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Systems Theory and Complexity Introduction

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ABSTRACT In this paper the central ideas and history of complexity theory and systems theory are described. It is shown how these theories lend themselves to different interpretations, and different interpretations lead to different political conclusions.

1. Introduction

At the turn of the millennium, the study of complex systems has become one of the most prominent fields of scientific study. This is, according to those engaged in it, a revolution of major proportions. 'Science has explored the microcosmos and the macrocosmos', wrote Heinz Pagels in *The Dreams of Reason*, 'The great unexplored frontier is complexity'.[1] But according to some of the more radical complexity theorists, there is more to complexity than an unexplored domain. While previously science had struggled to reveal the simple behind the complex, it is now being suggested by some theorists that the world is irreducibly complex. The task before us is no longer to identify the simple elements of reality underlying complex appearances but to work out how to study complexity in its own right. A whole range of phenomena, previously disregarded by mainstream science, has become the central focus of some of the world's most eminent scientists. Instead of being taken as the foundation of science, simplicity is now coming to be regarded by some theorists as one of the products of complexity.[2] Almost every discipline from physics and chemistry to neurobiology, economics, politics and history has been forced to confront the issues raised by complexity theorists and to explore the relevance of their ideas. And not only have the boundaries between scientific disciplines been crossed, including the boundaries between the natural and the human sciences; the boundaries between science, the humanities and the arts have also have been brought into question. As Brian Goodwin claimed at a conference at the Santa Fe Institute, 'complexity is moving towards … a nondisciplinary, integrated science which actually goes beyond science. It goes right into the so-called social sciences, and now I think

1. Cited by Roger Lewin, *Complexity: Life on the Edge of Chaos* (London: Phoenix, 1993), p. 10.
2. This is the thesis of Jack Cohen and Ian Stewart, *The Collapse of Chaos: Discovering Simplicity in a Complex World* (Harmondsworth: Penguin, 1994).
3. George A. Cowan, David Pines and David Meltzer, eds, *Complexity: Metaphors, Models and Reality*, Proceedings, Vol. XIX, Santa Fe Institute Studies in the Sciences of Complexity (Reading, MA: Addison-Wesley, 1994), p. 672.

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that it goes into the arts as well.'[3] The focus on complexity has revived interest in schools of thought and the work of philosophers and scientists who have in the past struggled to develop alternatives to reductionist science. Prominent among these are general systems theorists, process philosophers and dialectical naturalists. What is the science of complex systems? What is its relation to earlier movements of thought? And what is the relevance of all these ideas to the project of developing an inclusive democracy? This is the topic of this special edition of *Democracy and Nature*. Here I will give a brief overview of complexity theory and systems theory and the issues raised by their work.

2. The project of the Santa Fe Institute

Complexity theory came to public prominence with the establishment in 1984 of the Santa Fe Institute; and since then, the study of complexity has been almost identified with research at the Institute.[4] With the participation of several Nobel Laureates (Murray Gell-Mann, Kenneth Arrow and Philip Anderson) and other scientific celebrities along with a number of ambitious younger scientists, members of the Institute set out to create a new synthesis involving mathematics, computational science, physics, chemistry, biology, neuroscience and the social sciences. Focussing on the behaviour and evolution of 'complex, adaptive systems', researchers at the Institute set out to reintegrate the fragmented interests in complex phenomena of much of the academic community. 'Complexity' was taken to refer to, in the words of the Founding President of the Institute, George Cowan, 'systems with many different parts which, by a rather mysterious process of self-organization, become more ordered and more informed than systems which operate in approximate thermodynamic equilibrium with their surroundings'.[5] 'The central goal of the sciences of complex systems,' wrote Mitchell, Cruchfield and Hraber, 'is to understand the laws and mechanisms by which complicated, coherent global behaviour can emerge from the collective activities of relatively simple, locally interacting components.'[6] The flight of a flock of birds flying in formation or schools of fish swimming in a coherent array suddenly changing direction although there is no leader guiding the group, are simple examples of such emergence. And much the same crowd behaviour is identifiable in the buying and selling of stocks in the stock market. In complex adaptive systems, interacting components generate an emergent global order that is able to adapt to new circumstances and, in doing so, to act

