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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August 1, 2016

2 Neurons & the Nervous System

17 The Memory Elements of the Neural system[1]

[xxx see chapter 5 of Fuster, 3rd ed]
[xxx draw up or copy a taxonomy of memory, Fuster pg 122]
[xxx perceptual versus executive memory [
[xxx perception action cycle]
[xxx squire 1994]
[xxx lecture 7 from nottingham.ppt]
xxx incorporate material from Rolls, E. & Deco, G. (2002) Computational Neuroscience of Vision. NY: Oxford Univ Press as presented in Chapter 4 in this chapter.]

[xxx Chap 9 of Baars & Gage (2007) on learning and memory needs to be incorporated into this chapter. Includes amnesia as well]

17.1 Introduction

The approach to defining memory differs greatly between the neuroscience and psychology communities.

The psychologist, Fuster has enjoyed a long career in neural research focused on memory, primarily through observation of behavior – in both humans and monkeys. As the title and preface to his 1995 book emphasize, his premise at that time was that most memory centered on the cerebral cortex (alias, the neocortex or new cortex)[2]. "Thus, the scope of this book is broad but limited almost entirely to the neocortex, for the 'new cortex' is the seat of human experience and the focus of my research experience (page ix)."

Fuster's recent (2003) book presents a more timely paradigm which he outlines carefully in his preface[3]. It continues his preposition that all memory is associated with the cerebral cortex (the cerebrum). He notes the previous work in the neurosciences has failed to yield causal relationships between mind and brain. He notes the recent and current progression from the modular model to a large-scale, widely distributed view of cortical cognition. He develops and explores seven "ideas" underpinning this new paradigm. It should be noted, Fuster's work does not involve study of the neuron and the actual neural system or how it exists in (forms) the central neural system. His only neural circuit diagrams are elementary block diagrams.

This work does not share Fuster's claim that all memory resides in the cerebrum, even though it may be controlled from other bodies such as the hippocampus. The obvious neurological role of the cerebellum and pulvinar in memory is difficult to ignore, as required by Fuster's proposed paradigm. As is common among psychologists, Fuster defines a broad and largely overlapping range of memory types based entirely on behavioral and therefore primarily conscious studies. He does not explore the very large realm of learning and memory associated with the sensory and motor systems unrelated to cognition.

While Furster defines his terms much more precisely than is common in his field, the added

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[1]Released: 1 August 2016

[2]Fuster, J. (1995) Memory in the Cerebral Cortex. Cambridge, MA: MIT Press

[3]Fuster, J. (2003) Cortex and Mind: Unifying Cognition Cambridge, Eng: Oxford Univ Press

precision introduces significant difficulties. His basis for organizing and discussion the books content (page 20) is the distinction between perceptual and motor memory. He defines perceptual memory (page 21) as “the knowledge of the world and of the self acquired through the senses. It includes the primary sensory qualities themselves, objects, events, facts and concepts.” He differentiates perceptual memory from declarative memory. He defines motor memory as “including motor learning, motor skills, and classical conditioning.” Unfortunately, he does not recognize the role of the superior colliculus or the cerebellum in motor skills memory. The role of these non-neocortex elements in motor memory is extremely well documented in the clinical literature. His motor aspects of the frontal lobe are generally limited to the pre-motor function by most investigators, with subsequent motor functions related to the cerebellum and superior colliculi acting as memory generally described as consisting of lookup tables.

His assertion that perceptual memory is focused on the frontal lobe and the motor memory is focused on the posterior cortex differs significantly from many other investigators and dismisses any role for the colliculi, the cerebellum and pulvinar in memory. In this work, his term perceptual memory is probably associated most closely with the saliency map (short term or scratch pad memory) and long term memory in general. It is yet to be shown that these types of memory are present within the frontal cortex.

Furster has restated Hebb’s first and second postulates related to synapse formation in the context of memory. Hebb’s postulates related to memory were similar to those of Cajal related to motor neuron operation.

Hebb’s 1st Postulate– When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A’s efficiency, as one of the cells firing B is increased (Hebb, 1949, p. 62).

Hebb’s 2nd Postulate– Any two cells or system of cells that are repeatedly active at the same time will tend to become ‘associated,’ so that activity in one facilitates activity in the others. . . [W]hat I am proposing is a possible basis of association of two afferent fibers of the same order–in principle, a sensory-sensory association (Hebb, 1949, p. 70).

Furster then discusses the subsequent work of Marr and Stent related to these concepts. He notes, “There is no empirical evidence that two inputs must coincide precisely in time to produce effective association. (page 30).”

Furster presents some useful graphics as part of his discussion of linguistics (Chapter 9).

Furster notes an interesting relationship between what he calls perception and volition (page 294). In this work, the similarity is between the cognitive mode (the frontal lobe receiving information from short term, scratch pad, memory) and the volition mode.(the frontal lobe sending information to the short term, scratch pad, memory for further processing).

Hawkins takes an opposite view from Furster, that is supported in this work. Hawkins observed (page 168) relative to the large brain structures, the basal ganglia, the cerebellum and the hippocampus, that lie under the cerebral cortex and communicate with it. “All three existed prior to the neocortex. With a very broad brush, we can say that the basal ganglia were the primitive motor system, the cerebellum learned precise timing relationships of events, and the hippocampus stored memories of specific events and places.” Furster and Hawkins cannot both be right. Recent work has shown beyond question that at least a major part of memory resides in the hippocampus.

Hawkins takes a broad view of how the neocortex works[4]. His version can be extended to include the paleocortex and therefore the entire cortex. He notes the cortex in not like a computer, parallel or otherwise (page 68). Instead of computing answers to problems the

[4]Hawkins, J. (2004) On Intelligence. NY: Times Books

cortex uses stored memories to solve problems and produce behavior.

• 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.

The word sequence is important in the first Hawkins axiom. All memories are of this type. They consist of a concatenated series of individual memories that can be recalled beginning at any point in the sequence. He notes that it is virtually impossible to sing the song, "Over the Rainbow," backwards because the pieces of the song are stored in sequential memory.

Auto-associatively is extremely important in the second axiom. When you recall a specific aspect from memory, you are typically presented with a series of associated events to add context to the information recalled.

The fact that the information is stored in an invariant form is crucial in the third axiom. It is the feature that allows you to recognize a friend while looking at the back of his/her head or at a strange angle.

Hawkins also stressed the seriousness of a loss of hippocampal memory (page 169). "Without the hippocampus you can still talk, walk, see and hear, and for brief periods of time appear almost normal. But in fact, you are profoundly impaired: you can't remember anything new. Even if you met with your doctor five times a day for a year, each time would be like the first time."

Hawkins' assertion that the hippocampus sits at the top of the neural pyramid (page 123) is not supported here. He has lost perspective and proportion with respect to the hippocampus, the frontal lobe and the thalamus. He begins to explore this situation in "An alternate path up the heirarchy (page 171)," where he recognizes the critical role of the thalamus. His first example fails the reason test related to reading words (see **Chapter 19** in "**Processes in Biological Vision**"). This weakens his baseline case considerably. On page 174, Hawkins notes, "I have introduced many speculative ideas on how the neocortex works. I expect several of these ideas will prove to be wrong, and probably all of these ideas will be revised." The role of the hippocampus will surely be one of these.

Fuster has introduced more neural system imaging in Chapter 7 of the 4th edition of his long popular text[5]. He has described the material carefully but some readers may miss the fact that the figures are the result of "memory tasks" that frequently involve both sensory and motor aspects unrelated to memory. His segmentation of some of the data temporally is an effort to separate sensory, motor and memory aspects of the neural activity. However, in the context of this work, the neural system cannot be analyzed based on a single thread assumption. Neural signal processing is a highly parallel operation within stages 4, 5 & 6. Alarm mode and analytical mode activity frequently precedes general awareness activity by significant fractions of a second. The memory activity associated with the alarm and analytical activities may occur simultaneously with other subsequent activities. Memory activities should not be indiscriminately associated with every area that lights up in neuroimaging figures.

Fuster concludes (page 295), "There are very few solid facts from neuroimaging concerning the localization of specific working-memory content in lateral prefrontal cortex."

Buzsaki has prepared a significant book on the operation of the brain from the perspective of a non-invasive researcher relying upon MEG and now MRI techniques[6]. The book is a significant work and deserves more detailed analysis following the major discussion of this chapter (See **Section 17.6.xxx**).

