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THE MEANING OF GENERAL SYSTEM THEORY

The Quest for a General System Theory

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Modern science is characterized by its ever-increasing specialization, necessitated by the enormous amount of data, the complexity of techniques and of theoretical structures within every field. Thus science is split into innumerable disciplines continually generating new subdisciplines. In consequence, the physicist, the biologist, the psychologist and the social scientist are, so to speak, encapsulated in their private universes, and it is difficult to get word from one cocoon to the other.

This, however, is opposed by another remarkable aspect. Surveying the evolution of modern science, we encounter a surprising phenomenon. Independently of each other, similar problems and conceptions have evolved in widely different fields.

It was the aim of classical physics eventually to resolve natural phenomena into a play of elementary units governed by "blind" laws of nature. This was expressed in the ideal of the Laplacean spirit which, from the position and momentum of particles, can predict the state of the universe at any point in time. This mechanistic view was not altered but rather reinforced when deterministic laws in physics were replaced by statistical laws. According to Boltzmann's derivation of the second principle of thermodynamics, physical events are directed toward states of maximum probability, and physical laws, therefore, are essentially "laws of disorder," the outcome of unordered, statistical events. In contrast to this mechanistic view, however, problems of wholeness, dynamic interaction and organization have appeared in the various branches of modern physics. In the Heisenberg relation and quantum physics, it became impossible to resolve phenomena into local events; problems of order and organization appear whether the question is the structure of atoms, the architecture of proteins, or interaction phenomena in thermodynamics. Similarly biology, in the mechanistic conception, saw its goal in the resolution of life phenomena into atomic entities and partial processes. The living organism was resolved into cells, its activities into physiological and ultimately physicochemical processes, behavior into unconditioned and conditioned reflexes, the substratum of heredity into particulate genes, and so forth. In contradistinction, the organismic conception is basic for modern biology. It is necessary to study not only parts and processes in isolation, but also to solve the decisive problems found in the organization and order unifying them, resulting from dynamic interaction of parts, and making the behavior of parts different when studied in isolation or within the whole. Again, similar trends appeared in psychology. While classical association psychology attempted to resolve mental phenomena into elementary units—psychological atoms as it were—such as elementary sensations and the like, gestalt psychology showed the existence and primacy of psychological wholes which are not a summation of elementary units and are governed by dynamic laws. Finally, in the social sciences the concept of society as a sum of individuals as social atoms, e.g., the model of Economic Man, was replaced by the tendency to consider society, economy, nation as a whole superordinated to its parts. This implies the great problems of planned economy, of the deification of nation and state, but also reflects new ways of thinking.

This parallelism of general cognitive principles in different fields is even more impressive when one considers the fact that those developments took place in mutual independence and mostly without any knowledge of work and research in other fields.

There is another important aspect of modern science. Up to recent times, exact science, the corpus of laws of nature, was almost identical with theoretical physics. Few attempts to state exact laws in nonphysical fields have gained recognition. However, the impact of and progress in the biological, behavioral and social sciences seem to make necessary an expansion of our conceptual schemes in order to allow for systems of laws in fields where application of physics is not sufficient or possible.

Such a trend towards generalized theories is taking place in many fields and in a variety of ways. For example, an elaborate theory of the dynamics of biological populations, the struggle for existence and biological equilibria, has developed, starting with the pioneering work by Lotka and Volterra. The theory operates with biological notions, such as individuals, species, coefficients of competition, and the like. A similar procedure is applied in quantitative economics and econometrics. The models and families of equations applied in the latter happen to be similar to those of Lotka or, for that matter, of chemical kinetics, but the model of interacting entities and forces is again at a different level. To take another example: living organisms are essentially open systems, i.e., systems exchanging matter with their environment. Conventional physics and physical chemistry dealt with closed systems, and only in recent years has theory been expanded to include irreversible processes, open systems, and states of disequilibrium. If, however, we want to apply the model of open systems to, say, the phenomena of animal growth, we automatically come to a generalization of theory referring not to physical but to biological units. In other words, we are dealing with generalized systems. The same is true of the fields of cybernetics and information theory which have gained so much interest in the past few years.

