Science & Society, Vol. 62, No. 3, Fall 1998, 375–399

Dialectics and Systems Theory

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ABSTRACT: Systems Theory is best understood in its dual nature as an episode in the generic development of human understanding of the world, and as the specific product of its social history. On the one hand it is a "moment" in the investigation of complex systems, the place between the formulation of a problem and the interpretation of its solution where mathematical modeling can make the obscure obvious. On the other hand it is the attempt of a reductionist scientific tradition to come to terms with complexity, non-linearity and change through sophisticated mathematical and computational techniques, a groping toward a more dialectical understanding that is held back both by its philosophical biases and by the institutional and economic contexts of its development.

IN A GENERALLY SYMPATHETIC REVIEW of *The Dialectical Biologist* (Maynard Smith, 1986), and in personal conversations, John Maynard Smith argued that the development of a rigorous, quantitative mathematical systems theory makes dialectics obsolete. Engels' awkward "interchange of cause and effect" can be replaced by "feedback," the mysterious "transformation of quantity into quality" is now the familiar phase transition or threshold effect, while "even in my most convinced Marxist phase, I could never make much sense of the negation of the negation or the interpenetration of opposites." He could have added that hierarchy theory grasps some of the insights of "integrated levels" or "overdetermination."

On the other hand, Mary Boger, a leader of the New York Marxist School, has been urging me for years not to allow dialectics to be subsumed under systems theory. Despite systems theory's concern with complexity, interconnection and process she has argued that it is still fundamentally reductionist and static, and despite the power of its mathematical apparatus it does not deal at all with the richness of dialectical contingency, contradiction or historicity. Finally, she added that systems-theoretic "interconnection" does not grasp the subtleties of dialectical "mediation."

This essay is a first attempt to systematize my own views as they have evolved in discussions with Mary Boger, Rosario Morales, Richard Lewontin and other comrades.

As I entered this exploration I became aware of two opposing temptations. On the one hand I wanted to emphasize the distinctness of dialectics from contemporary systems theory, to proclaim that our theoretical foundations are not obsolete and continue to have something important to say to the world of science that systems theory has not already adopted. On the other hand, along with Engels I found it gratifying to see science, grudgingly and haltingly and inconsistently but nevertheless inexorably, becoming more dialectical. Both affirmations are true, but their emotional appeal can also lead to errors of one-sidedness. I attempted to use this awareness to question my conclusions as I made one or another claim.

Any description of systems theory and of dialectical materialism is subject to two kinds of problems: in both areas there are many practitioners with quite divergent views. I will not attempt any kind of comprehensive survey of systems theory or "a systems approach," but limit myself to systems theory in the narrow sense as a mathematical approach to "systems" of many parts. And second, systems theory and dialectics are not mutually exclusive. Some systems theorists are also Marxists or have been influenced by Marxism in their research contributions to the development of the theory. Other Marxists have had at least a passing contact with systems theory and have used some of its notions in their Marxist research. For example, Göran Therborn, a Swedish Marxist social scientist influenced by systems theory, approached the nature of the state from two perspectives: the traditional Marxist view of the role of the state as an expression of class rule, and the systems theoretic examination of its dynamics as a system with inputs and outputs. The publisher's blurb for his book *What Does the Ruling Class Do When it Rules?* (Therborn, 1978) summarizes the work: "Therborn uses the formal categories of systems analysis — input mechanisms, processes of transformation, output flows — to advance a substantive Marxist analysis of state power and state apparatuses . . ."

Nonetheless, the two are quite different in their origins, objectives and theoretical underpinnings. In what follows I will discuss several general themes that unite and differentiate them: wholeness and interconnection, selection of variables or parts, purposefulness, and the outcomes of processes. Materialist dialectics[1] is not offered as a complete philosophy of nature, a System in the classical sense. Dialecticians are too aware of the historical contingency of our thinking to expect that there will ever be a final world view. Rather it is first of all polemical, a critique of the prevailing failings of both the mechanistic reductionist approach and its opposite, the holistic idealist focus. Together these have dominated Euro–North American natural and social science since its emergence in 17th century Britain as a partner in the bourgeois revolution. They have also dominated politics as the broad liberal–conservative consensus that has defined the "mainstream" politics of democratic capitalism.

Therefore dialectical materialism has focused mostly on some selected aspects of reality while ignoring others. At times we have emphasized the materiality of life against vitalism, as when Engels said that life was the mode of motion of "albuminous bodies" (*i.e.*, proteins; now we might say macromolecules). This seems to be in contradiction with our rejection of molecular reductionism, but simply reflects different moments in an ongoing debate where the main adversaries were first the vitalist emphasis on the discontinuity between the inorganic and the living realms, and then the reductionist erasure of the real leaps of levels. At times we have supported Darwin in emphasizing the continuity of human evolution with the rest of animal life, at other times the uniqueness of socially driven human evolution. We could classify our species as omnivores, along with bears, to emphasize that we are just another animal species that has to get its energy and substance by eating other living things, and are not limited to only one kind of food. Or we could underline our special status as "productivores" who do not merely find our food and

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[1] The term "dialectical materialism" is often associated with the particular rigid exposition of it by Stalin and its dogmatic applications in Soviet apologetics, while "dialectical" by itself is a respectable academic term. At a time when the retreat from materialism has reached epidemic proportions it is worthwhile to insist on the unity of materialism and dialectics, and to recapture the full vibrancy of this approach to understanding and acting on the world. Here I use materialist dialectics and dialectical materialism as synonyms.

our habitat but produce them. Both are true; the relation of continuity and discontinuity in process is an aspect of dialectics that systems theory does not deal with at all.

