# Human Memory and Creativity

**Hangjiong Chen**

## 1. Introduction

The human brain and the spinal cord make up the central nervous system (CNS), and the brain is the least understood part of the human body. The basic functional unit of the nervous system is the nerve cells, known as neurons, and there are about 80-100 billion neurons in the brain alone. The neuron is morphologically unique and it produces and propagates electrochemical signals over distances to other neurons in the central and peripheral nervous systems via releasing and receiving neurotransmitters. The brain exerts centralized control on many of the physiological activities of the body and is responsible for processing, integrating, and coordinating signals acquired from the surroundings for cognitive activities of perception, movement, thought, memory, decision-making, and etc. The brain is organized into different functional areas, each of which serves its own unique functions.

Nearly all neurons in the nervous system have three main components, dendrites, a cell body, and an axon, though the actual morphology of a neuron varies depending on its roles and tissue location. Neurotransmitters are special type of chemicals that are produced and released into the synapses by neurons. The dendrites of a neuron receive neurotransmitters released by the axon terminals of pre-synaptic neurons and generate electric signals in response. The cell body of a neuron is responsible for maintaining the cell structure and producing energy needed for all neural functions and activities. The axon of a neuron is a thin fiber protruded from the cell body and can extend a distance from short to enormously long. An axon ends up at the dendrites of other neurons in the peripheral or central brain. The axon conducts electric signals initiated at the dendrites to its terminals, where the electric signals are converted into chemical signals again by releasing neurotransmitters into the synapses. In this way a neuron propagates the electric signals to its post-synaptic neurons. Conversion and transmission of electrochemical signals from one neuron to others are the basic biochemical processes that fulfill numerous fascinating nervous functions essential to animal life.

The inside of a resting neuron body carries negative charges, typically a cross membrane potential of −70 mV, relative to the positively charged outside. Gaining positive charges inside of a neuron is the process of depolarization. A synaptic input of either external stimuli or neurotransmitters allows influx of cations into the cell, raising the membrane potential to approximately −55 mV. −55 mV is the threshold potential for signal propagation. If the depolarization continues, the membrane potential rises rapidly beyond the threshold potential and peaks at +40 mV. This peak membrane potential lasts only a short period, quickly polarizing to around −90 mV. The neuron finally returns to the resting potential of −70 mV, the opposite of depolarization. The refractory period is the time spent between −90 mV and −70 mV, during which the neuron loses its responsiveness to new stimuli. An action potential is the rapid rise and fall of the cross membrane potential from the resting -70 mV to peak +40 mV, then back to resting −70 mV, or simply depolarization followed by polarization. A neuron fires and propagates electric signals mainly through action potentials down the axons.

Dendrites are tree-like projections and the end of an axon is also quite branched with many terminals, making one neuron possibly have synaptic connections with a large number of neighboring neurons. Such a highly intertwined neuron-neuron connectivity together with the complicated neurotransmitter and receptor system makes almost endless function possibilities for the brain, and in the meantime it poses daunting challenges and difficulties for the research scientists to develop laboratory methodologies and design experiments in quest of the true workings of the brain.

Despite many decades of intensive studies worldwide, our understanding of the brain is still limited. In a high level computer language, the programming logic are expressed in syntax in the form of common English words, which has the advantage to shield away the extreme complexities in direct dealing with the low level computer code and hardware. With similar approaches, here I set aside the underlying complicated connectivity and details of message generations and transmission between individual nerve cells, instead try to shed light on the mystery of the brain from the point of high level phenotypes of nervous system with an emphasis on human memory and creativity.

## 2. Major Challenges in Brain Research

We must recognize the uniqueness of the nervous system. The nervous system differs from all other parts of a higher animal in a critical way. Take liver as an example. Liver consists of billions of liver cells, whose major biochemical activities have been illustrated quite well. On the organ level, what the liver does is not much more than what an individual liver cell does. As a matter of fact, the liver is simply an organ that provides a home to these billions of liver cells in which they can busily perform their tasks harmoniously. In another word, the liver is simply an aggregate of all liver cells and its phenotype is largely identical to the phenotype of an individual liver cell. Do we feel anything about the liver in our body? No, not at all under healthy condition.

By contrast, although all major biochemical activities, especially trans-membrane ion movements occurring in an individual nerve cell, have been illustrated quite well, what the nervous system does as a whole seems totally irrelevant to what an individual nerve cell does. A single neuron can't be extrapolated to draw a picture on a larger scale involving millions of neurons. The nervous system, in terms of high level phenotype, is not simply the aggregate of all individual nerve cells that compose the nervous system. This is true especially for the central nervous system. It's the collective actions of many individual nerve cells that confer us such an astonishing state of mental awareness about everything around us and about ourselves.

There are no clear functional correlations between biochemical activity patterns of individual nerve cells and the high level phenotype of the system which these nerve cells belong to. Excitatory signals can be easily turned into inhibitory signals in their transmission, and vice versa. Highly interwoven connections between individual nerve cells also make it very hard to identify the roles of individual nerve cells played in a phenotype that is of interest to researchers. In addition, all nerve cells behave seemingly quite similar in production of electric signals in responses to internal or external stimuli, but the functional phenotypes of individual zones in the peripheral and central systems are never even similar. Consequently, any over-interpretations and extrapolation of experimental data obtained from individual nerve cells are meaningless, reckless, and even detrimental to the advance of neuroscience. Taking all these into consideration, it would be the best approach to paint a picture of how the central nervous system works at high levels without thinking too much of what occurs in individual nerve cells. At high levels that something is happening to neurons is more meaningful than what is happening in neurons, and that neurons in different functional zones are interconnected in some mysterious way is more meaningful that how neurons in different functional zones are interconnected in such an intricate way. With this in mind, I have tried to conjure up nerve memory about its creation, maintenance and roles in human cognitive activity, especially in human creativity.

To normal people, memory is their innate ability to recollect the past experiences, recognize things they have encountered before, and is taken for granted. But to research scientists, the human memory is as mysterious as the brain itself and is a research subject as daunting as brain research itself. Just like neuroscience research in general, the difficulties come as a single neuron can't achieve memory, but millions of them must connect to each other and work together to achieve memory. As a result, progress in memory research is slow.

Over the years, a modern computer is often used as an analogue of human memory, from which it is concluded that human memory also involves steps to encode, store, and retrieve or recall information collected from sensory organs in the past. However, the cellular organization of neurons that makes up the central nervous system can't provide any possibilities that the information from the sensory organs are encoded and stored in the brain tissues to form long term memory. If the information is stored in the brain in certain ways, is it stored in some special materials? As a matter of fact, researchers didn't find any special chemical components in the brain that could be potentially used to store data. The biological system must have developed its own mechanisms to create and maintain memory.

**3. How Much Information Does Our Brain Retain for Memory?**

First what is memory? Regardless of being dissimilar to any human products, our brain must store a certain amount of information as memory in order to recognize or recall, although the word "store" here doesn't have the meaning used in computer science or our daily routine to stock something in some storage places. How much information must be stored as memory and considered as sufficient? Memory is the information stored for something and can be retrieved to restore the original thing in the brain without input from external sources. There are two ways to help us to estimate the minimum amount of information that the brain retains and that can be regarded as memory.

If I close my eyes to recall a high school classmate, whom I haven't met for nearly 40 years, I can project his face in my mind. Although the face isn't clear in any sense, but is good enough to be recognized as his. Experiences tell us that the face image projected in the mind is recognizable but not very clear and lacks details, no matter the face is from our spouse or children whom we live together every day or someone we haven't seen for a long time. This suggests that the amount of information retained in the brain about an object is just enough to project a barely recognizable image of that object, and the image is sufficient to allow us to recognize it unambiguously when we see it in the real world.

Similar to image projection, what we see in a dream is also fuzzy and barely recognizable. If the live image in the dream was known to the dreamer, it's certain that the image was formed using information retained in the brain from the original source. The image was live because the dreaming was like playing a movie, despite the scene or persons in the dream either familiar or totally strange. The appearance of totally unknown images in the dream suggests a fundamental nervous activity that underlines the human thinking process.

