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Complexity Theory and Systems Theory

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Abstract

I use the label, “complexity theory,” for the research program which studies nonlinear dynamics, “complexity,” “complex adaptive systems,” “artificial life,” etc., and whose intellectual Mecca in the United States is the Santa Fe Institute. I use the label, “systems theory,” for the research program which crystallized after World War II under the names of “general systems theory” and “cybernetics,” and which subsumed such postwar scientific developments as information theory, game theory, feedback control theory, and the beginnings of computer science and artificial intelligence. The central thesis of this paper is that complexity theory is a continuation and revitalization of systems theory.

The paper makes extensive use of a characterization of systems theory made by Mario Bunge which applies equally well to complexity theory. Bunge described systems theory as an attempt to construct an “exact and scientific metaphysics.” The attempt to construct such a metaphysics represents a fundamental rejection of the possibility and desirability of a sharp demarcation separating science and metaphysics. At the very least, metaphysics can serve as a heuristic for science, but systems theory holds out a more radical promise: the recovery of metaphysics via its scientific reconstitution. Such a metaphysics would be less abstract than mathematics but more abstract than the theories of specific scientific disciplines. It would be “stuff-free” (materiality-independent) and only “vicariously” testable. It would represent an attempt to develop a “theory of everything” on an altogether different basis than the way such theories are conceived of in theoretical physics. A systems theoretic TOE, were one available, would genuinely unify the sciences, and not merely offer the illusory unity of a cascade of promised inter-theoretic reductions all the way down to elementary particle physics. Of course, a systems theoretic TOE is not currently available, but ample materials for constructing one are already at hand.

1. Introduction

I demonstrate the validity of this assertion in two steps. First, I describe the essential properties of the research program of systems theory, so that the underlying unity in the diverse manifestations of this program is evident. Second, I show that complexity theory shares in these properties, and thus continues this earlier research program. (While complexity theory is systems theory’s predominant contemporary manifestation, the “classical” system tradition, more strongly and explicitly rooted in the aspirations and literatures of general systems theory and cybernetics, also continues.) To many people this assertion may be obvious, but from my discussions with researchers working in systems theory or complexity theory and from my preliminary encounters with relevant work in the philosophy and sociology of science, this proposition is far from being even recognized, not to speak of being generally accepted.

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1. Central Proposition of Talk: CT=ST
2. Exact and Scientific Metaphysics (ST = ESM = CT)
3. Examples of ESM in ST and CT
4. Aspects of ESM: (a) abstraction, (b) immateriality
5. Just Mathematics? No. (Exactness in ESM is insufficient.)
6. Just mathematical modeling in sciences? No. Aspirations for a TOE. Problems of coherence.
7. Other points of view -- ST as methodology -- and related projects -- systems analysis.
8. Reaffirmation: the Systems-Theoretic Project, Invigorated by CT.

2. Bunge's Definition of Systems Theory

The primary insight which will be deployed in this study is Bunge's interpretation of systems theories as attempts to develop an "exact and scientific metaphysics." "Metaphysics" here means an integrated system of concepts of wide applicability. "Exact" means mathematical, or capable at least in principle of being cast in mathematical terms. "Scientific" means deriving from and contributing to theories and models in specific scientific disciplines. This conceptualization is fully consonant with the views and programmatic goals stated by such founders of systems theory as Norbert Wiener (1961, 1967), W. Ross Ashby (1976), Ludwig von Bertalanffy 1979), Kenneth Boulding (1956), Anatol Rapoport (1986), George Klir (1991), and many others.

A "scientific metaphysics" may sound like an oxymoron, but Bunge is not using the word "metaphysics" exactly in its traditional philosophical sense, where it refers to such basic issues as existence, space and time, causality, identity, and agency. "Metaphysics" here simply connotes a system of abstract ideas of broad generality and applicability. The word is used in a spirit similar to Toulmin's (1982) use of the term "cosmology." Still, it is clear that Bunge here opposes the strict demarcationist position, which asserts -- both descriptively and normatively -- the sharp separability of science and metaphysics.

Bunge proposes that information theory, game theory, feedback control theory, and the like are part of a research program aimed at constructing such a metaphysics, and it is my argument that the same can be said of the new theories of nonlinear dynamics and complex adaptive systems (CAS). Collectively, all these developments can be given the label of "systems theory." In the past this was called general systems theory or cybernetics; today it is called the theory of complexity or of CAS. The systems theory label has made some of the best practitioners of such theory uncomfortable, leading many to explicitly disavow any connection with the systems program, even while in the act of contributing to it (see, e.g., Simon, 1962). It is my conviction that this discomfort arises partially from the general failure, both by systems theoreticians themselves and by the general scientific community at large, to understand the common program which underlies much research in dynamics, complexity, and adaptation. Bunge's bold and succinct formulation identifies this program. While it was developed for classical systems theory, it can be productively applied to contemporary systems theory.

