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EMERGENT COMPLEX SYSTEMS

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Complex systems are becoming the focus of important innovative research and application in many areas, reflecting the progressive displacement of classical physics and the emergence of a new and creative role for mathematics. This article makes a distinction between ordinary and emergent complexity and argues that a full analysis requires dialectical thinking. In so doing the authors aim to provide a philosophical foundation for post-normal science. The exploratory analysis developed here is complementary to those conducted with a more formal, mathematical approach, and begins to articulate what lies on the other side of that somewhat indistinct divide, the conceptual space called emergent complexity.

In response to the new leading problems for science, in which the traditional reductionist approach is patently inadequate, complex systems are becoming the focus of important innovative research and application in many areas.[1] This development reflects the progressive displacement of classical physics as the exemplar science of our time, and the emergence of a new and creative role for mathematics. Now, formalisms and computations are no longer taken to represent the core of immutable truth and certainty in a world of flux; but they are used with respect for the variability and uncertainty of the world of experience.

The distinction has already been made between simple and complex systems;[2] we find it useful to further refine 'complexity' into ordinary and emergent. These types are characterized by two different patterns of structure and relationships. In ordinary complexity, the most common pattern is a complementarity of competition and cooperation, with a diversity of elements and subsystems. By contrast, emergent complexity frequently oscillates between hegemony and fragmentation (which is a conflict among plural attempted hegemonies). This pattern is rare in ordinary complexity; and another characteristic of emergent complexity, the autolytic state of

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a system, is not found there. Thus the two polar-opposite patterns, diversity and hegemony, occur typically in ordinary and emergent complexity respectively. We posit that the former state is desirable; in ordinary complexity it occurs without intentionality; while in emergent complexity it requires a special commitment and awareness for its achievement and maintenance.

We show that a full analysis of emergent complexity requires dialectical thinking, with 'contradiction' as a key concept. In this way we can integrate apparently paradoxical concepts such as 'creative destruction'[3] into a general framework. We also use a mathematical metaphor, of a multidimensional phase space in which complex systems are embedded. This enables us further to illustrate the plurality of legitimate perspectives which are at the foundation of diversity. With these conceptual tools we can provide a philosophical foundation for 'post-normal science'.[4] By its means, we can resolve the contradiction between hegemonic reductionism and fragmented relativism, which characterizes the post-modern condition.

Ordinary and emergent complexity

In recent years the theory of 'systems' has been developed and enriched by a number of approaches in which dynamical properties have been grafted onto what was originally a rather static concept; among these is complexity, which is now seen as manifesting itself in many scientific contexts. These new systems ideas, developed in conjunction with new concepts of structure, growth, qualitative change and chaos have provided powerful tools of analysis, guiding practice in many fields. As the concepts have expanded in their application from the abstract fields of their origin to the study of phenomena in the biological and social worlds, the problems of their relation to external realities have needed to be addressed. The ascription of some degree of reality to any intellectual construct involves many factors, including culturally conditioned metaphysics, occupational or social group practice, and personal commitment. Thus we generally consider that some 'things' and 'causes' are good reflections of reality, while others are understood to be more artefactual. (For example, the concept of 'mass', as distinct from weight, has its roots in ordinary experience but has been articulated within the theoretical frameworks of Newtonian and Einsteinian dynamics.) In some cases, a difference in ontological commitment will relate closely to practice; this was the case with the concept of 'set' among mathematicians concerned with foundations. For ourselves, we do not need to invest 'system' with a strongly self-subsistent reality; it is enough that it is a powerful heuristic concept. Others may disagree; such arguments are never completely resolved, but in a dialectical fashion will evolve or decay in subsequent history.

Emergent complexity can be distinguished from other states that have been studied. The simplest state is that which can be described by the tools of classical mathematical physics; this has functioned as the standard for generations of natural and social scientists. More recently, 'complication' has been discovered, characterized by the non-linearity of its processes; beyond that lies ordinary complexity, which involves structure and self-organization (implying some teleology). Whereas complication has no teleology (although there can be unidirection, as in Fourier's theory of the dissipation of heat), ordinary complexity has a simple teleology. The boundaries between the classes are not distinct; thus the dissipative systems studied by Prigogine are at the lower end of complexity. We can contrast ordinary and emergent complex systems in terms of their patterns of stability and change. Keeping biological species in mind as examples, we can list some relevant properties of ordinarily complex systems. Much of their behaviour can be explained in terms of mechanisms enriched with a functional teleology, with simple systems goals such as growth and survival. The normal state for such systems is one of diversity of elements, coexisting in (what *we* see as) a complementarity of competition and cooperation. The ordinary complex systems tend to maintain a dynamic stability against perturbations until they are overwhelmed. This may be the result of direct assaults, such as by fire or aggressive invaders. (Of course, for some purposes it is useful to enlarge the boundaries of the system to include such occasional extreme events.) The new ideas of chaos and its edges enable simulations and analyses of processes of extraordinary articulation, variability and apparent design.[5]

