GENERAL SYSTEMS THEORY

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Summary

General system theory is a theme in the philosophy of science concerned with recognition of parallel approaches or methods in various disciplines, which are not generally recognized as related because of increasingly specialized languages. This program is most promising in the context of disciplines in which the conception of a system is that of an “organized whole,” specifically a portion of the world that is recognized as “itself” in spite of continual changes taking place within it. A living organism is a prominent example. Regarded as a system, a living organism can be recognized as an amalgam of “subsystems,” for example, in the case of an animal, a skeleton, tissues, organs, and cells; and also embedded into a hierarchy of “supersystems,” for example, species, genera, classes (in the biological hierarchy), or family, tribe, and nation (in the social hierarchy). In the last few millennia, the history of our species was marked by successive concentric integration of the social hierarchy, resulting in increase of cooperation internally and intensification of conflict externally. In the course of the last century, the latter effect has become a conspicuous threat to the survival of humanity. It seems that only the extension of these integration processes to include humanity as a whole and even the biosphere beyond can remove this threat.

1. Contributions of General System Theory to the Philosophy of Science

The term "general system theory" is usually ascribed to Ludwig von Bertalanffy (1901–1972) and traced to his criticism of the teleological approach to biological phenomena. This approach was characteristic of a school of thought represented by so-called "vitalists."

Aristotle distinguished between two kinds of causes—efficient and final. Metaphorically speaking, efficient causes can be said to "push from behind," so to say, whereas final ones "beckon from ahead." To put it in another way, an efficient cause of an event B is assumed to be an event A, which precedes B. That is, B occurs *because* A occurred. B is conceived as a final cause of A if A occurs *in order that* B may occur. In this interpretation, B is regarded as a goal "pursued" by some agency, and A as a way to reach that goal (make B happen.) Thus, "final" causes imply goals, and these, in turn, are usually associated with actions of sentient beings.

Vitalists, in particular, emphasized "final" causes in explaining biological processes. Characteristic of this sort of explanation was that of H. Driesch, a vitalist, who in 1905 attributed the result of an experiment to the operation of a "final cause. Driesch regarded his experiment as a manifestation of "equifinality," a principle associated with teleology. He cut a sea urchin embryo in its early stage into two and placed the two halves in separate milieus containing nutrients necessary for their development. Both embryos developed into full sea urchins. Driesch argued that had the process been "mechanical," in other words guided by a chain of efficient causes ("pushing from behind," so to say), each half embryo would develop into a half of an urchin. Instead, both embryos developed into whole urchins, as if the goal of becoming an urchin "beckoned from ahead." In this way Driesch claimed to have demonstrated a biological process guided by equifinality—a manifestation of vitalism. In this sense one could say that identical twins demonstrate equifinality. Such twins are born when the fertilized egg splits in two. Both halves develop into normal babies, not into two halves of a baby.

Bertalanffy argued that the principle of equifinality was manifested in a class of systems more general than biological ones, namely, so called "open" systems. That is to say, equifinality characterizes behavior of biological systems because they are open rather than because they are living beings "pursuing goals" characteristic of their type.

To illustrate that equifinality can be explained without recourse to "final causes," Bertalanffy called attention to the growth of fishes. If the growth of a fish is arrested in some period of its life, say by restricting intake of nutrients, then after the restraints are removed, the fish will "catch up" and eventually grow to its characteristic size. A vitalist would explain this phenomenon by appeal to a "goal," that is, becoming a fish of a size characteristic of its species. Bertalanffy explained this phenomenon by analyzing the behavior of an open system (see *History and Philosophy of the Systems Sciences: The Road towards Uncertainty*.)

