Complex Systems

(Brief History, Main Communities and Open Questions)

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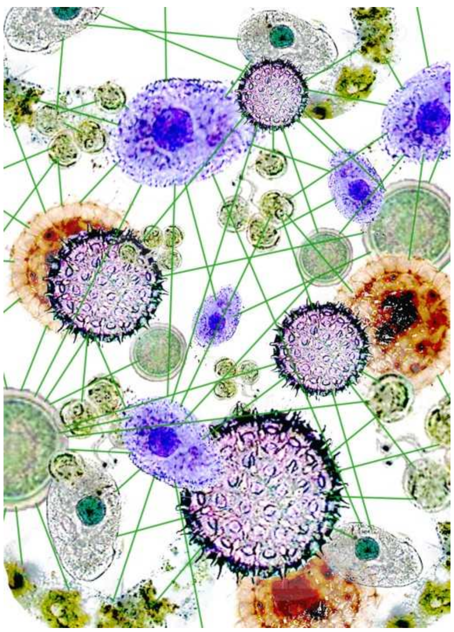

Brief History

As Science has begun to ask where the enduring features of nature come from and how they work, the answer seems to be "complex systems". Every kind of thing and event seems to require them. As the science has advanced, and as the modern problems of economies and environmental conflicts emerge, a new kind of science is emerging that requires being very openly exploratory, using all the tools and combining all the related perspectives of others, to develop complex knowledge systems matching the variety of the complex system problems they respond to.

Systems are storms or "like storms" in many respects, complex distributed phenomena that may be either unexpectedly eventful or highly predictable. There's still a rather wide range of opinion within science as to what complex systems are, even whether they are made of information or something physical that is beyond information, and how best to explain or investigate them. One reason for the range of opinion is that different branches of science developed systems thinking taking different paths, developing what seem to be three main and several minor branches. Like different "wise men" describing different parts of the same elephant they all tend to use conflicting 'paradigms' of explanation.

The more successful branches each built a different way to follow the success of classical [[physics]] as a model for describing nature with complex sets of equations following fixed rules. Those were principally the practical ecologists, economists, and the energy, information & control system physicists. Another group might be called the holistic system theorists, attracted the theoretical biologists, philosophers, designers, psychologists and teachers who saw the use of fixed rules inappropriate for a subject so full of subjects that appeared to learn and change on their own, and to not be deterministically well defined.

Theoretical [[ecology]] solidified in the 1920s significantly prompted by [[Lotka, Alfred_J|Alfred J. Lotka's]] representation of population dynamics in ecologies and selection in [[evolution]] as pressures of random motion using equations like for the physics of fluid flows{{ref|1}}. A generalized theory of complex holistic systems was proposed by [[Von Bertalanffy, Ludwig|Ludwig Von Bertalanffy]] in 1928 to become "General Systems Theory"{{ref|2}} {{ref|3}} in the 1940's in later conjunction with contributions from a group of generalists. The physics group of systems theories represents systems as models of information theory and control. "Cybernetics"{{ref|4}} was proposed by [[Wiener, Norbert|Norbert Wiener]] and was combined with information (control) theory using the physics of [[Quantum mechanics|Quantum Mechanics]] as a theoretical basis. Each of the above three broad approaches attempt to be an encompassing theory containing each other, but find that controlled systems are unable to be wholes and whole systems unable to be deterministic, and real environments inexplicable by either. As well as the natural tendency of different views of "the elephant" seeming to describe different things, one could see this as a case of the general systems principle that each problem definition calls for a different mode of explanation. That is to the difference might not be in the part of the subject being looked at, but in the question the observers are looking with. One of the main common features all seem to concern are complexly connecting loops of relationships, though generally the ecology group interprets them as material, the general systems group as conceptual, and the control theory group as a sets of definitions and rules.

