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Consciousness, Evolution, and the Self-Organizing Brain

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Abstract

While evolution is guided by natural selection, it is internally driven by self-organizing processes. The brain encompasses these complementary forces and dynamics of evolution in both its structure and dynamics by embodying a historical record of the factors that have shaped it throughout its evolutionary past, as well as by being shaped by selective parameters in real time. Self-organization is evident in not only the brain's structure and form, but also in the processes that support consciousness. From the convergence of complex structure and the novelty-generating dynamics of chaos that both characterize the brain arises the experience of explicit consciousness, with its endless scope of possible expressions.

Keywords: Brain, chaos, complexity, consciousness, emergence, neocortex, reticular activating system, selection, self-organization, strange attractor, systems

While the theory of evolution through natural selection has provided a powerful explanatory framework for many biological phenomena ever since its momentous discovery, it continues to leave many important questions unanswered. Some of the most persistently puzzling mysteries that Darwin’s theory presents concern consciousness, the development of increasingly complex brains, and human mentation. As philosopher Thomas Nagel (2012) points out, if mind is a product of evolution, then biology can’t be a purely physical science. Perhaps a logical consequence of this staggering yet simple insight is Stuart Kauffman’s (1995) belief that a deep theory of biological order would necessarily be dependent on key robust and typical properties that do not depend on the details of structure and function.

Ilya Prigogine’s seminal work on self-organization, and the subsequent development of systems theory, have begun to point in the direction of solutions to these puzzles by expanding our understanding of evolution to incorporate processes intrinsic not just to organisms, but to all complex systems. Bolstered by Prigogine’s vision of systems, and ultimately organisms, that are capable of reorganizing themselves at increasingly high orders of complexity by utilizing environmentally sourced energy and releasing entropy as a byproduct, the view of evolution has expanded beyond strictly chance-based scenarios in which random mutations are vetted by the selective environment. It now encompasses deep and mutually transforming interactions between self-organized, autopoetic entities and their complex environments, which include social interactions, physical conditions, and the selective pressures of reproductive fitness. Kauffman believes that the world of ever-increasing complexity driven by such intelligent and purposively acting agents is the result of what he terms criticality, or the evolution of highly ordered systems at the edge of chaos. This hypothesis extends well beyond the self-organizing organism to encompass ecology, and even the unfoldment of evolution itself. One of the most intriguing domains where such an evolution plays out is in the evolution and function of the brain.

Self-Organization

Self-organizing behavior emerges unpredictably in systems, leaving in its wake a causal gap between one level of description and next (Sole and Goodwin, 2000). Erich Jantsch offers a possible metaphysical bridge across levels of organization with his notion of chreodes, or developmental lines, which guide the system's development through the recursive processes that coalesce into self-organization (Conforti, 2013). It is through this recursiveness, he offers, that chreodes link back to their origin to replenish the system with fresh vitality while creating the possibility of bringing new chreodes, or expressions of creativity, into play. This systems-centered vision of evolution reaches beyond natural selection to suggest a source of generativity that is internal to the agent itself as a driver of evolution. Kauffman also picks up on this thread, suggesting that the laws of complexity spontaneously generate much of the order of natural world; selection only comes into play secondarily.

The most inviolable law of complexity that Kauffman (1995, p.15) cites is that it is the "fate of all complex adapting systems in the biosphere…to evolve to a natural state between order and chaos, a grand compromise between structure and surprise." This compromise reconciles what would otherwise be the dilemma of a signal's inability to propagate through either a chaotic or a rigidly ordered system. The critical juncture of self-organization thus finds itself delicately wedged between the two opposing tendencies. From the orderly end of its spectrum, the system draws structure, continuity, and even identity in the form of internal regularities that adapt to external conditions. The realm of chaos supplies the flexibility for open-ended evolution and resilience to inner and outer sources of perturbation. From the critical combination of the two, the system constitutes an orderly yet flexible channel for propagating information. In mediating a balance between two different dynamical regimes, the system conducts itself along the creative ledge to which natural selection pushes spontaneously formed systems. Systems on edge of chaos shift between predictable behavior and chaotic activity, inviting potentially growth-producing transformations (Combs, 2002). Thus, the ingredients of self-organization are implicit in chaotic dynamics.

Chaos and Emergence

Instead of sheer, uncorrelated randomness, chaos can be described as “a superposition of a periodic motion and a chaotic motion in state space” (Grossman and Thomas in Williams, 1997, p. 229). The turbulence of chaos is distinctly punctuated by characteristic forms of order, such as the strange attractor, which draws wandering trajectories from throughout the system into its rough orbit. Although fundamentally unpredictable, chaotic dynamics are deterministic. The system continually iterates its basic function on the products of its previous evolutions to quickly grow into a system of nonlinear trajectories that stretch and fold throughout their phase space in self-interacting loops.

