

Excerpts from

The NEURONS and NEURAL SYSTEM

This material is excerpted from the full β -version of the text. The final printed version will be more concise due to further editing and economical constraints.

A Table of Contents and an index are located at the end of this paper.

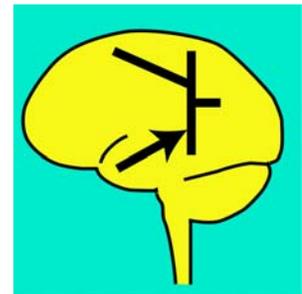
A few citations have yet to be defined and are indicated by "XXX."

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Neural Concepts

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18 The Elements of Consciousness ¹

18.1 Introduction

It is useful to discuss a variety of aspects related to and inter-related between the mind, brain and body. Principle among these are the subjects of consciousness and intelligence. In recent times, the literature has used the term consciousness as the preferred synonym for the mind. At an earlier time, the term mind replaced (the non-theological aspects of) the term soul².

Dehaene has provided a comprehensive discussion of consciousness and the brain based on 21st Century concepts³. He begins with a historical review of the discussion of consciousness from Greco-Roman times up through the Philosophy era and prior to the Scientific era involving the 19th and 20th Centuries. He explicitly notes the pause in discussions related to consciousness imposed by the dons of psychological research during the mid portion of the 20th Century; the pause (virtually a ban) was based on the position that the tools needed to conceptualize consciousness at a meaningful level were not available at that time. Baars began to lift the ban in his large scale book of 1988⁴. The book remains foundational among the psychology community. Dehaene attempts to lift that ban/pause further and provide a 21st Century discussion of the subject of consciousness. However, he continues to develop the subject without the benefit of a neurological framework. As a result, his material relies upon a disparate set of behavioral findings lacking a framework. As an example, his figure 3 in Chapter 1 presents a useful illustration of "Troxler fading" without any reference to the adaptation mechanism of the sensory neurons of vision, or their interconnection and signal summation associated with stage 2 signal processing within the visual modality. As a result, he treats the Troxler fading phenomenon as associated with the higher levels of brain activity associated with consciousness when it is in fact a direct result of the adaptation amplifiers within the stage 1 sensory neurons and the stage 2 field angle dependent signal summation mechanism.

No one should undertake an in-depth study of consciousness without first reviewing Dehaene's book (preferably after first establishing a physiological framework based on this work). A variety of figures appear in his book but they are primarily to illustrate concepts, frequently based on anecdotal encounters with the brain (within the medical community context) rather than histological, morphological or neurological facts. Even under these circumstances, the clarity of Dehaene's discussion is very valuable. His effort in Chapter 1 to

¹Released: 1 August 2016

²Uttal, W. (2005) *Neural Theories of Mind*. Mahwah, NJ: Lawrence Erlbaum Assoc. pg 50

³Dehaene, S. (2014) *Consciousness and the Brain*. NY: Viking

⁴Baars, B. (1988) *A cognitive theory of consciousness* Cambridge: Cambridge Univ Press Subsequently published in electronic form, including a Kindle edition <http://www.theassoc.org/files/assoc/BJBaars%20-%20Cognitive%20Theory%20of%20Consciousness%20%28Cambridge%201988%29.pdf>

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simultaneously subdivide and greatly clarify the definitions related to consciousness is to be lauded.

Hawkins has presented interesting material concerning the state of consciousness and related subjects aimed at the layman⁵. His goal was to establish a coherent theoretical framework for discussing intelligence.

Recently, Gazzaniga et al. allocated a significant part of a large neuroscience book to the subject of consciousness⁶. Following an introductory piece by Koch, the philosopher Chalmers begins with the provocative title, "How can we construct a science of consciousness?" Sun has also dedicated a significant part of his book to a discussion of consciousness⁷. The fourth edition of Gazzaniga et al. appeared in 2014. It continues to support the view that the term "neuroscience" has been captured by the psychology community and its use remains largely conceptual (**Section 18.9**). The fourth edition (2014) remains dominated by caricatures of the major pieces of the neural system with no subject matter devoted to the morphology, histology or cytology of the underlying neural system. Figure 1.13 shows a nice 2D shadowgraph of a "Purkinje cell of the cerebellum that fails to distinguish between the dendritic and poditic structures of this bi-stratified neuron. Both frames a & b are labeled as Purkinje Cells even though a is bi-stratified while b is an example of an amercine neurons. The introduction provides a nice pictorial record of historical workers in the field. Further comments appear in **Section 12.1.3**.

At about the same time, Bennett & Hacker offered a book that takes exception to the views of nearly everyone else with regard to consciousness on philosophical grounds⁸. They appear to offer little to advance understanding of the subject. Their use of common or garden psychological terms has been related to "folk philosophy (page 415)."

Searle has introduced a framework that appears to be important in discussions relating the "mind" to the "brain" or CNS. He attempts to separate the philosophical realm from the scientific realm, and explain the peculiar relation of philosophy to science. Quoting Bennett & Hacker, "Searle claims, as soon as we can revise and formulate a philosophical question to the point where we can find a systematic way of answering it, it ceases to be philosophical and becomes scientific." This view is supported in this work.

Some experiments and resulting conclusions of Libet continue to play an important role in discussions of consciousness and the mind⁹. A 1985 paper in that volume, and the accompanying multi-correspondent critique is very important. The volume needs to be examined closely in the light of the multistage character of the neural system proposed in this work (specifically how he accounted for the time delay related to the stages 6 & 7, in responses to the mental states of his subjects). Such analyses may provide additional insight to the operation of the prefrontal cortex in the context of the mind. Bennett & Hacker (page 228) provide a superficial discussion of his work. Taylor has also addressed the Libet work within one page of text¹⁰. Much of the discussion of Libet's work is appropriately addressed in **Section 19.7**.

⁵Hawkins, J. (2004) *On Intelligence*. NY: Times Books

⁶Gazzaniga, M. *ed.* (2004) *The Cognitive Neurosciences*, 3rd Ed. Cambridge, MA: MIT Press pp 1107-1210

⁷Sun, R. (2002) *Duality of the Mind*. Mahwah, NJ: Lawrence Erlbaum Assoc.

⁸Bennett, M. & Hacker, P. (2003) *Philosophical Foundations of Neuroscience*. NY: Blackwell

⁹Libet, B. (1993) *Unconscious cerebral initiative and the role of conscious will in voluntary action in Neurophysiology of Consciousness*. Boston: Birkhauser page 269-309

¹⁰Taylor, J. (2006) *The Mind: A User's Manual*. NY: Wiley page 66

The following discussion follows directly from the discussions of cognition from a neuroscientific perspective in Chapter 12.

18.1.1 The character of consciousness

Consciousness has been left largely undefined, or defined only anecdotally, in the literature for a very long time. Various investigators have defined it based on their narrow needs. Buzsaki (pages 360-370) discusses the recent ideas concerning the definition of consciousness without converging on a new definition. His final comment is quotable, "It may turn out that the rhythms of the brain are also the rhythms of the mind." Taylor has provided a broad discussion of its aspects for the general reader. Usually, it is defined in terms of awareness of the surrounding environment and of itself. Dehaene has provided a new book in 2014 covering the role of consciousness related to the brain¹¹. The book is aimed at the popular press but does provide a variety of useful definitions that will be considered below.

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Consciousness can be defined as the ability of an animal to recognize a situation and control the response. This definition clearly applies to a wide range of animals.

The question of whether animals exhibit consciousness or not is proceeding unabated within the philosophical community¹².

Consciousness is initially defined for the purposes of this work, as the awareness exhibited by an individual of its surrounding environment, its awareness of its physical self, and its awareness of declaratory neurological (mental) and motor activity being conducted by the self. This definition applies to a at least a wide range of mammals and birds. It will be expanded as we proceed.

With the definition of consciousness, several synonyms can be defined. Aconsciousness is defined as the presence or activity of objects in the external environment, and/or the presence or activity of elements of its self, of which the subject is not aware.

Between these two end points, there are a series of conditions that can be defined.

Arousal– A physiological state of readiness elicited by the subjects's perception of the environment (Huebner & Lane, pg 69).

Attention– A hyper-state of consciousness with respect to certain aspects of the external environment or related to self, with the suppression of other states.

Sleep– A hypo-state of consciousness with respect to certain aspects of the external environment or related to self, accompanied by other physiological processes designed to conserve and/or restore bodily functions to homeostasis.

Coma– An extended form of sleep designed to more fully isolate the state of awareness from the surrounding environment and other elements of the self.

Consciousness–

Preconscious– Neurological activity, that may result in muscular activity, occurring before the subject becomes aware of the process.

Subconsciousness– Frequently used to describe the state of awareness to external and internal activities outside the hyper-state described as attention.

¹¹Dehaene, S. (2014) *Consciousness and the Brain: Deciphering how the brain codes our thoughts*. NY: Viking *Softcover from Penquin Books*.

¹²Aleksander, I. (2005) *The World in My Mind, My Mind in the World*. Imprint-academic.com pages 89-92

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Unconsciousness– Used variously;

1. A state of coma induced by trauma and typically temporary in nature designed to protect the self.
2. The lack of awareness of a multitude of bodily functions under the control of the autonomous nervous system.

Autonomous nervous system– The system designed to supervise and carry out a myriad of functions related to homeostasis in a subject. Typically subdivided into the sympathetic and para-sympathetic nervous systems

Somatic nervous system– Infrequently used to describe the aspects of the nervous system supporting awareness of the subject, including the sensory modalities, but not including the autonomous nervous system.

Central nervous system– That portion of the somatic nervous system located within the cranium (skull) of *Chordata* (*Vertebrata*) and generally consisting of the paleocortex and neocortex (where present). In this work, the CNS does not include the peripheral elements of the olfactory, gustatory, visual or auditory sensory modalities also located within the cranium.

Peripheral nervous system– That portion of the efferent neural system located outside of the cranium and the afferent sensory modalities not part of the paleocortex or neocortex.

Wakefulness– The quiescent state of consciousness when the subject is not asleep or in coma.

It is extremely difficult to interpret the operation of the neural system of animals without at least two representations of the system. **Figure 18.1.1-1** reproduces a top level block diagram from Section xxx. It includes the stage 3 signal projection circuits, which are the only circuits within the neural system that actually operate in the pulse mode and generate “action potentials.” The vast majority of neurons within the neural system (over 95%), including virtually all of the neurons of stage 5, operate in the analog signal regime.

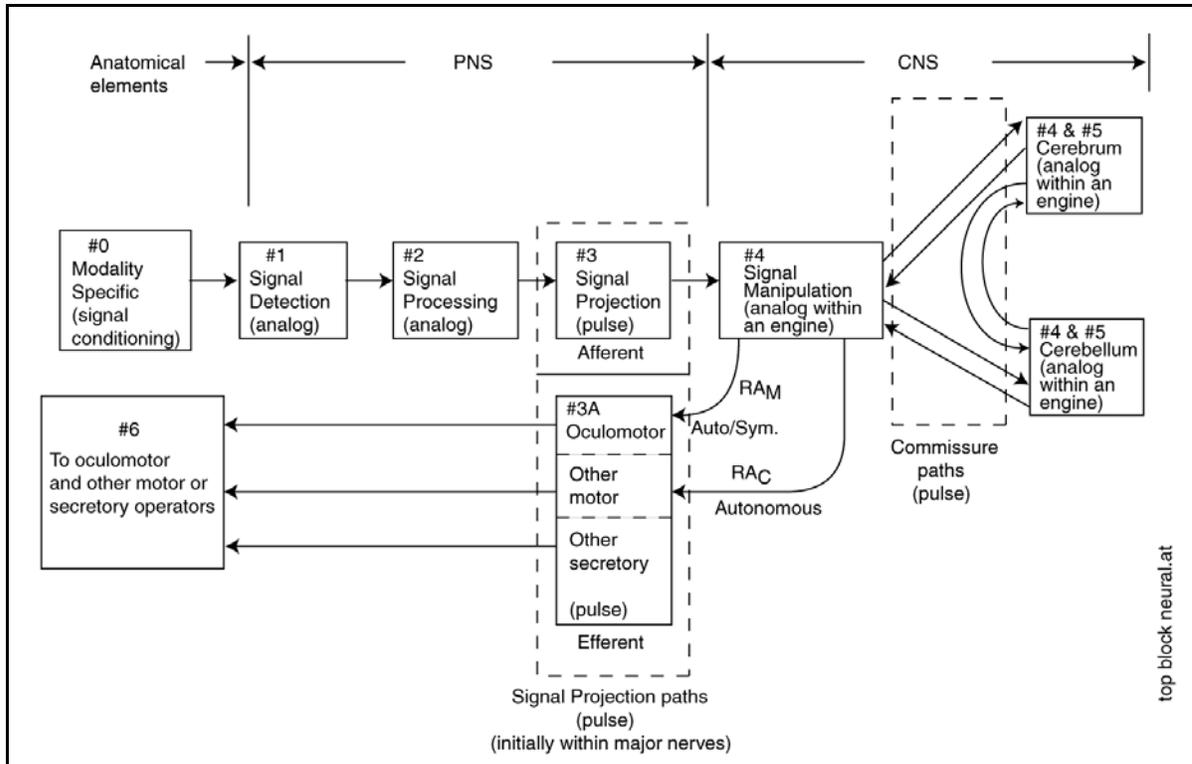


Figure 18.1.1-1 Top level block diagram of the animal neural system ADD. The activity of the stage 5 engines of the cerebrum, frequently described morphologically as the prefrontal cortex, are principally responsible for cognition. This involves processing the information provided by the engines of stage 4 and volition (independent thought) prior to the issuance of instructions to the stage 6 neural elements, generally via the saliency map (not shown) but associated with both the input and output of stage 5. Stage 5 is proposed to be the seat of the more ephemeral concept of “the mind.”

Figure 18.1.1-2 reproduces a more flow oriented top level schematic of the animal neural system from Section xxx. At a more detailed level, the schematic presented in **Section 4.6.3** develops the role of learning and memory within the neural system.

