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Emergence of Mind and the Baldwin Effect

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1 Introduction

Darwin laid the foundation for the program of a naturalistic, nondualistic account of mind by providing an evolutionary view of how the human mind might have originated (Darwin 1871).¹ Darwin's proposal was taken up by Chauncy Wright to account for the evolutionary origin of human self-consciousness (Wright 1873). Evolutionary theorizing of this sort played a crucial role in the growth of the philosophy and psychology developed by the American pragmatists (Wiener 1949; see also Godfrey-Smith 1996).

Recently, however, most theories of cognitive structures have been based upon contemporary human minds in literate, postindustrial societies and have stressed metaphors of the mind based upon computational and information-processing models, unconstrained by evolutionary biology (Donald 1991). Darwin's view of the mind as an evolutionary adaptation has receded from the view of many cognitive scientists as they have emphasized the discontinuity of human mind from its evolutionary origins (see, for example, Chomsky 1980; Fodor 1983). To the extent that evolutionary biologists have concerned themselves with such questions, they have assumed that the emergence of mind and human language is to be explained by the extrapolation of the microevolutionary processes described by neo-Darwinism to the creation of optimally adapted modules of neural and morphological function (Pinker and Bloom 1990). This assumption underlies the past decade of "evolutionary psychology" (see, e.g., Cosmides, 1989; Barkow, Cosmides, and Tooby 1992; and Pinker 1994, 1998).

A related line of speculation is informed by the evolutionary gene concept of Richard Dawkins. It gives a gene's-eye and meme's-eye view of how interacting replicators can give rise to ever more complex "interactor/vehicles" that serve to increase their own survival in the face of natural selection conceived algorithmically (Dawkins 1976, 1982; Dennett 1991, 1995; Blackmore 1999). Susan Blackmore, for example, speculates that meme/gene coevolution was important in the origin of language (Blackmore 1999). In this, she admits that she is following up in Dawkinsian terms on the suggestion of Merlin Donald, who attempted to shift the focus of inquiry onto the steps by which the emergence of symbolic reference became the selective pressure that drove the coevolution of mind and brain (Donald 1991). Indeed, some evolutionary theorists have invoked mechanisms to help account for the very rapid evolution of human language by either assuming a role for mind in evolution or by positing a coevolution of brain and language in which emerging linguistic ability produces a feedback loop upon which selection acts (Dennett 1991, 1995; Pinker 1994; Deacon 1997).

Currently popular approaches such as that of Pinker, however, make unrealistic assumptions about low amounts of human variance and cultural diversity. They also view the mind as a set of problem-solving modules of independent evolutionary origin, which are capable of independent optimization. This latter view perpetuates the atomistic description of traits assumed by Sir Ronald Fisher, a view challenged by Sewall Wright almost immediately (Wright 1935a,b, 1986; see also Dobzhansky 1937). In spite of these difficulties, Pinker goes even further by assuming that problem-solving modules behave analogously to genes, showing phenomena such as crossing over and recombination—an unsubstantiated assertion that reflects a misplaced concreteness as well as a case of mixed metaphor. I cannot help but feel that such use of evolutionary biology results in a view of mind that either falls far short of our experience of consciousness, or sets consciousness aside as an intractable epiphenomenon, thus negating the promise held out by Darwin's evolutionary perspective.

How, then, should we proceed to develop a robust theory of the emergence of mind? A starting point is to assume hypothetically that mind, language, consciousness are emergent phenomena and then ask whether the

received evolutionary theory has an account of emergent phenomena in general. I mean this in the following sense. Sterelny and Griffiths argue that any theory of evolution must account for adaptation, pattern of life (diversity, disparity, and speciation), and development of organisms over their life cycles (Sterelny and Griffiths 1999). To this list I would add emergence of large-scale evolutionary novelties (see for example: Müller and Wagner 1996; Gerhart and Kirschner 1997; Hall 1999; Carroll, Grenier, and Weatherbee 2001; Weber and Depew 2001; Arthur 2002).

2 Why Emergence Is Important

Emergence occurs when new properties appear in a system that were not present in, and could not easily have been predictable from, the properties of the components of the system. Emergent phenomena obey laws that arise with the novel properties. Emergent phenomena impose conditions on their constituents that depend on the nature of the emergent phenomena (Collier and Muller 1998; Holland 1998). A related point has been made by Stuart Kauffman, whose simulations of a range of dynamical regimes shows that the order produced in emergent systems reflects system properties of the ensemble of constituents as a whole (Kauffman 1993).

