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Modern Theories of Development
(in German, English, Spanish)

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General System Theory

Foundations, Development, Applications

Revised Edition

by Ludwig von Bertalanffy

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and superficial—is that in the gamut of modern sciences and life new conceptualizations, new ideas and categories are required, and that these, in one way or another, are centered about the concept of "system." To quote, for a change, from a Soviet author:

> The elaboration of specific methods for the investigation of systems is a general trend of present scientific knowledge, just as for 19th century science the primary concentration of attention to the elaboration of elementary forms and processes in nature was characteristic (Lewada, in Hahn, 1967, p. 185).

The dangers of this new development, alas, are obvious and have often been stated. The new cybernetic world, according to the psychotherapist Ruesch (1967) is not concerned with people but with "systems"; man becomes replaceable and expendable. To the new utopians of systems engineering, to use a phrase of Boguslaw (1965), it is the "human element" which is precisely the unreliable component of their creations. It either has to be eliminated altogether and replaced by the hardware of computers, self-regulating machinery and the like, or it has to be made as reliable as possible, that is, mechanized, conformist, controlled and standardized. In somewhat harsher terms, man in the Big System is to be—and to a large extent has become—a moron, button-pusher or learned idiot, that is, highly trained in some narrow specialization but otherwise a mere part of the machine. This conforms to a well-known systems principle, that of progressive mechanization—the individual becoming ever more a cogwheel dominated by a few privileged leaders, mediocrities and mystifiers who pursue their private interests under a smokescreen of ideologies (Sorokin, 1966, pp. 558ff).

Whether we envisage the positive expansion of knowledge and beneficent control of environment and society, or see in the systems movement the arrival of *Brave New World* and *1984*—it deserves intensive study, and we have to come to terms with it.

On the History of Systems Theory

As we have seen, there is a consensus in all major fields—from subatomic physics to history—that a re-orientation of science is due. Developments in modern technology parallel this trend.

So far as can be ascertained, the idea of a "general system theory" was first introduced by the present author prior to cybernetics, systems engineering and the emergence of related fields. The story of how he was led to this notion is briefly told elsewhere in this book (pp. 89ff.), but some amplification appears to be in order in view of recent discussions.

As with every new idea in science and elsewhere, the systems concept has a long history. Although the term "system" itself was not emphasized, the history of this concept includes many illustrious names. As "natural philosophy," we may trace it back to Leibniz; to Nicholas of Cusa with his coincidence of opposites; to the mystic medicine of Paracelsus; to Vico's and ibn-Khaldun's vision of history as a sequence of cultural entities or "systems"; to the dialectic of Marx and Hegel, to mention but a few names from a rich panoply of thinkers. The literary gourmet may remember Nicholas of Cusa's *De ludo globi* (1463; cf. von Bertalanffy, 1928b) and Hermann Hesse's *Glasperlenspiel*, both of them seeing the working of the world reflected in a cleverly designed, abstract game.

There had been a few preliminary works in the field of general system theory. Köhler's "physical *gestalten*" (1924) pointed in this direction but did not deal with the problem in full generality, restricting its treatment to *gestalten* in physics (and biological and psychological phenomena presumably interpretable on this basis). In a later publication (1927), Köhler raised the postulate of a system theory, intended to elaborate the most general properties of inorganic compared to organic systems; to a degree, this demand was met by the theory of open systems. Lotka's classic (1925) came closest to the objective, and we are indebted to him for basic formulations. Lotka indeed dealt with a general concept of systems (not, like Köhler's, restricted to systems of physics). Being a statistician, however, with his interest lying in population problems rather than in biological problems of the individual organism, Lotka, somewhat strangely, conceived communities as systems, while regarding the individual organism as a sum of cells.

Nevertheless, the necessity and feasibility of a systems approach became apparent only recently. Its necessity resulted from the fact that the mechanistic scheme of isolable causal trains and meristic treatment had proved insufficient to deal with theoretical problems, especially in the biosocial sciences, and with the practical problems posed by modern technology. Its feasibility resulted from various new developments—theoretical, epistemological, mathematical, etc.—which, although still in their beginnings, made it progressively realizable.