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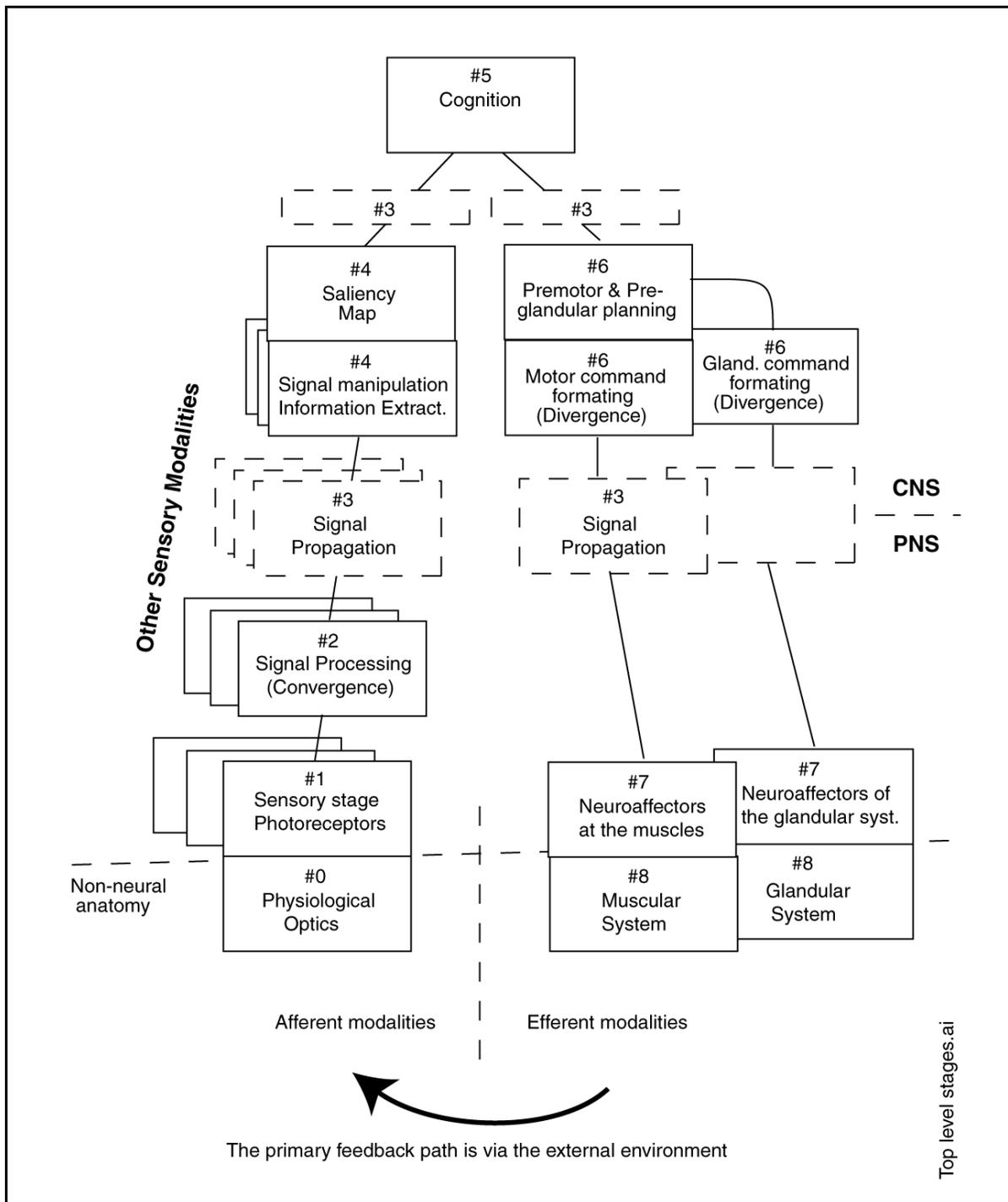


Figure 18.1.1-2 Top level schematic of the neural system focused on vision. As noted by the arrow, the principle feedback path of the visual modality is via the external environment. As in the previous figure, stage 5 – cognition involves both the physiological engines of the prefrontal cortex and the more tenuous concept of “the mind.” It both receives high level afferent information from stage 4, is able to initiate the recall of information from memory and take independent action at its own volition, and issue instructions to the efferent signaling path(s) leading to stage 6 engines.

18.1.1.1 Consciousness according to Baars, 1988

Baars has provided what might be called the bible related to consciousness among the psychology community. His Section 1.2.5 describes his major themes and how they are explored in each of the nine chapters of his book. Baars introduces many conceptual situations that he proposes to rationalize, such as; "Philosophers have noted for many centuries that we are conscious of the perceptual world in ways that differ from our awareness of concepts. Perception has qualities like color, taste, and texture. Concepts like 'democracy' or 'mathematics' do not. And yet, ordinary language is full of expressions like 'I am conscious of his dilemma,' 'I consciously decided to commit murder' and the like. Abstract beliefs, knowledge, intentions, decisions, and the like, are said to be conscious at times." In section 1.3, Baars summarizes four mid century hypotheses concerning consciousness,

- The Activation Hypothesis
- The Novelty Hypothesis
- The Tip - of - the- iceberg Hypothesis
- The Theater Hypothesis

None of these appear to employ any physiological foundation. Baars approach was, "Each of the four hypotheses can be developed into a modern model. All four have some truth, and in a way, our job in this book is to find a viable and testable mix of these metaphors." He continues, "There are currently a few psychological models with implications for attention and consciousness, but most current thinking is stated as single hypotheses, with no specified relationship to other hypotheses."

His figure 1.4 provides a broad overview of what others have written about areas of his global workspace (GW) theory. He notes, "We will speak of *conscious experience* of percepts and images, and *conscious access* to abstract concepts, intentions, beliefs, and the like." This definition of conscious access is significantly narrower than that used by Dehaene in the following material.

Baars notes in Section 1.4.2, "A crucial claim in this book is that the nervous system contains many specialized processors that operate largely unconsciously." This assertion is clearly consistent with the multitude of engines within various stages and modalities defined in this work. However, his assertion attributed to Mountcastle (1978) that the human cerebral cortex includes 55 billion neurons, each with about 10,000 dendritic connections and each neuron firing an average of 40 and a maximum of 1,000 pulses per second, is not supported in this work.. **95% of the neurons do not generate action potentials (and hence do not "fire" at all)**. 55 billion was a common estimate for the 1978 time period. The current estimates are closer to 100 billion (Section xxx).

Baars makes an important observation in the introduction to his chapter 2. "Almost everything we do, we do better unconsciously than consciously. In first learning a new skill we fumble, feel uncertain, and are conscious of many details of the action. Once the task is learned sometimes after only a few repetitions, we lose consciousness of the details, forget the painful encounter with uncertainty, and sincerely wonder why beginners seem so slow and awkward." This assertion parallels the wording of Dehaene in **Section 18.1.1.3** and is descriptive of the learning process discussed in **Section 4.6.3**.

His introduction to chapter 3 includes a correct but less than laudable assertion, "There is a curious traditional dichotomy between psychologists and neuroscientists in the way they tend to regard the nervous system. By and large, neuroscientists tend to see a gigantic assemblage of complex neurons, extremely densely interconnected, operating in parallel and at a fairly fast rate. Psychologists have traditionally seen a very different system. Their nervous system was slow, appeared to do comparatively simple tasks with high error rates, and seemed to operate serially, performing only one task at a time (with citations)." The system described in this work is quite different. At the CNS level, it is clearly a mesh rather than a parallel network. The information processing rate within the CNS is largely limited by the stage 3 signal projection rate and the cytoarchitecture of the brain. It is highly matched

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to the requirements of its environmental niche and based on that criteria is quite adequate.

Section 3.1.2 of Baars introduces "The reticular-thalamic activating system: Evidence for a global workspace in the nervous system." In this work, the critical engine of this system is the thalamic reticular nucleus (TRN). It is the nonconscious executive of the brain. Most of the other elements of the thalamus (particularly the pulvinar) are major elements of stage 4 providing information to the saliency map for inspection and cognition by the conscious executive of stage 5. While he associates this region with his conscious executive and the global workspace, it is in fact the nonconscious executive. Its operation is totally non-declaratory in animals. However, it is critically important in controlling the states of consciousness, awake, asleep, dreaming, etc. Within these global states, the conscious executive operates largely independently of the nonconscious executive. In his discussion, this is one of the few areas where a cartoon of the CNS is actually introduced (at a very coarse level). The figure defines an Extended Reticular-Thalamic Activating System (ERTAS). The ERTAS is very similar functionally to the top level block and top level schematic diagram introduced above and **Figure 4.6.3-1** of this work but at a cartoon level. His cartoon does not include the prefrontal cortex (PFC) in his nominal global workspace. Everything in his cartoon can be associated with the nonconscious executive and nonconscious operation of the CNS. Based on that delineation, the PFC is the seat of the conscious executive and the seat of the global workspace (not the ERTAS). Baars does note the role of the TRN is receiving and distributing signals from all elements of the afferent (sensory) and efferent motor (and glandular) neural system. The TRN is the switchboard for the CNS. In that sense it is like a control tower at an airport rather than a radio station. It directs information to where it should go but only rarely "broadcasts" a message to all engines of the CNS and/or PNS. Baars develops multiple scenarios concerning how his ERTAS might work. His discussion does involve the TRN (using the Latin name, nucleus reticularis thalami), but it is imprecise due to a lack of any functional diagrams beyond his initial cartoon.

In later chapters, Baars, deals with a broad range of examples presented semantically and subsequently provides a broad range of opposing examples relating to the same experience under discussion. Again, without detailed block and schematic diagrams, it becomes difficult to properly address the subtleties of these examples that are not always addressed semantically. In later phases, the discussion appears to veer toward an in depth psychological discussion drawn from pedagogy.

In chapter 7, Baars does address aspects of hypnosis that may be useful in the discussions of this work. However, they are currently outside the scope of this work. Baars notes the apparent similarity between the actions of someone under hypnosis and an excellent actor on stage.

Chapter 10, on "The functions of consciousness" makes interesting reading but does not appear to contribute significantly to understanding the underlying functioning of consciousness. He concludes that "Conscious processes are functional, just as unconscious (nonconscious) ones are." Baars summary of conclusions in chapter 11 is less than compelling. He notes, "Our theoretical framework has really only a few entities: specialized unconscious processors, a global workspace, and contexts." He concludes with a glossary that closer to a select list of views of different investigators rather than a definitive list of terms.

18.1.1.2 Consciousness according to Hawkins, 2004

Hawkins has defined the state of consciousness as the condition in which the subject can form declarative memories (pg 196), a condition that normally does not (but may) occur in the sleep state.

Hawkins notes that zombies are often invoked when philosophers talk about consciousness. He defines a zombie as physically identical to a human, but lacking consciousness. Such a creature would not be able to move rationally within the environment. A better definition might be a conscious creature physically identical to a human but lacking moral judgement or compassion.

Hawkins divides consciousness into two parts; one that is similar to self-awareness and a second, qualia– the idea that feelings associated with sensation are somehow independent of sensory input. He asserts the second is more difficult to understand but very important. He relates it to the physiological fact that the cognitive elements cannot distinguish the sensory inputs from one modality from another. Therefore, the sensory inputs are independent of the sensory modality.

Hawkins's concept of qualia requires more refinement. Based on the concept of a saliency map, the location of the sensory inputs are identified to the cognitive elements just as clearly as the retinotopic or cochleotopic inputs are identified to the stage 4 elements of the neural system. While there may be some misalignment of the actual and expected saliency map values, as in the case of synesthesia, this is an abnormal condition.

Aleksander provided his Five tests for being conscious (page 35), that he asserts is not original but a compilation of ideas from within the philosophical community.

- “1. I feel that I am a part of, but separate from an “out there” world.
2. I feel that my perception of the world mingles with feelings of past experience.
3. My experience of the world is selective and purposeful.
4. I am thinking ahead all the time in trying to decide what to do next.
5. I have feelings, emotions and moods that determine what I do.”

[xxx add considerable discussion of Dehaene's conceptualization of consciousness, Chap 1
]

18.1.1.3 Consciousness according to Dehaene, 2014

As noted above, the 2014 book by Dehaene, a mathematician and psychologist, has contributed a much better founded set of definitions relating to consciousness than available previously. In a long preamble, he introduces his expanded, largely semantic, framework.

Dehaene remains true to the psychologists use of the term unconscious while simultaneously noting its many definitions, and looking at it hypocritically on page 79. This work will assert that a clearer delineation of the states of neural activity is needed. It will seek to limit the use of the word unconscious to its medical meaning and introduce the concept of non-conscious for a wide range of mental activities that Squire & Knowlton¹³ have categorized as non-declaratory, i.e., the subject is unable to perceive and express a wide range of neural activities. These neural activities proceed continuously and frequently generate declaratory activity. Such nonconscious activity, when intellectual in character, frequently result in “insights” appearing spontaneously in the declaratory regime of consciousness. This spontaneous appearance is frequently described as the “aha” experience.

Dehaene noted Descartes' concept of dualism dating from the 1600's, , “the thesis that the conscious mind is made of a nonmaterial substance that eludes the normal laws of physics.” He described Descartes' concept of dualism as follows. “Descartes dualism was no whim of the moment—it was based on a logical argument that asserted the impossibility of a machine ever mimicking the freedom of the conscious mind.” Dehaene goes on;

“Descartes's challenges to materialism stand to this very day. How could a machine like the brain ever express itself verbally, with all the subtleties of human language, and reflect upon its own mental states? And how might it make rational decisions in a flexible manner? Any science of consciousness must address these key issues.”

¹³Squire, L. & Knowlton, B. (2000) The medial temporal lobe, the hippocampus, and the memory systems of the brain *In Gazzaniga, M. ed. The New Cognitive Neurosciences, 2nd Ed. Cambridge, MA: MIT Press*

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Dehaene proceeds to elucidate his concept of consciousness (page 8);

"As we will see, the contemporary science of consciousness distinguishes a minimum of three concepts:

- **vigilance**— the state of wakefulness, which varies when we fall asleep or wake up;
- **attention**— the focusing of our mental resources onto a specific piece of information; and
- **conscious access**— the fact that some of the attended information eventually enter our awareness and becomes reportable to others.

What counts as genuine consciousness, I will argue, is conscious access—the simple fact that usually, whenever we are awake, whatever we decide to focus on may become conscious. Neither vigilance or attention alone is sufficient."

The above is carefully worded and may obscure certain elements that are important.

1. He uses the word minimum with regard to the three concepts.
2. He does not elaborate on the fact the "alarm mode" within the hearing modality is fully functional during sleep. The term awareness is used in place of vigilance in this work.
3. He describes a condition where attended information may not be within our awareness (conscious access) and therefore reportable.

Dehaene carries on an interesting soliloquy on pages 10-& 12 concerning what is seen (presented to the visual fields of the retinas) versus what is perceived (by the brain) without clearly differentiating between the two concepts. He does not address the other sensory modalities. He concludes, "These three ingredients—focusing on conscious access, manipulating conscious perception, and carefully recording introspection—have transformed the study of consciousness into a normal experimental science."

He then defines a "Signature of Conscious Thoughts" based on the recent development of crude (with respect to spatial resolution) non-invasive imaging tools such as VEP and various forms of computer aided tomography; PET, MRI & fMRI. Other than VEP, the temporal resolution of these techniques is also significantly limited. Unfortunately, the spatial resolution of these techniques does not isolate his signatures into unambiguous forms. It only supports a relationship between an observed gross pattern and a specific stimulus or stimulus pattern. The gross pattern is not necessarily unique to the stimulus. He goes on to associate his signature of conscious thought to a potentially holographic pattern within the brain;

"My collaborators and I have elaborated a theory that we call the 'global neuronal workspace.' We propose that consciousness is global information broadcasting within the cortex; it arises from a neuronal network whose *raison d'être* is the massive sharing of pertinent information throughout the brain."

This formulation of a neuronal workspace and the simultaneous redefinition of consciousness from a state of existence to a functional mechanism requires much more study. His comments on page 14, describing "giant cells whose long axons crisscross the cortex integrating it into a whole" are anecdotal at best.

After his assertive definition of their neuronal work space, Dehaene concludes the discussion (page 15) with, "Our understanding of consciousness remains rudimentary."

