# Foundations of the Brain (Part I)

By Michael Feldhake

## Introduction

This is Part I of a two part series of articles that attempts to elaborate on the essential Physiological & Psychological aspects of the animal mind. If one were attempting to duplicate functionality and purpose, as in the case to reverse engineer it, it would mandate that the mind be dissected and analyzed. But since the brain is overly complicated and mysterious and without adequate analysis tools, it is difficult to ascertain functionality solely based on available empirical evidence. Therefore, in an attempt to overcome this problem, an examination of evidence of important parts shall be used to provide some insight into the "big picture" and help us understand what is going on. While Part II deals with the Psychological aspects of the brain, this part deals with the Physiological evidence. After review of the essential components, layout and infrastructure of the brain, a summary and conclusion is provided.

## Neurons

Our brain is part of the central nervous system and is comprised of nerve cells, called neurons. Each neuron, protected by other cells, has a cell body, one or more dendrites which are like branches on a tree, and an axon stretching out from the cell body. This axon, the largest of the branches, is like a tree trunk ending in terminal nodes and connecting to other cells. Both dendrites, that can number into the thousands, and axons can reach short distances to adjacent cells or long distances spanning the entire brain.

There are two general categories of neurons. First, the myelinated neuron (white matter), has Schwann cells wrapped around the axon at regular intervals. Spaces between the myelin or Schwann cells are called Nodes of Ranvier. The myelin insulates the axon and the nerve impulse jumps from node to node down the axon. This greatly increases the speed that these cells transmit information. The second type of neuron is unmyelinated (grey matter), these neurons transmit the nerve impulses more slowly, but are able to branch and form far more interconnections for highly specialized controls and higher order thought. Both of these neuron types are critical for complex and efficient thought to occur.

The Synapse is the junction between each connection point between nerve cells. These small junctions provide important functions of signal relaying and inversion. Nerve impulses are generated by the cell body and reach the synaptic connections through the axon. These impulses are generated from terminal knobs, located at the end of the axon releasing chemical neural transmitters that excite or inhibit the connecting cell based on its interaction. Once this connecting cell reaches a stimulus threshold, it fires its own axon. Synaptic connections can also include connections between cell bodies, muscles or glands.

Many different neural transmitters are present in the body adding to its complexity and scale. These include; Monoamines Serotonin, located in the pons, medulla and midbrain areas, that regulate mood and pain; Dopamine, located in the midbrain & ventral tegmantal areas help manage movement, attention, learning and reinforcement; Norepinephrine, located in the pons, medulla and thalamus connect to a large number of areas including the hypothalamus, hippocampus and basal ganglia and controls the increase in vigilance or arousal; Gamma-aminobutyric acid or GABA, the most important inhibitory transmitter in the brain; Glycine, located in the spinal cord and lower portions of the brain, is also an inhibitory neurotransmitter; Peptides provide many different signals, including pain reduction, inhibition of fleeing & hiding responses and stimulation of reinforcement neurons, when these opiate receptors are stimulated.

## The 3 Brain System

Papez-Maclean theory of brain evolution is comprised of three major parts commonly referred to as the 3-brain system. The reptilian brain, located at the top of the brain stem, acts to coordinate basic functions of behavior. The reptilian brain, wrapped with a paleomammalian brain, includes the limbic system. The limbic system controls the emotional and species-specific behavior characteristics (or hereditary traits) of the brain. Wrapped around this paleomammalian brain is the neocortex, responsible for complex thought and has been referred to as the "thinking cap." All animal species on this earth possess one or all of these pieces. Birds have both the reptilian brain and the paleomammalian brain sections where as mammals such as dogs and humans possess all three.

### Mammalian Brain & Cerebellum

A primitive form of the cerebellum is present in all reptilian brains. This area is responsible for the ability of an organism to make smooth, rapid and complex movements. For example, when we learn to walk, it takes constant concentration. Once we have practiced enough, the cerebellum takes over and walking becomes "automatic." Also included is the brain stem consisting of the midbrain, pons and medulla and located deep in the posterior part of the brain. This section of the brain represents vital response systems tapping into the auditory & visual cortexes and controlling respiratory control & cardiac systems.

### Limbic System (Medial Temporal Lobe)

Primate survival can be attributed to its Limbic regions. Many highly evolved brain regions make up this critical region. The limbic region is located between the cerebellum and the cerebrum. It includes many parts, among which are the amygdala, parahippocampal gyrus, basal ganglia, hippocampus, hypothalamus and more. The limbic system generally produces chemical reactions that act upon other biological systems, including cerebral development, emotional reactions and motivation issues of the organism. Hereditary behaviors, the natural or innate ability of any species, are centered in this system.

