An Outline of General System Theory (1950)

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1 Parallel Evolution in Science

As we survey the evolution of modern science, we find the remarkable phenomenon that similar general conceptions and viewpoints have evolved independently in the various branches of science, and to begin with these may be indicated as follows: in the past centuries, science tried to explain phenomena by reducing them to an interplay of elementary units which could be investigated independently of each other. In contemporary modern science, we find in all fields conceptions of what is rather vaguely termed 'wholeness.'

It was the aim of classical physics eventually to resolve all natural phenomena into a play of elementary units, the characteristics of which remain unaltered whether they are investigated in isolation or in a complex. The expression of this conception is the ideal of the Laplacean spirit, which resolves the world into an aimless play of atoms, governed by the laws of nature. This conception was not changed but rather strengthened when deterministic laws were replaced by statistical laws in Boltzmann's derivation of the second principle of thermodynamics. Physical laws appeared to be essentially 'laws of disorder,' a statistical result of unordered and fortuitous events. In contrast, the basic problems in modern physics are problems of organisation. Problems of this kind present themselves in atomic physics, in structural chemistry, in crystallography, and so forth. In microphysics, it becomes impossible to resolve phenomena into local events, as is shown by the Heisenberg relation and in quantum mechanics.

Corresponding to the procedure in physics, the attempt has been made in biology to resolve the phenomena of life into parts and processes which could be investigated in isolation. This procedure is essentially the same in the various branches of biology. The organism is considered to be an aggregate of cells as elementary life-units, its activities are resolved into functions of isolated organs and finally physico-chemical processes, its behaviour into reflexes, the material substratum of heredity into genes, acting independently of each other, phylogenetic evolution into single fortuitous mutations, and so on. As opposed to the analytical, summative and machine [135]theoretical viewpoints, organismic conceptions[1] have evolved in all branches of modern biology which assert the necessity of investigating not only parts but also relations of organisation resulting from a dynamic interaction and manifesting themselves by the difference in behaviour of parts in isolation and in the whole organism.

The development in medicine follows a similar pattern.[2] Virchow's programme of 'cellular pathology,' claiming to resolve disease into functional disturbances of cells, is to be supplemented by the consideration of the organism-as-a-whole, as it appears clearly in such fields as theory of human constitutions, endocrinology, physical medicine and psychotherapy.

Again we find the same trend in psychology. Classical association psychology tried to resolve mental phenomena into elementary units, sensations and the like, psychological atoms, as it were. *Gestalt* psychology has demonstrated the existence and primacy of psychological entities, which are not a simple summation of elementary units, and are governed by dynamical laws.

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[1] L. von Bertalanffy, *Das biologische Weltbild,* Band I. Die Stellung des Lebens in Natur und Wissenschaft, Bern, 1949

[2] L. von Bertalanffy, *Biologie und Medizin,* Wien, 1946

Corresponding developments are found in the social sciences. In classical economic doctrine, society was considered as a sum of human individuals as social atoms. At present there is a tendency to consider a society, an economy, or a nation, as a whole which is superordinated to its parts. This conception is at the basis of all the various forms of collectivism, the consequences of which are often disastrous for the individual and, in the history of our times, profoundly influence our lives.[3] Civilisations appear, if not as superorganisms, as was maintained by Spengler, at least as superindividual units or systems, as expressed in Toynbee's conception of history.

In philosophy, the same general trend is manifest in systems so radically different as Nicolai Hartmann's theory of categories, the doctrine of emergent evolution, Whitehead's 'organic mechanism,' and dialectic materialism; all these are systems which are diametrically opposed in their scientific, metaphysical and social backgrounds, but agree in maintaining that principles of dynamic wholeness are basic in the modern conception of the world.

Thus, similar fundamental conceptions appear in all branches of science, irrespective of whether inanimate things, living organisms, [136]or social phenomena are the objects of study. This correspondence is the more striking because these developments are mutually independent, largely unaware of each other, and based upon totally different facts and contradicting philosophies. They open new perspectives in science and life, but also involve serious danger.

Thus it appears that there is a general change in the scientific attitude and conceptions, and the question arises: what is the origin of these correspondences?

2 Isomorphic Laws in Science

Not only are general aspects and viewpoints alike in different fields of science; we find also formally identical or isomorphic laws in completely different fields. This is a well-known fact in physics where the same differential equations apply, for example, to the flow of liquids, of heat, and of electric currents in a wire. But it appears that the significance of this fact, and the possibilities it opens in fields outside physics, have hardly been considered.