Over time each community developed somewhat separately, but informing each other as each needed to be "interdisciplinary" in nature. Fragments of each tended to be taken up and reinterpreted for use in literally every other field of study, by individuals from those disciplines, and then developed in a way that fit those disciplines. In the 1970's and 80's a growing number of universities established independent departments or professorships of systems theory, but no unifying theory emerged and methods particular to individual disciplines rather than a truly inter-disciplinary field is what developed. So this seems to be why there is no common approach, though "[[systems theory]]" has now become a foundation for most modern scientific disciplines, our methods of education, learning, business, financial and environmental management, as well as the basis of social policy as human ecology. Its success in all these areas is real and valued, but also seems as reliably unpredictable as the subject matter, still as hard to predict as the [[weather]].

The basic Idea

The problem is that many things in nature now appear to have exceedingly complex design, and to take care of themselves rather than to be controlled by other things. Science started with great success using simple rules, that still seem valid where they work, but don't seem to help with the issues of life that most interest and concern us. Perhaps the best representation of the dilemma is the simple diagram used by Robert Rosen (Figure 1). Our minds are organized as a complex system according to principles that we don't understand that are observably different from the principles of organization in nature's equally complex systems. The diagram shows an "observing system" with its own set of internal loops of effects (feedbacks) and the observed system in the physical world with its own separate loops of effects of different kinds. So the challenge is to get the "implications" in the "formal system" (our thoughts) to correspond to the "causality" of the "natural systems" of our world.

The 'complexity' comes in when both are found to be 'networks' of communicating parts of various different kinds, often of different scale and requiring different modes of description to understand... That's complicated by observing that whenever such systems seem to be following a 'track' they then unexpectedly 'go off track' and just keep going, as if having never been following the track we thought they were on at first. Human cultural systems are a primary interest, of course, but have a combination of natural and artificial features. For example, the 'formal systems' of our thoughts can be considered to be of "intentional design", but get their meaning from the larger discourse of ideas within our schools and communities or thought and the general culture, and so are part of natural systems too that are of "unintentional design". What we find is that nothing can be done or built that is entirely artificial and preconceived, and always relies heavily on the unintentional natural systems we ourselves are built out of and that our plans then interact with.

The kind of network that composes natural systems can be represented by one of Albert-Laszlo Barabasi's diagrams of the connectivity of links on the internet (Figure 2). The ideas to build a new kind of communication were intentional, but which ones would take hold and how they would evolve were quite a surprise and can only be understood by discovery after the fact. The nature of the 'communication' relationships is often considered as an electrical circuit of 'governors' like complicated thermostats (Figure 3). Complex systems also consume resources and dissipate [[energy]] as part of a larger system ecology (Figure 4), accumulate layers of progressive redesign as they develop (figure 5) and tend to follow ordered histories of development and decay (Figure 6).

[[Image:RosenDiagram.jpg|thumb|310px|Fig 1. Rosen Observed System Diagram]]

[[Image:ALB-internet2s.jpg|thumb|310px|Fig 2. Barabasi Network Map]]

[[Image:ControlCircuit.jpg|thumb|310px|Fig 3. Control Diagram]]

[[Image:OdumFig.jpg|thumb|310px|Fig 4. Resource diagram]]

[[Image:LCurveDram_sold.jpg|thumb|310px|Fig 5. Technology Succession Curves]]

[[Image:PrHierarchyDD.jpg|thumb|310px|Fig 6. Development Phases]]

