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LIVING SYSTEMS

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ABSTRACT

General systems behavior theory is concerned with seven levels of living systems — cell, organ, organism, group, organization, society, and supranational system. The following article is an exposition of the basic concepts in this integrative theoretical approach. It is a condensation of a more detailed statement (Miller, 1965a; 1965b; 1965c).

The second article is an analysis in terms of this conceptual system of present knowledge concerning one level of living system — the organism. In order to emphasize the cross-level formal identities among levels of living systems, a major consideration of general behavior systems theory, this article follows exactly the same outline, with identical subheadings and section numbers, as other articles written by the author. These deal with the lower levels of living systems — cell and organ (Miller, 1971a) — as well as higher levels — group (Miller, 1971b), organization (Miller, 1972), society, and supranational system. (All the articles will be published together as chapters of the author's forthcoming book, Living Systems.) *The primary intent of this article, in addition to its analysis of the content it covers, is to show that the structures and processes of organisms and of living systems at all the levels are directly comparable.*

Since anatomists and physiologists are usually laymen in organization theory or international relations, psychologists are commonly laymen in economics, and social scientists are ordinarily laymen in cellular biology, all parts of the book, including the two following articles, are necessarily written for intelligent laymen rather than experts, even though the articles deal with many technical topics. Some statements in them will seem to experts to be too elementary to be worth repeating. If a fact is fundamental and may not be known to specialists in other fields it is stated here, even if it is elementary to the experts. The complex division of labor of modern science, often characterized by pluralistic insularity, requires this.

The multitude of detailed and specialized experiments and studies that have been carried out provide the substance of the scientific investigation of organisms. Their findings constitute the trees. But an overview of these results and of the relationships among them — a view of the forest — is also essential. Such a telescopic rather than

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a microscopic view may suggest the proper balance for research on various aspects of organisms and clarify the priorities for future efforts.

The following articles view organisms broadly. They deal with all living systems at this level — protistans, fungi, and plants, as well as animals. Why such a range? To make manifest the continuity of organismic life in structure, process, and history (including evolution). To demonstrate how structure and process go together, so that anatomists, physiologists, and psychologists understand the common task they share and how each field can enrich the others.

Most of the ideas presented in these articles are not new even though the conceptual integration is original with the author. The concepts are derived from many aspects of science and have been developed by many workers, including various former associates of the author at the Universities of Chicago and Michigan, and systems scientists in many other places. The articles necessarily select for discussion only a few researches out of the vast published repertoire, and this selection has necessarily been arbitrary. Experts in each special field might agree on other studies as more important. Some of the author's statements may be wrong and his analysis ill advised. If so he would appreciate corrections — it is hard to cover such a wide range and still make no errors.

The constant reference in the second article to cross-level hypotheses stated in the first article has the purpose of showing that propositions possibly valid at other levels may also apply to organisms.

At each level there are scientists who apply system theory in their investigations. They are systems theorists but not necessarily general systems theorists. They are general systems theorists only if they accept the more daring and controversial position that — though every living system and every level is obviously unique — there are important formal identities of large generality across levels. Such cross-level similarities can potentially be evaluated quantitatively, applying the same model to data collected at two or more levels. This possibility is the chief reason why the author has used the same outline with identically numbered sections to analyze the present knowledge about each of the seven levels of living systems. The following survey of what is known about organisms as systems, therefore, is to be read as a single segment of a larger, integrated whole.

I. THE NATURE OF LIVING SYSTEMS

GENERAL SYSTEMS behavior theory is a set of related definitions, assumptions, and propositions which deal with reality as an integrated hierarchy of organizations of matter and energy. General systems behavior theory is concerned with a special subset of all systems, the living ones.

Even more basic to this presentation than the concept of "system" are the concepts of "space," "time," "matter," "energy," and "information," because the living systems discussed here exist in space and are made of matter and energy organized by information.

1. SPACE AND TIME

In the most general mathematical sense, a *space* is a set of elements which conform to certain postulates. The *conceptual spaces* of mathematics may have any number of dimensions.

Physical space is the extension surrounding a point. Classically the three-dimensional geometry of Euclid was considered to describe accurately all regions in physical space. The modern general theory of relativity has shown that physical space-time is more accurately described by a geometry of four dimensions, three of space and one of time.

This presentation of a general theory of living systems will employ two sorts of spaces in which they may exist, *physical* or *geographical space* and *conceptual* or *abstracted spaces.*

1.1 Physical or Geographical Space

This will be considered as Euclidean space, which is adequate for the study of all aspects of living systems as we now know them. Among the characteristics and constraints of physical space are the following: (a) From point A to point B is the same distance as from point B to point A. (b) Matter or energy moving on a straight or curved path from point A to point B must pass through every intervening point on the path. This is true also of markers bearing information. (c) In such space there is a maximum speed of movement for matter, energy, and markers bearing information. (d) Objects in such space exert gravitational pull on each other. (e) Solid objects moving in such space cannot pass through one another. (f) Solid objects moving in such space are subject to friction when they contact another object.

The characteristics and constraints of physical space affect the action of all concrete systems, living and nonliving. The following are some examples: (a) On the average, people interact more with persons who live near to them in a housing project than with persons who live far away in the project. (b) The diameter of the fuel supply lines laid down behind General Patton's advancing American Third Army in World War II determined the amount of friction the lines exerted upon the fuel pumped through them, and therefore the rate at which fuel could flow through them to supply Patton's tanks. This was one physical constraint which limited the rate at which the army could advance, because they had to halt when they ran out of fuel. (c) Today information can flow worldwide almost instantly by telegraph, radio, and television. In the Seventeenth Century it took weeks for messages to cross an ocean. A government could not send messages so quickly to its ambassadors then as it can now because of the constraints on the rate of movement of the marker bearing the information. Consequently ambassadors of that century had much more freedom of decision than they do now.

Physical space is a common space, for the reason that it is the only space in which all concrete systems, living and nonliving, exist (though some may exist in other spaces simultaneously). Physical space is shared by all scientific observers, and all scientific data must be collected in it. This is equally true for natural science and behavioral science. Most people learn that physical space exists, which is not true of many spaces I shall mention in the next section. They can give the location of objects in it.

1.2 Conceptual or Abstracted Spaces

Scientific observers often view living systems as existing in spaces which they conceptualize or abstract from the phenomena with which they deal. Examples of such spaces are: (a) Peck order in birds or other animals. (b) Social class space (lower lower, upper lower, lower middle, upper middle, lower upper, and upper upper classes). (c) Social distance among ethnic or racial groups. (d) Political distance among political parties of the right and the left. (e) Sociometric space, e.g., the rating on a scale of leadership ability of each member of a group by every other member. (f) A space of time costs of various modes of transportation, e.g., travel taking longer on foot than by air, longer upstream than down.