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1.1 A Mathematical Model of Equifinality

Consider the simplest model of a living organism, say a sphere with a permeable surface. The environment contains nutrients, which pass through the surface of the sphere into the interior. Wastes are secreted out of the system through the same membrane. Now the metabolism of an organism can be broken up into two processes—anabolism, that is a constructive process, which transforms nutrients into substances of which the organism consists, and catabolism, a destructive process, which breaks down these substances. Thus, anabolism contributes to the growth of the organism, catabolism to an opposite process. In our model we have supposed that the wastes are excreted through the permeable surface, hence at a rate proportional to the area of the surface. The rate of anabolism, on the other hand, can be assumed to be proportional to the mass (or volume) of the organism, being a result of multiplying "cells" throughout the whole organism. Since the organism in our model is a sphere, the volume is proportional to the cube of the radius, while the surface is proportional to the square of the radius. All these assumptions can be represented by the following differential equation:

$$\frac{dv}{dt} = c_1 r^3 - c_2 r^2 \qquad (1)$$

where v is the volume of our sphere and r its radius. Or, choosing appropriate constants, we have

$$\frac{dv}{dt} = k_1 v + k_2 v^{2/3} \qquad (2)$$

Now the solution of this differential equation will display v (the volume) as a function of t (time) and a constant, which will depend on the initial condition, say the magnitude of v at time 0. It can be easily shown, however, that as t tends to infinity, that is, after "a long time," v will tend to be independent of this initial condition. That is to say, in the long run, the volume of our "organism" will be the same, no matter what volume we started with. And this implies that if the growth is impeded for any stretch of time, then after the removal of the impediment the organism will grow to the same size regardless of the duration of the impediment. In other words, we have an instance of equifinality deduced from properties of a system, which is not necessarily a living system, although living systems do have properties similar to the ones assumed in our model.

We can observe this effect in organisms other than fishes. We note that in general very small animals (for example, humming birds) must absorb much more nutrient per unit weight than very large ones, suggesting that it is the ratio of surface to volume rather than some teleological goal-seeking principle that governs the process associated with their development.

1.2 A More General Model of Equifinality

We need not assume any characteristic of specifically "living" systems to demonstrate equifinality of open systems in contrast to non-equifinality of closed systems. Consider a system of monomolecular chemical reactions modelled by a system of linear differential equations with constant coefficients, where x_i is the mass of substance i (i = 1, 2, … n).

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$$
\begin{aligned}
\frac{dx_1}{dt} &= a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n + c_1 \\
\frac{dx_2}{dt} &= a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n + c_2 \\
&\vdots \\
\frac{dx_n}{dt} &= a_{n1}x_1 + a_{n2}x_2 + \ldots + a_{nn}x_n + c_n
\end{aligned}
\tag{3}
$$

The sign of a_{ij} indicates whether substance j contributes to increase or decrease of substance i. The sign of constant c_i indicates whether substance x_i flows through the permeable surface out of the tank (if $c < 0$) or from the environment into the tank (if $c > 0$). Note that if some of the c's are non-zero, the system is open; if all are equal to zero, the system is closed.

Consider the latter case. Since no substance can either enter from the environment or leave the tank, it follows that the total mass of the substances in the tank must remain constant. Imposing this condition, we have the following additional equation:

$$x_1 + x_2 + \ldots x_n = M \quad \text{(a constant)} \tag{4}$$

Or

$$x_n = M - Sx_i \qquad (i = 1, 2, \ldots, n-1) \tag{5}$$

Substituting this result in the above system of differential equations with all $c_i = 0$ (closed system), we see that the equilibrium state will now depend on M, that is, on the mass of the substances involved, in other words on the initial state of the system. Hence the system will not exhibit equifinality.

If the system is open, the condition of constant total mass of the substances involved need not be imposed. Now some c_i will be different from zero. They will represent sources or sinks. If the determinant of the coefficients does not vanish, the system will have a unique solution in which it will persist if it is stable. Note that this final state of the system will now be a function of the system parameters only (the a_{ij} and the c_i) and will be independent of the initial condition (that is, the initial masses of the substances involved.) Thus, no matter what it starts with, it will end up in the same state. It will exhibit equifinality.