Attempts to analyze emergent phenomena have been hindered both by the ambiguity of the concept of emergence and by the different ways it is used in different contexts (Weber and Deacon 2000; Deacon, chap. 5, this volume; Camizine et al. 2001). Deacon has made careful distinctions between *supervenient emergence*, which is time-independent (synchronic); *emergence through chaos/self-organization*, which is time-dependent (diachronic symmetry breaking), includes developmental systems, and occurs away from thermodynamic equilibrium; and *evolutionary emergence*, which involves specified information and memory instantiated in genetic systems imposing stability and constraints on accessible future states. Deacon terms these first, second, and third order emergence respectively (Deacon, chap. 5, this volume). This threefold pattern constitutes a hierarchy of increasing complexity: higher-order forms are composed of relationships between lower order forms. This means that evolutionary emergence occurs only in lineages of reproducing organisms and contains

self-organizing emergence as a limiting case, just as self-organizing emergence in turn contains supervenience as its limiting case. Thus evolutionary emergent phenomena must include self-organization and supervenience, but not the reverse. The issue is not whether an emergent novel trait is an adaptation and an evolved phenomenon, but rather how such a novelty came into existence in the lineage at all (Deacon, chap. 5, this volume).

Ultimately the emergence of consciousness must in some sense take advantage of the possibility that evolutionary emergent systems build complexity over time by increasing the causal loops among information, semiosis, and teleology. Under approaches such as these, there is the hope that a theory of evolutionary emergence will prove sufficiently robust to provide a causal account of the emergence of consciousness and language. The steps toward such a theoretical framework are only beginning to become clear, however, as we will see in section 4 below.

Problems of emergence, such as that of life itself, have been only of remote interest to many neo-Darwinians. Indeed, Darwin himself set aside the issue of emergence, except in so far as he dealt with the appearance of a complex, sophisticated adaptive structure arising from a primitive one. In discussing the evolution of the eye—an exemplar of organs of extreme perfection—he wrote, “How a nerve becomes sensitive to light hardly concerns us more than how life itself originated. . . .” (Darwin 1859, 187). Although this was an appropriate strategy for Darwin’s time, critics unfriendly to Darwinism charge that the Modern Evolutionary Synthesis continues to ignore such crucial issues as the origin of complex biochemical systems, including those involved in photosensitivity, blood clotting, and the immune system, as well as the origin of life (see, for example, Behe 1997; but also see a response in Weber 1999). Of late, Darwinians of various stripes have deployed information and ideas from biochemistry and molecular genetics to address these problems, including some who use the resources of complex systems dynamics (see discussion and references in Depew and Weber 1995; Weber and Depew 1996; Weber 1998, 2000; see also Maturana and Varela 1980; for a different approach to these problems see also Maynard Smith and Szathmáry 1995, 1999).

The question of how life began must, in any case, be part of any complete evolutionary theory. As the reduction-minded philosopher Kenneth

Schaffner has argued, the project of reducing Mendelian genetics to molecular genetics requires a plausible account of the origin of life if it is actually to explain the presence of the cellular structures that function to make DNA replication, transcription, and translation to protein possible (Schaffner 1969). Dawkins’s invocation of an ur-replicator/interactor at the origin of life was deployed to make all-too-short work of this problem; he simply postulated the existence of a self-replicating RNA molecule in dilute solution in the ocean. An alternative scenario for the emergence of life is given below (section 4).

Even Darwinians who are committed to adaptive natural selection as the *only* significant causal and explanatory mechanism of evolutionary change, as well as genic reductionism, are beginning to address the general problem of emergence within their causal framework. For example, Maynard Smith and Szathmáry identify eight transformations in the history of life on earth (Maynard Smith and Szathmáry 1995, 1999). Three of these are involved in the process of the emergence of life from chemical systems, and hence can be regarded as aspects of a single process of the emergence of life. Another four involve transformations leading, respectively, from prokaryotes to eukaryotes, from unicellular to multicellular organisms (with the attendant appearance of developmental systems), and the appearance of organisms living in complex communities. Beyond that, they include one emergent process that is of special concern for this paper and this volume—the emergence of language and mind. Like Dawkins, Maynard Smith and Szathmáry assume a “replicator first” scenario for the origin of life (Dawkins 1976, 1989). Like Dawkins too, they say that DNA “lives” in cells. This is a position that is astonishing to most biochemists studying DNA replication in the context of cells. Cells alone fit the usual criteria of living entities. In them, replication is but one component of several interlinked processes including the dissipation of matter/energy gradients through metabolism, the ability to respond and adapt to changing circumstances, and signal transduction and information processing (Emmeche 1998; Whitesides and Ismagilov 1999).

