Summary of Cortex and Mind

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Introduction

Joaquín Fuster, Professor of Psychiatry and Biobehavioral Sciences at UCLA, is one of the world's foremost experts on the cerebral cortex. The list of his academic achievements is too long to list (although you may find them at: www.joaquinfuster.com).

His book, Cortex and Mind: Unifying Cognition (Oxford, 2003) is a monument of lucidity, economy, and profundity. While most books that treat the mind / brain problem rely almost entirely upon reasoning for conclusions, Fuster seeks to present what is known about the cortex from a strictly scientific point of view. He is unafraid to draw philosophical conclusions from his understanding of the cortex, and he is equally unafraid to suggest caution where the jump from our scientific understanding to more philosophical conclusions seems speculative.

The general theme of the book is that the cortex is better understood as a distributed and temporally innovative "structure". By this I mean that the best way to understand the brain is by attempting to understand its functions without assuming that functions arise from the activities of specific brain regions. While isolation of brain regions pays considerable dividends in understanding certain functions, this approach also limits a more holistic understanding of higher level activities.

Cortex and Mind

By

Joaquín Fuster

Preface

Despite tremendous progress toward an understanding of the relationship between brain and mind, we face considerable obstacles in understanding that relationship in a definitive way. The problem is intensified by the needs and claims of reductionism, one form of which is represented by efforts to abstract "principles of cognitive function from the study of cognitive dysfunctions in brain injury." [Page viii] In order to make progress, we need to change existing paradigms. In particular, we need to accept the fact that correlation is all that we currently have to lead us to an understanding of the relationship between brain and mind. This requires revamping "our current functional models of the cortex" [page viii].

We have made great strides toward mapping the regions of the brain involved in sensory perception. This has led to a theory and description of the modular basis of such perceptions, but does not explain underlying causes. In other words, the experimental confirmation of the modular hypothesis cannot be extended with equal explanatory power to other areas.

Part of the trouble lies with the longstanding tendency to treat separate functions as manifestations of separate entities. This tendency arose from the success that this paradigm had in the field of psychology. Unfortunately, "it does not follow… that [cognitive functions] have separate neural substrates, although this is precisely the unfounded assumption that has spilled into cortical neuroscience." [Page ix] Current neurological investigations are profoundly impaired by the assumption—and the intent to prove—"that there is a cortical region, or module, for every cognitive function." [Page x]

We are beginning to see a shift away from this tendency in newer explanations that use a "network model" in which function is distributed over noncontiguous regions, although modules may be involved in the process. Interestingly, this shift began outside the area of neuroscience proper as theoretical efforts were made to understand distributed networks in general. The validity of the paradigm has convinced researchers to seek empirical backing for the theory.

The goal of the book is "to substantiate the correlations between neural order and a phenomenal order, the isomorphism of cortex and mind." [Page xi] To do so, the book will explore seven hypotheses:

1. "Cognitive information is represented in wide, overlapping, and interactive neuronal networks of the cerebral cortex."
2. "Such networks develop on a core of organized modules of elementary sensory and motor functions, to which they remain connected."
3. "The cognitive code is a relational code, based on the connectivity between discrete neuronal aggregates of the cortex (modules, assemblies, or network nodes)."
4. "The code's diversity and specificity derive from the myriad possibilities of combination of those neuronal aggregates between themselves."
5. "Any cortical neuron can be a part of many networks, and thus many percepts, memories, items of experience, or personal knowledge."
6. "A network can serve several cognitive functions."

7. “Cognitive functions consist of functional interactions within and between cortical networks.” [Page xi]

One result of this effort should be to free philosophical dialogue from dependence upon an equation between functionality and “cortical geometries”, i.e., from the reductionist localization of cerebral function.

Chapter 1: Introduction

The question is: “whether the mental order corresponds to the order of the structures, events, and processes in one part of the neural order, namely, the cerebral cortex.” [Page 3] The goal will be to “map cognitive networks onto cortical networks.” [Page 4] Currently, the connectionist model is the most accurate in describing actual brain networks. Despite the promise of connectionism, reductionist discoveries have lessened the impact and import of connectionism, isolating it as general theory, rather than allowing it to explain the findings of modular empirical results.