These conceptual and abstracted spaces do not have the same characteristics and are not subject to the same constraints as physical space. Each has characteristics and constraints of its own. These spaces may be either conceived of by a human being or learned about from others. Interpreting the meaning of such spaces, observing relations, and measuring distances in them ordinarily require human observers. Consequently the biases of individual human beings color these observations.

Social and some biological scientists find conceptual or abstracted spaces useful because they recognize that physical space is not a major determinant of certain processes in the living systems they study. For example, no matter where they enter the body, most of the iodine atoms in the body accumulate in the thyroid gland. The most frequent interpersonal relations occur among persons of like interests or like attitudes rather than among geographical neighbors. Families frequently come together for holidays no matter how far apart their members are. Allies like England and Australia are often more distant from each other in physical space than they are from their enemies.

It is desirable that scientists who make observations and measurements in any space other than physical space should attempt to indicate precisely what are the transformations from their space to physical space. Other spaces are definitely useful to science, but physical space is the only common space in which all concrete systems exist.

1.3 Time

This is the fundamental "fourth dimension" of the physical space-time continuum. *Time* is the particular instant at which a structure exists or a process occurs, or the measured or measurable period over which a structure endures or a process continues. For the study of all aspects of living systems as we know them, for the measurement of durations, speeds, rates, and accelerations, the usual absolute scales of time — seconds, minutes, days, years — are adequate. A concrete system can move in any direction on the spatial dimensions, but only forward — never backward — on the temporal dimension.

2. MATTER AND ENERGY

Matter is anything which has mass (m) and occupies physical space. Energy (E) is defined in physics as the ability to do work. The principle of the conservation of energy states that energy can be neither created nor destroyed in the universe, but it may be converted from one form to another, including the energy equivalent of rest-mass. Matter may have (a) *kinetic* energy, when it is moving and exerts a force on other matter; (b) *potential* energy, because of its position in a gravitational field; or (c) *rest-mass* energy, which is the energy that would be released if mass were converted into energy. Mass and energy are equivalent. One can be converted into the other in accordance with the relation that rest-mass energy is equal to the mass times the square of the velocity of light. Because of the known relationship between matter and energy, throughout this chapter the joint term *matter-energy* is used except where one or the other is specifically intended. Living systems require matter-energy, needing specific types of it, in adequate amounts. Heat, light, water, minerals, vitamins, foods, fuels, and raw materials of various kinds, for instance, may be required. Energy for the processes of living systems is derived from the breakdown of molecules (and, in a few recent cases, of atoms as well). Any change of state of matter-energy or its movement over space, from one point to another, is *action*. It is one form of process.

3. INFORMATION

Throughout this presentation *information* (H) will be used in the technical sense first suggested by Hartley (1928). Later it was developed by Shannon (1948) in his mathematical theory of communication. It is not the same thing as meaning or quite the same as information as we usually understand it. *Meaning* is the significance of information to a system which processes it: it constitutes a change in that system's processes elicited by the information, often resulting from associations made to it on previous experience with it. *Information* is a simpler concept: the degrees of freedom that exist in a given situation to choose among signals, symbols, messages, or patterns to be transmitted. The total of all these possible categories (the alphabet) is called the *ensemble*. The amount of information is measured by the binary digit, or *bit* of information. It is the amount of information which relieves the uncertainty when the outcome of a situation with two equally likely alternatives is known. Legend says the American Revolution was begun by a signal to Paul Revere from Old North Church steeple. It could have been either one or two lights "one if by land or two if by sea." If the alternatives were equally probable, the signal conveyed only one bit of information, resolving the uncertainty in a binary choice. But it carried a vast amount of meaning, meaning which must be measured by other sorts of units than bits.

The term *marker* refers to those observable bundles, units, or changes of matter-energy whose patterning bears or conveys the informational symbols from the ensemble or repertoire (von Neumann, 1958, p. 6–7) (*1*). These might be the stones of Hammurabi's day which bore cuneiform writing, parchments, writing paper, Indians' smoke signals, a door key with notches, punched cards, paper or magnetic tape, a computer's magnetized ferrite core memory, an arrangement of nucleotides in a DNA molecule, the molecular structure of a hormone, pulses on a telegraph wire, or waves emanating from a radio station. The marker may be static, as in a book or in a computer's memory. Communication of any sort, however, requires that the marker move in space, from the transmitting system to the receiving system, and this movement follows the same physical laws as the movement of any other sort of matter-energy. The advance of communication technology over the years has been in the direction of decreasing the matter-energy costs of storing and transmitting the markers which bear information. The efficiency of information processing can be increased by lessening the mass of the markers, making them smaller so they can be stored more compactly and transmitted more rapidly and cheaply. Over the centuries engineering progress has altered the mode in markers from stones bearing cuneiform to magnetic tape bearing electrons, and clearly some limit is being approached.

In recent years systems theorists have been fascinated by the new ways to study and measure information flows, but matter-energy flows are equally important. Systems theory deals both with information theory and with energetics — such matters as the muscular movements of animals, the flow of raw materials through societies, or the use of energy by neurons.

It was noted above that the movement of matter-energy over space, *action,* is one form of process. Another form of process is information processing or *communication,* which is the change of information from one state to another or its movement from one point to another over space. Communications, while being processed, are often shifted from one matter-energy state to another, from one sort of marker to another. If the form or pattern of the signal remains relatively constant during these changes, the information is not lost. For instance, it is now possible to take a chest x-ray, storing the information on photographic film; then a photoscanner can pass over the film line by line, from top to bottom, converting the signals to pulses in an electrical current which represent bits; then those bits can be stored in the core memory of a computer; then those bits can be processed by the computer so that contrasts in the picture pattern can be systematically increased; then the resultant altered patterns can be displayed on a cathode ray tube and photographed. The pattern of the chest structures, the information, modified for easier interpretation, has remained largely invariant throughout all this processing from one sort of marker to another. Similar transformations go on in living systems.

One basic reason why communication is of fundamental importance is that informational patterns can be processed over space and the local matter-energy at the receiving point can be organized to conform to, or comply with, this information. As already stated, if the information is conveyed on a relatively small, light, and compact marker, little energy is required for this process. Thus it is a much more efficient way to accomplish the result than to move the entire amount of matter-energy, organized as desired, from the location of the transmitter to that of the receiver. This is the secret of success of the delivery of "flowers by telegraph." It takes much less time and human effort to send a telegram from one city to another requesting a florist in the latter place to deliver flowers locally, than it would to drive or fly with the flowers from the former city to the latter.

Shannon (1948, p. 380–382) was concerned with mathematical statements describing the transmission of information in the form of signals or messages from a sender to a receiver over a channel such as a telephone wire or a radio band. These channels always contain a certain amount of noise. In order to convey a message, signals in channels must be patterned and must stand out recognizably above the background noise.

