THE CONSEQUENCES OF METAPHYSICS: OR, CAN CHARLES PEIRCE'S CONTINUITY THEORY MODEL STUART KAUFFMAN'S BIOLOGY?

by John Bugbee

Abstract. At the heart of the most radical proposals in Stuart Kauffman's *Investigations* is his attempt to show that we find in evolutionary biology some configuration spaces—the sets of possible developments for any given system—that (unlike those in traditional physics of Newtonian, relativistic, and quantum stripes) cannot be completely described in advance. We bring Charles Peirce's work on the philosophy of continuity to bear on the problem and discover, first, that Kauffman's arguments do not succeed; second, that Peirce's metaphysics provide new and sounder arguments for the same propositions; third, that Peirce's rigorous but nonstandard treatment of mathematical continuity shows great promise for modeling the unpredictability and growth we find in evolutionary biology; fourth, that it also strengthens a development only hinted at by biologists thus far—the inevitable involvement of the observer's mind in constituting the objects of science. We close with a logical argument for the surprising relevance of metaphysical hypotheses in the natural sciences and with suggestions for future work that will connect these questions to what Kauffman terms the "narrative stance" in biology.

Keywords: abnumerable; Georg Cantor; category; complexity; configuration space; continuum; emergence; evolutionary biology; exaptation; Firstness; growth; hypothesis; *Investigations*; Stuart Kauffman; mind-dependence; non-prestatable; Charles Sanders Peirce; possibility; potential; preadaptation; prediction; prestatable; purpose; reduction; unpredictability

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The reflections that follow grew out of two observations about Stuart Kauffman's *Investigations* (2000). First, the book raises a great many more philosophical questions than it answers; and second, reading it calls Charles

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Sanders Peirce to mind. The latter remark, although simple, may be somewhat uncommon, because probably few of Kauffman's readers have spent much time with this most neglected of the great modern philosophers. Kauffman's book itself hazards some use of Peirce, but only of his semiotics, and that briefly.[1] In fact, the areas of sympathy are broad and deep, the most obvious being Kauffman's suggestion that the laws of nature, including the laws of evolution, themselves evolve—a notion that also stirred Peirce's blood at the end of the nineteenth century (Peirce *CP* 6.13ff., from 1891; Peirce [1898] 1992, 238–41, 263–68). Kauffman also gives a central place to the notion of growth, or novelty production, which is again in deep sympathy with Peirce's picture of the world.

Here, however, we focus on only one of Kauffman's similarities to Peirce, though one closely related to what he calls his "most astonishing" proposal (Kauffman 2000, ix). It is one of the reasons he (not without a wry acknowledgment of the presumptuousness) named his book after Ludwig Wittgenstein's *Philosophical Investigations*, and it is the reason he says that the book is "not normal science" (p. xi). His proposal is that, just as Wittgenstein's book spelled the end of the program of logical atomism in philosophy, so Kauffman's work demonstrates the incompleteness of a set of natural-scientific methods reaching back three centuries—"the way Newton, Einstein, and Bohr taught us to do science," as he puts it (p. ix).

THE CONFIGURATION SPACE AND THE LIMITATIONS OF TRADITIONAL SCIENCE

At the heart of Kauffman's argument for the limitations of what I very loosely call traditional science we find the concept of a *configuration space*. A configuration space is just the mathematical set of all possible "states"—arrangements, configurations, attitudes—that a system can find itself in. For example, if we are doing a basic problem in Newtonian dynamics, following the motion of a single particle in three-dimensional space, we can express the state of our very small system at any instant by six real numbers: three for the particle's three-dimensional position and three for its velocity (or momentum). Thus the system's configuration space is the set of all possible sextuples, or strings of six, real numbers. Mathematicians are very familiar with such spaces and call this one R^6.

The method of Newtonian science, as Kauffman points out, involves the assumption that we "are able to state ahead of time what the full space of possibilities is, that is, we can finitely prestate the configuration space of possibilities of the system in question" (p. ix). This assumption is left untouched by the twin revolutions of quantum mechanics and Einsteinian relativity. But Kauffman claims to have discovered that for some spaces, preeminently though not exclusively in evolutionary biology, this method is literally impossible; in such cases, he thinks, a different kind of science is required, one that relies in part on telling stories about the development of the studied system. It is not a new fact, or even a new observation, that "biologists tell stories" or adopt a "narrative stance" (pp. 134, 135). What is new is Kauffman's attempt at a rigorous explanation of why that should be the case, based on a peculiarity of the subject matter of biology—namely, that the configuration spaces of its systems are not finitely prestatable.

Kauffman's proposal must accomplish two things to succeed. He must convince his audience that there exist non-finitely-prestatable configuration spaces (a mouthful that I abbreviate NPCS), and he must show that when we encounter them we cannot rely purely on traditional science but must add other methods, including the telling of tales. It is in clarifying and completing his beginnings in these two directions that Peirce's work (respectively in metaphysics and in logic) is extremely useful. In this essay we take on only the first clarifying exercise, leaving the second to possible sequels. But even this beginning will lead us to valuable illuminations: for example, we discover a Peircean object that shows promise for future attempts to model biological complexity, and we observe several points at which metaphysics and natural science inform each other to a much greater extent than workers on both sides often assume.

The Non-Prestatable Configuration Space: Kauffman's First Argument. The quickest way to learn about the NPCS is by considering some concrete situations Kauffman proposes as demonstrations: phenomena that Darwin already recognized and labeled "preadaptations" and that Stephen Jay Gould called "exaptations" (Kauffman 2000, 130). These are features of an organism that initially have no selective significance but that acquire it when the environment changes, thus suddenly gaining what we might call a purpose. Kauffman tells a number of stories, whimsically modeled on Rudyard Kipling's just-so stories, to illustrate the point. A particularly memorable one is the inspiring tale of a "particularly ugly squirrel named Gertrude," who, shunned by all the other squirrels because of the strange flaps of skin connecting her limbs, is eating lunch alone in a tree one day when an owl plunges out of the sky at her. Having no time to think the situation over, Gertrude leaps from the tree, four legs flung wide—and discovers that her extra skin flaps catch air and she can glide down to safety at a steep angle. Naturally she becomes the center of squirrel society after this feat and so leaves many descendants, who, since Gertrude's armpits "turned out to be a consequence of a simple Mendelian dominant gene," are endowed with similar owl-avoidance mechanisms. "And that," the story concludes, "is how flying squirrels got their wings, more or less" (p. 131).