The modular school of thought has been sustained by important discoveries about the isolated functionality of certain specific regions, and by the obvious conclusions that arise from the relationship between trauma and impairment. Those with a holistic view of the brain (connectionists) claim that the empirical results of modular theory provide evidence of the first stage of higher mental processes. The movement gained influence from the Gestalt school of psychotherapy, although no empirical evidence whatsoever supports their general claims. That school’s thesis that perception emerges from the complex interaction and coordination of many brain parts and systems, however, is certainly viable.

In 1950 Lashley proposed that memory is a highly distributed process that defies any modular explanation. Donald Hebb proposed a more general theory of neuronal networks that integrated synaptic plasticity and distributed connectivity with feedback loops to explain the possibility of memory and general cognitive processes arising out of broad neuronal activity. Hayek was able to advance a theory of cerebral function based solely upon his understanding of networks. Hayek's theory suggests that all memory is represented by a map of "temporal coincidence of inputs" whose strength is determined by the frequency of activation. In 1978 Gerald Edelman proposed a more fully-developed theory of distributed network connectivity that included a theory of "group" selection whereby groups of neurons gain functional affinity via environmental influences.

In separate but parallel efforts, those working in Artificial Intelligence were able to mimic certain mental processes with purely computational models. Advances in artificial intelligence allowed neuroscientists to extend the computational model to actual brain functions and elaborate a theory of cortical network activity. One such effort by Kohonen proposed that "self-organization by hebbian principles suffices for the acquisition of memory and learning." [p. 10] Such networks would be characterized by "parallel distributed processing." [p. 10] Despite the successes of connectionism on this level of computational modeling, it has yet to actually explain true cortical processes.

Three areas are contributing the most to our understanding of the cortex: "cortical axonal connectivity" (connectivity between and among regions), electrophysiology (in which neuronal activity is measured and compared to behavior or mental state), and neuroimaging, which relies on the correlation among neuronal activity, blood flow, and brain metabolism.

The term “cognit” means “any representation of knowledge in the cerebral cortex”. It is “defined by its component nodes and its relations between them.” [p. 14] Because of the fact that neurons may belong to any one of a number of groups, each group representing a cognitive state, the number of total possible states is practically limitless. These cognits are dynamic, responding to the demands of experience and learning. “Cognits… have immense variety in terms of their information content, their complexity, and the number and nature of their components.” [p. 15] While the perceptual cognits are stable and consistent, they can nonetheless contribute to a variety of higher order cognits. Complex cognits may begin with perceptual input but involve large areas of the cortex for their representation, while highly personalized cognits might vary tremendously from individual to individual. The plasticity, size, and dynamism of these networks implies that “the same cortical networks can be used in perception, attention, memory, intellectual performance, and language.” [p. 15] This stance contradicts a standard notion that “different cognitive functions reside in different brain locations.” [p. 15] This, in turn, implies that “cognitive functions per se have no definite cortical topography.” [p. 16]

Chapter 2: The Neurobiology of Cortical Networks

Approximately 250 million years ago certain reptiles “developed mammalian features” [p. 18] that were accompanied by an expanded neocortex. While there is a direct correlation between evolutionary time and mass of the cortex, that correlation has not always been linear. Some species, such as primates, demonstrate a disproportionate cortical growth in comparison with overall brain size. While there can be a vast difference in size of the neocortex from one species to the next, the more important and telling distinction is neuronal connectivity. This may be explained partially by genetic variation since "an essential genome for the basic sensory and motor functions of the neocortex can cover the basic adaptive needs of all mammalian species, while slight modifications in that genome can generate enormous variability in behavior and cognitive ability." [p. 22] Neocortical growth does not necessarily imply greater density, although it does correlate to greater connectivity among neurons, and to dendrites of greater length. We also see a great difference in the amount of white matter that constitutes the cortex, with the white matter of higher species composing a much larger percentage than the white matter in simpler species. This evidence suggests that networks of greater perceptual and computational complexity emerge from increased cortical size, dendrite lengthening, and increased volume of white matter.

