A Volume in
Exploring Complexity

Volume Four

Emergence, Complexity, and Self-Organization:

PRECURSORS AND PROTOTYPES

Exploring Complexity Series

Volume 1: **Reframing Complexity: Perspectives from the North and South**
Fritjof Capra, Alicia Juarrero, Pedro Sotolongo, & Jacco van Uden (eds.)
ISBN 9780976681465.

Volume 2: **Classic Complexity: From the Abstract to the Concrete**
Kurt A. Richardson & Jeffrey A. Goldstein (eds.)
ISBN 9780979168833.

Volume 3: **Origins of Self-Organization, Emergence and Cause**
Vincent Vesterby
ISBN 9780981703206.

Volume 4: **Emergence, Complexity, and Self-Organization: Precursors and Prototypes**
Alicia Juarrero & Carl A. Rubino (eds.)
ISBN 9780981703213.

Exploring Complexity: Volume Four

Emergence, Complexity, and Self-Organization:

PRECURSORS AND PROTOTYPES

Edited and Introduced by
Alicia Juarrero & Carl A. Rubino

ISCE Publishing

17947 W Porter Ln
Goodyear, AZ 85338

Credits

Thanks goes to the following for help in obtaining original texts, and/or for permission to allow reprinting: Clarendon Press (Chapter I), Longman (Chapter II), Indiana University Press (Chapter III), Macmillan (Chapters VI and X), Routledge and Kegan Paul (Chapter VIII), Cambridge University Press (Chapters IX and XII), and University of Minnesota Press (Chapter XIII).

Emergence, Complexity, and Self-Organization: Precursors and Prototypes
Exploring Complexity Book Series: Volume 4
Edited and introduced by: Alicia Juarrero & Carl A. Rubino

Library of Congress Control Number: 2008928120

ISBN13: 978-0-9817032-1-3

Printed in the United States of America

To the Memory of Ilya Prigogine

CONTENTS

Emergence, Complexity, and Self-Organization:

PRECURSORS AND PROTOTYPES

Introduction

Alicia Juarrero & Carl A. Rubino

Does nature resemble a ramp or a ladder? Are nature's ubiquitous discontinuities merely apparent differences, fully reducible to quantitative differences, or do they signal qualitative ruptures that cannot be understood to be the smooth accumulation of simple accretions or growth? Are qualitative differences merely illusory, fully explicable once we capture the laws of the deepest level of subatomic particles? Would such a "theory of everything" demonstrate that what *seem* to be novel and different properties and levels of organization are just that—mere appearances reducible to that fundamental level and thus predictable according to its laws? Is there really "nothing new under the sun?"

Or, on the contrary, is Ilya Prigogine correct in maintaining, as Robert Artigiani puts it, that "nature is too rich to be described in a single language" because qualitatively new ontological levels of organization emerge in the course of evolution?[1]

These problems have perplexed human beings as far back as we can see. In times whose view of the world focused on the inviolate and qualitative discontinuities between the earthly and divine—or the physical and the non-physical—realms, fundamentally novel properties, species, and similar phenomena were presumed to have appeared only as the products of separate, individual acts of creation that took place at the beginning of time. In the book of Genesis, for example, their distinctiveness is marked metaphorically (or literally, if you wish) by the day of their occurrence, and their "nature" does not change over time. One legacy of this way of viewing the world is the presumption that the universe is a fundamentally static place in which only superficial characteristics can change. Essential properties are thought to be unchangeable and eternal *because* they were uniquely and separately created. But now that advances in cosmology and the theory of evolution have refuted the notion that species and galaxies are eternal and unchanging, the question has become "Is change to be

1. Robert Artigiani, "The Evolution of Humans and Human Evolution," *Evolution and Cognition* (2002) 8.1, 2-19, referring to Ilya Prigogine, *From Being to Becoming: Time and Complexity in the Physical Sciences* (San Francisco: W. H. Freeman, 1980), p. 51.

understood as an unfurling of preformed potentialities, or do qualitatively new phenomena emerge over time?"

Uncritically examined presuppositions about emergence, which have been with us for centuries, are the product of various inheritances. Take, for example, the beginnings of philosophy in ancient Greece. In the sixth century B.C.E., Heraclitus concluded that change alone is real and stability is illusory. "Everything is in flux," he said, "and nothing stands still"; and, comparing existing things to the flow of a river, he adds that we could not step into the same river twice[2]. In this view, change is a fundamental constituent of the universe, and thinkers are obliged to offer a satisfactory account of it.

Parmenides, on the other hand, came down decisively on the side of permanence and order, arguing that the universe is motionless and immutable and that change, development, and evolution are therefore impossible. In his view, what is mutable, complex, and unpredictable, what evolves or develops—that is, the world we live in and perceive with our senses—is nothing more than an illusion. This view establishes a stark contrast between the false world of belief and opinion, whose object is the phenomenal world, and the real world of truth, whose object is the immutable and eternal world of being.

Plato's elaboration of Parmenides' position was put forth in a manner so persuasive that it became the touchstone of subsequent Western thought—European philosophy being, in Whitehead's words, no more than "a series of footnotes to Plato"[3]. For Plato, our imperfect and uncertain world is an illusory imitation of a perfect world of forms to which we are called to return. His pupil, Aristotle, on the other hand, attempted to save the world in which we live by offering an account of change, introducing the notions of potency and actuality and of composite being consisting of mutable matter and immutable form. In the last analysis, however, Aristotle too remained captivated by order and permanence, seeing them as the sole sources of reality and truth. Thus Heraclitus, the ancient Greek champion of change and transformation, was effectively swept under the rug by Plato, Aristotle, and their numberless heirs.

Those who contemplate the American battle about evolution with disbelief often seem to forget that the argument about change and permanence was around long before the coming of today's fundamentalist Christianity. Classical thinkers who, like Aristotle, subscribed to the reality of change nonetheless remained convinced that the heavenly bodies were of a different nature and type than our earthly abode. The understanding of change as the unfolding of existing potentialities—a form of preformationism—and the concomitant denial of true emergence have been deeply pervasive features of Western thought. Indeed, it would difficult to underestimate their reach: to take but one striking example, they underlie Herbert Spencer's use of the term *evolution* in his description of the ideas of Darwin (who never used the term himself).