Adding to the pronounced complexity of the brain is the forebrain and all its parts. The basal forebrain in the limbic region contributes to emotions through its connections with other prefrontal cortex and limbic forebrain structures. The limbic forebrain itself is believed to be the "chief executive part" of the brain. It works to control behavior through activity planning and reaction selection. This limbic forebrain also includes the orbitofrontal cortex that specifically alters moods and mental states.

The basal forebrain comprises many groups of structures and is located near the bottom of the front of the brain. These structures are responsible for the production of acetylcholine. Acetylcholine, distributed throughout many parts of the brain, controls information access, information flow and learning.

### Cerebral Cortex (a.k.a. neocortex)

The cerebrum makes up 85% of the brain's mass. It is made up of both white matter and gray matter. The outer covering of the brain, the cerebral cortex, is made up entirely of gray matter, giving the brain it's gray color. In humans, when this part is stretched out, the cerebral cortex covers one-quarter square meter and is 2-5 millimeters thick. At the top layer of cells, we see very structured pyramidal cells and are primarily the motor areas of the cerebral cortex. They have long axons to communicate with the basal ganglia, brain stem, cerebellum, and the spinal cord. The next layer has a mix of granular and pyramidal cells and this is an area of association between the motor area and the sensory area, the third layer. The third layer is comprised of granular cells and is the primary sensory area of the brain. These neurons have short axons and transmit multiple signals within the neural network of the cortex. There are also horizontal cells between the adjacent areas of the cerebral cortex that are used to communicate information between the different areas of the cortex. Communications between these different layers and regions of the cerebral cortex is critical for appropriate responses.

## Prime Circuits

Primate & mammalian brains are comprised of even more specific components that help in the overall process; Hippocampus, our novelty and information center works to develop memories. It is part of the Limbic system and is connected to the temporal lobes and other limbic system components. This system is responsible for novelty detection, memory formation and storage based on the emotional context of the information; Hypothalamus, a complex system of many parts, is also part of the limbic family and regulates body functions. These innate functions include body pressure, temperature & weight, vomiting reflexes, heart rate and also help regulate eating and reproduction.

The Superior Colliculus, located in the thalamus, innately helps us coordinate the Multi-Sensory-Spatial map. This system is involved in spatial orientation of the host to sensory stimulus like auditory noise and visual objects. Evidence also suggests that this large region assists in visual stability by compensating for motion on the images of the retina. Also included in visual skills is the Occipital lobe. This lobe provides attention controls and recognition of information being sent by the over 1,000,000 retina nerves that make up the visual cortex of each eye. The Parietal lobe is responsible for somatosensation - the relaying of information about touch, temperature and limb position – and is also linguistically important.

A dual system of interconnection, extremely important to the survival of the species, exists in the brain. Joseph LeDoux, a Professor at the center of Neural Science at New York University, explained the "low road" and "high road" of neural pathways. The low road was the direct interconnection of raw stimulus that was required for emergency action from the brain's response system. Whereas the high road was the interconnecting pathways where the cortex was involved in allowing more robust information to be obtained about the danger.

### Thalamacortical System

Interconnected to every part of the brain's neurology is the Reticular Activation Systems or RAS. The RAS, radiating from the thalamocortical system, is suspected of channeling attention, memory access and alertness. The brush like connections of the RAS provide a conduit for spatially & temporally oriented signals to digress into the cerebral cortex to control the body's alertness level to stimulus and accessibility of memories. This network has been attributed to neurosis and social disorders because of its ability to control the information flow into the other regions of the brain. As in the case of psychopaths, they have a higher level of activation generating more information into the conscious parts of the brain making them overly extravert in nature.

Howard Hughes Medical Institute investigator Randy L. Buckner, Mark E. Wheeler and Steven E. Petersen at Washington University in St. Louis found that the upper regions of cerebral cortex were stimulated when people attempted to access memories. This confirms years of debate and propositions that the brain has the ability to direct attention towards specific memories. Because of the ability of the thalamacortical system to activate small portions of the cortex, as well as the hypothalamus, using chemo electric signals, the brain can reactivate neuron cells for memory recall.

## Summary & Conclusions

Neurons, the infrastructure of the brain, operate more like logical components than analog ones and operate much differently than the computational version of the Neural Network. Since the synaptic configurations determine how the signals are interpreted, they provide logical functionality by stimulating or inhibiting the connected cell, muscle or gland. Also, once the neuron reaches a particular threshold, the cell fires pulses down its axon to connecting cells. Furthermore, the neural infrastructure is inherently asynchronous and temporal. Asynchronous neural networks provide a system where temporal signals can coincide adding to the complexity of the signal processing the brain can and must support.

