Chapter II. The Neural Encoding Function

Within our skulls lives a fleshy organ of almost unimaginable complexity with functional dynamics that range from macro-level morphology to micro-level chemical and electrical activity at the cellular level.[1] Gerald Edelman (2004) points out that if you started now counting the synapses (the structures that allow electrochemical signals to pass from one neuron to another and that are involved in establishing networks or webs of neuronal structures) in the brain at a rate of one per second, it would take you 32 million years to count them all (p. 16).[2] Beyond what we are learning about brain function (for example, the sheer number of synapses,[3] the delicate balance of membrane properties that give neurons their subtle electrical charge, the cellular-level action of neurotransmitters, the molecular binding of neurotransmitters to post-synaptic receptors, the distributed and interconnected activity among different brain regions with different neurotransmitters and chemicals whose properties change the timing, amplitude, and sequences of neuronal firing, the reciprocal connections between different brain structures that provide what are called reentrant processes that seem to be key to consciousness and self-awareness (Edelman, 1992; Edelman and Tononi, 2000; Edelman, 2006; Tucker, 2007; Tucker

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[1] "In the 50 million years of primate evolution…,the relative size of the neocortex accelerates; it grows disproportionately to such a degree that it seems legitimate to speak of a 'neocortical explosion.'" (Fuster, 2003, p. 19)

[2] Some estimate that there may be in the neighborhood of 10,000 distinct types or classes of neurons in the brain.

[3] Even speaking of synapses is a kind of coarse generalization that hides the complexity of the physical reality. As Michael Hendricks describes them, "Synapses are the physical contacts between neurons where a special form of chemoelectric signaling—neurotransmission—occurs, and they come in many varieties. They are complex molecular machines made of thousands of proteins and specialized lipid structures. It is the precise molecular composition of synapses and the membranes they are embedded in that confers their properties… The features of your neurons (and other cells) and synapses that make you "you" are not generic. The vast array of subtle chemical modifications, states of gene regulation, and subcellular distributions of molecular complexes are all part of the dynamic flux of a living brain. These things are not details that average out in a large nervous system; rather, they are the very things that engrams (the physical constituents of memories) are made of." (September 15, 2015, http://www.technologyreview.com/view/541311/the-false-science-of-cryonics/?utm_campaign=newsletters&utm_source=newsletter-daily-all&utm_medium=email&utm_content=20150916)

and Luu, 2012; Fuster, 2013)), there remains so much that we don't know, and very much more than we do know. What we do know remains disjointed and not unified, parts of a puzzle not all of which yet fit together. The vocabulary of neural structures, networks, matrices, circuits, etc. is to some degree only metaphorically representative of an organic reality that is much more complex and dynamic than we can easily visualize. The brain is in a constant hum of activity with millions of synapses firing simultaneously in a vast array of inter-related and overlapping patterns beyond our capacity to map at this point.

Neuroscience is in its relative infancy or perhaps its early adolescence, active, adventurous, and full of new discoveries and understandings. There are competing theories of how learning and memory work (for a review, see LeDoux, 2003), different frames of focus and emphasis (e.g. Dehaene, 2001), and, as is true of all scientific frontiers, cumulative research is exploring dead ends and making course corrections as it constructs a reliable map of this new territory. Our tools, though increasingly powerful and able to provide access to finer detail, remain relatively blunt. Researchers are eager for the next generation of technology.[4] Moreover, different researchers work on different areas of the territory, from different perspectives, with different guiding premises and areas of focus,[5] make different interpretations of the evidence we

[4] One of the newest technologies is called optogenetics, invented by scientists at Stanford University and first described in 2005. With this technology, scientists are able to insert a genetically modified light-sensitive gene into specific neurons and then activate or turn off the neuron with a hair-thin fiber-optic thread inserted into that brain cell, thereby determining specific neural involvement in brain function and behavior. For example, with the manipulation of particular neurons, the behavior of a mouse can be changed from violently aggressive to tranquil in an instant. This technology offers specificity beyond that of other technologies like fMRI and dense-array EEG to further our understanding of neural function. As another example, a new chemical treatment allows researchers to directly see nerve fibers in mammalian brains. Newly developed sophisticated computer programs let researchers match nerve cells and fibers in micro-thin brain slices to create a three-dimensional map of the connections. Another technique, called Clarity, immobilizes biomolecules such as protein and DNA in a plastic-like mesh in a postmortem brain, after which, the fats in the brain tissue are dissolved to expose the three-dimensional wiring pattern to view. (As reported in https://www.technologyreview.com/s/528226/neurosciences-new-toolbox).

[5] "Figuring out how the brain works is a daunting task. For that reason, neuroscientists usually work only on pieces of the puzzle – like aspects of cognition, emotion, or motivation – rather than on the whole organ and its systems at once." (LeDoux , 2003, p. 301)

have been able to decipher thus far, using different metaphors and terminology to describe brain function, the nature of consciousness, the self, and the interrelationship between conscious and unconscious activity. Somewhere in the neighborhood of 30,000 brain researchers gather each year for the Society of Neuroscience conference. As the accumulative research project progresses, there is some disagreement among the attendees about how the brain works and what is suggested about who and how we are. We are too early in our exploration for there to be a grand, universally agreed upon, coherent theory of brain function universally agreed to. We are like the proverbial blind men describing the elephant. The brain is a very complex elephant.