For example, the exponential law or law of compound interest applies, with a negative exponent, to the decay of radium, the mono-molecular reaction, the killing of bacteria by light or disinfectants, the loss of body substance in a starving animal, and to the decrease of a population where the death rate is higher than the birth rate. Similarly, with a positive exponent, this law applies to the individual growth of certain micro-organisms, the unlimited Malthusian growth of bacterial, animal, or human populations, the growth curve of human knowledge (as measured by the number of pages devoted to scientific discoveries in a textbook on the history of science), and the number of publications on *Drosophila*.[4] The entities concerned—atoms, molecules, bacteria, animals, human beings, or books—are widely different, and so are the causal mechanisms involved. Nevertheless, the mathematical law is the same. Another equation, the logistic law of Verhulst, is, in physical chemistry, the equation of autocatalytic reaction, and in biology, it describes certain cases of organic growth. It was first stated in demography to describe the growth of human populations in a limited space of living. It governs also the advancement of technical inventions, such as the growth of the railway system in the United States during the last century, or of the number of wireless sets in [137]operation. What

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[3] F. A. Hayek, *The Road to Serfdom,* Chicago, 1944

[4] A. H. Hersh, 'Drosophila and the Course of Research,' *Ohio J. of Science*, 1942, **42**, 198-200

is known in national economy as Pareto's law[1] [5]of the distribution of income within a nation, represents, in biology, the law of allometric growth, describing the relative increase of organs, chemical compounds, or physiological activities with respect to body size. Volterra[6] has developed a population dynamics, comparable to mechanical dynamics, working with homologous concepts such as demographic energy and potential, life action, etc., and leading to a principle of minimum vital action, corresponding to the principle of minimum action in mechanics. Actually, principles of minimum action appear in widely different fields besides mechanics, for example, in physical chemistry as the principle of Le Chatelier and in electrodynamics as Lenz' rule. Again, the principle of relaxation oscillations governs the neon lamp, but also important phenomena in nerve physiology and certain phenomena of biocoenoses or organic communities.

The same is true for phenomena where the general principles can be described in ordinary language though they cannot be formulated in mathematical terms. For instance, there are hardly processes more unlike phenomenologically and in their intrinsic mechanisms, than the formation of a whole animal out of a divided sea-urchin or newt germ, the re-establishment of normal function in the central nervous system after removal or injury to some of its parts, and *gestalt* perception in psychology. Nevertheless, the principles governing these different phenomena show striking similarities.

Again we ask: what is the origin of these isomorphisms?

There are three obvious reasons. The first is in the trivial fact that while it is easy to write down any complicated differential equation yet even innocent-looking expressions may be hard to solve, or give, at least, cumbersome solutions. The number of simple differential equations which are available and which will be preferably applied to describe natural phenomena is limited. So it is no wonder that laws identical in structure will appear in intrinsically different fields. A similar consideration holds for statements formulated not in mathematical but in ordinary language: the number of intellectual schemes available is rather restricted, and they will be applied in quite different realms.

However, these laws and schemes would be of little help if the world (i.e. the totality of observable events) was not such that they [138]could be applied to it. We can imagine a chaotic world or a world which is too complicated to allow the application of the relatively simple schemes which we are able to construct with our limited intellect. Fortunately, the actual world is not of this sort, and does allow the application of our intellectual constructions.

But there is yet a third reason for the isomorphism of natural laws and this is most important for our present purpose. Laws of the kind considered are characterised by the fact that they hold generally for certain classes of complexes or systems, irrespective of the special kind of entities involved. For instance, the exponential law states that, given a complex of a number of entities, a constant percentage of these elements decay or multiply per unit time. Therefore this law will apply to the pounds in a banking account as well as to radium atoms, molecules, bacteria, or individuals in a population. The logistic law says that the increase, originally exponential, is limited by some restricting conditions. Thus in autocatalytic reactions, a compound formed catalyses its own formation; but since the number of molecules is finite in a closed reaction vessel, the reaction must stop when all molecules are transformed, and must therefore approach a limiting value. A population increases exponentially with the increasing number of individuals, but if space and food are limited, the amount of food available per individual decreases; therefore the increase in number cannot be unlimited, but must approach a steady state defined as the maximum

[5] W. Pareto, *Cours de l'Économie Politique*, 1897

[6] V. Volterra, *Lécons sur la Théorie Mathématique de la Lutte pour la Vie*, Paris, 1921

population compatible with resources available. Railway lines which already exist in a country lead to the intensification of traffic and industry which, in turn, make necessary a denser railway network, till a state of saturation is eventually reached; thus, railways behave like autocatalysers accelerating their own increase, and their growth follows the autocatalytic curve. The parabolic law is an expression for competition within a system, each element taking its share according to its capacity as expressed by a specific constant. Therefore the law is of the same form whether it applies to the competition of individuals in an economic system, following Pareto's law, or to organs competing within an organism for nutritive material and showing allometric growth.

There exist therefore *general system laws* which apply to any system of a certain type, irrespective of the particular properties of the system or the elements involved. We may say also that there is a structural correspondence or logical homology of systems in which the entities [139]concerned are of a wholly different nature. This is the reason why we find isomorphic laws in different fields.

