# C. S. PEIRCE, G. W. F. HEGEL, AND STUART KAUFFMAN'S COMPLEXITY THEORY: A RESPONSE

*by Joyce M. Cuff*

*Abstract*. Stuart Kauffman's work on complexity and self-organization echoes ideas found in writings of C. S. Peirce and G. W. F. Hegel. Included in these common threads are the understanding of science as historical narrative, the recognition of emergence as a phenomenon associated with complex systems, and the appreciation of agency as an emergent property that serves as both a creative and determining force in evolution.

*Keywords:* adjacent possible; agency; complexity theory; contingency; emergence; Stuart Kauffman; self-organizing systems

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The breadth of background and level of expertise represented by the authors of essays in this section of *Zygon* speak to the range of disciplinary connections as well as the depth of ideas found in Stuart Kauffman's articulation of complexity theory (Kauffman 1995; 2000). The essays were first presented at a conference at which the authors were panelists. The panel itself demonstrates key elements of Kauffman's model: organization was evident, elements were selected out of the space of possibilities, meaningful connections were made, and then it was left to the biologist to tell the story. Consistent with the model, I structure these comments at the edge of chaos and hope to narrate a story that, like the story of life itself, is more intelligible than predictable.

Just as the panelists found that Kauffman's ideas are not all that new and have parallels in the ideas of C. S. Peirce and G. W. F. Hegel, so we should remember that elements of Kauffman's ideas are rooted in particular areas of biology—ecology, morphogenetics, and paleontology, for example. Among scientists, biologists may be best positioned to receive Kauffman's

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ideas, because even the simplest biological system is incredibly complex. In addition, biologists generally are happy to settle for probabilities rather than certainties, and we gave up on formulating laws long ago. It does appear that the issues Kauffman raises are topics of conversation that we have been having in our compartmentalized, departmentalized academies for a very long time. This panel models the sort of cross-disciplinary dialogue that enriches and challenges our thinking.

As stated by the panelists, Kauffman is one of a growing number of scientists who find Darwinian evolution acceptable within its realm of applicability but far too narrow to include all relevant considerations, even within biological evolution. However, as the panelists highlighted, today evolutionary models, including Kauffman's, need to go beyond the limits of biological evolution if a really useful model is to emerge. If the concept of evolution truly presents a sort of grand unifying theory, the evolution of the universe, evolution of cultures, evolution of economies, and evolution of mind and spirit ought to both inform and be informed by evolutionary theory. This grand-unifying-theory approach should assist us in relinquishing the constraints imposed by disciplines and allow us to end up with, to paraphrase William Kiblinger (2007), a coherent conceptual scheme anchored by the way the world is.

Rather than responding to the panelists' individual essays, my comments are organized around three of Kauffman's themes that were highlighted in their presentations. The first is the element of history and story that was most directly addressed by Kiblinger and Rocco Gangle. The second is the element of emergence, or generation of novelty, that is central to all of the presentations but the primary focus of John Bugbee. The third is the element of agency, a particular focus of Mark Graves and Kiblinger.

## HISTORY AND STORY

It was the history of life revealed in the fossil record that served as the initial impetus for the development of a theory of evolution. Neo-Darwinists have, perhaps, been so focused on the molecular genetic explanation for homeodynamics and measured introduction of change that the message of that history, the story that is told, has been hidden if not lost. As the panelists remind us, the sequence of frozen accidents, of contingent choices, of emergent systems that is the history of life on Earth, is unique and, by virtue of its uniqueness, might be relegated to a position outside of the realm of science as we currently define it. In addition to historical uniqueness, evolution lacks the element of prediction that is also a characteristic of science. The inability to "prestate the configuration space" (Kauffman 2000, 123) means that possibility itself emerges. In the presence of nonergodic history (one in which all alternative states or pathways are not equally possible) and in the absence of predictability, we are left with story.

Kauffman acknowledges the contingent history and the emergence of possibilities and concludes that we need to change our concept of science to include, paraphrasing Gangle (2007), the use of empirical models coupled with the necessity of a narrative approach. Kiblinger (2007) asks what will suffice as the story in place of the traditional scientific explanation.

## EMERGENCE

Complexity theory is Kauffman's primary area of study and expertise. A central notion in complexity theory is the phenomenon of emergence and is a common theme among the panelists' essays. Bugbee focuses on Peirce's categories of Firstness (potential) and Thirdness (regularities) as they relate to emergence, Gangle on the use of existential graphs, particularly gamma graphs, to represent levels of complexity in emerging systems, Graves on emergence in cognitive systems, and Kiblinger on subjectivity as it relates to the interpretation of evolving reality.

Kauffman's model has been well described by the panelists. Elements interrelate. The larger the number of elements, the larger the number of possible relationships. Elements increase arithmetically, relationships exponentially. At critical points, elements in relationship link with other sets of interrelating elements. The product of one relationship generates the substrate of another. Pathways are born. Eventually the product of one relationship facilitates the formation of another. Catalysis emerges. Reciprocal production of catalysts by two sets of relationships produces autocatalytic systems. Autocatalytic systems associate in such a way that energy-releasing reactions are coupled with energy-conserving reactions, and metabolism (autonomy) emerges. At each level the system is constrained externally by the environment, in terms of available opportunity, and internally by the nature of the system and its components. At each level the possibilities emerge from the adjacent possible—that which is, exploring that which is not yet. Contingent choices are made. The story continues.

