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ESSAY

Life, the universe and emergence

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Complexity theory claims to resolve the classic conflict between vitalists who believe evolution is externally caused by spirit or other vital forces and mechanists who believe evolution is bottom-up, with survival of the fittest or adaptation as the key variable. In contrast, complexity theory asserts that evolution occurs through emergence. New variables naturally develop over time. Organisms, individuals and societies self-organize, ie they do not need an outside force to guide their growth. Thus, from simple conditions emerge complex conditions. This essay explores the meaning of complexity and its implications through a review of three recent books: Roger Lewin's *Complexity: Life at the Edge of Chaos*; Stuart Kauffman's *The Origins of Order*; and Mitchell Waldrop's *Complexity: the Emerging Science at the Edge of Order and Chaos.*

Complexity takes a dynamic view of life. Indeed, dynamism comes from life itself. 'Biological systems are dynamical, not easily predicted, and are creative in many ways', argues Chris Langton.[1] 'In the old equilibrium worldview, ideas about change were dominated by the action–reaction formula. It was a clockwork world, ultimately predictable in boring ways', he adds.[2] While boring, such predictability did allow humans to land on the moon. If all movement was non-linear, warns Lewin, we would clearly be stuck on the Earth, unable to leave it since our trajectories could not be predicted.

But does this not mean that complexity throws us into a world where prediction is impossible? Not at all. Rather, since all complex systems are based on simple origins, or all simple systems generate complex patterns, we can understand these deep patterns and thus better comprehend biological, environmental and even social change. While this is obvious to physicists, it is not so obvious to biologists. The thrust of Lewin's *Complexity* is a dialogue with leaders in the field on how complexity theory is changing our understanding of traditional evolutionary theory. Up to now, through computer modelling, complexity theorists have managed to show that emergence can occur naturally; ie from a few simple species, a host of evolutionary possibilities can occur. But for those biologists less enthused with computer simulation, Darwin still reigns supreme.

While some believe that complexity theory moves towards a Theory of Everything, others are rightfully more cautious since within different systems—from cellular automata to Gaia itself—there might be different types of complex relationships.

While Lewin attempts to remain objective, it is clear that the one variable

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scientists fear is the mystical—that is, an external source that is fuzzy, that cannot be operationalized. And this, many see, is the problem with vitalism, the belief that an *élan vital* somehow plays a role in our biological and social development. The reaction to this position has been reductionism, as per the work of ant theorist and sociobiologist Edward O. Wilson, who believes that genetic causes are primary in understanding human behaviour.

Complexity theory, however, borrows more from ecological theory and the view of the interrelatedness of life as developed by James Lovelock. From this perspective, there are reciprocal links between tropical forests and climate. 'No rain, no trees, but equally, no trees, no rain', argues Lovelock.[3] It is this interrelated view to which Norman Packard speaks. When asked what the implications of complexity theory would be, he answers: 'We would see the world as having more unity'.[4]

Complexity theory attempts to make links between evolutionary systems and social systems as well, primarily suggesting that civilizations, like species, rise and fall. For societies and species there are periods of stasis and then periods of rapid change, of punctuated equilibrium. With the fall of the Soviet Union, Chris Langton tells us that we are in a period of global instability. 'You can see these two species coexisting in a long period of stability; then one of them drops out and all hell breaks loose. Tremendous instability. That's the Soviet Union'.[5] He adds, 'I am no fan of the Cold War, but my bet is that we're going to see a long period of instability in the real world now that it's over'.[6] Moreover, what happened to the Soviet Union will happen to liberal capitalism as well, unless of course, one believes that different organizing principles are at work.

But complexity theory's greatest contribution has been to show that the second law of thermodynamics is only part of the story, since some systems tend towards order, not disorder. Within nature there is deep order. But this order is not caused by the hand of God; instead, it emerges naturally, as complexity theorists are quick to point out. For physicists, emergence is an unproblematic concept, but for biologists self-organization still appears mystical, a return to pre-Darwinian theories.

But even as complexity theory develops, a new science, modern molecular biology might make complexity theory useless, since its proponents believe that with the ability to manipulate and analyse DNA, the process of evolution will finally be completely understood. In Lewin's words: 'Simply read the messages in the genes, and all would be revealed . . . No nod in the direction of the complexities of development. No indication that population biology may play a role in the fate of a species. No suggestion that species are part of ecosystems, which themselves are components of evolutionary history. And, of course, nothing at all about the immanent creativity of dynamical systems'.[7] Through genetic research our history will be available to us, the causes of the rise and fall of nations will be obvious, right there in our genetic structure. But while we wait for these remarkable developments in genetics, complexity theorists believe that it is the science of complexity that will lay bare history and the mind of God. Physicist Heinz Pagels writes: 'I am convinced that the nations and people who master the new science of complexity will become the economic, cultural and political superpowers of the next century'.[8] Quite a claim, and a clear indication that science is not merely about research but about power and control, about comparative advantage.