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[5]Fuster, J. (2008) the Prefrontal Cortex, 4th Ed. NY: Elsevier Chapter 7

[6]Buzsaki, G. (2006) Rhythms of the Brain. Oxford Univ. Press

Figure 5.1 in Buzsaki, reproduced as **Figure 17.1.1-1** , is important in understanding the terminology of the neurophysiologists involved in non-invasive signal recording. The signals labeled beta generally represent difference signals (such as those carrying color information) with a quiescent frequency in the 10-30 pps range. All of the classes found above 1.5 Hz can be associated with either stage 3 summing or differencing channels. The slower classes are typically the result of recording the cumulative electrical field from a great many stage 3 neurons performing different signaling functions without accounting for the difference in travel time between the individual stage 3 neurons and the location of the cumulative recording.

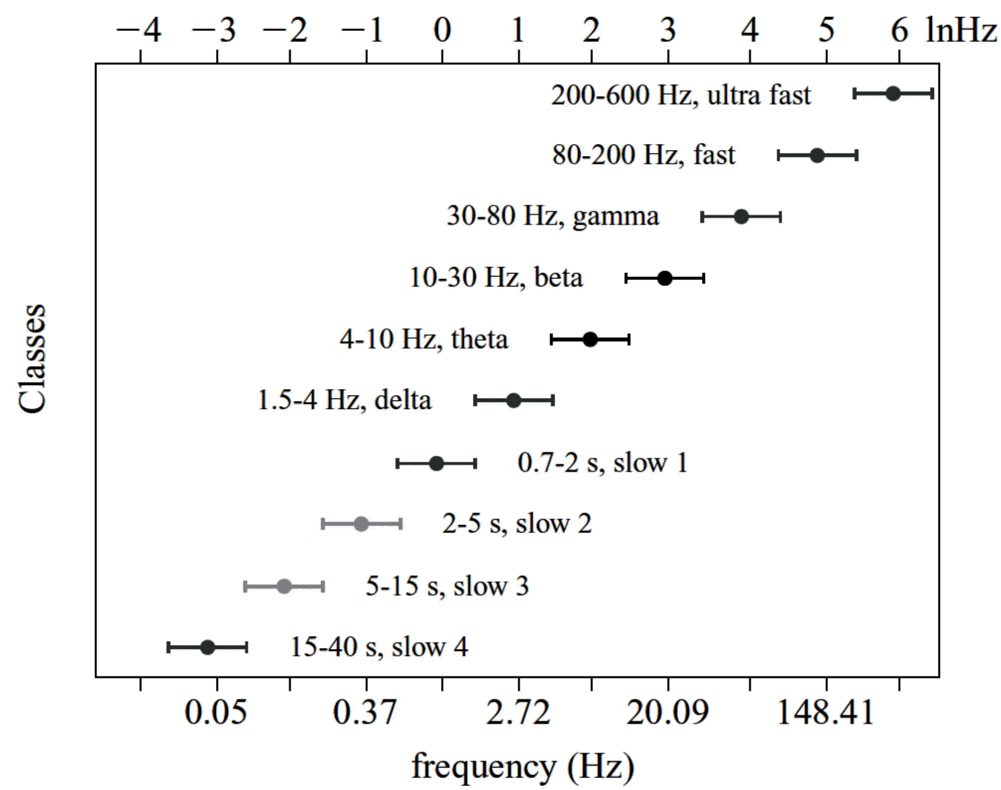

Figure 17.1.1-1 Multiple oscillators form a hierarchical system in the cerebral cortex. Oscillatory classes in the cerebral cortex show a linear progression of the frequency classes on the log scale. In each class, the frequency ranges ("bandwidth") overlap with those of the neighboring classes so that frequency coverage is more than four orders of magnitude. Note the natural logarithmic scale at the top which accounts for the unusual scale at the bottom. Pulse frequencies in the 1.5 to 600 Hz range are normally associated with individual, or small groups of adjacent, stage 3 signal projection neurons. The lower frequencies are generally artifactual and due to the summation of the fields from a multitude of individual neurons. From Buzsaki, 2006

17.1.1 Framework of memory in the neural system

The terms associated with memory in the psychology literature lack a framework. They generally reflect the context of the experiments of individual investigators. Memories take on a wide variety of forms within the neurological system. Eriksson has recently defined a mixed set of memory types along with their proposed primary locations[7]. A taxonomy of memory is necessary to understand the wide range of memories described in the literature, frequently without formal definition. **Figure 17.1.1-2** presents a framework for discussing memory.

Neurological memory can be separated into two major forms; declaratory memory which is accessible by the conscious mind and non-declaratory memory. Declaratory memory is frequently called explicit memory. The high level information stored in declaratory memory consists of cognits in this work. The variation in degree of accessibility of the cognits leads to the definition of a subordinate class of consciousness, described as the subconscious state. Declarative memory can be accessed from the subconscious mind with appropriate cues or pharmacology.

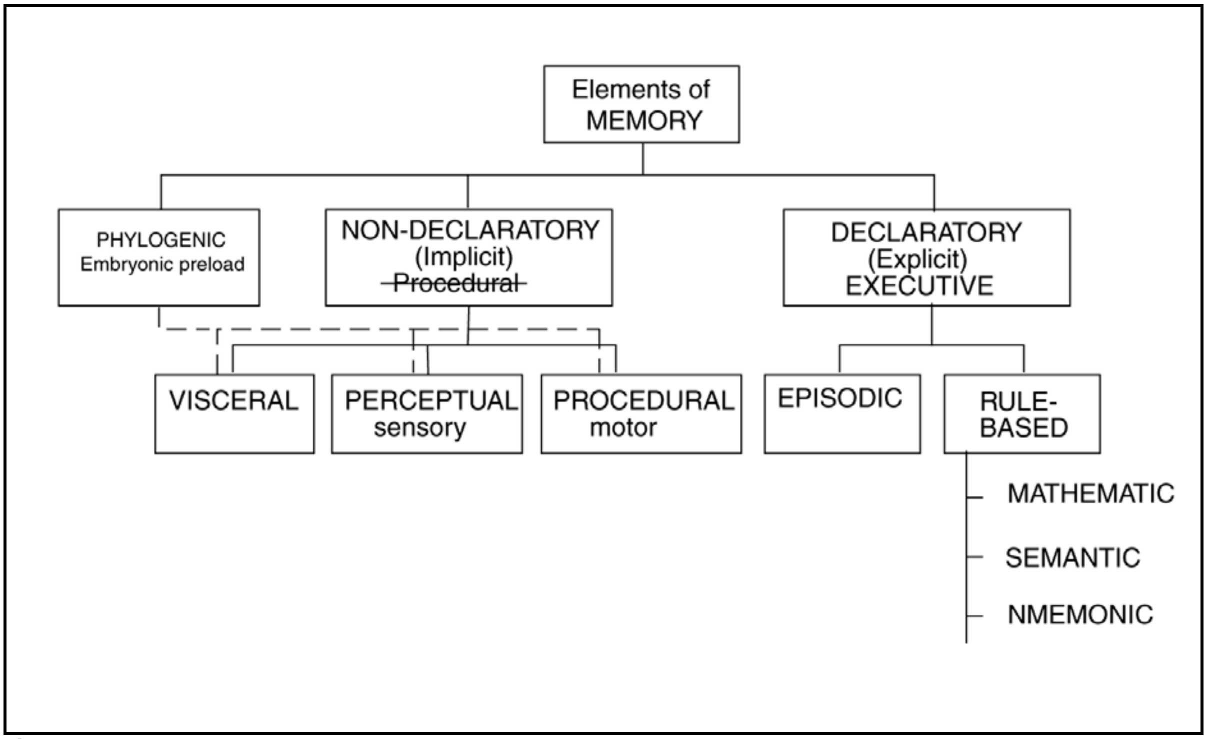

Figure 17.1.1-2 A framework for discussing memory. Non-declaratory memory is used extensively throughout the neural system. There is clear evidence for a phylogenic preload of the memory system at birth. Declaratory memory may consist of a short term "working memory" along with permanent memory. Working memory appears to have a retention period typically measured in seconds. See text.

With reference to the psychology community, the current version of the saliency map will be described as the working memory portion of declaratory memory; the long term memory database forms the majority of the declaratory memory (**Section 1.2.1** & **Section 15.1.1**).

Non-declaratory memory is often called implicit memory. It is not accessible by the conscious mind under any circumstance. Therefore it is associated with the non-conscious state, or alternately the non-cognitive state(s) of the neural system. It can be subdivided into visceral, perceptual and motor memory. The information in non-declaratory memory is stored in the form of interps, percepts and other equivalent motor forms.