But critique is not just criticism, and dialectics goes beyond the rejection of reductionist or idealist thinking to offer a coherent alternative, more for the way in which it poses questions than for the specific answers its advocates have proposed at any particular time. Its focus is on wholeness and interpenetration, the structure of process more than of things, integrated levels, historicity and contradiction. All of this is applied to the objects of the study, to the development of thought about those objects, and self-reflexively to the dialecticians ourselves so as not to lose sight of the contingency and historicity of our own grappling with the problems we study.

Dialectical materialism is unique among the critiques of science in that its roots are outside the academy in political struggle as well as within, that it directs criticism both at reductionism and idealism, that it is consciously self-reflexive, and that it rejects the goal of a final "system." But it is unlike postmodernist criticism of science which uses the contingency of scientific claims to deny the historically bounded but no less real validity of some claims over others, in favor of an acritical pluralism.

Systems theory has a dual origin, in engineering and in the philosophical criticism of reductionism. On the one hand it comes out of engineering as cybernetics, the study of self-regulating mechanisms with often rather complex circuitry. Norbert Weiner introduced the term cybernetics in his book of that name (*Cybernetics, or Control in the Animal and Machine*, 1961). The term became part of common usage in the Soviet Union, but was mostly replaced in the USA by control theory, the theory of servomechanisms, or systems theory. In this form it is the mathematics of feedback, the study of mathematical models. The preface to *The Theory of Servomechanisms* (James, *et al.*, 1947), one of the early classical texts in this field, states:

> The work on servomechanisms in the [Livermore] Radiation Laboratory grew out of its need for automatic radar systems. It was therefore necessary to develop the theory of servomechanisms in a new direction, and to consider the servomechanism as a device intended to deal with an input of known statistical character in the presence of interference of known statistical character. (ix.)

> A servomechanism involves the control of power by some means or other involving a comparison of the output of the controlled power and the actuating device. The comparison is sometimes referred to as feedback. (2.)

This form of systems theory is highly mathematical and formal. Its earlier versions assumed systems that were given, the equations known, and measurement precise. But soon systems analysis was taken up by military designers, with the idea of a weapons system replacing the development of particular weapons as the theoretical problem, and by management systems as the scientific aspects of directing large enterprises. Here the measurements are fuzzier, the equations not known, and therefore other techniques become necessary. Herbert Simon at Carnegie Mellon University, Mesarovic at Case Western Reserve, the International Institute for Applied Systems Analysis in Austria as well as mathematicians and engineers in the Soviet Union and other centers worked to advance the conceptual frameworks and mathematics of many variables interacting at once and the computing routines for following what happens. More recently, the Santa Fe Institute has made the study of complexity itself the core intellectual problem.

The major role of engineering and management systems in developing systems theory is reflected in the assumption of goal-seeking. Thus Meadows, *et al.* (1992) define a system as "an interconnected set of elements that is coherently organized around some purpose. A system is more than the sum of its parts. It can exhibit dynamic, adaptive, goal-seeking, self-preserving and evolutionary behavior."

But the "system" of systems theory is not reality itself but a model of reality, an intellectual construct that grasps some aspects of the reality we want to study but also differs from that reality in being more manageable and easier to study and alter. Therefore models are not "true" or "false." They are designed to meet a number of criteria that are in part contradictory, such as realism, generality and precision (Levins, 1966). It is the hope of systems analysts that the departures from reality that make them easier to study do not lead to false conclusions about that reality.

The wholeness, interconnectedness of parts and the purposefulness of systems are emphasized. The first two qualities are inherent in what we mean by a system.

Wholes

The other source of "systems" theory has been in critical attempts to counter the prevailing reductionism in science since the last century. Here its boundaries are not well defined but shade off gradually into various holisms.

Holism is not new. The history of science is not the history of its mainstream, the succession of dominant paradigms popularized by Thomas Kuhn. There has always been dissidence in science, dissatisfaction with the dominant ideas, alternative approaches within the various disciplines, and quite divergent "mainstreams" among disciplines. "Holistic" criticism has always coexisted with the dominant reductionism. It was expressed in such currents as vitalism in developmental biology, Bergson's "emergence," in psychology (Bronfenbrenner, Perl, Piaget), ecology (Vernadsky's biosphere, the Soviet "geo-biocoenosis," Clements' and later Odum's ecosystems), anthropology (Kroeber's "superorganic") and other fields as a grasping for wholeness and interconnection. In this aspect it is usually referred to in the United States as a "systems approach" or "systems thinking." Some authors engage in systems theory in both the narrow and the broad meanings. Especially ambitious and central was L. von Bertalanffy's General Systems Theory starting in the 1930s (von Bertalanffy, 1950). Biological complexity was usually a central challenge. W. Ross Ashby's *Design for a Brain* poses the problem as one of reconciling mechanistic structure and seemingly purposeful behavior:

> We take as basic the assumptions that the organism is mechanistic in nature, that it is composed of parts, that the behavior of the whole is the outcome of the compounded actions of the parts, that organisms change their behavior by learning, and that they change it so that the later behavior is better adapted to their environment than the earlier. Our problem is, first, *to identify the nature of the change which shows as learning*, and secondly *to find why such changes should tend to cause better adaptation for the whole organism*. (Emphasis in original.)

