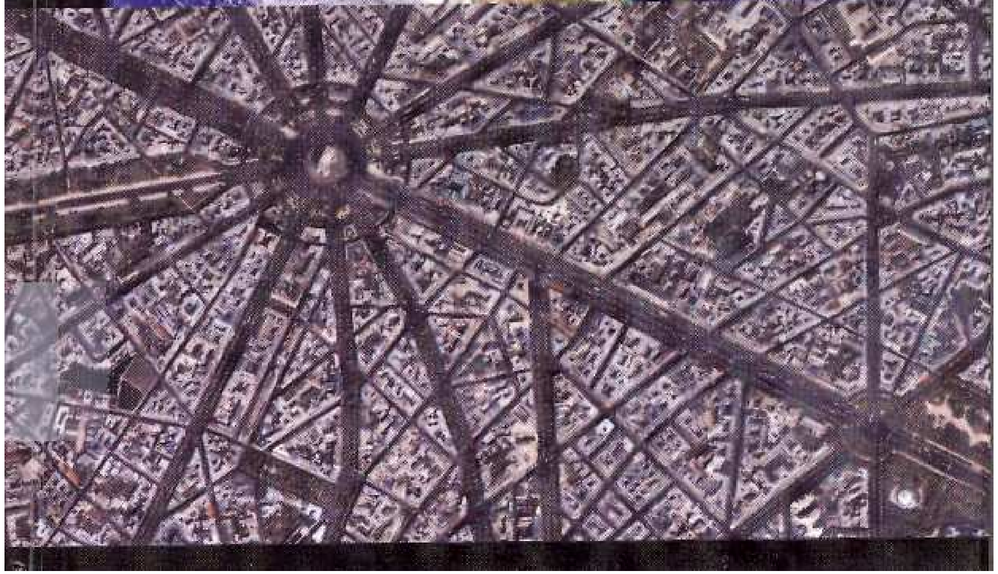
Exploring Complexity: Volume 1

Reframing Complexity

Perspectives from the North and South

Edited by

Fritjof Capra, Alicia Juarrero, Pedro Sotolongo, and Jacco van Uden



A Volume in

Exploring Complexity

Volume One

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Reframing Complexity: Perspectives from the North and South

Havana's Instituto de Filosofia's *First Biennial International Seminar on the Philosophical, Epistemological and Methodological Implications of Complexity Theory*, held in January 2002 in Havana, Cuba's capital city, was aimed at familiarizing Cuban researchers and professors in a more direct way with some of the current trends – and widespread scope – of the expanding field of complexity thinking, affording them the possibility of personal contacts with some of the people engaged in that effort.

Although the organizers launched the call for papers barely six-months before the seminar's opening day, they could not have found a more encouraging response: the seminar was attended by specialists from fifteen countries, ranging from Chile to Australia along the West-East axis, and from Norway to South Africa along the North-South one. There were participants from developed and underdeveloped countries. Of course, Cuban colleagues were amply represented.

It is also fair to say that in spite of the September 11th's terrible tragedy, only a few months before the seminar, the presence of the ten US delegates who did come to Havana, and who made a significant contribution to the success of the seminar, was much appreciated. They were publicly welcomed and applauded at the seminar's opening. That was, in fact, the first of a series of January gatherings, on even years, that has now issued the call for paper for its fourth edition, each time counting with an ever increasing number of foreign participants, which have included relevant personalities in the complexity thinking area as Fritjof Capra, Isabelle Stengers, Edgar Morin, Gregoire Nicolis and John Casti, among others.

The first seminar opened with a two-hour Special Lecture on "Complexity and Life" (Chapter 1) by Prof. Fritjof Capra – University of California at Berkeley – who also presented the seminar with a copy of his most recent book, *The Hidden Connections*, closely related to the topic of his opening lecture. In his lecture Prof. Capra focused convincingly on how a complexity approach can help us attain a better understanding of the unity of the dynamics of non-living and living phenomena. He also stressed the central role played in living phenomena by epigenetic networks of nonlinear biological interactions – cellular, tissue, organic, organismic and ecological – thus challenging the 'genetic determinism' that is still widespread in many quarters.

The seminar also benefited from special lectures by Prof. Paul Cilliers (University of Stellenbosch, South Africa), who discussed issues relating complexity and post-modernism, and by Prof. William Bechtel (Washington University, St. Louis), who explored the topics of mechanism, dynamics and cognition. Panels/round tables on 'Complexity and Subjectivity', 'Complexity and Society' and 'Complexity, Ecology, Environment' were also held, with the participation in all cases of visitors and Cuban specialists.

The ideas expressed at the seminar – and this came as no surprise – made clear that current developments in complexity stem from circumstances linked to the profound change that is taking place in human practice, both in its material and in its ideal or spiritual dimensions. This change, and its characterization, are having (and could not avoid having) a significant influence on contemporary philosophical thought.

Thus, Havana contributions by Capra (US), Delgado (Cuba), Ulanowicz (US), and Rubino (US) among others, focused on the mutual implications of complexity and life. From an ontological perspective, complexity thinking gives us a new understanding both of the origin and of the nature of life itself as an emergent phenomenon with myriad forms, dynamically constrained but nevertheless unpredictable. From an epistemological angle, complexity thinking clearly points to the limits of our knowledge of the living. These two facts together should help us become aware of the enormous responsibility we have taken on when we try to develop such fields as biotechnology and genetic engineering. They should be put to the service of life and not vice versa.

When we face our inherently limited epistemic possibilities with regard to the emergence of new forms of the living with unforeseen and unpredictable characteristics, we would do well to take into consideration what Cilliers stressed: human knowledge, having *limits*, has no *borders* or *frontiers*. We should distinguish between the two. Our world has borders that can be "approached from both sides," while

our knowledge of the world has limits which allow only "approaches from one side." Where the limits of our knowledge lie, there precisely begins the domain of ethics. Any careless trespassing of those limits is epistemically naive and worse, ethically wrong.

As Cilliers also stressed, this topic, concerning the relationship between our descriptions of the world and the world itself – the old philosophical problem of the dialectical correlation between 'the ontological' and the 'epistemological' – has nothing to do either with an "end of science" or with the impossibility, or the undesirability, of building models. It has to do only with the undeniable circumstance that we have to deal with the world in real time and with finite means.

Delgado also talked about limits – in this case about the cultural limits of Western man and Western civilization. His topic was complexity and environmental education, and he asked how deeply environmental education must question the cultural foundations of Western man's model of the relations between himself and nature. Delgado urged us to seek an answer to those cultural limits along three directions: epistemological, socio-political and educational.

Man's current material damage to the environment is a consequence of a predatory model of man's relations to nature that stems from our spiritual consideration about *what* that environment is, and *what* it means to us. This model was framed by Western culture's view of nature as a dichotomous domination and opposition between an external – natural – world and an internal – social – one. From this perspective we could argue that the "environmental problem" is not a problem of man's relation to his natural surroundings, but first and foremost a problem of man's relation to himself. It is not enough, then, to talk about – and work on – environmentally clean technologies, or to further enhance our environmental education efforts, or even to better understand the dynamics of natural processes from a complexity perspective. Fine efforts as they are, they will fall short if at the same time we do not place before us as the central problem the cultural limits of that predator-man provoking the environmental damages.

Sotolongo (Cuba) explored how life is also threatened, not only through environmental damage, but also through economic exclusion and cultural impoverishment by the ongoing process of *neoliberal* globalization. Not by globalization as such, which is irreversible and unavoidable, but by its present neo-liberal character, which is not inevitable and ought to be reversed towards a more solidarity-minded type of globalization in which economic exclusion and cultural homogenization had no place. The complexity approach is instrumental for understanding both current trends in neo-liberal globalization and possible ways of reversing it.

All these facts therefore point to the need to keep in mind:

- the fortuitous character of life;
- the limits in our knowledge of the living and its forms;
- the unpredictability of the emergence of new forms of life;
- the precarious character of life under neo-liberal globalization.

All of which lead to an ethics of life, that is, of a concern for life, a responsibility for life, and a defense of the sustainability of life. In Delgado's words: they lead to a "global bio-ethics".

Furthermore, the fortuitous character of the origin of life mentioned above, including our own origin, should not thrust us into despair, urged Rubino, as he focused on the consolations (and the hopes) of uncertainty. Although the longing for order, perfection and certainty has deep roots in Western culture, a longing that goes hand in hand with Western man's desire for immortality, the acceptance of our human condition – of mutability, disorder, and "the end of certainty" (as Gould and Prigogine have shown us) – should prompt not despair but an abiding confidence in the future and our place in it. We stand on the threshold, as Prigogine says, of "a period of multiple experimentation, of an increased awareness of both the incertitude and the great possibilities implied by our human condition." We are embedded in nature, not set apart from it, playing the role of spectators – and this should be a cause for rejoicing, not of despair, Rubino noted.

Ulanowicz also examined the links between complexity and life. He argued in favor of a so-called "ecological metaphysics," that is, a metaphysical middle ground, as he called it, that treats life's origin as an ecosystem dynamic. This approach should prove more neutral towards both the living (the quick) and the non-living (the dead) in terms of functional correlations between dead and live components.

Ulanowicz argued that if prior to the 17th century life was seen as ubiquitous and ascendant and death as exceptional (an ontology "of the living"), and the origin of life was no problem, the origin of life became a problem after the Enlightenment. Life itself became irreversible, contingent, asymmetrical and death was now preeminent and inexorable (the equivalent of an ontology 'of the dead'). The proposed metaphysical "middle ground" should restore the lost balance between the living and the non-living. Instead of earlier metaphors such as those of the "dead machine", "stochastic units" or "living organisms," we should turn to a "ecosystem" metaphor, the combination of a living community of organisms interacting with the non-living elements of their environment as a whole functional unit.

Other contributors to the seminar turned their attention to other links between complexity and globalization, emphasizing its economic mechanisms and significations (Cole, UK), its networked character and its emergent phenomena. Likewise, Falconer (Canada), and Mateos, Valderas, *et al.* (Spain) focused on various aspects of a Complexity approach to management, business and economics, and examined topics such as cooperating firms, small enterprises, change in organizations and the links between chaos and the economy. These efforts to understand globalization, economics, management and business, as well as those other efforts interpreting physical, chemical and biological phenomena from a complexity perspective – Moreno, *et al.* (Spain) in this last case – shed light on the relevance of knowledge about the world that is currently being articulated around complexity thinking. This approach moves us away from a focus on isolated objects and linear processes to a focus on complex networks of distributed non-linearly interacting components.

Indeed, complexity thinking is inherently linked to our experiencing both what is relevant to the world that surrounds us, and in which we are immersed, and what is relevant in our interactions in this world as a very complex web of mutually linked networks of nonlinear, and distributed, interactions of local and non-hierarchical components out of which, in a non-predictive fashion, new patterns of complex order spontaneously emerge.

This appreciation of a web-like world also leads us to acknowledge the ontological creativity of the entire world – not exclusively of human beings – as a world of multiple possible alternatives always dynamically creating themselves along with the dynamical constraints that eventually favor some and disfavor other possible evolutionary alternatives. This complex understanding of the creative nature of the world emphasizes the emergent character of phenomena. The world and its instances are never "ready and finished" and are not "waiting there for us to explain them."

The complexity approach, furthermore, legitimizes the ontological role of instabilities, asymmetries, chance and disordered phenomena. We learn that these processes show no ontological disadvantage vis á vis stabilities, symmetries, and causal and orderly phenomena. The latter would not come to be without the former. This assertion, which mythical and ancient knowledge mastered so long ago, but was later lost along the way, is returning to us again (walking backwards) along with the complexity approach. At long last we have another chance, hopefully not the last one, to allow us to accept the world, the societies we build and live in, and ourselves as unrepeatable human subjectivities, as a world of heterogeneities. Let us understand that we should not try to homogenize it artificially in our ideal of comprehending it.

Complexity thinking thus points to the fact that this creative world has no privileged ontological level. As scientific data from mega and ultra-micro dimensions of this world increasingly show, our world "bites its tail" as a true cosmic Uroborus. In it, we always face – and are ourselves part of – an ever changing multiplicity of mutually linked entropic and synergic processes involving flows of mass, energy, information and meaning with morphogenetic endogenous capacity.

This becomes a major methodological challenge for complexity studies: we should take into consideration not only the 'focus level' we are interested in characterizing, but also two other ontological 'levels': that of the interacting dynamical components (the 'underlying level') and that of the environment (the 'overlying level'). None of them has any "ontological preeminence" over the other two; in fact, the 'focused level' is always "nested" or "embedded" between the 'levels of the components and the environment'. The emergent pattern of new complex order is then the result of at least four 'inter-level' interactions: environmental constraints, compositional constraints, emergent constraints, and component-environment affordances.

Epistemological implications of complexity thinking were also amply present at the seminar. Thus Najmanovich (Argentina), Cilliers, Strand (Norway), Mateos, Valderas, *et al.*, and Delgado, among others, spoke at length about reframing our understanding of the cognitive processes under the impact of complexity thinking.

Epistemologically, we have departed from the absolute and transcendental subject of cognition so dear to modern philosophy, and have to deal instead with an involved and specific (historically and socially) subject of cognition. We must come to grips with a reflexive subjectivity that must give account of itself, its whereabouts, and its activity in the cognitive process. After centuries of pretended uncontaminated objectivism, this brings to the forefront the interpretative, or hermeneutical, dimension of the cognitive enterprise and the intertwining of values and knowledge.

Along with other contemporary lines of thought, the complexity approach allows us to view the characteristic objectivism of modernity as an alleged "non-narrative narrative" (in Derrida's words), as a discourse that denies itself as a discourse, a speech without a speaker, and without a speaking modality. This alleged "pure truth of facts", as Najmanovich reminds us, is the "trick" of modernity's objectivism, the founding paradox of positivist philosophy and of "simplicity thinking."

The immense success of modernity's philosophy, she stressed, proves its power, not its truthfulness. Modernity's emphasis on methodic thinking served the needs of the time to change the criteria of what had to be considered relevant and legitimate. In doing so Modernity shaped the need for new ways of producing, circulating and legitimizing knowledge. That methodological emphasis was the weapon of a new rising ruling class against the speculative knowledge of traditional religious authority. Today, several centuries later, that emphasis is an obstacle to understanding complexity thinking. Complexity thinking involves a radical transformation of the global system of production, circulation and validation of knowledge.

The foregoing, however, does not mean the rejection of different methodologies, procedures or technologies to obtain new knowledge. It only emphasizes that method is not independent from – nor does it precede – experience; and also that there are always many alternatives to explore, think and make sense of in our interactions with others and with the world at large. These various possibilities arise from man's everyday life practices. As Strand expressed it: "through complexity thinking we are developing a new understanding of the links between knowledge and action." Passion for knowledge cannot be excused nor accepted if divorced from moral considerations. Modernity's alleged axiological neutrality disguises its true value commitments with an instrumental rationality. Whether we like it or not, we cannot and should not hold an unconditional love-cult and trust in science and in technology any longer. We should consider their merits by judging science and technology's contributions to a sustainable future for humanity and its natural environment

Complexity thinking, together with relativity theory and quantum mechanics, phenomenology and cognitivism, constructivism, dialectics and hermeneutics, has led us further to recognize the inseparability of subject and object of cognition. Today we know that we must not only construct explanations about our objects of cognition; we have also to be able to comprehend the subject of cognition that explains them and the conditions and circumstances from which s/he does it.

The importance of complexity thinking for the comprehension of society and of its individual members was stressed by Juarrero (US) and by several Cuban speakers (e.g., Sotolongo, Franco), among others.

Sotolongo focused on how a complexity approach could shed new light on the old, but nevertheless still unresolved, problem of the correlation between the so-called 'macro' social and the so-called 'micro' social phenomena. He argued that both of these social dimensions – that is, objective ('macro') social structures and individual ('micro') social subjectivities – emerge simultaneously and in a parallel way from the concomitant processes of social objectivation and social subjectivation of various patterns of social collective practical interactions in everyday life.

Each of these patterns of social interactions is no more – but no less – than characteristic regimes of collective practices (family practices, educational practices, labor, religious, classist, gender, race and/or ethnic practices, and so forth) that act as true dynamical social attractors for those involved in them, through the tacit and thus prereflexive process of building up mutual expectations about each other's social behavior in everyday life (a sort of proto-normative fiber of every society). The

"social cement" that glues together these attractor patterns of everyday life are those mutual tacit social expectations, and its "ingredients" are our prereflexive "local" practices of power, of desire, of knowledge and of discourse ("local" in the sense that they take place within the so-called "situations of social interactions with co-presence" in which we are constantly involved).

In turn, these local practices of power, desire, knowledge and discourse set themselves up against the background of four types of social affordances, which characterize basic social asymmetries (power inducing and/or power induced; desire inducing and/or desire induced; knowledge inducing and/or knowledge induced; discourse inducing and/or discourse induced) in the interactions of social individuals – as the basic ontological component-level of society – with their specific social environment. Each one of these basic social asymmetries is capable of triggering social complexifying processes, and is linked "circularly" with the others.

Franco (Cuba) stressed the importance for managers of social organizations to cope with the need to provide both what he called a "control zone" and a "creativity zone" within each organization (linked by what he called a "filter area") in order for it to be able not only to implement forecasts, plans, tasks and objectives, but also to be creative, flexible, democratic and to adapt to the inevitable presence of non-predictable variations in the organization's environment. Mateos, Valderas, *et al.* emphasized the importance of organizational learning, creativity and innovation for strategic management.

We were reminded by Cilliers, Juarrero, Najmanovich, Sotolongo, and others that human subjectivities are neither independent wholes nor free-floating egos, and that they are not reducible to either mere subjective observations or decisions. On the contrary, subjectivity is a complex phenomenon in itself, and should be approached as a web of interactions with other subjectivities and with the world at large. It is precisely from this intersubjective web of interactions that meaning emerges as a result of a process of interpretations. In other words, subjectivities are always contextualized, situated and immersed in a process of intersubjective constitution that extends from birth to death. As is the rest of the world, subjectivities are also never "completed" and "ready".

Juarrero focused on the problem of complex dynamics and identity. As old as philosophy itself and involving questions relating to the dialectics of permanence in change, and "sameness" within difference, this important problem is of concern to complex dynamical thinking. As something changes, is it the same thing (as before)? – an ontological question. By what criteria do we tell if it is or isn't? – an epistemological question. Because complex dynamical systems are "structures of process" existing in time, any attempt to formulate criteria for identifying a given dynamical system as the same one as before, or as the same type as another, becomes very difficult. For example, with international corporations and web-based communities in effect decoupled from any particular spatial location, what identifies such organizations and associations as *that* corporation or community? The lesson of complexity's sensitive dependence on initial conditions is that there exist only particular, individual – and increasingly individualized – phenomena. But these are processual individuals, not static, thing-like objects. Moreover, they have the potential to qualitatively evolve, not just develop.

Aside from the ideas expressed at the seminar, some of which have been outlined above, a remarkable human phenomenon emerged in Havana. Very different people indeed, who had come from near and far – Europeans, Latin-Americans, Asians, Africans, and North Americans, including US citizens – and who had never met before, gathered together in Cuba's capital in an amiable, open and democratic manner, made new friends, and felt at home with each other. This wonderful and emergent human atmosphere was also a most remarkable result of the Havana seminar and has further developed in the subsequent editions of the seminar.

In many ways, the seminar was also a huge success because, in addition to coming from very different *geographical* locations, participants were also from a great number of *disciplines* and *backgrounds*. As a result the talks not only spanned the entire field of complexity studies, they also carefully considered implications and applications of complexity theory to fields other than their own.

In the field of organization studies and management research, complexity theory has been in vogue for quite a while and many articles have been dedicated to finding ways of 'making this complexity thing work for organizations.' At least two interesting things can be said about the way in which ideas and concepts from the field of complexity are brought to the field of organization studies.

One practice worth mentioning is that students of organization who have imported ideas and findings from complexity scientists have done so very selectively. For example, complexity concepts such as *self-organization, edge-of-chaos*, and *fitness landscapes* can already look back on successful careers in the field of organizations. That is, for one reason or the other, organization researchers felt that it made sense to introduce these words into their discipline. At the same time, and again for various reasons, other ideas and concepts from complexity discourse – like *gradients, situatedness*, or *multiplicity* – have received little or no attention in organization studies. So, students of organization have not accepted the complexity sciences whole. Instead, some ideas were embraced and others have largely been ignored.

What is also interesting to mention about the use of complexity theory in organization studies is that, as is always the case when students of organization 'borrow' insights from their disciplines, there is confusion and disagreement as to what exactly complexity concepts (are supposed to) mean in their new habitat. Pick up any two books on complexity and organization and you will find two very different views of what, for instance, 'emergence' means in an organizational setting. Everything about complexity is open to many interpretations.

According to some authors, both these practices should be regretted. Their argument is that you either accept everything that the complexity sciences have to say or you simply don't accept them at all. And when you do embrace the complexity sciences, unless you are willing to work with 'unfounded' and 'faddish' applications of complexity theory to the field of organizations studies, you must accept that the message of complexity is to be interpreted in only one way.

Our view is rather different. If we believe that complexity is a very rich source to draw from, imposing strong limits on what the numerous concepts of complexity can mean smothers complexity's great potential. In the very same way that 'once awkward-now indispensable' business concepts such as 'strategy', 'culture', or 'mission' were massaged in order to make them of any use to organizations, complexity discourse cannot be understood as something that 'just is'. For concepts such as 'emergence', 'attractors', 'fitness landscapes' and 'self-organization' to be useful to students of organization, it is important that they are never quite fixed in their meaning. The notion of 'strategy', for example, remains helpful to those who use it to make sense of organizations because the question of what 'strategy' means is never answered once and for all. People play with the concept of 'strategy', they turn it upside down, they adjust it, undermine it again, look at it from a new perspective, and so on. And that is how 'strategy' is kept meaningful. Were the concept not open to reinterpretation at some point it simply would have stopped being of use.

The same applies to the concepts of complexity. Already, the meaning of notions such as 'emergence', 'attractors', etc. have come to be taken for granted to some degree. And while there is nothing wrong with that in itself, it is important to bear in mind that it could very well be worthwhile to put the many complexity concepts into a new perspective. One particular way of doing just that – but not the only one – is by presenting the views of complexity scholars from different parts of the world, especially from its North and from its South. The world – and complexity thinking – is not always the same from these two world regions.

Another way to do it is by going back to what we might consider to be the roots of complexity research. This has at least two advantages. First, by going to the basement of the house that is complexity theory-informed organization studies, we may come across concepts or ideas that have not been picked up before but which seem worthy of exploration now. The second benefit comes from re-reading the material that led us to specific understandings of the concepts that we *already* use. By going beyond the meanings of notions of complexity as they hardened in organization studies, and by revisiting the 'basics' and exploring some of the general philosophical implications of complexity, students of organizations allow themselves to open things up, thereby freeing themselves to look for possible new ways to apply complexity theory in the field of organization studies.

Havana's complexity seminar allows us to march along both ways. And that is what the editors aim to achieve with this book.

The selection of the papers and the way they are structured in this book reflects that ambition. The editors selected the fourteen submitted papers they thought would be most appropriate and useful to readers. The selected papers have been organized in four parts:

I. Sources of Complexity: Science and Information.
II. Philosophical, Epistemological and Methodological implications.
III. Organizational Implications.
IV. Global and Ethical Implications.

The papers in Part I can be said to approach the phenomenon of complexity at a very basic level. Here the issues being addressed revolve around the very fundamental question of why the complexity sciences are so important: What are the most fundamental lessons to be learned from studying complex systems? Papers included in Part II engage in a broader, philosophical investigation of some of the most general ontological, epistemological and methodological implications of the complexity approach, showing how very old questions are currently being reformulated and/or reinterpreted in the light of complexity thinking. Papers that appear in Part III address various important issues about the links between complexity and social, organizational, business and management questions. Finally, Papers in Part IV return once again to more global implications of Complexity thinking, this time dealing with Ethical and Globalization issues of contemporary world.

In a time all too often plagued by repeated misunderstandings between North and South, *Complexity 2002* demonstrated how fruitful and enriching the dialogue between the two hemispheres can be. Each of us lives in a complex personal and social world, and if complexity thinking has anything to offer, it is a more nuanced appreciation of the divergences and convergences of different perspectives.

We the editors invite you to participate in this invigorating and exciting intellectual exchange between recognized scholars from the North and South. Originally published in electronic format the essays herein appear now (updated and revised) for the first time in print, thanks to the auspices of ISCE Publishing.

Complexity 2008 will be held in 15th-18th January, 2008. We heartily invite you to join us at this upcoming, fourth *Biennial Seminar on the Philosophical, Epistemological and Methodological Implications of Complexity Theory*, in Havana, Cuba, and sponsored by the island's five Cathedrae of Complexity Studies, and the Camagüey Center for Medicine and Complexity. For more information see www.complexity-cuba.org.

Section 1

Sources of Complexity: Science and Information

Chapter One

COMPLEXITY AND LIFE

Fritjof Capra

Introduction

My theme here is "Complexity and Life," and I shall present my thoughts to you in two parts. In the first part, I shall discuss the nature of biological life and the relevance of complexity theory to understanding living systems. In the second part, I shall review the recent achievements, current status, and future promises of complexity theory.

The Nature of Life

Let me begin by discussing some dramatic recent developments in our understanding of the nature of life (Capra, 2002). Over the past ten years, molecular biologists have been engaged in one of the most ambitious projects in modern science – the attempt to identify and map the complete genetic sequence of the human species, which contains tens of thousands of genes.

As you know, the first stage of the Human Genome Project was successfully completed about a year ago. The results of this tremendous achievement, together with the successful mappings of other genomes, have triggered a conceptual revolution in genetics that is likely to radically change our understanding of life (Keller, 2000; Capra, 2002: 142). To appreciate these changes, let me briefly review the history of the modern scientific concept of life.

In 1944, the Austrian physicist Erwin Schrödinger wrote a short book titled *What is Life?*, in which he advanced clear and compelling hypotheses about the molecular structure of genes. This book stimulated biologists to think about genetics in a novel way and opened a new frontier of science, molecular biology.

During subsequent decades, this new field generated a series of triumphant discoveries, culminating in that of the DNA double helix and the unraveling of the genetic code. For several decades after these discoveries, biologists believed that the "secret of life" lay in the sequences of genetic elements along the DNA strands. If we could only identify and decode those sequences, so the thinking went, we would understand the genetic "programs" that determine all biological structures and processes. This view of life, known as "genetic determinism," is now being seriously challenged.

The newly developed sophisticated techniques of DNA sequencing and of related genetic research increasingly show that the traditional concept of a genetic program, and maybe even the concept of the gene itself, are in need of radical revision. And so more and more biologists are looking for a different answer to Schrödinger's old question, "What is Life?"

The conceptual revolution that is now taking place in biology is a profound shift of emphasis from the structure of genetic sequences to the organization of metabolic networks. It is a shift from reductionist to systemic thinking. The issue, simply stated, is this: to understand the nature of life, it is not enough to understand DNA, proteins, and the other molecular structures that are the building blocks of living organisms, because these structures also exist in dead organisms, e.g., in a dead piece of wood or bone.

The difference between a living organism and a dead organism lies in the basic process of life – in what sages and poets throughout the ages have called the "breath of life." In modern scientific language, this process of life is called "metabolism." It is the ceaseless flow of energy and matter through a network of chemical reactions, which enables a living organism to continually generate, repair, and perpetuate itself (Capra, 2002: 5).

Metabolism and the Epigenetic Network

The understanding of metabolism includes two basic aspects. One is the continuous flow of energy and matter. Living systems are open systems. They continually take in food and produce waste. In other words, a living system operates far from equilibrium. Matter continually flows through it, and yet the system maintains a stable form.

To visualize this non-equilibrium state, think of a vortex; a whirlpool in a bathtub for example. Water continually flows through the vortex, yet its characteristic shape remains stable. Metaphorically, we can visualize a living organism as a whirlpool – that is, as a stable structure with matter and energy continually flowing through it.

The second aspect of metabolism is the metabolic network – a network of chemical reactions that breaks down the food and uses the nutrients to grow the organism's biological structures. One of the most important insights of the new understanding of living systems is the recognition that networks are the basic pattern of life. Ecosystems are understood in terms of food webs (networks of organisms); organisms are networks of cells, organs, and organ systems; and cells are networks of molecules. The network is a pattern that is common to all life. Wherever we see life, we see networks.

The first key characteristic of these living networks is that they create their own boundary. A cell, for example, is enclosed by the cell membrane which discriminates between the system – the "self" as it were – and its environment. The membrane is semi-permeable, keeping certain substances out and letting others in, and in this way it regulates the cell's molecular composition and preserves its identity. These semi-permeable membranes are a universal characteristic of cellular life.

The second key characteristic of living networks is that they are self-generating. In a cell, all the biological structures – the proteins, enzymes, the DNA, the cell membrane, etc. – are continually produced, repaired, and regenerated by the cellular network. Similarly, at the level of a multicellular organism, the bodily cells are continually regenerated and recycled by the organism's metabolic network.

When we try to describe the metabolic network of a cell in detail, we see immediately that it is very complex, even for the simplest bacteria. Most metabolic processes are catalyzed by enzymes and receive energy through special phosphate molecules known as ATP. The enzymes alone form an intricate network of catalytic reactions, and the ATP molecules form a corresponding energy network. Through the messenger RNA, both of these networks are linked to the genome, which is itself a complex interconnected web, in which genes directly and indirectly regulate each other's activity. In other words, the metabolic network includes the genetic level but extends to levels beyond the genes. It is therefore also known as the "epigenetic" network.

The recent advances in genetics have shown that this epigenetic network plays a critical role in all biological processes involving genes. The fidelity of DNA replication, the rate of mutations, the transcription of coding sequences, the selection of protein functions, and the patterns of gene expression are all regulated by the epigenetic network in which the genome is embedded. This network is highly nonlinear, containing multiple feedback loops, so that patterns of genetic activity continually change in response to changing circumstances.

Let me now summarize my description of metabolism by identifying four key characteristics of biological life (Capra, 2002: 13).

1. A living system is materially and energetically open – it needs to take in food and excrete waste to stay alive;
2. It operates far from equilibrium – there is a continual flow of energy and matter through the system;
3. It is organizationally closed – a metabolic network bounded by a membrane;
4. It is self-generating – each component helps to transform and replace other components.

Nonlinearity

These four characteristics all have one thing in common: they are characteristics of a system whose dynamics and pattern of organization are nonlinear. Non-equilibrium systems are nonlinear systems; networks are nonlinear patterns of organization. This is where complexity theory comes in. It is so important for understanding living systems, because it is a nonlinear mathematical theory. Indeed, its technical name is "nonlinear dynamics."

In science, until recently, we always avoided the study of nonlinear systems, because the mathematical equations describing them are very difficult to solve. Whenever nonlinear equations appeared, they were immediately "linearized," i.e., replaced by linear approximations. Instead of describing the phenomena in their full complexity, the equations of classical science deal with *small* oscillations, *shallow* waves, *small* changes of temperature, and so on, for which linear equations can be formulated. This became such a habit that most scientists and engineers came to believe that virtually all natural phenomena could be described by linear equations.

The decisive change over the last three decades has been to recognize the importance of nonlinear phenomena, and to develop mathematical techniques for solving nonlinear equations. The use of computers has played a crucial role in this development. With the help of powerful, high-speed computers, mathematicians are now able to solve complex equations that had previously been intractable.

In doing so, they have devised a number of techniques, a new kind of mathematical language that revealed very surprising patterns underneath the seemingly chaotic behavior of nonlinear systems, an underlying order beneath the seeming chaos. Indeed, chaos theory, an important branch of nonlinear dynamics, is really a theory of order, but of a new kind of order that is revealed by this new mathematics.

Phase Space and Attractors

Let me now review some of the main features of nonlinear dynamics, the theory of complexity (Capra, 1996: 112). When you solve a nonlinear equation with these new mathematical techniques, the result is not a formula but a visual shape, a pattern traced by the computer known as an "attractor." The mathematics of complexity is essentially a mathematics of patterns.

To illustrate this, let me show you a typical example, known as the "chaotic pendulum," which was studied first by the Japanese mathematician Ueda in the late seventies. It is a nonlinear electronic circuit with an external drive, which is relatively simple but produces extraordinarily complex behavior. Each swing of this chaotic oscillator is unique; the system never repeats itself. However, in spite of the seemingly erratic motion, the attractor representing the system's complex dynamics is simple and elegant. It is now known as the Ueda attractor (Figure 1). As you can see, it generates patterns that almost repeat themselves, but not quite. This is a typical feature of the so-called "strange attractors" of chaotic systems.

Let's take a closer look at this attractor. It is a pattern in two dimensions, which are defined by the two variables needed to describe a pendulum – its position (or angle) and its velocity. These two variables

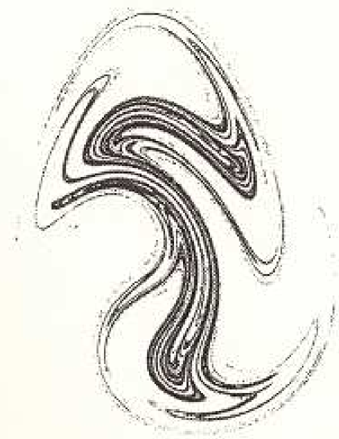

Figure 1 *The Ueda Attractor*

define a mathematical space called "phase space." Each point in the space is determined by the values of the system's two variables, which in turn completely determine the state of the system.

In other words, each point in phase space represents the system in a particular state. As the pendulum moves, the point representing it traces out a trajectory that represents the dynamics of the system. The attractor is the pattern of this trajectory in phase space. By the way, it is called "attractor," because it represents the system's long-term dynamics. A nonlinear system will typically move differently in the beginning, depending on how you start it off, but then will settle down to a characteristic long-term behavior, represented by an attractor. Metaphorically speaking, the trajectory is "attracted" to this pattern whatever its starting point may have been.

It is important to realize that this trajectory in phase space is not the physical trajectory of the chaotic pendulum. It is a visual representation of the pendulum's complex dynamics in an abstract mathematical space. In this case, the phase space has two dimensions, because the system is determined by only two variables. For more complex systems, the phase space will have more than two dimensions, one for each variable of the system.

Fractal Geometry

When we magnify the picture of the Ueda attractor, we discover a multi-layered substructure in which the same patterns are repeated again and again. This property of similar geometric patterns appearing repeatedly at different scales is known as "self-similarity" and is the defining characteristic of fractal geometry, which is another important branch of nonlinear dynamics.

Fractal geometry was developed originally by Benoît Mandelbrot to study the geometry of a wide variety of irregular natural phenomena, and it was only later that its connection with chaos theory was discovered. Since then it has become customary to define strange attractors as trajectories that exhibit fractal geometry.

Over the past twenty years, scientists and mathematicians explored a wide variety of complex systems. In case after case they would set up nonlinear equations, and have computers trace out the solutions as trajectories in phase space. To their great surprise, these researchers discovered that there is a very limited number of different attractors. Their shapes can be classified topologically, and the general dynamic properties of a system can be deduced from the shape of its attractor.

Simplicity and Complexity

The exploration of nonlinear systems over the past decades has had a profound impact on science as a whole, as it has forced us to re-evaluate some very basic notions about the relationships between a mathematical model and the phenomena it describes. One of those notions concerns our understanding of simplicity and complexity.

In the world of linear equations we thought we knew that systems described by simple equations behaved in simple ways, while those described by complicated equations behaved in complicated ways. In the nonlinear world – which includes most of the real world, as we begin to discover – simple deterministic equations may produce an unsuspected richness and variety of behavior. One of the most fascinating examples is the now well-known Mandelbrot set (Figure 2), a fractal structure that displays a richness defying the human imagination and yet can be generated with a very simple iterative procedure.

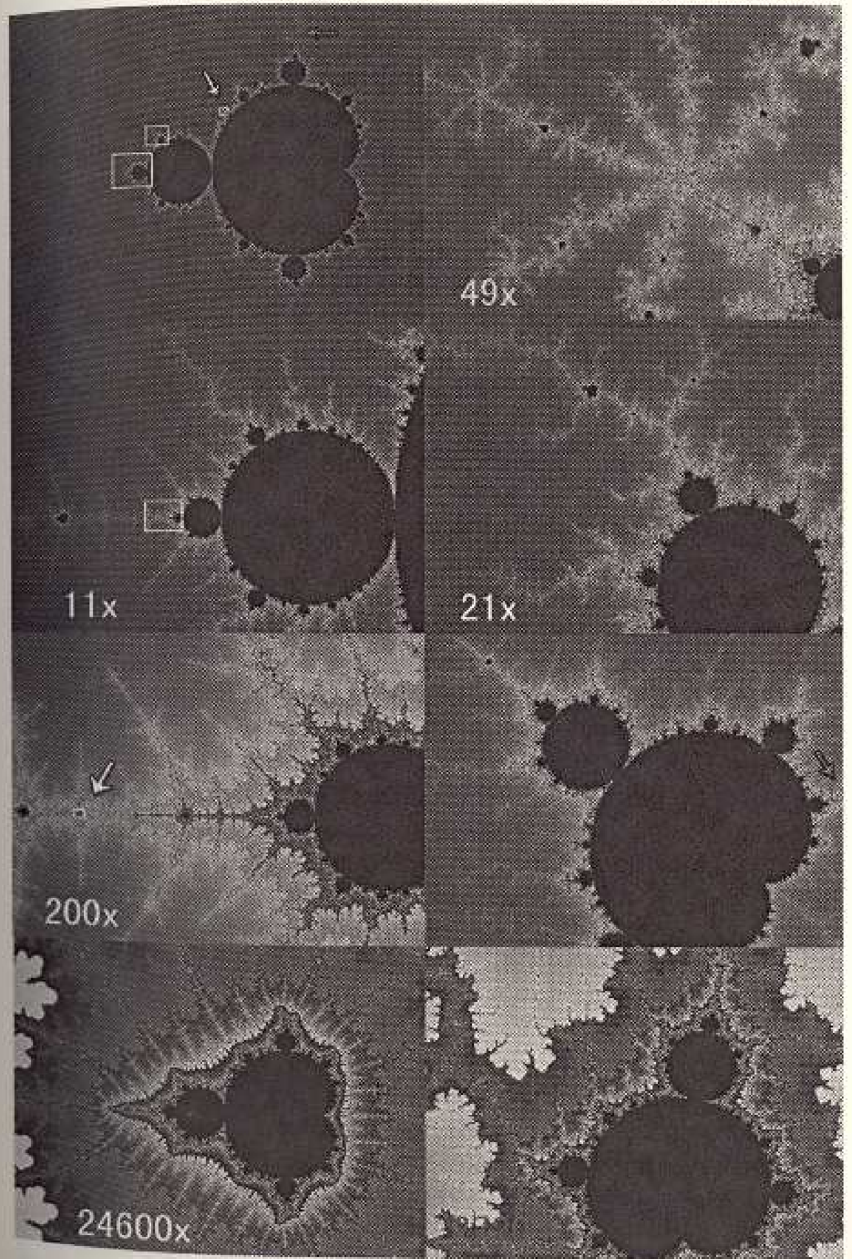

Figure 2 *The Mandlebrot set*

On the other hand, complex and seemingly chaotic behavior can give rise to ordered structures, to subtle and beautiful patterns. Indeed, the term "chaos" has acquired a new technical meaning. The behavior of chaotic systems is not merely random, but shows a deeper level of patterned order.

A central feature of nonlinear systems is the frequent occurrence of self-reinforcing feedback processes. This has several surprising consequences. In linear systems, small changes produce small effects, and large effects are due either to large changes or to a sum of many small changes. In nonlinear systems, by contrast, small changes may have dramatic effects because they may be amplified by repeated feedback.

From Quantity to Quality

Because of the possibility that small differences may be amplified by repeated feedback, nonlinear systems are extremely sensitive to their initial conditions. Minute changes in the system's initial state will lead over time to large-scale consequences. In chaos theory this is known as the "butterfly effect" because of the half-joking assertion that a butterfly stirring the air today in Beijing can cause a storm in New York next month.

The butterfly effect was discovered in the early sixties by the meteorologist Edward Lorenz, who designed a very simple model of weather conditions consisting of three coupled nonlinear equations. He found that the solutions to his equations were extremely sensitive to the initial conditions. From virtually the same starting point, two trajectories would develop in completely different ways, making any long-range prediction impossible.

This discovery sent shock waves through the scientific community, which was used to relying on deterministic equations for predicting phenomena such as solar eclipses or the appearance of comets with great precision over long spans of time. It seemed inconceivable that strictly deterministic equations of motion should lead to unpredictable results. Yet, this was exactly what Lorenz had discovered.

Mathematically, this means that we can never predict at which point in phase space the trajectory of a chaotic system will be at a certain time,

even though the system is governed by deterministic equations. The point is that, in order to calculate the trajectory's evolution, we always need to round off the calculation after a certain number of decimal places, even with the most powerful computers; and after a sufficient number of iterations, or feedback loops, even the most minimal round-off errors will have added up to enough uncertainty to make predictions impossible.

The impossibility of predicting at which point in phase space the trajectory of a chaotic attractor will be at a certain time, does not mean that chaos theory is not capable of any predictions. We can still make very accurate predictions, but they concern the qualitative features of the system's behavior rather than the precise values of its variables at a particular time. Nonlinear dynamics thus represents a shift from quantity to quality. Whereas conventional mathematics deals with quantities and formulas, complexity theory deals with quality and pattern.

Indeed, the analysis of nonlinear systems in terms of the topological features of their attractors is known as "qualitative analysis." A nonlinear system can have several attractors, and they may be of several different types. All trajectories starting within a certain region of phase space will lead sooner or later to the same attractor. This region is called the "basin of attraction" of that attractor. Thus the phase space of a nonlinear system is partitioned into several basins of attraction, each embedding its separate attractor.

The qualitative analysis of a dynamic system consists in identifying the system's attractors and basins of attraction, and classifying them in terms of their topological characteristics. The result is a dynamical picture of the system, called the "phase portrait." The mathematical methods for analyzing phase portraits are based on the pioneering work done by Henri Poincaré at the beginning of the 20th century, and were further developed and refined by the American topologist Stephen Smale in the early 1960s.

Bifurcations

Smale also discovered that in many nonlinear systems, small changes of certain parameters may produce dramatic changes in the basic characteristics of the phase portrait. Attractors may disappear, or change into one another, or new attractors may suddenly appear. Such systems are said to be structurally unstable, and their critical points of instability are called "bifurcation points."

As there are only a small number of different types of attractors, so too there are only a small number of different types of bifurcation events, and like the attractors the bifurcations can be classified topologically. One of the first to do so was the French mathematician René Thom in the 1970s, who used the term "catastrophes" instead of "bifurcations" and identified seven elementary catastrophes. Today mathematicians know about two dozen bifurcation types (such as saddle node, transcritical, Hopf, and pitchfork bifurcations for example).

Mathematically, bifurcation points mark sudden changes in the system's phase portrait. Physically, they correspond to points of instability at which the system changes abruptly and new forms of order suddenly appear. The discovery of this spontaneous emergence of order at critical points of instability is one of the most important discoveries of complexity theory.

Achievements and Status of Complexity Theory

Let me now turn to the achievements and current status of complexity theory. We need to remember, first of all, that complexity theory, or nonlinear dynamics, is not a scientific theory, in the sense of an empirically based analysis of natural or social phenomena. It is a mathematical theory, i.e., a body of mathematical concepts and techniques for the description of nonlinear systems. As we have seen, to describe nonlinear systems mathematically, and to solve the corresponding equations, is radically different from the conventional linear descriptions. The most important achievement of nonlinear dynamics, in my view, is to provide the appropriate language for dealing with nonlinear systems.

I have discussed some of the key concepts of this language – chaos, attractors, fractals, bifurcation diagrams, qualitative analysis, etc. Twenty-five years ago, these concepts did not exist. Now we know what kinds of questions to ask when we deal with nonlinear systems.

Having the appropriate mathematical language does not mean that you know how to construct a mathematical model in a particular case. You need to simplify a highly complex system by choosing a few relevant variables, and then you need to set up the proper equations to interconnect these variables; or you can try to build a computer simulation. This is the interface between science and mathematics.

So, the creation of a new language is the overall achievement of nonlinear dynamics. Then there are partial achievements in various fields, and among those I shall concentrate on the life sciences, the understanding of living systems.

Theory of Dissipative Structures

The Russian-born chemist and Nobel Laureate Ilya Prigogine was one of the first to use nonlinear dynamics to explore basic properties of living systems. What intrigued Prigogine most was that living organisms are able to maintain their life processes under conditions of non-equilibrium. During the 1960s, he became fascinated by systems far from equilibrium and began a detailed investigation to find out under exactly what conditions non-equilibrium situations may be stable.

The crucial breakthrough occurred, when he realized that systems far from equilibrium must be described by nonlinear equations. The clear recognition of this link between "far from equilibrium" and "nonlinearity" opened an avenue of research for Prigogine that would culminate a decade later in his theory of dissipative structures, formulated in the language of nonlinear dynamics (Capra, 1996: 172).

As I mentioned before, a living organism is an open system that maintains itself in a state far from equilibrium, and yet is stable: the same overall structure is maintained in spite of an ongoing flow and change of components. Prigogine called the open systems described by his theory "dissipative structures" to emphasize this close interplay between structure on the one hand and flow and change (or dissipation) on the other. The farther a dissipative structure is from equilibrium, the greater is its complexity and the higher is the degree of nonlinearity in the mathematical equations describing it.

The dynamics of these dissipative structures specifically include the spontaneous emergence of new forms of order. When the flow of energy increases, the system may encounter a point of instability, or bifurcation point, at which it can branch off into an entirely new state where new structures and new forms of order may emerge.