Matter-energy and information always flow together. Information is always borne on a marker. Conversely there is no regular movement in a system unless there is a difference in potential between two points, which is negative entropy or information. Which aspect of the transmission is most important depends upon how it is handled by the receiver. If the receiver responds primarily to the material or energic aspect, it is a matter-energy transmission; if the response is primarily to the information, it is an information transmission. For example, the banana eaten by a monkey is a nonrandom arrangement of specific molecules, and thus has its informational aspect, but its use to the monkey is chiefly to increase the energy available to him. So it is an energy transmission. The energic character of the signal light that tells him to depress the lever which will give him a banana is less important than the fact that the light is part of a nonrandom, patterned organization which conveys information to him. So it is an information transmission. Moreover, just as living systems must have specific forms of matter-energy, so they must have specific patterns of information. For example, some species of animals do not develop normally unless they have appropriate information inputs in infancy. As Harlow and Harlow (1962) showed, for instance, monkeys cannot make proper social adjustment unless they interact with other monkeys during a period between the third and sixth months of their lives.

4. SYSTEM

The term *system* has a number of meanings. There are systems of numbers and of equations, systems of value and of thought, systems of law, solar systems, organic systems, management systems, command and control systems, electronic systems, even the Union Pacific Railroad system. The meanings of "system" are often confused. The most general, however, is: A *system* is a set of interacting units with relationships among them (*2*). The word "set" implies that the units have some common properties, which is essential if they are to interact or have relationships. The state of each unit is constrained by, conditioned by, or dependent on the state of other units (*3*). The units are coupled.

4.1 Conceptual System

4.1.1 Units. *Units* of a *conceptual system* are terms, such as words (commonly nouns, pronouns, and their modifiers), numbers, or other symbols, including those in computer simulations and programs.

4.1.2 Relationships. A *relationship* of a conceptual system is a set of pairs of units, each pair being ordered in a similar way. For example, the set of all pairs consisting of a number and its cube is the cubing relationship. Relationships are expressed by words (commonly verbs and their modifiers), or by logical or mathematical symbols, including those in computer simulations and programs, which represent operations, e.g., inclusion, exclusion, identity, implication, equivalence, addition, subtraction, multiplication, or division. The language, symbols, or computer programs are all concepts and always exist in one or more concrete systems, living or nonliving, like a scientist, a textbook, or a computer.

4.2 Concrete System

A *concrete system* is a nonrandom accumulation of matter-energy, in a region in physical space-time, which is organized into interacting interrelated subsystems or components.

4.2.1 Units. The units (subsystems, components, parts, or members) of these systems are also concrete systems (Hall and Fagan, 1956, p. 18).

4.2.2 Relationships. Relationships in concrete systems are of various sorts, including spatial, temporal, spatiotemporal, and causal.

Both units and relationships in concrete systems are empirically determinable by some operation carried out by an observer. In theoretical verbal statements about concrete systems, nouns, pronouns, and their modifiers typically refer to concrete systems, subsystems, or components; verbs and their modifiers usually refer to the relationships among them. There are numerous examples, however, in which this usage is reversed and nouns refer to patterns of relationships or processes, such as "nerve impulse," "reflex," "action," "vote," or "annexation."

4.2.3 Open System. Most concrete systems have boundaries which are at least partially permeable, permitting sizeable magnitudes of at least certain sorts of matter-energy or information transmissions to cross them. Such a system is an *open system*. Such inputs can repair system components that break down and replace energy that is used up.

4.2.4 Closed system. A concrete system with impermeable boundaries through which no matter-energy or information transmissions of any sort can occur is a *closed system*. No actual concrete system is completely closed, so concrete systems are either relatively open or relatively closed. Whatever matter-energy happens to be within the system is all there is going to be. The energy gradually is used up and the matter gradually becomes disorganized. A body in a hermetically sealed casket, for instance, slowly crumbles and its component molecules become intermingled. Separate layers of liquid or gas in a container move toward random distribution. Gravity may prevent entirely random arrangement.

4.2.5 Nonliving system. Every concrete system which does not have the characteristics of a living system is a *nonliving system.*

4.2.6 Living systems. The *living systems* are a special subset of the set of all possible concrete systems, composed of the plants and the animals. They all have the following characteristics:

(a) They are open systems.

(b) They use inputs of foods or fuels to restore their own energy and repair breakdowns in their own organized structure.

(c) They have more than a certain minimum degree of complexity.

(d) They contain genetic material composed of deoxyribonucleic acid (DNA), presumably descended from some primordial DNA common to all life, or have a charter, or both. One or both of these is the template — the original "blueprint" or "program" — of their structure and process from the moment of their origin.

(e) They are largely composed of protoplasm including proteins and other characteristic organic compounds.

(f) They have a decider, the essential critical subsystem which controls the entire system, causing its subsystems and components to interact.

(g) They also have certain other specific critical subsystems or they have symbiotic or parasitic relationships with other living or nonliving systems which carry out the processes of any such subsystem they lack.

(h) Their subsystems are integrated together to form actively self-regulating, developing, reproducing unitary systems, with purposes and goals.

(i) They can exist only in a certain environment. Any change in their environment of such variables as temperature, air pressure, hydration, oxygen content of the atmosphere, or intensity of radiation, outside a relatively narrow range which occurs on the surface of the earth, produces stresses to which they cannot adjust. Under such stresses they cannot survive.

4.3 Abstracted System

4.3.1 Units. The units of *abstracted systems* are relationships abstracted or selected by an observer in the light of his interests, theoretical viewpoint, or philosophical bias. Some relationships may be empirically determinable by some operation carried out by the observer, but others are not, being only his concepts.

4.3.2. Relationships. The relationships mentioned above are observed to inhere and interact in concrete, usually living, systems. In a sense, then, these concrete systems are the relationships of abstracted systems. The verbal usages of theoretical statements concerning abstracted systems are often the reverse of those concerning concrete systems: the nouns and their modifiers typically refer to relationships and the verbs and their modifiers (including predicates) to the concrete systems in which these relationships inhere and interact. These concrete systems are empirically determinable by some operation carried out by the observer. A theoretical statement oriented to concrete systems typically would say "Lincoln was President," but one oriented to abstracted systems, concentrating on relationships or roles, would very likely be phrased "The Presidency was occupied by Lincoln" (*4*).

An abstracted system differs from an *abstraction,* which is a concept (like those that make up conceptual systems) representing a class of phenomena all of which are considered to have some similar "class characteristic." The members of such a class are not thought to interact or be interrelated, as are the relationships in an abstracted system.

Abstracted systems are much more common in social science theory than in natural science.

Parsons and Shils (1951) have attempted to develop general behavior theory using abstracted systems. To some a social system is something concrete in space-time, observable and presumably measurable by techniques like those of natural science. To Parsons and Shils the system is abstracted from this, being the set of relationships which are the form of organization. To them the important units are classes of input-output relationships of subsystems rather than the subsystems themselves.