Emergent complex systems, by contrast, cannot be fully explained mechanistically and functionally; in them, some at least of the elements of the system possess individuality, along with some degree of intentionality, consciousness, foresight, purpose, symbolic representations and morality. Attempts to reduce human society completely to ordinary complexity can result either in unrealistic theories (as those of B. F. Skinner) or catastrophic policies (as those of Pol Pot). Another difference between ordinary and emergent complexity relates to novelty. In ordinary complex systems, although numerical properties of subsystems (population size and density) can vary strongly, genuine novelty among the elements (a true *Origin of the Species* as opposed to the formation of varieties) is rare, and still not easy to explain in mechanistic systems terms. On the other hand, continuous novelty may be considered as a characteristic property of emergent complexity. This can appear in different degrees of development; thus we refer to 'traditional societies', where the emergent properties of the society (and its members) were not so fully developed as in our own. Among ourselves, the pace of novelty constantly increases in all spheres of life, including the symbolic realm and consciousness. The phenomenon of post-modernity reflects this flux; for its adherents, there is no stable interpersonal reality out there at all; everything is epiphenomenal to consciousness and fashion. (For a discussion of post-modernity in relation to science-based technology, see Funtowicz and Ravetz.[6])

We have mentioned that emergent complex systems can sometimes be studied and successfully managed as if they were ordinarily complex. Indeed, since we are natural as well as social beings, the emergent aspects of our social and technical systems will always be, as it were, the tip of an iceberg of which the greater part is ordinarily complex. We should also expect a significant border zone where the two types of criterion are present in varying degrees; these will tend to become foci of scientific and ideological debate, for they are crucial in the determination of our own identity. Thus the higher mammals, possessing some cognitive and social skills, tease our conception of humanity in various ways. Pets are friends, primates can reason, and cetaceans are said by some to re-educate us in feeling. Species apparently lower on the evolutionary scale, such as ants, can exhibit highly organized hegemonic behaviour that never ceases to fascinate and perhaps also to frighten. A completely different sort of system, based on computers, presents challenges along different lines. Artificial intelligence raises questions about our definition of 'rationality', and now virtual reality throws open questions of being and existence, personal and social. As the technology of cyberspace develops, we can imagine closer integration and symbiosis of humans and machines; and at that stage the border zone between ordinary and emergent complexity might well require re-examination.[7] It could be argued that in some respects there are no longer any cases of pure ordinarily complex systems. Any natural system that is of interest to us has properties that affect our welfare; and these will be salient for us. Our descriptions of systems and relations, like 'competition' (to say nothing of 'selfishness') structures our perceptions, concepts and research activities.

The *ancien régime* syndrome

In emergent complexity, technique is complementary to consciousness; by its means one species can influence all related systems for its hegemonic benefit. This factor may explain the phenomenon of large-scale and long-lived hegemonies within the human species. By hegemony we understand a systems-state where the goals of one element or subsystem are totally dominant, to the point where all others are either annihilated or survive on the margins. This state alternates (structurally and temporally) with fragmentation, which is a conflict among plural attempted hegemonies. The mixture of these polar opposite forms of relationship will depend strongly on the context; but (as we now see), the dangers of collapse of hegemonic societies into fragmentation are greater than we had previously imagined. In its way, modern intensive agriculture can be considered as a form of species hegemony; supported by ever more sophisticated technologies, it is obviously and increasingly unstable in its relations with its ecosystem context.

In the hegemonic state, the internal contradictions of the system are not resolved, but are suppressed. We can speak of an *ancien régime* syndrome, characterized by underperformance in key attributes, by prohibition of diversity, and by prevention of novelty. The regime refuses to deal with or recognize its problems even when they become obvious to everyone else. In traditional societies, there was a tendency to a cycle, analysed by ibn Khaldun, where after some generations a dynasty becomes totally corrupt and indifferent to the elementary requirements of governing. Instead of an adaptation to challenge and change (as in preventing or ameliorating techno-natural disasters such as floods or droughts), the system fails to respond. Then when there is a threat to the regime, there are no reserves of loyalty on which to call; a relatively minor external challenge can topple it. This may explain the unlikely sequence of events described in Franklin's aphorism, 'For want of a nail the shoe was lost', and so through horse, message, battle, war and empire; clearly a system with so little resilience against the uncertainties of battle and warfare was in the *ancien régime* syndrome.[8] More mundane examples of the same phenomenon in the political realm are the Chernobyl accident in the Soviet Union, and the earthquake in Managua, Nicaragua; in both cases, public confidence in the authorities was fatally weakened by the mismanagement of the event and its aftermath.