This spontaneous emergence of order at critical points of instability, often simply referred to as "emergence," is one of the most important concepts of the new understanding of life. Emergence is one of the hallmarks of life. It has been recognized as the dynamic origin of development, learning, and evolution. In other words, creativity – the generation of new forms – is a key property of all living systems. And since emergence is an integral part of the dynamics of open systems, this means that open systems develop and evolve. Life constantly reaches out into novelty.

The theory of dissipative structures explains not only the spontaneous emergence of order, but also helps us to define complexity. Whereas traditionally the study of complexity has been a study of complex structures, the focus is now shifting from the structures to the processes of their emergence. For example, instead of defining the complexity of an organism in terms of the number of its different cell types, as biologists often do, we can define it as the number of bifurcations the embryo goes through in the organism's development. Accordingly, the British biologist Brian Goodwin speaks of "morphological complexity" (Goodwin, 1998).

Cell Development

The theory of emergence, known to mathematicians as "bifurcation theory," has been studied extensively by mathematicians and scientists, among them the American biologist Stuart Kauffman. Kauffman used nonlinear dynamics to construct binary models of genetic networks and was remarkably successful in predicting some key features of cell differentiation (Kauffman, 1991: 194).

A binary network, also called "Boolean network," consists of nodes capable of two distinct values, conventionally labeled ON and OFF. The nodes are coupled to one another in such a way that the value of each node is determined by the prior values of neighboring nodes according to some "switching rule."

When Kauffman studied genetic networks, he noticed that each gene in the genome is directly regulated by only a few other genes, and he also knew that genes are turned on and off in response to specific signals. In other words, genes do not simply act; they must be activated. Molecular biologists speak of patterns of "gene expression."

This gave Kauffman the idea of modeling genetic networks and patterns of gene expression in terms of binary networks with certain switching rules. The succession of ON-OFF states in these models is associated with a trajectory in phase space and is classified in terms of different types of attractors.

Extensive examination of a wide variety of complex binary networks has shown that they exhibit three broad regimes of behavior: an ordered regime with frozen components (i.e., nodes that remain either ON or OFF), a chaotic regime with no frozen components (i.e., nodes switching back and forth between ON and OFF), and a boundary region between order and chaos where frozen components just begin to change.

Kauffman's central hypothesis is that living systems exist in that boundary region near the so-called "edge of chaos." He believes that natural selection may favor and sustain living systems at the edge of chaos, because these may be best able to coordinate complex and flexible behavior. To test his hypothesis, Kauffman applied his model to the genetic networks in living organisms and was able to derive from it several surprising and rather accurate predictions.

In terms of complexity theory, the development of an organism is characterized by a series of bifurcations, each corresponding to a new cell type. Each cell type corresponds to a different pattern of gene expression, and hence to a different attractor. Now, the human genome contains between 30,000 and 100,000 genes. In a binary network of that size, the possibilities of different patterns of gene expression are astronomical. However, Kauffman could show that at the *edge of chaos* the number of attractors in such a network is approximately equal to the square root of the number of its elements. Therefore, the human network of genes should express itself in approximately 245 different cell types. This number comes remarkably close to the 254 distinct cell types identified in humans[1].

1 It has been suggested recently, however, that the square root relationship between number of cell types and number of elements (i.e.,

Kauffman also tested his attractor model with predictions of the number of cell types for various other species, and again the agreement with the actual numbers observed was very good.

Another prediction of Kauffman's attractor model concerns the stability of cell types. Since the frozen core of the binary network is identical for all attractors, all cell types in an organism should express mostly the same set of genes and should differ by the expressions of only a small percentage of genes. This is indeed the case for all living organisms.

In view of the fact that these binary models of genetic networks are quite crude, and that Kauffman's predictions are derived from the models' very general features, the agreement with the observed data must be seen as a remarkable success of nonlinear dynamics.

The Origin of Biological Form

A very rich and promising area for complexity theory in biology is the study of the origin of biological form, known as morphology. This is a field of study that was very lively in the 18th century, but then was eclipsed by the mechanistic approach to biology, until it made a comeback very recently with the emphasis of nonlinear dynamics on patterns and shapes.

A key insight of the new understanding of life has been that biological forms are not determined by a "genetic blueprint," but are emergent properties of the entire epigenetic network of metabolic processes.

To understand the emergence of biological form, we need to understand not only the genetic structures and the cell's biochemistry, but also the complex dynamics that unfold when the epigenetic network encounters the physical and chemical constraints of its environment. In this encounter, the interactions between the organism's physical and chemical variables are highly complex and can be represented in simplified models by nonlinear equations. The solutions of these equations, represented by a limited number of attractors, correspond to the limited number of possible biological forms.

$C\propto\sqrt{N}$) is the result of sampling bias and is not generally the case. Bilke and Sjunnesson (2002) provide strong evidence that the number of cell types (or limit cycles) grows linearly with the number of elements (N).

This technique has been applied to a variety of biological forms, from branching patterns of plants and the coloring of sea shells to the nest building of termites. A good example is the work of Brian Goodwin (1994: 77) who used nonlinear dynamics to model the stages of development of a single-celled Mediterranean alga, called Acetabularia, which forms beautiful little "parasol" caps (see Figure 3).

Like the cells of plants and animals, the cell of this alga is shaped and sustained by its cytoskeleton, a complex and intricate structure of protein filaments. The cytoskeleton is subject to various mechanical stresses, and it turns out that a key influence on its mechanical state – its rigidity or softness – is the calcium concentration in the cell. The cytoskeleton is anchored to the cell wall, and its behavior under the mechanical stresses, therefore, gives rise to the alga's biological form.

Since the mechanical properties of the cytoskeleton at the molecular level are far too complex to be described mathematically, Goodwin and his colleagues approximated them by a continuous field, known in physics as a stress-tensor field. They were then able to set up nonlinear equations that interrelate patterns of calcium concentration in the alga's cell fluid with the mechanical properties of the cell walls.

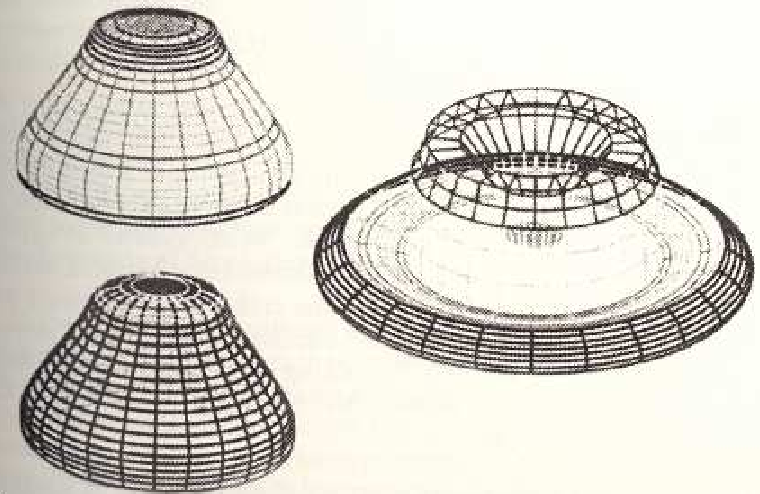

Figure 3 *Computer simulations of algal structures, arising from the interplay between patterns of calcium concentration and mechanical strain*

These equations contained numerous parameters, such as the diffusion constant for calcium, the resistance of the cytoskeleton to deformation, and so on. In nature, these quantities are determined genetically and change from species to species, so that different species produce different biological forms.

Goodwin and his colleagues proceeded to try out a variety of parameters in computer simulations to explore the types of form that a developing alga could produce. They succeeded in simulating a whole sequence of structures that appear in the alga's development of its characteristic stalk and parasol (see Figure 3). These forms emerged as successive bifurcations of the attractors representing the interplay between patterns of calcium and mechanical strain.

The lesson to be learned from these models of plant morphology is that biological form emerges from the nonlinear dynamics of the organism's epigenetic network as it interacts with the physical constraints of its molecular structures. The genes do not provide a blueprint for biological forms. They provide the initial conditions that determine which kind of dynamics – or, mathematically, which kind of attractors – will appear in a given species. In this way genes stabilize the emergence of biological form.

Developmental Stability

From the origin of biological form, let me now move on to the development of an embryo (Capra, 2002: 152-153). Complexity theory may shed new light on an intriguing property of biological development that was discovered almost a hundred years ago by the German embryologist Hans Driesch. With a series of careful experiments on sea urchin eggs, Driesch showed that he could destroy several cells in the very early stages of the embryo, and it would still grow into a full, mature sea urchin. Similarly, more recent genetic experiments have shown that "knocking out" single genes, even when they were thought to be essential, had very little effect on the functioning of the organism.

This very remarkable stability and robustness of biological development means that an embryo may start from different initial stages – for example, if single genes or entire cells are destroyed accidentally – but

will nevertheless reach the same mature form that is characteristic of its species. The question is, what keeps development on track?

There is an emerging consensus among genetic researchers that this robustness indicates a redundancy in genetic and metabolic pathways. It seems that cells maintain multiple pathways for the production of essential cellular structures and the support of essential metabolic processes. This redundancy ensures not only the remarkable stability of biological development, but also great flexibility and adaptability to unexpected environmental changes. Genetic and metabolic redundancy may be seen, perhaps, as the equivalent of biodiversity in ecosystems. It seems that life has evolved ample diversity and redundancy at all levels of complexity.

The observation of genetic redundancy is in stark contradiction to genetic determinism, and in particular to the metaphor of the "selfish gene" proposed by the British biologist Richard Dawkins. According to Dawkins, genes behave as if they were selfish by constantly competing, via the organisms they produce, to leave more copies of themselves. From this reductionist perspective, the widespread existence of redundant genes makes no evolutionary sense. From a systemic point of view, by contrast, we recognize that natural selection operates not on individual genes, but on the organism's patterns of self-organization. In other words, what is selected by nature is not the individual gene but the endurance of the organism's life cycle.

Now, the existence of multiple pathways is an essential property of all networks; it may even be seen as the defining characteristic of a network. It is therefore not surprising that complexity theory, which is eminently suited to the analysis of networks, should contribute important insights into the nature of developmental stability.

In the language of nonlinear dynamics, the process of biological development is seen as a continuous unfolding of a nonlinear system as the embryo forms out of an extended domain of cells. This "cell sheet" has certain dynamical properties that give rise to a sequence of deformations and foldings as the embryo emerges. The entire process can be represented mathematically by a trajectory in phase space moving inside a basin of attraction toward an attractor that describes the functioning of the organism in its stable adult form.

A characteristic property of complex nonlinear systems is that they display a certain "structural stability." A basin of attraction can be disturbed or deformed without changing the system's basic characteristics. In the case of a developing embryo this means that the initial conditions of the process can be changed to some extent without seriously disturbing development as a whole. Thus developmental stability, which seems quite mysterious from the perspective of genetic determinism, is recognized as a consequence of a very basic property of complex nonlinear systems.

Origin of Life

My last example of applying complexity theory to problems in biology is not about an actual achievement but about the potential for a major breakthrough in solving an old scientific puzzle – the question of the origin of life on Earth (Capra, 2002: 17).

Ever since Darwin, scientists have debated the likelihood of life emerging from a primordial "chemical soup" that formed 4 billion years ago when the planet cooled off and the primeval oceans expanded. The idea that small molecules should assemble spontaneously into structures of ever-increasing complexity runs counter to all conventional experience with simple chemical systems. Many scientists have therefore argued that the odds of such prebiotic evolution are vanishingly small; or, alternatively, that there must have been an extraordinary triggering event, such as a seeding of the Earth with macromolecules by meteorites.

Today, our starting position for resolving this puzzle is radically different. Scientists working in this field have come to recognize that the flaw of the conventional argument lies in the idea that life must have emerged out of a chemical soup through progressive increase of molecular complexity. The new thinking begins from the hypothesis that very early on, *before* the increase of molecular complexity, certain molecules assembled into primitive membranes that spontaneously formed closed bubbles, and that the evolution of molecular complexity took place *inside* these bubbles, rather than in a structureless chemical soup.

It turns out that small bubbles, known to chemists as vesicles, form spontaneously when there is a mixture of oil and water, as we can easily observe when we put oil and water together and shake the mixture. Indeed, the Italian chemist Pier Luigi Luisi and his colleagues at the Swiss Federal Institute of Technology have repeatedly prepared appropriate "water-and-soap" environments in which vesicles with primitive membranes, made of fatty substances known as lipids, formed spontaneously (Luisi, 1996).

The biologist Harold Morowitz has developed a detailed scenario for prebiotic evolution along these lines (Morowitz, 1992). He points out that the formation of membrane-bounded vesicles in the primeval oceans created two different environments – an outside and an inside – in which compositional differences could develop. The internal volume of a vesicle provides a closed micro-environment in which directed chemical reactions can occur, which means that molecules that are normally rare may be formed in great quantities. These molecules include in particular the building blocks of the membrane itself, which become incorporated into the existing membrane, so that the whole membrane area increases. At some point in this growth process the stabilizing forces are no longer able to maintain the membrane's integrity, and the vesicle breaks up into two or more smaller bubbles.

These processes of growth and replication will occur only if there is a flow of energy and matter through the membrane. Morowitz describes a plausible scenario of how this might have happened. The vesicle membranes are semi-permeable, and thus various small molecules can enter the bubbles or be incorporated into the membrane. Among those will be so-called chromophores, molecules that absorb sunlight. Their presence creates electric potentials across the membrane, and thus the vesicle becomes a device that converts light energy into electric potential energy. Once this system of energy conversion is in place, it becomes possible for a continuous flow of energy to drive the chemical processes inside the vesicle.

At this point we see that two defining characteristics of cellular life are manifest in rudimentary form in these primitive membrane-bounded bubbles. The vesicles are open systems, subject to continual flows of energy and matter, while their interiors are relatively closed spaces in which networks of chemical reactions are likely to develop. We can recognize these two properties as the roots of living networks and their dissipative structures.

Now the stage is set for prebiotic evolution. In a large population of vesicles there will be many differences in their chemical properties and structural components. If these differences persist when the bubbles divide, we can speak of "species" of vesicles, and since these species will compete for energy and various molecules from their environment, a kind of Darwinian dynamics of competition and natural selection will take place, in which molecular accidents may be amplified and selected for their "evolutionary" advantages.

Thus we see that a variety of purely physical and chemical mechanisms provides the membrane-bounded vesicles with the potential to "evolve" through natural selection into complex, self-producing structures without enzymes or genes in these early stages.

A dramatic increase in molecular complexity must have occurred when catalysts, based on nitrogen, entered the system, because catalysts create complex chemical networks by interlinking different reactions. Once this happens, the entire nonlinear dynamics of networks, including the spontaneous emergence of new forms of order, comes into play.

The final step in the emergence of life was the evolution of proteins, nucleic acids, and the genetic code. At present, the details of this stage are still quite mysterious. However, we need to remember that the evolution of catalytic networks within the closed spaces of the protocells created a new type of network chemistry that is still very poorly understood. This is where complexity theory could lead to decisive new insights. We can expect that the application of nonlinear dynamics to these complex chemical networks will shed considerable light on the last phase of prebiotic evolution.

Indeed, Morowitz points out that the analysis of the chemical pathways from small molecules to amino acids reveals an extraordinary set of correlations that seem to suggest, as he puts it, a "deep network logic" in the development of the genetic code. The future understanding of this network logic may become one of the greatest achievements of complexity theory in biology.

Conclusion

This brings me to the conclusion of my talk. I have reviewed some of the most important achievements of complexity theory in the life sciences. At present, the mathematical language of nonlinear dynamics is still very new, and many scientists are not familiar with it. However, this is bound to change as we become more and more aware of the importance of nonlinear phenomena at all levels of life. Whenever scientists engage seriously in modeling nonlinear systems, especially in biology, complexity theory will be an essential tool. Indeed, according to the neuroscientist and Nobel Laureate Gerald Edelman, "The understanding of complexity is the central problem of biology today" (Edelman, 1998). And the British mathematician Ian Stewart writes:

"*I predict – and I am by no means alone – that one of the most exciting growth areas of twenty-first-century science will be biomathematics. The next century will witness an explosion of new mathematical concepts, of new kinds of mathematics, brought into being by the need to understand the patterns of the living world*" (Stewart, 1998: xii).

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Chapter Two

ECOLOGY: A DIALOGUE BETWEEN THE QUICK AND THE DEAD

Robert E. Ulanowicz

Introduction

At a recent lecture hosted by the American Academy for the Advancement of Science, John Haught (2001a) outlined two extremes between which philosophical opinions on the core issues of life and death have shifted over the last three centuries. By his account, life was regarded prior to the Seventeenth Century as ubiquitous and ascendant. It was perceived to be everywhere, even in what now is commonly regarded as purely physical phenomena. The chief problem for pre-Enlightenment philosophers, therefore, was to explain the exceptional nature of death.

With the dawn of the Enlightenment, the pendulum swung radically in the opposite direction. The preponderance of the universe is now considered to consist of dead, quiescent matter that moves according to deterministic and inexorable laws, which by their simple natures appear to leave no room for the irreversible, asymmetric and contingent phenomena associated with living systems. Under the Enlightenment vision, ontological priority is accorded to dead material, resulting in what Paul Tillich has called "the ontology of death". Haught (2001b) adds that such ontology leads ultimately to a "cosmology of despair". Under such presuppositions, it should come as no surprise that one of the most pressing scientific and philosophical questions of our day has become the emergence of life – how could it possibly have arisen from amongst such a dead universe?

When this shift in assumptions is regarded from a millennial perspective, the possibility that humanity has been entertaining (in sequence) two unrealistic extremes cannot easily be dismissed. Might not there exist an excluded metaphysical middle ground – one that is centered more towards the interface between the quick and the dead? We note, for example, that over the course of the Twentieth Century physicists have been backtracking ever so slowly from the overzealous application of Occam's Razor that had culminated in the Newtonian metaphysics of the early Nineteenth Century (Capra, 1975.) Biologists, however, have been reluctant to follow suit (e.g., Dennett, 1995.) I wish to suggest that if we are to search for such a middle ground, there is no more appropri-

ate concept with which to begin than with that of the *ecosystem*, which Tansley (1935) defined as the combination of the *living* community of organisms, acting with the non- living [*dead*] elements of their environment as a functional unit.

Our choice of ecology as a point of departure towards a revised perspective is reinforced, furthermore, by the feeling (widespread among investigators in many fields) that there is something *special* about ecology. Why else would so many diverse researchers wish to cloak their own endeavors with the mantle of ecology? One encounters, for example, books on "the ecology of computational systems" (Huberman, 1988) or entire institutes devoted to the "ecological study of perception and action" (Gibson, 1979.) I wish to suggest that this predilection on the part of many to assume the guise of ecology for their work derives at least in part from recognition that ecology spans the interface between the quick and the dead. In fact, the sub-discipline of ecosystems research is often pursued under fundamental assumptions that depart markedly from those that have channeled our worldview over the past two centuries.

Before we try to formalize those ecological presuppositions, we first need to review the basic postulates that guided science during its "classical" period early in the 19th Century, so that we may establish a set of references against which to distinguish a new ecological vision.

According to Depew and Weber (1995), science during the 19th Century was overwhelmingly Newtonian in scope. They identified four postulates under which Newtonian investigations were pursued:

1. Newtonian systems are causally *closed*. Only mechanical or material causes are legitimate. Newtonian systems are dead.
2. Newtonian systems are *deterministic*. Given precise initial conditions, the future (and past) states of a system can be specified with arbitrary precision. Newtonian systems are driven wholly from the outside.
3. Newtonian systems are *reversible*. Laws governing behavior work the same in both temporal directions.
4. Newtonian systems are *atomistic*. They are strongly decomposable into stable least units, which can be built up and taken apart again.

After consulting with these authors, I have added a fifth article of faith (Ulanowicz, 1997), namely that:

5. Physical laws are *universal*. They apply everywhere, at all times and over all scales.

As I mentioned above, ecologists are hardly the first to have distanced themselves from some of these five postulates. Early in the 19th Century, the notion of reversibility had been challenged by Sadi Carnot's thermodynamical elaboration of irreversibility and several decades later by Darwin's historical narrative. The development of relativity and quantum theories early in the 20th Century served to bring into question the assumptions of universality and determinism, respectively. As a result, almost no one today continues to adhere to all five postulates. Most biologists (and even many ecologists) still cling, however, to the remains of the Newtonian framework. Fortunately, not all do so.

In his historical analysis of ecosystems theory, Joel Hagan (1992) identified three distinct metaphors by means of which ecologists have attempted to make sense of ecological phenomena. The most familiar and widely-accepted metaphor is that of the ecosystem as a (dead) machine, or clockwork, which, of course, runs according to the Newtonian scenario. This tradition has been kept alive and well by the likes of George Clarke (1954), Howard Odum (1960) and Thomas Schoener (1986). Interestingly, however, the mechanical metaphor was preceded in the ecological arena by Frederic Clements's (1916) suggestion that ecosystems behave like (living) organisms. Clements credited Jan Smuts (1926) as his inspiration, but ultimately he was following in the traditions of Leibniz and Aristotle. The organic analogy was advanced in subsequent decades by G. Evelyn Hutchinson and Eugene Odum. Early on, however, Henry Gleason (1917), a contemporary of Clements, countered the latter's notion of ecosystems as organisms with the idea that ecological communities arise largely by chance and in the absence of any major organizational influences. Such stochasticism was in the tradition of nominalism and prefigured deconstructivist postmodernism (Haught's "cosmology of despair".) It has found voice in contemporary ecology through the writings of Daniel Simberloff (1980), Kristin Schrader-Frechette (and McCoy, 1993) and Mark Sagoff (1997), all of whom deride the mechanical and organic metaphors as unwarranted realism.

Ecosystems and Contingency

One of the key attributes of living systems is their tendency to exhibit chance, unpredictable behaviors. It happens that reconciling chance with deterministic mechanics is no easy task, and the problem has challenged some of the best minds over the past two centuries. Because the various attempts at reconciliation were so limited in scope, biology today remains somewhat "schizophrenic" in nature, much like the polar attitudes as to whether the universe is fundamentally living or dead cited above. Narrative is constantly switching back and forth between the realms of strict determinism and pure stochasticity, as if no middle ground existed. In referring to this regrettable situation, Karl Popper (1990) remarked that it still remains for us to achieved a truly "evolutionary theory of knowledge," and we will not do so until we reconsider our fundamental attitudes toward the nature of causality. True reconciliation, Popper suggested, can be effected only by an intermediate to stochasticity and determinism. He proposed, therefore, a generalization of the Newtonian conception, "force". Forces, he posited, are idealizations that exist as such only in perfect isolation, like the cold, non-living environment of outer space. The objective of experimentation is to approximate such isolation from interfering factors as best possible. In the real world, however, where components are loosely, but definitely coupled, one should speak rather of "propensities". A propensity is the tendency for a certain event to occur in a particular context. It is related to, but not identical to, conditional probabilities.

Deterministic systems are characterized by certainty: If A, then B – no exceptions! At the other extreme, stochastic events are completely independent of past or surrounding events. With propensities, however, the frequency with which an event might occur can be influenced strongly by antecedent events (history) and contemporary surroundings (including other propensities).

This interconnectedness of propensities highlights an unsung aspect of the role of contingency in systems development – namely, that contingencies are not always simple in nature. Chance events can possess highly distinct characteristics, making them rare, or possibly even unique in occurrence. The conventional wisdom, however, is to consider chance events as being almost point-like in extent and instantaneous in duration. In fact, we rarely ever think of chance events as anything but simple and generic. Thus, when Prigogine (and Stengers, 1984) writes about macroscopic order appearing via microscopic fluctuations, it is implicit that the latter are generic and structure-less. Perturbations, however, happen to come in an infinite variety of forms, and any given system may be very vulnerable to some categories of disturbance and rather immune to others. For example, a given organism could be vulnerable to a particular bacterium but immune to another virus. In short, contingencies can be *complex* (Ulanowicz, 2001).

Even if disturbances should come in different flavors, a further implicit assumption is that any individual type of disturbance will always occur repeatedly. The repetition of phenomena is, after all, the Baconian cornerstone of normal science. Once one allows that contingencies may be complex, however, one must face up to the possibility that some contingencies might be *unique* once and for all time. In fact, it is even possible that our world might be absolutely rife with one- time events. Such possibility follows as soon as one ceases to regard contingencies merely as simple point- events, but rather as configurations or constellations of both things and processes.

Because propensities always exist in a context (in accordance with the ecological vision), and because that context usually is not simple, it becomes necessary to consider the reality and nature of complex contingencies. To capture the effects of chance, it won't suffice simply to modulate the parameters of a mechanical model with generic noise (cf. Patten, 1999). In a complex world unique events are occurring continually. Perhaps fortunately, the overwhelming majority of unique events happen and then pass from the scene without leaving a trace. Occasionally, however, a singular contingency can interact with a durable system in such a way that the system readjusts in an *irreversible* way to the disturbance. The system then carries the memory of that contingency as part of its *history*. No amount of waiting is likely to result in an uncontrived repetition of what has transpired.

The efficacy of Popper's concept of propensity is that the rubric applies equally well to law-like behavior, generic chance *and* unique contingencies. We note for reference below that the concept of development generally involves proceeding from less- constrained to more constrained circumstances. We now ask the questions, "What lies behind the phenomena we call growth and development?" and "How can one quantify the effects of this agency?"

Autocatalysis and Organic Systems

A clue to one agency behind growth and development appears as soon as one considers what happens when propensities act in close proximity to one another. Any one process will either abet (+), diminish (-) or not affect (0) another. Similarly, the second process can have any of the same effects upon the first. Out of the nine possible combinations for reciprocal interaction, it turns out that one interaction, namely mutualism (+,+), has very different properties from all the rest. Investigators such as Manfred Eigen (1971), Hermann Haken (1988), Umberto Maturano (and Varela, 1980), Stuart Kauffman (1995) and Donald DeAngelis (1986) all have contributed to a growing consensus that some form of positive feedback is responsible for most of the order we perceive in organic systems. I now wish to focus attention upon a particular form of positive feedback, autocatalysis. Autocatalysis is that form of positive feedback wherein the effect of each and every link in the feedback loop remains positive. In words more germane to the theme of this essay, one could say that the action of each and every element in the cycle quickens[1] the activity of the next member. In the framework of the Newtonian assumptions (as autocatalysis is usually viewed in chemistry) such feedback appears merely as a particular type of (dead) mechanism. As soon as one admits some form of indeterminacy, however, several highly non- mechanical attributes characteristic of living systems suddenly emerge.

To be precise about what form of autocatalysis I am referring, I direct the reader's attention to the three- component interaction depicted in Figure 1. We assume that the action of process A has a propensity to augment a second process B. I wish to emphasize the use of the word "propensity" to mean that the response of B to A is not wholly obligatory. That is, A and B are not tightly and mechanically linked. Rather, when process A increases in magnitude, most (but not all) of the time, B also will increase. B tends to accelerate C in similar fashion, and C has the same effect upon A. Chance is an important element in this form of feedback.

My favorite ecological example of autocatalysis is the community that builds around the aquatic macrophyte, *Utricularia* (Ulanowicz, 1995.) All members of the genus *Utricularia* are carnivorous plants.

1 *Quicken* vt. 1. To make alive: 2. To make more rapid. [*Webster's New Collegiate Dictionary*. G.&C. Merriam Co.: Springfield Massachusetts. 1981.]

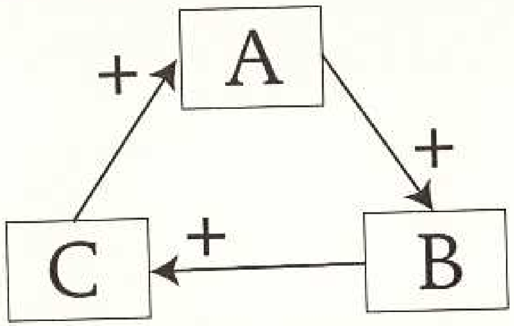

Figure 1 *Schematic of a hypothetical 3-component autocatalytic cycle.*

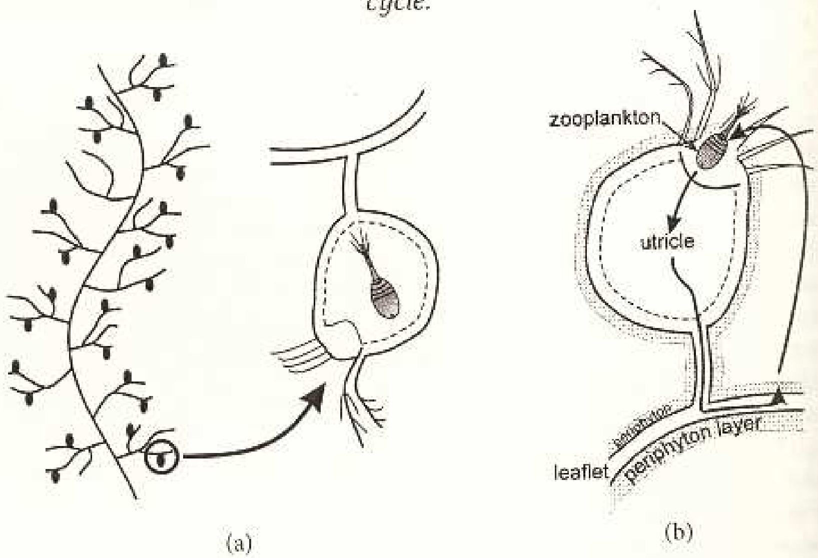

Figure 2 *(a) Sketch of a typical 'leaf' of Utricularia floridana, with detail of the interior of a utricle containing a captured invertebrate; (b) Schematic of the autocatalytic loop in the Utricularia system. Macrophyte provides necessary surface upon which periphyton (stippled area) can grow. Zooplankton consumes periphyton, and is itself trapped in bladder and absorbed in turn by the Utricularia.*

Scattered among its feather- like stems and leaves are small bladders, called utricles (Figure 2a). Each utricle has a few hair- like triggers at its terminal end, which, when touched by a feeding zooplankter, opens the end of the bladder and the animal is sucked into the utricle by a negative osmotic pressure that the plant had maintained inside the bladder. In the

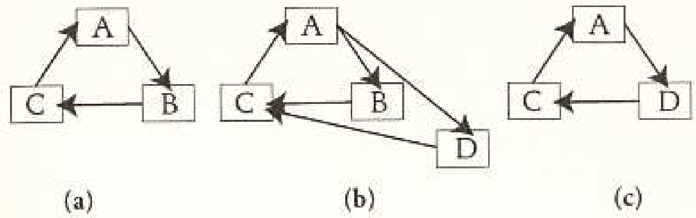

Figure 3 *(a) Original configuration. (b) Competition between component B and a new component D, which is either more sensitive to catalysis by A or a better catalyst of C. (c) B is replaced by D, and the loop section A-B-C by that of F-D-E.*

field *Utricularia* plants always support a film of algal growth known as periphyton (Figure 2b). This periphyton in turn serves as food for any number of species of small zooplankton. The catalytic cycle is completed when the *Utricularia* captures and absorbs many of the zooplankton.

Autocatalysis among propensities gives rise to at least eight system attributes, which, taken as a whole, comprise a distinctly non-mechanical dynamic. We begin by noting that by our definition autocatalysis is explicitly *growth- enhancing*, or quickening. Furthermore, autocatalysis exists as a *formal* structure of kinetic elements. More interestingly, however, autocatalysis is capable of exerting *selection* pressure upon its ever- changing constituents. To see this, let us suppose that some small change occurs spontaneously in process B. If that change either makes B more sensitive to A or a more effective catalyst of C, then the change will receive enhanced stimulus from A. Conversely, if the change in B either makes it less sensitive to the effects of A or a weaker catalyst of C, then that change will likely receive diminished support from A. We note that such selection works on the processes or mechanisms as well as on the elements themselves. Hence, any effort to describe or simulate development wholly in terms of a fixed set of mechanisms is doomed eventually to fail.

It should be noted in particular that any change in B is likely to involve a change in the amounts of material and energy that flow to sustain B. Whence, as a corollary of selection pressure, we recognize the tendency to reward and support changes that bring ever more resources into B. As this circumstance pertains to all the other members of the feedback loop as well, any autocatalytic cycle becomes the center of a *centripetal* vortex, pulling as many of the needed resources as possible into its do-

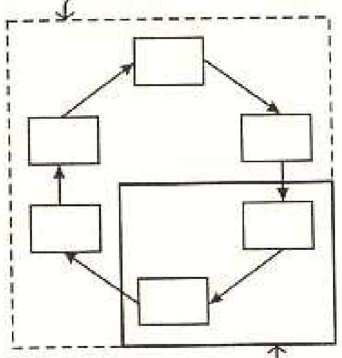

Figure 4 *Two hierarchical views of an autocatalytic loop. The original perspective (solid line) includes only part of the loop, which therefore appears to function quite mechanically. A broader vision encompasses the entire loop, and with it several non-mechanical attributes.*

main. In its centripetality the system is not acting passively at the behest of its environment. It is exhibiting active agency upon those non-living (and living) surroundings.

It follows that, whenever two or more autocatalytic loops draw from the same pool of resources, autocatalysis will *induce competition*. In particular, we notice that whenever two loops partially overlap, the outcome could be the exclusion of one of the loops. In Figure 3, for example, element D is assumed to appear spontaneously in conjunction with A and C. If D is more sensitive to A and/or a better catalyst of C, then there is a likelihood that the ensuing dynamics will so favor D over B, that B will either fade into the background or disappear altogether. That is, selection pressure and centripetality can guide the replacement of elements. Of course, if B can be replaced by D, there remains no reason why C cannot be replaced by E or A by F, so that the cycle A, B, C could eventually transform into F, D, E. One concludes that the characteristic lifetime of the autocatalytic form usually persists beyond those of most of its constituents.

Autocatalytic selection pressure and the competition it engenders define a preferred direction for the system – that of evermore effective

autocatalysis. In the terminology of physics, autocatalysis is *symmetry-breaking*. One should not confuse this rudimentary directionality with full-blown teleology. It is not necessary, for example, that there exist a pre-ordained endpoint towards which the system strives. The direction of the system at any one instant is defined by its state at that time, and the state changes as the system develops.

Taken together, selection pressure, centripetality and a longer characteristic lifetime all speak to the existence of a degree of *autonomy* of the larger structure from its constituents. Again, attempts at reducing the workings of the system to the properties of its composite elements will remain futile over the long run. In particular, attempts to reduce living behaviors wholly to the agencies of non-living components are likewise inappropriate.

In epistemological terms, the dynamics I have just described can be considered *emergent*. In Figure 4, if one should consider only those elements in the lower right- hand corner (as enclosed by the solid line), then one can identify an initial cause and a final effect. If, however, one expands the scope of observation to include a full autocatalytic cycle of processes (as enclosed by the dotted line), then the system properties I have just described appear to emerge spontaneously. Furthermore, should any restructuring of the system follow from the action of a unique aleatoric event, that new configuration could be said to have emerged (ontologically) in a wholly natural way.

It is important to note that the selection pressure that arises from autocatalysis acts from higher scales downwards. Top-down influence is familiar to ecologists in the context of trophic interactions, but the Newtonian metaphysic allows only influences originating at lower realms of time and space to exert their effects at larger and longer scales. Prior to Newton, however, the prevailing view on natural causalities had been formulated by Aristotle, who explicitly recognized the existence of downward causation (Ulanowicz, 2001).

The Achilles heel of Newtonian-like dynamics is that they cannot in general accommodate true chance or indeterminacy (whence the "schizophrenia" in contemporary biology.) Should a truly chance event happen at any level of a strictly mechanical hierarchy, all order at higher levels would be doomed eventually to unravel. By contrast, an Aristotelian hierarchy of causalities, is far more accommodating (and

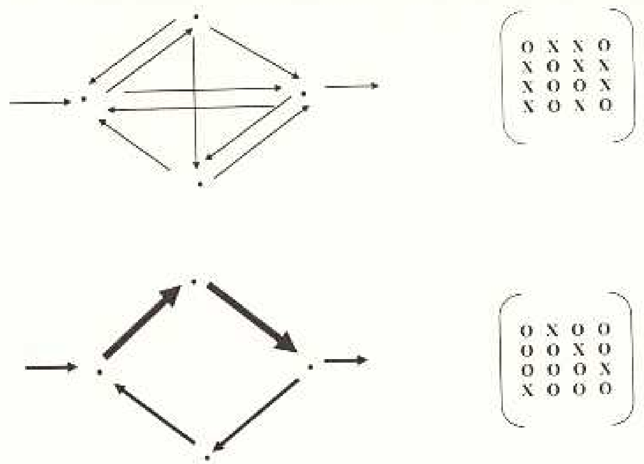

Figure 5 *Schematic representation of the major effects that autocatalysis exerts upon a system. (a) Original system configuration with numerous equiponderant interactions. (b) Same system after autocatalysis has pruned some interactions, strengthened others, and increased the overall level of system activity (indicated by the thickening of the arrows.) Corresponding matrices of topological connections indicated to the right.*

organic.) Any spontaneous efficient agency at any hierarchical level is subject to selection pressures from formal autocatalytic configurations above. These configurations in turn experience selection from still larger constellations, etc. One may conclude, thereby, that the influence of most irregularities remains circumscribed. Unless the larger structure is particularly vulnerable to a certain type of perturbation (and this happens relatively rarely), the effects of most perturbations are quickly dampened.

The Excluded Organic Middle Ground

Popper has suggested that we should no longer be satisfied with the prevailing image of rigid mechanisms set opposite to complete disorder, if for no other reason than that the dichotomy leaves no room in between for the process of life. He, therefore, urges us to consider a middle ground, wherein propensities interacting with each other are behind the emergence of non-rigid structures that nonetheless retain their coherence over time, i.e., he describes a world

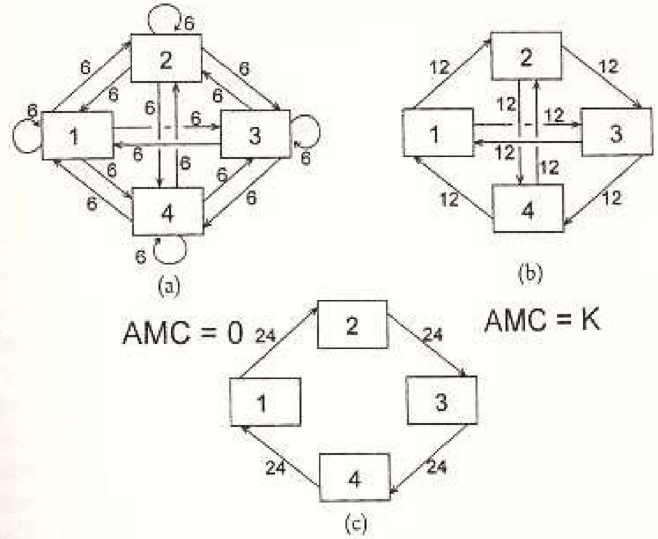

Figure 6 *(a) The most equivocal distribution of 96 units of transfer among four system components; (b) A more constrained distribution of the same total flow. (c) The maximally constrained pattern of 96 units of transfer involving all four components.*

rife with the potential for life. The major problem with earlier organic metaphors has been that their proponents, such as Fredric Clements (1916), cast them in rigid, non-living mechanical terms. We turn our attention, therefore, to agencies that potentially could give rise to organic-like, non-rigid structures, and our focus returns once again to autocatalysis.

Out of our considerations on autocatalysis we abstract two major facets of its actions: Autocatalysis serves to increase the activities of all its constituents, and it prunes the network of interactions so that those links that most effectively participate in autocatalysis become dominant. Schematically this transition is depicted in Figure 5. The upper figure represents a hypothetical, inchoate 4-component network before autocatalysis has developed, and the lower one, the same system after autocatalysis has matured. The magnitudes of the flows are represented by the thicknesses of the arrows.

There is not sufficient space to present in full detail how the two facets of autocatalysis can be quantified. We have room only to sketch out qualitatively the major points. We begin by choosing as the factor that best gauges the extent of system activity the simple sum of the magnitudes of all the system processes, or what has been called elsewhere the "total system throughput" (Finn, 1976). Growth thereby becomes an increase in the total system throughput, much as economic growth is reckoned by any increase in a very similar measure, the Gross Domestic Product.

As for the "pruning", or the intensive (scale-independent) development effected by autocatalysis, it is the manifestation of progressive constraints that appear in the system to guide flows along those links that most effectively contribute to autocatalysis itself. We can never know all these constraints in complete detail. Such ignorance, however, does not preclude us from being able to measure their effects. (If this sounds strange to some readers, they should recall that in thermodynamics one measures the macroscopic properties of matter in complete abstraction from the molecular details that bring about those attributes.) The measure we use to gauge the "pruning" is taken from information theory and is called the "average mutual information" (Ulanowicz, 1980).

To give the reader an idea of what the average mutual information (AMI) represents, we consider a quantum of medium leaving a system compartment. If there are few constraints upon where next that quantum might flow, the contribution to the average constraint will be small. Conversely, if many constraints exist that serve to "channel" or direct the quantum to only one or a very few other compartments, then the contribution to the average constraint will be proportionately large. The average mutual information (or more accurately the *average constraint*) will behave as shown by the three hypothetical configurations in Figure 6. In configuration (a) where medium from any one compartment will next flow is maximally indeterminate. Constraints are completely missing, so that the average constraint is identically zero. The possibilities in network (b) are somewhat more constrained. Flow exiting any compartment can proceed to only two other compartments, and the AMI rises accordingly. Finally, flow in schema (c) is maximally constrained, and the AMI assumes its maximal value for a network of dimension 4.

Because autocatalysis is a unitary process that exhibits both of the extensive and intensive factors just discussed, we can incorporate these two factors of growth and development into a single index by multiplying them together to define a measure called the system *ascendency*

(Ulanowicz, 1980). In his seminal paper, "The strategy of ecosystem development", Eugene Odum (1969) identified 24 attributes that characterize more mature ecosystems. These can be grouped into categories labeled species richness, dietary specificity, recycling and containment. All other things being equal, a rise in any of these four attributes also serves to augment the ascendency. It follows as a phenomenological principle that "*in the absence of major perturbations, ecosystems have a propensity to increase in ascendency.*" Increasing ascendency is a quantitative way of expressing the tendency for those system elements that are in catalytic communication to reinforce each other to the exclusion of non- participating members (i.e., quickening).

I should hasten to emphasize in the strongest terms possible that increasing ascendency is only half the story. Ascendency accounts for how efficiently and coherently the system constraints serve to process medium. Again using information theory, one can compute as well an index called the system overhead that is complementary to the ascendency (Ulanowicz & Norden, 1990). Overhead (called the "conditional entropy" in information theory) quantifies the degrees of freedom, inefficiencies and incoherencies present in the system. Although these latter properties may encumber overall system performance at processing medium, they become absolutely essential to system survival whenever the system incurs a novel perturbation. At such time, the overhead becomes the repertoire from which the system can draw to adapt to the new circumstances. Without sufficient overhead, a system is unable to *create* an effective response to the exigencies of its environment.

It can be demonstrated analytically that the sum of the ascendency and the overhead is proportional to the variety of processes extant in the system. This sum is referred to elsewhere as the system capacity (Ulanowicz & Norden, 1990). That ascendency and overhead are complementary indicates a fundamental tension between the two attributes. When environmental conditions are not too rigorous (as one might find in a tropical rain forest, for example), then the tendency for ascendency to increase will occur at the expense of overhead. The configurations we observe in nature, therefore, appear to be the results of two antagonistic tendencies (ascendency vs. overhead). Whereas the tendency for ascendency to rise describes the process of development (or quickening), it is constantly being opposed by the opposite (but necessary) tendency (increasing overhead) towards disorder and incoherence (death). It is by analogy to this fundamental tension that one may speak of an ecosystem being the result of a "dialogue" between the quick (ascendency) and the dead (overhead).

An Expanded Metaphysic

Let us now take stock of the ecological worldview and how it deviates from the conventional assumptions that characterize Newtonian thought. Far more than calling only one or two of the Enlightenment postulates into question, the emerging ecological framework differs from the classical assumptions on *each and every* point:

1. Ecosystems are not causally closed. They appear to be *open* to the influence of non-mechanical agency. Spontaneous events may occur at any level of the hierarchy at any time, but their domains of influence remain circumscribed by top-down selection processes. Chance does not necessarily unravel a system.
2. Ecosystems are not deterministic (dead) machines. They are *contingent* in nature. Biotic actions resemble propensities more than mechanical forces.
3. The realm of ecology is *granular*, rather than universal. Models of events at any one scale can explain matters at another scale only in inverse proportion to the remoteness between them.
4. Ecosystems, like other biotic systems, are not reversible, but *historical*. Irregularities often take the form of discontinuities, which degrade predictability into the future and obscure hindcasting. The effects of past discontinuities are often retained (as memories) in the material and kinetic forms that result from adaptation. Time takes a preferred direction in ecosystems – that of increasing ascendency (quickening.)
5. Ecosystems are not easily decomposed; they are *organic* in composition and behavior. Propensities never exist in isolation from other propensities, and communication between them fosters clusters of mutually reinforcing propensities to grow successively more interdependent.

The ecological worldview is not entirely subversive, however. By following Popper's evolutionary leads we have retained some connections with the orthodox and the classical. Because propensities are generalizations of Newtonian forces, it can be shown how the principle of increasing ascendency resembles a generalization of Newtonian law *upwards* into the macroscopic realm, in a way that resembles how Schrödinger's wave equation was an extension of Newton's second law *downwards* into the netherworld of quantum phenomena (Ulanowicz, 1999).

