COLLECTIVE SELF-ORGANIZATION IN GENERAL BIOLOGY: GILLES DELEUZE, CHARLES S. PEIRCE, AND STUART KAUFFMAN

by Rocco Gangle

Abstract. Stuart Kauffman's proposal in *Investigations* to ground a "general biology" in the laws of self-organization governing systems of autonomous agents runs up against the methodological problem of how to integrate formal mathematical with semantic and semiotic approaches to the study of evolutionary development. Gilles Deleuze's concept of the virtual and C. S. Peirce's system of existential graphs provide a theoretical framework and practical art for answering this problem of method by modeling the creative event of collective self-organization as both represented and practiced in the scientific community.

Keywords: Gilles Deleuze; evolution; existential graphs; general biology; Stuart Kauffman; Charles S. Peirce; scientific method; self-organization; semiotics; virtual

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When Americans consider whether and how to teach evolutionary biology in schools they encounter concerns crossing any clear boundaries between science, religion, and politics. We may legitimately ask how the questions surrounding the teaching of evolution ought even to be formulated, given their unique and problematic position at the shared coordinates of religious, scientific, cultural, educational, and political debates. Certainly, public discussion of evolution is a key factor, yet the various arguments set forth in this regard often fail to broach two fundamental questions: How does evolutionary biology as a particular science relate to the broader social, academic, religious, and political fields within which it is inscribed? And how ought this relationship itself to affect the practical methods of

Rocco Gangle is Research Associate in the Department of Religion at Oberlin College and Lecturer in the Writing Program at the University of California, P.O. Box 2039, Merced, CA 95344; email rgangle@ucmerced.edu.

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evolutionary science? Religious, political, and cultural phenomena may be understood as definite expressions of human life and therefore as subject to biological and evolutionary study. Biology itself, however, remains a particular science that arises only in a contested sphere of academic, scientific, political, cultural, and religious concerns. How might the methods of investigation and teaching peculiar to the evolutionary science of life be adequate to the complex, reflexive dimension of life's knowledge that this science necessarily involves?

In his *Investigations* evolutionary theorist Stuart Kauffman calls for a "general biology," that is, a new science addressing "the vast new task of understanding what properties and laws, if any, may characterize biospheres anywhere in the universe" (Kauffman 2000, 9). For such a science, the complexity of life as it has evolved and today exists on Earth—the concrete object of biology in the normal sense—would become but one particular instance of a more general, indeed universal, phenomenon. Because, as Kauffman puts it, "life is an expected, emergent property of complex chemical reaction networks," and it is highly likely that such conditions occur in very many places in the universe other than Earth, we would expect that, rather than arising as a miraculous anomaly, life as such "suddenly becomes almost inevitable" (2000, 35). Within this new and more general framework the scientific object of biology becomes altered and extended, and a corresponding change in scientific method becomes necessary.

In proposing a general biology, Kauffman broaches the question of what can be known not just about our biosphere, the Earth, but about biospheres or ecologies as such. What generic properties, structures, and laws obtain for any possible collectivity of diverse and interactive living things anywhere in the universe? Such questioning relativizes life as it has appeared in Earth's specific evolutionary history with respect to a more abstract and general field of life as such. By investigating this more extensive —or, alternately, intensive—conception of life, a general biology indicates what life as we happen to know it might otherwise have been and could yet be. Just as the subtraction of the axiom of parallels from Euclid's geometric axioms opened up the more general field of non-Euclidean geometries in the nineteenth century (Kramer [1970] 1982, 50–54), or as Ferdinand de Saussure's structuralist innovations in the study of language constituted an advance from empirical to general linguistics in the early twentieth century (de Saussure [1915] 1966), the bracketing of geospecific and empirical elements in Kauffman's general biology would establish a new twenty-first–century scientific field of *biologies in general.*

What exactly would such a science investigate? Included within the purview of such a program, according to Kauffman, would be not only biological organisms and populations but also cultural systems generally understood to be the object of social science—economies, consumer product design, even political systems (Kauffman 1995, 279–98; 2000, 219–

29). What do these different domains have in common? In each case, discrete elements of a system (organisms in a biosphere; producers and consumers in an economy; modular components in a factory; citizens, parties, and laws in a modern state) interact both cooperatively and competitively in a milieu that is itself continually organized and displaced as various interactive strategies among the system's elements appear, disappear, and mutate within it. Such systems, which Kauffman calls "self-organizing" (2000, 21), tend to preserve themselves over time precisely through the constant incorporation—within the limits of a basic, system-preserving repetition—of novelty, differentiation, and growth. In short, such biological, cultural, and political systems *evolve*. A general biology would abstract from the particular contents of these various systems to investigate the laws or patterns ordering their evolutionary form as such.

