

The Neural Architecture and Operating Modes related to attention, and image information extraction¹

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Abstract

Electrophysiology defines dual, conscious and nonconscious, executive functions. It also defines five major operating modes within a neural system of seven discreet functional stages. Biological computation is described in terms of analog calculations in multiple dimensions and conformal transformations achieved through “anatomical computation.” A distinction is drawn between declaratory and procedural computation. The mathematical repertoire (rule of evolution) of the neural system is distinctly limited. Plausible biological mechanisms for computing transcendental functions have not been documented within the neural system. Simple programmable lookup tables provide the equivalent capability. Analog comparators are widely used within the neural system.

Keywords: Associative processing · Attention · Brain Architecture · Cognition · Consciousness · Scene perception · Saliency map

1.0 Introduction

The goals of this paper are two. First, to provide an extended framework, in both scope and detail, of the neural system required to accommodate the ever increasing number of facts being teased from the system by exploratory research. Second, to provide for the first time outside the author’s earlier work, an overview description of how the percepts considered by the cognitive stage of the brain are extracted from the sensory signal streams within the CNS during fixation intervals.

The results of modeling the physical plant of the visual system have not appeared in the literature of the neuroscience community involved in understanding image information extraction. Merging the modeling from these two fields can provide valuable understanding of the process of information extraction, specifically reading. Providing a discussion that crosses disciplinary fields requires clear terminology. A large scale glossary of neuroscience terminology is provided on the author’s website².

The vast majority of the signal processing within the neural system is performed using techniques associated with analog asynchronous computer technology. This field has virtually disappeared from human endeavors since the advent of the phasic synchronous digital computer in the 1950’s. As a result, many researchers find it difficult to relate to the computational capabilities of the neural system. World War II was fought with very sophisticated analog computers such as the Norden Bombsight.

Describing the scope of “computation” within the neural system has been difficult for the psychology

¹Released: 22 April 2010

²Fulton, J. (2010) Glossary of Neuroscience www.neuronresearch.net/vision/pdf/glossary.pdf

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and philosophy community. The broadest school favors a computational environment within the neural system exhibiting all of the flexibility inherent in a modern digital computer (including its central mathematical processing unit, MPU). As noted by Van Gelder³, in defense of that position, that school generally presents the “what else could it be?” argument. This is hardly a rational defense of a scientific position. This paper will support Van Gelder and present an analog-based description applicable to all natural neural systems. In this context, computation will be taken to include the manipulation of, and comparison between, analog representations of the sensed external and internal environment. Computation will also be taken to include “anatomical computation,” the spatial rearrangement of –topically oriented neurons within a nerve while traveling between neural engines to perform specific transcendental manipulations (primarily conformal transformations of the Riemann type) *without requiring an MPU*.

While of major importance in the neural system, and covered elsewhere in detail^{4,5}, the conformal transformations within the visual and auditory systems (both continuous in the case of vision and noncontinuous in the case of hearing), are outside the scope of this paper. Two examples of such transformations are included in the ESM material.

A critical element impacting both the computational hypothesis and the dynamical hypothesis of computation as it applies to the neural system, is the available mathematical function set described as the “rule of evolution” in the philosophical community. It is critically important that the biologically plausible set of functions employed in the neural system be specified. This paper notes the lack of any evidence in the physiological literature for a signal resulting from transcendental *calculation* within the neural system. Limiting the neural system to nontranscendental calculations, and the obvious analog character of over 95% of the neurons in system, particularly the central nervous system (CNS), form two pillars supporting this paper. It is proposed the neural system consists of a large number of state-dependent systems whose states are numerically measurable analog quantities and whose rule of evolution does not include transcendental functions (beyond exponentiation and the taking of the logarithm involving the natural base, e and conformal transformations). Analyses lead to the proposition that computation in the neural context is dominated by n-dimensional comparators operating on either serial analog values or multiple parallel value analog words with respect to time and comparing those values to similar values in either declaratory or procedural memory. Instead of an MPU, the desired output representing a transcendental calculation is obtained from a simple programmable lookup tables in procedural memory, or a physical conformal transformation of neural paths.

The psychology and cognitive computation communities have not focused on the crucial activities of the neural system occurring during fixation intervals. It is during this interval that high resolution information concerning the external environment is actually extracted from the signals generated by the visual modality.

2.0 Discussion

2.1 Description of the generic neural system: stages and modes of operation

Gurney⁶ has asserted that in cognition, “a very powerful stratagem is to ‘reverse engineer’ the brain and that computational neuroscience plays a pivotal role in this program.” In implementing this approach, he defined four levels; “computation, algorithm, mechanism and biological substrate.” He

³Van Gelder, T. (1995) What might cognition be, if not computation? *J Phil* vol 92(7), pp 345-381

⁴Fulton, J. (2010) Higher Level perception: part II, In “Processes in Biological Vision” <http://neuronresearch.net/vision/pdf/15Higher2.pdf> Section 15.6

⁵Fulton, J. (2008) Hearing: A 21st Century Paradigm. Bloomington, IN: Trafford Section 8.4

⁶Gurney, K. (2009) Reverse Engineering the Vertebrate Brain: Methodological Principles for a Biologically Grounded Programme of Cognitive Modelling *Cogn Comput* vol 1, pp 29–41

did not pursue levels three and four in depth. This author has used this stratagem over many years to tease out the operational relationships between elements of the neural system, down to his fourth level, the biological substrate level. There is a major unstated problem with the largely philosophical Gurney hierarchy. A computation, or an algorithm, or a mechanism cannot be used in a model unless it can be shown to be plausible at the biological substrate level.

The following section will describe the block diagrams appropriate to the neural system as a result of this methodology while maintaining biological plausibility. It will be followed by a section describing the phenomenology associated with the system that led to the block diagrams, and a set of premises that can be relied upon to advance the field further.

2.1.1 Functional Modeling of the Neural System

The functional model in **Figure 2.1.1-1** attempts to describe the “fundamental signaling path” through the definable stages of the neural system. It shows the relationships between these stages and the parallelism among the afferent (sensory) and efferent (action) modalities. However, it must be recognized that multiple paths are the norm in the peripheral neural system (PNS) at a more detailed level. In the central nervous system (CNS), the system is even more complex. The star network architecture (in at least three dimensions) is used within and between the major morphological elements of the CNS. Aggleton has summarized these connections in the macaque cerebral cortex where 768 nodes or more have been identified⁷. Such complexity indicates how difficult it is to design laboratory experiments that stimulate the neural system at points other than the normal stage 1 input. Such a stimulus invariably affects more than one neural path because of the dimensions of the probe. It is extremely difficult to describe the state of the system when it is stimulated by an arbitrary electrical potential or current applied at a poorly delineated histological location.

The stages were initially numbered beginning at the sensory inputs, with a stage 0 introduced to preserve parallelism with the numbering system generally used in the visual modality. As development of the framework progressed, it was recognized that the stage 3 circuits were replicated throughout the system whenever signals were to be propagated more than a few millimeters. Thus, stage 3 is shown at multiple locations throughout the system, including within the major stages of the CNS when drawn at a larger scale.

⁷Aggleton, J. (2000) The Amygdala. NY: Oxford Univ. Press Chapter 1

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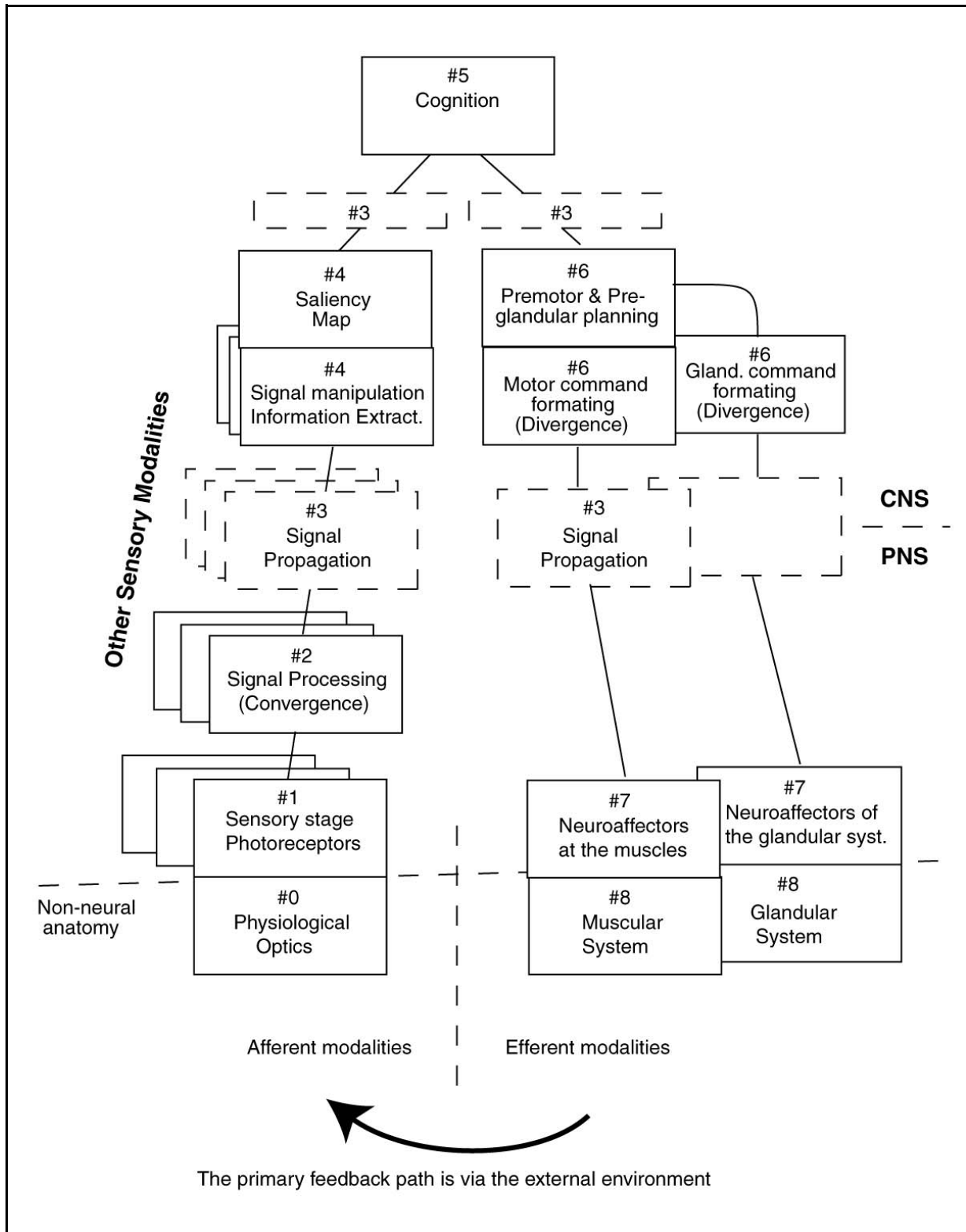


Figure 2.1.1-1 The generic stages of the top level block diagram of the neural system. Note the recurrence of stage 3, the signal projection stage, connecting major engines and stages more than a few millimeters apart. Note also the importance of feedback via the external environment. See text.

All of the major sensory modalities employ the same PNS architecture leading to a common CNS architecture as shown in **Figure 2.1.1-2**. This figure uses vision as a template because it has been extensively explored.