A similar phenomenon has been observed in the case of natural systems; thus the Krumholz spruce can produce stands of very old trees, with a high density of small trees and no understory, a sort of hegemonic 'biotic desert', which in spite of underperformance can persist for a long time, resisting collapse, until an external force or a broader-scale phenomenon finally destroys it. Such an *ancien régime* state might be imagined to occur in isolated ecosystems, as on islands; perhaps Australia could be counted as one. The vulnerability of emergent complex systems can be even more subtle. Thus, the collapse of the communist bloc precipitated radical changes in several other countries, which had no obvious links with it. But their political systems, some in an *ancien régime* state, had been buttressed ideologically by a response to a presumed Soviet threat. As that became officially recognized as non-existent, many different sorts of conservative or repressive policies lost their justification. Thus in South Africa, the release and rehabilitation of Nelson Mandela could be seen as a remote consequence of the fall of the Berlin Wall.

Emergent complex systems can also exhibit a more extreme version of the collapse of hegemony. This occurs even before the external threat is presented; the system simply grinds down and approaches paralysis in many of its functions. This happened in Czarist Russia, when the Bolsheviks only needed to capture the postal and telecommunications centre in the capital; by contrast, the Irish insurgents, who the previous year had captured the post office in Dublin, were speedily defeated and then hanged for their efforts. We can therefore speak of an 'autolytic' property, distinguishing emergent complex systems from those of ordinary complexity. This and the *ancien régime* syndrome can be seen to apply, not only to political systems, but to particular technologies, and indeed in some ways to our industrial culture as a whole. For this, E. M. Forster's prophetic short story *The Machine Stopped* might be considered as an example; it exhibits an *ancien régime* passing into its autolytic state.[9] This state can be fruitfully contrasted to the 'autopoiesis' which has been identified as characterizing genuine complex systems.[10]

The autopoietic state has been fruitfully analysed in system terms. The evocative metaphor of 'the revolt of the slaved variables' has been used to describe the concatenation of discontinuous changes upwards from lower (less inclusive) levels of organization to the higher, bringing about an 'anagenic moment'. It seems that anagenicity can take place through a general intensification of the *ancien régime* state, leading to 'rigidification' and paralysis. Alternatively, there can be increasing oscillation of the total system, approaching chaos, 'through a critical degree of synergetic entrainment of oscillations at a lower level'; instead of seizing up, the system shakes itself to bits. This phenomenon is most easily seen in the political and financial spheres. It manifests as a series of frantic and mutually contradictory attempts to restore a vanished stability.[11]

Contradiction

We have mentioned contradiction; and since it is a key concept for this analysis, we should provide some clarification. It expresses a very general heuristic, a way of looking at the world, which encompasses complexity, change and conflict as natural and essential. In one way it has affinities with Oriental philosophy, in which the Yang and the Yin are complementary aspects of all things and processes. But there are also connections with Western science; thus Newton's third law of motion, that for every action there is an equal and opposite reaction, is an expression of the presence of contradictory forces inherent in many systems.

Contradiction, as part of dialectics, emphasizes the coexistence of antagonistic forces, and provides a perspective which prevents oversimplified analyses of situations and problems. Within this style, one cannot envisage a beneficial progress without looking for its costs; the growth of knowledge without its interaction with ignorance; or the achievement of good without some production of evil. With that approach, we might have been spared the naiveté and subsequent disillusion about many of the social and environmental crusades of the past half-century, such as for the global eradication of hunger, disease and war. In current systems theory there are explanatory schemes which express the dynamic, contradictory aspects of ecosystems very well; thus Holling has a four-phase cycle of change which includes creative destruction as an essential part of the process of renewal.[12] When applied to emergent complex systems, such a concept is highly charged ethically. In one sense it is always with us, as in the free elections that periodically unsettle the careers of politicians and the structures of government; but if used to justify political change brought about by violence, creative destruction can be labelled 'extremist'. However, if a society is already in an *ancien régime* or especially an autolytic state, its creative destruction is less subject to simple ethical judgment.

For our purposes, we can consider contradictions as being of several sorts. One is of complementarity, where the opposed elements are kept in dynamic balance. Another is of destructive conflict, where the struggle results in the collapse of the system in which they coexist. Finally there is creative tension, in which the resolution is achieved by the qualitative transformation of the system—this is the well known Hegelian sense. In natural, ordinarily complex systems, the contradictions are found among competing subsystems or elements, typically members of species whose relations are more of competition than cooperation. In such systems, it is most common for the competing populations to oscillate between limits, none ever completely displacing any of the others. In those cases, the contradictions are of complementarity; for if (as in the standard models) the predators should eat all the prey, they would then starve! Thus the active and the passive subsystems are bound together; in a sense each needs the other in spite of the inequity (anthropomorphically viewed) of the situation. By contrast, in emergent complex ecosystems the contradictions can all too easily get out of hand and become simply destructive. Fisheries are a notable example, where the livelihood of fishermen and their communities from week to week depends on an exploitation of the resource that regularly leads to damage or even destruction of the stock of fish.[13] Managing such contradictions involves a complex adjustment of local, regional, national and transnational relations on the economic, political and sociocultural planes, as well as attempting to control a natural resource whose behaviour is imperfectly understood.