---

2. Heraclitus, Fragment 218 in the standard edition by Diels and Kranz (Hermann Diels and Walther Kranz, *Die Fragmente der Vorsokratiker* [Zurich: Weidmann, 1985]).
3. Alfred North Whitehead, *Process and Reality*: *An Essay in Cosmology*, corrected edition, ed. by David Ray Griffin and Donald W. Sherburne (New York: The Free Press, 1978), p. 39. *Process and Reality* was first published in 1929.

For millennia, then, the standard explanation for any apparent discontinuities in nature has either been the *deus ex machina* (i.e., "divine intervention") argument or, in the case of non-Christian thinkers such as Aristotle, the belief that "It has always been so." The position is that nothing truly new can emerge from antecedent natural sources. Although Aristotle, unlike Plato, believed in the reality of change, for him change is possible only in non-essential matters: there can be no such thing as significant, qualitative change. For Aristotle, then, genuine change could only be what modern science would label *development*, the unfolding of established dispositions, not the sudden or even gradual appearance of qualitatively distinct characteristics, phenomena, or species. The idea that entirely novel traits or phenomena might emerge over time was as foreign to Aristotle as it is to today's "literal interpreters" of the Bible.

Adhering to Aristotle's notion that nothing can change itself, either fundamentally or otherwise, the medieval scholastics who were inspired by Aristotle also envisioned a more or less static universe where emergence was illusory, not fundamentally real. The germs for subsequent denials of emergence can be found, for example, in the scholastic principle that denies the possibility of a universe in which substantive emergents pop into existence. Indeed, and in conformity with the same tendency in Aristotle, the axiom that "there cannot be more in the effect than there is in the cause" was deployed as a central feature in arguments for the existence of a First Mover or Cause, or God, by thinkers as seemingly diverse as Aquinas and Descartes.

What counts as a legitimate scientific or philosophical explanation? This is a question that crucially affects our conclusions about emergence. As far back as Aristotle, for an explanation to count as scientific—as *episteme* or *scientia*—the *explanandum*, the phenomenon to be explained, was held to be deducible from universal laws functioning as the major premise in a syllogism that served as the *explanans*. Aristotle held that other forms of explanation, such as *phronesis* (practical wisdom), were appropriate in certain circumstances (see below), but after Francis Bacon and the scientific revolution of the seventeenth century deduction became the only legitimate form of explanation. As a result of this new view of science, explanation became identified with prediction. Moreover, to serve as ideal *explanantia* by allowing for precise prediction, laws must be exceptionless or "strict," a requirement that effectively excludes the laws of the "special sciences" (psychology, sociology, etc.—and *a fortiori* those areas of study) from qualifying as sciences per se. Hence the schism described in C. P. Snow's notion of the two cultures, and the dismissal of the special sciences as suspect at best, subjective at worst[4].

The principle "If not deducible and therefore not predictable, hence not explained" becomes particularly problematic whenever explanations bridging levels of organization are attempted—that is, for example, whenever one tries to deduce chemical phenomena from physical phenomena, or biological phenomena from chemical phenomena. The issue of reductionism thus becomes

4. C. P. Snow, *The Two Cultures and the Scientific Revolution* (Cambridge: Cambridge University Press 1959); reprinted, with an introduction by S. Collini (Cambridge: Cambridge University Press, 1993).

invariably tied to the ontological status of emergents. Those who do not believe that reductionism is possible in principle (because, for example, of the fundamental indeterminism of quantum mechanics) are more likely to subscribe to the ontological reality of emergence. Those who hold that reductionism may be possible in principle but not in fact (because, say, of our inability to specify initial conditions to the degree of precision required for deduction to be carried out) at best grudgingly admit to a notion of emergence that applies only to our scientific theories or explanatory frameworks.

Differences in scale or level are often at the heart of the question of emergence. When a number of individual particles interact to form a larger collective, clear distinctions appear between events that occur at the particulate level and those that occur at the collective level. Interaction—now often called feedback—is a necessary if not a sufficient requirement for hierarchization. Without interaction among the parts, a collective is a mere aggregate, with no new or perhaps no interesting properties that cannot be predicted from the sum of the particles that make up the aggregate. But when interaction or feedback is present, systemic wholes different from the components that made them up can suddenly appear. With differences in the scale of form or organization, a systemic level of novel properties or laws, absent at the "lower" or particulate level, suddenly appears on the "higher" or collective scale, often surprisingly or unpredictably so, requiring scientists to consider—or reconsider—relationships between parts and wholes.

Equating explanation with deduction and therefore prediction became (and continues to be) such an entrenched unquestioned principle that even Darwin, despite arguing that natural selection is the mechanism whereby one species emerges from another, maintained that evolution was inexplicable in principle because the central role that random, chance mutations played in producing the variability on which natural selection operates foreclosed any possibility of deduction and therefore explanation. Perhaps this is the reason why Darwin's writings are more like *narratives* than scientific treatises.

As C. Lloyd Morgan notes, the term *emergence,* first proposed in the 1870s by George Henry Lewes in *Problems of Life and Mind* and then taken up by Wilhelm Wundt in his *Introduction to Psychology*, was coined precisely to identify instances in chemistry and physiology where new and unpredictable properties appear as products that are emphatically not the mere sum of the separate elements from which they arise. Mechanical *mixtures* display only properties that are additive and subtractive, and that are hence predictable and hence explainable. Chemical *compounds*, in contrast, are neither. Are they therefore true emergents?

By the first third of the twentieth century, the so-called British Emergentists, a group that, in addition to Morgan and Lewes, includes D'Arcy Thompson, Samuel Alexander, C. Lloyd Morgan, and C. D. Broad, along with Henri Bergson and Alfred North Whitehead, all noticed features in chemical processes that cannot be explained solely in terms of physics and its laws. Their diagnosis was often quite accurate, correctly indicting the assumptions of a mechanistic science for its inability to account for special laws, mereological causation, which involves relationships between parts and wholes, self-organization, morphogenesis, and the like. Not everything, they argued, is reducible to the basic laws of physics or the basic laws of physical causality. Unfortunately, however, their proposed solutions to the problem were often couched in terms such as *élan vital*, *nisus* towards deity, or other modern-day equivalents of the ether; thus their proposals possessed no more explanatory power than the old *deus-ex-machina* appeals to divine creation.

Recent advances in physical chemistry and biochemistry, molecular biology, and other such bridge disciplines have held out hope that all seemingly emergent properties could eventually be reconciled and thereby deduced from lower level characteristics and laws. In a world long marked by physics-envy, emergence became discredited by a combination of Laplacean determinism and what might be called a sort of promissory reductionism. These proposals also delayed the production of a serious account of emergent phenomena, for in the meantime biology—and in the twentieth century, the burgeoning of the new science of ecology—continued to resist being shoehorned into the reductionist mold of physics.

