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Memory and Localization: How the Biological Influences Thought and Action

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Abstract
Taking biology seriously presents a biological view of man (where movement, history, context, and the environment sway the balance) and reveals some of the attendant factors of having a body. It is not simply that the idea of localization of function could be faulty, it is rather that the basic assumption that memories are carefully filed and stored fixed traces, seems hardly able to withstand the evidence against it any longer. In his "The invention of memory," Rosenfield (1988) associates the whole problematic, in the first place, with a misreading of the evidence. Freud had meant it differently, he has only been bypassed.

Keywords: environment, human brain, imagination, memory, mental image

Introduction

Orthodoxy and Localization

The orthodox view is that memories as *fixed images* are imprinted and permanently stored in our brains. Our recognition process, thought, and action are believed to be grounded in these fixed images. It would be impossible in the absence the fixed images to recognize a thing, it is held. The discovery by Paul Broca, in 1861, that loss of the ability to speak could be accounted for by a somewhat tiny lesion on the brain's left side, was shortly accompanied by the discovery of other language centers that seemed specialized for separate linguistic tasks. Areas of the brain that appeared to control movement in specific parts of our bodies (the fingers, the tongue, the hands etc.) were also discovered. Other areas too were found to respond to stimuli in specific parts of the body and limbs. At the close of the nineteenth century, a lot of neurologists had come to the conclusion that the brain involved a variety of highly specialized functional regions that controlled movement, vision, speech and so forth. Clinical studies predicted exact sites of brain lesions from symptoms of patients and confirmed these at the death of those patients. Localization of functions was thus established.

With this localization and specialization of function, came the division of memory into several specialized subunits. Subunits were designated as centers for "auditory word images", visual word images, and so forth. Should one fail to recall, it was either explained in terms of the loss of a specific memory center/image or in terms of the brain being unable to "search" its files, following some breach in the connecting nerves. These views are still held in various forms today.

The Alternative to and Evidence against Localization

Rosenfield argues against this view of memory. He admits we recognize things and persons inasmuch as we match up what is felt, seen or heard with what is stored in our brains. We also recall persons and things by reactivating the images stored in our brains. The stored images, however, have been "learned", he notes. We must first be taught what the world is, so as to understand it. Memories are not the fixed images that orthodoxy and commonsense would like us to accept they are. This urges a reexamination of the nature of thought and action, and their biological basis in brain functioning.

It is not simply that the idea of localization of function could be faulty, it is rather that the basic assumption that memories are carefully filed and stored fixed traces, seems hardly able to withstand the evidence against it any longer. In his "The invention of memory," Rosenfield (1988) associates the whole problematic, in the first place, with a misreading of the evidence. Freud had meant it differently, he has only been bypassed.

(i) ***Freud***

Already in the late nineteenth century, Freud had doubted the localization of functions, although he did not succeed in giving up the idea of a permanent memory. He believed memories to be fragmentary and that recognition could, thus, hardly be a matching of what is perceived with the images that are stored. Freud had noted that bits and pieces of one's past frequently exhibited themselves in dreams and neurotic symptoms; and only when linked to emotions were they recognizable as memories. The view of emotions as structuring perceptions and recollections was essential to Freud.

Contemporary neuroscience and psychology, argues Rosenfield, might have bypassed the full magnitude of Freud's discovery. Freud, he writes, was in essence describing the functioning of the limbic system, ages pretty prior to the identification of its significance for emotional behavior, by findings in the 1930s. The *limbic system* is a set of interrelated structures deep within our brains. Presently limbic structures are known to affect memory too.

(ii) ***Memories as Fragmentary Impressions, and the Limbic Activity***

When in the 1930s Wilder Penfield observed that electrical stimulation of some brain regions in conscious patients evoked recollections of forgotten experiences, some felt that was a decisive proof for localization of function and permanent memory traces. Recent studies show, though, that memories are but fragmentary impressions, comparable to pieces of a dream, incorporating elements that do not belong to the original experience. Most importantly they do not occur save in the event of activity in the limbic system. An emotional link, a limbic activity of sorts, does seem to be necessary for the sensation of a memory. Limbic activity could well be important for introducing coherence or order into our memories.

Emotions are, as it were, central in the creation and categorization of memories. The activity of the limbic system (emotion) connects the ambivalent memory-fragments into better coherent wholes that could have some bearing on the immediate setting. The brain does not contain any symbols. There are simply activity patterns, fragments, so to say, acquiring different meanings consequent upon different contexts. Personal needs and desires decide our classification of the events, places and persons around us. Even the categories we employ rest on context (Rosenfield, 170).

It is neither the case that perception gives a true view of the environment, nor is it correct that perception and recognition are independent brain functions. Instead, the brain categorizes stimuli in line with past experiences and current needs and desires. What we see, it has been noted, does not rely on computations of any sort, but on what has been seen and experienced in the past, as well as what we are now experiencing. When we encounter the environment for the first time, we try several manners of categorizing the stimuli thereof; those that help us into meaningful or useful behavior are reinforced.

Experiences, feelings and thoughts vary extensively from one person to the other; computations, or any inflexible processes of the sort, cannot account for these differences. Our

immediate world is forever changing, and we must be capable of responding to it in manners that take the new and the unanticipated as much as the personal past experiences into account. We cannot subject this whole lot merely to hitherto stored, fixed images that do not synchronize with anything in our milieu anymore.

What could be necessary for our manipulating and understanding our world are *procedures*, rather than fixed images. Again, because it is not possible to keep specific memory images for the enormous varieties and changes that symbols and objects have in varying contexts, procedures are essential for recognition, also. A theory of mind in this direction, is thus equipped to account for how we give sense to stimuli in line with their current context and our personal experiences. Instead of fixed images, we rely on *recreations* - imaginations - whereby the past is remolded in manners appropriate for the now. It is a categorization of sorts.

(iii)***Categorization rather than localization***

The cerebral cortex, Edelman observes, is so organized that even inside a single sensory modality, as in vision, we find a multitude of specialized regions and functionally separate maps (Edelman, 1993, 120). Despite this, we only receive the awareness of a "unitary and coherent perceptual scene" that appears to be a condition for adaptive behavior. The unified appearance of the world we perceive and the capacity to act in coherent manners in the face of manifold and frequently contrasting sensory signals imply some operation of neural integration at various organizational spheres.

Inside a particular cortical region some connecting, perhaps, takes place between the responses of groups of neurons belonging to the "*same* feature domain". *Perceptual grouping* inside a single sub-modality, as in color or movement, offers an instance of "integrative linking" at a rather early stage. Withinthe responses of the groups of neurons in the various feature fields across the regions of the cortex, binding should also occur. The fundamental process through which integration takes place, and of course without any "master plan" in the cortex, is reentry, which takes place locally and between the maps. Kreiter and Singer (1992) show that "reentrant interactions" inside a single region of the cortex does generate "temporal correlations" among adjoining and far-off groups. Experiments with monkeys and cats provide evidence for this.

Even movements result from a combination of neuronal groups, rather than from any specialized module for movement analysis. Experiments on neural responses as monkeys reach for targets reveal that each and every movement proceeds from the "contributions of multiple" neuronal populations, with each one tuned to a certain movement direction (Georgoppoulos et al, 1986). Any one movement, then, is practically, the result of the right combinations of groups of neurons. It is about selecting the right movements from a collection of variant movements based on the selection of groups of neurons.

