God and the World of Signs: Semiotics and the Emergence of Life

with Andrew Robinson and Christopher Southgate, "Introduction: Toward a Metaphysic of Meaning"; Christopher Southgate and Andrew Robinson, "Interpretation and the Origin of Life"; Bruce H. Weber, "Selection, Interpretation, and the Emergence of Living Systems"; Jesper Hoffmeyer, "A Biosemiotic Approach to the Question of Meaning"; Robert E. Ulanowicz, "Process Ecology: Stepping Stones to Biosemiosis"; Andrew Robinson and Christopher Southgate with Terrence Deacon, "Discussion of the Conceptual Basis of Biosemiotics"

SELECTION, INTERPRETATION, AND THE EMERGENCE OF LIVING SYSTEMS

by Bruce H. Weber

Abstract. The autocell proposal for the emergence of life and natural selection through the interaction of two reciprocally coupled self-organizing processes specifically provides a protein-first model for the origin of life that can be explored by computer simulations and experiment. Beyond the specific proposal it can be considered more generally as a thought experiment in which the principles deduced for the autocell could apply to other possible detailed chemical scenarios of catalytic polymers and protometabolism, including living systems emerging within membranelike barriers. The autocell model allows for the analysis of the emergence of not only agency and purpose but also of interpretation and semiosis as true living systems arise.

Keywords: autocell; biogenesis; chemiosmotic; emergence; information; interpretation; membrane; natural selection; origin of life; semiosis

Terrence Deacon's "autocell" proposal for the emergence of *telos* (functional purpose) in the process of the emergence of life seems at first blush to be reviving an earlier approach to the problem of the origin of living systems

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from inanimate matter and processes assuming a protein-first scenario (Deacon 2006). However, Deacon's autocell model is meant to be a thought experiment to focus on how the general principle of reciprocity of coupled self-organizing processes, arising spontaneously in the absence of life, could coemerge in synergistic relationship to produce autonomous entities. These entities would have a range of possible variation upon which physical selection for stability and chemical selection for thermodynamic and kinetic efficiency could act (Weber 2007; 2009; Weber and Deacon 2000; Weber and Depew 1996). This provides an elegant conception for thinking about how entities could meet Immanuel Kant's criteria of being an organized being with self-propagative power in which each part is reciprocally both end and means. But we also have to ask how this enterprise relates to the considerable body of ongoing research on the origin of life (for recent reviews see Fry 2000; Luisi 2006; Weber 2007; 2009; Zimmer 2009).

Most origin-of-life research has emphasized some aspect that characterizes current life as providing the first step of emergence: protein-first models, replicating-template molecules first, metabolism first, membrane first, or even a cell-first model in which several aspects arise synergistically (Fox 1965; Woese 1967; Oparin 1938; Deamer and Pashley 1989; Morowitz 1992, respectively). Shortly after the demonstration by Stanley Miller and Harold Urey that some amino acids could be produced by an electric spark passing through gases believed to have been present on primitive Earth, there was considerable work, particularly by Sidney Fox, on how proteins might have arisen and interacted to produce some sort of superstructure, such as proteinoids (Miller 1953; Fox 1965).

A significant problem was that of how the polymerization of amino acids to proteins would be favored since it was a dehydration reaction that either had to occur in 18M water or that the proteins, however formed, would be subject to hydrolysis and depolymerization. Several strategies were suggested, including Fox's of high temperature as well as Cliff Matthews's observation that hydrolysis of HCN polymers, which also formed in the Miller-Urey experiment, produced polypeptides (Matthews and Moser 1967). Jeffrey Wicken (1987) proposed that nonequilibrium thermodynamic driving forces would favor complexification and that kinetic mechanisms involving phosphorylation could allow polymerization under milder conditions. He assumed that protein-protein interactions (and later protein–nucleic acid interactions) would help stabilize random sequences, or "generic proteins," from hydrolysis.

David Depew and I proposed that Wicken's putative role of phosphorylation and David Deamer's proposal of vesicles of amphiphilic molecules, derived from meteorites, suggested that chemiosmotic-type mechanisms might have fundamental and primordial roles in the emergence of life (Deamer and Pashley 1989; Deamer 1992; Deamer et al. 2002; Depew and Weber 1995; Weber and Depew 1996; Weber 2000; 2009). This conception seemed even more likely in light of Stuart Kauffman's notion of autocatalytic sets of peptides with a sequence space that overlapped catalytic-task space even unto catalytic closure and the emergence of autonomy (Kauffman 1993; 2000; 2004).

Pier Luigi Luisi has empirically explored the properties of randomly generated sequences of 50-mers. So far 10^9 such sequences, of the 10^{65} possible, have been generated, of which about a quarter appear to fold up into physically stable structures and show some weak catalytic activity (Luisi 2006). Although the geochemical evidence suggests that Earth's atmosphere was not as reducing as Miller and Urey assumed, there is still the possibility that in local regions it was, or that they obtained elsewhere in the universe, and that amino acids were brought to Earth via meteors and so forth (Bada and Lazcano 2003; Bada 2004).

By one means or another amino acids and peptides are plausible constituents in the early-Earth chemistry, and there are even mechanisms that could prefer one optical isomer form over another (Kondepudi 1988). So it is not unreasonable to explore models in which "generic proteins" might participate in autocatalytic sets or in the type of reciprocal self-organizing processes of the autocell. Indeed, Deacon's model assumes that proteins will be available, some subset of which could participate in an autocell. The crucial focus for Deacon does not include the details of amino-acid production, polymerization, or how nonequilibrium thermodynamics drives the formation and action of such sets of catalytic polymers, but ultimately these issues of a proto-ecosystem need to be considered when connecting Deacon's proposal to research on the origin of life more generally.