These grand claims, however, have been made before by catastrophe and chaos theory. The former is now no longer seriously investigated and it is still too soon to tell what will happen to the latter. For complexity theorists, chaos is focused on order and disorder and merely one dimension of complexity, since chaos theory does not explain the mechanisms of change. Complexity is similar to chaos in that both are concerned with non-linear systems, both focus on interrelatedness, and both seek an underlying pattern to all physical and social phenomena. But the key to understanding complexity theory is *emergence*. Lewin writes, 'For an ecosystem, the interaction of species within the community might confer a degree of stability on it; for instance, a resistance to the ravages of a hurricane, or invasion by an alien species. Stability in this context would be an emergent property',[9] since it naturally arises from the conditions present. It is not there in the realm of ideas nor can it be merely understood from a part thereof (the Platonic and Aristotelian positions). This is true for economic systems, biological systems, and cultural systems as well. For example, according to physicist Gell-Mann, 'In biological evolution, experience of the past is compressed in the genetic message encoded in DNA . . . in the case of human societies, the schemata are institutions, customs, traditions, and myths'.[10] Complex systems thus *learn* from their environment, coding this information in different ways.

Is there progress?

Complex systems exhibit organizing factors, structures into which the system is drawn. In cultural evolution these might be bands, tribes, states and empires, and now nation-states. Within this model, structures move towards these various systems. Sociality is an attractor for humans as well as insects. But for ants, for instance, the biological attractor of sociality is not dynamic as it is for humans since humans have a range of social structures (family to nation). History then has patterns, but then is it purposeful, is there progress?

For complexity theorists, increased complexity and increased order or progress do not necessarily mean the same thing, however. A complex system might be more likely to collapse, for example. A watch is more complex than a sundial but the latter is less likely to break down. This then counters the Spencerian and Darwinian idea of the great chain of being, from the simplest to the most complex with humans at the head. Progress is problematic, moreover, since there is no way to measure complexity. For example, if we measure it by the morphological complexity in vertebral columns among species, then by this measure, according to biologist Dan McShea, there has been no change at all.[11] Are there, then, better measures of complexity? Of progress? There is some agreement in the field that computational ability is a measure of complexity. 'There has been a general increase in information processing over the last 550 million years, and particularly in the last 150 million years'.[12] Computational ability, where survival is contested, gives the species an advantage. But then isn't this progress? Those societies that have a higher intelligence, more information, are they not higher up on the chain of evolution, one could ask? Norman Packard sidesteps this possible return to social Darwinism by arguing that 'people don't believe it for sociological, not scientific, reasons . . . I don't impute a value judgement to computational superiority'.[13]

But for others, progress is a noxious idea not only because it is not operationalizable and thus not testable but because it reproduces hierarchy among societies and among species. For current biologists, the idea of progress brings back the fundamentally racist 19th-century Western view of life. At the same time, Lewin argues that 'just because a scientific idea is imported into social values—however improperly used—doesn't invalidate the original idea'.[14]

But if computational ability is associated with progress, then complexity theory might return the idea of progress to Western society and science. Indeed, Spencer is believed to be a founder of complexity theory. While Spencer had an internal theory of complexity, that is, emergence, his theory did not adequately address external factors, such as natural selection, which provide the external mechanism of change. In this sense, complexity theory unites both Spencer and Darwin, Lewin argues. 'The pure Spencerian view of the world, therefore, is that increased complexity is an inevitable manifestation of the system and is driven by the internal dynamics of complex systems: heterogeneity from homogeneity, order out of chaos'.[15] This is the classical position; that history is linear, rational and progressive. It is humankind which has the ability to transform nature. Lewin continues: 'The pure Darwinian view is that complexity is built solely by natural selection, a blind, non-directional force; and there is no inevitable rise in complexity'.[16] Natural selection removes teleology from the scheme of history. However, while biologists may cling to this perspective, most have adopted a neo-Darwinian view, merging Spencer and Darwin. Complexity theory takes a third approach. According to Lewin, 'the new science of complexity combines elements of both: internal and external forces apply, and increased complexity is to be exacted as a fundamental property of complex dynamical systems'.[17] Through natural selection, adaptation and evolution occur. Computational ability increases as species become more complex. Consciousness then becomes a bottom-emergent phenomenon.

This, as should be obvious, is classical dialectical materialism. As Marx reminded us in his laws of dialectics, the complex arises out of the simple. Consciousness emerges from the material factors of history. There is no God arranging the world, nor does consciousness exist hidden in evolution. It is an emergent property.

Consciousness and Gaia

But from the perspective of complexity theory, while derived from matter, consciousness is not central. Complexity theory does not argue for a brain-centric view of history. There are degrees of consciousness, of computational ability. In Norman Packard's words, 'The way I see the science is that it's concerned with information processing throughout the entire biosphere; information processing is central to the way the biosphere evolves and operates. Consciousness is just one part of that larger puzzle, and it's important to remember that. Most studies of consciousness focus just on the phenomenon itself, and that's solipsistic'.[18] What, then, is the unique contribution of complexity to the study of consciousness? Again, according to Packard, 'it is to place consciousness into the larger puzzle of information processing in the biosphere'.[19]

But what of the planet itself, isn't it conscious as some proponents of Gaia theory argue? To attempt to prove that the Earth itself is a dynamic, self-regulating complex mechanism, Lovelock invented computer models such as Daisyworld which show that there are homeostatic regulating principles at work in the Earth's evolution—that is, life, or the biosphere, regulates or maintains the climate and the atmospheric composition at an optimum for itself.[20] The stability of the system, however, does not emerge from consciousness or some other teleological principle but from the system itself, from its ability to adapt and survive.