Given that the theory of neuronal group selection implies a nervous system that is variable, a question that comes immediately to mind is how an animal, whose nervous system varies now and again, would be able to sort his world into events and objects. When one moves, Edelman explains, there is an interaction between the brain's local visual maps, those coming from other sensory modalities, and those that guide motor output. Perceptual categorization never happens exclusively in one specific area. Rather, since the outcomes of continuous motor activity are a crucial aspect of the process of perception itself, and perception relies on activity, the neural structures that execute different categorizations must have "multiple sensory and motor maps," generating what Edelman refers to as *global mappings*. Neuronal group selection inside these mappings happen in a set of "dynamic reentrant loops" that steadily match movements

associated with gesture and posture to various types of sensory stimuli (Edelman, 1993, 121).

The idea that acquired images are stored as fixed images in specific centers, argues Rosenfield, means that the world is knowable only if already known; a shape could only be recognized if a fixed image of it were already stored in the brain. David Marr (1945-1980) had successfully contested this notion when he proved that, devoid of any prior knowledge of them, shapes could be recognized as shapes. Although Marr could not completely break ties with the notion of fixed memories, he has at least given one instance of recognition by undertaking some *procedures* on visual stimuli, rather than matching stimuli to earlier stored images. This is a case of recognition without fixed memory.

This one instance of *memory as procedure* was the sort of memory Broca also alluded to when he discussed the patient, Tan, and motor memory. Shortly before he died, Tan had lost his power of speech and was paralyzed. But he understood all that was said to him, responding with the word *tan* and gestured considerably. Broca argued in his autopsy report that patients like Tan had lost nothing other than the faculty of the movement coordination, which articulated language demanded. Those who have lost this faculty, he observed, instead of losing the memory for words, have merely lost the memory of the "procedures" needed for word articulation. It is, thus, memory for the movement-procedures needed for word-articulation that is at issue here (Rosenfield, 18).

The point that is being made here is that no word center exists anywhere in the brain. Instead, an interrelated activity-pattern among numerous so-called brain "centers" makes us perceive a certain word in a certain context. It is a question of context and categorization, or better, of appropriate contexts and *perceptual groupings*. This categorization is bereft of absolute rules. It is simply a fluid process, enabling us to construct novel categories. The categorizations which our brains form are abstract. They are not explainable in terms of combinations of rudimentary stimuli (Rosenfield, 111).

Animals and birds are known to categorize and generalize; and they do these in the absence of any known language, observes Edelman. He cites two instances of categorization; the first, by pigeons who categorize visual images and scenes; and the second, by babies who categorize objects and their boundaries. Herrnstein (1982) performs an experiment in which he presents pigeons with unsystematically picked and contextually varied photos of fish. After viewing a little quantity of these photos and receiving operant rewards for their performance, the pigeons begin to make a *distinction* between *the novel* and *the familiar*. They begin to pick out photos of fish from not-fish, based on a "general mode of visual pattern recognition".

Edelman also cites the work of Kellman & Spelke (1983) who have to their credit a study with three-month Olds. Their experiments reveal that babies visually discern boundaries of objects via the systemic movement of these boundaries in relation to "occluding objects and a background". Babies see the systematic relative movements of the boundaries they perceive as constituting objects. It is a quality and a capacity, mirroring the features of the baby's visual motor system, rather than reflecting any conventional learning. Babies apply this to every "moving collection," indicating a general characteristic (Edelman, 1985a, 14). This view is consistent with the essential Darwinian evolutionary principle.

(iv) ***Darwin***

The notion of fixed universal categories, observes Rosenfield, is questionable on plausible biological grounds. For one, it is at odds with the essential principles of the theory of evolution

that Darwin proposed. The cardinal idea in Darwin is that variations in populations do happen from which selection could ensue. With the mechanisms of inheritance through genes, diversity in populations arise. Selection from these populations lets some organisms survive in unpredictable surroundings. Again, this is consistent with the theory of brain development Edelman proposes.

(v) ***The brain***

Edelman proposes a brain theory that accounts for neurophysiological functions in relation to a system of Darwinism that embodies variation and selection. He likens his findings on immunology to the evolutionary theory and argues that the brain could function as a selective system and that learning could simply be a type of selection. He grounds his theory on three principal elements. First, he holds that at the brain's development in the embryo, a very variable and individual connection pattern between brain cells (neurons) builds up. Second, he postulates that a pattern of connection of neurons becomes fixed in every individual after birth, though some combinations of connections get selected in preference to others, on account of stimuli that get to the brain through the senses. Third, he posits that selections, of the sort discussed above, happen especially in groups of brain cells connected in maps, sheets, that communicate to and fro with one another to generate categories of things and events (Rosenfield, 1988, 174).

Edelman believes that the brain is, in its functions, Darwinian. Neural circuits and neuronal groups build up populations that consist of individuals that vary from one another. During ontogeny and behavior, the neuronal groups that are adaptive for the organism are selected from those populations of variant individuals. The brain, Edelman observes, is made up of sheets, or laminae, and of nuclei. The evolutionary history of these structures has equipped them with the power to function in complex connection networks. Each of the structures contains huge quantities of neurons. Sensory transducers -- specialized neurons -- that form our sense organs, link up these structures with the external world. In this way the brain receives its inputs. The brain sends its output through neurons to muscles and glands. Besides, brain parts receive inputs from and give outputs to one another bereft of any outside intervention. Through synapse, neurons link up with one another and get organized inside and around the nuclei and laminae.

Synapse is a specialized structure where electrical activities go down the axon of pre-synaptic neurons and trigger the release of a neurotransmitter, a chemical, that in turn triggers electrical activations in post synaptic neurons (Edelman, 1985a, 2-3). At synaptic sites, a myriad of neurotransmitters are unbound to bind later to receptors on the cells of post-synapses. Studies on synaptic plasticity reveal that intercellular communications could be either "potentiated or depressed". These changes are thought to be at the basis of an animal's capacity for learning, remembering or forgetting (Edelman & Gally, 2001, 13765).

Studies have long associated the capacity for learning and memory with rise in synaptic efficacy that hinges on activity (Maren, 1999). But then stable alterations in synaptic strength requires a huge but temporary and constantly changing rise in intracellular calcium. Edelman and his colleagues register a breakthrough in analyzing synaptic activity and plasticity impelled by huge calcium transients. They analyze the molecular and cellular mechanisms that underlie synaptic plasticity through the resolution of the issue of functional alterations of individual synapses at the very level of their history. Their study identifies the "calcium-dependent protease μ-calpain" as the enzymatic reporter or the marker enzyme that marks individual synapses that have had functional changes (Vanderklish, Krushel, Holst, Gally, Crossin, Edelman, 2000).

Though the brain has the semblance of a huge electrical network, it is not arranged as any artificial network known to man. Its network is only formed at development through the

movement of cells, extension processes, and connections of ever growing quantities of neurons. The brain is a flawless instance of a self-organizing system. In their movements, extensions, and connections neurons differ from one another, making it difficult for any neuron to be similar to the other, given their history, and rendering any precise, computer-like hardwiring in the nervous system impossible. To make matters worse, the bulk of synapses manifest no detectable activation. These have been called silent synapses, since they are not expressed. Neurons are at times arranged into maps, though they could also be organized differently. And every other map differs from the other; a variability that issues from available inputs. This variance is continuous and extensive. It stems from the fact that the world does not come to the organism with its objects and events well labeled in any "a priori scheme or top-down order". Our generalizations and object definition must incorporate this phenomenon (Edelman, 1985a, 4-6).