For the convenience of discussion, any physical or chemical stimuli from the external world acting on the peripherals are described under an umbrella name "reality". A visual scene is a visual reality to the visual system, and a noise is an auditory reality to the hearing system, and so on. In this sense, a real person, a real animal, a real sense, a real sound, a real smell, a real taste, and etc, are all realities and different from what we project about them in the brain without external input.

Dreaming and image projection in the brain imply that the amount of information the brain retains about a reality as long term memory is neither abundant nor accurate. Nevertheless, the reality recognition by the brain based on limited amount of information the brain retains about that reality is exceptionally quick and accurate. Mother nature has developed a mechanism that isn't present in any man-made products to achieve such an extraordinary capability.

## 4. Focused Mental Activities and Focused Processing Space or FPS

The human brain is multi-threaded to process a large number of nervous activities simultaneously, but its ability to think is single threaded. When we read or pay close attention to a reality that we are interested in, we are focusing our mind on that reality and ignoring what is happening around us. More intensely we focus on the reality, more unknowingly we ignore something else, a mental state described as an absent minded state. Experiences tell us that we can focus only on one thing, not two or more things. Therefore, when we are engaged in a mental activity, such as reasoning, recalling a past event, solving a problem, projecting a familiar face, or a scene, or a sound, reading or listening attentively, and so on, we forget about other things. It implies that our brain contains only a single area that allows our mental activity to focus on one thing, and one thing only. Such a focused brain function is called focused mental activity.

The human brain anatomically is divided into three main parts: the forebrain, midbrain and hindbrain, each of which has its roles in brain functions. Forebrain, also known as the cerebrum or cerebral cortex, is the largest of three, and composed of four lobes, frontal lobe, parietal lobe, occipital lobe, and temporal lobe. Each of these lobes is known to be associated with specific functions ranging from higher-order thinking, visual and auditory perceptions, language, memory, to reasoning and others. Although we do not yet know which part of the brain is engaged in focused mental activities, it is believed to reside somewhere in the forebrain.

Nevertheless, we could make a rough guess where the focused mental activities occur in the forebrain. Again if you close your eyes and project the face of someone you know, and try to see where the face appears in your mind, you would see the face above the left-center top of your brain. Similarly if you play a song in your mind , you hear the sound appearing in the same place as the projected face. Anatomically this place is right within the range from the frontal lobe to the parietal lobe, and functionally we have reasons to believe that this is the place that houses the focused processing space or FPS for all focused mental activities to take place.

## 5. The Neuron Signaling Chains and Reality Representation

Let's try to understand how the perception could occur using visual perception as an example. The visual signal transmission could be viewed as a signaling chain. The photoreceptors receive light stimulation and transform the light energy into nervous impulses along the visual signal transformation pathway, which consists of photoreceptors, bipolar cells, and ganglion cells. The visual signals then enter the central nervous system via optical nerves made of ganglion cell axons. What happens next to the visual signals becomes a mystery once they enter the central nervous system.

If our eye is given a very brief exposure of light, our brain experiences a correspondingly very brief perception of the visual scene. This implies that there is an end destination area in the occipital lobe where the movement of visual signals stops and disappears after the brief visual perception occurs. Since the nerve connections are fixed in a developed brain, the signals generated by a given photoreceptor always end up at the same fixed neuron or fixed group of neurons in the occipital lobe. These end neurons are the final destination of the original signals. Such a nerve signaling path makes up the neuron signaling chain, and the end neurons of the chain are effect neurons, representing that fixed and stimulated photoreceptor of the retina, the origin of the visual signals, in the central nervous system. The effect neurons are the central neurons that decipher the nervous signals back into the external realities and allow the brain to perceive the external world. The visual signaling chain stops once consumed in visual perception. Therefore, the signals generated in the sensory organs are transmitted via neuron signaling chains to their corresponding pre-wired effect neurons in the central brain, where they are perceived as what they are in the external world. Simply put, there is one to one correspondence between nerve cells in the peripheral and nerve cells in the central brain wired together through fixed neuron signaling chains.

The retina is a curved surface on which there are embedded millions of photoreceptors to accept light energy for visual perception. Correspondingly, there must exist similar number of effect neurons in the occipital lobe. These effect neurons are arranged in space in such a way that represents precisely the external light stimuli or external reality intercepted by the photoreceptors. This must be true for all external realities. The effect neuron representation of an external reality is called reality representation or R representation, and the area associated with R representation in the central brain is the R locus.

Since the neuron signaling chains are fixed from the peripheral nerve terminals to their corresponding effect neurons in the central brain, and there are all types of peripherals in the body that respond to different types of external stimuli and have their neuron signaling chains ended in the brain, it's expected that there are a number of R loci located in different brain lobes where each type of external reality will be represented for perception. R representation based perception is R perception or external perception as what is perceived are realities from outside of the central brain. The perception of reality through R representation is the first and also the most basic function of the central nervous system.

The existence of R loci for R representations is based on the fact that the brain perceives external stimuli or realities at their sources, not within the brain, and the perception is clear and definitive. For example, the pain is perceived at the place where the pain is incurred, and an object is seen at the place where the object exists. By contrast, all focused mental activities take place in the brain and the products of focused mental activities are perceived in the brain as well, and what's perceived is just recognizable, it is fuzzy and like hanging somewhere. Fox example, a projected face is seen in FPS within the brain, and the results of mental calculations are displayed in FPS within the brain as well. It's clear that the perception of external realities occurs in areas that are separated from areas for focused mental activities. Perception that occurs in FPS is the internal perception to distinguish with the R representation based external perception.

## 6. The Focused Processing Space and Abstract Reality Layout

An individual peripheral sensory neuron produces nervous signals in response to an external stimulus and passes the signals to fixed effect neurons at a R locus via a neuron signaling chain, where a R representation is set to represent that particular external stimulus in the central brain. All peripheral sensory neurons that cover the entire reality send the signals to their corresponding effect neurons as a whole at a R locus via a bundle of the neuron signaling chains, where a full R representation, or simply R representation, is formed to represent the entire reality.

When the signals from a R locus enter FPS via fixed dendrite-axon connections, they also form specific representations to represent the external reality in FPS. Differing from R representations, a reality representation in FPS is abstract with possible loss of some signals from the R locus in transmission, and brings an external reality into the central nervous system, where the reality is perceived in the brain, not at its external source. The images formed from such abstract representations are not clear, but recognizable, just as the images that appear in the dream or are projected in FPS. To distinguish with the R representations, a representation in FPS built from a R representation is called an abstract reality layout or AR layout. An AR layout won't take up as many neurons as a R representation does. The R representation in R locus is for precise perception of the external reality at its source, and AR layout based perception that occurs in FPS is fuzzy and lacking details. Hence external perception is actually a R representation based perception, simply R perception, and internal perception is actually an AR layout based perception, simply AR perception. The importance of AR layout is far beyond simple neural responses or internal perception of external realities. It's the foundation of all focused mental activities that are unique to humans, reasoning, thinking, recognition, past event recall, problem solving, decision making, and all others. Establishing AR layouts in FPS through R representation input is the second function of the central nervous system.

The nerve cells in a R locus must have axons or dendrites connected to dendrites or axons of nerve cells in FPS at the boundary. These cross-boundary cell-cell connections determine that an AR layout is essentially an extension of a R representation in FPS. Seemingly not-so-perfect AR perception is necessary because there is a need for such a state of being not-so-perfect. In normal situation, R perception overwhelmingly dominates AR perception, and the AR perception is among all to recognize the external reality in R perception as known or unknown. Otherwise the person would be always occupied by mental activities and fall in a state of absent-mindedness. Transition of the reality from one functional area to another in the central brain is essentially the process of transformation of signal representations from one form to another.

Like the two ends of a neuron signaling chain, the nervous connections between a R locus and FPS are fixed in the developed brain as well with one prominent difference. There is only one single FPS, but many R loci located at different lobes of the forebrain, midbrain and hindbrain, with each individual R locus responsible for representing one of a kind reality nervous signals, for example, hearing or visual or pain. If this is the case, these many R loci must be situated around the singular FPS to have equal access convenience. In theory, in FPS one AR layout built directly from one R locus, for example, visual R locus, could move to anywhere where other AR layouts built directly from other R loci, such as auditory R locus or pain R locus, through the extensive, fixed neuron-neuron interconnections, which of course isn't possible with the isolated neuron signaling chains.

