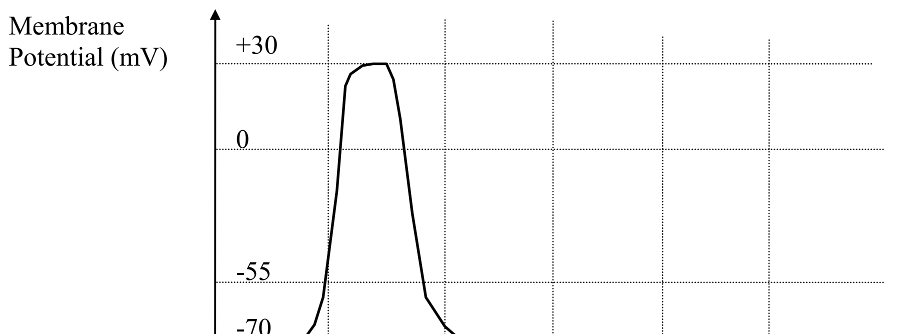
1.2 Operation of neurons

Having seen how the neurons connect to form a network, let us consider what each individual neuron actually does. At the simplest level, neurons produce pulses, called "Action Potentials," and they do this when stimulated by other neurons (or, if they are sensory neurons, by outside influences, which they pick up through their modified dendrites).

When a neuron is at rest, before it becomes stimulated, it is said to be polarised. This means that, although the neuron is not receiving any electrical signal from other neurons, it is charged up and ready to produce a pulse. Each neuron has associated with it a level of stimulus, above which a nerve pulse or action potential will be generated. Only when it receives enough stimulation, from one or more sources, will it initiate a pulse.

The mechanism[1] by which the pulses travel and the neuron maintains its general electrical activity is rather complex and we need not go into it in detail here. It works through an exchange of ions in the fluid that surrounds the cell, rather than by the flow of electrons as you would get in a wire. This means that signals travel very slowly - at a couple of hundred metres per second. The pulse, which the neuron generates and travels down the axon, is shown in figure 1.4.

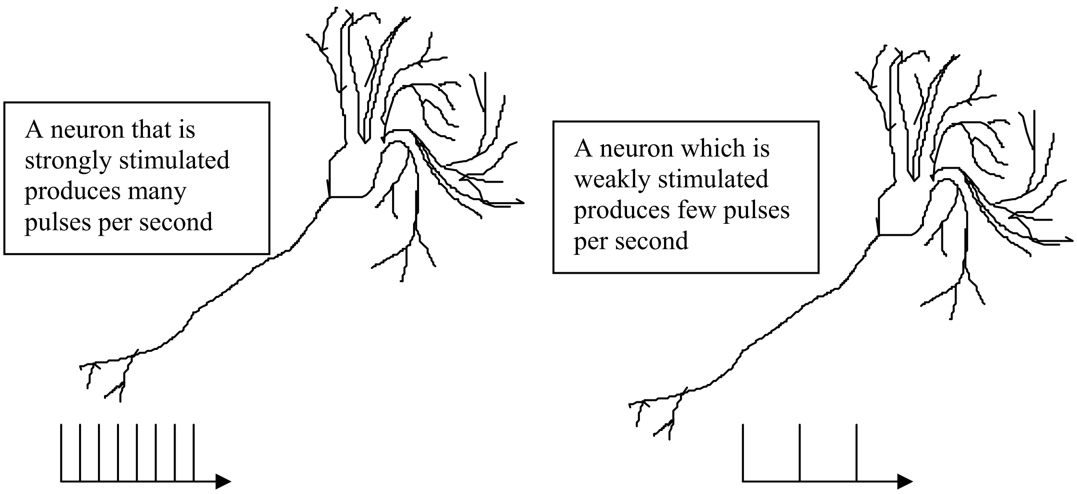
Figure 1.4, the action potential.



Because these pulses are only a couple of milliseconds wide, they often appear as spikes if viewed on an oscilloscope screen.

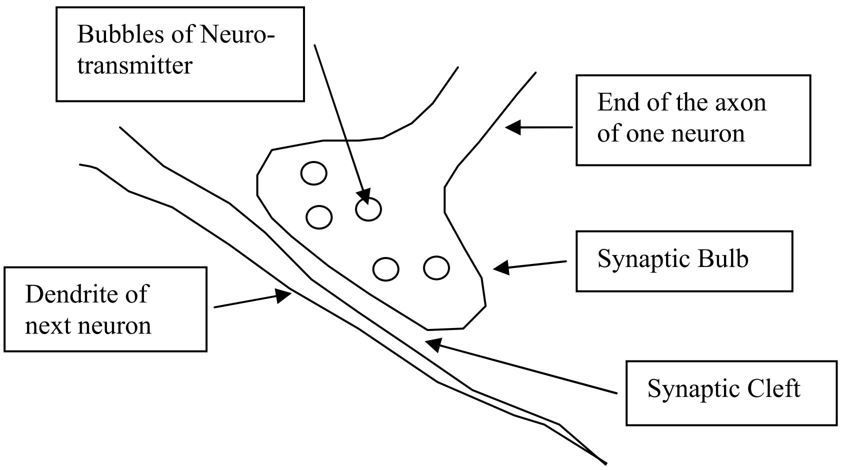
So, if one neuron is receiving lots of stimulation from another (receiving lots of pulses through its dendrites) then it will itself produce a strong output - that is more pulses per second, figure 1.5.

Figure 1.5, strongly and weakly stimulated neurons.



1.3 Learning
We've just described a process whereby the action potentials are conducted down the Axon rather like a wire - although much more slowly. Where the end of the Axon meets the dendrites of the next neuron is called the Synapse (look back at figures 1.2 and 1.3) and it is important to the functioning of the neuron and to learning. Figure 1.6 shows an enlargement of this area.

Figure 1.6, the Synapse.



The Axon ends in a tiny bulb called the Synaptic Bulb and this is separated from the next cell by a gap (only a few tens of nanometers wide) called the Synaptic Cleft. When the Action Potential reaches the end of the Axon, it stimulates the release of chemicals called Neurotransmitters, which are present in the Synaptic Bulb. These cross the cleft and stimulate the next cell.

This may seem a strangely inefficient way to transmit the signal, but the amount of Neurotransmitter released when the Synaptic Bulb receives a pulse, varies - it may release a large quantity of chemical which causes a lot of stimulation or release other types which inhibit stimulation.

In 1949 Donald Hebb[2] postulated one way for the network to learn. If a synapse is used more, it gets strengthened – releases more Neurotransmitter. This causes that particular path through the network to get stronger, while others, not used, get weaker. You might say that each connection has a *weight* associated with it – larger weights produce more stimulation and smaller weights produce less. These were the first steps to understanding the learning mechanism of the network. There are still gaps in our understanding of learning in the Biological Network, but this need not delay us from turning to Artificial Networks and how they are trained.