Brain study and its impact to the understanding of its workings it is hampered by the physical nature of its existence. Since the brain must communicate over its vastness, the study & understanding of it is mired by the plethora of connections and cells that handle its management. Also, these structures provide more functionality due to their dual connection systems. These connections systems provide signal transmission as well as memory access operability that increase its purpose and effect.

Intelligence is not attributed to just one part of the brain. Whereas humans, monkeys and other primates have all components of the 3-brain system, birds and mice only have mammalian and paleomammalian brains. Further down in the animal kingdom, reptiles including lizards and fish have only the reptilian brain. Each part of the 3-brain system has adaptive qualities based on observable traits of each species, but it is clear that complex brain function is tied to the upper two parts of the brain. As brain size increases, there is an exponential rise in functionality due to signal processing capacity and heredity.

Heredity, the innate aspect of the brain, is mostly misunderstood and under-appreciated but turns out to be quite important. This quintessential part provides primates with survival skills, social skills, attention skills and learning skills. Learning, through emotional stimulus, becomes the basis of all learning developed and provides the supervisory response mechanism that is relied upon during life. All learning has a foundation upon our hereditary innate responses causing us to change the nature vs. nurture debate over behavior to a nature AND nurture derivation of behavior.

Similar to a distributive control system, the brain is designed with many specialized parts that are involved in the control and behavior of the host. These distributive circuits combine to provide the system with important & relative information pertaining to the circumstance at hand so a clear decision can be decided upon or the proper item learned. With one "executive level" component that is most likely fed with information that has already been preprocessed, tagged and weighted for an efficient but effective analysis.

## Resources & Links

1up Info™ Online Encyclopedia

Guyton, Arthur. (1986). Textbook of Medical Physiology. W.B. Saunders Co., Philadelphia.

Hampden-Turner, Charles. (1981). Maps of the Mind. Mitchell Beazley Publishers, Ltd., London; Macmillan Publishing Co., New York.

HHMI News "Researchers Trace Roots of Vivid Memories", September 26, 2000

James Madison University, Department of Integrated Science and Technology, Brain Knowledge Base

LeDoux, Joseph. (1996). The Emotional Brain: the Mysterious Underpinnings of Emotional Life. Simon & Schuster, New York.

PsychEducation.org Online Mental Health Information

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# Foundations of the Brain (Part II)

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## Introduction

This is Part II of a two part series of articles that attempts to elaborate on the essential Physiological & Psychological aspects of the animal mind. Artificial Intelligence has developed into a wide-ranging field of study that includes Neural Networks, Alife, Agent Systems, and Supercomputing because of the lack of understanding of human intelligence. Psychology, the study of the mind, has proven very abstract and is riddled with more theories than concrete evidence. Therefore, AI suffers from a lack of understanding of how and why we work the way we do. In order to overcome this problem, an appraisal of brain theories and research shall be used to provide an insight into the "big picture" and help us understand what is going on. While Part I deals with the Physiological aspects of the brain, this part deals with Psychological theories and brain concepts. After review of some essential aspects of heredity, learning and cognition, a summary and conclusion is provided.

## The Importance of Heredity

Heredity, a very misunderstood concept, is defined as the transfer of physical and psychical qualities from parent to progeny. In a more practical sense, heredity is the medium on which innateness is stored and can be categorized in two groups - Needs and Emotions.

### Needs

At the fringes of heredity is some form of a needs structure. This structure, although uncertain and debated, tends to be formed in layers and upward enabling as needs become satisfied. Abraham Maslow is recognized globally in developing the hierarchy of human needs. Maslow posited that two distinct groups, deficiency needs and growth needs, comprised the needs structure. The deficiency needs acted as error signals requiring neutralization by the host. These included physiological requirements like hunger and bodily comfort, safety and security needs, belongingness, love, and esteem needs. Once these interconnecting layers of needs were satisfied, they enabled the second set of Growth needs including cognitive needs to know and understand, aesthetic needs for order and symmetry, self-actualization needs for self-fulfillment, and self-transcendence needs for helping others reach their goals.

All needs work as a set of simple or complex responses, affecting us physically through innate actions and emotionally through reactions in our Limbic system. This model may not actually fit all personalities, allowing for introvert and extrovert behavioral differences, but it serves to provide some understanding of how and why we act in certain given situations. And although this model represents human Psychology, simpler less developed structures have also been noted in animals possessing physical and emotional responses.