While most believe Gaia to be a stable system, from complexity theory we learn that, given certain conditions (changes in solar radiation, for example), Gaia has had and can have periods of rapid change, of punctuated equilibrium. This is in contrast to conventional evolutionary theory which would predict gradual change. In this sense while Gaia stabilizes life at the global level, at the level of particular species, there can be stasis and rapid change. There is dynamic change. But most significantly this change is based on emergent properties which act as though they are moving towards fitness or survival, not on the will of a goddess. Gaia is conscious but not self-reflective.

But, then, does emergence always follow the same pattern or are there an infinite number of species and societal possibilities? Simon Conway Morris asks, what if the Cambrian explosion (the beginning of complexity after 3 billion years of simplicity in which in a matter of a few million years life exploded on the scene) was rerun? How would creatures look this time around? According to Morris, the same development would occur and herbivores, carnivores and insectivores would result.[21] But they would not look like anything we have experienced. In this view, our present world is simply one of an infinite number of possible worlds. For others, such as Brian Godwin, the mechanics of embryological development are constrained.[22] Writes Lewin, 'In the language of complex dynamical systems, the space of morphological possibilities is thinly populated by attractors'.[23] There are only certain possibilities. There is not an infinite range of attractors. In this perspective if one reran the Cambrian explosion, the world today would not look that different. There are not an infinite number of possible pasts or possible futures.

The grand unification and the search for the new law

Going far more into scientific and mathematical detail than Lewin, *The Origins of Order: Self-Organization and Selection in Evolution* represents Stuart Kauffman's life work, a work he hopes will unify self-organization with Darwinian evolutionary theory. It is the search for the new second law of thermodynamics, one that takes into account the ability of life to self-organize and not move towards entropy. 'It is the search for a general law of pattern formation in non-equilibrium systems throughout the universe',[24] based on the belief that woven into the very fabric of nature is a deep undeniable creative order. It is a journey for Kauffman that is based on love, on the Einsteinian view of science—'that science was a search for the secrets of the Old One'.[25] Indeed, as N. Katherine Hayles argues, we cannot separate the metaphysics of scientists from their physics.[26] From this position, both complexity and chaos reproduce the paradigm of classical physics as the world remains orderly but more so as even chaos now has deep patterns. It remains a fundamentally classical and religious view of the world, a world where God has given us the secrets, we just need to go out and discover them. At every step of the way, we are given directions. Yet this God is no longer active, he is the blind watchmaker. Truth is found through connections, serendipity, but the task remains the same, to discover the beauty and elegance of the universe.

Written very much for the scientist, still Kauffman does his best to be communicable by providing succinct intelligible summaries of chapters. In addition, *The Origin of Order* does attempt to find links between the pure sciences and the social and policy sciences. His thesis is simple: 'Simple and complex systems can exhibit powerful self-organization. Such spontaneous order is available to natural selection and random drift for the further selective crafting of well-wrought designs or the stumbling fortuity of historical accident'.[27] And yet self-organization—the flip side of natural selection, for Kauffman—has not yet been incorporated into evolutionary theory.

And while Kauffman is ever the rigorous scientist, he does not suffer from scientism, nor is he afraid of sounding mystical. Indeed the task for his book is to answer the question, 'what are the sources of the overwhelming and beautiful order which graces the living world?'.[28] Kauffman believes that if his autocatalytic set story is valid then he would have a plausible explanation of life. Life could have emerged through self-organization, life is not an accident. But it is the aesthetics of it that is the theoretical clincher. Writes Mitchell Waldrop, 'The whole story was just too beautiful, Kauffman felt. It *had* to be true'.[29]

But Kauffman is not here to bury Darwin, merely to expand on him, to integrate the rise of spontaneous order within evolutionary theory. To do so, Kauffman attempts to delineate the sources of order with which evolution has to work, to show how 'self-ordered properties, *permit*, *enable*, and *limit* the efficacy of natural selection'.[30]

But while the individual scientist may have a moment of awe, theories that evoke non-material factors governing evolution—such as Rupert Sheldrake[31] who postulates morphogenic fields, or P. R. Sarkar[32] who believes that our larger mind, or cosmic mind, plays almost a Lamarckian role, as species collectively 'desire' themselves into new forms—are problematic, not only because they are extra-paradigmatic but because they are not testable. Moreover, these theories imply teleological order and structure, a position Darwinists reject. The rise of Darwin has been the rise of a view of organisms as ultimately accidental and historically contingent. More for Sheldrake than Sarkar, while there is emergence, it is consciousness that is still the key: it is consciousness in and through its various forms that communicates, not the social organization of species. Without the subjectivity of consciousness, higher levels of complexity could not emerge.

For traditional scientists, the way out of the question of consciousness and the origin of life has been time. With a duration of 2 billion years to play with, anything could have happened. Time allows the variable consciousness to be controlled for. Self-organization, while being holistic, does not sponsor non-material approaches to evolution, but it does search for universal laws. Complex systems are selected because they harbour behaviour which is the most flexible and adaptable. Poised between the boundary of chaos and order, they can best respond to changes in the environment. Kauffman puts this in the form of a hypothesis, and, eventually, hopefully for complexity theorists, a law: 'Living systems exist in the solid regime near the edge of chaos, and natural selection achieves and sustains such a poised state'.[33] But, writes Kauffman, 'systems deep in either the ordered regime or in the chaotic regime are probably neither capable of complex behaviour nor highly evolvable'.[34] In the ordered regime, mutations cause only slight changes. Conversely, in the chaotic regime, slight changes cause dramatic changes in behaviour. Hence, it is on the edge of chaos that evolution is possible.