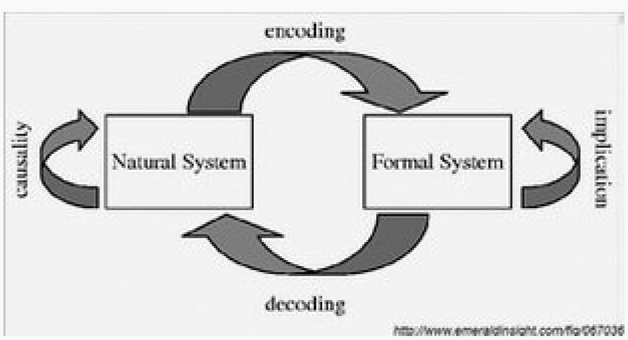

Fig 1. Rosen Observed System Diagram

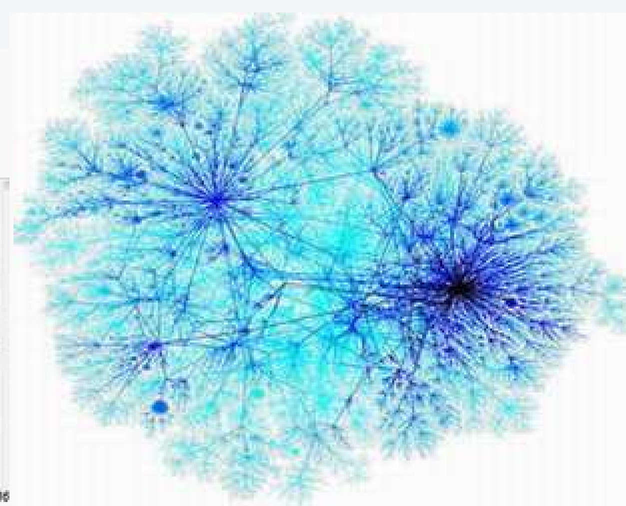

Fig 2. Barabasi Network Map

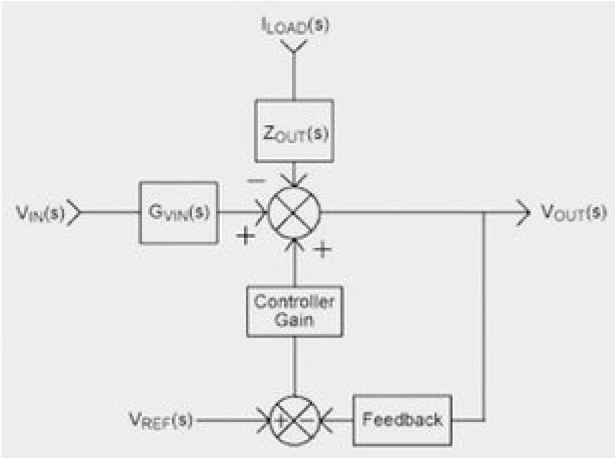

Fig 3. Control Diagram

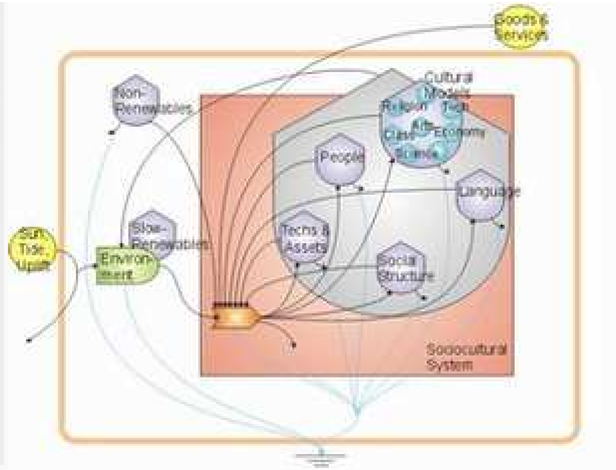

Fig 4. Resource diagram

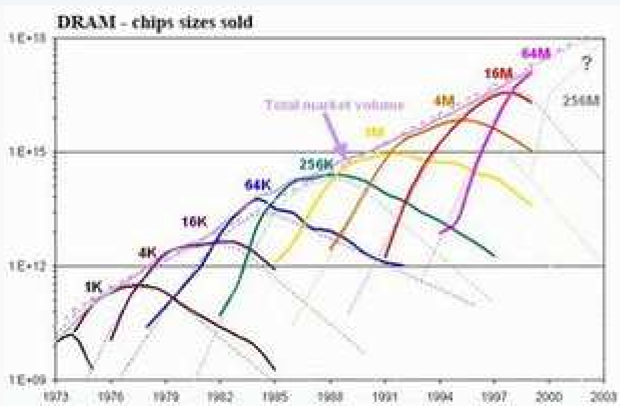

Fig 5. Technology Succession Curves

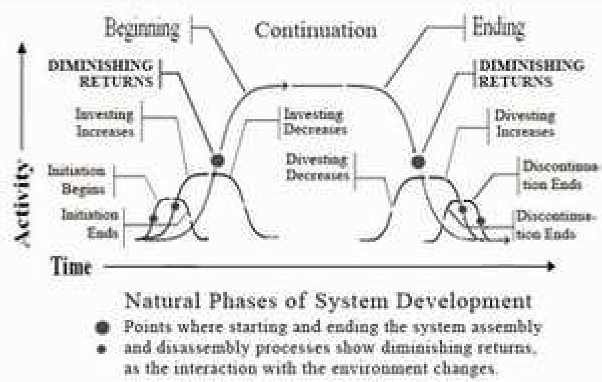

Fig 6. Development Phases

Modern Systems Theory

Complex systems theory is used very differently by different people. The main divide is between the theories that involve very large complex computer programs with sophisticated mathematical programs, theoretical systems, and direct work with natural complex systems in the natural sciences, business, environmental protection or community relations. Computers are themselves complex systems, but are completely defined by their programs. Computer programs designed to adapt to their real or artificial environments are the basis of robot and free agent models. Natural systems that arise directly from real environments are quite different. Real systems and environments have numerous overlapping connections to others, for which there are no representations, and the rules each follows appear to continually change. So there's a mismatch between the approaches to systems of defined and undefined complexity. Each type and approach involves different methods that tend not to inform each other. In a few cases, as with [[climate change]], the invariant rules of nature are enough, [[heat]] and [[fluid]] flow, that some very significant progress has been made in predicting current and future conditions from past conditions. The real system still behaves significantly differently from the models. That itself, of course, is very informative.

So, for most situations where people work directly with complex systems of their world they develop general experience with systems that they use as a mental model and compare it to what is actually happening to see how it is different from their experience. That gives them pointers to what local rules and changes are significant. The interesting thing is that this is precisely the general method a scientist uses doing fundamental research. A scientist starts by studying the world for how it does <u>not fit</u> the familiar pattern, to discover and then confirm a better way to see it. So, applied [[systems theory]] is revolutionary in this way. It's a study of naturally undocumented phenomena using tools for original scientific research that gives any observer with sufficient reason and patience a way to discover more about how their immediate world works. Partnerships between people and institutions with different views of social and environmental problems each couldn't solve alone build a common insight into common realities to find ways to address them cooperatively. They identify overlapping