Of course, much of this work has in more recent years focused on the role of RNA polymers as providing simultaneously templates and catalysts. J. D. Bernal quipped, however, that nucleic acids did not just wash up on the beach (Bernal 1951; 1967). Therefore, the types of containers for the chemistry that might produce RNA might be provided by Deamer's proposed amphiphilic vesicles or the FeS membranes, which are naturally chemiosmotic, suggested as a "cradle" for life by Michael Russell (2007). Also, recent experiments involving RNA in lipid vesicles suggest that transient temperature excursions could allow components to accumulate in such vesicles (Deamer 2008; Mansy and Szostak 2008; Mansy et al. 2008). Alternatively there is evidence that nucleotides could accumulate in the FeS hydrothermal pore systems (Baaske et al. 2007).

Be that as it may, the value of Deacon's proposal is that it draws our attention to a specific process by which purposeful function could emerge without getting bogged down in the chemical details, even though those details must ultimately be addressed.

Not only does Deacon's autocell suggest how autocatalysis can self-amplify the chemical reactions, producing local asymmetry, but it also requires limited diffusion of the interdependent catalysts; enclosure by self-assembly constrains molecular diffusion but requires persistently high local concentrations of a single species of capsid protein. Both processes share complementary boundary conditions but have the potential of unlimited reproduction, and thus stability, to stay ahead of entropy. Indeed, Deacon claims this acts as a type of entropy ratchet. Further, autocell opening and closing can trap other molecules, generating a type of variation. Because variant autocell "lineages" would be competing, there would be not only physical and chemical selection but also the emergence of selection of the reproductively fit, even in the absence of template molecules. This type of weakly analogic information about reproductive fitness would become digital when templates and genetic codes emerged and at which point natural selection as we know it would emerge.

As Deacon points out, however, there is a limitation on the complexity and evolvability of autocells, which is why, if they existed in this form, they would have been replaced as more modern living systems arose. Deacon makes an interesting proposal that, rather than ATP as "energy currency" being derived from RNA, it was the other way around. ATP may have come first, derived from the putative role of polyphosphate as the earliest energy currency (Westheimer 1987; Williams and Fraústo da Silva 1999; 2006). This seems plausible, even if it does run counter to the assumptions of an RNA world. RNA could have been initially useful as a storage of NTPs, but such polymers may have interacted with proteins resulting in mutual stabilization, as suggested by Wicken (1987). Out of such interactions might have evolved the triplet code of contemporary organisms.

Deacon makes some specific claims based on the autocell model. The emergence of information in living systems did not necessarily have to depend upon RNA or DNA, although when such digital information became available it had a significant advantage. Although nucleic acids are not necessary for generative and reproductive powers of Autea generally or for Morphota more specifically, and evolved later as a specialization, they likely did participate in synergistic, complementary self-organizing processes that could lead to the emergence of semiosis and the Semiota. (For definitions of these terms see Deacon 2006.) Less convincing is Deacon's assertion that a nonequilibrium thermodynamic metabolism is not necessary. It is not essential for the issue of the emergence of *telo*s per se, but it seems unlikely that protometabolism would not have arisen concurrently. The autocell cycle need not be constantly nonequilibrial, but it depends on such processes to maintain itself and to grow and reproduce.

Finally, Deacon claims that a semipermeable membrane is not necessary. Clearly it is not for his model, but this is a concern because his overall goal is to develop a general biology. He proposes the autocell model, based upon proteins, as the simplest system about which to think. The crucial point is that the essence of his model is that there is a coupling of reciprocal, self-organizing processes, regardless of the chemical instantiation. It seems quite plausible that catalytic polymers (protein likely but RNA possibly) might sustain, with appropriate mechanisms of energy capture, a protometabolism that could produce amphiphilic molecules capable of self-assembly into a container of the types proposed by Deamer and by Russell. It would be interesting to see if experiments with lipid vesicles could generate this type of autocell, which would be consistent with Deacon's notion of a general biology.

Producing theoretical scenarios for the emergence of agency, *telos*, and semiosis is an important effort per se. But for such a model to be taken seriously, and to have the possibility of connecting robustly with empirical research on the emergence of life, there needs to be a "proof of principle," as Deacon avers. Laboratory simulations will be daunting, but kinetic analysis and computer simulations are within reach.

The work of Christopher Southgate and Andrew Robinson (2010) provides exactly such a test of principle. They focus on the nature and emergence of interpretation. More correct interpretations of the environment would be expected to confer at least some degree of selective advantage on an entity. It is plausible to consider interpretation as a distinct property that emerged early in the process of the emergence of life, along with agency and *telo*s. Hence it seems reasonable to use the autocell model to see if it shows the emergence of interpretation while simultaneously thus providing a test of the autocell principle. Southgate and Robinson assume that the autocell would be under kinetic control receiving pulses of substrate molecules and define how the autocell, and a control that lacks the capacity for interpretation, would behave. In response to substrate molecule A, or pseudosubstrate A', the autocell dissociates, and constitutes a rudimentary interpretation. Southgate and Robinson develop five simultaneous differential equations that describe the dynamics of the autocell system (see *www.evolutioncreationsemiotics.org*). They demonstrate that if interpretation is possible there is increased autocell synthesis over an autocell system lacking the capacity for interpretation, as well as pseudosubstrate A' causing a misinterpretation. This elegant proposal should provide a clear test of a model system by which the process of the emergence of interpretation could be analyzed as well as evidence of the value of the autocell model and one type of proof of principle.

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