The chapter contains a number of details about fetal and early cortical ontogeny, the most interesting of which is a theory proposed by Changeaux that explains the inordinate proliferation of neurons during this time and their eventual partial attrition by suggesting that synaptic usage assists in determining which neurons remain in use. One example is: visual stimulation evidently assists in neurotransmitters being released that "enhance the formation of synapses and the efficacy of their transmitting properties." [p. 31] [This suggests that neuronal excitation is part of an electro-chemical feedback loop whose growth and viability determines and is determined by the overall activity of the loop itself].

The following is Fuster's summary of cortical development:

"In summary, then, there is a clearly genetic plan for the development of the entire observable structure of the neocortex. The plan covers all the macro- and microscopic features of that structure, including neurons and their connective appendices—dendrites, synapses, and axons. However, at every step of development the expression of that genetic plan, the structural phenotype of the neocortex, is subject to a wide variety of internal and external influences. These influences create the necessary and permissive conditions for the normal development of the neocortex and its neuronal networks. Among the essential factors is the interaction of the organism with its environment. Through sensory and motor interactions with that environment, the afferent, efferent, and association fibers of the neocortex will develop and form the networks that are to serve cognitive functions. The development of these networks involves most like a process of selection of neural elements among those that in earlier stages have been overproduced (selective stabilization). A degree of competition for inputs among cells and terminals is probably part of that selective process. Thus the elements that succeed in the competition would thrive and survive the normal attrition; others would be eliminated."

Even though the structures of the human brain are essentially in place at birth, the brain's neurology continues to be shaped by experience, particularly at the synaptic level. Two schools of thought dominate what this process of change is like: selectionism and constructivism. "Selectionists maintain that cortical representation is the result of the competitive selection of neural elements." The "constructivists emphasize the idea that cortical representation is the result of growth and combination of neural elements that develop in the cortical structure promoted by experience." [p. 37] In reality these two views overlap and complement, with both being necessary for a satisfactory explanation of cortical growth processes. The primary evidence for selectionism comes from the fact that when perceptive nerves that terminate in the cerebral cortex are severed, the cortical elements to which they were formerly attached are adopted for other uses within the cortex—uses that have nothing to do with their original use. Evidence for costructivism comes from the measurable axonic and dendritic increase (both volume and length) due to stimulation and from the lack of growth in these areas due to sensory deprivation.

All neuroscientists agree, however, on the importance of the synapse in neurological representation. Synapses are the practical side of the Hebbian postulate that temporal coincidence of synaptic activation strengthens the association between and among neurons and that physical linkage between neurons is strengthened by synaptic activity as well. Thus cells that are physically separated may become part of the same neuronal activity (cognit) from repeated synchronicity, while others may become functionally related by topological proximity.

Extracortical factors also influence cortical growth. The hippocampus, for example "participates in the making… of perceptual memory… [and] motor memory." [p. 46] In addition, a number of neurochemical systems contribute a good deal to cortical function and development. Synaptic inhibitors such as GABA play important roles, for example, in the promotion of attention through inhibition of other channels. Glutamate and NMDA receptors promote "neocortical representations" [p. 48] in the network.

In general, cortical networks have three traits: convergence (the idea that information received external to the organism follows disparate paths to a localized neural region), divergence (the idea that low level neuronal representations passes information upward and outward toward disparate cortical regions), and redundancy (the idea that these paths are characterized by duplication and crossover). The complexity of this situation provides for emergent phenomena such as “imagination, creativity, and intuition” [p. 53].

Chapter 3: Functional Architecture of the Cognit

Any model of the cortex must integrate various opposing viewpoints. Currently, connectionist models (models of neural nets) do this best. They rely upon distribution, feedback, synaptic fortification through repeated use, and parallel processing to explain cortical activity, all of which seem to be actual features of the brain. This model also incorporates learning. Their structure imitates that of the brain sufficiently well to be able to imitate some of its functionality.

All cognitive function depends upon categorization.