4. Abstraction and Immateriality

To be an exact (mathematical) metaphysics, a body of knowledge must be very abstract and hence at a great remove from the possibility of empirical confirmation or disconfirmation. Systems theories, to use Bunge's expression, are thus only "vicariously testable," that is testable only when they are concretized, via supplementary specifications, in the form of specific theories, or, still more precisely, models of particular phenomena. This property reflects the proximity of systems theory to mathematics, which is traditionally (but not universally) considered not to be empirically testable, but subject only to the requirements of internal consistency. What constitutes evidence for an "exact and scientific metaphysics" is thus necessarily different from what constitutes evidence in normal scientific research. That is, to the degree to which systems theory is simply mathematics, it is not directly testable.

At a high level of abstraction, systems theories are also necessarily "stuff-free," or to put it more elegantly, materiality independent, that is, oriented towards form and process rather than substance. Since phenomena involving very different entities, of different materiality, may be similar in form, systems theories organize knowledge "orthogonally" to conventional classifications. For example, the central premise of Artificial Intelligence, an offshoot of the classical systems program, that intelligence inheres in software, independent of its hardware implementation, is an example of a stuff-free orientation to the phenomenon of intelligence. This holds as well for the new field of Artificial Life (Langton, 1989), a component of contemporary systems theory, which explicitly denies the necessity of a carbon basis for life.

The properties of vicarious testability and materiality independence well characterize such systems theories as information theory, game theory, and feedback control theory. These are theories about such materiality-independent and abstract subjects as communication and organization, competition and cooperation, and regulation and control, respectively. For example, game theory does not concern itself with the specific entities engaged in competitive or cooperative interactions. Most commonly, the players are persons, but they could be other types of organisms (even viruses), or economic, social, or political entities, or technological artifacts, or virtual creatures in some computer medium. Game theory must also be supplemented with more concrete specifications to yield testable hypotheses. Similarly, Norbert Wiener hoped that cybernetic ideas would be used not only for engineering design, but to provide insights into both animal physiology and the behavior of social systems. The materiality of the control system is irrelevant, but the specific content of some appropriate scientific discipline must be added to control theory for it to yield useful insights.

These notions apply as well to the new field of nonlinear dynamics. Although much of the work on chaos has been done by physicists, investigations of chaos are often viewed as being too detached from empirical testing to belong to physics (Kellert, 1993). The same is true for other areas of contemporary systems theory. Indeed, some observers of research at the Santa Fe Institute, e.g., in Artificial Life or complexity studies, have expressed alarm that so much of it appears to be "fact-free" (Horgan, 1995). From Bunge's perspective, this would not be surprising, but this perspective is not widely known, not to speak of being accepted, so it is understandable that the scientific status of work which seems immune to (even oblivious of) empirical test should be troubling. Clearly also, chaotic dynamics does not specifically refer to the materiality that physics usually deals with; it applies as well to biological, economic, and other systems. It is stuff-free, or as many physicists might assert, "just mathematics." However, to mathematicians, the extensive reliance of chaos research upon simulations rather than proofs has placed these studies beyond the pale of standard mathematics. It is hardly surprising that the study of nonlinear dynamics has not found a completely congenial home in either physics or mathematics.

A similar story might be told about the genetic algorithm (Holland, 1975) which plays an important role in the new theories of complexity and of CAS. The genetic algorithm (GA) is an abstract conception of evolutionary adaptation, with clear links to population and evolutionary biology, but it is not biology. It is neither confirmable nor disconfirmable by any biological findings and it is totally stripped of any association with biological materiality. Nor is GA research simply computer science or applied mathematics; while being stuff-free, it nonetheless retains distinct semantic content. One could also cite the research area of cellular automata (CA), launched by Wolfram's work (1986) which encountered a cool reception in certain segments of the physics community, no doubt in part because such automata are used not only to model specific phenomena, but more abstractly to represent dynamic systems in general. Both GAs and CAs are important components of the emerging field of Artificial Life, which abstracts out the formal essence of such phenomena as metabolism, morphogenesis, self-replication, and evolution, and which by virtue of its extreme abstraction is only vicariously testable.

5. Is Systems Theory Just Mathematics?

It is clear that these "new sciences," to generalize the term Gleick (1987) used to describe chaos theory, are not simply physics or biology or economics, etc., but since they are abstract and depend intensively upon mathematical and computer modeling, why can they not be simply encompassed within mathematics? In fact, accepting Bunge's framework, one might ask why mathematics itself might not be considered to be an "exact and scientific metaphysics"? One answer has already been noted. A substantial portion of the work in contemporary systems theory relies upon computational simulations, and not on proofs. This fact alone makes it difficult to include systems theory within mathematics. One might call such work "experimental" mathematics, where computation is not used as bookkeeping support for rigorous, if difficult to check, proofs, but for the demonstration of substantive findings. There is no proof at all in simulations, and their robustness is always problematic. They are like fictional "stories" which depict plausible worlds. The scientific status of simulation-based research is a difficult and important issue for the philosophy of science which has not been sufficiently explored.