Life and Death Redux

In closing we return to the fundamental issues of life and death with which we began this essay. In antiquity it was always assumed in one form or another that life preceded the appearance of matter (and death). This belief was displaced by the Enlightenment message that the unchanging (dead) material world (and its attendant eternal laws) preceded any living forms. Physicists and cosmologists, however, have begun to draw a far more dynamical view of the processes that brought our universe into existence. After the initial Big Bang, subtle asymmetries led to the emergence of various enduring forms out of the initial homogeneous substrate, and with them arose the accompanying laws of interaction that are known to us today. Through various feedbacks these forms of matter and their interactions became quite precise and stable, and the physical world as we now know it eventually took shape.

What is notable about this recent cosmological narrative is that the same sorts of processes appeared to be at work during the evolution of the early universe that we have invoked as being active in the development of contemporary ecosystems. Not only do the processes of development appear to antedate the appearance of matter as we know it, but it is also thought by many that ecosystemic feedbacks were already in place to facilitate the appearance of the first identifiable organisms (Odum ,1971). This revised nested sequencing provides an interesting counterpoint to the dilemmas posed by the mediaeval and Enlightenment extremes. In their places we suggest a phased emergence of one realm from the preceding, all under the modulating influence of the *same selection processes*. That is, we entertain the sequence {physical {ecological {ontogenetic}}} (Salthe, 1993), where each interior realm emerges from the preceding one according to the same developmental scenario, which imparts ever-higher definition (increasing ascendency) to the successive forms. In this elaboration of forms, some vague precursors of the subsequent stage possibly exist within the antecedent realm (*ibid.*). Whenever such predecessors emerge, however, it must be borne in mind that natural creation always *requires* the intervention of at least some contingencies (overhead) (Norton & Ulanowicz, 1992). Furthermore, it is entirely conceivable that such antecedents cannot be identified for each and every example of emergent phenomena. In such cases the resulting forms emerge primarily via the influence of unique chance events.

We thus come to appreciate how the yawning disparity between dead matter and living forms can be bridged simply by shifting our focus toward the developmental processes that preceded and gave rise to both. In this framework the appearance of life was no more exceptional than was the appearance of matter. The facts that matter became more highly defined before life appeared and that all natural life forms require a material substrate do not imply a superior position for matter in any ontological hierarchy. Hierarchies are predicated upon modalities that are selected by those who build them. Most hierarchies are ordered along time and/or space, but one could as well choose organization to define ordinality within a hierarchy (Ulanowicz, 2001.) In such an ordering, a howling dog would occupy a higher position than the moon at which it is baying, despite the fact that the moon so vastly exceeds the animal in spatial and temporal extents.

The very practice of ecology forces us to treat the living and the mechanical more evenhandedly, and by paying close attention to the ongoing "conversation" between the quick and the dead, ecology appears to serve as a very effective interlocutor.

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Chapter Three

COMPLEXITY AND ENVIRONMENTAL EDUCATION

Carlos J. Delgado Díaz

By titling this article "Complexity and Environmental Education" I want to call the reader's attention to the implications of the change of scientific paradigm for the analysis of a specific problem, environmental education, from the perspective of my own philosophical specialization.

Beginning in the second half of the twentieth century, a change has been occurring in the logic of scientific explanation of different branches of knowledge. This change has at its center the substitution of the simplifying paradigm inherited from modern classical science with another that takes into account the multiple interactions that occur in the processes studied. We have begun to understand the world in terms of dynamic systems, where the interactions between the constituents of the systems and their environment are as important as the analysis of those same components. The world has begun to cease being a group of isolated objects and is being presented to the mind and to knowledge as a reality of interactions, emergences, and becoming.

That paradigm shift has important consequences for our vision of the world, for knowledge, and for its social status. Independently of the deep changes occurring in special areas of science, changes in our very understanding of knowledge itself, its production, and its social reach are extremely important.

As the use of the term complexity is still diffuse, I will begin clarifying my interpretation of it. When I speak of complexity I distinguish, following Maldonado (1999), three main approaches:

1. Complexity as *science* (the study of nonlinear dynamics in various specific systems);
2. Complexity as *method of thought* (the proposal of a method that over comes the dichotomies present in traditional epistemology and that consists basically in learning to think relationally);
3. Complexity as *worldview* (the articulation of a new understanding of both the world and knowledge, an articulation that overcomes reductionism and takes advantage of holistic considerations emerging from systemic thinking).

These three approaches are complementary and intertwined despite the fact that, because it constitutes the scientific substrate for any methodological and worldview articulations and thus is at the heart of any paradigm shift, research into nonlinear dynamics is the basis of the other two. However, as a philosopher and researcher in the field of environmental studies, I am specially interested in the worldview scope of the new ideas.

From modernity to today we can distinguish three ideals of rationality that have been present in the production of scientific knowledge. First, classic scientific rationality, characterized by the absolute opposition between the subject and object of cognition and by the elaboration of a worldview constituted by objects separated in space and time. This worldview prevailed until the beginning of the twentieth century, when relativistic and quantum-mechanical thinking broke for the first time with the antinomic opposition between the subject and object of cognition by taking into account observation conditions and the observer's intervention as constitutive elements of cognitive reality. The breakthrough caused by this second ideal of scientific rationality, however, was not total. Essential elements of classical thinking and worldview remained, particularly the notion of simplicity as an attribute of reality. It was only beginning in the 1960s that, thanks to advances in cybernetics and electronic mathematical calculators, and the so-called scientific–technical revolution, important unresolved scientific and practical problems – the problem of the environment in particular – triggered research into what we today gather under the common denominator of complexity.

I should mention that changes in ways of scientifically approaching the research object were not always accompanied by corresponding changes in the field of philosophical epistemology. Classical epistemology – with its exact differentiation of truth and error, of what is objective and subjective, of the subject and object of cognition – persisted in various forms until well into the second half of the twentieth century. This way of thinking finds its last representative in Karl Popper.

Breakthrough ideas occurred in both the dialectical tradition and the historical school of epistemology, both of which recognized the need to acknowledge the subject of cognition as contextualized, historically as well as culturally. However, these more advanced epistemological proposals were still not able to overcome the earlier and dichotomous canons of classical epistemology. For this reason, complexity thinking was initially considered by many philosophers to be a scientific theory important only for its content and by its research objects, and not for its particular cognitive nature nor its original way of formulating problems of cognition. From this scientific theory, however, there has emerged an epistemological reflection of philosophical and worldview significance, linked to scientific debates around implications of the new concepts for issues pertaining to scientific responsibility, the scope of knowledge, and its objectivity. (Among the participants in these debates we highlight relevant scientists such as F. Capra, H. von Foerster, M. Gell-Mann, J. Lovelock, H. Maturana, I. Prigogine, R. Thom, and F. Varela).

Even if we do not pretend to be exhaustive, it is nevertheless important that we attempt to answer the question: What is the worldview scope of the new theories, of the new emergent thinking? I will summarize it in four aspects:

1. Humankind's history and the history of knowledge, which seemed until very recently Parmenidean, have begun to turn increasingly Heraclitean.
2. The world is not zero-sum. Emergence is an essential characteristic of the new paradigm.
3. Complexity is not unique. Multiple complexities do exist.
4. The new scientific rationality has outlined in a radical and new way the problems of the artificiality of man's world and of his knowledge; of the value of knowledge, of its proper status, and the correlation among subject, subjectivity, and objective knowledge.

These aspects have special importance for reframing our understanding of the world, in particular the view that more or less reduces it to a specific group of simple and discontinuous entities.

Oft-repeated and always disturbing questions such as "What is the world?" and "What relationship do the world and human knowledge have to each other?" have been restated and they are being given new answers.

The nature of those answers is central to our understanding of the environmental problem and to outlining a direction for the environmental education of people living in contemporary societies. It is even

more significant if we consider that the environmental problem, seen from a historical perspective, is one of the sources of the emergent complexity paradigm.

It is important to distinguish the epistemological level of complexity from the ontological one. If from an epistemological perspective the problem of complexity is about the knowledge of reality, in the ontological perspective we have before us the problem of the nature of reality. Both problems form an indissoluble unit, since the subject and object of cognition are functional epistemological categories. Complexity thinking, especially some of its most disturbing ideas such as autopoiesis, has forced us to restate the philosophical problems of the artificiality of man's world, the identification of being, and knowledge as a unique process. The dialectical thesis affirming that "there is no object of cognition without a subject of cognition" has now been deepened in the direction of the subject of cognition. "Cognition implies a subject that knows, and it doesn't have sense or value outside of this" (Le Moigne); or, as von Foerster (1998) has outlined, "an epistemology that takes account of itself," that is responsible to the interior of the subject of cognition, suddenly becomes necessary. (See also Maldonado, 1999.)

"The subject of cognition builds a knowledge of reality that is no other than that of his/her own experience of that reality, so what is necessary to know is the subject of cognition, enriched by the knowledge that has forged and his/her capacity to construct or to reconstruct reality" (von Foerster, 1998).

It is not, therefore, a solely external affair, that of knowledge of an external reality, nature, environment, world. It is simultaneously an internal one.

This is a radical outline of the problem of the relationship between knowledge and value and one that we ought to consider. Knowledge is such in so far as the subject of cognition attributes some value to it. Thus reality is constructed through activity, where the subject of cognition constructs his or her experience of that reality through symbolic representations (outlines, letters, phonemes, etc.). In Bachelard's terms, "Nothing is given, everything is built"; or, if we prefer Machado's poetry, "Walker, there is no road, the road is made through walking" (Maldonado, 1999).

From the seventeenth to twentieth centuries we have moved in philosophical epistemology from the notion of an absolute and transcendental subject of cognition separated from the object of cognition, toward the idea of a relative (historical and social) and specific subject of cognition. Now we have begun to talk about the necessity of understanding the subject of cognition as a reflexive entity that accounts for itself. That means that there is no unsurpassable barrier between knowledge and value; that knowledge is not only a value in itself, but rather it acquires sense as knowledge by being a value. I understand that this is an extremely delicate matter, because it affects almost all traditional notions of the objectivity of knowledge. What is important is not to substitute the unsurpassable barrier that separated the objective from the subjective by a bridge of absolute subjectivism. What we need is to understand the artificial, constructed nature of the products of human activity (in this case, of that supreme product we call knowledge, which is now seen to be historic-social).

Our knowledge of the world is a constructed value that allows us to create a representation of that world, but it is not the world in itself. It is a human product that has its origins in human subjectivity. Modern thought excluded subjectivity and built an objectivity based on the exclusion of the subject of cognition. Thus, it endowed knowledge with extraordinary attributes of power and obligation. For too long we thought that the world was just as our knowledge – historically and culturally limited – affirmed that it was. What we now need is to consider the presence of subjectivity in all knowledge. However, this has an extremely important philosophical consequence: If man's world is an artificial world, constructed from knowledge, and if that knowledge is a result of the integration of the subject of cognition and the object of cognition in cognitive acts (which gain significance for that subject of cognition from the involved values), then it is not possible to affirm an objective cognitive relationship that excludes the subject of cognition and transcends it.

If we examine some of the definitions of the environmental problem, we will see that these epistemological debates are not fruitless. One of the most frequent definitions of the environmental problem considers it a problem of the relationship between society and nature. This is a very common definition that takes into consideration the damage that man's actions cause to the natural systems of the environment. However, it is sufficient to ask ourselves "Has the environmental problem always existed?" to become convinced that it is not a problem of the relationship between "society" and "nature," but rather a problem of the relationship between a certain historical type of society and its environment. This precision is not trivial at all, because for a long time in the socialist world it was thought that the environmental problem was the exclusive problem of capitalist society. The fact is that both opposed political systems of the twentieth century, capitalism and socialism, have harmed the atmosphere equally. So this has introduced an important correction in the historical type of society considered, western society. But what really is western society?

Western society is a diverse and integral cultural and social phenomenon. It has become the predominant society in the contemporary world, based on two kinds of influence, material and spiritual. Material influence is associated with the political and economic relationships of dominance and colonization imposed on the world with modernity. Spiritual influence has to do with the generalization of a certain view of the world, the extension of an instrumental relationship with nature, and a unified vision of the natural world (as opposed to a view of the social world with man as its central dominant entity).

If we look carefully, however, the environmental problem cannot be defined, as is often suggested, either as that of the relationship between society and the environment, or as that of the relationship of a certain type of society with its environment. It never occurs to me to think that man doesn't damage the natural environment; there is sufficient proof of that at each stage of modern life. But material damage to the environment is a consequence of our spiritual consideration of what that environment is and of what it means to those of us immersed in western culture. The environmental problem is not the problem of man's relationship with his environment; it is above all the problem of man's relationship with himself. If we are not able to understand that cultural dimension of implicit subjectivity, we will hardly be able truly to understand this problem.

It is from a relationship of cognitive dominance and exclusion, from a dichotomous idea of the world that divides it into a natural and external part and an internal and properly social part, and from a notion of objective knowledge that forces a subordination of obedience that the development of a material model of predatory relations within the environment became – and still becomes – possible. Although it is important from the practical point of view to control predatory practices in their wilder and more destructive forms, it is extremely important from the educational point of view to pay attention to the epistemological and cognitive foundations of those instrumental predatory models. Our idea of the world must be revised and, with it, the absolute dichotomy between nature and society as opposed ends.

Man and the natural environment, and society and the natural environment, constitute an integral unit. We do not have here a relationship between external entities. Rather, we have a problem internal to man's world. It is the cultural world of a historical type of man that has caused this problem and that reproduces it every day. It is of no value to try to endow man with positive knowledge of the dynamics of nature, as there is no value in the breakthroughs that our models of productive interaction with nature cause if we don't take into consideration as a central matter the cultural limits of that provocative subject of environmental damage.

In my opinion, environmental education must be thought of as overcoming cultural limits and should be directed specifically to consideration of the cultural ways in which we perpetuate the dichotomous and reductionist idea about nature as an external environment. This cultural mindset persists in western society, adopting proper "faces" in various disciplines, especially in economics, politics, and ideology.

Without a doubt, the environmental problem is a social problem of a cognitive nature, economically, politically, and ideologically. Overcoming a problem like this cannot be thought of simply as a change of attitudes, as an inculcation of ideas, of conceptual clarifications, or as either a forging of abilities or a modification of sensibilities, although all these aspects must be included in the total process. The predominant focus today in environmental education makes it clear that the environmental problem has sources within the cognitive and social order that must be revealed. Educational tasks should be directed toward overcoming these deeper obstacles. Otherwise we won't be able to achieve the necessary human change.

In short, at the foundation of the environmental problem there are some epistemological presuppositions that we still acritically assume as if they were unchangeable truths. They deeply condition material predatory attitudes in our spiritual constitution and can be summarized

as follows:

1. The absolute delimitation of the subject and object of cognition that is a legacy of modernity and conditions humankind's social perception of the relationship with the environment as one of opposed ends in an absolute way. This opposition led to the articulation of a simplified idea of the natural world as an opposed, passive, and simple entity, easy for man to understand and reproduce. This model's conceptual simplification has prevented man from capturing the wealth of natural interactions, and has facilitated his evaluative impoverishment by viewing nature only from the angle of some of the human interactions with it, particularly as an economic resource;
2. The epistemological justification of scientific truth and science as exact and objective knowledge maintained since the seventeenth century and based on the exclusion of subjectivity and of the subject's absolute opposition to the object of cognition. Thus, man was considered to possess knowledge able to guarantee him domination over natural processes, an idea that is at the foundation of depredatory technologies of the natural environment. That is, the destruction and material impoverishment of the natural environment by man have as their epistemological antecedent serving as their base the destruction of natural integrity and its impoverishment in scientific theories (Capra, 1996). The idea of man's domain over nature is based on this impoverishment of the world;
3. Overcoming the impoverishment of the world by the subject of cognition demands recognition of the participative character of reality. Man's world is an artificial one in which nature is incorporated. Consideration of the participative character of reality allows us to understand what is human and what is natural as a totality and to consider overcoming the problem of the environment as "humankind's problem";
4. Recognizing the participative character of reality, integrated by the subject and the object of cognition, indicates that knowledge is value and its objectivity includes the evaluative moment. Science and morals are indissoluble parts of the objectivity of human knowledge in the participative reality in which they are integrated. The reality of the evaluative dimension in knowledge is not an external attribute coming from society and from social

requirements. It emanates from the bases of science and forms part of knowledge as a social construction. Values are constitutive of activity and therefore of the structure of science and its product; scientific knowledge is not an absolute and superior value, but is nonetheless a value and as such must be subjected to social and cultural scrutiny;

5. Man's understanding of the artificiality of his relationship with the world is a decisive step in overcoming objectivism in scientific approaches, which has led from an epistemological point of view to environmental damage. This understanding can serve as a basis for overcoming the strongest cultural barriers that environmental education encounters in western civilization. These are:
    a. the idea of the absolute legitimacy of knowledge;
    b. its pretended independence with regard to human values, and;
    c. the legitimacy of objective knowledge to guarantee man's supposed domination over nature.

Each of these five erroneous epistemological notions has had its specific manifestations and its own impact on economic theory, politics, and ideology. Among these, as a synthesis we can mention:

- The excessive dimensioning of economic value in political economies of all types, and consequently in contemporary man's way of thinking. The environmental problem cannot be solved without changing the patterns of economic construction and development that have followed industrialization in the nineteenth century. Environmental damage manifests itself in social and economic environments as the realization of the idea of man's domination over nature and also over other social environments that should be assimilated and thus disappear;
- The extension of the ideas of domination and exclusion to politics has become the general ideological, political, and spiritual instrumentation of dominance of some people by others. Cultural intolerance to the diversity of human environments is a specific social manifestation of the environmental damage caused historically by man to himself. This intolerance has included political subordination and the implementation of economic systems that harm human diversity. The impoverishment of the natural and social environment has been the final result of this tendency;

- The dominant idea in ideology that a unique or preferable model of development exists that all societies should adopt, an idea that has led to spiritual justification of the extermination of some people by others. According to this logic there are people and ways of human development that should not exist.

Environmental education must include a deep change in the interior world of the subjects of cognition and a modification of their material relationship with other forms of life and natural processes. The educational task is dual: It demands a change of mentality and a transformation of ways of living.

It is not enough to modernize environmental education so as to actualize us with regard to ecology or alert us to predatory technologies. Environmental education must provide man with an integrative theoretical framework that allows the subjects of cognition to orient themselves within a complex system of cognitive, economic, political, and ideological interactions. Western man's biggest impoverishment is an evaluative one. In the course of the development of western culture, historical man has lost the capacity to produce multiple evaluative judgments; evaluation has been divided into several compartments that make us see only the economic side of things, or the human side, or the natural side, or the social one, or the political one, and so on. Economically understood value frequently subordinates the other values in human evaluations.

Environmental education must be formulated as an education in values that contributes to restoring the evaluative integrity that western man has lost. This includes integral consideration of the natural and human environment, and reconsideration of the predominant cognitive relationships that stem from modernity up to the twentieth century. It includes the rebuilding of morals within the system of knowledge, and the overcoming of modernity's schematicism about the subject and the object of cognition as absolutely opposed ends of knowledge. It includes education about a new worldview based on the construction of a different model of cultural man.

The final result of this transformation must be the intellectual transition from historical man to ecological man. The essential task of environmental education is the reconstruction of the human integrity lost in the process of historical man's formation.

The recovery of that lost integrity (to do which we need to overcome the dichotomies between society and nature, man and environment) will be possible only by means of a cognitive and material effort. The first intellectual step can be made by an educational effort that reestablishes the evaluative integrity that historical man has lost in the process of his social and economic homogenization. This will be followed by the active and transforming recovery of social and economic diversity by ecological man.

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Chapter Four

THE MAINTENANCE AND OPEN-ENDED GROWTH OF COMPLEXITY IN NATURE: INFORMATION AS A DECOUPLING MECHANISM IN THE ORIGINS OF LIFE

Alvaro Moreno &
Kepa Ruiz-Mirazo

Introduction

Human beings are used to building, maintaining, destroying or managing highly complex systems. The development of language, technologies, weapons, laws, social structures, etc. has made it possible. This could lead someone to think that the generation and preservation of complexity is not a big issue; that complexity, somehow, comes for granted. However, whenever we try to make complexity develop in a scenario where there is no human presence, nor possible intervention of other living organisms, things become much harder. Yet most of us are convinced that there had to be a time when matter 'itself' progressively turned into more and more elaborate forms of organization, eventually into some sort of *biological* organization, initiating a process of evolution out of which humankind (only very recently) arose. Thus, it seems necessary to understand the spontaneous origins of complexity in nature if we really want to grasp its actual meaning and its relevance as a scientific concept.

Some important steps have already been taken in that direction. During the last fifteen years we have witnessed the development of the "science of complexity" (Waldrop, 1992; Lewin, 1992), even if quite diverse conceptions of complexity were put forward in the literature, and nowadays there is still no clear consensus on how to define the term. A widespread view considers complexity as a phenomenon universally present wherever densely interconnected sets or networks of elements are established (Weaver, 1948; Simon, 1969; Kauffman, 1993; Horgan, 1995). According to this view, the study of complexity would basically consist in understanding and specifying the conditions under which certain sets of components cross a critical threshold of interconnections, triggering the emergence of new global properties in the system. So complexity, or complex behavior, would be associated to critical transition processes, which occur somewhere "at the edge of chaos" (Langton, 1990) and in such a broad variety of systems (physical, chemical, biological, ecological, neural, social, computational...) that it

can certainly be regarded as a universal type of phenomenon.

Nevertheless, this generic way of conceiving complexity misses a very important point: it does not address the problem of how complexly organized systems can be preserved and, furthermore, how their level of complexity can increase indefinitely in time. In other words, it focuses on identifying which are the most basic spontaneous processes of generation of complexity (at different phenomenological levels), disregarding what could cause the long-term maintenance or the evolutionary growth of that complexity. Even the term "complex adaptive system", so common in the field, is typically used to refer to the natural tendency of these self-organizing critical phenomena to stay in that area "in-between order and chaos" (as a sort of dynamic attractor boundary). So complex behavior is portrayed as a ubiquitous phenomenon in nature even if, rather interestingly, most complex systems that surround us today are the result of previous forms of complex systems, which long ago developed the capacity to endure and evolve through time.

The fundamental problem to be tackled in the following pages is, precisely, how this special type of complexity (open-ended evolutionary complexity) can originate and be characterized in general terms. Our approach will be based on a conception of complexity as a *system* property, as embedded in a real dynamic organization; a property that cannot be completely grasped in strict formal terms, but must be explained rather in terms of the causal roles that components and processes – or relations among components – play in the actual organization. As a result, we will have to search into the origins of minimal self-organizing and self-maintaining systems that develop mechanisms to self-produce and self-reproduce *reliably*. In particular, we will have to focus on how the issue of *generating* complexity becomes entangled with the issue of *preserving* it, in an ever more efficient way. This is quite tricky because, as the level of complexity in the system increases, its preservation, in principle, also becomes harder and harder. Apart from inescapable thermodynamic reasons, our experience in the design of artificial/in vitro systems confirms the latter: as the amount of different components or the number of steps to build each component goes up, so does the brittleness of the system. The question is, then: what would be the minimal set of material mechanisms necessary and sufficient to allow the appearance and maintenance of progressively more complex forms of organization?

Biological and human organizations (like social systems) constitute the only type of system we know that can generate and increase complexity indefinitely. In the course of biological evolution there has been a non-stop generation of new forms of metabolic organization, of increasingly complex internal re-structuring processes (e.g., those leading to the appearance of eukaryotes, multicellular organisms, etc.) and of very diverse types of adaptive behavior (some of which gave rise to cognitive capacities – through the development of a nervous system). At the level of human organizations, cultural evolution has also shown a constant yield of new and ever more complex arrangements of social communities and institutions. Despite the many – and important – differences between all these various systems/phenomena, there is a basic organizational principle common to all of them, as we will try to explain below. In essence, this principle involves the idea of a *dynamic decoupling* within the system that, depending on the particular case/transition, requires a specific set of self-constraining mechanisms. Here we will focus on the minimal or most elementary form of this decoupling, so our analysis will be carried out in the context of the transition from physico-chemical self-organizing phenomena to new and progressively more complex proto-biological systems.

Producing and Preserving Complexity: Two Deeply Interrelated Problems

The central question to be posed here is, therefore, what kind of system – and under what conditions – achieves a level of complexity that allows it to keep growing in complexity indefinitely (according to McMullin (2000), that was also the main problem von Neumann (1966) was trying to tackle with his 'self-reproducing automata'). Our purpose is to formulate this question in basic and universal terms, in the sense that we will search for the most fundamental or elementary set of mechanisms through which a generic type of material organization can give rise to an open-ended evolutionary process. As we already mentioned in the introduction, this issue shows two main sides: first, specifying how it is possible to establish a continuous, unlimited process of *production* of complexity; and, second, finding out the way in which that complexity (or part of it) becomes capable of ensuring its long-term *preservation*. It is convenient to distinguish these two aspects of the problem, even if they will turn out to be deeply interrelated.

Most typical self-organizing phenomena generate some dynamic complexity but are not so good at preserving it (without external aid, we mean): for instance, a hurricane consists in a spontaneous dissipative pattern that fades away when the specific boundary conditions that produced and maintained it disappear. In contrast, self-assembling processes that lead to equilibrium patterns are often capable to preserve their complexity, but the potential for subsequent increase of this complexity turns out to be rather trivial: for example, certain growing crystals show a high degree of reliability in keeping their complex structural designs, but are strongly limited in the production of further complexity. The purpose of this article is to focus on systems that can create by themselves ever new forms of complexity as well as preserve them reliably.

On those lines, it is important to recall that the production of complexity by any physical system requires material and/or energetic resources. This might be different for systems that tend towards thermodynamic equilibrium, but – as we just mentioned above – the complexity that such systems can develop is very low. A frozen pattern, however elaborate it may be, only constitutes an inert sign of the actual dynamic phenomenon that brought it about. So, even if conservative structures may hold a fair degree of complexity, this is just in a formal sense, because that complexity hardly generates causal differences in the future behavior of the system. As a result, we will be interested in processes with potential to produce operational, functional complexity (i.e., not only structural but also organizational complexity). Acknowledging that this kind of *dynamic complexity* can only take place in far-from-equilibrium conditions, where non-linear, long-range correlations between different processes are established, we are forced to deal with (thermodynamically) open systems, in continuous interaction with their environment.

Indeed, this is the case of "dissipative structures" (Nicolis & Prigogine, 1977), where complex patterns of spatial/temporal order are produced quite spontaneously. Long-range connections/interactions among the basic components/processes of the system (plus the constant flow of matter/energy through it) are responsible for the appearance and maintenance of those patterns. However, in these phenomena the production of complexity is still severely limited. Physico-chemical self-organizing processes depend too much (or too critically) on external boundary conditions. Without any control over the material-energetic resources necessary to create complexity, when the latter disappear, or vary significantly, the processes decay (as in the case of the hurricane that we mentioned before).

So how does a dissipative, self-organizing system become more robust and capable of acquiring or managing by itself the material-energetic resources needed for its longer-term maintenance? A fundamental requirement is that the self-maintenance of the system becomes, in Bickhard's terms (1993), a *recursive* kind of self-maintenance. That is to say, the self-organizing system should have some capacity to change the processes and boundary conditions that are responsible for its own maintenance, i.e., it should have the possibility to restructure or redefine itself, to a certain extent – in order to overcome perturbations that threaten its persistence. Now, this is only possible if the dissipative organization of the system develops a remarkable degree of plasticity, which implies that the type of system to investigate must be *chemical*.

Physical systems (or "motion dynamics", in general) do not have the possibility to create a wide enough variety of self-constraining (and at the same time self-*enabling*) mechanisms to allow for that plasticity. In contrast, the chemical domain provides systems with a very flexible and multiform type of organization, based on processes of continuous transformation of molecules, which give rise to new molecules and new transformation processes, and so on. In the context of chemical reaction networks, many of the components being produced act as new local and selective constraints, which have an effect on other processes of production and, ultimately, on the global maintenance of the network. So even the distinction between components of the system and rules of interaction between those components is difficult to draw.

From a thermodynamic perspective, far from equilibrium chemical systems constitute a special type of dynamic systems, in which the construction of new molecular variety through *dissipative processes* creates new *(semi-)conservative constraints* (molecular shapes) which, in turn, can modify the properties of the organization as a whole and, thus, get engaged in a sort of recursive/cyclic dynamics. In this way, such systems can give rise to accumulative construction, a process of interactive feedback between the organization and the assembly of increasingly diverse/complex components, which exploits the combinatorial character of chemical interactions.

Therefore, the jump from physics to chemistry seems necessary for material systems to have at reach a diverse enough spectrum of dynamic, constructive and emergent behavior. This opens up the space of possibilities to be explored by a system, since the variety of new molecular combinations and transformation processes is, in principle, unlimited. However, in order to realize this potential chemical systems must find concrete mechanisms to ensure the robust production of complexity, along with some preliminary capacity to preserve it. In sum, recursive self-maintenance requires chemistry, but a *functional* type of chemistry, in the sense that the components of the system must contribute to its global maintenance, by modulating self-production processes as well as gaining some control on the boundary conditions that allow their far-from-equilibrium dynamics. We will address this point specifically in the next section.

Autonomy: The First Step to Solve the Problem

Although it is, in principle, possible for a chemical system to incorporate a growing number and diversity of components (together with an also growing number of reaction pathways among them), in practice this is not so easy to achieve, because it tends to make the whole system more and more fragile. So the only way to maintain an increasingly complex organization is that the self-organizing system recruits new chemical structures and processes that contribute to its global maintenance, i.e., to the active reconstruction of the necessary conditions for its persistence as such a system. Therefore, the chances for any significant increase in complexity in primitive self-maintaining chemical organizations depend on their degree of internal plasticity, together with the progressive take-over of the external conditions required for their viability. Now, this requires that the dissipative organization of the system develop *functional-homeostatic* mechanisms[1] that provide: (i) capacity to select among

1 Thus, the first step that may be taken so as to tackle our central problem involves the introduction of the concept of 'functionality': that is, consideration of the causal role that the components of a system may have in its maintenance as a whole and, thereby, in their own maintenance as components. This, in fact, is the main idea underlying Rosen's conception of complexity, for instance. He defines a complex system as that in which (the presence and activity of) each component cannot be explained but resorting to the internal efficient causal interaction in the system (Rosen 1991). This is an important concept because of two different reasons: on the one hand, because it directly connects the degree of complexity of

a range of possible eigen-behaviors those that will reinforce their production activity in response to perturbations; and (ii) capacity to define (or, at least, channel) by themselves the mode of interaction with their environment.

When the maintenance of a system is more a consequence of its own organizational dynamics than of the structure and conditions of its external environment it can be considered autonomous. A fundamental step in the evolution towards autonomy was the appearance of systems whose productive activity included the construction of a selective and functionally active membrane. Such a deep structural and organizational change allows the components of the system to carry out reaction processes in much more favorable and stable conditions (regulation of concentrations, selection of particular types of components, etc.), making possible the generation and maintenance of systems with an obviously higher level of complexity. In fact, at this stage the (internal) organization will appear much more integrated and complex with respect to its environment than in previous phases (either in a scenario of primitive autocatalytic networks without a global boundary or in the case of compartments that are still not functionally integrated with the reaction network).

Self-encapsulation will sharply differentiate the organization of the system (the set of relations that constitute it as a distinct unity) from the environment (with which different types of interaction, anyway, must be kept). Thanks to it, a distinctive inner medium progressively develops: a space where not just concentrations, but also components will become increasingly different from those of the "external" medium. However, the most important point here is that the boundary is a result of the productive organization and activity of the system (since it is an integral and integrated part of the proto-metabolic network, not a mere "wall" whose properties are externally defined). This entanglement between the physical border and the recursive processes of production of components constituting the system as an autonomous unit, is basically the idea of an autopoietic system, as it was put forward by Maturana and Varela (1973) more than 30 years ago.

the system with the problem of its maintenance or preservation; and, on the other hand, because it also connects it with the problem of the 'identity' and the clear-cut distinction between system (operational unit) and environment.

Despite its importance, the idea of autopoiesis was formulated in a too abstract way (Ruiz-Mirazo & Moreno, 2004). If we take into account the thermodynamic requirements, an autopoietic system should also manage autonomously the flows of matter and energy necessary for its maintenance, and this has important structural and organizational implications. To be autonomous, a primitive self-maintaining system needs to get some control on the boundary conditions that make it viable, i.e., it needs to constrain the flows of energy (and matter) so as to ensure the physical realization of the processes that constitute it as a proto-metabolic system. In other words, the constructive logic (the recursivity of the relations among the components of the system) should be entangled with the energetic logic of the system (Moreno & Ruiz-Mirazo, 1999). This implies that the membrane is not only a physical border protecting the system against perturbations and ensuring adequate concentration levels, but also a key ingredient in the organization because it articulates the interaction with the environment and channels energy resources for the maintenance of the system.

This thermodynamic view of autonomy goes beyond the idea of logical closure found in the theory of autopoiesis and reveals specific features of the system that are crucial for its realistic implementation. For instance, that the boundary – or interface with the environment – has to be a semi-permeable structure where coupling mechanisms (particularly energetic transduction and active transport mechanisms) are anchored. In this way, as a far from equilibrium organization, the constitutive processes of an autonomous system – the recursive network of production of components – is essentially entangled with a set of *interactive* processes with the environment. Somewhere else (Ruiz-Mirazo & Moreno, 1998, 2000, 2004; Ruiz-Mirazo, *et al.*, 2004) we have introduced and more thoroughly described such forms of organization as "basic autonomous systems" (BAS).

The Long-Term Maintenance of Autonomous Systems

The constitution of systems with an autonomous machinery to construct (and re-construct) all their material components solves a good part of the problem of establishing a continuous and robust process of production of complexity. By means of a functional self-constructing organization (autonomous and at the same time necessarily open and interactive) it is possible to create ever new components and ever new relations among them, some of which will certainly involve an increase in complexity. However, this solves neither the problem of preserving the complexity that emerges in the process, nor the problem of how this complexity could grow indefinitely.

Of course, the productive and reproductive dynamics of an autonomous (proto-metabolic) network would contribute to maintaining the structural and organizational complexity achieved by the system, as a cohesive set of components – and aggregates of components – operationally interconnected. But this still rudimentary functional dynamics cannot ensure that the components (together with their way of organization) remain unaltered for much longer than their typical lifetimes (or the typical lifetime of the whole organization), and the system faces a serious bottleneck: as complexity rises, its preservation becomes more and more difficult. Therefore, basic autonomous systems have to develop specific mechanisms to stabilize and retain the structural and organizational complexity they create. Only once they become capable of preserving that complexity with a fairly high degree of reliability can they begin unfolding new, subsequent levels of complexity and, furthermore, set up the first pillars to ensure their *long-term* maintenance as an emergent kind of natural system.

This constitutes a narrow evolutionary bottleneck because basic autonomous systems cannot overcome a certain threshold of complexity unless they solve two interrelated problems: the synthesis of highly efficient catalysts and their reliable conservation. The first problem requires capacity to generate big molecular components, keeping a specific order in a long chain of building blocks. Specificity in the sequence of building blocks is important because it determines the shape (global structure) of the catalyst, which in turn determines its catalytic function. So the system has to explore different (equally improbable) combinations of building blocks that put together different functional macromolecules and, once the most suitable ones are found, it should be able to keep them unaltered. Otherwise the specific organization of the system would get lost very soon, in very few generation steps. Now, the way to retain these new functional components (more and more fragile as their size and complexity increases) is to establish some sort of "template" or "blueprint" copying device: i.e., some local and robust material mechanism which ensures the exact – or almost exact – renewal

of such complex components.

The preservation of increasingly complex patterns through a template mechanism requires a very special type of component. This must consist of a chain of interchangeable discrete units, which form a specific one-dimensional (1D) sequence, and whose global three-dimensional (3D) shape allows the recurrent copying – by chemical complementarity – of complete equivalent sequences. Only in this way can the system achieve a highly reliable way of synthesizing specific molecular chains and, thereby, of maintaining the functional properties associated to those chains. In fact, not until autonomous systems started producing complex molecular aggregates capable of fixing and transmitting their basic sequence (and thereby, their structural and functional properties) would it be significant to introduce concepts like "memory" or "heredity" in the description of the system (Pattee, 1967).

Thus, we are not talking here about simple template components, like the ones present in the growth of a crystal, for instance. Rather, about *modular* templates (Maynard Smith & Szathmary, 1995), which are the type of molecular structures that may act as real material *records* of an autonomous organization. That is to say, polymers that fulfil the following two conditions: (i) first, their building blocks or basic subunits must be big enough to have three molecular groups, needed to establish the different bonds that will allow their actual constitution as a modular chain and the linkage with other basic subunits in the process of producing a copy or complementary chain; and (ii) second, the 3D structure that these components fold into must not be altered significantly as a result of particular changes in the sequence of subunits (since this will seriously threaten their capacity to replicate by template), which implies that the states associated to the different sequences of subunits must be, energetically speaking, almost equivalent or *quasi-degenerate*.

At a first stage, possibly a single type of complex polymer (consider an "RNA world" type of scenario) could have realized (even if it was in a, somehow, frustrated or limited way – see below) both template and catalytic tasks. Later, however, the system is forced to develop two very different types of polymer and two different – though complementary – modes of operation, bringing about a more intricate situation. The reason is that the material basis of a truly efficient modular template has to be different from the catalytic units controlling/regulating precisely the processes that make up the complex network of production of components (i.e., the metabolism that actually constitutes the system). This incompatibility has to do with the structural limitations of any system based on a single type of polymer (like those systems put forward by Benner, 1999). Indeed, the capacity to store and replicate sequential complexity increases as the capacity to express sequential variety in 3D variety – diversity of shapes – decreases (see Moreno & Fernández, 1990). The latter is the key to the dynamic/functional organization of the system, since the fine tuning of chemical rates depends crucially on the stereo- and substrate-specific features of the molecules involved. Therefore, it becomes necessary to convert the sequential complexity present in the chain of subunits making up the template-components into another kind of subunits or building blocks, apt to integrate chains whose 3D structure expresses their sequential differences.

All this amounts to say that a new kind of autonomous, self-constructing, organization should develop, based on two types of modular (macro-molecular) components, which are made up with different molecular subunits. In that scenario the connection or interrelation between 1D stable sequences and 3D functional configurations cannot be articulated by direct molecular recognition mechanisms, founded on the physico-chemical affinities between the subunits of those different components (for instance, through a base-pairing mechanism). So how can this be achieved?

The solution is to set up an indirect, mediated relationship in which the records instruct the synthesis of the functional components; and these, in turn, control and catalytically regulate all the processes in which the records are involved (replication, translation, reparation, etc.), even if they do not take part directly in the creation and alteration of those records. The key lies, therefore, in the establishment of a certain circularity (causal correlation) between the two operational modes so that the system can "self-interpret" the sequences of the records. Pattee (1977, 1982) carries out a thorough and insightful analysis of this kind of material organization where there already exist two different levels of operation: one involved in the system's fundamental productive-metabolic processes (i.e., "dynamic", "rate-dependent" processes); and the other, partly decoupled from all that muddle of chemical reactions, putting together a group of special processes and components ("rate-independent" processes), with particular rules of composition and functioning.

This *decoupling* turns out to be fundamental from the organizational point of view, since it allows the recruitment for/by single autonomous systems of the results (end-products: selected patterns) of a slow, much more encompassing process of natural selection taking place outside these autonomous systems. The changes that occur at the level of the records are largely independent of (decoupled from) the dynamical processes of the system that these components instruct. In particular, the instructive content of the records must be determined by an evolutionary process in which the whole population and its environment are involved, not just by the metabolic dynamics of each autonomous system. And precisely when the system incorporates and integrates inert records as fundamental components in its operational organization, components whose linear-sequence configuration is not directly linked to the dynamic processes of metabolism, it becomes possible that those sequences start playing a causal "top-down" role in the control of the synthesis of new, specific and increasingly complex functional components.

In this way, through the emergence of a new type of metabolic organization (that we could call "instructed – or genetically instructed – metabolism"), autonomous systems can successful and consistently combine the individual dimension of their activity (related to the self-construction/self-maintenance of each system) with a progressively more important collective dimension (related to their long-term maintenance and evolution as a whole population).

Linking the Individual and Collective Spheres: The Origins of Information

The most natural and convenient way to understand this new ordering in the system (as Pattee 1977, 1982 also claimed) is through the idea of *information*, meaning by information a causal mechanism which operates infusing or propagating *forms* and whose final effect is to re-structure selectively the organization of a material system (Moreno, 1998). We should highlight here that the causal implications of the term "form" go beyond the intrinsic way of matter to self-constrain and re-structure itself, like in the case of those stable patterns self-maintained by means of a selective action on the constituents of the lower level (Van Gulick, 1993).

What is most relevant about the causal action of information is: (i) that those forms are explicit, in the sense that they consist of discrete units realized on a material basis (or material carrier) that transcend the individual system where they operate; and (ii) the fact that there is no direct – material – causal link between those structures carrying the information and the structures whose configuration is selectively modified by the former. Information, thus, is a special type of formal causation, in the sense that it infuses or propagates structures (and, indirectly, organizations), but in a way that is *dynamically decoupled* from the system which it constrains. It is an explicit, rate-independent, formal causation, not a mere self-constraining rate-dependent mechanism based on a dissipative kind of organization. Accordingly, we can say that information is founded on material structures that allow compositional or syntactic-like processes, processes which are dynamically decoupled from the level of the system where the information operates.

Quite clearly, the concept of information (understood as above) serves adequately to characterize the type of metabolic organization described in last section. The sequential pattern of discrete units making up the records, in so far as it acts as an instruction to specify the sequence of subunits that will constitute the functional-catalytic components, appears as a purely formal constraint, for there is no direct causal relation between the materiality of one and the other kind of subunits/components. What is crucial in that causal relation is *form* itself. Moreover, it is a type of form that, due to the nature of its material basis, stays decoupled from the metabolic dynamics of the (individual) system where it causally operates; in fact, it does not really originate in that system, nor does it normally disappear with it.

From a more specific and thorough analysis, let us point out the main reasons why it is suitable to apply the concept of information to explain this type of (genetically) instructed autonomous organization:

1. The system is composed of discrete, digitalizable structures – that we are calling here "records" – whose accessible states are highly degenerate (i.e., all possible sequences or linear-configurations have similar energy levels, are more or less equally likely) and, consequently, they have a high degree of *compositionality* (capacity for multiple processes of free combination with other similar structures). This is also reflected in the fact that sequential changes do not convey alteration of the 3D structure of the molecular carrier.

2. The organization of the system as a whole creates (and depends on) an arbitrary, non-inherent (but stable) relation between the sequence of the records and the functional components whose synthesis is instructed by them. Accordingly, there exists an indirect link (a *translation code*) between a given form – the 1D sequence of the records – and the dynamical processes controlled by the complex functional component – by means of its 3D configuration/stereospecific properties – whose construction is instructed by the former.
3. These 1D sequences behave as "formal-syntactic" structures because they achieve a high degree of decoupling from the intrinsic dynamics and physico-energetic conditions to which their particular material basis is subject (i.e., they establish their own rates and their own processing rules, and remain at an inert, passive, referential state). Hence, there is a dynamical decoupling between two kinds of (complementary) processes in the system: those that concern the formal structure of the records, which appear as rate independent, and those that concern its causal effects (its expression), which appear as rate dependent.

Ultimately, this decoupling is the expression of a radical insertion of autonomous systems into a historical-collective network (an *ecosystem*) where the "slow" processes of creation and modification of informational patterns take place, and where an additional circular relation of cause and effect is established between the individual metabolic organizations and the eco-evolutionary global organization. The origin of information (of genetic information) takes place precisely when the link between both unfolding dimensions is established.

Therefore, the generation of an informational machinery seems critical for the increase in complexity of primitive types of autonomous systems, toward novel systems whose more complex attributes will be developed through the operation of records. Provided that the sequences responsible for the production of functional components become explicit, and that their specific "form" is generated in the course of processes which are independent of the internal dynamics of the system where they operate (processes that involve many generations of such systems and, thus, take place at a different spatial-temporal scale), we can safely state that the construction of new, increasingly complex systems turns out to be fully open-ended. It is not until then that autonomous systems can put in practice a radically different way to change and innovate, in which the variations of the records (i.e., the mutations, the new combinations of sequences, etc.) take place free of functional-ontogenic constraints. Consequently, the evolutionary process that these systems begin may be regarded as the laboratory where new informational sequences are built up, out of which natural selection will only pick or retain those whose expression gives rise to viable and adaptive organisms.

Conclusion: Information as a Universal Requisite for Open-Ended Evolution

The great relevance of information in increasing the complexity of pre-biological systems lies in the fact that it constitutes a new and very powerful organizational mechanism, which allows for new causal connections between domains that are not necessarily linked by physico-chemical laws. Although we can already identify in self-organizing and primitive autonomous systems some kind of "recursivity" through which it is possible to establish such physically "non-inherent" causal connections, without the advent of informational records these emergent causal connections are fully dependent on the actual dynamic organization to which they contribute to maintain. As we have said throughout this article, in those conditions the growth in complexity of the system comes together with a growth in fragility, which implies a serious evolutionary bottleneck.

In contrast, the appearance of information brings forward a radically new level of organization: it makes possible that a great deal of causal specifications be assigned to some inert components, decoupled from the dynamical organization of the system. As a result, those specifications will be – in a first approximation – independent of the dynamic and energetic conditions implied by their material expression. And it is precisely their decoupling from the dynamics of the system what endows those components with compositional properties. Thus, it becomes evident that underneath the re-structuring capacity of informational causation is found a mechanism of dynamic decoupling.