4.4 Abstracted vs. Concrete Systems

One fundamental distinction between abstracted and concrete systems is that the boundaries of abstracted systems may at times be conceptually established at regions which cut through the units and relationships in the physical space occupied by concrete systems, but the boundaries of these latter systems are always set at regions which include within them all the units and internal relationships of each system.

A science of abstracted systems certainly is possible and under some conditions may be useful. When Euclid was developing geometry, with its practical applications to the arrangement of Egyptian real estate, it is probable that the solid lines in his figures were originally conceived to represent the borders of land areas or objects. Sometimes, as in Fig. I-1, he would use dotted "construction lines" to help conceptualize a geometric proof. The dotted line did not correspond to any actual border in space, Triangle *ABD* would be shown to be congruent to Triangle *CBD*, and therefore the angle *BAD* was equal to the angle *BCD*. After the proof was completed, the dotted line might well be erased, since it did not correspond to anything real and was useful only for the proof. Such construction lines, representing relationships among real lines, were used in the creation of early forms of abstracted systems.

If the diverse fields of science are to be unified, it would help if all disciplines were oriented either to concrete or to abstracted systems. It is of paramount importance for scientists to distinguish clearly between them. To use both kinds of systems in theory leads to unnecessary problems. It would be best if one type of system or the other were generally used in all disciplines.

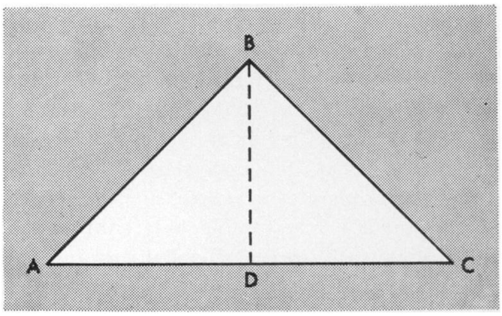

FIG. I–1. A EUCLIDEAN FIGURE.

All three meanings of "system" are useful in science, but confusion results when they are not differentiated. A scientific endeavor may appropriately begin with a conceptual system and evaluate it by collecting data on a concrete or on an abstracted system, or it may equally well first collect the data and then determine what conceptual system it fits. Throughout this paper the single word "system," for brevity, will always mean "concrete system." The other sorts of systems will always be explicitly distinguished as either "conceptual system" or "abstracted system."

5. STRUCTURE

The *structure* of a system is the arrangement of its subsystems and components in three-dimensional space at a given moment of time. This always changes over time (*5*). It may remain relatively fixed for a long period or it may change from moment to moment, depending upon the characteristics of the process in the system. This process, halted at any given moment, as when motion is frozen by a high-speed photograph, reveals the three-dimensional spatial arrangement of the system's components as of that instant.

6. PROCESS

All change over time of matter-energy or information in a system is *process*. If the equation describing a process is the same no matter whether the temporal variable is positive or negative, it is a *reversible* process; otherwise it is *irreversible*. Process includes the on-going *function* of a system, reversible actions succeeding each other from moment to moment. Process also includes *history*, less readily reversed changes like mutations, birth, growth, development, aging, and death; changes which commonly follow trauma or disease; and the changes resulting from learning which is not later forgotten. Historical processes alter both the structure and the function of the system.

The statement "less readily reversed" has been used instead of "irreversible" (although many such changes are in fact irreversible) because structural changes sometimes can be reversed: a component which has developed and functioned may atrophy and finally disappear with disuse; a functioning part may be chopped off a hydra and regrow. History, then, is more than the passage of time. It involves also accumulation in the system of residues or effects of past events (structural changes, memories, and learned habits). A living system carries its history with it in the form of altered structure, and consequently of altered function also. So there is a circular relation among the three primary aspects of systems — structure changes momentarily with functioning, but when such change is so great that it is essentially irreversible, a historical process has occurred, giving rise to a new structure.

7. TYPE

If a number of individual living systems are observed to have similar characteristics, they often are classed together as a *type*. Types are abstractions. Nature presents an apparently endless variety of living things which man, from his earliest days, has observed and classified — first, probably, on the basis of their threat to him, their susceptibility to capture, or their edibility, but eventually according to categories which are scientifically more useful. Classification by species is applied to organisms, plants or animals, or to free-living cells, because of their obvious relationships by reproduction. These systems are classified together by taxonomists on the basis of likeness of structure and process, genetic similarity and ability to interbreed, and local interaction, often including, in animals, ability to respond appropriately to each other's signs.

There are various types of systems at other levels of the hierarchy of living systems besides the cell and organism levels, each classed according to different structural and process taxonomic differentia. There are, for instance, primitive societies, agricultural societies, and industrial societies. There are epithelial cells, fibroblasts, red blood cells, and white blood cells, as well as free-living cells.

8. LEVEL

The universe contains a hierarchy of systems, each higher *level* of system being composed of systems of lower levels (*6*). *Atoms* are composed of *particles; molecules,* of atoms; *crystals* and *organelles,* of molecules. About at the level of crystallizing *viruses,* like the tobacco mosaic virus, the subset of living systems begins. Viruses are necessarily parasitic on cells, so cells are the lowest level of living systems. *Cells* are composed of atoms, molecules, and multimolecular organelles; *organs* are composed of cells aggregated into *tissues; organisms,* of organs; *groups* (e.g., herds, flocks, families, teams, tribes), of organisms; *organizations,* of groups (and sometimes single individual organisms); *societies,* of organizations, groups, and organisms; and *supranational systems,* of societies and organizations. Higher levels of systems may be of mixed composition, living and nonliving. They include *planets, solar systems, galaxies,* and so forth. It is beyond the scope of this article to deal with the characteristics — whatever they may be — of systems below and above those levels which include the various forms of life, although others have done so (Neyman and Scott, 1957; Neyman, Scott, and Shane, 1954–1955). The subset of living systems includes cells, organs, organisms, groups, organizations, societies, and supranational systems.

It would be convenient for theorists if the hierarchial levels of living systems fitted neatly into each other like Chinese boxes. The facts are more complicated. No one can argue that there are exactly these seven levels, no more and no less. For example, one might conceivably separate tissue and organ into two separate levels. Or one might maintain that the organ is not a level, since no organ exists that can live independent of other organs.

What are the criteria for distinguishing any one level from the others? They are derived from a long scientific tradition of empirical observation of the entire gamut of living systems. This extensive experience of the community of scientific observers has led to a consensus that there are certain fundamental forms of organization of living matter-energy. Indeed the classical division of subject-matter among the various disciplines of the life or behavioral sciences is implicitly or explicitly based upon this consensus.

It is important to follow one procedural rule in systems theory, in order to avoid confusion. Every discussion should begin with an identification of the level of reference, and the discourse should not change to another level without a specific statement that this is occurring (*7*). Systems at the indicated level are called systems. Those at the level above are *suprasystems,* and at the next higher level, *suprasuprasystems.* Below the level of reference are *subsystems,* and below them *subsubsystems.* For example, if one is studying a cell, its organelles are the subsystems, and the tissue or organ is its suprasystem, unless it is a free-living cell whose suprasystem includes other living systems with which it interacts (*8*).