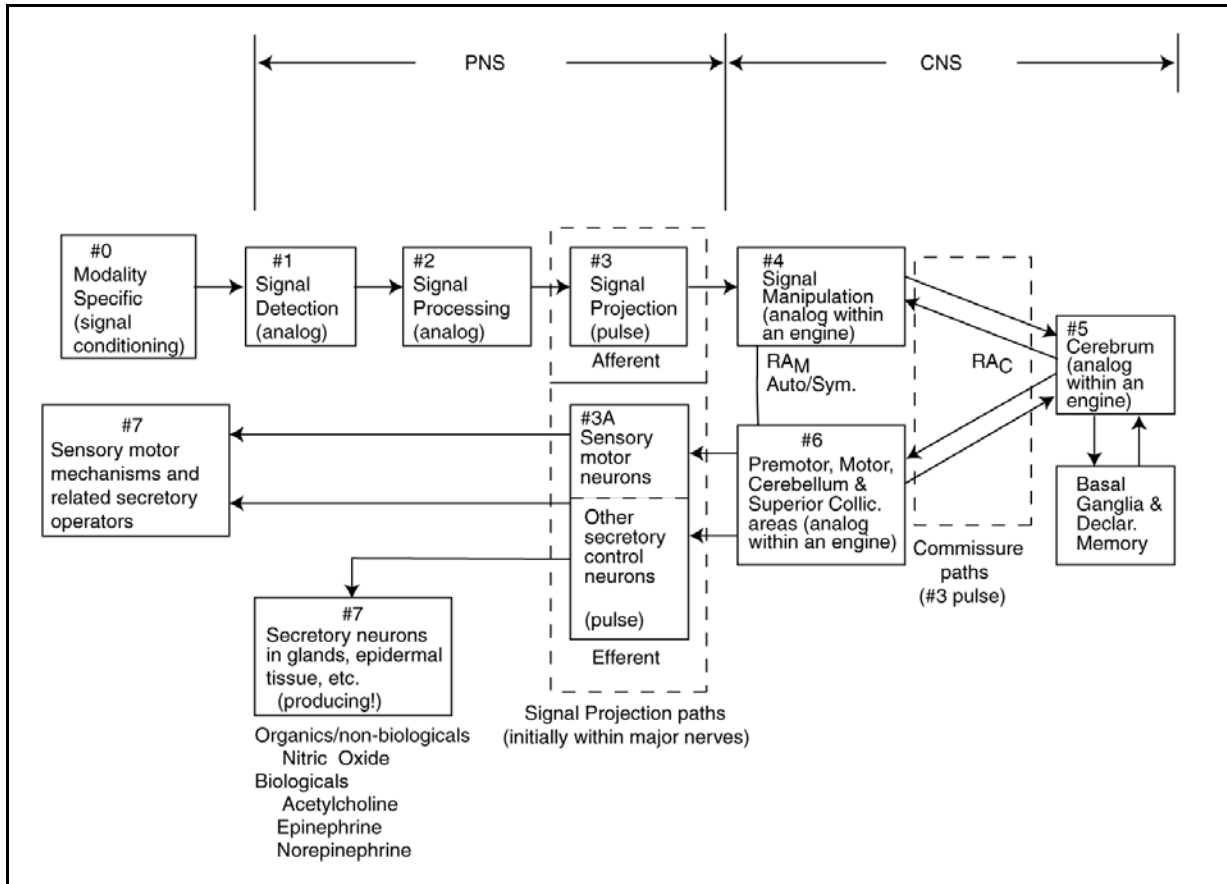


Figure 2.1.1-2 The operating stages of the neural system with vision as a template. All of the engines operate internally in the analog signaling mode. The signals between engines are propagated in the phasic signaling mode. These phasic signals are encoded and decoded within stage 3 circuits where ever they are used. RA_M ; reflex arc of the midbrain. RA_C ; reflex arc within the cognitive stage.

Stage 1, encompasses the neural circuits involved in the detection of the stimulus and **signal generation** subsequent to that stimulus. This stage will end with the presentation of the signals at the pedicels of the sensory neurons.

A **stage 0** can be defined if desired to encompass the non-neural physiological elements of each sensory modality, such as the optics of vision. This will allow the stages defined here to remain generally compatible with the two and three stage models currently found in the color vision literature.

Stage 2, consists of the neurons associated with **signal processing** and manipulation carried out between the pedicels and the encoding elements of the stage 3 ganglion neurons. Being a functional element in the signal processing stage, the synapses associated with the pedicels will be considered part of Stage 2. Similarly, the neurites of the ganglion cells are also key players in the signal processing of Stage 2.

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Stage 3, includes those neurons involved in the **signal projection** circuits of the neural system. The signal projection function is highly developed and easily characterized in *Chordata*. It is used wherever it is necessary to transmit neural signals over significant distances (typically a millimeter or more). This includes both the efferent and afferent signal paths of the peripheral nervous system (PNS) and the paths within the brain, or central nervous system, (CNS).

Within the visual system, the stage 3 projection function is used routinely. It is used to transmit signals over the optic nerve to both the LGN and the PGN. It also used to transmit signals from the LGN to area 17 of the cortex and to transmit signals from the PGN/pulvinar couple to the saliency map and Brodmann area 5 of the cortex. Within the cortex, projection neurons (called commissure) are used to interconnect the different feature extraction engines, logic units of the brain and with the initial motor system command generation centers.

In the nominal case, the projection function extends from the input terminal of the Aactiva within each ganglion cell to the output pedicle of each stellate cell within the brain. Note: the dendritic structure of the ganglion cell is looked upon as part of the signal manipulation function of **stage 2**, and not as part of the signal projection function of **stage 3**. Such a division highlights the role of ganglion and stellate neurons as transition devices between analog and phasic (pulse) signaling.

Stellite is the functional label used to describe any stage 3 neuron performing a decoding of phasic signals back to an analog (tonic) form. Stellate is the morphological label assigned to a neuron resembling a multi-pointed star.

Further detailed discussion of **stage 3** operations, including the coding of the signals, can be explored via the internet⁸.

Stage 4 consists of all of the higher level **signal manipulation** associated with information extraction from the signals. It occurs subsequent to the arrival of signals at the brain from **Stage 3**. It is often useful to subdivide this stage to clarify the fundamental difference in the signal manipulation occurring within the thalamus from that occurring in the cerebellum and the cerebral cortex.

Stage 5 consists of “cognition,” **information manipulation** and **volition instruction generation** within the prefrontal cortex and monitored by the thalamic reticular nucleus (TRN) of the midbrain acting as gatekeeper.

Stage 6 consists of the **premotor and motor areas** of the cerebral cortex along with the motor portions of the **cerebellum** and the **superior colliculus**. This stage accepts volition instructions from the prefrontal cortex and generates adversive instructions and command signals responding to the volition instructions emanating from the prefrontal cortex. It also accepts alarm mode signals directly from the TRN and even from the stage 2 alarm circuits of the sensory modalities.

Stage 7 consists of the **command implementation neurons**. These include the muscle actuator neurons (end plates) and the enzyme secretion neurons.

The terminal neurons, the neuro-affectors, of stage 7 secrete a wide variety of chemicals affecting all other tissue types, including acting as neuromodulators of other neurons. The performance of all other neurons, of stages 1 through 6, can be described completely by their electrolytic characteristics. The axons of the analog neurons operate over a range of -20 mV to -154 mV relative to the surrounding neural matrix with a quiescent value typically near -70 mV. The myelinated axons of phasic stage 3 neurons have a typical resting potential near -140 mV and a saturation voltage near -20 mV to -40 mV providing action potentials with an amplitude on the order of $+100$ mV.

The figure highlights a key feature of the neural system. The total number of neurons in any neural system is not well quantified. It tends to rise by at least an order of magnitude each decade or so in

⁸Fulton, J. (2010) <http://neuronresearch.net/vision/pdf/14Tertiary.pdf> Processes in Biological Vision

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humans (Carter suggested 10 billion in 2000⁹, Taylor suggested 100 billion in 1999, Uttal¹⁰ suggested 10¹³ in 2005), it is reported that over 95% of those neurons operate in the analog signaling mode (**Processes in Biological Vision, Section 10.1.1.2**). It is only the neurons involved in stage 3 signal projection that operate in a phasic mode (and generate action potentials). Recognizing this fact is critical to any understanding of the neural system. Only the myelinated neurons of the PNS and commissure and association neurons of the CNS employ phasic signaling techniques and generate action potentials. All of the other neurons in the system employ analog signaling techniques.

Taking the retina as a generic portion of the CNS, it contains about 15 million photoreceptor neurons, about 7 million horizontal neurons, 5 million bipolar neurons and 2 million amercine neurons, all operating in the analog mode, and about 1 million stage 3 ganglion neurons operating in the phasic mode and forming the optic nerve. The analog neurons represent 96.6% of the neurons of the retina.

The figure also suggests another feature of the system. At the output of stage 4, and particularly as presented in the saliency map, all of the information derived from the environment is in totally non-topical form. The cognition mechanisms of stage 5 see only internally derived representations of the environment. This makes the use of the term picture awkward in a neural system context and the terms image and scene must be used in their broadest context, to include aural images and scenes; and somatosensory maps. A picture may be presented to the visual modality but the brain only sees it as a spatial region of the visually sensed external environment.

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The neurons of the phasic stage 3, signal projection do not participate significantly in the signal processing of the neural system aimed at signaling minimization in stage 2 or information extraction in stage 4, cognition in stage 5 or command generation in stage 6. The phasic stage 3 neurons are formed into a very complex non-switched packet transmitting network similar to the dedicated telephone network lines used to transmit facsimile information. Only stage 3 neurons exhibit myelinated axons. The axons are typically more than two millimeters long. The code used within the phasic system is a simple time-delay encoding (TDE) modulation widely used on telemetry systems and not easily adapted to computational purposes¹¹.

All of the neurons, other than those of stage 3 exhibit axons less than two millimeters long and are capable of a wide range of signal processing activities. However, no reports have appeared of the neural system processing transcendental signals. As noted in the section on computational modeling, this limitation eliminates the calculation of a wide range of correlation functions and other complex mathematical manipulations from plausible neural functions.

The separation of the neural system into analog and phasic elements also causes a further delineation of functional concepts. While phasic circuits can be easily inhibited (blocked), analog circuits are typically only suppressed through the process of subtraction. This is particularly relevant when the analog circuits are operating in the linear domain. A particularly important feature of the analog neurons, so clearly documented with respect to the stage 2 neurons of the retina, is their ability to take differences. This capability is due to their three-terminal character that has been discussed in detail elsewhere^{12,13} but will not be explored or developed here.

A dominant feature of the computations performed within the neural system is the settling time associated with the analog neural circuits. Flicker tests in vision typically suggest this interval to be

⁹Carter, R. (2000) Mapping the Mind. London: Orion Books page 288

¹⁰Uttal, W. (2005) Neural Theories of Mind. Mahwah, NJ: Lawrence Erlbaum Assoc. page97

¹¹Fulton, J. (2008) Hearing: A 21st Century Paradigm. Bloomington, IN: Trafford Chapter 7

¹²Fulton, J. (2004) Biological Vision: A 21st Century Tutorial. Bloomington, IN: Trafford Chapter 4

¹³Fulton, J. (2008) Hearing: A 21st Century Paradigm. Bloomington, IN: Trafford Chapter 3

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on the order of 30 ms or longer. In many electrophysiological measurements, this interval is as long as 300 ms. In the case of phasic stage 3 neurons, their top reported pulse rate is less than 1000 pps and typically less than 300 pps. These circuit settling times and limiting pulse rates, all but rule out any high speed computations such as required to obtain the results of transcendental function calculation in a reasonable time. Alternately, they do support a repetitive settling time that upon averaging a large number of signals could approximate a 40 Hz cycle time¹⁴. Similarly with respect to the volition mode, it is reasonable for the executive to wait a reasonable time for the interpretation and perception of the desired information. The typical interval required for one saccade plus the perception interval is on the order of the “attention blink”¹⁵.”

While the lack of a transcendental computation capability via an MPU is a limitation on the capabilities of the neural system, its ability to perform pattern comparisons appears to be unequaled in the man-made circuit field. A very important circuit configuration is found in the morphologically identified striated (one-dimensional) and reticulated (two-dimensional) regions of neural tissue. These areas can be described as multi-plane structures of orthogonal analog associative correlators. Each of these planes are formed of long arrays of parallel neurites (dendrites or podites) with many boutons forming synaptic junctions with perpendicularly arranged arrays of axons. While the striated and reticulated structures of the cerebral cortex have most frequently been reported to consist of only one plane, the LGN of the thalamic reticulated nucleus (TRN, or NRT¹⁶) has been accepted to exhibit three and in some species four distinct planes. These structures, which can be conveniently modeled as diode junction associative correlators, are extremely important in the operation of the visual and hearing modalities.

The TRN is a more complex structure than described by Taylor, it incorporates two major functional subdivisions, a switching and control function as discussed by Taylor and an information extraction function associated with the posterior masses formed by the TRN sheet, the PGN's, MGN's and LGN's¹⁷. I would modify his description of the TRN (pg 156) by adding one word, “I suggest the NRT as a possible candidate for the site of global control of *nonconscious* cortical activity.” This formulation is compatible with a nonconscious executive (the control portion of the TRN) and a conscious executive (within the prefrontal cortex and probably within BA 46).