The neocortex itself consists of six layers. Each layer has characteristic cells as well as connections to different parts of the brain. These layers consist of bundled “vertical columns of cells and fibers.” [p. 62] In the primary somatic, visual, and motor cortices, these “ensembles” seem responsible for discrete kinds of perceptions. Thus the sensory and motor cortices are functionally modular. This is not true of the associative cortex. Non-fundamental knowledge is distributed across the associative cortex, meaning that such knowledge is a state of associations between and among many neurons and groups of neurons. While “elementary sensations” are responsible for the initial neuronal activity, this activity cascades upwards from the primary cortices into the distributed networks that make up the associative cortex.

The neurons of the fundamental sensory cortex extend upward to other regions of the cortex, providing pathways to larger regions with more complex functionality. This primary sensory cortex provides information to the unimodal association cortex, which groups inputs into areas that perform higher-level—yet specific—functions such as face recognition, motion recognition, and word recognition. Pathways then lead out of the unimodal association cortex to the transmodal (posterior) cortex, which bundles groups of inputs into highly complex systems of recognition, memory, and interpretation. The "lowest cortical level [the primary motor cortex], [coordinates and represents] skeletal movements… in discrete [modular] neuronal networks. In the level above, the premotor cortex, motor networks and their representations are more ample and defined by goal and trajectory; in one premotor area, the SMA, some of the cognits represented consist of movement sequences. In prefrontal cortex, the highest executive level, the representations of actions are made up of more extensive networks that encode novel, temporally extended schemas, plans, and programs of action, including linguistic experiences." [p. 80]

In general, although these two regions of the brain can be described in hierarchical terms, they are not actually structured that way. They exist as parts of a highly distributed and highly connected (redundant) network. Sensory information gets processed in discrete, modular areas, but that information is passed up a hierarchy of increasing complexity and connectivity. M1 is connected to the premotor cortex, which is not modular, and which in turn connected to the prefrontal cortex, which is highly distributed, and in turn connected back to limbic structures, linguistic areas, and even to trans-hemispheric areas.

From a philosophical standpoint, Hayek's statement is important: "All we can perceive of external events are therefore only such properties of these events as they possess as members of classes which have been formed by past 'linkages'. The qualities which we attribute to the experienced objects are strictly speaking not properties [of those objects] at all, but a set of relations by which our nervous system classifies them or, to put it differently, all we know about the world is of the nature of theories and all 'experience' can do is to change those theories." Fuster's comment is: "Those 'theories', by definition, have a higher rank as categories of knowledge than the new experience, which they help to categorize."

Contradictory to this, humans often tend to assume that a virtually infinite novelty of thought is available to them—and that their personal powers of reason will judge all new information objectively and independently of personal inclinations and prejudices and learning.

Chapter 4: Perception

The goal of the chapter is to describe the structure and shape of the brain areas involved in perception. An accurate account of perception must include not only the processing of external stimuli, but the autobiographical aspects of perception. Seen thus, "perception can be viewed as the interpretation of new experiences based on assumptions from prior experiences." [p. 84] This assertion is sustained by the fact that "the bulk of perceptual processing is executed in parallel and unconsciously." [p. 85]. That which matches an existing categorization (including emotional response) stands the greater chance of drawing conscious attention from the organism.

Gestalt theory effectively explains perception by positing that perception operates by categorizing wholes by apprehending relationships between and among objects against a field. If we could transfer this principle to brain structure, we would take large steps toward an isomorphic / neurologic explanation of perception in the brain. For example, Gestalt helps solve the problem of perceptual constancy, which is the ability to recognize things despite changes in dimension or other features.

Sensory inputs→pre-prepared perceptual apparatus→sensory gestalt matched to existing neurological gestalt→categorical fit or re-categorization. (Re-categorization may involve only the slightest modification or inclusion).

We know this about perception:

- It involves widely distributed networks of neurons.
- Perception, therefore, does not need to "converge" in order for it to be a perception.

"The overriding idea in this chapter should be that an object is represented at several hierarchical levels, from the sensory to the symbolic." [p. 106]. Indeed, even during symbolic representation (such as words), lower brain regions are involved in the overall network activity that represents the symbol and which is identified in turn by the global, distributed network activity.