But for this to happen, organisms at the edge of chaos must 'know their worlds. Whether we consider *E. coli* swimming upstream in a glucose gradient . . . or a hawk diving to catch a chick, organisms sense, classify, and act upon their worlds'.[35] But how do they know their worlds? Here Kauffman uses an expanded definition of the word, classify. 'The capacity to know a world requires that sufficiently similar states of that world be able to be classified as "the same"'.[36] It is this definition that allows Kauffman to generalize his argument to Boolean networks and even business firms. *E. coli* knows its world because a wealth of molecular signals pass between a bacterium and its environment. In this, Kauffman and other complexity theorists are in search of structures, hoping to find similar classification schemes, much as Talcott Parsons did for sociology. We see this clearly in his jump from bacteria to the economic sphere. Just as

> a colony of *E. coli* integrates its behavior . . . the organisms of a stable ecosystem form a functional whole. The niches occupied by each organism jointly add up to a meshwork in which all fundamental requirements for joint persistence are met. Similar features are found in an economic system. The set of goods and services making up an economy form a linked meshwork of transformations. The economic niches occupied by each set allow the producers of that set to earn a living and jointly add to a web in which all mutually defined requirements are jointly met. Both biological and technological evolution consist in the invention of slightly or profoundly novel organisms, goods and services which integrate into the ecological or economic mesh and thereby transform it. Yet at almost all stages, the web retains a functional coherence.[37]

At this point we can be misled into thinking that this is Spencerian evolutionism or Parsonian structural-functionalism, but as we see, it is the ecological metaphor where the individual is nested in the larger environment that provides the framework for complexity theory. Self-organization allows for a dynamism that is missing from traditional evolutionary thought. The metaphors and policy implications of complexity theory are not those that favour equilibrium-oriented politics or reductionist isolationism; rather, they privilege transformation and change; variety and diversity; interconnectedness and unity.

Changing one part of the system can radically transform the entire system. While Waldrop's *Complexity* uses this perspective to understand the fall of communism, the same argument can be used to predict the transformation of the US system as well, particularly since one of the functions of Americanism was to stem the Soviet tide. With the fear of the enemy gone, either the US system must transform or find a new enemy. Clearly, however, Iraq and South Korea have functioned as a way to keep the equilibrium of the USA in *status quo*. But we should expect disequilibrium as the continuous construction of enemies leads to social and financial fatigue. Moreover, the world itself is in chaos. And after chaos then what? New levels of complexity, what else!

The biological and the social

To answer the question, what is a functional whole and how does it transform when its components are altered, Kauffman develops an alternative metaframework, what he calls, regimes of grammar. In these regimes, 'the objects of the theory are strings of symbols which may stand for chemical, goods and services, or roles in a cultural setting'.[38] Remember, we are searching for an overall language for a theory of everything from the smallest to the largest, from the biological to the societal to the astronomical. Using this model, Kauffman hopes to lay down a theory of what is appropriate for the biological and social sciences:

> Among the features we find are phase transitions between finite and potentially infinite growth in the diversity of symbol strings in such systems. As we have seen, the phase transitions may well underlie the origin of life as a phase transition in sufficiently complex set of catalytic polymers. *Similar phase transitions may underlie 'takeoff' in economic systems*, such as the industrial revolution, once the systems attain a critical complexity of goods and services that allows the set of new economic niches to explode supracritically, and may provide models for the conceptual explosion wrought by the redevelopment of science three centuries ago.[39]

The critique should be obvious, and this is not only because of the obsessive search for links between the biological and the social—again we saw this earlier in Spencer—the problem is more fundamental. How to explain the exploitation that was needed for the industrial revolution? How to explain the slave trade, the massive appropriation of wealth from India and the extensive plundering of the colonies. For those of us outside evolutionary theory, it is obvious; in two words: brutal exploitation. While complexity theorists are concerned about the environment, the exploitation of the colonies and of the Other does not enter their dialogue.

But within the evolutionary framework they are able to explain economic take-off. Britain was poised at the edge of chaos while India was either too chaotic or too stable—too many regions vying for power after the weakening of the Delhi Sultanate or too stable after centuries of fatalistic Hinduism. In either case the conditions needed for self-organization were not present. But we could argue that they already lived in ecological communities that were locked into positive cycles. It was military and cultural power that destroyed them, the predator was too strong. But isn't this merely 'survival of the fittest'? India deserved to be defeated because it could not adapt to changing social conditions but now, not only could it not adapt, but it also could not self-organize and lock into positive cycles of increasing returns as well.

Again, this is the central problem of all evolutionary thought that has progress immanent in it. Progress forces one to create a great chain of being from the lowest to the highest. While the scientific basis for the 'great chain of being' perspective is no longer valid, the image maintains its mythic influence on us, but instead of species we have nations. Kauffman and others do not see the links between centre–periphery and predatory–prey or, if they do, they naturalize social and economic exploitation, seeing it as evolutionary. But if computational ability defines evolution then we should not be surprised. Moreover, complexity theorists do not always make the distinction between information and wisdom, between pattern recognition and meaning, and between knowing what is possible and determining what is ethical. The social is merely a reflection of the biological. Fortunately, as we see from Waldrop's *Complexity*, when one is less focused on evolution, one can make arguments for diversity and not linear progress, not selection but coevolution.