Morphology and histology have not provided a clear classification of neurons. The designation pyramid cell is used in many different contexts, beside the larger and smaller variants. In this work, pyramid cells with myelinated axons are associated with the encoding function of stage 3 neurons. All such neurons are described functionally as ganglion cells in this work based on the extensive use of that terminology in documenting the retina. They are frequently found in layer five of CNS tissue. Pyramid cells with unmyelinated axons are used in all other stages except stage 1. These neurons vary greatly in size based on their function. Their size ultimately correlates with their electrolytic impedance level. The largest pyramid neurons without myelinated axons are generally associated with the decoding function of stage 3 neurons. Neurons of this type within the CNS are generally found in layer 4 of the cerebral tissue and receive myelinated axons from other stage 3 neurons. These neurons are defined as stellate neurons in this author's work (a generic label including the many stellate neurons defined histologically).

¹⁴Llinas, R. & Ribary, U. (1993) Coherent 40-Hz oscillation characterizes dream state in humans *Proc Nat Acad Sci (USA)* vol 90, pp 2078-2081

¹⁵Fragopanagos, N. Kockelkoren S. & Taylor, J. (2005) A neurodynamic model of the attentional blink *Cogn Brain Res* vol 24(3), pp 568-586

¹⁶Taylor, J. (1999) *The Race for Consciousness*. Cambridge, MA: MIT Press pg 144

¹⁷Fulton, J. (2010) <http://neuronresearch.net/vision/pdf/15Higher2.pdf> Figure 15.6.1-1

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To fully appreciate the operation of the neural system, it is mandatory to recognize the multiple operating modes of the neural system, particularly within the CNS, as an overlay on the system schematic. The nominal modes within the CNS related to vision are illustrated in **Figure 2.1.1-3**.

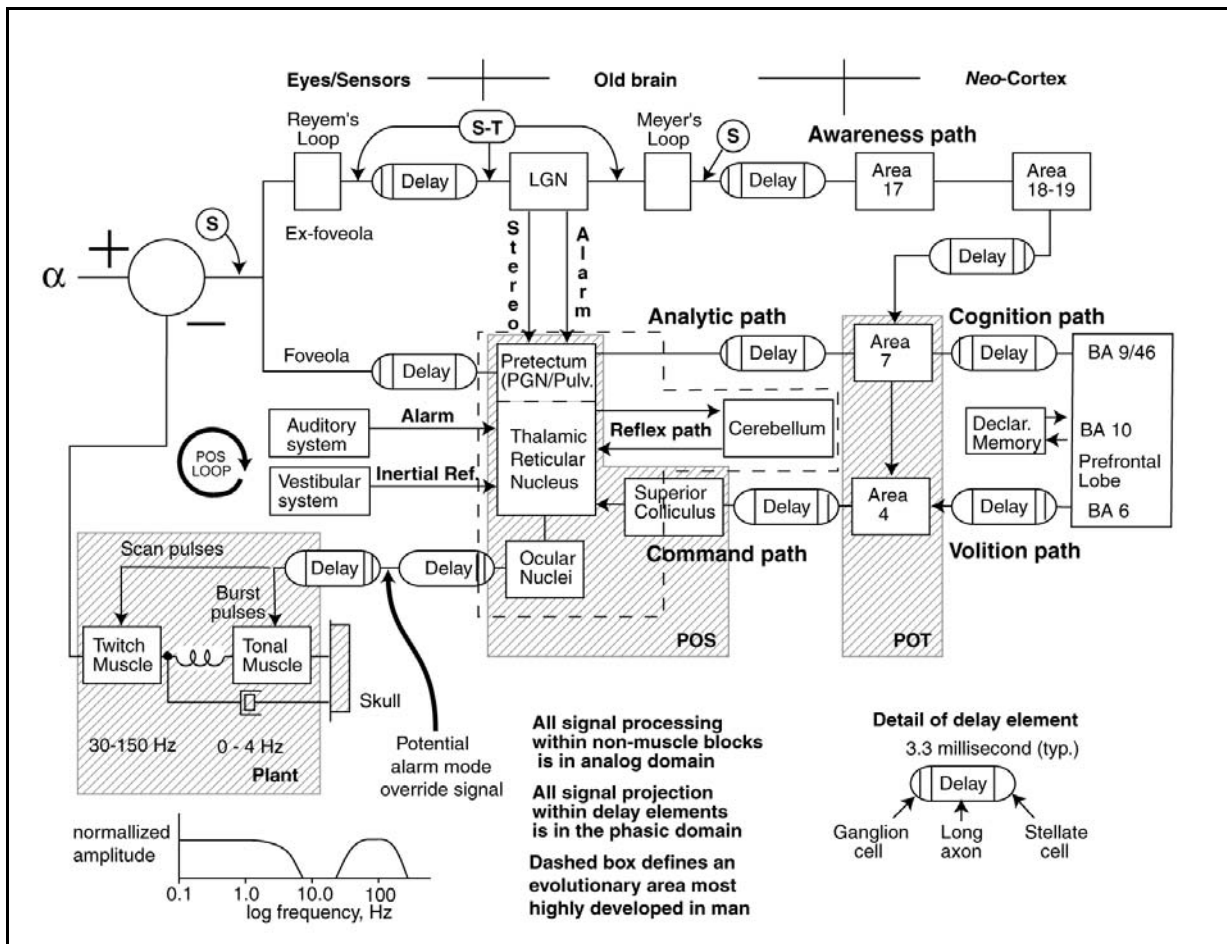


Figure 2.1.1-3 Overall description of the visual sensory system and multiple operating modes. Other modalities are represented by the auditory and vestibular modalities shown in brief to the left of the POS. Note the frequency separation at lower left between the analog and phasic aspects within the ocular plant. The employment of stage 3 encoding introduces a delay of at least 3.3 milliseconds. BA; Brodmann area. See text..

The path indicated from the symbolic differencing element at upper left through the foveola to the PGN/pulvinar, to the ocular nuclei, through the physical plant of the eye, and back to the differencing element composes the precision optical system (POS) servo loop. The neural elements of the POS are shown in the central hatched block. Some of these elements have been known morphologically as the auxiliary optical system (AOS) before their purpose became known.

Note the dual character of the ocular muscles within the hatched box labeled “plant.” While the pedagogical literature (and the cited paper by Gurney) frequently describes the motions of the ocular within the servo loop as ballistic, their motions are only ballistic to a first order approximation as

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demonstrated in the laboratory by Becker¹⁸ and others. [xxy 7.3] The impedance properties of the ocular are such that the twitch muscle drives the ocular in a sawtooth or oscillatory (sinusoidal) displacement that is demonstrably not ballistic.

Time delay plays a major role in the operation of the neural system^{19,20,21}. Individual stage 4 feature extraction engines tend to contain a few million analog neurons and result in a significant delay between input and output. Similarly, a stage 3 commissure of 100 mm length introduces a delay of about 3.3 milliseconds. Picton has documented the major delays in the human neural system based on EEG techniques²². It has been shown that information appears in BA 7 before it appears in BA 17 showing the visual cortex is not a participant in at least some sensory signal analysis.

Effective operation of the POS requires minimal delay within the servo loop. This requires most of the elements of the loop be physically adjacent. The distances involved effectively eliminate all of the cerebral cortex from analytical mode operation (because of the POS requirement) and alarm mode operation. Many investigators have been chagrined to find information present in Brodmann's area 7 (the saliency map) before related signals from the same scene are detected in the visual cortex. The heavy arrow at the bottom represents a potential alarm mode path where the visual and auditory modalities even bypass the bulk of the POS.

The functions performed within the prefrontal cortex remain inadequately defined but three areas can be labeled as shown. BA 46 is probably associated with the conscious executive defined earlier.

2.1.2 Operational modes of neural circuits

The neural system is capable of operating in a variety of definable modes. There are multiple operating modes and a few that can be considered non-operating.

The nervous system, and the sensory neurons of stage 1 specifically, are always operative. However, accessing of the sensed information within the saliency map by the conscious executive of stage 5 may be suppressed at times. This suppression is probably a responsibility of the the TRN, the nonconscious executive within the paleo-cortex. These times are described by the label **STANDBY** mode and relate to the unconscious state. Dreaming is an example; the eyes are closed but the conscious executive continues to manipulate data (particularly imagery) much as if the eyes were open and functioning. The conscious executive of the *neo*-cortex continues to create instructions directed at the motor (muscle) system. However, these are largely interrupted by the nonconscious executive, the TRN.

Even when awake, the nervous system can enter a semiconscious mode involving an apparently fixed visual stare (day dreaming) and less than optimum operation of other sensory modalities. This will be described as the **STARE** mode. In both the standby and stare modes, the fine motion of the eyes defined as tremor continues. Further delineating the standby and stare modes can lead to interesting predictions concerning hypnosis and the concept of a zombie.

¹⁸Becker, W. (1991) Saccades *In* Carpenter, R. *ed.* Eye Movements, vol 8, Vision and Visual Dysfunction. Boca Raton, FL: CRC Press Chapter 5

¹⁹Libet, B. Gleason, C. Wright, E. & Pearl, D. (1983) Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential): The unconscious initiation of a freely voluntary act *Brain* vol 106(3), pp 623-642

²⁰Llinas, R. & Ribay, U. (1993) Coherent 40-Hz oscillation characterizes dream state in humans *Proc Nat Acad Sci (USA)* vol 90, pp 2078-2081

²¹Fulton, J. (2008) Hearing: A 21st Century Paradigm. Bloomington, IN: Trafford Section 7.4

²²Picton, (1980) The use of human event-related potentials in psychology *In* Martin, I & Venables, P. *eds.* Techniques in Psychophysiology. NY: Wiley pp 357-395

When alert (fully conscious), the visual system (used as an example in the above figure) exhibits three major operating modes related to sensing events in the environment and one related to controlling the musculature of the eyes. These are awareness, alarm, analysis and command. The operation of these modes, plus the subsidiary mode supporting stereopsis are under the direct control of the TRN of the *paleo*-cortex. Together, these operating modes are closely associated with servo system known as the precision optical system (POS) shown on the left. They are largely responsible for providing information to populate the visual portion of the saliency map within Brodmann area (BA) 7. This area is shown as the Parietal-Occipital-Temporal lobe junction area, POT, in the above figure²³. The POT is broadened to include areas 1-3 & 7 when other sensory inputs are included. BA 4 & 6 are generally considered the pre-motor and motor areas of the POT directing stage 6 activity.

The **AWARENESS** mode is shared among all but the very lowest phylogeny of animals. This mode provides the interpretive and cognitive centers of the animal with a multi-sensor description of the surrounding environment. It employs an earth-oriented (gravity-oriented) inertial framework that is not related or restricted to the field of view of the eyes of the animal. The interpretations placed in the saliency map based on this framework, are not “- topic” to the sensory mode. They are entirely symbolic but their location within the POT describes their associated receptive field.

The **ALARM** mode may be the primary mode of the neurological system. It is shared by all known animals (including those excluded from the awareness mode). The first order task of the alarm mode is to decide if the trajectory of an object in the environment will cause an imminent collision with the animal. If true, the general response is some degree of flight to escape potential threats. If not, the threat is considerably reduced. Failure to escape by flight can lead to a defensive posture. However, this posture does not appear to represent a separate functional mode.

In many animals, the alarm mode appears to operate as several different levels in response to at least two distinct threat conditions. The simplest case involves the single threat level. The response at this level relates to the naivete of the subject. In small children, the appearance of a threat for the first time may not generate any response. However, this experience can be considered training. On the second appearance of this same threat, the response may be significantly different. Through further training, the response can become quite sophisticated.

The dual (multiple) threat level within the **ALARM** mode becomes quite important within the sports and military regimes. The response to near simultaneous threats at this level is also a strong function of training. Training frequently separates the successful player from the mundane players. The ability to respond to dual threats in the absence of cognition is intimately related to the attention-blink phenomenon discussed by Taylor²⁴.

The **ANALYSIS** mode is most common among the higher chordates and most optimized, both physiologically and programmatically, among humans. The mode depends on the fovea for its operation. For humans, it is optimized in the even more restricted area (1.2° diam.) of the foveola. The operation of this mode appears to differ significantly with respect to scene content.

For the natural scene, or non-symbolic image, the analysis mode appears to operate at one of two sub-levels. In the most general sub-level, the visual system performs a routine search of the field of view to analyze the characteristics of the scene of interest to the animal. This mode appears to rely upon previous images of the scene stored in memory to a remarkable degree. Through this reliance, the animal can restrict the time required to complete an evaluation of the scene based on a search. This type of analysis is encountered when a person enters a room for the first time. On subsequent entries, much less time is used to discover the features of the room. The second sub-level involves specific analyses, performed in response to a signal from the alarm mode, of a given scene element to decide whether it is a threat. These analyses go beyond the calculation of the trajectory of any object moving within the field of view. It seeks to determine the nature of the threat within a more precise context; does the scene element have big teeth?

