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The History and Status of General Systems Theory

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HISTORICAL PRELUDE

In order to evaluate the modern "systems approach," it is advisable to look at the systems idea not as an ephemeral fashion or recent technique, but in the context of the history of ideas. (For an introduction and a survey of the field see [15], with an extensive bibliography and Suggestions for Further Reading in the various topics of general systems theory.)

In a certain sense it can be said that the notion of system is as old as European philosophy. If we try to define the central motif in the birth of philosophical-scientific thinking with the Ionian pre-Socratics of the sixth century B.C., one way to spell it out would be as follows. Man in early culture, and even primitives of today, experience themselves as being "thrown" into a hostile world, governed by chaotic and incomprehensible demonic forces which, at best, may be propitiated or influenced by way of magical practices. Philosophy and its descendant, science, was born when the early Greeks learned to consider or find, in the experienced world, an order or *kosmos* which was intelligible and, hence, controllable by thought and rational action.

One formulation of this cosmic order was the Aristotelian world view with its holistic and telelogical notions. Aristotle's statement, "The whole is more than the sum of its parts," is a definition of the basic system problem which is still valid. Aristotelian teleology was eliminated in the later development of Western science, but the problems contained in it, such as the order and goal-directedness of living systems, were negated and by-passed rather than solved. Hence, the basic system is still not obsolete.

A more detailed investigation would enumerate a long array of thinkers who, in one way or another, contributed notions to what nowadays we call systems theory. If we speak of hierarchic order, we use a term introduced by the Christian mystic, Dionysius the Aeropagite, although he was specu-

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lating about the choirs of angels and the organism of the Church. Nicholas of Cusa [5], that profound thinker of the fifteenth century, linking Medieval mysticism with the first beginnings of modern science, introduced the notion of the *coincidentia oppositorum,* the opposition or, indeed, fight among the parts within a whole which, nevertheless, forms a unity of higher order. Leibniz's hierarchy of monads looks quite like that of modern systems; his *mathesis universalis* presages an expanded mathematics which is not limited to quantitative or numerical expressions and is able to formalize all conceptual thinking. Hegel and Marx emphasized the dialectic structure of thought and of the universe it produces: the deep insight that no proposition can exhaust reality but only approaches its coincidence of opposites by the dialectic process of thesis, antithesis, and synthesis. Gustav Fechner, known as the author of the psychophysical law, elaborated in the way of the nature philosophers of the nineteenth century supraindividual organizations of higher order than the usual objects of observation; for example, life communities and the entire earth, thus romantically anticipating the ecosystems of modern parlance. Incidentally, the present writer wrote a doctoral thesis on this topic in 1925.

Even such a rapid and superficial survey as the preceding one tends to show that the problems with which we are nowadays concerned under the term "system" were not "born yesterday" out of current questions of mathematics, science, and technology. Rather, they are a contemporary expression of perennial problems which have been recognized for centuries and discussed in the language available at the time.

One way to circumscribe the Scientific Revolution of the sixteenth-seventeenth centuries is to say that it replaced the descriptive-metaphysical conception of the universe epitomized in Aristotle's doctrine by the mathematical-positivistic or Galilean conception. That is, the vision of the world as a telelogical cosmos was replaced by the description of events in causal, mathematical laws.

We say "replaced," not "eliminated," for the Aristotelian dictum of the whole that is more than its parts still remained. We must strongly emphasize that order or organization of a whole or system, transcending its parts when these are considered in isolation, is nothing metaphysical, not an anthropomorphic superstition or a philosophical speculation; it is a fact of observation encountered whenever we look at a living organism, a social group, or even an atom.

Science, however, was not well prepared to deal with this problem. The second maxim of Descartes' *Discours de la Methode* was "to break down every problem into as many separate simple elements as might be possible." This, similarly formulated by Galileo as the "resolutive" method, was the conceptual "paradigm" [35] of science from its foundation to modern laboratory work: that is, to resolve and reduce complex phenomena into elementary parts and processes.

This method worked admirably well insofar as observed events were apt to be split into isolable causal chains, that is, relations between two or a few variables. It was at the root of the enormous success of physics and the consequent technology. But questions of many-variable problems always remained. This was the case even in the three-body problem of mechanics; the situation was aggravated when the organization of the living organism or even of the atom, beyond the simplest proton-electron system of hydrogen, was concerned.

Two principal ideas were advanced in order to deal with the problem of order or organization. One was the comparison with man-made machines; the other was to conceive of order as a product of chance. The first was epitomized by Descartes' *bete machine,* later expanded to the *homme machine* of Lamettrie. The other is expressed by the Darwinian idea of natural selection. Again, both ideas were highly successful. The theory of the living organism as a machine in its various disguises—from a mechanical machine or clockwork in the early explanations of the iatrophysicists of the seventeenth century, to later conceptions of the organism as a caloric, chemodynamic, cellular, and cybernetic machine [13] provided explanations of biological phenomena from the gross level of the physiology of organs down to the submicroscopic structures and enzymatic processes in the cell. Similarly, organismic order as a product of random events embraced an enormous number of facts under the title of "synthetic theory of evolution" including molecular genetics and biology.