Until our more recent advances in neuroscience, human behavior has been described and understood without reference to the underlying physical determinants of those behaviors and often with recourse to explanations that assume a disembodied consciousness,[6] though some early theorists, including William James and Sigmund Freud, understood that there was very likely a neural basis to human consciousness experience and behavior. Tucker and Luu (2012) note that, "the neurologist and neuroanatomist Sigmund Freud had attempted to explain learning and memory within a model of self-organizing connections within neuronal networks…In his *Project for a Scientific Psychology*, Freud proposed that memory could be explained as a strengthening of neural connections through use…As the process of learning modifies neuronal connections, Freud recognized that neuronal networks face an inherent dilemma of maintaining stability or allowing plasticity." (p. 4). In the face of the inadequate technology of the time,

[6] "We believe that this convergence between neurobiology and phenomenology is not a mere coincidence. On the contrary, it can yield valuable insights into the kinds of neural processes that can account for the corresponding properties of conscious experience." (Edelman and Tononi, 2000, p. 111-112)

Freud abandoned his anatomical experimental approach to pursue his psychological theory-building and therapeutic practice.[7]

Though how the system of encoding, storage, recall, and connectivity works is not fully understood and theories are being built upon limited but advancing empirical evidence[8] (See, for example, Barsalou, Galese, Tucker, Damasio, Edelman, Seung, Fuster, Kandel), there is growing consensus that we are embodied beings and the functional characteristics of the body will explain and determine the nature of our consciousness experience and behavior.[9]

Without going into the precise and intricate details of what we currently know of the biology, we can speak at the conceptual and non-technical level about the developmental process that encodes perceptual experience in neural networks (learning)[10] that are preserved and accessible (memory)[11] in a dynamic[12] structure within which novel connections can be made (creativity). This is the fundamental brain activity that allows for consciousness, cognition, and identity.[13] The process is ever-active as present experience combines with past experience to

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[7] More than thirty years later, in *Beyond the Pleasure Principle,* Freud wrote, "Biology is truly a land of unlimited possibilities. We may expect it to give us the most surprising information, and we cannot guess what answers it will return in a few dozen years to the questions we have put to it. They may be a kind that will blow away the whole of our artificial structure of hypotheses." As quoted in Casey Schwartz, *In the Mind Fields: Exploring the New Science of Neuropsychoanalysis, 2016, p. vii-viii.*

[8] "We do not know exactly, of course, how functional patterns are distributed across the corticolimbic networks. Judging from the way memories are activated, these network patterns often seem to resonate and recruit new patterns, as if forming complex waves of meaning." (Tucker, 2007, p. 183)

[9] "Mental activity is brain activity." (Churchland, 2002, p. 30); "We also know that the mind arises from the brain and that all psychiatric illnesses involve organic processes." (Cozolino, 2014, p. 77)

[10] "At the core of cognition is adaptive memory consolidation, through which learning produces structural changes in the brain and the self." (Tucker and Luu, 2012, p. vi)

[11] "An innate capacity for synapses to record and store information is what allows (brain) systems to encode experiences. If the synapses of a particular brain system cannot change, this system will not have the ability to be modified by experience and to maintain the modified state. As a result, the organism will not be able to learn and remember through the functioning of that system." (LeDoux, 2003, p. 9)

[12] "…in each brain, the consequences of both a developmental history and an experiential history are uniquely marked. For example, from one day to the next, some synaptic connections in the same brain are likely not to remain exactly the same; certain cells will have retracted their processes, others will have extended new ones, and certain others will have died, all depending on the particular history of that brain." (Edelman and Tononi, 2000, p. 47)

[13] "…the mind must be achieved by the connectional architecture of the brain." (Tucker, 2007, p. 179)

create the new and ever-evolving individual identity.[14] It's interesting and notable that we use the term "belief system" in an unintended reference to the fact that beliefs exist as a physical system of neural structures. We speak also of being "shaped" by our experience and of "formative" experiences. These metaphors apply literally. It is the body that is shaped and formed by experience, and particularly the neural structures of the brain. The "we" we speak of is our body.

The activity taking place within the organism as, for example, our head turns to follow an object or as we track the behaviors of two individuals with whom we are speaking, the vast amount of visual and auditory information we absorb and process in a constantly changing context against the backdrop of our previous experience in life, with processing happening at the microsecond scale and with no interruption in the assimilation, accommodation, and categorization processes taking place, boggles the mind (so to speak!). We remain unaware of the almost inconceivably complex internal events, active every moment, that determine our conscious and unconscious experience and our behavior.[15] We don't directly observe the physical processes that produce our lived experience, and until recently, our science, has not provided much of a view into those processes.[16] As a consequence, we have not tended to understand our behavior and experience in terms of the basic brain function of encoding perceptual experience in neural structures.

The neural encoding process begins at the very earliest stages of our development and continues throughout our lives. As Fuster (2003) puts it, "…at every step of development, the expression of (the) genetic plan, the structural phenotype of the neocortex, is subject to a wide

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[14] "…the phenomena of mind are due to the ongoing developmental changes in neuroanatomical differentiation. Every thought reorganizes the tissue." (Tucker and Luu, 2012, p. v.)