8.1 Intersystem Generalization

A fundamental procedure in science is to make generalizations from one system to another on the basis of some similarity between the systems, which the observer sees and which permits him to class them together. For example, since the Nineteenth Century, the field of "individual differences" has been expanded, following the tradition of scientists like Galton in anthropometry and Binet in psychometrics. In Fig. I-2, states of separate specific individual systems on a specific structural or process variable are represented by I_1 to I_n. For differences among such individuals to be observed and measured, of course, a variable common to the type, along which there are individual variations, must be recognized (T_1). Physiology depends heavily, for instance, upon the fact that individuals of the type (or species) of living organisms called cats are fundamentally alike, even though minor variations from one individual to the next are well recognized.

Scientists may also generalize from one type to another (T_1 to T_n). An example is cross-species generalization, which has been commonly accepted only since Darwin. It is the justification for the labors of the white rat in the cause of man's understanding of himself. Rats and cats, cats and chimpanzees, chimpanzees and human beings are similar in structure, as comparative anatomists know, and in function, as comparative physiologists and psychologists demonstrate.

$$\begin{array}{l}\underbrace{I_1 \cdots I_n} \\ \quad \underbrace{T_1 \cdots T_n} \\ \qquad\quad L_1 \cdots L_n\end{array}$$

FIG. I-2. INDIVIDUAL, TYPE, LEVEL.

The amount of variance among species is greater than among individuals within a species. If the learning behavior of cat Felix is compared with that of mouse Mickey, we would expect not only the sort of individual differences which are found between Mickey and Minnie Mouse, but also greater species differences. Cross-species generalizations are common, and many have good scientific acceptability, but in making them interindividual and interspecies differences must be kept in mind. The learning rate of men is not identical to that of white rats, and no man learns at exactly the same rate as any other.

The third type of scientific generalization indicated in Fig. I-2 is from one level to another. The basis for such generalization is the assumption that each of the levels of life, from cell to supranational system, is composed of systems of the previous lower level. These cross-level generalizations will, ordinarily, have greater variance than the other sorts of generalizations, since they include variance among types and among individuals. But they can be made, and they can have great conceptual significance.

That there are important uniformities, which can be generalized about, across all levels of living systems is not surprising. All are composed of comparable carbon-hydrogen-nitrogen constituents, most importantly a score of amino acids organized into similar proteins, which are produced in nature only in living systems. All are equipped to live in a water-oxygen world rather than, for example, on the methane and ammonia planets so dear to science fiction. Also they are all adapted only to environments in which the physical variables, like temperature, hydration, pressure, and radiation, remain within relatively narrow ranges (Henderson, 1958). Moreover, they all presumably have arisen from the same primordial genes or template, diversified by evolutionary change. Perhaps the most convincing argument for the plausibility of cross-level generalization derives from analysis of this evolutionary development of living systems. Although increasingly complex types of living systems have evolved at a given level, followed by higher levels with even greater complexity, certain basic necessities did not change. All these systems, if they were to survive in their environment, had, by some means or other, to carry out the same vital subsystem processes. At any given stage of evolution, if a mutation had eliminated any of these processes, the system could not have survived. Consequently all living systems at all levels have the same critical set of vital subsystem processes. While free-living cells, like protozoans, carry these out with relative simplicity, the corresponding processes are more complex in multicellular organisms like mammals, and even more complex at higher levels. The same processes are *"shredded out"* to multiple components in a more complex system, by the sort of *division of labor* which Parkinson has made famous as a law (Parkinson, 1957, p. 2–13). This results in formal identities across levels of systems, more complex subsystems at higher levels carrying out the same fundamental processes as simpler subsystems at lower levels.

A formal identity among concrete systems is demonstrated by a procedure composed of three logically independent steps: (a) recognizing an aspect of two or more systems which has comparable status in those systems; (b) hypothesizing a quantitative identity between them; and (c) demonstrating that identity within a certain range of error by collecting data on a similar aspect of each of the two or more systems being compared. It may be possible to formulate some useful generalizations which apply to all living systems at all levels. A comparison of systems is complete only when statements of their formal identities are associated with specific statements of their interlevel, intertype, and interindividual disidentities. The confirmation of formal identities and disidentities is done by research.

What makes interindividual, intertype, or interlevel formal identities among systems important and of absorbing interest, is that — if they can be conclusively demonstrated — very different structures, which carry out similar processes, may well turn out to carry out acts so much alike that they can be quite precisely described by the same formal model. Conversely, it may perhaps be shown as a general principle that subsystems with comparable structures but quite different processes may have quantitative similarities as well.

8.2 Emergents

The more complex systems at higher levels manifest characteristics, more than the sum of the characteristics of the units, not observed at lower levels. These characteristics have been called "emergents." Significant aspects of living systems at higher levels will be neglected if they are described only in terms and dimensions used for their lower-level subsystems and components.

A clear-cut illustration of emergents can be found in a comparison of three electronic systems. One of these — a wire connecting the poles of a battery — can only conduct electricity, which heats the wire. Add several tubes, condensers, resistors, and controls, and the new system can become a radio, capable of receiving sound messages. Add dozens of other components, including a picture tube and several more controls, and the system becomes a television set which can receive sound and a picture. And this is not just more of the same. The third system has emergent capabilities the second system did not have, emergent from its special design of much greater complexity, just as the second has capabilities the first lacked. But there there is nothing mystical about the colored merry-go-round and racing children on the TV screen — it is the output of a system which can be completely explained by a complicated set of differential equations such as electrical engineers write, including terms representing the characteristics of each of the set's components.

9. ECHELON

This concept may seem superficially similar to the concept of level, but is distinctly different. Many complex living systems, at various levels, are organized into two or more *echelons* (in the military sense of a step in the "chain of command," not in the other military sense of arrangement of troops in rows in physical space). In living systems with echelons the components of the decider, the decision-making subsystem, are hierarchically arranged so that usually certain types of decisions are made by one component of that subsystem and others by another. Each is an *echelon*. All echelons are within the boundary of the decider subsystem. Ordinarily each echelon is made up of components of the same level as those which make up every other echelon in that system. Characteristically the decider component at one echelon gets information from a source or sources which process information primarily or exclusively to and from that echelon. It may be that at some levels of living systems — e.g., cells — there are no cases in which the decider is organized in echelon structure.