What has this touching tale to do with the claim that the Newtonian and Einsteinian paradigm for natural science is incomplete? Kauffman's point is that there is something about such unexpected developments that traditional science, based on well-understood configuration spaces, cannot capture. He writes, Now, after the fact . . . we would all say in wonder, "Did you see what Gertrude just did?!" And we would tell the story of Gertrude. But could we have said beforehand that Gertrude's ugly skin flaps would happen to be of use that day? Perhaps, perhaps not. Could we have said it four billion years ago? Or said it today about all possible future exaptations? No. (pp. 131–32)

And in such preadaptive situations more generally:

. . . here is my troublesome question. Do you think that you could state, ahead of time, all possible causal consequences of bits and pieces of organisms that might in some odd circumstance or other turn out to be preadaptations and hence be selected and come to exist in the biosphere? Stated more starkly, do you think that you can finitely prestate all the context-dependent causal consequences of parts of all possible organisms that might be preadaptations. . . ? I believe, and it is a matter of central importance if I am correct, that the answer is no. . . another way of stating this is to say that there is no finite prestatement of the configuration space of a biosphere. (p. 131)

We can follow the argument. A lone particle moving in three dimensions has an infinite, but easily described, mathematical "space" of possibilities that it might occupy: R^6. A biosphere, even a small one, containing flabby-armed squirrels or their ancestors, presumably also has an infinite number of possible states it could visit—but in its case we cannot predict well enough to describe the set of possibilities in advance. Nonetheless, Gertrude's armpits-turned-wings are real, Kauffman reasons, and cannot be left out of any adequate physical account of the world, since "the evolution of the biosphere is manifestly a physical process in the universe. Physicists cannot escape this problem by saying 'Oh, that's biology'" (p. 245).

There are, however, two hazy issues that must be brought into focus here. First, it is not as obvious in the biological as in the physical case what should constitute a "state." Kauffman appears to be taking "contains flying squirrels" as a significant attribute of a biosphere, so that the biosphere's position in its imagined configuration space a generation or two after Gertrude's feat will be different from its position before—if, indeed, the shift is not made at the moment of her descent. But who decides what will count and what will not count as a state-determining property of a biosphere? A quick and dirty answer would be that every possible property must be included, but a little reflection digs up serious trouble there. (Here are some possible properties: "containing an odd number of reptiles"; "having a mammal located at such-and-such longitude and latitude"; "containing precisely such-and-such a percentage of its total mass in living organisms." To include those properties would be to say that a biosphere shifts to a new state every time a snake egg hatches, a bear goes for a walk, or a vulture has lunch.)[2] Another solution might be to reduce the configuration space of a biosphere to the less ambiguous configuration space of all the elementary particles that make it up, and hope that one thereby covers all possible properties of the living organisms and their environments. But this is exactly what Kauffman does not wish to do, because *that* configuration space *is* finitely prestatable: it is just the physicist's familiar R^n, though for some enormous n.[3] To make his argument, he must believe that something different, and more complex, happens when we move to a biological configuration space, even though doing so must mean dropping some possible properties from consideration.

The second hazy issue concerns the relation between prediction and Kauffman's prestatement. This informal first argument for the NPCS relies on our inability to predict how a biosphere will develop.[4] But this is odd; our inability to predict how a physical system will behave (when the drops will fall from a chaotically dripping faucet, say) does not ordinarily hinder us from prestating a configuration space for the problem (the only possible answers are strings of real numbers representing the times at which drops fall; the drops will not, for example, suddenly turn into elephants). Normally we learn about the total configuration space of a system, and the particular orbit that the system will take through the space, from entirely different sources. Failure of one source need not imply failure of the other.

These two problems will dog all our tracks through this material and find something approaching a solution only toward the end. For now, we can move toward clarification by considering another of Kauffman's stories, this time about an exaptation of his own devising. This is his sudden insight that if he wedges the power cord of his computer into a luckily placed crack in his living room table, passersby who stumble over the cord will not disconnect the power and rain sorrow upon his hard drive. Could a simple description of the table in its context have predicted this use of the crack? By no means, says Kauffman—or at least it could not have done so by listing all possible uses of every feature of the table. He remarks the "old philosophic realization that there is no finite description of a simple physical object in its context": the coffee table in question features

> three wooden planks, four short squat legs, runners between all pairs of legs. The middle board has a crack in it some eight inches long, a quarter of an inch wide at the end of the board, narrowing to nothing along a particular curved arc. A second crack, smaller, is six inches from the first crack. . . . The first crack is seven feet from the door. . . . Both cracks are 256,000 miles from the moon and 4.3 light years from the nearest star. . . . How would one, in describing all the context-dependent features of the table, happen to list the crack and its distance to the floor socket that happen to turn out to be relevant for my brilliant solution of a sudden problem? (pp. 133–34)

One would not. That sort of top-down or universalizing approach to the problem, which would lay out all possibilities in advance and choose among them, is not tenable here.

It is noteworthy, though Kauffman does not make it explicit, how many of his examples invoke some kind of *purpose*. This apparently small observation turns out to be crucial to the question of the NPCS. I claim that the real difficulty with giving a complete description of the coffee table is not its position relative to the floor socket (or to the moon); both of those are simply numbers, and, if need be, some vast but easily prestatable R^n could encompass the relative distances to every object in the universe. The real difficulty—or, putting it more positively, the only plausible source of the nonprestatable complexity Kauffman hopes to find—is the quite different question of the relevance of the crack's relative position *for* Kauffman's "brilliant solution."

This claim that something special occurs when purpose enters the picture is not without philosophical support, and here at last Peirce's work can come to bear in a serious way. We need to know a bit about what he called his fundamental categories for what follows.[5] The three categories Peirce famously (if at times regretfully, because the suggestion of ordering can be misleading) called Firstness, Secondness, and Thirdness. Probably the fastest way to begin understanding them is to note other sets of labels he sometimes gave: Quality, Reaction, Representation;[6] Potential, Actuality, Law.[7] For our immediate purpose the important point is to register the classification of purposes as a kind of Firstness, or potential. A purpose, considered as such, is neither a thing in the world that can react with other things in the world (a secondness) nor a regularity among such reactions (a thirdness). It is a mere possibility, indifferent to whether it will ever be fulfilled: these loose folds here *could be used* as wings. This crack here *could* handily pinch a power cord in place.