This difference of behavior observed and theoretically explained between closed and open systems was, perhaps, the point of departure of what came to be called general system theory. The term suggests that systems can be classified into types each characterized by some "laws" or regularities peculiar to it. Knowledge accumulated in this way could then be systematized into a general theory of systems.

Bertalanffy's emphasis on openness as the cardinal characteristic of living systems may have inspired I. Prigogine to develop a far-reaching study of open systems, both living and nonliving with special emphasis on the ability of such systems to persist in steady

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states far from thermodynamic equilibria, which is also a cardinal principle of sustained life. Recognition of this property provides another refutation of vitalism. The Second Law of Thermodynamics preludes decrease of entropy within a closed system (that is, one whose boundaries are impermeable to either matter-energy or information). In the course of its development, however, a living system exhibits a growth of "organized complexity," which, in view of the identity established between information and negative entropy, amounts to a decrease of entropy. Contrary to the contention of some vitalists, this phenomenon does not imply that the Second Law is "invalid" in living systems, inasmuch as the imperative of maximization of entropy applies only to closed systems, which living organisms cannot be. Indeed, cutting a living organism off from its environment leads inexorably to its death. It is this principle that E. Schroedinger expressed in his book addressed to the layman, *What is Life?*, namely, in the maxim "Life feeds on negative entropy" (see *Living Systems Theory*.)

1.3 The Search for a Unified Language of Science

Another stimulus to the development of general system theory was the alarming growth of highly specialized branches of science, each generating specific methodologies both theoretical and empirical and in the process spawning a multitude of specialized jargons, each understood only by narrow specialists and precluding fruitful communication between scientists pursuing and developing these specialties. One need only glance at a page of a dictionary of mathematics to get an idea of why the builders of the Tower of Babel had to abandon the project. ["And the earth was one language, and one speech…And they said…let us build a tower, whose top may reach unto heaven…And the Lord said, Behold the people are one, and they all have one language…Let us confound their language, that they may not understand one another's speech And they left off to build the city…Therefore is the name of it called Babel." Genesis 11: 1 - 9]

A way of conceptually unifying sciences in which systems play a central role was proposed by R.W. Gerard. System in this context is to be understood as some circumscribed portion of the world that can be recognized as "itself," in spite of the fact that its constituent parts are subject to perpetual change or flux. Living organisms are clear examples of systems in this sense. Also in some ways, organized assemblies of organisms such as a beehive, an anthill, a herd, a flock, a human community, an institution, and so on, are well known examples of systems. To illustrate invariance in the course of constant change, consider a human body composed of organs, which, in turn, may be composed of tissues, and these of cells, which, in turn are composed of molecules of chemicals, etc. Clearly, in the course of metabolism, these constituent parts undergo continual change. It has been estimated that in some relatively short period, say a month, every molecule in our body may have been replaced by another. Likewise, no officer or employee of the Bank of England who lived a century ago is alive today. Except for some ruins, no present-day building in Rome stood in the days of the Caesars. Still each of such systems retains his/her/its identity: you, reader, are still you, the Bank of England is still the Bank of England, Rome is still Rome.

This characteristic of systems is subsumed under the term *organization*. Gerard pointed out that organization of living systems (in either the biological or the social sense) can

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be regarded as consisting of at least three fundamental components: structure, behavior and evolution. Also discernible are levels of organization. As the lowest level of a living organism, Gerard arbitrarily chose the cell. In an animal, cells are organized into tissues, tissues into organs, and so on, built up to the individual organism. In many species multitudes of organisms are organized into communities. In the case of humans, there is a hierarchy of communities: family, clan, tribe, in various historical periods, chiefdom, state, alliance, the international system. These hierarchies are observed in the social dimension. In the biological dimension we recognize species, orders, families, classes, phyla, ecospheres and, finally, the biosphere—the vast web of life on the planet. Organization is reflected in the interactions among the parts, for example, predation, symbiosis, parasitism, aggression, cooperation, competition, communication, and so on. Gerard constructed a partial representation of the relationships between systems of this sort, partly in terms of biological, and partly in terms of social organization. The hierarchy from the cell at the bottom to the international system on top was represented by the rows of a matrix; the three aspects—structure, behavior, and evolution, or, as Gerard was fond of saying, being, acting and becoming—were represented by the columns. The cells of the matrix were filled in, with the disciplines associated respectively with each level and each aspect. In this way the disciplines representing the main areas of biological and social sciences were exhibited as an organized whole. The relationships suggest how the concepts, terms, hypotheses, and theories of one discipline could be seen to be analogous of those of another.