After a decision is made at one echelon on the basis of the information received, it is transmitted, often through a single subcomponent which may or may not be the same as the decider, but possibly through more than one subcomponent, upward to the next higher echelon, which goes through a similar process, and so on to the top echelon. Here a final decision is made and then command information is transmitted downward to lower echelons. Characteristically information is abstracted or made more general as it proceeds upward from echelon to echelon and it is made more specific or detailed as it proceeds downward. If a given component does not decide but only passes on information, it is not functioning as an echelon. In some cases of decentralized decision-making, certain types of decisions are made at lower echelons and not transmitted to higher echelons in any form, while information relevant to other types of decisions is transmitted upward. If there are multiple parallel deciders, without a hierarchy that has subordinate and superordinate deciders, there is not one system but multiple ones.

10. SUPRASYSTEM

10.1 Suprasystem and Environment

The *suprasystem* of any living system is the next higher system in which it is a component or subsystem. For example, the suprasystem of a cell or tissue is the organ it is in; the suprasystem of an organism is the group it is in at the time. Presumably every system has a suprasystem except the "universe." The suprasystem is differentiated from the *environment*. The immediate environment is the suprasystem minus the system itself. The entire environment includes this plus the suprasuprasystem and the systems at all higher levels which contain it. In order to survive the system must interact with and adjust to its environment, the other parts of the suprasystem. These processes alter both the system and its environment. Living systems adapt to their environment, and in return mold it. The result is that, after some period of interaction, each in some sense becomes a mirror of the other.

10.2 Territory

The region of physical space occupied by a living system, and frequently protected by it from an invader, is its territory (Ardrey, 1966). Examples are a bowerbird's stage, a dog's yard, a family's property, a nation's land.

11. SUBSYSTEM AND COMPONENT

In every system it is possible to identify one sort of unit, each of which carries out a distinct and separate process, and another sort of unit, each of which is a discrete, separate structure. The totality of all the structures in a system which carry out a particular process is a *subsystem*. A subsystem, thus, is identified by the process it carries out. It exists in one or more identifiable structural units of the system. These specific, local, distinguishable structural units are called *components* or *members* or *parts*. Reference has been made to these components in the definition of a concrete system as "a nonrandom accumulation of matter-energy, in a region in physical space-time, which is organized into interacting, interrelated subsystems or components." There is no one-to-one relationship between process and structure. One or more processes may be carried out by one or more components. Every system is a component, but not necessarily a subsystem of its suprasystem. Every component that has its own decider is a system at the next lower level, but many subsystems are not systems at the next lower level, being dispersed to several components.

The concept of subsystem process is related to the concept of *role* used in social science (Levinson, 1959). Organization theory usually emphasizes the functional requirements of the system which the subsystem fulfills, rather than the specific characteristics of the component or components that make up the subsystem. The typical view is that an organization specifies clearly defined roles (or component processes) and human beings "fill them" (Weber, 1947). But it is a mistake not to recognize that characteristics of the component — in this case the person carrying out the role — also influence what occurs. A role is more than simple "social position," a position in some social space which is "occupied." It involves interaction, adjustments between the component and the system. It is a multiple concept, referring to the demands upon the component by the system, to the internal adjustment processes of the component, and to how the component functions in meeting the system's requirements. The adjustments it makes are frequently compromises between the requirements of the component and the requirements of the system.

The way living systems develop does not always result in a neat distribution of exactly one subsystem to each component. The natural arrangement would appear to be for a system to depend on one structure for one process. But there is not always such a one-to-one relationship. Sometimes the boundaries of a subsystem and a component exactly overlap, are congruent. Sometimes they are not congruent. There can be (a) a single subsystem in a single component; (b) multiple subsystems in a single component; (c) a single subsystem in multiple components; or (d) multiple subsystems in multiple components.

Systems differ markedly from level to level, type to type, and perhaps somewhat even from individual to individual, in their *patterns of allocation* of various subsystem processes to different structures. Such a process may be (a) localized in a single component; (b) combined with others in a single component; (c) dispersed laterally to other components in the system; (d) dispersed upwardly to the suprasystem or above; (e) dispersed downwardly to subsubsystems or below; or (f) dispersed outwardly to other systems external to its hierarchy. Which allocation pattern is employed is a fundamental aspect of any given system. For a specific subsystem function in a specific system one strategy results in more efficient process than another. One can be better than another in maximizing effectiveness and minimizing costs. Valuable studies can be made at each level on optimal patterns of allocation of processes to structures. In all probability there are general systems principles which are relevant to such matters. Possible examples are: (a) Structures which minimize the distance over which matter-energy must be transported or information transmitted are the most efficient. (b) If multiple components carry out a process, the process is more difficult to control and less efficient than if a single component does it. (c) If one or more components which carry out a process are outside the system, the process is more difficult to integrate than if they are all in the system. (d) Or if there are duplicate components capable of performing the same process, the system is less vulnerable to stress and therefore is more likely to survive longer, because if one component is inactivated, the other can carry out the process alone.

11.1 Critical Subsystem

Certain processes are necessary for life and must be carried out by all living systems that survive or must be performed for them by some

TABLE I-1

THE CRITICAL SUBSYSTEMS

MATTER-ENERGY-PROCESSING SUBSYSTEMS	SUBSYSTEMS WHICH PROCESS BOTH MATTER-ENERGY AND INFORMATION	INFORMATION-PROCESSING SUBSYSTEMS
	Reproducer	
	Boundary	
Ingestor		Input Transducer
		Internal Transducer
Distributor		Channel and Net
Converter		Decoder
Producer		Associator
Matter-Energy Storage		Memory
		Decider
		Encoder
Extruder		Output Transducer
Motor		
Supporter		

other system. They are carried out by the following *critical subsystems* listed in Table I-1.

The definitions of the critical subsystems are as follows:

11.1.1 Subsystems Which Process Both Matter-Energy and Information

Reproducer, the subsystem which is capable of giving rise to other systems similar to the one it is in. (In Table I-1 a line is placed under it because it is the only subsystem critical for survival of the *species* but not critical for the survival of the *individual* system. A system can survive without a reproducer, but not without any of the other subsystems.)

Boundary, the subsystem at the perimeter of a system that holds together the components which make up the system, protects them from environmental stresses, and excludes or permits entry to various sorts of matter-energy and information.

11.1.2 Matter-Energy-Processing Subsystems

Ingestor, the subsystem which brings matter-energy across the system boundary from the environment.

Distributor, the subsystem which carries inputs from outside the system or outputs from its subsystems around the system to each component.

Converter, the subsystem which changes certain inputs to the system into forms more useful for the special processes of that particular system.

Producer, the subsystem which forms stable associations that endure for significant periods among matter-energy inputs to the system or outputs from its converter, the materials synthesized being for growth, damage repair, or replacement of components of the system, or for providing energy for moving or constituting the system's outputs of products or information markers to its suprasystem.

Matter-energy storage, the subsystem which retains in the system, for different periods of time, deposits of various sorts of matter-energy.

Extruder, the subsystem which transmits matter-energy out of the system in the forms of products and wastes.