Nothwithstanding the singular success achieved in the explanation of ever more and finer life processes, basic questions remained unanswered. Descartes' "animal machine" was a fair enough principle to explain the admirable order of processes found in the living organism. But then, according to Descartes, the "machine" had God for its creator. The evolution of machines by events at random rather appears to be self-contradictory. Wristwatches or nylon stockings are not as a rule found in nature as products of chance processes, and certainly the mitochondrial "machines" of enzymatic organization in even the simplest cell or nucleoprotein molecules are incomparably more complex than a watch or the simple polymers which form synthetic fibers. "Surival of the fittest" (or "differential reproduction" in modern terminology) seems to lead to a circuitous argument. Self-maintaining systems must exist before they can enter into competition, which leaves systems with higher selective value or differential reproduction predominant. That self-maintenance, however, is the explicandum; it is not provided by the ordinary laws of physics. Rather, the second law of thermodynamics prescribes that ordered systems in which irreversible processes take place tend toward most probable states and, hence, toward destruction of existing order and ultimate decay [16].

Thus neovitalistic currents, represented by Driesch, Bergson, and others, reappeared around the turn of the present century, advancing quite legitimate arguments which were based essentially on the limits of possible regulations in a "machine," of evolution by random events, and on the goal-directedness of action. They were able, however, to refer only to the old Aristotelian "entelechy" under new names and descriptions, that is, a supernatural, organizing principle or "factor."

Thus the "fight on the concept of organism in the first decades of the twentieth century," as Woodger [56] nicely put it, indicated increasing doubts regarding the "paradigm" of classical science, that is, the explanation of complex phenomena in terms of isolable elements. This was expressed in the question of "organization" found in every living system; in the question whether "random mutations *cum* natural selection provide all the answers to the phenomena of evolution" [32] and thus of the organization of living things; and in the question of goal-directedness, which may be denied but in some way or other still raises its ugly head.

These problems were in no way limited to biology. Psychology, in gestalt theory, similarly and even earlier posed the question that psychological wholes (e.g., perceived *gestalten)* are not resolvable into elementary units such as punctual sensations and excitations in the retina. At the same time sociology [49, 50] came to the conclusion that physicalistic theories, modeled according to the Newtonian paradigm or the like, were unsatisfactory. Even the atom appeared as a minute "organism" to Whitehead.

FOUNDATIONS OF GENERAL SYSTEMS THEORY

In the late 1920's von Bertalanffy wrote:

> Since the fundamental character of the living thing is its organization, the customary investigation of the single parts and processes cannot provide a complete explanation of the vital phenomena. This investigation gives us no information about the coordination of parts and processes. Thus the chief task of biology must be to discover the laws of biological systems (at all levels of organization). We believe that the attempts to find a foundation for theoretical biology point at a fundamental change in the world picture. This view, considered as a method of investigation, we shall call *"organismic biology"* and, as an attempt at an explanation, *"the system theory of the organism"* [7, pp. 64 ff., 190, 46, condensed].

Recognized "as something new in biological literature" [43], the organismic program became widely accepted. This was the germ of what later became known as general systems theory. If the term "organism" in the above statements is replaced by other "organized entities," such as social groups, personality, or technological devices, this is the program of systems theory.

The Aristotelian dictum of the whole being more than its parts, which was neglected by the mechanistic conception, on the one hand, and which led to a vitalistic demonology, on the other, has a simple and even trivial answer—trivial, that is, in principle, but posing innumerable problems in its elaboration:

> The properties and modes of action of higher levels are not explicable by the summation of the properties and modes of action of their components *taken in isolation*. If, however, we know the *ensemble* of the components and the *relations existing between them,* then the higher levels are derivable from the components [10, p. 148].

Many (including recent) discussions of the Aristotelian paradox and of reductionism have added nothing to these statements: in order to understand an organized whole we must know both the parts and the relations between them.

This, however, defines the trouble. For "normal" science in Thomas Kuhn's sense, that is, science as conventionally practiced, was little adapted to deal with "relations" in systems. As Weaver [51] said in a well-known statement, classical science was concerned with one-way causality or relations between two variables, such as the attraction of the sun and a planet, but even the three-body problem of mechanics (and the corresponding problems in atomic physics) permits no closed solution by analytical methods of classical mechanics. Also, there were descriptions of "unorganized complexity" in terms of statistics whose paradigm is the second law of thermodynamics. However, increasing with the progress of observation and experiment, there loomed the problem of "organized complexity," that is, of interrelations between many but not infinitely many components.