[7]Eriksson, P. (2002) Nerve cells and memory *In* Ramachandran, V. *ed*. (2002) Encyclopedia of the Human Brain. San Diegeo, CA: Academic Press vol 3, page 309

6 Neurons & the Nervous System

Squire & Knowlton have expanded the non-declaratory section of this figure to include many other types of non-procedural and non-perceptual learning identified psychologically[8]. [xxx expand on this in order to make the above figure more comprehensive. Be sure the cerebellum gets highlighted in some way]

Ullman frequently identifies procedural memory as the counterpart of declaratory memory[9]. However, his studies are primarily concerned with the motor portion of non-declaratory memory in the context of language. Accordingly, he does not provide a conceptual space for visceral and perceptual memory components of non-declaratory memory. He discusses his definition of procedural memory in his section 3.2. Procedural memory is a synonym for the motor portion of non-declaratory memory in this work.

Ullman and his colleagues have written extensively on a declaratory/procedural (DP) model of the human brain. "The basic claim of the DP model: the brain systems which subserve declarative and procedural memory play analogous roles in language as in their non-language functions." The writings are dominated by text, with few or no graphics. The cited paper does include a 13 page bibliography that is very useful. This work considers the generation of motor commands of phonology to be a subset of the broader procedural memory system, as supported by Ullman & Pierpont in the psychology community and expressed in their Procedural Deficit Hypothesis (PDH)[10]. The problems their PDH is attempting to solve will be addressed in Section xxx on neural deficits. That section will suggest a broader functional model of language production than assumed by Ullman & Pierpont.

Sun has discussed the loading of declaratory versus non-declaratory memory[11]. He relates "bottom-up" learning with the learning of procedural skills (a subset of non-declaratory memory) before the learning of explicit skills that are declarative. His "top-down" learning is the opposite, the learning of explicit information before mastering the associated procedural skills.

Declaratory memory is the home of episodic memory, memory related to personal experience and associated with a spatial dimension and a temporal dimension. It is also the home of rule-based memory, generally the result of the education process. While frequently associated with semantic memory, it is not limited to that type. It is also the home of mathematical memory and mnemonic memory, memory incorporating its own cuing device.

Hepp has recently written a paper from the perspective of a mathematical physicist. He asserts without any support that there is a mathematical memory heavily involved in, and supported by, the learning process[12]. He inserts that hypothesis into his "toy model" containing a description of a simple model of the ocular motor system. See **Section 19.10.6** for a more sophisticated model supporting both the coarse (beneric scene) and fine (analytical) operation of the object recognition process. While the paper is heavily mathematics oriented, his model is largely semantic and conceptual when he builds his

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[8]Squire, 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

[9]Ullman, M. (2004) Contributions of memory circuits to language: the declarative/procedural model *Cognition* vol. 92, pp 231-270

[10]Ullman, M. & Pierpont, E. (2005) Specific language impairment is not specific to language: the procedural deficit hypothesis *Cortex*, vol 41, pp 399-433

[11]Sun, R. (2002) Duality of the Mind. Mahwah, NJ: Lawrence Erlbaum Assoc.

[12]Hepp, K. (2009) The eye of a mathematical physicist *J Stat Phys* vol 134, pp1033-1057

framework on the conceptual "Blue Brain" of Markram[13], Hepp's (MBB). While his text describes at least four figures, they do not appear in the published paper.

Wolters & Raffone have provided a paper involving both memory and consciousness in a complex conceptual framework[14]. 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.

Yu et al. have provided an alternate definition[15], "Working memory (WM) refers to aspects of online cognition, such as monitoring, processing, and maintenance of information. Since Baddeley and Hitch (1974) first published a chapter on WM, many theories have been proposed. One of the most widely supported theories is the controlled attention theory of WM (Engle & Kane, 2004). The theory suggests that individuals with high working memory capacity (WMC) may have better control of attention in integrating information from different domain-specific subsystems."

Sheremata, Malcolm & Shomstein[16] have made the assertion that "visual short-term memory represents information in retinotopic, not spatiotopic coordinates." If correct, this suggests that visual short-term memory is found prior to integration of the extracted information regarding the scene into the saliency map (**Figure 19.10.6-1** in **Section 19.10.6**).

To complete the framework of neurological memory, it is necessary to recognize the existence of some information in memory at the time of birth. This information is typically discussed in terms of an embryonic preload (similar to the hard-wired code used to bootstrap a computer into full operation). This preload is often discussed as representing, or developed from, the phylogenic history of the species involved. It may involve information in perceptual form, motor form or visceral form.

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The difference between knowledge and memories is a subtle one at best. Several authors have attempted to distinguish between them.

Knowledge– A collection of facts and relationships between facts. It is timeless. It may be stored in many forms

Memory, A– (narrowly) A collection of facts and relationships between facts stored within a neural system. The memory may be stored for a short term (in rewritable memory) or stored for a long term.

Fuster makes the case, there are no new neurological memories, only updated memories beginning with the initial "phylogenic memory" installed genetically during embryogenesis. Without going into detail, he argues (page 112) a new percept is uninterpretable and

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[13] Markram, H. (2006) The blue brain project *Nature Rev Neurosci* vol 7, pp 153-160

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

[15] Yu, J-C. Chang, T-Y & Yang, C-T. (2014) Working memory capacity predicts workload capacity Visual Cogn vol 22(8), pp 1046-1048

[16] Sheremata, S. Malcolm, G. & Shomstein, S. (2014) Visual short-term memory represents information in retinotopic, not spatiotopic coordinates *2014 OPAM Convention*, Long Beach, Calif.

therefore unencodable as a new memory in the absence of a related prior memory. [xxx analyze this in context of this work.

Memory exhibits a number of different dimensions leading to a broad range of discussion in different contexts.

autobiographical memory– A frequently but poorly defined form consisting of both episodic and semantic elements of memory personally associated with an individual.

Brand & Markowitsch discuss the properties of autobiographical memory, and several other types defined psychologically, but do not provide a convincing case for its independence of episodic and semantic memory[17]. Their figure shows it as a sub-category of both of these types of memory. Their logic suggests that autobiographical memory may be supported by a range of memory addresses rather than a discreet physical memory. In separate figures, they suggest two possible conceptual circuits for creating long term memory. Both involve the thalamus as an important element.

phyletic memory– memory associated with the phylogenic,development of the species and frequently associated with the embryonic development and initial neural programming of the individual subject

declarative memory– all memories that are consciously accessible.

Nmemonic memory– memory associated with a device to aid in its recall

Semantic memory– the memory of meanings, understandings, and other concept-based knowledge unrelated to specific experiences

Episodic memory– the memory of events, times, places, associated emotions, and other conception-based knowledge in relation to an experience

non-declarative memory– memories that are not consciously available (perceptual memory, procedural memory...)

explicit memory– also known as declaratory memory. knowledge that can be consciously brought to mind and 'declared'.

implicit memory– also known as procedural memory

procedural memory– "knowing how to do a certain thing." long-term memory of skills and procedures, or "how to" knowledge

emotional memory– Some episodic memory may be so harsh, that the system attempts to obliterate details related to it, and to be on extra alert to avoid similar situations in the future.

The psychology community frequently uses the additional term,

working memory– Short-term memory contained within the concept of declaratory memory.

Ingram has presented a popular book describing the above terms in more precise but still common language[18]. His focus was on Alzheimer's Disease, its history, current understanding of its cause and progression, and the potential for a cure during the next few decades.

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[17]Brand, M. & Markowitsch, H. (2006) Memory processes and the orbitofrontal cortex *In* Zald, D. & Rauch, S. *eds*. The Orbitofrontal Cortex. Oxford: Oxford Univ Press. Chapter 11

[18]Ingram, J. (2016) The End of Memory. NY: St. Martin's Press

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This work supports four primary forms of memory associated with the functional organization of the neural system;

•**executive memory** associated with the cognitive function,
•**perceptual memory** associated with the afferent neural signals of the sensory modalities, and
•**motor memory** associated with the translation of executive instructions into individual efferent neural commands to a specific muscle or gland.
•**visceral memory** associated with the homeostasis of the subject

Only the executive memories associated with the cognitive function are usually considered conscious memories, or memories that can be recalled to conscious memory. It is the executive, of declaratory memory that is the usual subject of the psychology community.

The figure includes a preprogramming capability to load individual neural circuits during embryogenesis. The capability appears to exist for any and all types of memory at the circuit level. This preprogramming and the subsequent expansion of memory through learning appears very similar to the bootstrapping operation employed in current computer systems. The machine begins with a very meager "boot" routine that looks around to find what assets it has access to and how they operate. It then configures a rudimentary operating regime that it can use to expand the capability of the complete system. This expansion of memory from a very limited embryonic memory is compatible with, but adds a different perspective to Fuster's view (page 112) that there is "no such thing as a new memory."