As we have seen, this mechanism operates for the first time in the re-organization of the processes of self-maintenance/self-production in prebiotic metabolisms, in which some *genetic* components start to act as dynamically inert material instructions for the synthesis of specific *functional-catalytic* components. This is the origin of life understood as an evolutionary aperture, as the opening opportunity for autonomous systems to increase indefinitely in complexity.

In the course of biological evolution, this organizational mechanism has been subsequently applied to allow and articulate different major transitions. In particular, we can see that it must be also operating at the origins of cognition, at that stage when some multi-cellular organisms (those whose way of life was based on movement) developed new forms of complex behavior by means of decoupling their adaptive-interactive strategies from their actual metabolism (giving rise, later, to the whole complexity of the cognitive phenomenon; Moreno, *et al.*, 1997; Moreno & Lasa, 2003). More recently (always relatively speaking), we can also find other – perhaps more intuitive or clearer – examples in the evolution of human organizations. For instance, the invention of written language constituted a mechanism that allowed a great increase of social organizations thanks to the decoupling of the way of storing information from the bio-neuronal processes running in each human being; or, in a somewhat different context and with different implications, the development of mathematics was made possible thanks to the creation of formal languages, through which certain operations/calculations could be carried out decoupled from all empirical connotations.

In conclusion, the principle of dynamic decoupling within a complex integrated system probably constitutes the most effective way to re-organize the system, allowing the growth of its complexity at the same time as keeping the level of robustness required for its maintenance, reproduction and evolution. Without this fundamental mechanism of re-organization, there would be no solution to the problem of increasing fragility associated to the growth of complexity. Given that the physico-chemical world is inherently variable and, thus, a continuous source of perturbations, natural systems would not be able to overcome a primary (pre-biological) threshold of complexity, necessary to start an open-ended evolutionary pathway. Furthermore, without this mechanism, complex systems would not be capable to carry out other transitions that involve a radically new way of organizing their constituent and interactive processes.

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Section 2

Philosophical, Epistemological, and Methodological Implications

Chapter Five

WHY WE CANNOT KNOW COMPLEX THINGS COMPLETELY

Paul Cilliers

Introduction

Despite wonderful advances in the mathematics and science of complexity, despite clever modeling techniques, despite fantastic computing machines, and above all, despite being a little fashionable, I wish to argue that complexity theory will not lead to a grand science that will solve many of those difficult outstanding problems of science and philosophy. Rather, I wish to argue that the study of the characteristics of complex dynamic systems are showing us exactly why limited knowledge is unavoidable – or, to be more precise, why knowledge *has to be* limited. The study of complexity, in other words, is not going to introduce us into a brave new world in which we will be able to control our destiny, it confronts us with the limits of human understanding.

Before this position is elaborated, it should be made clear what is *not* being claimed. In the first place, the argument has nothing to do with the dispute about the so-called "end of science"[1]. No claim is made that science cannot progress further, or that we have already discovered most of the fundamental scientific theories, and that new science will only be derivative. This is a hubristic position that glorifies the present. Nor is it claimed that fundamental advances will not be made in those sciences (like the human sciences) normally perceived as too complex. This is a defeatist position, often triggered by an over-evaluation of so-called "hard scientific" results or methods. There is no reason not to believe that there is much to be learned. The argument is just that, as far as complex systems are concerned, our knowledge will always be contextually and historically framed.

It is also not claimed that there is something wrong with modelling complex systems. Computational and mathematical models of different kinds are doing wonderful things, and new avenues should be pursued all the time. However, we should be careful about the claims made about the "knowledge" we gain from many of these models. The models are often as complex as that being modelled, and thus just as difficult to

1 See a.o. Horgan (1996), Lindley (1993) and Durlauf (1997).

understand. In order to gain "knowledge" from complex models, they have to be interpreted, and these interpretations will always involve a reduction in complexity. Thus the main argument is not that there is something metaphysically unknowable about complex systems, but rather that we cannot "know" a system in all its complexity despite the fact that we may be able to model its behavior on a computer[2]. We are returned to the old philosophical problem concerning the relationship between our descriptions of the world and the world itself.

Ontology vs. Epistemology

The traditional way of dealing with this problem is to distinguish between epistemological and ontological issues. Epistemology has to do with the way in which we understand and describe the world, and ontology with the way the world is. One can therefore talk of epistemological complexity (how complex are our descriptions?) and ontological complexity (how complex are things really in themselves?). Using this distinction, one could deal with the problem of our knowledge of the world in the following way: The world itself is not complex, it just is. There is nothing mystical about complex systems. It is just that we cannot keep track of all the millions of non-linear interactions when we have to describe it. Complexity is therefore only an epistemological matter. This is how McIntyre (1998: 28) describes this position:

"[Complex systems, like human systems] *are not complex 'as such' but only complex as described and defined by a given level of inquiry. What is the nature of our interest in human behavior? What sort of questions do we ask about it? That is what will determine the level of complexity that we are dealing with when we seek to understand certain features of human interaction. For the subject matter of social science is not a "natural kind" just sitting out there waiting for us to discover it. A subject matter is created only when we begin to ask questions about features of reality that are puzzling us. Thus, on this interpretation, complexity is derivative rather than inherent.*"

2 This allowance that good models of complex systems may exist is a generous one. Most models of complex systems are used to display general complex behavior, not to model specific, empirical complex systems. This state of affairs may remain so, again not for metaphysical reasons, but because the behavior of complex models will be as unpredictable as that of the systems they model.

This argument has the advantage that it demystifies complexity somewhat. For example, we do not have to let go of causality in order to acknowledge complexity. The world is not dependant on our descriptions. McIntyre, however, uses the ontological\epistemological distinction to make another point, namely that this would mean "that there is no 'fundamental' limit to our understanding of 'complex' systems" (28).

Once one accepts that complex systems are only complex "as described", there is always the possibility that some alternative description – some "re-description" – of the system will yield regularities that will be simpler and can be handled by science... The job of science, then, is to search for those descriptions of the phenomena that will unlock the regularities that are behind the surface noise of complexity. (29)

This argument is in general a useful one, but on certain points somewhat problematic. At heart it is an instrumentalist position, made explicit by the claim that "in attempting to understand reality, we have many descriptive tools at our disposal... There may be one world, but there are an infinite number of alternative ways of describing it" (29). Despite his attempts to deny it ("nature rules out infinitely many descriptions that are inconsistent with it"), this position will have serious difficulties in defending itself against the accusation of relativism.

These difficulties are the result, I would argue, of a too simplified, or perhaps even contradictory understanding of the relationship between our description of the world and the world itself. On the one hand McIntyre separates the two quite clearly, accusing others (e.g., Hayek) of failing to distinguish "sharply" between ontology and epistemology (28), but at the same time it wants to affirm that science is about *reality*. This is to have your cake and eat it. In the end such a sharp distinction between epistemological and ontological issues cannot be maintained. Even if we acknowledge that our descriptions of the world are not perfect, we would like to maintain that they are not merely instruments, but that they enhance our knowledge of the world *as it is*. There is a complex dialectical relationship between the world and our descriptions. When we try to understand the world we are always dealing with ontological *and* epistemological issues simultaneously. To maintain a clear distinction between the two leads to an essentialist metaphysics which should be resisted.

What is Knowledge?

If it is argued that epistemology and ontology cannot be kept apart systematically, what becomes of the notion "knowledge"? This is one of the words that have become commodified in our times. We talk of a "knowledge industry" and of "knowledge management". These terms create the impression that knowledge is something we can trade in, independently of the subject which has the knowledge. In this way knowledge is reified, turned into something that "exists", that can be put on a disk or a website. Of course there are many things we can put on a disk, but perhaps one should reserve the terms "data" or even "information" for this. The term "knowledge", I suggest, should be reserved for information that is situated historically and contextually by a knowing subject. Knowledge is that which has meaning, it is the result of a process of interpretation[3].

There is nothing new about linking knowledge and the knowing subject. It may also look as if it reinstates an independent epistemological level. However, from the perspective of complexity theory, these issues look a little different. In the first place, the subject is not an independent whole, not a free-floating ego which makes "subjective" observations or decisions. It is a complex thing in itself, constituted through the web of relationships with others and the world. The subject itself can therefore only be understood as something contextualized through and through[4].

Secondly, complexity theory also helps us to understand the process by which things and concepts acquire meaning differently. I argue in detail elsewhere (Cilliers, 1998: 58–88) that we cannot maintain a representational theory of meaning. Meaning is not something complete and abstract, linked to the sign which represents it, but is the result of a dynamic interaction between all the meaningful components in the system (37-47), itself a complex process.

If meaning is relational, not representational, there are potentially an infinite amount of relationships at stake each time the meaning of something is generated. Complex systems are open systems, interactions take place across their boundaries. But if an infinite number of interactions have to be considered, the production of meaning will be

3 See also Cilliers (2000).
4 See Cilliers and De Villiers (2000).

indefinitely postponed. This, we know, is not the case. Meaning is generated in real time. How is this possible? Because meaning is constituted in a specific context where some components are included and others not. It would not be possible to have any real meaning if the number of relationships is not limited. In other words, for meaning or knowledge to exist at all, there have to be limits. We cannot comprehend the world in all its complexity. We have to reduce that complexity in order to generate understanding. This is not some terrible fate that befell human subjects, it is merely the result of having to deal with the world in real time with finite means.

To summarize: we are simultaneously in the world and reflecting on the world. These processes are intertwined and involve the interaction of an infinite number of factors. The knowing subject is, however, contextualized. The context limits the number of factors, and thereby makes meaning possible. The context can change, of course, and thereby involve other factors. However, the new context will involve new limits. We cannot have knowledge without limits. An interesting question I will not pursue here is whether we can have knowledge of emergent properties. Perhaps the answer is no!

Limits and Boundaries

Talking about the limits or boundaries of complex systems is not an easy task. On the one hand we acknowledge that complex systems are open, that they exchange information (or matter and energy) with their environment. This would tend to underplay the role of the boundary. On the other hand, the very notion of "system" presupposes the existence of a boundary to the system. For the system to be identified as such it has to be distinguished from what is not part of the system, i.e. the environment or other systems. Both positions can be problematic.

One can, and often should, emphasise the interrelatedness of systems. Often the boundaries of systems are constructions we impose in order to reduce the complexity. This can lead to oversimplifications, to reductive descriptions of the system. However, if boundaries become too vague, we end up with a kind of holism which does not allow much to be said. We cannot consider life, the universe and everything in its totality all the time. We need limits in order to say something.

One can, however, also overemphasize the role played by the boundaries of a system. To my mind, this is the case with Luhmann's position in his elaboration of Maturana and Varella's arguments concerning autopoiesis[5]. The claim that a system can only make representations in terms of its own resources results in what Luhmann calls "operational closure". Thus the legal system, for example, can only operate in legal terms. It organizes legal procedures, so there is change in the system, but this change is always in terms of evolutionary processes taking place within the system. This position makes it difficult to see how any intervention in the dynamics of the system can take place. The claim for operational closure leads to a self-sufficient conceptualization of the system. Since the "knowledge" contained within the system has to be constructed in terms of the internal resources of the system, it is again difficult to see how this position can escape the charge of relativism.

Perhaps one can evade some of these complexities by making a distinction between boundaries and limits. Since this distinction attempts to reduce complexity, it will, like most distinctions, come under pressure in certain contexts. However, it also allows us to say new things about complex systems. The suggestion is that a boundary is something with two sides, like the boundary of a country. A limit, on the other hand, we can only know from one side, i.e. we cannot know what is beyond it. Let us examine the two concepts briefly.

The notion of a boundary seems fairly clear cut. It refers to that which contains and constrains a system. The skin is the boundary of the body; a dam ends where the water ends. However, more often than not it is extremely difficult to determine where the boundary exactly is. Think, for example, of the boundary as those elements of a system that interact directly with the environment of the system. If one conceives of a complex system as something constituted through a rich interaction of all its components, there is only a short route between any element and the environment. In a sense, the whole system is close to the boundary, the boundary is "folded in" and one is never quite sure whether one is dealing with the inside or the outside of the system. The boundary is there, but one cannot pin it down. At the same time, one should also not think of the boundary as something confining the system, but rather as something that constitutes the system. By differentiating the

5 For an excellent discussion of these positions, "Immanent systems, Transcendental Temptations, and the Limits of Ethics" by William Rasch in Rasch, W. and Wolfe, E. (eds.) 2000.

system from the environment, and simultaneously allowing for the transcending of the boundary, the system can be and become what it is. A good example to illustrate this principle is that of the eardrum. It separates the inner and outer ear, but exists in order to let sound come through. Moreover, it would not have been possible for the sound to come through if the boundary was not there[6].

The notion of the limit is a difficult one (and needs a more detailed discussion than will be attempted here). For example, if we concede that there are limits to our knowledge, how do we know when we have reached that limit? It is exactly this claim – that we have reached the limit and that we know it – that leads to the "end of science" argument. Furthermore, how do we talk about limits if we do not know what lies beyond? Do we maintain a Wittgensteinian silence, or do we make assumptions about what lies beyond – a move that will return us to the traditional world of metaphysics.

Perhaps complexity theory can help us to deal with this problem in somewhat different terms. Without falling back into a crude dichotomy between epistemology and ontology, we could argue that the world itself does not have limits, only boundaries. Limits exist in our understanding and descriptions of the world (keeping in mind that these descriptions are not arbitrary constructions, but that they are constrained by reality, that they are "about" the world). The limits are not transcendentally given, but a result of having to deal with complexity with finite means. If this is the case, then there is no reason why the limits cannot be shifted. There will always be limits, thus there will always be something that eludes our understanding of a complex system, but from different perspectives, following different strategies, these limits will be different. To keep on confronting these limits is what science – and life – is all about. Nevertheless, they will remain limits in the sense that we cannot say what it is that eludes us. We cannot calculate what it is that escapes our grasp.

What we need, therefore, are ways of dealing with that which we cannot calculate, of coping with our ignorance. There is a name for this. It is called "ethics", and no amount of complexity theory will allow us to escape it.

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6 See Cilliers (2001) for a further discussion of boundaries, although the distinction between limits and boundaries is not explicitly used there.

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Chapter Six

FROM PARADIGMS TO FIGURES OF THOUGHT

Denise Najmanovich

Introduction

To move from an intellectual perspective, dominated by the simplicity principle, toward a complex approach implies a radical transformation of the global system of production, validation, and circulation of knowledge. A complex approach to complexity involves the decision to give up the desire to formalize or trap complexity in a model or to constrain its possibilities in a paradigm. Complexity is not the end of a race but the main characteristic of a cognitive style that does not rely on standards or *a priori* models.

Complexity is not a new canon, global theory, worldview, or *Weltanschauung*, but a project in evolution. In order to extend the power of the complexity metaphor and allow it to embody and live in multiple figures of thought, fertilizing different domains of knowledge, crossing boundaries and eroding the wall built up in the modern age – in short, to honor complexity – it is necessary to take seriously Deleuze's warning: "There is no method, no recipe, only a long preparation" (Deleuze & Guattari, 1987).

There are many thinkers, researchers, and even journalists who want the "copyright" on complexity (and, of course, to take advantage of it). If we intend to develop a fruitful and powerful complex way of thinking, we have to face the people who pretend to be the "owners" of the concept (some even look like priests of a new cult). They claim, a brilliant but insubstantial claim, that a "complexity paradigm" or "complexity theory" is possible.

Very few people can deny nowadays that there is a vast proliferation of metaphors, models, theories, and professional practices that induce and allow us to think in terms of a shift in paradigms. What I want to suggest is that the complexity approach is far more than a paradigm shift and that complexity metaphors go far beyond the field of science itself. Here we find a beautiful paradox: The simplicity approach usually tries to present a unified or syncretic worldview while reducing the scope of our view. The complexity approach cannot provide such a *Weltanschauung* but, on the other hand, can enlarge, refine, and sophisticate our scope. I am not denying that there are some people (very well-known and important authors among them) who refer to a "new synthesis" or speak in terms of a "complexity paradigm," or even call for a "new worldview." What I intend to show in this article is that the complexity approach is opposed to this point of view, because complexity can neither be totalized nor reduced to an *a priori* theory, and can by no means be constrained to a completely standardized practice.

The Method

The classical notion of method, essential to the birth, growth, and legitimation of modern science, has become a straitjacket for the development of complex thinking. An urgent revision of its genealogy, relevance, virtues, limits, and dangers is therefore necessary.

Alexandre Koyré (1978) taught us that no single science has begun with a method treatise or a body of knowledge that progresses based only on an abstract set of rules, even if this was the exact aim of Descartes, his disciples and followers. The *Discourse on Method* (Descartes, 1999) was written after the scientific essays of which it is the preface and not the other way round, as one would logically expect. However, the author led us to believe that the *Discourse* was prior to the essays and independent of them.

This temporal loop, this supposed priority and independence of the method in relation to the content, is a key to understanding the privilege awarded to methodology in modernity and the danger that it implies for complex thinking. Poets, as Antonio Machado beautifully said, "make the way as they walk," but believers in the method usually assume that the way precedes even the creation of the Earth. The "idealized way" (the etymological meaning of method) excludes the living history of thought, its difficulties, errors, confusions, and sidetracks, showing us a straight road that takes us from ignorance to knowledge. There are no loops, no trials, we are only guided by the brilliant light of its rules. In doing so, the devotees of the method have to place it before the main research, so as to abstract it from the muddy field of complexity, uproot it from the problematic human world, and take it up to heaven and pure essence. Evidently, this goal is absolutely impossible to achieve in the real practice of research, but it is always possible to show *a posteriori*, thanks to a "pedagogic description," which in fact is a reconstruction and depuration of the historical process.

The method's apologists proceed in the style used by Hollywood scriptwriters: In a film, after a cruel battle the soldiers are always clean and impeccably dressed. The same happens with scientific researchers: They never lose their way and always perform their duties with a clear mind, no doubts, and strict rules, in a straight line, without ever getting dirty. Hollywood has accustomed us to this mystifying style: We can cry and shake with the hero who has finished his journey through the desert, under a torrid sun, without a single drop of perspiration. In spite of the incongruity between the scene on the screen and our experience – in fact, we are sweating just watching the film – we tend to believe it. In the same way, Descartes acted as if knowledge were possible without colliding with errors, without getting lost in confusion, without getting dirty with perplexity or groping in the mist of nonsense. He rejected the cultural legacy and appealed only to a non-contaminated faculty: reason. This point of view became deeply rooted and we find it widespread in western culture even today; it is starting to collapse, but it is still alive.

The Nonnarrative Narrative

In order to free ourselves from the "charm of the method," we need to think about the conditions that made it possible for it to become the dominant belief of modernity. It is necessary to pay attention to the narrative style that characterized it and, at the same time, made it possible. Derrida (1997), with his sharp and sophisticated style, denounced this "nonnarrative narrative." This type of discourse is basically of a kind that denies itself as a discourse. The main strategy consists in stating that a "neutral" and "impersonal" speech is possible; in other words, a speech without a speaker and without a speaking modality.

The "great trick" of objectivism is precisely this: to speak as if there were no talking at all, only the pure truth or the fact itself in the words of the "objective speaker." Of course, there is an underlying paradox: "The nonnarrative narrative is a narrative." I want to state that this is the founding paradox of positivist philosophy and, in general, the basis of "simple thinking."

The "nonnarrative narrative" style erases the real path of research, which usually is tangled, intricate, uneven, full of holes, with straight paths and multiple bifurcations – in other words, its historic complexity – and replaces the real paths of knowledge with a happy-ending, linear fable. Thanks to a "temporal loop," the methodic doubt gave birth to a methodic illusion: When we finally reach the desired goal, after a long and tortuous journey, full of difficulties and detours, we are able to invent a linear, simple – and abstract – route that links the beginning to the end. Taking shelter in the pedagogic advantages and virtues of rhetoric clarity, we can rewrite history, reconstruct it, straighten it out. The modern educational system has devoted its best efforts to the job of cleaning up, simplifying, and transforming the complex, vivid, and exciting intellectual path of human knowledge into a linear, insipid, and simple cartoon.

The notion of method was essential to the construction of the rhetoric of simplicity and the "nonnarrative narrative" style, because the very idea of method is key to the practices of historical standardization and depuration. The modern concept of method always implies a linear way, an abstract recipe, a standard training in an *a priori* way of thinking. Real and lively history is rejected on principle. The idea of method makes the illusion of a linear and simple history possible and, at the same time, legitimizes it. "Method" is the name for the hard work of combing a disheveled history, depurating the past, exorcizing complexity, and inventing a highway where only a diffuse mesh of interweaved paths can be found.

Cartesian coordinates allow us to find any two points on the surface of the Earth and link them with a line. Nevertheless, nobody can say that this operation enables us to link the two points by walking in a straight line. The simplicity of maps does not correlate with that of the territory. The map gives us a useful geometric abstraction, which excludes (by method) the specific topography, the weather and its changes, the predators and their efforts, the marshes and their dangers, the bifurcations and their threats.

The Development of Modern Science

As mentioned earlier, Descartes wrote the rules of the method *a posteriori* and let us believe that he was guided by them. He had, with their help, found the right way and obtained the certainty he was searching for: a guaranteed absolute knowledge.

Descartes was not a lonely giant who constructed modern science with his method and all by himself. Francis Bacon (1854), his contemporary, suggested in his *Novum Organum* the methodological solution to the "knowledge problem." Although it was not at the heart of the philosopher's concerns, the method question occupied an important place in medieval debates. Neither Grossetteste nor Duns D'Escoto nor Occam aspired to overthrow the traditional authority or wanted to establish a new court that would pass judgment on the truth or falsity of knowledge. However, this was exactly the aim of both Bacon and Descartes; this was the difference that made the difference and it paved the way for modern thinking.

At this point it is convenient to consider the fact that Bacon and Descartes' important contributions to the birth of modern science did not take place in the field of methodology. On the contrary, their legacy in this area was mostly irrelevant, if not harmful. Bacon's pedestrian empiricism had very little in common with the "experimental model of science" and Descartes' mechanistic rationalism was so extremely abstract that it could not fertilize any of the fields of scientific knowledge (as a metaphor perhaps, but never as an explicit methodology).

Modern science was born from the fortunate hybridization of the traditions of empiricism and mathematical rationalism, leading to a great sophistication of the experience and finding a new place: the laboratory. The idea of an *a priori* method considered valid for all sciences was, as are all pure things, sterile. However, in spite of the little importance that abstract methodology has had for the development of scientific theories, methodological questions, paradxically, have been very successful among philosophers and, through them, have had a great impact on social imagination. Modern science was born at a time when it was necessary to transform the criteria about what had to be considered relevant and legitimate; debates on methodology were, therefore, very popular.

When we criticize a methodology we don't aim at the specific content but at the "form." We don't merely question the possible truth, but the pertinence and relevance of the point of view, its entities, variables, and parameters. We don't only judge the results of a specific inquiry but the system that enabled us to produce meaning and validate knowledge. As Kuhn (1996) and Koyré (1978) put it, when a theory, paradigm, or worldview is going through a crisis, the methodological questions appear in the foreground. The prominent place that the method occupied for Bacon and Descartes satisfied the need for a new source of certainty felt during the chaotic times that connected medieval and modern societies, at a time when science, as we know it today, was born. Because of that, no matter how inappropriate or irrelevant Descartes and Bacon's particular solutions to the methodological questions may seem, their value is not related to their suitability for the real development of the new science, but to the hope of a new way of producing, validating, and legitimizing knowledge that they provided.

By placing the method question in the foreground, Renaissance thinkers first and modern scholars later waged the battle to establish a new authority to judge their productions. Galileo had been a pioneer in this battle, and had made it clear that the question was the struggle between two different kinds of truth: the first written directly in heaven – with mathematical characters – and the second inscribed in the Bible. The ecclesiastical hierarchy had the monopoly on interpretation of the holy scriptures and was challenged by the new methodic knowledge embodied in a new ruling class. The idea of a methodic way of thinking was the great weapon to defy religious authority. The immense success of modern philosophy proves its power, but not its truthfulness.

The idea of a new way of validating knowledge by means of an impersonal procedure – the central concept of methodic thinking – proved to be effective in the battle for chairs in the court of knowledge (always occupied by human beings, not gods or abstract procedures). Unfortunately, we cannot say the same for the capability of *a priori* methods to direct and empower research. The contribution of the idea of method to this field was modest and restrained.

Shaking Off the Tyranny of Method

Nowadays, after some centuries under the empire of method yet hypnotized by the modern discourse, we are starting to shake off the tyranny of method. It is not an easy task. We are still shy and cautious because the remaining power of the positivist discourse is still strong in our society. We are witnessing the beginning of a new adventure of knowledge, nevertheless: the navigation of the seas of complexity and the exploration of their strange and changing territories. This journey is a dynamic one, one that always implies fluid territories, uncertainty, and creativity. The price we have to pay for this trip is to forgo the illusion of an absolute and guaranteed knowledge. This is not a simple task or decision. On the contrary, it requires acceptance of our limitations and of the incomplete character of our knowledge. However, this is the only way to open the door of our world to imagination, chance, and diversity; in short, to creativity at large.

To give up the general idea of the one and only method that will guide us directly to the truth, and that is capable of guaranteeing it, does not necessarily imply that we don't need or accept different methodologies, techniques, and proceedings in order to produce knowledge. It only implies that the method is not independent nor precedes (*a priori*) the experience, and that we always have many possibilities for exploring, thinking, and making sense in our interaction with the world. We only have to give up the fetish of method (the golden but abstract way), but we still have many ways, paths, routes, and roads left and we can always construct new ones, or simply create them by walking. To abandon the modern idea of method does not imply that we will fall into an abyss of nonsense. On the contrary, we need to do it in order to open our minds to the multiplicity of meanings.

Complexity is closely related to this resignation, but the loss is at the same time a profit. We abandon the security of the permanent and stable territories of modernity to move toward the waves of changing fluxes. We not only need to invent new cartographies and new paradigms; we need to go further and build up new ways of making maps: We need new ways of figuration and new figures of thought. ("Figures of thought" refers to thinking styles and expresses a more fluid and dynamic conception of knowledge than does "paradigm." Figures of thought appear, evolve, and reshape in a complex way, in a social, nonlinear process of producing meaning or figuration.) Complexity does not end at the products of knowledge, it goes further up to the processes of production of meaning and experience.

The idea of method was the battering ram used by the bourgeois mentality to knock at the door of the medieval citadel. Under its fascination, but not because of its merits, a new way of experiencing and legitimizing knowledge was created. In the sixteenth and seventeenth centuries the idea of method implied a great expansion in terms of thinking, but soon its absolutist connotations appeared and led the way to a new closure. The new "nobility of knowledge" tended to replace the "nobility of blood" and that of the clerical hierarchy. A new knowledge appeared and developed, but freedom from religious restrictions did

The epistemological turn
From "pure reason" to an "embodied social knowledge"
From a monologue-like logic to a dialogue between multiple logics
From analytical thinking to polyphonic thinking
The turn in global metaphors
From atoms to networks
From the universe to multiple worlds
The turn in the global approach and strategies
From *a priori* theories to cognitive complex practices
From controlled experiments to evolving simulations
From universal knowledge to a situational production of meaning
The turn in the paradigms of science
From conservative laws to nonlinear dynamics
From homeostasis to creativity far from equilibrium
From causality to emergence

Table 1 *Dimensions of the contemporary change: from simplicity to complexity*

not mean complete freedom, just different constrictions: the simplicity principle, linear mathematics, causal explanation, analytical thinking, the natural forces and entities in mechanical relationships, and, last but not least, classical logic.

The challenge of our time is to think without certainties and to accept diversity in the ways of thinking and in the styles of producing meaning. In order to accomplish this, complex thinking cannot accept *a priori* methodological restrictions nor impermeable boundaries between disciplines. It is necessary to jump the cognitive walls built up by the way of approaching the knowledge of modernity and its methodological restrictions, and open our minds and our practices to a multidimensional thinking capable of producing rich and fertile, but not absolute or guaranteed, knowledge.

Table 1 shows the basic dimensions of the contemporary change: from simplicity to complexity.

From a Passive Representation to an Active Configuration

The transformation in epistemology, the paradigm shift in sciences, the emergence of new global metaphors and the metamorphosis in strategies are not independent processes. On the contrary, they mutually affect each other in multiple ways, inducing a mutation in the way we conceive knowledge, in the way we experiment ourselves as human beings and the world to which we belong. These turns pivot on the passage from a static and isolated conception of being (both at the epistemological and ontological levels) to a dynamic and interactive perspective. This movement is capable of presenting knowledge as a *poiesis* (production - creation) of material and symbolic worlds. The complexity approach is restoring its place to *poiesis*, to practices and collective know how, which had been underrated by the Modern conceptions that privileged theoretical knowledge.

"Theory" and its verb "Theoreîn" refer, in Greek, to the act of watching, as those who watched the Olympic games were called "theorists". This visual and distant conception of knowledge came about and spread due to the development of a new technology: writing. Socrates refused to write but Plato, his disciple, was one of the main promoters of a culture that adopted writing without abandoning oral transmission. In order to impose the priority of writing, Plato had to face the poets with all his strength, as they were, at that time, the greatest exponents of Greek culture (Plato, 1977). In order to understand Plato´s bitterness towards the poets we must bear in mind that in oral cultures the role of poetry differed a lot from the one it has today. It was no "cultural luxury" or "subjective expression" of an author, nor an individual activity for leisure moments. In Ancient Greece the poetic activity played an educational, political, social and community role. We could mention real poetic "performances" in which, the rhythm of the words, the music and dancing would develop a bodily and intellectual memory, both emotional and cognitive, that shaped a cultural tradition in a collective activity. These "feasts" of knowledge were the core of education, they offered the community the opportunity to contact the "tribal encyclopaedia" and the possibility to learn and maintain its tradition (Havelock, 1963; Goody, 1986; Ong, 1988).

Plato opposed the empathy of poetic performances , advocating detachment, reflection and methodic abstraction. Writing transformed the traditional ways of producing, sharing, experiencing and legitimizing knowledge. The possibility to express in an external object – a book or its equivalent – part of our knowledge, enabled the development of that inner experience which was called "Psyché" in Greece and which, in Modernity, became the "Subject".

The language of action, characteristic of Homer's poems, was not totally lost with writing, which gave rise to a new syntax – and therefore, to a new form of thinking – which did not previously exist in oral culture. In the written text, the grammar of becoming, which characterized oral culture, gave way to a form of discourse structure which tended to be expressed in being. The action, which had always been performed by individuals – gods, heroes and other characters – lost space and abstract entities such as "justice" and "kindness" occupied the foreground.

According to this, word technologies, communication forms and media, are not mere "external" resources: they imply the transformation of conscience, of our thinking and our way of interacting with the world. Oral cultures favored hearing as the most important form of learning. Sound surrounds and goes through the listener. Hearing is the sense related to rhythm, to living temporality, to resonance, to the bonds which relate human beings. In contrast to oral cultures, a society based on writing as the main source of knowledge considers sight as the most important sense, it needs distance and tends to divide, to separate the observer from what is observed.

In Modernity, sight was at the privileged top. "Clarity and distinction", Descartes's values par excellence, are typically visual virtues. They were the basis for the conception of knowledge as a representation, an intellectual perspective which has been the common factor for most modern epistemological trends.

This idea of knowledge was not born, as some may claim, from a brilliant philosopher´s pure reason; it rather comes from a specific form of human experience which arose from writing and, specially, from the development of the printing, among other influences. It was not a fate pre-determined by technology, as long before the Chinese could print and this did not radically alter their approach of knowledge (Needham, 2004). In China, printing was used by the government bureaucracy without generating changes; but in the Western world, this technology radically transformed the established practices and was used in religious and political struggles which led to the creationl of modern states. It is worth noting the peculiar form in which printing was related to culture as a key device in the struggle for power among protestants (who needed Bibles for everybody) and the Catholic Church (which had had the monopoly of texts and knowledge so far). Princes also used this technology in their struggles with the religious power and supported the creation of workshops outside churches, which enabled them to standardize, normalize and extend the experience which gave rise to modern states, generating a fundamental transformation in the form of knowing and thinking about knowledge (Eisenstein, 1983).

In Modernity, knowledge was thought of as a reflex, a *"mimesis"*, produced by a rational individual who feels separated from Nature and who is capable of creating an internal image which corresponds one to one with that of the real world, which is considered as completely independent (Rorty, 1981). Both the material and the conceptual cosmos of Modernity – which were considered as completely separated – had the ideal structure of a crystal. The Universe was represented as a gigantic mechanism that followed Newton´s laws of movement. Knowledge took the form of a linear perspective, which was based on geometric optics in such a way that it only focused on products, i.e. in those theories already existing, leaving aside the *poietic* process of knowledge creation. From the multiple ways of producing meaning, only those which fit the grid of the method, characterized by the prevailing standard, mechanical, orderly style, were considered as legitimate. The radical difference between discovery and justification contexts (Reichenbach, 1938) which positivist epistemology set, clearly show the division and parceling of knowledge characteristic of the disciplinary architecture of Modernity. Thinking as an activity, as a form of encounter of the human being with the world, as an interrogation and exploration, as an invention and production, was of no interest to an epistemology only concerned with logic and the justification of theories.

The approach to complexity, considered as dynamic and interactive, implies a change in the global treatment of knowledge which calls for leaving aside the notion of a wholly independent world. Complex thinking does not accept watertight compartments, absolute divisions or isolated systems. Its architecture is not compatible with the rigidity of crystal or with the evanescence of smoke (Atlan, 1990). In order to

accept the challenge issued by the era of complexity, both in relation to our conception of the material world and to the way in which we think about knowledge, requires that we find a way out of the vicious circle which supposes that our only option is to choose either the rigidity of the objective crystal and its absolute descriptions, or the relativism of smoke which turns the Universe into an evanescent interpretative illusion. Trying to avoid the unfortunate confrontation of "Modernity vs. Postmodernity", Zygmundt Bauman has proposed that we are living in the time of Liquid Modernity (Bauman, 2000). Ways of life and forms of knowledge characteristic of modernity are disappearing, new figures are being born and, above all, new forms of imagining are emerging. Complex approaches characterized by thinking in terms of non-linear interactions give us the possibility to abandon the vicious circle and adopt a fluid thinking, capable of adopting various configurations without necessarily achieving the rigidity of crystal or vanishing like smoke. Knowledge, understood as a configuration which emerges from a multidimensional interaction, is no longer a rigid and external product crystallized in a theory, but rather an activity. The configuration emerges from the encounter of human beings with the world to which they belong, a multiple and mediated encounter, from which the subject and the world simultaneously emerge in their mutual making, in an endless becoming (Najmanovich, 2005b).

In liquid Modernity (which is also the "Internet Era"), thinking is clearly a network activity which does not process knowledge but which generates meaning in a bonding dynamics which does not belong to an isolated performer but rather to the collective formed for each situation. In Modernity, thinking corresponded to the individual and depended on the rules of classical logic and the method. At present, we face the challenge of building a grammar based on action and *poiesis*. Paradoxically, new means have returned us the possibilities we had lost in the transition from oral culture to writing and offer us new ones. I would like to point out the interactive, multidimensional and fluid dimension of new technologies which, at the same time, are demanding us and taking us from the conception of knowledge-product (the flat and static image of theoretical representation) to one which stresses configurative thinking (multidimensional *poietic* activity). In this context, it is fundamental to reconsider who thinks and what thinking is.

From a interactive point of view, it is possible to create answers that differ a lot from Descartes's "I think" and start thinking in "Us" as the subject of thinking. It is not only about pluralistic thought in relation to its production, but also to the forms of production: we think in, with, together with, against the group with which we live. It is the collective that enables us to think and legitimizes knowledge. A collective which not only includes human beings, but also technologies, active spaces, which shape and transform it (Latour, 1993). From this perspective, to think is a form of interaction, a *poietic* activity (productive and poetic) which leaves a wake as it sails: knowledge.

Conclusion

Complexity is not an expansion of simplicity, not even a complication, it is a global reconfiguration of the ways in which we create, validate and share knowledge. An approach that honors complexity has to be able to make the different levels of change fit together in multiple ways, and allow us to construct specific itineraries referring to the particular problems with which we have to deal. From my perspective complexity is not an imperative but a free choice.

However, it is not merely an intellectual choice but an esthetic, ethic, pragmatic, and political one. It is not a simple shift from one paradigm to another, but a radical transformation of our way of experiencing life and producing meaning, of interacting and living together; in other words, a complete and multidimensional transformation of ourselves and our ever evolving world.

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Chapter Seven

COMPLEX DYNAMICAL SYSTEMS AND THE PROBLEM OF IDENTITY

Alicia Juarrero

Who am I?

The philosophical problem of identity has a long history, dating back to ancient times of classical Greece. Quite early in the history of philosophy questions about the problem of identity arose in tandem with the recognition of change: if there is no change the problem of identity does not arise, as a static thing that undergoes no alterations is simply taken to be what it is – and can clearly be identified as such. Questions concerning sameness and difference arise, however, as soon as the thing in question changes. Is it *the same* thing (as before) – an ontological question? By what criteria do we tell if it is or isn't – an epistemological question? So questions of identity often suggest the presence of difference, and differences in time, i.e., change, occasion the even more difficult philosophical question of time.

With the rise of Modernity and its concern with the person, the question "Who am I?" became an even more pressing philosophical issue. Interested not so much in the issue of what makes my body the same as that of the baby I once was (which after all would be the problem of identity that arises with any thing), the question "Who am I?" comes to be understood to mean, "What makes me a *person*, indeed, *this person*?" In turn, this question elicits other troubling ones such as, "What is the relationship between me (qua person) and my body?" "What is the relationship between me as a person and my circumstances, my history?" – along with related epistemological puzzles: "How do we identify and/or re-identify persons despite their psychological changes?" The moral implications of these questions are too numerous – and obvious – to mention.

The quick and dirty encapsulation of the history of the philosophical subject of identity might be summarized with the sentence, "Parmenides and Plato won; Heraclitus and Aristotle lost." By which I would mean, that Parmenides's answer to the question "What makes something *the same*?", "Whatever persists unchanged throughout the changes," became entrenched as western philosophy's answer to the problem of identity. Heraclitus's ontology of process just seemed incapable of handling the problem of identity: constant, relenting, pervasive change, as it seemed to imply no continuity whatsoever, was just too intractable.

As the *Encyclopedia of Philosophy* notes, there are in fact two distinct philosophical Problems of Identity. First, the problem of Identity as Permanence, is captured by the question "What makes something *the same thing as it was before?*". The second, the problem of Identity as Unity (amidst diversity), is captured by the question, "What makes those two things *the same kind of thing?*" The first question involves the philosophical problems of change and permanence, which in turn evolved into two other philosophical problems, that of substance and personal identity. The second question, which can arise independently of the observation of change, gave rise to the philosophical problem of universals, and historically evolved into the problem of individuation.

Because complex dynamical systems are "structures of process" existing over time, both issues arise in any attempt to formulate criteria for their identity: how to identify a complex dynamical system as such, and how to identify a given dynamical system as the same one as before; with international corporations and web-based communities in effect decoupled from any particular spatial location, what identifies such organizations and associations as *that* corporation or community?

As heir to Parmenides, western philosophy has for the most part explained change as a function of Substance, a substrate that sustains and underlies change: for any given thing, its Substance was not thought to change; only its superficial (accidental) attributes did.

By *substance* Aristotle meant primarily a concrete individual, but over the centuries the concept morphed into the concept of essence. A substance, on this view, is a nucleus of qualities that jointly embody the nature of the thing in question, a nucleus, moreover, capable of independent existence. At the end of the paper we will explore whether the original Aristotelian concept of substance might be making a reappearance as a result of the new appreciation of what is now called complex dynamical systems, but in the meantime, just follow the logic of the notion of substance as a nucleus of qualities that jointly embody the nature of the thing they qualify: if the object's essential attributes were to change, the thing would no longer be that "type" of thing, much less that particular thing. So the concept of substance as essence, a concept that can be traced to Plato's theory of Universal Forms or Ideas, was successful because of its claim to be able to answer both problems of identity. Because it also presupposes stable and immutable qualities, this way of looking at substance and identity got a boost from an ontology derived from Newtonian science that emphasized intrinsic qualities such as the atom's mass. On this view only accidental qualities (such as temperature and color), which have to do with the object's relations to other things, are subject to change. Intrinsic qualities, permanent and immutable, are what confer identity on their bearer.

Such a worldview embodied the following presuppositions:

- a thing's essence is independent of its environment and/or its history, which do not affect that essence;
- the furniture of the world consists of isolated, immutable and static things;
- essential/defining attributes are intrinsic to any substance (such as atomic mass) and related internally by deduction.

In short, the common thread that held this conceptual framework together was the belief that a *thing's identity is given by its substance, substance is that which is capable of independent existence, and only that with intrinsic unchanging properties can exist independently*. This cognitive framework has permeated most of our categories, including axiological ones, insisting as it did, for example, that the identity (and autonomy) of a nation-state, a society, or a culture, was to be found only in those unchanging, autochthonous features of the system in question. Anything absorbed from without was assumed uncritically to be a pollutant, a contaminant. The emphasis existentialists such as Sartre placed on autonomy could be traced to this worldview, as was the theological understanding of God as eternal and immutable Being (rather than the more Eastern view of the path of Becoming).

Who am I? In Descartes's wake, this conceptual framework became the battleground between dualism and materialism in what came to be known as the problem of Identity. I (a person) am either my mind (defined/identified by its immaterial essential attribute, thought); or, I (a person) am my body (defined by its physical essential attribute, matter). Insofar as the problem of Identity as Permanence is concerned, from Descartes to Kant an object's identity is thought to be given by its "self-sameness": in Leibniz's famous formulation of the Principle of the Identity of Indiscernibles, "no two substances can be exactly alike except numerically." Unlike Newton's followers, Leibniz held that spatial relations were internal/essential attributes of substance, but

with Ernest Nagel in the twentieth century, the very concept of internal versus external properties and relations is called into question – thereby making the notion of real essences and substance incoherent. The coup de grace to the traditional understanding of the concept of identity, however, was administered by Darwin. With the discovery of evolution, contemporary biology demonstrated that the notion of "essences" is illusory. There is simply no such thing as an organism's "invariable nature", unchanging immutable substance, or Platonic universal.

Now what? For those studying complex dynamical systems the problem of identity appears particularly acute because two moments of a dynamical process might be very different and yet (intuitively) be understood as moments of the same process. Since Heraclitus's process ontology has long been consigned to the dustbin, however, western philosophy is simply unable to account for the identity of complex adaptive processes.

In particular, it is difficult to pin down the identity of complex dynamical systems (CDS) because of their following properties:

- Because CDS's are open to their environment, sharp boundaries between the system and its environment are difficult, if not impossible, to draw;
    - A CDS's external relations are as critical to it as its internal ones;
    - A CDS's environment and history are as critical to it as its intrinsic attributes;
- Because CDS's adapt and evolve, the concept of essence as a nucleus of intrinsic and immutable qualities cannot handle CDS's dynamical characteristic, particularly its embeddedness in time and space.

In order to identify a CDS:

- Do not ask: What is the substrate that changes?
- Do not ask: What universal Platonic substance or Form does the CDS exemplify?
- Do not ask: What are the CDS's intrinsic and essential attributes?
- Do not ask: What is the bearer of those attributes?

In particular do not inquire about the identity of the History or Structure or Essence of Substance or Universal... of Phenomena... *in general.* The lesson of CDS's sensitive dependence on initial conditions is that there exist only particular, *individual – and increasingly individualized* – phenomena. When dealing with individuals that are structures of process, in other words, the problem of *identity as permanence* shares preeminence with the problem *of identity as unity.* On the one hand it is the concrete individual, not the species (much less the genus), that reappears as the primary locus of identity. But it is a processual individual, not a static, thing-like object that is in question. Moreover, it is one with the potential to qualitatively evolve, not just develop.

Aristotle, the first biologist, knew whereof he spoke. Whether animals, hurricanes... or organizations such as businesses, governments, organizations or and communities, complex dynamical systems are organismic phenomena. And living things are embedded in their environment and their history, both onto- and epi-genetically. Autonomy and independence – the classical measures of identity – now suddenly come to be seen as values associated only with dead, isolated things. Living organisms and their creations must instead be judged by their degree of resilience and *flourishing.* Once again, Aristotle knew whereof he spoke: the primary ethical category for Aristotle was *eudaimonia,* usually and incorrectly translated as *happiness,* but more accurately as *flourishing.* And robust resilience, which is large measure is a function of connectivity and interdependence, plays a significant role in the dynamic integrity and flourishing of communities, organizations and associations. With the advent of complex dynamical systems, therefore, the importance of interdependence replaces the former emphasis on autonomy – which now comes to be equated with isolation; and the importance of robust resilience replaces that of independence – which now comes to be associated with stasis and stagnation.

Elsewhere I have examined the difference between stability and resilience in the context of dynamical systems. Stability, which consists of "low fluctuation around specific states" (Holling, 1976: 83), can be contrasted with resilience, the system's ability to absorb perturbations and evolve into a metastable level of organization (ibid). Complex dynamical systems theory teaches that survival and extinction are a function of resilience, not stability. A system which is very resilient can have very low stability – that is, it may fluctuate greatly – but survive. Conversely, a system with high stability may lack resilience such that

any change or disturbance simply destroys the system. Ecosystems, furthermore, teach us that "[t]he more homogeneous the environment in space and time, the more likely is the system to have low fluctuations and low resilience." (*ibid.*). We also learn that the more interconnected a system (both internally and externally), the more robust and resilient it will be. The integrity and identity of a complex system is therefore fundamentally related to its dynamical connectivity.