In chapter 1 (page 17), Dehaene reinitiates his discussion. He begins by noting the feature of consciousness and attention discussed at several locations and in several contexts in this work. [xxx]

Dehaene provides an interesting anecdotal discussion of "blindsight" along with much other anecdotal material in his chapter 2. Much of the discussion would be aided by a better understanding of the physiology of the neural system, and a clearer delineation between consciousness and non-consciousness (defined below) using the Occam's razor to separate the knowable (declaratory) and unknowable (non-declaratory) aspects of neural activity.

Dehaene concludes chapter 2 with, "We are now ready to walk into the unique realm of the conscious mind." His chapter 3, "What is consciousness good for?" focuses on the (possible) origin and (arguably from some psychologist's and philosopher's perspective) utility of consciousness. The discussion must be considered philosophical. His discussion of consciousness versus the Turing Machine makes a broad range of assumptions and makes certain assertions about the neural system that are not supported in his text or by this work. His assertions on page 105 contain a grain of reality but must be evaluated carefully, and not at face value. He then asserts on page 106, "Don't get me wrong—I do *not* intend to revive the cliché of the brain as a classical computer."

Beginning on page 125, Dehaene incorporates his analysis of the time lags associated with "consciousness." Unfortunately, he does not rely upon any model of the neural system. His assertion on page 126 concerning the delay at low light levels does not address or recognize the deterministic delay associated with the stage 1 sensory neurons as a function of stimulus intensity (**Section xxx**). His analogy between the change detector of the biological eye with the integrating receptor used in an astronomer's long exposures is totally unrealistic. The soliloquy at this location cannot be relied upon.

Dehaene's chapters 4, 5 & 6 contain a variety of numerical values related to the operation of the brain (particularly related to various times to perceive a signal and various time delays relative to when certain signals appear at certain morphological locations. Unfortunately the coarseness of the time scales and the lack of a top level schematic lead to discussions lacking the physiological precision desired. When adopting the schematics of this work, much of the psychophysical data presented can be interpreted much more precisely. He does assert on page 137 when discussing the use of frequency domain techniques within the brain, "Evidence is mounting that frequency analysis, although a useful mathematical technique, cannot be the whole answer." He does provide some results from disturbing the operation of the CNS using transcranial magnetic stimulation (TMS). His discussion appears limited to the conscious brain but it applies equally to the non-conscious brain.

In chapter 5, Dehaene does introduce a concept that may be useful in describing the architecture and activities occurring within the pre-frontal cortex (PFC) and related to consciousness. He asserts, Consciousness is "Global Information Sharing" and illustrates the concept in his figure 24. The concept¹⁴ resembles that of the *conscious executive* of this work (**Section 4.6.3**). He does not consider a potential *non-conscious executive* centered on the thalamic reticular nucleus (TRN) of the thalamus as described in this work (**Sections 4.6.2 & 11.6**). The nonconscious executive to a large extent controls the signals reaching the global workspace via the perceptual systems as well as the signals distributed to the motor and glandular systems from the global workspace. **Figure 18.1.1-3** provides a suggested revised illustration. It is widely recognized that virtually all of the sensory modality input signals pass through the TRN of the diencephalon on the way to the "cerebral cortex." The only major potential exception is the olfactory modality. Its signals may first pass through the prepiriform complex (Brodmann area 28) of the CNS much like the visual and auditory modality signals are preprocessed in the geniculate nuclei on the way to the TRN. This exception may allow the olfactory signals to be shared with the limbic system without initially passing through the TRN to the stage 5 cognition engines. Similarly, virtually all of the instructions from the stage 5 cognitive engines pass through the TRN as they are expanded into commands suitable for activating the muscular and glandular modalities. The saliency map is shown as the intermediate data display board available to the more scratchpad oriented blackboard described by Dehaene within his global neuronal workspace (and probably the global workspace previously defined by Baars).

As noted earlier, the cognitive engines may direct their attention to any portion of the saliency map of the environment. Their attention causes the nonconscious executive to call on the appropriate sensory modalities to upgrade the information (quality-wise) in the specified area of the saliency map. It is this call by the TRN that causes the eyes to point in the direction of the desired scene elements. It is this fixation by the eyes that is generally

¹⁴Dehaene, S. Kerszberg, M & Changeux, J-P. (1998) A neuronal model of a global workspace in effortful cognitive tasks *PNAS-USA* vol 95, pp 14529-14534

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assumed by psychologists to indicate the current point of attention by the cognitive engines

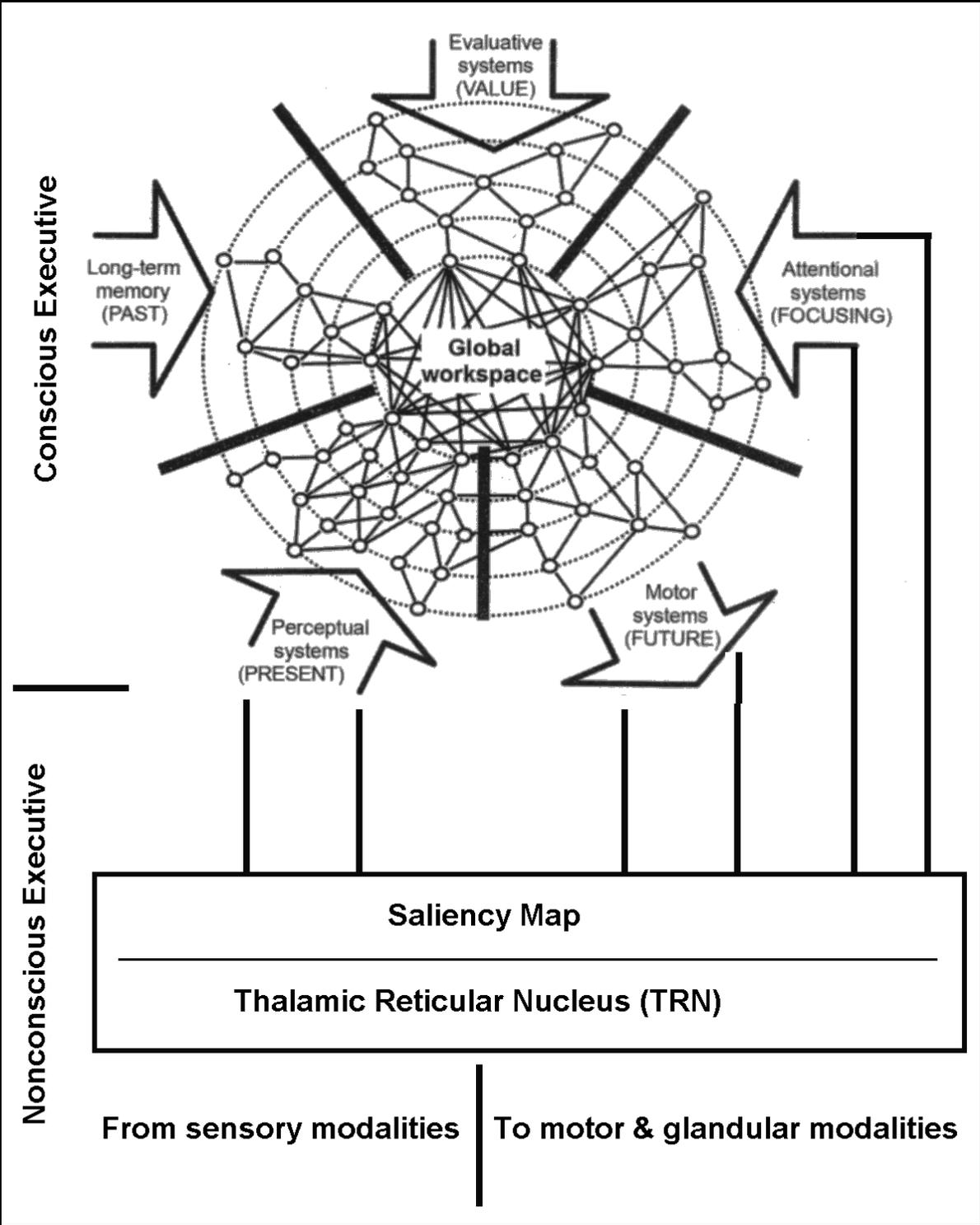


Figure 18.1.1-3 Global neuronal workspace with nonconscious executive. See description in text. Modified from Dehaene, 2014.

(the mind). To a limited extent, the TRN can inhibit this pointing action.

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As noted in [Figure 4.6.2-7], the situation relating to long term memory may be more complicated than suggested in Dehaene's original figure. Functionally, the saliency map may be thought of as an interface between the nonconscious and conscious executives.

In chapter 6, Dehaene described an attempt to build an emulation of the brain based on "integrate and fire" neurons only, no analog neurons. The model did include his concept of a "small thalamus—a structure consisting of multiple nuclei, each strongly connected with a sector of cortex or with a broad array of cortical locations." (Page 181) The key point developed by his model was its restlessness, "Another fascinating phenomenon emerged in our stimulation: spontaneous neuronal activity. We did not have to constantly stimulate our network. . . and this chaotic activity self-organized into recognizable patterns." This spontaneous activity of a large group of interconnected neurons may come to be known as conscious thought over a period of further investigation and model improvement. Dehaene notes, "A similar phenomenon exists in the human brain. A key point made in suggesting a spontaneous circuit activity appears on page 191, "Remember the main message from chapter 2: most of the brain's operations are unconscious. We are unaware of most of what we do and know, . . ." He continues to address this subject on page 259, "Conscious Machines," without presenting any new substantive material. His soliloquy relating to the work of Chalmers is interesting.

On page 216, Dehaene addresses what is labeled the alarm mode of neural operations under the title, "Conscious Novelty Detection." In fact, most of the operation of the alarm mode of a sensory modality occurs in the non-conscious regime. He does provide some useful background on auditory modality experiments that test one aspect of the alarm mode. His work in this area does appear to be at the forefront of psychophysical testing.

18.1.1.3.1 Problems in moving the Dehaene approach forward

Dehaene's approach to understanding consciousness in his chapter 1 begins running into serious technical problems in the absence of a detailed functional model of the neural system. Restricting the discussion to the visual modality for the moment,

1. it is impossible to understand Troxler fading (his page 18) without understanding adaptation mechanism associated with the stage 1 sensory neurons.
2. it is impossible to understand attention without understanding the pointing mechanism employed by the eyes during scene analysis, i.e., during the analytical mode of the visual modality.
3. it is impossible to understand cognition without understanding the role of memory in providing part of the pattern matching function that is key to scene recognition.
4. it becomes impossible to understand the temporal aspects of cognition without understanding the role of learning in "loading" the memory mechanisms of the neural system.
5. it becomes impossible to support the concept of a neuronal work space without recognizing the actual role played by the different types of nerves (bundles of neurons) within the neural system.

The subject matter listed above is discussed in greater detail elsewhere in this work. Item 1 is discussed in Section xxx. Item 2 is discussed in Section xxx. Item 3 is discussed in Section xxx. Item 4 is discussed in Section xxx. Item 5 is discussed in Section xxx. Other items will be introduced and discussed as appropriate below. It is also of great help to have a functional diagram of the animal nervous system to place these items in context. The top level block and top level schematic diagrams introduced above help put these mechanisms into better context. The flow diagram developed in Section 4.6.3 is also very helpful. It explores the operation of the higher level engines of cognition and volition, and the critical role of memory and its predecessor learning..

Expanding on conscious, unconscious and non-conscious states

Dehaene's concept on page 20 relating to the environment surrounding an individual is not

sufficiently delineated.

“As I sit at my desk and concentrate on writing this book, my retina is bombarded with information about the surrounding objects, photographs, and paintings, their shapes and colors. Simultaneously, my ears are stirred with music, birdsong, noise from the neighbors—and yet all of these distraction bits remain in the unconscious background while I focus on writing.”

As will be addressed further in the next section, it is useful to differentiate between the state of unconsciousness (wherein the subject is unaware of his environment, both within and external to his own body) and non-consciousness, where many sensual inputs are available to the subject but his attention is focused on one sensory modality or another. When unconscious, the subject is nominally in a coma. With regard to the non-conscious state, the alarm and awareness modes of the subject’s sensory modalities are fully functional but he has focused his attention on a more narrow field of sensory input via the analytical mode.

Dehaene may not be aware of the high rate of information transfer employed within the stage 4 and 5 engines of the CNS (due to word serial/bit parallel signal handling) compared to the low rate of signal transfer employed by the PNS (due to word serial/bit serial signal handling). As a result, the CNS operates much as a packet switched network similar to the internet rather than as a dedicated signaling channel network such as the historical telephone network. Packets related to audio stimuli may be interspersed with packets from the intermittent operation of the visual modality when reading, and with the relatively long intervals between skeletal-muscular activity during writing. The stage 5 engines of the CNS operates much faster than either the sensory modalities or the muscles of the eye and hand. Much of the activity related to the sensory modalities and neuro-muscular system is non-conscious (i.e., non-declaratory—defined in the following paragraphs).

Preconsciousness vs information at low resolution within the saliency map

Dehaene discusses what he describes as a preconscious state of perception on page 21. Without differentiating between sensory modalities, he infers that there is a large reservoir of information stored and available within the neural system.. This reservoir appears to equate to the saliency map within the neural system. It maintains just such large reservoir of current environmental information. However, it is an element of the memory system and it does not represent a subdivision of the conscious state. The saliency map is rapidly accessible by the engines of stage 5, cognition, during both the conscious and dream state. The term quickly may be misinterpreted as used by Dehaene. The quality of the information stored in the saliency map varies dramatically between sensory modalities and the “fields of view” of these modalities. In the case of vision, the spatial resolution of this peripheral information is almost a factor of 100:1 lower than in the current area of attention being processed by the analytical mode (**Section xxx**). When attention is redirected to this peripheral information, the first action of the visual modality is one or more saccades of the eyes to bring the area of interest into the central field of vision, the 1.2 degree diameter foveola. Time is then consumed by the analytical mode pathways in order to increase the quality of information available concerning the objects of interest in the scene.

Dehaene’s introductory sentence on page 22 is in consonance with this work, “Clearly then, most if not all of the selective functions of attention have to operate outside our awareness.” He is seeking to define the analytical mode of this work as it appears in each sensory modality. This author would prefer to use the term subconsciously, and to a large extent non-consciously, rather than his word unconsciously in the sentence following the above quotation. The mechanisms and states of operation involved are largely “non-declaratory” in the language of Squire and Knowlton (**Section 17.1.1**). The subject is unaware of these activities and can not verbalize (or otherwise) describe these activities.

Operating modes within the neural system

Dehaene needs to recognize the operational difference between the awareness mode, the alarm mode and the analytical mode of each of the sensory modalities at his disposal. Except in response to the alarm mode of one sensory modality or another, and/or his volition capability as it relates to the physical mechanism involved in attention, most of the

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extraneous visual material he refers to is only presented to his retinas at significantly lower spatial resolution than he appreciates (**Section xxx**) [xxx same as previous citation]. Most of his perception of these extraneous material, in both the present and past, is actually drawn from the subjects long term memory. When he refocuses his attention away from his writing, he does not recall information already presented to his retinas. Instead, he requires a significant period of time (on the order of 0.2 to 0.5 seconds or more) to acquire a high resolution perception of the small portion of the environment that is now the center of his attention. These circumstances seriously impact his statement following the above quotation relative to conscious access. "Conscious access is, at once, extraordinarily open (at low resolution) and inordinately selective (at high resolution)." The two parenthetical phrases have been added to stress the actual conditions at a given time and state of attention. The modes of operation of the visual modality are discussed extensively in Chapter xxx of "Biological Vision: A 21st Century Tutorial."