J.G. Miller used a similar model in his representation of the "general organism." The rows of the matrix are essentially the same as Gerard's. The columns, however, represent the various components of the organism's functioning, for example, "ingestor," "extruder," "reproducer," "motor," "decider," etc. The entries in the cells of Miller's matrix are surveys of literature dealing with the assumed aspect. Some matrix entries are empty, indicating that no literature was found related to the particular function at a particular level. In a way, the scheme is similar to Mendeleev's periodic table of elements, in which empty cells represented elements still to be discovered. That their ultimate discovery confirmed Mendeleev's model became a major contribution to the systematization of chemistry and its eventual integration with physics. Whether Miller's scheme will serve a similar function is not certain in view of the fact that the functioning components of living systems were identified *a priori*; in some cases their identification appears forced.

1.4 The Evolutionary Approach to the Problem of Unifying the Language of Science

Kenneth E. Boulding, economist, regarded the main task of general system theory as that of counteracting the splitting of scientific language into mutually incomprehensible jargons. He found the rapid specialization in science not simply inconvenient but alarming, in the sense of leading to a complete breach between specializing scientists and so essentially the end of science. Boulding evidently took the legend of the Tower of Babel seriously; he wrote:

> ... communication between the disciplines becomes increasingly difficult, and the Republic of Learning is breaking up into isolated subcultures with only tenuous lines

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> of communication among them ... The reason for this breakup … is that in the course of specialization the receptors of information themselves become specialized. Hence physicists talk only to physicists, economists to economists ... worse still nuclear physicists only to nuclear physicists and econometricians to econometricians. One wonders sometimes if science will not grind to a stop in an assemblage of walled-in hermits, each mumbling to himself in a private language that only he can understand.

The task of a general theory of systems, in Boulding's estimation, should be to replace the multitude of isolated cells (which has emerged in the wake of burgeoning specialization) by a stately edifice, where the successive levels represent increasing complexity of concepts and methods of inquiry, which have marked the evolution of knowledge, along with the evolution of our species. Specifically, Boulding sketched the crucial features of each of nine levels.

1. **The structure level**. Theory on this level does not involve any "dynamics", that is processes occurring "in time," simply because time does not enter into the conceptual repertoire of the investigator. The principal cognitive act on this level is classification. Classical (Greek) geometry and pre-evolutionary biology (culminating in the taxonomy of Linnaeus) are foremost examples of cognition operating on this level.

2. **The simplest dynamic level**. Here motion (and hence time) enter the cognition process but only in the simplest contexts, where the rates of processes remain constant. Systems called "clockworks" are objects of study on this level of cognition. For example, Descartes, arguably the founder of the philosophy of science, thought that animals (except humans) were complex clockworks. Eventually, mathematics developed to include non-uniform motions, for example of heavenly bodies and paved the way for celestial mechanics, the crowning achievements of Newton and Laplace. But the planetary system could still be conceived as a sophisticated clockwork. Determinism was the unshakable foundation of this level of cognition. The only causation recognized was that associated with "efficient" causes, "pushing from behind." There was no place for the idea of a "final" (teleological) cause guiding a process to a preconceived goal.