4. For an entertaining account of the Santa Fe Institute, see M. Mitchell Waldrop, *Complexity: The Emerging Science at the Edge of Order and Chaos* (New York: Touchstone, 1992). The Santa Fe Institute have published an enormous number of proceedings on a wide range of topics, but the volumes that gives the best overview of their work are David Pines, ed., *Emerging Syntheses in Science*, Proceedings, Vol. I, Santa Fe Institute Studies in the Sciences of Complexity (Reading, MA: Addison-Wesley, 1987), and Cowan *et al.*, *Complexity: Metaphors, Models and Reality.*
5. George A. Cowan, 'Conference Opening Remarks', in Cowan *et al.*, *Complexity: Metaphors, Models and Reality*, p. 1.
6. Melanie Mitchell, James P. Crutchfield and Peter T. Hraber, 'Dynamics, Computation, and the "Edge of Chaos": A Re-Examination', in Cowan *et al.*, *Complexity: Metaphors, Models and Reality*, p. 498.

back on the components. The operation of complex adaptive systems, according to Gell-Mann, 'encompasses such diverse processes as the prebiotic chemical reactions that produced life on Earth, biological evolution itself, the functioning of individual organisms and individual communities, the operation of biological subsystems such as mammalian immune systems or human brains, aspects of human cultural evolution, and adaptive functioning of computer hardware and software'.[7] The programme of the Santa Fe Institute was defined by Cowan at one of the Institute's conferences:

> The program deals with the appearance of folded proteins and the beginning of highly interconnected, self-organizing, and adaptive systems. It ranges from the formation of cells and organs, particularly including the brain, to organism, particularly man, and the enormously interactive systems studied in social science. The human dimension really begins with nature's invention of the human cortex, a prerequisite for the invention of symbols, language, culture, electronic communication, and the evolving behavior of collective units which have increased in size until they now embrace a truly global community.[8]

Members of the Institute have made advances in most of these fields. Their achievements have inspired work in a host of disciplines beyond those considered by members of the Institute, including management studies.

Cowan has acknowledged von Bertalanffy's general systems theory, Whitehead's philosophy of organism, McCulloch and Pitts on neural networks, von Neumann on cellular automata and complexity, Wiener on cybernetics, Prigogine on dissipative structures associated with non-linear thermodynamics and Haken's synergetics as precursors to the Santa Fe's study of complexity. He attributes renewed interest in complexity to the greater accessibility of computers. Many of the Institute's members have been concerned to exploit the potential of computers to examine mathematical relationships previously too difficult to study and for their powers to simulate natural processes. In doing so, members of the group have drawn on the mathematics of dynamical systems (including chaos theory, catastrophe theory and bifurcation theory) characterised by point, limit cycle and strange attractors. They have also embraced fractals, information theory, artificial intelligence, computational theory, cellular automata, Boolean networks, neural nets and genetic algorithms (which mimic a Darwinian selection process to arrive at solutions to problems). Dynamical systems theory and cellular automata have been particularly significant.

3. Central ideas and approaches of the Santa Fe Institute

Dynamical systems are not systems in the world but mathematical models of systems. The advantage of dynamical systems as a form of representation is that it makes possible use non-linear equations, equations in which dependent variables (y in the equation $y = f(x)$) must appear in higher powers than one.

7. Murray Gell-Mann, 'Complex Adaptive Systems', p. 18.
8. Cowan, 'Conference Opening Remarks', p. 2f.

Computers have enabled us to deal with such equations that previously, because they were insoluble, were ignored. What this means is that with dynamical systems using non-linear equations there are no longer simple ratios between causes and effects; in the long run a small cause can have a major effect. This notion has been popularised as the butterfly effect—a butterfly flapping its wings in USA could cause a hurricane in China.