However, past research has established that the occipital lobe is associated with the visual processing and the temporal lobe is associated with the hearing processing. Visual signals aren't different from auditory signals as both signals are electric potential based signals. This suggests that the two lobes must not share common areas for signal processing and storage though visual perception is tightly associated with hearing perception. For example, if we can determine that a voice belongs to a friend, we are able to project this friend's face in the brain. If we recognize a friend in the crowd, we are able to project this friend's voice in the brain as well. This suggests again that there exists an area in the brain that itself is unlikely to receive any signals directly from the external sources or R loci, but is shared by vision, hearing, and other senses for information association. Despite association one signal can't be mixed with other signals. For example, visual AR layouts are still visual AR layouts after association, and hearing AR layouts are still hearing AR layouts after association, and so on. This guarantees that AR layouts from eye are always projected as visual objects, and AR layouts from ears are always projected as auditory sounds, and etc. If we draw a 3-D map for FPS, we must demarcate the space into separate parts as sub-spaces. Each sub-space is responsible for AR layouts from a particular peripheral sensory organ. One sub-space will be a common area to associate AR layouts from different peripherals. Such a division of FPS would guarantee that a given nervous message would be interpreted correctly as what reality it represents despite common trans-membrane electric potential nature.

### 7. Memory and Abstract Reality Record

The reality representations in R loci are responsible for perception of the external reality, but it alone won't be enough as perception without recognition and remembering is meaningless. Perception of the external reality must be associated with memory or what is known. As a step forward, the R representation moves further into FPS to form an abstract reality layout or AR layout. The AR layout is the neural representation of an external reality in FPS and a precursor to memory.

Human mental activities are a controlled process and you must focus on a mental activity to direct its input and perceive its output. In an absent minded state, we don't notice what we see or hear even though what we see or hear is also represented in the R locus. It's hard to think if the R representation doesn't move into the FPS in an absent-minded state, but the R representation must move into the FPS to form abstract reality or AR layout for all sober and focused mental activities. One of the roles of an AR layout is to build a memory for the external reality which this AR layout represents, a routine function of the central nervous system.

AR layouts in FPS are changing dynamically as the external realities change fast. Therefore, any AR layouts exist only transiently. On the other hand, the word "memory" indicates that something remembered must last in time, hence, something in memory must last contrary to transient signal representations in R loci or FPS. In addition, brain-wise neuron interconnections ascertain that FPS has access to areas responsible for memory storage. Much like AR layouts being the extensions of R representations, it could be assumed that an AR layout could extend into the memory area.

A R representation is essentially the mirror image of the external reality in the brain, in which each neuron's electric potential corresponds to a physical or chemical stimulus acting on a peripheral recipient cell. Such a source and destination correlation makes perception of the external reality definite and precise. When an AR layout is formed from a R representation, essentially it is still the mirror image of the external reality except possible loss of some signals. If the AR layout moves into the memory area, it might settle down as a mirror image of the external reality as well. Such a mirror image in memory is the memory record for the external reality, or simply an abstract reality (AR) record. Only R representation at a R locus allows accurate perception of an external reality. Any AR layout based projections are fuzzy, vague, and undetailed.

An AR record should possess at least four important characteristics. First, the record, as stated earlier, must be stable or lasting. Second, the initial neural signals for a new record or existing record must be input into the memory area from FPS. Third, the AR record must be capable of being retrieved as an output into FPS where it will be used to either check an AR layout as known or be fed into focused mental activities. Fourth, an AR record must be extensible to accept new records as new additions to the existing records. The input and output properties of an AR record dictate that each neuron in the record is circuital in terms of neural signal flow. This means that a memory neuron has its axon extending into FPS to form synapses with the dendrites of neurons in FPS. Therefore, an AR record is more appropriate as a set of neural circuits. The memorization is the process of setting up an AR records in the memory area upon exposing to external realities or stimuli.

We could depict a possible picture of perception as we know it. When a car was coming in the distance, it was first represented in R locus and perceived as an object with a look of car. Then this R representation turns into an AR layout in FPS, which further extends into the memory area as an input. If this AR layout already has a mirror AR record in the memory area, the record will generate an output to indicate that the object is a car known to the eye. Otherwise, the car is recognized as an unknown object and FPS will try to establish an AR record for the car in the memory area. As the car gets closer, its R representation contains more details. If there are AR records in the memory area that match R representations of the car with additional brand information, then its brand will be recognized aw well.

**8. Concept Memory and Physical Memory**

Human brain has a huge volume for memory, and no one knows how many things a person remembers in life. Despite of this there are two types of memory regardless of the duration of the memory. One type of memory lets you remember a thing, but you can't replicate that thing in your brain. For example, you know the taste of honey, but you can't reproduce honey taste in your brain. You recognize that you are eating honey only when your taste buds send honey nervous impulses to the central nervous system. You know that the sky is blue in the cloudless day, but you can't project a blue color in your brain. You enjoy the blue sky only when your eyes send blue color nervous impulses to the central nervous system. This type of memory belongs to concept or property memory, because what it remembers is concepts or properties, like color, smell, sound level. Another type of memory allows you not only to remember a thing, but also to project that thing in your brain, for example, someone's face or voice. This type of memory is the physical memory. The physical memory generally results only from the input from visual or auditory sensory organs.

Separation of memory into concept and physical types could help explain why the visual system diverges nervous signals generated by photoreceptor cells into classic action potential based positive channel and hyperpolarization based negative channel. Positive channel conducts nervous signals representing colorless light intensity and negative channel conducts nervous signals representing light wavelength or color. What we project in the mind about any things we have seen is similar to grayish black-white photo pictures which are based on light intensity only. Light-intensity dependent part of the visual image will be remembered as physical memory and can be projected in the mind, while color dependent part of the visual image will be remembered as concept memory and can't be projected in the mind. Similarly, sound that impacts the auditory system is absorbed by two types of hair cells in the inner ear. Inner hair cells are the mechanoreceptors for hearing: they convert sound frequency into electric activity and transmit them into the central nervous system. Outer hair cells serves to represent sound amplitude or loudness in a frequency specific manner. When we play a song in our brain or recall someone's voice, we can only project part of the song or voice that is determined by the sound frequency, not sound loudness. Therefore, frequency dependent part of the sound received by inner hair cells will be remembered as physical memory, and amplitude dependent part of the sound received by outer hair cells will be remembered as concept memory.

There is another fundamental difference between concept memory and physical memory in terms of an AR record. The AR record for physical memory is likely to be a copy of an AR layout of the object in the memory area and is made up with a largely fixed certain number of neurons, the neural basis of image projection in our brain. The projected image has fuzzy bounds which roughly but correctly match the physical shape of the object, which is sufficient for recognizing what the object is. On the other hand, the concept memory represents the properties of an object, which are usually boundless, shapeless, sizeless, and dimensionless. Such properties are unable to exist without attaching to an object, but are able to be attached to any objects of completely different nature. For example, honey taste must be associated with the intake of honey or food mixed with honey and blue color must be appreciated when seeing a blue sky. Nevertheless, honey taste isn't unique to honey, and color blue is everywhere. Therefore, concept memory and physical memory must be processed and stored not only in separate areas, but also in very different ways. It could be assumed that an AR record for the concept memory requires only a small portion of the signals in an AR layout to represent a property, for example, a small portion of signals for the color blue from the entire blue sky. When we see blue sky again, the AR record for the color blue could easily match blue color signals in the AR layout and allow us to recognize the blue color of the sky. For the convenience of discussion, a concept AR record or CAR record is used for the concept memory to distinguish a physical AR record or PAR record for the physical memory. A CAR record must differ from a PAR record on assumption that unlike PAR with a relatively clear boundary for the record, it's a question how many memory neurons are needed to remember a concept like colors or tastes.