There are other reasons why systems theory cannot be regarded simply as (applied) mathematics. Perhaps the most fundamental of these is that mathematics is concerned with all possible consistent worlds, while systems theory addresses our actual world and those specific forms most ubiquitous and significant in it. From this point of view, systems theory might still be regarded as a particular subset of mathematics, namely that subset most applicable to real-world modeling. But this is still unsatisfactory. Mathematics does not require any specific semantic interpretation of its formal components, and is organized around the logical interrelations of these components. Systems theory, by contrast, is organized around phenomena-centered domains. Very different formal approaches may be united in their common effort to explicate a particular phenomenon. For example, in Artificial Life research, processes of intracellular metabolism might be modeled by systems of differential equation or by the very different λ-calculus (Langton et al, 1992). Game theory is about competition and cooperation; the semantics of its formal aspects are prominent and essential. Its specification of the players is stuff-free, but it is still phenomenon-centered. As Boulding notes (1956), systems theory is less abstract than mathematics and thus is necessarily at least partially interpreted.

There is a still simpler reason why systems theory is not part of mathematics: there is a great deal of significant systems-theoretic work which is completely non-mathematical. This is particularly true in the social sciences. To give just three examples: Parsons (1971) was the principal promulgator of systems ideas in sociology years ago. Niklas Luhmann (1982) is a major sociological systems theorist today. Bateson (1979) made significant systems-theoretic contributions to several of the social sciences. (Note that Bateson is included by Toulmin (1982) as one of a new generation of scientists and writers interested in “cosmology,” i.e., metaphysics.) The writings of these authors are completely verbal, yet have clear affinity with “exact” systems theory. Indeed, much of “grand theory” in the social sciences, theory which by virtue of its high abstraction crosses disciplinary boundaries, might be considered to be part of -- or at least is a potential contributor to -- systems theory.

A verbally-expressed metaphysics may still be scientific though it lacks mathematical exactness. It is normative for the systems program that, other things being equal, exactness is preferred. But other things are not equal and many profound and useful views of the world resist formalization. Exactness is an aspiration, a long-term project, and a scientific but not exact metaphysics is still of interest. Indeed, it may be more fertile as it virtually calls out for -- at least to systems theorists -- some appropriate mathematical treatment. One can identify metaphysical ideas and works of the past which were once expressed strictly in verbal form, which *in part* can be given mathematical treatment today. For example, aspects of Hegel’s dialectics can be cast in the precise language of catastrophe theory (Zwick, 1978), and other aspects in the language of fuzzy sets (Kosko, 1993).

6. Grand Aspirations and the Problems of Coherence

While the traditional disciplinary distinctions within science roughly derive from a classification of entities and their material bases, e.g., fundamental particles, molecules, and organisms being the foci of interest for physics, chemistry, and biology, respectively, systems theory organizes knowledge orthogonally around phenomena of interest. One thus has theories and models about dynamics, organization, regulation and control, information processing, morphogenesis, adaptation and learning, competition and cooperation, etc. The issue arises: how can scientific knowledge organized in this way achieve coherence? While the conventional discipline-based framework of science has unity, at least in principle, because of the downward reducibility of description from level to level (from entity to smaller, constituent, entity), systems theory requires some different architectural principle to achieve coherence.

To formulate this issue more sharply, if elementary particle physics seeks a "theory of everything" (TOE) which unites the four fundamental physical forces into one basic interaction between some family of fundamental entities, what might be the comparable basis of unity for the existing multiplicity of systems theories? Such unity is required if a singular "systems theory" is to be taken seriously, i.e., if there is be *one* coherent exact and scientific metaphysics, rather than many. This after all was the classical objective of general systems theory and cybernetics; this is also the aim of contemporary researchers who speak about a theory of complexity.

As Horgan writes (1995), "Complexologists are not the first scientists in this century to think they could create a mathematical theory of, well, almost everything." He then lists, in effect as disparate and unconnected phenomena, "some notable predecessors": cybernetics, catastrophe theory, information theory, and chaos, all of which, he alleges, were failures at similarly grand aspirations. The first three are part of classical systems theory while the fourth, along with the theories of complexity or of complex adaptive systems, define what I have called contemporary systems theory. Horgan is correct in implying that the systems program seeks a "theory of everything;" this is precisely what is meant by an exact and scientific metaphysics. The critical issue, of course, is the realizability of such aspirations. While the coherence of a physics-based TOE would inhere in the theoretical integration of the four fundamental forces and the explanation of the properties of elementary particles, a comparable basis for the coherence of some future systems-theoretic TOE is hard to imagine.