[15] "We do not presently understand fully how this categorization (neural mapping) is done but…we believe it arises through the selection of certain distributed patterns of neural activity as the brain interacts with the body and the environment." (Edelman and Tononi, 2000, p. 48)

[16] "…we can never be conscious of the inner workings of our cerebral processes, but only of their outputs." (Dehaene, 2001, p. 16)

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 the environment, the afferent, efferent, and association fibers of the neocortex will develop and form the networks that are to serve cognitive functions." (p. 35) and, "Because the potential functional connections between neuronal assemblies and networks are practically infinite, there is no such thing as the complete cognitive development of the cortex. Networks and knowledge are open-ended. Never in the life of the individual do they cease to grow or be otherwise modified." (p. 37).

Prenatal beginnings

As fetal development advances, the nervous system takes shape, from brain stem to mid-brain to cortex along with the extended peripheral nervous system. As the neural anatomy and perceptual systems develop, the establishment of neural matrices that encode proprioceptive and perceptual experience becomes possible.[17] We do not enter the world as a blank slate. Our genetic endowment prepares us with the capacity to engage with the world and we meet the world with given internal motives that are the survival imperatives of the lower and midbrain structures, brain stem and limbic system (Tucker, 2007).[18] That is to say, how we engage with the physical reality that is accessible to our senses is conditioned by our unconscious and preconscious survival motives. Genetic inheritance provides the structural capacity for consciousness, learning, and memory. Endowed with that structure, the individual is then shaped

[17] "At the physical level, there must be mechanisms that encode the data of experience within neural networks." (Tucker, 2007, p. 94)
[18] "To be adaptive, memory and cognition must be motivated…" (Tucker and Luu, 2012, p. 70)

(literally) by experience.[19] Each individual interacts with the environment with her or his genetic inheritance and temperamental predisposition.[20] Perceptual experience is not, by itself, determinative of outcome. But whatever the composition of nature and nurture, the mix is encoded in neural structures that are relatively stable.[21]

As the fetus's perceptual apparatus begins to function, its brain is able to begin the process of learning, encoding perceptual and proprioceptive experience[22] in neural structures or networks or pathways or matrices or webs[23] that are established by the nerve signals triggered by perceived stimuli arriving from the peripheral nervous system as it interacts with the external world, the uterine environment to begin with.[24] Random spasmodic movement by the fetus begins to wire neural connections as the organism begins to discover and learn about itself and its surroundings, begins to experience its body in relation to the space around it.[25] The physical

[19] "…the gross connectivity of the brain's networks and the structure of the brain are controlled by genetics, but the fine connectivity is achieved through experience. Functional differentiation is experience dependent." (Tucker, 2007, p. 160-1)

[20] "Nature and nurture become one during development, and the line between organic and functional dissolves into what is now called *experience-dependent plasticity*. This term denotes that our brains are structured and restructured by interactions with our social and natural environments." (Cozolino, 2014, p. 77-8)

[21] "According to the now most plausible network models, knowledge and memory are contained in an immense array of overlapping, interactive, and widely distributed networks of interconnected neurons of the cerebral cortex. The networks are formed by life experience and constitute the substrate of all cognitive functions." (Fuster, 2013, p. 62)

[22] "…it may even be that a spontaneously moving fetus in late development distinguishes between brain inputs arising from self-generated bodily movements and those inputs generated by motions induced from without. There is enough evidence to make the case that input from value systems (Edelman's term for neural systems responsible for releasing survival-related neurochemicals) and proprioceptive systems can combine with modal sensory inputs to yield some of the earliest conscious experiences. It is likely that such fundamental adaptive systems remain central for the rest of an individual's conscious life, whatever the additional qualia may be that develop with ongoing experience." (Edelman, 2004, p. 133)

[23] Pick your terminology: Edelman (2006) calls them neuronal groups, neural circuits, and even at one point meshworks (2000); Damasio (1999) calls them variously neural pathways, neural patterns, neural ensembles, neural maps, neural circuits, and neural networks; Feldman (2006) calls them neural clusters; Tucker (2007) calls them neural networks; Dehaene and Naccache (2001) use the term workspace; Fuster (2013) uses the terms cognitive networks, neuron assemblies, or cognits; and Freud (1990) used the term associative paths.

[24] "…every one of your sense organs contains neurons that are activated by some type of physical stimulus. Sensory neurons kick off the journey along neural pathways from stimulus to response…It is clear that these pathways exist; if they didn't, you wouldn't be able to respond to stimuli." (Seung, 2012, p. 52)

[25] "…the mind evolved from the brain's mechanisms of bodily control…" (Tucker, 2007, p. 12)

sensations of movement and touch begin to define identity.[26] These early experiences are stored in developing neural structures.[27] Without such storage, there would be no continuity, no accumulation of knowledge, and no development of self. The process of learning and memory accumulation begins in these early pre-birth stages and then accelerates upon birth when the infant is exposed to the myriad stimuli of the world into which it enters.[28] Thus begins the learning process and the formation of the structures that will subsequently allow and produce cognition and identity.[29] The processes that begin encoding perceptual experience and organizing corticolimbic networks through embryonic activity-dependent formation continue from birth throughout life, structuring the brain, with the canvas of knowledge increasingly busy with the neural structures formed from experience in the world.[30] The organizational process shaping the network anatomy is motivated by the organism's survival imperatives as they interact with the contextual conditions of the environment moment to moment (Tucker and Luu, 2012).[31]

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[26] "The embryo's own spontaneous, spasmodic actions become the motive vehicle for the early stages of neural self-organization." (Tucker, 2007, p. 281)