The present author, in the early 20's, became puzzled about obvious lacunae in the research and theory of biology. The then prevalent mechanistic approach just mentioned appeared to neglect or actively deny just what is essential in the phenomena of life. He advocated an organismic conception in biology which emphasizes consideration of the organism as a whole or system, and sees the main objective of biological sciences in the discovery of the principles of organization at its various levels. The author's first statements go back to 1925–26, while Whitehead's philosophy of "organic mechanism" was published in 1925. Cannon's work on homeostasis appeared in 1929 and 1932. The organismic conception had its great precursor in Claude Bernard, but his work was hardly known outside France; even now it awaits its full evaluation (cf. Bernal, 1957, p. 960). The simultaneous appearance of similar ideas independently and on different continents was symptomatic of a new trend which, however, needed time to become accepted.

These remarks are prompted by the fact that in recent years "organismic biology" has been re-emphasized by leading American biologists (Dubos, 1964, 1967; Dobzhansky, 1966; Commoner, 1961) without, however, mentioning the writer's much earlier work, although this is duly recognized in the literature of Europe and of the socialist countries (e.g., Ungerer, 1966; Blandino, 1960; Tribiño, 1946; Kanaev, 1966; Kamarýt, 1961, 1963; Bendmann, 1963, 1967; Afanasjew, 1962). It can be definitely stated that recent discussions (e.g., Nagel, 1961; Hempel, 1965; Beckner, 1959; Smith, 1966; Schaffner, 1967), although naturally referring to advances of biology in the past 40 years, have not added any new viewpoints in comparison to the author's work.

In philosophy, the writer's education was in the tradition of neopositivism of the group of Moritz Schlick which later became known as the Vienna Circle. Obviously, however, his interest in German mysticism, the historical relativism of Spengler and the history of art, and similar unorthodox attitudes precluded his becoming a good positivist. Stronger were his bonds with the Berlin group of the "Society for Empirical Philosophy" of the 1920's, in which the philosopher-physicist Hans Reichenbach, the psychologist A. Herzberg, the engineer Parseval (inventor of dirigible aircraft) were prominent.

In connection with experimental work on metabolism and growth on the one hand, and an effort to concretize the organismic program on the other, the theory of open systems was advanced, based on the rather trivial fact that the organism happens to be an open system, but no theory existed at the time. The first presentation, which followed some tentative trials, is included in this volume (Chapter 5). Biophysics thus appeared to demand an expansion of conventional physical theory in the way of generalization of kinetic principles and thermodynamic theory, the latter becoming known, later on, as irreversible thermodynamics.

But then, a further generalization became apparent. In many phenomena in biology and also in the behavioral and social sciences, mathematical expressions and models are applicable. These, obviously, do not pertain to the entities of physics and chemistry, and in this sense transcend physics as the paragon of "exact science." (Incidentally, a series *Abhandlungen zur exakten Biologie*, in succession of Schaxel's previous *Abhandlungen zur theoretischen Biologie*, was inaugurated by the writer but stopped during the war.) The structural similarity of such models and their isomorphism in different fields became apparent; and just those problems of order, organization, wholeness, teleology, etc., appeared central which were programmatically excluded in mechanistic science. This, then, was the idea of "general system theory."

The time was not favorable for such development. Biology was understood to be identical with laboratory work, and the writer had already gone out on a limb when publishing *Theoretische Biologie* (1932), another field which has only recently become academically respectable. Nowadays, when there are numerous journals and publications in this discipline and model building has become a fashionable and generously supported indoor sport, the resistance to such ideas is hard to imagine. Affirmation of the concept of general system theory, especially by the late Professor Otto Pötzl, well-known Vienna psychiatrist, helped the writer to overcome his inhibitions and to issue a statement (reproduced in Chapter 3 of this book). Again, fate intervened. The paper (in *Deutsche Zeitschrift für Philosophie*) had reached the proof stage, but the issue to carry it was destroyed in the catastrophe of the last war. After the war, general system theory was presented in lectures (cf. Appendix), amply discussed with physicists (von Bertalanffy, 1948a) and discussed in lectures and symposia (e.g., von Bertalanffy et al., 1951).