natural and social systems and discover how to connect the options. For businesses the challenge is for the organization as a whole to become effective in using everyone's insight and develop a rewarding culture of creative adaptation to change. That makes systems theory an evolving common language for a new kind of shared scientific research into the things of our world that most interest us, frequently using socially communicated learning tools.

Open Questions

The main open question is how complex systems can be so very unpredictable and still exist at all. There is no real theory for where most kinds of systems come from or why they would persist instead of deteriorate over time. There is a high level recognition that what is called 'punctuated equilibrium', 'revolutionary' , 'transformational' or 'emergent' change seems to be observed in every field and central to what systems are, both their quickly responsive and stubbornly immoveable complex designs. Few if any of the "hard systems" models of the natural and theoretical sciences that attract most of the effort are able to replicate the phenomenon. It's also not known what should be controlled to prevent disastrous economic collapses, for example, despite our centuries of painful experience with them and the clear visibility of every part involved. It's also not really known why equally creative systems like the [[weather]] and [[ecology|ecologies]] have persistently stable variety instead of tending toward unstable mono-cultures which erupt and collapse all the time, as might be expected. The usual 'atomistic' explanation that there must be some hidden explanation is usually the only one available still has to be relied on. Systems have so many scales and kinds of complex interconnecting parts and interlocking dynamic relationships it seems they could only work if designed from the inside, as if 'alive' in some sense. We also don't quite see anything that would cause them to be alive, though, even for the ones that really are alive.

We also don't yet understand their "eventfulness" in how simple phenomena like air currents or crystals emerge as physical changes of state, displaying "divergent" behavior ending in complex "emergent" new designs that often seem uniquely individual. We also don't see quite where the designs of systems are located, since they seem thoroughly connected to a whole world of other complexly changing things and so might possibly be boundless. We also have no form of representation adequate for recording the multi-featured changes that continually occur in complex systems, so that we not only can't predict them, but we can't even follow what they do accurately. Still, everything in life is dependent on them, and made "normal" by them, and the concept of systems resonates with the common observation that "things get connected" to become the dominant forces in our lives.