Curbed by externally imposed boundaries, nonlinear dynamical systems also generate internal constraints that establish a stable set of conditions for the system. As the nonlinear evolution draws low-level, microscopic dynamics away from reversibility, the trajectories emanating from a range of starting conditions asymptotically converge on a region of attraction and begin to generate macroscopically observable statistics (Pattee, 2000). Within the turmoil of nonlinear evolution, attractors offer havens of relative order by condensing the infinite possible configurations of lower-level dynamics into orbits that confine them to a few small regions of state space, thus uniting their various trajectories under a single statistical description (Wolfram, 1994). When the region of convergence not a fixed point, nor periodic or even quasi-periodic, it is the topological constant of chaotic systems: a strange attractor. Clothed by an accretion of unpredictable trajectories, the basin of attraction is a center of relative stability within a tangle of sporadic orbits that can best be described by their probabilities of passing through different regions on the attracting set—some of which tend to be more densely populated than the rest, like nested attractors-within-attractors (Ruelle, 1989). When a system parameter changes due to a bifurcation, both the number and stability of attractors within a system can shift. An increasing number of attractors increases the overall symmetry of the system, enhancing its ability to self-organize. As chaos tightens toward order, it approaches the critical line of self-organization that allows efficient transmission of information, in contrast to the minimal propagative capacity offered by systems of either pure chaos or rigid order.

When the tumult of chaos is sufficiently stabilized by order, their union begets the organization of evolvable complexity as an emergent offspring. The system absorbs and reforms the energetic oscillations between the two poles, rendering order's stability and chaos's flexibility into a nonlinear, sustained convergence. The overall balance between the two poles is tuned within an organism by its interactions with selective environmental forces. The highest fitness occurs near the cusp of the phase transition from stability toward chaos—a narrow ledge of congruence that nevertheless allows abundant room for diversity to flourish (Kauffman, 1995).

The basis of chaos, and one of its crucial contributions to complex systems, is the spontaneity of lower-level dynamics. Once ensnared in an attractor's orbit, each trajectory occupies its phase space probabilistically, drawing uncertainty up through the system's increasingly ordered tiers. While continually, unpredictably novel, chaotic dynamics inhabit proscribed parameters. In contrast, the emergent properties ushered in by symmetry breaking represent a foray into unprecedented possibility (Kauffman, 2008). Unfolding beyond the bounds of previously established parameters, the irruption of non-determinism yields new formal patterns that express conserved principles with expanded degrees of freedom to create a new level of potential (Juarrero, 1999). This is made visible in physical dissipative systems, which tend to grow in both complexity and hierarchical organization (Combs, 2019). An increase in complexity does not necessarily mean an "ascent," as Jantsch (1980, p. 296) points out, but rather an enriched ensemble of expressive possibilities and dimensions of autonomy. Autonomy, in turn, indicates an openness to novelty. Instead of suspending the agent's relations with the environment, it accentuates them.

Brain Organization

The properties of chaos and emergence—two distinct sources of unpredictability—are ubiquitous throughout nature and are hallmarks of evolving systems. When restrained by order-creating parameters, they are sources of novelty, adaptability, generativity, and creativity. All of these properties are distilled in the structure, function, and evolution of the brain (we will focus mainly on the human brain). Organization channels chaos into the distinctively ordered experience of consciousness. As a "working community of subsystems that ultimately form a single fabric," the brain is a modular network of "relatively independently functioning units that work in parallel" (Combs, 2002). The high order embodied in brain organization provides a spectacularly complex backdrop for the chaotic dynamics that generate and support the contents of conscious experience. Lynn Margulis envisions that order ecologically, featuring a complex hierarchy of levels within levels. Paul MacLean's theory of the triune brain is perhaps the best-known hierarchy model. Its three layers represent successive elaborations to both brain structure and function over evolutionary time.

Foundations: Reptilian Brain and Reticular Activating System

The most foundational level of MacLean's triune mental pyramid is the "reptilian brain," which comprises the basal ganglia. This system governs basic motor capacities and possibly even a "primitive feeling of motor presence," including primitive instinctual movements and behavioral responses to primary organismal drives like fear, aggression, and sexuality (Panskepp, 1998, p. 40).

Another primitive brain structure that will figure prominently in this discussion of consciousness is the reticular activating system (RAS). This network of neurons, which projects anteriorly to the hypothalamus, posteriorly to the thalamus, and diffusely throughout the cortex, is located in the brain stem and is instrumental in regulating sleeping and waking. As a locus of input from the visceral, somatic, and sensory systems, the RAS plays an integral role in mediating behavior and different arousal states through the deployment of neurotransmitters including acetylcholine, serotonin, noradrenalin, dopamine, histamine, and hypocretin (Garcia-Rill, 2015). The diffuse projections that deliver these information-laden chemical messengers throughout the brain are referred to by Edelman and Tononi (2000, p. 89) as "neural value systems." With their intricately interdigitating projections and termini, the value systems facilitate informational cascades that can generate subtle psychological capacities (Panskepp, 1998). This makes the RAS instrumental in not only supplying the "context" of sensory experience, but also as a potential seat of primary consciousness itself (Garcia-Rill, 2015). This is suggested by the effects of localized brain lesions, which tend to result in the loss of consciousness only when they affect the RAS (Edelman and Tononi, 2000). The central cholinergic pathways—with axons projecting to all parts of the neocortex, hippocampus, and amygdala—stand out as potential candidates for the unification of consciousness (Woolf, 2002). Although rooted in the brain region most obdurate to learning, the value systems are modifiable by learning experiences, and so are amenable to the cultivation of responsive, emotive, and behavioral repertoires that allow behavioral conditioning. Their rich connections to concept-forming regions like the frontal and temporal cortex, as well as to the limbic system, ensure the intimate integration of thought and emotion (Edelman and Tononi, 2000).