While brilliant at biology and mathematics Kauffman does not consider the politics of his epistemology and theory building, at the interpretive costs of his science. He is unable to see the larger episteme, the boundaries of knowledge within which he works, even as he attempts to search for patterns in disparate fields. The archetypical nature of his enterprise, the effort to reconcile classical antinomies of order/chaos or individual/whole remains straightforward science. And when the social does enter his discourse, it does so in an apolitical way, constructing a world where power, force and culture are transparent and silent.

Coevolution

But more sophisticated is his interpretation of coevolution, particularly how different species model each other's behaviour and how this modelling in itself changes one's own evolutionary behaviour. He writes that 'adaptive agents may persistently alter their models of one another's behavior. Once an agent adopts a changed model of another agent, then his own decision rules, and hence behavior, will change'.[40] Now comes the key: 'it follows that such agents must *coevolve* with one another using changing models of one another's behavior'.[41] What this means is that evolution, research, indeed, all activities are done in an holistic coevolving environment. This coevolution can be orderly, chaotic or at the edge of chaos, that is, self-organizing. But the site of emergence, of the beginnings of complexity, is at the edge of chaos. The edge of chaos is more than a simple boundary between disordered and ordered systems, it is a region special to itself. It was Chris Langton through his computer simulation programs of cellular automata who convinced Kauffman of this. This realization allowed Kauffman to argue that 'living systems are not entrenched in order systems but are in the area of phase transition, where things are looser and fluid'.[42] Natural selection pushes systems to the edge of chaos, forcing them to adapt, to emerge, to find new solutions as they move around in their fitness landscape.

Forecasting, adaptation and transformation are different in these three phases. As the amount of data of other agents (again, political systems, economic agents, or organisms) increases, models of the behaviour of other agents become more complex since agents attempt to improve their capacity to generalize about the behaviour of the other agent. In evolutionary language, they live on a more rugged fitness landscape. These models drive agents into more chaotic regimes since more complex models are better able to predict small alterations in behaviour. But in chaotic regimes, models are less complex since less data are available. They live on smoother landscapes. Agents thereby move into more ordered regimes. 'At the edge of chaos, models of one another would be poised, tending to change, unleashing avalanches of changes throughout the system of interacting agents'.[43] Thus, instead of the invisible hand, Kauffman posits a model based on coevolution. Agents coordinate their behaviour based on the phase they are in and in turn move to other system phases. 'If correct, [this model] may help us understand that *E. coli* and corporate executives build optimally complex, boundedly rational, models of the other agents constituting their worlds'.[44] Kauffman's grammar models allow the study of linked processes, he believes, thus turning biology into a science that is law-like. In his words: 'Coevolving adaptive agents attempting to predict one another's behavior as well as possible may coordinate their mutual behavior through optimally complex, but persistently shifting models of one another. Again, we suspect, the deluge of chaos will be obtained. We may find that *E. coli* and IBM do indeed know their world in much the same way'.[45] Planning in this model would have to be an endeavour that worked with the object of planning, necessitating sensitive feedback loops.

As it has turned out IBM did not know its world, as it did not understand that it now lived in a coevolving ecology of high-tech firms. It did not move towards a chaotic phase or to a complex phase; rather, revolutions in technology merely forced IBM into an ordered stable organization; one that did not lock into changes in computer technology. Instead of increasing returns as with Microsoft, it had diminishing returns. It remained a large hierarchical organization that failed to negotiate itself and the changing environment.

Even though Kauffman is not arrogant in his attempt to create a physics of biology, his wanderings into a sociology of biology are often trite and overly burdened by the systems paradigm. By removing values and ethics at one level but keeping the linear, progress- and equilibrium-based values of Spencerian systems theory, Kauffman does not add to discussions of the sociology of knowledge or grand system building. His contribution is in expanding the boundaries of Darwinian biology to emergence and coevolution.

Kauffman, himself, believes that his contribution is helping show that one can have evolutionary self-organization without creationism. We do not need a divine watchmaker. His mission is to find the laws of biology, 'to suspect with quiet passion that below the particular teeming molecular traffic in each cell lie fundamental principles of order any life would reexpress'.[46] But again this does not mean that Kauffman is irreligious. Indeed, once his computer model showed the possibility of emergence, he knew he had come 'face to face with the secret of the Old One'.[47] In Kauffman's words, 'I had a holy sense of a knowing universe, a universe unfolding, a universe of which we are privileged to be a part . . . I felt that God would reveal how the world works to anyone who cared to listen . . . I knew that God had revealed to me a part of how his universe works'.[48]

Increasing returns and system dynamics

Unlike Gleick's *Chaos*,[49] where discoveries are made in solitary settings, *Complexity* is a story of the Sante Fe Institute. Waldrop traces how it began as a dream to create a multidisciplinarian institute with the aim of putting complexity on the map. While Lewin and Kauffman are more concerned with biology, Waldrop follows more closely the life of the Institute and those associated with it, such as George Cowan, the Institute's long-time president, Nobel award winner Murray Gell-Mann, and computer scientist John Holland. But the central figure in this tale is Brian Arthur, an economist who brings back into economic discourse the idea of increasing returns. For Arthur, finding colleagues who knew something about the real world, instead of merely about that which could be mathematized, was nearly impossible. It was at the Sante Fe Institute, however, where he found his home. It is here that Arthur eventually finds himself moving into philosophy and metaphysics. Indeed, in the final section of Waldrop's *Complexity*, Arthur concludes by comparing complexity to Taoist thought. He contrasts this to traditional science and economics which he associates with Newtonian Christian thought. But while the conclusion of the book is impressive for its metaphysics, the first 100 pages is stunning for its naivety. Waldrop describes a major revolution in thought when Arthur and colleagues discover on a trip to Bangladesh that Third World women have many children to increase their life chances, ie that there are social and cultural reasons to population growth and control.