The proposal of system theory was received incredulously as fantastic or presumptuous. Either—it was argued—it was *trivial* because the so-called isomorphisms were merely examples of the truism that mathematics can be applied to all sorts of things, and it therefore carried no more weight than the "discovery" that $2 + 2 = 4$ holds true for apples, dollars and galaxies alike; or it was *false* and *misleading* because superficial analogies—as in the famous simile of society as an "organism"—camouflage actual differences and so lead to wrong and even morally objectionable conclusions. Or, again, it was philosophically and methodologically *unsound* because the alleged "irreducibility" of higher levels to lower ones tended to impede analytical research whose success was obvious in various fields such as in the reduction of chemistry to physical principles, or of life phenomena to molecular biology.

Gradually it was realized that such objections missed the point of what systems theory stands for, namely, attempting scientific interpretation and theory where previously there was none, and higher generality than that in the special sciences. General system theory responded to a secret trend in various disciplines. A letter from K. Boulding, economist, dated 1953, well summarized the situation:

> I seem to have come to much the same conclusion as you have reached, though approaching it from the direction of economics and the social sciences rather than from biology—that there is a body of what I have been calling "general empirical theory," or "general system theory" in your excellent terminology, which is of wide applicability in many different disciplines. I am sure there are many people all over the world who have come to essentially the same position that we have, but we are widely scattered and do not know each other, so difficult is it to cross the boundaries of the disciplines.

In the first year of the Center for Advanced Study in the Behavioral Sciences (Palo Alto), Boulding, the biomathematician A. Rapoport, the physiologist Ralph Gerard and the present writer found themselves together. The project of a Society for General System Theory was realized at the Annual Meeting of the American Association for the Advancement of Science in 1954. The name was later changed into the less pretentious "Society for General Systems Research," which is now an affiliate of the AAAS and whose meetings have become a well-attended fixture of the AAAS conventions. Local groups of the Society were established at various centers in the United States and subsequently in Europe. The original program of the Society needed no revision:

> The Society for General Systems Research was organized in 1954 to further the development of theoretical systems which are applicable to more than one of the traditional departments of knowledge. Major functions are to: (1) investigate the isomorphy of concepts, laws, and models in various fields, and to help in useful transfers from one field to another; (2) encourage the development of adequate theoretical models in the fields which lack them; (3) minimize the duplication of theoretical effort in different fields; (4) promote the unity of science through improving communication among specialists.

The Society's Yearbooks, *General Systems*, under the efficient editorship of A. Rapoport, have since served as its organ. Intentionally *General Systems* does not follow a rigid policy but rather provides a place for working papers of different intention as seems to be appropriate in a field which needs ideas and exploration. A large number of investigations and publications substantiated the trend in various fields; a journal, *Mathematical Systems Theory*, made its appearance.

Meanwhile another development had taken place. Norbert Wiener's *Cybernetics* appeared in 1948, resulting from the then recent developments of computer technology, information theory, and self-regulating machines. It was again one of the coincidences occurring when ideas are in the air that three fundamental contributions appeared at about the same time: Wiener's *Cybernetics* (1948), Shannon and Weaver's information theory (1949) and von Neumann and Morgenstern's game theory (1947). Wiener carried the cybernetic, feedback and information concepts far beyond the fields of technology and generalized it in the biological and social realms. It is true that cybernetics was not without precursors. Cannon's concept of homeostasis became a cornerstone in these considerations. Less well-known, detailed feedback models of physiological phenomena had been elaborated by the German physiologist Richard Wagner (1954) in the 1920's, the Swiss Nobel prize winner W. R. Hess (1941, 1942) and in Erich von Holst's *Reafferenzprinzip*. The enormous popularity of cybernetics in science, technology and general publicity is, of course, due to Wiener and his proclamation of the Second Industrial Revolution.