[27] "…the control of neural development, through regulating the spatiotemporal organization of neural activity, is a process of self-organization. Initially, it proceeds under general embryological guidelines, but even in the early intrauterine phases it is self-organizing, in that the fetus's own spontaneous actions shape its experiential activity-dependent plasticity. In childhood, the primary motive vectors of approach (hedonic expectancies) and avoidance (anxiety and discrepancy) appear to continue the embryological activity controls of habituation and redundancy." (Tucker and Luu, 2012, p. 137)

[28] "Through continued neural ontogenesis, mammals continue to grow and differentiate their neural networks throughout life. Neural growth is continuous…Learning is then a literal neurodevelopmental process…Just as cognition must be understood as a neurodevelopmental process, mammalian brain development must be understood as a cognitive process." (Tucker and Luu, 2012, p. vii)

[29] "This discrimination (the notion of self) may actually originate in utero during the late fetal stages, but certainly occurs during early postnatal development. It provides a reference for distinguishing self from nonself through kinesthetic inputs that may act in addition to, and separately from, explicit sensory contributions to qualia space." (Edelman 2004, p. 129)

[30] "Because of the practically infinite combinatorial power of the 10 to 20 billion neurons or brain cells in our cerebral cortex, the breadth and specificity of our individual memories and knowledge are potentially infinite." (Fuster, 2013, p. 15)

[31] "As the mind operates, it reflects the ongoing neurodevelopmental process, continuing the self-organization of neural connections that began in the embryonic differentiation of the neural tube and that continues throughout life." (Tucker and Luu, 2012, p. v.)

As a side note, but significantly, the embryonic brain produces many more potential synaptic connections among neurons than are ultimately used. Those that are used remain. Those that are not are eliminated[32] in a "use it or lose it" winnowing process of subtractive elimination.[33] This process of activity-dependent pruning continues after birth.[34] It is known that the newborn arrives with a surplus of synaptic capacity (what Tucker and Luu (2012) refer to as "exuberant synaptogenesis") that provides a broad canvas of learning potential.[35]

Birth and the Beginning of Meaning Making

Very much over-simplifying the complex and not-yet-fully understood neurophysiology, we can say that the newborn begins to "make sense" of the flood of stimuli to which it is exposed by linking one encoded perceptual experience with another.[36] We can describe this process in a kind of diagrammatic or analogic illustration of the actual global and integrated developmental experience of an individual. In actual life, no perceptual learning element is isolated from or independent of the full, multi-modal "world flow" consciousness experience of the individual

[32] "The specification of the fine structure of neural connections is activity-dependent, meaning that only synapses that are engaged by ongoing brain activity are retained." (Tucker and Luu, 2012, p. 2)

[33] "The brain's infantile architecture is woven from an overly dense pattern of neural connectivity, and the functional networks are sculpted through Darwinian subtractive elimination – the death of unused connections." (Tucker, 2007, p. 281); "The maturation process of the memory substrate, however, consists not only of a gradual increment of elementary structure, but also of the pruning of that structure. Neurons, Axons, and synapses that are not used are eliminated from an early exhberance of them. That attrition results from the selection of those elements that the growing organism utilizes at the expense of those that it does not." (Fuster, 2013, p. 74)

[34] "The activity-dependent sculpting of neural connectivity in embryonic differentiation is now only the beginning of a momentum of adaptive information structure that continues throughout life. As it continues, activity-dependent sculpting forms the fine architecture of cortical anatomy to encode the distributed representation of memory." (Tucker, 2007, p. 162)

[35] "In humans, this sculpting of cortical anatomy by experience occurs not just for a few months or years as in most mammals, but over a decade or more. If there is a single biological fact that allowed language to evolve from prelinguistic cognition, it was probably not a unique gyrus of the brain, nor a particular segment of the vocal tract. Rather, it was the radical neoteny that allows culture rather than the genome to specify the connectional anatomy of the human brain." (Tucker, 2001, p. 3)

[36] An infant, once able to perceive and recognize discrete objects and people, is at first surprised and intrigued when one disappears and reappears from behind an object. The disappearance is complete and utter until the baby begins to "learn," encoding perceptual experience that says the other doesn't disappear when he or she is not seen.

moving through time and space. But a simplified description will remind us of, and allow us to talk about, the basic function of neural encoding and structural elaboration that is learning and memory formation.[37] So, for example, we can say that the physical sensation of mother's breast, experienced and encoded by the newborn, is linked with the neurally-encoded experience of warmth and the sensation of hunger-satisfying nourishment, and later linked with the encoded perceptual experience of the mother's face to create matrices of meaning. Step by step, experience by experience, in interaction with its immediate physical surroundings to begin with, then its family, and, ultimately, its culture,[38] a world of meaning is constructed within the brain of the developing individual via encoding and associative linking of one perceptual experience with another, the basis of understanding, meaning, cognition, and self.[39] Fuster (2003) notes, "…knowledge, memory, and perception share the same neural substrate: an immense array of cortical networks or cognits that contain in their structural mesh the informational content of all three." (p. 112).

As another discrete example to illustrate the global process, an infant learns a new word by associating the sound, a nonsense syllable to begin with, with another perceptual experience.[40]

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[37] "Learning is neural morphogenesis, continued into postnatal development…Learning is then the continuation of neural differentiation throughout development…" (Tucker and Luu, 2012, p. 1)

[38] Our perceptual focus begins with the physical world, the world of objects, their edges, dimensions, movement, texture, solidity, taste (note how the infant brings physical objects to its mouth to learn about them) and their salience to our survival needs (food, water, shelter, warmth, etc.) and secondarily, though no less importantly, moves to the social world, the dynamics of the other humans in our environment (Note our tendency, both in our projections and our attachments, to anthropomorphize animals that are neither inanimate objects nor human beings.)

