# GENERAL SYSTEM THEORY: A NEW APPROACH TO UNITY OF SCIENCE

## 1. PROBLEMS OF GENERAL SYSTEM THEORY[1]

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IN HIS novel *Time Must Have a Stop,* Mr. Aldous Huxley introduces a gentleman whose concern is bridge-building between the dissevered parts of our spiritual life: physics and sociology, science and mysticism, power politics and world peace. The author, who feels like no one else the secret pulse of our epoch, makes us understand that this time of crisis needs new syntheses and a universal and profound reorientation—although in his private life Mr. de Vries is an uncurable fool. In this discussion let me also do some bridge-building, hoping, however, not to share all the shortcomings of Mr. de Vries.

Surveying the evolution of modern science, we find the remarkable phenomenon that similar general problems and viewpoints appear in the different branches of science. From its beginning, scientific thinking was governed by principles of an elementalistic type. This is natural because they represent the simplest modes of thinking. However, the progress in all sciences presents problems of a non-elementalistic or synholistic type. Thus, principles of wholeness, of organization, of dynamic interaction, appear in modern, as opposed to classical, physics; they appear in modern biology in the form of organismic conceptions in contrast to the analytical, summative, and machine-theoretical conceptions of the biology of yesterday; they are manifest in psychological *gestalt* theory, in contrast to classical association psychology, as well as in the modern conceptions of sociology. Thus, similar general viewpoints are present in all branches

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of science, irrespective of whether inanimate things, organisms, mental or social phenomena are concerned.

This parallelism is the more striking because these developments are mutually independent and largely unaware of each other, and differ in one important respect from the mechanistic conception of the nineteenth century. This parallelism is not based upon the Laplacean belief in a final reduction of all phenomena to physics and chemistry, and ultimately to a play of atoms, but rather we are aware of the autonomy of laws in the different levels of reality. The problem is of a catholic nature and it asks for a universal doctrine of "wholeness" and "organization."

Modern science is characterized by its highly developed specialization which became necessary because of the vast amount of facts and the complication of scientific techniques, experimental as well as theoretical. On the other hand, there is a strong tendency towards generalized systems of scientific laws which is based upon the insight that important developments frequently arise on borderlines and by way of a synthesis of formerly unconnected fields.

We may recall Koehler's (15) physical *gestalten*, taking into account physical systems, biological phenomena and the neurological basis of mental phenomena, supposedly based upon physical *gestalten*. Lotka (18) was probably the first to apply a concept of system which is general and not, like Koehler's, limited to systems in physics, though with him, as a statistician, we find the somewhat paradoxical situation that populations are conceived as systems, individual organisms, however, as "sums of cells." More recently, Cybernetics (24) was developed as a general theory, intended to embrace communication engineering, neurophysiology, psychology, and sociological aspects. Trimmer (22) has given a presentation of the "Response of Physical Systems." The notion of "system" being defined as "any arrangement or combination, as of parts or elements, in a whole," applies to a cell, a human being, a society, as well as to an atom, a planet, or a galaxy. Trimmer's treatment, closely linked with Cybernetics, is restricted to physical systems, which are the simplest for study, but he hints explicitly to a wider scope, emphasizing that the study of physical systems may pave the way towards that of non-physical ones. Lienau (17), starting from sociology, aims at a general quantitative theory of organization. His scope is identical with ours, although his mathematical approach (group theoretical considerations) is different from ours. Forms of a generalized kinetics have been used by von Bertalanffy (7, 8, 9) in the theory of metabolism and growth, by Spiegelman (21) in a theory of competition and regulation in the organism, by Volterra and others (11, 16, 23) in the theory of biocoenoses and in demography. The concept of equilibrium is applied not only to physical, but also to biological and economic phenomena (12). Other examples of the same trend can easily be found in recent literature.

Thus there is a strong, though never clearly expressed, feeling that a generalization of scientific theory is necessary. The system of "laws of nature" was as yet almost identical with physics. It seems necessary to expand our conceptual schemes in order to establish systems of exact laws also in those fields where an application of physico-chemical laws is unfeasible.

These considerations lead us to postulate a new basic scientific discipline which we call General System Theory (3, 4, 5). A survey of some principles of General System Theory has been given recently (6). There are principles which apply to the entities called "systems" in general, whatever the nature of their component elements and the relations or forces between them. The fact that all sciences mentioned are concerned with "systems," leads to a formal correspondence or isomorphy in their general principles, and even in their special laws if the conditions correspond in the phenomena under consideration.