A system can be any collection of objects or processes deemed to be of interest. Dynamical systems have two parts: a representation of all possible states of the system, called the manifold of the system (often represented using phase space), and a set of equations that describes how the state of the system changes with time. This is the vector field of the system. The path traced out through the manifold by an object is the trajectory of the system. The object moves from an initial state to an end point, one of the system's attractors. A system can have one or more attractors. It can also have repellors and saddle points between attractors and repellors. The simplest attractor is a fixed point, a final point to which an object will move. An object will tend to move towards this end point when it is captured by its domain of attraction. A second kind of attractor is a limit cycle. In this case an object captured by the domain passes endlessly through a sequence of points. That is, it enters into periodic motion. Finally there are strange attractors. An object captured by a strange attractor continues in motion indefinitely without ever traversing the same point with the same velocity. Where there appears to be periodic motion, it is unstable and gives way to unperiodic motion. This is the attractor associated with chaotic motion characteristic of turbulence. The study of this is chaos theory. A system can also be structurally stable or unstable. A structurally stable system is unaffected by minor changes in its parameters, while an unstable system is one in which a minor change results in a major change in the whole system. The nature of such structural stability and instability is the subject of catastrophe theory. Chaos theory and catastrophe theory can be combined in bifurcation theory. Where a system has many attractors, a minor change in the parameters of the system can result in sudden changes in the system's trajectory. This is called a bifurcation. There are three different kinds of these: subtle, catastrophic and explosive.

While computers can solve non-linear equations and represent the trajectories of dynamical systems on a screen, in general it is extremely difficult to use dynamical systems to make predictions. Their role is to characterise the quality of the system and to explain rather than to predict. As Mitchell, Crutchfield and Hraber put it:

> The central contribution of dynamical systems theory to modern science is that exact solutions are not necessary for understanding and analysing a nonlinear process. Instead of deriving exact single solutions, the emphasis of dynamical systems theory is on describing the geometrical and topological structure of ensembles of solutions. In other words, dynamical systems theory gives a geometric view of a process's structural elements, such as attractors, basins, and separatrices. … Dynamical systems theory also addresses the question of what

> structures are generic; that is, what behaviour types are typical across the spectrum of complex systems.[9]

It is for this reason that Goodwin refers to such mathematics as a mathematics of qualities.

Cellular automata have been another major tool of analysis by members of the Institute. Cellular automata are abstract arrays of cells programmed to carry out rules *en masse*. They consist of lattices of squares, referred to as cells. Time is discrete. The state of an automaton at each instant is given by the state of all its sites at that moment. It evolves through a simple set of rules that determine how any cell changes from one instant to the next. These rules pertain not only to the state of the square at each moment, but also to the state of neighbouring squares. Each cell is then a unit that receives inputs from its immediate neighbours and communicates its internal state to the same immediate neighbours. Performing computations in unison, collections of cells can be viewed as organisms running on pure logic.

The approach of members of the Institute is illustrated by the work of Norm Packard, Chris Langton and Stuart Kauffman in developing and utilising the notion of 'edge of chaos'. Integrating non-linear mathematics with self-reproducing cellular automata, Packard and Langton were led through their work with computers to the notion that order emerges 'at the edge of chaos.' Similar ideas were developed by Stuart Kauffman, again aided by the power of computers, integrating dynamical systems and Boolean networks—which have much in common with cellular automata. 'Edge of chaos' is now understood as a complex regime within dynamical systems, a regime that generates coherent structures that propagate, grow, split apart and recombine in complex ways. It is the state between rigid forms of order and chaotic behaviour. Packard hypothesised that cellular automata most capable of performing complex computations will most likely be found in this regime, and he suggested that this would be the equivalent of adaptation.[10] Here nature is most creative. This state is characteristic of some phase transitions, and the notion of 'edge of chaos' was used to explain the importance of such phase transitions for life. As Chris Langton put it:

> … cell membranes are barely poised between a solid and a liquid state … Twitch it ever so slightly, change the cholesterol composition a bit, change the fatty acid composition just a bit, let a single protein molecule bind with a receptor on the membrane, and you can produce big changes, biologically useful changes … [T]he edge of chaos is where information gets its foot in the door in the physical world, where it gets the upper hand over energy. Being at the transition point between order and chaos not only buys you exquisite control—small input/big change—but it also buys you the possibility that information