The second required step before Peirce's work can be of use here is the somewhat odder realization that for him *all* attributes of objects must be classed as firstnesses (hence the label Quality for the first category).[8] With that adjustment, we can restate the question of the NPCS in a way that makes the connection to Kauffman clear: Is it possible to give a complete account of all the Firstnesses inherent in a given situation, or even in a given single organism? In a moment we will hear Peirce's resounding "no," and also some metaphysical reasons behind the "no" that will bear further fruit for us. But in order to let Peirce speak to maximum effect, we must first return to Kauffman and consider his attempted proof of the reality of the NPCS.

The Non-Prestatable Configuration Space: Kauffman's Second Argument. What I am calling the second argument for the NPCS proceeds along more formal lines. We might call it the Argument from Very Large Numbers. Kauffman summarizes its strategy:

> I begin by vitiating my assumption that one cannot prestate the configuration space of a biosphere, then try to show that the implications are that the number of potentially relevant properties is vastly hyperastronomical and that there is no way in the lifetime of the universe for any knower within the universe to enumerate, let alone work with, all the possible properties or categories and their causal consequences. (p. 137)

In other words, he will assume for the moment that one *can* prestate a complex space and then "discover" that, although we can imagine a possible universe in which the space is prestatable, it is not so in this one. In Kauffman's eyes that makes it an NPCS for all practical purposes. Let us watch and gauge his success.

Kauffman first describes some simple models of physical systems—a molecule, for example, modeled by an array of one hundred magnetic dipoles, each of which can take two directions, up or down. The possible number of "configurations" for this molecule is of course 2^{100}, a largish number somewhere around 10^{30}. Then, Kauffman suggests, a possible "property" of the molecule should be some collection of the possible configurations. But the number of collections (or subsets) one can make from a set with *n* elements is 2^n. In this case, the number of possible properties is 2 raised to the power of 10^{30}; this works out to roughly 10 to the 10^{29}, or 1 with 10^{29} zeroes after it. Very quickly we have arrived at, in Kauffman's words, a "gargantuan" number, one that swallows as an insignificant mote the 10^{80} particles of the physicist's estimate for our entire universe[9]; and the numbers may rise still more when one considers interactions among two such "molecules" and the procession of each through its own possible states. Kauffman does not go into much detail about this space (which for ease of reference I hereafter call *G*), but his conclusion seems likely to hold: from entities living in such a space, "it becomes easy to conjure multimolecular systems, indeed [living things] are examples, in which . . . it would [never] be possible to compute the detailed dynamics . . . in the lifetime of the universe. . . . There is a sense in which the computations are transfinite—not infinite, but so vastly large that they cannot be carried out by any computational system in the universe" (p. 138). Why not? Because even if one had the entire lifetime of the universe, subdivided to Planck-scale quanta, available as a computing machine, "there are combinatorial problems that are still vaster. Presumably, no physical process in the unfolding universe could have foreknowledge of all features of such problems" (p. 138). Q.E.D., he might have added—such spaces are in our universe non-prestatable, not simply so but because of the limited space and time available.

There is trouble here—some of the same trouble we found with the first argument. For one thing, we again must ask "What space do you mean?" The problem comes into sharper focus here, because there is no debating the fact that *G* itself is prestatable, indeed easily so. Here is a compact description of it: Each element of *G* is a set of some number of 100-length strings of zeroes and ones; *G* is the space of all possible such sets.[10] Having such a description means that we know quite a bit about the solutions of these equations in advance, insoluble though they may be: we know the precise form that any solution must take. Given any entity in the universe, we could say at sight whether or not it falls into the class of possible solutions.[11] This is just the sort of (limited, but real) predictability that the well-behaved configuration spaces of "traditional science" afford us—the analogue of the drops from the faucet that do not turn into elephants.[12] It is not what Kauffman thinks happens in biology.

How, then, can he claim to have arrived at a NPCS, even a merely practical one? It follows that he must be thinking not of *G* itself (or its more complex but still prestatable relatives) but of another set of properties, probably one that emerges out of the in-practice-unfathomable mathematical dancing of *G*. We see a hint of that idea just as he concludes the second argument. After describing the impossibility of computing "the detailed dynamics" of some of these "coupled spin system[s]," he adds, "But it is just such detailed wiggling by the coupled system that allows discovery of the preadaptation that a particular wiggling of one molecule senses a subset of states of another molecule and is useful for some survival purpose" (p. 138). Suddenly, between two sentences, we have moved from the world of strictly delimited and somewhat bloodless mathematical models to a world in which properties of objects can count as "adaptations" and "purposes." We can infer that Kauffman's picture of the situation must run something like this: *G* is an enormously complicated (but finite and prestatable) space; it is easy to write equations over *G* that cannot be solved; a "state" or element of *G* corresponds to a "property" in some more everyday sense (perhaps for a macroscale observer) that can include purpose and adaptation; because the equations governing a typical entity's dance through *G* cannot be solved, we also cannot know in advance what macroscale or everyday properties the entity will visit in its real-world orbit; therefore, we cannot prestate the space of possibilities through which the real-world system moves. This must be the NPCS that Kauffman claims to have found.

