The Brain

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"The mind is what the brain does." – Marvin Minsky

1 Human Brain

The human brain has about $10^{10} - 10^{11}$ neurons. The neurons are highly connected: a neuron is typically connected to 1,000 others, or even as many as 10,000 others. The brain is highly parallel, but its operations are slow compared to computers: neurons can fire at a maximum pulse rate of about one pulse per millisecond.

A neuron receives inputs from other neurons, both excitatory and inhibitory. If total excitation exceeds a threshold, the neuron fires: an electrical pulse, involving exchange of sodium and potassium ions across the cell membrane, travels down the axon. The pulse travels at about 90 meters/sec. The cell must "recharge" before it can fire again. At the end of the axon are axon terminals that connect to dendrites of other nerve cells across synapses. At the synapse, the electrical pulse of the nerve firing causes the release of chemical neurotransmitters; these diffuse across the small gap between the cells and reach receptors on the target cell, stimulating or inhibiting it. Scavenger chemicals clean up the neurotransmitters afterwards. The strength of a signal is indicated not by strength of a pulse, which is roughly constant, but by the pulse rate: no pulses or infrequent pulses represent a weak signal, while frequent pulses represent a strong signal.

Depression involves a depressed level of neuron firing. Some mental illnesses (and, e.g., alcohol intoxication) are associated with changes in neurotransmission: lack or excess of neurotransmitters, problems with scavenging them, lack or blockage of receptors, etc.

There is evidence that learning is associated with strengthening of synaptic connections; growth of dendrites also occurs. In some cases, neurons that are not used will die out.

There is often a "mapping" that associates nearby areas of the body or retina with nearby areas of the brain; this is called *somatotopy*.

Vision: about 22 "frames" per second are processed. Roughly 1/3 of the human brain is devoted to vision processing.

2 Brain Structure and Function

The brain is not just a large mass of random neurons. For some parts of the brain, there is a good understanding of the specific structure and function; these include early vision, speech output, body sensation, and motor control. Other parts of the brain, and other mental functions, are less well understood.

3 Experimental Investigation of Brain

The fine structure of neural connections is ordinarily difficult to see under the microscope. Camillo Golgi (1843 - 1926) discovered a stain that stained only about 1% of the neurons, making individual neurons and their connections visible. Santiago Ramón y Cajal (1852 - 1934) improved Golgi's method and studied the neural structure of the brain and retina.

Much early knowledge about association of brain location and function has come from study of brain-injured patients. A. R. Luriia͡ carefully studied many brain-injured Russian soldiers during World War II, correlating their psychological deficits with the location of injury. Particular aphasias (speech disorders) are often associated with injury to specific brain areas.

Brain waves, measured at the scalp, give some information, but are sums of activity of many neurons. Micro-electrodes can be inserted into the brain to observe the firing of individual neurons; when amplified and played through a speaker, neural firings can be heard as clicks, or as buzzes when firing is rapid.

Magnetic resonance imaging (MRI) and positron emission tomography (PET) provide real-time pictures of brain activity. Chemicals such as glucose are made containing radioactive chemical isotopes that decay fairly quickly and emit positrons (which do not cause radiation injury to the patient). The positrons can be detected outside the head, and a three-dimensional image of activity inside the brain can be reconstructed by computer. The positron activity is proportional to the amount of glucose present in blood. Blood flow is modulated by brain activity, so the positron picture shows what areas of the brain are active at a given time.

An interesting recent technique is to *subtract* averaged positron pictures taken from a number of normal volunteers and a number of patients with a mental problem. The difference pictures yield clues about how the patients differ from the controls.

Aplysia is a marine mollusk. It has about 40,000 neurons, and the neurons are especially large. Therefore, *Aplysia* is widely used for brain studies [17].

4 Interesting Experiments

McCullough and Pitts [16] performed a pioneering study of the visual system of the frog. The frog only perceives a few things:

1. Small moving dark spots. (bugs)
2. Large moving dark areas. (predators)
3. Large stationary dark areas. (water)
4. Large stationary light areas. (rocks)

Hubel and Wiesel [15] won a Nobel Prize for their study of information processing in the visual cortex of the cat. A cat was anesthetized and its skull opened. Micro-electrodes were inserted to record from single neurons in the visual cortex. Visual patterns were projected onto a screen until a pattern was found that would cause the observed neuron to fire. Neurons were classified according to the types of visual patterns that would make them fire, e.g.:

- Line detectors: these neurons detect a line oriented at a particular angle (about 6° resolution).
- Edge detectors: these detect an edge between light and dark.
- Moving line detectors: these detect an edge at a particular angle, moving in a particular direction.

These are *early vision* processes. The earliest visual processing is done in the retina itself (which begins its development as part of the brain). The information that is sent down the optic nerve is already processed somewhat, rather than being a "TV picture".

David Marr's book *Vision* [19] mathematically analyzes computations that visual processing *should* be doing and compares these with the findings of Hubel and Wiesel. The computations derived by Marr are in fact performed in the cat visual system.

Intelligence tests sometimes include a multiple-choice test that requires finding a rotated version of a given figure among other similar but incorrect choices. Psychological studies have shown that response time on such a question is linearly proportional to the amount of angular rotation [25], suggesting that a "mental rotation" is taking place. The existence of mental images has been controversial, but Georgopoulos *et al.* [12] have found evidence of rotation at the neural level in the rhesus monkey.

An experiment with tadpoles is an interesting demonstration of specificity of neural connections. A square of skin is cut from each side of a tadpole, and the squares are switched to the opposite side. If the adult frog is tickled on one of these patches, it will scratch the opposite side. This seems to indicate that the sensory neurons of the skin "know where to plug in" when they connect to the brain, and the neurons make the same connections even after they have been moved.

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