Here is the reason why, even though the problems of "system" were ancient and had been known for many centuries, they remained "philosophical" and did not become a "science." This was so because mathematical techniques were lacking and the problems required a new epistemology; the whole force of "classical" science and its success over the centuries militated against any change in the fundamental paradigm of one-way causality and resolution into elementary units.

The quest for a new "gestalt mathematics" was repeatedly raised a considerable time ago, in which not the notion of quantity but rather that of relations, that is, of form and order, would be fundamental [10, p. 159 f.]. However, this demand became realizable only with new developments.

The notion of general systems theory was first formulated by von Bertalanffy, orally in the 1930's and in various publications after World War II:

> There exist models, principles and laws that apply to generalized systems or their subclasses irrespective of their particular kind, the nature of the component elements, and the relations or "forces" between them. We postulate a new discipline called *General System Theory.* General System Theory is a logico-mathematical field whose task is the formulation and derivation of those general principles that are applicable to "systems" in general. In this way, exact formulations of terms such as wholeness and sum, differentiation, progressive mechanization, centralization, hierarchial order, finality and equifinality, etc., become possible, terms which occur in all sciences dealing with "systems" and imply their logical homology (von Bertalanffy, 1947, 1955; reprinted in [15, pp. 32, 253].

The proposal of general systems theory had precursors as well as independent simultaneous promoters. Kohler came near to generalizing gestalt theory into general systems theory [33]. Although Lotka did not use the term "general system theory," his discussion of systems of simultaneous differential equations [39] remained basic for subsequent "dynamical" system theory. Volterra's equations [21], originally developed for the competition of species, are applicable to generalized kinetics and dynamics. Ashby, in his early work [1], independently used the same system equations as von Bertalanffy employed, although deriving different consequences.

Von Bertalanffy outlined "dynamical" system theory (see the section on *Systems Science),* and gave mathematical descriptions of system properties (such as wholeness, sum, growth, competition, allometry, mechanization, centralization, finality, and equifinality), derived from the system description by simultaneous differential equations. Being a practicing biologist, he was particularly interested in developing the theory of "open systems," that is, systems exchanging matter with environment as every "living" system does. Such theory did not then exist in physical chemistry. The theory of open systems stands in manifold relationships with chemical kinetics in its biological, theoretical, and technological aspects, and with the thermodynamics of irreversible processes, and provides explanations for many special problems in biochemistry, physiology, general biology, and related areas. It is correct to say that, apart from control theory and the application of feedback models, the theory of *Fliessgleichgewicht* and open systems [8, 12] is the part of general systems theory most widely applied in physical chemistry, biophysics, simulation of biological processes, physiology, pharmacodynamics, and so forth [15]. The forecast also proved to be correct that the basic areas of physiology, that is, metabolism, excitation, and morphogenesis (more specifically, the theory of regulation, cell permeability, growth, sensory excitation, electrical stimulation, center function, etc.), would "fuse into an integrated theoretical field under the guidance of the concept of open system" [6, Vol. II, pp. 49 ff.; also 15, p. 137 f.].

The intuitive choice of the open system as a general system model was a correct one. Not only from the physical viewpoint is the "open system" the more general case (because closed systems can always be obtained from open ones by equating transport variables to zero); it also is the general case mathematically because the system of simultaneous differential equations (equations of motion) used for description in dynamical system theory is the general form from which the description of closed systems derives by the introduction of additional constraints (e.g., conservation of mass in a closed chemical system) (cf. [46], p. 80 f.).

At first the project was considered to be fantastic. A well-known ecologist, for example, was "hushed into awed silence" by the preposterous claim that general system theory constituted a new realm of science [24], not foreseeing that it would become a legitimate field and the subject of university instruction within some 15 years.

Many objections were raised against its feasibility and legitimacy [17]. It was not understood then that the exploration of properties, models, and laws of "systems" is not a hunt for superficial analogies, but rather poses basic and difficult problems which are partly still unsolved [10, p. 200 f.].

According to the program, "system laws" manifest themselves as analogies or "logical homologies" of laws that are formally identical but pertain to quite different phenomena or even appear in different disciplines. This was shown by von Bertalanffy in examples which were chosen as intentionally simple illustrations, but the same principle applies to more sophisticated cases, such as the following:

> It is a striking fact that biological systems as diverse as the central nervous system, and the biochemical regulatory network in cells should be strictly analogous. . . . It is all the more remarkable when it is realized that this particular analogy between different systems at different levels of biological organization is but one member of a large class of such analogies [45].

It appeared that a number of researchers, working independently and in different fields, had arrived at similar conclusions. For example, Boulding wrote to the present author:

> I seem to have come to much the same conclusions 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 [15, p. 14; cf. 18].