Major Fields

There are a great many fields and each have their own way of using [[systems theory]], as well as a diverse variety of theoretical communities and 'boutique' versions of system theory to use, sometimes designed around a single application or the leadership of a single individual. They all reflect that a 'system' is somewhat of a world onto itself, and they are all somewhat structured as views of such whole worlds, intended to be useful.

General theory: Somewhat "under the radar" because no central discipline of systems theory ever formed, are the networks of high level discussion on the theoretical underpinnings about how to think about systems. They occur on the internet and through many kinds of journals involving people in diverse, theory, planning, management, government and community action fields, all working on the basic problem, how do nature's lively designs, and the rules we sometimes see in them, work and change?

Developmental change: The observation that things are formed by how they develop is at once the oldest and most common approach to complex system theory and design. The study of local developmental processes goes back to the ancient origins of agriculture, business planning and military strategy, etc., but have been hard to understand scientifically because the complex parts of real complex systems hard to define. Scientists have always favored studying their substitutes for the real thing, using abstract rules and definitions. The canonical sequence of system development from beginning to ending, (germination, growth, continuation, decline and termination; fig 6) corresponds to the mass-specific energy flow sequence though systems {{ref|11}} and to the energy flow sequence for ecologies as studied by Odum, business development throughputs, and the history curves of developmental change generally. People who are experts in observing the sequences of development in their areas of interest use them as a guide. A simple example is measuring the weight of a newborn child as a diagnostic indicator of whether the newborn is thriving or tenuously clinging to life and in need of help. Business planners use indicators of their progress of their own development the same way, perhaps seeking fresh capital to intervene when the development a product is not reaching completion in time. That biological development, economic and business growth, the development of storms and fires, cultural and ecological shifts, etc. can all be studied from their patterns of development links a great many of the more scattered fields of systems theory and application.

Economic Theory: Economics{{ref|14}} is the oldest of the modern theories of environmental systems. It's most established form is as [[Neoclassical economic theory]], but is primarily a theory of money, and does not directly deal with physical systems generally, or the physical aspects of economic systems. Economic thinking more consistent with modern complex systems science in other fields is represented by the work of [[Georgescu-Roegen,_Nicholas|Nicholas Georgescu-Roegen, and [[Ecological_Economics_(collection)| Ecological economics]] . They focus on the relation of natural systems and their limits to economic decision making, but have not succeeded in being integrated with traditional economic theory because of the number of undefined relationships they deal with, and the traditional economists prefer not to.

Ecological Systems: [[Ecosystem|Ecosystem theory]] begins with considering all human and natural systems as processes using [[energy]] that, as systems, emerge interdependently within their own environments. Two of the modern scientists who contributed to making mathematical models applicable to environments were [[Odum, Howard T.|H.T. Odum]]{{ref|6}} and [[Holling, C.S.|C.S. Holling]] {{ref|5}}. Their methods are now used extensively in guiding global environmental science in understanding human impacts. One famous application of these kinds of models are those sponsored by the Club of Rome in studying the [[The Limits to Growth|Limits to Growth]] in the 1970's.

Mathematical Complexity: Early contributors to the pure [[physics]] theory of complex systems were [[Prigogine, Ilya|Ilya Prigogine]] for [[bifurcation]], [[Feigenbaum, Mitchell Jay|Mitchell Feigenbaum]] for [[chaos]], and [[Mandelbrot, Bernard|Bernard Mandelbrot]] for [[fractals]]. They work with dynamic equations for far from equilibrium relations, exhibiting bifurcating paths, chaotic attractors, fractal scales, often using non-linear dynamics, successive approximation and mathematical imitations of natural [[http://www.eoearth.org/article/Evolution|evolution]] as their guiding principle. One main goal is to create robots that can navigate real environments and computer models with "independent agents" that exhibit "artificial life". It's used for scenario building and to design "expert systems" that learn from their experience in complex environments such as oil fields and power utility management. It's used for designing adaptive software & controls for managing emergent network traffic patterns and to discover solutions to military as well as medical questions using exploratory methods for complex information environments.