Two factors influence the transition from perception to action: the internal state of the organism, and the associative power of the percept.

Chapter 5: Memory

The fundamental points regarding memory are:

- Memory is a neuronal state of the cortical network.
- There is no direct evidence or compelling rationale for a distinction between short and long-term memory. In fact, evidence strongly suggests that the cortex is the only available memory store, and that synaptic reinforcement is the only method for memory initiation and propagation. [p. 121]

- All memory is associative memory.
- To the degree that memories are initiated by excitatory processes, they are probably also enhanced by inhibitory processes of some kind.
- Neurotransmitters play some role in memory formation, although we do not have a clear or complete picture of that process.
- Memories are most commonly formed from diverse interactions of distributed neuronal systems ranging from basic sensory regions to high-level associative regions. Hence the statement, "heterogeneity is a universal trait of all memories." [p. 121]
- "Any neuron or any group of neurons anywhere in a cognitive hierarchy can become part of many memories." [p. 116]
- Certain memories—particularly those that depend most directly upon primary sensory input and are stored in localized low-level areas—are more susceptible to loss through damage than others. Highly distributed memories tend to be more resilient.

Executive memory. In an attempt to understand the prefrontal cortex, neuroscientists commonly attempt to categorize its parts in terms of functionality, ignoring its role in representation and memory. One important function is to facilitate the ordering of action in repeated accounts. Another (that Damasio writes about) is the ability to plan and execute complex behavior, especially regarding the valuations of different possible behaviors. These are commonly called "schemas of action". Because the prefrontal cortex does not seem to be involved in motor actions (despite being contiguous with the motor cortex) and because it is involved in schemas of action, it has been termed the "executive cortex". Here, "neurons of the frontal cortex will integrate sensory information for the execution of behavioral acts that are contingent upon" other feedback information [p. 129]. "Further abstraction, by dispersion and convergence of executive information, would lead to even more global frontal networks representing general concepts of action. In the human brain, these conceptual networks would include value systems of behavior and such concepts as those of responsibility, altruism, and the rule of law." [p. 130].

Retrieval of memory. All memory is associative memory. Accessibility of memories is a measure of the synaptic strength of the cognit. The hippocampus is involved in memory retrieval through its connections with the neocortex [p. 134]. Memory retrieval can be activated by sensory stimulation (through association), via other internal memory networks, or through emotional memory. The vast majority of these memories, however, happen outside consciousness.

Chapter 6: Attention

The neural mechanism of attention. Attention is made possible by the simultaneous activity of excitatory and inhibitory processes that allow the organism to dedicate greater neuronal resources to the task requiring attention. Attention is not controlled by any modular mechanism or neural center dedicated to that task. "…[A]ttention is the process of timely and selective activation of cognits to attend to the ever-changing demands of adaptation to the environment." [p. 149] The prefrontal cortex is responsible for the feedback regarding the effectiveness of action resulting from attention. Interpretations of decreased or inadequate effectiveness serve as the impetus of top down control that guides increased attention.

Working memory is the active selective cognit necessary for processing what the organism has as its focus. Specific prefrontal cells have been identified that fulfill this function of maintaining in accessible memory that which may be need in the very near future (thereby forming part of the near term behavioral plan). Despite evidence that suggests granularity, working memory exists within a distributed network that shifts constantly according to the demands of the task and the nature of the input. Thus perceptual and executive cortices are involved, and stay involved as long as attention is required to hold the memory in attentive space for action. That attention is held by means of a feedback loop (reentry network) between the prefrontal cortex and the posterior cortex.

Executive attention. The study of attention has long focused on varying modes of perception (auditory, visual, etc.) and neglected executive and motor functions as viable aspects of attention. Like other systems "no neural structure, separate from those systems, has been found or appears necessary for the control of executive attention." [p. 165]. "Executive attention is widely distributed in frontal cortex as are the networks involved in the process of selection of inputs and outputs underlying executive action." [p. 166]. In turn, low-level attention tasks are pushed to mirror networks behind the frontal region.