General System Theory would be an exact doctrine of wholeness as a "pure natural science" or *reine Naturwissenschaft,* to use Kant's expression,—that is, it is a hypothetico-deductive system of those principles which follow from the definition of system and by the introduction of more or less special conditions. In this sense, system theory is *a priori* and independent of its interpretation in terms of empirical phenomena, but is applicable to all empirical realms concerned with systems. Its position is similar to that, for example, of probability theory, which is in itself a formal mathematical doctrine but which can be applied, by way of empirical interpretation of its terms, to different fields, from games to thermodynamics, to biological and medical experimentation, to genetics, to life insurance statistics, and so on. Speaking more precisely, fields of application of system theory are all levels of science: first, the level of physical; second, of biological; third, of sociological units. Essentially it represents a generalized kinetics and dynamics which is applicable not only to physical systems, but to phenomena of any kind.

General System Theory allows logico-mathematical definitions of many ill-defined and much disputed concepts such as those of wholeness, summativity, emergent and resultant evolution, progressive segregation, mechanization and centralization, individuality, hierarchical order, controlling parts, trigger action, competition, finality and equifinality, physical and biological time, and so forth. It can be demonstrated that these notions and the characteristics concerned are consequences of the general definition of systems or of certain system conditions. In this way, many pseudo-problems which have caused endless discussions and which supposedly trespass the limit of science, disappear in logico-mathematical analysis.

It is a striking phenomenon, the significance of which is hardly understood, that laws which are structurally identical or isomorphic apply to fundamentally different fields. For example, the exponential law applies to radioactive decay, to the breakdown of a chemical compound in monomolecular reaction, to the death of bacteria under the influence of light or disinfectants, to the consumption of an animal by starvation, and to the decrease of an animal or human population where death rate is higher than birth rate. It is equally basic for the principle of diminishing returns, i. e., the fact that in many phenomena the per unit effect of a causal factor decreases with increasing magnitude of that factor. This applies to the relation, in domestic animals, of meat, milk, and egg production to food consumption, as well as to the stimulus-sensation ratio in Weber-Fechner's law. With a positive exponent, the exponential law applies to the unlimited Malthusian growth of bacterial, animal or human populations, to the increase of human knowledge, as measured by the number of pages devoted to scientific discoveries in a textbook on the history of science (18), or by the number of publications on the genetics of drosophila in the last few decades (14). The entities concerned —atoms, molecules, bacteria, animals, human beings, or books—are widely different, and so are the causal mechanisms involved. There is no reduction of the laws of higher levels to physics in the sense of the classical mechanistic view. But the mathematical expressions are identical for all these phenomena. Another equation, the logistic, represents in physical chemistry the expression for autocatalytic reactions; in biology it describes certain cases of organic growth; it was first stated by Verhulst about 1820, and re-discovered by Pearl, for describing in demography the laws of growth of populations in a limited space of living. Equally it governs the advancement of technical inventions such as the expansion of the railroad network in the United States or the increase of the number of wireless sets in operation. The same system of simultaneous differential equations represents in physical chemistry the general expression of the law of mass action, and in demography the general expression for the interaction of species, wherefrom the laws of the struggle for existence and of biological equilibria between groups of organisms can be derived; essentially the same equations can be used to develop a theory of competition and regulation within the individual organism (21). What is known, in national economy, as Pareto's law (19) of the distribution of income within a nation, and is a general expression for competition, represents in biology the law of allometric growth describing the relative increase of organs, chemical compounds or physiological activities with respect to body size. In biology, the power formula was rediscovered by Lapicque in 1907, and then by J. Huxley in the twenties. A curve describing the growth of certain animals can equally be used for the burden of taxation (personal communication by Professor W. A. Joehr, St. Gallen). Volterra has developed a population dynamics which is isomorphic to mechanical dynamics, and uses concepts such as demographic energy and potential, life action, etc.; it leads to a principle of minimum vital action corresponding to the principle of minimum action in mechanics.

Isomorphies are basic for the use of models and model conceptions in science. The use of models in metal or wood in technology and the abundance of model-conceptions in physics is commonplace. Actually, the progress of science is largely based upon suitable model conceptions. General System Theory will be an important means to facilitate and to control the application of model-conceptions and the transfer of principles from one realm to another. It will no longer be necessary to duplicate or triplicate the discovery of the same principles in different fields isolated from each other.