9. Mitchell *et al.*, 'Dynamics, Computation, and the "Edge of Chaos" ', p. 498.
10. N.H. Packard, 'Adaptation Toward the Edge of Chaos', in J.A.S. Kelso, A.J. Mandell and M.F. Shlesinger, eds, *Dynamical Patterns in Complex Systems* (Singapore: World Scientific, 1988).

processing can become an important part of the dynamics of the system.[11]

It is postulated that there is a tendency for systems to develop to this complex regime, which is then the regime where adaptation can take place. Kauffman drew the conclusion that it is here that better adaptations could be selected for; we have the basis for self-organisation, and with self-organisation we can have selection, evolution and, since evolution provides new conditions for other evolutionary developments, for co-evolution.[12] We have a conception of physical existence, analysable mathematically, which is able to incorporate the creative processes of life. Here, it seems, the division between the physical and the biological world has been overcome.

4. Assessing the Santa Fe Institute

The Santa Fe members have so far not yet developed an integrated research programme, and to the extent that it has, their work does not exhaust the study of complexity. There is scarcely an idea put forward by any member of the Institute that is not contested by other members or by other scientists engaged in the study of complexity. The notion of 'edge of chaos', for instance, especially as developed by Langton and Packard, has been criticised by Melanie Mitchell and others.[13] Different members of the group favour different ideas, different approaches and different techniques while being unsympathetic to others. Anderson, for instance, a key figure at the Institute, has questioned the relevance of a mathematical/computer science subject called 'The Theory of Complexity' and, to a lesser extent, cellular automata.[14] 'I have never in person met a computer that was not my enemy', he wrote.[15] It is not clear that all the ideas and approaches being deployed at the Institute are consistent with each other. And key philosophical issues have not yet been settled.

The state of the notion of emergence, a central concept in complexity theory, exemplifies this. As a theoretical concept it remains crucially unclear.[16] The very idea of emergence would appear to be inconsistent with the mathematics being deployed. Unless chance is explicitly built into at least one of these components, dynamical systems are deterministic, irrespective of whether the mathematics are linear or non-linear. As Roger Lewin wrote, following Gleick's interpretation of the development of chaos theory:

11. Conversation with Chris Langton reported by Lewin, *Complexity*, p. 51.
12. Stuart A. Kauffman, 'Self-Organization and Adaptation in Complex Systems', *The Origins of Order: Self-Organization and Selection in Evolution* (New York: Oxford University Press, 1993), ch. 5.
13. Mitchell *et al.*, 'Dynamics, Computation, and the "Edge of Chaos" ', pp. 497–513.
14. Philip W. Anderson, 'The Eightfold Way to the Theory of Complexity: A Prologue', in Lewin, *Complexity*, pp. 7–16.
15. Anderson, 'The Eightfold Way to the Theory of Complexity', p. 12.
16. For one effort to clarify the issue, see J.P. Crutchfield, 'Is Anything Ever New? Considering Emergence', in Cowan *et al.*, *Complexity, Metaphors, Models, and Reality*, pp. 515–537 and subsequent discussion.

> Classical physics regarded complex systems as exactly that: systems that, when powerful enough analytical tools were eventually at hand, would require complex descriptions. The central discovery of the recent interest in nonlinear dynamical systems is that this assumption is incorrect. Such systems may indeed appear complex on the surface, but they may be generated by a relatively simple set of sub-processes.[17]

Non-linear dynamical systems are capable of revealing the world to be unpredictable and capable of generating macroscopic patterns with their own dynamics; but this is at the level of appearance. The underlying dynamics are deterministic and would appear to rule out anything but the appearance of emergence.

This is true also of the concepts used in relation to emergent phenomena. As Per Bak, one of the leading members of the Institute pointed out: '[W]hat is adaptability of a complex system? Since "purpose" and "rationality", and thus "learning" and "adaptability" do not really exist in deterministic dynamical system, the question should really be: which are the features of complex systems that an outside observer might interpret as adaptability?'[18] If this were the case it would appear that far from breaking with traditional science, the Santa Fe Institute, despite their claims, is at last providing reductionist explanations for all those phenomena that anti-reductionist scientists and philosophers had been calling attention to as requiring holistic forms of thinking to understand.