Limbic System/ Emotion

The second layer of MacLean's model, termed the paleomammalian brain or the limbic system, has long been regarded as the seat of emotion. Its subcortical position suggests the neurologically primitive origins of emotional states, and its components are both profoundly interconnected with afferents from the RAS, and integrated with cortical regions. Nestled between the structures of the limbic system, the thalamus is a vital way station in the networks involved in sensory processing, thus giving it a central role in controlling the flow of information that generates the perceptual contents of consciousness. Integral to emotive experiences is the amygdala, which serves as an interface between higher informational processing and states of emotional arousal, thus firmly binding cognitive processes and learning to emotional affect. The role of the limbic system therefore appears largely geared toward modulating behaviors that originate in the reptilian brain, although it also plays a vital role in generating various emotions associated with social behaviors including maternal care, playfulness, gregariousness, and competition (Panskepp, 1998).

Given their centrality in ordering brain dynamics, emotional systems can be envisioned as strange attractors within widespread neuronal networks. The low-level dynamics of such chaotic systems are supplied by the spontaneous activity that characterizes all animals. These dynamics are “attracted” by certain emotional states, which bias behavior in a particular way, especially when associated with learning mechanisms. Not only do emotional systems sustain unconditioned behavioral tendencies, but they also guide new value-coded, salient behaviors that allow the organism to categorize world events efficiently and to adaptively control future behaviors (Panskepp, 1998).

Limbic system circuitry is much more amenable to modification that the reptilian brain, allowing a great deal of behavioral flexibility. This openness is augmented by more recently evolved hierarchical layers of control, and points to the critical dependence of the most recent brain structure, the neocortex, on preexisting emotional circuit functions. Thus, while the neocortex is apparently functionally geared toward skill-related neural computations—unlike subcortical areas, which appear more oriented toward generating emotional states or primary-process consciousness—it is integrally dependent on these functions, for which it provides elaboration (Panskepp, 1998).

Neomammalian Brain/neocortex

The most recently evolved layer in MacLean’s model is the neomammalian brain, or neocortex. With its flexibility, capacity for language, other social skills, and higher intellectual functions, it is generally regarded as the thinking brain. While subcortical neuroanatomy is extensively preserved among mammals and most other vertebrates, cortical organization is much more variable among species. This suggests that recent evolutionary diversification has elaborated the surface details of behavioral and cognitive abilities much more extensively than the deeper architecture from which instincts and emotions arise (Panskepp, 1998).

The primary driver of primate encephalization is the evolution of the neocortex, whose advent led to an enormous expansion of brain surface area (Freeman, 2011). This expansion is evidenced in the wrinkles of gyri and sulci, and is likely driven by the addition of the defining anatomical feature of the neocortex, the minicolumn (Casanova and Tillquist, 2008). This fundamental neocortical organizing unit, which is the foundation of an ascending hierarchy of order and complexity, comprises the ordered arrangement and connectivity of multiple layers and sublayers of neurons, with those in vertical arrays across the layers being more densely interconnected than those along the layers (Kaas, 2012). Ultimately, an increase in the number of minicolumns—not simply an increase in the overall number of cortical neurons—appears sufficient to explain cortical expansion, increased gyrification, brain connectivity, and, ultimately, discrete and global brain functions (Casanova and Tillquist, 2008).

Relatively uniform in arrangement, minicolumns act as a multitude of parallel processors that are dynamically clustered into macrocolumns. The anatomical uniformity of the latter indicates that they are capable of performing similar transformations on incoming information. Functional differences among brain regions can therefore be attributed to variations in input sources, output targets, interconnectivity, and inhibition rather than to intrinsic properties of the neurons themselves (Casanova and Tillquist, 2008). These functional differences delineate different cortical areas, the so-called “organs of the brain” that process different inputs and generate different outputs (Kaas, 2012).

An increase in functionally differentiated cortical regions is one important consequence of primate encephalization. With an increase in differentiation comes the heightened challenge of interconnectivity between regions, particularly distant ones. One evolutionary solution to this challenge has been the spindle, or mirror neuron, which allows more and novel connections—a distinguishing feature of larger brains that supports emergent cognitive properties. Another anatomical solution to the challenge of connectivity is a placement strategy in which connected neurons remain as close together as possible, resulting in highly convoluted cortical surfaces. The short-range connections promoted by cortical gyrification facilitate the processing of time-dependent and highly discriminate tasks by the connected neurons (Casanova and Tillquist, 2008).