Dynamical systems theory includes in its toolbox a notion somewhat similar to that used by Parmenidean ontology: I have in mind the concept of "invariance," which purports to identify a *dynamical* set of relations that remain the same despite undergoing certain transformation. The difference between the concept of invariance and the traditional concept of identity is not only on the concept of invariance's focus on *relations,* but in particular its inclusion of *external* as well as *internal* relations, which are conceptualized as dynamic, not just static, links.

The concept of dynamical invariance might serve as dynamical systems theory's preliminary answer to the problem of Identity as Unity. Thinking of Coca-Cola or Toyota in terms of dynamic, invariant relations of a self-organizing web of production and distribution processes becomes a more natural and fruitful way to confer identity on these organizations than trying to spatially localize or identify their internal components. The same can be said for e.g., the "Vietnamese" identity: instead of worrying about trying to identify a set of unchanging, autochthonous characteristics – which only leads to the question, "Are Vietnamese living in Los Angeles (really) 'Vietnamese'?" it might be best when attempting to formulate criteria of identity of complex systems to think in terms of number and quality of dynamical relations.

Just as Aristotle employed one sense of the concept of substance to suggest that the more qualities an object displays the more substantial it is, so too students of dynamical systems might begin by exploring whether the more numerous (and more diverse) qualities a process displays the more uniquely individuated it is; whether, in other words, the richer its internal and external relations both, the more individual and individuated – and the more resilient and robust – the process. Given the static connotation of the concept of "qualities," however, perhaps that term is not quite the right descriptor we need to identify CDS's. As mentioned, dynamical systems not only *develop* in a regular and predictable way; they also evolve in unpredictable directions.

The real puzzle thus becomes, "How to identify them in light of their *evolutionary* capacity?" In light of the fact that a CDS's identity must include both its dynamic etiology and its potential, how are we to address the problem of Identity as Permanence with respect to complex dynamical systems?

In this volume Paul Cilliers (2007) differentiates between boundaries and limits. Whereas limits are rigid barriers that separate – and beyond which one cannot transgress – boundaries, as exemplified in the eardrum, Cilliers, notes, are permeable. *Indeed, it is their very permeability that makes possible many of qualities of the system in question.* Without the presence of the eardrum, for example, as Cilliers points out, hearing is impossible. Instead of functioning as what logicians call an exclusive disjunction (either/or – but not both) the way the traditional concept of identity did (inside or outside – but not both), then, the permeable boundaries of dynamical systems are fuzzy, *active sites* where qualitatively new phenomena emerge. As such, boundaries of dynamical systems are best conceptualized as sites of phase changes, sites where a different phase portrait can suddenly appear. The paradoxical characteristics of permeable membranes – which both exclude some potential inputs (thereby maintaining system integrity) at the same time as they include others (thereby allowing for the possibility of dynamic transformation) – are thus ultimately responsible for both a system's actual identity as well as its potential and actual evolution.

Consider the (unintentional) permeability of the Rio Grande border between the United States and Mexico, a fascinating active site of great sociological interest currently under construction, a dynamical site that would not be so were it not for the simultaneously (supposedly) impermeable but de facto permeable border. Although in one sense it is easy to determine whether one is on the Mexican or U.S. side of the border, there is another sense in which it is not so easy: Laredo, Texas, and Nuevo Laredo, Mexico, are more one regional "dynamical system" with its own identity than is the conjunction of Laredo and Minneapolis, for example. If recent articles in the popular media can be trusted, events taking place at the country's edges are responsible for the United States's current robustness. Even more interestingly, however, those same articles have noted – but have had a hard time characterizing – the appearance of a completely new "border" phenomenon that, precisely because it straddles both sides, is creating something entirely new – and exciting. If so, then one can say that these border active sites are also responsible for the country's resilience. Since any real individual is embedded in numerous dynamic attractors, the multiplicity of identities this implies makes individuals more diffuse than heretofore assumed.

Although the Rio Grande example rests heavily on the role a shared physical space can play in identifying a system, spatiality is not the only way such permeable, dynamical boundaries can appear. Imagining that all boundaries are like the eardrum or the Rio Grande is therefore misleading: these are too physically localizable. More and more one hears of European regionalism described in terms, for example, not just of the Catalan or Basque communities, which straddle physical frontiers, but even more interestingly described in terms of a newfound identification between citizens of Ireland and the Spanish province of Galicia. What do these two groups have in common? A Celtic heritage, for one – a permeable, temporally based, dynamic boundary, in this case – an active site that is creating a dynamic community of fans involved in, among many other activities, international festivals devoted to Celtic music, folklore, tradition, etc. Similar dynamics are emerging among members of the Chinese, Vietnamese, South Asian, or Mexican "diaspora" and their compatriots in the homeland. Whether it is an interest in trade or culture that binds each side to the other, at any dynamic (not spatial!) boundary there exists the potential to create a newly emergent phenomenon. As complex dynamical systems theory would have predicted, this creative potential was absent during earlier periods of immigration when immigrants lost all contact with the friends and relatives they left behind.

It might be useful to expand Cilliers's views on boundaries by comparing the boundaries of dynamical systems to e.g., proteins – proteins qua *active sites* that emerge at the intersection of folded-up amino acid sections. If what we mean by calling these sites *active* (whether an ear drum or a protein) is that they are the (not spatial but dynamical) locus of emergent properties, boundaries would constitute functional entities responsible for a system's evolutionary change. As active sites, boundaries are creative because they are the locus of evolutionary potential: Whereas the essentially unchanging furniture of the old conceptual framework was stagnant; the dynamic processes of the new framework are characterized by the potential to evolve into qualitatively new forms [not just develop into larger (but more of the same) systems]. At a given point in time, any CDS's identity will therefore encompass not only what it currently is (given by its invariant relations) but also what it has the potential to become. Since openness to the environment (via feedback and feedforward) is crucial to evolutionary processes, the degree of permeability of a given CDS's boundary – even as that same dynamical membrane or information closure confers the requisite robustness to maintain the system's integrity – will be a central aspect of its Identity as Permanence.

Thinking of a dynamical entity's boundaries in this way, for example, would mean drawing both the Turkish community in Hamburg, Germany and the in-country Turks back home on "one side" of the boundary, with the non-Turkish German community on the other. But even phrasing it this way is misleading, because non-Turk Germans trading with Turks would also fall on the "Turkish" side of this "boundary." We are so accustomed to spatial, reified categories that thinking of identity in terms of dynamical processes becomes very difficult. We must try hard to do so, however, because problems such as those mentioned in this volume that arise with globalization often come ready-formatted by spatial, static categories. For example, when referring to global organizations or enterprises, the very labels "international" and "transnational" presuppose that the physical boundaries of a nation state (and concomitant place of registry of a business) are what confer identity. That might have been true at one time, but it is no longer so.

In contrast, an autopoeitic web, as Ulanowicz (2007) in this volume and elsewhere points out, is informationally decoupled from its material components; it also has the ability to add and delete nodes while maintaining its identity and integrity. If General Motors stops purchasing parts from a supplier in Lansing and begins to purchase them from a supplier in Hamilton, Ontario, is the Cadillac it makes with those parts still an American car? *Mutatis mutandi* the same question can be asked of Honda Accords, for example. (Several acquaintances of mine, American citizens all, who for patriotic reasons insist on "buying American" (cars), in recent conversations have expressed their dismay at not even being able to identify a particular make as American!) Or think of General Electric (GE): there is certainly nothing in that company that would qualify as "a nucleus of qualities that have gone unchanged" since its inception; nor could General Electric survive as that company without its extensive external relations with suppliers, foreign government agencies, etc.

Since dynamical systems are describable by networks and graphs, it might be fruitful to look there for metaphors and descriptors of identity. As active sites, boundaries can – from one perspective – be viewed as *nodes* in a network. From another, however, permeable boundaries can appear as *weak links* between nodes, somewhat along the lines suggested by Mark Granovetter's now classical 1973 work on "weak ties." Just as Wittgenstein undermined the concept of Platonic essences with his work on "family resemblances," so too the concept of dynamical "clustering" of nodes and links might take the place of that of identity and its much more static connotations. On this reconceptualization, whereas *strong* dynamical links among components (characterized as nodes) result in a "strong cluster," weak links between strong clusters give rise to a community or a world. Since any given node can simultaneously belong both to a strong cluster and to a larger networked community, society, or world, boundaries become diffuse, but also dynamic and creative. Complex dynamical systems thus begin to look a lot more like bramble bushes in a thicket than like stones. And it is extremely difficult, as any outdoorsman will tell you, to determine precisely where a particular bramble bush ends and the rest of the thicket begins. As referenced by Albert-Laszlo Barbasi in his new book, *Linked* (Barabasi, 2002), Gary Flake, Steve Lawrence and Lee Giles (2000) suggest that "documents belong to the *same* community if they have more links to each other than to documents outside of the community" (my emphasis, 171).

We must think in terms of concepts such as "active sites," "linked clusters," "robust resilience," and the like if we are to make any sense of the concept of identity in reference to complex dynamical systems.

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Chapter Eight

COMPLEXITY, SOCIETY, AND EVERYDAY LIFE

Pedro Sotolongo

Introduction

It is hardly debatable that contemporary societies are much more than the simple sum of their parts, or that their development unfolds from the dynamics of their own characteristics. Neither can one hold that the future of societies can be predicted, in so far as apparently insignificant and casual events can have very strong influence on future ones. We know today that societies exhibit the systems-like characteristics of self-organized systems far from equilibrium. In other words, societies behave like nonlinear complex systems with a self-organized unfolding. Contemporary societies also have numerous characteristics that can serve as empirical evidence of the presence of social complexity. All of this means that the important question to ask is how better to characterize social complexity as such.

From Where Does Social Complexity Emerge?

We ask ourselves the following questions: Which of the numerous features providing empirical evidence of social complexity should we emphasize in making such a characterization? From where does social complexity emerge? From anthropological constants that men and women living in those societies exhibit as individual social subjectivities? From the various social structures that have an objective existence in those societies? From these *and* those, that is, from social individuals *and* social structures, thereby repeating with this question, albeit in a new formulation, the old and as yet unresolved dilemma of the correlation between what social scientists call "the micro" and "the macro"?

For the last four years we at the Instituto de Filosofia have been engaged in an endeavor to conceptualize social complexity. This effort has led us to propose what we might call a *third-way approach* to that old dilemma, one on which the "complexity approach" can shed new light. This third-way approach focuses on the emergence of patterns of complexity in everyday social life (or, more precisely, just "everyday life," that relatively and paradoxically "unknown territory" of much

contemporary social theory). Such patterns of complexity are those *characteristic regimes of collective social practices* (family, educational, generational, community based, political, classist, religious, gender, racial, ethnic, etc.) through which real, individual men and women in any society become tacitly, or pre-reflexively, involved in authentic *networks of social interactions*.

It can be shown empirically and theoretically that it is precisely from one or another such pattern of social interactions of everyday life[1] – that is, from one or another of those networks of everyday social interactions – that *social* complexity emerges. In particular, it can be shown how *both* the above-mentioned objective social structures and individual social subjectivities issue in a parallel and simultaneous manner from such patterns of social interaction of everyday life.

Why can it be said that it is from these that *social* complexity emerges? Because each one of those regimes of characteristic collective practices of everyday life functions as a true *social-dynamical attractor*; that is, as a context-sensitive social constraint[2] that has at the same time limiting and enabling effects on those engaged in them, thereby generating an overall social network of their correlations.

The "cementing" or "glueing" power of those patterns of social interactions of everyday life (of such networks of everyday social interactions) stems from the mutual social expectations (family, educational, generational, community based, political, classist, religious, gender,

1 The following can be conventionally distinguished: "horizontal" patterns of social interactions (family, educational, classist, etc.) that refer back to factors of social origin, and "vertical" patterns of social interactions (gender, race, ethnic, etc.) that refer back to so-called invariants of origin of an ethno-biological nature. The latter "transversally" cross-sections the former and thus one can distinguish in the same classist pattern of a specific society subpatterns relating to color; or, for example, in the same family pattern of that society, masculine and feminine subpatterns; or in the same educational pattern different subpatterns for the autochthonous ethnic population and for the immigrant population. In other words, a pattern of social interactions in the same society is not "lived," is not "practiced" in the same manner by people of different colors; or by a man and a woman; or by someone belonging to an autochthonous ethnic tribe, an immigrant, etc.

2 "Context-sensitive" means that such networks of social interactions of everyday life carry the imprint of "what-has-happened-to-them" (of their history), as well as of "whatis-happening-to-them"(of their specific context of interaction). See Juarrero, A. (1999) *Dynamics in Action: Intentional Behavior as a Complex System*, Cambridge, MA: MIT Press.

racial, etc.) that tacitly or pre-reflexively establish themselves among those involved in those interactions. Issuing top down from the global network of everyday social interactions on each individual involved in that network, those mutual social expectations serve as limits preventing certain behaviors that then tacitly become known as "socially undesirable." Simultaneously, and in a bottom-up fashion directed from each of those involved in the interactions to the network as a whole, the interactions enable and make possible certain other behaviors tacitly known as "socially desirable."

Complexity-Generating Social "Affordances"

In themselves the above-mentioned mutual social expectations stem from what we call *social affordances*, specifically social asymmetrical circumstances arising from the practical interactions of men and women involved with their surrounding social environment, within the limits of any given pattern of social interactions. Among the resulting specifically social affordances that are always present among those involved, we have identified at least four that have special "social-complexity-generating" incidence:

- *Inequality of circumstances in favor of some (and disfavoring others)*, in other words empowering or disempowering (power-inducing and power-induced) social asymmetries (family, educational, generational, community based, political, classist, religious, gender, racial, ethnic, etc.).
- *Differences in satisfactions and dissatisfactions*, in other words desiring (desire-inducing and desire-induced) social asymmetries (family, educational, generational, community based, political, classist, religious, gender, racial, ethnic, etc.).
- *Multiplicity of heuristic positionings*, in other words epistemic (knowledge-inducing and knowledge-induced) social asymmetries (family, educational, generational, community based, political, classist, religious, gender, racial, ethnic, etc.).
- *Multiplicity of enunciative positionings*, in other words discursive (discourse-inducing and discourse-induced) social asymmetries (family, educational, generational, community based, political, classist, religious, gender, racial, ethnic, etc.).

These social affordances are characterized by complexity-generating specific social asymmetries that, because of their intrinsic nature, lead (and cannot help but lead) to the social domains defined by *power*, *desire*, *knowledge*, and *discourse*[3]. They thus act as the ingredients of that cementing mixture (as we choose to call it metaphorically) of mutual social expectations with respect to each of the networks of everyday social interactions, or, in other words, with respect to each pattern of social interaction of everyday life. Even more precisely, we could say that these social affordances lead (and cannot but lead) to "local"[4] practices of power, desire, knowledge, and discourse (each of which in turn is circularly linked to the others) in which each of us is involved (and cannot help being involved) in his or her everyday life.

Parallel and Simultaneous Objectivation and Subjectivation of Our Patterns of Social Interactions in Everyday Life

In our latest work, *Social Theory and Everyday Life: Society as a Complex Dynamical System* (which we hope can be published soon), we discuss how objective social structures (which we call the "*macro-social*") are produced, and how individual social subjectivities (which we call the "*micro-social*") are constructed. In this work we argue that this production and construction take place as *parallel* and *simultaneous* processes of collective social objectivation (that is, of *objective exteriorization*) and individual social subjectivation (that is, of *personal interiorization*) of those same networks of social interactions that conform our everyday practices (family, educational, generational, community based, political, classist, religious, gender, racial, ethnic, etc).

The biological metaphor stating that the "macro" accumulates as aggregates of the "micro" therefore seems not to work in society. Instead, what we social researchers name the "macro-social" (extended objective

3 Michel Foucault has convincingly elaborated on these social "domains," especially with respect to what he called social "positivities," that is, prereflexive regimes of social practices that conform to much of what we are interested in, need, tacitly know, and currently enunciate in our everyday life.

4 "Local" social practices in the sense that they take place within so-called situations of social interactions with co-presence of those involved. Such "situations of social interactions with co-presence" of everyday life provide the social scenarios (settings) – always situated and specific – where each time one or the other of our patterns of social interactions unfolds in everyday life.

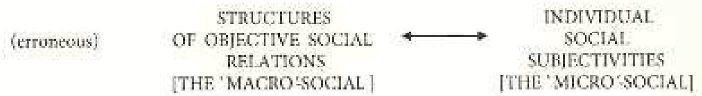

Figure 1 *Erroneous representation of macro- and micro-social*

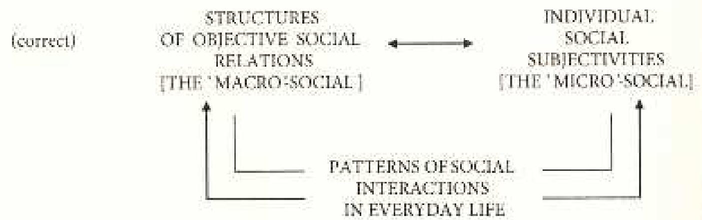

Figure 2 *Indirect representation of macro- and micro-social*

structures of social relations) and the "micro-social" (individual social subjectivities) are respectively produced and constituted, in parallel and simultaneous fashion, through the concomitant objectivation/subjectivation of the various patterns of networks of social interactions in everyday life.

That is, the macro-social and the micro-social are both constituted through the concomitant objectivation/subjectivation of the various regimes of collective practices characteristic of our day-to-day actions, patterns in which we find ourselves engaged from birth to our final day in their role as true dynamical social attractors. And it is in relation to these social dynamic attractors (social patterns) and through a variety of inter-pattern (inter-attractor) articulations of everyday life that our correlated behaviors emerge. *In other words, it is as a function of these social attractors and inter-attractor links that social complexity emerges.*

Once constituted, both the social objectivation (social relations thereby objectively structured) and social subjectivation (subjectivities constituted as social agents) of these regimes of everyday collective practices can impinge on the next "turn" or "circuit" of the pattern of social interaction in question, thereby contributing to the reproduction or modification of those everyday collective practices and to the further contextualization of what was produced by them in the first place.

The generation of and articulation between the macro- and the micro-social, which is thus one of concomitance, mutual inclusion, reciprocal incidence, and co-generation, is therefore frequently and erroneously

represented in the direct and immediate manner shown in Figure 1.

Representing the relationship between the macro- and the micro-social in this manner imprisons us in the usual confrontational opposition between the two. We argue that, on the contrary, the macro- and the micro-social[5] should be apprehended and represented in the indirect and mediated way shown in Figure 2.

As we emphasize in our above-mentioned work, patterns of social interactions in everyday life are always situated; that is, they always involve some whos, a where, a when, a what, a how, a what for, and a why (the seven so-called indexicals). Moreover, in addition to always presenting this indexical character, patterns of social interactions are always reflexive and open. That is, the results of each of their turns or cycles feed into the next one, and there is always in principle the possibility of another turn or cycle in their unfolding. All of this makes any pattern of everyday social interactions amenable to characterization in terms of a corresponding arsenal of qualitative social methodologies[6] that can shed light on the specific content of those indexicals.

In order to characterize the determination directionality of inter-pattern articulations, we also emphasize the dynamical and processual nature of these interactions: their different "social reach or rank," for example, the determining characteristic of classist patterns over family patterns of social interactions, the determining nature of both these patterns over the educational, cultural, religious, and other patterns of social interactions of everyday life, and so on.

It is also very important to keep in mind that each and every one of our patterns of social interactions (that is, of our regimes of characteristic collective practices of our everyday lives) unfolds within the already-mentioned "situations of social interaction with co-presence." Because these situations are the true and *sui generis* "social settings," we can

5 We should note by the way that such representation is "trapped" inside the dichotomous, bivalent (Aristotelian) logic that we usually employ, without such utilization being accompanied by a reflexive attitude about its limits and limitations; as if it were *the only* logic that we could employ or as if this dichotomous form were *the only* adequate one to a dialectical thinking.

6 Participating observations; open-ended interviews; in-depth interviews; life histories; discussion groups; real-group dynamics; case studies; field studies; institutional studies and/or interventions; action-oriented researches; participating action-oriented researches; a combination (triangulation) of two or more of these qualitative approaches.

distinguish *social bonds* (for which the co-presence of those involved is unavoidable and for which the names of those involved are essential) from *social relations* (for which, although the co-presence of those involved is possible, it is nonetheless not unavoidable, and for which the names of those involved are not essential).

On the other hand, it is precisely within the limits of these situations of social interactions with co-presence that our "local" everyday practices of *power*, *desire*, *knowledge*, and *discourse* unavoidably unfold (that is, whether or not we are aware of them or like it). These situations are also where each of the practices articulates in circular fashion with the others. As has been stressed above, it is along with their objective exteriorization (objectivation) that structures of social relations are produced (educational, generational, community based, political, classist, religious, gender, racial, ethnic, etc.); and it is along with their subjective interiorization (subjectivation) throughout our lifetime that we constitute ourselves as social subjectivities (family, educational, generational, community based, political, classist, religious, gender, racial, ethnic, etc.). This last subjectivation process always proceeds, unavoidably, through three "ways of subjective registering": consciously (reflexively), tacitly (pre-reflexively), and unconsciously (a-reflexively), all three of which contribute throughout our lifetime to the process whereby we become social agents.

Our Multiple-Collective and Individual-Personal Identities

The foregoing helps us understand that each of us constituting any given society is simultaneously a "carrier" of multiple objective social relations (one for every pattern of social interactions of their everyday life), as a consequence of the fact that they are always objectively involved in those multiple objective social relations in a collective generic manner, an involvement in which their name is not essential.

This multidimensionality accounts for each individual's multiple social *collective* identities: father or daughter, teacher or student, young man or old woman, city man or village woman, political leader or rank-and-file partisan, worker or bourgeois, priest or parishioner, man or woman, black or white, indigenous or immigrant, and so on. Each of us is a social agent of multiple, individual, subjective dimensions, one for every pattern of social interaction of their everyday life, through they are always constituted in a specific personal manner, and for which individual subjectivity their name is essential. This subjectivity in turn accounts for their multiple individual personal identities: John Smith, or Juan Gonzalez, or Kim Ho Pak, or Hguyen Ti Sin, or Rabindranath Lore, as a *particular* father, teacher, old city man, political leader, worker, priest, white man, black man, and so on. Or Mary Stewart or Maria Sanchez, or Apsara Pindi, or Bukaya Manda, or Li Lien, as a specific daughter, student, village woman, youth, rank-and-file partisan, bourgeois, white, black, indigenous, parish member, and so on.

These characterizations also allow us to better understand *what changes* in the oft-cited processes of so-called *social change*.

What Changes in "Social Change"?

We commonly express ourselves in terms of the need to "change the actual social structures" (evidently when they do not please us), or in terms of the need to "change people's mentality (ways of thinking)," that is, to change individual social subjectivities (obviously when those do not please us either). When we do so, we are dealing of course with the all-important topic of "social change." However, in an explicit manner – or more frequently in an implicit one – we address (and even try to produce) those changes operating on those structures of social relations (and their institutions) and/or on those social subjectivities, *directly and immediately* (without mediation, that is). Nevertheless, given what has been argued earlier, we can assert that those purposes (well intentioned as they might be) never turn out to be directly realizable.

They do not prove themselves directly realizable for the simple reason that those objective social structures (and their institutions) and those individual social subjectivities, which do not please us, have been the result of (have been produced or generated by) specific regimes of characteristic collective practices of the everyday actions of real and specific men and women of that specific society. That is, they stem from specific patterns of social interactions in the everyday life of that specific society, and so *it is these collective practices that are susceptible to being changed in a more or less immediate (that is, unmediated) fashion*. Whether doing so is easy or difficult is a different matter.

In other words, the patterns of social interactions characteristic of everyday life in communities (human collectivities) in their role as *sui generis* dynamic social attractors are not the "what-ought-to-be-changed," they are precisely the "what-changes-in-the-so-called-social-change."

When they change – when those regimes of collective social practices characteristic of everyday life change – the objective social structures and the individual social subjectivities that were generated by the previous patterns cannot avoid changing, because the new patterns of social interactions (those new types of characteristic and recurrent collective practices), as they renew the dynamic landscape of social attractors in that specific society, produce and generate *different* objective social structures and their institutions, and *different* individual social subjectivities (people with another mentality and another "way of thinking").

Social Institutions and Organizations as Regimes of Concomitant Permissions and Prohibitions

In our work on patterns of social interactions in everyday life, we argue extensively that one or another social "institution" represents no more – but no less – than a social "space" (that of the state, the law, the family, education, religious life, etc.) in which a parallel and simultaneous regime of social permissions (the "what-is-socially-allowed") and social prohibitions (the "what-is-socially-forbidden") has been established ("has been instituted," we are accustomed to saying).

Social "spaces" – and social permissions and prohibitions – are associated with one or another characteristic collective social practice (political, juridical, educational, family, and religious day-to-day practices, etc.). Social institutions, therefore, are no more – but no less – than the institutionalization of one or another pattern of social interaction of everyday life, regimes of concomitant permissions (socially allowed practices) and prohibitions (socially prohibited practices) that are established in one or the other of those social "spaces of practices."

Thus, depending on the specificity of the pertinent type of practice institutionalized, that regime of parallel social permissions and prohibitions can be:

- *Tacit* (for example, that of the family as a social institution), when it is not necessary to enact those social permissions and prohibitions explicitly in order to have the "what-is-allowed" and "what-is-prohibited" by them observed by the vast majority of those concerned.
- *Explicit* (for example, that of the law as a social institution), when it is necessary to have those social permissions and prohibitions explicitly known in order to have the "what-is-allowed" and "what-is-prohibited" by them observed by the vast majority of those concerned.
- *Organized* (for example, that of the school we attend, the enterprise we work in), when besides making them explicit, those social permissions and prohibitions need to be properly regulated, overseen, and controlled on a more continuous basis in order to have the "what-isallowed" and "what-is-prohibited" by them observed by the vast majority of those concerned. (When that necessity arises, the concerned social institutions create the *organizations* that they deem suited for that more day-to-day regulation, overview, and control.)[7]

Thus, an organization (school, church, political party, enterprise, club, etc.) is an *explicit and organized* social institution, an *explicit and organized* regime of concomitant social permissions and prohibitions concerning a specific "space" of characteristic collective social practices. So when we want to change an organization, what we ought to change first is not its structure of objective social relations, or the minds of those engaged in it, but its characteristic collective social practices. The new, alternative pattern of collective organizational social interactions

7 Needless to say, all organizations (organized institutions) are inherently explicit institutions, but the inverse is not always the case; not all explicit institutions are organizations, although many of them do have organization. In this latter case, we need additionally to distinguish the organized institutional space (the organization, properly speaking) that has been necessary for the explicit institution to function from the often co-existing explicit (but not organized) wider social "space" occupied by that institutional regime. The juridical, educational, and religious realms, as social "spaces," are examples of the co-existence of both, explicit (but not organized) juridical, educational, and religious institutions, and juridical, educational, and religious *organizations*.

achieved will generate a new structure of organizational objective relations and a new mentality in those engaged in it.

Neither an *a priori* structural "change" nor bringing someone with another frame of mind into a key post changes the organization as such. Such changes can only be instrumental retrospectively (and by previously modifying what is currently allowed and what is currently prohibited in the practices of those involved in the organization) in achieving the proper change in the collective social practices characteristic of the organization (its characteristic pattern of organizational social interactions). And the best way to achieve that new pattern of social organizational collective practices—as the "complexity approach" shows—is not by top-down, voluntaristic, I-order-and-you-obey, global-pattern-imposing, hierarchical-minded means, but, on the contrary, through bottom-up, emergent, self-organized, local-pattern-recognizing, network-minded means.

As we try to show in our work, for this to be achieved proper account must always be given to the above-mentioned four social-complexity-generating specific social affordances (power inducing and/or power induced; desire inducing and/or desire induced; knowledge inducing and/or knowledge induced; discourse inducing and/or discourse induced) that always conform and characterize one or other of the different regimes of concomitant allowances and prohibitions that inherently constitute the organization concerned as such. It is only through the adequate modification of these organizational social asymmetries that unfold in terms of power (ambitions, interests, goals, etc.), desire (compulsions, needs, demands, etc.), knowledge (intuitions, tacit wisdom, formalized knowledge, etc.) and/or discourse (linguistic abilities, everyday speech, argumentative enunciations, etc.) that convenient bottom-up, emergent, self-organized, network-like, local-pattern-recognizing, socio-organizational correlated interactions can be elicited. They cannot be dictated, imposed, or declared, but instead can only be facilitated, promoted, and encouraged. This is what good contemporary organizational management and direction are all about.

Dialectics of Articulation Between the "Personal" and the "Social" in Social Change

That the "what-needs-to-be-changed" and the "what-does-change" in social change are in fact the above-mentioned features of patterns of social interactions or regimes of characteristic collective social practices of everyday life does not eliminate, but on the contrary presupposes, the important question of the need for a dialectic between the "individual" and the "collective," or the "personal" and the "social," or, even better phrased, between the "individually social" and the "collectively social" in social change.

In this connection, in our work we have argued that in principle, for a new pattern to be realizable and for that new pattern to become eventually a new reality, it suffices that either a *single* "who" or a *small number* of those involved in any given pattern of social interactions initiates efforts (which at first frequently have all the odds against them) to establish a new (because of different and alternative to the current one) pattern of characteristic everyday practices (family, educational, generational, community based, political, classist, religious, gender, racial, ethnic, etc.) for that new pattern to be in principle realizable, to turn eventually into a social reality. Whether the change is probable is an entirely different question, one that depends strongly on the specifics of the pattern of social interactions attempting to be modified.

In light of this last comment, it is pertinent to emphasize that in the context we have been dealing with (the individual/personalcollective/social involved in processes of social change), the fact that the dialectics of social articulation is heavily dependent on the specifics of the social pattern involved means that the "social price" to pay (the social risk to face) by those "whos" intent on social change can be extremely varied. As ancient, medieval, modern, and contemporary history shows, efforts to change qualitatively a specific society's current pattern of everyday *political* or *religious* social interaction can come at a high price, including the loss of the agent's life. Thus it follows that it is only when and if the new and alternative pattern of social interactions has successfully become typical of everyday life that the individual who initiated that change, and those who were the first to go along with them in that effort, can be identified – and only *a posteriori* – as the religious, political, classist, educational leader, and *avant garde* respectively (depending on the pattern of social interactions that has been qualitatively changed).

This sociological understanding leads to a definition of leadership and vanguardist action that, unlike the usual definitions, is not *a priori*, since it depends on the prior establishment and verification of some specific social results of the process of social change involved.

Section 3

Organizational Implications

Chapter Nine

EMERGENCE HAPPENS! MISGUIDED PARADIGMS REGARDING ORGANIZATIONAL CHANGE AND THE ROLE OF COMPLEXITY AND PATTERNS IN THE CHANGE LANDSCAPE

James Falconer

Introduction

"We are independent of the change we detect. The longer the lever, the less perceptible its motion. It is the slowest pulsation which is the most vital. The hero then will know how to wait, as well as to make haste. All good abides with him who waiteth wisely; we shall sooner overtake the dawn by remaining here than by hurrying over the hills of the west."

Thoreau

In our history much study has been undertaken on the nature of change, many pronouncements made, many interesting viewpoints proffered. Our struggle to understand how we should reflect upon change and respond to it continues to this day. In recent years, more attention than ever has been directed to it, particularly in the business world. In a recent paper (Falconer, 2001) I decry as misguided the 'change management' discipline from its most superficial manifestation down to its very fundaments. In particular, I challenge the assumptions that change is linear and that it is discrete, and allude to the emergent nature of change and the potential applicability of patterns in understanding, abstracting, and contextualizing emergent properties. The intent of this paper is to expand that particular scope of the earlier one, challenging 'change management' on more fronts and giving more attention to the complex nature of change. While the solution offered here is essentially the same as in the earlier paper, the concept of business patterns and the use of patterns in this regard are here deployed as a more cogent means of addressing change as a complex system.

Change cuts across disciplines and spheres; thereby, the scope of analyzing it is daunting in its potential. I am again focusing on the business world and on organizational change as the context for the topics I am treating here, as it is not only topical and ready-to-hand, but already an area of a great deal of the research attention (and, indeed, of the output of the business-book-writing fraternity) related to change. Most of the observations should, however, be applicable in other disciplines and spheres where understanding the nature of change could be turned to advantage.

Unseating the Commonly Held Beliefs about Organizational Change

Change Is Not 'Managed'

In vogue over the past couple of decades, in particular as a recurring theme in business, is the notion of 'management'. As tenuous as this concept is, even in rigid, authoritarian, hierarchical structures like government, the military, and the church, in the business world it has always been something of a 'dirty secret' that managers are surprisingly powerless to 'manage' anything, and that this powerlessness increases exponentially for every summational increment in organizational level a manager attains. Some more astute business observers (Block, 1987; Kotter, 1990; Mintzberg, 1994; Bartlett & Ghoshal, 1995; Hirschhorn, 1997) have noted that the skill-sets evident in the best business leaders are not always dominated by the traditional notions of management (setting strategy, designing and partitioning tasks, measuring and reporting progress, assigning and controlling actions) and have more to do with 'soft', people-oriented skills like inspiring, empowering, listening and observing, understanding, and coaching.

In short, 'management' as a euphemism for 'control' is simply a non-starter in the business world of today, a Dilbertian relic of scientific management and workhouses. Despite this, there appears to be no end to the number of familiar concepts that are having 'management' tacked onto them in order to achieve some sort of relevancy; thereby, we have 'project management', 'human resource management', 'strategic management', 'knowledge management', and what you might suspect would be the overarching concept to all of these (but which often is not, ironically), 'change management'. The very idea of 'change management', no less than the rest of these, strikes one as problematic; overlaying a control-based concept onto one that seems largely antithetical to control *must* be wholly inefficient.

Initially, the main problem with the concept of 'managing' change is that it *does* connote control-oriented behavior. Anyone with an understanding of human dynamics, particularly as evinced in groups, will be aware that the least effective approach to moving people through a change experience is to direct them, measure their progress, have outsiders tell them what to do, ostracize the resistant, and declare success based solely on events involving inanimate objects like information technology, organizational routines, performance metrics, and the like - yet, this is often exactly what is done, and, unbelievably, people still wonder why change, underwritten in this manner, is inefficacious.

If organizations get past this stage, and achieve a slightly higher level of understanding, often they find themselves in the domain of a great deal of the business literature. Other key fundaments of business-guidance writing will be dealt with in subsequent sections of this paper (most of which still tend to offer formulaic 'silver bullet' solutions to complex problems), but with regard to the concept of change 'management', the next level of understanding is generally built around the notion that you can 'lead', 'enable', or 'steward' (guide, navigate, help, support, coach) change more readily than you can 'manage' it; this hints at concerns that are 'softer' but still falls prey to the fallacy of influence where change is concerned. The truth is that there is but to observe, and learn. Change *exists*, perturbations are a fact of life, and the human systems will adapt. Interlopers cannot 'manage' change, but they can learn and adapt along with the people who are more directly and consequentially a part of it.

The other issue reflected in 'management' is management toward an *objective*. This is management as teleology, or as determinism, and still mired deeply in the control mentality. The change merchants' tragic error in thinking here is holding to the idea that change is about *being* (and the various states thereof); the reality is that this can never be practicable, as the landscape never remains in one state long enough to permit accurate definition – the map *did* resemble the territory, but now does not anymore. Change is, instead, all about *becoming*, and the only learning that exists amidst change teeters on the edge of observing and describing the becoming, of which we are in the midst, in a way that can be conceived later, at another time of becoming.

A great deal of change in organizational contexts is focused around 'projects', often collections of impactful change elements with funding and nice logos. Projects are, at bottom, all about becoming, not about being. If we were to take a look at the track record of steering projects to precisely their intended objectives in precisely the time-frames envisaged on precisely the budgets set aside, we would find a very low success rate. The message to project teams, therefore, should be to focus on what they can learn along the way, because they will not likely get to where they think they are going anyway. They will get somewhere, and it may

be a good place for them to be, but to dwell overmuch (as is their wont) on the 'planned outcome' is misguided – this is a harsh, *realpolitik* truth that is more truth than wishful business thinking regarding project management can ever be. And you will not read it in books.

A fundamental point stated above is one that I will re-emphasize here: change *exists*; not only that, but it will exist regardless of what you do to it. Change exists independently of the attention that is paid to it. Observations about change *change*. Change just *is*, except where it 'evolves' as a stable system far from equilibrium, constantly seeking tension, rather than resolution – change will happen, and continue to happen, without intervention, and intervention does not necessarily cause change to happen, affect change, or alter the outcome of the change, at least in the way envisaged. If this all sounds a bit contentious, this is perhaps because our attitudes to change, particularly organizational change, have been conditioned by the common wisdom and published opinion about it. These beliefs, I argue, are inaccurate, misleading, and deleterious, and need to be unseated.

Change Is Not Linear

Another fallacious tradition that pervades our modern existence is the concept of linearity. Shortest distance from A to B. If A, then B. Predictable outcomes. The scientific method. Euclidean geometry. Newtonian physics.

We now are beginning to understand that, while linear relationships are often a simple and useful entry point into any concept, the likelihood that the relationships present in any system are actually *nonlinear* is far greater than the likelihood that they are linear. The more the system involves animate objects – people, the natural environment, etc. – the more certainly it will be rooted in nonlinearity. The rise in prominence of the discipline around complexity and complex systems (Holland, 1995; Kauffman, 1995; Bak, 1996; Holland, 1998; Cilliers, 1998; Heylighen, *et al.*, 1999; Juarrero, 1999) is a clear sign that this is an inspiring research path that is illuminating many areas of interest. It is worth noting also that there is already a noteworthy corpus applying complexity to the firm (Kay, 1984; Stacey, 1992; Wheatley, 1992; McMaster, 1996; Sherman & Schultz, 1998; Wang & von Tunzelmann, 2000; Olson & Eoyang, 2001).

Change can also be viewed as a complex system. In this context, it becomes obvious why it is very difficult to comprehend how change works or to describe or model it. While thinking about complex phenomena may produce comparably complex knowledge, models, by their nature, are explicit artefacts that reduce the complexity of the modelled phenomena, and the more complex the phenomena, the less likely are the models to describe them adequately. Many writers in the 'change management' field (Connor, 1992; Kotter, 1996; Brynjolfsson, *et al.*, 1997; Connor, 1998) seem to believe otherwise (ostensibly holding, instead, that change can quite satisfactorily be modelled), and there is a substantial body of work that describes organizational change on some sort of linear continuum that comprises the change lifecycle. These writers generally consider change to be a linear process, bounded by a clearly articulable beginning, end, and circumscribing boundary conditions, with discrete steps (on which more later) leading methodically (and often effortlessly, if you believe) from the murk of current reality to the utopia of some shared, lofty objective state.

Change is clearly never this way, and anyone who believes it is has, I would suggest, never considered it more than superficially and is potentially in for a surprise. Change 'starts' with a system of people, culture, processes, artefacts, and technology in some complex configuration and circumstances, consists largely of them behaving unpredictably for an indefinite period of time, and has them continuing to behave unpredictably when one stops observing and describing the state of affairs. Change never 'ends', regardless of whether you choose to observe the landscape or (heaven forefend) attempt to apply interventions. It is anything but linear.

Setting aside for a moment whether change is in fact complex, it can still quite persuasively be argued that change is certain other things that are directly at loggerheads with the notion that it is linear. First, change is iterative and acquisitive – it cycles around and, in so doing, 'augments' itself. This is not necessarily to imply that change is a self-optimizing system – often it seems like a self-degrading system – but merely that it is cyclical outside of whatever transformational cycle it happens to be in, and this cycle is subjecting change, and any change that happens to be going on at the time, to evolution. Sometimes the cycles have nothing whatsoever to do with advancing the cause of any foregoing change, either, but are simply re-exploring the general domain; the earlier points about change and its disinterest in objectives is relevant here. Change plays with us; we do not play with change. Change cycles, and we do *not* get more astute as a result in terms of understanding what this means for us.

Similarly, change tends to be recursive – the 'here we go again' aspect of change. In other words, it is not uncommon for the same or a similar type of change to recur numerous times, or to spawn change cycles similar to itself but which differ in scope or scale. If the occurrence of this form of renewal were in any way predictable, then knowledge derived from accumulated experiences might actually be useful, but alas it is not.

This characteristic of change – its lack of linearity – is the second key factor that renders the majority of methodologies for 'managing' change ineffectual. The inevitable, associated attempts to force-fit approaches to change into linear continua have also played havoc with approaches to managing product lifecycles, systems development lifecycles, and the like. In the systems development field, in particular, iterative development (McConnell, 1996), evolutionary prototyping (Boar, 1984), joint application design (August, 1991), and, latterly, 'agile development' or 'extreme programming' (Beck, 1999), as well as more innovative approaches to the lifecycle model, such as the spiral (Boehm, 1988), the fountain (Henderson-Sellers & Edwards, 1993), and the like have clearly been reactions to the traditional, incredibly constraining linearity of the waterfall model (Royce, 1970). Similarly, business theory is turgid with product lifecycle models, Levitt's legacy (Levitt, 1965), most of which fail to describe the nonlinear, unpredictable nature of the life of a product, especially in our increasingly complex market, consumer, business, and economic landscapes.

Change Is Not Formalizable

Somewhat related to the two previous arguments about change is the notion that you cannot specify a formalized approach to dealing with it. Outside of choosing the wrong lifecycle metaphor, the problem with many methodologies in various domains is that they are attempting to formalize something that will occur differently every time, like trying to mandate the appearance of a tree; the approach strikes one as meaningless.

Change, for its part, has two characteristics that play against a formal definition. First, change is an open, not a closed, system. Most approaches to change management, as stated earlier, define the change landscape as being bounded by a clearly articulable beginning, end, and circumscribing boundary conditions. This is not the way change behaves. It plays with spatial, temporal, participatory, operational, organizational, technological, and any other sort of boundaries people generally like to try to impose on it, violating them, adjusting them, making people unsure of their existence or their parameters. Viewing change as a complex system allows us to call into question this conventional notion of 'bounding' as regards change. While it is true that there must be an 'environment' to provide dynamic interplay with a system *qua* system, the notion of change as system makes evanescent the situating of boundaries 'between' environment and system in any of the ways listed above. Instead, where change is the thing under consideration, we need to consider 'boundaries' more conceptually; otherwise, we may discover that change is as problematic to circumscribe as it is to define. Approaches to 'managing' change, like similar approaches to 'managing' other unmanageable phenomena, always appear to need to establish boundary conditions; otherwise, in using any typically mechanistic approach favoured by designers of methodologies, that would say that a methodological framework must circumscribe all aspects of the phenomena being modelled, defining the approach would take an infinite amount of time. The problem is that complex phenomena cannot be so conventionally circumscribed, cannot be understood in their spatial, temporal, etc., entirety and squeezed into a static framework, yet can be accommodated systemically if methodologists are willing to break their own rules, which so far they appear unwilling to do.

The second characteristic of change that obviates formal definition is that change is adaptive. In complexity science lexicon, change is a *complex adaptive system*, a system that changes its behavior in response to its environment or its own circumstances. This statement may appear to be in contradiction to my earlier statement that change may not respond to interventions in the way that is expected, but the reality is that change *always* responds, just not *predictably*. An intervention will always have some result, and in some less complex landscapes – they do exist – the result may be close to what was expected, but the degree to which the nature of that result can be predicted in advance is generally small. Also, the degree of confidence that the intervention introduced is the factor that brought about a given result, or that results – desirable or not – are attributable to interventions introduced, is as fuzzy and mutable as you would expect in a nonlinear system. The real issue here, however, is not the degree to which change responds to artificially introduced interventions, but how change responds to the similarly changing circumstances in the environment it inhabits (on which more below), which is also difficult to predict even if – and this is rare enough – the potential for these ancillary changes is known and well understood. Generally, though, the entire change landscape is so complex that this sort of understanding cannot be achieved, and change is better at adapting than we are at predicting how it will adapt or under what conditions such adaptation is more liable to occur. It is for this reason that instances of a single unforeseen event putting a major project back to zero are more common than people care to admit. Because the methodologies in use are not nearly as adaptive as change, often the only recourse in these situations is to reset everything, redefine the target, and hope what is left of the funding will get some elements of the project back on their feet and slouching toward an objective.

Open and adaptive approaches to things are rare. Most of the time people think such approaches are too vague and tend to be dismissive of them – they like structure, specifics – and this is a careless and unfortunate error.

Change Is Not Discrete

Perhaps the most fundamental – and counterproductive – component of 'change management' methodologies, and which seems to be common to them all, is a lifecycle that is discrete – rather than continuous – and allows for the segmenting of the (linear) change lifecycle into 'phases' or 'stages of concern' that have independent characteristics and are intended for the application of specific methods, techniques, tools, etc. This characteristic feeds off the misguided assumptions of manageability, linearity, and formalizability already treated, and gives these a very specific presence that runs deeply and fundamentally counter to the nature of change.

The idea of stages of concern reflects a need to break up linear, formalized lifecycles into 7±2 easily digestible parts, a notion that pervades all known lifecycle frameworks. While this reductionist approach might work very well – and in fact be advisable – in more linear systems (the construction of a building comes to mind), it is not only an awkward construct when applied to nonlinear systems, it can in fact be greatly deleterious to the understanding of the system. Complex systems must be approached in an open, holistic manner; otherwise, there is a spatiotemporal disconnect, a kind of cognitive dissonance between the dynamic of how the system is behaving (and how your mind is observing and processing the behavior of the system), and the methodological construct that is supposed to be 'managing' both – a full-on impedance mismatch. What generally results are sweeping, ramshackle assumptions about change – in all its complexity – in order to shoehorn it into the rigid confines of the stage of concern in which it is supposed to be operating at a given moment, or, in reaction to the frustration this engenders, applying misguided and ineffectual – or harmful – interventions to try and get the change mechanism to fall into line and behave the way it is 'supposed to'. The very deep need for interaction with change to be on a continuum that is flexible, adaptable, and self-organizing runs so contrary to a construct based on discrete stages that it is surprising more failures in 'managing' change do not reach catastrophe status.