Edelman cites two studies by Merzenich *et al.* (1983,) showing that every monkey has a unique map that differs from those of others. These researchers observe changes involving steady mobility of boundaries of maps in the monkey cortex. Their findings reveal that these changes are due to synaptic changes stemming from changes in inputs. An analysis of these results suggests that, even in adult brains, selection is ongoing (Edelman, 1985a, 4-6).

Given that the pressure of evolutionary selection generally is wielded on a lengthy chain of events that includes a lot of interacting elements at various scales in time and space, it is improbable, in biological systems and networks, that clear-cut and strictly defined functions could be so clearly allocated to independent subsets of elements or processes. For instance, Edelman and his colleagues explain, should the power to loco-mote be *selected*, then, there is bound to be degenerate modifications, to assist this novel power, in connections and links inside and about a lot of structures of the brain, brainstem nuclei, the cerebellum, the spinal cord, to mention but a few, in line with parameters of the outfits of the muscles and skeletons. The effect of this will surely reflect in locomotion, but so also will a lot other functions usually under some influence of these structures be concurrently affected. The result would be a concomitant rise in the system's degeneracy (Tononi, Sporns & Edelman, 1999).

The assumption of philosophy since Plato is that nature is of classes and defined in terms of fixed properties from the top downwards. This gives rise to a brand of essentialism where individual variation becomes a noisy diversion and threat. The contribution of Darwin to this debate, Edelman holds, is to highlight the importance of the individual. But for his completely flawed genetics and the terrible monster that is today known as social Darwinism, there is a certain reading of Darwin that is correct. It is that variance in a population is of the essence, and that the diversity that emanates from it is not a noisy diversion and a threat, but a sequence of life and a strength. Edelman finds such variance to be the root of change. Rooted in this, he argues, natural selection, acting through the environment, selects the individuals whose adaptations lead to higher reproduction rates (Edelman, 1985a, 7).

The essentialism of Plato and the typological thought of thinkers after him, Edelman argues, are erroneous. We rather form classes from the "bottom up by natural selection". Within the immune system, during the lifetime of an organism, the instructionist theory is again erroneous. Not-self is recognized by means of clonal selection. Instructionism holds that in the immune system, a foreign molecule transfers information on its structure to a cavity in the antibody molecule, and withdraws]. In both instances, an adaptive way of classifying novelties unfolds, an adaptive power so refined that we mistake it for a pre-established instruction.

Thus, the brain, in its orderliness, does not supply its groundwork for novelty recognition and generalizations through instruction and information processing. Instead, in its most rudimentary

plane of functioning, the brain is a "somatic selective system" grounded in variance in neuronal populations (Edelman, 1985a, 7). The brain with its nervous system does not function as a mere single neurotransmitter operating a software in some information processing system. It rather consists of a multiplicity of neurotransmitters, receptors, and signaling modes, indicative of selective brain functions. This kind of model does not embody codified cues functioning in strictly pre-delineated "linear circuits". Instead, it consists of correlations in time and space taking place among multiplicities of tissues (Edelman, 1993, 119).

These findings and analyses of the brain have their consequences for higher brains. First, individuality is of high importance in higher brains. We do not know the value of a variant until adaptive selection takes place, and given the uncertainty of the future, a modest and restrained approach becomes the only informed and rational one. Second, perceptual acts are creative acts. There is hardly any sole manner of perceiving. Memory in this kind of set up is hardly a recall of replicas of stored material descriptors. It is instead an imaginative act, a kind of dynamic re-categorization decorated by exemplars. In the light of these revelations, not even the scientific method has any rationale or justification to dismiss any idea as inauthentic *a priori*. Such a selective system implies free agency and free will too.

The brain rather than being a machine for logic is a selective system. It constructs meaning in a bottom-up fashion by means of evolution and ontogeny, using "natural and somatic selection". The brain is formed to exploit generalizations to handle "open-ended situations" associated with adaptations in an unlabeled world. Though the brain is not strictly programmed, it has a certain robustness about it, and lacks the privilege of reversibility. It is governed by sense and survival. It is this selective character of the brain's evolution and its somatic process of selection that mediate our basic cognitive behaviors (Edelman, 1985a, 24-25).

(vi) ***Movement, Context, and Embryology***

During the development of an embryo, cells divide, move from one place to the other, and finally get specialized, holds Edelman. What determines if a cell will turn into a nerve cell or a liver cell, is where it is when specialization starts and where it has previously been. The movements and shapes of cells unavoidably differ in every individual. In this way predicting precisely where a certain cell would be at a certain time becomes impossible. The genetic mechanisms that decide what a certain cell would become are themselves determined by the divisions and movements of the cells. They (genetic mechanisms) must show sensitivity to where (location) a cell is at a given point in time, following cell movements, Edelman maintains.

The process is a simple one. While the embryo's tissue grows, borders that establish the limits of the organism's various functional parts are built up. This procedure is not, as it were, supervised by any "architect". The borders are built up between various cell groups by various glues, intercellular cements, called cell adhesion molecules (CAMs). Two of these CAMs are called the liver cell adhesion molecules (L-CAMs) and the neural cell adhesion molecules (N-CAMs.) These two appear on cell surfaces quite early in the development of the embryo. N-CAM on a neural cell binds to N-CAM on another neural cell (The N-CAMs on a cell surface adhere only to N-CAMs on another cell surface, while L-CAMs on a cell surface adhere only to L-CAMs on another cell surface). N-CAMs do not stick to L-CAMs. The sticking together of the CAM genes relies on the past and present positions of the cells that carry them. Thus, the assembling of cell groups joined together in a certain CAM varies even in individuals that are genetically identical. Cell differentiation is epigenetic rather than genetic; since it is indirectly decided by the joint activity of the genes and signals from groups of cells that activate genes.

Another cell adhesion molecule from the nervous system, which is the third that one finds on

surfaces of cells on embryos and through which one cell is attached to another, is the Ng-CAM (neuron-glia cell adhesion molecule). Whereas N-CAM on a neural cell binds to N-CAM on another, Ng-CAM on the same cell binds to this other molecule called glia. Neuronal movements on glia and the movement of neural processes on one another bring about the brain's network patterns. CAMS participate in making these movements, and the patterns that arise from them, happen (Edelman, 1985a, p.18). Given that L-CAM and N-CAM molecules do not adhere to each other, cells that have been joined in collectives by each of them form borders. Signals traded at the border between ensembles of the L-CAM and N-CAM cells fix, so to say, the successive formation of vastly diverse sorts of cells on every side of the border, depending, of course, on the historical antecedents of the two groups of cells.

So it is that all these functions rest on the context, namely the neighboring cells and the cells's antecedent history. The same rules apply to both CAM, brain neurons, and other body structures. Given that the borders of cell groups rest on movement dynamics, individual variations ensue that are not determine merely by genes and whose diversity warrant different brains having dissimilar structures. Epigenetic mechanisms such as this, show why no two brains could be identical, reveals Edelman (through this selection-based brain functions: the CAM mechanism). Nevertheless, the general patterns that have already developed and the broadly similar sequences of the development of the embryo, make individual brains of members of a species look like one another.

It becomes, therefore, clear why genes do not tell about morphology. The mechanism of CAM generates diversity in the anatomical connections of the brains of individuals. The context and historical antecedents of the development of cells decide, to a great extent, the structure of an individual brain. Function, development, and structure thus being closely related, the functional activities of the brain's linked-up cell group could not but be reliant not only on its historical antecedents but also on the activities of its neighbors (Edelman, Rosenfield, 180).