Given this retrodictive enscription of “life” into base replicators, it is not surprising that Maynard Smith and Szathmáry should postulate that the emergence of all new levels of biological organization and phenomena is due solely to the power of natural selection, and that they should discount

contributions from any kind of self-organization or other factor (Maynard Smith and Szathmáry 1995). Even then, however, real questions arise as to whether this account of emergence by Maynard Smith and Szathmáry is sufficiently robust to account for full range of the emergent phenomena they discuss, including both the origin of life and of mind.

3 Origin of Life and Natural Selection as Emergent Phenomena

Maynard Smith and Szathmáry, who are committed to the primacy of selection as sole causal and explanatory agent, as well as to a stress on replicators as the fundamental units of selection, avoid the term emergence, preferring instead "transformation" or "transition." To countenance emergence does not require commitment to holism. But it does mean that the call for explanatory reduction needs to be relaxed and/or that a causal pluralism that allows for parity among a variety of possible agents should be permitted.² The process of emergence of a new replicator, whether it be a gene or a meme, is really not addressed by Dawkins, Maynard Smith and Szathmáry, or Blackmore; rather they assume that once a replicator appears, no matter by what path or how unlikely, selection will take over and provide the explanation. This is really not any advance on Darwin's setting aside the question of the origin of a photosensitive nerve. As interesting as these approaches are, it is not clear that they provide any deep insight into the actual crucial events that lead to the emergence either of life or of language.

An alternative account for the emergence of life, which draws upon nonequilibrium thermodynamics and nonlinear dynamics (what might be characterized as complex systems dynamics), uses notions of self-organization and selection, and their *interaction*. Depew and I have argued that, rather than using natural selection to explain the origin of life, we might view natural selection itself as an emergent phenomenon that arises from the interplay between chemical selection and chemical self-organization in catalytically-closed, autocatalytic cycles in ensembles of protocells (Depew and Weber 1995; Weber and Depew 1996; Depew and Weber 1998; Weber 1998, 2000). That is, evolutionary emergence (in the sense used by Deacon, chap. 5, this volume) itself emerged from self-organizational emergence along with the emergence of life. As we have argued, this view about the origin of life constitutes a critique of the magic

molecule theory, according to which life emerged once, and by accident, in the form of an improbable RNA molecule that thereupon acquired cellular survival machines. Our view of prebiotic, or what Depew and I have called "chemical," selection, also contains a critique of the rather promiscuous, substrate-neutral conception of natural selection that currently flourishes (see, for example, Dennett 1995). The implication is that natural selection can emerge in only a very specific range of physical and chemical systems, and that it is deeply dependent on the properties of its substrate.

In effect, this account of the natural selection as an emergent phenomenon addresses how third-order emergent phenomena could arise from second-order emergent systems. In this view, natural selection, properly so-called, is not primarily an explanatory model, or a universal mechanism, or algorithm. It is itself an *emergent* phenomenon uniquely characteristic of systems in which information retention and variation facilitates, coordinates, and regulates autocatalytic cycling of chemical systems within a set of thermodynamical constraints and imperatives. Further, any theory of natural selection worth its realistic salt must account for the fact that organisms, like the cells that make them up, are, in point of fact, informed, autocatalytic dissipative structures. It does not follow from this that natural selection is reducible to chemical selection.³ What follows is that natural selection presupposes, and is uniquely predicable of, systems in which chemical selection, as we have described it, is at work. It also implies that in hierarchical, evolving systems, we might expect that other selective and self-organizational principles, such as neuronal group selection and reentry discussed below, will emerge and be differently instantiated at other levels.

4 Steps Toward a Theory of the Emergence of Mind

It seems at least intuitively reasonable, and by weak induction plausible, to expect that if natural selection emerged from an interplay of chemical selection and self-organization, this might provide clues about the dynamics and interactions that might produce appropriate, selective, and self-organizational principles at even more complex hierarchical levels.