While the different layers of the triune brain vary in significant ways, such as possessing distinct chemical signatures, electrical patterns, and anatomical configurations, their functions are deeply integrated, with more recent evolution influencing the expression of ancestral areas by expanding the openness of circuits rooted in subcortical regions and thereby enabling greater behavioral flexibility (Combs, 2002; Panskepp, 1998). Whereas the ventral forebrain, which houses the olfactory system and the hippocampus, appears sufficiently equipped to support the autonomous, intentional patterns of behavior necessary for survival, it is the neocortex that supports emotion and intellect (Freeman, 2011). This has led some researchers to suggest that it is actually the neocortex that is “the organ of emotion,” rather than the limbic system. Whether or not such a distinction holds, however, there is reason to believe that allocortical and neocortical areas share a single dynamic code, initially developed in pre-mammalian species for exchanging neural information (Freeman, 2011).

This surmise regarding the dynamical organization of different brain regions points to the fact it is in the global integration of functionally modularized parts, rather than the parts themselves, from which consciousness arises. According to Roger Perry, “The causal power attributed to the [conscious mind] is…seen to reside in the hierarchical organization of the nervous system combined with the universal power of any whole over its parts…The whole has properties as a system that are not reducible to the properties of the parts" (In Combs, 2002, p. 36). Indeed, "it is this tendency of the whole experience to support its constituents, and for them in turn to create the whole, that gives consciousness its stability" (Combs, 2002, p. 56). From this reciprocal and mutually reinforcing tangle of top-down and bottom-up dynamics, the brain functions as a "pattern-forming, self-organizing system, governed by nonlinear dynamic laws" (Casanova and Tillquist, 2008, p. 101). The unique organizational features of the neocortex differ from those of more reflexive brain regions in a very crucial way: while the latter are governed by nonlinear regulatory feedback mechanisms, the former support the dynamics of chaos.

Conscious Dynamics

Complementing the primary-consciousness functions of the RAS, the neocortex articulates and explicates the contents of consciousness in concert with the subcortical systems. This complex integration of different levels of consciousness—primary, emotive, and calculative—occurs not only as a function of structural organization, but also as a result of dynamical organization. According to Edelman and Tononi's (2000) dynamic core hypothesis, the contents of consciousness are supplied by the rapid, coordinated activation and deactivation of widely distributed groups of cortical neurons, known as functional clusters. In order to generate conscious experience, activated clusters must change constantly, be sufficiently differentiated both spatially and temporally, and persist on the order of a few hundred milliseconds. Under this hypothesis, the same group of neurons may sometimes contribute to explicit consciousness, and at other times be part of unconscious processes. Thus, as we have seen, it is not neuronal properties alone that explain consciousness, but the dynamic integration and differentiation of distributed processes. The single most distinguishing feature of these interactions is that they are reentrant.

With its diffuse, fanlike patterns of connectivity, the thalamocortical system is uniquely suited to sustain reentry, which is the process of signaling back and forth along reciprocal connections. Reentry differs from feedback in that it involves many parallel reciprocal paths, signaling simultaneously, instead of a single one-way fixed loop. Unlike feedback, which uses previous instructionally derived information to control or correct processes, the information associated with reentry is not prespecified. Instead, it coordinates and synchronizes the mutual functions of different cortical areas by selectively altering signal correlations among them (Edelman and Tononi, 2000). Reentry is also distinct from feed-forward processes, which are generally hard-wired, incapable of generating conscious awareness, and tend more toward parallel arrangements than thalamocortical-like meshwork (Perry, 2002). One consequence of reentry is widespread synchronization of activity among different functional clusters, including those that are distributed across functionally distinct areas (Edelman and Tononi, 2000). The generation of conscious states out of lower-level dynamics points to the reciprocal causality—the balance between bottom-up and top-down controls—that not only sustains consciousness but is characteristic of all self-organizing systems: the global level tends to support its constituents, which in turn create the whole; this gives consciousness its stability (Combs, 2002).

Chaos and Consciousness

Although there is no simple mapping between neurological processes and the thoughts they support, the "convergence between neurobiology and phenomenology is not mere coincidence"

(Deacon 2012; Edelman and Tononi, 2000, p. 111). Such interdependence between structure and function is the basis for the autonomy that arises from self-organizing processes, in which spontaneously emerging structures correspond to systemic functions (Jantsch, 1980). Accordingly, the structure and dynamics of the brain meld to support the creative chaos underpinning conscious experience, allowing “the changing events in this system to call into play new and previously unseen variables that alter the very definitions of the systems themselves” (Combs, 2019, p. 13). The tendency of a complex, self-organizing system to “naturally [transform] itself in creative directions” is intimated in the power law that critically self-organized systems adhere to; the scale-free dynamics implied in the power law curve suggest the fundamental unpredictability of self-organized criticality (Kauffman, 1995). It is not surprising, then, that research reveals the presence of scale-free dynamics throughout the neocortex at all frequencies in the beta and gamma ranges (Freeman, 2011).

The dynamics of conscious perception reflect those of chaos as they creatively interact with the external environment, with the chaotic activity of each cortical area self-organized by local synaptic interactions. In particular, these dynamics reflect a defining property of chaos in that they generate signals that cannot be predicted because they are both novel and non-periodic (Freeman, 2011). The layer of novelty generated by chaotic dynamics lays the groundwork for second-order emergent events by interacting with prior processes to generate a whole new permutation of novelty (Combs, 2002). This kind of learning in a chaotic milieu, with emergent events interacting with each other and with established processes, occurs in rapidly repeated small steps, which cumulatively give the appearance of a non-replicating trajectory in state space (Freeman, 2011). This is the strange attractor, which “represent[s] patterns of activity that, though contained within certain broad boundaries, never quite repeat themselves" (Combs, 2019, p. 9).