3. **The control mechanism**. Here the fundamental idea of cybernetics took root. The thermostat, the simplest example is a device based on the principle of feedback. The goal is, say, the desired temperature of the room. Information about the actual temperature is fed to a generator of heat, which responds by increasing the flow of heat (if the actual temperature is below that desired) or restricting it (if the actual temperature is higher). In this way, the desired temperature is attained and kept. Note, however, that teleological causation need not be invoked. It only appears, as if a pre-set goal is "pursued" by the mechanism. Actually its action can be explained by the operation of efficient causes. Amusing toys have been used to illustrate the illusion of "purpose" supposedly guiding the behavior of inanimate objects. A toy turtle keeps following lines drawn on the floor, as if this were its "aim in life." When its battery begins to give out, it quits following the lines, makes for a source of charge and plugs itself in. Recharged, it returns to its "aim in life"—to follow the lines on the floor.

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4. **The open system**. Such a system is able to "maintain itself," that is, resist disintegration ("death") for some time by an elaborate interchange of input (matter, energy, information) from its environment with responses, that is action on the environment. We are now in Gerard's second column—behavior. The lowest row in Gerard's generalized living system is the cell. Already the cell is able to "maintain its identity" (for some time) by matching behavior (output into the environment) with input. We are now in the realm of life.

5. **The genetic social level** (exemplified by a plant). Such a system is characterized by a division of labor by its fundamental structural components—the cells with differentiated mutually dependent parts—roots, leaves, seeds, etc. There are, however, no specialized sense organs. Information receptors are diffuse. There is no "communication," as we know it. A tree can "distinguish" light from dark, cold from hot, but not anything analogous to an "if so, then so" relationship.

6. **The animal level**. This is characterized typically by increased mobility and highly specialized information receptors (e.g. eyes, ears). Now we observe quasi-teleological behavior patterns and infer self-awareness. The most conspicuous characteristic of living systems on this level is the presence of nervous systems, in some animals of impressive complexity and organization, including a "brain," where an enormous amount of information can be stored, organized, and processed. This information is passed among specialized channels to all parts of the organism, stimulating appropriate effectors. In short we are now dealing with "behaving" systems.

7. **The human level**. We conceive an organism on this level as endowed with "consciousness," an assumed potential of developing a language of symbols rather than signals. Signals are totally bound by some concrete situation. Thus, a cloud is a signal of possible rain. Animals communicate by signals, e.g. postures or sounds, denoting the state of affairs here and now, such as "Keep out! My territory." Or "I'm ready to mate." Or "Danger! A predator!" Or "We're off! Follow me!" A dog can say, "Hark! Some one is coming!" Or "Give me some of what you are eating." Or "I love you." Or even, "I'm sorry". But no dog can say, "While you were out, some one was trying to break in, but I scared him away by barking." Or "If you don't give me some of what you are eating, I shan't love you any more, and then *you* will be sorry!" In short, unlike signals, symbols can express states of affairs long past, expected in the future, or non-existent. To quote Boulding, "... man is probably the only organization that knows that it dies, that contemplates in its behavior a whole life span and more... Man exists not only in time and space but in history."

8. **Human society**. Its units ("cells") can be identified as individuals. But more important than the individual as a biological system is the "role" that an individual represents. An individual invariably dies, but the "role"—a slot in the structure of a human society—remains, filled by successive individuals. In studying systems on this level we must concern ourselves with the meaning of communications in their social and historical contexts, with dimensions of value systems, with the transcription of images into historical record, the subtle symbolic languages of the

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arts, the enormously complex symbolic languages of scientific disciplines, and with problems of translating one of these languages into others. On this level we are dealing with life in all its complexity and richness.

9. **The transcendental level**. Being a devout Christian, Boulding extends the system concept to "transcendental" constructs. These include the "ultimates," "absolutes," and "inescapable unknowables," which somehow also exhibit intuitively conceived systemic structures and relationships. According to Boulding, it will be a sad day for man when nobody is allowed to ask questions that do not have any answers.

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Bibliography

Agrell S. and Holmberg S. (1998). Operational research in Swedish military long term and complex development projects. *Systems Research and Behavioral Science* **15**, 1–65. [This describes procedures of organizing military units into efficiently functional systems.]