To help formulate the general laws of evolutionary change, Kauffman introduces the concept of the *adjacent possible*—that set of specific and immediate possibilities available to an evolutionary system at any particular moment of its duration. As a system evolves—biologically, economically, politically—it not only passes from particular state to state but also develops intrinsically within shrinking or expanding zones of what kinds of events might subsequently occur, the possible next steps the system might take. For Kauffman, evolving systems tend to maximize the expansion of their adjacent possible so that the zones of possibility open to them broaden and diversify over time. This would be equally true of ecosystems, economies, and technologies. Kauffman writes:

> I will suggest that a biosphere gates its way into the adjacent possible at just that rate at which its inhabitants can just manage to make a living, just poised so that selection sifts out useless variations slightly faster than those variations arise. We ourselves, in our biosphere, econosphere, and technosphere, gate our rate of discovery. There may be hints here too of a general law for any biosphere, a hoped-for new law for self-constructing systems of autonomous agents. (2000, 22)

A general tendency to expand the adjacent possible may characterize evolving systems as diverse as coral reefs and financial markets: "Biospheres, on average, may enter their adjacent possible as rapidly as they can sustain; so too may econospheres" (2000, 22). Kauffman proposes that this tendency be expressed as a "candidate law" of (evolutionary) thermodynamics: "the hoped-for fourth law of thermodynamics for such self-constructing systems will be that they tend to maximize their dimensionality, the number of types of events that can happen next" (p. 22). Elsewhere Kauffman expresses the same formal law as follows: "Biospheres enlarge their workspace, the diversity of what can happen next, the actual and adjacent possible, on average, as fast as they can" (p. 209). "Biospheres" in a general sense would consist of dynamic relationships of competition and cooperation structuring interactions between discrete "agents" within a system—whether cell organelles, rabbits and foxes, or junk-bond brokers. In general, according to Kauffman, "Communities of agents will coevolve to an 'edge of chaos' between overrigid and overfluid behavior" (p. 22). Under the auspices of a general biology, then, life is conceived as an interactive process realized in systems of individuals and relations that possess intrinsic developmental tendencies.

Kauffman claims that by failing to include cooperative factors in theorizing the evolution of life, Darwinian theory in particular is unable to account for the actual rate of expansion of life's adjacent possible (2000, 16–20). Darwinian biology considers random genetic mutation and natural selection to be the sole engines of the evolution of life. Kauffman argues that only in a time frame far greater than the age of the universe could random mutation and natural selection alone possibly suffice to explain the actual complexity of organisms and ecosystems as manifest all around us. The process of mutation and selection is too slow. There must therefore be some additional cause of this complex order, something other than just natural selection at work in biological development (Kauffman 1995, 16–28). In this one respect his argument parallels those made by creationists and supporters of intelligent design. He differs from these groups by locating in natural self-organization the source of the complexity left unexplained by natural selection alone. Rather than positing some intelligent designer as an extrinsic cause of life, Kauffman claims that collective self-organization, together with competition and selection, accounts for life's evolution.

Collective Self-Organization and Autonomous Agency

What does Kauffman mean by collectively self-organized order? This concept delimits the object of a general biology: the evolutionary laws of collectively self-organizing systems. How does self-organization differ from, say, order that originates in intelligent design? Self-organization describes the way relations between randomly distributed parts of disorganized systems spontaneously form local networks that tend to stabilize and sustain themselves without being designed or ordered from outside. The structure of these networks is thus intrinsic to the sum of relations that compose them. Kauffman calls the emergence of such forms "order for free" in contrast with the order produced through natural selection (1995, 71–92). Selection is a costly process. The coordination of chaotic and random overproduction with the subsequent destruction of less-fit forms does create order, but only at the price of competition and death. Self-organization, by contrast, is "free" in that the order it produces does not require a balancing of survival with destruction. Self-organization is an intrinsic and positive order created from within the interactive structure of systems themselves rather than imposed or carved out by external pressures.

In general, self-organizing systems express three interrelated characteristics: holism, recursion, and a system/environment boundary. In the following basic example adapted from Kauffman's own account (2000, 30–48), these characteristics appear together in the form of a self-organizing event, the event of chemical autocatalysis. By tracing the emergence of an autocatalytic set from its background conditions, we may see how the three characteristics emerge together and function interdependently.