In technological systems, a design exercise can be understood as including the management of contradictions; for incompatible design specifications are produced by the various competing interests. The different prospective purchasers of (for example) an aircraft will have their special requirements in price, operating cost and performance characteristics of various sorts; and they will also contend with conflicting interests among the makers. A design synthesis can bring a creative solution to the problem, at the price of leaving some interests unsatisfied. But on occasion the design process fails; the competing demands cannot be reconciled, and designs and prototypes are simply scrapped; in our terms, the contradiction becomes a destructive conflict. The design process, as a management of contradictions, can also apply to an ongoing system. Then the design criteria can include the optimizing of internal peace (along with productivity) over other attributes such as flexibility or response to challenges. Interestingly, such a phenomenon can occasionally be seen among ordinary complex systems, as a feature of stable climax cultures. Their fragility against external assault can be analysed in terms of depleted stocks of available energy; and alternatively in design terms it can be interpreted as an optimization of the management of internal contradictions at the expense of defence.

This last example reminds us that systems, as we imagine them to encompass real natural and social phenomena, are strongly articulated internally, and have multiple relations externally. Thus an individual copy of a commercial aircraft is an element of a system of production and use of a particular aircraft design; this system overlaps with other systems realized in various organizations; it is also part of a broader system of air transport; and it is further involved with systems of employment, training, resource use, defence etc. In many respects such systems are ordinarily complex, particularly in cases where the actions of individuals are mainly significant in their aggregrate. Indeed, 'the market' (as idealized in economic theory) could be considered as an example of a most effective use of an ordinarily complex system to organize transactions among those emergent complex systems of desires and needs that are called individual people. However, since any successful market requires external regulations, as for the prevention of dishonest or criminal activities of various sorts, and in many cases also requires the establishment of trust between key actors, the impression of ordinary complexity is only partly true, and perhaps conceals more than it reveals. Also, the rapid replacement of central planning by market economies has in some contexts led not to the hoped for diversity, but only to increased fragmentation.

Dimensions of emergent complexity

In order better to understand emergent complexity, we may borrow a mathematical metaphor from chaos theory, that of a multidimensional phase space. The dimensions include those of the relevant mechanistic attributes (space, time, measurable properties), the ordinary-complex attributes of structure and function, and in addition those of the technical, economic, societal, personal and moral realms. These highest dimensions relate to knowledge and consciousness, and of course do not have the same type of metric relations as the lower dimensions. As Aristotle said, we cannot expect the same precision of reasoning in ethics as in geometry.[14] We may use the term 'topology' to indicate this difference: the lower dimensions have a 'harder' topology, permitting measurement and quantitative gauges along with (say) ordinal scales; while the higher dimensions have a 'softer' topology, in which the more qualitative properties are described.

In mathematics or physics, configurations of more dimensions are sometimes studied through their projections on subspaces of lower dimensions; thus, in a four-dimensional problem, it can be useful to look at the various three-dimensional mappings of the object. The analogue in our interpretation of systems theory is the use of mathematical relationships to describe biological or social realities. However, it is also known in mathematics that the partial views of fewer dimensions do not encompass the whole; thus, even three-dimensional manifolds have properties that cannot be conceived in one or two dimensions. Or the higher-dimensional properties may appear paradoxical or counterintuitive, as the well known Möbius strip, or Klein bottle. These examples remind us that 'dimensions', as deployed here, are qualitatively different from the levels of integration that are familiar in biology. For those are generally stratified by inclusiveness; thus the organism includes the cell etc; and the emergent properties apply to the more aggregated wholes. The phase-space dimensions overlap with those biological levels, but extend over more aspects of systems; and there is no need for a higher dimension (as in the realms of symbolism and consciousness) to include the lower. The awareness fostered by this metaphor makes it easier to avoid category errors in discussion of systems, either being anthropomorphic about lower dimensions or mechanistic about higher dimensions.[15]

A useful analogy here is with *Flatland*, the classic Victorian science-fiction and social parody.[16] There, the inhabitants of spaces with more dimensions had a richer awareness of themselves, and also could see beyond and through the consciousness of the simpler creatures inhabiting fewer dimensions. At this stage it is not unfair to reveal the denouement of the story, namely that the Sphere of three-dimensional space was just as limited in his consciousness as were the pointlanders and linelanders; for he felt existentially threatened by the attempted generalization of reality to dimensions beyond three. By the use of the metaphor of phase space, we hope to enable people of our own time to become aware and then transcend their own defensive limitations of imagination.