This problem manifests a deeper philosophical issue, the relationship between mathematics and reality. Howard Pattee, a venerable theorist of complexity has argued that members of the Institute, and Langton in particular, have confused '(1) computer-dependent realizations of living systems, (2) computer simulations of living-systems behaviour, (3) theories of life that derive from simulations, and (4) theories of life that are testable only by computer simulations.'[19] Since computers can simulate virtually anything, that a simulation appears life-like is of no great significance. The simulation needs be a development of a theory, and it is not clear that complexity theorists have a theory of life. Yet Langton is claiming that his goal is to 'build models that are so lifelike that they would cease to be models of life and become examples of life themselves'.[20] Pattee is well qualified to appreciate the limitations of the work being done at Santa Fe. He has been engaged with many of the issues being raised by members of the Institute since at least the 1960s.[21]

17. Lewin, *Complexity*, p. 12.
18. Per Bak, 'Self-Organized Criticality: A Holistic View of Nature', in Cowan *et al.*, *Complexity: Metaphors, Models, and Reality*, pp. 477–496, p. 492.
19. H.H. Pattee, 'Simulations, Realizations, and Theories of Life', in Margaret Boden, ed., *The Philosophy of Artificial Life* (Oxford: Oxford University Press, 1996), pp. 379–393, p. 381.
20. Pattee, 'Simulations, Realizations, and Theories of Life', p. 379. Cited from C. Langton, 'Studying Artificial Life with Cellular Automata', *Physica D*, Vol. 22 (1987), pp. 120–149.
21. Pattee published an anthology entitled *Hierarchy Theory: The Challenge of Complex Systems* (New York: George Braziller, 1973) which strongly influenced T.F.H. Allen and Thomas B. Starr, *Hierarchy: Perspectives for Ecological Complexity* (Chicago: University of Chicago Press, 1982).

5. The broader context of complexity theory

If there is no unified perspective among the members of the Santa Fe Institute, what are they studying? What is a complex system if there is not some accepted theory through which complexity can be posited theoretically as an object to be investigated? A review of recent work at the Santa Fe Institute or in the area generally is not enough to specify the field of complexity studies. What is required to see how the study of complexity became an issue is a broad overview of the whole of science.

In particular, we need to look again at the claims of some complexity theorists that complexity is the great unexplored frontier. What does this mean? Does complexity theory bear no relation to the work of those anti-reductionist thinkers engaged in biology and the human sciences over the last two centuries? As we have seen, Cowan recognises that complexity theory has its roots not only in the work of Prigogine and Haken, McCulloch and Pitts, von Neumann and Wiener, but also von Bertalanffy and Whitehead. He might also have mentioned Waddington's work on epigenesis, Erich Jansch's work on self-organisation and Maturana's and Varella's work on autopoeisis (or self-making) and Pattee's work on hierarchy theory. More significantly, it is quite clear to anyone who has read the work of von Bertalanffy that the research into complexity is continuous with the development of general systems theory.[22] Von Bertalanffy not only struggled to develop a science of the phenomena focussed on by members of the Santa Fe Institute, he also worked towards developing appropriate mathematical techniques to deal with such phenomena. In *General System Theory* published near the end of his career in 1968, he wrote:

> Classical physics … was highly successful in developing the theory of unorganized complexity. … In contrast, the fundamental problem today is that of organized complexity. Concepts like those of organization, wholeness, directiveness, teleology, and differentiation are alien to conventional physics. However they pop up everywhere in the biological, behavioural and social sciences, and are, in fact, indispensible for dealing with living organisms as social groups. … General system theory is, in principle, capable of giving exact definitions for such concepts and, in suitable cases, of putting them to quantitative analysis.[23]

To this end von Bertalanffy embraced the ideas and theories of those who immediately influenced members of the Institute. All that was lacking was the more highly developed mathematical techniques available to members of the Santa Fe Institute.