An autocatalytic set appears as follows. As the diversity of types of molecules in a given solution increases, the number of possible reactions also increases, but at an exponentially faster rate. Statistically speaking, as more kinds of molecules are added to a solution, we expect to see a sharp rise in the number of actual chemical reactions. Some of these reactions may result in molecular products serving in turn as catalysts for yet other chemical reactions, and so on. Eventually, this chain of catalysis may lead back recursively to the initial reaction, thus forming a loop. More generally, at a critical point a subset of total chemical reactions in the system is likely to emerge as an interconnected and recursive network, a network structured such that each of its chemical reactions is catalyzed by some product of another reaction in the same network, thus forming a closed subsystem. With each reaction of this network catalyzed by some product of another reaction in the network, the network of reactions as a whole forms a holistic system clearly distinguishable from its environment. The parts of the system (molecules and reactions) work together as a whole that is collectively self-catalyzing, or autocatalytic. In basic terms, A and B react to produce a molecule X that catalyzes the reaction of C and D, while C and D's reaction in turn produces a molecule Y catalyzing A and B. This positive-feedback system of chemical reactions will tend to sustain itself as a whole so long as reserves of the basic molecules A, B, C and D remain available to the system.

A science of self-organizing systems must ask: Where do the holism, self-recursion, and system/environment distinction evident in this example come from? If the answer to this question is to be sufficiently general, it must apply equally to systems of higher-order complexity such as ecologies, "econospheres," and "technospheres." In our example, it should be clear that the principle of order governing the system is located not in some extrinsic form or in the intention of an intelligent designer but rather in the interdependence of the relationships of catalysis, reaction, and production obtaining between the different molecular kinds. The emergence of collectively autocatalytic chemical systems becomes statistically probable at a certain point simply because possible relations between components of a system increase exponentially as the number of components increase arithmetically (Kauffman 2000, 44–45). Yet in our example the interactive dynamism is missing that allows systems as such to evolve by expanding their adjacent possible. The relations constituting autocatalysis are conceived as purely combinatorial and do not mutually affect one another to create new, qualitatively distinct phenomena. Thus, while the example shows what Kauffman means by self-organized order, evolutionary self-organization must involve relations that themselves change and constitute new kinds of events. In ecosystems and cultural formations it is precisely the changing and increasingly complex relationships between parts that constitutes the system's evolutionary development.

Autocatalytic systems lead to living organisms and collective evolution once they function interactively as "autonomous agents." This takes place only when a given autocatalytic system becomes able, as Kauffman puts it, to "act on its own behalf," by doing work (2000, 49). To do work, the difference between system and environment must itself *make* a difference, acting effectively in some observable or measurable way. Technically, an "autonomous agent must be an autocatalytic system able to reproduce and able to perform one or more thermodynamic work cycles" (p. 49). It is only when a system is no longer merely *distinguished* from its environment (from the standpoint of a neutral observer, for example) but *actively transforms* that environment in ways corresponding to the system's own internal structure that the full dynamism of collective self-organization becomes realized as evolution. This occurs when a community of individual "agents" gives rise to regular patterns of interaction and as the correlative effects of these patterns become collectively appropriated through anticipation and response. In this sense, "autonomous agency" serves as the catalyst for collective self-organization in the strong sense, transforming static autocatalysis into dynamic evolution.

MATHEMATICS AND SEMANTICS: A PROBLEM OF METHOD

How does a general biology account for this additional element of autonomous agency? Much of Kauffman's own research in emergent order uses mathematical models—combinatorial Boolean nets, NK fitness landscapes, and category theory—to represent self-organization.[1] Indeed, the very abstraction of a general biology from empirical constraints would seem to require mathematical formalization. Yet Kauffman admits that the character of agents acting on their own behalf (autonomous agency) cannot be understood adequately without introducing semantics, or considerations of meaning, and semiotics, the analysis of signs, into the study of self-organization. The very meaning of autonomous agency demands this because, correctly considered, the concepts of autonomous agency and semantics are ultimately inseparable; the "attribution of semantics to autonomous agents is purely tautological" (Kauffman 2000, 114).

What mathematical models cannot account for is precisely the creative aspect of self-organization, the event in and through which autocatalytic structure becomes autonomous agency. Can self-organization be modeled and studied in its very emergence as a naturally creative event rather than as the stable consequence of such an event? The capacity to create previously unforeseeable possibilities (and thus to extend the dimensionality of the adjacent possible) is directly related to the emergence of autonomous agency, an event that Kauffman argues can be accessed only by way of semantics and semiotics. This is because for Kauffman the notion of an autonomous agent involves consideration of how things seem from that agent's own "point of view." An autonomous agent is thus inseparable from a context of significance—signs and meanings—in which events and entities occurring in the agent's vicinity become oriented in relation to that agent's specific needs and purposes. This constellation of concepts requires analytical tools that mathematics alone cannot provide. Even at the level of a unicellular organism, an external body appears as either good to eat—"yum"—or not—"yuck."