Thus, there exist models, principles, and laws that apply to generalized systems or their subclasses, irrespective of their particular kind, the nature of their component elements, and the relations or "forces" between them. It seems legitimate to ask for a theory, not of systems of a more or less special kind, but of universal principles applying to systems in general.

In this way we postulate a new discipline called General System Theory. Its subject matter is the formulation and derivation of those principles which are valid for "systems" in general.

The meaning of this discipline can be circumscribed as follows. Physics is concerned with systems of different levels of generality. It extends from rather special systems, such as those applied by the engineer in the construction of a bridge or of a machine; to special laws of physical disciplines, such as mechanics or optics; to laws of great generality, such as the principles of thermodynamics that apply to systems of intrinsically different nature, mechanic, caloric, chemical or whatever. Nothing prescribes that we have to end with the systems traditionally treated in physics. Rather, we can ask for principles applying to systems in general, irrespective of whether they are of physical, biological or sociological nature. If we pose this question and conveniently define the concept of system, we find that models, principles, and laws exist which apply to generalized systems irrespective of their particular kind, elements, and the "forces" involved.

A consequence of the existence of general system properties is the appearance of structural similarities or isomorphisms in different fields. There are correspondences in the principles that govern the behavior of entities that are, intrinsically, widely different. To take a simple example, an exponential law of growth applies to certain bacterial cells, to populations of bacteria, of animals or humans, and to the progress of scientific research measured by the number of publications in genetics or science in general. The entities in question, such as bacteria, animals, men, books, etc., are completely different, and so are the causal mechanisms involved. Nevertheless, the mathematical law is the same. Or there are systems of equations describing the competition of animal and plant species in nature. But it appears that the same systems of equations apply in certain fields in physical chemistry and in economics as well. This correspondence is due to the fact that the entities concerned can be considered, in certain respects, as "systems," i.e., complexes of elements standing in interaction. The fact that the fields mentioned, and others as well, are concerned with "systems," leads to a correspondence in general principles and even in special laws when the conditions correspond in the phenomena under consideration.

In fact, similar concepts, models and laws have often appeared in widely different fields, independently and based upon totally different facts. There are many instances where identical principles were discovered several times because the workers in one field were unaware that the theoretical structure required was already well developed in some other field. General system theory will go a long way towards avoiding such unnecessary duplication of labor.

System isomorphisms also appear in problems which are recalcitrant to quantitative analysis but are nevertheless of great intrinsic interest. There are, for example, isomorphies between biological systems and "epiorganisms" (Gerard) like animal communities and human societies. Which principles are common to the several levels of organization and so may legitimately be transferred from one level to another, and which are specific so that transfer leads to dangerous fallacies? Can societies and civilizations be considered as systems?

It seems, therefore, that a general theory of systems would be a useful tool providing, on the one hand, models that can be used in, and transferred to, different fields, and safeguarding, on the other hand, from vague analogies which often have marred the progress in these fields.

There is, however, another and even more important aspect of general system theory. It can be paraphrased by a felicitous formulation due to the well-known mathematician and founder of information theory, Warren Weaver. Classical physics, Weaver said, was highly successful in developing the theory of unorganized complexity. Thus, for example, the behavior of a gas is the result of the unorganized and individually untraceable movements of innumerable molecules; as a whole it is governed by the laws of thermodynamics. The theory of unorganized complexity is ultimately rooted in the laws of chance and probability and in the second law of thermodynamics. In contrast, the fundamental problem today is that of organized complexity. Concepts like those of organization, wholeness, directiveness, teleology, and differentiation are alien to conventional physics. However, they pop up everywhere in the biological, behavioral and social sciences, and are, in fact, indispensable for dealing with living organisms or social groups. Thus a basic problem posed to modern science is a general theory of organization. General system theory is, in principle, capable of giving exact definitions for such concepts and, in suitable cases, of putting them to quantitative analysis.