Mereological relationships, i.e., relationships between parts and wholes—which in the case of ecological systems and organisms such as the slime mold, for example, include the relationship between organisms and their environment—have never been satisfactorily explained. How should relationships across levels be understood? In particular, how are causal relationships between levels to be explained, especially top-down causality?[5]

During the long period of Aristotelian domination, the integral nature of an organic whole, of an *organism*, conferred on it the status of substance possessing a *sui generis* type of top-down causal power. This was the *formal cause*, which could exert causal, but not efficiently causal, power on its components. This notion enabled Aristotle to explain the voluntary motion of animals. With the scientific revolution of the seventeenth century came the insistence that wholes—including living organisms—are no different from aggregates, and that secondary qualities are mere causally inert epiphenomenal and/or subjective appearances. Legitimate scientific methodology denied all ontological status to higher-level phenomena, insisting that any truly causal relationships between organizational levels be one-way only: bottom-up.

But by claiming that only the lowest level of reality—the purview of physics—is real and causally effective, modern science in effect dismissed the entire problematic of mereological relationships. If systemic, organic wholes are in reality no different from aggregates, emergence is merely quantitatively different. Since the only type of causality mechanism would accept is efficient causality, modern science also claimed that higher levels of organization and their properties were mere epiphenomena. Such was the case with the characteristic features of, for example, the emergent we call *mind*: its so-called *qualia* (color, taste), consciousness, and the rest were assumed to be mere epiphenomena,

5. See Alicia Juarrero, *Dynamics In Action: Intentional Behavior as a Complex System* (Cambridge, Mass: MIT Press, 1999).

causally inert, ontologically moot, and therefore scientifically irrelevant. Talk about top-down causation was dismissed as nonsense.

But once divine intervention or any dualist ontology is excluded from consideration, how *does* one explain mental phenomena, in particular, consciousness and *qualia*, those two bêtes noirs of neurophysiology? These, the so-called hard problems of neuropsychology, neuropsychopharmacology, cognitive behaviorism, and the rest of the macroscopic zoo that constitutes contemporary Cognitive Science, are virtually the sole remaining topics of interest to those examining the Mind-Body problem. Once life has been more or less explained, they would also appear to be the sole remaining candidates today for the role of emergents.

Because the prism of emergence reflects different hues depending on the angle from which it is approached, this anthology might have included much the same selections if its title had been *Anti-Reductionism*, *Against Mechanism*, *Problems with Efficient Causality*, or even *Organismic Philosophy*, *Holism*, *Self-Organization*, or *Complexity*. As editors we had to exercise judgment in our choice of what to include. Thus, although the topic of self-organization and the question of whether the systemic whole thus created is emergent or reducible are central to our subject, the emphatically technical character of the writings by Alan Turing on morphogenesis and by W. Ross Ashby on self-organization led us not to include them in this volume.

Since this collection is intended for English-speaking readers, we also decided (reluctantly, we must admit) to limit our selection, with the exception of a few easily obtainable items, to material written in English.

Our decision to stop in the middle of the 1950s may also seem somewhat arbitrary, but it is clear that by the end of that decade Behaviorism was casting its shadow over the philosophy of science. Perhaps propelled initially by Hempel and Oppenheim's influential paper on the logic of explanation, and later buttressed by the hegemony of J. B. Watson and B. F. Skinner, the distinction between legitimate, that is, reductionist, science, and the "soft sciences"—forever suspect *because they are irreducible*—had become crystallized into the form described in Snow's delineation of the two cultures[6].

In the middle of the 1950s the reigning mechanistic worldview required that nonlinear phenomena like turbulent flow be labeled *chaotic*, in the traditional sense of the term that suggests complete disorder akin to chance and randomness. From the vantage point of the early twenty-first century, we can now see that it was not until the last quarter of the twentieth century, with the discovery of dissipative systems and self-organizing phenomena, the renewed examination of turbulent flow, and the research into cellular automata and other such forms of A-Life, that scientists and philosophers came to appreciate that some deterministic systems can exhibit a hierarchy of apparently novel properties, seemingly emergent characteristics of systems that are sometimes predictable in principle but not in fact. (The surprising discovery that seemingly random phenomena in fact embody a highly sophisticated degree of order is ar-

6. Gustav Hempel and Paul Oppenheim, "Studies in the Logic of Explanation," *Philosophy of Science* 15 (1948), 135-175.

guably the reason why James Yorke's expression, *chaos*[7], was so quickly adopted as a catchall name for these phenomena.) Prior to the middle of the 1950s, however, philosophers and scientists inevitably couched their arguments in favor of emergence in the context of their objections to mechanistic presuppositions. The subtle distinctions among mere development (the unfurling of preformed potentialities), the emergence of novel but epiphenomenal properties and entities, and the emergence of higher order properties that can exert top-down influence on their particulate components remained unappreciated. Today, they are still not fully understood.

Not until Ilya Prigogine was awarded the Nobel Prize in 1977 for his work on Dissipative Structures and, with Isabelle Stengers, published the surprisingly popular *La Nouvelle Alliance* two years later, did many serious scientists and philosophers dare question "the goals, methods, and epistemology" of modern science[8]. Doing so required scientists to reconsider the creative aspects of nature, made manifest in an evolutionary process displaying irreducibly emergent properties.

The results of this "new alliance" and new dialogue with nature are most spectacularly evident in the appearance and elaboration of what has come to be called Complexity Theory. This mode of thought is founded on the notion, eloquently and persuasively developed in Prigogine's work, that nature speaks with too many voices to be reduced to a single tone or captured by a single narrow mode of observation. It is the conviction of the editors of this volume that what has come to be called Complexity Theory can "account" for the strong emergence of higher ontological levels of complex organization.

A number of scientists and philosophers anticipated many of the objections to mechanism that have now become commonplace. Some of them even advanced bold hypotheses that can now be acknowledged in retrospect as legitimate adumbrations of some of the notions about self-organization and complexity that are current today. Because scientific understanding had not yet advanced to the point where it could offer positive alternatives (and because, as a result, the solutions they offered were of the *deus-ex-machina* variety), these pioneers were often dismissed and even ridiculed during their lifetime. Now, however, with the advantage of hindsight, we can map out an entire trajectory of missed or ignored possibilities.