The need for a general superstructure of science, developing principles and models that are common to different fields, has often been emphasised in recent years, for instance, by the Cybernetics group of N. Wiener, by the General Semantics of Count Korzybski[7] in the claim for Scientific Generalists' as recently advanced by Bode and others[8] and in many other publications. But a clear statement of the problem and a systematic elaboration has apparently never been made.

3. General System Theory

Such considerations lead us to postulate a *new basic scientific discipline* which we call *General System Theory*.[9] It is a logico-mathematical field, the subject matter of which is the formulation and deduction of those principles which are valid for 'systems' in general. There are principles which apply to systems in general, whatever the nature of their component elements or the relations or 'forces' between them. The fact that all sciences mentioned above are concerned with systems, leads to a formal correspondence or logical homology in their general principles, and even in their special laws if the conditions of the systems correspond in the phenomena under consideration.

General System Theory is a logico-mathematical discipline, which is in itself purely formal, but is applicable to all sciences concerned with systems. Its position is similar to that, for example, of probability theory, which is in itself a formal mathematical doctrine but which can be applied to very different fields, such as thermodynamics, biological and medical experimentation, genetics, life insurance statistics, etc.

The significance of the General System Theory may be characterised in different ways.

So far, exact science, meaning a mathematical hypothetico-deductive system, has been almost identical with theoretical physics, and the only systematic scientific laws that have been acknowledged [140]universally and without restriction have been the laws of physics and chemistry. To be sure, there are rudiments of systems of laws, i.e. hypothetico-deductive systems, also in other realms such as national economy, demography, and certain fields of biology. For example, references are often made to biological or

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[7] A. Korzybski, *Science and Sanity,* 2nd ed. New York, 1941

[8] H. Bode, *et al.,* 'The Education of a Scientific Generalist,' *Science,* 1949, **109,** 553

[9] L. von Bertalanffy, 'Zu einer allgemeinen Systemlehre,' *Blätter f. dtsche Philos.,* 1945, **18,** No. 3/4. (Not known if published.) 'Zu einer allgemeinen Systemlehre,' *Biologia Generalis,* 1949, **19,** 114-129.

economical 'equilibria.'[10] But it remains somewhat obscure what the concept of 'equilibrium' means, if applied outside the fields of physical magnitudes, and so conceptions of this and similar kinds have remained little more than loose, if ingenious, metaphors. Few attempts to state exact laws in non-physical fields have gained universal recognition; they lack the consistency of the system of physics, and their methodological background remains obscure.

In consequence of the predominant development of the physical sciences, it was thought that, in order to state exact laws for any field, and to render it an exact science, it had to be reduced to physics and chemistry. This is, of course, the methodological principle of the so-called mechanistic view.

Quite apart from the question whether the mechanistic principle is justified in the last resort and for some remote future, it appears, however, that it does not in fact work in wide fields of science. For example, we can isolate processes occurring in the living organism and describe them in the terms and laws of physico-chemistry. This is done, with enormous success, in modern biophysics and biochemistry. But when it comes to the properly 'vital' features, it is found that they are essentially problems of organisation, orderliness, and regulation, resulting from the interaction of an enormous number of highly complicated physico-chemical events. To grasp in detail the physico-chemical organisation of even the simplest cell is far beyond our capacity. So we come to the conclusion that it is not possible to state exact laws for the basic biological phenomena, such as self-regulation in metabolism, growth, morphogenesis, behaviour, etc., because they are much too complicated to allow a thorough understanding and an analysis of all the processes involved. This is, in fact, the common opinion in present biology. The same applies, of course, even more to sociological phenomena, because of their even higher complexity and the impossibility of resolving them into physico-chemical events.

[141] Thus it seems necessary to expand our conceptual schemes if we wish to deal with these complex realms, and to make it possible for them to be included in the exact sciences; to establish systems of exact laws also in those fields where an application of the laws of physics or chemistry is not sufficient or even possible. Even physical concepts need to, and in fact do undergo expansion and far-reaching modifications when applied to new realms, as we shall see when considering the recent extension of kinetics and thermodynamics to open systems.

As opposed to the mechanistic conception, we are led to a different view. The task of science is to state laws for the different strata of reality. Even in physics, quantum statistics, molecular statistics, and macrophysical laws represent different strata. Similarly, we may apply statistical values and laws on any level, if this gives results consistent with experience and within a theoretical system. If you cannot run after each molecule and describe the state of a gas in a Laplacean formula, take, with Boltzmann, a statistical law describing the average result of the behaviour of a great many individual molecules. If you cannot follow the enormous number of processes in intermediary metabolism, use average values such as total metabolism quotients of anabolism and catabolism, representing the outcome of all these processes, and you may be able to state exact laws for phenomena such as metabolism, growth, and morphogenesis of the organism as a whole, without the hopeless undertaking to press all individual physico-chemical processes into a gigantic formula. You cannot resolve the individuals within a biocoenosis or a social unit into cells and finally into physico-chemical processes. Very well, take the individuals as units, and eventually you will get a system of

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[10] H. Dotterweich, *Das biologische Gleichgewicht und seine Bedeutung für die Haupt-probleme der Biologie*, Jena, 1940

J. Dumontier, *Equilibre Physique, Equilibre Biologique, Equilibre Economique*, Paris, 1949.

laws which is not physics but is of the same form as exact physical science, that is a mathematical hypothetico-deductive system.