If we have briefly indicated what general system theory means, it will avoid misunderstanding also to state what it is not. It has been objected that system theory amounts to no more than the trivial fact that mathematics of some sort can be applied to different sorts of problems. For example, the law of exponential growth is applicable to very different phenomena, from radioactive decay to the extinction of human populations with insufficient reproduction. This, however, is so because the formula is one of the simplest differential equations, and can therefore be applied to quite different things. Therefore, if so-called isomorphic laws of growth occur in entirely different processes, it has no more significance than the fact that elementary arithmethic is applicable to all countable objects, that 2 plus 2 make 4, irrespective of whether the counted objects are apples, atoms or galaxies.

The answer to this is as follows. Not just in the example quoted by way of simple illustration, but in the development of system theory, the question is not the application of well-known mathematical expressions. Rather, problems are posed that are novel and partly far from solution. As mentioned, the method of classical science was most appropriate for phenomena that either can be resolved into isolated causal chains, or are the statistical outcome of an "infinite" number of chance processes, as is true of statistical mechanics, the second principle of thermodynamics and all laws deriving from it. The classical modes of thinking, however, fail in the case of interaction of a large but limited number of elements or processes. Here those problems arise which are circumscribed by such notions as wholeness, organization and the like, and which demand new ways of mathematical thinking.

Another objection emphasizes the danger that general system theory may end up in meaningless analogies. This danger indeed exists. For example, it is a widespread idea to look at the state or the nation as an organism on a superordinate level. Such a theory, however, would constitute the foundation for a totalitarian state, within which the human individual appears like an insignificant cell in an organism or an unimportant worker in a beehive.

But general system theory is not a search for vague and superficial analogies. Analogies as such are of little value since besides similarities between phenomena, dissimilarities can always be 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, 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 sacial 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 logicomathematical 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.

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 t0. 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.

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 information. In many cases, the flow of information corresponds to a flow of energy, e.g., if light waves emitted by some objects reach the eye or a photoelectric cell, elicit some reaction of the organism or some machinery, and thus convey information. However, examples can easily be given where the flow of information is opposite to the flow of energy, or where information is transmitted without a flow of energy or matter. The first is the case in a telegraph cable, where a direct current is flowing in one direction, but information, a message, can be sent in either direction by interrupting the current at one point and recording the interruption at another. For the second case, think of the photoelectric door openers as they are installed in many supermarkets: the shadow, the cutting off of light energy, informs the photocell that somebody is entering, and the door opens. So information, in general, cannot be expressed in terms of energy.

There is, however, another way to measure information, namely, in terms of decisions. Take the game of Twenty Questions, where we are supposed to find out an object by receiving simple "yes" or "no" answers to our questions. The amount of information conveyed in one answer is a decision between two alternatives, such as animal or nonanimal. With two questions, it is possible to decide for one out of four possibilities, e.g., mammal—nonmammal, or flowering plant—nonflowering plant. With three answers, it is a decision out of eight, etc. Thus, the logarithm at the base 2 of the possible decisions can be used as a measure of information, the unit being the so-called binary unit or bit. The information contained in two answers is $\log_2 4 = 2$ bits, of three answers, $\log_2 8 = 3$ bits, etc. This measure of information happens to be similar to that of entropy or rather negative entropy, since entropy also is defined as a logarithm of probability. But entropy, as we have already heard, is a measure of disorder; hence negative entropy or information is a measure of order or of organization since the latter, compared to distribution at random, is an improbable state.

A second central concept of the theory of communication and control is that of feedback. A simple scheme for feedback is the following (Fig. 2.1).

FIGURE 2.1

The system comprises, first, a receptor or "sense organ," be it a photoelectric cell, a radar screen, a thermometer, or a sense organ in the biological meaning. The message may be, in technological devices, a weak current, or, in a living organism, represented by nerve conduction, etc. Then there is a center recombining the incoming messages and transmitting them to an eflfector, consisting of a machine like an electromotor, a heating coil or solenoid, or of a muscle which responds to the incoming message in such a way that there is power output of high energy. Finally, the functioning of the effector is monitored back to the receptor, and this makes the system self-regulating, i.e., guarantees stabilization or direction of action.

