A Neuronal Model for Memory and Learning

Human behavior as observed by one human A looking and listening to another B results from the movement of the voluntary muscles of B. The muscle movements may be of the arms, hands, legs etc. or of the lips, tongue, larynx etc. The question to be answered is; How does the brain generate the electrical signals to the voluntary muscles so that the muscles move and exhibit learned behavior?
The brain is an electrical organ. Its inputs from the sensory and stretch receptor cells are electrical and its outputs to the voluntary muscles are electrical. How does the brain modulate the input signal into the output signal that causes the voluntary muscles to contract and thereby exhibit human behavior?

The sensory nerve impulses generated by the sensory nerves of the head are directly routed by the cranial nerves to the upper brain stem. The sensory nerve impulses generated by the sensory nerves of the neck, torso, arms and legs are directly routed by the peripheral nerves to the spinal nerves and to the upper brain stem. Thus all sensory nerve impulses on a millisecond by millisecond basis are routed to the upper brain stem. From the upper brain stem the sensory nerve impulses travel through the limbic brain (The White Matter) and are modulated by one's memory and routed to the cells of the middle frontal and precentral gyrus. From the middle frontal and precentral gyrus via hard-wired nerves, the signal travels to the voluntary muscles and cause them to contract. This contraction is what is called, human behavior. Stretch receptors on the voluntary muscles are caused to fire generating an fm signal that via hard wired nerves make there way either by cranial nerves or by peripheral and spinal nerves to the upper brain stem thus providing an input signal for the continuance of the memory trace.

What one's memory is, (The engram) and how memory modulates and routes the signals from the upper brain stem to the middle frontal and precentral gyrus is the subject of this paper.

Consider the following situation. A harpsichordist walks on stage, sits down and plays Scarlatti's harpsichord sonata No. 422 . If one imagines just the skeleton of the harpsichordist's hands moving, what is seen are the bones of the hand moving in a very coordinated manner, striking the keys and creating the sound one calls harpsichord sonata No. 422. The skeleton of course is inert, it cannot move by itself. It is caused to be moved by the muscles of the hand, attached to the bones of the hand, expanding and contracting in pairs. The muscles are caused to contract by nerve impulses originating in the brain which travel down the efferent nerves to the spinal cord, then to the nerves of the arm, then hand, and finally to the muscles of the fingers. It is the physical characteristics of this nerve impulse which determines both the instant at which a given muscle fiber contracts and the strength of the contraction. Therefore in so far as sonata 422 is caused by the expansion and contraction of pairs of muscles of the hand, and as the expansion and contraction is caused by nerve impulses from the brain and as the brain is the seat or creator of the impulses, then in order to understand how man can play sonata 422 one must analyze how the brain creates the train of nerve impulses resulting in sonata 422.

Once this process is known, in principle it will be applicable to any given learned behavior pattern in order to reduce it to the neuro physical mechanisms that result in the given behavior pattern; Be it a mathematician writing down the definition of the derivative of a function or a baseball player fielding a fly ball.

The brain of man when viewed as an organ system is unlike any other organ system in one's body. In normal healthy men, all hearts, lungs, livers and so on, have more or less the same appearance and perform identical functions on both the macro and microscopic level. The brain on the other hand while appearing more or less the same from healthy individual to healthy individual, performs markedly differently from individual to individual.

If one sits in turn identical twins before a harpsichord, one of whom knows how to play sonata 422 and the other of whom does not; One is forced to conclude that in spite of the similarities, there is a physical difference between the two brains of the identical twins. What is the difference?

In the late fifties and early sixties it was assumed that the DNA molecule, would prove to be the storehouse of learned information, just as it had proved to be the storehouse of genetic information. Under this view the base sequences in the DNA molecules in the brains of the twins would be the physical difference in the brains of the twins and this difference would presumably be caused by the fact that one twin practiced the harpsichord while the other did not.

The view that DNA stores learned information is no longer held in favor and one of the arguments posted against it is that it takes on the order of one to ten minutes for its base sequences to be translated into an average size protein. This means that no information stored in the molecule can be retrieved in less than one minute, however information can be retrieved from the brain in less than one second. For example, one can begin to answer the question "What is your name?", in less than one second after the completion of the question. Therefore it is impossible for DNA to be the storehouse of learned information.