This invocation of emergence, however, has gotten us out of one trouble and into several others. The simplest problem is that Kauffman offers no reflection on the arrival of purpose between the two sentences but simply declares it. If it holds, he has successfully demonstrated a kind of pathway (albeit not a purely deductive one) from simple discrete mathematics to the enormous complexity of macroscale purposes. But some discussion is needed to account for our sudden recognition of purposes in a system where before there had been only the combinatoric dance of a vast number of simple discrete possibilities. (There is one promising possibility hiding behind that word *recognition*: We might want to say that talking of purposes in a system begins to make sense precisely when we stop trying to talk about the system as it is in itself, a mathematical object with no relation to any observer, and start talking about the system as observed. When human cognition comes on the scene, perhaps, we cannot help but discover purposes where before there were none. This line of thought would harmonize fairly well with Peirce's ideas about Firstness.)[13]

Another trouble with the idea of a space emergent from *G* is that our second "hazy issue" from the first argument is still with us. Here, as there, Kauffman seems to confuse a demonstration of the impossibility of *predicting* a particular entity's orbit *through* a configuration space with a demonstration of the impossibility of prestating of the space itself. These should be separate questions, with no necessary implication between them; there are plenty of spaces that are easily prestatable but in which it is possible to concoct equations too vastly complicated for numerical solution (*G* and R^n are both examples). Thus, even if Kauffman can convince us of the existence of a second space, related to *G*, in which purposes have somehow emerged from a combinatoric background, it is not clear that our inability to predict the movements of entities in *G* implies an inability to know anything about the general nature of its emergent shadow. We certainly know plenty about the general nature of *G* itself, and it is not obvious that our only source of knowledge about its shadow would be from examining our predictions of systems' motion through *G*. As already noted, it would be very unusual for us to learn to prestate a configuration space that way.

The third trouble with the explanation via emergence is just a more sophisticated version of a refrain we have heard twice before: What space are we talking about? If we are not talking of combinatoric *G*, but an emergent partner space made of macroscopic properties, fine; but whose space? Which properties? To speak of all possible properties is to speak of something unmanageable for our ordinary science—as Peirce will shortly show us. To speak of any more limited space is to deploy some criterion for choosing which properties we find significant, and therefore to inextricably inject human subjectivity, and probably some measure of arbitrariness, into the objects of our science.[14]

In summary, we see two possible ways to interpret Kauffman's second argument. Either Kauffman means that *G* itself (or its close relatives) is practically non-prestatable, in which case we must simply disagree; or, more likely, he is thinking of a second space that emerges therefrom. The second possibility is interesting, but the argument has problems that vitiate its status as proof that such a space must be practically non-prestatable.

In the wake of such doubts, we now turn back to our other resource, Peirce, to see whether we can find there an argument that will more convincingly reach Kauffman's laudable goal.[15]

Peirce's Continuity as a Replacement for the Second Argument

In our previous glance at Peirce, we learned of his claim that the properties of objects are a different kind of entity from material objects themselves: they are instances of Firstness, and their being is potential. Now we can investigate the importance of that claim. Doing so connects our inquiry to Peirce's lifelong concern with continuity, a notion that he elevated (as the principle of "synechism") into a fundamental tenet of all his work (see Peirce [1898] 1992, 243ff., esp. 261; *CP* 6.169ff.). The period in question stretches roughly from 1867 to 1914, so his investigations naturally involved him with the work of mathematicians Georg Cantor and Richard Dedekind, who were similarly seeking a rigorous mathematical construction of a continuous set—an effort not unlike Kauffman's attempt to provide a rigorous mathematical construction of an NPCS, and dogged by similar difficulties. Peirce followed them and in some cases appears to have anticipated their results by several years (*CP* 5.256n), but the philosophical relevance he attached to continuity went far beyond anything they proposed. He believed, and claimed to prove, that a mathematical continuum was a more general case of what in formal logic we call a general term (Peirce [1898] 1992, 160, 189–90, 258, 261–62). Thus, for him, the late–nineteenth-century mathematicians' work on continuity also revolutionizes our logic; and revolutionary changes in our metaphysics, and eventually our physics and all the sciences, should not be far behind.

To trace out the implications of this line of thinking would be a life's work—the life's work Peirce left unfinished, in fact—and I do not attempt it here.[16] But we can attend to some of the logical consequences of continuity most relevant to Kauffman's projects. We can scarcely avoid the topic, which arises in a Peircean context as soon as talk about properties or qualities begins. Consider the following incidental observation, from a 1903 lecture on the visual logical notation Peirce called "existential graphs":

> Now, *qualities* are not, properly speaking, individuals. All the qualities you actually have ever thought of might, no doubt, be counted, since you have only been alive for a certain number of hundredths of seconds, and it requires more than a hundredth of a second actually to have any thought. But all the qualities, any one of which you readily can think of, are certainly innumerable; and all that might be thought of exceed, I am convinced, all multitude whatsoever. For they are mere logical possibilities, and possibilities are general, and no multitude can ever exhaust the narrowest kind of a general. (*CP* 4.514)

After a few quick annotations, we should hear some important echoes of our recent discussions. First, because logical generality is for Peirce just a special case of mathematical continuity, his talk here of possibilities as general also implies that they collectively make up a continuum.[17]

That leaves us with two mathematical ideas to understand. Peirce says that the number of properties available for any given person to think of at any one moment is not only infinite but "innumerable": this is not the metaphor of today's common speech but a precise technical term for which mathematicians today would substitute "nondenumerable" or "uncountable." In any of these guises, the word refers to a set that is in a precise sense "larger" than the infinite set of natural numbers 1, 2, 3, 4. . . . The real numbers are the most familiar example.

Peirce then adds his frequent claim that the total "number" of possible properties *tout court* (as opposed to properties available to any one person's thought at a given instant) is still larger—so vastly large, in fact, that it is improper to speak of it as a number at all. He is being quite literal in saying that properties "exceed all multitude." He means that the real situation-in-the-world of properties cannot be adequately modeled by *any* set of individuals, even an "innumerable" one, even any of the infinite series of ever-larger multitudes that Cantor christened the alephs.[18] As long as a set can be constructed from individual points in a way that the individual points retain their identity, for Peirce, the set is not "big" (perhaps we should say "rich") enough to match the richness of possible properties. And *this* is what Peirce means by saying that the properties form a continuum. A continuum is for him something other than a collection of individuals, a different kind of being; strictly speaking it "does not contain any individuals at all. It only contains general conditions which *permit* the determination of individuals" (Peirce [1898] 1992, 247; cf. *CP* 6.185).