This spreading interest led to the foundation of the Society for General Systems Research (initially named the Society for the Advancement of General System Theory), an affiliate of the American Association for the Advancement of Science. The formation of numerous local groups, the task group on "General Systems Theory and Psychiatry" in the American Psychiatric Association, and many similar working groups, both in the United States and in Europe, followed, as well as various meetings and publications. The program of the Society formulated in 1954 may be quoted because it remains valid as a research program in general systems theory:

> 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.

In the meantime a different development had taken place. Starting from the development of self-directing missiles, automation and computer technology, and inspired by Wiener's work, the cybernetic movement became ever more influential. Although the starting point (technology versus basic science, especially biology) and the basic model (feedback circuit versus dynamic system of interactions) were different, there was a communality of interest in problems of organization and teleological behavior. Cybernetics too challenged the "mechanistic" conception that the universe was based on the "operation of anonymous particles at random" and emphasized "the search for new approaches, for new and more comprehensive concepts, and for methods capable of dealing with the large wholes of organisms and personalities" [25]. Although it is incorrect to describe modern systems theory as "springing out of the last war effort" [19]—in fact, it had roots quite different from military hardware and related technological developments—cybernetics and related approaches were independent developments which showed many parallelisms with general system theory.

TRENDS IN GENERAL SYSTEMS THEORY

This brief historical survey cannot attempt to review the many recent developments in general systems theory and the systems approach. For a critical discussion of the various approaches see [30, pp. 97 ff.] and [27, Book II].

With the increasing expansion of systems thinking and studies, the definition of general systems theory came under renewed scrutiny. Some indication as to its meaning and scope may therefore be pertinent. The term "general system theory" was introduced by the present author, delibberately, in a catholic sense. One may, of course, limit it to its "technical" meaning in the sense of mathematical theory (as is frequently done), but this appears unadvisable because there are many "system" problems asking for "theory" which is not presently available in mathematical terms. So the name "general systems theory" may be used broadly, in a way similar to our speaking of the "theory of evolution," which comprises about everything ranging from fossil digging and anatomy to the mathematical theory of selection; or "behavior theory," which extends from bird watching to sophisticated neurophysiological theories. It is the introduction of a new paradigm that matters.

Systems Science: Mathematical Systems Theory

Broadly speaking, three main aspects can be indicated which are not separable in content but are distinguishable in intention. The first may be circumscribed as *systems science,* that is, scientific exploration and theory of "systems" in the various sciences (e.g., physics, biology, psychology, social sciences), and general systems theory as the doctrine of principles applying to all (or defined subclasses of) systems.

Entities of an essentially new sort are entering the sphere of scientific thought. Classical science in its various disciplines, such as chemistry, biology, psychology, or the social sciences, tried to isolate the elements of the observed universes—chemical compounds and enzymes, cells, elementary sensations, freely competing individuals, or whatever else may be the case—in the expectation that by putting them together again, conceptually or experimentally, the whole or system—cell, mind, society—would result and would be intelligible. We have learned, however, that for an understanding not only the elements but their interrelations as well are required—say, the interplay of enzymes in a cell, the interactions of many conscious and unconscious processes in the personality, the structure and dynamics of social systems, and so forth. Such problems appear even in physics, for example, in the interaction of many generalized "forces" and "fluxes" (irreversible thermodynamics; cf. Onsager reciprocal relations), or in the development of nuclear physics, which "requires much experimental work, as well as the development of additional powerful methods for the handling of systems with many, but not infinitely many, particles" [23]. This requires, first, the exploration of the many systems in our observed universe in their own right and specificities. Second, it turns out that there are general aspects, correspondences, and isomorphisms common to "systems." This is the domain of *general systems theory.* Indeed, such parallelisms or isomorphisms appear (sometimes surprisingly) in otherwise totally different "systems."

General systems theory, then, consists of the scientific exploration of "wholes" and "wholeness" which, not so long ago, were considered to be metaphysical notions transcending the boundaries of science. Novel concepts, methods, and mathematical fields have developed to deal with them. At the same time, the interdisciplinary nature of concepts, models, and principles applying to "systems" provides a possible approach toward the unification of science.