However, to apply the procedure consistently, it seems necessary to establish the principles which apply to those entities which are called 'systems,' and of which physical systems are only a subclass. Thus, we are led again to the conception of a General System Theory, as a doctrine which is generalised with respect to physics. 'Kinetics' and 'dynamics' have been, as yet, branches of physics concerned with entities such as molecules, energy, and the like. We ask for a generalised kinetics and dynamics, where the entities concerned can be interpreted as any entities that present themselves in different fields.

[142] General System Theory is not a mere catalogue of well-known differential equations and their solutions. On the contrary, the general system conception raises new and well-defined problems which do not appear in physics, because they are not met with in its usual problems, but which are of basic importance in non-physical fields. Just because the phenomena concerned are not dealt with in ordinary physics, these problems have often appeared as metaphysical or vitalistic. It will be an important task to generalise physical principles such as those of minimum action, of Le Chatelier, or the conditions of the existence of stationary and periodic solutions and of steady states, etc., in such a way that they apply to systems in general. Problems and concepts such as progressive mechanisation, centralisation, individuality, leading part, competition, etc., are unfamiliar to the physicist, but they are basic in the biological and sociological realms, and require exact treatment.

Moreover, General System Theory should be an important regulative device in science. The existence of laws of similar structure in different fields enables the use of systems which are simpler or better known as models for more complicated and less manageable ones. Therefore General System Theory should be, methodologically, an important means of controlling and instigating the transfer of principles from one field to another, and it will no longer be necessary to duplicate or triplicate the discovery of the same principles in different fields isolated from each other. At the same time, by formulating exact criteria, General System Theory will guard against superficial analogies which are useless in science and harmful in their practical consequences.

The central position of the concept of wholeness in biology, psychology, sociology and other sciences is generally acknowledged. What is meant by this concept is indicated by expressions such as 'system,' '*gestalt*,' 'organism,' 'interaction,' 'the whole is more than the sum of its parts' and the like. However, these concepts have often been misused, and they are of a vague and somewhat mystical character. The exact scientist therefore is inclined to look at these conceptions with justified mistrust. Thus it seems necessary to formulate these conceptions in an exact language. General System Theory is a new scientific doctrine of 'wholeness'—a notion which has been hitherto considered vague, muddled and metaphysical.

Considered from the viewpoint of philosophy, General System Theory is to replace that field which is known as 'theory of [143]categories'[11] by an exact system of logico-mathematical laws. Those general notions, which as yet have been formulated only in common language, will acquire, by the General System Theory, that unambiguous and exact expression which is possible only in mathematical language.

[Sections 4 – 7 omitted. For full text, see here.]

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[11] N. Hartmann, 'Neue Wege der Ontologie,' in *Systematische Philosophie,* ed. N. Hartmann, Stuttgart and Berlin, 1942.

8 Closed and Open Systems

We now come to a consideration which leads to important problems and discoveries in physics, biology and other fields.

It is the basic characteristic of every organic system that it maintains itself in a state of perpetual change of its components. This we find at all levels of biological organisation. In the cell there is a perpetual destruction of its building materials through which it endures as a whole. Recent research, the investigations with isotope-tracers, have shown that this exchange of building materials goes on at a rate much higher than was formerly supposed. In the multicellular organism, cells are dying and are replaced by new ones, but it maintains itself as a whole. In the biocoenosis and the species, individuals die and others are born. Thus every organic system appears stationary if considered from a certain point of view. But what seems to be a persistent entity on a certain level, is maintained, in fact, by a perpetual change, building up and breaking down of systems of the next lower order: of chemical compounds in the cell, of cells in the multicellular organism, of individuals in ecological systems.

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

So far, physics and physical chemistry have been almost exclusively concerned with closed systems. However, the consideration of organisms and other living systems makes necessary an extension and generalisation of theory. The kinetics and thermodynamics of open systems have been developed in recent years. The present writer has advanced since 1932 the conception of the organism as an open system and has stated general kinetic principles and their biological [156]implications.[12,13] Similar investigations have been made by Burton,[14] Dehlinger and Wertz,[15] Skraba1,[16] Reiner and Spiegelman,[17] Denbigh,[18] and others. The thermodynamic of open systems has been developed by Prigogine,[19] and Prigogine and Wiame.[20] Since a survey of the theory of open systems has been given recently[21] we mention here only a few points of general and philosophical significance.

The consideration of open systems is more general in comparison with that of closed systems; for it is always possible to come from open to closed systems by equating the transport terms to zero, but not *vice versa.* In physics, the theory of open systems leads to basically new, and partly revolutionary, consequences and principles. In biology it accounts, first, for many characteristics of living systems which have appeared to be in contradiction with the laws of physics, and have been considered hitherto as vitalistic features.