For the symbolic image, there is a specific analysis mode, with two sub-levels, limited primarily to

²³Fulton, J. (2008) Hearing: A 21st Century Paradigm. Bloomington, IN: Trafford Section 8.5

²⁴Taylor, J. (2006) The Mind: A User's Manual. NY: Wiley page 15

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humans. It involves the detailed analysis of fine detail related to small objects within the instantaneous image on the foveola. These objects can be small objects of art or technology but most often are symbols related to communications (letters and words). The first or routine sub-level relates to objects of previously unknown characteristics. This is the typical analysis performed when a person picks up an unusually shaped rock or a sea shell on the beach. It is also the analytical mode used when someone looks at a document written in a foreign language or unfamiliar script. The analysis involves apparently random motions of the eyes within a few degree field of view. The amplitudes of many individual motions are measured in microradians. These motions are frequently related to tremor and are not random. They are programmed by the POS in accordance with memories associated with any similar object. To construct a perception of the whole object, the eye performs a series of microsaccades (tremor), minisaccades, and if necessary small saccades, to analyze the entire object. This mode involves a large degree of memorization of characteristics and can be considered training.

There is a second sub-level associated with the analysis of symbols. It is strongly influenced by training and memory. It allows the human to quickly evaluate a familiar member of a class of objects previously studied. Although not limited to text symbols, it is most recognizable in that context, i. e. reading. It is based on training in the syntax and vocabulary of a given language. For a language like English, written from left to right and where the first syllable of a word is usually important, the fixation point of the eyes will jump to the right after reading a word. The point of fixation will land on or about the third letter from the start of the word. This nominal motion is known as the "dumb default" in reading. The POS of the visual system will proceed to analyze the group of letters imaged on the foveola and store its interpretation temporarily until the remainder of the word is interpreted. Following sufficient time to analyze the first group of about five letters, the point of fixation will move to the next syllable until it completes analysis of all of the syllables of the word. It will then perform another dumb default to the start of the next word. At the end of a line of text, the point of fixation will drop down to the left end of the next line. Again, it will land on about the third letter from the start of the first word. The process will continue indefinitely. It is not clear how the POS works at the detail level. It may only assemble the interpretations associated with one complete word and pass that information on to the higher cognitive centers via the Pulvinar Pathway. Alternately, it may assemble the interpretations related to whole phrases before performing a global interpretation and sending that interpretation on to the higher cognitive centers.

The **COMMAND** mode is involved primarily with the execution of changes in the external environment (from the subject's perspective) in response to sensory inputs. These responses are predominantly timely but may involve significant delay at the will of the conscious executive. The command mode signals are primarily low level and directed to particular neuro-affectors. They are an expansion of higher level signals that have passed through the cerebellum and/or superior colliculus.

Besides the high level commands circulating within the nonconscious system in response to sensory inputs, there are signals labeled instructions received from the conscious cognitive stage via the **VOLITION** mode. The interplay between this mode and the modes related to sensing is complex and highlights the important role of the TRN. It is the switching and control portion of the TRN that controls the passing of sensory information to the anterior lobe via the cognition path and the passing of the initial (highly condensed) instructions formed in that lobe back via the volition path to the old brain for command generation and execution. The TRN has the final say as to whether to respond to volition generated commands or reflexive commands generated via the alarm mode.

These definitions of physical stages based on electrophysiology and histology and modes of operation based on behavioral characteristics appear compatible with the ideas of Revonsuo²⁵, of Schacter²⁶, of

²⁵Revonsuo, A. (1993) Cognitive models of consciousness *In* Kamppinen, M. ed. *Consciousness, Cognitive Schemata and Relativism*. Dordrecht, Netherlands, Kluwer pp 27-130

²⁶Schacter, D. (1990) Toward a cognitive neuropsychology of awareness: implicit knowledge and anosagnosia *J Clin Exper Neuropsychol* vol 12(1), pp 155-178

Baars²⁷, of Damasio²⁸ and others as cited in Sun (page 162-172), but are more detailed (such as showing procedural elements in both the afferent sensory modalities and the efferent motor-glandular modalities). They also appear able to explain some of the inconsistencies within the psychological literature such as those related to Underwood's saliency map hypothesis discussed below..

2.1.3 The fundamental operating loop of the neural system

Static block diagrams describe the organization of the neural system but a top level feedback loop or state diagram is needed to describe the operation of the neural system. **Figure 2.1.3-1** presents a generic top level feedback loop attributable to virtually any operation within the neural system of any mammal. It can be used to represent the multiple loops described by Alexander et al²⁹. It is also applicable to other animals with a few changes in nomenclature. The figure can be compared to a 1991 figure by Fisher et al³⁰. It has been expanded and further annotated. A fundamental difference is the absence of any "efferent copy" of the motor commands. There is no documented record in the literature of an efferent copy within the neural system. The system is designed on the assumption that the instructions given to stage 6 of the efferent neural (and motor) system are carried out faithfully and within the response time of the sensory system.

The lack of a precise efferent copy, and a true blanking circuit active during visual saccades, is readily demonstrated by looking at a strobe light on an airplane at night. If you move your eyes during the interval including a strobe pulse, your sensory system will report the location of the strobe with a gross error in position that is not consistent with an efferent copy signal.

The figure has been expanded to include a number of functional elements between the sensory integration block and the motor planning block of Fischer et al.. To aid interpretation, the first informational block on the right provides labels to the individual neural paths between the blocks. These labels are augmented by a few labels on the left of the string of functional blocks. The second informational block on the right provides anatomical labels corresponding to the functional blocks. Note the change from –topic sensory signals from the PNS to non–topic "information" within the CNS following the stage 4 sensory information extraction block.

The elements above the cognitive element form the afferent neural system and the elements below the cognitive element form the efferent neural system. It is noteworthy that the sensory cerebellum is functionally separate from the motor cerebellum although they are both elements of the same morphological block, the cerebellum, and appear to be interconnected by commissure.

²⁷Baars, B. (1988) *A Cognitive Theory of Consciousness*. NY: Cambridge Univ. Press

²⁸Damasio, A. (1994) *Descartes' Error: Emotion, Reason and the Human Brain*. NY: Grosset/Putnam

²⁹Alexander, G. DeLong, R. & Strick, P. (1986) Parallel organisation of functionally segregated circuits linking basal ganglia and cortex *Annu Rev Neurosci* vol 9, pp357-381 (also in Taylor, J. 1999 Op. Cit. pg 202)

³⁰Fisher, A. Murray, E. & Bundy, A. (1991) *Sensory Integration: Theory and Practice* Philadelphia, PA: F. A. Davis pg 86

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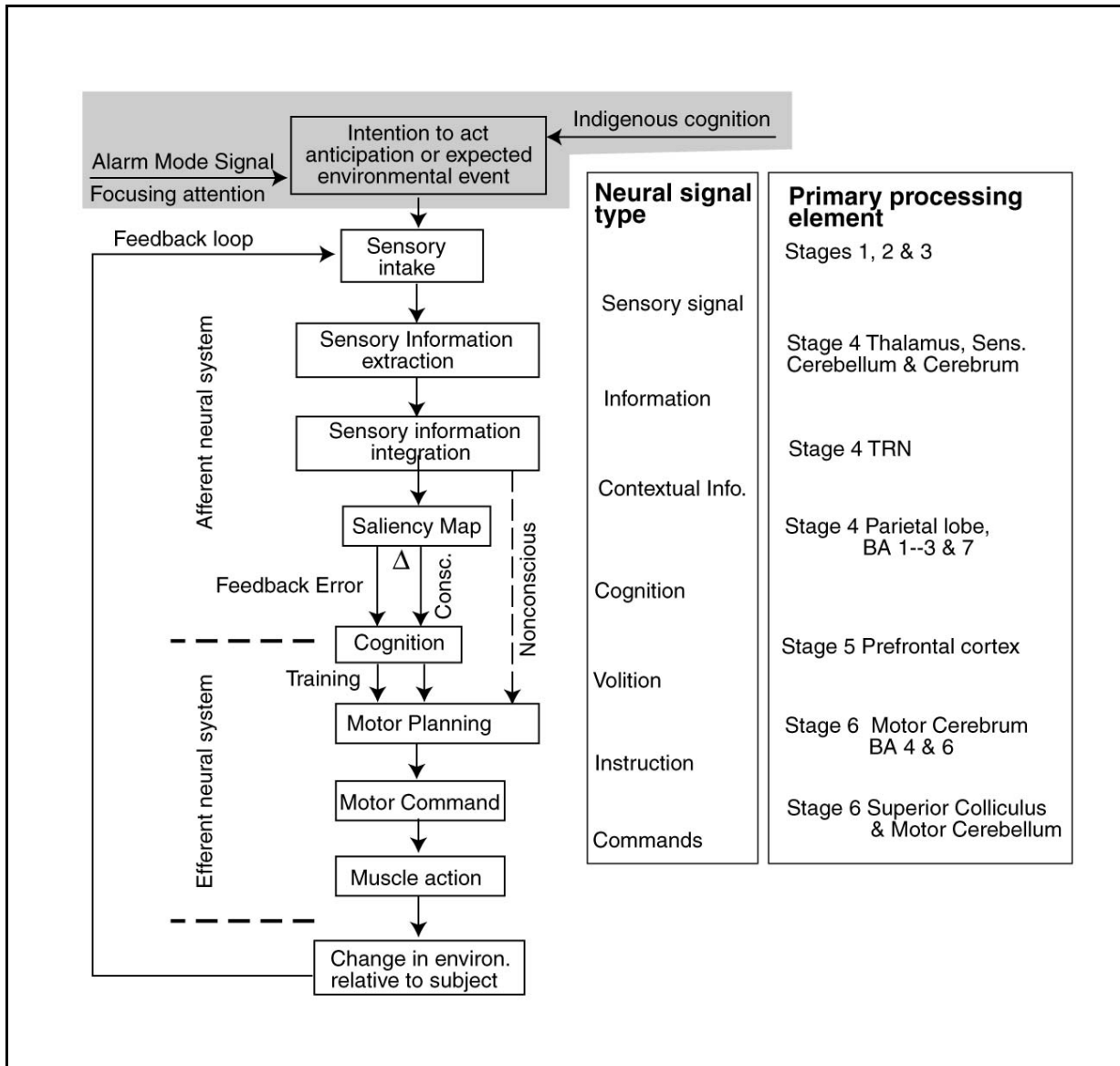


Figure 2.1.3-1 A generic top level feedback loop used in mammalian neural systems. The feedback loop is closed by a path *external* to the subject. See text.

The top block in their figure (intention to act) is misplaced but has been retained for continuity. The block is a statement of the intention of stage 5 cognition to act based on either indigenous thought (volition mode) or stimulation by the various modes associated with sensory operation not otherwise discussed in this figure. As such, it can not change the “intake” of sensory information without going through the blocks described within the efferent system. It should be an integral part of the cognition element in the middle of the diagram. In that role, it sets the initial conditions (the state) of the state diagram of the feedback loop. The nonconscious path from the extraction portion of the TRN to the motor planning elements is shown explicitly as is the training mode path associated most closely with the conscious state.

The saliency map summarizes and presents information from all sensory modalities. It incorporates

what Fisher et al³¹. describe as the “Reference of correctness.” It might better be described as the “Perceived state of the environment and the subjects body” described largely within an earth-oriented (gravity-oriented) inertial reference system. The term gravity-oriented is probably preferred as it allows motion along a curved earth’s surface without interfering with the concept.

The feedback loop path along the left side does not include an error component. The error component is developed at the saliency map by comparing the previous state of the saliency map with the latest state (note the delta symbol for change near the left channel). If greater than a selected magnitude, the cognitive system can decide to take action to reduce the magnitude of the error by issuing further volition channel signals.