The goal obviously is to develop general systems theory in mathematical terms (a "logico-mathematical field," as this author wrote in the early statement cited in the section on *Foundations of General System Theory)* because mathematics is the exact language permitting rigorous deductions and confirmation (or refusal) of theory. Mathematical systems theory has become an extensive and rapidly growing field. "System" being a new "paradigm" (in the sense of Thomas Kuhn), contrasting to the predominant, elementalistic approach and conceptions, it is not surprising that a variety of approaches have developed, differing in emphasis, focus of interest, mathematical techniques, and other respects. These elucidate different aspects, properties and principles of what is comprised under the term "system," and thus serve different purposes of theoretical or practical nature. The fact that "system theories" by various authors look rather different is, therefore, not an embarrassment or the result of confusion, but rather a healthy development in a new and growing field, and indicates presumably necessary and complementary aspects of the problem. The existence of different descriptions is nothing extraordinary and is often encountered in mathematics and science, from the geometrical or analytical description of a curve to the equivalence of classical thermodynamics and statistical mechanics to that of wave mechanics and particle physics. Different and partly opposing approaches should, however, tend toward further integration, in the sense that one is a special case within another, or that they can be shown to be equivalent or complementary. Such developments are, in fact, taking place.

System-theoretical approaches include general system theory (in the narrower sense), cybernetics, theory of automata, control theory, information theory, set, graph and network theory, relational mathematics, game and decision theory, computerization and simulation, and so forth. The somewhat loose term "approaches" is used deliberately because the list contains rather different things, for example, models (such as those of open system, feedback, logical automaton), mathematical techniques (e.g., theory of differential equations, computer methods, set, graph theory), and newly formed concepts or parameters (information, rational game, decision, etc.). These approaches concur, however, in that, in one way or the other, they relate to "system problems," that is, problems of interrelations within a superordinate "whole." Of course, these are not isolated but frequently overlap, and the same problem can be treated mathematically in different ways. Certain typical ways of describing "systems" can be indicated; their elaboration is due, on the one hand, to theoretical problems of "systems" as such and in relation to other disciplines, and, on the other hand, to problems of the technology of control and communication.

No mathematical development or comprehensive review can be given here. The following remarks, however, may convey some intuitive understanding of the various approaches and the way in which they relate to each other.

It is generally agreed that "system" is a *model* of general nature, that is, a conceptual analog of certain rather universal traits of observed entities. The use of models or analog constructs is the general procedure of science (and even of everyday cognition), as it is also the principle of analog simulation by computer. The difference from conventional disciplines is not essential but lies rather in the degree of generality (or abstraction): "system" refers to very general characteristics partaken by a large class of entities conventionally treated in different disciplines. Hence the interdisciplinary nature of general systems theory; at the same time, its statements pertain to formal or structural commonalities abstracting from the "nature of elements and forces in the system" with which the special sciences (and explanations in these) are concerned. In other words, system-theoretical arguments pertain to, and have predictive value, inasmuch as such general structures are concerned. Such "explanation in principle" may have considerable predictive value; for specific explanation, introduction of the special system conditions is naturally required.

A system may be defined as a set of elements standing in interrelation among themselves and with the environment. This can be expressed mathematically in different ways. Several typical ways of system description can be indicated.

One approach or group of investigations may, somewhat loosely, be circumscribed as *axiomatic,* inasmuch as the focus of interest is a rigorous definition of system and the derivation, by modern methods of mathematics and logic, of its implications. Among other examples are the system descriptions by Mesarovic [41], Maccia and Maccia [40], Beier and Laue [4] (set theory), Ashby [2] (state-determined systems), and Klir [30] (UC=set of all couplings between the elements and the elements and environment; ST=set of all states and all transitions between states).

Dynamical system theory is concerned with the changes of systems in time. There are two principal ways of description: internal and external [47].

Internal description or "classical" system theory (foundations in [9; 11; and 15, pp. 54 ff.]; comprehensive presentation in [46]; an excellent introduction into dynamical system theory and the theory of open systems, following the line of the present author, in [3]) defines a system by a set of n measures, called state variables. Analytically, their change in time is typically expressed by a set of n simultaneous, first-order differential equations:

$$\frac{dQ_n}{dt}=f_i(Q_1,\ Q_2,\ .\ .\ .\ ,\ Q_n). \tag{1.1}$$

These are called dynamical equations or equations of motion. The set of differential equations permits a formal expression of system properties, such as wholeness and sum, stability, mechanization, growth, competition, final and equifinal behavior and others [9, 11, 15]. The behavior of the system is described by the theory of differential equations (ordinary, first-order, if the definition of the system by Eq. 1.1 is accepted), which is a well-known and highly developed field of mathematics. However, as was mentioned previously, system considerations pose quite definite problems. For example, the theory of stability has developed only recently in conjunction with problems of control (and system): the Liapunov (†1918) functions date from 1892 (in Russian; 1907 in French), but their significance was recognized only recently, especially through the work of mathematicians of the U.S.S.R.

Geometrically, the change of the system is expressed by the trajectories that the state variables traverse in the state space, that is, the n-dimensional space of possible location of these variables. Three types of behavior may be distinguished and defined as follows:

1. A trajectory is called *asymptotically stable* if all trajectories sufficiently close to it at $t=t_0$ approach it asymptotically when $t \rightarrow \infty$.