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12 L. von Bertalanffy, *Theoretische Biologie,* Band II

13 L. von Bertalanffy, ' Der Organismus als physikalisches System betrachtet,' *Naturwissenschaften,* 1940, **28,** 521-531

14 A. C. Burton. 'The Properties of the Steady State as Compared to those of Equilibrium as Shown in Characteristic Biological Behavior,' *J. cell. comp. Physiol.,* 1939, **14,** 327

15 U. Dehlinger and E. Wertz, 'Biologische Grundfragen in physikalischer Betrachtung,' *Naturwissenschaften,* 1942, **30,** 250

16 A. Skrabal, 'Das Reaktionsschema der Waldenschen Umkehrung. III,' *Oesterr. Chemiker Ztg.*, 1947, **48,** 158-163

17 J. M. Reiner and S. Spiegelman, 'The Energetics of Transient and Steady States,' *J. phys. Chem.,* 1945, **49**, 81

18 K. G. Denbigh, *et al.* 'The Kinetics of Open Reaction Systems,' *Trans. Faraday Soc.,* 1948, **44,** 479-494

19 I. Prigogine, *Étude Thermodynamique des phénomènes irréversibles*, Paris, 1947

20 I. Prigogine and J. M. Wiame, 'Biologie et Thermodynamique des phénomènes irréversibles,' *Experientia* (Basel), 1946, 2, 450-451

21 L. von Bertalanffy, 'The Theory of Open Systems in Physics and Biology,' *Science,* 1950, **3**, 23-29

Secondly, the consideration of organisms as open systems yields quantitative laws of basic biological phenomena, such as metabolism and growth, form development, excitation, etc.

In the case in which the variations in time disappear, systems become stationary. Closed systems thus attain a time-independent state of equilibrium where the composition remains constant. In fact, closed systems *must* eventually reach a state of equilibrium, according to the second law of thermodynamics. Open systems *may,* provided certain conditions are given, attain a stationary state. Then [157]the system appears also to be constant, though this constancy is maintained in a continuous change, inflow and outflow of materials. This is called a *steady* state. Since there is no equivalent for this expression in German, the term *Fliessgleichgewicht* was introduced by the author. Steady states can be realised in certain physico-chemical arrangements and are, in fact, widely used in technological chemistry. Living systems are the most important examples of open systems and steady states.

9 Equifinality

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

Vital phenomena show a different behaviour. Here, to a wide extent, the final state may be reached from different initial conditions and in different ways. Such behaviour we call equifinal. Thus, for instance, the same final result, namely a typical larva, is achieved by a complete normal germ of the sea urchin, by a half germ after experimental separation of the cells, by two germs after fusion, or after translocations of the cells. It is well-known that it was just this experiment which was considered, by Driesch, the main proof of vitalism. According to Driesch, such behaviour is inexplicable in physico-chemical terms. For a physico-chemical system cannot achieve the same performance, in this case the production of a whole organism, if divided or injured. This extraordinary performance can be accomplished only by the action of a vitalistic factor, entelechy, essentially different from physico-chemical forces and governing the processes in foresight of the goal to be reached. It is therefore a question of basic importance whether equifinality is a proof of vitalism. The answer is that it is not.

Analysis shows that closed systems cannot behave equifinally. This is the reason why equifinality is found in inanimate nature only in exceptional cases. However, in open systems, which are exchanging materials with the environment, in so far as they attain a steady state, the latter is independent of the initial conditions, or is equifinal. Thus, in an open kinetic system, irrespective of the content in the beginning [158]or any other time, the steady state values will always be the same because they are determined only by the constants of reaction and of inflow and outflow. Steady state systems show equifinality, in sharp contrast to closed systems in equilibrium where the final state depends on the components given at the beginning of the process.

Equifinality can be formulated quantitatively in certain biological cases. Thus growth is equifinal: the same final size which is characteristic for the species can be reached from different initial sizes (e.g. in litters of different numbers of individuals) or after a temporary suppression of growth (e.g. by a diet insufficient in quantity or in vitamins). According to the quantitative theory advanced by the author[22] growth can be

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[22] L. von Bertalanffy, 'Das organische Wachstum und seine Gesetzmässigkeiten,' *Experientia* (Basel), 1948, **4**, 255-269

L. von Bertalanffy, 'Problems of Organic Growth,' *Nature,* London, 1949, **163,** 156-158 considered the result of a counteraction of the anabolism and catabolism of building materials. Since in the most common type of growth, anabolism is a function of surface, catabolism of body mass, the surface-volume ratio is shifted in disfavour of surface with increasing size. Therefore a balance between anabolism and catabolism will eventually be reached which is independent of the initial size and depends only on the species-specific ratio of the metabolic constants. It is therefore equifinal.