This model includes several ideas that are departures from classical evolutionary thinking. The first deals with the pace at which change is introduced. Periods of somewhat predictable activity are interrupted by major episodes in which unanticipated levels of organization are introduced. Elements engage in interactions generating pathways that give rise to catalytic pathways that form reciprocal or autocatalytic pathways that ultimately introduce autonomous agency. All of these unanticipated changes represent emergent events—events that are almost impossible to predict but understandable once they occur—which generate novel entities that have features not present in the previous step. Interactions introduce relationships; pathways introduce flow; catalysis introduces speed; autocatalysis closes the loop; agency introduces self-interest. Darwin's gradualism meets Stephen Jay Gould and Niles Eldredge's (1972) punctuated equilibrium. On a smaller scale, even during periods when mechanistic activity appears to dominate, ongoing exploration of the adjacent possible is occurring; new representatives of each level of organization emerge—new catalysts, new regulators of pathways, new species.

The second feature of Kauffman's model that is nicely incorporated in all of the presentations and constitutes a strong departure from classical Darwinian theory is the notion of cooperativity. Descent with modification, which was Darwin's phraseology, sounds a bit more positive than the popularized version that includes a struggle for survival and survival of the fittest. However phrased, Darwin's model was competitive. Many biologists, Richard Dawkins among the most familiar, have used the competitive model as the centerpiece of their evolutionary theory (Dawkins 1989). Kauffman, Lynn Margulis, and others are more focused on cooperation, indicating that cooperation may trump competition in the grand scheme of evolution. Kauffman's integrated networks represent coordinated and cooperative relationships. The endosymbiotic theory of Margulis (1998) provides a clear example of emergence through the merger of two or more autonomous agents. Cooperation joins competition as a chief driving force of evolution. Natural selection is a whittling away of nonadaptive alternatives; symbiosis is the creative exploration of adaptive alternatives. Systems or networks are collections of interrelating components that together achieve something that is impossible or unlikely to be achieved by their parts. Complexity theory, by dealing with such systems, acknowledges the strong role of cooperation in evolutionary development.

The third feature of Kauffman's model refers to constraints, which keep organized autonomous agents balanced on the edge of chaos. Darwin's model clearly locates the constraining or limiting factors in evolution in the environment, external to the entity evolving. The environment, both biotic and abiotic, selects the variants based on a variety of factors present in that environment. Selection is based on the situation and the variants available. Variation, in turn, comes from biochemical changes and recombinations of existing trait options. Kauffman and others posit the existence of intrinsic constraints that combine with external limitations to move evolution. Brian Goodwin (1996) has described evolution as a dance through morphospace. This may be a very apt analogy. The dance is considered an expressive and creative art form, but even a tango has rules, structural elements, and sequences that qualify it as a tango. Too much creativity makes it unrecognizable; too little creativity renders it uninteresting. The notion of intrinsic limitation can be even more easily understood if we consider the prebiotic or chemical world. Kauffman says, on the very first page of *Investigations:* "The snowflake's delicate sixfold symmetry tells us that order can arise without benefit of natural selection" (2000, 1). The snowflake's symmetry is a reflection of the limits placed on it by its component parts—a form of selection from within. This would explain why, of all of the conceivable amino acid variants or nitrogenous base variants or simple sugar variants that might be used in the construction of living systems, in each case only a handful of potential variants are actually found consistently in those systems. It appears that intrinsic filters limit the options. As the possible emerges, so does the impossible. What is not yet is contingent upon what is.

### AGENCY

Self-organizing systems are nonequilibrium systems. In order to have agency, to have entities acting on their own behalf, there must be net movement—of matter, energy, or information. At equilibrium there is no movement, no work cycles; there is being but no becoming; the system experiences a cold death. Too far from equilibrium, the drive to become swamps the being; frenetic becoming loses agency; the system experiences meltdown. Just as external resource limitations have been used to explain the difference between reproductive potential in a population and its actual growth rate, Kauffman posits the possible existence of a self-regulating mechanism that gates entry into the adjacent possible: "It is a plausible hypothesis that the rate of exploration of the adjacent possible endogenously converges to the rate that is maximally sustainable" (2000, 156). The balance between order and chaos is self-sustained.

What it means to act on one's behalf is itself dependent upon the system or entity that is acting. Agency also evolves. Acting on one's behalf is responding in a way that generates a favorable result for the entity. Responsiveness, or behavior, is an important characteristic of systems. Kauffman uses the example of a bacterium swimming up a glucose gradient (2000, 8). The behavior that he describes in this example is a primitive form of agency. The bacterium does not swim directly to the food source but "runs" and "twiddles," as microbiologists put it. It is more kinetic, moves more, in unfavorable (Kauffman's "yuck") conditions than in favorable ("yum") conditions. The result is that bacteria tend to aggregate where the food is.