Major memory consists of two major components; what is called declaratory memory that is recallable by the subject and can be expressed (declared) to the attentive psychologist or clinical worker, and non-declaratory memory in which the subject is unaware of its utilization, but an investigator can establish exists. These are respectively called explicit memory and implicit memory. Implicit memory is also occasionally called procedural memory but this use of the term is dying out in favor of an alternate usage, to describe the memory associated with the motor system..

17.1.1.1 Aspects of executive memory

Declaratory memory is generally described using three terms. Episodic memory is memory of events that the subject participated in before forming a long term record of the event. This type of memory is initially short term but can be transferred to long term memory, using a mechanism that is subconscious or non-declaratory. Semantic memory is not uniformly defined in the literature. Frequently, semantic memory is memory associated with the use of language. Alternately, semantic memory is described as the memory describing the characteristics of objects. Considerable progress is being made in determining the location of memory associated with language, or its associated subconscious control mechanisms. Mnemonic memory is a category where mneumonic devices are used to recall memories that are otherwise episodic or semantic. The mnemonic device may involve rhyming, sequencing, cross-correlation of features, etc. Some psychologists prefer to consider episodic and semantic memory as forms of mnemonic memory. The relative dictionary entries do not help clarify this situation or support a more precise set of definitions.

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Episodic memory, semantic memory, and amnesia.
Squire LR, Zola SM.
Veterans Affairs Medical Center, San Diego, California 92161, USA.

Episodic memory and semantic memory are two types of declarative memory. There have been two principal views about how this distinction might be reflected in the organization of memory functions in the brain. One view, that episodic memory and semantic memory are both dependent on the integrity of medial temporal lobe and midline diencephalic structures, predicts that amnesic patients with medial temporal lobe/diencephalic damage should be proportionately impaired in both episodic and semantic memory. An alternative view is that the capacity for semantic memory is spared, or partially spared, in amnesia relative to episodic memory ability. This article reviews two kinds of relevant data: 1) case studies where amnesia has occurred early in childhood, before much of an individual's semantic knowledge has been acquired, and 2) experimental studies with amnesic patients of fact and event learning, remembering and knowing, and remote memory. The data provide no compelling support for the view that episodic and semantic memory are affected differently in medial temporal lobe/diencephalic amnesia. However, episodic and semantic memory may be dissociable in those amnesic patients who additionally have severe frontal lobe damage.

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Semantic memory is memory that is knowledge, factual or conceptual. Here are some sentences that demonstrate semantic memory:

I know what a Dalmatian looks like.
I know that there are 50 states in the U.S.
I know the alphabet.
I have my doctor's phone number memorized.
With semantic memory, you may not remember where, when, or how you learned the information, you just know it.

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Wikipedia– Semantic memory refers to the memory of meanings, understandings, and other concept-based knowledge unrelated to specific experiences. The conscious recollection of factual information and general knowledge about the world, generally thought to be independent of context and personal relevance.

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17.1.1.2 Memory described in the time domain

Short term memory– (STM), memory stored in the saliency map prepared by the TRN. This portion of memory is "over-writable" and is continually updated by the sensory modalities. With effort, some short-term memories can accessible to the executive system for several seconds but seldom for a major fraction of a minute.

The term "working memory" has recently found a place in the neuropsychological literature. LeDoux has diagramed working memory in the same role as the saliency map of this work in presenting "immediately present stimuli" for the benefit of the "immediate conscious experience[19]." In the context of this work, immediately present stimuli are not sensory inputs but the informantion extracted from those inputs by the signal manipulations of stage 4. Burgess & Bird have briefly discussed working memory[20]

In this work, "working memory" (WM) is synonymous with short term memory. The content of working memory are found in the saliency map of stage 4. However, it may be useful to consider a copy of selected portions of the saliency map being transferred into the comparators of stage 5 during cognition. This portion would be related to the current focus of "attention" of the subject at that time. This copied portion of the saliency map could

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[19]LeDoux, J. (2000) The amygdala and emotion: a view through fear *In* Aggleton, J. *ed*. The Amygdala, 2nd Ed. NY: Oxford Press pg 302

[20]Burgess, N. & Bird, C. (2009) Place cells indentify hippocampus with location-specific construction of mental images. *In* Mizumori, S. *ed*. Hippocampal Place Fields. NY: Oxford Press pp 156-157

correspond to the cognitive map of O'Keefe & Nadel[21].

O'Keefe & Nadel describe their concept as follows, "a cognitive map is a representation that "permits an animal to locate itself in a familiar environment without reference to any specific sensory input, to go from one place to another independent of particular inputs (cues) or outputs (responses), and to link together conceptually parts of an environment which have never been experienced at the same time. This is a very broad description that requires additional expansion and specification in current contexts of the brain. It appears to incorporate elements involving the recall of long term memory, the focus of attention in response to immediate sensory inputs and the reprocessing of the saliency map to include new data, etc. Jeffery focuses on these additional aspects of the definition and reviews many similar definitions[22]. After noting that most of these definitions appear to involve the concept of a *relationships* between objects in the environment, she notes, "While this seems intuitively plausible, the difficulty is that *relationship* is a vague concept and the definition, in themselves, rarely specify strict criteria by which the existence of such a map may be proved or disproved."

The fourth edition of Fuster has used the term working memory extensively[23]. He has noted a "dualistic" concept of memory without further citation. He suggests its standing is fading in favor of a single unitary view of working memory. His definition of working memory remains largely conceptual, noting (page 4) that it "may be sensory, motor or mixed; it may consist of a reactivated perceptual memory or the motor memory of the act to be performed, or both." His definition of perceptual memory appears to be equivalent to current short term memory as developed in the posterior cerebral cortex, but without further definition as to its precise location.

In this work, it is clear that the "representation" of O'Keefe & Nadel is based on the information extracted from the sensory signals in stage 4. This representation includes the essence of the complete environment extracted currently and it is stored in the saliency map (the primary short term memory). These essences have nothing to do with the geometry or chemistry or pitch of the environment, they include only the features of the environment determined to be important by the organism through prior training and/or heredity.

> ***As an example***, a representation of O'Keefe & Nadel might be, I am in the presence of a friend, who is emotionally distressed, within a room familiar to me, in the evening; while simultaneously, I am in a calm and assertive mood and have prepared a response concerning the last communication from the friend, and am standing upright with my hand extended in friendship ready to speak at the appropriate instant. This representation does not involve any retinotopic, tonotopic or chemotopic characteristics. The information is entirely allocentric and abstract. Jeffery uses the term allocentric as synonymous with "world-centered." It could equally well be considered environment-centered. Alternately, it could be considered subject-centered in an inertial coordinate system.

The cognitive elements of stage 5 are free to examine the entire saliency map or to direct its attention to only elements of the saliency map.

[xxx edit the following]
Definitions of **working memory** on the Web:

1.
memory for intermediate results that must be held during thinking
wordnetweb.princeton.edu/perl/webwn

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[21]O'Keefe, J. & Nadel, L. (1978) The Hippocampus as a Cognitive Map. NY: Oxford Press

[22]Jeffery, K. (2008) The place cells–cognitive map or memory system In Mizumori, S. *ed*. Hippocampal Place Fields. NY: Oxford Press Chapter 4

[23]Fuster, J. (2008) The Prefrontal Cortex, 4th Ed. NY: Elsevier pg 4+

Working memory (also referred to as short-term memory, depending on the specific theory) is a theoretical construct within cognitive psychology that refers to the structures and processes used for temporarily storing and manipulating information. ...
en.wikipedia.org/wiki/Working_memory

the memory system used for holding and manipulating information while various mental tasks are carried out. See articulatory loop.
homepage.ntlworld.com/vivian.c/Linguistics/LinguisticsGlossary.htm

One well studied memory module that stores information needed for ongoing tasks over tens of seconds (such as a phone number). ...
www.klab.caltech.edu/~koch/glossary.html

Component of production rule system containing information that the system has gained about the problem thus far.
www.dbmi.columbia.edu/homepages/wandong/KR/krglossary.html

Short-term (recent) memory. See the entire definition of Working memory
www.emedicinehealth.com/attention_deficit_hyperactivity_disorder/glossary_em.htm

Ability to hold a small amount of material in memory for a short time while simultaneously processing the same or other material.
suffolk.edu/campuslife/11495.html

Sometimes also called `short term memory' by psychologists, it is a mental workspace consisting of a small set of data items representing the current state of knowledge of a system at any stage in the performance of a task, and which is transformed into a new set, in humans by the application of ...
www.cs.bham.ac.uk/research/projects/poplog/computers-and-thought/gloss/node1.html

Is also sometimes called short-term (recent) memory. Working memory is a system for temporarily storing and managing the information required to carry out complex cognitive tasks such as learning, reasoning, and comprehension. ...
www.brainrehab.org/NeuropsychTerms.html

A broad and multi-aspect memory class. In addition to a temporary store of information, it also performs manipulation of stored information ...
wps.pearsoned.co.uk/wps/media/objects/2784/2851009/glossary/glossary.html

Jeffery provides a lengthy discussion of the options related to working memory in the literature, including the rhetorical, “Might the Real Cognitive Map be Somewhere Else?” That discussion opens with, “A number of lines of evidence point to the possibility that the place cells are only one of several place representations in the brain.” In this statement, the term place as an adjective appears to be used in two different contexts. Place cells have been specifically identified histologically whereas place representations remain largely conceptual at this time.