These examples remind us that no single perspective from within a subsystem of fewer dimensions can fully encompass the reality of the whole system. In the terms of our heuristic phase space, a mathematical model of an ecosystem, although legitimate in its own terms, cannot be sufficient for a complete analysis of its properties. At the other end, institutional and cultural representations of the same system, also legitimate, are similarly insufficient for specifying what should be done on the ground in any particular case. The various dimensions are not totally disjointed; thus the institutional perspective can be a basis for the study of the social relations of the scientific processes. To take any particular perception, or projection onto a subspace, as the true, real or total picture, amounts to reductionism. It is important to realize that this reductionism need not be 'downwards', as in the common assumption that environmental problems are purely a matter of engineering. There is also a radical *social* reductionism of scientific thought. This was applied, in the context of technological risks, to the attempted discrediting of US environmental organizations[17] (see comment in Funtowicz and Ravetz[18]). Also, some anthropologists of science have difficulties in finding a role for nature in the naked power struggle that they imagine science to be.[19]

Disasters and emergent complexity

The dialectical approach includes an analysis of any situation in terms of its characteristic contradictions; and we can do this to distinguish between ordinary and emergent complexity. When we contrast the two sorts of system, the impression we get from nature is that stability usually asserts itself, not always immediately but eventually. After a disaster, an ecosystem experiences fragmentation as pioneer species compete for resources; but eventually a more stable succession ensues. We do not see indefinite instability in such systems; even the catastrophes are part of a cycle. Conversely, the *ancien régime* syndrome is uncommon, and autolysis rare at best. By contrast, in emergent systems, either political or sociotechnical, gross pathologies on a lengthy timescale are common. It is not that cruelty and destruction are more common in human society than in nature, but that among us they frequently seem so pointless.

To explore the source of these marked differences, we consider two sorts of contradiction that occur in emergent complex systems. Perhaps the more fundamental is the conflict between the intentional individuals and the various structured aggregates in which they are embedded. The other is continuous novelty, which necessarily involves a concomitant destruction. The first contradiction appears in two opposed sorts of cases: the first where individuals are expected to endure harm, independently of their wishes, for the sake of a general good; and the second, where individuals are indifferent to the bad effects of the actions which they, as part of an aggregate, undertake. In technology policy, the first form appears in connection with risks, and the second with pollution. For industrial risks are by their nature unequally distributed, being focused on particular installations and their workforces and neighbouring residents. The rise of NIMBY ('not in my back yard') politics, frequently centring on 'wastes' (another contradictory concept), is a result of the rejection by the affected minority of risks that are imposed on them nominally on behalf of the majority. Conversely, pollution arises when individuals refuse to recognize the principle of Kant's 'categorical imperative'; since *my* car contributes only a negligible amount of extra pollutant to the environment, why should I make the great sacrifice of diminishing its use? The contradiction of continuous novelty and its attendant creative destruction can be responsible for the pathologies of governments: where a few individuals have much to lose by change, and the power to stave it off, there will be a temptation for them to engage in policies which are not merely damaging to the system as a whole but also eventually counterproductive to their class. But they can quite rationally be working for the 'long run', at the end of which they expect to be personally invulnerable. By means of such personal motivations, operating in their structural context, the *ancien régime* syndrome, autolysis and disasters can be explained.

Disasters are now a topic of great concern for practice and policy. It is now commonly understood that the distinction between 'natural' and 'man-made' disasters is obsolete; indeed all disasters are in some sense man-made[20] and even 'normal'.[21] Since disasters involve such great losses and suffering, it may seem inconceivable that society should in any way allow them to happen. Turner and Perrow explain that there is a tight connection between what we call the various dimensions of the system. The performance of the physical devices that constitute the operating and control subsystems, and even their state of maintenance, depends on the highest dimensions of the system, including management commitment and morale. It is no different in the case of disasters whose physical causation is more natural, as weather phenomena; in this case, the systems for containment, planning, warning, protection, amelioration and recovery are of the same emergent complex character as in the case of industrial disasters.