The close correspondence of the two movements is well shown in a programmatic statement of L. Frank introducing a cybernetics conference:

> The concepts of purposive behavior and teleology have long been associated with a mysterious, self-perfecting or goal-seeking capacity or final cause, usually of superhuman or super-natural origin. To move forward to the study of events, scientific thinking had to reject these beliefs in purpose and these concepts of teleological operations for a strictly mechanistic and deterministic view of nature. This mechanistic conception became firmly established with the demonstration that the universe was based on the operation of anonymous particles moving at random, in a disorderly fashion, giving rise, by their multiplicity, to order and regularity of a statistical nature, as in classical physics and gas laws. The unchallenged success of these concepts and methods in physics and astronomy, and later in chemistry, gave biology and physiology their major orientation. This approach to problems of organisms was reinforced by the analytical preoccupation of the Western European culture and languages. The basic assumptions of our traditions and the persistent implications of the language we use almost compel us to approach everything we study as composed of separate, discrete parts or factors which we must try to isolate and identify as potent causes. Hence, we derive our preoccupation with the study of the relation of two variables. We are witnessing today a search for new approaches, for new and more comprehensive concepts and for methods capable of dealing with the large wholes of organisms and personalities. The concept of teleological mechanisms, however it may be expressed in different terms, may be viewed as an attempt to escape from these older mechanistic formulations that now appear inadequate, and to provide new and more fruitful conceptions and more effective methodologies for studying self-regulating processes, self-orientating systems and organisms, and self-directing personalities. Thus, the terms *feedback, servo-mechanisms, circular systems,* and *circular processes* may be viewed as different but equivalent expressions of much the same basic conception. (Frank *et al.*, 1948, condensed).

A review of the development of cybernetics in technology and science would exceed the scope of this book, and is unnecessary in view of the extensive literature of the field. However, the present historical survey is appropriate because certain misunderstandings and misinterpretations have appeared. Thus Buckley (1967, p. 36) states that "modern Systems Theory, though seemingly springing de novo out of the last war effort, can be seen as a culmination of a broad shift in scientific perspective striving for dominance over the last few centuries." Although the second part of the sentence is true, the first is not; systems theory did not "spring out of the last war effort," but goes back much further and had roots quite different from military hardware and related technological developments. Neither is there an "emergence of system theory from recent developments in the analysis of engineering systems" (Shaw, 1965) except in a special sense of the word.

Systems theory also is frequently identified with cybernetics and control theory. This again is incorrect. Cybernetics, as the theory of control mechanisms in technology and nature and founded on the concepts of information and feedback, is but a part of a general theory of systems; cybernetic systems are a special case, however important, of systems showing self-regulation.

Trends in Systems Theory

At a time when any novelty, however trivial, is hailed as being revolutionary, one is weary of using this label for scientific developments. Miniskirts and long hair being called teenage revolution, and any new styling of automobiles or drug introduced by the pharmaceutical industry being so announced, the word is found as well. The isomorphism under discussion is more than mere analogy. It is a consequence of the fact that, in certain respects, corresponding abstractions and conceptual models can be applied to different phenomena. Only in view of these aspects will system laws apply. This is not different from the general procedure in science. It is the same situation as when the law of gravitation applies to Newton's apple, the planetary system, and tidal phenomena. This means that in view of certain limited aspects a theoretical system, that of mechanics, holds true; it does not mean that there is a particular resemblance between apples, planets, and oceans in a great number of other aspects.

A third objection claims that system theory lacks explanatory value. For example, certain aspects of organic purposiveness, such as the so-called equifinality of developmental processes (p. 40), are open to system-theoretical interpretation. Nobody, however, is today capable of defining in detail the processes leading from an animal ovum to an organism with its myriad of cells, organs, and highly complicated functions.

Here we should consider that there are degrees in scientific explanation, and that in complex and theoretically little-developed fields we have to be satisfied with what the economist Hayek has justly termed "explanation in principle." An example may show what is meant.

Theoretical economics is a highly developed system, presenting elaborate models for the processes in question. However, professors of economics, as a rule, are not millionaires. In other words, they can explain economic phenomena well "in principle" but they are not able to predict fluctuations in the stock market with respect to certain shares or dates. Explanation in principle, however, is better than none at all. If and when we are able to insert the necessary parameters, system-theoretical explanation "in principle" becomes a theory, similar in structure to those of physics.

Aims of General System Theory

We may summarize these considerations as follows.