The same is true of the relationship between form, structure, movement, shape, and behavior. Rutishauser, Yahara, & Edelman (1974) demonstrate the relationship between cell movements and cell surface. They provide experimental evidence to show that cell movements alter and maintain the shape of a cell. Their cinematomicrographic studies on cells that stick on fibers implicate "movements of the lymphocytes attached to fibers" in the morphological changes in cells.

These experiments trace changes that occur in the shapes of cells to "local and global movements" of cells. They also find that when local regions of the lymphocyte surface and some ligands and substrates interact, it heavily affects and modifies the whole cell's movement and morphology. This suggests that some of the structures that govern the movement of cell-surface receptors do also participate in regulating cell movements as well in altering and stabilizing the shapes of cells.

Edelman's (1984) study and discussion of the development of form and structure relates developmental genetics to patterns of evolutionary chemistry. Using the regulator hypothesis he proffers a molecular framework that relates the genetics of development to morphogenesis and evolutionary processes. First, he proposes that cell adhesion molecules (CAMs) do a cardinal function in the development of form and structure by letting adhesion act as regulators for other rudimentary processes, especially morphogenetic movements. CAMs do their function as regulators by modulating local cell surface. Second, he suggests that genes for CAMs express themselves in schedules antecedent to and somewhat separate from schedules for specific "networks of cytodifferentiation" in various organs. Third, he opines that the control of the genes

of the cell adhesion molecules by the regulatory genes accounts for the body plan we see in fate maps. In the chicken, this plan manifests itself in an order of topology, where a modestly linked central area of neural CAM is encircled by a neighboring modestly linked cell-ring that expresses the liver CAM. Fourth, he posits that morphogenetic movements issue from the intrinsic mobility of cells and the elective possibilities offered by cell-cell adhesion, which cell adhesion molecules mediate, and by the adhesion of cell substrates**,** which substrate adhesion moleculesmediate. These movements, which CAM modulation regulates, bring cells of diverse history together resulting in a variety of "embryonic inductions." Fifth, in the course of its activities, natural selection eliminates organisms whose expression of CAM genes are in sequences that lead to a flop in induction. Contrarily, variant movement combinations and CAM gene expression timings that bring about suitable inductive successions or chains become selected. While allowing for the conservation of the fundamental body plan, this permits much variations in fate-map details from one species to the other. Minor changes in the regulatory genes of CAM that do not nullify this selection principle could still occasion huge alterations in form in comparatively brief evolutionary spans.

Edelman argues that the cell adhesion process is one of the basic processes crucial to morphogenesis. The temporally regulated expression of cell adhesion molecule genes would supply a huge portion of the selection that directs and "kinesthetically constrains" how these processes interact as forms get generated (Edelman, 1984, 1416). Studies by Edelman and his colleagues have been able to determine the mechanisms by which cell adhesion mediates cell-cell binding. They find that reciprocal interactions between two N-terminal immunoglobulin domains, immunoglobulin1 and immunoglobulin 2, could be "necessary and sufficient" for cell adhesion molecule homophilic binding, but that binding to the maximum would require "intra-molecular domain-domain interactions" (Atkins, Gallin, Owens, Edelman & Cunningham, 2004).

In what follows, we discuss Edelman's theory of neural Darwinism to see how it provides an alternative, probably, to mainstream view and ushers in a biological understanding of brain and memory.

(vii) ***Neural Darwinism***

Gerald Edelman's theory of neural Darwinism describes another approach to brain and memory function that provides a biological footing to the alternative perspective we have been presenting in this section. Edelman underscores the categorical character of recognition and its intense ties to *motor functions -- our earlier and current explorations of our world*. He holds that perception and recognition are not functions of the brain that are independent of one another. The Darwinian principle of selection, he affirms, helps us account for the perceptual categorizations that are at the basis of memory and recognition. The selected structures, Edelman elucidates, are those neuronal groups reacting more forcefully to particular groups of stimuli than they do to others. There could be substantial overlap in their manner of reacting to environmental stimuli, though. A certain dream image, for instance could stand for multiple objects.

The groups of neurons are arranged into sheets, called maps. Information is categorized following the interactions among the many maps and given that all the maps are linked to a motor output and to the original sensory input. Hence, information is defined only after selections and adaptations have taken place. What is built into biological systems is only the potential to make good choices (Edelman, 1985a, 27). Contrary to some theories, neurons neither use codes nor carry information as do electronic devices such as chips. Movements and contexts instead propel brain processes and neuronal patterns. Local environments decide the sequences of the switching on and off of CAMS on cell surfaces. Cell mobility patterns,

attachment processes, and formation of connections all are changed by this "dynamic switching". These dynamic changes introduce patterns as well as variations to neurons.

The somewhat orderly circuitry patterns we see, is a function of cell "surface modulation of CAMs on neurons," that relies on orderly progression of environments. It is not a product of any pre-established strict binding of a specific process of neuronal cell to another. It is rather a principle, in the configurational constellation of all nervous systems, of both "structure and regulation" and "necessary variation." This is the place of the dynamics of cell surface modulation of CAMS in neuronal cellular processes (Edelman, 1985a, 18-20). Perception and recognition are, thus, only part and parcel of the same unitary process.

This idea of brain or embryology as influenced by movement and context and the view of memory as procedure and categorization is consistent with Edelman's theory of neuronal group selection. The theory of neuronal group selection rests on the view that the nervous system functions as a selective system (similar to the evolutionary natural selection). At somatic time (inside an organism during its life-span), specific groups of interlinked neurons get selected instead of other groups. Groups are defined by the intensities of their synaptic links. Neurons inside a group are better solidly coupled than those outside and are inclined to share functional properties such as receptive fields -- those parts of skin surface that make neurons fire. The cardinal mechanism for group selections and competitive interactions is the mechanism of modification of synaptic efficiency. Edelman accounts for shifts in synaptic strength. He demonstrates that post-synaptic modifications bring about specificity and context-dependence in short-term alterations inside a certain neuronal network, while pre-synaptic modifications engender long-term alterations in the spread and placement of succeeding short-term modifications (Finkel & Edelman, 1985, 1291).

The notions of memory as procedure and of perceptual categorization, argues Rosenfield, were already implied in the theory of localization of function. The proponents of localization only forgot to inquire after why the seeming specialized centers existed. What would justify the brain, one would ask, going for numerous memory centers, whereas what it required was the capacity to fit the bits and pieces together, not detaching them from one another. What one reads are words and sentences rather than letters. To make sense of words and sentences, though, one must be capable of recognizing the multiple manners in which identical stimuli could be organized. This, of course, entails one bracing oneself for orderings of words one hitherto was never confronted with. What has the semblance of localizations, says Rosenfield, are but disparate manners of grouping stimuli. They are but aspects of forming possible suitable combinations and orderly organizations of stimuli. The environment, he argues, does not school the organism. The organism must, instead, give the environment the meaning it wants it to have. This *giving-meaning-to* or *making-sense-of* does not have a specific mode of doing it.