Concept memory contributes to a huge amount of human memory and is fundamental to cognitive thinking and human intelligence. The vast knowledge a person has accumulated exists in the brain as concept memory. For example, all abstract things like numeric values and scientific knowledge are remembered as concept memory and stored in memory area as CAR records. The CAR records can be associated with PAR records if they have the chance to be associated with in life. For example, a person remembers the meaning of numeric value 1 as a concept memory before this person learned that 1 is the physicalized form of concept numeric one. Learning allows CAR records for numeric values to be associated with PAR records, the written forms of numeric values or numeric figures. This will be discussed later in more details.

The advantage of separating visual and auditory signals into physical memory and concept memory is to save the number of neurons needed for storage. Visual or auditory physical memory is grayish black and white or flat. The size of a black and white picture is far smaller than its color version, and the size of a flat sound is also far smaller than its live version. In other words, the brain just needs to remember the part of a sound or object that is essential for distinction between different sounds (tones, not loudness) or objects (shapes or contours, not look and feel). For example, we recognize a tomato regardless of its ripe state and we know whose voice it belongs to regardless of its loudness. In addition, one physical memory could be used to store all objects that share the same physical dimension of various sizes but different properties. For example, a black and white line could be used to store all lines with different colors. As long as you know the color, you will know a line with that color. What's remembered as concept memory could be attached to any objects, sound, and etc.

## 9. Neurotransmitter Receptor-Dependent Switch between Depolarization and Hyperpolarization

There are many varieties of nerve cell types in a higher animal, but all nerve cells usually display three main features. First nerve cells conduct electric current along its body protrusions dendrites and axons. Second, nerve cells express neurotransmitter receptors mainly at their dendritic tips and release neurotransmitters into synaptic clefts at their axon terminals. It's neurotransmitter specific receptors on the postsynaptic nerve cells that respond to the neurotransmitters released by pre-synaptic nerve cells. This feature offers nerve cells ability to transmit electric current from one nerve cell to the next through synapses. Third, dendrites and axons among nerve cells can arborize to vastly different degrees, depending on their functions and locations in the nervous system. Larger arborization, wider impact in the system. One nerve cell differs from another largely because of their differences in the second and third features, and the extreme complexity of the nervous system is largely because of the extreme complexity of the second and third features as well.

The exact number of different neurotransmitters in the human brain is unknown, but it could be at least 100, and the number is increasing as new neurotransmitters are being discovered. Regardless of the number of different neurotransmitters, they impact the target neurons largely in two ways. The effects of a neurotransmitter on the target cell depend on the biochemical properties of the receptor for that neurotransmitter expressed on the target cell. In general neurotransmitter receptors can be either ion specific channels themselves - ionotropic receptors or regulatory proteins - metabotropic receptors that influence the activity of another ion specific channel. If an ionotropic receptor opens its channel to allows specific ions to pass through the cell membranes upon binding of its neurotransmitter ligand, it is activated by the neurotransmitter, and the neurotransmitter exerts an excitatory effect on the receptor. The influx of ions will change the membrane potential of a neuron, leading to depolarization or action potential. If an ionotropic receptor closes its channel to block specific ions to cross the cell membranes upon binding its ligand, it is inhibited by the neurotransmitter, and the neurotransmitter exerts an inhibitory effect on the receptor, leading to hyperpolarization in the target cell. If a neurotransmitter receptor falls in the metabotropic type, it regulates the ion channels in an indirect and far more complex way. In this case, upon binding its ligand, the receptor either activates or inhibits another ion channel to change the ion influx, thus changing the membrane potential of the target cell. In addition to the excitatory or inhibitory effects on ion channels, metabotropic receptors can have other functions as well. A single neurotransmitter can be a ligand for more than one totally different receptors and exert both inhibitory or excitatory effects on the target cells.

Some neurotransmitters may exert a modulatory effect on the postsynaptic cells upon binding to their receptors, changing the sensitivity to future stimulus by changing the density of receptors on the synaptic membrane. AMPA receptor is a simple ion channel that allows the influx of sodium and potassium ions to depolarize the cell. If the post-synaptic membranes also express NMDA receptors in addition to AMPA receptors, the effect of their common neurotransmitter glutamate can be long lasting. NMDA receptor is a non-selective cation channel, and can be activated by ligands glutamate and glycine, depending on its subunit composition. However, binding of the ligands to NMDA receptor is not sufficient to open the channel to cations as it may be blocked by magnesium ions. Depolarization of the cell by AMPA receptors removes the blocking magnesium ions from NMDA receptors, allowing cations to move into the cell, among them is the calcium ion. The calcium ion functions as the second messenger in various signaling pathways, and an increase in its concentration in a cell could permanently change the glutamate receptor subunit compositions and amounts on the level of gene expression. NMDA receptor has been recognized to be involved in long term memory for many years.

Although the process of depolarization or action potentials is relatively well understood and the excitation of a neuron will result in propagation of action potentials along its axon, the process of hyperpolarization and its roles in the central nervous system is less clear. It's generally agreed upon that an inhibitory effect decreases the probability of the postsynaptic neuron to produce an action potential by increasing the stimulus required to move the membrane potential to reach the action potential threshold. However, this could be a too simplistic view. Even with simple nervous activities like depolarization, multiple processes, such as cation influx, anion efflux, ion pumping, and others, could be involved to complete the production of an action potential.

While the action potential resulted from the excitatory action of a neurotransmitter is of all-or-nothing nature, hyperpolarization from the inhibitory action of a neurotransmitter is of graded potentials. The greater negativity is positively correlated with the larger magnitude of the stimulus. Graded potentials from either within the postsynaptic cell or adjacent synapses can build up on each other to gain an accumulative effect. Both excitatory or inhibitory effects work on postsynaptic neurons only. If the postsynaptic neurons pass their action potentials or hyperpolarization further down to their own postsynaptic neurons, the impact on the second level postsynaptic neurons can be completely different, depending on the receptors on their surfaces. If the initial neurons release a neurotransmitter that exerts an inhibitory effect on the first level postsynaptic cells, the target cells will hyperpolarize and reduce the release of its own neurotransmitter into the synaptic clefts. This reduced amount can have opposite effects on the second level synaptic neurons. If it exerts an inhibitory effect, less of it will make its receptors more active and increase the cation influx, thus, increasing the transmembrane potentials and even depolarizing. If it exerts an excitatory effect on its receptor, less of it means less of cation influx, thus maintaining the transmembrane potentials in an hyperpolarized state. If the initial neurons release an neurotransmitter with an excitatory effect on its receptor, the first level postsynaptic cells will be depolarized, increasing the release of its own neurotransmitter into the synaptic clefts. This increased amount can have opposite effects on the second level synaptic neurons. If it is inhibitory, then its higher amount will make its receptors less active and increase the cation efflux or anion influx, resulting in hyperpolarization. If it is excitatory, then its higher amount will make its receptors more active and increase the cation influx or anion efflux, resulting in depolarization or action potentials.

This happens in the photoreceptor signal pathway in the animal retina. Photoreceptors become hyperpolarized upon activation by light and as a result, its release of neurotransmitter glutamate is greatly reduced. The axon terminals of the photoreceptors are connected synaptically to two types of bipolar cells. One type of bipolar cells expresses ionotropic AMPA/kainate glutamate receptors or iakGluRs. The iakGluRs depend on glutamate for cation influx. A decline in glutamate release makes this type of bipolar cells more negative inside to become hyperpolarized. Another type of bipolar cells expresses metabotropic glutamate receptors or mGluRs. The mGluRs depend on glutamate to shut down an ion channel TRPM1. A decline in glutamate release makes TRPM1 more active for cation influx, making this type of bipolar cells depolarized and producing action potentials. In this way, the visual signals diverge into two pathways, one propagates through action potentials and the other through hyperpolarization.

A large number of neurotransmitters in the central brain mean a large number of neurotransmitter receptors. This isn't enough. There exist multiple receptors for a single neurotransmitter. Furthermore, a single receptor can consist of more than one different subunit, and each subunit can have multiple isoforms. The great variations of the subunit composition of a single neurotransmitter receptor offer enormous possibilities in its biochemical properties in terms of sensitivities to its ligand, ability in ion influx or efflux, regulatability, and so on. If a single neuron expresses more than one forms of the receptor for a single neurotransmitter, and or it responds to more than one type of neurotransmitter, the complexities of a R representation or AR layout or AR record consisting of hundreds of thousands of such neurons is far beyond our comprehension. Without such complexities, our central nervous system wouldn't have the capacity for such a grand scale of intelligence and memory.

