Section Four — Biological Information and Self-Organizational Complexity Theory: Introductory Comments

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No discussion of new perspectives on biological information would be complete without consideration of the anti-reductionist approach of the self-organizational school of thought. The reductionist approach focuses on systematically taking apart complex systems and analyzing their individual components, seeking to explain the behavior of the whole in terms of its parts. This strategy has been very fruitful and such research undoubtedly will continue, but, like the intelligent design scientists and researchers exemplified by the editors and other contributors to this volume, self-organizational theorists believe that new theoretical approaches are necessary to understand the hierarchically integrated information networks that undergird morphogenesis in developmental biology and evolution. How do systems of genes and proteins integrate into holistic information structures? How do dynamic organelle structures form in cells? What controls cell growth, division and differentiation in organisms? How is genomic information regulated in the construction of an organism? How do selective environmental pressures integrate through time with organismal development to affect the evolution of species? How do integrated ecosystems form and evolve? Both self-organizational theorists and intelligent design (ID) theorists believe that natural selection operating on random genetic mutation is an insufficient basis on which to explain the origins of biological complexity and irrelevant to the origin of life. ID theorists also believe that the self-organizational capacities of physical systems are limited, falling far short of the order we observe, so the *ultimate* source of information for the origin of life and hierarchically integrated morphogenesis in both organismal development and speciation must be extrinsic to biological systems and their physical environments. In contrast, self-organizational researchers argue that global pattern development, including the highly complex hierarchical information structures characteristic of life, can emerge solely from the interactions of lower-level components and part-whole dynamics *without* ultimate or proximate goal-directed input. Whether biological information is somehow self-originating is thus a central point of disagreement between intelligent design theorists and self-organizational complexity theorists.

Taking their cue from non-equilibrium thermodynamics, self-organizational theorists maintain that living systems rely on a continuous flow of energy to maintain themselves far from equilibrium, and it is this constant flux of energy and material passing through living systems that enables autopoiesis as energy-dissipating components spontaneously self-organize into complex structures under a variety of physical and selective constraints. As Franklin Harold summarizes the situation in *The Way of the Cell: Molecules, Organisms, and the Order of Life* (2001: 232), "living organisms are autopoietic systems: self-constructing, self-maintaining, energy transducing autocatalytic entities" that are "capable of evolving by variation and natural selection: self-reproducing entities whose forms and functions are adapted to their environments and reflect the composition and history of an ecosystem." It is the hope of self-organizational theorists to elucidate the complex systems dynamics which, subject to internal systemic constraints and the external constraints of physical law, catalyze the spontaneous emergence of order and dynamic organization in the molecular systems constitutive of living organisms.

The contributors to this discussion of biological information from the standpoint of complex systems dynamics are well-known names among self-organizational theorists: Stuart Kauffman and Bruce Weber. Their involvement in this project traces back to a 2007 conference I organized in Boston under the auspices of the Discovery Institute's Center for Science and Culture. The conference commemorated the famous 1967 Wistar Symposium on "Mathematical Challenges to the Neo-Darwinian Interpretation of Evolution." Several of the ID scientists whose work is represented in this volume also participated in this Wistar retrospective. The general perception among the participants in the Boston symposium, as with the participants in the Cornell University conference giving rise to this compendium, is that the mathematical and biological challenges posed to the modern evolutionary synthesis (neo-Darwinism) have *not* been resolved, but actually *have grown more acute* as our knowledge of molecular biology, cell biology, developmental biology, and genetics has exploded. A different — or at least modified and vastly supplemented — approach is needed, along with different mathematical models. Of course, ID theorists and self-organizational theorists diverge both individually and collectively in their heuristic strategies and in the models they propose, but they have things to learn from each other, and it is in this spirit that Kauffman and Weber have contributed to this volume.

Stuart Kauffman's essay, "Evolution Beyond Entailing Law: The Roles of Embodied Information and Self-Organization," radically revises evolutionary modeling on the premise that no law entails the evolution of the biosphere. The worldview of physics, he maintains, terminates at the doorstep of life. In making this point, Kauffman argues (among other things) that the phase space of biological evolution is always changing, rendering the "sample space" of adjacent biological possibilities unknowable in a way that precludes information-theoretic analysis (thus creating an insurmountable barrier for intelligent design). In particular, evolution unites the irreducible indeterminacy of genetic mutation with deterministic natural selective pressures so as to rule out the possibility of monolithic nomological development: part-whole interactions in the autopoietic context of living systems give rise to an autocatalytic network of top-down and bottom-up causes with unpredictable results. Nonetheless, despite the absence of entailing laws, Kauffman proposes that ensembles of interactive systems are subject to *statistical* laws and profound self-organization in ways that enable us to understand how undirected abiogenesis and speciation are possible, albeit a form of "natural magic." He concludes his argument with three examples of the ensemble approach to evolutionary modeling that exhibit strong self-organizational properties: (1) models of ensembles of genetic regulatory systems; (2) the emergence of collectively autocatalytic sets argued to be relevant to the chemical origin of life; and (3) the statistical features of tunably rugged fitness landscapes. In closing, Kauffman invites us to envision a new kind of science that explores the growth of embodied information beyond entailing law.

In his paper "Towards a General Biology: Emergence of Life and Information from the Perspective of Complex Systems Dynamics," **Bruce Weber** argues that the "Darwinian Research Tradition" (understood as an interlinked set of research programs embracing natural selection as one major source of biological adaptation, order, and innovation, but allowing for other intramundane sources as well), can be extended into a general theory of biology that includes origin of life research by appropriating the background assumptions and resources of complex systems dynamics. After reviewing the history of neo-Darwinism and the Modern Evolutionary Synthesis and making the case for complex systems dynamics as the foundation for evolutionary research, Weber discusses its application to the emergence of life. He begins with an account of Kauffman's computer simulations of autocatalytic ensembles of peptides and Ghardiri's experimental studies to test their accuracy and viability, acknowledging the difficulty of finding a reasonable model for the appearance of nucleic acids and discussing the shortcomings of RNA-world, metabolism-first, and cell-first models, ultimately favoring the protocell approach as the one most amenable to articulation and experimental investigation using complex systems theory. Natural selection emerges as a phenomenon along with the emergence of life (characterized by the transmission of representational information via genetic encoding), which he theorizes in turn to be the synergistic result of multiply interacting self-organizational and general selectional principles. Non-equilibrium thermodynamics drives self-organization, but kinetic mechanisms are the pathways of emergence, especially after life itself has made an appearance and kinetic control (as evinced, for example, in replication) gives birth to the teleonomic and semiotic character of living systems. As Weber describes it, therefore, in contrast to intelligent design, the emergentist perspective of self-organizational complexity theory sees organisms as "begotten not made, that is, they are the result of developmental processes individually and of evolving lineages," all these phenomena issuing from the continual holistic interplay of selection and self-organization.

Considered together, the essays by Kauffman and Weber provide both an excellent overview of the state-of-the-art in self-organizational thinking and an extremely useful guide to the literature on the subject. It is to be hoped that self-organizational theorists and intelligent design theorists will continue to engage in mutually beneficial and constructive dialogue as these new perspectives on biological information grow to maturity.