This work concurs with Dehaene's assertion that in his third concept, the meaning of the two terms wakefulness and vigilance should probably be separated. In this work, the awareness mode of sensory operation is equivalent to his functional term wakefulness. The operation of the alarm mode is roughly equivalent to his functional term vigilance. His statement that both terms need to be delineated sharply from conscious access i.e., the analytical mode associated with attention. Using these definitions, his subsequent sentence,

"Wakefulness, vigilance and attention are just enabling conditions for conscious access"

can be restated as;

The awareness, alarm and analytical modes of operation within the neural system are just supporting mechanisms for establishing and/or directing attention.

Binocular rivalry

Dehaene's discussion of rival visual images is not in good conformance with the physiological framework and mechanisms of the visual modality. His references to stereovision are superficial. Marginal differences in the images presented to the two eyes are critical elements that provide important vergence and focus information when processed within the lateral geniculate nuclei (LGN, early stage 4). The same marginal image differences provide important depth information for individual elements within a scene when processed by the peri-geniculate nuclei (PGN) of the neural system. Grossly different binocular images are to a great extent not found in the natural world. Gross binocular rivalry is generally a man-made contrivance for the amusement of scientists and exploitation by magicians. Dehaene describes gross binocular rivalry as; "an experimenter's dream because it provides a pure test of subjective perception:" He properly notes that the signal processing and information extraction related to binocular rivalry are not under the subjects control. They are non-conscious and non-declaratory activities.

When Dehaene discusses "When Attention Blinks" on page 30-37, it is important to recognize he is speaking primarily of gross binocular rivalry. His last sentence on page 31 should be interpreted as [gross binocular rivalry depends on attention: . . . gross rivalry requires an active, attentive observer.] Marginal image differences are employed routinely within the non-conscious activities of the CNS to achieve visual accommodation, vergence and depth perception.

Later in that section, Dehaene describes experiments that do not recognize the temporal activities of the neural system. He merely reports on the limitations on the system from a behavioral perspective resulting from psychophysical experiments. His observations appear appropriate but no creditable mechanisms are described to account for them. Introducing more physiology into the discussion would provide much more useful science than relying on psychology alone. The remainder of the section consists of largely anecdotal comments without adequate attention paid to the time scales involved. Contrary to the impression given "blink photometry," the rapid comparison of two scenes on a repetitive basis, is widely used in astronomy and intelligence communities to detect minute changes between two

scenes. The discovery of the subplanet Pluto and the discovery of the V1 flying bomb during World War II are both attributed to blink photometry.

Dehaene's soliloquy in chapter 6, although interesting, does not yet lead to any hypothesis that can be tested.

18.1.1.4 Combining recent concepts of consciousness

With the greater level of detail related to the neural system and memory of this work, it is important to redefine consciousness. **Figure 18.1.1-4** provides a first order framework for discussing the various states of consciousness. Various authors have defined many categories of consciousness using additional adjectives. The profusion of prefixes available in English allow a simpler set of definitions that parallel colloquial usage. Consciousness can generally be defined in parallel with memory. There is clearly a large volume of nonconscious activity within the CNS that can not be described by the subject and is associated with the procedural aspects of the neural system (and the associated procedural memory). The aspects of memory associated with the declaratory activity (and declaratory memory) are many. The fully conscious subject is maximally aware of its external and internal environment and fully subject to the actions of the alarm mode of neural activity. This statement may be too general as the subject is typically fully aware of only selected and specific aspects of its environment. These aspects are frequently associated with the concept of attention. Other aspects of awareness are readily available to the subject but must be considered as present in the subconscious brain until recalled by changing the focus of attention.

Closely associated with the subconscious (non-declaratory) "brain" is a large scale saliency map of the animal's environment (explicitly the external environment but also selected aspects of the internal environment). It is shown to the left of the subconscious state to highlight its importance in the above discussion. This saliency map is the equivalent of Dehaene's preconscious state. However, the map is an element of the memory system (Section 17.xxx) and not a portion of the conscious state.

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A problem here arises with using the terms nonconscious, unconscious and subconscious. Aleksander noted (page 69), "...the concept of 'the unconscious' is inescapably linked to the ideas and practices of Sigmund Freud. It implies that there is an area of thought that cannot be accessed during waking normal thought but nonetheless can influence waking life despite its inaccessibility. Such thoughts can, however, be accessed during dreams or possibly the induced sleep states of hypnosis." In the situation described by Aleksander, the unconscious is clearly limited to recallable memory. It does not apply to the nonconscious state described above, which is not recallable even under hypnosis. It is also limited to the active mind and does not apply to the medically induced, or natural state of being unconscious. Freud's usage of unconscious would correspond to the subconscious of this work.

Wolters & Raffone have provided a paper involving both memory and consciousness in a

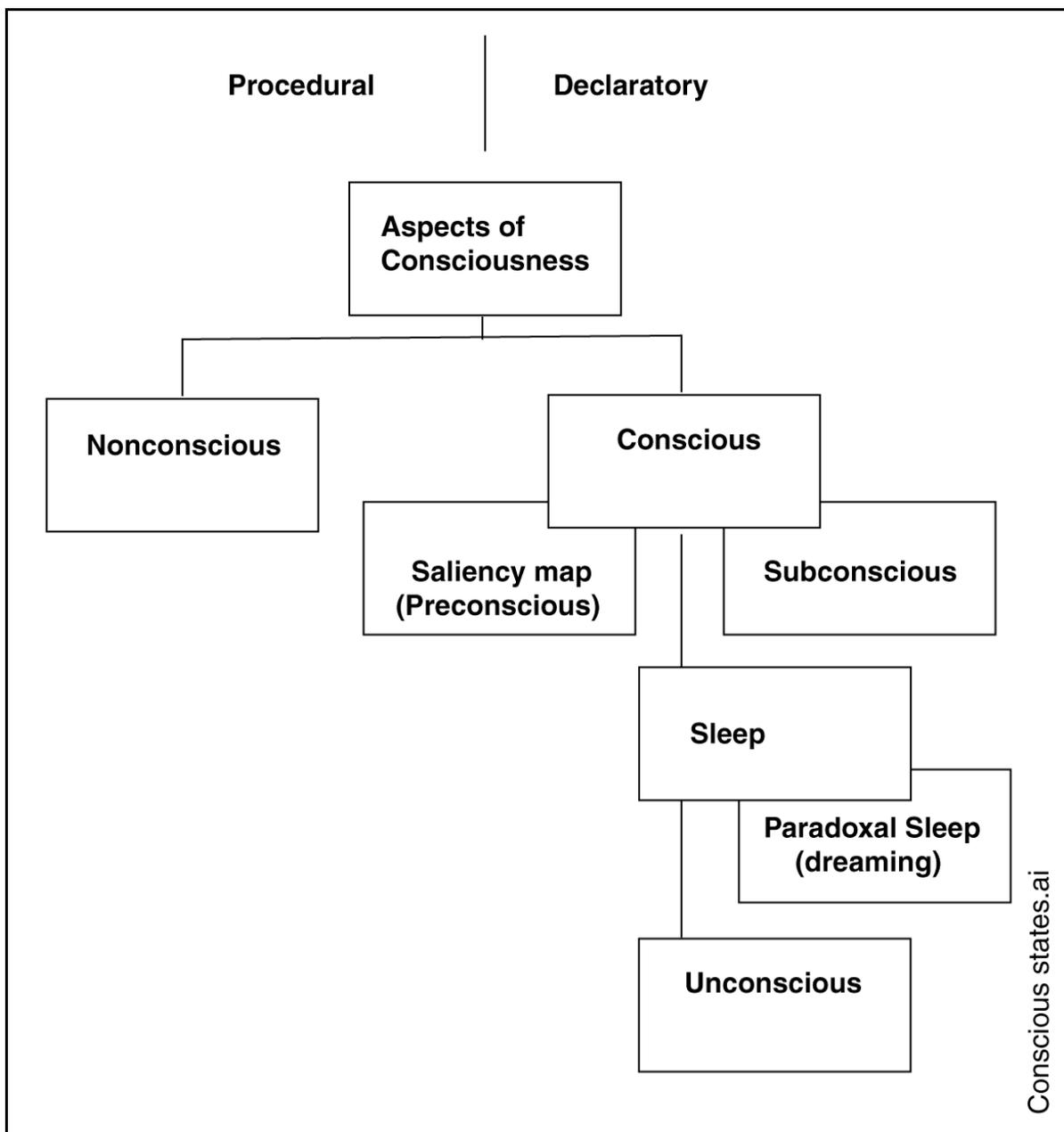


Figure 18.1.1-4 First order states of consciousness. The nonconscious is labeled aconscious in Chapter 4 to accentuate its active, but unaccessible state. The state is home to the myriad functions performed under the nonconscious executive, the thalamic reticular nucleus (TRN). The saliency map is actually an element of short term memory describing the current environment of the subject. Dehaene described this function as preconscious. See text.

complex conceptual framework¹⁵. They describe a “working memory (WM), including a ‘central executive’.” “We suggest that WM is best described as a set of three interdependent functions which are implemented in the prefrontal cortex (PFC). These functions are maintenance, control of attention and integration.” While providing a large number of citations, they provide only a greatly simplified block diagram of the PFC in relation to the overall CNS. Their terminology needs to be rationalized in terms of this discussion.

The term unconscious will be used here in its medical context. The unconscious state exhibits a complete lack of awareness of the environment and a failure to respond to alarm mode stimuli. Recognizing the difference between the unconscious and subconscious states is important. Subconscious is used here to mean that aspect of consciousness that is not the subject of current attention but that can be brought into conscious focus (full awareness) at will. By replacing his term unconscious with subconscious, Sun defines attention as used here, “the regulation of the proportion of conscious and subconscious processing.”

Sleep appears to be an intermediate state between the conscious and unconscious states. The sensory modalities of the subject remain functional although the attention of the subject may be directed away from the percepts developed by those modalities. However, the subject’s brain remains responsive (at least partially) to many of the alarm mode stimuli. The motor and glandular elements of the subject also remain functional although the volition mode instructions to those systems appear to be inhibited. It is possible that the sensory and motor/glandular elements of the nonconscious state may also be inhibited during the sleep state. Sleep provides continuing access to the external environment, access to the computational aspects of consciousness as well as at least limited access to the subconscious. Sleep is not closely associated with the state of unconsciousness. It is more closely related to the state of consciousness.

Dehaene notes (page 1) Jouvett’s concept of dreaming as a paradoxical form of sleep during which the brain is nearly as active as during the awake state¹⁶. The brain appears to have significant access to the saliency map (possibly in a limited form) as well as other memory elements that it can use to fabricate a largely ad hoc scenario.

18.1.2 The phenomenon of attention

Page 69 of Bonica’s 4th Edition, provide a description of attention from a psychologists perspective¹⁷. It includes the aspects of arousal, vigilance, perception etc.

Attention began to play a role in the philosophy of vision during the 1980’s. Treisman & Gelade introduced “A new hypothesis about the role of focused attention¹⁸.” It was largely philosophy based.

The feature-integration theory of attention suggests that attention must be directed serially to each stimulus in a display whenever conjunctions of more than one separable feature are needed to characterize or distinguish the possible objects presented. A number of predictions were tested in a variety of paradigms including visual search, texture segregation, identification and localization, and using both separable dimensions (shape and color) and local elements or parts of figures (lines, curves, etc. in letters) as the features to be integrated into complex wholes.

¹⁵Wolters, G. & Faffone, A. (2008) Coherence and recurrency: maintenance, control and integration in working memory *Cogn Process* vol 9, pp 1–17

¹⁶Jouvett, M. (1999 in translation) *The paradox of sleep: The story of dreaming* (trans. L. Garey). Cambridge, Mass: MIT University Press [Original publication date 1993]. pp 169-171

¹⁷Fishman, S. Ballantyne, J. & Rathmell, J. (2010) *Bonica’s Management of Pain*, 4th Ed. NY: Lippincott Williams & Wilkins

¹⁸Treisman, A. & Gelade, G. (1980). A feature integration theory of attention. *Cogn Psych*, vol 12, pp 97-136.

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The results were in general consistent with the hypothesis."

They begin with a brief historical summary,

"The controversy between analytic and synthetic theories of perception goes back many years: the Associationists asserted that the experience of complex wholes is built by combining more elementary sensations, while the Gestalt psychologists claimed that the whole precedes its parts, that we initially register unitary objects and relationships, and only later, if necessary, analyze these objects into their component parts or properties. This view is still active now."

The Gestalt belief surely conforms to the normal subjective experience of perception. However the immediacy and directness of an impression are no guarantee that it reflects an early stage of information processing in the nervous system. It is logically possible that we become aware only of the final outcome of a complicated sequence of prior operations. "Topdown" processing may describe what we consciously experience.

We have recently proposed a new account of attention which assumes that features come first in perception (Treisman, Sykes, & Gelade, 1977). In our model, which we call the feature-integration theory of attention, features are registered early, automatically, and in parallel across the visual field, while objects are identified separately and only at a later stage, which requires focused attention. We assume that the visual scene is initially coded along a number of separable dimensions, such as color, orientation, spatial frequency, brightness, direction of movement. In order to recombine these separate representations and to ensure the correct synthesis of features for each object in a complex display, stimulus locations are processed serially with focal attention. Any features which are present in the same central "fixation" of attention are combined to form a single object. Thus focal attention provides the "glue" which integrates the initially separable features into unitary objects. Once they have been correctly registered, the compound objects continue to be perceived and stored as such. However with memory decay or interference, the features may disintegrate and "float free" once more, or perhaps recombine to form "illusory conjunctions" (Treisman, 1977).

We claim that, without focused attention, features cannot be related to each other."

The hypothesis of Treisman & Gelade is worth pursuing, but requires a greater appreciation of the role of memory in the initial perception of a scene. When one opens his eyes to observe a scene previously observed, memory immediately provides a great deal of information about the scene. Attention is used under such circumstances to collect and update the information concerning specific figures in the scene.

The primary conclusion of Treisman & Gelade, "The findings also suggest a convergence between two perceptual phenomena-parallel detection of visual targets and perceptual grouping or segregation." The parallel detection of visual targets is a major function of the peripheral retina and the occipital lobe of the cerebral cortex. The grouping and segregation of figures is a primary responsibility of the lateral geniculate nuclei. These two functions are shared within the LGN/occipital couple of **Section 15.6.5**. Information extraction, although not discussed in their paper is the primary responsibility of the PGN/pulvinar couple as discussed in **Section 15.6.3**.

Fuster has provided an interesting review of the concepts of attention and alertness¹⁹. If an animal is not asleep, it can be considered fully alert to its environment. However, the phenomenon of attention implies a level of concentration on a specific element of the environment to the near exclusion of other elements. Fuster describes two aspects of attention, that associated with inputs to the sensory-neural system, and that associated with outputs of the

¹⁹Fuster, J. (1995) Memory in the Cerebral Cortex. Cambridge, MA: MIT Press pp 217-219

neuro-muscular system. Attention when discussed in the context of the motor system is often called "set," as in readying oneself to swing at a pitched ball.