Ecology also has brought to public consciousness the rich interconnectedness of the world. Examples are regularly put forth of the unexpected, often counterproductive effects of interventions directed at solving a particular problem. Pesticides increase pest problems, draining a wetland can increase pollution, antibiotics provoke antibiotic resistance, clearing forests to increase food production may lead to hunger. And Barry Commoner's dicta that everything is connected to everything else and that everything goes somewhere have become part of the common sense of at least a part of the public.

The powerful impact of the realization that things are connected sometimes leads to claims that "you cannot separate" body from mind, economics from culture, the physical from the biological or the biological from the social. Much very creative research has gone into showing the connectedness of phenomena that are usually treated as separate. It is even said that because of their interconnectedness they are all "One," an important element of mystical sensibility that asserts our "Oneness" with the Universe.

Of course you *can* separate the intellectual constructs "body" from "mind," "physical" from "biological," "biological" from "social." We do it all the time, as soon as we label them. We have to in order to recognize and investigate them. That analytical step is a necessary moment in understanding the world. But it is not sufficient. After separating, we have to join them again, show their interpenetration, their mutual determination, their entwined evolution and yet also their distinctness. They are not "One." The pairs of mutualist species or predator and prey are certainly linked in their population dynamics. Sometimes the linkage is loose, as when each affects the life of the other but the effect is not necessary. Sometimes very tightly, as in the symbiosis of algae and fungi in lichens. Snowy owls and Arctic hares drive each other's population cycles in a defining feedback loop. Mutualists may evolve to become "one," as Lynn Margulis has pioneered in arguing for the origins of cellular structures. But predator and prey are not "One" until the last stages of digestion. Psychotherapists work both with asserting connection in examining family systems and with criticizing "codependence," the pathological loss of boundaries and autonomy. There is a one-sidedness in the holism that stresses the connectedness of the world but ignores the relative autonomy of parts.

As against the atomistic and absolutized separations of reductionism, holists counterpose the unity of the world. That is, they align themselves at the "oneness" end of a spectrum from isolated to "One." They look for some organizing principle behind the wholeness, some "harmony" or "balance" or purpose which gives the wholes their unity and persistence. In technological systems, there is a goal designed by the engineers that is the criterion for evaluating the behavior of the system and for modifying the design. To the extent that the development of systems theory has been dominated by designed systems, goal-seeking behavior appears as an obvious property of systems as such, and therefore it is sought also in the study of natural systems.

In the study of society, this may lead to a functionalism which assumes a common interest driving the society. But a society is not a servomechanism; its component classes pursue different, both shared and conflicting goals. Therefore it is not a "goal-oriented" system, even when many of its components are separately goal-seeking.

Within the framework of static holism it is difficult to accommodate change as other than destructive, so that conservation biology often emphasizes preservation of a particular species or ecological formation, rather than conditions that permit continued evolution.

Dialecticians value the holistic critique of reductionism. But we reject the sharp dichotomy of separation/connection or autonomy/wholeness and an absolute subordination of one to the other. This is not a complaint about being "extreme." "Extreme" is a favorite reproach by liberals, for whom the desired condition is moderation, a middle ground "somewhere in between," mainstream, compromise. Their favorite colors are "not black or white but shades of gray." In contrast the dialectical criticism is "onesidedness," the seizing upon one side of a dichotomous pair or a contradiction as if it were the whole thing. *Our spectrum is not a gradient from black through all the grays to white, but a fractal rainbow.*

Of course, despite Hegel's dictum that "the truth is the whole" we cannot study The Whole. The practical value of Hegel's affirmation is twofold:

First, that problems are larger than we have imagined so that we should extend the boundaries of a question beyond its original limits. Even systems theory construes problems too small, either because the domain is assigned to the analyst as a given "system" or because additional variables known to interact with the initial system are not measureable or do not have known equations, or because of traditional boundaries of disciplines. Thus a systems analysis of the regulation of blood sugar may include the interactions among sugar itself, insulin, adrenalin, cortisol and other molecules but is unlikely to include anxiety, or the conditions that produce the anxiety such as the intensity of labor and the rate of using up of sugar reserves, whether or not the job allows a tired worker to rest or take a snack. Models of heart disease are likely to include cholesterol and the fats that are turned into cholesterol but not the social classes of the people in whom the cholesterol is formed and breaks down. Systems analysis would not know how to deal with the pancreas under capitalism or the adrenals in a racist workplace. Models of epidemics may include rates of reproduction of viruses and their transmission but not the social creation of a sense of agency that may allow people to take charge of their exposure and treatment.

The second application of the understanding that the truth is the whole is that after we have defined a system in the broadest terms we can at the time, there is always something more out there that might intrude to change our conclusions.

Dialectics appreciates the pre-reductionist kind of holism, but not its static quality, its hierarchical structure with a place for everything and everything in its place, nor the *a priori* imposition of a purposefulness that may or may not be there. Thus it "negates" materialist reductionism's negation of the earlier holism, an example of the negation of the negation that Maynard Smith found so opaque but could have recognized as the non-linearity of change.

What Are Parts?

Wholes are thought of as made out of parts. Systems theory likes to take as its elements unitary variables that are the "atoms" of the system, prior to it, and qualitatively unchanging as they ebb and flow. Their relations are then "interactions" as a result of which the variables increase or decrease, emit "outputs" and thus produce the properties of the wholes. But the wholes are not allowed to transform the parts, except quantitatively. The long distance conversation does not transform the telephone, the market does not change the buyer or seller, and power does not affect the powerful nor love the lover. It is the priority of the elements and along with it the separation of the structure of a system from its behavior — rational assumptions for designed and manufactured systems — that keeps systems theory still vulnerable to the reproach of being large-scale reductionism.