[39] "By considering these questions, we will see how it may be possible to relate the mind's psychological structures to the brain's physical architecture. This is an architecture formed by the pattern of connections among neurons." (Tucker, 2007, p. 31) and "…the structures of intelligence are achieved through neural connections, such that the pattern of those connections implies the pattern of mind." (Tucker, 2007, p. 92)

[40] Tuck and Luu emphasize that the intention of the speaker contributes significant content in the information exchange that produces meaning. "Studies of infants learning new words in a naturalistic context of interaction with the mother have shown that infants attend carefully to the mother's intention in speaking a new word, and use the context of her gaze or actions in interpreting the significance and meaning of the word…A word is not learned out of the context, such as if the mother speaks it randomly. The meaning of the word is then literally 'what Mom means'. The child then internalizes this as her own meaning. The brain's representations, and the implicit self assembled from them, are residuals of the social context. Self-regulation then continues to be built on the templates of internalized social transactions." (Tucker and Luu, 2012, p. 137)

The nonsense syllable “tree” is associated with the visible object (or the tactile perception for a blind child) that the culture, by convention, has named “tree,” along with any additional perceptual impressions that are encoded with the first experience of a tree, particular scents or the moist greenery of spring, for example.[41] With repeated exposure, the nonsense sound is encoded as is the perceptual experience with which the sound is associated and the two are linked neurally, thereby creating meaning for each in their relationship.[42] When the sound is encountered again, parts of that neural structure are activated to produce the experience of knowledge, in this case knowledge of the word sound and the naming of the object so called. Until there is something with which the nonsense syllable can be associated, there can be no meaning; the nonsense syllable will remain just that. This is why nonsense syllables are nonsense. They don’t yet correspond to another perceptual experience established in a neural structure. As soon as a nonsense syllable is associated with a phenomenon, it takes on meaning and becomes a word. Assigned meaning through association is the process of language acquisition.[43] The ability to learn a language is the ability to encode and then match sounds with elements of experience (creating meaningful words) and to learn patterns of arrangements among categories of those sounds (grammar).[44]

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[41] “As Freud wrote in his monograph on aphasia, a word ‘acquires its meaning by being linked to an ‘object-presentation’. . . . The object-presentation itself is . . . a complex of associations made up of the greatest variety of visual, acoustic, tactile, kinaesthetic, and other presentations.’ (1915, Appendix C, p. 213).” (Gallese, 2011, p. 198)

[42] “The image we see is based on changes which occurred in our organism – including the part of the organism called brain – when the physical structure of the object interacts with the body. The signaling devices located throughout our body structure – in the skin, in the muscles, in the retina, and so on – help construct neural patterns which map the organism’s *interaction* with the object. The neural patterns are constructed according to the brain’s own conventions…” (Damasio, 1999, p. 320)

[43] “…*information is relational*. The information that achieves such interesting functions in the parallel-distributed networks is formed through the *patterns* of relations among elements, not the content of elements themselves…Information is formed by connecting elements.” (Tucker, 2007, p. 99)

[44] Theories of language acquisition remain under debate and offer another example of our incomplete understanding of brain function.

Gradually, additional perceptual experiences are connected to the initial elementary neural structure.[45] Subsequent perceptual experiences having to do with trees build a complex, nuanced, and varied experience of "tree" encoded in extended, dynamic neural networks. Exposure to variations of case form the category,[46] and additional experiences of and with trees, climbing trees, falling from a tree, chopping down a tree, becoming lost in a forest, squirrels, birds, and other animals nesting in trees, picnicking or making love beneath a tree, as well as the link with arbitrary shapes on a page or computer screen that are the letters of a written language that have themselves been associated with particular verbal sounds to give them meaning, elaborate a vast neural matrix of associations having to do with trees and the individual's related experience over time – camp, car accident, lumber and building, deforestation, national forest management regimes, global respiration and atmospheric composition, climate change, concepts of growth and seasonality, fire cycles, etc.[47] There accumulates ever-more-complex and extensive neural circuits or networks, nets of networks, networks within networks (Fuster, 2013),

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[45] "With learning and experience, cognits grow and connect with one another, sharing notes that represent common feature. Consequently, in the cerebral cortex, cognits interconnect and overlap profusely, whereby a neuron or group of neurons practically anywhere in the cortex can be part of many memories or items of knowledge. The strength of the synapses within and between cognits varies widely, depending on such factors as selective attention, saliency, repeated experience, rehearsal, and emotional impact…Cognits originate and evolve in the course of life. Some expand as new memory or knowledge is acquired and synaptic connections are strengthened with it. Others shrink and weaken from lack of use or aging, each factor accompanied by attrition of synaptic contacts." (Fuster, 2013, p. 14)

[46] This movement continues to the development of concept and the use of metaphor. See, as one source of discussion of conceptual thought, Johnson, 2007.

[47] I recall realizing at one moment in my late teens that a tree is a large plant. I had always seen trees, known trees, as a separate category. I had not included trees in the category of plants. Plants were defined in my mind as smaller than trees. The category of plants was limited by a size parameter and a quality parameter different than what had defined trees for me. Suddenly, I looked at trees differently. They were big plants. It was a bit of a "mind-bending" experience.

systems of circuits (Damasio, 1999).[48] Meaning becomes elaborated in nets of associations.[49] These are the structures of understanding and the basis of cognition and identity.