Kauffman alludes suggestively to the work of Charles S. Peirce in this context: "Once there is an autonomous agent, there is a semantics from its privileged point of view. The incoming molecule is "yuck" or "yum.". . . Once yuck and yum, we are not far from C. S. Peirce's meaning-laden semiotic triad" (Kauffman 2000, 111).

The triad to which Kauffman refers is the formal structure at the heart of Peirce's semiotics in which signs are conceived as irreducibly threefold relations between signs, objects, and interpretants (Peirce [1907] 1998, 410). The conjunction and coconstitution of these three formal elements in a single, effective relation marks what Peirce calls "Thirdness," that is, thought or mind as such understood as "of the nature of a habit, which determines the suchness of that which may come into existence, when it does come into existence" (Peirce [1903] 1998, 269). For Peirce signs are the very stuff of thought insofar as thought itself determines future events as possibilities in the world. By linking autonomous agency to the Peircean semiotic triad, Kauffman suggests that the concept of an "oriented agent" as a necessary analytical component of a general biology is intrinsically semiotic, that we cannot adequately model the relationships involved in evolutionary self-organization without at once modeling the triadic relations characterizing signs in Peirce's sense. The question of how autonomous agency emerges in nature becomes the question of how triadic relations, or effective signs, appear in the world.

This referral to semiotics in no way implies consciousness or language as a defining feature of autonomous agency. Instead, we are closer to the way "affects" are understood in ethology as specific ways an organism can affect and be affected meaningfully by its environment. Affects in this sense are real relations that are significant rather than merely causal; they embrace logical properties or types—"good to eat," "dangerous," "potential mate"—rather than mathematically rendered homogeneities. For example, after a heavy rain earthworms crawl onto suburban sidewalks. This is not merely an observable fact but also the kernel of an explanatory hypothesis, or what Peirce calls *abduction* (Morris 2005, 283–87). In this case, we infer from the available facts the hypothesis *Worms avoid drowning*. This hypothesis does not imply that worms are conscious of water, but it does mean that worm behavior cannot be adequately accounted for except as viewed with respect to affects of moisture and dryness that must be conceived as significant with regard to the worms' activity. There may be in principle a mathematical representation of the physical and chemical interactions of water and worm cell molecules, even atoms, but no mathematical description, however exact, could ever adequately depict the simple semantic content of our claim "Worms avoid drowning," because the meaning of that claim is dependent upon a field of analysis recognizing centers of oriented action and differentiated ways of being affected and motivated by qualitative states. The meaning of the claim is open in principle to a spectrum of varying interpretations that cannot be fully delimited in advance. Such affects and motivations are necessarily implied in the very concept of autonomous agency. One might describe the worms' condition as ineluctably dramatic, a condition of life, death, and temporary reprieve staged on a terrain of wet and dry. This dramatic and semantic staging would be characteristic of autonomous agency in general.

At this level of analysis, therefore, the mathematical models that furnish physics and chemistry with exact predictive power no longer suffice. As scientists of a general biology we must have recourse to the powerful ambiguities of meaning and narrative. As Kauffman puts it, "we must tell stories to understand the oriented actions of agents in their worlds" (2000, 113). Here we begin to see the implications of collective self-organization on scientific method. Because the significance of stories can never be reduced to mere algorithms of syntax, scientists should not seek comprehension or explanation of affective significance outside of narratives or hypotheses themselves, just as natural possibilities that emerge with self-organization and autonomous agency in biology should not be sought a priori or as established once and for all by an external designer. In neither storytelling nor biological behavior may the total space of possible configurations or states be fully given in advance. This is so because actualized relations—real events—generate entirely new kinds of possibility in turn. The creative potential of nature revealed in these processes thus appears not at all as an infinite reservoir of abstract possibles that might equally be or not be but must be understood rather as an actual power in nature to develop unforeseen avenues for the future in the stirrings and narrations of the present. This would be especially true with regard to analyses of human agency and human potential.

Kauffman writes, "In short, we do not deduce our lives; we live them. Stories are our mode of making sense of the context-dependent actions of us as autonomous agents. And metaphor? If we cannot deduce it all, if the biosphere's ramblings are richer than the algorithmic, then metaphor must be part of our cognitive capacity to guide action in the absence of deduction" (2000, 135). Stories, metaphors, and the hypotheses they generate cannot be exhausted in a pregiven set of possibilities. Strictly speaking, it is unpredictable what kinds of stories and metaphors will be produced tomorrow or the day after within a given community. Yet, even though we do not know what exactly they will be, we can be sure that once they appear they will exhibit some sort of order in rough continuity with the past. This is because stories and metaphors are generated not randomly but always in some anterior context for some ulterior, if indistinct, purpose. If collectively self-organizing processes in nature have a storylike or metaphorlike dimension, this aspect of their development will necessarily resist mathematical or logical formalization, and science will be capable of investigating this semantic dimension only by participating in it through supplementary reflection, by reading significance through significant narration.