Long term memory– (LTM), permanent memory where the information is transferred from short term memory under the control of the hippocampus.

17.1.1.2 Aspects of motor memory

Motor memory is best described as the lookup entries in the motor portion of the cerebellum that allows high level instructions from the cognitive portion of the neural system to be converted into detailed instructions addressed to a wide variety of muscles to ensure smooth and frequently complex motions of the overall skeletal system.

17.1.1.3 Aspects of perceptual memory

Perceptual memory is best described as the lookup table entries in the pulvinar and sensory portion of the cerebellum that support conversion of the individual sensory signals received at the CNS into information packets generally described as higher level percepts and sometimes described as cognits. Furster (page 96) is less than precise, possibly due to the level of the object in the neural system, as to whether a cognit is a circuit associated with a specific piece of information, or is the piece of information that he also describes as a "symbol." In general, he appears to treat the cognit as a high level percept, or alternately symbol. The ability of higher level cognits to assemble and/or represent multiple lower level cognits suggests one group of higher level cognits are the entries into the saliency map of this work.

17.1.1.4 Aspects of visceral memory EMPTY

8.6.2 Additional discussion of memory

While the operation of memory remains far from being understood, major progress has occurred in the last fifty years. A framework has begun to evolve that has provided significant, although still preliminary, answers about memory. A review by Milner, Squires & Kandel in 1998 is absolutely required reading if one is to understand where the field stood at the turn of the century[24]. The framework they review defines the type of memory of greatest interest in hearing as declarative memory. Declarative memory is associated with "knowing that" (the knowledge of abstract facts and events) as opposed to nondeclarative memory, the memory involved in "knowing how" (as in the knowledge of motor skills).

Figure 17.1.2-1 shows the conceptual framework they established for discussing long-term memory. Their discussion also included short-term memory. Their discussion did not address the short term memory required in the operation (and particularly the information extraction functions) of the sensory systems. This type of memory would be associated with an expansion of the lower left of their figure, particularly the section labeled the diencephalon. The figure has been modified to highlight the additional relevant areas. Their label "medial temporal lobe" includes the hippocampal formation. The physiological portion of their discussion did not consider the electrolytic theory of the neuron presented in this work. Some of their diagrams (figures 7, 8 & 9) could be simplified considerably based on the electrolytic theory.

The definition of the medial temporal lobe in the above figure has not been standardized in the field of neuroscience. It frequently included the hippocampal formation. In some analyses[25], the hippocampus itself is thought to play a role in establishing sequences related to "knowing that" similar to the role of the cerebellum in "knowing how."

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[24]Milner, B. Squire, L. & Kandel, E. (1998) Cognitive Neuroscience and the study of memory *Neuron* vol 20, pp 445-468

[25]Fortin, N. Agster, K. & Eichenbaum, H. (2002) Critical role of the hippocampus in memory for sequences of events *Nature Neurosci* vol 5(5), pp 458-462

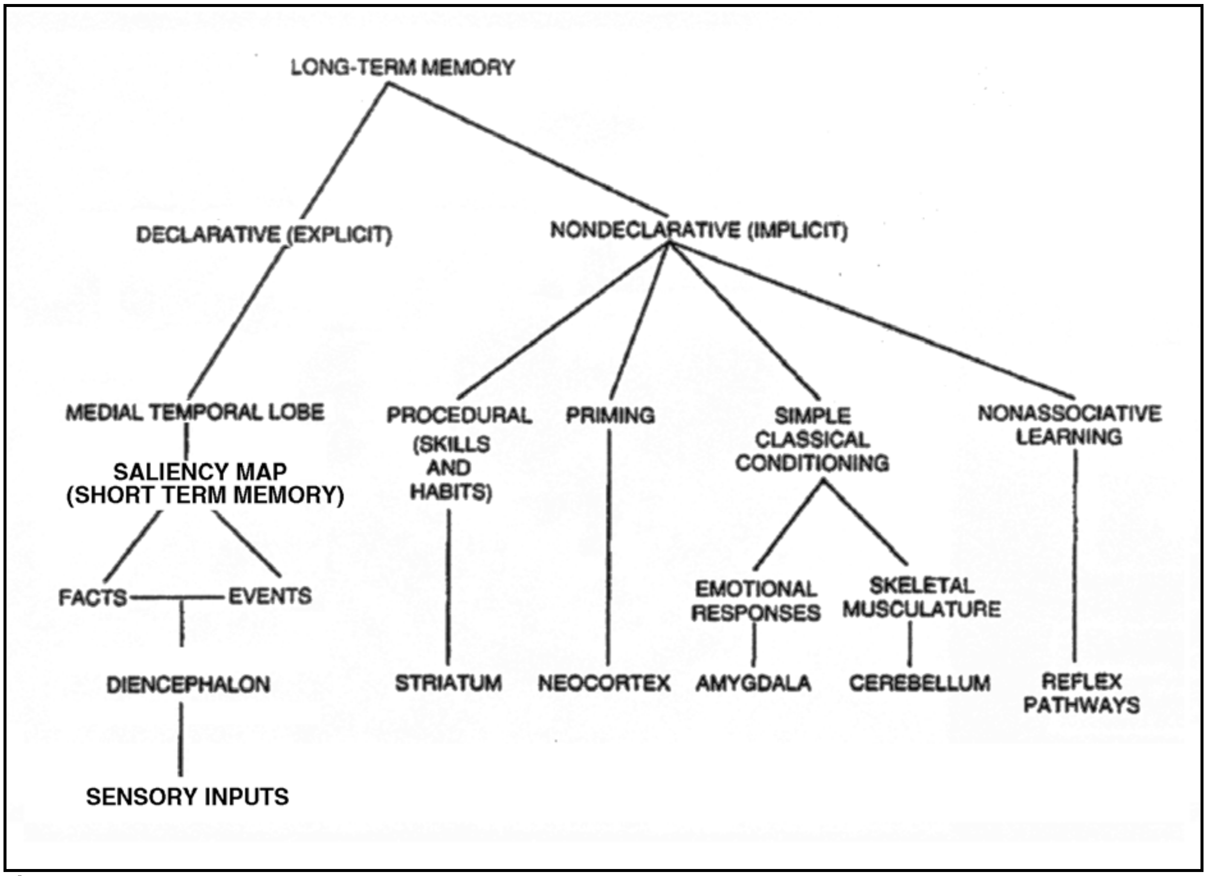

Figure 17.1.2-1 A taxonomy of mammalian memory systems. This taxonomy lists the brain structures and connections thought to be especially important for each kind of declarative and non-declarative memory. The lower right of the figure has been expanded. No specific physical location is associated with the various types of memory. Based on Milner, Squire & Kandel, 1998.

Burgess, Jeffery & O'Keefe have edited an excellent work providing significant data on the complex operations of both the parietal lobe and the hippocampus[26]. The editors are members of the anatomy community but appear to present considerable material gathered by the psychology community. The text provides no significant model or block diagram of these elements. However, it is clear that each of these morphological designations incorporate a wide variety of functional engines performing clearly disparate roles. The text describes the ongoing debate over whether the parietal lobe supports an egocentric or allocentric framework for sensory information without considering the possibility that a totally abstract database framework is used at that level within the neurological system. Burgess (page 11) asserts, "There are no direct projections from the hippocampus to the parietal cortex but there is an indirect projection which proceeds via the entorhinal cortex. . ." On page 19, Burgess suggests the perirhinal cortex may be the gating structure controlling the transfer of short term memory within the parietal lobe to the site of long term memory storage (**Section 8.2.3xxx**). Chapter 15 of the text provides more background on the organization of memory. The recent fMRI studies by Giovanello et al. confirm the role of the hippocampal

[26]Burgess, N. Jeffrey, K. & O'Keefe, J. (1999) The Hippocampal and Parietal Foundations of Spatial Cognition. Oxford: Oxford Univ. Press

formation in long term memory formation[27]. However, the resolution of the 3T MRI machine is not adequate to determine the role of the smaller elements such as the rhinal cortex.