The complex system modeling community has grown dramatically in scope and influence since the mid 1990s. There are various institutes around the world dedicated to advancing Complex Systems science to solve large-scale problems in healthcare, peacekeeping, military, systems engineering, and international development. Leading institutes include the New England Complex Systems institute, the Santa Fe Institute, the Center for the Study of Complex Systems at The University of Michigan, and the Center for Complex Systems and Brain Sciences at Florida Atlantic University are established places for scientists to pursue Complex Systems research.

Complex Physical Systems: Because of the high value of predicting the weather and some of the most successful complex systems research has been done on tracking hurricanes and predicting [[Future_climate_change:_Modeling_and_scenarios_for_the_Arctic|climate change]]. The universe also seems to be a complex system. The general evidence is that the scales of natural structures are not distributed normally, but follow a power law, or "Pareto" distribution{{ref|15}}. Network science has associated that with scale free networks{{ref|16}} and how they evolve, indicating that the distributions of scales developed by a complex accumulative growth process.

Network Science: Unlike the other mathematical complexity fields, network science studies the real geometry and topology of linkages in real emergent natural complex systems. It originated with studying communication patterns on the internet. Partly because of the great volume of easily obtained data showing how complex systems evolve dynamically that subject has been very fruitful for suggesting ideas for application to many other kinds of system networks. As discovered by [[Barabasi, Albert-Laszlo|Albert-Laszlo Barabasi]]{{ref|10}}, the connectivity of a natural network displays a "[[power law]]" statistical distribution that seems uniquely associated with the kinds of emergent systems we find so hard to explain. Networks seem to originate by growth, using diversification followed by selection, and that creates the power law distribution pattern. Some nodes of the system drop unneeded connections and others accumulate many more. It gives the network as a whole unusually high connectivity through central hubs at minimal cost. The approach allows pure mathematical physics to study the changing natural structures of complex systems in their natural context. Usually science has had a problem of having to dismantle living things to study them, or otherwise interfere in a way that distorts the data.

Systems learning and practice:

Management science{{ref|17}}

Scientists and practitioners have long studied how corporations work both internally and in relation to their environments, what makes a work group work, and the importance of community relations. The study of how groups of people and environmental systems work together arises partly from the socio-technical systems thinking of Eric Trist using the general systems theory of von Bertalanffy as a basis of systems sociology. One simple principle is that they all work like economies and ecologies, with each part connecting to others through what they do differently, providing each other complementary services. How such systems form, change and interact is an active field of study partly because of how economies are outgrowing the earth. Still, there is little consensus on whose choices affect what systems, either locally or globally, or why unintended conflicts arise, and many kinds of change seem quite opportunistic.

[[Ecological_Economics_(collection)| Ecological economics]]:

Systems learning is a key part of the theory and practice as in [[Collectively_seeing_complex_systems]] developing global partnerships between scientists the UN and international groups for ecological protection, bio-diversity, climate change and compatible economic development. Though progress is quite far from satisfactory from numerous points of view, such as resource depletion and financial instability, there is also an accumulation of solid methodology taking place.

Sustainability Partnerships:

A great variety of different agencies form associations of stakeholders with insights and capabilities for addressing either global or local complex cultural, economic and ecological systems problems. Government sponsored [[Environmental_management_systems|environmental management systems]] have developed global standards and various organizations develop [[Measuring_sustainable_economic_growth_and_development|sustainability standards]]. Responding to needs of socio-economic systems, though, is different for every part, and so the scientific understanding of local issues or interest is typically low, and most of the problems appear to come from unexpected consequences of our own solutions. “Social entrepreneurship”, various local and regional “sustainability partnerships”, “action learning” and the “sustainable design” approaches of the design and environmental professions are quite active. Each uses one or another model for how to steer various uncontrolled natural and social systems which are the problem. Partly because this also includes the learning process of the communities of problem solvers themselves, the efforts also amount to new approach to the classic subject-object problem{{ref|18}}.