The correspondence can be between a word sound and an external object or an internal experience. When we are first exposed to the distinction between, for example, passive and active vocabulary, we can link the words "passive" and "active" to our internal experience of words used and words understood but not used. In that linkage, we learn something new. Prior to hearing these word sounds linked to our internal experience, we had not known of these categories applied to language use. And we are able to make the connection between the words "passive" and "active" in this unfamiliar usage context because we had previously learned the meaning of the word sounds "passive" and "active" in other contexts. So is constructed the edifice of knowledge day-by-day, moment-by-moment as we are exposed to new experience that we make meaning of by relating the new to the already known. As Bruce Hood puts it in his book The Self Illusion (2012), "These spreading patterns of electrical activity are the language of mental life. They are our thoughts. Whether they are triggered from the outside environment or arise from the depths of our mental world, all thoughts are patters of activation in the matrix that is our mind." (p. 8). The mind arises from the patterns of neural connections in the network architecture in a state of constant associational activity (Tucker, 2007).

The encoded information is what we call knowing and is the structure of our identity.[50] We experience the patterns of activation as colors, objects, thoughts, meaning, recognition,

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[48] "Take, for instance, the memory of a hammer. There is no single place in our brain where we will find an entry with the word *hammer* followed by a neat dictionary definition of what a hammer is. Instead, as current evidence suggests, there are a number of records in our brain that correspond to the different aspects of our past interaction with hammers…These records are dormant, dispositional, and implicit, and they are based on separate neural sites located in separate high-order cortices." (Damasio, 1999, p. 220)

[49] "Information implies relation." (Tucker, 2007, p. 227)

[50] "Psychologically, the self is the coherent system of concepts, memories, and regulatory capacities for attention and intention that operate to maintain internal consistency, as well as consistency in interpersonal relations. For the embryo and fetus, the self is the biological process of organizing internal consistency... For the child and adolescent,

emotions, self, etc., but what is actually happening is the firing of neuronal circuits. When we say we "know," really what we are saying is that we are experiencing the activation of neural structures that are configured through associative, combinatorial processes incorporating elements of various neural matrices previously established either as a result of perceptual experience or internal experience or both. In the act of perception, the continual interplay between perceived object and organism, dynamic and continuous, changes the organism, or at least changes the state of the organism. The degree of change depends on the nature of the relationship between organism and object and the significance or meaning of the object to the organism (Dehaene, 2001, 139). As Tucker and Luu (2012) put it, "Each cognitive process is a developmental event, an act of the historical self. Furthermore, each cognitive process is a transformational event; as the representation is consolidated, the self is then changed. The degree of change depends on the negotiation between assimilation and accommodation, effecting the consolidation of cognition…Thought shapes the literal anatomical structure of the brain, and the self." (p. 209).

Without an internal referent for a new perceptual experience, there can be no understanding and a new set of knowings must be developed, a new set of neural matrices established that will extend or link in one way or another to the matrices of meaning already existing.[51] We can imagine a flying pig only if we are already familiar with pigs and with flying.[52] We all have had the experience of trying to learn a new word-sound for which we have

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the same neurodevelopmental process of maintaining internal consistency continues, but now achieved within the social context to create the integrated psychological patterns of a coherent self, or when dysfunctional, the fragmented self of psychopathology." (Tucker et al, 2016, p. 39)

[51] "With learning and experience, cognits (Fuster's word for neural matrices or networks) grow and connect with one another, sharing nodes that represent common features. Consequently, in the cerebral cortex, cognits interconnect and overlap profusely, whereby a neuron or group of neurons practically anywhere in the cortex can be part of many memories or items of knowledge." (Fuster, 2013, p. 14)

[52] "Everything the child learns must be based on what she or he already understands." (Feldman, 2006, p. 199)

no easily identified referents. It might have been “heuristic” or “ouster,” for example. Trying to learn the word, we might have asked ourselves whether heuristic was a noun or an adjective. Was ouster a noun or a verb? And if a noun, did it identify a person or an act? We might have had trouble finding associative links by which to give meaning to the word-sound. Perhaps you remember when you were young trying to “get” the meaning of words like irony or metaphor or cynic or euphemism, or the difference between paradox and dilemma. These words were more difficult to learn because it was more difficult to connect them with something we already knew, to make associations with previously encoded experience, or to attach them to any object of physical perception. This is the source of the problem that adult learners of English have with prepositions, a problem of referent, having the right association between word-sound and meaning. On this point, there was an interesting story in a New York Times article (July 19, 2015, Those Who Would Remake Myanmar Find That Words Fail Them, Thomas Fuller) on a problem being faced in Myanmar as it opens to the rest of the world after fifty years of isolation. The native language has no words for many of the objects and ideas that are standard and essential currency in global political, economic, commercial, and technical conversations. Not only are there no native words for racism, federal, globalization, institution, or privacy, for example, but the concepts don’t exist so that even when an English word is imported or a new Burmese word-sound is created, speakers have no neural structure referent to which to associate the word-sound.[53]

We begin language use with words for physical objects and basic action, nouns and verbs (and in single syllables), because of the tangible accessibility of the word-sound’s perceptual

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[53] In a similar vein, we can understand the common confusion about the use of some of the grammatical forms of “effect” and “affect.” The neural wirings of association get crossed or confused because the terms are so similar in sound.

referent, allowing neural structures of meaning to be more directly and easily established. “See Spot run.” not “See Spot hesitate.” or “See Spot contemplate.” or “Consider Spot’s running.” Many words take some time and repeated exposure to learn and understand. The capacity for abstract thought requires a number of years to develop.