The discovery of flaws in the mechanistic worldview began at least as early as Leibniz, who, according to Whitehead, was the first to base philosophy "on the presupposition of organism"[9]. Much emphasis has been placed on Leib-

7. See Tien-Yien Li and James A. Yorke, "Period Three Implies Chaos," *The American Mathematical Monthly* 82 (1975), 985-992.
8. Ilya Prigogine and Isabelle Stengers, *La Nouvelle Alliance: Métamorphose de la Science* (Paris: Gallimard, 1979), adapted into English as *Order out of Chaos: Man's New Dialogue with Nature* (New York: Bantam, 1984).
9. Whitehead, *Science and the Modern World* (New York: Macmillan, 1925), p. 223. Whitehead credits Bertrand Russell, *A Critical Examination of the Philosophy of Leibniz: With an Appendix of Leading Passages* (Cambridge: Cambridge University Press, 1900), for suggesting this line of thought.

niz's notion of monads that are "windowless." In our terminology, "windowless" would mean "closed," and we know that emergence can only be accounted for in a theory about open, not closed, systems. In a letter written in 1704, Leibniz implicitly acknowledges this difficulty when he admits that the principle reason for postulating his "System of pre-established Harmony" is that it appears to be the only thing that can explain mind-body interaction—what we call "downward causation"[10].

In 1893, Henri Poincaré, whose essay holds an important place in this volume, argued that the science of thermodynamics has revealed a complex universe in which the time-honored laws of mechanics no longer apply universally. How are we to overcome the contradictions that arise? Poincaré's reply raises a question central to the philosophy of science: must all legitimate explanation be deductive?

The problem is so complicated that it is impossible to treat it with complete rigor. We are therefore compelled to make simplifying hypotheses. Are they legitimate? Can they be reconciled with one another? I do not believe so.

We have not, Poincaré concludes, managed to resolve the enormous difficulties involved in reconciling mechanics and thermodynamics, and it is unlikely that we ever will.

This last point brings to mind some prophetic words of Aristotle, speaking in this case about ethics, which he defines as a branch of "political science":

Our account of this science will be adequate if it achieves such clarity as the subject-matter allows; for the same degree of precision is not to be expected in all discussions … it is the mark of a trained mind never to expect more precision in the treatment of any subject than the nature of that subject permits; for demanding logical demonstrations from a teacher of rhetoric is clearly about as reasonable as accepting mere plausibility from a mathematician[11].

Ethics and politics, which involve making choices and decisions whose consequences extend into an uncertain future, cannot yield absolute certainty. Poincaré's remarks suggest that, with the coming of thermodynamics, Aristotle's words might extend to the world of natural science as well; and Prigogine's elaboration of his discovery of dissipative structures has made the connection explicit. We live, he says, in a world in which "the future is no longer given" and "is no longer implied in the present." The old ideal of certainty has lost its force, along with the ideal of omniscience. The world of processes in which we live and which is part of us can no longer be rejected as a world of mere appearance or a set of illusions determined by our mode of observation[12].

10. *Die Philosophischen Schriften von Gottfried Wilhelm Leibniz,* ed. C. I. Gerhardt (Hildesheim: Georg Olms, 1960), vol. 3, pp. 341-342. As far as we can determine, this letter has never been translated into English.
11. Aristotle, *Ethics* 1094b11-27, trans. by J. A. K. Thomson, revised by Hugh Tredennick (London: Penguin, 1976).
12. Ilya Prigogine, "Probing into Time," *Discovery: Research and Scholarship at The Uni-*

Both Poincaré and Prigogine echo the essay by Charles S. Peirce that we have included in this volume. One of us has written the following about Peirce:

As Peirce argues, the laws of mechanics cannot account for the "inexhaustible multitudinous variety" produced by the evolution of species: "that variety," he notes, "can spring only from spontaneity." There is no way to reconcile the theory of evolution, which defines a universe of inexhaustible variety marked by spontaneous developments, in which time is irreversible, moving forward inexorably, and the future remains open, with a world in which "everything is given," where there is no room for chance and spontaneity, where time is an illusion, and the future is implied in the present[13].

That article goes on to say that Prigogine's discoveries about the behavior of non-linear systems far from equilibrium confirm the wisdom of Peirce's observation that while force, the driving principle of classical mechanics, is dissipative, chance, an essential constituent of thermodynamic processes, is concentrative. As Peirce puts it, "the dissipation of energy by the regular laws of nature is by these very laws accompanied by circumstances more and more favorable to its reconcentration by chance." Entropy, the measure of disorder in a system, now becomes a creative principle by which systems reorganize themselves to face the future.

We can end this section with a reference to Hegel. In the Preface to his great work *The Phenomenology of Spirit*, written at the beginning of the nineteenth century, he argues that substance is subject, by which he means that the heart of the universe is restless, constantly on the move toward its future. Attempts to explain both the world and philosophical and scientific systems that offer accounts of the world must recognize the "fluid nature" of such phenomena:

The bud disappears as the blossom bursts forth, and one could say that the former is refuted by the latter. In the same way, the fruit declares the blossom to be a false existence of the plant, and the fruit supplants the blossom as the truth of the plant. These forms do not only differ, they also displace each other because they are incompatible. Their fluid nature, however, makes them, at the same time, elements of an organic unity in which they do not only not conflict, but in which one is as necessary as the other; and it is only this equal necessity that constitutes the life of the whole[14].

---

versity of Texas at Austin 5.1 (September 1980), 7.

13. Carl A. Rubino, "Joyous Entropy: The Phenomenon of Laughter and the Science of Thermodynamics," in Siegfried Jäkel and Asko Timonen (eds.), *Laughter Down the Centuries*, Vol. 1, *Annales Universitatis Turkuensis* Ser. B, Tom. 208 (Turku: Turun Yliopisto, 1994), p. 135.

14. G. W. F. Hegel, Preface to the *Phenomenology of Spirit*, Section 2; translation in *Hegel: Texts and Commentary*, ed. and trans. by Walter Kaufmann (Garden City: Anchor Books 1966), p. 8.

Fluid phenomena and the fluidity required of explanations that might provide a satisfactory account of them can never satisfy the old ideals of certainty and omniscience.

If there were any hope for certainty in explaining a fluid and emergent process, it would come only when that process has reached its end—in Hegel's words, "only when actuality is already there cut and dried after its process of formation has been completed." By the time that opportunity arrives, the world has already passed it by: "the owl of Minerva," Hegel concludes, "spreads its wings only with the falling of the dusk"[15].