The relevance of this to our explorations of Kauffman should be coming clear.[19] Kauffman's second argument attempts to model a richly innovative biosphere, aswim in properties and purposes, by starting with a discrete and finite set and observing as it brings forth a vast (though finite) space of "properties." But Peirce tells us that when we want to understand any property, or any other instance of Firstness, any finite model will fall dizzyingly short. This finding is much more than just a no-go argument that heads off Kauffman's second argument at its start: It simultaneously delivers, by another road, the argument's goal. Once Peirce's three categories are accepted, it follows almost by definition. Can we prestate the configuration space of a biosphere? No, for Peirce, because a biosphere—whatever choices we may make about which properties count—will certainly be awash in properties and purposes. Because these come from a continuum, we simply cannot give a complete account of them. We will see more clearly why this is true once we have learned how a Peircean continuum behaves, and that in turn will suggest the surprising and promising result that such a continuum may prove useful in a capacity where no mere collection of points will serve—namely, that of a rigorous logical object that usefully models the complexity of a biosphere.

It seems a strange claim. After all, Peirce's continuum sounds like a rather inert, and annoyingly abstract, mathematical object. This is just the point, however: Peirce's continuum cannot properly be called inert. One could demonstrate the fact by tracing Peirce's writings on the subject from, say, 1898 to his death in 1914. Some of that rewarding work has already been done, and for reasons of space we here rely on earlier workers. In a commentary on Peirce's 1898 lecture series, Hilary Putnam and Kenneth Lane Ketner write, "A metaphysics of continuity, in Peirce's sense . . . is a metaphysics which identifies ideal continuity with the notion of inexhaustible and creative possibility" (Peirce [1898] 1992, 37). At the end of the commentary they explain this identification, and their explanation relies on large numbers, or rather entities larger than numbers, in a way that cannot but call Kauffman to mind. Discussing the "number" of possible subdivisions of a line as a paradigm of the attempt to relate a continuum to individual points, they write:

> The Peircean picture is that the multitude of possibilities is so great that as soon as we have a possible world in which some of these possibilities are realized—say, a possible world in which some abnumerable[20] multitude of the divisions are made—then we immediately see that there is a possible world in which still *more* divisions can be made, and hence there is no possible world in which all of these *nonexclusive* possibilities are *all* actualized. We might summarize this by saying that the metaphysical picture is that possibility intrinsically outruns actuality, and not just because of the finiteness of human powers or the limitations imposed by physical laws. (Peirce [1898] 1992, 54)[21]

For Peirce, a continuum is that when faced with which we are in a situation of strangeness and insistent novelty. This is because no matter what vast set of particulars we describe, by enumeration or rule, in an effort to capture the continuum, we will learn that there are opportunities for finding still more properties. It is almost as if a continuum shifts or expands as necessary to elude our nets. We might borrow a thought from the opening of the *Tao Te Ching*: The continuum that can be named is not the true continuum.

We also find in Putnam and Ketner's language a hint that the additional properties we "immediately see" "as soon as" we make our attempt to pin the continuum down could not have been seen earlier. How can this be true? Consider Peirce's observation that the continuum contains no points (properties, in our case), only conditions that permit their determination. This means that a continuum is, as it were, a dialogue waiting to happen. When we approach the continuum with a particular will, particular questions and interests, particular habits of thought both species-wide and individual, it responds by disclosing the properties that our will, questions, and habits "determine." Other questions, interests, or habits would determine other properties. In order to arrive at the commentators' conclusion that those other properties are wholly unpredictable, we need only believe that we cannot learn what response a continuum will give to any particular approach in any way shorter than by making the approach.

In that case, however, we can see why the continuum is a viable candidate for modeling biospheres in a way that sets of individual points, like *G*, were not. First, it is in principle impossible to prestate it. We can never communicate all the possibilities resident in a true continuum, because it is a misunderstanding even to speak of "all the possibilities"; there are none until we make our approach, and then the ones that appear will depend in part on our own interests and attitude.[22] This strange fact, of course, is actually a second piece of evidence for the great promise contained here, because this strange behavior of a continuum is very much like the strange behavior we twice detected in biospheres. The approach of a will that determines which individual points will appear from a continuum is very much like the approach of the biologist or community of biologists who determine which of a biosphere's properties, out of the continuum of all possible properties, will be selected as important to our science and determinative of the biosphere's state. The questions Whose space? and Which properties? turn out to be real ones, for continua as for biospheres; in each case the objects we find ourselves working with depend in part on the mental tools we bring to the site.[23]

THE CONSEQUENCES OF METAPHYSICS

Much unexpected fruit has followed quickly on the consideration of Peirce's metaphysical categories—not only a replacement for Kauffman's second argument but also a new entity that shows signs of modeling the intractable characteristics of biospheres, namely, their resistance to prestatement, their unpredictable growth, and the apparent mind-dependence of what we reckon as their properties. With such an impressive track record, Peirce's metaphysics would seem ripe for at least hypothetical adoption by anyone wanting to work out Kauffman's suggestions further.

It does, of course, have one major disadvantage—it is a metaphysics, and some will find its adoption, even provisionally, too bitter a pill to swallow. Is it not of the essence of scientific method to forgo all dispute over metaphysics? Are not metaphysical claims by definition insusceptible to empirical investigation? Is not Peirce's own pragmatism an attempt to steer us away from conflicts futile because insoluble?[24]

One need not go far to find someone professing just these views, but we have several good reasons to believe the opposite. For one, we have just witnessed a counterexample, a case in which the provisional adoption of a particular metaphysics proves fruitful for explaining and unifying scientific propositions. For another, we have the witness of some of the best-versed workers in the philosophy of science: see, for example, Karl Popper's essay "Philosophy and Physics" ([1960] 1996) for reflections on the appropriate role of metaphysics in empirical science.

Beyond that, there are at least two ways to make our own argument for the scientific relevance of metaphysics. One is to investigate the role metaphysics plays in Peirce's larger system. His 1903 "Outline Classification of the Sciences" reveals that it is not delivered by arbitrary fiat, nor is it the ultimate ground of everything else, but itself relies on logic, phenomenology, and mathematics (*CP* 1.180–201). Thus there are, in Peirce's mind, antecedent justifications for his metaphysical categories. Unfortunately, these justifications will be a hard sell to people already suspiciously disposed toward philosophy in general, and they also require extensive exploration of Peirce's corpus before they become convincing.