Such is the case that the ostensibly specialized brain centers are merely facets of the brain's broader combinatory strategy, procedure. Their operation has meaning only in relation to the operations of other combinatory tactics (the so-called centers could be mere combinatory tactics) and of the setting in which the organism finds itself. The view of the brain as a collection of highly specialized functional units, localization, has indeed overlooked much, such as the objections of Sigmund Freud, John Hughlings-jackson, and so on. It is hard to see why people clung to localization, even as several computer simulations applied in the computational view of brain function pointed to the need for procedures that made sense of stimuli, instead of stimuli that attempted to school the brain or the computers. Rosenfield objects to this localization view, arguing that the brain is a biological structure. Understanding it is only possible in harmony with biological principles. Localizationist researchers simply opted for superficial observations of

localization and ostensible permanent memories. They should have instead been informed by the biological principles such as Darwinian selection, whereby, as Edelman holds, the groups of neurons that react more forcefully to certain groups of stimuli than the rest are selected.

This perceptual categorization is also about the capacity of the organism, bereft of any programming or hard-wiring, contrary to machines, to construct its own perceptual and semantic world from the multitudes of untagged surrounding stimuli and, maybe, to construct consciousness and language devoid of any innate capacities. Oliver Sack finds in Edelman's theory the most appropriate explanation of the visual adaptations and power of visual categorizations that blossom in persons born deaf. Without instruction, they adapt to entirely novel perceptual forms, categorizations, orientations, and approaches to world, he notes (Rosenfield, xvii).

It has been said now and again that no two brains can be alike. This makes sense given the numerous mappings and re-mappings that are at the basis of brain function. Thus, Edelman's neuronal groups selection is said to be also about one's uniqueness, the capability one has to create one's life and history. One's perceptions are hence to an extent one's making, and one's memories are aspects of a continuing imagination-process. This makes it untenable attempting to reduce the mental life to mere molecules. The mind, rather, is, in addition to acquiring more knowledge, also about reworking, re-categorizing, and hence generalizing information in novel and startling ways. It is likely that psychoses, for instance, is brought about by inappropriate categorizations from dented maps, in the same way as the lack of the power to correlate the sequence of events or objects in time could, to a great extent, account for the loss of specific memories in some incidents of amnesia (Rosenfield, 197-198).

So it is that Edelman replaces Freud's fixed memories with memory as categorization. Re-categorization takes place when the links between separate maps are temporarily reinforced. It rests on movement, sensation, and selective processes, and this skill is gained with experience. One recollects in different contexts; this entails the activation of different maps that interact in fashions that vary from those of one's original encounter with the event or object, including maps that interact in ways different from those that led to the re-categorization of one's original contact with the object. Rather than storing images and pieces, one increasingly acquires the power to categorize in linked-up fashions. Remembering is thus an imperfect reconstruction.

The insight on the nervous system that underlies Edelman's harmonization of structure and function, namely the brains structure and cognitive functions, makes the reality of the absence of a computer-like precise connectivity and hardwiring in the brain and the fact of divergence in the overlaps in the "dendritic and axonal arbors," all necessary features of variance. These features of variance instead of being noisy distractions, he proposes, are needed for the creation of "rich degenerate repertoires" for the process of selection in the neuronal populations. Their relevance reminds us of CAMs' regulation of cell interaction in the development of the embryo that is necessary for the formation of pattern and diversity. This settles the problem of structure.

Regarding the question of cognitive functions, the fact that most synapses do not manifest any detectable activations, does not indicate failure in the transmission of messages, as is wrongly held. Instead, this indicates that selection is taking place in the whole population of synapses within the affected area. When map boarders fluctuate, it points to the selection of neuronal groups and to a success in the competition among groups. Reentrant maps that connect variant degenerate repertoires of neuronal groups guarantee generalization. Multiple parallel re-entry processes (not requiring any pre-labeling by any *a priori* scheme or any top-down, linguistically based order of things) are necessary for the construction of a perceptual response. Thus,

connected maps, with their independent inputs, structurally constitute classifications, indicating that they have a generalizing property necessary, though not sufficient, for us to be aware of the coherence of perception (Edelman, 1985a, 23). Edelman's theory of neuronal group selection helps us understand these facts.

(viii) ***Neuronal Group Selection***

(viii a) ***Preamble***

Edelman's theory of neuronal group selection intends to provide a theoretical framework far-reaching enough to bridge the gap between biology and psychology in ways true to evolutionary and developmental mechanisms. It aims at reconciling two arrays of findings that contradict the dominant view of brain function. Firstly, studies on individual nervous systems reveal their immense "structural and functional variability". There is evidence of variability in both space and time at the levels of the molecules, cells, anatomy, physiology, and behavior. Though among a species we observe unmistakable "commonality of neural structure," the extent of individual variation goes beyond what is tolerable for an efficient performance in any artificial system. Despite this variation, adaptive behavior, proper to each species, unfolds in the train of development of the individual (Edelman, 1993, 115).

Secondly, the experiencing-newborn is hardly born into a stimulus-world with handy already-existing unambiguous bulletin, waiting to be exploited in line with fixed regulations akin to those of a computer carrying out a program. Whereas our world conforms to the laws of physics, it is hardly strictly segregated into events and objects. For survival an organism either inherits or devises enabling yardsticks for assigning perceptual categories to the world's stimuli in line with its adaptive exigencies. When, consequent upon his experiences, the organism succeeds in dividing up his world and slotting its stimuli into categories, his world still remains somewhat a *novelty-ridden* place (Edelman, 1993, 115).

In sharp contrast to the aforementioned two sets of findings, information processing accounts of higher brain functions give the impression of, if not explicitly claim, a computer-like brain, presupposing that neuroanatomy and the meaning of signals are fixed and clear-cut (as in instructions). Edelman's neuronal group selection theory contends these assumptions. It establishes that the power of organisms for categorizing untagged worlds and their capacity for adaptive behaviors emanate neither from instructions nor from coded information transfers, but from selection processes associated with variations. In this well-informed understanding, the hitherto enigmatic "variability of individual brains" becomes a pivotal feature of our function. As in natural selection theories and those of clonal selection in the immune system, the neuronal group selection theory is a theory of population.

In Edelman's neuronal group selection theory, our world receives tags or perceptual categories following a twofold interactive process of "selection upon variation". The first process takes place mainly during development in the "embryonic and postnatal" stage, where adjoining neurons are inclined to be intensely interlinked in *cooperatives* of inconstant or changeable sizes and structures termed neuronal groups. The second process is made up of shifts in synaptic intensities in the course of the animal's activities, as she selects the responses that correlate to the groups of neurons that afford adaptive behaviors (Edelman, 1993, 115).

The theory aims at giving details of how our categorization of perceptions and concepts spring up as an outgrowth of selection on preexisting structural and functional variation in the nervous system. In their connectivity, nervous systems are bereft of any strict computer-like wiring. Though the bulk of anatomical links do not show any detectable activity at any given moment,

studies reveal outstanding shifts in physiologically ascertained borders of the neural regions and maps that receive the inputs of these links. To make matters worse, every individual has a unique map. So much for structure!

At the level of psychological function, two findings remain pertinent. Firstly, even in species known to be bereft of any detectable language, we observe notable manifestations of the ability for generalization in their perceptual categorizations. Work with pigeons show that exposing them to some instances of specific shapes of certain categories of things makes them identify new shapes in those categories. Secondly, irrespective of the fact that a certain perception comes from parallel brain activation of many varied maps, each having dissimilar proportion of "functional specialization," yet we have a unitary perception of objects and their properties. This remains true of our perceptions even as we do not have any master map that unifies the diversely mapped attributes into a scene made up of differing objects.