Motor, the subsystem which moves the system or parts of it in relation to part or all of its environment or moves components of its environment in relation to each other.

Supporter, the subsystem which maintains the proper spatial relationships among components of the system, so that they can interact without weighting each other down or crowding each other.

11.1.3 Information-Processing Subsystems

Input transducer, the sensory subsystem which brings markers bearing information into the system, changing them to other matter-energy forms suitable for transmission within it.

Internal transducer, the sensory subsystem which receives, from all subsystems or components within the system, markers bearing information about significant alterations in those subsystems or components, changing them to other matter-energy forms of a sort which can be transmitted within it.

Channel and net, the subsystem composed of a single route in physical space, or multiple interconnected routes, by which markers bearing information are transmitted to all parts of the system.

Decoder, the subsystem which alters the code of information transmitted to it through the input transducer or the internal transducer into a "private" code that can be used internally by the system.

(It is useful to distinguish three sorts of codes, increasing in complexity, which are used in decoding and encoding — alpha, beta, and gamma codes. An *alpha code* is one in which the ensemble of markers is composed of different spatial patterns of structural arrangement of physical artifacts, like chemical molecules. Such arrangements represent the coded "message" or "signal" in a hormone or in such molecules as DNA and RNA. A *beta code* is one based on variations in process, such as different temporal patterns of signals or different patterns of intensity of signals. Such codes are used by living systems which have decoders and encoders with stable programming that changes a signal in one input code into a different output code. Neurons do this. A *gamma code* is a symbolic language used by systems which have decoder and encoder subsystems that alter the code on the input markers to a different one on the output markers by comparing the input to a stored thesaurus of information and selecting the output from it. This sort of symbolic information transmission is ordinarily dealt with when thought and linguistic communication are discussed in the social sciences.)

Associator, the subsystem which carries out the first stage of the learning process, forming enduring associations among items of information in the system.

Memory, the subsystem which carries out the second stage of the learning process, storing various sorts of information in the system for different periods of time.

Decider, the executive subsystem which receives information inputs from all other subsystems and transmits to them information outputs that control the entire system.

Encoder, the subsystem which alters the code of information inputs to it from other information-processing subsystems, from a "private" code used internally by the system into a "public" code which can be interpreted by other systems in its environment.

Output transducer, the subsystem which puts out markers bearing information from the system, changing markers within the system into other matter-energy forms which can be transmitted over channels in the system's environment.

Of these critical subsystems only the decider is essential in the sense that a system cannot be dependent on another system for its deciding. It can be dependent on another system for any other critical subsystem process, but a living system does not exist if the decider is dispersed upwardly, downwardly, or outwardly.

Since all living systems are genetically related, have similar constituents, live in closely comparable environments, and process matter-energy and information, it is not surprising that they should have comparable subsystems and relationships among them. All systems do not have all possible kinds of subsystems. They differ individually, among types, and across levels, as to which subsystems they have and the structures of those subsystems. But all living systems either have their own full complement of the critical subsystems carrying out the functions essential to life (i.e., they are totipotential) or they lack some critical subsystems (i.e., are partipotential) but are intimately associated with and effectively interacting with systems which carry out the missing life functions for them.

11.2 Inclusion

Sometimes a part of the environment is surrounded by a system and totally included within its boundary. Any such thing not a part of the system's own living structure is an *inclusion.* Any living system at any level may include living or nonliving components. The amoeba, for example, ingests both inorganic and organic matter and may retain particles of iron or dye in its cytoplasm for many hours. A surgeon may replace an arteriosclerotic aorta with a plastic one and that patient may live comfortably with it for years. To the two-member group of one dog and one cat an important plant component is often added — one tree. An airline firm may have as an integral component a computerized mechanical system for making reservations which extends into all its offices. A nation includes many sorts of vegetables, minerals, buildings, and machines, as well as its land.

The inclusion is a component or subsystem of the system if it carries out or helps in carrying out a critical process of the system; otherwise it is part of the environment. Either way the system, to survive, must adjust to the inclusion's characteristics. If it is harmless or inert, it can often be left undisturbed. But if it is potentially harmful — like a pathogenic bacterium in a dog or a Greek in the giant gift horse within the gates of Troy — it must be rendered harmless or walled off or extruded from the system or killed. Because it moves with the system in a way the rest of the environment does not, it constitutes a special problem. Being inside the system it may be a more serious or more immediate stress than it would be outside the system's protective boundary. But also, the system that surrounds it can control its physical actions and all routes of access to it. For this reason international law has developed the concept of extraterritoriality to provide freedom of action to ambassadors and embassies, nations' inclusions within foreign countries.

11.3 Artifact

An *artifact* is an inclusion in some system, made by animals or man. Spider webs, bird nests, beaver dams, houses, books, machines, music, paintings, and language are artifacts. They may or may not be *prostheses,* inventions which carry out some critical process essential to a living system. An artificial pacemaker for a human heart is an example of an artifact which can replace a pathological process with a healthy one. Insulin and thyroxin are replacement drugs which are human artifacts. Chemical, mechanical, or electronic artifacts have been constructed which carry out some functions of all levels of living systems.

Living systems create and live among their artifacts. Beginning presumably with the hut and the arrowhead, the pot and the vase, the plow and the wheel, mankind has constructed tools and devised machines. The Industrial Revolution of the Nineteenth Century, capped by the recent harnessing of atomic energy, represents the extension of man's matter-energy processing ability, his muscles. A new Industrial Revolution, of even greater potential, is just beginning in the Twentieth Century, with the development of information- and logic-processing machines, adjuncts to man's brain. These artifacts are increasingly becoming prostheses, relied on to carry out critical subsystem processes. A chimpanzee may extend his reach with a stick; a man may extend his cognitive skills with a computer. Today's prostheses include input transducers which sense the type of blood cells that pass before them or identify missiles that approach a nation's shores; photographic, mechanical, and electronic memories which can store masses of information over time; computers which can solve problems, carry out logical and mathematical calculations, make decisions, and control other machines; electric typewriters, high speed printers, cathode ray tubes, and photographic equipment which can output information. An analysis of many modern systems must take into account the novel problems which arise at man-machine interfaces.

Music is a special sort of human artifact, an information-processing artifact (Meyer, 1957; Cohen, 1962). So are the other arts and cognitive systems which people share. So is language. Whether it be a natural language or the machine language of some computer system, it is essential to information processing. Often stored only in human brains and expressed only by human lips, it can also be recorded on nonliving artifacts like stones, books, and magnetic tapes. It is not of itself a concrete system. It changes only when man changes it. As long as it is used it is in flux, because it must remain compatible with the ever-changing living systems that use it. But the change emanates from the users, and without their impact the language is inert. The artifactual language used in any information transmission in a system determines many essential aspects of that system's structure and process (Whorf, 1956).