The parts of dialectical wholes are not chosen to be as independent as possible of the wholes but rather as points where properties of the whole are concentrated. Their relation is not mere "interconnection" or "interaction" but a deeper interpenetration that transforms them so that the "same" variable may have a very different significance in different contexts and the behavior of the system can alter its structure. For instance temperature is important in the lives of most species. But temperature has many different meanings. It acts on the rate of development of organisms and therefore their generation time and also on the size of individuals; it limits the suitable locations for nesting or reproduction; it may determine the boundaries of foraging or the time available for searching for food. It influences the available array of potential food species and the synchrony between the appearance of parasites and their hosts. It modifies the outcomes of species encounters.

But temperature is not simply given to the organisms. The organisms change the temperature around them: there is a layer of warmer air at the surfaces of mammals; the shade of trees makes forests cooler than the surrounding grassland; the construction of tunnels in the soil regulates the temperatures at which ground nesting ants raise their brood; the color of leaf litter and humus determines the reflection and absorption of solar radiation. Through the physiology and demography of the organism, *effective* temperature, its range and its predictability are quite different from the weather box temperature of a place. On another time scale, temperature acts through various pathways as pressures of natural selection, changing the species, which again changes its effective temperature. Thus "temperature" as a biological variable within an ecosystem is quite different from the more easily measured physical temperature that can be seen in the weather box as prior to the organisms.

Although systems theory is comfortable with the idea that a certain equation is valid only within some limits, it does not deal explicitly with the interpenetrations of variables in its models, their transformations of each other. In a sense, Marx's *Capital* was the first attempt to treat a whole system rather than merely to criticize the failings of reductionism. His initial objects of investigation in Volume I, commodities, are not autonomous building blocks or atoms of economic life that are then inserted into capitalism, but rather are studied as "cells" of capitalism chosen for study precisely because they reveal the workings of the whole. They can be separated out for inspection only as aspects of the whole that called them forth. To Marx, this was an advantage because the whole is reflected in the workings of all the parts.

But for large-scale reductionists the relationship goes from given, fixed parts to the wholes that are their product. The priority and autonomy of the part is essential to systems analysis. "Autonomy" does not of course mean they have no influence on each other. The "variables" of a system may increase and decrease but remain what they are.

Parts of a system may themselves be systems with their own structure and dynamics. This approach is taken by hierarchy theory in which nested systems each contribute as parts to higher level systems (O'Neill, *et al.*, 1986). This allows us to separate domains for analysis. However, the reverse process, the defining and transforming of the subsystems by the higher level, is rarely examined.

Much statistical analysis, for instance in epidemiology, separates the independent variables which are determined outside the system from the dependent variables which are determined by them. The independent variables might be rainfall or family income; the dependent variable might be the prevalence of malaria or the suicide rate. In contrast, systems approaches recognize the feedbacks that give mutual determination: predators eat their prey, prey feed their predators; prices increase production, production leads to surpluses that lower prices; snow cools the earth by reflecting away more sunlight, and then a cooler earth has more snow. In feedback loops, changes in each variable are in a sense the causes of the changes in the others. What then happens to causation? What makes one "cause" more fundamental than another?

We can attempt to answer this question in two ways. First, we may ask where a particular pattern of change was initiated at a particular time. For instance we might ask of a predator/prey system, why does the abundance of both predator and prey vary over a five hundred mile gradient? We can analyze the feedback relationship to show that if the environmental differences along the gradient enter the system by way of the prey, say through temperature increases increasing its growth rate, this will increase the predator population so that the two variables are positively correlated. But if the environmental differences enter by way of the predator, perhaps because the predator is itself hunted more in some places than others, then increases in hunting reduce the predator and therefore increase the prey. This gives us a negative correlation between them. Therefore if we observe a positive correlation we can say that the variation is driven from the prey end and if a negative correlation then the variation is driven from the predator end. The prey mediates the action of the environment and is the "cause" of the observed pattern in the one system, the predator in the other. Similarly in a study of the capitalist world economy I examined production and prices during the 1960s and 70s and found that the major agricultural commodities exhibited a positive correlation between production or yield per acre and prices on the world market. This supports the view that price fluctuations arise mostly in the larger economy and affect production decisions rather than appear as responses to fluctuations in production, and this despite obvious and dramatic changes of production due to the weather or pests.

Whether this is generally true or not is an empirical question. In a complex network of variables the driving forces for change may originate anywhere. When we attempt to ask "does economics or geopolitics determine foreign policy?" or "is the content of TV driven by sales or ideology?" the question is unanswerable in general. The complex network of mutual determinations requires a complex answer that is hinted at in the awkward term "overdetermination" which recognizes causal processes as operating simultaneously on different levels and through different pathways. Or it brings us back to Hegel: the truth is the whole.

Then where is the locus of historical materialism? Doesn't it require that the economy determine society?

No! "The economy" as a set of factors in social life has no inherent priority over any of the other myriad interpenetrating processes. Sometimes it is determinant of particular events, sometimes not. As long as we remain within the domain of a systems network tracing pathways, everything influences everything else by some pathway or other. Changes in the productive technology change economic organization and class relations and beliefs about the world, but changes in the technology arise through the implementation of ideas, and exist in thought before they are made flesh. Or as the founding document of UNESCO stated, "Since wars are made in the minds of men . . ." Then is social life a product of intellect? Or is intellect an expression of class and gender? Approached in this way, all is mediations, and the assignment of absolute priority is dogmatism.