Strange attractors are analogous to the normal, attentive brain state. When a stimulus spurs the memory to recognition, a new and more highly ordered pattern resembling a limit cycle emerges (Sole and Goodwin, 2000). In this way, brain activity is constantly modified by experience. As Combs (2002) points out, the attractor that responds to a single stimulus may be small portion of a much larger and multidimensional attractor landscape. Freeman (2011) similarly envisions each sensory cortex as a landscape comprising multiple basins of attraction that correspond to discriminable inputs. When an attractor is activated, cortical dynamics, and therefore attentional focus, is constrained to oscillate within that single basin. Such a restriction suggests that states of consciousness are discreet, although "it is possible that two attractors lie near each other in phase space" (Combs, 2019, p. 10). This proximity allows ready transitions, or bifurcations, across states to new stable patterns if, as Combs (2002, p. 48) notes, the "control variables [that define the context in which the system operates] bring about sufficient alterations." The interpretation of the discreet nature of conscious states from the perspective of the dynamic core hypothesis is that since each fleeting configuration of the dynamic core is a unified global state created out of the integrated mutual interactions among its neural constituents, this very structure automatically precludes the simultaneous occurrence of other global core states (Edelman and Tononi, 2000).

The role of chaos is evident, not just in the process of perception, but also in intentionality. A brain activity pattern that expresses an intent to move toward a goal, known as preafference, has two facets that are facilitated by cooperation between the limbic system and the neocortex. While the former activates the descending motor systems, the latter responds to a copy of the motor command by selectively engaging sensory cortical attractor landscapes to anticipate the inputs likely to result from the intended action. The output is transmitted broadly from each sensory cortex by millions of axons that carry the transmission in parallel to cortical targets, each of which sums the inputs it receives. In this way, the pathways diverge from their sources and then converge when they reach their targets. The spatial integration of the transmission in the target areas ensures that only the activity that has the same frequency of oscillation everywhere is what gets amplified; this cooperative process generates the signal of the cortex (Freeman, 2011).

Ultimately, the brain can be regarded not as an computer-like information processor, but as an autonomous entity that creates patterns of thought, each bound by an intrinsic logic that mirrors that of the whole. Emergent patterns of thought continually bind into larger, emergent patterns that can, in turn, break off into smaller patterns that carry an imprint of the originating pattern like seeds for a new cycle of chaos and emergence (Freeman, 2011). These dynamics allow a view of different states of consciousness as attractors that reflect the nature of the global system, and to which its various trajectories are consequently drawn (Combs, 2002).

Order Through Multimodality

The exquisitely complex structure of the brain conspires with the chaotic milieu it supports to create the coherent complexity of conscious experience. The brain’s multimodality makes this terrific feat of unification the result of a “cooperative effort between separate and relatively autonomous subsystems which have come together to support [the] very special unity” of conscious awareness (Combs, 2002, p. 27). The chaotic noise generated in the wide-ranging but correlated activity of these various subsystems is transmuted into a clear signal by the multimodality that arose as an evolutionary solution to encephalization, but also provides the ideal solution to creating information out of chaos.

The process of preafference, whose output achieves multimodal binding via signal redundancy, highlights the role of multimodal signals in elevating the dynamics of chaos to the coherent order of a message, or the unified state of conscious experience. The various channels in a multimodal system all convey highly correlated sets of information, producing complex associative networks that promote both robustness and adaptability through redundancy. Network robustness, which depends on the unique information provided by each channel, represents a lower bound on network complexity (Nihat et al., 2007). The high level of robustness achieved through multimodality produces a complex output by promoting structured correlations among the channels. The potency of multimodality therefore rests on a fine balance between the redundancy and uniqueness of the information represented in each channel or modality. Further, output robustness is maximized by clusters of subsystems within which activity is highly correlated, and between which activity is weakly correlated (Nihat et al., 2007). This is precisely the arrangement that prevails in the neocortex, with highly coordinated neuronal activities concentrated within cortical areas, but only weak correlations transpiring between modalities. The various pathways that have emerged between different cortical regions in increasingly large—and correspondingly well-connected—primate brains facilitate both signal amplification and redundancy (Casanova and Tillquist, 2008). This arrangement, which maximizes the robustness of a signal and makes it available for exaptation, offers the additional benefit of minimizing the cognitive cost of perception. This is due to the overlap between modalities, which is great enough to ensure that each one contributes to signal meaning, is sufficient to decode meaning if other modes are eliminated, and enhances the diversity of information that can be processed (Nihat et al., 2007).