What's the limitation of action potentials in the nervous system? Firstly, action potentials are an all-or-nothing, threshold based neural response, which means that a neuron doesn't have the ability to respond to any sub-threshold stimuli. In other words, action potential based responses are not granular enough for all stimuli. An interesting question is whether all sub-threshold stimuli are neurologically insignificant. There are no reasons to believe it's the case. Secondly, an action potential has a peak membrane potential of +40mV and a refractory period of 2 milliseconds. The frequency of action potentials is restrained by its refractory period. Therefore, the magnitude of a stimulus can't be reflected actually by the action potential that this stimulus elicits. However, our peripheral nervous terminals can sense any stimuli, like pain or temperature, in granular levels. The greater magnitude of a stimulus doesn't mean a larger number of neurons engaged in response. For example, a sharp needle can incur a little pain or an acute pain depending on the magnitude of the impact the tip of the needle has on the tiny surface area of the skin. The limitation of action potential based responses implies that there are other ways to fill the response space left by the action potentials.

Hyperpolarization usually makes a neuron more resistant to stimulation, but as stated earlier, this is not always the case, depending on the neurotransmitter receptors on its postsynaptic cells. Since hyperpolarization is a type of graded potentials, it scales more accurately with the magnitude of the stimulus, and can be summated into a larger or more negative potential from multiple synapses. Unlike action potentials, which do not decay with transmission distance, hyperpolarization is only for short distance signal transmission, making it a mechanism of choice to propagate messages produced by sub-threshold stimuli in the central brain.

Having said all about the excitatory or inhibitory effect of a neurotransmitter on postsynaptic cells to produce action potentials, an equally important role is to act as a switch, with which the inhibitory effect would turn on the postsynaptic cells to produce action potentials and possibly start a new propagation route, and the excitatory effect would turn off the postsynaptic cells and block the propagation of action potentials. In this sense, it is not appropriate to describe the effect of a neurotransmitter as inhibitory or excitatory as generally accepted. With such a receptor arrangement between a presynaptic cell and its postsynaptic cell, nervous messages can be not only transmitted alternately from hyperpolarization to depolarization or vice versa, but also blocked or started anew. In normal situations, nervous messages are transmitted always from depolarization to depolarization or hyperpolarization to hyperpolarization. Changes from depolarization to hyperpolarization or vice versa not only make signal transmission more varieties in form to distinguish one nerve cell from another, but also act as a switch to change the transmission route of the nervous signals. Neurotransmitter receptors that can function as a switch along the nervous signaling pathway are literally a pair of yingyong receptors. Yingyong receptors could play a vital role in establishing memory and retrieving memory for recognition and recall.

## 10. Establishment of Abstract Reality Record and Railway Track Switch Principle

The human nervous system looks messy and has confounded numerous researchers for years. What can be drawn from so much that we have learned so far? If the memory could be understood correctly even to a small extent, it would be a big step towards revelation of the brain mystery.

The memory can't be the results of encoding information in certain materials, such as proteins or special polymers, it must be spread among numerous nerve cells in the form of abstract reality (AR) records. By taking into consideration the fact that our memory is vast, one piece of information isn't standing alone, but is highly associated with numerous other information small or big, and its retrieval can lead to numerous other things being retrieved at the same time. Therefore, an AR record must display certain special features that could at least partially explain what is known about the memory.

All peripheral neurons respond to external stimuli or realities by generating electric signals or messages followed by transmitting them to other nerve cells. It's this simple form of electric signals that encodes all information about the external realities no matter whether they are physical or chemical. Deciphering these generic electric signals back to the original realities is the responsibilities of the effect neurons in different lobes of the central nervous system, where the signals are interpreted according to the roles assigned to each of these lobes. For example, visual effect neurons in the visual lobe decode the electric signals as images, while auditory effect neurons in the auditory lobe decode the electric signals as sound despite the fact that visual signals don't differ from auditory signals in terms of trans-membrane potentials. This implies that visual information and sound information must be stored in separate spaces in the memory area and retrieved back into their own sub-space in FPS for interpretation. A general neurological mechanism could have been developed to establish AR records in memory area for all external realities and internal nervous activities.

After an object was memorized, its existence as an AR record should be well defined in a certain way. The AR record should be able to be retrieved into FPS whenever it is requested. The AR record should be able to be reduced back into a fuzzy, undetailed, grayish image of the original reality. All of this requires that all neurons in the record in memory be confined in a not-too-clear boundary and arranged in such a way that once in FPS it would become an AR layout that created this AR record in the first place. Most of all all neurons in the record must be inter-connected in such a way that they could be retrieved as a whole into FPS. In a sense, establishing such a record and connectivity within the record is basically the process of memory formation.

If the memory for an AR takes the form of a record, we could try to conceive a mechanism to illustrate how memory could be created and retrieved. Suppose a red line lies on a piece of white paper. By looking at the line, the line sheds light onto the retina like casting a shadow of the line over the surface. If, say, 100 cone cells falling in the line shadow are exposed to the red light and become activated to generate visual electric signals. In the R locus, the signals end up at 200 effect neurons to represent the line. At this point the red line is being perceived by the central nervous system. Among 200 effect neurons, 100 neurons are for intensity signals and 100 for color signals. Once the line's R representation moves into FPS, they forms two AR layouts – one for the intensity and one for the color. The need of two AR layouts for one visual object is necessary as the color of the object belongs to concept memory and the physical object belongs to physical memory. As the final step to complete the life cycle of nervous signals from production in the peripherals to final disposal in the central brain, the two AR layouts will pass on their signals to the memory area to create an AR record for the line. Only physical memory of the line will be discussed to avoid special nature of the concept memory.

If the eye didn't see the line before, then there isn't an AR record for the line, instead an AR record will be set up using the line AR layout as an input. An AR record consists of a number of neurons, each of which forms a circuit in which the neuron accepts input from a neuron in an AR layout, and returns output to FPS where it forms an AR layout with other neurons retrieved from the record during retrieval. All neurons in the AR layout will transmit their signals into the memory area at the same time, and if a set of neurons are available to accommodate the signal set from the AR layout, these neurons will change their state to a charged state, forming an AR record. The state "charged" indicate that this neuron bears memory information. All neurons in the record must link with one another to keep the record as a unit for recall or recognition. Each neuron in the record seems required to accept signals not only from a neuron in the AR layout, but also from few of its neighboring neurons. Similarly each neuron must pass signals not only to a neuron in FPS upon recognition or recall, but also to few of its neighboring neurons. It's possible that signals from an AR layout would span one or more layers of memory cells to reach the destination.

If a match with an existing AR record for the line succeeds, neurons in the record fire their signals back to the AR layout due to circuital nature to indicate that the line is known to the memory. From the perspective of external perception, we got the feeling that we recognized this line as known. An issue with memory digging is that a R representation of an object could only represent part of the object as the object could be seen from different angles of view. In this sense, a particular R representation is unlikely the one used for the AR record. Therefore, any matching operations are largely partial only and not necessarily sufficient for recognition. It seems that a memory record such as a colorless line record doesn't need to be precise and unambiguous, instead it is good to be highly plastic to fit lines of different colors, different lengths, and even different shapes.

Human vision is a two-dimensional business as the cone cells are attached to the curved surface of the retina. Therefore, R representations, AR layouts and AR records all should have a flat map like configuration. In contrast, the whole central nervous system is a three-dimensional structure. A 3-D space provides more possibilities to efficiently utilize limited memory resource to store 2-D nervous information. One possibility is that an AR record can be extended in all directions to enlarge a memory record. If a partial match between an incoming AR layout and an existing AR record is sufficient to recognize the external reality as known, there are several ways with which the unmatched part of an AR layout could be added to the matched part of the AR record as an extension. For example, if an AR layout and a AR record share a cluster of neurons and differ at the same sides or the opposite sides. If differing at the same sides, the existing AR record is extended into the third dimension at the matched and unmatched interface. If differing at the opposite sides, the unmatched AR layout will simply elongate the matching edge towards the same direction of the shared side. I was still able to project the maintain ranges that surrounded my childhood hometown village 360 degree continuously in my mind. This is a typical AR record built by elongation.