8.6.2.1 The general requirements/features of the neurological memory

Kohonen has noted features of the memory system that make defining it a bit awkward, including the awkward relationship of the mind versus the brain. He noted, "One particular difficulty in the physical modeling of memory arises from the fact that the human mind, as a result of a long intellectual evolution, is able to deal with *concepts* that appear to be distinct and unique items, almost like material objects." This statement also applies to the perceptions of hearing. They can be treated like material objects. He continues, "The degree of specificity connected with the concepts is so high that very complex abstract structures of knowledge have been formed into our thinking."

Kohonen highlighted the important feature of associative memory and processing, the concept of content-addressing. In content addressing, the mechanism uses the content of a message to search a memory for other examples of that, or a similar, message. On page 3, he expanded on a paper by Aristotle on the observations on human memory which were later compiled as the Classical Law of Association." This Classical Law says:

> <u>The Classical Law of Association</u>
>
> Mental items (ideas, perceptions, sensations or feelings) are connected in memory under the following conditions:
>
> 1. If they occur simultaneously ("spatial contact").
> 2. If they occur in close succession ("temporal contact").
> 3. If they are similar.
> 4. If they are contrary.
>
> These remain the key features of the biological memory and recall system.

Kohonen develops this proposition further. He lists three significant features in the operation of a human associative memory: "(i) Information is in the first place searched from memory on the basis of some measure of *similarity* relating to the key pattern. (ii) Memory is able to store and recall representations as *structured sequences*. (iii) The recollections of information from memory in the most general sense are *dynamic processes*, similar to the behaviour of many time-continuous physical systems." Finally, Kohonen noted, "Aristotle made several remarks on the recollection being a synthesis of memorized information, not necessarily identical to the original occurrences."

The above material appears to describe the critical memory portion shared by Stages 5 & 6 of the neurological system.

A distinction continually arises between short-term memory (STM) and long-term memory (LTM). The former is usually considered to involve a retention time measured in minutes at most while long-term memory is generally considered permanent (especially if immediate recall is not required). Hypnosis and merely day-dreaming can cause the recall of a great many events back to an early age, as far back as three years of age for uniquely significant events.

Experimental results are conflicting concerning the nature of long term memory (and probably the saliency map). Many investigators have concluded long term memory must be holographic in character since no specific area has been found that is dedicated to such memory. On the other hand, electrical stimulation of specific locations on the outer surface of the temporal lobe causes the recall of old memories. Repeated stimulation of the same location causes recall of the same memory.

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[27]Giovanello, K. Schnyer, D. & Verfaellie, M. (2004) A critical role for the anterior hippocampus in relational memory: Evidence from an fMRI study *Hippocampus* vol 14, pp 5-8

8.6.2.1.1 The capacity of a holonomic memory

A feature of any holonomic memory is its ability to overlay multiple records on the same recording space. The individual records can be recovered by accessing the record holonomically from different positions, or at different scales, essentially without limit. In this context, the stored information is similar to that associated with multiple spread spectrum signals occupying the same radio frequency spectrum simultaneously. Unless, the receiver is listening with the same decoding algorithm, he only receives a low level noise like background. Kohonen has provided an example of the number of records that can be stored using a given array of neurons (pages 227-230). While highly idealized, it provides a perspective on what is possible. "Let us assume that a 'column' about 100 μm wide is regarded as one pattern element, whereby it contains about 500 neurons. If it is now assumed that each neuron has on the average some 5000 (modifiable) synaptic inputs, there would be more than 10^6 inputs to such a 'group,' by which it can be encoded. This is then the parameter which roughly describes the number of linearly independent patterns, by which the 'group' can selectively be controlled. In other words, in a piece of network which consists of 'groups' of this kind, it is possible to superimpose over 10^6 patterns in distributed form."

A critical feature of the holonomic method of storing information is the total inability of a laboratory investigator to probe for a specific piece of stored information at a specific location. The information relating to any event, present or past is stored in a distributed form. The situation is the same as for a holographic record. Globally, the record looks like a two-dimensional piece of film exposed to a noise source where one can occasionally observe some periodic wavy lines of limited extent[28]. Microscopically, every minute area looks like it contains a single grain of silver halide, or it doesn't. It is only when a finite area of the entire record is reconstructed through a transform that the original information is recovered. Until the transform used is determined, prospects for successful electrophysiological laboratory investigations of memory and cognition are distinctly limited.

8.6.2.1.2 An example of recall based on a content-address

Figure 17.1.2-2 is a graphic example of the capability of an associative memory to use content-addressing[29]. A simple holographic form of holonom was used in this case. The image of the young girl was input to the optical system and stored on a reusable thermoplastic substrate in holographic form. The original source was removed and a fraction of the original image was input into the system to interrogate the stored image. As a result, the complete image was formed at the output aperture of the system (albeit at a lower performance level). The more complex holonomic concept allows additional dimensions of information to be stored in one record.

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[28]Pribram, K. (1981) Op. Cit. fig. 8-8

[29]Soffer, B. Dunning, G. et. al. (1986) Associative holographic memory with feedback using phase-conjugate mirrors *Opt Lett* vol 11, pp 118+

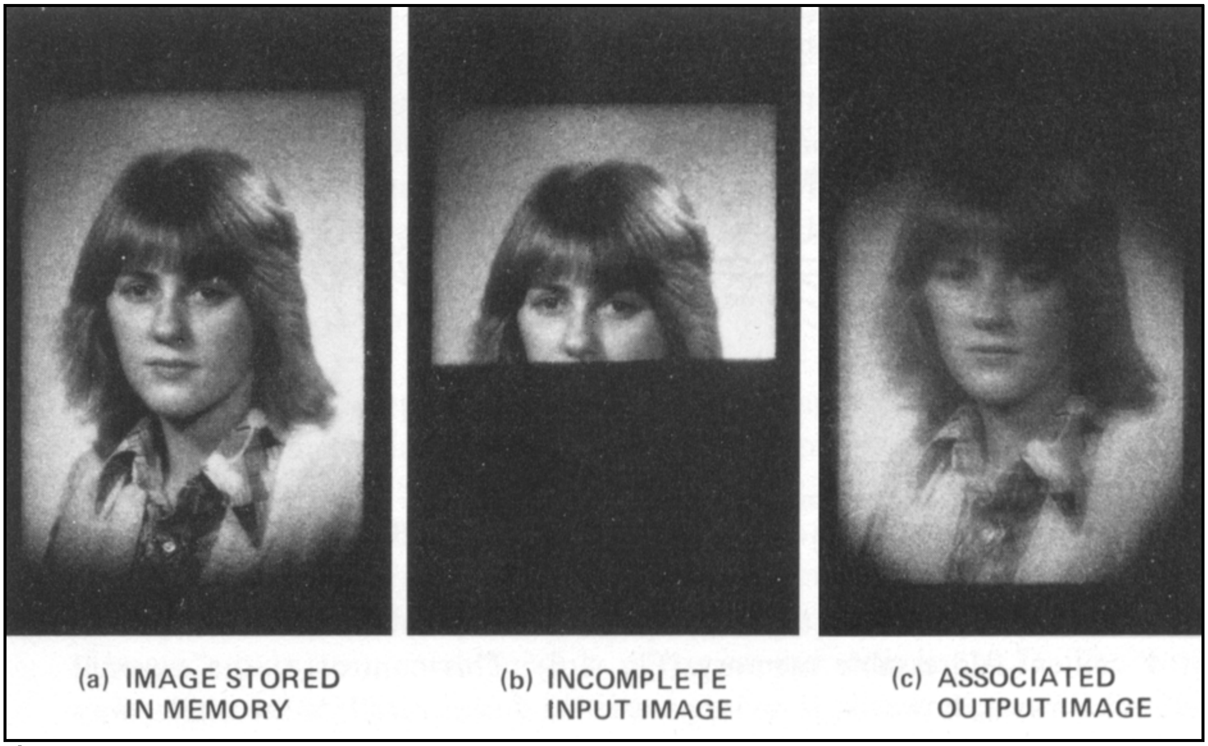

Figure 17.1.2-2 An associative holographic memory system can retrieve full information even if only part of it is specified. The image was stored on an erasable medium. From Soffer, et. al, 1986.

The papers of both Pribram and Kohonen provide many insights into how an associative memory might be implemented but no clear physiological model. Imig & Adrain provided useful data in 1977 that relate to the work of Hubel et al. in vision[30].

17.1.2 The location and means of memory storage

Science has yet to discover the code used to store memories within the neural system..This has made it more difficult to specify the location and means of memory storage. However, traffic analysis has made it relatively easy to determine the location of memory storage supporting the afferent and efferent neural systems.