2. A trajectory is called *neutrally stable* if all trajectories sufficiently

close to it at $t=0$ remain close to it for all later time but do not necessarily approach it asymptotically.

3. A trajectory is called *unstable* if the trajectories close to it at $t=0$ do not remain close to it as $t \rightarrow \infty$.

These correspond to solutions approaching a time-independent state (equilibrium, steady state), periodic solutions, and divergent solutions, respectively.

A time-independent state,

$$f_i(Q_1, Q_2, \ldots, Q_n)=0, \tag{1.2}$$

can be considered as a trajectory degenerated into a single point. Then, readily visualizable in two-dimensional projection, the trajectories may converge toward a stable node represented by the equilibrium point, may approach it as a stable focus in damped oscillations, or may cycle around it in undamped oscillations (stable solutions). Or else, they may diverge from an unstable node, wander away from an unstable focus in oscillations, or from a saddle point (unstable solutions).

A central notion of dynamical theory is that of *stability,* that is, the response of a system to perturbation. The concept of stability originates in mechanics (a rigid body is in stable equilibrium if it returns to its original position after sufficently small displacement; a motion is stable if insensitive to small perturbations), and is generalized to the "motions" of state variables of a system. This question is related to that of the existence of equilibrium states. Stability can be analyzed, therefore, by explicit solution of the differential equations describing the system (so-called indirect method, based essentially on discussion of the eigenwerte λ_i of Eq. 1.1). In the case of nonlinear systems, these equations have to be linearized by development into Taylor series and retention of the first term. Linearization, however, pertains only to stability in the vicinity of equilibrium. But stability arguments without actual solution of the differential equations (direct method) and for nonlinear systems are possible by introduction of so-called *Liapunov functions;* these are essentially generalized energy functions, the sign of which indicates whether or not an equilibrium is asymptotically stable [28, 36].

Here the relation of dynamical system theory to control theory becomes apparent; control means essentially that a system which is not asymptotically stable is made so by incorporating a controller, counteracting the motion of the system away from the stable state. For this reason the theory of stability in internal description or dynamical system theory converges with the theory of (linear) control or feedback systems in external description (see below; cf. [48]).

Description by ordinary differential equations (Eq. 1.1) abstracts from variations of the state variables in space which would be expressed by partial differential equations. Such field equations are, however, more difficult to handle. Ways of overcoming this difficulty are to assume complete "stirring," so that distribution is homogeneous within the volume considered; or to assume the existence of compartments to which homogeneous distribution applies, and which are connected by suitable interactions (compartment theory) [44].

In *external description,* the system is considered as a "black box"; its relations to the environment and other systems are presented graphically in block and flow diagrams. The system description is given in terms of inputs and outputs *(Klemmenverhalten* in German terminology); its general form are transfer functions relating input and output. Typically, these are assumed to be linear and are represented by discrete sets of values (cf. yes-no decisions in information theory, Turing machine). This is the language of control technology; external description, typically, is given in terms of communication (exchange of information between system and environment and within the system) and control of the system's function with respect to environment (feedback), to use Wiener's definition of cybernetics.

As mentioned, internal and external descriptions largely coincide with descriptions by continuous or discrete functions. These are two "languages" adapted to their respective purposes. Empirically, there is an obvious contrast between regulations due to the free interplay of forces within a dynamical system, and regulations due to constraints imposed by structural feedback mechanisms [15], for example, the "dynamic" regulations in a chemical system or in the network of reactions in a cell on the one hand, and control by mechanisms such as a thermostat or homeostatic nervous circuit on the other. Formally, however, the two "languages" are related and in certain cases demonstrably translatable. For example, an input-output function can (under certain conditions) be developed as a linear *n*th-order differential equation, and the terms of the latter can be considered as (formal) "state variables"; while their physical meaning remains indefinite, formal "translation" from one language into the other is possible.

In certain cases—for example, the two-factor theory of nerve excitation (in terms of "excitatory and inhibitory factors" or "substances") and network theory (McCulloch nets of "neurons")—description in dynamical system theory by continuous functions and description in automata theory by digital analogs can be shown to be equivalent [45]. Similarly predator-prey systems, usually described dynamically by Volterra equations, can also be expressed in terms of cybernetic feedback circuits [55]. These are two-variable systems. Whether a similar "translation" can be effectuated in many-variables systems remains (in the present writer's opinion) to be seen.

Internal description is essentially "structural," that is, it tries to describe the systems' behavior in terms of state variables and their interdependence. External description is "functional"; the system's behavior is described in terms of its interaction with the environment.

As this sketchy survey shows, considerable progress has been made in mathematical systems theory since the program was enunciated and inaugurated some 25 years ago. A variety of approaches, which, however, are connected with each other, have been developed.