But this is quite different from identifying *the mode of production and reproduction,* which is present not as a "factor" in the network but as the network itself. It is the structure of that network, that mode, that defines workers and capitalists as the actors or "variables" in the network, makes it possible for sexism to have commercial value, makes legislation a political activity, or allows major events to be initiated by the caprices of monarchs. It is the context within which the various mediations play themselves out and transform each other rather than a factor among factors.

Goal Seeking

The third quality of systems, purposefulness, also betrays the origin of systems theory. The outcomes are evaluated for their correspondence to the built-in purpose, while deviations from that purpose are seen as non-adaptive, contradictory and self-destructive behaviors. These appear as system failures. The engineer can discard or a manager can reorganize the structures that lead to them. But in reality only some systems are purposeful even when they are constructed to satisfy some purpose. In others, while the "elements" are actors each with their own purposes and may be said to seek goals, the system as a whole does not.

Dialectical "wholes" are not defined by some organizing principle such as harmony or balance or maximization of efficiency. In my view, a system is characterized by its structured set of contradictory processes that gives meaning to its elements, maintains the temporary coherence of the whole and also eventually transforms it into something else, dissolves it into another system, or leads to its disintegration.

Outcomes

Once mathematical systems theory defines a set of variables and interrelations it then asks the simple mathematical question, what is the future trajectory of those variables starting from such and such initial conditions? From then on, all depends on the mathematical agility of the analyst or the computer program to come up with "solutions" of the equations. A solution is the path of the variables. The desired result is prediction, the correspondence between the theoretical and observed values of the variables.

There are only a few possible outcomes of equations:

a) The variables may increase or decrease out of bounds. This may mean a real explosion, disrupting the system. But it can also mean that past a certain point the equations are not valid.

b) The variables may reach a stable equilibrium. It then remains there unless perturbed, and returns toward equilibrium after a perturbation. If the processes include randomness, then a solution may be a stable probability distribution.

c) There may be more than one equilibrium, in which case not all of the equilibria are stable. Each stable equilibrium is the end result for the variables that start out "near" that equilibrium, within some range called its basin of attraction. The basins of attraction around the equilibria are separated by boundaries where there are unstable equilibria. The outcome then depends on the starting place, and the variables move toward the equilibrium in whose basin of attraction they start out.

d) The variables may show or approach cyclic behavior, in which case how quickly the variables cycle and the magnitude of the fluctuations describe the solution. A cyclical pattern also has its basin of attraction, the range of initial conditions from which the variables approach that cycle.

e) The trajectories may remain bounded but instead of approaching an equilibrium or a regular periodicity show seemingly erratic pathways, sometimes looking periodic for a while and then abruptly moving away, and different initial conditions no matter how similar may give quite different trajectories. This is referred to as chaos although in fact it has its own regularities.

The behavior of a system will depend on the equations themselves, the parameters, and the initial conditions. Much of the content of systems theory is the description of the relations between the assumptions of the model and the outcomes for the variables, or identifying the procedures for validating the models.

The outcomes are expressed as quantitative changes in the variables. This is an extremely useful activity for making predictions or deciding upon interventions in the system or system design. But it is also limiting, and imposes constraints on the models. Most models require specifying the equations and estimating the parameters and variables. Therefore those that are not readily measureable are likely to be omitted. For instance, we can write compartment models for epidemics that take as variables the numbers of individuals in each compartment, those who are susceptible, infected but not infective yet, infective, or recovered and immune. We make some plausible assumptions about the disease (rates of contagion, duration of latent and infective periods, rate of loss of immunity) and turn the crank, watching as numbers shift from one compartment to another. Then we can ask questions such as, will the disease persist, how long will it take to pass the peak, how many people will die before it is over, what would be the effect of immunizing $x\%$ of the children? We could add complications of differences due to age and even subdivide the population into classes with different parameters.

Contagion also depends on people's behavior, the level of panic in the population. This changes in the course of the epidemic as people observe acquaintances getting sick and dying, and may take protective action. But how much experience is needed to change behavior? How much panic before they will lose their jobs rather than face infection? What degrees of freedom do people have? How long will an altered behavior last? Do people really believe that what they do will affect what happens to them? Will they remember for next time? Since we have neither the equations for describing these aspects nor measurements of panic or historical horizon or economic vulnerability, such considerations will not usually appear in the models but at best only in the footnotes. In recent years, modeling has become a recognized major research activity. But this has had the effect of reducing modeling to the quantitative models described above.

Most systems modelers take it for granted that quantitative information ("hard" data) is preferable to qualitative ("soft") information and prefer prediction or fitting of data to understanding. In their view of science, progress goes simply from the vague, intuitive, qualitative to the precise, rigorous and quantitative. The highest achievement is the algorithm, the rule of procedure which can be applied automatically by anyone to a whole class of situations, untouched by human minds. That is the rationale behind Maynard Smith's suggestion that systems theory replaces dialectics. Marxists argue for a more complex and non-hierarchical relation between quantitative and qualitative approaches to the world.

A much smaller effort goes into qualitative systems modeling which would allow us to deal with these "soft" questions. Instead of the goal of describing a system fully in order to predict its future completely or to "optimize" its behavior, we ask how much we can get away with not knowing and still understand the system?

Whereas the engineering systems presume rather complete control over the parameters so that we can talk about optimizing the parameters, the systems we are most concerned with in nature and in society are not under our control. We try to understand them in order to identify the directions in which to push but do not trust our models to be more than useful insights into the structure or process.