This question of coherence is especially compelling if one takes the goal of systems theory to be an ontology, which, because it would be based in form as opposed to substance, would be orthogonal to and thus not mutually exclusive with the standard ontology of science. One might instead consider the systems program to be an epistemological or a methodological project and these alternative conceptions will be discussed in the next section. In my own view, however, the ontological goal has greater intrinsic scientific interest. (It has also richer connections with the humanities and the arts, but these are outside the scope of this paper.) It is only by taking systems theory as being about what exists, rather than being about how we come to know what exists, that full emphasis is given to its phenomenon-centeredness.

This also suggests a line of approach to the problem of coherence. *Some* systems-theoretic themes, e.g., organization, dynamics, relationship between a system and its environment, apply to nearly all entities, while other themes, e.g., morphogenesis, regulation and control, adaptation, competition and cooperation, apply only to certain entities. Perhaps by ordering phenomena by degree of universality one might be able to organize the multiplicity of systems theories about these phenomena. Alternatively, one can restrict the domain of investigation to some limited subset of systems, e.g., complex adaptive systems. Here the key word is “adaptive,” which restricts our attention to biological, social, and certain technological systems. This is still pretty ambitious, but less so than a “general theory of systems” or a “theory of complexity.”

7. Systems theory as Methodology; Systems Analysis

Systems theory, generally, and its problem of coherence, more specifically, might be understood in epistemological rather than ontological terms. One could here consider Bunge’s “epistemological hierarchy” (my terminology) with which he locates systems theory. This hierarchy begins with (a) a “model object,” a specification of a set of observables defining the phenomenon under examination, (b) particular and testable relations (hypothesized laws) between these observables, (c) a system of such relations, which taken as a whole constitutes a “model” of the phenomenon under study, (d) a formal theory which encompasses (or can encompass) many such models of different phenomena; (e) a semi-interpreted theory of greater abstraction than an ordinary theory, capable of yielding such ordinary theories upon more detailed specification. It is to level (e) that Bunge assigns systems theory.

This is exactly the view of Boulding (1956), who defines systems theory as occupying an epistemological niche intermediate in abstraction between mathematics -- Bunge here adds philosophy which is comparably abstract -- and the less abstract specific theories of the various scientific disciplines. The feasibility of an exact and scientific metaphysics is the question of the intellectual viability of such a niche. (The viability of such a program within the scientific community is a different question, which I hope also to illuminate.) In terms of this epistemological hierarchy, the issue of coherence becomes the more familiar problem of the relationships between representations of knowledge at these different levels.

One can alternatively regard the systems program as concerned not with ontology or epistemology, but with methodology. The use of information-theory for multivariate statistics and fuzzy-set theory for expert systems are classical examples; genetic algorithms and simulated annealing for optimization and neural nets for unprogrammed learning are contemporary examples. Systems methodology is “exact,” being centered in mathematical and computer modeling. It is “scientific” -- not simply applied mathematics -- in being often derived from scientific theories by abstracting away their material content. For example, in the genetic algorithm, the content of population biology and ecology is abstracted away; in neural nets, the content of neurophysiology; in simulated annealing, the content of statistical mechanics. Despite this abstraction, these methods retain the semantic “aura” of their scientific origins; this, for systems [viewed as...] methodology, is what is analogous to the phenomenon-centeredness of [viewed as...] systems theory.

Systems methodology seeks generality of scope but is clearly not metaphysics in the terms of Bunge. Methodology does not explicitly characterize what exists in the world, and one would hardly consider a systems methodology, however broadly applicable and coherent, to be a “theory of everything.” Coherence is still an issue, however, for though it is less pressing a requirement for methodology than for ontology, as a pragmatic matter it is still highly desirable. Methodological coherence requires the integration of mathematical and computer modeling frameworks and tools, and Klir (1985) has made a major contribution in this direction.

Systems methodology might be considered to be the "technology" associated with systems theory, providing mathematical and computer modeling tools for a variety of academic and worldly contexts. A focus on methodology is especially natural where systems activities extend into (draw upon and contribute to) engineering and the professions, but systems methodology is equally important to the sciences. The nature of the interaction between systems science (theory) and systems technology is an interesting and important question, outside the scope of this short essay.

Associated with this issue is the relationship between systems theory and "systems analysis," which together actually constitute the systems field.

8. Conclusion

Since World War II, the systems movement has been *the* interdisciplinary movement in the natural and social sciences. The models and theories generated by this movement have permeated all of the sciences to the point where they are largely taken for granted, and no particular note is taken of their common -- and essentially interdisciplinary -- point of view. To illustrate: game theory, which has had extensive applications in the natural and social sciences (not to speak of its many worldly uses) was not a development within any particular scientific discipline, von Neumann's linking of it to economics notwithstanding. Similarly, the theory of nonlinear dynamics, with its enormous scientific impact, was not simply a discovery within physics and/or mathematics. No one calls either game theory or nonlinear dynamics instances of "systems theory," and such a label does not facilitate or illuminate their specific uses, but it is only by seeing these and many similar theories as part of the systems research program can their underlying commonality be grasped and their significance for the philosophy of science appreciated.