### Emotions

Throughout history, many crusades have been made to find the emotional "Holy Grail" – the location of the brain region that produces the complex array of emotional responses in animals. By 1952, having expanded on James Papez, Kluver-Bucy and Freudian Psychology, Paul MacLean had created a widely accepted theory that the limbic system was the mechanism that mitigated and controlled our emotions. This theory, popular but contested today, is based on a range of lesion studies that isolated emotional responses in the hypothalamus and further studies that included the thalamus and hippocampus. Recent research, though, has shown that lesions involving the hippocampus and "Papez" circuit have inconsistent effects on emotions but affects cognitive abilities like declarative memory problems.

It should not be debatable at this stage to declare the limbic system central to our emotions and cognitive abilities. Consistent with the latest research, the limbic system helps mediate attention, emotion, learning and resulting memories. Psychologists have recognized eight primary dimensions that this system holds in balance; Expectation-Actuality; Rage-Fear; Fight-Flight; Tension-Relaxation; Pain-Pleasure; Warding Off-Participating; Self Asserting-Self Transcending; Instability-Stability. These intertwined emotional states are normally mutually restraining and complementary, like Rage and Fight, but can reverse-poll thus causing psychological and social pathologies.

As a learning mechanism, the emotional brain provides the ultimate feedback system. All Artificial Intelligence models have one thing in common, a primary feedback system to provide learning signals. Sometimes, these signals come from computational methods and sometimes the end user provides them. In the primate and human mind, this signal is provided by the emotional responses installed as a hereditary component of the brain. Responses for hot & cold, hunger & sick, attachment & threat always provide an emotional response for our brains to use as a learning attribute.

## Learning Paradigms

Psychologically, or inherently, animals possess the ability to organize and adapt information to suite some purpose. These invariant functions provide the overall ability to learn and survive in our environments. Hull, Pavlov, Skinner, Thorpe and Watson have all contributed and argued about the brain's learning mechanisms. Although contested, this plethora of great minds has provided some insights into how the brain learns and what methods are used. W.H. Thorpe defined learning as a simple framework of the adaptation of individual behavior as a result of experience. As he developed his theories, he defined six categories of learning that provide an excellent framework to discuss the inner working of the brain's learning mechanism.

***Habituation***, learning what not to do, is perhaps the simplest form of learning. Habituation involves the loss of responses over time due to lack of reinforcement. As the brain learns, it builds a response network for different stimuli. If a response lacks some form of reward, i.e. feeding reflex and the stimulation of the satiety center of the hypothalamus, they weaken and become functionally irrelevant in the response system. As C.J. Barnard suggests, the time and energy costs to respond to any and all stimulus is prohibitive thus the body learns to only respond to the rewarding or cost effective stimuli.

***Classical Conditioning***, or Pavlovian conditioning, is the associative learning method of the brain. Pavlov explained this phenomenon with great detail has he wrote and discussed his historically important dog experiment using food and a bell. The experiment clearly showed that the dogs, after being subject to food and a bell ring over time, eventually learned to expect food when only the bell was rung.

***Operant Conditioning***, or Trail-and-Error learning, is the discovery of responses when no clear response is initially obvious. For example, when an animal is searching for food, it performs a variety of responses. If it succeeds in finding food in a particular location over multiple feedings, it will associate the location with food thus providing a sense of direction for the next time its hungry. Central to this concept as well as Classical Conditioning is reinforcement. As the animal learns, it encounters positive and negative reinforcement through emotional responses. This stimuli is interpreted and used to strengthen or weaken a set of responses, and as time goes by, begins to build definitive and separate response networks for stimuli.

***Latent Learning***, learning without patent reward, is a complex form of learning because of its implied functionality. Rats are said to display latent learning capability when they learn a maze. Since the rat does not get an immediate reward when it turns a corner or moves straight through the maze, and only gets rewarded if and when it finds the food, there must be some spatial & temporal causation. Research showed that once rats learned the maze, making some form of a mental map, they demonstrated the ability to access the learned map and use it to efficiently locate food.

***Insight Learning***, the process of reasoning, is arguably the most advanced form of learning. This form of learning is said to occur when decisions are made too rapidly, not allowing enough time for the trail-and-error style learning method. Examples of this method are illustrated by the rat finding shortcuts through newly provided doors in a maze, or by chimpanzees building stacks of boxes to get to bananas hung from above.