These realizations continue to defy an instructionism that accounts for the activities of the nervous system via an information processing that works on codes. It is in the light of this lacuna that the work of Edelman has its significance. He rightly harmonizes the variations and shifts we observe in neuroanatomy and neural dynamics with nature, appreciating them as essential features for the functioning of our nervous systems.

Edelman's theory has three mechanisms of selection through which the nervous systems produce adaptive behaviors. They are: developmental selection, experiential selection, and reentrant signaling. These, function inside cooperatives of intensely interlinked neurons. Neurons in a group are strongly interlinked, and shifts in their synaptic intensities improve, in different ways, the group's adaptive responses. Whereas the structures of the groups stem from local connections in the anatomy, each group in itself is a dynamic entity having borders and traits that changes in synapses and the type of signals it receives affect (Edelman, 1993, 116).

With the *developmental variations and selections* associated with embryology, we discover there is no strict programming of the structural diversity of the nervous system by a molecular code. Instead, what there is emerges during development from the dynamic epigenetic mediation of cell divisions, cell adhesions, cell migrations, cell deaths, and extensions and retractions in neurite processes. Whereas the temporal patterns and the degrees of activation or expression of the molecules that regulate morphology reflect the character and idiosyncrasies of a particular anatomical area, they are, however, modulated dynamically and influenced epigenetically. Molecules that regulate morphology affect the movement of cells and the extending of processes, generating much variance in local neuroanatomy in the axons and dendrites.

With *experiential selection*, we find that subsequent to the establishment of the bulk of the anatomical links of the primary collectives, the operations of certain functioning groups of neurons keep on being selected dynamically by progressive mechanisms of synaptic variance occasioned by behavioral tendencies and life experiences. This selection takes place in synaptic populations. Though it does not prompt significant anatomical alterations, it makes some synaptic populations stronger, while making others weaker. Experiential selection effectuates the creation of secondary collectives of groups of neurons as they respond to specific patterns of stimuli. Experiential selection, thus, grows out of the differential reinforcement of populations of synapses. These synaptic alterations, hence, in no way reflect information stockpiled in individual linkages between single neurons. It becomes evident that experiential connection is about the statistics of stimuli correlations between pre- and post-synaptic neuronal groups. It is not about one magical neuron carrying coded bulletin to another. Reentrant

signaling enables these "statistical correlations" to benefit adaptive behaviors by letting these correlations mirror the features of the stimuli emanating from the world of experience.

Neural mappings that relate sensory receptor sheets to specific areas of the central nervous system provide for some measure of regularity. Mapped areas trade and coordinate inputs via a process of selection known as reentry. The "simultaneous activation" of groups of neurons in various maps by a single signal and the influence of earlier reentrant activations all serve to reinforce some of the neuronal group connections, leading to temporal correlations in responses by a subset of groups (Edelman, 1993, 117). Following manifold contacts with an input, certain patterns of groups get selected in every mapped region. Edelman refers to this process as reentry, given that selection outcomes are recursively 'shuttled' to and fro among maps. Reentry generates novel neuronal responses. Unlike feedback that corrects errors and has a pre-delineated input-output function, reentry has neither any necessary directional preference nor any predetermined input-output function.

The existence of neuronal groups is supported by experimental evidence. Singer (1989) finds proof for this in the visual cortex. In other studies, presenting a lone-oriented stimulus leads to correlation of 40 Hz oscillations in areas of amply set apart regions of the visual cortex. Also presenting a single-oriented stimuli has been implicated in correlations in oscillatory behaviors in the two cerebral hemispheres (Engel et al, 1991). The vigorous "temporal correlations" between single-unit activation and potentials of local areas in the aforementioned studies show that, when a signal is encountered, adjoining neurons give a coordinated response, forming a neuronal group in the process. Besides, Edelman argues, the finding that widely separated groups of neurons in the "strait and extrastriate cortex and across the callosun" correlate, offers direct proof that reentry involves "long-range selective interactions."

Thus, the neuronal group selection theory rests on the continuous breeding of diversity, with selective processes doing their thing at various phases. In the "embryonic and maturing brain," selectional and variational processes take their toll on migrating populations of cells, during death of cells and the forming of synapses. In the mature brain, variational and selectional processes impress on and manifest in the differential enhancement of the effectiveness of synapses, which leads to the generation of neuronal groups, a process modulated again and again by reentrant signaling.

(*viii* b) ***The Theory***

Edelman (1985a) postulates that at development, groups of neurons get formed in the brain's laminae or nuclei. In these areas, neuronal groups, consisting of about hundreds or thousands of cells, come to stand in for neurons with closer connection to one another than they have to those in other groups. The collection of all these groups in a brain area makes up an array of "structural variants," referred to as a population. Following the anatomic formation of these neuronal groups at development, through dynamic cell adhesion processes that modulate the movement of cells and the extension of processes, some connections get selected, whereas others phase out. This first selection process is followed by a second that takes place as the animal inhabits her environment. At this selection phase, changes in the network shift from geometrical ones to changes in the efficiency and strengths of synaptic connections (Edelman, 1985a, 10).

The theory of neuronal group selection rests on the notion that our nervous system functions as a system of selection. It is similar to the natural selection process in the evolutionary biochemistry. It is a selective system that, at somatic times, selects specific groups of interlinked neurons in preference to others. Groups are demarcated by the intensities of their synaptic links. Neurons inside a group are better solidly connected to one another than they are to those in other

groups and they are inclined to share functional properties, for example, receptive fields. Modification of synaptic efficiency functions as the central mechanism that propels neuronal group selections and their competitive interactions (Finkel & Edelman, 1985b, 1291).

Edelman demonstrates that brain function, in much the same way as structure, rests on *context and history* rather than on localized functions and fixed memories. He shows that the brain's selection unit is a neuronal group, namely, a batch of interlinked neurons that operate together. The connection patterns built up among neuronal populations differ from one group to the other, following shifts in the dynamics of the intercellular cements, CAMs, at embryonic development. Hence, the brain has huge numbers of varying groups of neurons. Groups of neurons are linked to one another and to the sensory receptors for touch, sound, and light in the skin, ears, and eyes. Bordering groups of neurons in the brain obtain input from adjoining sensory receptors. Though the stimuli could overlap, neuronal groups respond to them differently. Given that neuronal groups have their individual internal link patterns, with each differing from the others, every group responds differently, even to identical inputs.

The operations of a certain group of interlinked neurons becomes prominent or significance not only on account of the anatomical connections and physiological mechanisms on which its activities rely, but also on account of its context and the history of the inputs it has attained. This rules out the possibility of a certain memory being stored in a particular location in the brain, given that adjoining or surrounding activities necessarily change, making it impossible for the context of any batch of neuronal cells to be constant.

The intercellular cements, CAMs, help in generating a huge array of varying groups of neurons, during the development of an embryo. This selection principle, however, shifts, after birth, from changes in intercellular cements to prevalence of changes in connection strengths rather than in connection patterns. These changes decide the trajectories and walkways of neuronal signals. As with the selection and mass-production of antibodies in the immune system, where selected cells are multiplied through cloning (clonal selection), in the brain the strengths of synaptic links are heightened. [The immune system is a non-cognitive system in our body with cells and molecules that differentiate self from what is not self at the level of molecules]. Inputs from the environment could propel a certain neuronal cell group to respond with increased activity contrary to others that obtain similar stimuli. This strengthens the links between the neurons of the said group.