We pass, therefore, to a different method more likely to find favor with devotees of natural science: justification by consequences. That is, a metaphysical hypothesis can be adopted provisionally, just as a physical one can, and its truth, validity, or fruitfulness judged according to how well its consequences match reality (although the judging does not work quite as simply or forcefully as in the case of physical hypotheses). I do not here lay out the argument in full but simply outline how this scientific testing of metaphysics might work.

First, we must know that Peirce's logic of science describes, alongside deduction and induction, a third form of reasoning he most often called "abduction," roughly corresponding to the formation of hypotheses to explain things. A salient characteristic is that, unlike with deduction and induction, we have very little in the way of external rules that can guide us toward making *correct* guesses; purely formally, any guessed explanation is as valid as any other. We do, however, seem to have an innate power of making surprisingly good guesses; this is Peirce's understanding of Galileo's *il lume naturale* (*CP* 6.477). For Peirce, this "instinct" of ours has evolved with the species but also can be trained by an individual's experiences. Thus, a veteran medical specialist's power of making hypotheses about the etiology of certain symptoms is vastly greater than mine.

If we adopt a large metaphysical hypothesis as a belief—for example, Peirce's claims about the three fundamental categories and the continuity of properties—that, too, will have an effect on the structure of our minds. Among other things, it will change the hypotheses we form when we encounter a new situation. One who adopts Peirce's metaphysical hypotheses will, over the long run, do science somewhat differently from one who adopts Kauffman's, or again from one who tries to adopt none at all. We might say that a large metaphysical hypothesis *A* helps give rise to a host of smaller empirical hypotheses p_1, p_2, and p_3, and a different metaphysical hypothesis *B* instead nudges its adherents toward q_1, q_2, and q_3.

These *p*- and *q*-hypotheses probably will concern empirically testable matters, just because that is what we most often form hypotheses about. It will be possible to deduce consequences from them, compare the consequences with generalized experiences, and thus falsify or strengthen the hypotheses, all according to the Peircean (and, roughly, Popperian) account of scientific inquiry.[25] Let us say that p_1, p_2, p_3 are all falsified. Can we confidently assert that *A* is also false? No; because the immediate consequences of *A* (the *p*-hypotheses) arose by abduction rather than deduction, falsifying those consequences does not necessarily falsify *A*.[26] However, it is still fair methodology to believe that in the very long run even these abductive linkages will behave themselves—that is, certain metaphysical hypotheses will over time give rise to more fruitful and more accurate physical hypotheses than others. Whether or not we are so bold as to call these "correct," we would do well to adopt them rather than their less successful competitors.[27]

Conclusion

Our approach to Peirce's metaphysics bearing in mind the question Kauffman raises has not only clarified the questions and answered a few of them; it also has suggested two directions for future work. First, what further fruit can be grown from the promising similarities of behavior between Peirce's continuum and Kauffman's non-prestatable biosphere? How can we pursue this hope for a rigorous-yet-relevant model of living systems, one especially well adapted to modeling growth and the necessary mind-dependence of the objects of science?

Second, pressing on to the next phase in our slow philosophical expansion of Kauffman's work, if we are now convinced by these stronger arguments that cases of non-prestatable configuration spaces do exist, do they also help us understand what Kauffman originally wanted us to understand, namely that the alternative science that follows must involve storytelling? Will Peirce's triadic logic, closely tied as it is to the triadic metaphysics that has proven so useful here, help us toward this understanding?

Finally, and importantly for the long term, our explorations remind us that the boundary between metaphysics and natural science is not as resistant to travelers as one might suppose. We have seen an example of and then an argument for the principle that metaphysics can be subject to scientific testing. That is just one of several ways in which both Kauffman and Peirce draw us toward a healing of the separation that the last three centuries have imposed between the "two cultures" of scientific and humanistic thought.

Notes

A version of this essay was read as part of a panel on "Peirce, Hegel, and Stuart Kauffman's Complexity Theory," sponsored by the Religion and Science Group and the Pragmatism and Empiricism in American Religious Thought Group, at the annual meeting of the American Academy of Religion, 20 November 2005, in Philadelphia.

1. And with some inaccuracies. Kauffman refers to Peirce's semiotics as based on the triad "sign, signified, significans" (Kauffman 2000, 111); in fact Peirce's mature triad is made up of sign, object, and interpretant, with the inclusion of the interpretant setting his semiotics apart from others'. This correction is merely noted for the record and does not affect our work here. See Peirce 1931–1958, vol. 2, para. 227 and 242–43. Citations from the eight highly nonchronological volumes of Peirce's *Collected Papers* are hereafter given in the standard format showing volume and paragraph number, with the original composition or publication date of each particular paper provided when necessary: Peirce, *CP* 2.227 (1897), 2.242–43 (1903).

2. Even if the instability of "states" so defined were an acceptable consequence (and I think it is not, because such constant change would obstruct our view of the limited number of

things about a biosphere that we find important), such a definition would render the configuration space a completely unmanageable, perhaps literally unthinkable, entity, as we will see Peirce arguing further on.

3. Kauffman is, moreover, explicit in his opposition to this kind of reductionism, which is probably another reason he chose his title to resonate with Wittgenstein's (Kauffman 2000, 125–29).

4. In fairness, Kauffman does not see this "first argument" as an argument but just as a heuristic setting of the scene, after which what I call his "second argument" attempts actual proof. I have paired them off by labeling them both arguments because that helps clarify what features they share.

5. The reference is to the unpublished paper "One, Two, Three: Fundamental Categories of Thought and of Nature," excerpted at *CP* 1.369–72 and 1.375–76. The fact that the categories apply both to thought and nature shows the intertwinedness of Peirce's metaphysics with his logic; indeed the two are inseparable to a degree that questions the propriety of speaking of them individually. These points will become more relevant in any sequels that use Peirce's logic to examine Kauffman's "narrative stance."

6. Peirce's breakthrough 1867 paper "On a New List of Categories" lists Quality, Relation, and Representation (*CP* 1.555); his comments circa 1905 on that paper amend Relation to Dyadic Relation (1.561). For Reaction, see Peirce [1898] 1992, 266; *CP* 6.19 and 6.32 (1891).

7. This characterization can be found at *CP* 6.343–44, among the "Notes on Metaphysics" from 1909; cf. also *CP* 1.427 ("The Logic of Mathematics," 1896) and 1.23 (Lowell Lectures, 1903). Good approaches to the three categories in general are via *CP* 1.284–353 and Peirce [1903] 1997, esp. 167–203.