Dialecticians take as the objects of our interest the processes in complex systems. Our primary concern is understanding them in order to know what to do. We ask two fundamental questions about the systems: why are things the way they are instead of a little bit different, and why are things the way they are instead of very different, and from these the practical questions of how to intervene in these complex processes to make things better for us. That is, we seek practical and theoretical understanding rather than a good fit. Precision and prediction may or may not be useful in this process, but they are not the goals of it.

The Newtonian answer to the first question is, things remain the way they are because nothing much is happening to them. Stasis is the normal state of affairs, and change must be accounted for. Order is the desired state, and disruption is treated as disaster. A dialectical view begins from the opposite end: change is universal and much is happening to change everything. Therefore equilibrium and stasis are special situations that have to be explained. All "things" (objects or patterns of objects or processes) are constantly subject to outside influences that would change them. They are also all heterogeneous internally, and the internal dynamics is a continuing source of change. Yet "things" do retain their identities long enough to be named and sometimes persist for very long times indeed. Some of them, much too long.

The dynamic answer to the first question is homeostasis, the self-regulation that is observed in physiology, ecology, climatology, the economy and indeed in all systems that show any persistence. Homeostasis takes place through the actions of positive and negative feedback loops. If an initial impact sets processes in motion that diminish that initial impact, we refer to it as negative feedback, while if the processes magnify the original change the feedback is positive. Thus positive and negative applied to feedback have nothing to do with whether we like them or not. When positive feedbacks have undesirable results that increase out of bounds, we refer to them as vicious circles.

It is often said that negative feedback stabilizes and positive feedback destabilizes a system. But this is not always the case. If positive feedback exceeds the negative then the system is unstable in the technical sense that it will move away from equilibrium. In that case, an increase of negative feedback is stabilizing. But if the indirect negative feedbacks by way of long loops of causation are too strong compared to the shorter negative feedbacks the system is also unstable and will oscillate. Then positive feedback loops can have a stabilizing effect by offsetting the excessive long negative feedbacks. Long loops behave like delays in the system. The significance of a feedback loop depends on its context in the whole. The complex systems of concern to us usually have both negative and positive feedbacks.

Homeostasis does not imply benevolence. A negative feedback loop should not be seen as the elementary unit of analysis or of design. A simple equation may give the appearance of "self regulation" in the sense that when a variable gets too big it is reduced and when it gets too small it is increased. But the reduction and the increase may have quite different causes. An increase in wages may lead to employers cutting the labor force, increasing unemployment and thus making it easier to reduce wages. A decrease in wages may lead to labor militancy that restores some of the cuts. The outcome (if nothing else happens) is a partial restoration of the original situation. Neither party is seeking homeostasis, and the wage/employment feedback is not designed or pursued by anyone to maintain economic stability. It is simply one possible manifestation of class struggle. Thus homeostasis does not imply functionalism, a view which assigns purpose to the feedback loop as such.

This distinction is important, especially when we examine apparently unsuccessful attempts to achieve socially recognized goals. Meadows, Meadows and Randers (1992) present the problem as follows:

> This book is about overshoot. Human society has overshot its limits, for the same reason that other overshoots occur. Changes are too fast. Signals are late, incomplete, distorted, ignored or denied. Momentum is great. Responses are slow . . . (2.)

From this systems-theoretic point of view, the socialized earth's error-correcting feedbacks are inadequate. And if you assume that social processes are aimed at sustainable, healthful, equitable relations among people and with the rest of nature, then the defect is in the feedback loops, the mechanisms for achieving these goals. But if agriculture fails to eliminate hunger, if resource use is not modulated to protect people's health and long-term survival, it is not because of the failings of a mechanism aimed at these goals. Rather, most of world agriculture is aimed at producing marketable commodities, resources are used to make profits, and the welfare effects are side effects of the economy. It is the contradictions among opposing forces (and between those of the ecology and the economy) rather than the failure of a good try by inadequate information systems and deficient homeostatic loops that are responsible for much of the present suffering and the threat of more.

When a change occurs in a component (or variable) of a system, that initial change percolates through a network of interacting variables. It is amplified along some pathways and buffered along others. In the end, some of the variables (not necessarily the ones that received the initial change or those nearest the point of impact) have been altered, while others remain pretty much the way they were. Therefore we identify "sinks" in the system, variables that absorb a large part of the impact of the external shock, and other aspects of the system that remain unchanged, protected by the sinks. We can even have situations where things change in ways that contradict our common sense, where for example adding nitrogen to a pond can lower the nitrogen level or an inflated military budget undermines national security. (This outcome depends on the location of positive feedbacks within a system.)

But "unchanged" requires some further examination. The "variable" is not a thing but some aspect of a thing, perhaps the numbers of individuals in a population, not "the population."

One simple system consists of a predator that feeds on a single prey. All else is treated as "external." It is sometimes the case that the predator is regulated only by the prey. Then a change in conditions that acts on the reproduction or development rate or mortality of the prey directly, that is not due to the predator, will be passed along to the predator. Increased prey leads to increased predators and this reduces the prey back toward its original value. The "prey" variable may remain unchanged while the predator population either increases in response to increased availability of prey or diminishes if fewer prey are produced. The predator variable acts as a sink in this system. Tracing the ups and downs of predator and prey finishes the tasks of the systems analysis.