Some variants of this figure show an efferent portion of the saliency map shown below the cognition block to indicate explicitly that a set of instructions is passed to the efferent saliency map before those instructions are passed to the cerebellum. For simplicity, the cognitive block is shown with two volition channels to the cerebellum. The goal of these channels varies with the state of learning of the subject. During ontogeny, the cognitive block sends training signals that aid the cerebellum in expanding or correcting its lookup tables. This activity helps the cerebellum improve the quality of its instructions to the superior colliculus. The repeated operation of the generic top level feedback loop in the pedagogical (ontogenic) mode (sometimes described as self-actualization) appears frequently in the occupational therapy literature (pages 5, 19 & 36 of Fisher et al.) Rydeen described a similar, but less detailed, sensory-motor-sensory loop in the context of sensory integration and neurodevelopment³². Fuster has also provides a highly simplified equivalent of this figure over the years and describes the operation of this loop in the training mode as the “perception-action cycle³³.” The difference between sensory integration during ontogeny and sensory integration during routine operation should be noted. The latter is not normally circular with respect to time unless the desired physical protocol calls for repetitious activity. After sufficient training, it is possible for the individual to short cut the complete top level feedback loop by employing a largely subconscious variant of the alarm mode of CNS operation. This mode of operation could be labeled preconscious because the subject is not aware of the action taken until after it has occurred. The subject perceives the implementation and results of the action through subsequent operation of the afferent portion of the feedback loop.

2.1.4 Detailed description of the neuro-ocular-motor system

The neuro-ocular-motor system is ideally suited for describing the multimode operation of a portion of the visual modality. **Figure 2.1.4-1** describes the physiological plant as it is currently understood after merging a variety of individual reports in the literature. It most closely resembles a simpler model reported by Hung³⁴. The detailed development of this model is available via the internet³⁵. The model of horizontal plane operations shown is duplicated in the vertical plane. The system employs a cascaded muscle architecture; it employs a tonal muscle element to control large motions of the eyes associated with version and vergence and it employs a twitch muscle element to perform more rapid but lower amplitude movements associated with the analytical mode of visual operation. These two elements are controlled largely independently by different neural ganglia as shown.

³¹Fisher, A. Murray, E. & Bundy, A. (1991) *Sensory Integration: Theory and Practice* Philadelphia, PA: F. A. Davis pg 86

³²Rydeen, K. (2001) *Integration of sensorimotor and neurodevelopmental approaches* In Huebner, R. ed. *Autism: A Sensorimotor Approach to Management*. Gaithersburg, MY: Aspen Chap 8

³³Fuster, J. (2008) *The Prefrontal Cortex*, 4th Ed. NY: Elsevier page 360

³⁴Hung, G. (2001) *Models of Oculomotor Control*. London: World Scientific, figure 35

³⁵Fulton, J. (2010) <http://neuronresearch.net/vision/pdf/7Dynamics.pdf> Section 7.4

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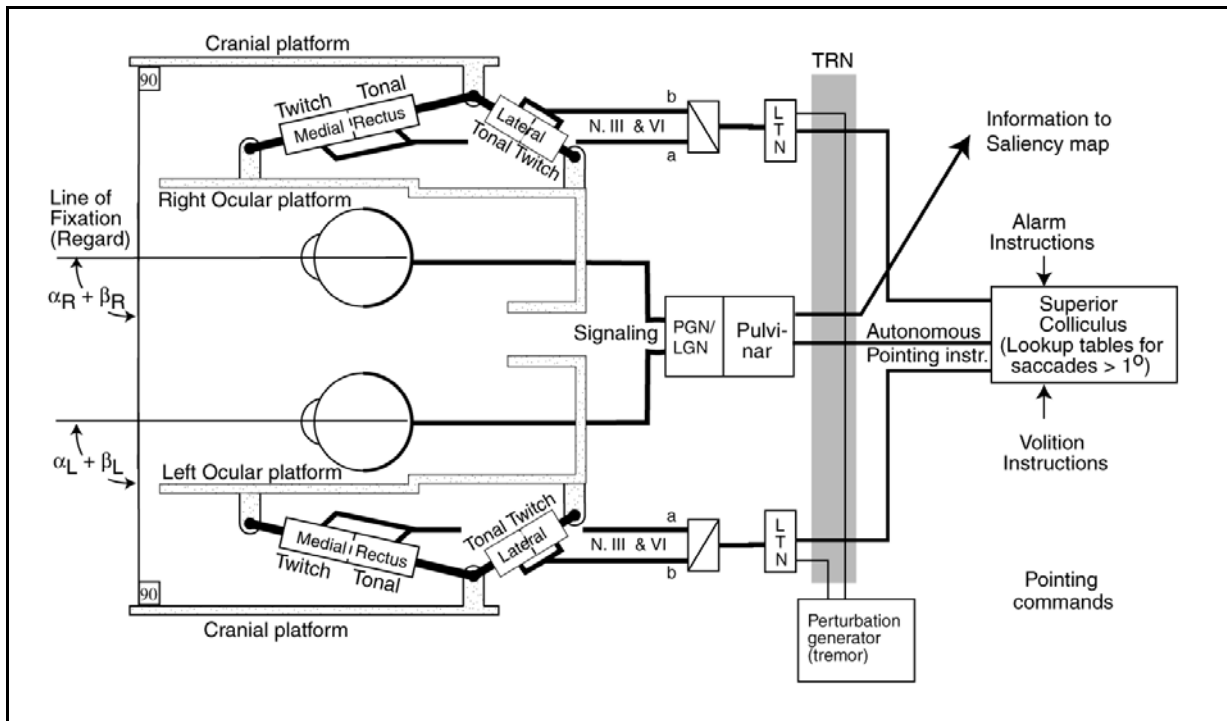


Figure 2.1.4-1 Block diagram of the horizontal vergence system of human vision. The heavy lines representing neural paths are stage 3 projection neurons. The dual character of the medial and lateral rectus muscles are shown explicitly. The oculars are driven in push-pull by the ocular muscles via the numbered nerves, N.). TRN; thalamic reticular nucleus. LTN; lateral terminal nuclei.

The horizontal axes at the left represent the lines of sight of the two eyes. The angles represented by α are determined by the version pointing portion of the system. The angles represented by β are determined by the vergence pointing portion of the system. The α angles generally increase or decrease together. The β angles generally move in opposite direction to achieve convergence. The thalamic reticular nucleus is shown simplified. Its relevant elements in this discussion are the LGN and the PGN. The pair of morphological bodies known commonly as the LGN are major elements responsible for merging the left and right fields of view obtained by the retinas. The sum signals from this merging are projected onto the visual cortex. The difference signals from this merging form the major component of the vergence signals used within the ocular pointing plant. The sum signals form the majority of the awareness mode information extracted from the visual image. They are also the source of both the alarm mode signals generated by the visual system and the signals used to focus the attention of the analytical mode of the visual system. Areas of high spatial contrast density are autonomously flagged as points of likely interest for the analytical mode. The eyes will systematically go to the flagged points of interest in support of the analytical mode of operations.

The above operations suggest a delineation between nonconscious and conscious perception and call for a definition of the term attention, or at least the point of attention. One can argue that *generation* of a percept is the nonconscious (stage 4) act of perception while *addressing* that percept in stage 5 is the conscious act of perception (compare to Taylor, 1999, pg 30). Although well studied, attention remains poorly defined. Taylor has provided a recent summary of his writings concerning attention³⁶.

The point of attention can be defined here in terms of the nonconscious operation of the eyes— as the instantaneous point of fixation of the visual system during nonconscious operation of the analytical

³⁶Taylor, J. (2009) cognitive computation *Cogn Comput* vol 1, pp 4-16

mode of vision. Alternately, it can be defined in terms of conscious operations. In this case, the eyes are not as helpful. The point of conscious fixation can be thought of as the location of a source of sensory stimulation in inertial space. This point need not be in the visual field of view. The point of conscious fixation can also be an abstract point within the mind.

The instantaneous vector from the head to a position of interest in the inertially defined environment usually defines the point of attention. In the short term, such a point of attention may be outside of the instantaneous field of view, especially when cued by another sensory modality.

In the above context, the subconscious includes information outside the range of attention but recallable by the conscious mind. This leaves unconscious as a state of the entire organism, largely incompatible with declaratory functions or mechanisms of consciousness, or the procedural functions or mechanisms of nonconsciousness..

- - - -

The resolution of the visual signals merged by the LGN and delivered to the visual cortex are of relatively low spatial resolution. However they are used to populate an initial saliency map at the output of stage 4 with a representation of the external environment. The saliency map is a non-topic representation of the primarily external environment within an inertial context. It is not limited to the visual field of view. It is generally associated with Brodmann's areas 1-3 & 7. The sensory homunculus graphic attributed to Penfield & Rasmussen³⁷ is frequently interpreted as a topic *divergent* projection of the somatosensory input to area 3. It is actually a non-topic description of the *convergent* receptive field of specific portions of area 3 of the cortex.

The analytical mode of visual operation employs a small region (1.2 degrees diameter) of the retinas centered on the point of fixation of the eyes. The signals from these photoreceptors are propagated to the pair of PGN forming a portion of the TRN. The electrophysiologically identified PGN are not commonly identified in the morphological literature. They are commonly known as the morphological "humps" along the brachia of the superior colliculus that have neurons projecting into the bulk of the pulvinar. The signals projected to the PGN are in a different form, and a significantly higher spatial resolution (nominally 30-100 times higher, see "Processes in Biological Vision," Fig. 7.4.5-1), than the signals propagated to the LGN and onto the visual cortex. These signals are also merged within the PGN/pulvinar couple for two purposes. They initially provide a precision convergence signal to improve the convergence performance associated with the LGN processing channel. They also provide a higher resolution representation of the environment to the visual portion of the saliency map. The PGN/pulvinar couple are also the initial element in the analytical mode of operation leading to the initial interps defining what the visual system is imaging. These initial interps are frequently merged into a second level of interp utilizing the limited ability of the short term procedural memory of the pulvinar. The higher level interp is frequently associated with an interval of about 250 ms associated with the duration of a typical gaze. Becker has provided a distribution describing the typical gaze more precisely. The accumulation of interps to form a more expansive percept is generally performed in or with the aid of the visual portion of cerebellum, prior to propagation to the saliency map..

The perturbation generator operates in two distinct regimes. It can operate in an independent regime where it generates two (horizontal and vertical) low level independent quasi-random signals that keep the oculars in perpetual low level motion (tremor) that insures any contrast edges in the field are swept across the receptive fields of individual photoreceptors in order to insure generation of a sensible neural sensation. This action amounts to a "keep alive" circuit. In the absence of tremor **and** spatial contrast in the visual field, there is no relative motion between contrast elements in the scene projected on the retina and the photoreceptors. As a result, the visual sensory modality goes functionally blind. The saliency map reports the visual field as a neutral gray field. The perturbation generator can also accept commands from the PGN/pulvinar couple as part of the analytical mode of visual operation. When accepting such commands, it generates programmed motions independently in its horizontal and vertical channels that support the analytical extraction of interps by the couple (as discussed below). Poor performance of the circuits associated with the perturbation generator is frequently associated with amblyopia (neurally limited visual acuity).

³⁷Penfield, W. & Rasmussen, T (1950) The Cerebral Cortex of Man: A clinical study of localization of function. NY: Macmillan

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Detailed description of the image information extraction mechanism

The conformal transformation between the scene in object space, the image on the retina and there projection on to the visual cortex are now well documented among the primates³⁸. The ultimate projection onto the cerebral cortex exhibits two very significant problems. First, although representing information at a resolution at least 30 times higher than for peripheral areas, the surface area of the cerebral cortex dedicated to the foveola of each eye is minuscule compared to that dedicated to the periphery. Second, the two foveola are represented at two widely separated positions (behind each ear). There is no known mechanism for merging the two cerebral representations of the foveola. These difficulties are overcome by a simple expediency. The signals from the two foveola presented to the PGN are used for a second critically important task, image information extraction. Like in the highly documented LGN's, the adjacent reticulated PGN's contain a multidimensional associative correlator. These correlators extract a representation, an interp, of the scene imaged onto each foveola. These two representations are combined in the adjacent pulvinar of the thalamus and compared with representations stored in its procedural memory to estimate the character of the imaged scene, described as a second level interp or alternately a percept.

The image information extraction mechanism can be described as shown in **Figure 2.1.4-2**. Each node of the two dimensional array within the PGN represents the signal at one pixel of the retina at a given time, t_k . The signal can be considered to have a null value unless there has been a contrast change since time, t_{k-1} . Each axon arriving at a node is connected to a vertical sensing column by a diode synapse. All of the synapses along each vertical column are summed by one of multiple sensing neurites associated with output amplifiers of the PGN. These signals constitute an interp describing the image on the retina at t_k . A similar process (not shown) occurs with respect to the horizontal rows. These initial interps are passed to the pulvinar where they are used in an associative correlator process to achieve a higher level interp, or percept.