The isomorphy of laws in different fields has an important bearing on the question of the Unity of Science. So far unification of science has been seen in the reduction of all sciences to physics, in the final resolution of all phenomena into physical events. This could be achieved, if ever, only in an inscrutable future. From our point of view, Unity of Science wins a much more concrete aspect. We are certainly able to state scientific laws for the different levels of strata of reality. And here we find, speaking in the "formal" mode (to use Carnap's (10) expression), a correspondence or isomorphy of laws and conceptual schemes in different fields. Speaking in "material" language, this means that the world shows a structural uniformity manifesting itself by isomorphic traces of order in its different levels or realms. The Unity of Science and the unitary conception of the world is based not upon the possibly futile and certainly far-fetched hope finally to reduce all levels of reality to the lowest level, but is based on the structural isomorphy of laws in the different fields of science and reality. The shortcomings of the mechanistic conception have led to vitalism, that is, to the opinion that certain fields are beyond the limits of and inexplicable by exact science. The system conception seems to be an important step toward the mathematization of non-physical realms and their development into exact science.

We have emphasized the usefulness and necessity of model conceptions in science, but they also bear serious danger.

We can distinguish three types of interpretation:

The first level is represented by analogies, that is, apparent similarities of phenomena which correspond neither in the active factors nor in the governing laws. To this class belong the *simulacra vitae,* much in vogue some decades ago, such as the artificial ameba which is a droplet of chloroform wandering about in a dish of water and eating shellac, or the osmotic vegetations of copper ferrocyanate that strikingly resemble a jungle of algae, and so forth. Analogies of this kind have led to the belief that the "riddle of life" is almost solved, that artificial organisms will be manufactured just the day after to-morrow—but, in fact, there is only a superficial similarity with certain biological phenomena.

A second level may be called logical homologies. In this case phenomena differ in the factors involved, but are governed by laws that are of an identical structure or are isomorphic. Such models are widely used in physics. For instance, the flow of a liquid and heat transmission are expressed by the same law, but the physicist is well aware of the fact that there is not a flow of a "heat fluid" but only an imparting of molecular movement. The general system laws of which we are speaking belong to this class of logical homologies.

The third level, finally, is explanation in proper sense, namely, the indication of the actual conditions and factors as well as of the specific laws of phenomena.

We have already mentioned that logical homologies or model-conceptions are one of the most potent tools in science. It will be a further important task of System Theory to control the application of model conceptions and to distinguish exactly between true homologies, i. e., isomorphic structure of laws, and misleading analogies. Take, for instance, the conception of social units, economies, nations, states or civilization, as "organisms." It can be stated correctly that social units are "systems," that is, complexes of elements in interaction to which certain system laws can be applied, a few of which we have mentioned. But System Theory easily shows that these units are not "organisms." The concept of organism involves further determinations, such as intimacy of the relations between the component elements, centralization, the existence of controlling parts, etc. The conception of social units as organisms is what Vaihinger called a "personificative fiction." It is harmless enough, though not correct if applied to bee-hives or ant communities; in human society, however, it paves the way to serfdom, to use Hayek's (13) expression, and makes the state or the nation a Hobbes' Leviathan, degrading the individual to a mere cell of the social organism. We are organismic philosophers but we remember what Nietzsche has stated as the philosopher's first obligation: namely, to warn against himself.

We are giving now a few examples in order to show how System Theory elucidates age-old problems in science and philosophy.

It is a basic characteristic of every organic system that it maintains itself in a perpetual change of its components. In the cell, there is a continuous destruction of chemical materials through which it persists as a whole. In the multicellular organism, cells are dying and are replaced by new ones, but it maintains itself as a whole. In the biocoenosis and the species, individuals die and others are born. And so every organic system appears stationary if considered from a certain point of view. But what seems to be a persistent entity at a certain level is maintained, in fact, by a perpetual change, building up and breaking down of systems of the next lower order,—chemical compounds in the cell, of cells in the multicellular organism, of individuals in ecological systems.

The characteristic state of the living organism is that of an open system. We call a system closed if no materials enter or leave it. It is open if there is inflow and outflow and therefore change of the component materials.

The characterization of organisms as systems in dynamic equilibrium is old enough but only in recent years the kinetics and thermodynamics of open systems have been developed. It is an expansion of current physical theory, and leads to results that are highly significant from the standpoint of science as well as of philosophy. Only a few consequences shall be indicated here (5).

A profound difference between most inanimate and living systems can be expressed by the concept of equifinality. In most physical systems the final state is determined by the initial conditions. Take, for instance, the motion in a planetary system where the positions at a time $t$ are determined by those at a time $t_0$, or a chemical equilibrium where the final concentrations depend on the initial ones. If either the initial conditions or the process is modified, the final state is changed.