Feedback arrangements are widely used in modern technology for the stabilization of a certain action, as in thermostats or in radio receivers; or for the direction of actions towards a goal where the aberration from that goal is fed back, as information, till the goal or target is reached. This is the case in self-propelled missiles which seek their target, anti-aircraft fire control systems, ship-steering systems, and other so-called servomechanisms.

There is indeed a large number of biological phenomena which correspond to the feedback model. First, there is the phenomenon of so-called homeostasis, or maintenance of balance in the living organism, the prototype of which is thermoregulation in warmblooded animals. Cooling of the blood stimulates certain centers in the brain which "turn on" heat-producing mechanisms of the body, and the body temperature is monitored back to the center so that temperature is maintained at a constant level. Similar homeostatic mechanisms exist in the body for maintaining the constancy of a great number of physicochemical variables. Furthermore, feedback systems comparable to the servomechanisms of technology exist in the animal and human body for the regulation of actions. If we want to pick up a pencil, a report is made to the central nervous system of the distance by which we have failed to grasp the pencil in the first instance; this information is then fed back to the central nervous system so that the motion is controlled till the aim is reached.

So a great variety of systems in technology and in living nature follow the feedback scheme, and it is well-known that a new discipline, called Cybernetics, was introduced by Norbert Wiener to deal with these phenomena. The theory tries to show that mechanisms of a feedback nature are the base of teleological or purposeful behavior in man-made machines as well as in living organisms, and in social systems.

It should be borne in mind, however, that the feedback scheme is of a rather special nature. It presupposes structural arrangements of the type mentioned. There are, however, many regulations in the living organism which are of essentially diflerent nature, namely, those where the order is effectuated by a dynamic interplay of processes. Recall, e.g., embryonic regulations where the whole is reestablished from the parts in equifinal processes. It can be shown that the primary regulations in organic systems, i.e., those which are most fundamental and primitive in embryonic development as well as in evolution, are of the nature of dynamic interaction. They are based upon the fact that the living organism is an open system, maintaining itself in, or approaching a steady state. Superposed are those regulations which we may call secondary, and which are controlled by fixed arrangements, especially of the feedback type. This state of aflairs is a consequence of a general principle of organization which may be called progressive mechanization. At first, systems—biological, neurological, psychological or social—are governed by dynamic interaction of their components; later on, fixed arrangements and conditions of constraint are established which render the system and its parts more efficient, but also gradually diminish and eventually abolish its equipotentiality. Thus, dynamics is the broader aspect, since we can always arrive from general system laws to machinelike function by introducing suitable conditions of constraint, but the opposite is not possible.

Causality and Teleology

Another point I would like to mention is the change the scientific world picture has undergone in the past few decades. In the world view called mechanistic, which was born of classical physics of the nineteenth century, the aimless play of the atoms, governed by the inexorable laws of causality, produced all phenomena in the world, inanimate, living, and mental. No room was left for any directiveness, order, or telos. The world of the organisms appeared a product of chance, accumulated by the senseless play of random mutations and selection; the mental world as a curious and rather inconsequential epiphenomenon of material events.

The only goal of science appeared to be analytical, i.e., the splitting up of reality into ever smaller units and the isolation of individual causal trains. Thus, physical reality was split up into mass points or atoms, the living organism into cells, behavior into reflexes, perception into punctual sensations, etc. Correspondingly, causality was essentially one-way: one sun attracts one planet in Newtonian mechanics, one gene in the fertilized ovum produces such and such inherited character, one sort of bacterium produces this or that disease, mental elements are lined up, like the beads in a string of pearls, by the law of association. Remember Kant's famous table of the categories which attempts to systematize the fundamental notions of classical science: it is symptomatic that the notions of interaction and of organization were only spacefillers or did not appear at all.

We may state as characteristic of modern science that this scheme of isolable units acting in one-way causality has proved to be insufficient. Hence the appearance, in all fields of science, of notions like wholeness, holistic, organismic, gestalt, etc., which all signify that, in the last resort, we must think in terms of systems of elements in mutual interaction.