We can imagine any ongoing industrial process as, in one sense, an 'accident-generating system'.[22] The products of the activity are partly planned, but also partly unplanned; and the latter sort will include occasional accidents along with regular waste and pollution. 'Precursor incidents', though possibly harmful or damaging in themselves, are very useful as signals of the danger. In this sense they have a contradictory evaluation, being 'good' for the more inclusive system while being 'bad' for the subsystem directly involved; this contradiction complements that of the productive process in general, in which the output of 'bads' is inseparable from that of the 'goods'. Typically, an industrial disaster results from the concatenation of small malfunctions or errors, when the control systems fail to correct, inhibit or even detect their occurrence. Control systems are themselves emergently complex, involving a mixture of technical, human, economic, societal and legal elements. In this sense, an installation that is an 'accident waiting to happen' is a system in an *ancien régime* state; the disaster represents sudden autolysis. There is an analogous situation with 'natural' disasters, particularly those which affect the poorest of the world's people. For them, daily life is dominated by coping with small disasters; those which attract the ephemeral attention of the worldwide TV audiences are becoming 'normal'.[23]

The characteristic contradictions of disasters include others besides those of output and of the evaluation of precursor incidents. A positive practical value of disasters is their function in creating the political conditions enabling the changing of the political systems so that recurrences are finally prevented. However, this does not always work; although Seveso led to a new set of regulations for industrial hazard control, the Managua earthquake ended the Somoza regime, Bhopal and Mexico City were closely similar disasters (respectively) with no such positive societal effect. Here, as in systems in an autolytic state, the moral ambivalence of creative destruction cannot be escaped.

Finally, there is a combined epistemic-axiological contradiction in disasters, which usually makes them very frustrating as objects of analysis and public policy. Precisely because of the interpenetration of the different dimensions of the emergent complex system that is (in retrospect) the disaster waiting to happen, it can be difficult to assign responsibility or blame for the event. The normal structure of command and responsibility in an organization is not designed around the task of assignment of blame after a disaster; hence this will require the deployment of assumptions about common, normal or desirable practices. It is all too easy to blame the operatives for breaking safety rules, when 'everyone knows' that they could not get through their assigned tasks in any other way. What is now called an 'accident culture', which is implicitly defined by the example of management rather than by their words, will be a primary cause of those concatenations of physical events that led to disaster; and yet it is too ineffable to be the subject of legal proceedings. Hence it is only exceptionally that a satisfactory history of a disaster can be achieved.

Post-normal science

The introduction of the notion of emergent complexity enables the development of new conceptions of scientific practice, involving its epistemology, methodology and power relationships. Traditional science assumed nature to be simple, and capable of reductionist mathematical explanations, themselves based on observations by a detached observer. This epistemological naive realism was matched by a lack of awareness of its societal power relations, and by an arrogant hegemonism over all other ways of knowing. This complacency could not be sustained as science developed and changed through the 20th century. First, physics and the social sciences seemed to justify relativism, and later the growing self-awareness of science as a social activity further eroded the experiential basis of naive realism. Kuhn's notion of 'incommensurability' raised the spectre of fragmentation in science;[24] and subsequently the post-modern movement extended fragmentation to all of knowledge.[25] Although relativism (the principle that every view is as valid as any other) appears to be totally opposite to fragmentation (the conflict among attempted hegemonies), in practice the former becomes the latter with little delay.

The social and intellectual contexts of scientific work have been transformed by the new problems of risks, the environment and public suspicion of the works of science. There have been many attempts to achieve more sophisticated versions of reductionist science, employing a variety of mathematical techniques, ranging from games theory to Bayesian statistics and catastrophe theory, and including systems analysis at one stage. The recent growth in the appreciation of complex systems indicates a change in attitude and direction. For mathematics is becoming a means of insight and understanding rather than a portrayal of a timeless essence. This new attitude will enable a resolution of the fragmentation of knowledge that has resulted from the collapse of the hegemonism of the old reductionist conception of science. Appreciation of diversity, which is not at all the same as relativism, can lead to a new practice of science in emergent complex systems. This is what we call post-normal science.

Emergent complexity provides a theoretical justification for post-normal science, in which the peer group for quality assurance is expanded beyond the certified experts to include all those with a stake in the issue. This concept helps us to appreciate that there is no single perception providing a comprehensive or adequate vision of the whole issue, nor any particular criteria of quality that can hegemonically exclude all others. Casti has expressed the point of a plurality of legitimate alternative perspectives by equating degree of complexity with the number of non-equivalent descriptions of a system.[26] Atlan has made a similar point: '*plus un phénomène est complexe et singulier, plus toute théorie susceptible d'en rendre compte est sous-déterminée, donc incertaine*'.[27] In our heuristic phase space for emergent complexity, the analogous property of dimensionality is that no particular partial view can encompass the whole. It is therefore necessary and legitimate for the dialogue on such issues to include persons representing all different interests, which may also include concerns for children, non-human species and ethical values. This point reflects the growing practice in the resolution of global environmental issues, where earlier attempts to privilege one set of dimensions corresponding to a hegemonism of Western culture have proved inadequate at all levels, including the practical, economic, political and ethical.[28]

We can understand the challenge that is met by post-normal science in systems terms, by invoking the property of complex systems of flourishing 'at the edge of chaos'.[29] This has a strict mathematical meaning for simulated complex systems; in the case of emergent complexity, we can translate the tendency to chaos as fragmentation, and the tendency to organization as diversity. Post-normal science provides concepts whereby in debates on policy issues lying 'at the edge of chaos', the contradictions appearing as differences of perception and value, normally involving debate and even tendencies to conflict, can be contained and made the occasion for mutual learning and respect. Such a respect can survive even in deadly conflict, as it is familiar from such diverse contexts as mediaeval chivalry and the Japanese samurai. The task is to foster it in the ordinary business of the politics of decison making.