The first task after identifying a problem that one group can’t solve by itself, is to start building a network of stakeholder who could. Such groups need regular funding and a regular learning process for people having different perspectives on a common problem to work together. The study of the problem is to first identify the boundaries of the systems involved. System boundaries may be “circles of accumulation”, “zones of influence”, “markets & mediums of connection”, “history curves” for their changes or other features. How the stakeholders can form a system with each other, designed to match the features of the natural system opportunities they find, is then studied for possible intervention. For example, corporate goodwill is critical to business health and involves community stewardship, working with diverse professional advisors, organized interest groups and government, perhaps.

[[Post-Normal_Science|Post Normal Science]] (PNS) represents this change-in-kind for the use of science in critical decision-making for the change-in-kind being found in public policy environments. PNS characterizes a developing practice for engaging complex knowledge communities, public and private authorities in responding to complexly interacting socio-physical systems and environments. It's related to the practices of [[Ecological_Economics_(collection)| Ecological economics]] for environmental intervention using applied complex systems theory, from the policy perspective.

At its core is the recognition that science needs to provide policy opinions even when uncertainties and consequences are great with scientific inputs having become "soft" in the context of the "hard" choices. Then uncertainties go beyond the systems, to include ethics as well. This situation is called post-normal, in contrast to the relatively tame world of normal research, in T.S. Kuhn's sense{{ref|19}}, in the partly controlled world of the professional consultant. The main practical conclusion is that an extended peer community, bringing their extended facts, are legitimate partners in any problem-solving activity, and needed for any inquiry in the realm of complex systems.

The originators of the term, S.O. Funtowicz and J.R. Ravetz{{ref|12}}{{ref|13}}, worked with leading members of the Ontario school of complexity theory, deriving from von Bertanlaffy and Henry Regier, through the late James Kay and David Waltner-Toews. This conception was reinforced by the work of Mario Giampietro on hierarchical systems. There are also affinities in PNS with work in the tradition of cultural theory created by Mary Douglas; there the leading concepts are wicked problems{{ref|20}}, uncomfortable knowledge and clumsy solutions, with Steve Rayner and Michael Thompson as the leading scholars.

Persistent Critics

In studying complex systems, nearly all scientists have accepted the established scientific paradigm, but some have pointed out how that may itself be a source of the theoretical problems. The theoretical biologists using tools of “hard science” have tried to make sense of the observations of “soft science”. Among the most respected and persistent of these are the three theorists, Walter Elsasser{{ref|7}}, Robert Rosen{{ref|8}}, and Stuart Kauffman{{ref|9}}. Each of these scientists came to the same conclusion from somewhat different directions, that organization in nature is not a statistical property which can be modeled using the equations of mathematical physics. For Elsasser it was partly understanding that statistical [[physics]] could not predict the astronomically unlikely persistent heterogeneity of common complex things. For Rosen it was partly seeing that the [[mathematics|mathematical language]] of science could not connect divergent progressions as seems central to natural processes and emergent designs. For Kauffman it was that these very persistent facts implied that every ordinary thing and event comes about through some unique creative processes, making it seem that the ‘inert’ appearance of things just marks our own profound lack of insight into what they are. Nearly everywhere you look in nature there is stable complex diversity, commonly distributed by locally emergent power laws, and the present interpretation of the laws of nature would not appear to produce that. So, at least the questions coming from successively improving methods of observation in every field seem to keep getting better, but still leave very large gaps.

Notes

- Thanks to Yaneer Bar-Yam, Stanley Salthe, Kurt Richardson, Charles Hall, Loet Leydesdorff, and Jerome Ravitz for helpful comments.