From these elementary though complex beginnings, the elaborate construction of world-knowledge and self-identity are built.[54] To repeat, what we call “learning” is the process of encoding perceptual experience.[55] What we call “knowing” is the activation of embodied perceptual experience in networks of encoded neural structures and associations. Memory, the requisite for self-identity, is the activation of encoded neural structures.[56] Thinking and creativity are the linking of encoded neural matrices of meaning. The elaborations and extensions of neural structures in response to successive perceptual experience[57] and the dynamic, variable linkages among them, continue in cascading nets of associations of decreasing salience from strong to faint, and from conscious to unconscious, depending on the circumstances of the moment.[58] Each new perceptual experience builds on what has already been encoded,[59] connecting in multiple

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[54] Introspective experience becomes more sophisticated with the development of identity, of the sense of self, but it begins in the infant with the basic internal experiences of hunger, pleasure, attachment, desire, intention, etc.

[55] “Millions of individual neurons link up to form neural networks that perform the many functions of the nervous system. In turn, neural networks can interconnect, allowing for the evolution and development of increasingly complex skills, abilities, and abstract functions. The specific combination of activated neurons involved in a particular function is known as its *instantiation*. Instantiations encode all our abilities, emotions, and memories and are sculpted and modified by experience. Once neural patterns are established, new learning relies on the modification of established instantiations patterns.” (Cozolino, 2014, p. 31)

[56] “It seems…probable that memories are stored as patterns of many connections.” (Seung, 2013, p. 80); “In a complex brain, memory results from the selective matching that occurs between ongoing, distributed neural activity and various signals coming from the world, the body, and the brain itself.” (Edelman 2000, p. 94)

[57] “…a child learns about a dog and then a short while later is excited to point out another dog – only this one is a cow. The attentive parent helps with the differentiation process by explaining the difference between dogs and cows. The increasing complexity in the child’s intelligence is achieved through increasing structural differentiation, that is, the separation of finer distinctions among the increasing variety of conceptual elements.” (Tucker, 2007, p. 101)

[58] “Brain maps are not static like those of classical cartography. Brain maps are mercurial, changing from moment to moment to reflect the changes that are happening in the neurons that feed them, which in turn reflect changes in the interior of our body and in the world around us.” (Damasio, 2010, p. 66)

[59] “…synapses are changed every time our brain records an experience.” (LeDoux, 2003, p. 68)

ways to different parts of the complex network with varying degrees of strength.[60] Meaning is always and only created by association.[61] As Mark Johnson (2007) puts it, "Meaning is relational." (p. 10). The process is cumulative and elaborative. We are constantly adding to our definition and experience of self and our understanding of the world, familiar experiences reinforcing and confirming already established structures and the unfamiliar presenting the brain with the challenge whether to incorporate the new information within, add to, or change its already established neural structures.[62]

In this way, the "you" as you are today is formed from the moment of your conception in the joining of sperm and egg to the fullness of your current experience of a complex self in a world rich with meaning. One's formative experiences will be more or less salutary. As we know, adverse childhood experiences and deleterious cultural identity messages will be as impactful as will be more positive self-definition messages, contributing to the fundamental architecture of the developing brain and having lasting effects on learning, relational responses, and resiliency.[63]

Each moment's new experience will either confirm or complement past experience, add new information, or contradict past experience.[64] Whatever the case, each moment's information

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[60] "Neural systems appear to acquire knowledge in two ways, weight change (change in the synapses) and structural recruitment (the strengthening of a previously latent connection between active neural clusters)…" (Feldman, 2006, p. 38)

[61] "…the human brain constructs the information of mind through linked patterns of meaning, patterns woven across the hierarchy of each hemisphere's corticolimbic (core to shell) networks. Each concept is then linked across these distributed network representations through waves of meaning recursively engaging each network in turn. Meaning is thus formed by neural network patterns traversing both the visceral (personal significance) and somatic (reality interface) structures of experience." (Tucker, 2007, p. 16)

[62] "The neurodevelopmental process of cognition is both cumulative and ongoing. It organizes experience within the fine connectional architecture of the brain's networks…" (Tucker and Luu, 2012, p. 25)

[63] See for example, Franks, D. D. and Turner, J. H. (2013).

[64] "Cognits (again, Fuster's term for neural matrices of meaning) originate and evolve in the course of life. Some expand as new memory or knowledge is acquired and synaptic connections are strengthened with it. Others shrink and weaken from lack of use or aging, each factor accompanied by attrition of synaptic contacts." (Fuster, 2013, p. 14)

must be addressed in one way or another and must be related to the neural structures already established, building a coherent and consistent understanding of the world. Confirming information will strengthen or reinforce previously established neural pathways. New information will add to the complex networks of encoded understanding. New information will always be measured against already established neural structures. The ease with which and how new information is incorporated into the elaborating structures will depend on many factors. Contradictory information has to be dealt with, either held in parallel with the previously encoded experience with which it is contradictory or replacing or revising some parts of the neural networks.[65]

The system is in a constant state of change and development. As Jerome Feldman (2006) puts it, "It is now clear that learning and permanent memory in animals come about through the strengthening of neural connections (synapses)…When the strength of connections between neurons is modified, we have a fundamental structural change. The neural network is now different and will respond differently to new experience. That is, *learning does not add knowledge to an unchanging system – it changes the system.*" (p. 72) The architecture of dynamic wiring among neural connections allows for novel associations, subtleties of meaning, variations of response to the same stimuli in different contexts, and the richness of meaning that characterizes the human consciousness experience.