Stages of concern, as discrete, isolatable events, tend in these frameworks to be separated either spatio-temporally – which again reflects the flaw of linearity – or conceptually from each other. While there is often a sketchy causal train connecting the stages, there is generally insufficient traceability between them through either their formal definition or their predefined artefacts to be able to treat a given methodology as a tightly integrated whole. This does not obviate the role of history as a possible trajectory through an imaginary 'space of possibilities', but even approximating trace-routes through spatio-temporal or conceptual landscapes *ex post facto* is risky; trying to prescribe them *a priori* is ineffective at best.

Untenable as this situation is, it gets worse. Between the discrete stages of concern in most of these lifecycle frameworks are imaginary boundaries that represent milestones to be achieved. These 'planes' are thin membranes, passage through which is openly challenged – often by invitation – by stakeholders in the change under consideration and by myriad other interlocutors. The very notion that the 'progress' of change – if such a notion were even tenable when a complex system is under consideration – can be checked or challenged in this way borders on the ridiculous, even if it is reasonable to suggest that the stage of concern from which passage is sought even adequately describes the current state of the change under consideration, which is not a practical

reality as discussed above. This is further exacerbated by the notion that these would-be challengers to the movement of change may not even be direct participants in the change under consideration, much less party to its inexorable evolution.

The stewardship of change, in its ideal form, is based on continuous, empirically-driven sense-making with respect to the fleeting, evolving spatio-temporal characteristics of the change – observation and description, in its simplest form, with all the biases, filtering, and base imperfections that implies – and the proper perspective of the steward is open, receptive, flexible, and adaptable – mirroring, as much as is practicable, the nature of the change that is being stewarded.

Change shares sparingly. If properties are to be revealed, in the collective sense of the change as opposed to the properties of some of its parts (which would legitimate the reductionist fallacy I have just identified), and as a result of change interacting with its environment and evolving as a system unto itself, then these properties reveal some new relationship to their environment (on which more below), or *emerge* in complexity theory parlance. In order for this to happen, our open, receptive, flexible, and adaptable steward must be present and prepared for the emergence to occur. "In the fields of observation, chance favours the prepared mind," in the words of Pasteur. Whether emergence is more a property of the system or its steward is a topic which is beyond the scope of this paper, but it is probably sufficient to view the emergence of the properties of a complex system like change as an *epiphany* – a tremendous 'aha!' on the part of the steward – than as some plateau or state of homeostatic equilibrium having been achieved by the complex system itself, which is not *per se* a feature of complex systems.

It is probably better to consider the epiphanies of change as singularities, as the appearance of highly unstable states of order that are then as quickly lost. If we could possibly hold these states in focus, however briefly, could they reveal something to us?

The act of emergence is one that is ephemeral and very hard to generalize. Generally the furthest thing from the mind of the person experiencing it is curiosity, awareness, and theorizing about how it is taking place – as this person is rather deeply involved in the experience of emergence itself, which can be rather demanding of concentration and focus. Emergent properties, then, could be viewed as having the properties of artefacts or of empirical episodes – albeit rather special ones – for the purposes of this discussion, in the same way that a person learning a new language from tapes or seeing an unfamiliar animal for the first time is very unlikely to stop and reflect upon how this new information is being taken in and processed, but is rather fully absorbed in the actual processing of the new information.

It is in fact the emergence of useful epiphanies about change that is the core of this discussion – and the most fundamental aspect of change stewardship – and one that is sorely under-researched. The four fallacies of understanding change that have been described so far have served to lead us to a point far from where we need to be in this regard. Having done a reasonably thorough job of exploring the erroneous structural elements of 'change management', and having presented the key problem requiring a solution that may start to get our relationship to change back on the right track, I now offer a potential investigative thread that might start to re-orient our thinking along the proper lines.

A Proposal

Supplant the Change Paradigm of Linear Trace-Routes through Discrete States with One of Patterns

Having challenged the four pillars of 'change management', it is necessary to attempt to replace this structure with something that more appropriately offers direction within the frame of complexity, openness, continuousness, and emergence.

In an earlier paper (Falconer, 1999) I introduce the concept of business patterns. In a later paper (Falconer, 2001) I suggest the utility of using business patterns within the frame of organizational change. Both of these papers serve as good precursor to the discussion here. I will expand on these ideas presently, but first a bit of background may be useful.

Briefly, *pattern* describes a knowledge metaphor, which encompasses instantiated artefacts, that is as closely analogous as is practicable to the thought-patterns envisaged as tacit mental metaphors (see Falconer, 2000) and which attempts to encapsulate and formalize them, and *business pattern* essentially lays out a metaphorical device for the capture and reuse of explicit organizational knowledge, in essence a pattern which lies in the domain of circumstances and behavior that characterize and define a general business milieu. A *pattern language* is to patterns what a conventional language is to words: a means of organizing patterns symbiotically, and weaving granularities of patterns together in a fabric, so that they may not only form the basis for discussion, but also for creative ideation and development. Patterns can be clustered or combined into *pattern sets*, which are analogous to concepts, schools of thought, or universes of discourse in more familiar parlance; pattern sets can be thematic, reflective of an exemplar, or highly abstract; and are highly volatile, resist revealing any inherent structure, and can only self-express a fleeting, tentative sense of their own existence.

Within the context of this paper, I am suggesting that patterns, pattern sets, and pattern language all provide the 'fabric' for the epiphanies of change to be 'thrown' into. In this sense, this 'fabric' can be said to constitute the 'environment' for the complex system that is change, a notion of representation as environment, and the only non-metaphysical description possible for an (external) environment for change as it has been characterized here; in this context, the 'boundaries' between system and environment become conceptual, fluid membranes between phenomena and ideas, or between complex system and pattern language. While the implication of any 'structure' may be antithetical to the intent here, the ultimate goal is not necessarily the better organization of explicit artefacts that serve to represent emergent change epiphanies, but rather the underlying fabric they comprise, which could then potentially be used to enhance our understanding of change, and while we may still not be able to 'manage' change, we may feel somewhat more comfortable in its presence. To this end, social interaction should drive the embodiment of this fabric, rather than the artefacts themselves. The evolution of the pattern language may, in its dynamic, approximate the evolution of the change under consideration, a yin to its yang. While the means of using this fabric to derive meaningful insight about change is probably beyond the scope of this paper, I would like to think it would provide a sort of contextual backcloth, or a *fitness landscape* in the language of complexity, to subsequent epiphanies about change. The patterns, thereby, act as *strange attractors* in the landscape and, like the epiphanies that both invoke and cleave to them, need to be allowed to emerge, and the environment the pattern language defines must permit, and if possible foster, this to occur. In other words, it provides a sort of continuous means of assessing pattern-to-epiphany 'fit' in the moment of comparison, from which pattern, epiphany, and comparison all can emerge. The patterns cannot be forced, and the fabric cannot be allowed to become too structured or to become prescriptive in the manner of the change lifecycle frameworks I have already dismissed; instead, the fabric must be open, continuous, flexible, and adaptable.

To restate the proposal, I am recommending using patterns as the operational metaphor for observing, understanding, and expressing change, and using the pattern language that would emerge both as the representation of the inherent meaning of the change under consideration and, conceptually, as the environment in/with which it interacts. This solution would exhibit the following characteristics:

- open, holistic, continuous, nonlinear, flexible, and adaptable;
- having no implication of 'management', structuredness, prescription, or methodology;
- not modellable or describable in its essence,and;
- driven by emergent phenomena within the change landscape.

In short, it is offered up, optimistically, as a viable alternative to the concept of 'change management', and one that offers rich potential.

The concept is well understood to be a highly theoretical one. Even with that characterization it needs further development, and in order to evolve toward a state of practical application it needs further work still. This is the right direction, though, in my opinion, for dealing with change.

Implications, Opportunities, and Future Direction

In this chapter I complete my sweeping critique of traditional 'change management' that is begun in earlier papers. I cover the fundamental points. Then, I offer a proposal that I believe might serve to reverse the unfortunate trend on all these points.

I understand that much development of this proposal remains to be undertaken. It is my hope that this paper might generate sufficient interest that others may take up the mantle here.

Then, I would recommend extending the research to make application to a particular cycle of change – to test the efficacy in the real world of change we all inhabit – for this approach is only as good as its applicability.

The various ideas presented in this paper, because of their exploratory nature, augur substantial refinement. I make no apologies for this; in fact, it is my hope that this tentative state will make them more susceptible to insightful responses and recommendations for improvement. I welcome such input.

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Chapter Ten

MODELING OF SOCIAL ORGANIZATIONS: NECESSITY AND POSSIBILITY

Raimundo J. Franco Parellada

Introduction

It might seem not worthwhile or even be superfluous to wonder if there exists a need to model the evolutionary behavior of social organizations. Nevertheless, when one observes the world we live in, the conflicts that confront humanity – terrorism, repeated wars, environmental problems, inequalities, and increasing poverty – one cannot but think about the convenience and need for dealing better with social organizations.

On the other hand, humanity has reached such a degree of technological and scientific development that it can be asserted that there is no problem of a technological nature – if it is solvable and humans concentrate on solving it – that could not be solved within some timeframe. Think of the program to send a man to Mars. The approximate amount of resources that such a colossal task will consume and the time required have already been calculated, so it is a reasonable assumption that nobody doubts that at some time in the future, man will land on Mars. Nor does anyone doubt that sooner or later humans will find a cure for cancer and so on. However, at the same time how many people really believe that the problems of poverty, degradation of the environment, terrorism, or underdevelopment will be solved within the foreseeable future?

I am not making any political exhortations, I only want to emphasize the growing need for a better understanding of the evolution of *social organizations*, a term that includes companies, political parties, governments and their ministries, factories, schools, religious organizations, nongovernmental organizations, and innumerable others.

At the same time, when organizational management methods and theories currently in vogue are analyzed (Morgan, 1998), one can detect that they are based on two paradigms, which I have called the paradigm of good practices and the paradigm of talent (or the lack thereof). The first established that all management theories are really practices that have given good results in one context or another, and in many cases are generalized without bearing their context in mind. For example, management by objectives, project management, and others (Mintzberg, 1994). The second paradigm refers to a management method based on the capacity and knowledge (or the lack thereof) of the managers. Actual management processes are often a combination of some proportion of these two paradigms, and are in fact a process of test-and-correct. It is necessary to point out immediately that errors in management are very expensive and, given their markedly irreversible character, very difficult to correct.

To illustrate the above situation it is useful to quote Jeffrey Goldstein (Goldstein, 1997), who concluded:

"*1(a) When organizations succeed, it is mostly in spite of, not because of the way they are organized. 1(b) When organizations succeed, it is mostly in spite of, not because of, the way leadership is exercised. 1(c) The manner in which most organizational working units are organized, set up and managed serves more to stifle than to encourage the creativity and productivity of its members.*"

These conclusions might sound dramatic, but there is doubtless an unsolved problem here.

Why does this unsatisfactory situation exist? In my judgment it is because we lack an understanding of the evolutionary dynamics of social organizations. I think that complexity theory can contribute to attaining that knowledge. What makes me think that modeling the evolutionary behavior of social organizations is not only necessary but also possible? Below I will try to give an answer to this question, based on the one hand on the relationship between the sequence of appearance of different kinds of systems' laws of motion (mechanical, thermodynamical, chemical, and biological) and on the other hand on the degree and qualitative difference of systems that obey those laws.

Social Organizations (SO) are the Most Complex Systems

Without any doubt, the current world is characterized by the *complexity* of the problems it must face and solve on a daily basis. The term "complexity," however, has become popular in the most diverse branches of science and even outside of them. By way of illustration, we refer to studies on the science of complexity by the Santa Fe Institute (Zurek, 1990) and to a newsletter of the International Council of Scientific Unions (ICSU, 1994) devoted to ideas on the relationship between complexity, chaotic behavior, and systems dynamics presented at the seminar *Confronting Complexity in Science* by numerous eminent scientists in fields as varied as mathematics, physics, biology, neurosciences, and philosophy. Another recent reference regarding complexity, however, ends by declaring, after a page and a half of analysis:

"*In fact, complexity (together with the related terms of order and structure) appears as essentially undefinable in any way that allows objective measurements*" (Ayres, 1994: 13–14).

There are a lot of definitions of complexity. Bruce Edmond described more than 40 of them (Edmond, 1999). One can conclude, therefore, that there does not appear to exist much consensus in connection with complexity, as also evidenced by the fact that this lack of consensus was the topic of a recent conference (NECSI, 2001). The situation appears to be the same today. So I will try to strike out along a new road, not so much to attempt a definition of complexity but to capture the relationship between the types of motion a system is able to do and the degree or level of complexity that the this system con display. This approach will be based on the ideas expressed by Engels in his *Dialectics of Nature* (Engels, 1982) concerning the complexity of different types of motion, understanding as motion, and this is very important, any class of change in the system.

Engels proposed a classification of motion along an increasing scale of complexity; that is, complexity exists to a greater or lesser degree according to the type of complex motion that the system is able to perform. Accordingly, Engels identified mechanical motion as the simplest, followed by physical motion (understood as thermodynamics and electrodynamics, to which today one must add relativity theory and quantum mechanics). A more complex motion than physical motion would be chemical motion, that of the combination and transformation of some substances into others. Biological motion would come next, as linked to its main distinctive characteristic, reproduction. Following this logic, social motion would occupy the highest level of complexity, and would be the one characteristic of human organizations of whichever type.

Although very intuitive, this classification has its problems, as does any other. One can say that mechanical motion is the motion of the

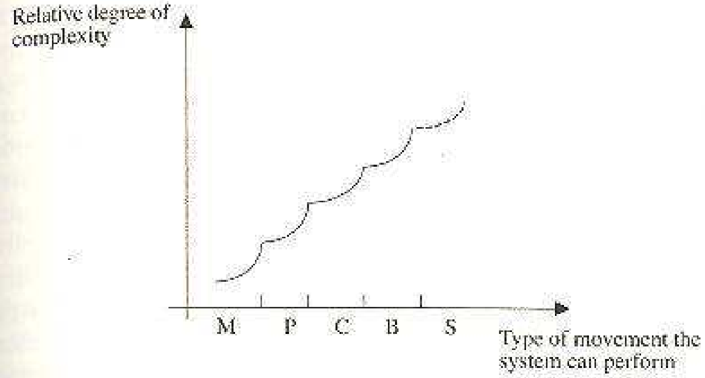

Figure 1 *Schematic representation of the increase of the degree of complexity in accordance with the type of motion. The appearance of a new generic type of motion represents the emergence of new irreducible qualities. This is represented in the figure by an abrupt leap in complexity*

whole as such. For example, when one studies the mechanical motion of the solar system one is not interested in – or it is not important to know – what occurs on the Sun itself. The laws of mechanical motion can say nothing about nuclear reactions on the Sun. If one wants to know about these one needs to use the laws of nuclear physics. In this sense, chemical motion is characteristic of interactions among different kinds of substances formed by millions and millions of entities that give rise to millions and millions of entities of another kind of substance. Naturally, these interactions can take place only in the presence of the mechanical motion of atoms and molecules, but you cannot reduce the process of chemical reactions to a mechanical displacement of any kind. In this sense chemical motion is richer, more complex than mechanical motion.

It is important to note that within each of these types of motion (mechanical, physical, chemical, biological, and social) one can find systems with simpler and systems with more complex motions. For example, the mechanical motion of a falling object is simpler than the mechanical motion of a planetary clock; and the biological motion that an amoeba can carry out is simpler than one that mammals can perform. Thus one can maintain that complexity in general has at least two very defined dimensions, one that corresponds to a generic type of motion and another one within each generic type.

To complete this introduction to complexity, I recall a factor that some authors seem to forget when they try to model the dynamics of "the living," including social organizations (Mack, 1994). These authors often use the same conceptual scaffolding (formalism) as they use to model simpler types of motion, without keeping in mind a very important qualitative aspect, also noted by Engels, that is summarized by the fact that the more complex generic type of motion includes, but cannot be reduced to, an aggregation of the simpler types.

An interesting example of these qualitative and irreducible differences can be found in the difference between thermodynamics and mechanics, that is, between the description or modeling of the motion of millions and millions of particles – say, a gas – and the description of the motion of only a few particles according to Newtonian laws. As is well known, the laws of mechanics are time reversible, with no differences in the direction in which time flows (toward the past or toward the future). In contrast, the laws of thermodynamics have an irreversible character and time flows only in direction of the future or, as some like to put it, in the direction of the increase in entropy.

Another very different example can be found in the study of language: The development of language and its dynamics could not be understood only from studying man as a biological being, because language is essentially a social phenomenon that, although developed on a biological substratum, cannot be reduced to it.

In my opinion, this methodological error prevents many authors from attending to the qualitatively different aspects of a particular type of motion with respect to other simpler ones. For modeling human social organizations, however, this aspect will turn out to be essential.

If we study the appearance of scientific discoveries and truly novel scientific ideas in light of these conceptions about complexity, we can see that they have appeared in a sequence that coincides with the sequence of increasing complexity of motion. The first scientific results in modern times, which appeared approximately in the seventeenth century, were related to mechanics and are associated with the well-known names of Newton and Galileo, among others. The nineteenth century, together with the beginning of the twentieth, can be characterized as the acme of physics. Formulated during that period were thermodynamics and its famous Second Law (entropy in an isolated system can only grow or remain constant), Maxwell's electrodynamics, Einstein's relativity theory, and quantum mechanics. Chemistry, which developed in parallel with physics, finally found a solid foundation in the first two decades of the twentieth century with the discovery of atomic structure. The 1940s saw the rise, as scientific disciplines, of information theory and cybernetics, which created the paradigmatic basis on which, to a large extent, all computer science is based. These two sciences went on to contribute in an important way to the understanding of the enigmas of the genetic code, on the basis of which decisive advances occurred in biology. This science took over as the *avant garde* of scientific progress by the middle of the twentieth century. A turning point in this changeover was the discovery of the structure of the DNA molecule in the 1950s, based on X-ray analysis discovered in the 1920s.

Worth keeping in mind is the fact that in spite of the considerable resources used in physical investigations in the last 50 years, relatively few truly new scientific principles have recently been discovered. The study of biological systems has advanced in a spectacular way in the last decades. Today we have reached the point where we can begin, in a systematic way, to turn biological knowledge into goods and services, as illustrated to some extent by the appearance of words such as biotechnology and genetic engineering.

To summarize, it can be maintained that results in science have been closely linked to the degree of complexity of the type of motion studied, and that the sequence has proceeded from the simpler to the more complex. At each stage, the shift has been marked by the formulation or discovery of laws that describe a particular type of motion, thereby giving predictive strength to the sciences related to its study. Today, it seems that the stage is being set for the transition to a dynamic modeling of social organizations. This modeling will bring with it remarkable and significant results, as has already happened as a consequence of the study of other simpler types of motion.

Some Characteristics of Social Organizations Studied as Complex Dynamics Systems

The conclusion of the previous paragraph that we are most interested in emphasizing is that a social organization (SO) – that is, any human organization, such as a laboratory, a factory, an institute, and so on – is a *dynamic system*; that is, a system that changes and will evolve over time. The complexity in the systems studied by human beings has thus grown, gradually, continually, and in parallel with the advancements of science. Today there are innumerable systems studied by the natural sciences and biology in particular that are classified as complex dynamic systems (CDS), among them lasers, the climate, the human brain, autocatalytic chemical reactions, ecological systems, huge electrical systems, systems of electronic communication, and many others.

The last few decades have seen considerable progress in the understanding and modeling of the dynamics of such systems. This research has shown that in these systems the transition from orderly (predictable) behavior to disorderly, unpredictable, or chaotic behavior goes through the same sequence of phases. I refer in particular to Lorentz's early work on climate prediction during the 1960s (Lorentz, 1963), Rene Thom's catastrophe theory (Thom, 1975), Feigenbaum's universalisms (Feigenbaum, 1978), and a multitude of other works, beginning in the 1970s, on the chaotic behavior of such systems. The same decade saw the start of the ideas on synergetics advanced by the German physicist Hermann Haken (Haken, 1987), which contributed to understanding the self-organized orderly (coherent) behavior of systems consisting of a multitude of elements (subsystems) that in general behave in an aleatory or disordered way but that, under certain conditions, also called constrains, behave in a coherent and orderly manner.

To all this it is necessary to add the development of the thermodynamics of irreversible processes, especially the work of the Brussels school with I. Prigogine at its head (Nicolis & Prigogine, 1977, 1989). Prigogine proposed the term "dissipative structures" for those dynamic systems with stable or stationary structures located far from thermodynamic equilibrium and maintained by the constant dissipation of energy. Today all living systems are thought to be dissipative structures; in other

words, these systems can only exist on the basis of a continuous flow of energy, information, and substances. These works helped significantly in the understanding of phenomena associated with the behavior of complex dynamic systems.

It is therefore convenient to enumerate some characteristics that social organizations possess as complex dynamical systems. I divide them into two different categories: first, those characteristics that they have in common with other complex systems belonging to other types of motion (in accordance with the classification that we have proposed); second, those characteristics that I consider to belong only to the social system's type of motion and that are, therefore, not found in any other type of system, whether biological or otherwise.

Common Characteristics

- Social organizations are open systems. This means that their relationships with the environment are essential to the existence of the system as such.
- These systems, situated far from thermodynamic equilibrium, constitute or form dissipative structures. This is evidenced by their possession of a certain "metabolism": energy, information, meaning and substances flow through them, and are transformed or metabolized by the system. These systems also can consume objects that are similarly transformed and used, and that embody in themselves certain quantities of information, energy, meaning and substances. These flows and products allow the systems to fulfill the function they perform, or to reach intended goals. As with any "metabolic process," that of social systems yields certain products and wastes: In addition to objects, these include energy, information, and substances. Being dissipative
- structures they confer a strongly irreversible character on those processes developed in social organizations.
- Social organizations evolve, adapting themselves to the changes that take place in their environment. They are therefore adaptive systems. At the same time
- Such systems are always feedback in terms of reaching the intended goals. This feedback can be stabilizing or enhancing.
- Social systems are comprised of other systems that we can

call subsystems. In turn, these subsystems are constituted from elements that are also systems. All of these systems, each formed from other systems, create a hierarchy of systems with approximately similar characteristics at each level. They are, in some sense, self-similar.

Particular Characteristics

- Social organizations always fulfill a certain function or seek to reach certain goals. In other words, they exist for something.
- Keeping in mind that in these systems the main element or basic cell is the human being, there is something that also flows and is metabolized by social systems but whose characterization and quantification form, in itself, a huge problem. We refer to the exchange or flow of ideas, feelings, and ethical, esthetic, moral, and cultural values. Without doubt they are transmitted, are shared or not shared, and are assayed in some way; that is, they are "measured".
- There is no doubt that the values, culture, and concepts that social systems embody have an important influence on their dynamics, as has been shown by the research and successes of organizational psychology and sociology. Successful modeling of these systems would not be possible if these factors are not integrated in a way amenable to this modeling. This shows why the integration of the social sciences and the natural sciences is the only commendable alternative for the study of the dynamics of these organizations.
- Human beings, the basic components of social organizations, have their own objectives. These can coincide or not with those of the social organization of which they are components, and in some cases can even end up as antagonistic objectives to those of the social organization. I do not know of any animal society like ants or bees or any other with these characteristics. It does not seem reasonable to doubt the influence that this feature can have on the evolutionary dynamics of a social organization: A situation in which 90 percent of its members share the objectives of a social organization is quite different from one in which only 10 percent of them do. Perhaps this variable can become an order parameter that determines the arrival of a critical point in the evolution of the social organization.

- Adaptation in social organizations can be actively creative. It means these systems can react very quickly, in real time, and in unexpected ways to environmental changes.

The Possible Role of the Environment in the Dynamics of Social Organizations

It is indubitable that social organizations are *open* systems, but *to what* are they open? With what do they interact? That with which social organizations interact can be called their "environment." Evidently this is not only a biological or ecological environment, it is mainly a social environment; or, more precisely, a socio-political-economic-natural environment, all together forming a certain totality.

Any social organization will evolve within the environment with which it interacts, by somehow influencing it and being influenced by it. In order to understand more precisely the evolution of social organizations, however, we need to examine those characteristics of any environment that are necessary or essential for social evolution.

I believe that two characteristics of the environment are very important for understanding – however incompletely – the evolutionary dynamics of social organizations. Both are interconnected and thus cannot exist independently of each other. I will formulate these properties as a postulate that I will call *The Postulate of The Predictable and The Unpredictable*:

For social organizations, the behavior of the environment is only partially predictable and, at the same time, it is in part also unpredictable.

There is a certain redundancy in this formulation, but, as we shall see later on, it is a necessary one in order to be able to differentiate clearly between the predictable and the unpredictable. It is also necessary to emphasize that when we speak here about the unpredictable, we refer precisely to what cannot *in principle* be foreseen by the system. At each moment of the system's existence there are changes in the environment that will be essentially new for the system and therefore impossible to foresee. In relation to the predictable, what the postulate means is that only an incomplete, partial, or limited forecast of the behavior of the environment is possible.

What consequences does the behavior of its environment have for the motion of a social organization? A social system, as we have seen, fulfills certain objectives or carries out certain functions. In light of the two caveats concerning the partial predictability and unpredictability of any environment, how should that system be organized in order to respond in such a way as to adapt or evolve successfully despite the essentially contradictory qualities of its environment? As a tendency, if a system does not "move" with success within its environment – that is, if the system does not attain its goals or functions – it will devolve and ultimately could even disappear.

I will try to illustrate this idea with an example from biology. Naturally, no social system, in my view, can be reduced to a biological one, but the social type of motion is possible only if it includes all other simpler types of motion. So we can always learn something from biological systems that we will surely find in social ones.

Think about the life of a lion in the forest. The lion can find the place where he hunts, the place where he drinks water, the place where he sleeps, and so on. He can, in this sense, "foresee" where these places are. What would happen if all these places begin to change randomly for the lion?; that is, when the lion goes for water he cannot find it, when he goes to sleep he cannot find his lair, and so on? Of course, the lion's life would be in serious danger. He thus requires some stability in his environment that enables him to find what he needs and, in this sense, he commonly can, as we said, "foresee" where these places are.

However, a lion's life is not reducible to the above-mentioned. There are other facts that the lion cannot really "foresee." For example, when he hunts he does not "know" in advance what the results will be and naturally he cannot "know" ultimately if he will be the hunted. So, a lion's life takes place in an environment that has for him the above two properties: being at the same time partially predictable and unpredictable.

What role does the unpredictable part of the environment play in this case? What does the lion need that part for? It can be said that for an individual lion that is a very bad part. Because he has no options, the only possibility for him is to resist those changes or otherwise he will go

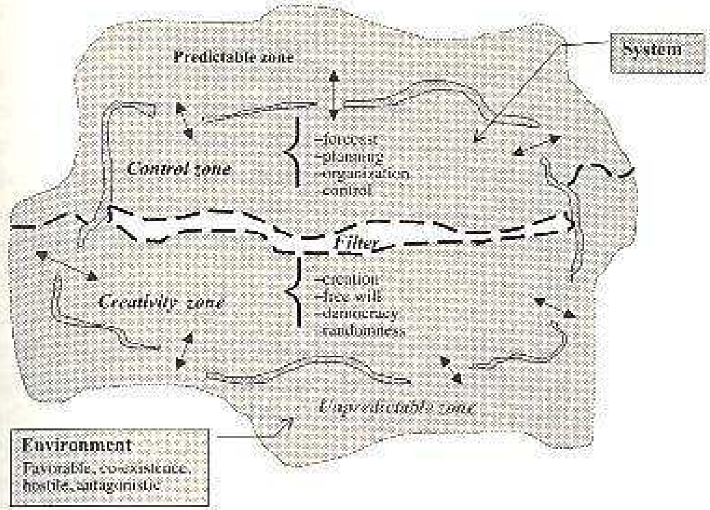

Figure 2 *General structure of a system that models a social organization*

hungry or be hunted. Nonetheless, that part is a very important one for the entire species, because it guarantees the capacity of lions to resist the environmental changes that always, sooner or later, will take place; thus in the long run, that part is also very important for each individual lion. I claim that social organization's environment behave the same way and this have important consequences for them, despite the fact that in the case of social organizations things are quite different, because for these it is possible to adapt to the random unforeseeable changes of the environment in real time, that is, in creative ways. That is a very important feature that differentiates human systems from animal ones.

A General Model of a Social Organization

The items outlined in the previous paragraph can have, in principle, a multitude of answers. However, not all answers will deal with equal success with reality, and therefore it is necessary to advance some hypotheses as possible answers and try to check how well they work.

We propose the following: A social system should be organized in such a way that it reproduces in its very functioning and structure as a result of its interactions with the environment in which it moves, evolves, end develops – the two above-mentioned properties of the environment. This means that a social organization's internal structure should contain at least two parts, one that corresponds to the predictable aspect of the environment and is subject to planning and control, and another that corresponds to the unpredictable, aleatory, stochastic behavior of that environment. One can speak here of a sort of structural, functional, dynamical coupling between the social system and its environment (see Figure 2).

We label "control zone" that portion of a social organization that reflects the predictable side of its environment. This part of an organization should be charged with continuously maintaining the possibility of attaining the objectives or executing the functions of the system. This structural portion of a social organization corresponds to that area of any system responsible for guaranteeing the coordination of all the system's efforts aimed at the attainment of the proposed ends.

We have named the "creativity zone" that portion of the system that reflects the unpredictable behavior of its environment. This organizational area is charged with foreseeing the unpredictable – which is of course impossible. How should this organizational area be conceptualized, and how should it work? We submit that this organizational area should be charged with continuously *creating and designing* tests of the system's possible adaptive responses to unpredictable changes in its environment. However, since those changes are truly unpredictable, the creativity zone should *conduct* those tests in a non-planned or organized manner. To put it another way, in this creativity zone an aleatory, random, or chaotic motion takes place that continuously searches all possible adaptive actions. This creativity zone is thus the organizational area where unforeseen responses to unpredictable problems should be continuously elaborated.

Perhaps the best way to convey this idea is with an example, that of the research in the field of superconductivity. Until 1986 research on superconductivity was carried out in the area we have been calling the creativity zone. That is, until then research on superconductivity was carried out in an unplanned and unorganized manner by those with resources who believed that superconductivity was achievable, that it was an interesting scientific problem, and so on. That research effort faced a formidable difficulty: the fact that the superconductivity

effect was at the time thought to be achievable only at temperatures of liquid helium, that is, very near absolute zero (–273K). Besides being extremely expensive, liquid helium also filters and escapes through any interstice or microscopic pore, which makes its industrial use practically impossible. As an instructive aside, it also is necessary to add the fact that the physical theories for explaining superconductivity in vogue at the time predicted a maximum temperature limit that rendered the phenomenon impossible.

During 1986, however, a small group of researchers discovered that, in spite of everything that was believed at the time, superconductivity was in fact possible at the temperature of liquid nitrogen, a liquid produced on an industrial scale and widely used. From that moment on, and in only few months, more than 100 laboratories with planned objectives, assigned resources, and future research plans on superconductivity were created by government programs throughout the world.

In this example, we clearly see a transition from an area where research is carried out by diverse interests – that is, with an aleatory character – to an area where the results are planned, foreseen, and to which resources are assigned in order to attain some specific results. The relationship between these two areas and their relative proportions depends at least:

- *On the specificity of the system itself (on its objectives and functions).* For example, a military entity as compared with an entity dedicated to R&D shows a probable prominence of the control zone.
- *On the particular historical moment in the system's development.* It is clear that any one of these systems goes through stages of childhood, maturity, and senescence; that they endure crises followed by renovation, and so on. In each one of these stages the control and creativity zones display different proportions within the overall structure.
- *On the correlation that at any given moment the predictable and the unpredictable have within the environment.* We can accept that any one of the systems we are studying will organize its structure – the proportions between the control zone and the creativity zone – according to the way the environment behaves; for example, during wartime, social revolution, economic booms or depressions, and so on, each zone would show different proportions within the system.

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- *On the character* – favorable, hostile or antagonistic – *that the environment presents to the social organization.*

The consequences that maximizing either one of these zones could have for a social system provide a good example. Traditional socialist planning is well known: It pretended to foresee everything, plan everything, control everything on the basis of defined social objectives. Why did it fail? Naturally it was not for one single reason, but its failure can in part be explained by its inability to adapt to the more or less quick changes of its environment. It had reduced the area of creativity to 0 bits.

At the other extreme stands neoliberalism. Under conditions of neoliberalism everything is economically possible: free trade, free flow of capital, and so on. But to what does it lead? Today, the Argentinean case makes evident that this economic pattern leads to serious social conflicts and ultimately also fails. Why? In this case the system loses its social objectives and in the long run leads to well-known conflicts. Here the zone of free will is maximized.

In summary, successful social operations require both zones distributed in varying proportions; in other words, a certain amount of planning combined with a certain freedom of action.

Some Consequences for the Management of Social Organizations

From the foregoing some considerations should be kept in mind for the efficient management of social organizations considered as complex dynamical systems:

- Management should, from the start, recognize the existence of the outlined general structure and thus consciously organize its operations accordingly.
- Systems management should determine, for each particular moment and bearing in mind the environment's dynamics, the relative proportion between the control zone and the creativity zone. Management should also determine what resources will be allowed to be spent on unplanned, uncontrolled activities; in other words, the strength that will be given to each zone.

- Management should specify the mechanisms that could facilitate the transition of whatever is created in the creativity zone into the control zone. We have called these mechanisms "filters" because it is evident that not everything created can afterwards be necessary or indispensable for the system to better develop as a whole.
- Management should investigate its environment so as to describe and characterize it as precisely as possible. One and the same environment can be – and in fact is – different for each system. For example, "the economic world environment" appears to mean the same for an underdeveloped country as for a developed country, but in reality it does not.
- When organizing these systems internally, management should keep in mind the system's property of being a system-of-systems, knowing beforehand that it should exercise its planning and controlling influence only on that part of the nested subsystem's activities that correspond to the control zone. In other words, each subsystem has its own control and creativity zones and the managers should take account of that fact, avoiding exercise of control actions over the creativity zone.
- Management should keep in mind that decisions and actions taken in these systems always have a certain irreversible character and that there is no going back in time.

Conclusions

1. The "social" must be explained by the "social"; it is not reducible either to the biological or to any other type of motion.
2. Social motion is the most complex type of motion.
3. Because a social organization, although identifiable, is intimately related to its environment, the latter must be characterized, even if only in a general way. For that purpose we propose also to use in the case of social organizations the dual characteristic of every environment: that of being at the same time partially predictable and partially unpredictable.
4. A general model of social organization is proposed that in the author's opinion possesses heuristic power and is derived from the interactions between the organization and its environment.
5. There exists a need to formulate specific laws of motion for the evolutionary dynamics of social organizations. To that end, in the last

three decades, mathematical methods for nonlinear systems have been developed and it is increasingly likely that we will obtain the necessary information. These circumstances lead us closer, and in an accelerated manner, to the possibility of solving this problem successfully.

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Chapter Eleven

FROM LINEARITY TO COMPLEXITY IN ECONOMICS AND MANAGEMENT

Elena Olmedo Fernández, Ruth Mateos de Cabo, and Juan Manuel Valderas Jaramillo

Introduction

From the beginning of time, men have tried to understand the reality that surrounds them to try to predict its future evolution and, insofar as possible, to control it. The way to come closer to this knowledge has evolved throughout history, depending on the vision that men had of the world. The concepts of complexity and chance have evolved in the same way. The evolution of these concepts has impregnated the form of understanding economic analysis and, recently, also the world of business and enterprises. This paper is devoted to the study of the cornerstones of the evolution of scientific knowledge, and in particular their relationship to the world of economics and industrial organization.

This paper is, in some parts, a critical review and an updating of Mateos, *et al.*'s (2002) *Emergence* article. Other parts are completely original and include the authors' insight in recent, and not so recent, advances in the field of complexity as related to economics, business and management theory.

The paper is divided into two major parts. Focusing on the evolution of the term 'complexity,' the first part of this work deals with the progress of the dominant scientific paradigm and its influence in economic analysis. The second part deals with the influence of this progress on organizational management.

Within the first part of this work are four major topics: a discussion of determinism and randomness, the new concept of complexity, the development of a new paradigm, and the influence of this paradigm on econometrics. Sections I to III are devoted to these topics. Sections IV and V correspond to the second part of this paper, in which the evolution of organizational management, as it follows the evolution of scientific process, and of complex management, is analyzed more thoroughly. Section VI contains the conclusions.

Evolution of Scientific Paradigms

From the beginning of time, men and women have tried to understand the reality that surrounds them in order to predict its future evolution and, insofar as possible, to control it. The way to come closer to this knowledge has evolved throughout history, depending on the vision of world that men had. The mental schemes that have guided the Western mentality have characterized the methods of analyzing what surrounds us. As a consequence of this fact, the knowledge of the paradigms that describe these methods, and how they have evolved, cannot be considered futile. These general paradigms give the basic facts of the techniques and models that scientific disciplines have used to model the surrounding phenomena, also in economic analysis and business management.

Since the 18th Century, the Newtonian conception of the world, based upon the three dynamic laws that described the movement of planets, has been the basis of the predominance of the so-called deterministic paradigm. The superiority of the Newtonian conception of the world, consequence of the success of its application to explain and predict natural phenomena, gave strength to the deterministic vision of the world and set this as the basis of the modern scientific method. For this reason, the deterministic paradigm is also called Newtonian paradigm. This paradigm has guided the development of science in the two centuries, supported by Cartesian reductionism, which stated that the comprehension of the laws and properties that govern any system could be achieved by studying the parts that make up the system.

Cartesian reductionism leads to the Principle of Strong Causation that guides the deterministic mentality of this paradigm: the same causes result in the same consequences. The best example of this deterministic vision of the world is the demon of Laplace which could predict the future with absolute accuracy once it was provided with knowledge of all the initial conditions. Consequently, the golden period that science enjoyed during those two centuries, based principally upon the success achieved by physics that constituted its main referent, lead us to the fact that the precise description, comprehension, and knowledge of any studied entity implies the capacity of predicting the past and the future evolution of this object with absolute accuracy. This accurate prediction could be made, provided that we knew the laws that control its evolution and the state of the object in a precise moment. In case that we were working with a more complex system, the key point was reducing the whole system into smaller parts, in order to work with the parts in the correct context according to the same procedures.

Nevertheless, Laplace himself, noted that this determinism was impossible to achieve at a practical level since, due to our lack of knowledge, it is impossible to be aware of all the initial conditions and all the causes that may affect any event. Consequently, determinism was not effective, but asymptotic (Mateos, *et al.*, 2002). Hence, given the impossibility of knowing all the interacting causes, motivated by the presence of many agents involved, the Principle of Strong Causation was replaced by the Principle of Weak Causation (approximately the same causes result in approximately the same consequences), which led to approximate predictions of events based upon statistical terms. The search for deterministic universal laws is replaced by the search for statistical laws. The statistical laws that are the basis of this paradigm were similar to the classical ones, but they operated based on averages and dealt with the uncertainty that arises from the lack of information about all the relationships that may rule an event. Chance is identified with the absence of information associated with the studied event. A new paradigm, the randomness paradigm arises, though some authors refer to these two paradigms as a single one called the Simplification Paradigm (Nieto de Alba, 1998).

Hence, both paradigms, the deterministic and the statistical ones, co-existed and were applied to diverse fields:

- The deterministic paradigm dealt with simple phenomena, with few degrees of freedom and where the knowledge of all the interacting causes was possible;
- The statistical paradigm dealt with complex phenomena, with many degrees of freedom and where the knowledge of all the interacting causes was not possible.

In addition to the Cartesian reductionism that led to these two paradigms, other underlying ideas surrounded the vision of the world and impregnated the reductionist principle. These ideas also can be considered as fundamental principles:

- The independence between the observer and the studied phenomena, in the sense that observation did not affect the behavior of the system;
- Causes and effects were linked by linear relationships.

These ideas led to concepts such as locality, linearity, stability, reversibility that were present in the basis of these two paradigms. Any model relied on:

- Closed systems: systems are studied in isolation and not related to other ones;
- Systems in equilibrium;
- Linearity: the whole is approximately the sum of the parts that compound it;
- Energy conservation, as a consequence of being closed systems;
- Reversibility: time is exogenous and external to the system;
- Order.

The business and economic reality has not been aware of this paradigm. The economic reality was conceptualized based on these formulations, even though the characteristic features of the economic reality, and also of the other "soft" sciences, do not fit well into this approach. The complexity of economic reality makes it impossible to support these principles any longer. It is hard to maintain the independence between the observer and the observation, or the assumption of linear relationships between causes and consequences. The success in the application of the Newtonian paradigm to natural phenomena fails for social sciences.

However, these principles have been questioned as well in the "hard" sciences since the beginning of the 20th Century. The Heisenberg's uncertainty principle showed that the independence between the observer and the observation was unreal. Later in the century, Chaos Theory overwhelmed the idea of linearity between the causes and the consequences, due to the property of sensitive dependence on the initial conditions amplifying insignificant divergences in those initial conditions exponentially. In consequence, these breakthroughs have concluded that an accurate description does not guarantee a good prediction. A new vision of complexity has arisen. The complex is qualitatively different from the

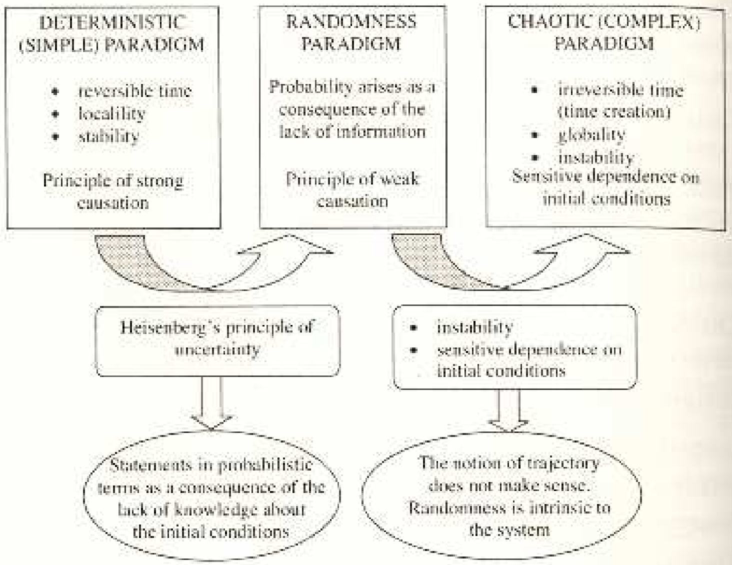

Figure 1 *The new paradigm of complexity*

simple. A new paradigm (see Figure 1) has been developed on the basis of this idea. Within this new paradigm, the gap between the "hard" and the "soft" sciences is not so sharp, and both disciplines work together with common concepts or common ideas, such as feedback, adaptability, relationship with the environment, that initially seemed more suitable for the "soft" sciences than for the "hard" sciences.

The new paradigm that breaks with the determinism-randomness duality, is not opposed to the Newtonian paradigm, but completes it with new concepts (see Prigogine, 1993, 1997) such as globality, instability, time-creation and nonlinearity. The study of reality deals with:

- Open systems and connectivity: systems are studied jointly and are related to the surrounding environment;
- Disequilibrium;
- Nonlinearity: the whole is not only the sum of its parts;
- Energy dissipation;
- Irreversibility (time-creation): time is an internal variable of the system and the time line is irreversible;
- Disorder.

The New Concept of Complexity

As we have introduced in the previous section, the application of the Newtonian paradigm to the analysis of the surrounding reality leads to a simple conception of the world even though its complexity is essentially evident. However, whereas the success of this approach is unquestionable as proven in the development of modern science and technology, this does not implies that this conception is unrestrained. In fact, as we have seen before, the limits to this conception are concerned with the development of the concept of Complexity.

As Rosser (1999) points out, there is no general agreement about the definition of complexity. In fact, following Rosser, every definition focuses on different features of the concept, and hence we necessarily have to admit that the concept of complexity is connected with different scientific disciplines. In fact, it is manifest that complexity has had a lot to do with closing the gap between science and philosophy, refusing to parcel the common basic problems to all the scientific subjects.

For instance, Day introduces a mathematical definition of complexity: a system is complex if it does not tend to either an endogenous fixed point, a limit-cycle or it does not portray an explosive behavior. Pryor and Stodder work with an structural vision of complexity, emphasizing the number of complicated structures involved in the system and the complex relationships among them. Other authors, such as Leijonhufvud (1993), Stodder (1995), Albin and Foley (1998), prefer a computational definition: a situation is complex if the calculations for an optimization problem are particularly difficult. Horgan (1995) also provides different definitions for the term. For example, he describes complexity as entropy, the disorder of a system, the capacity of a system to give information to an observer, the fuzziness of a system, the details that a system shows to increasingly smaller scales, the required time for a computer to describe the system, the necessary memory for such a description or the degree of information that a part of the system gives about the other parts.

To sum up, following these ideas, and according to the proposal induced by Edmonds (1995), we suggest the following definition:

Complexity is the property of a system of the real work that is characterized by the inability of any formal system to adequately capture all of the real world's properties, lacking complete behavior, even if complete information on the system's components and interrelationships is available.