In classical and contemporary systems theory, a new basis for the integration of the sciences, different from the conventional basis of inter-theoretic reduction, has emerged. The systems-theoretic program was launched in part by such major figures as Wiener, von Neumann, and Shannon. It has since involved, either directly or indirectly, the work of other prominent scientists as Bateson, Rapoport, Boulding, Simon, Klir, Prigogine, Arrow, and Gell-Mann. This program is currently undergoing a major "renaissance" -- with Santa Fe as Florence -- in contemporary studies of nonlinear dynamics and complex adaptive systems. The systems program is a major current in modern science. The scientific societies, journals, etc. which have been consciously and explicitly identified with this program represent only a small part of it.

This program is interdisciplinary, but not in the sense of merely "filling in" productive interstices between specific scientific disciplines. It is larger in scope and grander in ambition. It reflects a return to cosmology (Toulmin, 1982), an aspiration, in Bunge's terms, towards "an exact and scientific metaphysics." In both its classical and contemporary forms, systems theory raises important questions for the philosophy, history, and sociology of science, questions concerning the nature of theory and evidence, the origins of scientific innovation, and the construction of scientific and technological knowledge. Many of these questions involve the two issues of "abstraction" and "coherence" outlined above. The connections between systems theory, systems methodology, and systems analysis also pose significant questions for the understanding of interdisciplinary movements.

Even if the validity of this assertion is granted, one may ask what purpose is accomplished by the characterization of complexity theory as contemporary systems theory. A discussion of the significance of this characterization will then be the third part of this essay.

References Cited

Ashby, W. Ross (1976). *An Introduction to Cybernetics*. London: Methuen.

Axelrod, Robert (1984). *The Evolution Of Cooperation.*, New York: Basic Books.

Bateson, Gregory (1979). *Mind and Nature*. New York: E. P. Dutton.

Berlinski, David (1976). *On Systems Analysis: An Essay Concerning the Limitations of Some Mathematical Methods in the Social, Political, and Biological Sciences*. Cambridge: MIT Press.

von Bertalanffy, Ludwig (1979). *General System Theory*. New York: George Braziller.

Boulding, Kenneth (1956). "General System Theory - the Skeleton of Science." Management Science, 2, 197-208. Reprinted in Buckley, ed. (1968). *Modern Systems Research for the Behavioral Scientist*. Chicago: Aldine.

Bunge, M. (1973). *Method, Model, and Matter*. Boston: D. Reidel.

Casti, John (1995). *Complexification.* New York: Harper-Collins.

Churchman, C.W. (1979). *The Systems Approach*. New York: Dell.

Cowan, George A., Pines, David, & Meltzer, David (1994*). Complexity: Metaphors, Models, and Reality*. Reading MA: Addison-Wesley.

Gell-Mann, Murray (1994). *The Quark and the Jaguar*. New York: W.H. Freeman & Co.

Gleick, J. (1987). *Chaos. Making a New Science*. New York: Viking

Goldberg, David E. (1989). *Genetic Algorithms in Search, Optimization, and Machine Learning*. Reading: Addison-Wesley.

Heims, Steve J. (1980). *John von Neumann and Norbert Wiener. From Mathematics to the Technologies of Life and Death*. Cambridge: MIT Press.

Hesse, Mary (1970). *Models and Analogies in Science*. Notre Dame: University of Notre Dame Press.

Holland, John (1975). *Adaptation in Natural and Artificial Systems*. Ann Arbor: University of Michigan Press.

Holland, John (1995). *Hidden Order: How Adaptation Builds Complexity*. Reading, MA: Addison-Wesley.

Holling, C.S. (1976). "Resilience and Stability of Ecosystems." In: Erich Jantsch and Conrad H. Waddington (eds*.) Evolution and Consciousness: Human Systems in Transition*, Reading: Addison-Wesley, pp. 73 - 92.

Horgan, John (1995). “From Complexity to Perplexity.” *Scientific American*, June, pp. 104-109.

Kellert, Stephen H. (1993). *In the Wake of Chaos*. Chicago: University of Chicago Press.

Klir, George (1985). *Architecture of Systems Problem Solving*. New York: Plenum Press.

Klir, George (1991). *Facets of Systems Science*. Cambridge, Mass.: Abacus Press.

Kosko, Bart (1993). *Fuzzy Thinking: The New Science of Fuzzy Logic*. New York: Hyperion.

Langton, Christopher, ed. (1989). *Artificial Life.* Santa Fe Institute Studies in the Sciences of Complexity. New York: Addison-Wesley.