A recent article prepared for a popular audience describes the state of knowledge in 2013 concerning the location and character of memory in the human based on recent opportunities for "wiring the brain" in the management of epilepsy[31]. Quiroga et al. discuss the potential conceptual mechanisms for memory storage based on the very limited *in-vivo* data available. They do so from the perspective of a clinician and two computational neuroscience specialists. While discussing the potential "sparse" versus "distributed" form of memory storage, they do not precisely define these terms or recognize that distributed might mean storage involving many neurons in either a simple or holographic transform form of memory storage. At one point they do suggest the memory might be associative in character. Similarly, the term sparse is not used in the same sense as it frequently is in antenna theory and most mathematical treatises. Instead they use the term sparse to suggest a localized site for a specific memory of "grandmother." Such a site may involve a number of cells ranging from 10,000 to 100,000 (with an estimate of 18,000 by Lettvin in an earlier era remaining realistic). They note that "grandmother cells" may refer to cells that represent a "concept" related to grandmother rather than a specific representation of grandmother. Their general discussion is compatible with the architecture and morphology of the neural system developed in this work. However, all of their discussion is in terms of stage 3, action potential generating, neurons. They are apparently not aware of the analog character of the vast majority of neurons in the cerebral cortex.

17.1.2.1 The location of afferent and efferent memory storage

17.1.2.2 The location of executive (cognitive) memory storage

The trail related to how and where memory is stored in the neural system has become very vague at the posterior lobe frontal lobe interface, the Rolandic Fissure. While it is generally agreed there is little to no memory storage at discreet locations, there is great debate as to whether memory is stored "holistically" or "holonomically." The difference between these two terms may be more one of approach than fact. The holistic approach proposes the memories are stored using a relatively broadly based physical grouping of neurons. Fuster (page 112) suggests this grouping may be "an immense array of cortical networks or cognits that contain in their structural mesh the informational content." He goes on to assert, "Stored memories, like cognits, *are* cortical networks." However, there is an alternate interpretation that erases the boundary associated with the size of an immense array. The holonomic approach goes one step further and proposes memories are stored following a transformation into an information space that is not physically (spatially) identifiable (e.g., the waves of an optical hologram in Fourier space compared to the fixed spatial points of the decoded hologram). The holonomic approach is completely compatible with Fuster's thesis (page 116) that, "any neuron or group of neurons anywhere in a cognitive hierarchy can

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[30]Imig, T. & Adrian, H. (1977) Binaural columns in the primary field (A1) of cat auditory cortex *Brain Res*. vol. 138, pp 241-257

[31]Quiroga, R. Fried, I. & Koch, C. (2013) Brain cells for grandmother *Scient. Amer* February, pp 31-35

become part of many memories (emphasis in original)."

Employing the same networks of neurons in two different "real" domains is similar to the creation of phantom telephone circuits in man-made circuits. The use of individual power sources for each neuron does contribute to the feasibility of phantom circuits. However, extension of the phantom circuit concept to the same neuron participating in multiple domains becomes difficult. There is logic to converting over from a real to a synthetic domain for memory storage superimposed on an underlying functional network. More research is needed to answer the holistic versus holonomic question

17.1.2.3 The functional form of memory

Hebb described the formation of memory from an early perspective (1949)[32]. His insight, from a psychological perspective, was that;

> When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic changes takes place in one or both cells such that A's efficiency, as one of the cells firing B is increased (page 62).

By replacing the word firing with exciting, his insight remains valid today. The actual process appears to involve forming a new synapse as suggested by Hebb. Uttal's discussion of Hebb in a current context appears correct[33]. As suggested by this work, the "Hebbian synapse" is a conventional synapse involving the transfer of electrons across the junction, with the total area of the junction(s) defining the impedance of the junction. The formation of one or more new synapses as part of the formation of a new memory appears compatible with the formation of both declaratory and non-declaratory (procedural) memory. [xxx coordinate with intro to this chapter re Furster.]

Many investigators have speculated on the functional schematic of neural memory. Zipser et al. have described neural memory in the context of conventional electronic circuit memory technology and the concepts of Artificial Intelligence and neural networks prevalent in the 1990's[34]. They employed probabilistic neurons in feedback networks to emulate actual recorded neural patterns assumed to involve short term memory. No insight surfaced into the biophysical processes involved. Later, after the collapse of interest in Artificial Intelligence, Hawkins noted, "But the scientific frameworks underlying AI and neural networks were not the right ones to use in building intelligent machines (page 235)." A similar statement applies to understanding actual neural networks.

Zipser et al. chose between static and dynamic memory techniques. They chose the most demanding in electrical power, dynamic memory. Dynamic memory requires continual refreshing of the circuit state to maintain the state. Static memory retains a specific circuit state until some action is taken to change it (if possible). A permanent type static memory is generally described as a write once/ read often memory, or more succinctly a programmable read only memory (PROM). A re-writable PROM is generally described as an electrically programmable read only memory (EPROM). .Since the 1990's, man-made memory devices have essentially abandoned dynamic memory in favor of the more efficient static memory.

Zipser et al. and others have typically employed concepts presently found in "real" as opposed to holonomic, circuit configurations (See **Section 17.1.2.2**). There is a considerable possibility that neural memory circuits employ holonomic techniques to achieve their apparently limitless capacity using a finite substrate. It may be that the technology of man has yet to evolve the type of memory circuit employed in the neural system.

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[32]Hebb, D. (1949) The Organization of Behavior: A Neuropsychological Theory. NY: Wiley

[33]Uttall, W. (2005) Neural Theories of the Mind. Mahwah, NJ: Lawrence Erlbaum Assoc. Section 6.4

[34]Zipser, D. Kehoe, B. Littlewort, G. & Fuster, J. (1993) A Spiking Network Model of Short-Term Active Memory *J Neurosci* vol 13(8), pp 3406-3420

Hawkins proposed an alternate form of memory to that of Zipser et al., based on his explanation of how the cortex worked, and then noted, "At the same time, I want to stress that this new framework is incomplete (page 108). While Hawkins presents a variety of conceptual block diagrams, and offers his *memory-prediction framework* of intelligence, his work lacks detail. His analysis does not include any role for the thalamus in vision.

17.2 Forms of cognitive memory

[xxx nottingham lectures until I find Squire material.
[xxx episodic, semantic, mneumonic

Episodic memory is memory related to the spatial and/or temporal characteristics of events.

Semantic memory is memory related to the meaning of things. [xxx nottingham]

17.2.xxx Representational memory

Roesch & Schoenbaum have discussed "representational memory" in the context of reward experiments with monkeys[35]. In the context of their discussion (page 207), representational memory is long term memory that represents the external environment, even if it is later found to be incorrect (generally due to trickery by the experimentalist). It may be associated with a judgement as to the utility of the object of attention in that long term memory (such as a food reward).

17.3 Memory and the prefrontal lobe

Wagner et al. have provided very provocative discussion of the association of the prefrontal cortex with episodic memory[36]. Their material is reviewed in Section 12.xxx.

It is believed that most episodic memory is stored as long term memory with the aid of the hippocampus. Recent fMRI studies have begun to localize the part of the hippocampus associated with memory[37]. "fMRI studies have often demonstrated that much of the activation is located more posteriorly in the parahippocampal formation, at least for visual stimuli."

Wolters & Raffone have presented a quite different view concerning the role of a "central executive" that sounds like the conscious executive of this work[38]. However, they conceptually embed their central executive within their working memory (that sounds a lot like the declaratory memory of this work). Their discussion is largely conceptual with many caveats associated with their one block diagram of the engines of the prefrontal lobe.

17.4 Memory and the basal ganglia

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[35]Roesch, M. & Schoenbaum, G. (2006) From associations to expectancies: orbitofrontal cortex as gateway between the limbic system and representational memory *In* Zald, D. & Rauch, S. *eds*. The Orbitofrontal Cortex. Oxford: Oxford Univ Press. Chapter 8

[36]Wagner, A. Desmond, J. Glover, G. & Gabrieli, J. (1998) Prefrontal cortex and recognition: Functional MRI evidence for context-dependent retrieval processes Brain vol 121, pp 1985-2002

[37]Binder, J. & Detre, J. (2005) Functional MRI in elipepsy *In* Kuzniescky, R. & Jackson, G. *eds*. Magnetic Resonance in Epilepsy. NY: Elsevier Chap 10

[38]Wolters, G. & Raffone, A. (2008) Coherence and recurrency: maintenance, control and integration in working memory *Cogn Process* vol 9, pp 1-17

[xxx review 4th ed of Fuster and the material in 17.1.1 and 12.5.4]

17.5 Memory disorders

Kopelman has presented an extensive invited review on "Disorders of Memory" from a clinical perspective[39]. He was careful to define his terms. His focus was on "patients with disorders of episodic or semantic memory." He starts off defining amnesia as a syndrome quoting Victor (1971), 'An abnormal mental state in which memory and learning are affected out of all proportion to other cognitive functions in an otherwise alert and responsive patient.' He defines the related Korsakoff syndrome using the same words and adding "resulting from nutritional depletion, notably thiamine deficiency."