8. We must proceed carefully here. When Peirce says that the particular grainy-textured shade of bright red that confronts me from the book on my desk falls into the category of Firstness, he emphatically does not mean that this particular *instance* of grainy-bright-red so falls. The attachment of that particular quality to this book, and the event of my perception of the quality, are both encounterable facts about the world, and therefore heavier in Secondness than Firstness. What counts as Firstness is this quality of grainy-bright-redness understood purely as a possible perception that some mind could someday have. That is why it is classified as a potential. To say that an object "has" a certain "attribute" is, for Peirce, exactly to say that such-and-such kind of mind, which encounters the object under such-and-such conditions, will have such-and-such an experience. (I rely throughout on Peirce's mature revisions of his system, for example in "What Pragmatism Is," "Issues of Pragmaticism," and the following articles (*CP* 5.411–63ff.), in preference to the more widely known account of pragmatism and properties in the 1878 "How To Make Our Ideas Clear" (*CP* 5.388–410). The earlier piece is the birthplace of pragmatism and repays study, but Peirce later moved away both from it and from William James's branch of the tree.)

9. For that estimate, see Kauffman 2000, 137. As another measure of the size of the space Kauffman has cooked up, consider that if all the current inhabitants of Earth suddenly set themselves to doing nothing but writing zeroes, and could write them at about four per second, it would take us over 100 billion years merely to write the number down. The fabled googol (10^{100}), a large number by most reckonings, is minuscule in such company; it can be written out by a single person in half a minute.

10. Kauffman, it is true, asks us to consider interactions among molecules, *G* running up against some *H*, as well as a few other complications; but none of those changes will do more than lengthen by a phrase or two our description of the configuration space.

11. Kauffman's argument that this situation of "knowing one when we see one" constitutes knowledge only of sufficient but not necessary conditions for inclusion in a class (p. 128) seems a bit confused. We must know *some* universally necessary conditions for inclusion, or we would have no criterion against which to compare each candidate. Kauffman's own example gives a definition of "autonomous agent" that provides necessary characteristics of everything so classified. What he is after may be better expressed by saying that the necessary conditions that make up the criteria for inclusion are not themselves fully determinative of our knowledge of what can fill the category; they do not allow us to imitate or predict all *other* characteristics of every object that will meet the limited criteria. (It is likely that we will have to borrow quantifying concepts from the predicate calculus, perhaps including Peirce's tripartite quantification of subjects as general, singular, and vague, to handle this question adequately.)

12. Indeed, our situation with respect to *G* seems little different from our situation with respect to R^6: in neither case can we enumerate all the set's members, but in both cases we can describe them by rule. (Of course R^6, being infinite, is the larger of the two spaces by an infinite margin.)

We may note that the trouble with Kauffman's attempt to find non-prestatability in *G* is similar to the trouble he senses in some colleagues' attempts (called "algorithmic chemistry," or "Alchemy" for short) to find biological complexity in a computer-run simulation of molecules built up from simple well-defined entities. Kauffman suggests that such attempts fail precisely because they are algorithmic and thus bound by a degree of adherence to the original rules that does not hamper living systems (pp. 121–23, 135–36). We have seen here that *G* similarly fails to jump from its precisely defined origins to anything beyond prestatability.

13. I am not the first to suggest that Kauffman's handling of purpose needs further refinement. See for example Corning 2004, 766–77, for a plea for the inescapability of purpose in biological systems and a contention that approaches that start from the purposeless worlds of mathematics and information theory will never adequately add in purpose later.

14. Of course, the philosopher will step forward to claim that this injection of subjectivity is not a problem but clear evidence of one of the points where natural science demands consideration of questions usually branded "philosophical" and sealed off from the scientist's attention. Perhaps, the philosopher might suggest, we must start considering the role of the perceiving mind in all scientific accounts of the world, or at least in a much broader spectrum of cases than those involving quantum phenomena where the observer is already often invoked.

15. Why laudable? Because the "second argument," if it could be found, would resoundingly accomplish two (almost contradictory) things that Kauffman wants most: It would ground our talk about biological systems in rigorous mathematics and simultaneously demonstrate that there is something in living systems that cannot be reduced to such rigorous underpinnings. It holds out the promise of a science that combines the best features of today's "harder" and "softer" lines of inquiry—a science as rigorous as abstract mathematics and as relevant as ethics or psychology. Kauffman is aware of the bridge-building nature of what he desires, and he mentions the hope of overcoming the division between C. P. Snow's "two cultures" (Kauffman 2000, 22, 135). The next section demonstrates why Peirce should be his ally in that quest.

16. For a good start, following the principle of continuity through several areas of Peirce's philosophy and producing in the process one of the best general books on Peirce of the last few decades, see Parker 1998.

17. For more explicit statements that possibilities are continuous, see Peirce [1898] 1992, 247, 261; *CP* 6.182. For reasons of space, we bracket the question of whether Peirce here confuses the generality inherent in any one possibility (suggested in note 8) with the generality of the continuum of possibilities; or again whether he confuses the specific kind of generality Firstnesses have with the different generality—more often associated with continua—of Thirdness. At times Peirce associated possibilities or Firstnesses with a different kind of "indeterminacy" which he called not generality but vagueness. (See *CP* 5.447 for the vague and the general; *CP* 1.304 has a nontechnical statement of the different generalities possessed by Firstness and Thirdness.) Our concern in what follows is with the generality of the continuum of possibilities and the way in which particular possibilities may be extracted from it.

18. For attempts at rigorous demonstration of the claim that true continua are beyond all multitude, see Peirce [1898] 1992, 157–61, or, more simply, *CP* 6.168. As for Cantor's alephs, these are an infinite series (aleph-null, aleph-one, aleph-two . . .) of cardinalities or "sizes" for progressively "larger" infinite sets; Cantor believed every set of size larger than aleph-null (the cardinality of the natural numbers) to be continuous. The main streams of today's mathematics and physics seem to have accepted that judgment, in that physicists use the real numbers, whose cardinality is aleph-one, to model spacetime, even when they are ignoring its quantum graininess. (See Kleene 1971, 3–65, for an excellent presentation, technical but readable, of the development of mainstream mathematical opinion and a few of its discontents.) Peirce, however, found aleph-one vastly too small to count as continuous; *CP* 6.168 gives some of his reasons. For him, no collection of individual points can be continuous, so that the relation between continuum and point (and hence that in logic between general and singular) is something other than a relation of simple inclusion.