Fuster reproduces a definition of attention developed by James in 1890:

"the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. . .It implies withdrawal from some things in order to deal effectively with others. . ."

While highly controversial in its day and lacking in precision today, it describes the scope of the subject.

Taylor has addressed attention in some (philosophical) detail, reflecting on its intimate association with the control function of the brain (pp 78-100). However, his control block diagrams are quite conceptual. His Table 1 on page 113 appears quite usable, particularly if the parietal lobe is extended to the pre-central gyrus (to include the premotor areas). However, his concept of a corollary discharge, which he defines as the same as an efference copy, is misplaced based on the work of Libet (**Section 19.7**). The only signal available is the "instruction to act" or volition command occurring at the output of the prefrontal cortex (stage 5) *before* the actual stage 7 response.

Baars & Gage have devoted their chapter 8 to the complexities of consciousness and attention. Their table 8 specifically addresses the general capabilities of the conscious waking state (originally from Seth & Baars, 2005).

18.1.3 The attentional blink as a cognitive interval

Taylor has introduced the concept of an attentional blink and shown its close association with attention (page 15). While descriptive, he provided no accompanying citations. Subsequently, the phenomenon has drawn considerable attention in the psychology community. Krancziocha et al. noted, "The attentional blink is a phenomenon that can be described as a transitory impairment of attention that occurs if multiple targets have to be processed in close temporal proximity. Initially described in the mid-1980s, the phenomenon was named attentional blink by Raymond et al. While the attentional blink phenomenon has been addressed in a large number of behavioral studies, its physiological mechanisms are still largely unknown²⁰." The initial concept is consistent with this work and involves the loading of the saliency map as a separate function from the cognition of that part of the map specified by attention. The Krancziocha et al. results are also confirmatory of this work.

The attentional blink describes the cognitive interval required to evaluate a portion of the stage 4 saliency map copied into stage 5 working memory, or examined by stage 5 circuits. If the intent to examine a specific portion of the saliency map calls for an update of that map, the stage 4 acquisition cycle is implemented. In the case of vision, the fixation portion of this cycle takes 250-300 msec. If required, the duration of a saccade may need to be included in the temporal budget. In the absence of any need to update the map, it would be expected that the settling time of the stage 5 examination would be on the order of 30 msec. The Krancziocha et al. paper contains considerable information regarding this phenomenon. They discuss a two-stage model where stage one is clearly the stage 4 activity of this work and the second stage is the associated stage 5 activity. Using EEG techniques, they note separate signals arriving at the P3 electrode, suggesting delivery of both the first and second interps to the saliency map.

18.1.4 The character of sleep

A clear definition of the state or phenomenon of sleep has eluded precise definition for a very long time. It certainly is not a cessation of neural activity within the CNS. Quoting Buzsaki,

²⁰Krancziocha, C. Debener, S. & Engel, A. (2003) Event-related potential correlates of the attentional blink phenomenon *Cogn Brain Res* vol 17, pp 177-187

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"unlike most body parts, the brain is busy at night, as well". Many modes of neural operation continue unabated throughout the sleep period. Sleep clearly is a periodic departure from the fully aware state that is required among mammals in particular and most animals in general. While sleep can be labeled an unconscious state, it appears to be more the antithesis of attention than the antithesis of consciousness. During sleep, many of the sensory systems continue to be active and the brain is continually evaluating inputs from these modalities.

Buzsaki has described a series of sectionings within the cat brain that lead to more detailed information about the state of sleep (page 186).

Until the advent of magnetic imaging, the electroencephalogram (EEG) has been widely used to coarsely but quantifiably describe sleep states. **Figure 18.1.5-1** shows the character of these records for different sleep states. The traces are the result of summing the electrical signals from millions of neurons appearing between two positions on the external head. At best, such signals can only be suggestive of the internal neurological activity. The use of the term paradoxical in a scientific context indicates the level of precision in interpreting these records. Paradoxical sleep is more frequently described as rapid eye movement (REM) sleep. However, the significance of the eye movements remain largely unknown.

Vlahos, has recently provided an article for the popular press describing the more anecdotal aspects of sleep²¹. While focused on the failure of the system to maintain paralysis of the skeletal-motor system during some forms of sleep, it does not specifically address the continued activity level of the sensory neural system during routine and non-routine sleep. It should be obvious to all that the hearing and the somatosensory modalities (and less obviously the visual modality) do not cease operations during sleep. Sleep is more like an idling state for the higher areas (portions of stage 5) of the brain than a state of neural shutdown. Vlahos largely overlooks the continued operation of the visceral system during sleep. Vlahos did note the fact that all portions of the neural system did not enter and leave the sleep state simultaneously, sometimes resulting in bizarre situations like serious sleep walking with tragic consequences.

18.1.5 The concept of free will

The concept of free will is currently largely in the hands of the philosophers. Taylor (page 195) discusses traditional free will and notes its "standard description, "To have free will is to be able to act freely. When an agent acts freely—with no constraints on it whatsoever—it can thereby rightly be said to exercise its free will."

18.2 Introduction to Intelligence

Hawkins takes a novel approach to defining intelligence. He makes two assertions, "The biggest mistake is the belief that intelligence is defined by intelligent behavior (page 6)," and "making predictions is the essence of intelligence (page 84). Unfortunately, he does not evolve a single

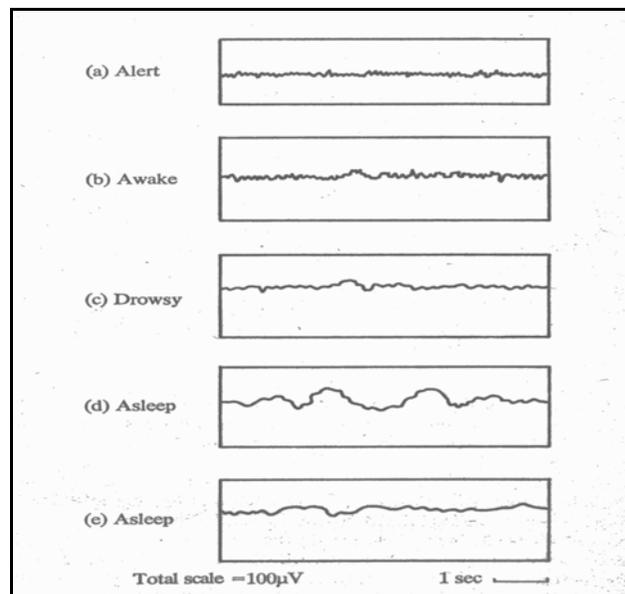


Figure 18.1.5-1 Typical human EEG patterns during different states of activity. Alpha waves (8-12 cycles per second) are seen in awake, resting and drowsy states (b and c). The trace in (e) shows "paradoxical" sleep. From Rose, 1976.

²¹Vlahos, J. (2012) The Case of the Sleeping Slayer *Scientific American* Sept. pp 46-53

meaningful definition of intelligence. Its definition may require a few more years before man is able to comprehend a clear and meaning definition of intelligence.

The essence of intelligence can be distilled from Hawkins' description of the features of memory (**Section 17.1**) and his thoughts on "genius" addressed below.

18.2.1 The essence of intelligence

According to Hawkins, the major features of memory relate to the following;

- The cortex stores sequences of patterns.
- The cortex recalls patterns auto-associatively.
- The cortex stores patterns in an invariant form.
- The cortex stores patterns in a hierarchy.

It may be necessary to embellish these simple statements related to memory in order to fully appreciate the meaning of intelligence.

Intelligence can be defined from a variety of perspectives, and frequently in a variety of contexts. A person can be labeled intelligent if he can master a wide variety of facts and be a erudite speaker simultaneously. Another can be labeled intelligent if he can rapidly recall a wide variety of facts. Another can be labeled intelligent because he is able to propose and describe new ideas derived from the previous state of the art.

Most of the various descriptions of intelligence include one major feature, the ability to store *and* recall memories based on a sophisticated, and possibly multidimensional, auto-association mechanism or framework. The idea of recalling patterns auto-associatively implies a very sophisticated mechanism for storing those patterns in a framework supporting the subsequent recall mechanism.

[xxx expand and add alternate concepts]

18.2.2 Definition of Genius

Using the above discussions of intelligence may still allow one to define genius.

Genius- One who is able to recall a set of memory patterns auto-associatively and compare them to a currently perceived situation and to successfully predict the outcome of the current situation by moving the recalled memories fore and aft and laterally in both time and space—repeatedly.

18.3 Electro- (EEG) and magneto-encephalographic (MEG) recordings

Two non-invasive methods of acquiring data on the internal operations of the brain are electroencephalography and magnetoencephalography. Both techniques offer very good time resolution in the millisecond range but relatively poor spatial resolution in the few millimeters range. Ramachandran contains a good overview of the EEG and MEG techniques²². However, it suggests the primary source of the signals is the gray matter of the cortex rather than the interface between the stage 3 neuron (white matter) pedicles carrying pulse signals and the analog neurons of stages 4, 5, & 6.

²²Ramachandran, V. (2002) Encyclopedia of the Human Brain. San Diego, CA: Academic Press vol 3, pp 494-496

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If an instrument can use the magnetic field generated by the normal operation of neurons as a measurement tool, it follows that a similar instrument can be used to introduce a magnetic field that will interfere with the operation of the same neurons. Such a technique is called transcranial magnetic stimulation (TMS) and has been used successfully to cause repeatable limb movements independent of the subjects intentions.

There is a significant theoretical problem in how the neuroscience and particularly the medical field is evaluating the results of EEG and MEG data collection. The problem is analogous to the "missing fundamental" problem in hearing and involves a misinterpretation of the physiology involved. With the ease of saying "Fourier Transform" and highly simplified interpretations of such transforms in pedagogy, the above groups have been attempting to locate sinusoidal oscillators in the CNS that generate low frequencies in the 1 Hertz to 600 Hertz region. Such oscillators do not exist. A more sophisticated understanding of the Fourier Transform would lead one to seek one or more series' of equally spaced action potentials with a period(s) equal to the reciprocal of the above frequencies.

18.3.1 Orthogonal transforms used in EEG & MEG

Introductory material on the EEG and MEG have introduced the Fourier Transform as a method of analyzing the noise like spectra produced by these technologies. The Fourier Transform is a widely used but not unique member of the mathematical class of orthogonal transforms. The Fourier Transform was introduced by Fourier in 1822 as a solution to what became known as the Sturm-Liouville Problem or System who developed the concept of orthogonal functions and transforms in greater detail (*Journal de Mathematique*, 1836-1838). Unfortunately, it is much easier to pronounce Fourier than Sturm-Liouville. This subject matter has been discussed widely in the mathematical literature. One author has been the Dean of this subject for over sixty years. He has been so prominent that he, most recently co-authoring a book that appeared 20 years after his death²³. A solution of the Sturm-Liouville problem involving the Transform labeled Fourier is now considered a special case of the general Sturm-Liouville solution.

When one proceeds beyond the college level introductory material explaining the operation of the neural system in the simplest terms, the generic relationship presented between frequency and time in the Fourier Transform is found wanting. The impression typically left with the student that a function in time can be transformed into a set of functions in the frequency domain and that this transform is reversible. The assumption is that the set of frequency domain functions are always based on sinusoidal waveforms in both cases. However, in fact, there are a large number of orthogonal functions that meet the more complete understanding of the problem developed by Sturm-Liouville, and there is no requirement that the set of functions used to generate a given time domain waveform is the same as that used by man to analyze the same time domain waveform. It is shown elsewhere in this work that the biological neural system does not employ transcendental transformations implied in both the Sturm-Liouville and Fourier transforms into frequency space (Section xxx). Furthermore, the neural system uses a great many relaxation oscillators to generate monopulses and strings of monopulses commonly described as action potentials or colloquially as "spikes." Relaxation oscillators can not generate sinusoidal functions directly.

The sets of waveforms that satisfy the Sturm-Liouville Problem are many. They are optimal in different situations. As an example sinusoidal functions are the simplest set available in Cartesian coordinates but do not work well in cylindrical or spherical coordinates. Bessel functions are ideal for cylindrical coordinates but are awkward in Cartesian coordinates, etc. In more advanced material, the global set of orthogonal and orthonormal functions are known as "general" or "generalized" functions^{24,25}. The first generalized function Rahman introduces is

²³Brown, J. & Churchill, R. (2008) *Fourier Series and Boundary Value Problems*, 7th Ed. NY: McGraw-Hill

²⁴Rahman, M. (2011) *Applications of Fourier Transforms to Generalized Functions*. Boston: WITpress Chapter 1

²⁵Al-Gwaiz, M. (2008) *Sturm-Liouville theory and its applications* London : Springer

Dirac's delta function. The general functions include; sinusoids (commonly but not exclusively used in man-made equipments), Bessel Functions (of several kinds and orders), Hankel Functions (used specifically in the cochlea of hearing), Hilbert Functions, etc.

A variable periodicity is the primary characteristic separating members of any orthogonal set of frequency waveforms. Rahman develops the theories and corollaries of generalized functions in detail. The cross-correlation of any two members of an orthogonal set is zero over an extended time interval. Pulse trains of quasi-delta functions (think action potentials) can satisfy this criteria by employing different periodicities.

It is proposed here that the fundamental characteristic observed in EEG and MEG measurements is the noise-like waveform in the time domain resulting from the summation of a multitude of individual pulse trains of action potentials with different periodicities. No sinusoidal oscillators are involved. The resultant noise-like waveform is then subjected to a second transform, generally of the Fourier type in order to return to a frequency domain that can be easily discussed in pedagogy.

When a researcher employs the Fourier Transform to create a frequency spectrum representative of a given noise-like temporal waveform, there is no relationship between the frequency spectra resulting from a Fourier Transform of that temporal waveform and the original periodicity controlled set of pulse trains used to create the noise-like spectra in the first place.

18.3.1.1 Synchrony versus phase locking in EEG & MEG --ADD

Physiological researchers have struggled with the question of synchrony versus phase locking within the temporal spectra recorded using EEG and MEG. The definitions of these terms become even more important when temporal waveforms of short duration are passed through frequency band limiting filters (as is common in EEG and MEG analyses).

18.3.1.2 Phase coherence over time EMPTY

As developed in detail in **Section 8.4.5.3** of "Processes in Biological Hearing," operations related to the Sturm-Liouville Problem or System are phase sensitive. However, this is seldom noted when discussing the Fourier Transform in pedagogical situations. **Figure 18.3.1-1** shows the effect of changing the phase between the frequency domain components forming a simple temporal waveform via the Fourier Transform. Similar changes are typically seen in the temporal waveforms used to illustrate different recorded EEG and MEG patterns from the laboratory after filtering.

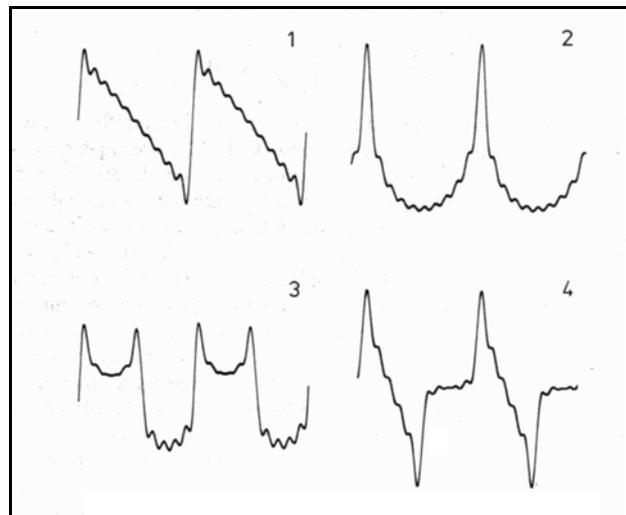


Figure 18.3.1-1 Effect of relative phase on a set of temporal waveforms of constant amplitude. components of constant amplitude. From Plomp & Steeneken, 1969.