Similar general conceptions and viewpoints have evolved in various disciplines of modern science. While in the past, science tried to explain observable phenomena by reducing them to an

interplay of elementary units investigatable independently of each other, conceptions appear in contemporary science that are concerned with what is somewhat vaguely termed "wholeness," i.e., problems of organization, phenomena not resolvable into local events, dynamic interactions manifest in the difference of behavior of parts when isolated or in a higher configuration, etc.; in short, "systems" of various orders not understandable by investigation of their respective parts in isolation. Conceptions and problems of this nature have appeared in all branches of science, irrespective of whether inanimate things, living organisms, or social phenomena are the object of study. This correspondence is the more striking because the developments in the individual sciences were mutually independent, largely unaware of each other, and based upon different facts and contradicting philosophies. They indicate a general change in scientific attitude and conceptions.

Not only are general aspects and viewpoints alike in different sciences; frequently we find formally identical or isomorphic laws in different fields. In many cases, isomorphic laws hold for certain classes or subclasses of "systems," irrespective of the nature of the entities involved. There appear to exist general system laws which apply to any system of a certain type, irrespective of the particular properties of the system and of the elements involved.

These considerations lead to the postulate of a new scientific discipline which we call general system theory. Its subject matter is formulation of principles that are valid for "systems" in general, whatever the nature of their component elements and the relations or "forces" between them.

General system theory, therefore, is a general science of "wholeness" which up till now was considered a vague, hazy, and semimetaphysical concept. In elaborate form it would be a logico-mathematical discipline, in itself purely formal but applicable to the various empirical sciences. For sciences concerned with "organized wholes," it would be of similar significance to that which probability theory has for sciences concerned with "chance events"; the latter, too, is a formal mathematical discipline which can be applied to most diverse fields, such as thermodynamics, biological and medical experimentation, genetics, life insurance statistics, etc.

This indicates major aims of general system theory:

(1) There is a general tendency towards integration in the various sciences, natural and social.
(2) Such integration seems to be centered in a general theory of systems.
(3) Such theory may be an important means for aiming at exact theory in the nonphysical fields of science.
(4) Developing unifying principles running "vertically" through the universe of the individual sciences, this theory brings us nearer to the goal of the unity of science.
(5) This can lead to a much-needed integration in scientific education.

A remark as to the delimitation of the theory here discussed seems to be appropriate. The term and program of a general system theory was introduced by the present author a number of years ago. It has turned out, however, that quite a large number of workers in various fields had been led to similar conclusions and ways of approach. It is suggested, therefore, to maintain this name which is now coming into general use, be it only as a convenient label.

It looks, at first, as if the definition of systems as "sets of elements standing in interrelation" is so general and vague that not much can be learned from it. This, however, is not true. For example, systems can be defined by certain families of differential equations and if, in the usual way of mathematical reasoning, more specified conditions are introduced, many important properties can be found of systems in general and more special cases (cf. Chapter 3).

The mathematical approach followed in general system theory is not the only possible or most general one. There are a number of related modern approaches, such as information theory, cybernetics, game, decision, and net theories, stochastic models, operations research, to mention only the most important ones. However, the fact that differential equations cover extensive fields in the physical, biological, economical, and probably also the behavioral sciences, makes them a suitable access to the study of generalized systems.

I am now going to illustrate general system theory by way of some examples.

Closed and Open Systems: Limitations of Conventional Physics

My first example is that of closed and open systems. Conventional physics deals only with closed systems, i.e., systems which are considered to be isolated from their environment. Thus, physical chemistry tells us about the reactions, their rates, and the chemical equilibria eventually established in a closed vessel where a number of reactants is brought together. Thermodynamics expressly declares that its laws apply only to closed systems. In particular, the second principle of thermodynamics states that, in a closed system, a certain quantity, called entropy, must increase to a maximum, and eventually the process comes to a stop at a state of equilibrium. The second principle can be formulated in different ways, one being that entropy is a measure of probability, and so a closed system tends to a state of most probable distribution. The most probable distribution, however, of a mixture, say, of red and blue glass beads, or of molecules having different velocities, is a state of complete disorder; having separated all red beads on one hand, and all blue ones on the other, or having, in a closed space, all fast molecules, that is, a high temperature on the right side, and all slow ones, a low temperature, at the left, is a highly improbable state of affairs. So the tendency towards maximum entropy or the most probable distribution is the tendency to maximum disorder.