No matter how big our brain is, the number of neurons in the memory area is fixed and limited for a person. If AR records are the way the memory is stored and if one neuron can appear only in one AR record, the number of neurons in a brain would be far not big enough up to the daunting task to remember the vast amount of information even to an average person. This suggests that a single memory neuron must be utilized in multiple AR records.

If one memory neuron is utilized by two AR records, how this neuron chooses the right AR record to go with when one AR record is retrieved into FPS? We could assume that there must be something to trigger the retrieval of an AR record, and these early steps determines the later right selection of memory cells that fall within this AR record. Take railway track switch as an  example. When a single railway track diverges into two tracks, there exists a mechanism at the branching point that will guide the train to move into the right track. During the establishment of a AR record, a mechanism could have been built into the connections that bridge two adjacent memory cells to guide the electric signal flows from one cell to the next within the record. This mechanism is essentially the application of the railway track switch principle in memory in the central nervous system. This could be made possible by high degree of connectivities of both synaptic and non-synaptic nature between memory cells, and especially by some neurotransmitter receptors with extraordinary biochemical properties that could confer the memory cells extraordinary capabilities, for example, yingyong receptors and NMDA/AMPA receptors for glutamate. As more neurotransmitter receptors are discovered and characterized to display interesting properties in memory neurons, more details of nerve memory could be exposed to view.

**11. More on Abstract Reality Record**

Before moving onto human creativity, it would be good to repeat something in more details.

Experiences tell us that there is nothing in nature that can be input into the memory system as physical memory alone. A physical memory is always accompanied with a concept memory, but not vice versa. The biological significance of this not only makes memory easier to understand and investigate, but also helps ascertain the validity of the dual channel system for color vision. The color vision in retina depends on dual channels to process and transmit visual signals - negative channel for wavelength signals and positive channel for intensity signals. Current view on color vision is largely derived from over interpretations of intracellular and extracellular electrical recordings of light responses from individual nerve cells of the vertebrate retina. It's a common understanding that a single cone type can be excited by light of different combinations of wavelength and intensity. By increasing the intensity, a weakly absorbed wavelength can evoke a cone response that is indistinguishable from the response evoked with strongly absorbed wavelength at a lower intensity. Therefore, a single cone type is not sufficient to differentiate between a response change in wavelength and a response change in intensity. The visual information must be extracted by comparing the responses across different types of cones. As a matter of fact, the current view not only fails to explain why and how a pair of M cone and L-cone collaborate for the full-color vision, but also has no any values to provide a neural basis for separating visual information into two types of memory. Only the dual channel system theory gives color vision a sound account.

As described in the beginning of this writing, if we project an orange in our brain, we see a grayish, orange shaped image without details, bounds, and orange color. To project an orange, the brain must retrieve the PAR record for the orange from the memory area into FPS to form an AR layout. Because this PAR record lacks color information, and the CAR record for color orange isn't unique to the orange, it can't be retrieved just because the orange bears color orange. Orange can be green too when not ripe. Only when we see an orange, our eye passes both color and intensity information to the R locus, and further into FPS as a color AR layout and an intensity AR layout. When the two AR layouts confirm the existence of corresponding AR records for color orange and object orange in memory area, we perceive a perfect, orange-colored orange as known.

Dreaming is another vivid play of retrieving PAR records into FPS in a spontaneous fashion. Similar to brain projection, what appears in the dream are like playing largely colorless or very light-colored movies, but you won't be able to enjoy good taste or smell. This means that only PAR records are fetched during dreaming. PAR records are physical existence or physical surrounding of the reality, both of which are void of properties that decorate the reality. Lack of CAR records in dreaming and mental projection as well suggests that CAR records must be retrieved with the signal input from peripherals as the bait.

One characteristic of the nerve cells is that nerve impulses start at the dendritic terminals upon receiving a stimulus, pass through the cell body, and finally terminate at axon terminals. To this point the cells return to the resting state if no more stimulus is applied. A R representation, an AR layout, and an AR record are three different stimulated nerve states, each of which represents the same external reality at a given stage of nervous responses. The transient nature of R representation indicates that upon stimulation by their pre-synaptic neurons, neurons in this R state won't retain the electric signals for any time. This makes sense as they must get ready for the arrival of next signals to avoid signal contamination. However, the duration of the signal state of a nerve cell in an AR layout varies. It is transient in most time unless the layout is engaged in a focused mental activity. It raises an interesting, but puzzling question, how neurons in the layout retain their electric signal state during a focused mental activity after the layout is formed in FPS. Does each neuron use a self-stimulation route as a mechanism to maintain an electric state? An advantage of self-stimulation is that the electric state can be accurately controlled so that each neuron carries its electric signals at a level that fits its role in the layout. The layout is dissolved when self stimulation is dissolved.

Differing from R representations and AR layouts, AR records can last up to life time. It is uncertain when an AR record will be recalled into a "wake" state, and if charged neurons maintain their own trans-membrane potentials other than the normal resting state. If yes, do new trans-membrane potentials consume more energy? It's imperative for the charged state to maintain a low energy consumption. Therefore, neurons in a record must have undergone biochemical changes at the gene expression level that allow them to fulfill their roles as memory cells without consuming more resources.

Memory cells are a type of nerve cells specialized from normal nerve cells for the purpose of storing information. Cell type specialization is not much more than the utilization of some protein molecules that are also specialized from their general forms. One of the neurotransmitters active in memory cells is the common amino acid glutamate, but its receptor is exceptionally rich in isoforms and variety. Specialized glutamate receptors are not widely used, but confer special functions that are exactly needed by certain specialized neurons, such as memory cells. In a sense, exploring the biochemical properties and functions of various glutamate receptors and their isoforms could shed light on how memory cells maintain memory states over time. AMPA receptors and NMDA receptors could be a perfect pair of partners in setting up an AR record. NMDA receptor increases the concentration of calcium ion in the cell, which in turn changes the glutamate receptor subunit compositions and amounts on the post-synaptic membranes. It could be expected that as more neurotransmitters, receptors, and their biochemical properties are discovered and studied, it will become clear gradually how a "naive" memory neuron are turned into a charged memory neuron, what is a memory state, and how a memory state is maintained over time.

**12. Human Language and Physicalization of Concept Memory**

Language is unique to humans. A very important use of language is to give names to many realities that are hard to describe. For example, computer is used to name devices that can perform calculation, molecule is used to name small, invisible chemicals, and red is used to name color red. Humans take all this as granted without much thought. However, language to humans is far more than for the convenience of routine communication. Names computer, molecule, and red are essentially concepts because these names act like an umbrella to cover any devices that can perform calculations, any small invisible chemicals, and all colors similar to the real color red, respectively. When we see these names, we immediately understand what these names refer to. In addition, every name has its own pronunciation, and when we hear these names, we immediately understand what these sounds refer to as well. As a matter of fact, name pronunciations are far more useful than names' written forms when we discuss about human creativity. In science and other disciplines, a concept means a general notion, thought or idea generalized from particular instances or conceived in the mind, such as computer, molecule, and red. In this article, the concept is strictly referring to an external stimulus or reality whose abstract reality (AR) layout can't be reproduced and projected in FPS from an abstract reality (AR) record stored in the memory area.

Suppose you suddenly felt a very strange taste in your mouth that never appeared in the language you spoke. You would recognize that taste the second time it appeared in your mouth, but you wouldn't be able to describe it because the taste couldn't be reproduced and projected in your mind. Next you read a report that someone else also had the same experience as you and named that strange taste "blah blah". Now every time you felt that strange taste, you associated that taste with the word "blah blah" or its pronunciation. When you recalled that strange taste, the word "blah blah" or its pronunciation appeared in your mind. To this point, that strange taste had been replaced with the word "blah blah" and its pronunciation. A point to make is that human language turns a concept memory into another physical memory, although this concept memory itself remains in the memory area. Without physicalization, we won't be able to recall a concept memory.