In light of the semantic and semiotic dimension of autonomous agency, Kauffman's proposed general biology thus runs up against a confounding methodological problem, which we may pose as a question: How are scientists to model the logic of self-organizing processes in a way that retains the rigor and abstract generality of mathematics while engaging the unpredictable semantic and semiotic dimension (storied and metaphorical) of autonomous agency?

Deleuze's Concept of the Virtual

A promising avenue for answering this question appears in Gilles Deleuze's concept of the *virtual*, a concept drawn from Henri Bergson's early twentieth-century philosophy of evolution (Bergson [1908] 1991) and central to Deleuze's overall project. Deleuze's method of "transcendental empiricism" has been described as the philosophical attempt "to understand the *actual conditions* under which new things (from ideas to political organizations) are created and produced" (Hayden 1998, 30). For Deleuze, this power to create the new is irreducible to any static or formal conditions but expresses instead a genuinely creative potential that manifests itself in the real becoming of singular events. This becoming, or difference, may be characterized as virtual insofar as it becomes but never stays fixed. As developed through the ramifications of this single concept as operative throughout the basic structures of being, Deleuze's philosophy as a whole is indeed an "ontology of the virtual" (Alliez [1998] 2004, 105). One reason to think that Deleuze's ontology may be appropriate to Kauffman's general biology is that the virtual may be interpreted (a) mathematically but also understood (b) semiotically, as a dimension of the sense of signs. In this twofold thought of the virtual—mathematical and semiotic—we may find a concept that speaks to Kauffman's methodological problem.

Viewed mathematically, the virtual may be understood as describing the role of attractors in complex dynamical systems. Virtual attractors represent those states of a system that need not ever be actualized directly but toward which multiple other states converge or near and between which they oscillate. In particular, Manuel Delanda has shown how this mathematical interpretation of Deleuze's virtual applies to recent developments in both physics and biology (Delanda 2002, chaps. 2, 3). Viewed through a Deleuzian lens, attractors can be understood as constructive rules or patterns for combining and structuring elements in variable systems so as to generate or individuate determinate forms within those systems. These rules may apply, or be realized, in highly diverse contexts such that the resultant actual forms need not resemble one another in any way. It is in this sense that Deleuze elsewhere speaks of virtualities as "abstract" or "diagrammatic" machines (Deleuze and Guattari [1980] 1987, 141–43).

Delanda gives the example of a virtual attractor expressible as the abstract rule *Minimize the total energy of the given system*. As applied to the molecules of a closed surface of soap solution, for instance, this rule minimizes the global surface tension of the system, thus generating the form of a sphere—a soap bubble. However, as applied to a system of sodium molecules, the same rule functions differently by minimizing chemical bond energy rather than surface tension. Minimizing the bond energy between sodium atoms as they crystallize generates the cubical forms familiar also in sodium chloride, ordinary table salt. The soap bubble sphere and the sodium crystal cube do not resemble each other either materially or formally, but the virtual rule governing the process of material formation in each case is characterized by the same mathematical attractor organizing both processes of generation—in this instance, the convergence upon a minimum of total system energy (Delanda 2002, 15–16).

As Delanda shows, this dynamical-systems interpretation of virtuality may be applied to the chemical and energetic composition of living cells as well as to processes of embryogenesis and species coevolution in biology (2002, 45–70). This mathematics of the virtual shows how regulative activity may be compatible with self-organization. In the example given above, one need not posit an exterior or transcendent rule that soap molecules and sodium crystals would independently follow. Instead, the virtual rule "Minimize the total energy of the given system" is itself immanent to the actual, material processes by which soap molecules cohere and sodium atoms electrostatically bind. The rule is built into the intrinsic order that emerges from the unregulated system of interactions among sufficiently large molecular or atomic populations. Similar patterns emerge in species coevolution. Just as the relations of catalysis and reaction in an autocatalytic set form a holistic and recursive system, the interactions here between molecules, atoms, or organisms form determinate structures. The important difference is that the relations between molecules or atoms or animals are not pregiven possibilities but rather emergent structures themselves. The virtual as an "abstract machine" governing independent processes of generation remains inseparable from those processes' concrete actuality and emergence, precisely what Kauffman characterizes as the "order for free" that emerges in chaotic systems. Ideal structures are here inseparable from material realization. Indeed, the virtual provides a way to consider philosophically the effective yet ideal aspect *of* material processes as creative transformation (Alliez [1998] 2004, 108–11).