Similarly, notions of teleology and directiveness appeared to be outside the scope of science and to be the playground of mysterious, supernatural or anthropomorphic agencies; or else, a pseudoproblem, intrinsically alien to science, and merely a misplaced projection of the observer's mind into a nature governed by purposeless laws. Nevertheless, these aspects exist, and you cannot conceive of a living organism, not to speak of behavior and human society, without taking into account what variously and rather loosely is called adaptiveness, purposiveness, goal-seeking and the like.

It is characteristic of the present view that these aspects are taken seriously as a legitimate problem for science; moreover, we can well indicate models simulating such behavior.

Two such models we have already mentioned. One is equifinality, the tendency towards a characteristic final state from different initial states and in different ways, based upon dynamic interaction in an open system attaining a steady state; the second, feedback, the homeostatic maintenance of a characteristic state or the seeking of a goal, based upon circular causal chains and mechanisms monitoring back information on deviations from the state to be maintained or the goal to be reached. A third model for adaptive behavior, a "design for a brain," was developed by Ashby, who incidentally started with the same mathematical definitions and equations for a general system as were used by the present author. Both writers have developed their systems independently and, following different lines of interest, have arrived at different theorems and conclusions. Ashby's model for adaptiveness is, roughly, that of step functions defining a system, i.e., functions which, after a certain critical value is passed, jump into a new family of differential equations. This means that, having passed a critical state, the system starts off in a new way of behavior. Thus, by means of step functions, the system shows adaptive behavior by what the biologist would call trial and error: it tries different ways and means, and eventually settles down in a field where it no longer comes into conflict with critical values of the environment. Such a system adapting itself by trial and error was actually constructed by Ashby as an electromagnetic machine, called the homeostat.

I am not going to discuss the merits and shortcomings of these models of teleological or directed behavior. What should be stressed, however, is the fact that teleological behavior directed towards a characteristic final state or goal is not something off limits for natural science and an anthropomorphic misconception of processes which, in themselves, are undirected and accidental. Rather it is a form of behavior which can well be defined in scientific terms and for which the necessary conditions and possible mechanisms can be indicated.

What ls Organization?

Similar considerations apply to the concept of organization. Organization also was alien to the mechanistic world. The problem did not appear in classical physics, mechanics, electrodynamics, etc. Even more, the second principle of thermodynamics indicated destruction of order as the general direction of events. It is true that this is different in modern physics. An atom, a crystal, or a molecule are organizations, as Whitehead never failed to emphasize. In biology, organisms are, by definition, organized things. But although we have an enormous amount of data on biological organization, from biochemistry to cytology to histology and anatomy, we do not have a theory of biological organization, i.e., a conceptual model which permits explanation of the empirical facts.

Characteristic of organization, whether of a living organism or a society, are notions like those of wholeness, growth, differentiation, hierarchical order, dominance, control, competition, etc. Such notions do not appear in conventional physics. System theory is well capable of dealing with these matters. It is possible to define such notions within the mathematical model of a system; moreover, in some respects, detailed theories can be developed which deduce, from general assumptions, the special cases. A good example is the theory of biological equilibria, cyclic fluctuations, etc., as initiated by Lotka, Volterra, Gause and others. It will certainly be found that Volterra's biological theory and the theory of quantitative economics are isomorphic in many respects.

There are, however, many aspects of organizations which do not easily lend themselves to quantitative interpretation. This difficulty is not unknown in natural science. Thus, the theory of biological equilibria or that of natural selection are highly developed fields of mathematical biology, and nobody doubts that they are legitimate, essentially correct, and an important part of the theory of evolution and of ecology. It is hard, however, to apply them in the field because the parameters chosen, such as selective value, rate of destruction and generation and the like, cannot easily be measured. So we have to content ourselves with an "explanation in principle," a qualitative argument which, however, may lead to interesting consequences.