Amos S. (1880). *Political and Legal Remedies for War*. 254 pp. London: Cassell, Potter, Galpin and Co. [This work is essentially a prognosis that in the near future wars will become ever less destructive and will eventually become altogether obsolete.]

Bertalanffy L. von. (1968). *General System Theory*. 295 pp. New York: George Braziller. [This work is an overview of general system theory as the field is conceived by the author.]

Boulding K. E. (1956). General System Theory—The Skeleton of Science. *Management Science* **2**, 197–208. [In this overview general system theory is represented as a hierarchy of systems of increasing complexity and autonomy.]

Dickson P. (1971). *Think Tanks*. 369 pp. New York: Atheneum. [A survey of groups engaged in applying current knowledge to design of public policies.]

Gerard R. W. (1958). Concepts and principles of biology. *Behavioral Science* **3**, 95–102. [This is a representation of the interrelationship among scientific disciplines according to the level of systems and their aspects (structure, behavior, and evolution) with which they are concerned.]

Landau H. G. and Rapoport A. (1953). Contributions to the mathematical theory of contagion and spread of information. *Bulletin of Mathematical Biophysics* **15**, 173–183. [This establishes via mathematical models of contagion and the spread of information the analogical aspects of the two processes.]

Malthus T. R. (1976). *An Essay on the Principle of Population*. 291 pp. Hammondsworth: Penguin. [In this essay, first published in 1796, it is shown that the growth of population is bound to outstrip the growth of available arable land and consequently the sustenance of the population.]

Meadows D. L. (1974). *Dynamics of Growth in a Finite World*. 637 pp. Cambridge, MA.: Wright-Allen. [This is a generalization of the Malthusian principle (eventual scarcity induced by growth of population and demand) applicable to out time.]

Meadows D. H., Meadows D. L., Randers J., and Behrens, W. W. III. (1992). *Beyond the Limits*. 300 pp.

Post Mills, Vermont: Chelsea Green.

Miller J. G. (1978). *Living Systems*. 1102 pp. New York: McGraw Hill. [This is a survey of general system theory based on a model of a generalized organism.]

Milner B. Z. (1980). Methods of Analysis and Formation of Organized Systems of Control (in Russian). *Sistemnye isledovania* 1980: 109–134.

Prigogine I. (1984). *Order out of Chaos, Man's New Dialogue with Nature*. 349 pp. Toronto: Bantam Books. [The "new dialogue with nature" is made possible by the recognition of the relationship between thermodynamic processes characteristic of open systems and the conversion of "negative entropy" into information, which enhances increase of order in a living system.

Biographical Sketch

Anatol Rapoport was born in Lozovaya, Russia in 1911 and emigrated to the United States in 1922, He was educated in Chicago Public schools, 1922-1929, Staatsakademie für Musik und darstellende Kunst in Vienna, 1929-1934 and University of Chicago, Ph.D. 1941 (Mathematics). He served in the US. Air Force as Lieutenant, then Captain (1942-1946) and upon discharge entered academe, holding positions at University of Chicago, Illinois Institute of Technology, University of Michigan and University of Toronto. His principal fields of interest were philosophy, and applications of mathematical methods in the behavioral sciences, particularly conflict theory, and general system theory. He was one of the four founders in 1955 of the International Society for General Systems Research.

Rapoport's publications include about 400 articles and twenty books, among them Operational Philosophy, Strategy and Conscience, Prisoner's Dilemma, Mathematical Methods in the Social and Behavioral Sciences, General System Theory, Decision Theory and Decision Behavior.
Among his honours and awards are Lenz International Peace Reserach Prize, Society for General Systems Research Comprehensive Achievement Award, Harold D. Lasswell Award for Distinguished Scientific Contributions to Political Psychology, Doctor of Humane Letters (Hon), University of Western Michigan, Doctor of Laws (Hon), University of Toronto, Doctor of Science (Hon) Royal Military College, Ehrendoktor, University of Bern.

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