Viewed semiotically, Deleuze's concept of the virtual appears as a dimension of *sense*. In this light, the virtual represents an incorporeal but nevertheless real dimension of the world that becomes manifest in the immediate transformations wrought by language and meaningful gesture. "The incorporeal transformation is recognizable by its instantaneousness, its immediacy, by the simultaneity of the statement expressing the transformation and the effect the transformation produces" (Deleuze and Guattari [1980] 1987, 81). Deleuze gives three examples of incorporeal transformations: the lover's declaration of love, the transubstantiation of the Christian Eucharist, and the act of hijacking an airplane. In each case, a physical and temporal interaction of bodies is contrasted with an immediate shift in the sense of those bodies:

> Love is an intermingling of bodies that can be represented by a heart with an arrow through it, by a union of souls, etc., but the declaration "I love you" expresses a noncorporeal attribute of bodies, the lover's as well as that of the loved one. Eating bread and drinking wine are interminglings of bodies; communing with Christ is also an intermingling of bodies, properly spiritual bodies that are no less "real" for being spiritual. But the transformation of the body of the bread and the wine into the body and blood of Christ is the pure expressed of a statement attributed to the bodies. In an airplane hijacking, the threat of a hijacker brandishing a revolver is obviously an action; so is the execution of the hostages, if it occurs. But the transformation of the passengers into hostages, and of the plane-body into a prison-body, is an instantaneous incorporeal transformation, a "mass media act" in the sense in which the English speak of "speech acts." ([1980] 1987, 81)

Such incorporeal transformations are virtual in that they express a pure event of becoming in which bodies act as signs. There is no series of physical causes that traces the transformation from friend to lover or from passenger to hostage; these changes are wrought only in the virtual and incorporeal dimension of sense.

With respect to Kauffman's methodological problem, the relevant question is: How do virtual attractors in mathematical systems and virtual senses in gesture or speech express a single concept? How can the virtual be at once mathematically and semiotically expressive but neither mathematical nor meaningful in essence? Both the mathematical and sensical interpretations of the virtual share a way of explaining possibilities in and for a given system as intrinsic to that system itself. Thus the virtual reconceptualizes possibility as immanent potential rather than as abstract possibility—in dynamical systems as in contexts of sense. Deleuze rigorously distinguishes the virtual from the merely possible; the category of the virtual is introduced in order to retain a distinction between ideal and actual aspects of entities, while holding to a integral view of real entities that conceives them as immanent to the events through which they emerge and develop:

> Every time we pose the question in terms of possible and real, we are forced to conceive of existence as a brute eruption, a pure act or leap which always occurs behind our backs and is subject to the law of all or nothing. What difference can there be between the existent and the non-existent if the non-existent is already possible, already included in the concept and having all the characteristics that the concept confers upon it as a possibility? (Deleuze [1968] 1994, 211)

In contrast with the merely possible, the virtual characterizes the real event whereby something new comes into existence, the process itself of individuation or self-organization rather than the result or product of that process. The virtual may thus be actualized mathematically or semiotically without thereby becoming one or the other. In Deleuze's formulation, the virtual is thus "real without being actual, ideal without being abstract" ([1968] 1994, 208).

Deleuze's category of the virtual is helpful for elaborating Kauffman by indicating a way to think according to the creative potential of events themselves, outside of the opposition of possible and real. By holding to the event itself as logically prior to its consequences and results, the virtual pertains to a domain irreducible to either mathematics or signification yet which may express itself equally in both. In this respect, the Deleuzian virtual suggests itself as a properly philosophical and strictly conceptual solution to Kauffman's methodological problem. However, the practical question remains: What methods and procedures would investigate the domain of the virtual as a dynamic aspect of processes observable in the natural world such as biological evolution, economic development, or political formations? This question concerns the methodologies of inquiry and exposition appropriate to those phenomena expressing what Deleuze calls the virtual. These phenomena would include all processes of natural emergence and development exhibiting self-organization as a continuing expansion of the adjacent possible, the very field of Kauffman's proposed general biology. If Kauffman is correct that a general biology is becoming possible, the question of scientific method and practice must be raised anew with respect to self-organization and answered in that same context.

Peirce's Existential Graphs

A guiding thread for approaching this more practical problem is to be found in Peirce's system of existential graphs, detailed introductions and elaborations of which are found elsewhere (Roberts 1973; Shin 2002). As Peirce's self-proclaimed "*chef d'oeuvre*" (Roberts 1973, 11), the existential graphs are iconic diagrams of logical relationships, composed, or "scribed," by a "graphist"—in Peirce's terminology—and read by an "interpreter." The relationships between these interdependent roles form a semiotic triad in the sense alluded to above, with the reasoning processes of the graphist and interpreter functioning as *co-interpretants*, the graph itself as *sign*, and the logical relations expressed in the graph as *object*. These basic elements are brought together in the context of what Peirce calls the "sheet of assertion," or "Phemic sheet"—the paper, chalkboard, cocktail napkin, or sandy beach upon which the graph is scribed and interpreted (Roberts 1973, 31–32). The semiotic relation constituted by these elements may be understood as a collective act of reasoning whereby the graphist and interpreter are brought by way of the graph's signs to act together in a unified logical process, or mind, that is itself a more complex sign. Because the logical relations expressed in all but the simplest graphs exceed any single, definitive reading, the graph as collective sign encourages an unfolding process of interpretation, a kind of commentary that may take place on the same sheet of assertion as an ongoing supplement to the graph.