Equifinality is at the basis of organic regulations. We find it everywhere where biological events are determined by the dynamic interactions of parts; it becomes progressively restricted and finally impossible when the originally unitary system segregates into separate causal chains determined by fixed structures, that is to say, with progressive segregation. There are two general restrictions of regulation. The first is the incompleteness of the open-system-character of the organism. For instance, the growth regulations mentioned will not be possible if insufficient diet has caused lasting irreversible disturbances, for example, in the ossification of bones. The second limitation of regulation lies in the hierarchical order, namely, in the progressive segregation of the organism into subordinate systems which gain a certain independence of each other. The extreme case is a tumour which behaves as if it were an independent organism, and thus destroys the whole of which it is a part.

Thus the investigation of open systems leads to a conclusion which is very remarkable for the philosophy of science. The equifinal form [159]of directiveness which is so characteristic for biological phenomena that it has been considered the vitalistic essence of life is, in fact, a necessary consequence of the steady state in organisms.

10 Types of Finality

Since it is not possible to enter here into a detailed discussion of the problem of finality, we are merely enumerating the different types found in experience. Thus we can distinguish:

I. Static teleology or fitness, meaning that an arrangement seems to be useful for a certain 'purpose.' Thus a fur coat is fit to keep the body warm, and so are hairs, feathers, or layers of fat in animals. Thorns may protect plants against grazing cattle, or imitative colourations and mimicries may be advantageous to protect animals against enemies.

II. Dynamic teleology, meaning a directiveness of processes. Here different phenomena can be distinguished which are often confused:

(i) Direction of events towards a final state which can be expressed as if the present behaviour were dependent on that final state. Every system which attains a time-independent condition behaves in this way

(ii) Directiveness based upon structure, meaning that an arrangement of structures leads the process in such a way that a certain result is achieved. This is true, of course, of the function of man-made machines yielding products or performances as desired. In living nature we find a structural order of processes that in its complication widely surpasses all man-made machines. Such order is found from the function of macroscopic organs, such as the eye as a sort of camera, or the heart as a pump, to the microscopic cell structures responsible for metabolism, secretion, excitability, heredity and so forth. Whilst man-made machines work in such a way as to yield certain products and performances, for example, fabrication of airplanes or moving a railway train, the order of process in living systems is such as to maintain the system itself. An important part of these processes is represented by homeostasis (Canon), i.e. those processes through which the material and energetical situation of the organism is maintained constant. Examples are the mechanisms of thermoregulation, of maintenance of osmotic pressure, of pH, of salt concentration, the regulation of posture and so forth. These regulations are governed, in a wide extent, by feed-back mechanisms. Feed-back means that [160]from the output of a machine a certain amount is monitored back, as 'information,' to the input so as to regulate the latter and thus to stabilise or direct the action of the machine. Mechanisms of this kind are well known in technology, as, for instance, the governor of the steam-engine, self-steering missiles and other 'servomechanisms.' Feed-back mechanisms appear to be responsible for a large part of the organic regulations and phenomena of homeostasis, as recently emphasised by Cybernetics.[23]

(iii) There is, however, yet another basis for organic regulations. This is equifinality, i.e. the fact that the same final state can be reached from different initial conditions and in different ways. This is found to be the case in open systems, in so far as they attain a steady state. It appears that equifinality is responsible for the primary regulability of organic systems, i.e. for all those regulations which cannot be based upon predetermined structures or mechanisms but, on the contrary, exclude such mechanisms and were regarded therefore as arguments for vitalism.

(iv) Finally, there is true finality or purposiveness, meaning that the actual behaviour is determined by the foresight of the goal. This is the original Aristotelian concept. It presupposes that the future goal is already present in thought, and directs the present action. True purposiveness is characteristic of human behaviour, and it is connected with the evolution of the symbolism of language and concepts.[24]

The confusion of these different types of finality is one of the factors responsible for the confusion occurring in epistemology and theoretical biology. In the field of man-made things, fitness (I) and teleological working of machines (II, ii) are, of course, due to a planning intelligence (II, iv). Fitness in organic structures (I) can probably be explained by the causal play of random mutations and natural selection. This explanation is, however, much less plausible for the origin of the very complicated organic mechanisms and feedback systems (II, ii). Vitalism is essentially the attempt to explain organic directiveness (II, ii and iii) by means of intelligence in foresight of the goal (II, iv). This leads, methodologically, beyond the limits of natural science, and is empirically unjustified, since we have, even [161]in the most astonishing phenomena of regulation or instinct, no justification for, but most definite reasons against, the assumption that, for example, an embryo or an insect is endowed with superhuman intelligence. A most important part of those phenomena which have been advanced as 'proofs of vitalism,' such as equifinality and anamorphosis (see below), are consequences of the characteristic state of the organism as an open system, and thus accessible to scientific interpretation and theory.

11 Catamorphosis and Anamorphosis

'According to definition, the second law of thermodynamics applies only to closed systems, it does not define the steady state.'[25] The expansion of thermodynamics to include open systems was elaborated by Prigogine[26] and has led to most important results of which we shall discuss only a few of far-reaching significance.