Constraining Chaos

The multimodal structure of the brain represents one vital constraint governing the dynamical activities hosted therein. Other principles guiding the brain's activities, including variability, differential amplification, degeneracy, and value[1] reveal brain activities to be a guided by the generative process of selection rather than by the confining rules of logic (Edelman and Tononi, 2000). Each of these principles acts in the role of a constraint (with the exception of degeneracy, which actually relaxes system restraints by allowing multiple structurally variable ways to produce an identical output), which serves to guide a system's development and expression by modifying its phase space or the probability distribution of events within that space. Some constraints reduce number of alternatives while creating new possibilities, which is the basis of emergence (Juarrero, 1999). Thus, emergence is not an additive property so much as the result of the constraints on lower-level dynamics that enable an ascent in the scale of complexity (Deacon, 2012).

At the broadest level, constraints introduce boundary conditions on maximally random movements to reduce degrees of freedom (Kauffman, 2008). In far-from-equilibrium states, constraints represent the statistical homogenization of lower-level dynamics that amplifies the highest-probability micro-dynamics to macroscopic expression, thus introducing a new level of description to the system. The attracting state, which summarizes "the most redundant micro-

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[1] Defined by Edelman and Tononi (2000, p. 88) as "the phenotypic aspects of an organism that were selected during evolution and constrain somatic selective events, such as the synaptic changes that occur during brain development and experience."

interaction effects" and thereby enables them to have causal influence at higher levels, limits bottom-up causality (Deacon, 2012, p. 199). This represents a context-free constraint, one of two levels of constraint that guide evolutionary systems. Top-down, context-free constraints are imposed by the structures of the system itself and take a system's components far from equilibrium (Juarrero, 1999).

The second type of constraint informing a selectional system is context-sensitive, which is bottom-up, arises from the selective modification of the dynamics themselves, and constitutes the phase change that induces self-organization at a global level by correlating previously separate parts into interdependent components of a single system (Juarrero, 1999). These self-organizing constraints incorporate a temporal element, making an adaptive system self-referential with respect to its own evolution through feedback loops that connect current systemic states to the system's history (Juarrero, 1999; Jantsch, 1980). Indeed, it is the emergence of context-sensitive constraints via entrainment with an external stimulus that brings a complex system into being and introduces a representational, or semiotic function. The behavior of a complex system, especially a neural one, is therefore semantically constrained, and thus the properties of self-organization are governed by meaning via the interpretation of stimuli (Juarrero, 1999). The process of interpreting of something as information requires recursive organization, entailing physical changes that propagate throughout the system by attractor-like dynamics. These changes alter the structure of the system in a way that reinforces the capacity to replicate the act of interpretation (Deacon, 2012). Information is therefore dependent on the propagation of constraints that link the system to its environment. With historicity embedded within systemic dynamics through recursive feedback-based—or for an exceptionally complex system like the brain, reentrant—processes, information is “not transferred in a one-way process, but is exchanged in circular processes and is born anew” (Jantsch, 1980, 51).

Sources of Evolution

Ontogenetic Selection

As this examination has made clear, it is just as necessary to account for the role of self-organization in evolution as it is to consider natural selection (Kauffman, 1995). Selectional systems, which exist near the phase transition between order and chaos, are fundamentally evolutionary. The human brain embodies both a historical record of the forces that have shaped it throughout its evolutionary past as well as the dynamics of evolution in real time. The latter expression of evolutionary properties is evident in the two main forms of selection that sculpt and frame the conscious experience ontogenetically. One type is developmental, or somatic selection. During development, the nervous system employs Darwinian logic in its overproduction and selective elimination of cells. Axons are only generally guided to their termini, but must compete with each other in contests of electrical excitation to claim their ultimate destination, according to the Hebbian axiom that “cells that fire together wire together,” and dooming unsuccessful contenders to self-immolation. The other level of selection is experiential and comprises a secondary level of modification of neural circuitry based on behavioral experience (Edelman and Tononi, 2000). These internal Darwinian processes are microcosms of the forces that shape brains over evolutionary time. The nondeterministic freedom of both developmental and experiential forms of selection allows a far greater potential for differentiation than is available to other organ systems, and is the basis for the variability and differentiation of distributed neural states that facilitates conscious experience (Deacon, 1997; Edelman and Tononi, 2000).

Social Brains

While ontogenetic forms of selection provide the dynamic contest-sensitive constrains that support the contents of consciousness at the individual level, the structure and organization of the brain incorporates a phylogenetic history of the cognitive demands that have guided it toward its current form. While some of these factors are environmental—for example, the primate visual cortex and lateral geniculate nucleus have greatly enlarged in response to the demands of frugivory—one of the most important drivers of brain evolution is social relations, as most animals devote a disproportionate share of cognitive resources to sociality (Lindenfors, 2005; Bradbury and Vehrencamp, 2011). Indeed, larger brains have been found to reflect the cognitive demands associated with complex social systems in primates, with group sizes covarying with the size of the neocortex relative to that of the total brain (Schillaci, 2008). Beyond group size, the complexity of the interactions themselves can influence neocortical development. This element of sociality is largely driven by the social demands of females, as evidenced by the larger neocortex found in species with larger female social networks. Such a fine-grained level of selective pressure can potentially lead to different outcomes between males and females, particularly for species in which males tend to monopolize access to females (Lindenfors, 2005). Lower levels of competition among male primates, particularly in monogamous species, appears to correlate with a greater overall brain-to-body-size ratio (Schillaci, 2008). This may relate the possible enhanced social intricacy of monogamous relationships, as well as the longer periods of juvenile maturation that such systems enable—an important contributor to the evolution of brain size in primates (Lindenfors, 2005).