As an example of the application of general system theory to human society, we may quote a recent book by Boulding, entitled The Organizational Revolution. Boulding starts with a general model of organization and states what he calls Iron Laws which hold good for any organization. Such Iron Laws are, for example, the Malthusian law that the increase of a population is, in general, greater than that of its resources. Then there is a law of optimum size of organizations: the larger an organization grows, the longer is the way of communication and this, depending on the nature of the organization, acts as a limiting factor and does not allow an organization to grow beyond a certain critical size. According to the law of instability, many organizations are not in a stable equilibrium but show cyclic fluctuations which result from the interaction of subsystems. This, incidentally, could probably be treated in terms of the Volterra theory, Volterra's socalled first law being that of periodic cycles in populations of two species, one of which feeds at the expense of the other. The important law of oligopoly states that, if there are competing organizations, the instability of their relations and hence the danger of friction and conflicts increases with the decrease of the number of those organizations. Thus, so long as they are relatively small and numerous, they muddle through in some way of coexistence. But if only a few or a competing pair are left, as is the case with the colossal political blocks of the present day, conflicts become devastating to the point of mutual destruction. The number of such general theorems for organization can easily be enlarged. They are well capable of being developed in a mathematical way, as was actually done for certain aspects.

General System Theory and the Unity of Science

Let me close these remarks with a few words about the general implications of interdisciplinary theory.

The integrative function of general system theory can perhaps be summarized as follows. So far, the unification of science has been seen in the reduction of all sciences to physics, the final resolution of all phenomena into physical events. From our point of view, unity of science gains a more realistic aspect. A unitary conception of the world may be based, not upon the possibly futile and certainly farfetched hope finally to reduce all levels of reality to the level of physics, but rather on the isomorphy of laws in different fields. Speaking in what has been called the "formal" mode, i.e., looking at the conceptual constructs of science, this means structural uniformities of the schemes we are applying. Speaking in "material" language, it means that the world, i.e., the total of observable events, shows structural uniformities, manifesting themselves by isomorphic traces of order in the different levels or realms.

We come, then, to a conception which in contrast to reductionism, we may call perspectivism. We cannot reduce the biological, behavioral, and social levels to the lowest level, that of the constructs and laws of physics. We can, however, find constructs and possibly laws within the individual levels. The world is, as Aldous Huxley once put it, like a Neapolitan ice cream cake where the levels—the physical, the biological, the social and the moral universe—represent the chocolate, strawberry, and vanilla layers. We cannot reduce strawberry to chocolate—the most we can say is that possibly in the last resort, all is vanilla, all mind or spirit. The unifying principle is that we find organization at all levels. The mechanistic world view, taking the play of physical particles as ultimate reality, found its expression in a civilization which glorifies physical technology that has led eventually to the catastrophes of our time. Possibly the model of the world as a great organization can help to reinforce the sense of reverence for the living which we have almost lost in the last sanguinary decades of human history.

General System Theory in Education: The Production of Scientific Generalists

After this sketchy outline of the meaning and aims of general system theory, let me try to answer the question of what it may contribute to integrative education. In order not to appear partisan, I give a few quotations from authors who were not themselves engaged in the development of general system theory.

A few years ago, a paper, entitled "The Education of Scientific Generalists," was published by a group of scientists including the engineer Bode, the sociologist Mosteller, the mathematician Tukey, and the biologist Winsor. The authors emphasized the "need for a simpler, more unified approach to scientific problems." They wrote:

We often hear that "one man can no longer cover a broad enough field" and that "there is too much narrow specialization." . . . We need a simpler, more unified approach to scientific problems, we need men who practice science—not a particular science, in a word, we need scientific generalists (Bode et al., 1949).

The authors then make clear how and why generalists are needed in fields such as physical chemistry, biophysics, the application of chemistry, physics, and mathematics to medicine, and they continue:

Any research group needs a generalist, whether it is an institutional group in a university or a foundation, or an industrial group.... In an engineering group, the generalist would naturally be concerned with system problems. These problems arise whenever parts are made into a balanced whole (Bode et al., 1949).

In a symposium of the Foundation for Integrated Education, Professor Mather (1951) discussed "Integrative Studies for General Education." He stated:

One of the criticisms of general education is based upon the fact that it may easily degenerate into the mere presentation of information picked up in as many fields of enquiry as there is time to survey during a semester or a year.... If you were to overhear several senior students talking, you might hear one of them say "our professors have stuffed us full, but what does it all mean?" . . . More important is the search for basic concepts and underlying principles that may be valid throughout the entire body of knowledge.