***Imprinting***, the last of Thorpes methods, is the narrowing of the range of stimulus which social orientation is managed. This can be explained as an innate tolerance for different classes of stimuli that is compatible with the animal. Here, we find neonatal attachments and courtship. An example of imprinting can be found in birds illustrating naïve preferences for objects with certain characteristics like color, shape and motion. This is also seen in newly hatched ducklings imprinting on the first big living thing as mom. But the most fascinating aspect of this mechanism is the timely institution of a particular preference over the course of the animal's development. Humans demonstrate these 'critical periods' as they develop from neonatal to early childhood, through juvenile to adult hood.

## Functional Theories of the Brain

For as many researchers who have worked on neuroscience, psychology and physiology, we have a theory on how the brain works. People like Plato to Piaget, LeDoux to Baars have all contributed to the conjecture. Before any real conclusions can be made about how the brain works, we must recognize that the animal brain has some inherent functional properties that could shed some light on its operation. The most obvious of these inherent properties is the reliance on Cognition. Cognition, which annexes perception, attention, emotion, planning and action, learning and memory, thinking and communicating, is the overall process of the brain that makes the whole system function in all its splendor. Using attention as the fuel, Cognition drives thoughts and reactions based on incoming information. As attention is 'tuned-in' to the information, and as emotions are gathered, the learning processes key in and build memories and associations.

Descartes' Cartesian Dualism theory is based upon a mind-body relationship of differing but interacting substances. The mind, the thoughts and emotional meanings, can act upon and be affected by the physical stimulus and processes of the body. This substance relationship theory suggests that the information normally labeled as thoughts are not just physical signals transmitting over neural pathways but more like magnetic waves of signals. These waves can then combine to affect the physical brain processes. Finally, the concept of Unconsciousness and Consciousness need to be explained in the brain. At best, these labels are ambiguous but shed some light on some obvious facts. Some responses and actions occur well below our awareness level while others tend to force our attention. These facts suggest that as the brain learns to pay attention to the more meaningful aspects of our environment, ignoring the less relevant information.

## Summary & Conclusions

Heredity, that that is instilled via some sort of transfer mechanism, is the process by which habits and preferences are imprinted from parent to child. This, heredity plays out in our need responses and emotional responses. Needs, the structures that provides feeding, defensive, language and even cognitive skills, initially provides the animals with survival skills and continues to affect daily life throughout the life span of the animal. Emotions, the indication of good and bad, are the primary source of feedback that is used to measure any learned stimuli or response.

A thorough study of epistemology clearly shows the presence of the invariant organization & adaptation functions. These functions, broken into several mechanisms, provide a stable and effective means for learning in animals. Conditioning, like Pavlovian or Operant, provide the basic rudimentary learning that builds stimulus-response pairs and associative networks. As the neural networks develop more advance learning processes, like Latent & Insight learning, start to use the learned knowledge to provide causation. Here we find the beginnings of Foresight, Hindsight and possibly imagination. All the while these mechanisms are developing the networks, our innate attitudes and preferences guide us to optimal Psychological states.

The Oxford Companion to the Mind defines Cognition as "The use or handling of knowledge" that uses knowledge-based processes to make sense of the "neurally-coded" information. Encompassing sub processes like attention, memory and learning, cognition is not an individual part but the whole that encapsulates and characterizes its mission. Thus, cognition can be defined as the processing of a time-series of thoughts and reactions that produce some result. The result, possibly having no distinction of intelligence, is based on the experiences of the host. As cognition works building experiences, Self establishes within the knowledge base and causes a separation between the neural substance of the body and the knowledge base of the mind.

In conclusion, the AI industry must make a concerted effort to understand the complexities and properties of the animal brain. As the brief review of the brain illustrates, Neural Network architectures are more complex than implemented in practice. Also, intelligence is rooted not only by the processes of a 3-brain system but includes heredity and its interaction with the said processes. Understanding the brain will provide a road map to intelligence, but will also confirm that intelligence is not even a guaranteed product of the brain. Therefore, we must concede that intelligence is not the product of the brain but the product of the process of the brain. Hence, correct knowledge and good experience is a fundamental requirement for true intelligent behavior.

## Resources & Links

C.J. Barnard. (1983). Animal Behavior: Ecology and Evolution, Wiley-Interscience Publication

Dictionary of Philosophy of Mind, Chris Eliasmith (Ed.)

Hampden-Turner, Charles. (1981). Maps of the Mind. Mitchell Beazley Publishers, Ltd., London; Macmillan Publishing Co., New York.

LeDoux, Joseph. (1996). The Emotional Brain: the Mysterious Underpinnings of Emotional Life. Simon & Schuster, New York.

The Oxford Companion to The Mind, (1987), Oxford University Press

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