The graphs themselves are divided into three categories or modes. *Alpha graphs* correspond to propositional logic. Using solely the conventions of assertion and negation, and the capacity to nest negations and assertions in higher negations, the alpha level allows the graphist to represent all of the logical statements we normally express with "not," "and," "or," "implies," and other basic logical operators. *Beta graphs* correspond to predicative logic. What remains compact at the alpha level becomes differentiated in beta; namely, atomic propositions become analyzable in terms of discrete subjects and relational predicates. *Gamma graphs* express the logic of modality and allow for second-order propositions. With gamma graphs one can on the one hand distinguish statements of necessity, contingency, and impossibility and, on the other, construct graphs that refer to other graphs.

The possible relevance of Peirce's graphs to Kauffman's problem of method appears especially at the level of the gamma graphs. Simplifying for the sake of clarity, the gamma graphs may be described as consisting essentially of two new graphical conventions. First, Peirce introduces the convention of a dotted closure symbolizing that whatever is asserted within the area of the closure should be qualified as possibly not the case, thus allowing modal distinctions (contingency, impossibility, and necessity) to enter the logic of the graphs (Roberts 1973, 82). Second, the convention is established that the graphist is able freely to stipulate new conventions at his or her discretion (1973, 75). It is this second, open-ended convention—the capacity to establish new conventions—that places the gamma graphs outside the limits of any formally deductive system and invites comparison with the creative aspect of stories and metaphors in Kauffman's account. In short, the gamma graphs are logical systems of notation in which the creative aspects of abduction, or hypothesis formation, as practiced within the scientific community may be both recorded and repeated iconically.

In practice, the formulation of a new graphical convention is equivalent to an *agreement* within a certain community—at least the two-person community of graphist and interpreter—to treat chosen symbols in a certain regulated way and to treat the meaning of those symbols as relative to the specific use in that context. This agreement establishes an effective triadic relation, a *symbol* in the sense in which Peirce defines it as "a law, or regularity of the indefinite future" (Peirce [1903] 1998, 274). In good pragmatic fashion, the meaning and use of such a symbol converge. In this way, the communicative relation developing over time between the graphist and the interpreter, including the process of agreement through which novel conventions are introduced and established, cannot be excluded from the actual *sense* of the gamma graphs. In practice, a gamma graph serves not just as the representation of a set of logical relations but rather constitutes, motivates, and serves as an open plan for continued communicative action—a "regularity of the indefinite future." As a graph is used, it attains a performative self-consistency—not the consistency of a closed, deductive system but that of a plausible and useful narrative, a self-organizing and self-corrective process of collective interpretation.

Recall that the "sheet of assertion," or "Phemic sheet," refers to the material upon which the existential graphs are actually scribed. While it may seem trivial to point out that these logical diagrams are in fact written on some surface or another, being able to represent this fact explicitly in the graphs themselves has at least one important consequence (Peirce himself introduced the convention "SA" to represent the sheet of assertion at the gamma level). The sign "SA" provides a formal convention for investigating the basic ambiguity of the sheet of assertion itself. This ambiguity would correspond both to Deleuze's distinction between actual and virtual and, more generally, to the complex problematic of material signs as the necessary vehicles of ideality (Derrida [1962] 1989). According to the SA's *actual aspect*, the sheet of assertion would be simply an object in the world, preferably flat and necessarily blank—in short, a material object that can be written on. Yet we may also identify the sheet's *virtual function*. This function would correspond to the way that the signs inscribed on the sheet of assertion are able to convey general meanings.

In this latter respect, the sheet of assertion serves as a virtual screen or site for a regulated process of recording and interpreting logical forms. By a mutually agreed-upon fiction, the sheet of assertion is treated by both graphist and interpreter as not just another thing in the world but as a place uniquely devoted to the analysis of purely possible meanings, a virtual screen for imaging formal and logical relations. By analogy, we may point to the page of a novel or to a television or theater screen as the conventional site of imaginary narratives in everyday culture; one learns how to read a novel or to watch television by looking in a new way, shifting one's focus from the actual paper and ink or the backlit glass surface of the television to the imaginary surface of perception and thought upon which the literary or televised meanings are projected. In Peirce's gamma graphs, the diremption of actuality and virtuality in logical notation and other semiotic systems may be recognized and analyzed formally, first of all as an intrinsic component of the graphs themselves. Use of the gamma graphs thus promises a strictly immanent investigation into self-organization at the semiotic level. Scientific method and practice here cannot be detached from the object which they study.