Von Bertalanffy did not claim to originate his central ideas. He acknowledged that he himself belonged to a tradition of thought going back to Nicholas of Cusa which included Leibniz, Hegel and Marx. In short, complexity is not an

22. See Ludwig von Bertalanffy, *General System Theory: Foundations, Development, Applications*, rev. edn (New York: Braziller, 1968).
23. Von Bertalanffy, *General System Theory*, p. 34.

unexplored frontier. It has long been the object of study by philosophers and scientists. These thinkers have been part of a counter-tradition within science, opposed to a way of thinking about the world that emerged triumphant in the seventeenth century with Newton's celestial mechanics and has ruled ever since. One way of characterising this opposition is between those promoting a mechanistic, reductionist view of the world and an organic view of the world; but this is too simple. To bring into focus the crucial issues raised by complexity theory it is necessary to see it in relation to the counter tradition emerging from the effort to overcome the mechanistic, reductionist view of the world. While Spinoza and Leibniz contributed to founding this tradition, it only crystallised as a school of thought that developed in Germany in the late 18th and early 19th centuries with the work of Herder, Goethe and Schelling. The crucial philosophical issues were raised in Schelling's opposition to Kant's efforts to privilege and provide the philosophical foundation for the kind of knowledge provided by Newtonian mechanics.

6. Kant, Schelling and the philosophy of nature

Originally, Kant had been part of the Leibnizian tradition of thought struggling to transcend Newtonian science. While he never finally rejected this starting point, Kant came to the conclusion that the concepts of Newtonian physics (the forms of intuition—space and time, and the categories of the understanding—of quality, quantity, relation and modality) are necessary to make the world intelligible; they are synthetic *a priori*. It is these concepts that made it possible to analyse the world and to grasp it through mathematically precise laws. While in the *Critique of Judgement* Kant outlined concepts to examine and interpret life, these concepts were seen as regulative of rather than constitutive for understanding. The kind of knowledge associated with biology was seen as inherently inferior, as was ethical knowledge through which people understand that they are free agents. Even though Newtonian physics has been replaced by the theories of relativity and quantum mechanics, Kant's privileging of mathematical physics and treatment of biological and ethical knowledge (and knowledge of ourselves as free agents) as in some way deficient, is still the orthodox view.

While embracing Kant's anti-Newtonian, dynamical conception of matter as the product of active forces (elaborated by Kant in *Metaphysical Foundations of Natural Science*), Schelling exposed the weaknesses in Kant's defence of Newtonian mechanics.[24] Assuming that nature should be construed to make intelligible the possibility of free, conscious agents emerging from it, Schelling argued that the process of self-constitution or self-organisation, rather than being a marginal phenomenon, must be the primal ground of all reality.[25] The

24. On this, see Dieter Jähnig, 'On Schelling's Philosophy of Nature', *Idealistic Studies*, (1989), pp. 222–230.

25. See Marie-Luise Heuser-Kessler, *'Die Productivität der Natur' Schellings Naturphilosophie und das neue Paradigma der Selbstorganisation in den Naturwissenschaften* (Berlin: De Gruyter, 1986).

inorganic or mechanistic, is derivative from the organic. Similarly, Schelling argued in opposition to Kant that 'community', characterized by reciprocal causation, is basic, and linear cause effect relations are derivative. As he put it, 'The organic … produces itself, arises out of itself. … No single part could arise except in this whole, and this whole itself consists only in the interaction of the parts. … Cause and effect is something evanescent, transitory, mere appearance.'[26]

Whatever product or form exists is in perpetual process of forming itself, and this is how nature should be understood. Dead matter, in which product prevails over productivity, is a result of the stable balance of forces where products have achieved a state of indifference. Living organisms differ from non-living organisms in that their complexity makes it even more difficult to maintain a state of indifference. They must respond to changes in their environments creatively to form and reform themselves as products. Life is the condition for the emergence of spirit, with its social forms and their history. Rejecting Kant's claim that organisms as organisms can never be the subject of science, that it is only as objects that they can be known, Schelling defended the role of non-objective intuition through which organisms can be viewed not as objects standing over against subjects, but as actively emerging. Nature regarded as mere product is for us an object; but as productivity, it is for us subject.