Parenthetically, it is believed however that DNA is the storehouse of innate behavior. Many invertebrates and vertebrates are abandoned by their parents as eggs; land snails and leopard frogs for example. These animals use innate motor programs genetically coded for by DNA to obtain food and move about. In this case, the DNA encodes the information to properly connect during embryogenesis, glial cell to glial cell, glial cell to nerve cell, and nerve cell to nerve cell so that innate behavior occurs.

Returning to the question as to what the brain stores as learned information, the hypothesis is made that what the brain stores as learned information, (Called the memory trace or engram) are electrical pulses similar to but of smaller voltage (~1/100Volt) than the action potentials generated by the sensory neurons of the body. These pulses are hypothesized to be stored within the proteinacious tube system of the glial cells in closed, genetically determined circuits. That is the tubes, connecting glial cell to glial cell, contain molecules that carry the stored electrical energy from glial cell to glial cell in a closed loop. These circuits are here called codons.

Further it is hypothesized that each glial cell is functionally connected to the nerve cells to which it is in physical contact by tubes, going from the glial cell, through a dendrite, and terminating on the neural cell axon hillock. The codons are individual circuits of glial cells with the ability to preserve within an individual circuit, the action potentials presented to it by the sensory nerve cells of the body. The action potentials have an DeltaE~70mV. The stored glial cell potentials are hypothesized to have a DeltaE≤10mV.

The function of the codon is to:

1. Store as mini action potentials the action potentials generated by the sensory nerve cells of the body. Which action potentials are stored and which are not is presumably dependent on how many times the action potentials are presented to the glial cells.

2. Modulate the action potential output of the nerve cells to which the individual glial cells of a given codon are functionally connected.

In accordance with this view the stored electric pulses in the brains of the twins are not the same. The set of stored electric pulses representing sonata 422 is present in one twin and not in the other twin. How do the stored electric pulses determine human behavior and in particular how do the stored electric pulses determine the playing of sonata 422? In order to answer the question, two further ideas central to the model are presented.

A.

On each muscle cell of the body there is a specialized nerve cell called a stretch receptor cell whose function is to send to the brain, action potentials whose frequency and duration are a function of the degree of tension the muscle cell is creating. By monitoring the stretch receptors of the hand for example, the brain can determine the position of the hand with respect to the body. Thus even with one's eyes closed, one can verbally state the position of one's hand with respect to one's body. At any instant, the total of all the signals generated by all the stretch receptors tell the brain the position of every muscle fiber in the body with respect to one another.

B.

Every neuron, (here called a motor neuron), located in the motor area of the brain, the middle frontal and precentral gyrus, is connected by a nerve fiber to a voluntary muscle cell. The connections between the motor neurons in the central sulcus and their associated voluntary muscle cell, are genetically determined. When a motor neuron in the middle frontal or precentral gyrus is caused to be fired, the resulting impulse travels down the afore mentioned nerve fiber to a muscle fiber and causes the muscle fiber to contract. Thus if one could cause the proper motor neurons in the middle frontal or precentral gyrus to fire in the right sequence and of the proper duration, one could elicit any sequence of desired muscle contractions. And in so far as normal human behavior is a well-defined set of muscle contractions in proper order and timing, then by causing the proper motor neurons in the middle frontal or precentral gyrus to fire in proper sequence, one could elicit any desired behavior pattern. The primary question to be answered is; How does the brain cause its own middle frontal or precentral gyrus neurons to fire in patterns that produce observed behavior?

Consider two people talking to one another. the first asks the second, "What is your name?", and the second replies, "My name is Ernest P. Jones". How does Jones' brain fire the correct motor neurons connected to the muscles of the lips, tongue, throat, larynx and diaphragm and do so in proper sequence and timing so that the muscles of the lips, tongue, throat, larynx and diaphragm contract properly to produce the words "Ernest P. Jones". What triggered off Jone's reply, were the words "What is your name?". The sensory neurons of the ear convert these words into a f.m. signal that is unique to the words "What is your name?". Thus the input to the brain is an electric signal that is unique to the external stimulus and in this case is the output of the sensory auditory neurons. If the brain could guide and modulate this input signal so that the modulated input signal would fire the correct motor neurons in proper sequence and timing, then the brain in and of itself would be producing the correct nerve signals to fire the correct motor neurons which in turn produce the correct response, "My name is Ernest P. Jones".

How might the brain accomplish this? Consider the analogous problem of how an electrical connection between phone #1 and phone #2 is made when one picks up the receiver on phone #1 and dials the phone number of phone #2. As each digit is dialed, an electric signal is generated that is unique to that digit and consequently a signal unique to the given dialed number is generate when the entire number is dialed.