Today mathematical system theory is a rapidly growing field, but it is natural that basic problems, such as those of hierarchical order [53], are approached only slowly and presumably will need novel ideas and theories. "Verbal" descriptions and models (e.g., [20; 31; 42; 52]), are not expendable. Problems must be intuitively "seen" and recognized before they can be formalized mathematically. Otherwise, mathematical formalism may impede rather than expedite the exploration of very "real" problems.

A strong system-theoretical movement has developed in psychiatry, largely through the efforts of Gray [26]. The same is true of the behavioral sciences [20] and also of certain areas in which such a development was quite unexpected, at least by the present writer—for example, theoretical geography [29]. Sociology was stated as being essentially "a science of social systems" [14]; not foreseen was, for instance, the close parallelism of general system theory with French structuralism (e.g., Piaget, Levy-Strauss; cf. [37]) and the influence exerted on American functionalism in sociology ([22]: see especially pp. 2, 96, 141).

Systems Technology

The second realm of general systems theory is *systems technology,* that is, the problems arising in modern technology and society, including both "hardware" (control technology, automation, computerization, etc.) and "software" (application of system concepts and theory in social, ecological, economical, etc., problems). We can only allude to the vast realm of techniques, models, mathematical approaches, and so forth, summarized as systems engineering or under similar denominations, in order to place it into the perspective of the present study.

Modern technology and society have become so complex that the traditional branches of technology are no longer sufficient; approaches of a holistic or systems, and generalist and interdisciplinary, nature became necessary. This is true in many ways. Modern engineering includes fields such as circuit theory, cybernetics as the study of "communication and control" (Wiener [54]), and computer techniques for handling "systems" of a complexity unamenable to classical methods of mathematics. Systems of many levels ask for scientific control: ecosystems, the disturbance of which results in pressing problems like pollution; formal organizations like bureaucracies, educational institutions, or armies; socioeconomic systems, with their grave problems of international relations, politics, and deterrence. Irrespective of the questions of how far scientific understanding (contrasted to the admission of irrationality of cultural and historical events) is possible, and to what extent scientific control is feasible or even desirable, there can be no dispute that these are essentially "system" problems, that is, problems involving interrelations of a great number of "variables." The same applies to narrower objectives in industry, commerce, and armament.

The technological demands have led to novel conceptions and disciplines, some displaying great originality and introducing new basic notions such as control and information theory, game, decision theory, the theory of circuits, of queuing and others. Again it transpired that concepts and models (such as feedback, information, control, stability, circuits) which originated in certain specified fields of technology have a much broader significance, are of an interdisciplinary nature, and are independent of their special realizations, as exemplified by isomorphic feedback models in mechanical, hydrodynamic, electrical, biological and other systems. Similarly, developments originating in pure and in applied science converge, as in dynamical system theory and control theory. Again, there is a spectrum ranging from highly sophisticated mathematical theory to computer simulation to more or less informal discussion of system problems.

Systems Philosophy

Third, there is the realm of *systems philosophy* [38], that is, the reorientation of thought and world view following the introduction of "system" as a new scientific paradigm (in contrast to the analytic, mechanistic, linear-causal paradigm of classical science). Like very scientific theory of broader scope, general systems theory has its "metascientific" or philosophical aspects. The concept of "system" constitutes a new "paradigm," in Thomas Kuhn's phrase, or a new "philosophy of nature," in the present writer's [14] words, contrasting the "blind laws of nature" of the mechanistic world view and the world process as a Shakespearean tale told by an idiot, with an organismic outlook of the "world as a great organization."

First, we must find out the "nature of the beast": what is meant by "system," and how systems are realized at the various levels of the world of observation. This is *systems ontology*.

What is to be defined and described as system is not a question with an obvious or trivial answer. It will be readily agreed that a galaxy, a dog, a cell, and an atom are "systems." But in what sense and what respects can we speak of an animal or a human society, personality, language, mathematics, and so forth as "systems"?

We may first distinguish *real systems*, that is, entities perceived in or inferred from observation and existing independently of an observer. On the other hand, there are *conceptual systems,* such as logic or mathematics, which essentially are symbolic constructs (but also including, e.g., music); with *abstracted systems* (science) [42] as a subclass, that is, conceptual systems corresponding with reality. However, the distinction is by no means as sharp as it would appear.