Langton, Christopher, Charles Taylor, J. Doyne Farmer, Steen Rasmussen (1992). *Artificial Life II*, Santa Fe Institute Studies in the Sciences of Complexity. New York: Addison-Wesley.

Laszlo, Ervin (1972). *Introduction to Systems Philosophy*. New York: Harper & Row.

Lilienfeld, Robert (1978). *The Rise of Systems Theory*. New York: John Wiley.

Luce, R. Duncan & Raiffa, Howard (1957). *Games and Decisions: Introduction and Critical Review*, New York: Dover Publications.

Luhmann, Niklas (1982*). The Differentiation of Society*. New York.

Mattesich, Richard (1978). *Instrumental Reasoning and Systems Methodology. An Epistemology of the Applied and Social Sciences*. Boston: D. Reidel Publishing Co.

May, Robert M. (1974). *Stability and Complexity in Model Ecosystems*. New Jersey: Princeton Univ. Press.

Parsons, Talcott (1971). *The Systems of Modern Societies*. Englewood Cliffs NJ: Prentice-Hall.

Pines, David, ed. (1988). *Emerging Syntheses in Science*. Reading MA: Addison-Wesley.

Poundstone, William (1992*). Prisoner's Dilemma. John von Neumann, Game Theory, and the Puzzle of the Bomb*. New York: Doubleday.

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

Principia Cybernetica Web Project (1993). http://pespmc1.vub.ac.be.

Rapoport, Anatol (1986). *General System Theory*. Cambridge, Mass.: Abacus Press.

Sante Fe Institute Studies in the Sciences of Complexity (many volumes: 1987-1996). Redwood City: Addison-Wesley.

Simon, Herbert A. (1962). "The Architecture of Complexity.*" Proc. Am. Philosophical Society*, 106: 467-482. Reprinted in *The Sciences of the Artificial*.

Simon, Herbert A. (1981). *The Sciences of the Artificial*. Cambridge: M.I.T. Press.

Toulmin, Stephen (1982). *The Return to Cosmology*. Berkeley: U. of California Press.

Wartofsky, Marx W. (1979). *Models*. Boston: D. Reidel.

Wiener, Norbert (1961). *Cybernetics*. Cambridge: MIT Press.

Wiener, Norbert (1967). *The Human Use of Human Beings*. New York: Avon.

Wolfram, Stephen (1986). *Theory and Applications of Cellular Automata*. Singapore: World Scientific.

Zwick, Martin (1996). "Towards an Ontology of Problems.*" Advances in Systems Science and Applications,* Special Issue I, pp. 37-42.

Zwick, Martin (1986). "Information, Constraint, and Meaning," *General Systems* (yearbook of the Society for General Systems Research) 29, 41-47.

Zwick, Martin (1984). "Incompleteness, Negation, Hazard: On the Precariousness of Systems." *Nature and System* 6, pp. 33-42

Zwick, Martin (1979) "The Cusp Catastrophe and the Laws of Dialectics*," Nature and System*, 1, 177-187. Abstract, entitled "Dialectical Laws and Elementary Catastrophes," in Proceedings and Addresses of the American Philosophical Association, 51, 467, February 1978.

Zwick, Martin (1978). "Dialectics and Catastrophe." In: Geyer, R.F. and van der Zouwen, J., eds., *Sociocybernetics*, Vol. 1. Boston: Martinus Nijhoff, pp.129-154

Zwick, Martin, Lovell, Byrne, and Marsh, Jim (1996). "Global Optimization Studies on the 1-D Phase Problem." *International Journal of General Systems.* (in press).

Zwick, Martin (1996). "Control Uniqueness in Reconstructability Analysis." *International Journal of General Systems*, Vol. 24, pp. 151-162.

Zwick, Martin, Shu, Hui & Koch, Roy (1996). “Information-Theoretic Reconstructability of Rainfall Time-Series Data.” *Advances in Systems Science and Applications,* Special Issue I, pp. 154-159.

Zwick, M. & Shu, H. (1996). “Set-Theoretic Reconstructability of Elementary Cellular Automata*.” Advances in Systems Science and Applications,* Special Issue I, pp. 31-36.

Bedau, Mark A., Zwick, Martin, and Bahm, Alan (1996). “Variance and Uncertainty Measures of Population Diversity Dynamics.” *Advances in Systems Science and Applications,* Special Issue I, pp. 7-13.

COMPLEXITY THEORY (CT) & SYSTEMS THEORY (ST)

- Central Proposition: CT = (major aspect of modern) ST

- Idea of an “Exact and Scientific Metaphysics”

- ST,CT as ESM

- ST,CT mathematics-like, but not *just* mathematics

- Methodology or ontology (TOEs)? The problem of coherence

CENTRAL PROPOSITION: CT $\subset$ ST.

Proposition:

CT = continuation/revitalization of ST

= the major current in "modern" ST

(But "classical" ST program continues.)