We can now turn to a discussion of the selections included in this book.

Immanuel Kant (1724-1804) claimed that he been awakened from his "dogmatic slumber" by the Scottish empiricist and skeptic David Hume[16]. When it comes to accounting for causality, however, Kant owes more to Leibniz's notion of *vis viva* he does than to Hume. In the *Critique of Teleological Judgment*, which appeared in 1790, Kant focuses on the only type of causal connection found in Newtonian science, mechanistic efficient causality, and notes its inability to explain the kind of causality present in phenomena whose forms are not possible "on purely natural laws," i.e., as a result of the "mere mechanical operations of nature." Whereas organized beings have *formative* power, an analogue of *life*, machines, Kant observes, have solely *motive* power. When parts combine on their own into the unity of a whole by being reciprocally cause and effect, a novel specific quality or form is produced that is unlike anything the "mere mechanism of nature" can provide. Kant invites us to consider living organisms such as trees, which are both the causes and effects of themselves. A tree produces itself as an individual by means of a material, its leaves; but the leaves themselves are the tree's own product. The components of such "physical ends" are, as living organisms, not only reciprocally dependent on the preservation of other parts (such as grafts); they are also reciprocally dependent on their relation to the whole. Every part owes its existence to the agency of all the other remaining parts and also exists for the sake of the others and of the whole—i.e., a physical end is an organized and self-organized being.

The kind of causality involved here, Kant concludes, is "nothing analogous to any causality known to us," involving as it does "regressive as well as progressive dependency." The Newtonian understanding of causality belongs to the categories whereby the human mind structures perceived phenomena—and circular or mereological causal relationships are banned from this worldview. Thus, Kant concludes, we have no option but to relegate entities we can only approach as physical ends to the regulative, not the constitutive judgment. It would not be until the late twentieth century that Ilya Prigogine would re-

15. Hegel, *Philosophy of Right*, trans. with notes by T. M. Knox (Oxford: Clarendon Press, 1952, rev. 1957), pp. 12-13.

16. Immanuel Kant, *Prolegomena to any Future Metaphysics*, trans. by Lewis White Beck (New York: Liberal Arts Press, 1950), p. 8.

ceive the Nobel Prize for raising precisely the issue of the self-organization of order out of chaos that Kant had raised two hundred years earlier.

Questions and problems surrounding the received (i.e., mechanical) view of causation presented ongoing difficulties for philosophers of science in the eighteenth and nineteenth centuries, problems which John Stuart Mill (1806-1873) takes up in "On the Composition of Causes," an essay that numerous thinkers concerned with the problem of emergence (such as Peirce, Morgan, and others) would later cite. Mill looks in particular at two of the fundamental principles of mechanistic science: the Principle of the Composition of Forces or Causes, and the Doctrine of Proportionality. According to the former, considered a basic axiom of mechanism, laws operating in situations where several agents (or causes) contribute to the production of an effect are but a "summing up" of laws that express the effect of each cause acting by itself: i.e., any law capturing the combined causal influence of several agents expresses the sum of the causal influence of each causal agent acting separately. Not only do all mechanical phenomena display this characteristic, the Principle of the Composition of Causes serves as a fundamental pillar of modern science by providing an explanation of why mechanics is a deductive and demonstrative science: the effects of combinations can be computed from the laws we know to govern those causes when acting separately.

Mill was among the first to point out that this principle does not prevail in all aspects of nature. Chemistry, he notes, is not a deductive or demonstrative science: the chemical combination of two substances such as hydrogen and oxygen produces a third substance, water, with properties different from those of the other two separately or combined. The same goes for the sugary taste of lead and the blue color of vitriol.

The second principle of Mechanism addressed by Mill is the "Principle of Proportionality," which holds that effects are proportional to their causes, a principle that presupposes that the world is linear. This doctrine, Mill points out, does not apply in those cases where increasing the cause alters the *kind* of effect—i.e., in those cases where "a totally different set of phenomena" arise. Not only are these new properties and entities not merely quantitatively different from what went before; they also bring entirely new laws into play. If Nature does not throw off emergent entities, how are we to account for this anomaly? The principles of Proportionality and the Composition of Causes do not apply in cases of apparent emergence, in other words. Mill concludes that the law of proportionality must be superseded by a more comprehensive principle.

It is clear from the selections included in this collection that these two issues in the field of chemistry puzzled thinkers precisely because of their implications regarding the questions of emergence and reduction.

Echoing Mill's concerns, Charles S. Peirce (1839-1914), whom we have already cited, explicitly challenges the Determinism of Mechanism. He does so by questioning the ontological status of the axiom "Nature is Uniform," which, like Mill's Principle of Proportionality, suggests a linear universe. Peirce notes that the principle "Nature is Uniform" is sometimes stated as "every event has a cause," and he recasts it as the belief that "every intelligible question ... is susceptible in its own nature of receiving a definitive and satisfactory answer." This principle presents two problems, the same problems implied by the Second Law of Thermodynamics: if it is true, then creativity is absent from nature, and the inexorable tendency of natural phenomena is to invariably run down towards destruction and death. But how then are we to explain the increasing complexity and order evident all throughout nature and cosmological evolution? The answer, Peirce argues, is "that *chance*, in the Aristotelian sense, mere absence of cause, has to be admitted as having some slight place in the universe."

Comparing his views to those of Darwin and therefore suggesting a mechanism for the evolution of emergent properties, Peirce suggests that perhaps chance may be the "one essential agency on which the whole process depends." He argues that in contrast to the dissipative effects of force that inevitably ends in destruction, absolute chance might have the opposite effect: it might serve as a concentrative influence that can produce new and constructive uniformities. Peirce, then, proposes that chance is the origin and source of creativity and emergence. It may even be the source of lawfulness itself: Peirce speculates that chance, representing indeterminacy and freedom, may paradoxically generate an even stricter rule of law.

Henri Poincaré, whom we also cited above, is often credited with anticipating many of the discoveries of non-linear thermodynamics. Thus we have included a short essay of his, translated into English for the first time, on the ubiquity and irreducibility of irreversible processes. How are we to explain the irreversibilities that emerge in conclusions derived from reversible premises? Poincaré, as we noted above, was unwilling to accept the notion that the irreversibilities present in macroscopic features of thermodynamical processes such as the direction of heat transfer can be explained—i.e., deduced—from premises pertaining to microscopic, reversible phenomena, despite simplifying hypotheses, such as Boltzmann's, that macroscopic phenomena merely represent statistical averaging of the indefinitely large numbers involved.