Apart from philosophical interpretation (which would take us into the question of metaphysical realism, idealism, phenomenalism, etc.) we would consider as "objects" (which partly are "real systems") entities given by perception because they are discrete in space and time. We do not doubt that a pebble, a table, an automobile, an animal, or a star (and in a somewhat different sense an atom, a molecule, and a planetary system) are "real" and existent independently of observation. Perception, however, is not a reliable guide. Following it, we "see" the sun revolving around the earth, and certainly do not see that a solid piece of matter like a stone "really" is mostly empty space with minute centers of energy dispersed in astronomical distances. The spatial boundaries of even what appears to be an obvious object or "thing" actually are indistinct. From a crystal consisting of molecules, valences stick out, as it were, into the surrounding space; the spatial boundaries of a cell or an organism are equally vague because it maintains itself in a flow of molecules entering and leaving, and it is difficult to tell just what belongs to the "living system" and what does not. Ultimately all boundaries are dynamic rather than spatial.

Hence an object (and in particular a system) is definable only by its cohesion in a broad sense, that is, the interactions of the component elements. In this sense an ecosystem or social system is just as "real" as an individual plant, animal, or human being, and indeed problems like pollution as a disturbance of the ecosystem, or social problems strikingly demonstrate their "reality." Interactions (or, more generally, interrelations), however, are never directly seen or perceived; they are conceptual constructs. The same is true even of the objects of our everyday world, which by no means are simply "given" as sense data or simple perceptions but also are constructs based on innate or learned categories, the concordance of different senses, previous experience, learning processes, naming (i.e., symbolic processes), etc. all of which largely determine what we actually "see" or perceive [cf. 34]. Thus the distinction between "real" objects and systems as given in observation and "conceptual" constructs and systems cannot be drawn in any common-sense way.

These are profound problems which can only be indicated in this context. The question for general systems theory is what statements can be made regarding material systems, informational systems, conceptual systems, and other types—questions which are far from being satisfactorily answered at the present time.

This leads to *systems epistemology.* As is apparent from the preceding this is profoundly different from the epistemology of logical positivism or empiricism, even though it shares the same scientific attitude. The epistemology (and metaphysics) of logical positivism was determined by the ideas of physicalism, atomism, and the "camera theory" of knowledge. These, in view of present-day knowledge, are obsolete. As against physicalism and reductionism, the problems and modes of thought occurring in the biological, behavioral and social sciences require equal consideration, and simple "reduction" to the elementary particles and conventional laws of physics does not appear feasible. Compared to the analytical procedure of classical science, with resolution into component elements and one-way or linear causality as the basic category, the investigation of organized wholes of many variables requires new categories of interaction, transaction, organization, teleology, and so forth, with many problems arising for epistemology, mathematical models and techniques. Furthermore, perception is not a reflection of "real things" (whatever their metaphysical status), and knowledge not a simple approximation to "truth" or "reality." It is an interaction between knower and known, and thus dependent on a multiplicity of factors of a biological, psychological, cultural, and linguistic nature. Physics itself teaches that there are no ultimate entities like corpuscles or waves existing independently of the observer. This leads to a "perspective" philosophy in which physics, although its achievements in its own and related fields are fully acknowledged, is not a monopolistic way of knowledge. As opposed to reductionism and theories declaring that reality is "nothing but" (a heap of physical particles, genes, reflexes, drives, or whatever the case may be), we see sicence as one of the "perspectives" that man, with his biological, cultural, and linguistic endowment and bondage, has created to deal with the universe into which he is "thrown," or rather to which he is adapted owning to evolution and history.

The third part of systems philosophy is concerned with the relations of man and his world, or what is termed *values* in philosophical parlance. If reality is a hierarchy of organized wholes, the image of man will be different from what it is in a world of physical particles governed by chance events as the ultimate and only "true" reality. Rather, the world of symbols, values, social entities and cultures is something very "real"; and its embeddedness in a cosmic order of hierarchies tends to bridge the gulf between C. P. Snow's "two cultures" of science and the humanities, technology and history, natural and social sciences, or in whatever way the antithesis is formulated.

This humanistic concern of general systems theory, as this writer understands it, marks a difference to mechanistically oriented system theorists speaking solely in terms of mathematics, feedback, and technology and so giving rise to the fear that systems theory is indeed the ultimate step toward the mechanization and devaluation of man and toward technocratic society. While understanding and emphasizing the role of mathematics and of pure and applied science, this writer does not see that the humanistic aspects can be evaded unless general systems theory is limited to a restricted and fractional vision.

Thus there is indeed a great and perhaps puzzling multiplicity of approaches and trends in general systems theory. This is understandably uncomfortable to him who wants a neat formalism, to the textbook writer and the dogmatist. It is, however, quite natural in the history of ideas and of science, and particularly in the beginning of a new development. Different models and theories may be apt to render different aspects and so are complementary. On the other hand, future developments will undoubtedly lead to further unification.

General systems theory is, as emphasized, a model of certain general aspects of reality. But it is also a way of seeing things which were previously overlooked or bypassed, and in this sense is a methodological maxim. And like every scientific theory of broader compass, it is connected with, and tries to give its answer to perennial problems of philosophy.

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