Classical ST	**CT**
general systems theory, cybernetics (also aspects of systems engineering, operations research)	nonlinear dynamics (chaos), theory of complexity, complex adaptive systems, artificial life
information theory, game theory, automata theory, feedback control, fuzzy logic	cellular automata & random nets, genetic algorithms, evolutionary computation
von Neumann, Wiener, Shannon, Rapoport, Klir, Zadeh, Mesarovic, Boulding	Holland, Langton, Wolfram, Kauffman, Bak, Gell-Mann, Crutchfield, Arthur
e.g., SUNY Binghamton	Santa Fe Institute

EXACT & SCIENTIFIC METAPHYSICS

(Mario Bunge)

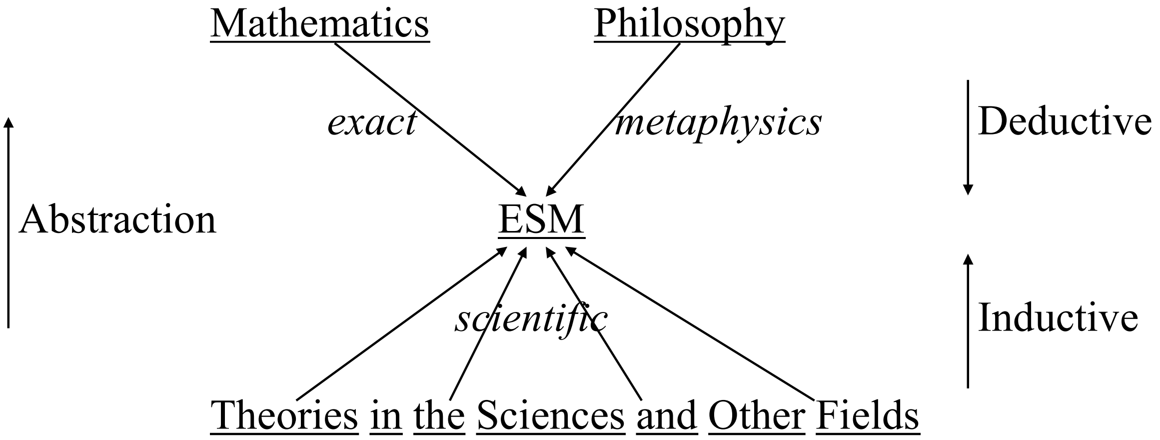
Metaphysics = a system of concepts of wide applicability
e.g., order, context, stability, essence, adaptation
(NOT about God, free will, etc.)

Exact = mathematical

Scientific = contributing to, drawing from, science

Metaphysics	GENERALITY	mostly correspondence
Exact	PRECISION	coherence (*consistency*)
Scientific	RELEVANCE	correspondence (*testability*)

EXACT & SCIENTIFIC METAPHYSICS (CT $\subset$ ST $\Rightarrow$ ESM)



but *centripetal* forces are weak vis-a-vis *centrifugal* forces

ASSERTIONS:

ST aims towards ESM. **(ST $\Rightarrow$ ESM)**

CT part of ST, has same aim. **(CT $\subset$ ST)**

EXAMPLES of ST and CT as ESM

	Metaphysics	Exact (formal theory of)	Scientific
classical ST			
Information Theory	Relation, structure, order	Shannon	Physics, biology, etc.
Game Theory	Competition & cooperation, rationality	von Neumann	Evolutionary theory, social sciences
Catastrophe Theory	dialectics (Hegel); form, information	Thom	Social sciences, biology
Non-equilibrium Thermodynamics	Being as flux (Heraclitus)	Prigogine	Natural sciences
CT			
Non-linear Dynamics	Order/disorder, information-generation	Shaw, Smale, etc.	Natural & social sciences
CAS (specifically GA, GP)	Adaptation, learning, optimality	Holland, Koza, etc.	Evolutionary simulations, computation
Artificial Life	Replication, metabolism, morphogenesis	Crutchfield, Fontana, Wolfram, etc.	Biology

ST,CT ARE MATHEMATICS-LIKE

Because of abstraction:

1. *Vicarious* testability (testability *only* with further specification)

Game Theory models (ST) cannot be falsified; can only *not apply*.

Evolutionary simulations in ALife (CT) do not make empirically-testable claims about specific biological systems.

2. *Materiality-independence* (“stuff-free”)

Game Theory (ST) applies to organisms, social organizations, engineering artifacts, etc..

Biochemistry irrelevant to ALife (CT) models of metabolism; cellular physiology irrelevant to ALife models of morphogenesis.

INTERMEDIATE (in abstraction) NICHE

<u>Epistemological hierarchy</u>

(Bunge; modified terminology)

---**MATHEMATICS**

--**SYSTEMS THEORY** GENERIC THEORY
semi-interpreted

-----**SCIENCES** THEORY
set of models within axiomatic-deductive system

MODEL
set of laws TESTABLE

LAW
relation between observables FALSIFIABLE

MODEL OBJECT
set of observables

BUT ST, CT NOT *JUST* MATHEMATICS.