The initial interp is the first recognized location in the neural system where a group of neurons are used to pass information to a subsequent engine. The information is passed using what is commonly known as the bit serial/word parallel format. An individual neuron does not pass a complete packet of information; a group of neurons is required. Barbas & Zikopoulos have reported "distinct clusters" of neurons trafficking between various stage 4 and stage 5 engines³⁹. Lieberman has also spoken of these "groups of neurons" when discussing the higher order stage 4, 5 & 6 neural functions⁴⁰.

The term associative correlator is used, rather than associative memory, to stress the function of comparison between a previously stored and current signal. This process typically involves two signal registers where one is a short term buffer and the other is a buffer associated with a unit of procedural memory. Such procedural memory is typically in the form of a modifiable lookup table (and shown here as a read-only memory, or ROM). If an acceptable match is not achieved by the correlator, the ROM can be updated via a learning protocol.

When a satisfactory match is achieved, a percept, generally formatted differently and more symbolic than either input interp, is issued by the correlator. The pulvinar is a large associative correlator consisting of many procedural memory planes that can all be compared to a single input interp very rapidly. The output of the pulvinar does not contain a copy of the input as frequently defined for the associative memories in artificial intelligence (AI) usage⁴¹. The percept is stored in the stage 4 saliency map along with other sensory percepts for access by the cognitive elements of stage 5.

At a more detailed level, the percept issued by the pulvinar may be routed to the saliency map via the cerebellum, which may employ an associative memory of the type favored in AI.

³⁸Fulton, J. (2010) <http://neuronresearch.net/vision/pdf/15Higher1.pdf> Figure 15.2.5-8

³⁹Barbas, H. & Zikopoulos, B. (2006) Sequential and parallel circuits for emotional processing in primate orbitofrontal cortex *In* Zald, D. & Rauch, S. eds. *The Orbitofrontal Cortex*. Oxford: Oxford Univ Press pp 57-83 page 73

⁴⁰Lieberman, P. (1998) *Eve Spoke*. NY: W. W. Norton page105

⁴¹Haikomem, P. (2009) The role of associative processing in cognitive computing *Cogn Comput* vol 1, pp 42-49

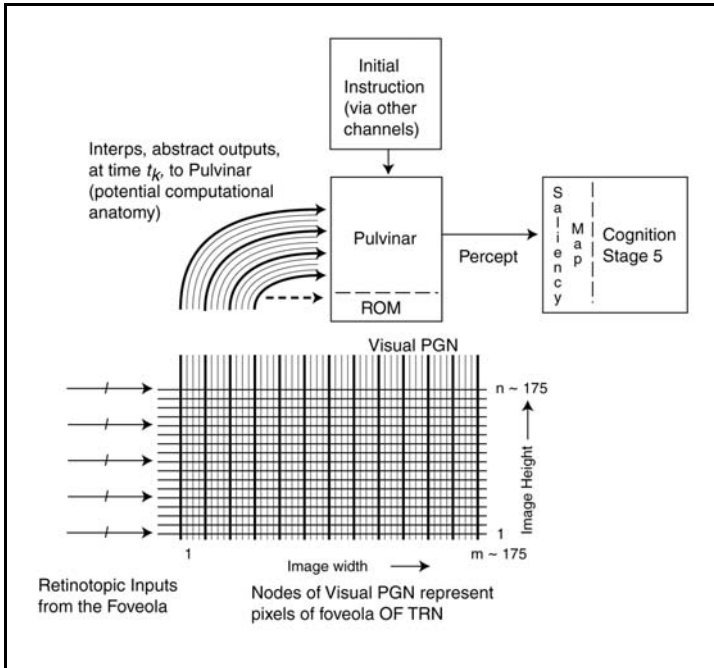


Figure 2.1.4-2 The image information extraction mechanism of vision. The axons of photoreceptors of the foveola connect rectilinearly to the nodes of a two-dimensional correlator. The signals at the nodes are summed in columns and rows to form initial interps that are correlated by association with the procedural memory (ROM) within the pulvinar. Upon suitable match, a percept is forwarded to the saliency map for further analysis by the cognitive element of stage 5. See text.

reasonable range.

Only about 23,000 neurons of the approximately one million within the optic nerve propagate to the PGN. This number would suggest that each plane of the correlator can process a two dimensional array of binary signals with a diameter of approximately 175 elements. Such an array size appears to be well matched to the nominal performance of the human visual system.

Figure 2.1.4-3 shows a five-letter English word imaged on the human fovea at the character size associated with 6/6 (20/20) vision. The word occupies about 43% of the total diameter of the foveola calculated above. This would suggest the human visual system from the foveola to the PGN/pulvinar couple can extract a word of about five letters length with a margin of about three letters and a space on each side of it. Such an estimate agrees very well with the pedagogical simulation provided in Dehaene's book⁴² on "Reading in the Brain." He uses the five-letter word "reads" and shows a few letters on each side of it clearly. DeHaene makes an interesting comment about the trade off between the limited resolution of the foveola and its maximum spatial extent result in a "sweet spot" in reading that is independent of font size over a

⁴²DeHaene, S. (2009) Reading in the Brain. NY: Viking pgs 14 & 222-225

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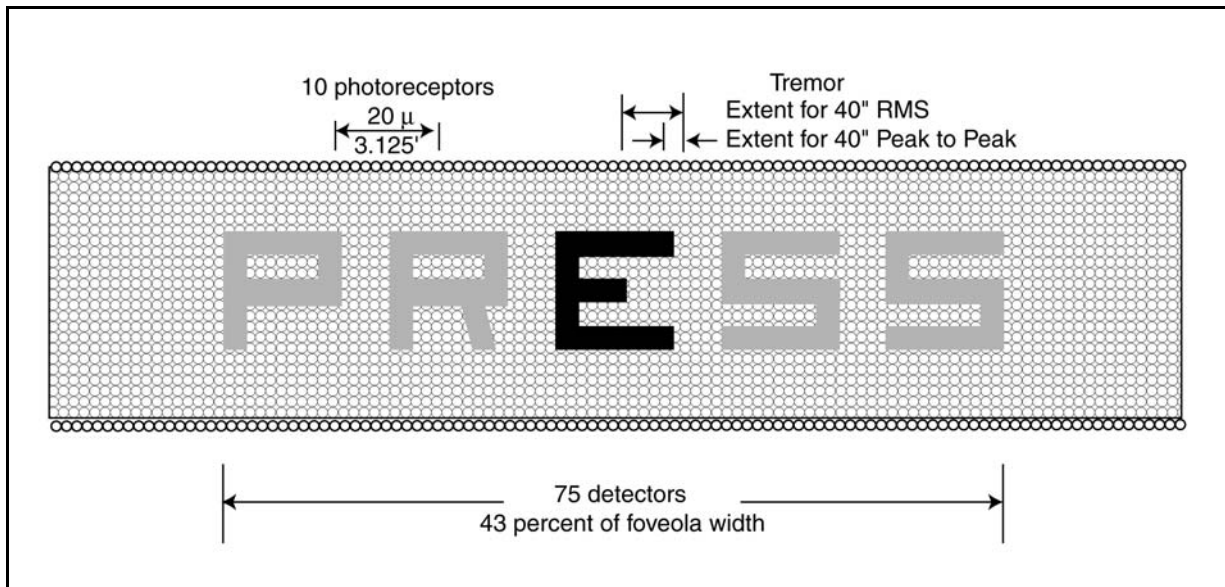


Figure 2.1.4-3 A one syllable word imaged on the human retina with each character the size specified for 6/6 (20/20) vision.

If each pixel element of the PGN correlator occupied 25-36 square microns, the correlator would only occupy one square mm of cortex surface and have a thickness of about 100 micron.. A correlator of this size would be very small relative to the size of the LGN correlators. Unfortunately, an array of this size is also unresolvable using current neuro-imaging techniques⁴³.

Space will not allow a major discussion of the structure of tremor. It is proposed here that tremor consists of independent horizontal and vertical microsaccades that may or may not appear to have a random amplitudes. The potential amplitudes of the horizontal tremor associated with human vision is shown at upper right. The literature is not always specific as to whether reported measurements are peak-to-peak or RMS. The peak-to-peak amplitude of 40 arc-seconds (~10 arc-seconds RMS) appears adequate to cause the edges of significant image features to move between photoreceptors.(shown as individual circles in the figure) during a single microsaccades of tremor.

DeHaene's section title, "The Myth of Whole-Word Reading," page 222, addresses a false dichotomy. He considers only individual letter-based reading versus whole word-based reading when ocular studies by Underwood and his own work on morphemes clearly show that syllable reading is highly significant for words in context of more than about 5 letters.

2.1.5 Computational Modeling of Neural Systems

Gurney has made the case for the Computational Modeling. He followed the logic of Marr who suggested that the description of a model of a particular neural system or cognitive function could be based on the decomposition of the individual tasks into three levels. The top level addressed *what* is being computed and *why*—the computational task. Gurney suggested,

"This top level is sometimes referred to simply as the 'computation'. In this case, the term 'computation' is used to mean 'function' rather than the act or process of computing. At the next level, we describe 'how' the computational is carried out in terms of an algorithm and any associated representations. Finally, we specify 'where' the computation is carried out—which brains system implements the computation. This scheme, therefore, enjoins us to specify the

⁴³Taylor, J. (1999) Op. Cit. page 92

cognitive computation as precisely as we can, before proceeding to detail an algorithm and implementation.”

Terminology is a major problem in a multi disciplinary meta-analysis. Individual specialties employ considerable jargon as a matter of convenience. While Gurney suggests that the noun computation is equivalent to the noun function in his introductory remarks (page 31), in most fields of neuroscience, the term computation is assigned the literal meaning, “The act or process of computing.” This is the meaning used by Gurney in a subsequent paragraph when using the word as an adjective in discussing a “computational problem” relating to an algorithm.

In pursuing this methodology, it is important to determine the mathematical environment in which the algorithms can be formulated. Gurney noted that from his perspective, “many of the detailed computational mechanisms [of the biological system] are still to be teased out.” The typical digital computer contains a module called the mathematical processing unit (MPU) that is specifically designed to process a wide range of mathematical operations, many of which involve transcendental functions. The electrophysiology community has yet to locate any capability, or any result suggestive of such a capability, to perform transcendental operations within the neural system. It is proposed there is adequate data to conclude the mathematical repertoire of the neural system is not capable of transcendental calculations (with the exception of the exponential and logarithm to the base e.). Gurney also noted “with some trepidation” the possibility of this situation. “. . ., when working in a top-down way, what would be the status of an algorithm which is compelling in this explanatory power, but which cannot be transcribed into an abstract neural mechanism or, even if this is possible, results in a mechanism which maps poorly onto the biology?” After a lengthy discussion, including historical elements, Gurney notes, “However, if we cannot discover sufficiently accurate representations of the algorithm in an abstract neural mechanism, and subsequently, a biological implementation (mapping) of that mechanism, we must ultimately abandon the algorithm as biologically plausible.” Instead of an MPU, the desired output representing a transcendental calculation is obtained from a simple programmable lookup tables in procedural memory. *Emulations of neural circuits by digital computers must not employ transcendental functions (other than exponentiation and the logarithm to the base e) or they become biologically implausible.* Failure to recognize this limited mathematical repertoire (a.k.a, rule of evolution) was a major element in the foundering of the AI field late in the last century. Recent papers need to be examined carefully as to their biological (neurological) plausibility⁴⁴.

2.2 Sequences and Protocols in laboratory investigations

A protocol will be taken as a procedure agreed to between a researcher and a subject. Pedagogically, the subject may be considered naive, informed or trained. The terms naive and informed relate to the status of the conscious executive defined above, along with its associated declarative memory. The term trained relates to the nonconscious executive and its associated procedural memory.

A sequence will be taken to describe the operations associated with the nonconscious executive in implementing the agreed protocol.