The lateral prefrontal cortex is involved in all complex behaviors that require temporal organization of contingent action. This involves the integration of working memory with the preparation of perceptual and motor systems for action. "Imaging studies reveal the activation of lateral prefrontal cortex in tasks that challenge the ability to plan ahead and to prepare for appropriate responses" [p. 172].

Chapter 7: Language

The main thesis of the chapter will be that despite some evidence for the importance of certain discrete areas in speech function, language emerges from broad cortical network integration.

Language in humans is tied closely to limbic structures and emotional motivation.

How much of the cortical region is "ready-made for language at birth?" [p. 181]. Language cannot be learned by a simple stimulus response mechanism. Vocabulary building, on the other hand, comes from reinforcement to the associate cortex. In all likelihood, the question cannot be answered by choosing between innate structures and learned behaviors, but rather by understanding how innate structures facilitate the acquisition of expanded knowledge and use. One key argument for the distributed nature of linguistic neurological structures is *plasticity:* the fact that different brain regions can be appropriated for linguistic functionality after primary linguistic areas have been damaged.

Most people have linguistic dominance of the left hemisphere.

Certain experiments show "large individual variation in the topography of language-active cortical assemblies," testifying again to the distributed nature of linguistic networks. Indeed, no modular model is needed to explain language outside the existing understanding of distributed and coordinated feedback networks of the cortex.

Because the centers responsible for syntax and meaning are located in the left hemisphere, the right hemisphere is exceptionally weak at language processing, usually being limited to a merely perceptive capacity. Studies of bilingual people indicate that both languages "reside" in the left hemisphere [p. 189].

Patients with prefrontal damage cannot use language to form complex plans, just as they cannot form the plans themselves. [Recall Damasio's discussion of Phineas Gage and other patients with severe trauma or brain damage].

"Generally the areas activated by written words coincide with the areas activated by spoken words." [p. 198] Most language is centered in the left hemisphere and is probably prepared and determined genetically. These language areas are well connected to higher order abstraction areas of the cortex. Still, "there is considerable topographical overlap between the networks that represent abstract categories and those that represent their more concrete constituents." [p. 203]

How does the brain provide order (and meaning) to syntax and spoken language in general? It is "the work of the cortex of the frontal lobe—an agent within an agent within an agent." [p. 206] This implies a question of how the brain translates a spatial order within itself to a temporal order represented in spoken language. Fundamentally, damage to Broca's area results in an incoherent syntax marked by the lack of basic "lexical elements" like prepositions and articles. Broad based damage to higher regions still allows language, but does not properly integrate the future of action.

The actual expression of language emanates from the bottom up: Broca's area is responsible for fundamental grammar, where the frontal lobe organizes expression temporally in the same fashion that the perception-action cycle organizes behavior.

Chapter 8: Intelligence

"The pertinent data from cognitive neuroscience indicate that intellectual performance can be best understood as the result of neuronal transactions between perceptual and executive networks of the cerebral cortex." [p. 213]

Understanding intelligence also involves structural and functional anatomy. The structural anatomy of intelligence is any neuronal system (cognit) involved in the processing of information. The functional anatomy of intelligence involves dedicated modular structures that vary depending upon the type of intellectual activity. [p. 220]

Intellectual performance is determined largely by attention.

Intellectual performance is further tied to synchronous neuronal firing across wide areas of the cerebral cortex.

Reasoning is the process of integrating (matching) incoming information with pre-existing knowledge. Neuronal activity synchronizes perceptions and internal perceptions with existing neuronal cognits to produce news cognits of effective consequence. "Studies of functional imaging… uphold the linguistic and prepositional nature of all deductive reasoning and the role in it of the language areas of the left hemisphere." [p. 227] Incredibly, linguistic areas are involved even in spatial reasoning, and may even be identical with all areas involved in deductive reasoning! Equally important to the ability to reason are inhibitory processes, which can be enhanced through training.