REASONS WHY NOT:

1	Centered in *phenomena*, not formalisms	ESM	E.g., metabolism, adaptation, morphogenesis; use of multiple formalisms
2	Organized around general *concepts*	ESM	E.g., order, stability, form, adaptation, competition
3	Simulations not proofs, so not "exact"	~~E~~SM	Computational simulations widely used in ALife
4	Not *possible* consistent worlds, but *actual* world.	*E*SM	Not *all* but only widely applicable mathematics; and differently organized
5	Exactness is aspiration, not prerequisite.	ESM	Scientific theory or formal metaphysics may not yet have been achieved
6	Very general *verbal* theory in social sciences.	*S*M	E.g., Bateson, Parsons, Luhmann

BUT ALWAYS THERE IS -- AND SHOULD BE -- MATH-ENVY!

ST, CT as modeling METHODOLOGY

A VIEW CLOSELY RELATED TO ST,CT AS MATHEMATICS.

Exact & **S**cience-based general problem-solving **M**ethodology”

ST:

- Klir, G., *Architecture of Systems Problem Solving*: set-, information-, automata-theoretic methods
- Control theory as applied mathematics
- Fuzzy mathematics for engineering technology
- Neural nets for AI

CT:

- Non-linear dynamics as another set of mathematical tools
- GA & simulated annealing as optimization methods
- Genetic programming, classifier systems, as extension of AI

ONTOLOGY	**is bolder than**	**METHODOLOGY**
“what is”		“how to describe it”

THE GRAND AMBITION: ST,CT as *THEORIES OF EVERYTHING*

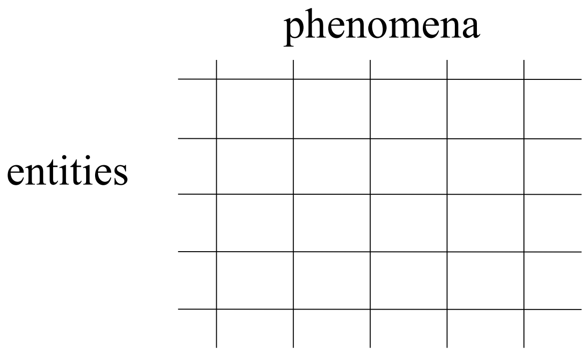
(different from physics-based, reductionist, TOEs.)

ST,CT = TOEs organized around **phenomena**,

e.g., organization, generalized metabolism (autopoiesis), growth, morphogenesis, information processing, adaptation, competition/cooperation, etc.;

NOT around compositionally- and materially-defined **entities**

e.g., subatomic particles, atoms, molecules, cells, organisms, social systems, etc.



MORE MODEST GOAL: *THEORIES OF A LOT* (TOL), e.g., in CT:

COMPLEX ADAPTIVE SYSTEMS (adapting populations of organisms, organizations, etc.)

SYSTEMS TOEs or TOE: PROBLEM OF COHERENCE

HOW TO INTEGRATE THEORIES ABOUT

- STATIC/DYNAMIC ORDER
- SELF-ORGANIZATION
- INFORMATION-PROCESSING
- MORPHOGENESIS
- REGULATION
- ADAPTATION
- COMPETITION/COOPERATION
- etc.

?

1. COHERENCE OF MATH *DOESN'T HELP* BECAUSE *ORGANIZED AROUND FORMALISMS*

2. *NEED THEORY* OF **LEVELS OF COMPLEXITY** (metaphysically, "levels of being") OF STRUCTURE/FUNCTION/HISTORY.

BOULDING'S HIERARCHY REVISITED

LEVELS OF COMPLEXITY ("*GREAT CHAIN OF BEING*")

FROM BOULDING'S CLASSICAL ARTICLE,
"GST -- THE SKELETON OF SCIENCE."

	Boulding Hier.	Phenomena				
		Order	Dynamics	Info.-Proc.	Morphogen.	Adaptation
8	(social organizations)	▨	▨	▨	▨	▨
7	(humans)	▨	▨	▨	▨	▨
6	(animals)	▨	▨	▨	▨	▨
5	genetic/societal systems (plants)	▨	▨	▨	▨	▨
4	open systems	▨	▨	▨	▨	
3	cybernetic systems	▨	▨	▨		
2	clockworks	▨	▨			
1	frameworks	▨				

Non-equil. thermodynamics (ST): #4

Feedback control theory (ST): #3

Nonlinear dynamics (CT): #2

Genetic algorithms (CT): #5

Catastrophe Theory (ST), L-Systems (CT): #6

Metaphysics	Bridge to the humanities & arts
Exact	(Bridge integrity assurance)
Scientific	Bridge to practice, applications