The phase-space metaphor for emergent complexity also provides a way of understanding uncertainty, including the sort that has hitherto not been amenable to a structural analysis. Many attempts have been made to quantify or formalize uncertainty for the purposes of decision making; but as the uncertainties become more remote from classical probabilities, the methodological difficulties in such programmes become more severe.[30] With the phase-space metaphor, we can appreciate irreducible uncertainty as a systemic property of emergent complexity. For any particular perception (or projection on a subspace) will be incapable of describing what goes on in the dimensions lying outside its scope. But there can be effects on the total system, including the subspaces under study, deriving from those ever-present 'hidden variables'. Should there be a change of perception to encompass them, then other subspaces will be lost to view, so that some irremediable uncertainty will always be present.

A simple example can illustrate the concept of emergent complexity. Let us imagine a group of people looking at a hillside.[31] Among the perceptions they might have are: just a hillside; a pleasant expanse of green; a case-study in geomorphology; an example of ecological succession; an archaeologically interesting site; an area of recreational potential; a prospective housing site; a centre for earth energies; and a launching point for departing souls. These perceptions overlap in some respects, but might also involve differences, or even conflicts, over values and realities. Some perspectives may claim to be 'true' or at least valid in some privileged way over all the others. Some of them are projections whereby *other* relevant perspectives are admitted only if they can be interpreted in their own terms. The classic scientific perspective, involving a reductionist quantification, attempted to legitimize itself in a logically closed way. It claimed to be both 'rational' and 'neutral', thereby claiming a privileged status, while denying that it was doing so. The reaction against scientific hegemonism has produced some of the contemporary tendencies towards scepticism and fragmentation, including post-modernism.

Post-normal science enables us to avert the nihilistic implications of post-modernism by observing that there really is a hillside there, even though no-one (including ourselves) can see it as a whole. The relations among the different perspectives, or projections, can vary widely. The participants may appreciate the complementarity among them; or they may have debate or even conflict over the issues that are reflected in the various perspectives and commitments of stakeholders. These alternatives may be seen as the polar opposites on a continuum: with complementarity we have diversity; and with attempted hegemony, fragmentation. Complementarity involves an awareness by each stakeholder that their own perception is partial, and (in terms of the phase-space metaphor) a projection of the whole configuration into their particular partial subspace. In the case of attempted hegemony, such an awareness of legitimacy of the other's perception (and with it, values and rights) is either discounted or (in the extreme case) denied altogether. This is fragmentation, after which life becomes, in Hobbes' description, nasty, brutish and short.

Emergent complexity, sustainability and ethics

In systems with emergent complexity, symbolic representations and ethical judgments interact through contradictions to produce some of the greatest achievements. Thus, contradictions in ethics lay at the basis of tragedy as an art form, and conceptual contradictions led to philosophy on the one hand, and to mathematics on the other. Thus human civilization, unlike an ordinary complex system, is constantly transforming itself, in a process involving loss and forgetting as well as conservation and change.

To what extent are such considerations relevant when we come to think about the general instabilities that threaten our planetary existence? First, it would be wrong to think of emergent complex systems, with all their refined pathos, as restricted to the realm of human culture, while the real business of life and survival can proceed at the level of ordinary complexity. For we are now realizing that the complexity of the ecosystem as a whole is not ordinary but emergent. Our actions, resulting from our lifestyles and visions of the good life, have created new natures that have transformed all existing ecosystems. Many of these (including agriculture and landscapes) have the paradoxical property of being 'unnatural', in that they did not and could not exist in our absence. There are no pristine habitats, any more than there are truly aboriginal peoples.

The phase-space metaphor enables us to distinguish between those parts of complex systems which are emergent, and those which are not. Thus a cornfield is devoted to a crop which is the product of human invention, and where even the individual plants need technology in order to grow and survive; but where natural processes, devoid of conscious intention, are the driving forces. On the other hand, in the system of private passenger transport, the dimensions of individual choice, socially constrained aggregated actions, systems of law and regulation, physical technologies, and resource and pollution problems, are all closely bound together. In this latter case, it is not so easy to sort out relatively independent subspaces lying in their own discrete dimensions.