By the beginning of the twentieth century, the possibility of a truly creative evolution had become a topic that thinkers were ready to address. Harkening back to the forgotten Heraclitus, Henri Bergson begins by stating categorically that everything changes; states of living organisms in particular—precisely because of the interactions responsible for the integration of their components into an organism—cannot be regarded merely as distinct elements massed together. In addition, because in living things the past overflows into their present and future states, organisms *endure*; the organized living being has a duration that the unorganized aggregate does not. Bergson calls this continuous progress of the past, which gnaws into the future and swells as it advances, *duration*: it represents the emergence of the new and unforeseeable, even in principle. Duration is responsible for nature's process of construction, the invention of the absolutely new, an "ascent" that does the inner work of creation. Duration involves a reciprocal creation of sorts: what we do depends on who we are, but we are what we do and we are creating ourselves continually.

Echoing Montaigne's precept "il faut tuer pour analyser" and Kant's emphasis on self-organization, Bergson also argues that organic creation is not subject to mathematical analysis. The calculation and analysis central to mechanics can only apply to organic destruction, he maintains. As we shall see, this seminal notion anticipates the noted physicist Erwin Schrödinger's reflections on whether life can be explained by the laws of physics.

The 1920s witnessed the rise of the so-called British Emergentists, who are represented in this collection by the work of Samuel Alexander (1859-1938), C. Lloyd Morgan (1852-1936) and C. D. Broad (1887-1971).

In *Space, Time, and Deity*, published in 1920, Samuel Alexander offered a "naturalistic realism" based on the notion of "space-time," a four-dimensional, absolute "stuff" from which things are differentiated. For Alexander, the universe is fundamentally processual, an ongoing process consisting in time's continual formation of changing complexes displaying genuinely new qualities at different organized levels, and matter is the emergent quality of the lowest level complex of Space-Time. These organized complexes of motion that emerge as the product of the universe's forward thrust are organized hierarchically, beginning from the lowest level (matter in physical structures, displaying the quality of inertia), with each level depending on the subvening one but displaying qualities not predictable from nor present in the subvening level. Thus Alexander's universe, in the words of the philosopher and historian R. G. Collingwood, "is a universe in which evolution and history have a real place"[17].

Without resorting to the notion of a God who preceded and created the universe, Alexander argues that the universe itself exhibits a creative tendency (*nisus*) that impels the production of new levels of order. He suggests that Diety, although not yet actualized, is "the next highest emergent quality which the universe is engaged in bringing to birth."

Alexander's ideas caught the attention of C. Lloyd Morgan. In the piece included here, Morgan goes beyond Alexander in maintaining that emergent evolution is in play whenever new and unpredictable *kinds* of existents appear, not just at the emergent levels of matter, life, and mind, but whenever any new kinds of matter, such as atoms and molecules, appear. Significantly, and unlike Mill and George Henry Lewes (1817-1878), Morgan also claims that there is nothing in emergence that precludes "a supra-naturalistic" explanation, that is, "an acknowledgment of God."

Before mentioning Alexander, Morgan briefly discusses Lewes, whose views on emergence he associates with the views of Mill. Morgan is particularly interested in Lewes's claim that a Principle of Creative Resultants (emergents) applies in those cases where the distinctive quality that emerges is not the mere sum of separate elements, but instead embodies a *new kind of relation* (by definition relations cannot be present in the relata as the relations are not yet in being at the lower level). Unlike the mere regrouping of existents, a new *kind* of existent represents integration achieved by a supervenient level of relatedness.

17. R. G. Collingwood, in a 1936 letter to Alexander cited by Dorothy Emmet, "Whitehead and Alexander," *Process Studies* 21.3 (Fall 1992), 143. Emmet's paper was originally published in *Die Gifford Lectures und ihre Deutung: Materialien zu Whiteheads Prozess und Realität*, ed. by Michael Hampe and Helmut Maassen (Frankfurt am Main: Suhrkamp, 1991), vol. 2, pp. 100-120.

Emergence thus represents a new kind of connectedness among pre-existing events, a specific new kind of integration that contradicts mechanistic dogma, which holds that organic wholes are mere epiphenomena and whose central themes are that all resultant effects are only calculable by algebraic summation and, therefore, that the whole is nothing but the sum of its parts. For Morgan, however, to claim that the emergent features of integration "can only be explained by invoking some chemical force, some vital elan, some entelechy, in some sense extranatural,"[18] amounts to "questionable metaphysics." Nevertheless, he argues, what is required for "an ultimate philosophical explanation, supplementary to scientific interpretation," is to be found in "the acknowledgment of God."

Alexander, Morgan notes, pins his claims on the appearance of three emergents: matter, the emergence of life, and, at the apex of the pyramid, the emergence of consciousness or mind (i.e., reflective thought). It is precisely in virtue of its integral unity that Alexander insists that each higher entity is an emergent *complex* of entities at lower grades. This thrust from lower to higher—a principle that goes beyond Spinoza's notion of *conatus*, since for Alexander the quality of the psychical emerges in time—is his notion of *nisus towards deity*, an active tendency that renders any insertion *ab extra* superfluous. According to Alexander, and in contradiction to Lewes, no external influence needs to be postulated to account for each emergent stage. The higher level "involves" the lower level but is an emergent, distinct level of its own that is produced by the nisus towards deity. Nonetheless, because each level is characterized by progressive individuation, it is possible to imagine the emergence, in time, of Deity, here understood as a "unique individual" characterized by an even higher level of "reflective consciousness."

Morgan himself, while agreeing with Lewes and Alexander on the reality of emergence, is at pains to argue that there is nothing in emergent evolution that precludes an appeal to God. Unlike Alexander, who works bottom-up and insists that the quality at each higher level is emergent from the lower, Morgan bases his argument in part on an examination of what we today would call top-down causality: the descending order of the pyramid, so to speak, from higher to lower.