The encoding of perceptual experience is not an exact recording, not a one-to-one mapping.[66] The tracings are partial and inexact, dynamic, variably persistent, malleable, often

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[65] Analogy, simile, metaphor are associative processes. The dynamic nature of associative linkages is what allows for creativity, originality, invention, imagination, intuition, deva vu, problem-solving, reasoning, abstract thinking, misunderstanding, confusion, synesthesia, and many other experiences of consciousness.
[66] "Brain-based epistemology contends that our knowledge is neither a direct copy of our experience nor a direct transfer from our memorial states." (Edelman, 2006, p. 152)

more impressionistic than a precise or exact representation of the mind-independent reality, though there is a good deal of precision, accuracy, and durability involved, sufficient, in most cases, to successfully, to one degree or another, navigate our physical and social environments.[67]

The networks that develop in response to perceptual experience are formed through changes in the strengths of the synaptic connections between neurons.[68] Repeated firing strengthens connections. Neurons that fire together, wire together.[69] Thus the impressive, in both senses of the word, impact of culture's repeated and pervasive messaging on individual identity.

Thinking is a process of accessing and linking encoded material.[70] The linking and combining of elements in the vast neural web is always happening, awake or asleep, as long as we are alive, in response to the stimuli of lived experience. The buzz of consciousness, the busyness of mind chatter, and the phantasms of dreams are the activity of neural firing, the hum of connections and associations being made.[71] There is a selection process involved that has to do with survival salience.[72] The sets of associations and linkages are determined by the conditions of the moment. The conscious aspect is what we are aware of. The unconscious portion allows functional activity without flooding conscious awareness. Much is unconscious because there is not need for attention in the moment. That said, the unconscious associations

[67] "Our memories are *prejudiced*, in the full sense of the term, by our past history and beliefs. Perfectly faithful memory is a myth…The brain holds a memory of what went on during an interaction, and the interaction importantly includes our own past, and often the past of our biological species and of our culture." (Damasio, 2010, p. 133)

[68] "Repetition of a pattern of successful firing also triggers additional intra-cellular changes that lead, in time, to an increased number of receptor channels associated with successful synapses – the requisite structural change for long-term memory." (Feldman, 2006, p. 80)

[69] This phrase is derived from the ground-breaking and ahead-of-its-time work of Donald Hebb. See Tucker, 2007; Tucker and Luu, 2012; Edelman, 2004; LeDoux, 2003; Seung, 2012; Feldman, 2006.

[70] "Thought is structured neural activity. (Feldman, 2006, p. 3) and "…a thought is embodied as a pattern of synaptic transmission within a network of brain cells…" (LeDoux, 2003, p. 319)

[71] Meditation practice is a kind of mind technology to still neural activity for consciousness-health benefits.

[72] "…cognition is not comprised of isolated mental skills, but rather emerges from the neural networks that evolved for motivational control of sensation and action, negotiating between both visceral and somatic constraints." (Tucker and Luu, 2012, p. 91)

influence behavior as much as, if not more than, our conscious associations (Haidt, 2013; Churchland, 2002).[73]

The complexity, subtlety, and scope of our thinking seems mysterious and impressive to us only when we forget that thinking is no more than the elaboration of associations or connections among previously encoded perceptual experience made complex because of the vast storage, retrieval, and associational capacities of the human nervous system.[74] Certainly, our thinking capacity is impressive, but it is built only upon the associational process of linking one item with another. The thinking process begins with the relatively simple and basic associations the infant makes among early-encoded neural structures, word-sound "hot" and the physical sensation of heat, for example. What we call "abstract" thought is thought like any other, built up of the elementary encoded elements of perceptual experience, composed of more or less complex and innovative neural nets of associations.[75] Thoughts, call them abstract or not, are a form of creativity, the novel linkage of neural structures. If no perceptual experience, then no encoded neural trace (learning) and no access to storage (memory) because nothing has been stored to access, and therefore no thought. From the infant's germinal experiences, gradually more complex thinking is elaborated. Learning to think is a bit like learning to juggle. We begin with two balls and work up from there. The difference is in the physical limits to the number of balls we are capable of keeping in the air, with juggling somewhere in the neighborhood of twelve or thirteen, with thinking many more by many orders of magnitude.

[73] "Non-conscious perception of emotional stimuli is generally associated with more rapid and intense responses in terms of physiological changes and facial expressions (in the observer) than conscious perception of emotional stimuli. This suggests an inverse relationship between stimulus awareness and its impact on behavioural and neurophysiological reactions." (Tamietto, 2010)

[74] "Every human brain has billions of neurons that together make trillions of synaptic connections among one another…At any one moment, billions of synapses are active." (LeDoux, 2003, p. 49)

[75] "Abstract thought grows out of concrete embodied experiences, typically sensory-motor experiences. Much of abstract thought makes use of reasoning based on the underlying embodied experience." (Feldman, 2006, p. 7)

As is suggested by this account of learning and knowing, there are features of the system of neural encoding and storage that are particularly relevant to the presence of conflict in our social relations and to the challenges we face in preventing or resolving conflicts. In the next chapter, I consider seven of those characteristics.