19. Its relevance for Peirce's work in general is, as mentioned, fundamental. A continuum is, among other things, the ideal type of Peirce's Thirdness, so that this divide between continua

and anything constructed from discrete points is the foundational instance of the irreducibility of Thirdness to Secondness. Peirce's (perhaps somewhat Trinitarian) insistence on the mutual irreducibility, but also inescapable asymmetrical intertwinedness, of the three forms of being-and-thought lies at the heart of his philosophy. It ultimately is this that provides the hope of his work's usefulness in dealing with reduction and emergence; the categories contain already built in the same sort of almost-paradoxical relationship lying somewhere between flat reduction and total separation. Also from here grows the antireductionism that has prompted several scholars (see Nubiola 1997, for example) to suggest Peirce's strong influence in transforming the early Wittgenstein into the late Wittgenstein. This hypothesis, if true, makes Peirce not only a potential contributor to Kauffman's current projects but their direct ancestor.

20. *Abnumerable* is Peirce's more usual term for *innumerable* or *nondenumerable*.

21. Readers of Kauffman will note that even the language Putnam and Ketner use recalls his description of complex systems as a core of actuality surrounded by a thin layer he calls the "adjacent possible" (pp. 142–44). Their conclusion exactly recalls his: The adjacent possible always grows with the growth of the actual, and in fact grows "faster" than the actual. (This is yet another reason why Peirce's metaphysics of continuity seems an ideal underpinning for Kauffman's mathematical biology.) The fact that our inability to compass a continuum does not depend on "the limitations imposed by physical laws" highlights a noteworthy contrast between Kauffman's argument for non-prestatability and the Peircean one here emerging. Kauffman's to-all-intents-and-purposes non-prestatable space turns out to differ even in practical ways from Peirce's continuum.

22. As we have just seen, it also always becomes clear that there are more possibilities to be had than we have managed to list or describe in any speech-act about the continuum. This ostensible "growth" may also be useful for modeling biospheres' unpredictable growth. At the very least it calls to mind Kauffman's discussion (pp. 136–37) of the possibility of modeling complex biological growth by the augmentation of axiom systems subject to Gödel's incompleteness theorems.

23. There is, however, an obvious challenge to the exciting prospects for modeling biospheres and other non-prestatable spaces with Peircean continua. For Peirce, *any* property of *any* object comes from a continuum of possible properties. The weirdness we are exploiting is not, for Peirce, limited to living systems but extends just as much to any situation of inert physical objects—particles in an electric field, for example. It would seem to follow that *all* configuration spaces should, for Peirce, be non-prestatable—in rather marked contrast to the success of "traditional science," which has worked most of its wonders for the last several centuries on the hypothesis of simple, well-understood, prestatable spaces.

I see two ways around the problem. One is to hold fast to the principle of continuity and claim that all configuration spaces *are* in fact non-prestatable, and that the apparently prestatable ones are merely approximations that hold good for a time in certain limited circumstances. I suspect that this is the position Peirce himself would adopt. It seems loosely analogous to the (debatable) view that Newtonian mechanics resides within quantum mechanics, or within general relativity, as a special case deducible when conditions are right; so too prestatable science resides within Peircean complex science.

A second possible solution derives from Charles Hartshorne, who finds Peirce's categories incorrectly skewed toward continuity. He notes that Peirce's death in 1914 prevented him from seeing the most successful years of the quantum revolution but believes that a "mistake . . . metaphysical and logical" played a greater role than "empirical ignorance" in the skew (Hartshorne 1997, 15; cf. 10, 11, 127, 166). He proposes a modification of Peirce's categories that gives greater space to the discrete, and it could be that an approach via these modified categories would yield a world with two kinds of configuration space, some prestatable and some not. (Others may argue that Hartshorne sometimes responds unfairly to early Peirce, whose later theories already encompass discreteness adequately under the category of Secondness; the debate is worth pursuing.)

24. For example, "The Fixation of Belief" (*CP* 5.358–87) investigates four methods by which humans may settle disputed questions, the scientific testing of consequences being the last and best. But readers who conclude that pragmatism must be an anti-metaphysical program of reduction to consequences are relying only on these early (1877–78) essays of Peirce and not reckoning with his later retractions; see note 8.

25. One of Peirce's latest and best accounts of the logic of science, interestingly enough for *Zygon* readers, appears in the course of complex theological work, in the 1908 piece "A Neglected Argument for the Reality of God" (*CP* 6.452–91, esp. 468–77).

26. Technically the situation is that *modus tollens* (the logical rule that makes proofs by contradiction work) cannot apply when the link between the two propositions under consideration is abductive rather than deductive. This is because the essence of deduction is its necessity, or, as Peirce liked to say, its property of never leading from true premises to a false conclusion. Abduction does not have that property, and therefore the discovery that the conclusion of an abduction is false need not imply, as it does with deduction, that one or more of the premises is also false.

27. We come then to a result that agrees in practice with Popper and Hartshorne: It is possible to falsify empirical statements conclusively but not metaphysical ones; it is possible to "support or confirm" both kinds of statement by comparing consequences with experience, but not to prove them (Hartshorne 1997, 30). All of this appears to give to metaphysical hypotheses something like the status of a research program. (For a thought-provoking account of the importance of which in today's science, with special reference to Darwinism, see Depew and Weber [1995] 1997, 1–30.) One thinks of the current situation in quantum mechanics, where the Copenhagen interpretation and David Bohm's pilot-wave model produce identical empirical predictions but give quite different pictures of the world and so eventually may lead to different sequences of experiment, of which one may prove more fruitful than the other. Religious "hypotheses," too, may play similar roles; see Peirce [1898] 1992, 259, for the claim that the notion of a Creator who "determin[es] so-and-so" represents, though in unscientific garb, the only good solution to a genuine philosophical problem. It, too, is likely to guide what questions its adherents ask and what experiments they undertake.

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