By emphasizing the descending order of the pyramid, Morgan addresses the still unresolved problem of *top-down causality*. If the emergent higher level is not to be a mere epiphenomenon, the relatedness that constitutes the higher level must be effective: it must change—guide—the "existing go of events" at the lower level. It is the "new manner in which lower events happen" that accounts for novelty in evolution. Morgan offers the example of perception, which depends on the guidance of consciousness. New relations on the higher level "guide and sustain the course of events distinctive of that level." Even though there would be no higher level without the "involvement" of the goings-on at the lower, it remains true that these lower level events "run their course" differently than they would have had the higher supervenient level been absent. What kind of causality is operative here? Morgan does not say, but the way in

18. Morgan does not accent *elan* in the passage quoted.

which he describes the "guidance" and "sustenance" that the higher level provides to the lower clearly has more in common with Aristotelian formal cause than with the efficient, forceful cause of mechanics. Finding a way to account for the apparent ubiquity of top-down causality has become a central topic in the philosophy of science.

Since Morgan claims that the lower level's "dependence" on the novel and emergent higher level is no less essential than the "involution" of the higher level on the lower, he also concludes that, although it is "beyond proof," postulating the existence of a God, here understood as the highest guiding, sustaining, and directive Activity on which all other levels below depend—and which is itself not emergent—may be demanded by explanatory consistency.

Does Alexander suppose that Space-Time can exist apart from matter? If so, does spatio-temporal relatedness possess such a high degree of causal power that matter can emerge from it? Morgan argues that Alexander must give an affirmative answer to both those questions. Morgan himself, however, insists that Space-Time cannot be postulated in the absence of physical (material) events. Morgan concludes that if, prior to the appearance of matter, a space-time basal level, however ubiquitous, would be non-effective, scientific research has reached its limit and must give way to critical philosophy, which deals with such foundational issues.

It is precisely at this juncture that we can see how both Morgan and Alexander frequently prefigure not only topics discussed in process philosophy but also, and especially, current notions of self-organization and "autopoesis." Can self-organization occur when there is still no-thing? The idea of a kind of forward thrust that impels the coming-to-be of a quality not yet realized, or, in Morgan's words, of a qualitative "transformation of types" that "takes place ... out of lower to higher levels," plays a central role in the discussion of such phenomena. If the basal level of Space-Time is causally powerless, while the nisus "directive of the course of events" is at work throughout, then the acknowledgement of God, understood as such activity, is not precluded.

C. D. Broad (1887-1971), is usually considered the last of the British Emergentists. In the discussion on mechanism and its alternatives that we have included in this collection, Broad expresses doubt that any working biologist is a strict mechanist, one who holds that there exists only one kind of "stuff" subject to only one kind of law. The fact that living bodies possess macroscopic properties different from and irreducible to the one fundamental kind of stuff that strict mechanism would require also requires the existence of laws connecting macroscopic qualities to microscopic properties. To satisfy even a weaker version of mechanism, such higher-level laws would, for example, have to correlate particular configurations of particles with a determinate value of a certain macroscopic quality. As Broad states, however, this reducibility is nowhere in the offing. Broad notes that for Alexander and Morgan, indeed for all emergence theorists, the difference is due wholly to a difference of structure. While composed of constituents that can occur in other kinds of complexes, emergent wholes show characteristic types of behavior that cannot be deduced from the components, separately or in combination.

Like many emergentists, Broad refers to chemical composition as an emergent phenomenon whose properties could not have been predicted. Even though there may be general laws connecting *some* properties of compounds with those of their structure, laws that would have to be discovered empirically, no *general* law of composition can predict the properties of any chemical compound.

As Broad notes, somewhat wistfully, the advantage of Mechanics is that it introduces unity and tidiness into the world. He concludes that those of us who accept the reality of emergence will have to be content with much less unity, and that no consolation is to be found in searching for analogies between teleology and design. The question of a Designer can only arise with respect to the emergence of teleological systems out of non-teleological materials. Despite acknowledging that it is consistent with the position that a God set things up like this, Broad is unwilling to postulate Deism, and he concludes that "what must be assumed ... is a general tendency for complexes of one order to combine with each other under suitable conditions to form complexes of the next order." In short, Broad concludes that the basis for emergence is a universal tendency towards self-organization.

It would be impossible to compile an anthology on Emergence and not include Alfred North Whitehead (1861-1947). Whitehead too bemoans a physics that is based solely on the measurement of an ideally isolated system free from causal contingent dependence. The central flaw of eighteenth-century science, he argues, is that it provides "no elementary trace of the organic unity of a whole." The traditional way of evading this problem has been to resort to an appeal to "vitalism," in his view an unsatisfactory compromise. In contrast to Whitehead's favored starting point of organicism, whereby events are all interlocked in a community, the materialist standpoint is that of independently existing substances, mind and matter. Whitehead agrees with Bergson that matter does not have the property of simple location (Whitehead calls this the Fallacy of Misplaced Concreteness). Instead Whitehead proposes that science should be recast upon the ultimate concept of the organism, which includes the idea that things endure in time, by which he means a unity, not merely an aggregate, whose parts form an ordered aggregate. What is an organism? For Whitehead an organism is "realized togetherness" (what we might call network effects), and as such it represents the achievement of an emergent value.

The South African thinker and politician Jan Smuts (1870-1950) focuses his discussion of emergence on what he calls the creativity of evolutionary "holism," a term he himself coined. Smuts argues that naturalism is as wrong in denying that real new entities have arisen in the universe as idealism is in postulating that Spirit or Psyche has existed *ab initio*. Instead, he claims, there exists a universe of "whole-making": holism is the inner evolving principle of direction and control that underlies variations. Whereas for Morgan emergence is a term that applies only to the new, a position that Smuts interprets as a variation of Spinoza's claim that the psychical is a correlate to the physical, for Smuts mind is an emergent in time that appeared once the universal tendency to wholes, when personified, became the Purpose of a transcendent Mind.

Smuts is one of the few early twentieth-century thinkers to emphasize the important role that context and the environment play in the creation of greater and greater wholes. Variations, which creatively arise from these wholes, are not accidental; they are the expression of the holistic development and evolution of wholes. Because of this inner trend beyond themselves, Smuts argues, things do not end at their boundaries: their surrounding *field* is essential both to the thing *qua* thing, and also to understanding things in general. Wholes are therefore not closed, isolated systems; they have fields in which they intermingle and influence each other, and as such they can only be understood in terms of the new science of ecology. Because evolution is the record of this whole-making activity, only an evolutionary standpoint can account for the appearance, structure, and organization of wholes; naturalism—Smuts' term for mechanistic science—is guilty of not taking the structuring activity of the universe seriously. The philosophy of holism therefore breaks with such naturalism when it denies the plasticity and creativity of nature.