A Special Case: Language

While various endogenous, social, and environmental sources converge on the evolution of all brains, the human brain seems to have responded to a very unique source of evolutionary pressure: the development of language. As Terrence Deacon (2012) notices, reference is ubiquitous throughout animal communication, with icon and index supplying universal ingredients among all communication systems. Symbolic language, in contrast, represents a highly specialized branch of semiotic evolution that requires a particular kind of brain with specializations that can uncouple mental processes from sensory perceptions.

Unlike symbolic language, an indexical meaning-token is not arbitrarily structured. Rather, it correlates in a direct way to its referent. For example, alarm vocalizations tend to be short, with abrupt onsets and broadband noisy spectra—features well suited to capturing receiver attention, and piquing physiological responses through arousal to flight-oriented behaviors (Rendall et al., 2009). Although the meaning of an index can be contextually conditioned, thus enhancing its referencing potential, its referent is always a whole, undifferentiated event. In contrast, a syntactically constructed statement is textured with layers of distinction through its role-based structural support of various classes of potential referents—actors, actions, and magnitudes—which allows the incorporation of pragmatics (Bradbury and Vehrencamp, 2011; Nowak, 2000). The rough correlation between brain size and intelligence predicts an increased processing capacity to be associated with a large brain—a capacity that could potentially facilitate lexical signaling rather than a more limited, one-to-one, indexical system (Bradbury and Vehrencamp, 2011). While the former greatly expands the potential scope of what can be communicated, it also bears a high cost. Because neural tissue is expensive to maintain, and the enhanced flexibility that increases expressive potential also increases the risk of error at any step in the communication and interpretation processes, most species attain maximal fitness by limiting their repertoires to a smaller number of objects, with correspondingly lower error limits (Bradbury and Vehrencamp, 2011).

Along with its larger overall size, the human brain comes equipped with a relatively large prefrontal cortex (PFC), notable for reentrant pathways and back projections (Bingman, 2011). It is the widespread connectivity of PFC with rest of the cerebral cortex that allows the coordination and integration of the various cortical modalities that are believed to facilitate symbolic representation. In a self-amplifying evolutionary feedback loop, symbolic language, so dependent on the PFC, may have played the recursive role of itself being a “prime mover in prefrontalization,” according to Deacon (2012, p. 336).

Some of the functions of the PFC in nonhumans foreshadow those that play a role in symbolic language. In particular, the inhibitory capacities of the PFC enhance learning and behavioral plasticity by not only allowing for conscious direction of attention, but also by possibly enabling learning through imitation (Shettleworth, 2010). Unlike nonlinguistic vocalizations—with the exception of vocal mimicry in birds—language is unique in relying on imitation to be learned. This highlights a crucial distinction between brains that support language and those that do not: whereas nonlinguistic signals, likely derived from a common ancestral source, arise from subcortical sensorimotor regions, temporal and frontal-lobe cortical structures play a large role in human language production and processing, likely because of the large role learning plays in language acquisition (Bass et al., 2008; Deacon, 1997).

The various sources of evolution that have molded the human brain toward its present form have imprinted upon it their logic and dynamics, and it has responded to these pressures as only a system whose structure and function are constrained by information can. As Maxine Sheets-Johnstone (1990, p.122) muses, “Living intact organisms can themselves be regarded as the ultimate result of meanings mediated by a form of corporeal representation.” The outsized roles that sociality and language acquisition have played in driving cognitive expansion in primate and hominid lineages, respectively, underscores the primacy of both interconnection and information in the self-organization process, and reveals evolution to be a profoundly intelligent, deeply participatory process.

Evolution of the Self

Just as countless rounds of natural selection have persistently pushed brain evolution to the critical edge where creativity flourishes, the forces of selection and self-organization have conspired to drive the evolution of an ever-complexifying conception of the self. As shown by the close association between the RAS and primary consciousness, the basis of a sense of self is likely subcortical and preconscious. Neurobiologist Jaak Panskepp (1998) speculates that a sense of self was first elaborated within the central motor-type regions of midbrain, supported by their rich connections with higher limbic and paleocortical areas. This view, which conceptualizes the incipient self-sense as an “ineffable feeling of experiencing oneself as an active agent in the perceived events of the world” (Panskepp, 1998, p. 310), concurs with Sheets-Johnstone’s (1990, p. 128) intuition of a foundational form of consciousness as rooted in the “pre-reflective tactile-kinesthetic corporeal experience” that is prior to the more explicit levels of awareness that support concepts. This “corporeally spawned” form of primordial awareness would likely arise from the close linkage of the intrinsically, spontaneously active neural network associated with body tone and gross axial movement (Sheets-Johnstone, 1990, p. 55; Panskepp, 1998). From this arrangement arises a consciousness of “corporeal powers,” which in turn give rise to “corporeal concepts” (Sheets-Johnstone, 1990, p. 29). These notions are based on Husserl’s “I can’s,” which are predicated on the concept of “I” as arising from the experience of bodily conditions such as boundedness and proprioception (Sheets-Johnstone, 1990).