The idea of contradiction becomes very powerful when we consider the total emergent complex system including humanity and the biosphere. The characteristic contradiction of this system is the incompatibility between the individual drive for material comfort, convenience and safety, and the ecological consequences of this being achieved even for a significant minority of humanity. This is a truly emergent system, for such drives in individuals are strongly conditioned by conceptions of the good life that are derived from a very special cultural milieu. Our own pollution is transforming the environment quite quickly enough, even without the help of those still 'developing'. But this produces the leading ideological contradiction of our special civilization, for it justifies itself on the humanitarian ideal of equality for all humankind. And this is quite impossible; just consider the ecological consequences of, say, 4 billion private automobiles and as many domestic air conditioners.

Both these contradictions could be considered as mere 'dilemmas', and masked by the title 'sustainable development'. For as yet only a few independent thinkers can imagine a 'development' that means anything other than the achievement of a consumer society; and that is unsustainable on ecological grounds. To encourage the world's poor to consider developing along less destructive lines than ourselves combines two further contradictions: one, the physical impossibility of an environmentally benign consumerist society; and the other, the sin of the rich preaching the virtues of poverty to the poor. The resolution of these contradictions will not be accomplished at the level of ordinary complexity alone. For that, we would need to imagine 'sustainability', which entails the characteristically human qualities, as being reduced to survival in the lower subspace of ordinarily complex systems. This latter concept of survival applies to fox-and-rabbit games, amoeba and artificial-life strings, through dynamic stability with no real novelty. In ordinary complexity, ethics is also mapped down, onto the single goal of group survival; and in the process, it loses it meaning.

The assumption that survival is the *only* thing that counts does not simply hold true, even in extreme situations like concentration camps. The characteristically human qualities reassert themselves even there, so that death is not the worst fate for communities or persons. The limited public response to the earlier 'doom-mongers' of the 1960s may have been due to a revulsion from their reduced vision. They gave the impression of not feeling the difference between the human race and a Petri dish culture; and their early proposals for the application of 'triage' to nations, abandoning some because of their feckless fecundity, came very close to blaming and punishing the victims of a situation for which 'our' share of the blame was commensurate with 'theirs'. In this way the logic of a mechanistic scientific worldview has taken it beyond ordinary morality (as had already occurred in connection with eugenics). It becomes no less counterintuitive than the vision of death and even disaster as symbolic exchanges with a meaningful nature, invoking higher dimensions of reality to which the common reaction would be like that of the Sphere of *Flatland*.[32]

Sustainability is therefore not a matter of mere survival; indeed a global strategy that focuses only on survival would be very likely to encounter crippling social and ideological contradictions and ultimately to fail. For emergent complexity requires something like solidarity to maintain its own sort of dynamic stability. This solidarity might, in extreme conditions, need to recognize that the continuation of an individual's life is not an absolute goal. But, in general, in the absence of solidarity, a society would degenerate, not into ordinary complexity, but into a horror. For this, history and fiction (such as *Lord of the Flies*) furnish us with examples.[33] The concept of 'coevolution' as developed by Richard Norgaard[34] offers the possibility of a synthesis with emergent complexity. Offering an enriched conception of sustainability, it provides a full articulation of themes that we have sketched in connection with post-normal science.

What we have called emergent complexity is a heuristic device for asserting and explicating, in the technical context of systems theory, what is human about humanity. In these terms, survival is a mere shadow of sustainability. There is such a thing as a life worth living, and also a life not worth living. The pursuit of a particular one-sided ideal of a life worth living, as if we were elements of an ordinarily complex system, has brought us to our present threatened state. The comforting simplicities of theoretical systems that assume ordinary complexity are achieved at a price: a denial of human reality, with all its contradictions, both the destructive and the creative.

Conclusion

The exploratory analysis developed here is complementary to those conducted with a more formal, mathematical or computational approach. In those, the properties of what we call ordinary complexity are being developed, and results of great importance and power are being derived. Our concern is to articulate what lies on the other side of that somewhat indistinct divide, the conceptual space we call emergent complexity. One possible use of this present discussion could be to inhibit any further sterile debates about whether machines, or computers, can be fully 'human' in some essential aspect. There is enough exciting and creative work to be done on ordinary complex systems, without needing to claim more for them than is justifiable or useful.

Our primary purpose is to begin the work of applying concepts, taken from other areas of philosophy, that will go into the construction of a systems theory that is appropriate, and provides explanatory power, for the specifically human aspects of human societies and human creations. In this way, there could be a fruitful interaction and synthesis between the enriched conceptions of science now being forged in studies of complexity, and a philosophical enquiry in which the perennial problems are recast in the light of the new realities that humanity is now creating.

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