Similarly anytime when we think of color red, what jumps into our mind is the word "red" or the sound we utter when pronouncing the word "red", not the color red itself . The concept color red is a property of a reality, such as a red flag or red ball. In other words, color red is what our brain perceives, not what our brain uses for any focused mental activities involving color red. The association of color red with word "red" or its pronunciation isn't the same as the association of color red with a red color reality. Word "red" or its pronunciation isn't red colored, but is used as a place holder for color red when we design or think of something red in color. In memory area, word "red" and its pronunciation are stored as two separate PAR records. For humans a lot of concepts or properties of realities are substituted with words or their pronunciations. In human cognitive functions, it's the words, especially their pronunciations, that are engaged in thinking, reasoning, designing, and other focused mental activities in place of the real concepts or properties of realities. These words and their pronunciation are stored in the memory area as PAR records. In other words, concept memory has been physicalized to become language-backed physical memory. Physicalized concept memory can be reproduced and projected in the mind, although what's reproduced and projected isn't the concept itself. It's reasonable to conclude that it's the PAR records, not CAR records, that are retrieved from the memory area and fed into FPS as the substrates for focused mental activities. For example, when a person performs numeric calculations in the brain, the physicalized concept AR records are projected and displayed in the mind as visible numeric figures and operations are performed on them just as we normally do on a piece of paper. Language physicalizes concept memory and physicalization in turn gives concept memory life in cognitive functions or focused mental activities.

## 13. Human Creativity and Synthesis of Novel AR Layouts

In addition to owning a vast amount of memory, humans also enjoy extraordinary creativity. Almost everything in our daily existence is the products of human creativity or changed or improved by human creativity. What is human creativity? And what is the neurological basis of human creativity?

As described earlier, if we withdrew a face PAR record from memory area into FPS, we could project that face in our brain. The face is fuzzy, messy, and colorless, but good enough to recognize its owner. We could play a song in our brain with right rhythm, melody, and tone, but without changes in loudness. The ability to project from memory is the neurological basis of human creativity. This ability is far beyond our comprehension by just looking at the underlying biochemical reactions that lead to generation and transmission of electric signals along or among nerve cells that can be recorded and analyzed with various instruments.

All cognitive activities or focused mental activities take place in the focused processing space or FPS. All images, songs, and anything resulted from a cognitive activity are confined within this space. A composer will play a piece of music he or she is going to compose first in his/her FPS, and make changes at places where changes are thought to be needed. When I was writing this paper, I first pondered what I wanted to express, then composed the sentences, and finally typed the composed sentences onto a computer screen if I felt they were right in both meanings and grammar. In either case, the information used to compose a song or write a paper are all from the memory and input into FPS where the information is projected into songs or sentences. When different pieces of information are mixed together in FPS, new pieces of information are brought forth to become a new song or a new paper and so on. However, this kind of composition or writing is thought as too routine and mundane to be considered as creative. Nevertheless, it is a type of basic creativity that generates something new from something old.

If we look into dreaming a little deeper again, we could learn something too. The central brain, especially FPS, is hardly shut down to rest during sleep. During sleeping, a partially active FPS could fetch AR records randomly and spontaneously from the memory and convert them to AR layouts, which could be a scene or an image. In FPS these AR layouts could move around and merge with another scene or image to spawn a new scene or image. These newly spawned scenes or images could more likely be new and unknown to the dreamer despite the fact that the initial scenes and images were known to the dreamer. When we woke up, we usually still remembered some scenes or images we knew, but largely forgot about those scenes or images blended anew in the dream.

What the above explanations reveal is that FPS has the capability to mingle multiple AR layouts to beget AR layouts. Human creativity is the application of this capability to bring forth something new from something old. However, not all begotten AR layouts are meaningful and worthwhile. They are discarded while in the making. Creativity refers only to begetting AR layouts that must be able to be interpreted or projected into realities that are novel, meaningful, practical, and operational. In chemistry, the production of a substance by the union of chemical elements is called synthesis. Similarly, the production of an AR layout by the union of existing AR layouts can be called synthesis as well. Creativity is the synthesis of novel, meaningful, practical, and operational AR layouts by the union of existing AR layouts. Any creativity is backed by necessary knowledge to bring forth, and must be backed as well by necessary knowledge to interpret or project validity and potential meanings of the synthesized AR layouts. AR layout synthesis during a dream can't be considered a kind of creativity, because synthesized AR layouts are mostly nonsense, not meaningful and practical.

Since human ancestors made tools out of stones and used fire to cook, the entire history of human evolution has been a history of human creativity. Especially in the recent centuries the creativity has lead to advance in science and technology, and exceptional creativity has lead to exceptional breakthrough in science and technology. Science has created numerous abstract concepts, which are hard to understand and essentially the same concepts as the concepts for concept memory. Thanks to languages, almost all of them have been physicalized and stored as PAR records in memory. When we refer to an abstract concept like something with the capacity to do work, what appears in the mind is the name or its pronunciation "energy" given to this abstract concept. Creativity is essentially the synthesis of new AR layouts using physicalized CAR layouts, not CAR layouts themselves as input. Therefore, it's the physicalization of vast concept memory that makes synthesis of novel, meaningful, practical, and operational AR layouts possible.

Invention of monoclonal antibody is a typical example of synthesis of the two concepts - a B-cell that produces only one antibody and a tumor cell that grows indefinitely. The fusion of these two cells leads to a hybrid cell. In this case, inventors had no difficulty to expect what the synthesized concept – the hybrid cell – would do: producing one antibody – monoclonal antibody, and dividing indefinitely, which means almost unlimited production of a particular antibody. The two input concepts were essentially the same, and synthesized concept had clear biological property. The only difficulty was to make it a reality in the laboratory.

In geometry class, teachers often compliment students for using creative approaches to solve a geometry problem. For some geometry problems, multiple approaches exist. Obvious approaches are often tedious and excessive, while creative ones are often short, but quite concealed and invisible to average eyes. Creative approaches often employ theorems that are so unrelated with each other and seem unlikely to be used together to solve the problem. The theorems as input concepts are dissimilar, but the result as synthesized concepts often make sense and obvious to average eyes.

In scientific research involving pure and abstract subjects, the input concepts are seemingly unconnected and irrelevant, no obvious synthesis methods are available, or any synthesized concepts hardly make sense and hardly can be given a meaningful account. Therefore, in some scientific fields, only the most brilliant brains can find and establish relationship to create new theorems and make new discovery out of the seemingly impossible. This is the highest level of creativity. The brain must inject all input concept layouts into FPS where new concepts are constantly synthesized by connecting and coalescing, conjure what meanings and significance the synthesized concepts have in relation to the subject of research, and discard any synthesized nonsense AR layouts. This is a type of intense focused mental activities, obviously requiring a FPS large enough to accommodate all AR records used in the synthesis.

Human creativity is the ability developed and built up gradually through learning during childhood and entire adulthood. Like manual dexterity which improves only through long time practice and training, learning not only accumulates more and more physicalized CAR records for the synthesis of new AR layouts, but also increases the smoothness and fluency in information flow among neurons in FPS and makes synthesis more likely to implement and finish. The difficult degrees of creativity depend on number of AR layouts involved, relevance among them, and easiness in interpretation or projection of the synthesized AR layout. Creativity can be expressed as below:

$$L_1 + L_2 + ... + L_n => SL$$

Here L means an input AR layout, and SL is the synthesized AR layout.

Creativity is unique to humans. If other primates had creativity, it would be of only rudimentary nature. Concept memory exists in primates as primates recognize colors, distinguish loudness of sound, and etc, but primates can't physicalize concept memory to become physical memory. It is possible that the creativity of primates could be enhanced to a certain degree if they can be trained by using human language to physicalize some concept memory like color, sound loudness, taste, etc.

**14. Summary**

Memory is the foundation of all human cognitive activities and understanding of its internal working is vital to our understanding of the entire nervous system. As an attempt to explore the subject in this field, this post will focus on observable phenomena of the nervous system to demystify nervous memory and human creativity. The external stimuli that drive peripheral nerve terminals to generate and transmit electric signals to the central nervous system are referred to as "reality", a generic name for the sake of clarity and simplicity in discussion. Chemical, physical, objects, sound, etc, are all realities.