A possible candidate for this sort of an emergent selection is Edelman's neuronal group selection. It was subsequently adopted by Deacon in his

account of the origin of language and consciousness (Edelman 1987, 1989, 1992; Tononi and Edelman 1998; Edelman and Tononi 2000; Deacon 1997, and this volume). Edelman has been careful to distinguish neuronal group selection from natural selection, even if he uses it in an analogous fashion. Edelman does not explicitly consider whether neuronal group selection might be an emergent form of selection, but this seems a plausible interpretation given the complexity of the developmental biology and structure of the human brain.

The complexity of even simple nervous systems is vastly greater than that of cells or organs or anything else encountered in nature. It would not be surprising, then, if new dynamical principles occur in the development of brains (Koch and Laurent 1999). There is ample evidence of a wide variety of self-organizational phenomena in the dynamics of brain organization and action (Kelso 1995). We might well expect that selective and self-organizational principles are important not only for brain development, but for brain evolution itself. Any account along these lines will involve different and richer notions of what counts as heritable, the mechanisms by which adaptive selection occurs, and what the relevant units of selection are.

For his part, Edelman explicitly accepts that the brain is a self-organizing system characterized by nonlinear and massively parallel subsystems (Edelman 1992). The spatial/temporal constraints on axonal development, the role of chemical gradients and helper and target cells with their essential supply of nerve growth factor, introduce one new type of self-organizational and selective principles (Edelman 1987, 1989, 1992; Tononi and Edelman 1998; Edelman and Tononi 2000). These processes produce the primary repertoire of organized neurons; those cells not making synaptic connections and getting nerve growth factor die.

The processes that give rise to Edelman's secondary repertoire involve a kind of selection in which synaptic connections are strengthened or weakened by biochemical processes reflecting synaptic activity or disuse due to the activities and experiences of the organism. The resulting loss of synapses and cells gives rise to functional circuits. The primary and secondary repertoires produce maps of massively parallel and reciprocal connections. The diversity of the patterns and the number of interactions between neurons produced by the primary and secondary repertoires sug-

gest a dynamical attractor on the (near) chaotic side of Kauffman's so-called edge of chaos. It should be noted, however, that although Edelman's formulation could well be framed in the discourse of complex systems dynamics, he has not chosen to employ such concepts explicitly in his published work. Rather he takes complex dynamical systems as the substrate upon which neuronal group selection acts.⁴

By the process of reentry, unique to neuronal dynamics, brain areas emerge that yield new functions. This process of reentry involves the rapid and massively parallel, reciprocal interaction of large numbers of neurons within and between neuronal groups. Such ongoing and recursive parallel interchanges between areas of the brain integrate and coordinate the neuronal activities in these neuronal groups both in space and time. What ultimately gets selected are neuronal groups as well as the reentry pathways within them and connecting them. As groups of neurons are selected, others in reentrantly connected, but different, maps may also be selected at the same time. The activity patterns of such neuronal groups are constantly changing and are significantly differentiated, due to the processes of developmental and experiential selection. They are integrated, through reentry, not only to coordinate widely dispersed perceptual and motor processes, but also to support the primary conscious experience present in animal brains. Primary consciousness, or the "remembered present" in William James's felicitous phrase, emerges from the functioning of a "dynamic core" of neuronal activity (Edelman 1989; Tononi and Edelman 1998; Edelman and Tononi 2000).

Pinker, along with many others, assumes that an expansion of brain capacity allowed an adaptation for language to emerge, that is, that brain evolution apparently preceded language acquisition and evolution (Pinker 1994). In contrast, Deacon envisions a coevolutionary emergence of both language and the brain capacity for language (Deacon 1997). Deacon describes this process in the dynamical language of Edelman. Deacon invokes the processes of neuronal group selection, developmental self-organization, and a Baldwin-type effect acting through reentry to provide a selection pressure operating for the organization of the brain for language (Deacon, chap. 5, this volume). Edelman sees language, as well as the sense of self, emerging from primary consciousness through novel elaboration of a special kind of reentrant connectivity between the expanding

brain systems that became involved in language and those already existing areas of the primate brain devoted to conceptual activity (Edelman and Tononi 2000). The underlying mechanism is considered to be sufficiently plastic to have facilitated articulation of neuronal organizational changes and a range of accompanying phenotypic changes that supported speech. "This plasticity relieves us of the genetic and evolutionary dilemma of requiring simultaneous correlated mutations that are reflected both in altered body parts and in correspondingly altered neuronal mappings" (Edelman and Tononi 2000, p. 196). Subsequently, of course, there could be selection for both further phenotypic gene changes as well as mutations in neuronally significant genes that enhanced the evolutionary success of the organisms in the lineage leading to modern humans. Edelman posits a coevolution of body, brain, language, and higher consciousness in which social and affective relationships play a central role in the emergence of qualia (the subjective, qualitative aspects of consciousness), self-consciousness, and rational thought.