Edelman and his associates account for these alterations in synaptic strengths, establishing the processes that regulate them. They demonstrate, as already stated, that short-term changes in a given neuronal network have a certain specificity and context-dependence about them that come from post-synaptic modifications, while pre-synaptic modifications generate long-term transformations in the spread and placement of succeeding short-term modifications (Finkel & Edelman, 1985b, 1291). They show that changes in molecules within the neurons and at the synaptic junctions predispose the neurons to become active on encountering similar inputs in successive encounters. The stimuli select, as it were, certain groups of neurons. Responding to an input may intensify the coupling of a certain neuronal group, fortify its links to other groups, and integrate neurons from them into its response pattern. This bolstering of synaptic links brings about groups of neurons that respond better to particular inputs, following from their selection and the reinforcing of their links.

The brain organizes this whole lot through the use of maps consisting of groups of neurons. A map is an assembly of groups of neurons organized in a manner that safeguards its relational patterns. Groups are organized in maps that communicate to and fro with one another, generating

categories of events and things. There are various forms of maps in various brain parts, and Edelman terms the interaction between these maps reentry. Given that the brain needs to be ready for unforeseeable situations, it is given to mapping stimuli in a variety of manners. Brain maps arrange inputs by similarity and by a combination of properties. Remarkably, stimuli are arranged into patterns that enable the organism get a handle on its milieu. This is the essential principle of evolution that operates here.

Given that information is distributed among numerous maps, there is constant reference to and fro between the maps, *reentry*, to enable categorization. No one neuronal map embodies all the requisite information for brain activities; this makes it necessary that neurons in a map interact with others in other maps. Edelman calls this process "reentrant connections," a process whereby nerves travel in both directions to connect the maps, with neuronal selection occurring in each. In this way, the brain forms its categorizations and generalizations. The maps interact with one another, constantly re-categorizing information. The brain refers more abstract mappings back to the earliest or rudimentary sensory maps, which have a unbroken relations with external stimuli, and by so doing keeps track of its manifold re-groupings of the sensory stimuli (Rosenfield, 1988, 188).

Edelman and his associates demonstrate that mappings could be related to one another in the absence of any pre-established instructions. They construct an automaton, patterned after selection principles, to simulate the brain's mapping activities. Their automaton abstracts assortments of categorizations from the mappings of visual stimuli, in the absence of any "specific instructions". This is one more proof that, in a system of selection, we categorize perceptions via interacting maps.

Moreover, Edelman (1993) constructs a "somatic" system of selection, Darwin111, that includes "structures and constraints" in its phenotype, reflecting prior evolutionarily selected values as well as networks responding to somewhat adaptive values of its motor activities in a way that makes prior experience unnecessary. Values do not explicitly specify categorization, though categorization relies on them. Categorization proceeds, rather, from selection grounded in behavior. The changes in synapses that ensue from a system that relies on values are probabilistic. Although their behavioral patterns incline toward their intrinsic system of values and phenotypes, yet not even one version of Darwin 111 shares identical behaviors with any other.

Given the simplification and specialization that characterize Darwin 111's environment, it hardly compares with the world of the experiencing animal. To address these shortcomings, Edelman and his colleagues assemble Darwin1V. Darwin1V is capable of in-built reflex actions and other movements regulated by sensors, which are under selective enhancement of synaptic intensities. Given a selection process grounded in value that gives rise to categorization, Darwin 1V, as with Darwin 111, effectively combines reflexes and the adaptive behaviors it acquires. We cite work with these automata here because they offer experimental scientists the opportunity to test the psychological ramifications of Edelman's neuronal group selection theory, especially in relation to learning (Edelman, 1993, 123). So much for automata!

A process of continuous selection whereby brain activities couple maps and mappings of maps enables the brain to generalize. Moreover, we recognize objects when we categorize them. And we create categories when we couple stimuli, or correlate various samplings of the inputs. Mappings that hold the potentials for generating diverse groupings of the inputs and, through reentry (i.e., cross-correlation,) relate various mappings to one another, do more for category formation than others. By repeatedly activating a certain set of neuronal groups, a specific input

occasions the enhancement of the strengths of this set's connections, predisposing them to tend toward responding on later exposures to the input. However, the reactions of the groups are degenerate, in the sense that no response to a particular input is entirely the same all the time, because the groups do not merely respond to (only) one type of input.

The consequence of all this is that whenever we recollect, we, to an extent, engage in a novel construction. Thus, what has the semblance of specialized functional memory units, modules, turn out to be divers abstractions generated by multiple interlinked maps. However, the mappings, the reentrant activities, and the related motor activities, all of which form the principles that occasion the creation of these abstractions, remain the same irrespective of the category type to which the abstraction may belong. The elementary categorization principles remain the same, while various categorizations become but different procedures of grouping stimuli. This is an alternative to the modular perspective, where "functional specialization" involves different operation principle for every module (Rosenfield, 194).

The mental operation continually refers back to original mapping of our experiences in order to furnish information with a "spatio-temporal continuity." This involves the brain making sense of our experiences, relying on prevailing environmental factors; and these factors keep changing, making prediction of response to stimuli difficult. Thus, it is the operation of the whole neuronal map-complex, in a given environmental setting that reveals what information is being spawned. This whole lot (raises the question of and) introduces us to the phenomena of complexity and degeneracy.

(viv). ***Complexity and Degeneracy***

Edelman and Gally (2001) affirm that the complexity of biological systems has generally broadened over time. Besides environmental influences that multiply complexity at evolution, the degeneracy of biological networks, inside populations that compete with one another, also contributes significantly to complexity. Degeneracy is the power of structurally disparate elements to carry out the same function or produce the same output. Unlike redundancy that happens when identical functions are done by identical elements, degeneracy, involving elements that are structurally dissimilar, could do identical as well as dissimilar functions consequent upon the context of its expression. Edelman and Gally maintain that degeneracy is an outstanding feature of neural and gene networks as well as of evolution and biological systems. Moreover, it is not only necessary for, but also an inevitable outgrowth, of natural selection.

Evidence for degeneracy has been detected in humans who lost the operation of a gene specifying a protein believed to do cardinal and indispensable functions in systemic or intercellular operations. Edelman and Gally cite the instance of a popular protein, albumin, that was unexpectedly found to be lacking in some persons, following screening for protein expression patterns in a population of arbitrarily picked humans (Buehler, B. A. 1978). One proper way of explaining this finding is that the networks of genes of the persons in question are degenerate, permitting extensive and "compensatory adjustments". Again, possibly, some substantial phenotypic effects could have resulted if the affected persons were in a different environment.

The dissimilarity between redundancy and degeneracy at the level of structure could be better highlighted if we compare selection in evolution and design in engineering. In engineering, observe Edelman and Gally, logic reigns, and, for "fail-safe operation," engineers build redundancy into design, and planned redundancy provides protection. This is not so with evolutionary systems. With no designs, a change in an area in biological systems could assist in

overall performance, mutating organs could induce compensatory operations, environmental interactions could prompt robust selection and the complexity of the interactions keeps multiplying. There is degeneracy at various levels of the biological organization. Even proteins with no ostensible relationship in structure, physiology, or evolution could together undertake degenerate functions (Edelman & Gally, 2001, 13763-13764.