The direction of happenings in closed systems is towards states of maximum entropy since, according to the second law, entropy must increase in all irreversible processes. But this is not true in open systems. In

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[23] L. K. Frank, *et al.* 'Teleological Mechanisms,' *Ann. N.Y. Acad. Sci.,* 1948, 50 N. Wiener, *Cybernetics,* New York and Paris, 1948

[24] L. von Bertalanffy, ' Das Weltbild der Biologie,' in *Weltbild and Menschenbild,* III. Internat. Hochschulwochen. des Oesterr. College, Salzburg, 1948, pp. 251-274

[25] L. von Bertalanffy, *Theoretische Biologie,* Band II

[26] I. Prigogine, *Étude Thermodynamique des phénomènes irréversibles*

an open system, and especially in a living organism, there is not only a production of entropy due to irreversible processes, but the organism 'feeds,' to use an expression of Schrödinger's, 'from negative entropy.' It imports complex organic molecules, uses their energy, and renders back the simpler end-products to the environment. Therefore the total change of entropy can be negative as well as positive. Though the second law is not violated, more strictly speaking, though it holds for the system plus its environment, it does not hold for the open system itself. Entropy may decrease in such systems, and their steady states are not defined by maximum entropy but, as demonstrated by Prigogine, by minimum entropy production.

As is well known, the significance of the second law can be expressed also in another way. It states that the general tendency of events is towards a state of maximum disorder. According to the second law, higher forms of energy such as mechanical energy, light, electricity and so forth, are continually and irreversibly degraded to undirected heat movement. Heat gradients, in turn, are gradually levelled down, and so the Universe approaches entropy death as its irrevocable fate when all energy is converted into heat of low [162]temperature, and the world process comes to a stop. There may be exceptions to the second law in microphysical dimensions since in the interior of stars, under very high temperatures, higher atoms are built up from simpler ones, especially helium from hydrogen. These processes are the source of sun radiation and are the basis of the hydrogen bomb. But on the macrophysical level, the second law seems essentially to command a transition toward maximum disorder and degradation.

But here a striking contrast between inanimate and animate nature seems to exist. According to the second law, physical events are directed towards a levelling down of differences and states of maximum disorder. In organic development and evolution, a transition towards states of higher order and differentiation seems to occur. It has often been assumed therefore that a tendency toward increasing complication is a primary characteristic of the living, in contrast to inanimate nature. This was called anamorphosis by Woltereck.[27]

These problems gain new aspects if we pass from closed systems, which alone are taken into account by classical thermodynamics, to open systems. Entropy may decrease in the evolution of such systems; in other words, such systems may spontaneously develop towards greater heterogeneity and complexity. Probably it is just this thermodynamical characteristic of organisms as open systems which is at the basis of the apparent contrast of catamorphosis in inorganic, and anamorphosis in living nature. This is obviously so in the transition towards higher complexity in organic development which is possible only at the expense of energies yielded by oxidation and other energy-yielding processes. The transition toward higher complexity is connected with the splitting up of a primary unitary system into partial systems. This seems to be the reason why we find what we have called progressive segregation only in the organic realm. With respect to evolution, these considerations show that the supposed violation of physical laws does not exist, or more strictly speaking, that it disappears by the extension of physical theory.

It is outside our present task to discuss the application of the theory of open systems to special problems in physics and biology.[28,29] But it may be emphasised that just the peculiar and supposedly vitalistic [163]characteristics of vital phenomena take on a new appearance in the theory of open systems. Equifinality, which was brought forward by Driesch as the 'first proof' of vitalism, is a consequence of

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[27] R. Woltereck, *Ontologie des Lebendigen,* Stuttgart, 1939

[28] L. von Bertalanffy, The Theory of Open Systems in Physics and Biology.' *Theoretische Biologie,* Band II

[29] I. Prigogine, *Étude Thermodynamique des phénomènes irréversibles*

steady state conditions. Similarly, self-regulation in metabolism was considered as explicable only by a governing entelechy; but its general characteristics follow from the laws of steady states. Anamorphosis conflicts with classical thermodynamics, but is in accordance with thermodynamics of open systems. Self-multiplication of biological elementary units, such as genes and chromosomes, was offered by Driesch as a 'second proof' of vitalism. If a hypothesis, advanced by the author[30] should prove to be correct, it would also be a consequence of the fact that these units are metabolising systems. I think therefore that we do not go far astray if we suppose that the principles of open systems are near the very root of the central biological problems.

12 The Unity of Science

We may summarise the main results of this presentation as follows:

(*i*) The analysis of general system principles shows that many concepts which have often been considered as anthropomorphic, metaphysical, or vitalistic, are accessible to exact formulation. They are consequences of the definition of systems or of certain system conditions.