5 The Baldwin Effect and Emergence

These reflections about the emergence of life and of language suggest a possible role of some type of mechanism that might go by the name of the Baldwin effect, considered as a process that is emergent from a combination of selection and self-organization. The Baldwin effect has been invoked by both Dennett and Deacon as a factor in the evolutionary emergence of consciousness and language (Dennett 1991, 1995, and chap. 4, this volume; Deacon 1997, and chap. 5, this volume). The history of this notion is complex, and the effect has been redefined a number of times (Depew, chap. 1, this volume; Downes, chap. 2, this volume; Godfrey-Smith, chap. 6, this volume). Depew has argued that the Baldwin effect is not a theory-neutral empirical phenomenon nor is it a theoretical concept that maintains a fixity of reference across different theoretical backgrounds. Indeed, the idea was not homogeneous even in Baldwin's mind as it was reformulated several times by him, especially in response to the rise of genetics (Plotkin 1988). Against the background of the Modern Evolutionary Synthesis, the Baldwin effect seemed theoretically possible but of little significance and was easily conflated with Waddington's genetic

assimilation—to the detriment of both (Depew, chap. 1, this volume; Deacon, chap. 5, this volume). Many phenomena that have been cited as evidence for the Baldwin effect are either examples of genetic assimilation or are adequately explainable by orthodox neo-Darwinian mechanisms. The Baldwin effect and genetic assimilation are conceptually distinct mechanisms and need to be evaluated separately (Gilbert 1997; Futuyma 1998; Downes, chap. 2, this volume).

The most noteworthy support for the Baldwin effect, as distinct from the mechanisms employed by Waddington and construed as effects that actually become genetically entrained, comes from computer simulation. Ackley and Littman combined genetic evolution with neural-network learning in an artificial life "experiment," demonstrating that learned adaptive behavior could, with a stability of both problem and adaptive solution, become encoded in the "genes" (Ackley and Littman 1992). The perceived advantage of the interplay of learning and genetics in this simulation is that the Baldwin effect allows the speed of Lamarckian evolution in a situation where acquisition of an acquired trait is specifically blocked. Hinton and Nowlan, in another simulation experiment, conclude that the Baldwin effect could be of selective advantage by speeding up the rate of evolutionary change (Hinton and Nowlan 1996; see also Puente-dura, chap. 11, this volume).

As Peter Godfrey-Smith argues, there is a sense in which Deacon makes a novel extension of earlier conceptions of the Baldwin effect by extrapolating from Lewontin's notion of organismal niche construction to niche construction in the social ecology of humans (Godfrey-Smith, chap. 6, this volume; but see also Dennett, chap. 4, this volume, and Deacon, chap. 5, this volume, as well as the postscript at the end of section one). Two of the examples cited by Deacon—appearance of lactose tolerance in populations of herders of milk-producing animals, and sickle-cell hemoglobin conferring adaptive value against malaria in areas where agricultural practices fostered mosquitoes—involve selection pressures arising out of environmental niche alteration due to human activity. The change in gene frequency or selection for a mutant allele that arises subsequently allows an adaptive response to the changed niche due to human activity.

These examples are not, however, directly parallel to the simulations mentioned above. Although there is a changed environment due to human

activity that is stable over generational time, the change in gene frequencies observed is not due to selection acting on or serving to support learned adaptive behavior. In a different example on which Deacon has reflected, the mechanism is more distinctly Baldwinian, but it does not involve the genetic encoding of learned behavior as implied in Hinton and Nowlan. Due to a proclivity to eat fruit, somewhere along the lineage leading to humans, there was loss of both alleles for the gene needed in the final step for the production of ascorbic acid. Deacon hypothesizes that the behavior that overcame this lethal mutation, namely eating fruit, was no longer elective but rather a necessary adaptation. Any traits that would support this adaptive response would have been favored by natural selection; populations in which this behavior was learned would have had a greatly enhanced frequency of survival of individuals. Over generational time, parallel mutations, which gave rise to genetic support of the adaptive behavior, such as taste and color preferences, would also have been selected. The moral of the story is that the adaptive behavior itself does not have to become entrained in the genome; the behavior (eating fruit in this case) can be indirectly underwritten by the genes.