The degenerate nature of an animal's immunoglobulins guaranties that she has the power to build antibodies to guard against foreign and invading bodies. In the development and functioning of the nervous system, the place of degeneracy is as essential as it is in the immune system. Although there are multitudes of neurons in the nervous system, no one neural cell is identical to the other in overall shape in any individual animal. In the same way, no matter how much we assume them to be equivalents, no two neurons extracted from two vertebrate individual animals, even when "genetically identical," possess identical morphology. The reason for this is quite straightforward. Brain neurons admit of synaptic stimuli from legions of other neurons such that in man, for instance, one finds roughly a "billion synapses in each cubic millimeter" of the gray matter of our brain. The connectivity pattern generated by such multitudes of synapses inside such an infinitesimal tissue volume in a single individual eludes any genetic pre-specification and, therefore, remains unique to every individual animal. Even inside the brain of a particular individual, the detailed neural connectivity pattern is unfixed. Synaptic plasticity, indeed, epitomizes degeneracy par excellence. Studies indicate that degenerate mechanisms offer much to overall shifts in synaptic efficiency. After stimulation, for instance, modifications have been observed in post- as well as in pre-cellular structures.

In our brains, to make for out-puts that are coordinated, reentry provides ways of linking up degenerate networks. In the dynamic processes of reentry, progressive and continuing spatiotemporal correlations, moderated by signaling via fibers that are parallel and reciprocate to one another, take place between functionally differentiated neural regions. Devoid of any logic and programming, this process sees to it that "complex functions and behaviors" are linked to one another and integrated (Edelman & Gally, 2001, 13765). The principal products of neural activity that aid survival are the ones associated with the initiation or inhibition of muscular contractions by the activities of motor neurons.In its evolution, such a system, as do others, also needs and creates degenerate repertoires.

Degenerate mechanisms are a criterion for natural selection inasmuch as natural selection only functions in a population of organisms that are genetically disparate. The implication is that many different networks of genes pull their resources together in overlapping manners to construct every one phenotypic property being selected. Notwithstanding that their functions converge, every variant degenerate structure imparts its own new properties to the organism and contributes a distinctive goal for evolutionary architecture. The degenerate functions of genetic codes allow various genes to respond differentially to selective pressures, even as they lead, in the end, to "identical polypeptide chains". This follows from the fact that they are differentially susceptible to the various processes and sequences.

The principles associated with redundancy and degeneracy could further be exemplified in the sexual reproduction process. For a species to endure and keep on existing while being confronted by a variable environment, demands that the populations of gametes that individual organisms produce should not merely be oversupplied but also show genetic diversity. This alone affords the required level of degenerate repertoires imperative for adaptations over evolutionary spans. Whereas excessive supply of gametes could demonstrate redundancy in guarding against failure, yet the species would phase out if the gametes should consist only of genetic elements that are identical.

Genetic variants, Edelman and Gally argue, do not simply provide novel prospects for evolutionary transformation, but even the very presence of an "unfilled or novel niche" in the milieu or neighborhood prompts our selecting degenerate batches of genes. A change in the environment that boosts the advantage in reproduction of "larger organisms of a species," perhaps, illustrates this fact. This could lead to the selection of those with bigger cells. A vast variety of "complementary mechanisms" may augment or play a role in this change. This may include, a rise in the rate of synthesizing or accumulating chemical compounds, a fall in their level of breakdown, a rise in the generation of cells, and a decline in the death of cells. As the organisms adapt to novel environments, natural selection chooses from and adjusts some of these factors. We might consider, on the one hand, African Americans of the 21st century being large, probably through eating fast food from Macdonald and drinking cola as they (possibly) prefer to play and work behind closed doors or riding in cars, given the cold weather. Their brothers in the African continent, on the other hand, remain tiny, probably following from lesser availability of food, and having to play in the sand and work under the sun, and trek for the most part of the day.

That which is true of a species' response to selecting for size would, naturally, also be true of selecting for physique generally, or for stature, appearance, demeanor, fertility, and "all other global properties of the organism". With this understanding the folly of talking of a gene for height, appearance, rationality, *et cetera*, becomes all the more evident. All of an organism's discernible properties are decided and mediated by the operations of a degenerate network of a myriad of genes. These are "far-ranging, across-levels" properties, and thus, always require this tradeoff between the activity of an individual gene and the interaction of a network of genes, including historical and environmental factors. Degenerate repertoires are not planned. Any ensuing compensation is a statistical consequence or outcome of the "tradeoff between specificity and range" that accompanies degenerate complex systems (Edelman, 2001, 13766).

Of course variations and mutations work alongside individual (differential) susceptibility to environmental stimuli and factors, which in turn has to do with history and statistics of encounters. Degeneracy and complexity belong together in biological systems. In complex systems, their minor aspects are functionally differentiated across diverse operations, but they manifest rising levels of integration as they experience a rise over time in the interactions among their aspects. Thus they may be said to manifest a curious interplay between the way their functions become specialized and the way their functions get integrated (Edelman, 2001, 13767).

Edelman and his colleagues devise an artificial instantiation of degenerate systems, Darwin X. In Darwin X, dissimilar inputs and elements lead to particular and repeatable reactions in neuronal units. Darwin X is an instance of degeneracy because in it structurally dissimilar circuits and dynamics produce neural and organismal behavioral options that are alike. Darwin X is an attempt at analyzing neural dynamics that underlie complex behavior by means of computational science. It is a brain-based devise capable of interacting with real environments. The behavior of Darwin X is directed by a simulated nervous system that incorporates detailed anatomical and physiological facets of the hippocampus and its bordering regions. It integrates environmental cues and flexible navigational options in solving spatial memory tasks. The way it responds to simulated neuronal units in the regions of the hippocampus as it explores its surroundings is akin to that of neurons in the rodent hippocampus. Location-specific units, akin to place cells in the rodent hippocampus, arise through the integration of cues on vision (sight) and locomotion during its exploratory behaviors, bereft of any *a priori* suppositions in the devise regarding environmental stimuli (Krichmar, Nitz, Gally & Edelman, 2005, 2111).

Given that synthetic neural models that employ brain-based devises permit simultaneous recording from all elements (namely, the state and interactions of every component) of the simulated nervous system at every level during a behavioral task in the real world, Edelman and his colleagues are able to identify various functional pathways of the hippocampus and assess how these affect behavior. They accomplish this by incorporating an analysis that traces back from a reference neuronal unit (in the CA1 sub region of the simulated hippocampus) to ascertain all the other neuronal units having any anatomic and functional relations to the activity of the reference unit, namely those synaptically linked neuronal units that show co-activation in a certain exploratory behavior. This pattern of analysis affords predictions on how the "perforant path and the trisynaptic loop" affect place cell activation and behavior during navigation, all of which are testable in living animals.

The analysis by Edelman and his colleagues pinpoints a couple of distinct functional pathways in the simulated hippocampus incorporating either the perforant path or the trisynaptic loop. They discover that place fields, made active by trisynaptic circuit, incline towards being additionally selective and informative. They nonetheless record the prevalence in the model of place units made active by perforant path as well as their crucial role in carrying out fitting exploratory activities (Krichmar, Nitz, Gally & Edelman, 2005, 2111). Hence, in the model, dissimilar functional pathways affect field activity and, by extension, behavior during navigation. Thus, the simulation manifests degeneracy, in that numerous dissimilar activity patterns come together to generate neuronal activations that give rise to appropriate behavioral options (Krichmar, Nitz, Gally & Edelman, 2005, 2111).

In the foregoing, we have attempted to show with Edelman and others how taking biology seriously presents a biological view of man (where movement, history, context, and the environment sway the balance) and reveals some of the attendant factors of having a body.

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