He also discovers the politics of his field's approach to modelling; that is (1) to make the world less messy, and (2) to use science and mathematics to run the world more rationally. 'Most people in development economics . . . believe that they are the missionaries of this century. But instead of bringing Christianity to the heathen, they're trying to bring economic development to the Third World', says Arthur.[50] The trip to Bangladesh confirmed Arthur's view that neoclassical economics had nothing to say to the real world most women and men live in. The obvious truth that economics is intertwined with history and culture was not made available to Arthur. But he is humble enough to say that even though the lesson is obvious, 'I had to learn it the hard way'.[51] From these experiences, Arthur began to appreciate the need for multivariate models that attempted to integrate divergent perspectives from various disciplinarian interests. Indeed, after reading the struggles of those within classical disciplines, one develops a deep appreciation for futures studies—its temporal focus, its multidisciplinarian approach, and its commitment to finding patterns and dysjunctures in social, cultural and evolutionary processes and systems. But what is so obvious to the futurist is not so for the economist or the systems engineer. Culture is soft, it cannot be mathematized and is thus not real, they argue. Fortunately for Arthur, he travelled to Bangladesh to meet real people who do not live in the virtual computer simulations of scientists or the irrational rationality of economists.

The economy as a self-organizing system

After reading Prigogine, Arthur immediately realized that the economy is best understood as a self-organizing system. While neoclassical theory assumes that systems exhibit negative feedback, the tendency for small effects to die away, system dynamics theory, chaos, in contrast, assumes that small effects get magnified under certain conditions. Diminishing returns mean that monopolies naturally disappear, that market mechanisms lead to system equilibrium (and if there are temporary problems the State can always step in and fix things). But increasing returns is based on the idea that a slight chance, a random occurrence, allows a particular product to gain more buyers. The new product then locks into positive growth cycles, until the product has huge advantages over other products. The VHS *v* Beta format for video recorders is one example. This was also the case with the QWERTY typewriter. It was designed to reduce type speed but eventually became the standard. As it was mass-produced, more people learned it, and thus more were sold and produced—until the industry became locked in. Microsoft's operating system is another example. New products may or may not be better but if by chance a few people purchase it, it soon becomes the standard.

In Arthur's vision, the new economics would be based on biology. The system would be dynamically unfolding with externalities internalized. Structures would coalesce, decay and transform. Individuals in this new economics would be part of an ecological web, acting in a variety of complex fashions not merely as rational maximizers.

But this type of economics would not be able accurately to predict the future, since one variable could throw off the initial equations. In this sense the legacy of chaos theory is that although there are deep patterns, these are, in effect, unknowable. The world is ultimately unpredictable. But we can *understand* the world. Good theory helps us explain how we act and how ideas relate to each other. It helps us search for similarities in structures and fields.

But during the Reagan years in the USA, these views were not popular and Arthur was frequently challenged to show examples of technologies that humans are locked into. But that the question was even asked is part of the problem. Arthur's most convincing example is the petrol engine. In its infancy, petrol was considered the least promising source of energy, with steam the most likely since it was safer and familiar. But as it turned out, largely by accident, petrol won. Because of the outbreak of foot-and-mouth disease in North America, which led to the withdrawal of horse troughs, where steam cars could refill, petrol power became locked in and society lost the chance to have a world with considerably less pollution, argues Arthur.[52] Of course, when Arthur gave talks in Russia, economists there countered that this would be impossible in communist countries since central planning optimized efficiency.

While increasing returns may seem obvious to historians of technology, he does provide useful insights. For example, according to classical economic theory, Japan has been successful because of its low cost of capital, powerful cartels, and the need to develop new technologies in the absence of natural resources. However, a low cost of capital can mean a low rate of return and thus few incentives to innovate. Moreover, cartels are inefficient, and most economies are weakened when raw materials are scarce. At the same time theories that look at culture and social structure also do not suffice, since collective decision making can slow down action, for example. In contrast, Arthur argues that Japan has been successful because, 'increasing returns make high tech markets unstable, lucrative and possible to corner, and Japan understood this better and earlier than other nations'.[53] Unfortunately for the USA, high-tech industries were treated like low-tech industries and thus no industrial policy was articulated.

Cultural simplicity

From Arthur, Waldrop moves to many of the themes that Lewin discusses, focusing on proofs of emergence from computer programs. Initial workshops at the Sante Fe Institute were full of excitement and the beginnings of a shared language:

> In particular, the founding workshops made it clear that every topic of interest had at its heart a system composed of many 'agents'. These agents might be molecules or neurons or species or consumers or even corporations. But whatever their nature, the agents were constantly organizing and reorganizing themselves into larger structures through the clash of mutual accommodation and mutual rivalry. Thus molecules would form cells, neurons would form brains, species would form eco-systems, consumers and corporations would form economies, and so on. At each level, new emergent structures would form and engage in new emergent behaviors.[54]

The challenge, of course, as we see from Kauffman's *The Origin of Order*, was to find the fundamental laws of emergence. To do this one could not have just physicists or biologists or economists; one needed experts in many fields. Bringing them together was the purpose of the Sante Fe Institute. For futures studies the lesson is obvious: we need agreement on some larger project for futures studies. Thus while conferences are wonderfully multidisciplinarian they have no focus, no problem to solve, no vision to make law-like.