1. {{note|1}}Robert P. McIntosh, 1985. The Background of Ecology: Concept and Theory,Cambridge Press. [{{ISBN| |1=0521270871}}].
2. {{note|2}}General systems theory was originally proposed by biologist Ludwig von Bertalanffy in 1928. Since Descartes, the "scientific method" assumed a system could be broken down into its individual components so that each could be analyzed as an independent entity, added in a linear fashion to describe the totality. Von Bertalanffy proposed that both were wrong, seeing a system as the whole of its components and interactions and the nonlinearity of those interactions. In 1951, he extended systems theory to include biological systems and three years later, it was popularized by Lotfi Zadeh. A Society of General Systems Research was founded the early 1950's by Von Bertalanffy, Kenneth Boulding the systems economist and Anatol Rapoport the Russian mathematical psychologist.
3. {{note|3}}Wikipedia. [http://en.wikipedia.org/wiki/Systems_theory Systems theory].
4. {{note|4}}Cybernetics, origin in control theory: In 1868 James Clerk Maxwell published an article on governors. In the 1940's the study of regulatory processes became a continuing research effort. Two key articles were published in 1943 -- "Behavior, Purpose and Teleology" by Arturo Rosenblueth, Norbert Wiener, and Julian Bigelow and "A Logical Calculus of the Ideas Immanent in Nervous Activity" by Warren McCulloch and Walter Pitts. These articles were followed by a series of conferences between 1944 and 1953 on Circular Causal and Feedback Mechanisms in Biological and Social Systems, attended by Ross Ashby, Gregory Bateson, Margaret Mead, Heinz Von Foerster, John von Neumann, and others. In 1948 Norbert Wiener, a conference participant, published his book, Cybernetics. See the [http://www.gwu.edu/~asc/origin.html Origins of Cybernetics].
5. {{note|5}} Wikipedia.[http://en.wikipedia.org/wiki/C.S._Holling]
6. {{note|6}}Wikipedia.[http://en.wikipedia.org/wiki/Howard_T._Odum Howard T. Odum].
7. {{note|7}}Walter Elsasser, 1987. Reflections on a Theory of Organisms, 1966, Atom and Organism.
8. {{note|8}}Robert Rosen. "On The Limitations Of Scientific Knowledge" in On The Limits To Scientific Knowledge, John L. Casli ed., Santa Fe Institute.
9. {{note|9}}Stewart Kauffman, 2008. Reinventing the Sacred.
10. {{note|10}}Albert-Laszlo Barabasi, 2002. Linked
11. {{note|11}}Stan Salthe, 1993 Development and Evolution: Complexity and Change in Biology, MIT Press.
12. {{note|12}}Funtowicz, S. and Ravetz, J.R., 1994. The Worth of a Songbird: Ecological Economics as a Post-normal Science, Ecological Economics, 10(3):197-207.
13. {{note|13}}Jerome R. Ravets, 2006 Post Normal Science and the complexity of transitions towards sustainability, Ecological Complexity 3/4, December 2006, 275-284
14. {{note|14}} Wikipedia.[http://en.wikipedia.org/wiki/Economics]
15. {{note|15}} Wikipedia.[http://en.wikipedia.org/wiki/Pareto_distribution]
16. {{note|16}} Wikipedia.[http://en.wikipedia.org/wiki/Scale-free_network]
17. {{note|17}} Wikipedia.[http://en.wikipedia.org/wiki/Management_science]
18. {{note|18}}Wikipedia.[http://en.wikipedia.org/wiki/Subject-object_problem|subject-object problem]
19. {{note|19}}.[http://en.wikipedia.org/wiki/Thomas_Samuel_Kuhn]
20. {{note|20}}.[http://en.wikipedia.org/wiki/Wicked_problem]

Notes

Articles to edit?

Kozo Mayumi	Draft:Entropy
Robert Costanza	Draft:Natural capital
Mohan Munasinghe	Draft:Sustainomics and sustainable development
	Draft:Conceptual framework linking ecological and socio-economic systems

Articles to reference

Cutler Cleveland :	Draft:Ayres, Robert U. and Draft:Biophysical economics and Draft:Boulding, Kenneth Ewart and Draft:Von Bertalanffy, Ludwig and Draft:Daly, Herman E. and Draft:Forrester, Jay and Draft:Gibbs, Josiah Willard (thermodynamics) and Draft:Odum, Howard T. and Draft:Meadows, Donella H. and Draft:Pimentel, David and Draft:Prigogine, Ilya
Ralph Stuart	Draft:Environmental management systems
John R. Ehrenfeld	Draft:Industrial ecology
Brad Allenby	Draft:Earth systems engineering and management and Earth systems engineering and management
Sergio Ulgiati	Draft:Thermodynamics
Tom Tietenberg	Draft:Environmental economics
Richard Norgaard	Draft:Collectively seeing complex systems
	Draft:Climate change