Vital phenomena show a different behavior. Here, to a wide extent, the final state can be reached from different initial conditions and in different ways. Such behavior we call equifinal. Thus, for instance, the same final result, namely, a normal larva of the sea-urchin will be developed from a complete embryo, from a half embryo after the experimental separation of the cells, from two embryos after their fusion, or after a translocation of the blastomeres. This experiment was considered by Driesch to be the main proof of vitalism. According to Driesch such behavior is inexplicable in physico-chemical terms and can be accomplished only by the action of a vitalistic factor, entelechy, which governs the processes in foresight of the goal to be reached. It is therefore an important question whether equifinality is a proof of vitalism. The answer is that it is not.

Analysis shows that closed systems cannot behave as equifinal. This is the reason why equifinality is found in inanimate nature only in rather exceptional cases. Open systems, on the other hand, where materials are exchanging with the environment, may attain a steady state which is independent of the initial conditions and is so equifinal.

There are certain biological cases where equifinality can be formulated quantitatively, as e. g., in organic growth (7, 8, 9). The same final size which is characteristic for the species can be reached from different initial sizes (e. g., in litters of a different number of individuals) or after a temporary suppression of growth (e. g., by a diet insufficient in quantity or in vitamins). According to quantitative theory, the growth of an organism can be considered as the result of a counteraction between the anabolism and catabolism of building materials. In the most common type of animal growth, anabolism is a surface function, catabolism a function of body mass. With increasing size, the surface-volume ratio is shifted in disfavour of surface. This eventually leads to a balance between anabolism and catabolism which is independent of the initial size and depends only on the species-specific ratio of the constants of metabolism. Therefore it is equifinal.

There is another striking contrast between inanimate and animate nature. In the physical world there seems to be a tendency towards maximum disorder and a chaotic state. According to the second law of thermodynamics, higher forms of energy, such as mechanical and chemical energy, radiation, etc., are continually degraded to indirected heat movement. Heat gradients, in turn, continually disappear, and so the Universe runs down and approaches entropy death as its irrevocable fate when all energy is converted into heat of low temperature and the world process comes to a stop. In contrast to this, there appears to be a tendency towards states of higher order and differentiation in organic development and evolution. In the billions of years of phylogenetic evolution, as well as in the short span of ontogenetic development, life rises to states of ever higher organization. It has often been stated that a trend towards increasing complication is a primary characteristic of life, in contrast to the inanimate nature. By Woltereck (25) this was called anamorphosis.

These problems gain new aspects if we pass from closed systems, which alone are taken into account by classical thermodynamics, to open systems. The direction of happenings in closed systems is towards states of maximum entropy, because entropy must increase in all irreversible processes according to the second law of thermodynamics. However, in the evolution of open systems, entropy may decrease because there is not only production of entropy due to irreversible processes but also transport of entropy, negative or positive, through the introduction of material from outside. Therefore, such systems may spontaneously develop towards greater heterogeneity and complexity (20). Probably it is just this thermodynamical characteristic of organisms as open systems which is at the basis of the apparent contrast of catamorphosis in inorganic, and anamorphosis in living, nature.

In this way, just the peculiar and supposedly vitalistic characteristics of biological phenomena take on a new appearance in the theory of open systems. We have already stated in 1929 (1) the principles of maintenance in a steady state and that of transition towards higher complication as general characteristics of the living world. Exactly these characteristics have their fulcrum in the kinetics and thermodynamics of open systems. Equifinality, which was brought forward by Driesch as the "first proof" of vitalism, is a consequence of steady state conditions. Similarly, self-regulation in metabolism was considered as explicable only by a governing entelechy, but its general principles follow from the laws of steady states. Anamorphosis contradicts classical thermodynamics, but is in accordance with thermodynamics of open systems. Self-multiplication of elementary biological units, such as genes and chromosomes, was offered by Driesch as a "second proof" of vitalism. If a hypothesis which was advanced by the author (2) should be correct, this phenomenon would also be a consequence of the fact that these units are metabolizing systems. Certainly we do not go far astray if we suppose that the principles of open systems are near to the very root of the central biological problems.

Unified science is an age-old dream, which has found its expression in

Leibniz' idea of *Mathesis Universalis* and in the demonstration *more geometrico* of the rationalist philosophers. It might be that future development of General System Theory will prove to be a major step towards this goal. The mechanistic world view has ushered the world into the unruled domination of physical technology, the mechanization of mankind and the catastrophic crises of our times. An organismic view may lead to a vaster synthesis and a better adjustment to the problems with which we are confronted—provided that we are aware that such a view also has its limitations, and that all our intellectual schemes are but a humble effort to re-draw a few traces of the great plan of reality.

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