(*ii*) Such investigation is a useful prerequisite with respect to concrete problems in science. In particular, it leads to the elucidation of problems which, in the usual schematisms and pigeonholes of the specialised fields, are not envisaged. Thus system theory should prove an important means in the process of developing new branches of knowledge into exact science, i.e. into systems of mathematical laws.

(*iii*) This investigation is equally important to Philosophy of Science, major problems of which gain new and often surprising aspects.

(*iv*) The fact that certain principles apply to systems in general, irrespective of the nature of the systems and of the entities concerned, explains that corresponding conceptions and laws appear independently in different fields of science, causing the remarkable parallelism in their [164]modern development. Thus, concepts such as wholeness and sum, mechanisation, centralisation, hierarchical order, stationary and steady states, equifinality, etc., are found in different fields of natural sciences, as well as in psychology and sociology.

These considerations have a definite bearing on the question of the Unity of Science. The current opinion has been well represented by Carnap.[31] As he states, Unity of Science is granted by the fact that all statements in science can ultimately be expressed in physical language, i.e. in the form of statements that attach quantitative values to definite positions in a space-time system of co-ordinates. In this sense, all seemingly non-physical *concepts,* for instance specifically biological notions such as 'species,' 'organism,' 'fertilisation,' and so forth, are defined by means of certain perceptible criteria, i.e. qualitative determinations capable of being physicalised. The physical language is therefore the universal language of science. The question whether biological *laws* can be reduced to physical ones, i.e. whether the natural laws sufficient to explain all inorganic phenomena are also sufficient to explain biological phenomena, is left open by Carnap, though with preference given to an answer in the affirmative.

From our point of view Unity of Science wins a much more concrete and, at the same time, profounder aspect. We too leave open the question of the 'ultimate reduction' of the laws of biology (and the other non-physical realms) to physics, i.e. the question whether a hypothetico-deductive system embracing all sciences from physics to biology and sociology may ever be established. But we are certainly able to establish scientific laws for the different levels or strata of reality. And here we find, speaking in

[30] L. von Bertalanffy. 'Bemerkungen zum Modell der biologischen Elementareinheiten,' *Naturwissenschaften,* 1944, **32,** 26-32

[31] R. Camap, *The Unity of Science,* London, 1934

the ‘formal mode’ (Carnap), a correspondence or isomorphy of laws and conceptual schemes in different fields, granting the Unity of Science. Speaking in ‘material’ language, this means that the world (i.e. the total of observable phenomena) shows a structural uniformity, manifesting itself by isomorphic traces of order in its different levels or realms.

Reality, in the modern conception, appears as a tremendous hierarchical order of organised entities, leading, in a superposition of many levels, from physical and chemical to biological and sociological systems. Unity of Science it granted, not by a utopian reduction of all sciences to physics and chemistry, but by the structural uniformities of the different levels of reality.

Especially the gap between natural and social sciences or, to use [165]the more expressive German terms, of *Natur- und Geisteswissenschafien* is widely diminished, not in the sense of a reduction of the latter to biological conceptions but in the sense of structural similarities. This is the cause of the appearance of corresponding general viewpoints and notions in both fields, and may eventually lead to the establishment of a system of laws in the latter.

The mechanistic world-view found its ideal in the Laplacean spirit, i.e. in the conception that all phenomena are ultimately aggregates of fortuitous actions of elementary physical units. Theoretically, this conception did not lead to exact sciences outside the field of physics, i.e. to laws of the higher levels of reality, the biological, psychological and sociological. Practically, its consequences have been fatal for our civilisation. The attitude that considers physical phenomena as the sole standard-measure of reality, has lead to the mechanisation of mankind and to the devaluation of higher values. The unregulated domination of physical technology finally ushered the world into the catastrophical crises of our time. After having overthrown the mechanistic view, we are careful not to slide into ‘biologism,’ that is, into considering mental, sociological and cultural phenomena from a merely biological standpoint. As physicalism considered the living organism as a strange combination of physico-chemical events or machines, biologism considers man as a curious zoological species, human society as a bee-hive or a stud-farm. Biologism has, theoretically, not proved its theoretical merits, and has proved fatal in its practical consequences. The organismic conception does not mean a unilateral dominance of biological conceptions. When emphasising general structural isomorphies of different levels, it asserts, at the same time, their autonomy and possession of specific laws.

We believe that the future elaboration of General System Theory will prove to be a major step towards the unification of science. It may be destined, in the science of the future, to play a role similar to that of Aristotelian logic in the science of antiquity. The Greek conception of the world was static, things being considered to be a mirroring of eternal archetypes or ideas. Therefore classification was the central problem in science, the fundamental organon of which is the definition of subordination and superordination of concepts. In modern science, dynamic interaction appears to be the central problem in all fields of reality. Its general principles are to be defined by System Theory.

Ludwig von Bertalanffy, “An Outline of General System Theory,” *The British Journal for the Philosophy of Science*, Vol. 1, No. 2 (Aug., 1950), pp. 134-165.