

Speculation on Neuron Functionality and Influence on Cognition

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Psychology 305 – Cognitive Psychology

NEURAL INFLUENCE ON COGNITION

## Neuron Functionality and Influence on Cognition

The Human Brain is the most complex and efficient computing array that human beings have ever encountered. At an estimated 10 trillion operations per second, a single human brain is over 10,000 times more powerful than the typical home desktop computer, but uses less than a third of the power. The study of this mass of proteins and fats between our ears has spawned numerous academic disciplines, ranging from neurobiology – the study of individual neuron processes, to social psychology – the study of how whole brains interact with each other. Despite so much work being done on the human brain, it seems that there is very little crossover between disciplines, which may be necessary for a full understanding of the brain. In Cognitive Psychology, most models of brain operation are top-down theories, descriptions of high-level processes based off of externally observable phenomena. This has worked well so far, but these theories are lacking in detail. A fuller understanding of brain operation might be obtained through a bottom-up approach, analyzing how the functionality and organization of groups of neurons can produce behavior and higher-level functionality.

Physically, Human neurons are one of the most complex types of cells in the human body. Sophisticated chemical reactions regulate how and when neurons fire, and how they make connections to other neurons in the brain. Despite their high chemical complexity, neuron high-level functionality can be described fairly simply as following a single rule: In – Integrate – Out. This In – Integrate – Out concept also scales to groups of neurons, brain regions, and even the brain as a whole as it senses and acts in it's environment. But this is not a full description of neuron functionality. This is only the short-term operational behavior of neurons. Real, biological neurons learn by changing

where they are connected, and this is where the real power of neurons lies. An early concept of neural learning was proposed by Hebb (1949) stating that “Neurons that fire together, wire together.” While interesting, this theory was greatly lacking in detail necessary to describe the full range of human learning. Neural Network models (Rumelhart, Hinton and McClelland, 1986) attempt to describe how groups of neurons learn and operate. In these models, a learning rule is applied to entire groups of neurons, and inter-neuron connections are modified to achieve a higher success rate. While useful for modeling learning in computers, this method is not effective for modeling learning in humans, as each individual neuron achieves learning by changing its own connections, somewhat independently of what its neighbors are doing. Instead of group-wide learning rules, neurons operate on a set of cellular rules that are defined by their biology, constituting what is known as cellular automata.

The study of cellular automata is a fairly new field of computer science and math concerned with how the interaction of many individual ‘agents’ or cells with very simple rules can produce complex system-wide behaviors. Applying concepts of cellular automata to neurons is complex, as neurons are part of an information processing scheme, where their inputs, or dendrites, are conduits of information that effect how the neuron behaves and also makes new connections. In this way, neurons can route information through the brain, while at the same time they are processing on it. As each neuron builds a set of connections based on information that arrives through those same connections, the neuron inserts itself into a ‘sweet spot’ where its internal rules are in balance with the amount of activity it is receiving from its connections. Connections that are used very little, or used too much are moved after a short duration, a behavior that is

the cellular analogue of short term memory. However, if a connection is made that is used with just the right pattern, a genetic trigger is fired that produces proteins that solidify the connection. These protein-enforced connections can last from days to years and are thought to be responsible for long-term memory.

The patterns of activation necessary to solidify neural connections are defined simply by the fatigue of the neuron. If a connection is causing the neuron to fire all the time, this is physically damaging to the neuron, and the neuron will destroy the connection in order to maintain itself. A connection that is not used enough will simply decay until it disappears. Intermittent patterns of activation that allow the neuron to rest for a period of time before firing again are reinforced. This makes sense from a biological standpoint, but since the brain is primarily concerned with information processing, it would be useful to examine this process from that perspective. If we think of each connection to a neuron as a channel for information, we can clearly see that a dead channel carries no information, and is not useful for information processing. This is also true of a channel that is overloaded and always active. If the channel is peaked all the time, it is too noisy to carry information and is a hindrance to the cell's information processing. However, in the intermediate range, where neurons reinforce connections, the Signal to Noise ratio is high, meaning that information can be clearly received, and information processing can proceed efficiently. In this way, a neuron attempts to settle into an efficient, fast, sweet spot of information processing.

The effects of these low level behaviors may be seen in high level behavior of learning, recognition, and memory. In classical conditioning, we see that reinforcement schedules that are variable or spaced distantly produce learning at the fastest rate of

speed, while continuous reinforcement only produces slow, but steady learning. This may be because the neurons responsible for learning these procedures are becoming fatigued, and leaving time for rest allows the neurons to ‘cool’ and be ready for deeper learning the next time the reinforcement comes around.

Another effect of neuron behavior that may be seen externally is related to representation of knowledge. As information is presented to the brain through the senses, each neuron finds its sweet spot relative to the types of information that are coming in. Since all information passes through the senses, and is translated into the same types of information codes (activation patterns), neurons will find sweet spots that span the sources of information. For instance, if a person is presented with a crackling fireplace, the person can both hear the fire crackling, and see the flames burning. The person can associate the two separate and distinct sensory stimuli with the concept of ‘fire’ because the signals are all of the same type, once they are in the brain. The only difference is where those signals are localized. Since the brain is a real, physical system, cells take up space, and they only have a finite region of connections. Auditory and Visual Stimuli have to travel from different parts of the brain to become associated with the concept of ‘fire’. This concept is analogous to the Levels of Processing Theory proposed by Craik (1972) and has a biological basis in the neural structure of the brain. As a stimulus travels through multiple portions of the brain, more neurons are tuning themselves into a sweet spot relative to the stimulus, strengthening the effect of a stimulus on the brain, and strengthening the response that the stimulus will elicit the next time it is presented.

We can also see effects of the distributed nature of neural processing on how the brain organizes semantic information. J.R. Anderson (1976) proposed the ACT semantic

network model, which states that knowledge is stored in a semantic network consisting of interconnected nodes and activation can spread down network paths from active nodes to activate new nodes and paths. This concept has a direct cellular analog in the hybrid hierarchical and parallel structure of the brain. The nodes and paths that Anderson describes could very easily be the neurons, or groups of neurons, and the paths between them. Since neurons tune themselves to respond to certain patterns of stimuli, while also routing the information they respond to, neurons effectively filter information through the brain, spreading the activation to areas that are appropriate for recall or processing.

Thus, it can be seen that when neurons with simple rules for operation are combined into groups, a large range of effects can result, some of them observable as high-level behaviors in human beings.

References

- Read, Steven K. (2004). *Cognition: Theory and Applications*. Belmont, California: Wadsworth/Thomson Learning.
- Chance, Paul (2003). *Learning and Behavior*. Belmont, California: Wadsworth/Thomson Learning.
- Engelbrecht, Andrias P. (2003) *Computational Intelligence: An Introduction*. Hoboken, New Jersey: Wiley Publishing
- Kolb, Bryan and Whishaw, Ian Q. (2001) *An Introduction to Brain and Behavior*. New York: Worth Publishers.