A protocol may include one or more surprise elements (such as a visual perimetry measurement) and/or one or more non-surprise elements (such as reading a piece of well written text). Implementation of a visual perimetry measurement is a good example of the effect of the protocol on the associated sequence. Normally, a low intensity light appearing in the peripheral field will cause an awareness mode response, a major saccade and an associated head rotation designed to bring the light source to the point of fixation of the eyes for further analysis. The appearance of a very bright light, especially if accompanied by a staccato sound, will cause a different alarm mode response; the closing of the eyes and a turning away of the head. These are the normal sequences resulting from training, during the early years. In a visual perimetry measurement, the protocol calls for a substantially different response. The conscious executive of the subject is to communicate different and overriding instructions to the nonconscious executive. The POS is to maintain the point of fixation on a target dot throughout the experiment. Upon the appearance of a low intensity light in the periphery, the awareness mode is to cause a motor response limited to a finger extremity pushing a button. No saccade is to be performed. This simple change in the sensory-response sequence frequently takes two

⁴⁴Poirier, F. & Wilson, H. (2010) A biologically plausible model of human shape symmetry perception
J Vision vol 10(1):9, pp 1–16

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or three flashes of the light to train first time subjects not to perform a saccade..

2.3 Phenomenology related to the generic system

2.3.1 Predicted performance of the neuro-ocular-motor system

The measured performance of the neuro-ocular-motor system can be precisely accounted for based on the above description. Yarbus⁴⁵ and Ditchburn⁴⁶, among others, [**Processes in Biological Vision, Sec. 7.3**] have shown the functional blindness of the visual system in the absence of adequate angular motion between the imaged scene and the photoreceptors. The loss of visual performance involves a time constant of about 3 seconds. Underwood has described the performance of this subsystem under a variety of normal conditions⁴⁷. Following the “saliency map hypothesis” of Underwood, and in the absence of volition activity, the system operates in the awareness mode and the saliency map initially reports a low resolution representation of a new scene imaged on the retinas. The analytical mode of operation is invoked by cues related to the areas of high spatial contrast density. As a result, the eyes fixate stepwise on the prioritized areas of the visual field. The analytic mode signal processing (information extraction) associated with these fixations generates a higher resolution representation of the important areas of the imaged scene that results in an upgrade of the saliency map.

Underwood has noted his saliency map hypothesis is not followed in all cases. These are cases typified by the overriding of the awareness mode of operation by volition on the part of the cognitive elements of stage 5. Since the analytical mode is building a representation of the real scene, it is possible that incongruous elements introduced into a test scene will conflict with the expected representations in the short term procedural memory of the pulvinar and cause a processing conflict that will disrupt the observed saccadic activity. If cued by other sensory inputs, including verbal instructions from a test conductor, the cognitive elements of stage 5 can direct the immediate fixation of the visual system on specific areas within or outside the visual field using the volition mode of operation. Underwood suggests instructions to find incongruous elements within a scene or to compare two scenes, or to compare a scene with the memory of a scene, leads to volition directed rather than autonomous analysis.

It is critically important that the alarm mode and analytical modes of neural activity provide results as quickly as possible for different reasons. The rapid response of the motor system to alarm mode sensory inputs is critical to the survival of the animal. The ability of the POS to provide representations of individual elements of the environment is critical to the transfer of information, whether symbolic or text, to the recipient. These requirements call for the sensory elements of the major sensory modalities (vision and hearing) be located as close to the information extraction mechanism of stage 4, the PGN/pulvinar complex, as possible. This is achieved in virtually all species. In the human and primate cases, requiring the signals to travel to Brodmann's area 17, 18 or 19 before information extraction introduces an untenable delay on the order of 200 ms or more (signals propagated by stage 3 circuits typically travel at 4 ms/mm). As noted earlier, many investigators have been chagrined to find information present in Brodmann's area 7 (the saliency map) before related signals from the same scene are detected in the visual cortex. The extended signal delays associated with signal paths via Meyer's loops, cannot be tolerated within the POS of the visual sensory system. The same can be said about the POS of the auditory system in animals more dependent on hearing than humans, and particularly if they have mobile penna (external ears) that must be steered.

2.3.2 Operation of the ocular-motor system in percept extraction

⁴⁵Yarbus, A. (1965-Rus., 1967-Eng.) Eye movements and vision. NY: Plenum Press

⁴⁶Ditchburn, R. (1973) Eye-movements and visual perception Oxford: Clarendon Press

⁴⁷Underwood, G. (2009) Cognitive processes in eye guidance: algorithms for attention in image processing In *Cogn Comput* vol 1, pp 64-76

The responsibility of the analytical mode of operation is not just to map the significant areas of the visual field at higher resolution. Its responsibility is to extract from the sensory signals the pertinent information about the character of those signals and present it to the saliency map in the form of percepts. These percepts are derived from the stage 4 signal processing (information extraction) of the PGN/pulvinar couple in conjunction with the visual portion of the cerebellum.

Section 19.8.2 of “Processes in Biological Vision” provides an overview of the reading process. Underwood⁴⁸ has explored the motions of the eye in examining a scene. However, he has not delineated the difference between this examination during analytic mode (a nominally learned nonconscious operation dependent on scene content and its organization) and volition mode (an override mode under direct cognitive control) activity. Becker, et. al. have also provided empirical material on the reading mechanism as of 1999⁴⁹. Both Underwood and Becker, et. al. concentrate on observable eye movements (at the minisaccade level) as the key to our understanding of reading. This work takes an entirely different view. It treats observable eye movement as merely a mechanism for imaging individual scene features, symbols and character groups onto the foveola where the actual process of perception is initiated. This perception involves eye movement at a level not normally observed by the clinician or academician, the microsaccades or tremor level.

Based on the conceptualization developed in this work, **reading can be defined as the act of assembling a sequence of perceptions acquired through the sequential analysis of individual symbols or character groups and interpreting these perceptions in accordance with a set of syntactical rules.** In this definition, symbols include hieroglyphics and other glyphs. The initial interpretation of each symbol or symbol group by the POS results in the generation of an individual “interp.” When a series of interps are combined, the resulting interpretation will be called a percept.

[xxy 19.8.2]

Figure 2.3.2-1 presents a modified, semi-standard figure from Liversedge, Paterson & Pickering in Underwood. It should not be inferred that most of each time interval shown relates to the latency before the next saccade. These saccades may be a part of a planned saccade sequence that does not require a significant latency between the end of analysis within one gaze and the beginning of a saccade to the next gaze location. Thus, a more specific set of subdivisions of the term latency is probably called for here. The times do define the maximum length of time required for the visual system to analyze the structure of the symbols within the foveola adequately for the subject to ascertain their semantic content (probably via a lookup table). The above authors did not address the size of the type (subtense of the height of the characters) used in their experiments but they did say the tracking data was quantized every millisecond.

3.0 Conclusions

The wide range of computational models

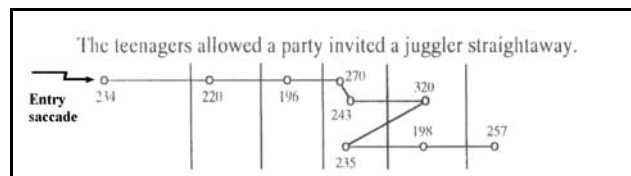


Figure 2.3.2-1 Hypothetical eye movement record showing the time in milliseconds spent in a gaze between saccades. The text being read is at the top of the page. The zig in the line is indicative of a regressive saccade. Total reading time is over two seconds for this single incongruous sentence. The process is highlighted by the regressive scan to analyze further the use of the word invited. From Liversedge, Paterson & Pickering, 1998.

⁴⁸Underwood, G. (1998) Eye Guidance in Reading and Scene Perception. NY: Elsevier

⁴⁹Becker, W. Deubel, H. & Mergner, T. (1999) Current Oculomotor Research. NY: Plenum

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reviewed or cited by Sun⁵⁰ and by Taylor⁵¹ use the same terms in conflicting concepts and with different definitions. They also employ very simple block diagrams to explain tasks (scripts and schema in Taylor, 1999) involving many separate elements of the neural system as recorded by fMRI experiments⁵². The neurological system appears to employ a variety of forms of procedural memory in support of both sensing and motor operations. The resulting configurations are more complex than available computational models suggest or accommodate.

There remains a large gap between the computational models and algorithms of cognitive computation and the documented mechanisms and elements of the neurological system.

The symbolic mathematics used in many of the computational models suggests they employ transcendental functions in their mathematical repertoire that have not been shown to be biologically plausible. As a result, it is difficult to rationalize these models with documented biological substrates and mechanisms.

A claim of biological plausibility in a computational model is inappropriate unless it can be shown the mathematical repertoire used in the model can be accomplished biologically.

4.0 Acknowledgment

All of the meta analyses of this paper were performed by the author. The analyses would not have been possible without the prior contributions of many authors across many multi-disciplinary lines.

5.0 Supporting Material

Rearrangement of the geometric position of neural axons within large nerves and commissure of stage 3 play an important role in information extraction within the sensory modalities. Two situations are important enough to include here.

5.1. Anatomical computation related to the striated cortex of vision

Figures 2, 3 & 4 (pgs 1535-37) of Tootell, et. al. provide significant information on the transformation from object space (not retinal space) to striate cortex space in *Macaque*, at least for the central seven degree circle of the field of view centered on the point of fixation. The figures are immediately suggestive of a conformal transformation of the parabolic form. **Figure 5.1.1-1** reproduces their figure 2 in modified form along with such a parabolic transformation that has been rotated and mirrored to form two lobes. The lobe on the left has been mirrored to create a profile view from the rear of a flattened striate cortex. How the operculi were flattened has an impact on the overall figure. The hatched line along the upper and lower periphery of each real lobe represents the vertical meridian in object space. The hatched line with the heavy dotted extension represents the horizontal meridian. The vertically aligned hatching represent circles of constant radius in the field of view. A shaded area has been added to represent the void between the two quasi-hemispheres of the occipital lobe. The area within the dashed lines represent the extensions of the operculums into their medial surfaces. For the monkey, the visuotopic projection enters the sulcus at about 11° from the point of fixation.

⁵⁰Sun, R. (2002) Duality of the Mind. London: Lawrence Erlbaum Assoc.

⁵¹Taylor, J. (2009) Cognitive computation *Cogn Comput* vol 1, pp 4-16

⁵²Fuster, J. (2008) The Prefrontal Cortex, 4th Ed. NY: Elsevier Chap. 7

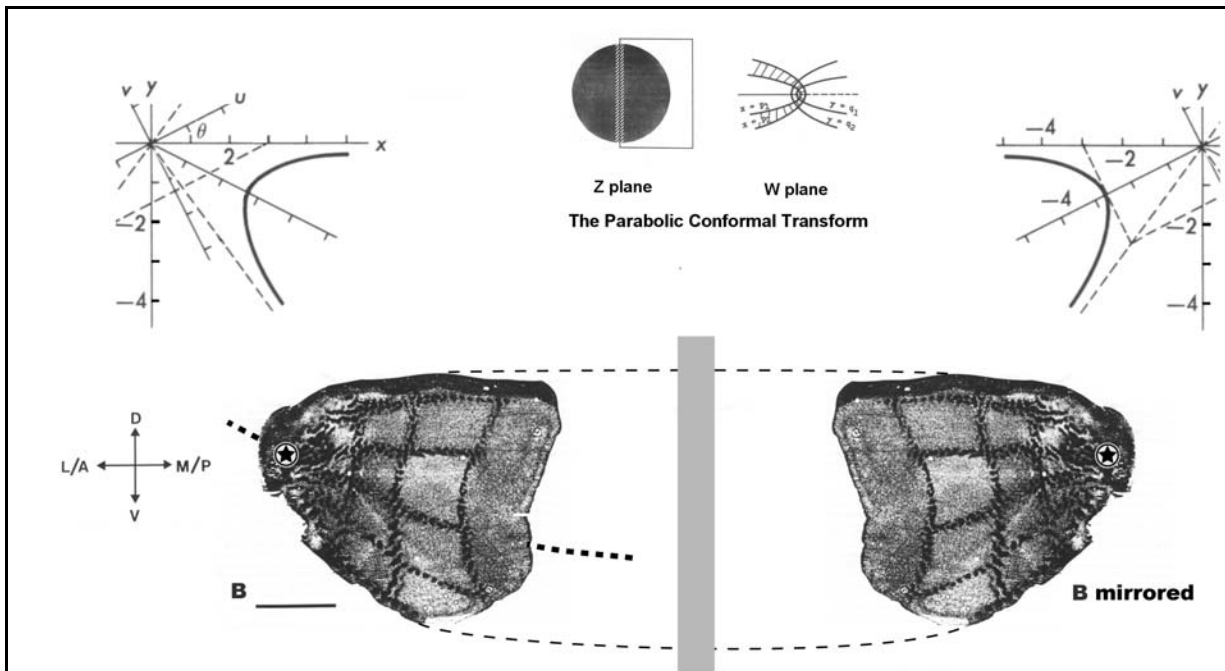


Figure 5.1.1-1 DG autoradiograph of striate cortex of *Macaque* and the conformal transform. Scale bar; 1.0 cm. Note the hatched line along the periphery of the operculum at lower left. This line represents the vertical meridian in object space. The point of fixation is shown by the star. The image has been mirrored to form the image at lower right and simulate an entire striate cortex. The shaded bar represents the separation between the two hemispheres at their most anterior medial location. The areas within the dashed lines to each side of this bar are located on the medial surfaces of the two hemispheres. The orientation cross is correct for the left operculum. The heavy solid lines in the drawings above each operculum represent the predicted vertical meridian based on a rotated parabolic conformal transformation from object space. The un-rotated transform pair is shown at the top center. Imagery from Tootell, et. al. 1988.