The primordial self-schema that Sheets-Johnstone intuits as founded in the most basic experiences of proprioception and motor coordination provides a basis for higher perceptual processes by enabling attentional focus and perceptual sensitivity. This proprioceptively attuned, sensorimotor-based self-schema may provide a foundational level of stability for the psychological binding that characterizes the human perceptual field (Panskepp, 1998). This rudiment of selfhood is elaborated first by emotional circuits, which establish the essential conditions of affective awareness, and is reified through higher cortical neurodynamics. Basic affective states may thus represent the essential psychic scaffolding from which arises all other forms of consciousness by providing an executively functional foundation for behavioral coherence and bodily awareness. These basic attributes of selfhood could become more sophisticated during ontogeny and phylogeny as new layers of neural control accrue—as opposed to the underlying mechanism being reshaped (Panskepp, 1998). These possibilities necessarily entail that higher computational and sensory-perceptual capabilities are deeply rooted in affective bodily representations, which are, in turn, layered upon the primary consciousness of a “sensory-kinetic lifeworld” (Sheets-Johnstone, 1990, p. 135).

The implicit orderliness that coheres astonishing levels of complexity into the unity entailed by an explicit sense of being, or at higher levels, selfhood, is described by Teilhard de Chardin (1955/2008, p. 42), “We do not get what we call matter as a result of the simple aggregation and juxtaposition of atoms. For that, a mysterious identity must absorb and cement them." The fabric of this "mysterious identity" threads through a legion of lower-level dynamical interactions that converge on basins of attraction that reflect both the internal logic of an organism and its evolutionarily conditioned relationship with its environment, conspecifics, and other salient factors that have nudged its dynamics, via biases and constraints, toward their present configuration. The character of this "mysterious identity" can be summarized by a statistical account of the small range of stable states that lower-level dynamics converge on, and which promote self-organization by preferentially amplifying the probabilities of certain system configurations over others until the incompressible intricacies of lower-level dynamics are subsumed by a simplifying global description. However vibrant the dynamics that describe the system are, however, they are merely descriptive trajectories orbiting the formless and empty heart of the attractor. Perhaps it is this stillness, untouched no matter how asymptotically close a trajectory comes to it, that is the "mysterious identity." In this duality between the empty attractor and the dynamical form that describes it resides the paradox of being and process, of consciousness and its contents—the "stillness in chaotic motion [that] is deeply suggestive of a deeper mystical awareness;" the "tension between impermanence and eternal pattern" (Combs, 2002, p. 13).

Perception and Self-Organization

The critical but nondeterministic balance between order and chaos at which all systems evolve leads to the surprisingly simple conclusion that cognitive evolution can be understood as being driven by the "shifting status of noise versus signal" (Deacon, 2012, p. 411). This is suggested by the complex, highly ordered structure of the modular brain, juxtaposed with the generative chaotic dynamics that it supports. From this perspective, the ultimate arbiter between order and disorder—meaning and noise—is consciousness; specifically, an embodied perspective conditioned by levels of constraints that span a spectrum of refinement ranging from evolutionary to individual. According to Ortega y Gasset (1961, p. 44), "The ultimate reality of the world is neither matter nor spirit, is no definite thing, but a perspective." Leibniz (1991, p. 76) seizes on the profound logic of a world ordered according to perspectives: "And this is the way of obtaining as much variety as possible, but with the greatest order possible, that is, it is the way of obtaining as much perfection as possible." From the subjective divide between order and chaos, salience and irrelevance, information and noise, arises every form of biotic expression, internally impelled by perceptually mediated interpretation.

Just as the strange attractors that describe sensory perception ensnare conscious attention into a single discreet state at a time can be imagined as individual basins within complex and multi-dimensional attractor landscapes, the drive toward ever-increasing complexity that characterizes evolving systems can be envisioned as the great attractor that all adaptive systems orbit in an intricately interwoven evolutionary phase space. With consciousness and the forms that host it mutually enjoined in a spiral of increasing complexity of form, interactions, and capacity for conscious expression, evolution truly comes into focus as far more than a physical science, as Nagel suggested. Every self-organizing agent recursively plays out a nondeterministic iteration, a unique instantiation, of criticality, complexity, and adaptation, tracing out a tiny path that, when combined with those of all other agents, contributes to the multiply realizable and non-replicative paths of chaos that circle an ineffable center. In the singularity underlying these multitudinous trajectories, selective forces vastly subtler and less empirical than natural selection become evident to the philosophical eye. Nagel (2012, p. 91) sees a teleological bias "toward the marvelous," perhaps encoded in some natural law beyond the physical that mandates an increase in value, effected through the expanded possibilities that the higher forms of organization toward which nature tends unfold. This most marvelous of attractors underlying such an enfoldment has patiently assembled itself through countless forms over innumerable ages and iterations, savoring the endless variations on the singular theme of sentience, all the while developing the structures, physical and cognitive, through which it could finally become perceptually transparent to itself. And so evolution continually reiterates and reforms through countless cycles, giving form through ever-refining orbits around an empty heart, to the strangest of attractors.

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