18.3.2 Background in EEG investigations

[xxx review this material for semantics]
The electroencephalogram (EEG) is a record of the actual potential of a local area of the scalp compared to an assumed innocuous second location on the head. The potentials involved are very small in magnitude and represent the summation of all of the electrolytic activity within the cranium within a given time period. The subject must not even activate his jaw muscles during this period for fear of introducing major artifacts

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into the recordings.

The EEG is inherently a noise like waveform as shown in **Figure 18.3.2-1**. The interpretation of the EEG presented by Baars & Gage (page 105-106) and accompanying this figure appears to be lacking. While they assert "The 'raw' (unprocessed) EEG shows visibly different waveforms like alpha, beta-gamma, theta and delta." this is clearly not the case to an investigator trained in reading such waveforms. In the absence of a power spectrum as shown at the bottom of the figure, the raw waveform appears to be "white noise" with no preferred or dominant frequency component(s). In fact, the power spectrum is an excellent example of $1/f$ or "pink noise," a power spectrum falling off monotonically as a function of frequency generally as the reciprocal of that frequency (the spectrum shown is not perfectly monotonic because of the limited time duration of the raw EEG used). The horizontal scales of the upper two waveforms were not indicated but appear to be in milliseconds. The horizontal scale of the power spectrum is assumed to be in Hertz. The limited power at low frequencies (below 3 Hertz) in the power spectrum is compatible with the 230 milliseconds duration of the EEG sample.

Baars & Gage make the common assumption that any waveform can be separated into its "original" components using elementary Fourier Analysis techniques. This elementary technique assumes the original waveforms were sinusoids of different periodicity. However, the underlying components need not be sine waves. They may be any mathematically orthogonal set of functions, such as a series of pulse trains of different periodicity. Thus, while a spectrum with noise-like properties can always be represented by a series of sine waves based on a Fourier transform, it does not follow that the original functions creating the noise spectrum were sinusoidal waveforms.

It is proposed here that the noise-like character of the EEG is actually composed of the summation of a great many pulse trains of varying length, periodicity and phase relative to each other. These pulse trains consist of action potentials. While the transformation of the noise-like spectrum into a representation of sinusoids of differing amplitude may provide insights to the researcher, it is not indicative of the actual underlying mechanisms.

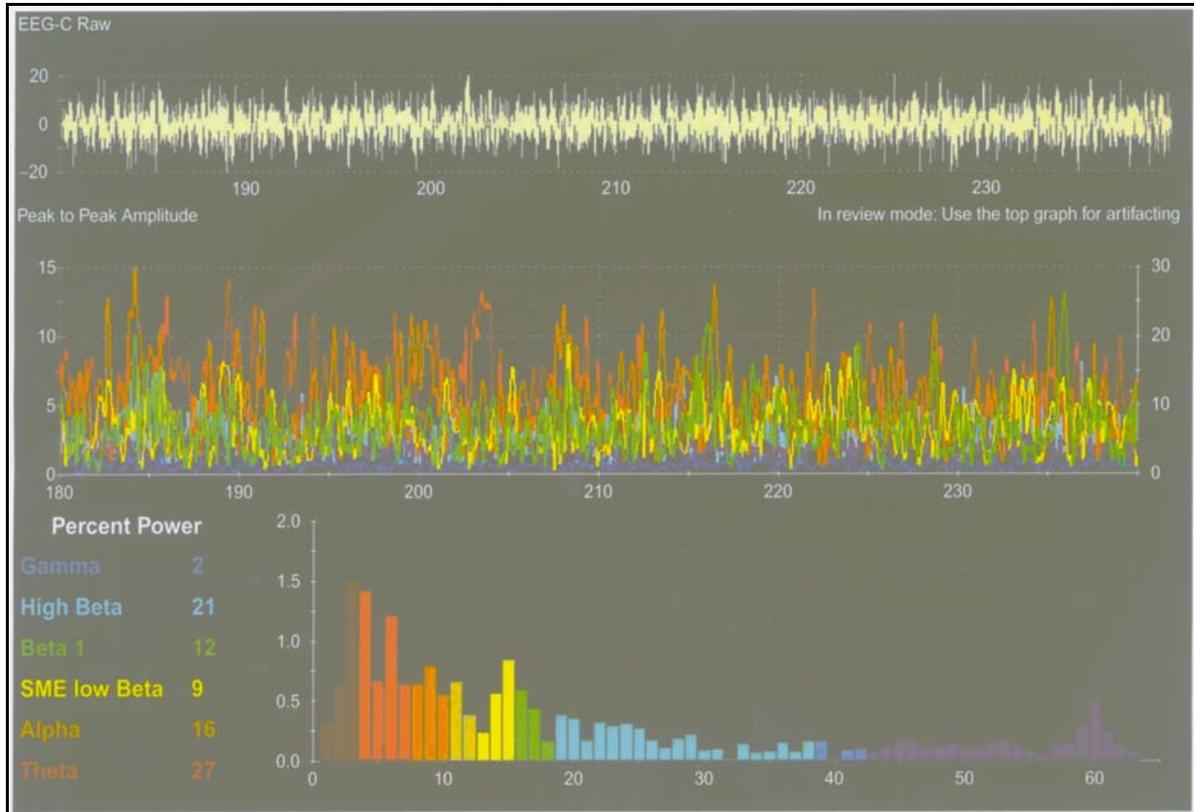


Figure 18.3.2-1 A raw EEG and various results of processing the signals ADD. Note the intrinsic “white noise” character of the raw EEG at top. There is no suggestion of any sinusoidal component in this waveform. However, by using band-limited filtering, individual “peak-to-peak amplitude” representations of individual frequency bands within the raw waveform can be obtained. From Zoran Josipovich as reproduced in Baars & Gage, 2010.

Buzsaki has provided a set of figures describing the signals typically encountered in EEG experiments²⁶. although written for a popular audience, they do provide an introduction.

Figure 18.3.2-2 shows a typical power spectrum of EEG from a sleeping human. The lowest frequency prominence in the power spectrum is at approximately 16 Hertz (frequently labeled alpha but appearing as the center of the beta band of Buzsacki as documented below). The two higher frequency prominences are in the beta band of Buzsacki and others. The location of these prominences are a strong function of the time of recording as suggested by the following spectrogram also from Buzsacki. The 16 Hertz prominence is highly suggestive of a series of action potentials separated by 62 msec emanating from the region of the CNS interrogated by the EEG probe. Whether this pulse stream originates from a single stage 3 neuron or from a combination of the pulses at the entrance and exit of a single engine of the CNS cannot be determined from this data. There are also more complex arrangements that could generate such pulse streams.

²⁶Buzsaki, G. (2006) Rhythms of the Brain. Oxford: Oxford Univ Press

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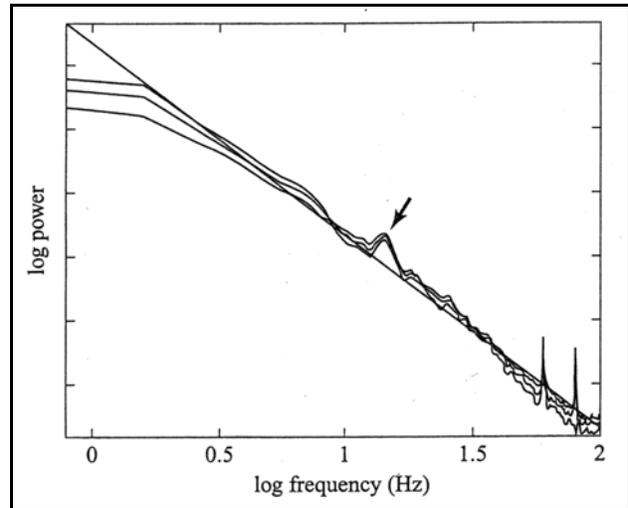


Figure 18.3.2-2 Power spectrum of EEG from a sleeping human averaged over a long interval. From the right temporal lobe region using a subdural probe. The “pink” or $1/f$ characteristic exists at all frequencies above about 2 Hertz and below 100 Hertz. Individual peaks focus investigators on particular regions. Arrow; peak frequently observed and labeled alpha (~16 Hertz). Originally from Freeman et al., 2000.

Figure 18.3.2-3 shows a spectrogram of a rat acquired over a period of time to indicate the spectral component varies almost continuously over time. It should be obvious that a given power spectrum taken over a short interval will vary almost continuously depending on the precise time of acquisition. It should also be clear that individual bands are not well delineated in this record and specific frequencies are not represented by even short horizontal lines.

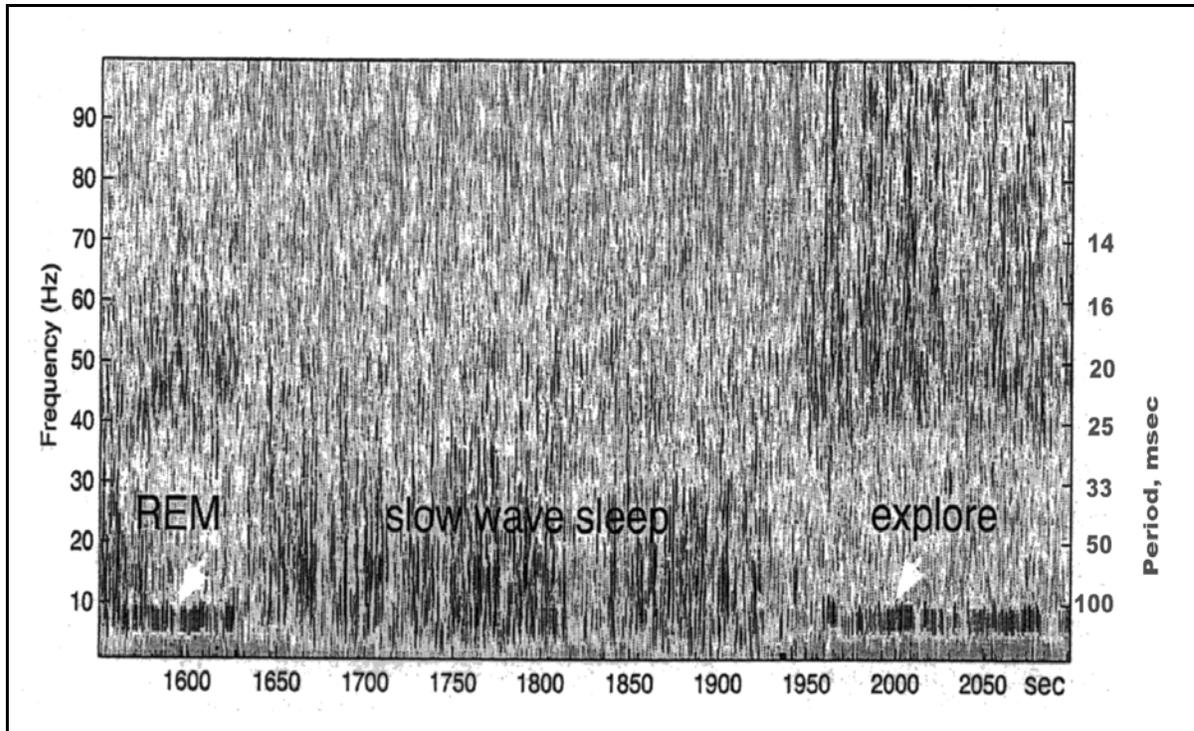


Figure 18.3.2-3 "Whitened" spectrogram of an EEG from the rat. Gray-scale-encoded power of neocortical local field potential in the rat during REM (rapid eye movement) sleep, slow wave sleep and waking exploration. Note arrows highlighting "theta band" oscillation attributed to the underlying hippocampus. Note the distinct theta and gamma (40-90 Hertz power density increase during REM sleep and waking. From Buzsaki, 2006.

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Figure 18.3.2-4 shows another “whitened” power spectrum acquired at a specific time in the mouse. It also displays a listing of sinusoidal frequency bands encountered frequently enough using a Fourier Transform of the power spectrum. They were standardized in 1974 based on pragmatic considerations, i.e., the bands were named using Greek letter following the practice of early investigators and the top of each band was taken as roughly 3 times the low end of each band. The frequency bands were initially confined by the EEG recording technology. Buzsaki describes some of the difficulties of these designations (page 112). The discussion on page 113 is interesting in there is a significant misprint or a serious misinterpretation of the natural exponential base, e , given as 2.17 rather than 2.718. The error is repeated on page 120. They did note a feature described here, “Since e is an irrational number, the phase of coupled oscillators of the various bands will vary on each cycle forever, resulting in a non-repeating, quasi-periodic or weakly chaotic pattern: this is the main characteristic of the EEG.” However, the explanation of the cause is not supported here. The cause is the interior operations of the engines of stages 4, 5 & 6, resulting in a variable periodicity between the input and output pulse trains due to the many inputs impacting the computational environment within a given engine at a given time. The subsequent discussion on pages 113-117 are largely irrelevant and innocuous. To date, no sinusoidal oscillators have been isolated within the cortex of a biological neural system. As a general rule, no oscillators have been isolated that are even capable of generating sinusoidal oscillations, although a form of phase shift oscillator found in the visceral system (both cardiac and enteric modalities) could be filtered so as to generate a reasonable sinusoidal waveform. However, a different form of neuron would be required, to provide the necessary amplification, than is reported in these modalities.

Period scales have been added to both the upper and lower frames of the Buzsaki figure to illustrate the compression observed in these scales (the reciprocal of frequency).

Buzsaki’s description of the oscillators of the neural system as members of the “limit cycle class” (page 137) is largely self serving. No evidence is provided for this assertion, although citations are provided discussing the limit cycle class in general. The paper by Pikovsky et al. has no association with biological oscillators. Although Glass did work in the area of parasystolic oscillations in the cardiac modality, he did not demonstrate the cardiac oscillators were members of the limit cycle class. The biological oscillators are inherently relaxation oscillators that belong to the “switching class” of oscillators as shown clearly in **Chapter 2** of this work. On page 171, Buzsaki accepts the position that “The behavior of an isolated single neuron, being a relaxation oscillator, is strongly asymmetric with very short discharge (action potential) and long charge periods.” His footnote on that page cites a highly abstract mathematical paper by Kopell et al that in fact assumes a relaxation oscillator as the intrinsic neural oscillator.