The phone system is designed so that it is the electrical characteristics of the signal generated by dialing that determine the signal's pathway through the phone system. The characteristics of the signal generated by dialing phone #1 operate a system of solenoid switches in older phone systems and solid state switches in more modern systems, whose switch position or state determine which path the electric signal shall take. Thus when one dials the number 532-1645, the resulting electric signal, unique to the number 532-1645, open and close the proper solid state switches thus completing, out of all the worlds telephones, the circuit to the phone in one's code area, whose number is 532-1645.

Imagine now that the hypothesized codons in the human brain behave like the solid-state switches in the phone system. That is, the unique train of action potentials generated by each auditory neuron in response to the words "What is your name?" are modulated and routed by glial cells to one of the muscle fibers responsible for producing speech. The net effect is that the total signal generated by the auditory neurons is frequency modulated and routed by the stored signal in the glial cell "Auditory Codons" to those motor neurons connected to the muscles of the lips, tongue, throat, larynx and diaphragm and cause those neurons to fire in correct sequence to cause the muscles of the lips, tongue, throat, larynx and diaphragm to move and produce the sounds "My name is Ernest P. Jones".

Consider now the analysis of the twin who knows how to play sonata 422. The analysis must begin somewhere so let it begin with the playing of the first chord. The resulting chord is transformed by the auditory neurons into an electric signal unique to the first chord. The stretch receptors of the arms and hands also generate a signal that is unique to the first chord. The output of the auditory neurons and stretch receptors of the arms and hands, whose stimulus was the first chord, is therefore the input signal to the brain. This input signal is modulated and routed by the glial cells, in direct contact with the nerve cells of the auditory nerve and those nerve cells that connect the stretch receptors with the brain, to produce a signal that is routed to the motor neurons of the middle frontal or precentral gyrus that directly control the tension in the muscle fibers of the hands. The modulated signal causes those motor neurons to fire and contract the muscles of the hand to produce the second chord.

The resulting chord is transformed by the auditory neurons into an electric signal unique to the second chord. The stretch receptors of the arms and hands also generate a signal that is unique to the second chord. The output of the auditory neurons and stretch receptors of the arms and hands, whose stimulus was the second chord, is therefore the input signal to the brain. This input signal is modulated and routed by the glial cells, in direct contact with the nerve cells of the auditory nerve and those nerve cells that connect the stretch receptors with the brain, to produce a signal that is routed to the motor neurons of the middle frontal or precentral gyrus that directly control the tension in the muscle fibers of the hands. The modulated signal causes those motor neurons to fire and contract the muscles of the hand to produce the third chord and so on to the completion of the piece.

The details of this model have yet to be experimentally tested, yet the implications of the model are of interest in the quest to find the neurobiological correlates of human behavior. First of all it is an electrical model. The brain's physical connection and knowledge of the external world is by electrical signals generated by the sensory nerve cells of the body in response to physical stimuli, light, sound, tactile stimulation etc., generated by the external world. The input signals to the brain, which are the sum total of the action potentials generated by the sensory and stretch receptor cells of the body, are hypothesized to be modulated by the stored electric signals of the glial cell codons, modulating the input signal into an output signal that is routed to the muscles of the body. The output signal is the direct cause of muscle contractions and muscle contractions are what are observed and called human behavior.

The permanently stored signal is being constantly added to as one enlarges one's experiential world. Thus one's entire life history is contained within the codons and one's entire life history determines on a millisecond-by-millisecond basis one's behavior. In this sense one can say that human behavior is integrative, that is, on a millisecond-by-millisecond basis human behavior is dependent on the sum total of one's stored sensory world experience.

Second, there are two types of behavior, learned behavior and innate or instinctive behavior. The glial cell codons used in learned behavior patterns are hypothesized to store electric signals generated by the sensory neurons of the body and presumably contain little or no information at birth.

The codons used in innate or instinctive behavior are hypothesized not to store electric signals generated by the sensory neurons but are hypothesized to store electric signals whose electrical characteristics are genetically determined by DNA. Both types of codons however are hypothesized to frequency modulate and route, the action potentials from the sensory neurons to the motor neurons causing them to fire in correct sequence and timing to cause a coordinated muscle contraction.

Third, learning at the neuronal level consists of adding or deleting stored electric signals so that the resultant stored electric signals represent the learned act. Which incoming signals are stored as long-term memory and which are not is a function of number of repetitions of the external event causing the long-term memory of the event and also of the importance of the event to the human organism. The importance of an event occurring at time t is a function of, depends upon, the stored electric signals comprising one's long-term memory formed before time t.