Thus the Baldwin effect can be construed to refer to behavioral initiatives by an organism that have an effect on development of neonates through forms of cultural mimesis that are sustained and directional enough to result in a shift in gene frequencies over time by whatever mechanism that this might occur. The Baldwin effect, so construed, does not necessarily mean that the genetic change must mean loss of behavioral plasticity through "hard-wiring" adaptive behavior, a frequent criticism. Rather, gene-frequency changes are selected that underwrite adaptive behavior and stabilize it. Niche construction by the organisms' activities alter the environment in a stable fashion over generational time so that there is an adaptive reward to any changes in genetic regulation and/or gene frequency that supports behavior that is adaptive. This formulation is not only in the spirit of Baldwin's original vision, but can be considered Darwinian in a broad sense (Baldwin 1896, 1902; Depew and Weber 1995).

From this perspective, in their tendency to identify heritability with transgenerational selection at the genetic level, Darwinians such as Mayr can all too readily underestimate the possibility that mimesis and other

forms of learning can be heritable over many generations at the phenotypic level and that variant behaviors can become adaptively established in a population before any shift in gene frequencies that stabilizes such an adaptation has taken hold. If there is a mechanism by which a selectively advantageous behavioral repertoire can become genetically entrained or underwritten, so much the better. However, there is some openness about when to call the resulting traits adaptations by natural selection (Weber and Depew 2001).

That behavior and even emotions could have an influence on natural selection was explored by Darwin. "Charles Darwin," says Edelman, "was the first to propose that natural selection alters behavior and vice versa" (Edelman 1987, p. 10). It is the "vice versa" that now needs to be included in any account of the evolutionary emergence of mind. Edelman himself goes on to argue that James Mark Baldwin "was the first to understand the importance of alterations of individuals during ontogeny, and he had the clarity of vision to see the issue in Darwinian terms" (Edelman 1987, p. 11).

The speculations of theorists such as Edelman and Deacon provide models of how consciousness, language, and culture may have emerged that might form the basis for research programs that will enable us to gain a deeper understanding of these phenomena. The neuronal group selection loop can be expected to ultimately modify the natural selection loop of organismic life cycles through the emergence of novel and complex patterns of behavior. Taken together the interaction of neural and organismic selection produces a genuinely emergent phenomenon in organisms with complex brains. Clues how to elaborate such theoretical approaches for this and other cases of emergent evolution (in Deacon's third sense) may come from an understanding of how the emergence of life itself resulted from an interplay between appropriate forms and modes of self-organization and selection.

To the extent that human agency and action played a role in the evolutionary emergence of the human mind, then mechanisms such as that implied in the Baldwin effect, as they are explored in this volume, need to be seriously considered. In contrast to genetic assimilation, which occurs over a wide phylogenetic range, it may well turn out that the Baldwin effect is an emergent phenomenon that arose in a lineage of primates when the

brains of these primates evolved to such complexity that it played a role in the further emergence of minds capable of symbolic language and much more.

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Notes

1. Interestingly, a preliminary attempt to describe mind in terms of brain physiology, although not in evolutionary terms, was published in 1859 by the Edinburgh professor John Laycock (Laycock 1859). From Darwin's correspondence it is clear that he was aware of this work during the time he was preparing his *Descent of Man*. Of course Herbert Spencer's book on psychology from both naturalistic and evolutionary perspectives was published in 1855 (Spencer 1855). However, Spencer's version of evolution was not Darwinian and had little role for selection; even the subsequent revision of 1870 was little informed by Darwin or natural selection (Spencer 1870).
2. Such causal pluralism and parity is assumed in developmental systems theory (Griffiths and Gray 1994, 2001, and Oyama, Griffiths, and Gray 2001).
3. In the latter, information is not yet reliable enough, or sufficiently internalized, to produce adaptations. It merely facilitates certain energetic processes. Rather, natural selection arises when the very process that facilitates autocatalytic cycling in open systems by enhancing reproductive fidelity spins off, as it inevitably will, forms of variation whose differential retention leads to specifically biological fitness.
4. Indeed, current work in the Neurosciences Institute directed by Edelman is developing a theoretical account of the mechanism of reentry using explicit models from complex systems dynamimcs (Eugene Izhikevich and Gerald Edelman, personal communication).

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