[xxx review the rest of Kopelman]

As noted in Section 15.4, disorders related to memory are becoming defined more precisely with the advent of non invasive neural imaging techniques.

A report by Spiers in Zillmer and Spiers is an important example, with citation. It describes in some detail the significant damage to memory resulting from a small injury to the thalamus[40].

17.5.1 Amnesia and its extent EMPTY

17.5.2 Alzheimer's Disease, its potential association with Down's Syndrome etc.

Ingram has presented a recent book interpreting the current scientific data base for the popular audience[41]. There are many anecdotes, some with citations, such as the fact the hippocampus is critical to the formation of long term memory but is apparently not involved in the storage or recovery of such memory. He discusses the histological record of the plaques and tangles found in the brain upon autopsy. As Ingram notes, the difficulty of investigating Alzheimer's Disease is the "contrariness of Alzheimer's, where you expect the disease and it doesn't show or where you don't and it does." He notes the inadequacy of recent (1980's to at least 2010) current reporting on research in genetics (page 172).

> "I don't want to wander too far from the DNA-protein relationship, but it has be be said that much of our DNE doesn't actually bother with all this. A mere 2 per cent is ddicated to protein production, while the rest is involved in regulating the 2 per cent or ensuring that the entire, vast mechanism is chugging loong properly. This 98% used to be called junk DNA, but I never actually met scientists back then who claimed that junk DNA didn't do anything. They just didn't know what it was doing."

Ingram notes the effort to correct an imbalance in the concentration of acetylcholine by introducing lecithin (with the current IUPAC name of choline phosphoglyceride). Choline phosphoglyceride (earlier, phosphatidyl choline) is the predominant molecule in the external bilayer of the lemma of all cells and neurons. Why a researcher would attempt to correct an acetylcholine imbalance with the significantly different structure of choline phosphoglyceride is difficult to rationalize. It was probably because of the archaic concept that acetylcholine was a neurotransmitter involved in synaptic signaling.

17.6 Comparison with Buzsaki of 2006

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[39]Kopelman, M. (2002) Disorders of memory *Brain* vol 125, pp 2152-2190

[40]Zillmer, E. & Spiers, M. (2008) Principles of Neuropsychology. US: Wadsworth pg 159

[41]Ingram, J. (2016) The End of Memory. Op. Cit.

The Buzsaki book of 2006 is a very comprehensive work from the perspective of a clinician specializing in non-invasive exploratory techniques and studying the associated works of others in order to establish an overall understanding of the neural system.

He makes the assertion in one of his section headings (page 285), ""The Hippocampus Is the Neocortex's Librarian," without defining what portion or type of memory he is discussing. Based on the framework of **Section 17.1.1**, it appears the remark only applies to episodic memory within the declarative memory context.

Not to disparage the work but to quantify its context, on page 4, he cites Berger[42] (1929) and notes,

> "The larger deflections measure at most 150 to 200 microvolts. . . ." In other words, the electrical field generated by millions of discharging neurons in the cerebral cortex is 10,000 times smaller than that provided by an AA battery."

His use of ellipses requires further discussion, Berger was either measuring a field strength in microvolts/meter using MEG or the reported voltage range was an indirect measurement such as measured with an electrode on the scalp or introduced into the tissue enclosing the cranium and measuring the cumulative voltage due to the electrical field generated by a large number of neurons at a remote distance. In either case, the analogy to a AA battery is imprecise and suggests a problem in understanding the electrolytics of the neural system. A typical action potential has an amplitude of approximately 100 millivolts, not microvolts, when measured directly and conductively at its axon or using patch-clamp techniques at the same axon.

Buzsaki describes the Fourier Transform in some detail. On page 105, he notes,

> "Because brain signals contain multiple frequency components, their relationship can be quantified using frequency domain methods. The complex EEG or MEG waveform can be reproduced by an appropriate combination of sine waves."

It is not clear whether Buzsaki is aware that the Fourier Transorm allows any recorded EEG or MEG waveform to be reproduced by an appropriate combination of *orthogonal functions*, whether they are sine waves or not. On page 106, he also discusses a "short-time Fourier transform and the technique of "wavelet analysis." It is not clear whether he is actually speaking of the technique more generally known as the fast Fourier Transform (FFT) widely used in electrical engineering. His assertion in footnote 35 that Fourier transforms and Hilbert transforms are identical needs to be analyzed further.

On a different subject, Buzsaki notes,

> "In autoassociative attractor networks, the maximum number of stored memories is limited by the decimal order of the number of converging synapses on a single cell from other cells. If memories are stored by static anatomical connections only, the upper limit of the number of memories that can be stored in the rat hippocampus would be tens of thousands, and the storage capacity may not increase much more as we go from rat to human." with citations and further discussion.

Clearly, this is not the order of memory volume we are concerned with in this work. On page 34, Buzsaki states;

"The most prevalent neuronal type of the cerebral cortex, the pyramidal cell, has 5,000–50,000 postsynaptic receiving sites."

Actually, as he notes on page 291 in the same paper, the granule cells outnumber the

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[42] Berger, H. (1929) Über das elektrenkephalogramm des menschen *Euro Arch Psych & Clinic*

pyramid cells by a factor of between 20:1 and 50:1.

He goes on to examine search strategies in a philosophical discussion,

> "Let's begin with some theoretical speculation." and later in the paragraph, "Construction of a full random graph from 200,000 CA3 pyramidal cells would require only 15–20 divergent connections from each cell. However, going from any neuron to any other neuron may require an excessively large number of steps (i.e., long synaptic path length, as referred to in Cycle 2). The theoretical minimum of 10–15 connections is in stark contrast to the 10,000–20,000 synapses that an average CA3 pyramidal cell establishes with its peers. With this large divergence, in principle, activity can jump from any neuron to any other through just two synapses. Furthermore, the large divergence implies that the number of possible routes between any randomly chosen start and goal cell is a truly galactic figure. Nevertheless, no matter how impressive this figure is, we do not get far with such anatomical reasoning alone, because synapses between pyramidal cells are weak, and the discharge of a single starter cell will not be able to fire any of its target peers. Yet, only discharging neurons can be used for encoding and retrieving memories."

There is much food for thought in these statements. In a following paragraph he introduces "granule cells" without describing their detailed characteristics. In fact, his pyramid cells are stage 3 encoding and decoding neurons and his granule cells are stage 2 analog neurons. His autoassociator is the equivalent of the associative correlators of this work (See particularly Chapter 8 of "Hearing: A 21st Century Paradigm".

> "Distribution of the input in the large space of the autoassociator requires a special mechanism, and this is where granule cells become critical. Each superficial entorhinal neuron receives inputs from large neocortical areas. In turn, an estimated 50,000 layer 2 stellate cells send inputs to 1,000,000 granule cells, each of which is a recipient of inputs from approximately 10,000 converging entorhinal neurons. Viewed differently, a single entorhinal stellate cell disperses its information to 20 times more granule cells. The goal of this arithmetic exercise is to contrast the large fan-out in the neocortex–entorhinal cortex–granule cell axis with the exceptionally low divergence and convergence of the granule cell projections to the CA3 recurrent system. An average granule cell contacts only 20 CA3 pyramidal cells, a mere 0.1 percent of the possible targets. Because of this low divergence, fewer than 50 granule cells converge on a single pyramidal cell."

On page 292, he addresses another important subject,

"How to Study the Mechanisms of Explicit Memory in Animals?

A major conceptual difficulty of studying the mechanism of memory storage involves the exclusive nature of memory definition. Episodic memory is claimed to be uniquely human, a mental travel back in time that endows the individual with the capacity to reference personal experiences in the context of both time and space. It is these life-long experiences, representing unique events through spacetime, that give rise to the feeling of the self and are the sources of individuality. The singular episodes can reemerge through the process of free recall. Semantic
knowledge, on the other hand, is largely a context-free form of information. It is the "meaning" of things. Against this background, how are we expected to work out physiological mechanisms of declarative memories in animals simpler than humans?"

He provides no citation for limiting episodic memory to humans. Elephants and many other animals are known to exhibit significant episodic memory.

He also addresses the potential methods of navigation in two-dimensional space. He restricts most of the discussion to 2D because most of the available research relates to mice and other small rodents who live in a largely 2D environment (at least in the caged laboratory).

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