But what I referred to as "prey" is really only the numbers of prey. If prey reproduction has increased with more food but the population of prey has not changed, it is because the prey are being produced faster and consumed faster. That is, the prey population is younger. Individuals may be smaller and therefore more vulnerable to heat stress. They may be more mobile, migrating to find unoccupied sites. If the prey are mosquitoes, a shorter life span may mean that they do not spread as much disease even if there are more of them. They may spend more time in cool moist shelters where they meet additional predators and the model has to be changed. Natural selection in a younger population might focus more on those qualities that affect the survival and early reproduction of the young. Thus the variable, "prey," that was unchanged in the model can be actively transformed in many directions not dealt with in the model.

The particulars of the dynamics, the relations among the positive and negative feedbacks in a system, sources and sinks, connectivity among variables, delays along pathways and their effects are all in the domain of systems theory in the narrow sense. The parts of the system become the variables of models, and equations are proposed for their dynamics. Systems theory studies these equations. Mathematical rules have been discovered for determining when the system will approach some equilibrium condition or oscillate "permanently," that is, as long as the assumptions still hold.

Modern computational methods allow for the numerical solutions of large numbers of simultaneous equations. The parameters are measured, the initial conditions of the variables are estimated or assumed. (The distinction between parameters and variables is that the parameters are assumed to be determined outside the boundaries of the "system" and are only inputs while the variables change each other within the "system.") The computer then calculates successive steps in the process and comes up with numbers, the predicted states of the variables at different times. The numerical results are compared to observations. If the correspondence is good enough, it is assumed that the model is valid, that it "accounts for" the behavior of the system being studied, or 90% of the behavior, or whatever level we decide is acceptable. If not, more data may be collected to get better estimates of parameters or the equations may be modified.

However, systems theory starts with the variables as givens. It deals with the problems of selecting variables only in a very limited way. When we approach any real system of any complexity, the question of what the right variables are to include in the model is itself quite complex. It is the classical Marxist problem of abstraction (see Ollman, 1993, for a detailed examination of dialectical abstraction). Some practical systems modeling criteria are: reciprocal interaction, commensurate time scales, measureability, variables that belong to the same discipline and can be represented by equations of change. The system should be large enough to include the major pathways of interaction, with identification of where external influences enter the network. Systems theory makes use of growing computing capacity to give numerical solutions to the differential or difference equations that describe the dynamics. In order to have precise outcomes it is necessary to have good estimates of the parameters, things like the reproductive rate of a population, the intensity of predation, the half-life of a molecule, or the cost/price ratio in an economic production function. The gathering of these measurements is difficult, so that estimates are often taken from the published literature rather than made afresh. Parameters that cannot be measured readily cannot be used.

Once variables are selected, they are then treated as unitary "things," whose only property is quantity. The mathematics will tell us which quantities increase, which decrease, which fluctuate or remain unchanging. The source of change is either in the dynamics of the variables in interaction or in perturbation from outside the system. ("Outside the system" means outside the model. In a model of species interactions a genetic change within a species is regarded as an external event, since it is external to the demographic dynamics although it is located inside the cells of the bodies of individual members of a population.) But all variables are themselves "systems" with internal heterogeneity and structure, with an internal dynamics that is influenced by events on the system scale and also changing the behavior of the variables. Thus dialectics emphasizes the provisional nature of the system and the transitory nature of the systems model.

The variables of a system change at different rates, so that some are indicators of long-term history while others are more responsive to the most recent conditions. Thus in nutritional surveys we use the height of children for their age as an indicator of long-term nutritional status, the growth over a lifetime, while weight for height indicates food intake over recent months or weeks and therefore measures acute malnutrition. Because each variable reflects its history on its own time scale, they are generally not in "balance" or harmony. Ideology need not "correspond" to class position, political power to economic power, or forests to climate. Rather, the links between variables in a system identify processes: ideology responding, not corresponding, to class position, economic power enhancing political power, political power being used to consolidate economic power, colder climate trees such as spruce and hemlock gradually displacing the oak and beech of a warmer period. But all of these processes take time, so that a system does not show a passive correlation among its parts but a network of processes constantly transforming each other. In Darwinian evolutionary theory both the adaptedness of a species to its surroundings and its non-adaptedness are required, the former showing the outcomes of natural selection and the latter identifying it as a process that is never complete and showing the history of the species. Complete adaptedness would have been an argument for special creation, not evolution, proclaiming a harmony that manifests the benevolent wisdom of the Creator.

The second question, why things are the way they are instead of very different, is a question of history, evolution, development. It is concerned with the long-term processes that change the character of systems. The variables involved in long-term change may overlap with the short-range ones, but are not in general the same. Many of the short-term processes are reversible, oscillating according to conditions without accumulating to contribute to the long run.

At any one moment the short-term events are strong processes, temporarily overwhelming some of the long-term directional changes that are imperceptible in the short run. Yet the two scales are not independent. The reversible short-term oscillations through which a system confronts changing circumstances have themselves evolved and continue to evolve as a result of their functioning in the long run. And they leave long-term residues: the breathing in and breathing out of ordinary respiration may also result in the accumulation of toxic or abrasive materials in the lung; the repetitive cycles of agricultural production can exhaust the soil; the periodicity of the tides also has its long-term effect of lengthening the day through tidal friction; the buying and selling of commodities can result in the concentration of capital. Long-term changes alter the circumstances to which the short-term system responds as well as the means available for that response.

Here mathematical systems theory is less useful, since the mathematics is much better developed for studying steady-state systems than evolving ones. (The work of Ilya Prigogine on dissipative systems is only a partial exception to this limitation.)