Nonetheless, complexity is necessarily related to concepts such as uncertainty, denial, and totality (Morin, 1995). Taking into account all these ideas, we should consider the reasons that make formal systems unable to resemble the properties of a complex system. Again, according to Edmonds (1995), the following elements should be taken into consideration:

1. *The size of the system*, understanding size as the difficulty in handling the system as a whole. However, size is not sufficient for a system to be complex, it is necessary that a large number of interrelationships among the elements of the system exist;
2. *Ignorance*. Complexity is one of the causes of ignorance, but it cannot be the only one;
3. *Information*. The amount of information in a system is connected to its complexity – less information implies a less complex system. However, a system that contains too much information is not necessarily complex, given that the amount of information can be large enough but not the number of relationships among the elements of the system;
4. *Diversity*. Diversity is a necessary condition, but not sufficient, for a system to be complex;
5. *Order and Disorder*. A complex system moves continuously between order and disorder. Something completely disordered is not always complex, neither something completely ordered.

So, what are the features of a complex system? In the same way as the term complexity, a single definition does not exist. In order to avoid any circular definition, we describe the following definitions that are usually stated (see for instance the special issue of *Science* devoted to this topic, vol. 284, no. 5411):

- a complex system is a highly structured system, but with a changing structure;

- systems with the sensitive dependence property to initial conditions or to perturbations and with infinite possible trajectories to evolve;
- systems hard to understand or to contrast with functions or designs;
- systems with a large number of interacting components;
- systems that evolve continuously with many possible bifurcations in their trajectories.

Given everything stated above and following Pavard and Dugdale (2000), Fitzgerald (2002), Fitzgerald and Eijnaten (2002a, 2002b), the following properties must be present in any complex system:

Emergence and Auto-Organization

The fundamental differences between a simple and a complex system have to do the emergent properties that arise as a result of the interactions among the elements of the system and with the environment. These interactions are not usually observable at a micro level.

These emergent properties cause the creation of new structures, changes in the properties and in the behavioral patterns of the elements of the system, auto-organization. Consequently, these facts generate many difficulties in discerning any system functions or the properties of the system itself, what is usually called distributed information (or representation). For this reason, it is by no means possible to comprehend the whole of a system from the knowledge of its parts.

Besides, the relationships among the elements operate either in the short run or in the long run, that is, direct relationships operate in the short run, but due to interactions and feedbacks between the elements, any element may influence the others in the long run. This multiplicity in the connections implies that effects will flow through the whole system, and at the same time, there will be modifications during the process as a consequence of the auto-organization of the system.

Open Systems

Complex systems are open systems, where energy and information flow through the system and beyond its frontiers. For this reason, complex systems are generally evolving continuously but in states far away from equilibrium. As a consequence of the interactions of the system with the surrounding environment and the energy and information flows, the frontiers of the system are fuzzy and hard to delineate.

Limited Decomposibility

A complex system has a dynamic structure. Therefore, there is no sense in studying the properties of a system, splitting it into stable elements. The permanent interaction among the elements of the system, and with the environment, induces the system to restructure itself and generate auto-organization properties. The parts of the system are unable to reproduce the whole system and cannot take it over.

Nonlinear Adaptive Relationships

Linear relationships among the elements of a system are rarely simple or linear. As a result, we are unsure about the effects that a slight alteration in the current conditions of the system may have. Additionally, feedbacks (the effects of an action in any element of the system may have on the element itself again and therefore its future behavior) may be present. These feedbacks can be either negative or positive. These nonlinear relationships can change as the system evolves, depending on the effects and the feedbacks, and consequently they are adaptive.

Long-term Dependence

The knowledge of the past evolution in complex system is very important. Recent alterations in a system, even slight, are very important, due to the sensitive dependence property. But changes that happened in the distant past continue having effects in the current state of the system due to nonlinearity adaptive relationships.

Absence of Determinism

It is not possible to forecast with certainty the future evolution of a system, even though we know the behavior of their elements and their relationships, due to all the properties stated above.

Complex Systems Connection

Complex systems are usually nestled in other complex systems. Hence, the elements of a complex system are, likewise, complex systems; these complex systems are components of other complex system as well, and so on.

The New Econometrics of Complexity

Econometrics can be defined as the discipline that, drawing upon models provided by economic theory, facts observed in the real world, and tools provided by statistical theory, focuses on the analysis of economic relationships by means of the elaboration of econometric models. These models are able to explain the underlying system and recognize the relationships among its variables, to predict its future evolution, or to analyze the implications of economic policies. When the economic reality is evaluated, it is necessary to realize that the category of behavior usually observed is seemingly disordered, erratic and even unpredictable. It is this kind of behavior that we are attempting to model.

There are two methods to model this behavior, either with models that are based on an extrinsic or exogenous explanation of complexity or with those that incorporate it in an intrinsic or endogenous way.

Models that are based on an extrinsic explanation (traditional or linear econometrics) are those whose endogenous dynamics, without external forces, are linear and simple. To produce complex behavior, it is necessary to introduce random external interferences (external variables to the model but with influence in it, such as meteorological variables, political events, and uncontrollable human factors).

Models that are based on an intrinsic explanation of the complexity (disequilibrium econometrics or non-linear econometrics) are based on hypotheses that lead to complex dynamics. The models' very dynamics (the endogenous dynamics) are what generate this type of behavior, which is observable in the real world. With these models, it is not necessary to use random perturbations to build a model with complex behavior.

In conclusion, on one hand, the importance of non-linearity and sensitive dependence on the initial conditions in the generation of a complex system is clearly manifest. Nowadays, it is hard to justify that the observed complexity in the real world must be the result of merely linear relationships and of random interferences that, in definitive, do not provide us information about the dynamic features of the system. On the other hand, it is necessary to admit the existence of random perturbations in the real world (for instance, the influence of the environment or economic policy, imperfect or asymmetric information, measurement errors). Hence, it is necessary to arrive at a synthesis of both points of view, emphasizing on one hand stochastic (and maybe chaotic) non-linear models and their wealth of behaviors (as a consequence of the property of sensitive dependence) and embracing, on the other hand, the possibility of measuring the uncertainty or complexity of the economic reality with new instruments.

So that there can be distinguished three different focuses inside the econometrics of complexity:

- The development of theoretical deterministic nonlinear models that produce dynamics qualitatively similar to that of the studied phenomenon. These models are not used for estimation and are considered "qualitative econometrics" (Day, 1993). Inside this focus we can point the analysis of the bifurcations and the complex characterization of the system using measures of quantification of complexity (in short, Lyapunov exponents, fractal dimension and entropy).
- The development and estimation of nonlinear stochastic models that seeks to explain economic reality and so to predict their future evolution. Tong (1990), Mandelbrot (1997) and Ruiz and Pérez (2001) are basic references on the topic. These models, apart from being nonlinear, are built upon some more relaxed hypotheses than standard linear econometric models. They are usually nonlinear Gaussian models that arise to deal with the complex features that economic time series present, such as the apparent non-stationarity of data, heavy tails, variability concentration, long-term dependence, or discontinuity among others. There is a great diversity of models within this trend evolving continuously, such as nonlinear auto-regressive models, threshold models, fractional auto-regressive models, auto-regressive with conditioned hetero-skedasticity models or multi-fractal models that deepen in the plethora of time series models but linked to the complexity theory approach.
- The development of tools to empirically characterize the time series from a complex point of view. In particular, Takens's Theorem (1980) looks for the reconstruction of unknown underlying dynamics that generated the series. Takens guarantees that this reconstructed system has the same dynamic properties of the unknown generating system. This way, we can use the reconstructed system to quantify the complexity of the original unknown system. Lastly, there have been developed some nonlinearity tests, including those of McLeod-Li, *et al.* (1983) and Engle (1982) to test nonlinearity in variance, that of Tsay (1986) to test nonlinearity in mean, that of Hinich (1982) to test third order nonlinearity, and BDS test (Brock, *et al.*, 1986) and Kaplan test (Kaplan, 1994, 1995) to contrast the general hypothesis of nonlinearity.

The Evolution of Business Management

When considering how a business should be organized and managed there is a direct relationship between paradigms or mental patterns and how these mental patterns should be applied. Therefore, it is logical to think that the organization of a company has traditionally been influenced and directed by a western way of thinking derived from Newtonian mechanics, which fosters the idea of prediction and control. This way of thinking takes into account three key assumptions:

1. Reality is objective (Positivism);
2. Cause and effect relationships and consequences are linear, and therefore the results are predictable (Determinism);
3. Knowledge is acquired through the senses: data collection and analysis (Reductionism)

Taking into account the success of this approach it is easy to understand why it is transposed into other fields of study, such as economics and business administration, which were developed during the eighteenth century. In fact, business companies that emerged with Industrialization were organized according to the above mentioned guidelines. The Machine Metaphor was used in the field of business administration: companies were seen as great machines and their workers regarded as pieces that could be directed, controlled or, merely, replaced. Relevance on prediction and control was also applied to traditional physics following the former three principles.

As a result of this traditional view of the world, companies were considered stable entities that functioned in a linear and predictable manner. This view was reinforced throughout the twentieth century with the efforts of Taylor, in the United States, and Favol, in France. Both considered of summon importance to apply predictability and control in a business company. Furthermore, the role of the administration manager was to observe, establish and understand the causal structure of the organization to, once determined the cause-and-effect relationship, keep it under control (Stacey, *et al.*, 2000). Under this perspective, the important concepts were locality, order and equilibrium -which contrasted with concepts of totality, chaos and disequilibrium.

In this first stage (Nieto de Alba, 1998, 1999), management assumes a closed organization, with a stable dynamic. The changes that the company confronts are predictable and, therefore, reactive management is in place: the process of adaptation to new changes operates *a priori*, from the past in order for the company to adapt itself to an already known future. This leads to a management that is characterized by its hierarchic and strongly centralized nature and by its aversion to take risks. As a consequence, this type of management generates restrictive limits among the different organizational levels and in the essential collaboration between them, creating conflicts. These are descending organizational values and the control is external.

The second stage corresponds to the Randomness Paradigm. This implies the existence of a certain degree of predictable uncertainty, which replaces, as we said above, the Principle of the Strong Causation for the Principle of Weak Causation. The existence of specific causal relationships is still assumed, although now it is in random terms. Hence, it is still feasible to determine and control these relationships by increasing the level of information. Management, in this stage, is anticipative, as it operates in the present to foresee the future. The growth of information makes necessary that hierarchy be replaced by horizontal nets. These nets come to manifest the importance of the group in order to achieve success. Success, then, is a direct consequence of the efforts of all the group members, as each individual success depends on the contribution from the rest of the members. Tasks, therefore, take precedence over ranks. The values emerge from the base to the top and give rise to self-control, rather than external control. It is from this phase that information and simple learning appear as fundamental concepts.

The last stage corresponds to the Complexity Paradigm. In sharp contrast with the previous stage, uncertainty stops being predictable. Cause and effect relationships can no longer be determined by increasing the information, due to the processes of positive feedback (sensitive dependence to initial conditions). In this stage organizations are systems that are characterized by the lack of equilibrium, non-linear relationships and emerging properties. They are also distinguished by their dynamic of limited instability. Management must be creative and innovative: the future is no longer anticipated, it is now created. Concepts such as order, stability and control lose importance against those of chaos, conflict, instability and dialogue, which become the starting point for creative strategies. This process favours spontaneous self-organization. Values can be both ascending or descending. Generative or complex learning becomes fundamental for management. Control alternates with normal management to supervise everyday work and strategic management through learning processes.

Implications of Complexity in Management

Due to the importance of prediction as a tool to determine cause and effect relationships and their consequences, management administration under the Simplification Paradigm was aimed to reduce uncertainty in order to increase control. Hence, fundamental values that governed the managerial mentality during that century were the following:

1. Planning;
2. Organization;
3. Leadership;
4. Coordination;
5. Control.

These traditional skills have been fundamental to the economic progress achieved throughout the twentieth century. However, in a complex and ever-changing world as the one we live in, this organizational abilities, although still useful, are becoming inadequate for present-day companies. Nowadays, our environment is not considered either stable or predictable. It is uncertain and ever-changing, and this makes the task of planning, organizing or managing a difficult one. If we transfer this to the company, managerial staff needs to accept that traditionally accepted skills are likely to become obsolete.

However, these basic facts of a Newtonian conception are questioned within the framework of Complex Science. The new vision of the world conceives it as a non-linear, subjective, unpredictable and self-organized dynamic system. If these characteristics are then transferred to the world of business management, they would explain the obsolescence of the before mentioned skills and would favour the new ones (Shelton & Darling, 2003):

1. Complex seeing;
2. Complex thinking;
3. Complex feeling;
4. Complex knowing;
5. Complex acting;
6. Complex trusting;
7. Complex being.

Complex Seeing

It is based on the premise that reality is inherently subjective. It is said that around 80% of the external perception works in function with the internal beliefs. In this way, individual experience depends to a great extent on one's own mental scheme. We are, then, confronted with a spiral situation where one's own beliefs influence on the perception of the world and, the perception of the world influences on these beliefs. If managerial directives are not conscious about this situation they run the risk of going into a repetitive cycle and they will continue to perceive reality as they always have, from their individual perceptions. The complex vision ability allows management to be more conscious about its own intentions – a behavior that could be seen to be more focused – so as to learn to know how to change them, modifying its own perception of the world and engaging in a learning process. It is

important that management takes into account all agents involved in the process so as to being able to offer different solutions from the ones that its own perception is likely to produce.

Complex Thinking

Sometimes the world functions in an apparently illogical and paradoxical manner. It is, therefore, important that management directives learns to think this way, a way that can be said to be a complex one. Many of the key matters in a company are paradoxical (e.g. increase quality vs. decrease costs) and, consequently, the decision making process should not be merely linear or logical but non-linear or complex. This way of thinking is related to the brain's right-hand side development – which is the side of the brain that could be described as the creative, where images govern over words and is not contoured by logic. It is important that people learn how to think in a creative way, to be in disagreement, since organizations need this creative energy generated by these differences in order to progress.

Complex Feeling

This skill is based on the premise that humans are made of the same energy than the rest of the universe, and that the heart is the prime source of energy for the mind, through electromagnetic signals. The power of these signals depends on emotions. Hence, positive emotions increase energy, while negative emotions reduce energy. Thus it is important that management directives are able to keep high levels of energy, focusing on positive aspects of each situation and, in summary, behave in a vital manner.

Complex Knowing

The need to acquire this skill comes from the premise that the universe emerges from an underlying energy field, a kind of cosmic data base. It is a matter of study the possibility of having access to this underlying information through processes based on intuition such as meditation. In this way, it is intended to arrive at a faster decision-making process in novel situations based on more personal confidence and better perception abilities.

Complex Acting

This skill is based on the acknowledgement of the whole. The entire universe is connected, it belongs to a complex entity in which each part influences and is influenced by the rest of the parts. Complex action is the ability to act in accordance with not only the benefit of the individual, but with the benefit of the wholeness. Leaders that follow this model of complex action will take decisions that can be regarded as responsible and ethical, being conscious of the fact that when they take a good decision this increases the probability that others would act in accordance with it, increasing the common welfare.

Complex Trusting

It is based on the principles of the Theory of Chaos and Complexity, which manifests the presence of chaos in the natural processes. Because of this reason, it is important that leaders trust in the natural processes and appreciate the need of the existence of chaos and complexity since systems that work under these premises are characterized by its self-organizing ability to increase their levels of coherence. These systems – which fluctuate in an unpredictable manner between chaos and order – are denominated chaordic systems (a term coined by Dee Hock, the designer of the VISA card). It is, thus, important that ideas about forecasting and control are abandoned in order to learn how to take advantage of the creative potential of chaos. In this way, flexibility increases in the organization as well as within individual behavior of the components.

Complex Being

This skill is related to the importance of the interactions within the nature of the universe. Complex being is the ability to be open to a process of continuous learning based on relationships, keeping in mind that all relationships represent an opportunity to learn. Anybody – and not always our favorite ones – could contribute towards this learning process. Furthermore, everything happens for a reason. Hence, it is important to have communication and comprehension within the company and in all directions – vertically as well as horizontally – in order to eliminate interdepartmental frontiers and confinement.

Complex Management

The evolution of scientific thinking – and of the very same business management – shows the need of a new approach that can make us think in non-linear, complex terms. The complex re-conceptualization of the universe gives way to a new way of contemplating, thinking, knowing, and being in the world and, therefore, in the company. The Paradigm of Complexity (Morin, 1995) provides a conceptual framework for complex thinking. And this complex thinking is purely another way of thinking that aims at not to complicate, but to open our minds to new concepts and to move towards understanding the complex. This implies knowing how to accept ambiguity, contradiction and lack of precision and, in summary, unpredictability.

According to Morin, there exist three fundamental characteristics in this complex thinking:

1. The dialogical principle, which allows the association of contradictory notions that form part of the same complex phenomenon;
2. The recursive principle, since the linear relationship between cause and effect is broken, with recursive relationships taking place between the two. It is the start point for self-organization;
3. The hologramic principle, that goes beyond reductionism – which is only centred on the parts – as well as the holism – which is only focused on the whole. It is based on assuming that not only the parts are in the whole, but that the whole is also in the parts.

This complex thinking is applicable to the organization so as to offer a different approach to existing relationships between individuals and the company. The dialogical principle allows the conjunction of individual and company relationships. The principle of recursiveness justifies individuals interacting and producing the company, at the same time that the company produces relationships between individuals. In regards to the hologramic principle, it is clear that the organization is present among its members through its norms and relations.

In conclusion and, as far as business management is concerned, it has been established throughout this exposition that this has to function within a limited instability dynamic – in what we can name "chaos frontier" – maintaining a high level of flexibility and learning that allows, instead of anticipating to, creating the future from the emerging properties of the company. To conclude, we comprise a summary of some of the most important characteristics of this new form of management – complex management – which are a direct consequence of the modification of the basic hypotheses that govern the idea of business management (Kiel, 1994; Nieto de Alba, 2000; Stacey, 1995):

1. In the environment of innovation, it is fundamental to assimilate new technologies and to invest in intangible contraptions. Success requires continuous creativity, and it is the company itself the one that needs to foment it though a creative destruction process. That is to say, it needs to generate uncertainty in a deliberate way to favour creativity and innovation. New models, techniques and prescriptions need to emerge for each situation, making use not only of quantitative but, also and fundamentally, qualitative experience.
2. In a dynamic organization it is fundamental to count with the ability of the directive staff to pose new scenarios and problems in an active and changing manner. To face these situations, it will be essential to set in place a complex learning process in real time, one that incorporates dialogue, questions points of view and modifies outlooks. Through this process people should discover and choose new perspectives, moving the process forward in a spontaneous and self-organized fashion.
3. Before putting in practice these proposals to undertake a problem, it is important that these are legitimized by the necessary support. This support should occur not out of a formal procedure, but rather through casual, spontaneous and self-organized relations.
4. The success that management might experience depends on the ability to combine common, everyday management – applying controls to the predictable and repetitive tasks – with complex, non-ordinary management. In this complex management, control must be understood as a general control, one that governs the restrictive conditions of the necessary uncertainty for self-organization and emergency. This uncertainty is of vital importance for new ideas and new projects to arise in the company. In fact, an excessive control might inhibit this great potential for progress. Hence, an excessively precise planning is not beneficial for the organization, as there are simply too many variables that can change and alter the plan.

5. Under this perspective there are no sharp differences between management and control. It is important that directives yield certain authority to their employees for them to control aspects of their daily responsibilities. In this way, the same employees will strengthen their ability to find creative solutions in order to face problems. This can be translated to the world of organizational design, which should be characterized by the existence of flexible structures of a fractal or informal nature that help to avoid authoritarianism and formal groups and that, in the contrary, help stimulating employees' polyvalence and the existence of self-governed groups. It is also important the existence of diverse elements that generate confronting opinions and produce the opportunity for dialogue and learning.
6. In the organizations that function within this limited instability and given the fact that it is impossible to forecast the long term future of the company – at least in quantitative terms – it is important the existence of a continual strategic way of thinking, based on the general qualitative models of the structure and the position the company maintains. In this way, we can identify and understand the problems that the company faces. There is, therefore, a strong need to move forward towards what we have called complex thinking, which is suitable to understand the qualitative nature of the interconnections.
7. Nowadays, society demands from companies the existence of certain ethical values. Hence, directives should favour client service skills, democratic and ecological values, as well as the continuous search for excellence.

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Section 4

Global and Ethical Implications

Chapter Twelve

COMPLEXITY, IDEOLOGY, AND GOVERNANCE

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Introduction

On one hand, modern societies have achieved an impressive level of organization and welfare with their great number of highly differentiated institutions and expertise. On the other hand, we live in a world of global inequity and unfairness as well as massive human impact on the environment, including pollution, the destruction of natural habitats and the excessive consumption of natural resources. Furthermore, even inside the apparently most successful countries, there are symptoms of distrust in the political system as well as in the expertise (DeMarchi & Ravetz, 1999), an extreme of which would be the issue of BSE (mad cow-disease) in the UK.

The point of departure of this paper is Ravetz's (1971) distinction between *practical problems*, defined in terms of ultimate purposes, such as human welfare, and *technical problems*, defined in terms of specifications, such as growth in the GNP. Clearly, modern societies are characterised by the belief in the strategy of reducing practical problems to a set of technical problems to be handled by the appropriate institutions and expertise. This belief, however, has been accused of implying a nonchalant attitude towards uncertainty and complexity (Funtowicz & Ravetz, 1993, 1994b). Indeed, it seems that the current popularity of the concept of *governance* within international governmental policy discourse reflects the desire to pay more attention to the broader perspective of the practical problems (Carlsson & Ramphal, 1995; Dahle, 1998), as natural and cultural complexity is seen to render certain strategies of modernity inadequate or even harmful because of unforeseen adverse effects (in particular of technological intervention). For instance, the Commission on Global Governance defined governance as "the sum of the many ways individuals and institutions, public and private, manage their common affairs. It is a continuing process through which conflicting or diverse interests may be accommodated and co- operative action may be taken. It includes formal institutions and regimes empowered to enforce compliance, as well as informal arrangements that people and institutions either have agreed to or perceive to be in their interest" (Carlsson & Ramphal, 1995).

Beliefs and discussions at this level of generality, i.e., the philosophical justification of our choice of societal organization, are profoundly inexact matters. Actual historical evidence as well as its digestion into theory in the historical and political sciences are of course highly important, but hardly sufficient to dictate the conclusions on, say, the design of sustainable governance. Our experience is too scarce; also, the questions are in part normative. On the other hand, to reject the discussion for being inexact is to run away from political choices that anyway have to be made. In conclusion, we cannot avoid that our decisions are informed by speculative beliefs about the general workings of the world (in my definition, ideology. Thus, contrary to some usages, it will not be assumed that ideology necessarily is false beliefs or false consciousness.) This is not to say that the decisions or beliefs may be made in isolation from scientific knowledge or subtle philosophical thinking. On the contrary, a striking characteristic of modern societies is the deep influence of science and academic philosophy upon ideology.

Of special interest to this chapter is to describe how the growing understanding of natural and cultural complexity affects and should affect our ideological basis for governance. This is no easy task because definitions, notions and understandings of "complexity" abound. Within some discourses and practices, complexity is a well-defined property, simulated in computers, managed by experts and sometimes even quantitatively measured. On the other extreme, there are discourses in which the word "complexity" would stand for the quality of neither allowing adequate scientific description nor technological control. The strategy of this chapter is not to search for one all-encompassing definition, but rather to see the different notions of complexity as different and individually important departures from notions of simplicity. Thus, I shall begin by explaining what I call *the Simple View*, a stereotype world-view of epistemological and metaphysical simplicity which is seen to support the belief in the reduction of practical problems to technical ones. I will then characterise various notions of complexity, and then, in final part of the chapter, outline possible implications for governance.

Simplicity, Thin Complexity and Thick Complexity

The Simple View

Most, if not all, usages of the word "complex" imply some contrast to "simple". Indeed, the belief that practical problems successfully may be reduced to a set of technical problems is already a claim of simplicity, in the sense that it is assumed that the practical problem only has a limited number of relevant aspects, that these may be sufficiently understood and controlled, and that the whole (practical problem) is "nothing more than the sum of the (technical) parts", so to speak. This kind of reductionism has deep roots in Western intellectual traditions, going back to Ancient Greece, through philosophical thinking related to and inspired by the scientific revolution in the 17th century and all the way up to our time. A comprehensive treatment of these traditions requires years of study; for our purpose it will suffice to sketch a stereotype of the world-view of simplicity that emerged from them. I call it *the Simple View.*

Imagine a person who believes firmly in the excellence of modernity, Enlightenment, natural science and in general Western traditions of (secular) thinking. We might picture him as being male; jokingly we may say this is a person who believes that there is a rational and objective answer to most questions, and that he knows quite a few of these answers himself. I suggest the following fiction to be a possible world-view of this person:

Objectivist and Mechanist-Materialist Metaphysics. The external world has an objective, man-independent existence and a structure that can be fully known by man and given a true (or approximately true) description in mathematical, logical and/or natural language by means of natural science. It consists of nothing but matter and energy in mechanistic action governed by natural law. Every entailment in the external world is really one of efficient causality; observations of others are epiphenomena. Furthermore, the entailment structure of the world is "consistent" in the sense that its true description in language will be logically consistent.

Simple Physics. The world forms a *system* of distinct and distinguishable parts, which can be exhaustively described by a limited set of state functions and physical laws. Furthermore, their behavior satisfies the Weak Law of Causality and most frequently also the Strong Law (that minor variations in the cause produces only minor variations in the effect).

Reductionism. Small parts may aggregate ("organize") into assemblies (molecules, organisms, ecosystems, minds, societies) that may exhibit patterns and regular behavior which in principle could be known, computed and understood in terms of the individual parts, but also sometimes can be understood and computed and in terms of logical and mathematical relationships emerging at the level of the assemblies ("emerging simplicity" allowing "top-down" approaches).

Simple Methodology. The external world is essentially a sparsely connected system that can be understood by investigating its proper parts and sub-systems in isolation ("cutting Nature at its seams"), and the sub-systems are generally close enough to equilibrium as to be understood by equilibrium considerations and perturbation techniques.

Simple Epistemology. Knowledge consists of representations of the external world, expressed in language in which the units of meaning are perfectly determinate and fixed. Good representations are those whose parts correspond with parts of the external world, and perfect correspondence is Truth. Production of knowledge is essentially a matter of neutral observation and description. This is also the case with experiments, in which observation follows the initial active phase of producing the desired material initial conditions. Hence, knowledge can be more or less useful, but since it always is just a matter of *saying how things are*, it cannot be the object of moral blame.

Simple Philosophical Anthropology. Several aspects and realms of the human condition are fundamentally independent form each other. Facts and values can be clearly distinguished, facts having an objective correlate in the world, while values do not. Next, man has the separate faculties of reason and passion. Factual knowledge is a matter of reason only, while values are a matter of both reason and passion: Passion for having them; reason for judging and acting rightly on them. However, the inborn passion for knowledge is good as knowledge per se cannot be bad. Furthermore, the human condition can be understood in terms of the individual human being, who has the capacity to know and act as a singular individual independently of his relationships to other subjects or objects.

Simple Reflexivity. Because the external world and the conditions for knowledge are simple in the explained sense, Man can know the truth about these conditions. In fact, the Simple View is the Truth.

I should stress that this description is a sketch of a stereotype and not a summary of any particular philosopher's position. In fact, the history of philosophy documents the immense difficulties and contradictions when working out the details of this world-view, such as the tension between rationalism and empiricism. We may even note a pragmatic inconsistency in the entire tradition of thinking that produced the Simple View, concluding with precepts of epistemological and methodological soberness while itself unfolding within a discourse of massive speculation. The celebrated example is the grand finale of David Hume's (1748) *Enquiry into Human Understanding*, in which he invites us to consider any book and ask: "Does it contain any abstract reasoning concerning quantity or number? No. Does it contain any experimental reasoning concerning matter of fact and existence? No. Commit it then to the flames: for it can contain nothing but sophistry and illusion," apparently being unaware that his own book would certainly not withstand these criteria.

The positive conclusion to be drawn is that there are ways out and away from the Simple View also from within its own philosophical tradition, and of course there are alternative philosophical traditions that more directly deal with complexity. A full review of these sources is impossible within the scope of this paper. Instead, I will briefly describe a handful of scientific, scholarly and philosophical developments that cast light upon and challenge the Simple View. We shall see that although all these developments in some sense add to our understanding of complexity, they cannot easily be integrated into a single concept or theory. However, I will try to show, in a possibly eclectic style, that quite a few of these insights may have implications for governance.

Thin Complexity

The present use of expressions such as "the sciences of complexity" generally refers to practices such as the study of self-organized critical behavior; cellular automata; agent-based modelling of all sorts; Artificial Life; and sometimes the study of chaos or fractal geometries. Clearly, these practices have produced some powerful insights into the limitations of the Simple View. Naïve belief in the Strong Law of Causality has been replaced by an understanding that many systems are sensitive towards change in initial conditions and more generally display dynamics unsuitable for description through equilibrium considerations or perturbation techniques.

Apart from this, however, not much of the Simple View has been challenged from within sciences of complexity. Individual researchers such as Robert Rosen (1991) have questioned aspects of the (above defined) simple physics and metaphysics, notably the idea that a limited set of state functions and laws of efficient causality can provide an exhaustive description of the external world. Such views are hardly mainstream within the field; rather, the internal discussion often takes reductionism for granted (in the sense that macro-phenomena emerge out of "nothing but" mechanistic interactions at the lowest level). Instead, it is argued about the methodological prospects of top-down modelling, i.e., the extent to which non-linear systems display emergent simplicity (Stewart & Cohen, 1994), or the general prospects of predictability and control of non-linear systems (Casti, 1990, 1997). Furthermore, as far as mainstream practices of "complex systems" are concerned, they definitely operate within a mechanist frame. In the case of agent-based models, for example, they are sometimes even unnecessarily mechanist and reductionist, with fixed, non-adaptive bottom-level rules of behavior (reviewed in Gross 2001). What emerges out of the sciences of complexity is thus little more than *thin complexity*, a notion of complexity which basically is compatible with the Simple View if the latter is revises some of its methodological prescriptions for science. Nature has seams, but they are finer, more intertwined and not in straight lines.

Quantum Mechanics

Decades before the advent of the sciences of complexity, quantum mechanics (QM) had already challenged aspects of the Simple View, since the metaphysics of the latter was more or less directly imported from the world-view of 17^{th} and 18^{th} century physics (classical mechanics). Thus, when the physics changed, the old philosophical theories came into trouble.

For an adequate presentation of this issues, the reader should consult the designated literature, for instance the philosophical writings of the Danish physicist Niels Bohr (1958, 1963). However, with the risk of oversimplification, we may say that QM as interpreted by Bohr (the so-called Copenhagen interpretation), challenges notions of simple correspondence between physical theory and an objective, observation-independent microscopic universe of elementary particles. In the words of Bohr, there "is no quantum universe": QM is not about the world as such, but what we can say about observations of it. The measurement design (and hence the observer) must be included in the physical description. Bohr even suggested a universal "principle of complementarity", i.e., that any phenomenon eludes complete description because any act of observation destroys prospects of information from certain other perspectives.

The debates on QM are perhaps not settled yet. What is clear, though, is that after the entry of QM, certain naïve beliefs about the nature of the universe and our knowledge of it cannot any longer claim to be a direct and obvious consequence of physical science. Indeed, our best physics seem to imply that the external world as well as its relationship to the knowing and observing subject *might be* anything but simple. Indeed, part of Bohr's effort has been to introduce a distinct notion of complexity: complementarity, or the presence of incompatible perspectives.

Intentionality and Values

Thin complexity is a property of a (mechanical) system, while the complexity suggested by QM in part resides in the relationship between system and observer. To understand the relationship between system and observer, or, almost equivalently, object and subject, matter and mind, and thing and idea, has been recognized as a difficult task ever since Plato (1996). The Simple View disregards the problem by assuming a sharp dualism which, however, makes thoughts and intentions have a double, unsettled status. Within the knowing subject, they play the primary role indeed, forming the space in which knowledge and claims of knowledge exist and arguments unfold. As properties of the external, studied world, however, they are epiphenomena that reflect cerebral, mechanical processes. The working hypothesis of academic institutions in the modern world has been that we may treat these two aspects in turn, letting the natural sciences explain non-intentional objects and processes, while the humanities deal with intentions.

This division of labour is to some extent defendable. For instance, the pioneer physiologist Claude Bernard (1865) believed that every human disease in principle could be explained in terms of a physiological imbalance, but warned against the "false application of physiology" (p. 199) in its present imperfect state. Thus, if Bernard had lived to see Thomas' and Thomas' theorem, he would probably not have denied it: "If men define situations as real, they are real in their consequences." (Thomas & Thomas, 1928). It is just that the cognitive act of defining the situation really can be explained as a complicated set of cerebral phenomena in the objectively existing world.

We will of course not live to see the completion of a full explanation of any such set of cerebral phenomena. Indeed, the successes of the natural sciences and the humanities have been due to their skilful choice (or construction) of "pure" objects of investigation. Whenever mind and body, subject and object, intentions and matter, and nature and culture mix more profoundly, such as in psychology and in the social sciences, research becomes incredibly more difficult.

The trouble is that most practical problems in the realm of governance do indeed involve such mixtures. This is in particular true of anthropogenic environmental problems. For instance, no comprehensive explanation of the isotopic composition of the atmosphere after 1950 can ignore the role of the highly cultural "balance of terror" in the production and detonation of hydrogen bombs. Indeed, a profound characteristic of our time is that the human impact upon nature is larger than ever, and that prediction by means of, say, biological knowledge, has become more conditional to the underlying assumptions of human behavior. Applying Thomas' and Thomas' theorem, human intentions and values have become very real to the entire biosphere. Thus, Funtowicz and Ravetz proposed to distinguish between ordinary complex systems, displaying thin complexity, and *emergent complex systems*, in which intentionality, bounded as well as unbounded, exists as an objective feature (Funtowicz & Ravetz, 1994a).

One can see many attempts to cope with emergent complexity, either by combining methods from the natural and social sciences (environmental sociology; ecological economics etc) or developing entirely new methodologies, such as the so-called post-normal science (Funtowicz & Ravetz, 1993) and actor-network theory. The latter is interesting in this respect since it tries to overcome the short-coming of dualism by insisting upon analytical symmetry between intentional and non-intentional "actants". In this way, Bruno Latour and others have studied the relationship between the intellectual separation between the natural and cultural domains and the simultaneous progressively stronger intertwining between them by means of technology, forming "hybrids" in the words of Latour (1988, 1993, 1998). Needless to say, however, an analytical framework that does not distinguish between intentional and non-intentional entities is not without its own problems.

Contextuality and Reflexivity

I shall now briefly reflect upon the role of science in the creation of emergent complexity in modern society. First, a lot of scientific practice is heavily involved with the development of technology for the isolation, control, measurement and even production of natural phenomena (Hacking, 1983). Now, technology cannot be de-invented afterwards, and as such is scientific research de facto an intervention in the world. Secondly, scientific investigation entails methodological choices of perspective: what is to be studied, by what methods, for what purpose? The (historical, philosophical and sociological) *science studies* of the latter decades have shown how such choices are neither trivial nor take place in a cultural or societal vacuum (see e.g., Longino & Keller, 1996; Pickering, 1992). Indeed, many theorists have called for attention to the complexity of scientific research. Already Bachelard (1946) saw how the world and our knowledge of it moves together by the construction of what he called *phenomenotechnique*; Polanyi (1964) described and Ravetz (1971) elaborated how craftsmanship and tacit quality judgements play an integral part in the process of transformation from a scientific finding to a fact. Pickering (1995) showed how the influences between the scientific and the extra-scientific domain go in both directions in an open-ended fashion. Thus, he insisted on the temporal and indeterministic character of history, including the history of science.

These insights depart from the Simple View into a notion of complexity with regard to the relationship between knowledge and action: Knowledge, however true or objective, cannot be thought of something entirely outside the realm of action. We have to choose what we want to know, imposing a context; and the research per se often irreversibly changes the world through its invention of technology; and the course of this development is not inevitable, but has a historical character. In

that case, the passion for knowledge cannot be excused from moral consideration. It is not even safe to distinguish sharply between facts and values, since the methodological set-up for the production of the fact could have made disguised value commitments. This ought to be clear from the debates on, say, the scientific studies of racial differences among humans.

These problems are difficult, and simple solutions invariably fail, such as the attempt of Stalin and Lysenko to replace Mendelian genetics with Lamarckism as a politically correct biology in the Soviet State, or the standpoint epistemologies of the Marxists and feminists of the 1968 generation. Indeed, in the academic disciplines that have been most sensitive to the aspect of contextuality, one has seen the growth of *reflexivity* as a methodological virtue, typically manifested in an introductory chapter where the author tries to discuss his or her own background as a possible source of bias and reason for distrust. Needless to say, the practice of reflexivity is still very infrequent in the natural sciences, although for example the British Medical Journal now requests that scientific authors declare their own vested interests.

Interdependence and Delocalization

Finally, the theoretical developments dubbed post-structuralism show aspects of complexity that depart from the semantics as well as the anthropology of the Simple View. Thus, from Derrida's writings we may learn how meanings of signs not only depend upon other signs and the structure of the entire language, but that this body also is subject of change through use. The meanings of words are never entirely fixed; and you cannot define yourself out of that situation without defining yourself out of the language community.

Other things than language may be understood in terms of interdependence and delocalization. Neural networks is one example (Cilliers, 1998). Taken home to philosophical anthropology, this type of perspective is not even necessarily controversial. Although Descartes could commit himself to prolonged meditations in which doubted if he was awake or dreamt (lending himself what has been called the persona of the idiot (Deleuze & Guattari, 1994)), this situation is rather atypical to the human condition, in which the anything but simple relationships to others (emotions, bonds, responsibilities, care) play a constitutive part. By common sense it seems that a substantial part of the agency of any human individual is delocalized in this sense. The effort of the post-structuralist move has been to show how this also may be the case for natural language. Thus, what is suggested is a notion of complexity that entails types of *interdependence and delocalization* that render analysis by parts a risky venture. We may use the analytical knife to obtain absolute distinctions between knowledge and action, facts and values, my will and the others, but this invariably happens at some cost.

Can There Be a Unifying Concept of Thick Complexity?

Above I have argued how the various elements of the Simple View are being called into question or even denied by cutting edge knowledge from a host of disciplines, ranging from physics to literary theory and philosophy. Taking the whole range of complexity notions, i.e., thin complexity, complementarity, emergent complexity (*sensu* Funtowicz and Ravetz), intertwining of nature and culture, contextuality and delocalization, could one not unify them into a definition of *thick complexity*?

One could, of course, but I doubt that the idea is of much sense. The list of this paper is by no means exhaustive. We could also have discussed other facets of complexity visible in other disciplines, such as biology or psychology; or in the philosophical characterization of the passage of time, as discussed in the works of Bergson, Heidegger and Serres; or indeed ordinary life-world experience. It seems that thick complexity would amount to the negation of the Simple View in its absolute form; we are then fairly close to just making noise, saying that there are no absolute truths or structures or principles. Thus, there may be a perfectly true *statement* that affirms the existence of thick complexity (in which case it is opened up for a sly discussion about self-referential problems) but perhaps no productive *concept*. What we are left with, then, are the different shades of grey from the Simple to the ungraspable, all with their potential utilities and disadvantages for governance, the evaluation of which in itself is a judgemental and contextual matter, but possibly also one of some systematic features. We shall turn to these now.

Governance of Practical Problems

Governance and the Simple View

If we imagine the Simple View to be true, governance becomes simple – it simply becomes the modern blend of representative democracy and technical expertise. The public expresses certain general value preferences by electing politicians who represent these values. The experts present objective information on the present state of affairs and delineate the technical means to achieve the desired values. Uncertainty in background information and in outcome of chosen policies can be expressed as quantitative risk and managed in a rational way by risk-cost-benefit-analysis. After the politicians have decided on the issues of value (and some meta-issues such as the level of risk aversion/risk acceptance), the required expertise may realize the technical plans.

Governance and Thin Complexity

Let us assume that our practical problem involves a system that displays thin complexity, i.e., richness in connections and non-linearity far from equilibrium. Prediction and control of the system are then sometimes possible, and at other times not. In particular, if there is unprecedented, large-scale human impact upon the system, transitions to hitherto unseen system behaviour may occur, rendering prediction and control a particularly difficult task, even if accurate information about the present state of the system is available (Gross & Strand, 2000). Rational governance under thin complexity accordingly requires a critical attitude towards the quantification of uncertainty in terms of risk (Wynne, 1992). In particular, in cases where the Strong Law of causality cannot be expected to hold for the predicted outcomes of the policy alternatives, the rational justification for risk-cost-benefit-analyses is no longer valid. The question then becomes: what is the rational strategy in the presence of thin complexity?

There are at least three answers to this question. The first is that we do not know yet, but that it might be good idea to consider some principle of precaution (The European Community, 1997). Another possibility is to retain the vision of governance of the Simple View and try to develop generalised forms of prediction and control. For instance, climate modellers know that the weather is chaotic, but work under the assumption that climate parameters are not. More generally, models of complex systems, notably agent-based or system dynamics models, are developed and sold as policy/management devices with the ambition to provide understanding and some kind of prediction or control of the qualitative dynamics of the modelled system. Belonging to the same category are the various attempts to provide "management on the edge of chaos", "chaos pilots" (see http://www.kaospilot.dk) etc.

The third option is to take thin complexity to have truly radical implications. I have described the Simple View as a list of separate of ideological components, but these are of course not independent. Indeed, the insight that the behavior of many systems eludes prediction beyond qualitative behavior does not only shake the foundations of risk-cost-benefit-analyses but also those of mainstream decision theory, the idea of the rational agent, most of academic economics and utilitarianist moral philosophy. One could argue that modernity's priority of reason over passion is justified only by the possibility of obtaining hard facts, of replacing ignorance and uncertainty with facts about risks and certainties. When hard facts in principle are unavailable, we are back at square one. Thus, there is a natural (though not unarguable) line of thought from reflections upon thin complexity to other aspects of complexity such as value-ladenness and contextuality, to be recognized in the writings of Stacey (2000), Funtowicz and Ravetz (1993, 1994a, 1997), Stengers (1997; Prigogine & Stengers, 1984) and others, leading us to the question of governance under thick complexity.

Governance and Thick Complexity 1: Conservative Visions

An initial observation is that we should not expect to find a unique, optimal theoretical solution to the problem of governance under thick complexity. The idea of unique and universal principles of guidance could be justified by the Simple View; without that ideology, we cannot a priori expect more than piece-meal, pragmatic and *imperfect* solutions, possibly with the exception of Stoic or Zen-inspired attempts to extinguish our desire for control or indeed governance of our own destiny. In more ordinary language: we cannot expect to succeed by thinking ourselves away from the fact that the world is a mess.

Technical Problems under Thick Complexity. A conservative vision of governance would be to adopt the vision of business management under thick complexity as expounded by Ralph Stacey, who clearly sees that the world-view of thin complexity has to be enriched with the understanding of complementarity and contextuality. Thus, for him, the implication faithful to complex systems theory is not the question "How can I govern the system into a new attractor (desired by me)?" but rather "What is my role in this system, and how does the action of me and others affect the system?" (Stacey, 2000). However, the frame of his discussion is essentially one of enterprise success, which remains as a *technical* problem insofar as the activity of the enterprise is defined. This is different from the typical governance situation, which is constituted not only by the substantive inclusion of the actors, but also the myriad of legitimate opinions on what counts as success and indeed what the issue really is.

Desperate Modernity: Pretending to Believe in the Simple View. A somewhat cruel interpretation of the political life of many countries is that the Simple View still apparently serves as the ideological justification for a number of institutions and practices, although the individual citizen, politician and expert to a large degree recognises the prevalence of complexity. How can a false view serve as a justification?

My clue for an explanation lies in the question of what it is not to feel like an idealist. Imagine that you confront a natural scientist working in an applied field with the uncertainties inherent to his practice. At first, he might utter something like the Simple View: We are heading for the Truth, we just need more data and better models, etc. However, when you remind him of the inherent irreducible uncertainties in his system, the contextuality of the methodology, etc, the defence typically changes: What else should we do? We do not know any other way. We know this is wrong, but there is no better alternative.

For me, this phenomenon (which I often encountered) seems to hit an essence of late modernity: The Simple View is retained exactly because of an awareness of complexity. In the political arena, many former radicals have turned into low-key voices, possibly because they saw how the great revolutions went: they did not have an awareness of complexity and went horribly wrong when things went contrary to the plan. Ravetz (2001) has dubbed this kind of phenomenon "safety paradoxes". We know that pesticides are unsafe; still, to stop them and upset the economy might be even more unsafe. We know that technical risk assessments cannot represent the uncertainties and complexity of the issues; but a general admittance of that fact might generate fear, instability and accordingly more danger. This is how the Simple View can be operative even if nobody believes in it: it is judged unsafe to stop pretending (Blasco & Strand, 2001).

The pretending game of Desperate Modernity is intellectually dishonest and hypocritical. However, under thick complexity probably every solution to the problem of governance will be imperfect as judged by some cognitive or moral standard, and so its real test will be if it is pragmatically acceptable. I can sometimes accept the ill-founded risk assessments made by my medical doctor if I believe them to provide part of an acceptable personal health care (see also Rortveit & Strand, 2001). Also, the use of technocratic forms of governance can be justified as a pragmatic way out of political conflicts and stalemates (Porter, 1995). Thus, under thick complexity, the criticism of Desperate Modernity will have to be based in experience of *harm and injustice* to living persons, future generations or other moral objects. More specifically, they will have to be based in harm and injustice for which strategies of Desperate Modernity can be blamed. This insight immediately shows why the discussions about government and governance are so difficult. Not only will there be a thousand voices with their conflictive expressions of harm and benefit. There will also be complex cognitive issues about the necessity of inflicted harm. For instance, some will see the Green Revolution as a technocratic disaster that ruined agricultural traditions and infrastructure and thus the long-term potential for food production and survival, while others consider it a great technological success that saved millions from hunger. And their prospects of arriving at a consensus are small: typically, they disagree about values, contexts and methodology for the evaluation of each other's claims. The present discussion about genetically modified plants experiences a similar stalemate of cognitive incommensurability (Strand, 2001).