A face that is projected in the mind or appears in a dream usually is grayishly black-and-white and undetailed. In this case the face could be formed only using stored information or memory as there was no input from the external sources. Despite poor quality the face is recognizable. The amount of memory isn't abundant, but has sufficient facial features essential for unambiguous recognition. Of course the poor quality could be equally attributed to the limitation of projection ability of the brain.

Images projected or seen in dreams all float inside the brain. This is the internal perception. Internal perception is a type of focused mental activities as the activities require mental concentration. All human cognitive activities are focused mental activities and performed in a special space within the brain, designated as focused processing space, or FPS.

An individual neuron in the peripherals dispatches its electric signals to one or more fixed neurons in the central brain via relay neurons, forming a neural signaling chain. The neuron signaling chain ends at a particular reality locus or R locus and the end neurons are fixed and designated as effect neurons for their special roles in perception. When all peripheral neurons that are stimulated by the same external reality transmit electric signals to their corresponding effect neurons in the form of signaling chain bundle, all effect neurons become transiently activated. The activation pattern of the effect neurons reflects the stimulation pattern of the peripheral sensory neurons by the external reality, therefore, representing the external reality in the central brain. Such a representation is called reality representation or R representation. External realities of different natures are represented at different R loci, each of which is specific for a given type of stimuli. For example, visual reality is represented at the visual R locus, and pain reality represented at the pain R locus, and etc.

Contrary to internal perception, perception through R representation at the R locus is external perception, because the feel of the reality perceived through a peripheral sensory organ is at the source outside the central brain. For example, what we see or hear isn't in the inside of the brain, but is where the reality is present or originated. A needle punch, cold touch, itching, etc are all felt at the skin surface where these stimuli are received. External perception can be blocked if signal transmission to the central nervous system is blocked, while internal perception can't. Therefore, the two types of perception takes place in separate areas in the central brain.

Although the brain perceives an external reality at its source, our awareness of it being known or unknown comes from the inside of brain. This indicates that the effect neurons in the R loci further extend their signals into FPS, where signals are represented once again among neurons. Signal details could be filtered to some degree during the extension. Signal representation in FPS is abstract comparing with the representation at the R loci, called abstract reality layout or AR layout. Once represented inside FPS, reality recognition happens.

Since the FPS is only for cognitive activities, and its nerve cells change their signal states dynamically, the lasting memory must occur outside FPS. Just like a R representation generating an AR layout in FPS, an AR layout must establish its own copy in the memory area in order to maintain a memory for this AR layout. Such a copy in memory area makes up an abstract reality or AR record. Memory for a reality is the construction of a AR record in the memory area with signal input from FPS. It seems necessary for each neuron in the AR record to be functionally connected in such a way that when any one neuron in the record was requested, all neurons in the record must be retrieved into FPS where they are reduced into an AR layout.

Over the evolution, the nervous system has gained a thorough understanding of the underlying properties of different types of external realities, light, sound and others that an organism must respond for survival, and developed different strategies to cope with each of them intelligently.

Light and sound are physics stuff and both display due properties. Correspondingly an object is defined with bounds and features within the bounds that are related to light intensity and decorated with colors that are determined by light wavelengths. A sound is defined with tones that are related to sound frequencies and decorated with loudness that is determined by sound wave amplitudes. If there are two round shapes each with color red and color green, they are identical in a grayishly black-and-white photo picture, because only intensities of the color, not their respective wavelengths matter. Similarly, if there are two sounds with low and high loudness but identical tone, they sound identical when played in memory. What's interesting is that sound frequencies and sound loudness are responded through their own hair cells in the ears, and nerve signals for light wavelength and light intensity are separated via the dual channel system during signal transmission. Generally speaking a reality with dual properties must require a dual system for full and accurate perception. Light and sound seem to be the only realities with dual properties that the nervous system must respond with a corresponding dual system.

Contrary to light and sound, smell and taste are elicited with chemical realities, which display only a single property for the nerve system. The nervous responses to chemicals are dependent on the affinity of receptors for these chemicals and the amount of chemicals that stimulate those receptors. However, they fundamentally differ from vision and hearing. Chemical realities don't impose space and time constraints on the nervous system for accurate perception. Smell and taste are an overall mixed effect of different chemical molecules acting on the olfactory tissues and taste buds simultaneously. There is no need to perceive what molecule a particular cell responds to. In another word, perception resolution is on the scale of peripheral sensory organ, not individual cells in these organ. In general, smell, taste, touch, pain, and etc are all simple realities and require single systems for perception.

Regardless of a large variety, all external realities can be categorized into two categories. The first category includes realities that can be projected in the mind, and the second refer to all remaining realities that can't be projected in the mind. Correspondingly, the memory for the first category is called physical memory and the memory for the second category concept memory. Physical memory stores signals generated from light intensity and sound frequency only, while concept memory stores signals generated from color, loudness, taste, smell, pain, and etc and etc. We can project only physical memory in FPS. An AR record for physical memory or concept memory is a PAR record or a CAR record respectively.

Although concept memory can't be projected in FPS, it has been associated with what's unique to humans – the language. In human language all useful concepts have been described with specific words, and each word has its own sound form – pronunciation. In general, mental projection of their sound forms is much easier and more clear and fluent to proceed than that of their written forms. Being associated with words, when we hear color red, we can't project a red color, but immediately associate it with the sound of word red. Association of concept memory with human language to achieve its mental projectability is the physicalization of concept memory, which is the foundation of immensely developed human cognitive functions. As a result, physical memory includes not only native physical memory, but also physicalized concept memory.

Human creativity is basically the synthesis of novel AR layouts from AR layouts converted from existing AR records. It occurs to a person all the time. For example, when a new idea suddenly jumped out of one's mind after persistent focused mental activities, a new and meaningful AR layout was synthesized from memory. When two or more AR records are converted into AR layouts in FPS, they can merge with each other to spawn new AR layouts that are unknown to the mind. This process is what the human creativity is all about.

Modern society has been built upon from an enormous amount of human creativity achieved gradually throughout the history. Human creativity is limited by two things. The first is the amount of information accumulated in one's memory area. Information as input to the synthesis process, more of it in memory, higher creativity, which critically depends on learning and training. The second is the mysterious ability of human brain to conjure up something out of an AR layout, for example, an alien face out of a synthesized novel AR layout. This ability is especially hard to comprehend when abstruse concepts are deciphered by brilliant minds. Deciphering a synthesized AR layout may take time. We often encounter situations in which something out of thinking is seemingly known, but the mind is unable to pinpoint exactly what it is. What it is can be spelled out only after fermentation for sometime in the mind. This ability could be the bottleneck for one's creativity.

Similar input AR layouts synthesize new, but similar output AR layouts. This is the simplest type of creativity - easy to synthesize and easy to conjure up what the output AR layouts are. As input AR layouts become less similar and more unrelated and the number of AR layouts involved increases, the synthesis gets more difficult and the output are harder to be deciphered. In general, human creativity can be described by a simple equation – creativity equation: A + B + C + … = Z. Here letters at left side of the equal sign are the input AR layouts, and letter Z at the right side is the output AR layout. Z must be meaningful and relevant.

All major functions of the human nervous system can be found in mammals, even be traced to lower animals. Although their brains are much smaller, they can be divided anatomically and functionally into different zones within different lobes for different functions. When electric signals triggered from stimulating the peripherals are sent to the central brain, they form R representations in R loci, AR layouts in FPS, and AR records in memory area. Comparing with human creativity, creativity of mammals is negligible. Nevertheless, mammalian creativity could be made more visible through training, especially through training with human language. Many pets, especially dogs, can be pretty smart and little creative as well. However, no matter how well these animals are trained, their creativity is limited by two factors. Firstly, animals have a very small FPS where focused mental activities occur. Without a large enough space, synthesis is limited to simple tasks. Secondly, animals don't possess a language ability, and as a result, many concept memory can't be physicalized to physical memory. However, as it's not permissible to perform experiments on live humans, these animals could be acceptable replacements for lab research after trained to gain more memory and creativity, and their nervous functions, low, but comparable to humans no doubt will make experiments easier.