In answer to what these basic concepts may be, Mather states:

“Very similar general concepts have been independently developed by investigators who

have been working in widely different fields. These correspondences are all the more significant because they are based upon totally different facts. The men who developed them were largely unaware of each other's work. They started with conflicting philosophies and yet have reached remarkably similar conclusions....
Thus conceived, [Mather concludes], integrative studies would prove to be an essential part of the quest for an understanding of reality."

No comments seem to be necessary. Conventional education in physics, biology, psychology or the social sciences treats them as separate domains, the general trend being that increasingly smaller subdomains become separate sciences, and this process is repeated to the point where each specialty becomes a triflingly small field, unconnected with the rest. In contrast, the educational demands of training "Scientific Generalists" and of developing interdisciplinary "basic principles" are precisely those general system theory tries to fill. They are not a mere program or a pious wish since, as we have tried to show, such theoretical structure is already in the process of development. In this sense, general system theory seems to be an important headway towards interdisciplinary synthesis and integrated education.

Science and Society

However, if we speak of education, we do not mean solely scientific values, i.e., communication and integration of facts. We also mean ethical values, contributing to the development of personality. Is there something to be gained from the viewpoints we have discussed? This leads to the fundamental problem of the value of science in general and the behavioral and social sciences in particular.

An often-used argument about the value of science and its impact upon society and the welfare of mankind runs something like this. Our knowledge of the laws of physics is excellent, and consequently our technological control of inanimate nature almost unlimited. Our knowledge of biological laws is not so far advanced, but sufficient to allow for a good amount of biological technology in modern medicine and applied biology. It has extended the life expectancy far beyond the limits allotted to human beings in earlier centuries or even decades. The application of the modern methods of scientific agriculture, husbandry, etc., would well suffice to sustain a human population far surpassing the present one of our planet. What is lacking, however, is knowledge of the laws of human society, and consequently a sociological technology. So the achievements of physics are put to use for ever more efficient destruction; we have famines in vast parts of the world while harvests rot or are destroyed in other parts; war and indiscriminate annihilation of human life, culture, and means of sustenance are the only way out of uncontrolled fertility and consequent overpopulation. They are the outcome of the fact that we know and control physical forces only too well, biological forces tolerably well, and social forces not at all. If, therefore, we would have a well-developed science of human society and a corresponding technology, it would be the way out of the chaos and impending destruction of our present world.

This seems to be plausible enough and is, in fact, but a modern version of Plato's precept that only if the rulers are philosophers humanity will be saved. There is, however, a catch in the argument. We have a fair idea what a scientifically controlled world would look like. In the best case, it would be like Aldous Huxley's Brave New World, in the worst, like Orwell's 1984. It is an empirical fact that scientific achievements are put just as much, or even more, to destructive as constructive use. The sciences of human behavior and society are no exception. In fact, it is perhaps the greatest danger of the systems of modern totalitarianism that they are so alarmingly up-to-date not only in physical and biological, but also in psychological technology. The methods of mass suggestion, of the release of the instincts of the human beast, of conditioning and thought control are developed to highest efficacy; just because modern totalitarianism is so terrifically scientific, it makes the absolutism of former periods appear a dilettantish and comparatively harmless makeshift. Scientific control of society is no highway to Utopia.

The Ultimate Precept: Man as the Individual

We may, however, conceive of a scientific understanding of human society and its laws in a somewhat different and more modest way. Such knowledge can teach us not only what human behavior and society have in common with other organizations, but also what is their uniqueness. Here the main tenet will be: Man is not only a political animal; he is, before and above all, an individual. The real values of humanity are not those which it shares with biological entities, the function of an organism or a community of animals, but those which stem from the individual mind. Human society is not a community of ants or termites, governed by inherited instinct and controlled by the laws of the superordinate whole; it is based upon the achievements of the individual and is doomed if the individual 1S made a cog in the social machine. This, I believe, is the ultimate precept a theory of organization can give: not a manual for dictators of any denomination more efficiently to subjugate human beings by the scientific application of Iron Laws, but a warning that the Leviathan of organization must not swallow the individual without sealing its own inevitable doom.