In summary, there appear to be two kinds of reasoning processes: reflexive and deductive. Reflexive reasoning involves automatic processes that incorporate lower cortical regions, while deductive reasoning involves "integrative processes" of the "perception-action cycle". Deductive reasoning involves more and higher cortical regions and seems particularly dependent upon linguistic areas.

"The logical training of a subject induces marked displacement of the activation of the cortex during performance of the task from posterior (i.e. perceptual) areas to frontal (i.e. executive) areas." [p. 230] [These results indicate that proper reasoning is a function of cortical location of neurons involved in the reasoning process. They also indicate that poor reasoning can be recognized by location as well. This removes some of the mystery from learning how to think well: training actually shifts the location of the reasoning within the human brain].

The actual use of the prefrontal cortex varies with the complexity of the task at hand, dedicating more resources to more complex and more time-constrained problems.

Decision making: This topic cannot be extricated from a discussion of free will.

Failure to critically assess the neurological basis of free will leads to the spurious conclusion that such an entity exists: "an unnecessary and indefensible entity." [p. 236] The issue of free will must confront four data: 1) many different organisms make decisions; 2) "not all decisions are rational" 3) "some decisions are unconscious" 4) many decisions arise from prior experience, yet are not acknowledged to be part of prior experience. Since all decision arises from some kind of perception, all decision "would be a product of perception" [p. 237]. Therefore, we can ask the question from another angle: are there "in the posterior cortex neuronal populations that react to identical, uncertain, or ambiguous stimuli in accord with the behavioral choices that the animal makes in response to them"? [p. 237]

One set of experiments can answer one question: “It can be concluded that some decisions are made or initiated on the perceptual side of the cortical perception-action cycle before the signals from perception reach the executive cortex.” [p. 238]

We must not forget that whatever “decision-making” processes that go on *within* the frontal cortex, do so while being connected to numerous systems that monitor everything from chemical states to visceral states to belief systems. This same frontal system also sends information that dampens the effectiveness of the limbic system in interfering in the decision-making process, effectively controlling the chemical basis and neurological basis of emotional influence.

Fuster indicates that there is no reason to believe in the concept of free will: “Essentially, then, the initiation of action, as well as its subsequent course, results from the competition of multiple influences arriving concomitantly in frontal cortex from assorted sectors of the organism. At any given time, by reason of their intensity or probability of occurrence, only a few of those influences prevail in that competition for executive attention. In humans, the influences may come from obscure sectors of the internal milieu that are the source of unconscious drives. Some of these may gain access to decision making unchecked by normal inhibitory control from frontal cortex. To the extent that we are unaware of those drives, we may feel free to execute the actions they determine. In any event, there is neither need nor evidence for a neural center of willed action. In terms of the brain, the old argument between determinism and free will may be theoretically resolved on intermediate probabilistic grounds. On the one hand, voluntary action is the result of competition between multiple input signals of varying strength and probability that arrive from many sources in the cortex of the frontal lobe. On the other, voluntary action is the result of competition between alternate executive cognits in this cortex." [p. 241-242]

Chapter 9: Consciousness

Although humans commonly assume that consciousness is a function, it is in fact no more than "a subjective experience". It is that sense of an experience that is bound together in perceptions, memory and attention within a temporal continuity. While there is a strong tendency to equate attention with consciousness, to do so oversimplifies the reality of the neurological processes that underlie consciousness. Attention, in fact, brings together several mental activities into temporal unity, giving the particular experience those qualities that we call "consciousness". Since attention is associated with working memory, "It is reasonable to assume that the conscious awareness of a cognit coincides with the temporary activation of its cortical network while it is being retained in working memory." [p. 254]

We do not know what threshold of cortical activity is necessary to enable the sensation of consciousness. It is, however, highly probable that reentry is the mechanism that makes possible the subjective experience of consciousness. While some have posited that the prefrontal cortex is the "seat of consciousness," evidence indicates that nearly any arena can participate in consciousness, and that it is more likely that consciousness is a shifting experience rather than an experience that arises from one particular brain region. "In conclusion, the seat of consciousness has eluded several generations of neuroscientists because consciousness is an epiphenomenona of activity in a shifting neural substrate." [p. 256].