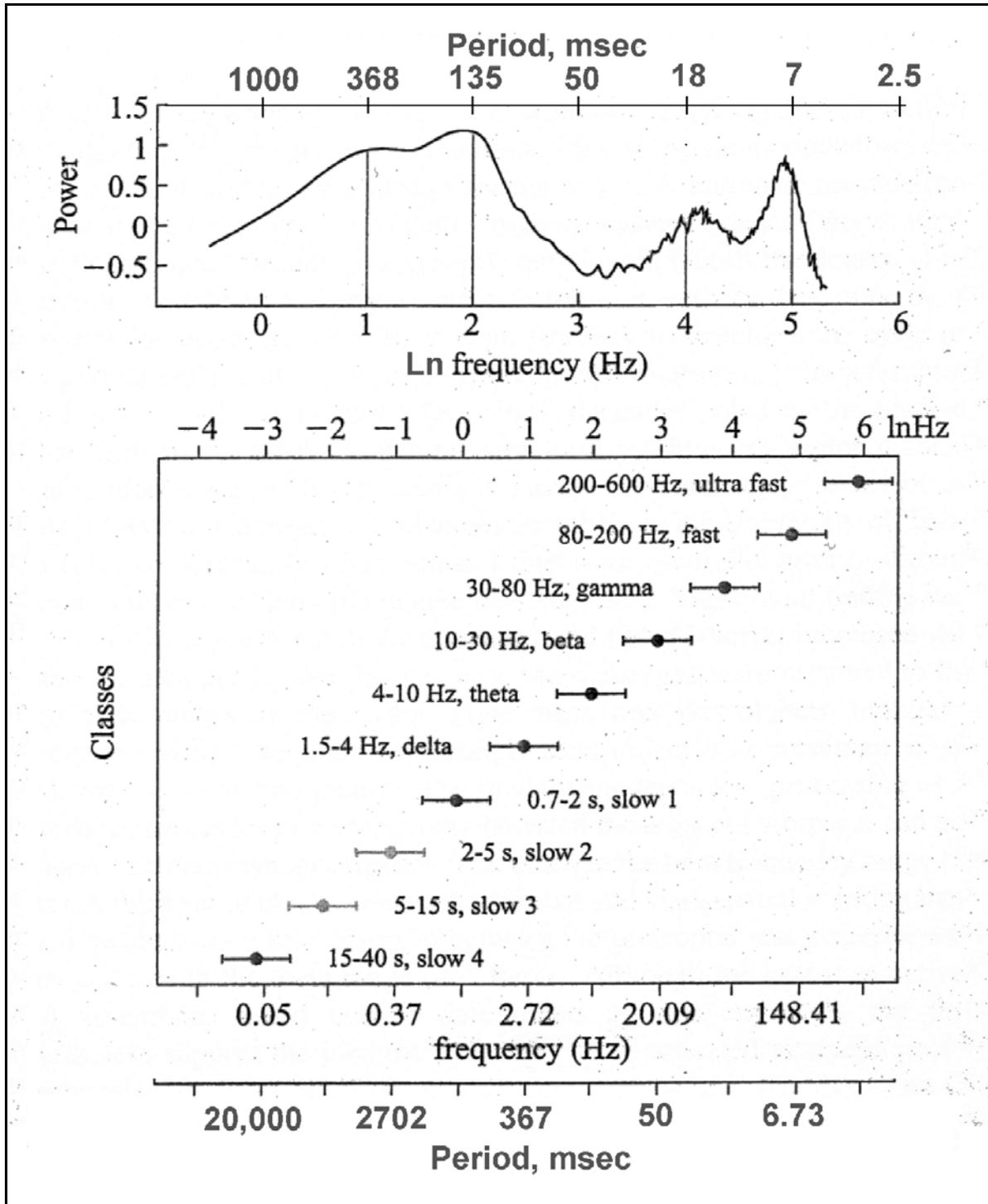


Figure 18.3.2-4 Typical whitened power spectrum & common band designations. Top; power spectrum of hippocampal EEG in the mouse recorded during sleep and waking periods. The four peaks correspond to the traditional delta, theta, gamma and fast (ripple) bands. Buzsaki asserts, "In this case, they are approximately multiples of natural log integer values (they form an exponential series)." Bottom; Bands conventionally defined based on long term observations. Bands below delta are infrequently observed and require specialized equipment. From Buzsaki, 2006, and modified from Penttonen & Buzsaki, 2003.

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The bands shown can be more closely related to the action potential density as a function of time in the actual cortex by taking the reciprocal of the frequency. The results are a density profile of the periodicity of the pulse trains present (ex: the theta band is dominated by action potential pulse streams with periodicities between 100 msec and 250 msec). No information concerning the phasing of the pulse streams is provided by the band designations or either the whitened or pink power spectra.

18.3.3 EEG results

[xxx address the fact that phase differences between the individual source waveforms can have major consequences in the appearance of the band-limited representations of the EEG.]

18.3.3.1 Synchrony versus phase locking REDEPLOY

Psychologists have long used the non-invasive EEG and its multiple probe variants to study consciousness and attention. They long ago discovered that the cumulative signals available at the scalp (and on occasion with implanted intercellular probes) contained sinusoidal components. The *assumption* has always been made that Fourier Analysis (which can describe the orthogonal, usually sinusoidal, signals that can be combined to emulate any continuous repetitive waveform) actually defines the presence of sinusoidal waveforms within the neural system. *In fact*, the situation is much more complicated. No one has ever located a sinusoidal wave generator in any neural system, human or lower animal.

The EEG is the result of summing a very large number of very narrow action potential (pulse) waveforms occurring at different times. These pulses typically occur at a nominal duty cycle of about 3% (a pulse of unit time width occurring every 33 units of time). When sufficient numbers of these pulse waveforms are summed as they occur without regard to phase, they will generate a waveform with a largely random amplitude content that can be described as noise like. However, the human investigator has a strong tendency to perceive a sinusoidal content in any noise like waveform (sometimes accentuated by the band limiting aspects of the recording technique).

In the case of the CNS, the number of stage 3 action potential (pulse) generators is very great. As a result, the summate EEG generally shows a component reflecting the nominal pulse frequency of the *ensemble* (as high as 600, and in some rare cases 1000, Hertz) and any sub-harmonic of such frequencies. The sub-harmonics are frequently related to a mechanism of synchrony. However, such synchrony is seldom found in the neural system, except in the case of some visceral subsystems associated with the heart and the gastrointestinal systems. Synchrony related to the CNS is endlessly discussed but has yet to be documented. A mechanism more clearly present is that of phase locking. Phase locking is most clearly the result of an individual neural engine (typically of the stage 4 information extraction type or stage 6 instruction to command generating type) completing its assigned task after a nominal interval. In this case, the output pulses are delayed by a relatively constant time delay relative to the stimulating pulses.

Usrey & Reid²⁷ have defined "three forms of synchrony;

- (a) synchrony from anatomical divergence,
- (b) stimulus-dependent synchrony, and
- (c) emergent synchrony (oscillations).

That are prevalent throughout the visual system, but their significance is unclear. The most important question is whether synchrony is used at the perceptual level. This question has been posed in a number of recent psychophysical studies, with varied results." In this work, the interest is in the application of synchrony irrespective of location within the neural system.

²⁷Usrey, W. & Reid, R. (1999) Synchronous activity in the visual system *Annu Rev Physiol* vol 61, pp 435–456

"The first category, synchrony from anatomical divergence, can include examples of the tightest synchrony, on the millisecond time scale. It is caused by strong, divergent input from a single source onto multiple targets," i.e., the recording of action potentials at two different pedicles of the same stage 3 signal projection neuron.

"The second category, stimulus-dependent synchrony, includes forms that can be independent of specific neural connections," i.e. the recording of signals from different stage 3 signal projection neurons that share a relationship unknown to the investigator.

"Finally, there is the category we call emergent synchrony, which includes phenomena that rely on the complex dynamics of the network as a whole. This category includes the oscillatory activity of ensembles of neurons in the visual cortex," i.e., the recording of signals from different stage 3 signal projection neurons that share a relationship that is at least thought to be understood by the investigator.

"At the outset, it is important to define what we mean by synchrony. The difference in spike timing between two neurons will never be exactly zero, thus synchrony must be defined in terms of an arbitrary upper bound on this difference. The distinction between synchrony and slower forms of correlated activity can be related to the distinction between a temporal code and a rate code. Although making this distinction is notoriously difficult, the debate can be recast in terms of either the interspike intervals of the presynaptic neurons or the time constants of integration by the postsynaptic neurons. In one formulation, 'the interesting question is whether sensory neurons produce large numbers of spikes or small numbers of spikes in the time windows relevant for behavior and decision making.' Here we make a similar distinction. We call correlated activity synchronous only when it occurs within a time window not much greater than the interspike interval or, alternatively, the integration time of postsynaptic neurons. A special case can be termed fast synchrony, when two neurons fire synchronous spikes at a scale significantly shorter than the interspike interval." And, "It is entirely possible that neural synchrony is an epiphenomenon and is not necessary for normal signal (visual) processing."

It is proposed here that synchrony over a much longer window, compatible with the sample time used to acquire data in EEG and MEG, must also be considered. Long strings of action potentials with different inter-spike intervals constitute a set of orthogonal functions that can be used to create an arbitrary frequency component in an EEG or MEG recording. The degree to which these strings of action potentials can be assigned to different sets of orthogonal functions is indicated by correlation functions that can be Fourier transformed into a complex power spectrum. While the resultant transformed power spectrum can be Fourier transformed into a set of sinusoidal waveforms (another set of orthogonal functions), the resultant set of sinusoidal waveforms may be interesting but they have no relationship to the intrinsic operation of the underlying pulse patterns of the neural system.

This subject is addressed further in **Chapter 9** including **Section 9.8.1**.

Figure 18.3.3-1 shows two frames of a figure from Baars & Gage of 2010. Frame (a) from Figure 3.24(a) of Baars & Gage illustrates this situation using a cross-correlogram adapted from a presentation prepared by Sherman & Guiller, 1998, based on an original figure by Mastronarde²⁸. The reciprocal of such a time delay can be interpreted *ensemble* as an underlying frequency. Frame (b) reproduces Figure 3.24 (c) uses a time-frequency spectrogram to illustrate one *ensemble* situation prepared by Lachaux et al, 2007²⁹.

There is a major problem with regard to the left frame. The captions and annotations for the

²⁸Mastronarde, D. (1987b) *J Neurophysiol* Vol 57, pp 381-413 Figure 3.

²⁹Lachaux, J-P. Baillet, S. Adam, C. et al. (2007) A simultaneous MEG and intracranial EEG study of task-related brain oscillations *Internat Congress Ser* vol 12300, pp 421-424

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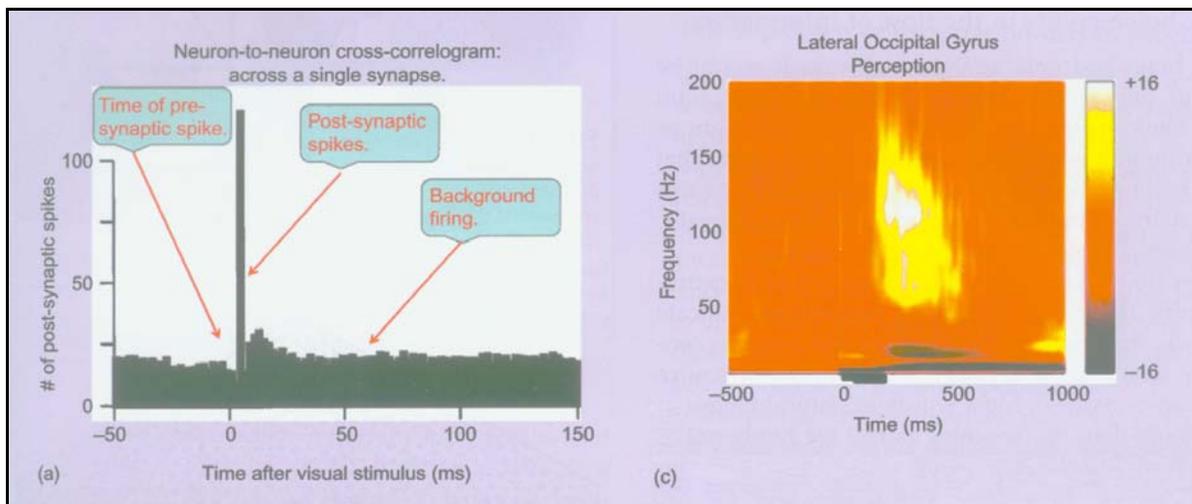


Figure 18.3.3-1 Components of an EEG recording ADD. (a); cross-correlogram showing the time delay between the signal recorded at a thalamic neuron and a related occipital lobe neuron EDIT and explain. (c); xxx Left frame adapted in several steps by Baars & Gage based on Mastronarde, 1987b, figure 3A. Right frame in Baars & Gage based on Lachaux et al, 2007.

figures as they appear in Mastronarde, Sherman & Guillery and colored in Baars & Gage differ significantly. The bin width in milliseconds was not provided in either Baars & Gage or in Sherman & Guillery. It appears to be between 2 and 5 milliseconds. Furthermore, none of the descriptions or discussion refer to the significant time delay between neurons in the thalamus (or similarly located LGN) and the occipital cortex that are related in a single continuous neural circuit. In the cat, this stage 3 signal projection delay is typically several milliseconds (see Sherman & Guillery, figure 2D).

The results in the figure from Baars & Gage are clearly not those obtained across a single synapse in the cat. That delay is typically in the tens of microseconds range (**Section xxx** in PBV). It is probably not as indicated in Sherman & Guillery where the delay is described as between a thalamic neuron and an occipital lobe neuron (presumably in serial connection with each other). Mastronarde describes how he collected the data and prepared the histogram based on the signal generated at an action potential generating neuron in the LGN and a ganglion cell in the retina (not a neuron in the occipital lobe) sharing common or similar receptive fields.

The Mastronarde papers are important and are discussed in greater detail in **Section 11.7.2**.

The right frame also exhibits considerable license in redrawing the data of Lachaux et al. No similar figure appears in the Lachaux paper that reported very early exploratory research in comparing EEG and MEG recordings. Baars & Gage assert the right frame shows a typical plot of the frequency versus time spectrogram based on a human EEG while stimulated by a "mooney face." The stimulus interval is shown by the black bar below the baseline of the figure. The response begins at ~100 ms following application of the stimulus and decreases rapidly after ~500 ms following initial stimulation. Note the lack of any dominant frequency during the stimulation (no fundamental frequency or harmonic frequency structure as typically found in vocalizations and other sounds associated with the auditory modality). It does show a cessation of signal energy in the 4-12 Hz region during the response interval. The significance of the yellow region after 800 ms was not indicated. Like the left frame, the annotation is questionable. There is no indication that this spectrogram of the lateral occipital gyrus (stage 4 information extraction engines) is in any way related to human perception among the stage 5 neurons of the prefrontal cortex. The right hand scale is uncalibrated but it can be assumed to be a linear scale developed by their instrumentation with some level of red corresponding to the average background noise encountered.

The frame on the left of the figure may have been confused with a similar figure in Usrey, 1999, with a similar histogram but different scales³⁰. That figure was comparing recordings from a magno- type neuron in the LGN with a neuron in Layer 4C of the visual cortex of a macaque. Unfortunately, that figure lacked a schematic accompanying it and introduced a semantic problem in its caption. The term monosynaptic was introduced without definition although it did cite an earlier paper by Reid & Alonso. Monosynaptic could suggest there was only one synapse involved between the two locations. In fact, the delay of 2.4 msec between the two recordings indicates the axon connecting the two locations contained a significant number of axon segments and Nodes of Ranvier. The cited paper³¹ gave a definition of; "The criteria we used for a monosynaptic connection was that the cortical neuron was significantly more likely to fire between 1 and 4.5 ms after a geniculate spike." Such a definition is totally operational and observational. It says nothing about the morphology or electrophysiology of the signaling channel.