However, we find systems which by their very nature and definition are not closed systems. Every living organism is essentially an open system. It maintains itself in a continuous inflow and outflow, a building up and breaking down of components, never being, so long as it is alive, in a state of chemical and thermodynamic equilibrium but maintained in a so-called steady state which is distinct from the latter. This is the very essence of that fundamental phenomenon of life which is called metabolism, the chemical processes within living cells. What now? Obviously, the conventional formulations of physics are, in principle, inapplicable to the living organism *qua* open system and steady state, and we may well suspect that many characteristics of living systems which are paradoxical in view of the laws of physics are a consequence of this fact.

It is only in recent years that an expansion of physics, in order to include open systems, has taken place. This theory has shed light on many obscure phenomena in physics and biology, and has also led to important general conclusions of which I will mention only two.

The first is the principle of equifinality. In any closed system, the final state is unequivocally determined by the initial conditions: e.g., the motion in a planetary system where the positions of the planets at a time t are unequivocally determined by their positions at a time t_0. Or in a chemical equilibrium, the final concentrations of the reactants naturally depend on the initial concentrations. If either the initial conditions or the process is altered, the final state will also be changed. This is not so in open systems. Here, the same final state may be reached from different initial conditions and in different ways. This is what is called equifinality, and it has a significant meaning for the phenomena of biological regulation. Those who are familiar with the history of biology will remember that it was just equifinality that led the German biologist Driesch to embrace vitalism, i.e., the doctrine that vital phenomena are inexplicable in terms of natural science. Driesch's argument was based on experiments on embryos in early development. The same final result, a normal individual of the sea urchin, can develop from a complete ovum, from each half of a divided ovum, or from the fusion product of two whole ova. The same applies to embryos of many other species, including man, where identical twins are the product of the splitting of one ovum. Equifinality, according to Driesch, contradicts the laws of physics, and can be accomplished only by a soul-like vitalistic factor which governs the processes in foresight of the goal, the normal organism to be established. It can be shown, however, that open systems, insofar as they attain a steady state, must show equifinality, so the supposed violation of physical laws disappears (cf. pp. 132f.).

Another apparent contrast between inanimate and animate nature is what sometimes was called the violent contradiction between Lord Kelvin's degradation and Darwin's evolution, between the law of dissipation in physics and the law of evolution in biology. According to the second principle of thermodynamics, the general trend of events in physical nature is toward states of maximum disorder and levelling down of differences, with the so-called heat death of the universe as the final outlook, when all energy is degraded into evenly distributed heat of low temperature, and the world process comes to a stop. In contrast, the living world shows, in embryonic development and in evolution, a transition towards higher order, heterogeneity, and organization. But on the basis of the theory of open systems, the apparent contradiction between entropy and evolution disappears. In all irreversible processes, entropy must increase. Therefore, the change of entropy in closed systems is always positive; order is continually destroyed. In open systems, however, we have not only production of entropy due to irreversible processes, but also import of entropy which may well be negative. This is the case in the living organism which imports complex molecules high in free energy. Thus, living systems, maintaining themselves in a steady state, can avoid the increase of entropy, and may even develop towards states of increased order and organization.

From these examples, you may guess the bearing of the theory of open systems. Among other things, it shows that many supposed violations of physical laws in living nature do not exist, or rather that they disappear with the generalization of physical theory. In a generalized version the concept of open systems can be applied to nonphysical levels. Examples are its use in ecology and the evolution towards a climax formation (Whittacker), in psychology where "neurological systems" were considered as "open dynamic systems" (Krech), in philosophy where the trend toward "trans-actional" as opposed to "self-actional" and "inter-actional" viewpoints closely corresponds to the open system model (Bentley).

Information and Entropy

Another development which is closely connected with system theory is that of the modern theory of communication. It has often been said that energy is the currency of physics, just as economic values can be expressed in dollars or pounds. There are, however, certain fields of physics and technology where this currency is not readily acceptable. This is the case in the field of communication which, due to the development of telephones, radio, radar, calculating machines, servomechanisms and other devices, has led to the rise of a new branch of physics.

The general notion in communication theory is that of in-