Schelling has had a massive influence on the subsequent development of science, both at the level of epistemolgy and ontology.[27] The most fully elaborated defence of the notion of intuition in science is in the work of Michael Polanyi (although Polanyi did not use this term). Polanyi argued that all explicit knowledge in science is grounded in tacit knowledge. Knowledge requires us to 'indwell' in that which is being explained and the theories which explain it so that whatever is focussed upon is made sense of in relation to a tacitly appreciated background knowledge.[28] Appreciation of wholes is, then, more basic than analysis, and is presupposed by, and the condition of understanding, what is analysed. Once this is understood, the appreciation of humans as subjects no longer involves an unbridgeable chasm with the natural sciences.[29] Correspondingly, the ontology of science has been transformed through the influence of Schelling. Oersted's discovery of electromagnetism, from which emerged modern field theories, was inspired by Schelling. The idea that energy is conserved through all transformations, and that energy is more basic than matter in understanding the universe, was also inspired by Schelling. And Schelling is a root source of anti-reductionism in biology and in the human sciences. Both Whitehead's philosophy of organism and von Bertalanffey's general systems theory (and before both of these, Bogdanov's tektology) are echoes of Schelling's philosophy.

26. F.W.J. Schelling, *Ideas for a Philosophy of Nature*, trans. Errol E. Harris and Peter Heath (Cambridge: Cambridge University Press, 1988), p. 30f.

27. See Joseph L. Esposito, *Schelling's Idealism and Philosophy of Nature* (Lewisburg: Bucknell University Press, 1977), ch. 5.

28. These ideas are developed in Michael Polanyi, *Personal Knowledge* (Chicago: University of Chicago Press, 1958).

29. On this, see Michael Polanyi, *The Study of Man* (Chicago: University of Chicago Press, 1959).

But here lies a problem. As the natural sciences have taken on board various core ideas of Schelling's philosophy of nature they have been reformulated. Kant's ideal of scientific knowledge as a deterministic mathematical structure has survived the demise of Newtonian physics and for the most part Schelling's ideas have been accepted only with a reductionist twist. Taking force fields, characterised mathematically, as the basic existents, is just as reductionist and deterministic as Newton's atomism. Thermodynamics, although it gave a place to statistics within nature, was also developed as a reductionist science. The same thing has occurred in biology and the human sciences by those who have embraced systems theory in opposition to the prevailing reductionism. As von Bertalanffy noted, 'there are, within the "systems approach", mechanistic and organismic trends and models, trying to master systems either by "analysis", "linear (including circular) causality", "automata", or else by "wholeness", "interaction", "dynamics" (or what other words may be used to circumscribe the difference)'.[30]

7. Interpreting and evaluating complexity theory

We can now see the problem of interpreting complexity theory. Complexity theory can be interpreted as the advance of reductionist science. When Pagels wrote of complexity being the unexplored frontier, he meant the frontier for reductionist physics. The question then becomes: 'Has physics, with the aid of computers able to deal with non-linear equations, model automata and simulate Darwinian evolution with genetic algorithms, finally been able to transform itself to meet the challenge posed to mathematical physics by Schelling and those he directly or indirectly inspired?' However, complexity theory can also be interpreted as a further advance of Schellingian science. This accords with the self-interpretation of Ilya Prigogine and his colleagues who define themselves in relation to the ideas of Bergson and Whitehead,[31] and Brian Goodwin and his colleagues strongly influenced by Waddington, who trace the roots of their ideas to Goethe.[32] Complexity theory should then be evaluated according to whether and how it has advanced this tradition, whether it has enabled ideas to be formulated more rigorously or revealed new facets of the world towards which earlier anti-reductionist thinkers were merely groping.

There are several ideas distinguishing complexity theorists who are promoting anti-reductionist thinking. To begin with, mainstream science, by being deterministic, tends to construe time as little more than an extra dimension of space. Prigogine has been most emphatic in opposing this.[33] However, even conservatively interpreted, complexity theory tends to support Schellingian dynamism.