The Reid & Alonso paper contains considerable information that can be interpreted more completely using the schematics of this work (Section xxx). The paper considers synchrony in some detail but without a schematic supporting the discussion.

18.3.4 Introduction to MEG investigations

18.3.5 MEG results

Llinas & Ribary have made long term studies using the magnetoencephalograph (MEG) to study the activities of the brain during various states of consciousness³². Their recent work has focused on data collected and filtered to include only the 35-45 Hz region. This has focused attention on a potential 40-Hz transient oscillation. They used a 37 channel MEG and collected data from the right cerebral hemisphere. Both single epochs and averages of 300 epochs were analyzed. While the work was well done, their conclusions are less specific than might be desired.

Recently the Llinas & Ribary team expanded their work into magnetic field tomography (MFT) in order to reconstruct the source of their 40 Hz signals³³. The approach provides a non-invasive technique with excellent temporal resolution but spatial resolutions of only 2-5 mm at best. They have noted signals at the parietal surface were delayed by 3 msec relative to signals at the thalamus.

18.3.6 TMS results EMPTY

18.6 The behavioral state system of the mind based on psychology

Swanson has developed a rudimentary state system to describe the operating modes of stage 5

³⁰Usrey, W. & Reid, R. (1999) Synchronous activity in the visual system *Annu Rev Physiol* vol 61, pp 435–456

³¹Reid, R. & Alonso, J-M. (1995) Specificity of monosynaptic connections from thalamus to visual cortex *Nature* vol 378, pp 281-284

³²Llinas, R. & Ribary, U. (1993) Coherent 40-Hz oscillation characterizes dream state in humans *Proc Natl Acad Sci USA* vol 90, pp 2078-2081

³³Ribary, J. Ioannides, A. Singh, K. et al. (1991) Magnetic field tomography of coherent thalamocortical 40-Hz oscillations in humans *Proc Natl Acad Sci USA* vol 88, pp 11037-11041

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cognition and focused on the sleep-wake cycle³⁴. The discussion lacks diagrams relating the different states. The analysis depends heavily on medical experience involving lesions to different elements of the hypothalamus, particularly the "hypothalamic visceromotor pattern generator network on either side of the third ventricle that is called the suprachiasmatic nuclei." His terminology is heavily biased toward the chemical neuron of the 1960's and involves a considerable number of -ergic neurotransmitters.

Baars & Gage provide their chapter 14, "Social cognition: perceiving the mental states of others" as a springboard into the connection between the psychologists "mind" and the physiologists cognitive circuits of stage 5. The subject remains largely one of philosophy at this time. Many of the generalities in this chapter must be closely examined based on our experience with other animals. It may be appropriate to subdivide the subspecies of dog, *Canis lupus familiaris*, into more specific categories based on their evolution (or breeding) to fill specific ecological niches. Specifically, many dog-owners would take exception to the assertion that only humans are capable of triadic activity involving two creatures and a third animate or inanimate object. and described as "I know that *you* are looking at *that*." Baars & Gage state their premise that "dogs have considerable intelligence but do not have shared attention." My experience with Basenji dogs has included many examples relating to this phenomenon. Try looking at or reaching for a leach without the Basenji taking notice, anticipating a walk and heading for the doorway in a state of frenzy. If you do not pick up the leach, he will return in a state of wonderment (and disappointment) as to why you did not follow through by picking up the leach and going to the doorway. The frontpiece to their chapter 14 also appears to oppose their hypothesis and suggest triadic activity among the monkeys. This activity frequently leads to theft of the item of attention and/or fights among groups of monkeys over ownership of the item.

The terminology used in Baars & Gage centers on three different groups of theories of mind (TOM) and their presence in some form of theory of mind module (TOMM). The three groups of theories, particularly the second, involve awkward semantic problems; the module theories, theory theories and simulation theories. They do not describe these groups, any members of a group (with one exception) or provide citations to them. They conclude, "It seems very likely that all three kinds of theories are needed to account for human 'mentalizing' abilities."

After discussing these frameworks briefly, they report recent activities attempting to isolate at least elements of the TOMM using PET and MRI techniques. The activity is moving forward rapidly. The tendency to define areas of the human brain as unique to the species appears inappropriate based on the general development of the brain following MacLean (**Section 4.2.3**) where the expansion of the cortex from a simple dome in reptiles to a folded structure in paleomammals into a crenelated structure in primates (and several other species) allows a rudimentary functional group to elaborate into a more capable group.

In their chapter 14, they tend to define large areas on the surface of the cerebral cortex as functional gyri that are totally unrelated to the previous topological definition of gyri as individual plateau-like area largely isolated by minor sulci.

18.7 Neural cognates of the mind

This work has moved the understanding of the anatomy and physiology of consciousness forward. It can be used to review the ongoing discussion of the neural correlate of consciousness. (NCC). Uttal has discussed this subject (page 46-49) based on the material of Chalmers. His quotation from Chalmers suggests one refer to the original material for a broader

³⁴Swanson, L. (2003) Brain Architecture. NY: Oxford Univ Press Chapter 7

context. Chalmers work was entirely philosophical^{35,36}. Chalmers (page 31 of the first reference) gave the definition for NCC as;

An NCC is a minimal neural system N such that there is a mapping from states of N to states of consciousness, where a given state of N is sufficient, under conditions C, for the corresponding state of consciousness.

Chalmers gave a broader definition earlier in the work. An NCC has to be a minimal sufficient system: that is, a minimal system whose state is sufficient for the corresponding conscious state. By this definition, N will be an NCC when (1) the states of N suffice for the corresponding states of consciousness, and (2) no proper part M of N is such that the states of M suffice for the corresponding states of consciousness.

Uttal proceeds to provide his analysis of the same subject matter. He summarized his position in a list.

1. The primary attribute of a neural theory of mind is the ontological assumption that the mind is a function of brain activity.
2. A true neuroscientific theory of mind must assume that some particular aspect of brain activity is the equivalent of mind; not just any correlated activity.
3. A general attribute of a neuroscientific theory of mind is that of accepted complexity (the contiguous, but not continuous, collection of discrete neurons).

18.7.1 Single neuron theories of the mind

Uttal has discussed the possibility that individual neurons react uniquely to very complex sensory signals describing a specific feature or event in the environment of the organism (his chapter 5). As he notes, theories of this type have arisen primarily as a result of single probe electrophysiology experiments. Such experiments offer no proof that the probed neuron is alone in its response. Furthermore, this work suggests that a major part of stage 4 output and most stage 5 cognition involves multiple bit words passed along using multiple neurons communicating in parallel. Thus, it is likely that a number of stage 5 neurons respond to a specific sensory event.

Uttal describes a number of logical missteps made by those manipulating neurophysiological probe data in coming to their single neuron theories.

18.8 Neurology of impaired consciousness

Schiff has presented a broad study of impairments to consciousness³⁷. Goodale has provided an extensive case study of people with serious impairment³⁸. His figure 83.6 appears to show robust thalamic activity in a subject that has serious lateral occipital lobe damage.

³⁵Chalmers, D. (2000) What is a Neural Correlate of Consciousness? *In Metzinger, T. ed. Neural Correlates of Consciousness. Cambridge, MA: MIT Press Chapter 2*

³⁶Chalmers, D. (2000) What is a Neural Correlate of Consciousness? <http://postcog.ucd.ie/files/What-is-a-Neural-Correlate-of-Consciousness%20Chalmers.pdf>

³⁷Schiff, N. (2004) The neurology of impaired consciousness: challenges for cognitive neuroscience *In Gazzaniga, M. ed. (2004) The Cognitive Neurosciences, 3rd Ed. Cambridge, MA: MIT Press Chap. 80*

³⁸Goodale, M. (2004) Perceiving the world and grasping it: dissociations between conscious and unconscious visual processing *In Gazzaniga, M. ed. (2004) The Cognitive Neurosciences, 3rd Ed. Cambridge, MA: MIT Press Chap. 83*

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Wolford et al have presented a chapter on split-brain subjects³⁹.

18.9 Philosophical discussions on the mind

There is a clear chiasm between the neurosciences and philosophy. As discussed by Searle, as neuroscience provides new understandings of the operation of the mind, the chiasm between the neurosciences and philosophy moves ever farther toward the philosophical end of the line of discussion.

The philosophical literature contains a large volume of material on the mind. However, little of it serves the purposes of this work.

18.9.1 Contribution by Taylor and others

Taylor provides his listing of features related to the mind (pages 10-11). He introduces the term cognition and attempts to separate it from mind. He associates cognition only with conscious processing (equal to his awareness) but finds emotional experience difficult to categorize clearly. The 2006 work of Taylor summarizes a large volume of work in his 1999 book⁴⁰. This book explores more of the philosophical framework for recent writings on the mind and consciousness. He sets the stage for his discussion in his preface, "The main thesis I will present is that consciousness is created through the relations between brain states." In the early part, he describes consciousness, the mind and the soul from a variety of conceptual perspectives. He develops three criteria for any model of consciousness.

Criterion 1- "Any model of consciousness should be developed with as much guidance (hints or clues) as possible from relevant data from the fields of at least psychology, neurophysiology and neuroanatomy."

Criterion 2- The models must be tested to (possible) destruction. This accords with the falsifiability principle of Sir Karl Popper, who posited that the only good scientific theory is a dead one and the next theory is in the process of being created from the skeleton and the recalcitrant death-dealing data." The term "falsifiability" does not translate well from European English to American English (where it contains an element of fraud, rather than legitimate overturning).

Criterion 3- A global viewpoint should be kept for as long as possible.

These criteria appear to lean toward the philosophical side more than the neuroscientific side.

Taylor follows the gross 1988 model of Norman & Shallice and introduces a variety of materials suggesting important roles for both the cerebral cortex and the thalamus.

He then presents his main thesis relating to relational consciousness. "*Consciousness arises from the active comparison of continuing brain activity, stemming from external inputs to various modalities, with somewhat similar past activity stored away in suitable memory receptacles.*" [the italics are his, page 125]

Taylor attempts to locate a source of inhibitory neurons that might temper the actions of the rest of the brain. He settles on the nucleus reticularis, NRT (the TRN of this work) and notes its important role in sleep. He also notes the waves of energy radiating from the TRN to multiple elements of the cerebral cortex. He concludes (page 156), "I suggest the NRT as a possible candidate for the site of global control of cortical activity." This concept places the NRT/TRN in a position equivalent to the conscious executive of the prefrontal cortex. In this work, it has

³⁹Wolford, G. Miller, M. & Gazzaniga, M. (2004) Split decisions *In* Gazzaniga, M. ed. (2004) *The Cognitive Neurosciences*, 3rd Ed. Cambridge, MA: MIT Press Chap. 85

⁴⁰Taylor, J. (1999) *The Race for Consciousness*. Cambridge, MA: MIT Press

been identified as the nonconscious executive (**Section xxx**).

Taylor also explores briefly the potential for distinct awareness and alarm modes and the potential for hypnosis to inhibit specific neural functions. "We can use the relational consciousness model to regard hypnosis as a dissociation between posterior (nonconscious) consciousness and its anterior (conscious) and self partners." [page 309, parentheses added] After asserting the posterior consciousness appears to isolate the anterior consciousness from episodic memory, he concludes, "To summarize, hypnosis is of relevance to relational consciousness since it provides a clear dissociation between the two main posterior and anterior parts of consciousness." While not reduced to a graphic model, this position appears compatible with this work.

In 2009, Taylor went so far as to propose a cognitive machine based primarily on his philosophical studies in a new journal⁴¹. He offers three figures but they are highly conceptual, fragmentary and lack discernable entry and exit points. He notes, "But many of the detailed computational mechanisms are still to be teased out (page 7)."

Sun (pages 167-170) discusses both multiple path views and unitary views of conscious signal processing based primarily on an investigator's interpretation of the cause of various observed phenomena. The few models provided, such as Schacter's are ambiguous and lack clear input and output pathways.

Aleksander provided a brief book in 2005 that is primarily his own introspective observations⁴². He provides an appendix describing his concept of a brain-like machine. It shows little resemblance to the neural system or a reasonable emulation of the neural system. It relies on the assumption that the neural system is a binary computing system (rather than an analog computing system).

If broadened, his configuration of a neuron is generally labeled a perceptron in the world of computer simulation⁴³. In that world, the input is the product of a stimulus, i , times a weight, w , that is not a binary quantity. The weighted sum can be considered a "graded" sum or linear sum. McCarley uses the term "quash" to describe the conversion of his graded sum into a quasi-binary output. Quash is a fair representation of the logarithmic conversion achieved due to the diode load characteristic of a nominal neuron. Quashing can result in a conversion varying from linear to logarithmic depending on the parameters of the diode.

Aleksander describes five axioms related to the operational mind. They do not stray far from the obvious. He does make some interesting observations concerning, but not directly explaining, the work of Libet (see **Section 19.7**). He introduced different symbols for Libet's parameters but did not provide any citations to other literature. Aleksander introduces a random process without any justification, and controlled by an emotional element, to explain Libet's finger lifting observations.

Haikonen has also provided thoughts related to consciousness based heavily on introspection⁴⁴. The concepts draw heavily on the concepts of associative processing similar to those used in the early associative digital computer processors of the 1960's.

18.9.2 A contribution by Dyson

⁴¹Taylor, J. (2009) Cognitive computation *Cogn Comp* vol 1, pp 4-16

⁴²Aleksander, I. (2005) *The World in My Mind, My Mind in the World*. Exeter, GB: Imprint Academic

⁴³McCarley, C. (2005) Neural Architecture <http://www.generation5.org/content/2005/NeuralArchitecture1.asp>

⁴⁴Haikonen, P. (2009) The role of associative processing in cognitive computing *Cogn Comp* vol 1, pp 42-49

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Dyson, a noted science historian and author in the field⁴⁵, has contributed an idea that seems to be compatible with the ideas of Taylor and synopses the hypotheses of this work. The idea was;

Selecting from a list prepared by a deterministic machine is a non-deterministic process that is critically important to the process of scientific *innovation*. He noted the similarity of this process to the Google process of presenting deterministic lists to the conscious inquirer to select from.

It is interesting to consider the complete neural system as a predominantly deterministic system that provides lists, many simultaneously assembled into the saliency map, to the cognitive element(s) of the prefrontal cortex for purposes of selection. This is actually the baseline of the present work.

18.9.3 Brain Bugs by Buonomano

Buonomano has contributed a book on phenomena providing insights as to how the central nervous system might operate, particularly at the higher levels related to consciousness and memory⁴⁶. His discussion of free association and associative architectures is particularly useful. [xxx add] It appears he interchanges the roles of the neurons and the synapses with regard to the fundamental unit of memory and Hebb's Rule. His comments concerning the rule are largely conceptual.

⁴⁵Dyson, G. (7 Mar 2012) Turing's Cathedral: The Origins of the Digital Universe. C-SPAN TV program from the Computer Museum in Mountain View California

⁴⁶Buonomano, D. (2011) Brain Bugs. NY: W. W. Norton

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