Conclusion

Systems analysis is one of the techniques for policy making. As its technical side becomes more sophisticated it also is usually less accessible to the non-specialist. Therefore it often reinforces a technocratic approach to public policy, and does that in the service of those who can afford to contract its services. The ruling class and its representatives are referred to in the trade by the more neutral term "decision makers." This is of course not unique to applied systems theory, but is a common correlate of its increasing use within a managerial framework. A special effort has to be made to counteract this tendency, to demystify the study of complexity and to democratize even complex decision making. The Soviet author Afanasyev, before he embraced the "free market," wrote an interesting book, *The Scientific Management of Society*, which emphasized the systems-theoretic aspects of planning as a technocratic procedure with only perfunctory nods in the direction of popular control of the planning process as a whole.

Systems theory can be understood as a "moment" in the investigation of scientific problems within complex systems by means of mathematical models. Its value depends in large measure on the context of its use, and here dialectics has a broader role that can inform that use:

1. The posing of the problem, the domain to be explored, what is taken as the "fundamental elements" and what as the givens of the problem, the boundaries that are not questioned. To do this well requires not only a substantive knowledge of the objects of interest, their dynamics and history, and an understanding of process. There is also frank partisanship, since what is taken as given and what is assumed to be "fundamental" is a political as much as a technical

problem. For instance a model of a society that consists of atomic individuals making decisions in the void can not escape the dead end of bourgeois individualist reductionism no matter how elegantly the mathematics is developed. An economic model that consists of prices and production and profits and such can give projections of trajectories of prices and production and profits and such (at best; in reality they do this very badly). But it will never lead to an understanding of economics as social relations.

Sometimes the variables are given to the systems analyst: the species in a forest, the network of production and prices, the gizmos in a radio, the molecules in an organism. That is, the "system" is presented to us as a problem to be solved rather than as an objective entity to be understood. But often it is presented more vaguely: how do we understand a rain forest or the health of a nation? The way in which a problem is framed, the selection of the system and subsystem is prior to systems theory but crucial to dialectics. A dialectical approach recognizes that the "system" is an intellectual construct designed to elucidate some aspects of reality but necessarily ignoring and even distorting others. We ask what the consequences would be of different ways of formulating a problem and of bounding an object of interest.

2. Selection of the appropriate mathematical formalisms (equations, graph diagrams, random or deterministic models, and so on). While technical criteria influence these choices there are also issues of the purposes of the model, the partially conflicting goals of precision, generality, realism, manageability and understanding. The important thing here is not to be limited by the technical traditions of a field but to examine all these choices not only for hidden assumptions but also for their implications.

3. Interpetation of results. Here qualitative understanding is an important supplement to numerical results. In the course of an investigation we may go from vague qualitative notions through quantitative explorations to more precise qualitative understanding. This is only one example of non-progressivist, nonlinear thinking that is captured in our "mysterious" negation of the negation.

Progress is not from qualitative to quantitative. Quantitative description of a system is not superior to qualitative understanding. When approaching complexity, it is not possible to measure "everything," plug it all into a model and retrieve intelligible results. For one thing, "everything" is too big. Qualitative understanding is essential in establishing quantitative models. It intrudes into the interpretation of the results. The task of mathematics is to make the arcane obvious and even trivial. That is, it must educate the intuition so that confronted with a daunting complexity we can grasp the crucial features that determine its dynamics, know where to look for the features that make it what it is, suspect mainstream questions as well as answers.

A dialectical understanding of process in general looks at the opposing forces acting on the state of a system. This is now accepted more or less in ordinary scientific practice. Excitatory and inhibitory neurons, sympathetic and parasympathetic stimulation, opposing selection forces or an opposition between selective and random processes are all part of the tool kit of modern science. However, this has still not been generalized to thinking of process as contradiction.

4. When does the system itself change and invalidate the model? We need a permanent awareness of the model as a human intellectual construct that is more or less useful within certain bounds and then can become nonsense. The internal workings of the variables in a model, the dynamics of the model itself or the development of the science eventually reveals all models as inaccurate, limited, and misleading. But this does not destroy the distinction between models that are terribly wrong from the start and those that have relative validity.

5. Structures doubts. Doubt is an essential part of the search for understanding. There are areas of science that have been consolidated to the point of near certainty. Others are border regions of our knowledge where there is a plurality of insights and opinions and conflicting evidence. Here doubt and criticism are essential. And beyond that the unknown, where we have divergent intuitions and where our biases can roam freely. But where we have the same doubts persisting for long periods this is not a sign of a postmodern pluralist democracy but of stagnation. Useful doubt is not the expression of an esthetic of indecision or a response to the petulant reproach of "you're so damn sure of yourself!" or an acknowledgement that truth is "relative," but a historical perspective on error, bias, and limitation.

The art of modeling requires the sensitivity to decide when in the development of a science a previously necessary simplification has become a gross oversimplification and a brake to further progress. This sensitivity depends on an understanding of science as a social process and of each moment as an episode in its history, a dialectical sensitivity that is not taught in the "objectivist" traditions of mechanistic systems analysis.

Thus systems theory is best understood as reflecting the dual nature of science: part of the generic evolution of humanity's understanding of the world, and a product of a specific social structure that supports and constrains science and directs it toward the goals of its owners. On the one hand it is a "moment" in the investigation of complex systems, the place between the formulation of a problem and the interpretation of its solution where mathematical modeling can make the obscure obvious. On the other hand it is the attempt of a reductionist scientific tradition to come to terms with complexity, non-linearity and change through sophisticated mathematical and computational techniques, a groping toward a more dialectical understanding that is held back both by its philosophical biases and the institutional and economic contexts of its development.

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