But it is this multidisciplinarian perspective that allows for comparisons between technological systems and ecological systems:

> Moreover, these technological webs can undergo bursts of evolutionary creativity and massive extinction events, just like biological ecosystems. Say a new technology comes in and replaces an older technology, the horse. Along with the horse go the smithy, the pony express, the watering troughs, the stables, the people who curried horses, and so on. The whole subnetwork of technologies that depended upon the horse suddenly collapse . . . But along with the car come paved roads, gas stations, fast-food restaurants, motels, traffic courts and traffic cops, and traffic lights. A whole new network of goods and services begins to grow, each one filling a niche opened up by the goods and services that came before it.[55]

Again while this might be obvious to futures researchers committed to holistic models of social change, it is remarkable for scientists to articulate perspectives outside the boundaries of their own discipline.

This lack of exposure to different worldviews unfortunately leads to a deficiency of critical thought. Thus instead of seeing these as isomorphisms among different metaphorical systems, complexity theorists often fall into the trap of misplaced concretism, confusing metaphor with objectivity. They do not locate the language of one theory within its own complex context. The larger cultural context for each theory, each discipline is inaccessible to them, as is culture in general.[56] Complexity theorists do not understand that cultures too are destroyed and created by new technological systems. And like the horse which becomes ceremonialized in weddings and coronations or reduced to leisure, cultures become museumized, re-created outside their context, and constructed as boringly eternal. But some cultures do fight back. Fundamentalism is one cultural form that sees its niche being taken away. Its agents—mullahs and priests—attempt to find ways to battle these new technologies. National sovereignty too can be seen in this light, as a system which, while on the verge of disappearance, is frantically reasserting itself.

But this is part of the problem for both physics and neoclassical economics that have agents who do not make decisions, do not suffer. Agents in the former merely follow universal laws, and agents in the latter follow rational greed. Neither exists in a web of cultural complexity, as complexity theory suggests. It is culture, then, that is the variable that remains silent in the language of complexity theory; and paradoxically, it is complexity theory that shows how culture emerges. Indeed, emergence is about the creation of culture. The numerous systems (biology, physics, economics) for which theorists hope to find a general law are all culturally nested within each other. And as Arthur astutely points out, the method of investigation is founded on a cultural metaphysic as well.

Still there are useful policy implications. With respect to global economic policy, complexity theory takes a post-liberal view of economics arguing that innovation leads to innovation, and after a certain level of complexity, a new economy emerges that is autocatalytic. The policy prescription is neither comparative advantage nor self-reliance but economic diversity, using raw materials for local manufacturing and then trading processed goods. Trade, then, between economies can lead to higher complexity, but not if one system is undeveloped and the other developed. In the latter case, the developed or more complex nation will merely feed off the undeveloped nation. The former will become extinct, not being able to move up the fitness landscape, unless both can become locked into positive coevolutionary cycles as was the case with the USA and Europe after World War II. But the problem of exploitation is not one that Waldrop discusses. Rather, the issue for him is transformation. For example, how 'injecting one new molecule into the soup could often transform the [system] utterly in much the same way that the economy was transformed when the horse was replaced by the automobile'.[57]

Unlike Kauffman, John Holland does have a place for exploitation in his theory of complex adaptive systems. For him, complex adaptive systems—the brain, the economy, the ecology, computer programs, firms, individuals, nations—have more than one niche, which can be exploited by other agents. Thus the economic world has a place for programmers and plumbers and the rainforest has a place for crocodiles and butterflies. *'The act of filling up one niche opens up more niches—for new parasites, for new predators and prey, for new symbiotic partners'*, writes Holland.[58] Each change creates new opportunities and failures. Complex adaptive systems are always in a state of flux, equilibrium is death. Agents can never optimize a system, they cannot optimize their utility, their fitness. Finding an optimum is impossible, all one can do is change, and one cannot predict this change since each agent is part of a larger ecology, a web of interrelationships.

It is this approach that led Arthur to conclude that the metaphysics of complexity theory is Taoist-based. God is not the watchmaker, there is no inherent order —as postmodernists too argue—what is, is always in a state of flux—as Marxists as well argue. In Arthur's words, the world 'is like a kaleidoscope: the world is a matter of patterns that change, that partly repeat, but never quite repeat, that are always new and different'.[59] In contrast, the neoclassical worldview is a world of ordered order, fundamentally Christian.

What results is a worldview based on accommodation and coadaptation. There is no duality between humans and nature since humans are part of nature. We are part of the system, although an arrogant part. Optimization assumes that humans are first, as in the case of environmental cost–benefit studies. These types of models assume that we are outside nature, and nature is inside a store: the shopping centre model. More productive are institutional policy analyses, where the actors are interactive and where culture and environment are intrinsic to the system and not considered externalities. In this sense typical phrases like 'the optimization of policy decisions concerning environmental resources' become absurd as they assume a static hierarchical world.

Amazingly, this type of thinking leads Arthur as well as others of the Sante Fe Institute into the realm of much of what is current in futures studies—the politics of metaphor. They argue that bad policy making usually involves a poverty of metaphors, of ways of constituting reality. For example, it may not be appropriate to think of a drug war, with assaults and guns, since each nation is complicit in drug use, drug production, drug culture, and the definitions of drugs themselves.