Arthur O. Lovejoy (1873-1962) returns to the mechanistic understanding of causality in his indictment of the understanding of emergence current in his time. Causal relationships, Lovejoy argues, are thought of as providing rational explanations by being assimilated into logical deductive relations. Insofar as "there cannot be more in the effect than there is in the cause," this preformationist assumption precludes any possibility of qualitative change and creativity. Science thus becomes the equivalent of deduction and analysis. In those cases in which complex things have properties that cannot be describable as multiples of properties of simple things, the preferred solution has always remained an unfortunate appeal to psychophysical dualism, a worldview with which Lovejoy clearly disagrees.

Lovejoy offers a classification of the various uses of the term "emergence." General claims of emergence, he says, refer to "any augmentative or transmutative event" that fails to conform to the preformationist maxim. In his view, the claim that anything seemingly new must be pre-contained in a universal set of causes is unconvincing. He sees no reason why the higher cannot come from the lower—in fact, it is positively unedifying to suppose that the entire "travail of creation" is but a barren "shuffling about of the same pieces." Any evidence of a "specific" occasion of emergence, he notes, would put the lie to those who declare general emergence to be impossible. Lovejoy divides doctrines of specific emergence into two types, determinist and indeterminist, proposing five features that must be present for true "emergent evolution" to have taken place. Such emergence—of which Lovejoy offers chemical synthesis as an example—would imply that science, understood as a fully realized reductionism, would not be completely unified. But there is no reason to suppose that the emergence of new "types" of entities and new "types" of events or process have not appeared in evolution; the latent generative potencies of matter are in fact evidenced in the discontinuities that appear in the evolutionary process.

In 1943, the noted physicist Erwin Schrödinger, a pivotal figure in the development of quantum mechanics, gave a remarkable series of lectures in Dublin, and a book based on those lectures appeared in the following year. That book, entitled *What is Life?: The Physical Aspect of the Living Cell*, came to influence Watson and Crick, the discoverers of the double helix, the structure of DNA. As we shall now see, Schrödinger's views also foreshadowed the groundbreaking analysis of complexity and emergence offered by Ilya Prigogine.

In chapter six, entitled "Order, Disorder, and Entropy," Schrödinger echoes Poincaré in alluding to the science of thermodynamics, especially to the famous Second Law, the so-called entropy principle. Drawing upon the work of Max Delbrück, another forerunner of modern genetics, Schrödinger argues that living matter, although it does not elude the "laws of physics" that have already been established, "is likely to involve 'other laws of physics' hitherto unknown." Once these new laws have been discovered, he says, they will form just as integral a part of science as those that have already been discovered. He goes on to argue that living organisms are able to delay their descent into thermal equilibrium by feeding on "negative entropy," and this leads him to the remarkable assertion that "entropy, taken with the negative sign, is itself a measure of order." Thus, he concludes, a living organism is able maintain a high level of order—i.e., a low level of entropy—by "continuing to suck orderliness from its environment"[19].

Our penultimate selection is a critique of Stephen Pepper's 1926 paper, "Emergence," that Paul Meehl and Wilfred Sellars published in 1956 (we decided not to include Pepper's paper itself, since Meehl and Sellars cite it extensively, giving us more than enough to reconstruct his argument). Meehl and Sellars aim "not to defend an emergentist picture of the world but to criticize an argument which, if successful, would make such a picture indefensible."

Pepper defines emergence as a kind of change "in which certain characteristics supervene upon other characteristics, *these characteristics being adequate to explain the occurrence on their level* (our emphasis). In other words, supervening characteristics as such are unnecessary to the explanation.

Pepper first distinguishes between theories according to which what emerges are *qualities* and those according to which what emerges are *laws*. He notes that in Alexander's system it is new qualities that emerge; but he argues that since all emergent qualities are mere epiphenomena (they make "no difference"), the possibility of emergent laws is absurd. Differences between concepts and laws at one level must be reducible to concepts and laws at the lower level, and descriptive laws predicting the development of the lower-level characteristics can be formulated without mention of higher-level variables; the supposed emergents would be included in the total set of variables describable by some functional relationship with the rest of the lower-level variables.

Meehl and Sellars appeal to phenomena such as "sense quality," "raw feels," and the like as good candidates for the role of emergents. They point out that for there to be a philosophically interesting instance of emergence, the variables of the emergent quality must at the very least "conform to a different function" than do the variables belonging to the lower-level complex. Some

19. Although we have not included Chapter 7, entitled "Is Life Based on the Laws of Physics?," in this book, we recommend it to readers interested in Schrödinger's conception of what those new laws might look like.

emergentist philosophers, however, have more in mind that merely that. When it comes to raw feels, sensations, images, etc., we cannot deduce their properties from the way regularities of hydrocarbon molecules, potassium ions, and electromagnetic fields perform outside of brains. Emergentists therefore conclude that these phenomena are not fully describable in terms of physical primitives—and are as such emergent.

The collection comes to a close with some excerpts from Ludwig von Bertalanffy's classic 1950 article, "An Outline of General System Theory." Despite the fact that it was published before the piece by Meehl and Sellars, we have placed Bertalanffy's essay at the end of the collection not only because of its prescience in predicting the rediscovery of systems, but also because of its positive contributions to the discussion of emergence, complexity, and self-organization.

Bertalanffy explicitly acknowledges the role that interactions among components play in producing organized complexity. By also recognizing the inescapable irreducibility of the interdependence that comes into play as a result of those interactions, he gives ontological status to the wholeness characteristic of systems. He also notes that, unlike the systems traditionally studied in physics and chemistry, organisms and living systems are open systems, and that the continuous exchange of matter and energy with the environment causes significant differences to appear, not the least of which is the ability of living systems to achieve a metastable steady state maintained by the flux of energy and materials.

Coming full circle to our first selection, which was taken from Kant, Bertalanffy ends with a discussion of the teleological character present in the structure and form that results from the self-organization of open systems, and, in particular, the equifinality in evidence in all living systems, that is, their tendency to reach the same final state despite tracing very different trajectories.

We would like to conclude this introduction with a succinct statement of what we believe lies at the heart of the concept of emergence and gives it its unique force. For those committed to emergence, it is process, and not substance, that is the fundamental metaphysical basis of reality. In this view, the key to understanding the universe, as Ilya Prigogine has emphasized, is to be found in the understanding of time. What counts is endurance over time, which has formed—and continues to form—the universe, not the instantaneous events to which mechanism remains attached. Time is a river, as the saying goes—and the river flows on, always moving forward, never running backward, and never the same.