30. Von Bertalanffey, *General System Theory*, p. 25.

31. Ilya Prigogine and Isabelle Stengers, *Order out of Chaos* (Toronto: Bantam, 1984).

32. Gerry Webster and Brian Goodwin, *Form and Transformation: Generative and Relational Principles in Biology* (Cambridge: Cambridge University Press, 1996).

33. See Ilya Prigogine, *From Being to Becoming: Time and Complexity in the Physical Sciences* (San Francisco: Freeman, 1980).

As Cowan noted, 'It is really the dynamic property of complexity, the motion pictures, not the snapshots, which characterize the systems … .'[34] However, for the notion of becoming to have any meaning, the future must be open, not predetermined. The deterministic unpredictability of chaos and complexity theory does not imply an open future. However, Prigogine construes deterministic trajectories as illegitimate idealisations, and his arguments in this regard have been supported by others.[35] This argument, if it is successful, undermines the core foundation of reductionism, and this allows us to appreciate that there can be real emergence, that emergent levels of ordering have to be appreciated as real in their own right. This appears to be difficult to appreciate by physicists steeped in reductionism, but it lies at the core of Goodwin's heretical views in biology.

Goodwin argues that traditional biology with its focus on gene populations, selection and molecular biology has forgotten the reality of organisms. He and his fellow 'process structuralists' have struggled valiantly to show that biology is meaningless unless it takes into account and makes its central concern the intrinsic dynamics of organisms. The difficulty he has had in this regard is evident in his tense exchange (in which he was supported by Kauffman) with Gell-Mann and others after presenting a paper at the Santa Fe Institute.[36] After Gell-Mann had attacked Goodwin for 'making this unnecessarily polemic version of a perfectly sensible scientific argument', Gell-Mann went on to praise the historical explanations of orthodox evolutionary theory and display his lack of understanding of the argument. Goodwin replied: 'It took me *thirty years* to try to work my way through this swamp of confusion that I find in the conceptual basis of biology'. He then pointed out the inadequacy of explaining anything in terms of initial conditions without acknowledging and explaining the reality and dynamics of the entity involved. This, Goodwin pointed out, is like explaining the elliptical orbit of the Earth around the Sun by pointing out that it was in an elliptical orbit last year. The point was lost on Gell-Mann.

Whether systems theory and complexity theory are interpreted reductionistically or in the spirit of Schelling largely determines their political implications. The orthodox reductionists are always on the lookout for ideas that might facilitate further control of the world and of people. There is no place for the spontaneous, free agency of people. Reductionists have generally been happy to treat complexity theory as supportive with only slight modifications of a market economy and a social Darwinist view of history. Gell-Mann is famous for his right-wing views. And management theorists have embraced chaos theory and complexity theory as the latest challenge for management. The anti-reductionists are sensitive to the reality of that which has emerged. They are prone to concern about the future of life and of human life on Earth, realities which, having emerged, could be destroyed. They grant a place to humans as free agents who can take responsibility for the future. For Prigogine and Stengers, one of the important implications of the new science of complexity is that it implies that

34. Cowan, 'Opening Remarks', *Complexity: Metaphors, Models, and Reality*, p. 3.

35. See Stephen H. Kellert, *In the Wake of Chaos: Unpredictable Order in Dynamical Systems* (Chicago: University of Chicago Press, 1994), esp. ch. 3.

36. *Complexity: Metaphors, Models, and Reality*, p. 217.

individual action could make a difference to the future of the world.[37] This is accepted by Goodwin who also draws out the social implications of recognising that creativity takes place at the edge of chaos.[38] Play is defended as the archetypal chaotic and unpredictable behavior from which new order emerges. Defending the work of Vandana Shiva he has extolled the forms of life and ways of thinking of small self-sufficient communities in India, and has portrayed the society of the Hunza valley people in northern Pakistan as a model for the future. A healthy society is one in which people spontaneously co-operate, not where they are regulated from above.

37. Prigogine and Stengers, *Order out of Chaos*, p. 313.
38. See Brian Goodwin, *How the Leopard Changed its Spots: The Evolution of Complexity* (London: Weidenfeld & Nicolson, 1994).