For Arthur, while one way to understand the new science of complexity is to look at metaphysics, the other is to look at psychological types. One type of scientist needs order and stasis, the other is comfortable with messiness and process. The first spend their efforts trying to make systems go back to equilibrium, the second are less Platonic and Newtonian and more influenced by Heraclitus who argued that the world is in a constant flux. What complexity adds to Heraclitus is that this flux can become self-organized, allowing consciousness to emerge.

For biologist and artificial intelligence specialist Chris Langton, the metaphor is not the clock but the growth of a plant from a tiny seed or, more appropriately *the unfolding of a computer program from a few lines of code* (indeed, much of this book is about the effort to create such a program where life is not designed by initial rules in the program but emerges spontaneously). This is the realization that reality cannot be captured by simple-minded logic, that messiness—or metaphor—is intrinsic to the system; what mathematician Kurt Godel, logician Alan Turing, chaos theoreticians with respect to the butterfly effect, and postmodernists with respect to language, have managed to suggest, if not show.

Thus instead of optimal solutions, the focus is on viable solutions. The task is to focus on robustness in the face of an ill defined future. That, believes Arthur, 'puts a premium on becoming aware of nonlinear relationships and causal pathways the best we can',[60] and thus attempt to bring economics from the 18th century of Darwin and Newton to the 20th century.

For Holland, we need to learn how to adapt to conditions of constant change and unpredictability, conditions at the edge of chaos. For example, the vision of sustainability is problematic since a sustainable society can become a dystopia where our lives are controlled with few freedoms and a loss of cultural diversity. What is needed, believes Murray Gell-Mann, is a 'society that is adaptable, robust and resilient to lesser disasters, that can learn from mistakes, that isn't static, but that allows for growth in the quality of human life instead of just the quantity of it'.[61] But this, then, is the paradox: what is needed are general principles on a world solution to pressing problems, but one that allows for mistakes, that is, learning, and cultural tolerance. We have to find ways to avoid the large avalanches of change, such as nuclear disaster, a third world war or environmental or economic disasters, and move to the edge of chaos where new forms of governance and society can emerge.

Complexity theory allows us to understand and explain (not predict, and in this sense it is a departure from traditional sciences and social sciences) why nations such as the Soviet Union collapsed. The Soviet system was not flexible enough, locking itself into negative cycles, not positive loops. It was too ordered. Anarchy, on the other hand, is too chaotic, too fluid. But unlike Alex Argyro's *A Blessed Rage for Order: Deconstruction, Evolution, and Chaos*,[62] in which he concludes that the US system of checks and balances, of liberal economics and individualism is the best of all worlds (since it is a self-regulating and self-learning system that combines chaos and order), theorist Doyne Farmer argues that *laissez-faire* systems also fail as they are too chaotic. Healthy societies need to be 'like a living cell. They have to regulate themselves with a dense web of feedbacks and regulation, at the same time they need to leave plenty of room for creativity, change, and response to new conditions'.[63] Evolution thrives at the edge of chaos, where neither chaos nor order is dominant. This balance allows for gradual controlled change, where flexibility can emerge. It is learning and evolution that pushes a system to the edge of chaos, into complexity. Perpetual novelty is about moving around at the edge of chaos. For many, this might be too much; what is needed are periods of transformation, and then new levels of organization and order— stasis and transformation not continuous revolution.

Consciousness and intelligence

When all is said and done, the problem of consciousness remains. All self-organization theory does is give us a free lunch; from nothing, something arrives. Even Spencer had his absolute principle. It is spirituality that complexity theorists feel but are intellectually unable to deal with given their fear of creationism. The attraction of the great or the divine, or the idea of paradise, of perfection are subjectivities that are silenced. But for complexity theorists life is neither in the material nor in the spiritual but in the social organization of organisms. If one posits a prior principal, whether consciousness or an initial programmer, one has not explained anything, merely pushed the analysis elsewhere. 'This is Darwin's . . . insight, that an agent can improve its internal models without paranormal guidance whatsoever'.[64] Clearly elegant, clearly part of the story, an important part of it; but the key for modern complexity theory —unlike Spencer's version—is that it does not require a strict theory of progress; new systems are not necessarily better since this definition of progress is not valorized. And given the fluid nature of the real, we can go back to the past and pick up past forms, and adapt them to novel conditions. Politically, it gives hope to those battling the *status quo*, those hoping for change. The task for them is to move the system they inhabit to the edge of chaos, where new social structures can emerge.

At the same time, complexity is also about understanding the future of life on the planet. Chris Langton writes that, 'Not only the specific kinds of living things that will exist, but the very course of evolution itself will come more and more under our control'.[65] Of course, since changes in initial conditions may dramatically change outcomes, as chaos theory would assert, what new life forms might emerge at the edge of chaos is not clear. Like other complexity theorists, Langton believes that these issues must be publicly and globally debated. Yet he remains positive. 'With the advent of artificial life, *we may be the first creatures to create our own successors* . . . It is quite possible that, when the conscious beings of the future look back on this era, we will be most noteworthy not in and of ourselves but rather of what we gave rise to. Artificial life is potentially the most beautiful creation of humanity',[66] a new type of emergence, a new level of complexity that arises from the present chaos.

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