Cowan⁵³, based on the 1977 work of Schwartz⁵⁴, has described the transform applicable to Tootell's (and earlier worker's) imagery as a complex logarithmic transform. This type of transform was considered initially in preparing this work but the complex parabolic transform appears to fit the situation more precisely. The analysis by Schwartz is largely conceptual and somewhat superficial. It suggests infinite magnification at the point of fixation and the horizontal lines in his Table 1 do not fit his cortical hemisphere in Figure 1C. The area of Figure 1C in the region of the dashed lines is not correctly portrayed. Schwartz revised his baseline in 1980⁵⁵ and called for a different complex logarithmic transform incorporating a sum in the w-plane expression for z to alleviate some of the above problems. Figure 1 in the new paper also exhibits problems. Schwartz was forced to limit his representation to the central 20-30° of the visual field. The complex parabolic transform proposed here does not suffer from these limitations.

⁵³Cowan, J. (2006) Dept. of Math., Univ. Of Chicago. (Lecture at Redwood Center for Neuroscience, 14 February 2006)

⁵⁴Schwartz, E. (1977) Spatial mapping in the primate sensory projection: analytic structure and relevance to projection *Biol Cybernetics* vol 25, pp 181-194

⁵⁵Schwartz, E. (1980) Computational anatomy and functional architecture of striate cortex: a spatial mapping approach to perceptual coding *Vision Res* vol 20, pp 645-669

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No effort was made to optimize the parameters of the transform or the angle of rotation. However, it is clear that the form of the parabolic transformation is appropriate. By adjusting the angle, θ , and the width of the heavy line in the transformation, an excellent mathematical overlay of the data is available. The equation defines a finite magnification at the location of the point of fixation. Note the parabolic transform results in an open architecture. This architecture allows the field of view of an animal to be increased by expanding the radius of the occipital lobe (over evolutionary time scales).

The parabolic transform used, shown at upper left, is from a dictionary by Kober⁵⁶ and the rotational procedure is presented in Roberts⁵⁷. The hashed area in each figure of the transform pair represent the same area. The lines marked q_1 & q_2 represent horizontal lines displaced from the axis in the left transform pair. Tootell, et. al. noted the experimental difficulty of aligning the vertical meridian of the test target with the point of fixation. Fortunately, they found that the individual operculi mapped an area slightly beyond the vertical meridian. Thus, a finite width vertical bar centered on the point of fixation was mirrored completely in both halves of the striate cortex. More significantly, two separate copies of the area near the point of fixation in object space were formed within the striate cortex.

Yamamoto et al. have recently provided an analysis of what they describe as the retinotopic projection on the human visual cortex using fMRI⁵⁸. Their clinical activity correlates well with the above discussion. They also introduce a number of new clinical techniques useful in diagnostics. They show that the foveola is not well represented in cortical space, disappearing off the representations at the left and right extremes.

It should be noted that while the community speaks casually of a retinotopic projection, this is not the precise case in this instance. Within about one degree of the line (and point) of fixation, object space is mapped linearly into a retinal image. At greater angles, the image of object space is no longer linear. It involves a trigonometric transform. The curvature of the right-most hatched lines in the Tootell figure (area farthest from the foveola) appear to highlight the presence of this additional transformation. In a truly retinotopic transformation, these lines (and the ones to their left) would be parabolic and concave to the left.

Data is available in Schwartz and elsewhere describing the mapping of the visual field onto the LGN and other visual areas but no information has been found mapping the visual field onto the PGN. It appears the mapping onto the LGN and the PGN are basically linear.

5.1.1 The cortical magnification factor in *Macaque*

Tootell, et. al. have provided the best available data on the cortical magnification factor, CMF, of monkey including a discussion of its uniformity among species of monkey⁵⁹. The data is relative to object space and shows a systematic difference in CMF along the horizontal and vertical meridians of object space. It also clearly documents the parabola shaped representation of the vertical meridian in striate space. As a result of this feature, the local sign varies by nearly 150 degrees over the surface of the striate cortex. Because of this fact, it is possible to define virtually any global sign desired for this projection, depending on what integration area is used.

The data only applies to the central seven degrees of the field of view associated with the visual cortex. Within this region, the CMF varies along the two meridians (one of which is greatly curved) by a factor of five or six to one. The variation of the CMF outside of this small central region of the field of view is not addressed.

Using the mesh technique discussed in **Section 15.1.2.3.4**, and the transform equations of the previous section, it is possible to define the theoretical CMF for the *Macaque* quite precisely. The transformed mesh provides the local cortical magnification factor along each of the primary axes of object space at each point in striate space. By summing these two factors vectorially, a local vector is provided that exhibits both magnitude and angle. The angle of this vector relative to the stereotaxic axis defines the local sign at that point. The theoretical form provides a more precise

⁵⁶Kober, H. (1957) Dictionary of conformal representations NY: Dover, pg 36

⁵⁷Roberts, A. (1972) Introductory Calculus. NY: Academic Press, pp 39-41

⁵⁸Yamamoto, H. Ban, H. Fukunaga, M. et al. (2008) Visual field representations in human visual cortex *In* Portocello, T. & Velloti, R. eds. Visual Cortex: New Research New York: Nova Science Publ. pp 195-226

⁵⁹Tootell, R. Switkes, E. Silverman, M. & Hamilton, S. (1988) Op. Cit. pp 1531-1568

interpretation of the CMF than defined to date empirically. Whereas Tootell, et. al. speak of a difference in CMF between the superior and inferior quadrants of the visual field, the theoretical CMF shows that the variation in magnification is continuous, varies significantly with position in the field, and depends on the rotation angle, θ . Only within a fraction of a degree of the point of fixation is the CMF remotely constant with angle in object space.

5.1.2 Retinotopic spread and acuity limits

Tootell, et. al. designed specific experiments to evaluate the resolution capability of the monkey based on the “Retinotopic” spread function (although their test configuration actually defined a spread function relative to object space). This is a minor point but is important from two aspects. The experiments focused on an eccentricity of 3° , well beyond the range of paraxial optics. At this point, the spread function of the physiological optics is significant in the overall performance of the eye. The spread function of the typical eye at 3° , derived from resolution tests, is considerably lower than for the foveal condition.

They found that the spread function at the striate cortex for the 3° eccentricity was about 2.2 minutes of arc in object space (140 microns in striate cortical space). While this may correspond approximately to the value of 1.5 minutes of arc given by Westheimer (1982), it is considerably below the limiting resolution of the human foveola which is less than 20 seconds of arc, based on either photoreceptor pixel size or tremor amplitude. Tootell, et. al. indicated the limiting spread function referred to the DG technique alone was about 100 microns at the half-amplitude points (pg 1505). Further development of the DG technique will be required to obtain a spread function size more indicative of the limiting resolution of the eye.

5.2 Anatomical computation related to tonal hearing

A similar discussion and description for the auditory information extraction mechanism is available⁶⁰. The material shows how a rectilinear Riemann transform is embedded in the cochlear ganglia or the acoustic nerve performing computational anatomy (anatomical computation). The correlation process is similar to that for vision but simpler as shown in **Figure 5.2.1-1**. The function appears to be performed in the auditory PGN located morphologically in the brachia of the inferior colliculus (a location analogous to that of the visual PGN). The discussion shows how a single chord of multiple notes is recognized regardless of the octave register in which it is played. It also shows how the concept of perfect pitch is a skill best learned at an early age and by those speaking tonal languages. The auditory system also employs a multi-dimensional correlator to extract “angle to the source” information from the binaural signals. The mechanism is usually associated with the inferior colliculus (IC). The precise location of this mechanism is not firm and it may be adjacent to the functionally similar auditory PGN.

⁶⁰Fulton, J. (2008) Hearing: A 21st Century Paradigm. Bloomington, IN: Trafford Section 8.4

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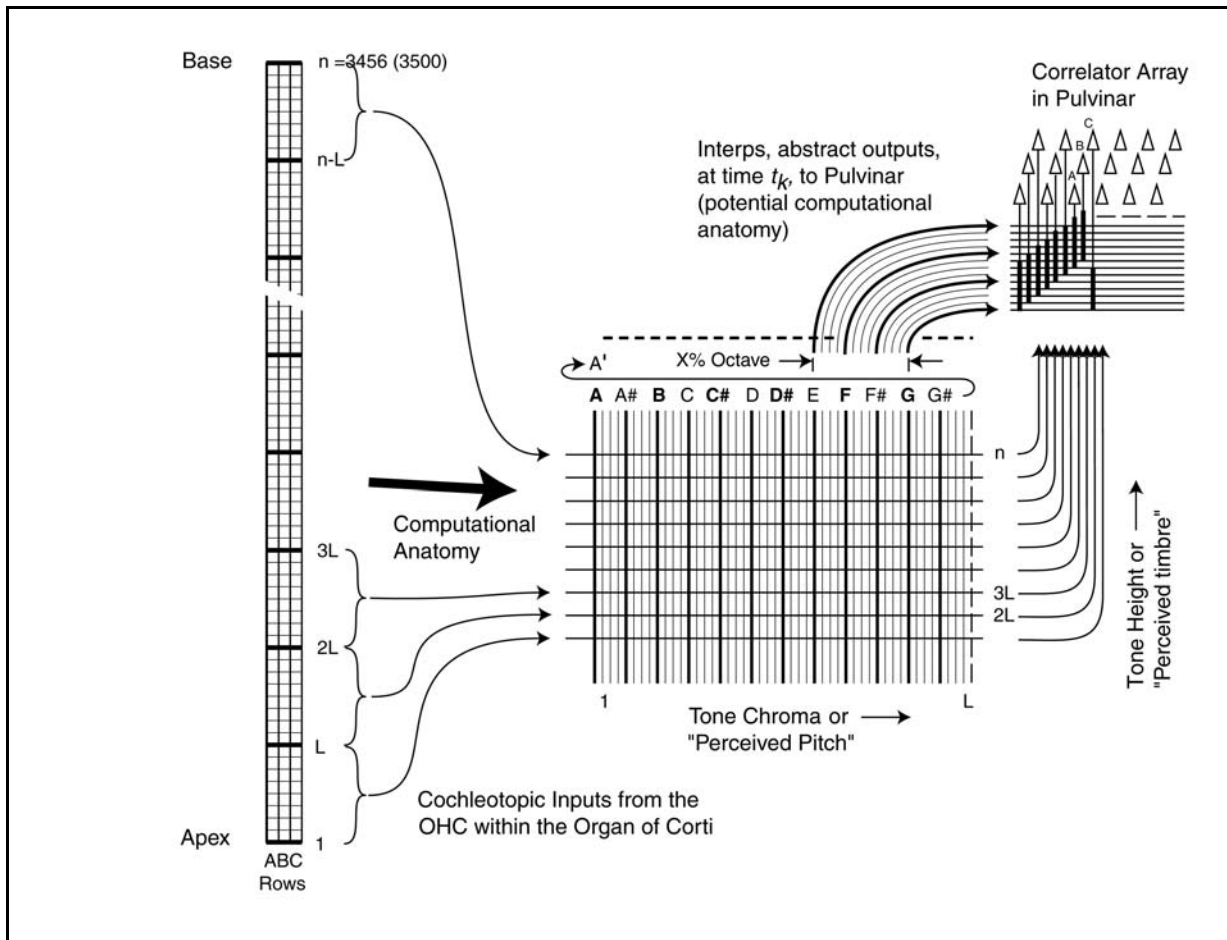


Figure 5.2.1-1 The conformal transformation of hearing with octave folds. The continuous auditory spectrum is divided into octaves by the cochlear ganglia and assembled into a two dimensional array by the PGN prior to extraction of the interps related to pitch and timbre.

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