In addition, although gamma graphs establish contingent relations between the graphist and interpreter, these relations themselves are not *merely* contingent, any more so than are the conventions of symbolic logic or category theory. By being materialized and potentially thematized in the composition of the graphs, these relations attain a certain independence from the particular graphist and interpreter they happen to mediate. Indeed, the gamma graphs themselves may be characterized as a transformative mechanism converting collective processes of thought occurring in specific situations into more generalized structures that may apply in alternate situations. Even in their generalized form, however, gamma graphs retain the marks of their contingent origins. Their general meaning becomes available only by participating at least minimally in the collective fiction and communicative process through which they were originally produced. In other words, gamma graphs map possibilities that emerge concretely within actual contexts of communication (and are thus not merely formal possibilities) but that transcend in at least some ways the particular limits of those contexts. The graphs may potentially function in new contexts, and, although the precise way they will work cannot be known in advance, the source of their communicative power will be drawn from their own intrinsic and virtual structure.

Peirce's graphs become relevant to Kauffman's methodological problem when we recognize that the sheet of assertion plays a role in the gamma graphs analogous to that of the system/environment boundary in natural, self-organizing processes. In both cases a boundary is posited as an artificial closure, a fictional but not unreal distinction that is available or meaningful to only one of its two sides. The ability of an autonomous agent to act on its own behalf is like the agreement between graphist and interpreter to treat the SA as a place for representing logical relations. In both instances an open-ended field of possibilities—a semantic and pragmatic field in each case—is disclosed in relation to a particular and determinate system. A community of molecules making up a living cell, distinguishing itself from its environment by a bilipid membrane, relates to its environment in terms of the bare semantics of "yuck" and "yum"; the community of graphist and interpreter distinguishes the SA from the rest of their shared semantic world as a designated ground for investigating logical relations according to agreed-upon rules. In each instance, new possibilities for action emerge as a triadic relation establishes and maintains itself as an event in the world.

CONCLUSION

How might Deleuze's concept of the virtual and Peirce's existential graphs together help us comprehend and explain Kauffman's idea of natural self-organization in contrast to a model of creationism or intelligent design? Both Deleuze and Peirce provide tools allowing the investigators of nature to treat creative possibility as an immanently emergent and effective property of the universe itself. Human science would be but one expression of nature's power to create self-organizing systems that evolve and diversify over time. The power of the virtual as it appears in scientific enterprises such as Peirce's graphs would lead to a concept of method that makes of knowledge a truth-tending fiction, the creativity and increasing complexity of which is generated internally to a collective system, although in real and measurable relation to external effects. The graphs are able to model triadic relations as logical possibilities and at the same time to establish and participate in actual triadic relations in the world. Deleuze's concept of the virtual provides a way to conceive of such representational and participatory processes without reference to the dyadic distinction of possible and real and to examine the event of creative emergence as a real aspect of nature. Peirce's existential graphs, particularly the gamma graphs, have the additional virtue of being able to represent self-organization while simultaneously performing it. The use of gamma graphs as a method for research and teaching in this emerging field would thus integrate exposition and invention, the represented themes and investigative practices of a general biology.

It is the link between representation and performance that may hold out the promise of a scientific practice that would be at once mathematically and logically rigorous and also collectively interpretative and creative. If, as Kauffman argues, self-organization has an intrinsically semiotic dimension, only a method that is both semiotic in itself and capable of representing the conditions for the production and systematization of signs will suffice to address self-organization adequately as a scientific theme. Just as the rediscovery of Aristotelian philosophy in late twelfth and early thirteenth-century Europe led to the later reformulation of theological concepts of nature and creation in such thinkers as Thomas Aquinas, the scientific research of Kauffman and others working in a similar vein in various fields today presents a challenge and opportunity to rethink creation and nature for the future. The task is nothing less than partly to learn and partly to invent our human share in the ongoing creative event of this world.

NOTE

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1. Boolean nets, or networks, may be used to represent the orderings of relative proximity of distinct states of a given system. See Kauffman's introductory discussion (2000, 161–65). NK fitness landscapes, in contrast, map the degrees of adaptive success for various evolutionary strategies (Kauffman 2000, 198–207). The promise of category theory rests more broadly in its power of mathematical generalization of diverse operations of "mapping" or "morphism," in short, of relation. See Kauffman's brief but intriguing comments (2000, 106–7).

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