Fourth, the model strongly implies that if a molecular drug modifies human behavior, it must modify the firing order of the motor neurons that control the given behavior. If the drug modified behavior is coordinated and well oriented with respect to the external world, the drug must modify the firing order in a non random way so that the resulting behavior is also non random.

Fifth, this is a reductionist model in that human behavior including human intellectual behavior is reduced to the neuronal action potentials that directly cause muscles to move. The action potentials that directly cause muscles to move at time t, are the result of the action potential out puts of the sensory nerves of the body at some time $t_1 < t$.

This reductionist process I believe can be applied to all learned human behavior from bicycle riding to reading to mathematics to the creation of this model for human behavior.

Summary of Neuronal Model for Memory

The external world is made known to the brain as a series of fm electric signals generated by the sensory nerves of the body. The sensory nerve impulses generated by the sensory nerves of the head are directly routed by the cranial nerves to the upper brain stem and the sensory nerve impulses generated by the sensory nerves of the neck, torso, arms and legs are directly routed by the peripheral nerves to the spinal nerves and to the upper brain stem. Thus all sensory nerve impulses are routed to the upper brain stem. From the upper brain stem the sensory nerve impulses travel through the limbic brain (The White Matter) and are modulated by the stored electric signals (The memory engram) in the glial cells of the limbic brain into a signal that is routed again by the stored electric signal (The memory engram) in the glial cells of the limbic brain to the cells of the cortex (The gray matter). There the signal is further modulated and routed by signals stored in the glial cells of the cortex to the cells of the middle frontal or precentral gyrus. From the middle frontal or precentral gyrus via hard wired nerves, the signal travels to the voluntary muscles and causes them to contract. This contraction is what is called, human behavior. Stretch receptors on the voluntary muscles are caused to fire generating an fm signal that via hard wired nerves make there way either by cranial nerves or by peripheral and spinal nerves to the upper brain stem thus providing an input signal for the continuance of the memory trace.

It should be remembered that in order for any idea to be communicated from one human to another, no matter how complex, that idea must result in creation of an fm signal generated by the brain and sent to the voluntary muscles. In particular the entire body of human knowledge including mathematics and physics is stored in the brain as an fm signal and in order to be communicated, the entire body of human knowledge including mathematics and physics results in an fm signal that is routed to the voluntary muscles causing them to move and thereby communicating ideas. Thus ideas or knowledge are the result of muscle movement.

End of Model

Post Script

I first started studying neurobiology during fall quarter 1972 at the University of California at Berkeley. At that time the electron pictograph of a synapse that stands out clearly in my mind, is of a synapse with tubes going from the presynaptic neuron to the postsynaptic neuron looking very much like a tight junction. I conjectured that the electric current was confined to the interior of the tubes. Shortly thereafter, no further pictographs were published showing tubes crossing the synaptic divide between nerve cells. I was informed by several neurobiological researchers, that electron microscopists in an effort to remove a background haze, had discovered that RNase removed the background haze.

My hypotheses are:

1. The tubes have a component that is decomposed by RNase and consequently that the tubes are decomposed on addition of RNase and no longer make an electron pictographic image. The tubes presumably therefore have a component composed of RNA.

2. The electric current in ALL synapses is carried in tubes whose origin is in the neuronal axon, thence across the synaptic cleft from the presynaptic neuron to the postsynaptic neuron.

3. The individual tubes travel from the postsynaptic neuron, through the cell body and end on the axon hillock. If enough of the tubes converging on an axon hillock from neighboring nerve and glial cells, cause an integrated voltage pulse above threshold at the axon hillock at time t, the axon hillock fires at time t and the current is passed along in tubes down and through the axon, through a synapse to the axon hillock of a neighboring nerve cell and so on…

4. The axon hillock is the voltage integrative component of the nerve that determines whether or not a nerve cell fires at time t. The synapse is simply a conduit that conveys a voltage pulse from the pre synaptic to the postsynaptic nerve cell.

5. The synaptic vesicles that are believed to contain the neurotransmitter, (Acetylcholine etc.) are hypothesized to be the remnants of cross section of tubules after the addition of RNase.

6. The neurotransmitter is hypothesized to be in the tube system and is the molecule that actually conveys the voltage pulse from nerve cell to nerve cell.

It is within the context of these hypotheses, that I have developed the model given above for memory and learning.

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