The institutions of Modernity are not designed to tackle cognitive incommensurability. In fact, we here see two possible justifications for the abandonment of Desperate Modernity: (1) In substantive claims that the strategies of Desperate Modernity inflict unnecessary harm or injustice, for instance between rich and poor countries, or towards the natural environment, and (2) in the mere observation that Desperate Modernity leads to unsolvable struggles, incommensurability and distrust. I shall now leave the question about the strength of these justifications and instead characterise possible visions of governance they

may lead to.

Governance and Thick Complexity 2: Radical Visions

Not Rules, but Elements of Judgement. A central tenet of the Simple View was that the straightforwardness of the external world and our relation to it allowed that informal and subjective judgement could be replaced with the universal rules and principles of modern science and society. In the light of complexity, this tenet no longer holds. Instead, old and new old principles (as those below) will have to be decided upon *with* judgement and with respect to the practical problem at stake.

Quality and Lay Participation. Most visions of governance include new forms of direct, deliberative or participatory democracy, including ordinary citizens to a larger extent than in representative democracy. This can be seen as a method for increasing public trust in the institutions, but also as a way to improve the quality of decisions. For instance, in the governance of biotechnology, the particular level of emphasis upon an ecological perspective or one of molecular biology may be quite important (Strand, 2001) and hardly a purely "scientific" matter. Rather, it is a choice with normative aspects, and as such it belongs to the public domain. Thus, the *extension of the peer community* to include non-expert ("lay") participants has been proposed (Funtowicz & Ravetz, 1993). I have met a few academics who were horrified by this proposal, arguing that non-academics cannot be trusted to make the right decisions. I interpret the feeling of horror as a partial understanding of thick complexity; what remains to discover is that neither can academics be trusted to know, and that part of the issue at stake is the choice of criteria for what counts as proper knowledge and a right decision (and for whom).

Reflexivity: Creating Fewer Problems. Quite a few (if not all) of our present, large-scale practical problems are man-made in a strong sense: they are by-products of the rapid development of technological sophistication and the concurrent population growth. Some of these problems may have no "solution" other than learning how to live with them. For instance, many animal and plant species are already extinct or their natural habitats are all destroyed. An important aspect of governance thus is to impede the creation or escalation of practical problems.

Stories of the creation of problems display elements of thick complexity: unpredictability, open-endedness, novelty, and interpretative / value incommensurability. For instance, the Earth is now a place in which intended rapid mass destruction of society and the biosphere can be achieved. For the sake of argument, let us take this as an example of a development towards being *worse off* (bracketing the possible but controversial benefits of civil nuclear power). It seems reasonable to expect that there may be more instances of nuclear warfare in the long run, with massive damage and tragedy. Indeed, the luck of the 20th century appears to be the immense technical difficulties of making nuclear bombs in a world of terrorism. However, our concepts of (and institutions for) *guilt* or *blame*, which are historically and philosophically related to simple, linear notions of causality, appear largely irrelevant and powerless with respect to this unfortunate development *as such* (although they may be highly relevant to various acts, such as the bombing of Nagasaki). The scientific discoveries of Einstein, Bohr, Szilard and others "simply" increased our physical knowledge of the world. The development of the nuclear arms technology happened inside a tragic dynamic, and it was by no means obviously wrong by the US to initiate the Manhattan project on the suspicion of German (Nazi) efforts to do the same.

How can we impede the creation of new problems, such as new, powerful but cheap weapons (for instance bio-technological terrorism)? What institutions of governance need to be developed, and what insights or ideologies will they have to rest upon? I see three alternatives, none of which excludes the others. First, one may enforce and scale up the present strategies, i.e., legislation and legal action against "misuse" of technology. The problems with this are well-known. Above all, the inflicted harm can sometimes be so large that there can be no legal compensation for the tragedy.

Secondly, it seems that many stories of problems begin with discoveries of simple principles in the physical world that can be reified into powerful technologies. In the tradition of thought flowing from Francis Bacon (1620) it has been taken for granted that the limit utility of scientific discoveries always is positive; under thick complexity we know it may be otherwise (Strand & Schei, 2001). To develop knowledge allowing the construction of transgenic organisms should probably neither be judged immoral or illegal; nevertheless it leads into a trajectory which might be horribly unwise from the viewpoint of the ecological

complexity. We will have to give up the unconditional love for and trust in science, replacing it with a continuous distrust and doubt about the desirability of research efforts. In light of the above discussion on lay participation, we might say that scientific research projects are not justified *per se* as a production of *truth*, they should also be accepted by the public to have *quality*, or *social robustness* in the words of Nowotny, Scott & Gibbons (2001).

Thirdly, and more generally, reflexivity seems to be required as a continuous exercise all along processes of governance, since we now are aware of how easily the ultimate good slips out of sight or becomes perverted by terrible by-products of our interventions. This means that under thick complexity, we should make even more use of the highly modern virtue of criticism, encouraging and giving more attention to "trouble-makers". We may recall how Ivan Illich's (1975) famous question surprised the medical doctors: He knew about the progress of medical knowledge and technology, but are the patients getting any better?

New Taboos. The primary mode of action under conditions of simplicity is finding the efficient alternative and performing it. Under thick complexity, we know that quite a few of apparently rational actions are going to have tragic consequences. The rational strategy under such conditions is to search for qualitative principles rather than making calculations which anyway will be inadequate.

This kind of situation is not new at all. Indeed, in any sane person's development, he learns to set aside impulses of making personally rewarding acts for a variety of reasons. Moral and law do not exhaust this domain of cultural convention: there are rules of etiquette, habits, taboos and also cultural patterns of attention. For instance, in some cultures there apparently was much less attention towards finding ways to control Nature than what was the case in Europe.

Taboos might be useful devices for the cultural learning of complexity (Giner & Tàbara, 1999). Indeed, one might speculate if this was their origin in pre-historic past: That one somehow got an imprecise suspicion that it was unhealthy to eat certain foods, or that there were medical and/or social problems related to sexual relationships between brother and sister. Then, over time, some of these vague, precautionary conventions may have developed into rules of etiquette and finally into a matter of moral disgust. In fact, there seems to be some public disgust for, say, human cloning or nuclear power. Such emotions might play a legitimate and important role in governance (Hjörleifsson, *et al.*, 2005).

More Talk and Less Action. Everything that has been proposed here, in reality implies more talk about the practical problems and less action in the sense of technical intervention. Indeed, when aware of the complex relationships between meaning, language and the world, for instance in the unequal distribution of the powers of language, we will even have to talk about how we talk about things in processes of governance. The processes will be slower and less efficient. Also, even the efforts of intervention will be less efficient, since the exercises of reflexivity will lead to more doubt and possibly less devotion. Even the exercise of doubt itself will often feel idle since the future may be unpredictable anyway.

The insights of complexity suggest a transformation towards a society which collectively chooses hesitant and inefficient behavior, following passions to say "stop" even when there seems to be no explicit reasons for it, declining proposals of novel food technology even if that might have stopped the next famine in Sudan. It is no easy way.

I do not know how the transformation to the governmental practices of thick complexity are to come about. Not only will their mere nature make them "uncompetitive" from the perspective of the endorsed values in present political discourse. It may even be that, say, the environmental catastrophe really cannot be stopped without rapid and massive development of novel technology, implemented in a technocratic and unprecautionary manner. In that case, I think we are doomed.

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Chapter Thirteen

GLOBALIZATION AND THE COMPLEXITY OF HUMAN DIGNITY

Ken Cole

Introduction

Is "complexity theory" – the investigation of dynamic, interactive systems of interconnected but relatively independent components – applicable to an understanding of the process of international economic integration – globalization?

Investors are ever more able to move funds around the world market in search of the highest economic return, with scant regard for national borders, or local needs. A complex, global, social order is emergent, as nation states are integrated into the international economy (see, Robinson, 1996, 2004; Cammack, 2005), in spite of local social priorities being subordinated to global economic exigencies. This order is dynamic and unpredictable, though not chaotic; "patterns" or relationships are emergent, although there is no apparent trend towards something that might be called "equilibrium": complexity is a process which changes with people's evolving, creative potentials.

How is such complexity to be understood?

In the 1990s a 'science of complexity' emerged, addressing the "... ancient idea that within life and the cosmos there might be fundamental ordering processes..." (Albrecht, 2000: 409).

"*...complexity ... refers to systems with many different parts which, by a rathermysterious process of self-organization, become ... ordered ... 'ordered complexity'...*" (Cowan, 1994: 1-2)

Complex systems evolve. They exist at a number of levels, or scales, which interact and change, so that it is impossible to describe these changes in terms of particular rules, nor is it possible to reduce understanding to one level of explanation. What is peculiar about complex systems is that within these changes *patterns* emerge and order is restored: "ordered complexity". And more than this, the patterns by which order is maintained *themselves* change.

Within this evolving ordered complexity there is a "*...spontaneous* emergence of new structures and new forms of behavior..." (Capra, 1996: 85, emphasis added) creating order in open systems out of apparent chaos.

Historically, complexity theory grew out of the natural sciences – physics, chemistry and biology – and really came into its own in the 1970s, when sophisticated computing hardware and software became relatively cheap, and developments in nonlinear mathematics allowed scientists to develop complex mathematical models of evolving, interconnected systems of independent components. And although there are still limits to the explanatory power of mathematical equations, there is a research agenda oriented towards making mathematical explanations of complex systems more generally relevant and accessible.

The science of complexity defines...

"*...both the extent to which phenomenological descriptions of apparently real world systems actually resemble one another in fundamental ways and the extent to which our metaphors and abstract concepts of such systems ... resemble one another*" (Cowan, 1994: 3-4).

Social processes have been conceived of as complex systems, in which people interact through language, symbols, cultures, communication mediums, production processes, etc., within social collectivities, which have evolved into a complex, integrated, global system. Complex systems are understood to maintain order, in spite of change, through *feedback mechanisms*. Which raises the question: in what sense is there a feedback mechanism between people and the international social order, which embodies individuals' choices on how to behave into a spontaneous, evolving, global order, which is ever more integrated and interdependent?

Humans are creative, social beings. *Progress* implies the enhancement of individuals' social potentials; and the concept of *development* addresses the social, institutional changes through which individuals' enhanced potentials might be realized. And complexity theory, to understand patterns of behavior which are created out of evolutionary social change, has to examine the feedback mechanism by which, individuals spontaneously organize themselves into dynamic social systems in order to progress and develop: to enhance and realize their social potentials. This research agenda must investigate the possibility of increasing understanding of emergent social orders through the mathematically modeling of complex individual/social interactions.

In complexity theory the world is modeled as a dynamic, non-linear mathematical system, with no simple relation between 'cause' and 'effect'; apparently insignificant causes may have major effects.

"*Conventional approaches to the analysis of the economy and of society must be altered fundamentally if we are to make progress in understanding how the world operates ... The behavior of the system as a whole can never be understood mechanistically adding together its component parts ... the economy and society are more than the sum of the individuals who inhabit it... In the living, constantly changing economic and social worlds, the connection between the size of an event and the magnitude of its effects is no longer routine and mechanical*" (Ormerod, 1998: x).

Models do not so much 'predict', as 'explain' and 'understand' (on scientific method, and analyses which "predict", "explain" and/or "understand", see Cole, 1999: Part 4).

What might be the social, cultural parameters to individual behavior which constitute the "feedback mechanism", establishing "patterns" of behavior – within which millions of individuals' choose how to behave, develop and progress?

The question for complexity theory is; how and why do people reconcile their individual (creative) ambitions to progress, to the customs and needs of a global social order? Is it a question of individuals', hedonistic choices creating patterns of social behavior? Alternatively, are individuals' preferences tempered by the social exigencies of human existence? Or is it a question of individuals organizing to overcome the constraints to people realizing their emerging social potentials?

Are people essentially, respectively, "independent of", "dependent on" or "interdependent within" society.

Independent Individuals

If individuals' potentials are understood to be essentially *independent* of society – people's characteristics are innate, biologically determined, a genetic endowment – then the analysis of an emergent social order has to focus on how millions of independent individuals' free choices, reflecting their particular, essentially genetically determined tastes and talents, are reconciled to each other within a social order.

Adam Smith described a complex mechanism for reconciling a multitude of individuals' independent choices: the 'invisible hand' of market forces. "Smith ... [observed] that economic growth had to be understood as a process involving increasingly *complex patterns* of specialization" (Rosenberg, 2000: 48, emphasis added). The dominant interpretation of the economics of Adam Smith is that, if people are assumed to be essentially "independent" beings, "endowed" with tastes and talents, then individuals' potentials (and choices) can only be fully realized through free-market exchange. Since the 1870s such an approach to reconciling individual choice and social order has followed parallel trajectories: neo-classical theory and Austrian theory (see: Cole, 1999: 35-9).

For neo-classical theorists, the ideal social environment in which independent individuals might realize their potentials (what neo-classical economists refer to as "maximizing utility") is the system of "perfect competition". In such a state, given individuals' biological endowments, there can be no increase in individuals enjoyment of utility (see: Cole, 1999: 37-43, 1995: Chapter 3). However neo-classical theory cannot account for or analyze activity *out of* equilibrium.

"*...mainstream [neo-classical] theory fails to explain how markets do in fact come to work. It explains in great detail the relationships that would prevail in markets that already work*" (Kirzner, 1997: 13, emphasis in original).

That individuals are independent and naturally competitive, and that as long as free-markets obtain their will be a trend towards "equilibrium" and the "maximization of utility" – the full realization of human potentials – is an assumption, an article of faith: a *belief* in human nature. "The markets advantage is that it allows things to evolve in a *very human way*, through free choices of millions of individuals" (*Economist* 11/9/99, emphasis added).

The belief that there is an inherent trend towards equilibrium, implies that there is no theory of complexity inherent within the neoclassical economic orthodoxy – no theory of the emergence of changing, complex, patterns of behavior by which social order is established through independent individuals choosing according to their unique subjective preferences.

However, for Austrian theorists markets do not necessarily tend to 'equilibrium', rather markets are processes through which individuals exchange information: individuals' become aware of each others' distinct preferences, as expressed through the market supply and demand for commodities.

"...[markets are] coordinative process[es] *during which* market participants become aware of mutually beneficial opportunities for trade..." (Kirzner, 1997: 67, emphasis added).

Since the analysis *assumes* the dynamic of social existence to be individuals' hedonistic expediency – people competing to realize their *own* potentials – problems of inequality can only be a consequence of limitations to individuals' free choices: or people are personally inadequate.

The solution? Freer, more competitive markets. Ontologically and epistemologically such an approach cannot even ask questions of *social* inequality: society is merely the sum of the individuals of which it is composed. An approach which is fundamentally politically conservative. As long as individuals live in an environment of free, competitive exchange, then the advantaged are privileged by dint of their hard work and talent and deserve to be wealthy. And if the economic environment is not fully (perfectly) competitive – and it never is – then the social and economic policy agenda should be oriented towards further liberalizing economic exchange and human existence. The social order is not a meaningful research question.

There is an implicit theory of complexity here: mapping out and identifying the mechanisms through which individuals' choices are coordinated within market mechanisms as information processes, as complex patterns of specialization emerge allowing individuals to fulfil as yet unrealized preferences. Development policy for emergent potentials must be directed towards facilitating the free flow of information between billions of independent consumers (see, Montgomery, 2000). Increasing complexity reflects the growing number of individuals independently choosing and competing to realize their unique potentials within global markets. A trend which can only, globally, increase individuals' welfare and the satisfaction of their emergent preferences, as people, as consumers, are able to access a greater pool of producers' talents; and people, as producers, can offer their particular talents to greater numbers of consumers.

This is reflected in the World Bank's endorsement of global economic integration.

"...*stimulating economic growth, making markets work better for the poor and building up their assets – is the key to reducing poverty [and realizing human potentials]* ... Future trade talks will require a forward-looking agenda for broader trade liberalization *[global free markets]*..." (World Bank, 2000: 1 and 5, emphasis in original)

Such a liberalizing agenda is to be implemented by institutions such as the World Trade Organization (WTO), the International Monetary Fund (IMF), the World Bank (WB), etc... controlling individuals' "natural", competitive economic activity within the social parameters of a legal system which mandates individuals to exchange freely. This is the social feedback mechanism which creates 'organized complexity'.

For instance, the Palestine Economic Policy Research Institute and the World Bank (Diwan & Shaban 1999), while acknowledging the constraint of Israeli occupation, the large refugee population, the difficulty of access to the world economy except through Israel, the separation of the West Bank for the Gaza Strip, the on-going process of institution building since 1993 Declaration of Principles on Interim Self-Government Arrangements sighed in Oslo (and following the 1989-91 *Intifada*), inadequate transport, electricity, telecommunications, water, sanitation, infrastructure, etc... – *all* of these constraints are considered in terms of how free market exchange is inhibited, which, for the World Bank explains Palestinian underdevelopment

The solution?

"...*a dynamic private sector ... [which after the] removal of regulatory constraints, theestablishing of supporting institutions and infrastructure, and reduced political uncertainty should ... allow the economy to grow. Once free of the legacy of high debts, inefficient public enterprise, and a revenue base too small to meet needed public expenditures, public policy can focus on creating a framework conducive to development. Direct foreign investment is likely to follow once profitable opportunities and a stable environment are established*" (Diwan & Shaban, 1999: 1 and

12).

Progress is a question of "getting the prices right", and development initiatives are intended to control individuals' competitive instincts within an appropriate social order.

Dependent Individuals

With regard to the reconciliation of individuals' choices and the maintenance of social order, rather than the analysis beginning with the activity of independent individuals (the micro level) – reductionism – we could just as coherently proceed from society and social order (the macro level) – holism. Individuals, in their nature, rather than being considered to be *independent of* society can equally be understood to be *dependent on* society.

Human beings exist within societies characterized by a division of labour – technical specialization. And individuals can only specialize in particular branches of production if there is a social system through which individuals can cooperate to their mutual advantage within extant technical parameters. Where the technical basis of production is primitive and undeveloped – production is necessarily based on individuals' particular talents and is small scale. In such a context, individuals are effectively "independent" and free markets can be an appropriate mechanism for achieving cooperation between producers and consumers. But with technical progress, increased efficiency, and rising standards of living, producers and productive systems become ever more sophisticated and technically dependent on each other: individuals are not independently "free to choose". People's potentials reflect their position within the (evolving) technical division of labour. Increasingly societies and economies have to be managed within the parameters of the technical division of labour, and free markets (addressing individuals' needs) become less relevant as a process of establishing cooperation within society.

Essentially individuals are socialized, and their potentials adapt to the needs of society. The basis of social existence is specialization within a technical division of labour, and social life has to be institutionally managed within these productive parameters: individuals are organized to cooperate within an institutionally based social structure.

"*If the economy is* truly complex *then individuals cannot rationally deal with every part of it ... People develop* institutions *to deal with the world*" (Colander, 2000: 33, emphasis added).

With the development and increasing efficiency of production the technical division of labour becomes ever more complex and individuals in their economic activity are ever more specialized. And the institutional feedback mechanism between individuals and society by which social order is emergent evolves and changes: "...a complex adaptive system acquires information about its environment ... [identifies] regularities in that information, condensing those regularities into a ... model, and ... [acts] in the real world on the basis of that schema [model]" (Gell-Mann, 1994: 17).

Social structures become differentiated and complex as individuals' mutual dependence deepens with technical change, and the institutional, structural management of social existence evolves: '...good economic policy is about '*Getting the Institutions Right*'" (Prasch, 2000: 222, emphasis added).

A technically integrated global economy needs international institutions in order to promote and organize co-operation between individuals as producers and reconcile their activity with individuals' choices as consumers. In particular there has to be an emphasis on "human" (social/cooperative) development as opposed to "economic" (individual/competitive) development. And if there is to be global economic co-operation to our mutual advantage, an emphasis on institutionally enforced universal human rights is paramount.

"*Human rights and human development share a common vision and a common purpose ... the mark of all civilizations is the respect they accord human dignity and freedom ... The concepts and tools of human development provide a systematic assessment of economic and* institutional *constraints to the realization of rights*" (UNDP, 2000: 1 and 2, emphasis added).

Human rights and human needs cannot be realized universally without purposeful international action to support the disadvantaged and the excluded, and offset growing global inequality.

International economic integration has to adapt to local needs: "The state has primary responsibility for ensuring that growth is pro-poor, pro-rights and sustainable..." (UNDP, 2000: 11). Corporations have to be held accountable: progress cannot be a consequence of global, competitive free-markets; individuals' potentials are *dependent* upon society and the global economy has to adapt to local needs (not vice-versa). The emphasis is on *localization* (not globalization). "The policies bringing about localization are ones which increase control of the economy by ... *nation states*. The result should be an increase in *community cohesion*..." (Hines, 2000: 5, emphasis added).

"...*new technology will lead to healthier lives, greater social freedoms, increased knowledge and more productive livelihoods ... Without* innovative public policy, *these technologies could become a source of exclusion [impoverishment], not a tool for progress*" (UNDP, 2001: 1, emphasis added).

The analytical agenda for the science of complexity then, is to specify the linkages, or "path dependency", between an increasing number of institutions within complex civil society. Identifying the institutional path dependency in complex social systems becomes the basis for social and economic policy to establish an institutional management framework appropriate to an expanding technical division of labour, emphasizing, "...the role that norms and institutions play in moulding social economic relationships..." (Prasch, 2000: 223).

There is now no justification for inequality. Income is not a reward to individuals for exercising their unique talents in production. Wealth is socially produced and should be socially distributed through pluralist, social democratic political institutions which function in the common interest; a degree of fairness and equality is essential if a co-operative economic environment is to be fostered.

"Democratic pluralism melds the forces of the market, government and civil society to maintain a dynamic balance among the often competing societal needs for essential order and equity, the efficient production of goods and services, the accountability of power, the protection of human freedom and continuing institutional innovation" (Korten, 1995: 98).

Interdependent Individuals

In the analysis of an emergent, complex global order, and the specification of a feedback mechanism between the individual and society, creating "organized complexity" out of apparent chaos, the World Bank, believing that societies adapt to individuals' evolving preferences (which have to be controlled within competitive markets) understands progress to be consequent on national economies adapting to the exigencies of global markets: *globalization*.

However, the analyses of the United Nations Development Programme assumes that the technical/social parameters of human existence constrain individuals' choices so that people have to adapt to the needs of society. Individual choice has to be managed to facilitate social cooperation within the exigencies of a technical division of labour. Local, technically defined social needs are paramount: *localization*.

That we approach the interaction between individuals in society, partially, from either the *individual* (independent individuals) – reductionism - or *society* (dependent individuals) – holism – reflects assumptions about the nature of human existence: beliefs about what is understood to be the *dynamic* of social experience and human motivation. How individuals' choices are reconciled to each other within a changing, complex, social order. Such beliefs arbitrarily define and dogmatically assert the intellectual parameters of particular interpretations of social reality: assertions which (as noted) have an ideological and a political dimension (see Cole, 1999: Chapter 18). However, because human beings, as social animals, *only* exist in some form of society; and societies can *only* be conceived of as a product of individuals' activity, an analysis of organized, complex systems of social activity cannot simply begin from either the "individual" nor "society": people are *social individuals*.

"...*individual beings do not exist in isolation, but arise as a* consequence of social life, *yet the nature of that social life is a* consequence of our being human" (Rose, *et al.*, 1984: 11, emphasis added).

The relationship is dialectical: individuals' are neither "dependent on" nor "independent of" society: people are *interdependent within* society. Order and disorder are not alternatives but a contradictory relation: they are not mutually exclusive but aspects of an emerging *process* of experience: "...order and disorder are [not] dichotomous and opposites ... but rather stages in a process of dynamic and *transformational becoming*" (Byrne, 2001, emphasis added).

"*For dialectics the universe is unitary but always in change; the phenomena we can see at any instant are parts of processes, processes with histories and futures whose paths are not uniquely determined by their constituent units. Wholes are composed of units whose properties may be described, but the interaction of these units in the construction of the whole generates complexities that result in products qualitatively different from the component parts ... In a world in which such* complex *developmental interactions are always occurring, history becomes of paramount importance ... the past imposes contingencies on the present and the future*" (Rose, *et al.*, 1984: 11, emphasis added).

And the past, the present and the future and *social* pasts, present and futures. And social context are created by individuals who are intuitively and constantly, dialectically, reconciling their individual experience to the social context of human survival.

The dialectic, as analytical methodology, does not predict anything, proves nothing, and causes nothing to happen: the dialectic is a method for understanding complex patterns of relationships which evolve in an interdependent but unpredictable manner. People exist in society which provides an institutional basis for social order: organized complexity. This social order has to be compatible with the basis of human existence: how we economically survive – how we produce and exchange. In class based societies the social relations of production reflect who has power in society: who controls/owns the means of production. In capitalist society based upon private enterprise, social power lies with capitalists, workers having to sell their ability to work in the labour market like a commodity: indeed power is exercised, and privilege maintained through relations of commodity exchange (see Cole, 1999: Chapter 5).

With an evolving technical division of labour, people's social potentials develop and social interaction expands and changes. At times the extant social norms and structures which are beyond individuals' control, militate against people realizing their emerging potentials: for instance with technical change people's work may become repetitive and unfulfilling, or individuals may become unemployed or forced to take a wage cut, etc...

Such frustrations can either be destructive – people feeling inadequate and worthless, perhaps suffering depression or resorting to alcohol or drugs – or constructive – people being conscious of others who share their frustrations (and class interest), with whom they can organize and mobilize to change society and establish a qualitatively different complex social order.

For people to realize their evolving social potentials implies that individuals are able to participate in the organization and direction of their social existence. For society to evolve in a process reflecting people's changing ambitions, needs and abilities, that society must be based upon individuals' participation in the establishment of social order: organized complexity.

"*Globalization and localization unite at all* societal levels ... *[and] local activities accumulate to create chaotic but global outcomes ... there is no collective vision on how sustainability and democracy [organized complexity] can combine ... This will need a* special form of governance..." (O'Riordan & Church, 2001: 1 and 24, emphasis added).

The individual/social feedback mechanism, that creates "ordered complexity", the '...special form of governance...', is *democracy*. But democracy as a *process*, the institutional form of which evolves with the changing nature of individuals', complex social interdependence, and their resultant social potentials and needs. Of course, the extent to which participatory democracy progressively evolves between social individuals will in part be a reflection of people's awareness of their own *individual*, emergent potentials, and in part a product of an emerging *social* consciousness of the constraints, beyond their individual control, which frustrate the realization of people's creative, evolving, social potentials.

What people know and think is important: the *mind matters*.

The "mysterious process" through which evolving, complex social systems organize themselves is the *human instinct* to realize their evolving creative potentials.

"*The production of ideas ... of consciousness, is ... the natural intercourse of men, the language of real life ... the direct efflux of their material behavior ... Consciousness can never be anything else than conscious* *existence, and the existence of men is their* actual life process" (Marx & Engels, 1970: 47, emphasis added).

The process of global economic integration is characterized by a concentration and centralization of economic power, essentially within the boardrooms of Trans-National Corporations (TNCs). The interests of privately owned and controlled capital, and the profitability of production are paramount. Yet, the social, political regulation of economic activity, the basis of complex social cooperation between individuals, is still located at the level of the nation state.

"*At the economic level, the global logic of a world economy prevails, whereas, at the level of the political, a state-centered logic of the world-system prevails*" (Robinson, 2001: 162)

Within the emergent, integrated, world economy, national governments (and by implication citizens) are powerless to regulate the basis of human social existence: production and consumption. The complex integration of individuals' choices and social order is stymied. The result? A process of impoverishment as (international) economic power is socially (nationally) unaccountable. A process which is increasingly as much a part of human experience in developed market economies as in the marginalized developing world. In both worlds more and more people are sinking below the poverty line; are more insecure; suffer worsening educational provision and declining health services; are increasingly alienated from the political system which cannot address their emerging (local/global) needs, etc.. People are being denied the right to realize their creative social potentials; it is a question of *human dignity*.

Confronted by unaccountable, global economic power, individuals' futures are constrained by economic forces beyond their control. Their frustrations, their anger, the denial of their dignity, will only be relieved when this power is subject to democratic, social control. Such a process of participation cannot be achieved within existing political institutions, which historically evolved to address the political dimension of *national* economic organization. The feedback mechanism by which "ordered complexity" in a *globally* integrated economy might be restored has yet to evolve: "This will need a *special* form of governance" (O'Riordan & Church, 2001: 24, emphasis added, quoted above). Such a process is in train, and such institutions are emergent: around the world social movements, challenging and addressing local constraints to people realizing their potentials – homelessness, hunger, environmental degradation, discrimination, unemployment, inadequate public services, etc – are uniting people in a spirit of solidarity, justice and human dignity, against unaccountable global economic power.

The factor which unites these disparate social movements is people's frustration at being unable to protect themselves and control their futures and the social conditions for the fulfillment of their emergent potentials. It is a struggle for human dignity: a struggle which will crucially reflect how people interpret their social existence. How people understand the social context of their individual experience; how people might participate in the social control of human existence in a spirit of solidarity and (in an integrated world) of internationalism.

Increasingly, the belief in individuals' *independence* within anarchic market forces, or their *dependence* on social and political institutions which are incapable of protecting their livelihoods within a complex global order, are being supplanted by an awareness that people are globally *interdependent*, and that their futures will mutually, creatively evolve as a social process in which individuals themselves will participate in building their own social future (see, Moyo, 2005).

"*We are part of a movement ... that understands that an alternative is possible ... The system that oppresses us in one corner of the world ... is the same system wreaking its havoc elsewhere. We have realized that a fundamental change in society is required*" (Bircham & Charlton, 2001: 3)

It is not a question of *globalization*, or *localization*, but the *mobilization* of all those people that share an interest in challenging the unaccountable, unregulated economic power of TNCs and private capital. Human existence is being increasingly *socialized* by the process of global economic integration; and yet the dictates of the IMF, WTO and WB require people to interact through competitive markets, individualizing social existence. This contradictory human experience is prompting people to reflect on their lives and develop new understandings to make sense of this confusing reality. People are becoming aware and conscious that their *individual* creativity – their humanity – can only be enhanced (progress) and realized (develop) within a changed and emergent *global* social and political order.

Within the process of human social experience, an emergent understanding of the need for complex, participatory, global integration, respecting human creativity and human dignity, will lead towards a *process* of socialist development (on understanding such a process, see, Cole, 1999: Chapter 13; Cole, 1998: Chapters 4 and 7).

"*Socialism is ... a process of successive upheavals not only in the economy, politics and ideology but in consciousness and organized action. It is a process premised on unleashing the* power of the people, *who learn how to change themselves along with their circumstances. Revolutions within the revolution demand creativity and unity with respect to principles and organization and* growing *participation. In other words, they must become a gigantic school through which people learn to direct social processes.* Socialism is not constructed spontaneously, nor is it something that can be bestowed" (Heredia, 1993: 64, emphasis added).

Such a process is evolving with people's greater understanding of, and insights into, the social basis of their existence. And while this process is not, of itself, amenable to abstract, complex, mathematical modeling, the science of complexity can be useful in producing knowledge of the processes of human existence, and aspects of and potentials within the human environment which *are not* primarily a reflection of an individual's evolving, social potentials.

Until there is an international process of political and social change, which accommodates individuals' emerging social potentials to an integrated global economy, a process of *human dignity* – the realization of human potentials - social existence will be more or less conflictual, and the complex international social order will be maintained by more or less repression. And the crisis of the world economy and global "complex" society can only deepen.

While the intellectual debate on "ordered complexity" and "progress" is restricted to questions of *globalization* or *localization*, a debate which is unable to address the *qualitative* change in human potentials consequent upon deeper social interaction, a theoretical consideration and understanding of the appropriate social and political institutionalization of economic activity for progress is impossible.

The social feedback mechanism reconciling individuals' evolving social needs and potentials with social organization, is political participation in people's daily existence – people's '...actual life process...' (Marx & Engels 1970: 4, quoted above) – not the illusory participation of periodic voting in competitive elections between alternative political parties for political control of national parliaments: parliaments which are more or less impotent to foster development and progress by being unable to address the most important aspect of social well-being: the social means of production. Social control over the processes of production and exchange is the foundation of people being able to realize their emerging social potentials: it is the basis of progress and development. Evolving, qualitatively distinct forms of social and political organization, based on democratic, political participation, in a context which allows individuals', global, social potentials to be realized – potentials which are increasingly internationally defined – can be the only development strategy.

When progress – the enhancement of individuals' emerging social potentials – and development – the realization of these evolving potentials – implying deeper complexity, is stymied by anachronistic market institutions, which maintain and preserve extant vested interests, the disadvantaged have to organize themselves to effect progressive social change and to socially develop.

Progress is not a reflection of globalization or localization, but *mobilization*. And action to promote development and progress is not a question of controlling (independent) individuals competing within free markets; nor institutionally managing (dependent) individuals' co-operation within society; and not even constructing mathematical models by which complex social organization can be understood; but actively facilitating (interdependent) individuals' self-empowerment and organization to participate in their social organization to enhance their potentials and promote human dignity in their existence.

The creative process of building an emerging, global society, to reflect changing human potentials.

People will increasingly "act locally" but think "globally".

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Chapter Fourteen

THE CONSOLATIONS OF UNCERTAINTY: TIME, CHANGE, AND COMPLEXITY

Carl A. Rubino

It has become something of a commonplace, although one that remains insufficiently explored, to say that the longing for order, perfection, and certainty has deep roots in Western culture (Rubino, 2000, 1993). That yearning received its first and perhaps most evocative formulation in Homer's *Iliad.* Achilles, the poem's central and paradigmatic figure, chooses to sacrifice his short life in exchange for an immortal glory that is free from change and decline. Here, in Achilles' own words spoken at Troy, are the stark terms of the choice he must make:

My mother Thetis, a moving silver grace,
Tells me two fates sweep me on to my death.
If I stay here and fight, I'll never return home,
But my glory will be undying forever.
If I return home to my dear fatherland
My glory is lost but my life will be long,
And death that ends all will not catch me soon.

(*Iliad* 9.412-416 = Homer, 1997: 71)

Achilles also tells us that the kind of honor he wants will come from the god Zeus himself (*Iliad* 9.607-107 = Homer, 1997: 176). This is fitting, since the Homeric poems associate immortality and deathlessness with divinity: we humans are mortal, subject to death and age, while the gods, the immortals, live forever, and do not age. Achilles' choice therefore involves giving up his humanity in order to bequeath a sort of immutable heroic essence to posterity.

Some four hundred years after Homer, the longing for order, perfection, and certainty was given an explicit and definitive philosophical formulation by Plato, for whom our imperfect, mutable, and disorderly world is at best only a poor copy of an extraterrestrial world of perfectly ordered and immutable reality. It might be argued that Plato's rejection of our fallible and imperfect world stems from a agonizing disillusionment that struck him twice, first when he realized the corrosive failings of Athenian political life, and again when he saw his master Socrates, the best of the Athenians, condemned to death by his fellow citizens. Such a thing could not happen in a world given to truth and justice, and

thus for Plato the world of truth and justice – the only real world – lies elsewhere. That Platonic world is, as we know, a perfect world of immutable and timeless essences or forms.

The world envisioned by Plato's is also a world of perfect order, as he tells us in the *Timaeus*, a dialogue that is sometimes described as his treatise on physics:

"*God, therefore, wishing that all things should be good, and so far as possible nothing be imperfect, and finding the visible universe in a state not of rest but of inharmonious and disorderly motion, reduced it to order from disorder, as he judged that order was in every way better*" (*Timaeus* 30a = Plato, 1965: 42).

For Plato and his followers, the real world is a world of order and rest, not one of motion and disorder. And thus the world of truth and certainty is a world of timeless, immutable, ordered reality, a motionless universe bereft of spontaneity and unpredictability.

Plato's dream of a perfectly ordered world did not die with him or with the end of ancient Greek civilization. On the contrary, it survived into the scientific revolution and remains alive and well in our era. Here, for example, is Roger Hausheer's summary of Isaiah Berlin's ideas on the founders of the scientific revolution:

"*They sought all-embracing schemas, universal unifying frameworks, within which everything that exists could be shown to be systematically – i.e., logically and causally – interconnected, vast structures in which there should be no gaps left open for spontaneous, unattended developments, where everything that occurs should be, at least in principle, wholly explicable in terms of immutable general laws*" (Hausheer, 1980: xxvi.)

The dream of timeless order and certainty reached dizzying heights in 1814, with Laplace's vision of what to him would be the ultimate scientific intelligence. Laplace's demon, a being of supreme intelligence, would be able to comprehend the exact position at any time of every particle in the universe and of all the forces acting upon it. For such an intelligence, says Laplace, nothing would be uncertain, and both the future and the past would become the present (1902: 4). In our own time, Einstein, writing on the occasion of an old friend's death, says that for those "who believe in physics, this separation between past, present, and future is only an illusion, however tenacious" (1972: 539; translation in Bernstein, 1991: 165). The tireless work of Ilya Prigogine, however, has called our attention to the shortcomings of this view. If time is an illusion, change, novelty, and surprise are rendered impossible. If there is no difference between past, present, and future, everything is simply a given, a mere function of the present (Prigogine, 1984, 1987, 1997).

The notion that we can somehow conquer time, the bearer of corruption and death, promises us a measure of immortality – even of divinity. When Napoleon asked Laplace about God's place in his system, the great savant replied that he had no need for such a "hypothesis" (Koyré, 1957: 276). Nor did Einstein shrink from presuming to speak for God: witness his famous saying that "God does not play dice with the world" (Bernstein, 1973: 215-221). Remember, too, Leon Lederman's musings about the "God particle" (1993) and Steven Weinberg's speculations about a "final theory" (1992).

A universe of perfect and immutable order is one in which we can know and predict future events with certainty. Such a world is, of course, also a deterministic world in which everything happens with absolute regularity. The ancient Epicureans were among those who clearly sensed the shortcomings of such a world, and they called attention to the fundamental importance of indeterminacy and uncertainty. Lucretius, the Epicurean poet in whose work Michel Serres locates the birth of physics (1977), underlines the significance of the *clinamen*, the "swerve" that interrupts the regular motion of atoms at indeterminate times and places, thereby making our universe – the complex world in which we live – possible. Were it not for this swerve, Lucretius says, "everything would fall downwards like rain-drops through the abyss of space. No collision would take place and no impact of atom on atom would be created." Without the swerve, without this fundamental indeterminacy, he concludes, "*nature would never have created anything*" (*De rerum natura* 2.216-224 = Lucretius, 1951: 66; emphasis mine).

The world of Lucretius is a world of motion, not rest, and it is a world in which complexity and indeterminacy play a fundamental role (Prigogine & Stengers, 1984: 303-305). It is the *clinamen* that makes our universe possible. That universe is a universe marked by chance, spontaneity, and unpredictability – by chaos as well as order. Our world,

unlike the perfect universe envisioned by Plato, is not a world in which order is "in every way better." It is a world in which disorder plays an indispensable role and must not be banished.

Where Plato urges us to transcend our mortality and become like gods, Lucretius admonishes us to understand and respect the limitations of our mutable world. Imagining and attempting to become part of an immutable and perfectly ordered divine cosmos can only lead to failure, frustration, and despair – even, as Karl Popper has argued, to the intolerable socio-political consequence of totalitarianism (1945). Lucretius exhorts us to abandon the quest for certainty and immortality, settling instead for the unmistakable virtues of the human and mutable.

The world described by visionaries like Lucretius has often been called a world without hope, a nihilistic world bereft of values and human feeling. In Sartre's novel *Nausea*, for example, the protagonist, sickened by his existence, has a "vision" of his own while sitting on a park bench contemplating a chestnut tree. His vision evokes a profound sense of alienation, leading him to feel that everything in the park, including himself, is "in the way" of everything else. Being "in the way" is the only relationship he can establish between the trees, the gates, the stones, and everything else in the park. To exist, he concludes, is merely to be "in the way." (Sartre, 1964; 126-128).

Nightmarish visions like these, I would maintain, are but one more unpleasant consequence of imagining ourselves to be privileged, god-like beings who are somehow set apart from nature. We should instead follow the lead of Yeats, in a wonderfully lyrical poem published only ten years before the appearance of Sartre's novel:

> *O chestnut tree, great rooted blossomer,*
> *Are you the leaf, the blossom or the bole?*
> *O body swayed to music, O brightening glance,*
> *How can we know the dancer from the dance?*

(Yeats, 1983: 217)

We are embedded in nature, not set apart from it, playing the role of spectators – and this should be a cause for rejoicing, not of despair.

Consider, for example, the phenomenon of evolution. The occurrence of evolution compels us to admit the reality of time, change, spontaneity, and uncertainty. As Peirce argues, the laws of classical mechanics cannot account for the "inexhaustible multitudinous variety" produced by the evolution of species: "that variety," he says, "can spring only from spontaneity" (Peirce, 1935: 41). There is no way to reconcile the theory of evolution, which defines a universe of inexhaustible variety marked by spontaneous developments, in which time is always moving forward and the future remains open, with a world in which "everything is given," where there is no room for chance and spontaneity, where time is an illusion, and the future is implied in the present.

Another of Peirce's prophetic observations points in the direction of thermodynamics. "The dissipation of energy by the regular laws of nature," he writes, "is by these very laws accompanied by circumstances more and more favorable to its reconcentration by chance" (Peirce, 1986: 551). Prigogine's pioneering work on the behavior of non-linear systems far from equilibrium has confirmed the wisdom of Peirce's observation. Force, the driving principle of classical mechanics, is dissipative, while chance, an essential constituent of the thermodynamic process, is concentrative. Thus entropy, the measure of disorder in a system, now becomes a creative principle by which systems reorganize themselves to face the future.

Let me end with a reference to Stephen Jay Gould. In his book *Wonderful Life*, he presents a study of the Burgess Shale, a small limestone quarry in British Columbia that holds the remains of an enormous variety of life (Gould, 1989). The study of this extremely rich fossil site leads Gould to some striking conclusions about evolution, time, contingency, and unpredictability... Imagining the possibility of "replaying life's tape," he argues that the fauna of the Burgess Shale support the conclusion that "any replay of the tape would lead evolution down a pathway radically different from the road already taken" (Gould, 1989: 51). He subsequently offers the following observation about what the site has to tell us about our own history:

"*It also fills us with a new kind of amazement (also a* frisson *for the improbability of the event) at the fact that humans ever evolved at all. We came* this close *(put your thumb about a millimeter away from your index finger), thousands and thousands of times, to erasure by the veering of history down another sensible channel. Replay the tape a million times from a Burgess beginning, and I doubt that anything like* Homo sapiens *would ever evolve again. It is, indeed, a wonderful life*" (Gould, 1989: 289).

That last sentence, which some may find it surprising, deserves our careful consideration. Gould's consideration of contingency does not lead him to conclude, as Sartre's hero does, that we are merely "in the way." Taking his lead from the 1946 Frank Capra film to which his book's title refers, Gould is concerned to show that our existence does make a difference, that the story of life would not have been the the same without us. Gould does not find contingency nauseating or depressing. On the contrary, for him life in our diverse and unpredictable universe is full of wonder.

As Gould and Prigogine have shown us, then, the acceptance of our human condition – of mutability, disorder, and "the end of certainty" – should prompt not despair but an abiding confidence about the future and our place in it. We stand on the threshold, as Prigogine says, of "a period of multiple experimentation, of an increased awareness of both the incertitude and the great possibilities implied by our human condition" (Prigogine, 1980: 7).

Such are the consolations – and the hopes – born of uncertainty.

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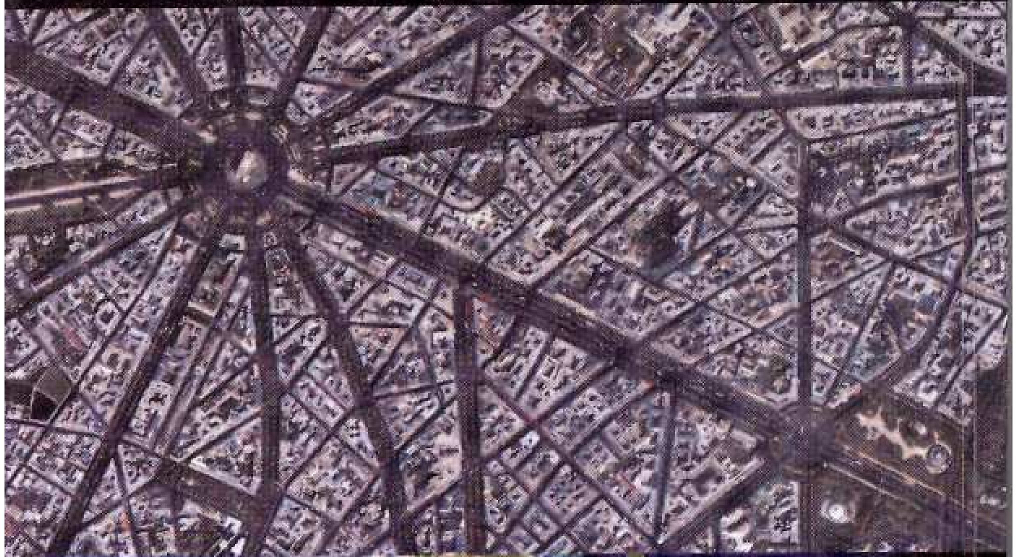

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