We can move up the ladder of behaviors. Taxes or tropisms are responses that are oriented by the stimulus. Plants bend toward light; roots grow toward water. With the emergence of nerves and nervous systems, new possibilities for effecting agency emerge. Instincts allow for behaviors that will fairly reliably work on the organism's behalf to ensure that it gets food or escapes harm. Conditioning allows for programming of behaviors to allow for consistent response to particular stimuli. If a stimulus begins to fail to be a reliable signal, reprogramming is possible. Finally, human agency allows freedom of response to both internal and external stimuli. What it means to act on our own behalf is less clear. We are aware of our own agency.

## CONCLUSION

For many of us, Darwinian evolution is necessary but not sufficient to explain evolution. Random variation and selection of variants, the bedrock of Darwin's theory, are recast by Kauffman as explorations of the adjacent possible and the emergence of autonomous agents that in their organization appear to defy thermodynamics and in their complexity imply an evolutionary direction and render the agents adaptive. Focus has shifted from the physical elements of reality to their interrelationships.

Connections are critical; cooperation is everywhere. The grand unifying theory may lie not in identifying the ground substance of reality but in how units of the ground substance connect, how they organize themselves. The grand unifying theory may be found not through the reductionist approach of the past few centuries but through the constructivist approach of more recent times. Connections are more than juxtapositions, more than transient encounters. Connections are stable relationships that produce functional, patterned networks. Connections also allow for directional flow—of energy, of matter, of information. Networks allow for feedback loops, coupled flow, and emergence of new properties. The question remains as to the degree to which connections are determined either externally by the context in which elements find themselves or internally by their intrinsic nature and in what ways connection sets are free to form larger, functional networks. The presence of alternative systems composed of very similar elements illustrates the contingent nature of reality. Alternative metabolic structures, alternative life forms, point to the emergence of novelty in biological evolution.

Kauffman is aware of posing more questions than he answers and acknowledges the tentative nature of the answers he does give. Introducing the notions of purpose and agency and story and challenging the notions of reductionism and strict determinism, Kauffman chips away at a way of thinking of science that could be described as business as usual. His writing style invites dialogue—it calls us to consider together the conceptual seeds that he sows.

The panelists in this section have responded to this invitation. Each presents insights—new connections in the expanding and deepening understanding of evolution. Gangle offers a model of the logic of self-organization in the form of Gilles Deleuze's and Manuel Delanda's concept of virtual attractor, the rules or patterns that guide the becoming or the point toward which multiple systems are moving (Gangle 2007). Bugbee suggests that greater clarity in understanding emergence may be derived from distinguishing between the potential (Firstness) of things, which helps to define the adjacent possible, and the regularities (Thirdness) of things that would include Kauffman's principles of self-organization (Bugbee 2007). Kiblinger connects the agency of mind or spirit with the freedom from strict determinism and the inner teleology of autonomous, self-organizing systems and sees in this connection echoes of Peirce, Kant, and Hegel (Kiblinger 2007). Graves calls upon systems theory to focus on constitutive relationships of social systems that give rise to culture and religion, and those of the individual that give rise to soul (Graves 2007). Gangle and Graves both propose the use of gamma graphs as a method through which emergence might be represented. In the end, an enriched understanding of evolution begins to emerge as the adjacent possible continues to be explored.

## NOTES

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## REFERENCES

Bugbee, John. 2007. "The Consequences of Metaphysics: Or, Can Charles Peirce's Continuity Theory Model Stuart Kauffman's Biology?" *Zygon: Journal of Religion and Science* 42:203–21.

Dawkins, Richard. 1989. *The Selfish Gene*. New York: Oxford Univ. Press.

Eldredge, Niles, and Stephen J. Gould. 1972. "Punctuated Equilibria: An Alternative to Phyletic Gradualism." In *Models in Paleobiology*, ed. T. J. M. Schopf, 82–115. San Francisco: Freeman, Cooper.

Gangle 2007. "Collective Self-Organization in General Biology: Gilles Deleuze, Charles S. Peirce, and Stuart Kauffman." *Zygon: Journal of Religion and Science* 42:223–39.

Goodwin, Brian. 1996. "Biology Is Just a Dance." In *The Third Culture*, ed. John Brockman, 98–110. New York: Touchstone.

Graves, Mark. 2007. "Peircean Approaches to Emergent Systems in Cognitive Science and Religion." *Zygon: Journal of Religion and Science* 42:241–48.

Kauffman, Stuart. 1995. *At Home in the Universe: The Search for Laws of Self-Organization*. Oxford and New York: Oxford Univ. Press.

———. 2000. *Investigations*. Oxford and New York: Oxford Univ. Press.

Kiblinger, William. 2007. "Evolution and Subjectivity: Peircean Suggestions and Hegelian Reminders." *Zygon: Journal of Religion and Science* 42:193–202.

Margulis, Lynn. 1998. *Symbiotic Planet: A New Look at Evolution*. New York: Basic Books.