12. TRANSMISSIONS IN CONCRETE SYSTEMS

All process involves some sort of transmission among subsystems within a system, or among systems. There are *inputs* across the boundary into a system, *internal processes* within it, and *outputs* from it. Each of these sorts of transmissions may consist of either (a) some particular form of matter; (b) energy, in the form of light, radiant energy, heat, or chemical energy; or (c) some particular pattern of information.

13. STEADY STATE

When opposing variables in a system are in balance, that system is in equilibrium with regard to them. The equilibrium may be static and unchanging or it may be maintained in the midst of dynamic change. Since living systems are open systems, with continually altering fluxes of matter-energy and information, many of their equilibria are dynamic and are often referred to as *flux equilibria* or *steady states.* These may be *unstable,* in which a slight disturbance elicits progressive change from the equilibrium states — like a ball standing on an inverted bowl; or *stable,* in which a slight disturbance is counteracted so as to restore the previous state — like a ball in a cup; or *neutral,* in which a slight disturbance makes a change, but without cumulative effects of any sort — like a ball on a flat surface with friction.

All living systems tend to maintain steady states (or homeostasis) of many variables, keeping an orderly balance among subsystems which process matter-energy or information. Not only are subsystems usually kept in equilibrium, but systems also ordinarily maintain steady states with their environments and suprasystems, which have outputs to the systems and inputs from them. This prevents variations in the environment from destroying the systems. The variables of living systems are constantly fluctuating, however. A moderate change in one variable may produce greater or lesser alterations in other related ones. These alterations may or may not be reversible.

13.1 Stress, Strain, and Threat

There is a *range of stability* for each of numerous variables in all living systems. It is that range within which the rate of correction of deviations is minimal or zero, and beyond which correction occurs. An input or output of either matter-energy or information, which by lack or excess of some characteristic forces the variables beyond the range of stability, constitutes *stress* and produces a *strain* (or strains) within the system. Input lack and output excess both produce the same strain — diminished amounts in the system. Input excess and output lack both produce the opposite strain — increased amounts within the system. Strains may or may not be capable of being reduced, depending upon their intensity and the resources of the system. The totality of the strains within a system resulting from its template program and from variations in the inputs from its environment can be referred to as its *values*. The relative urgency of reducing each of these specific strains represents its *hierarchy of values*.

Stress may be anticipated. Information that a stress is imminent constitutes a *threat* to the system. A threat can create a strain. Recognition of the meaning of the information of such a threat must be based on previously stored (usually learned) information about such situations. A pattern of input information is a threat when — like the odor of the hunter on the wind, a change in the acidity of fluids around a cell, or a whirling cloud approaching the city — it is capable of eliciting processes which can counteract the stress it presages. Processes — actions or communications — occur in systems only when a stress or a threat has created a strain which pushes a variable beyond its range of stability. A system is a constantly changing cameo and its environment is a similarly changing intaglio, and the two at all times fit each other. That is, outside stresses or threats are mirrored by inside strains. Matter-energy storage and memory also mirror the past environment, but with certain alterations.

13.1.1 Matter-Energy Stress. There are various ways for systems to be stressed. One class of stresses is the *matter-energy stresses,* including: (a) matter-energy input lack or underload — starvation or inadequate fuel input; (b) input of an excess or overload of matter-energy; and (c) restraint of the system, binding it physically. [This may be the equivalent of (a) or (b).]

13.1.2 Information Stress. Also there are *information stresses,* including: (a) information input lack or underload, resulting from a dearth of information in the environment or from improper function of the external sense organs or input transducers; (b) injection of noise into the system, which has an effect of information cut-off, much like the previous stress; (c) information input excess or overload. Informational stresses may involve changes in the rate of information input or in its meaning.

13.2 Adjustment Processes

Those processes of subsystems which maintain steady states in systems, keeping variables within their ranges of stability despite stresses, are *adjustment processes.* In some systems a single variable may be influenced by multiple adjustment processes. As Ashby (1960, p. 153–158, p. 210–211) has pointed out, a living system's adjustment processes are so coupled that the system is ultrastable. This characteristic can be illustrated by the example of an army cot. It is made of wires, each of which would break under a 300-pound weight, yet it can easily support a sleeper of that weight. The weight is applied to certain wires, and as it becomes greater, first nearby links and then those farther and farther away, take up part of the load. Thus a heavy weight which would break any of the component wires alone can be sustained. In a living system, if one component cannot handle a stress, more and more others are recruited to help. Eventually the entire capacity of the system may be involved in coping with the situation.

13.2.1 Feedback. The term *feedback* (Ashby, 1940; Rosenblueth, Wiener, and Bigelow, 1943, p. 19) means that there exist two channels, carrying information, such that Channel *B* loops back from the output to the input of Channel *A* and transmits some portion of the signals emitted by Channel *A* (see Fig. I-3.) These are tell-tales or monitors of the outputs of Channel *A*. The transmitter on Channel *A* is a device with two inputs, formally represented by a function with two independent variables, one the signal to be transmitted on Channel *A* and the other a previously transmitted signal fed back on Channel *B*. The new signal transmitted on Channel *A* is selected to decrease the strain resulting from any error or deviation in the feedback signal from a criterion or comparison reference signal indicating the state of the output of Channel *A* which the system seeks to maintain steady. This provides control of the output of Channel *A* on the basis of actual rather than expected performance.

When the signals are fed back over the feedback channel in such a manner that they increase the deviation of the output from a steady state, *positive feedback* exists. When the signals are reversed, so that they decrease the deviation of the output from a steady state, it is *negative feedback*. Positive feedback alters variables and destroys their steady states. Thus it can initiate system changes. Unless limited, it can alter variables enough to destroy systems. At every level of living systems numerous variables are kept in a steady state, within a range of stability, by negative feedback controls. When these fail, the structure and process of the system alter markedly — perhaps to the extent that the system does not survive. Feedback control always exhibits some oscillation and always has some lag. When the organism maintains its balance in space, this lag is caused by the slowness of transmissions in the nervous system, but is only of the order of hundredths of seconds. An organization, like a corporation, may take hours to correct a breakdown in an assembly line, days or weeks to correct a bad management decision. In a society the lag can sometimes be so great that, in effect, it comes too late. General staffs often plan for the last war rather than the next. Governments receive rather slow official feedbacks from the society at periodic elections. They can, however, get faster feedbacks from the press, other mass media, picketers, or demonstrators. Public opinion surveys can accelerate the social feedback process. The speed and accuracy of feedbacks have much to do with the effectiveness of the adjustment processes they mobilize.

13.2.2 Power. In relation to energy-processing, *power* is the rate at which work is performed, work being calculated as the product of a force and the distance through which it acts. The term also has another quite different meaning. In relation to information-processing, *power* is control, the ability of one "master" system to elicit compliance from another at the same or a different level. A system transmits a command signal or message to a given address with a signature identifying the transmitter as a legitimate source of command information. The message is often in the imperative mood, specifying an action the receiver is expected

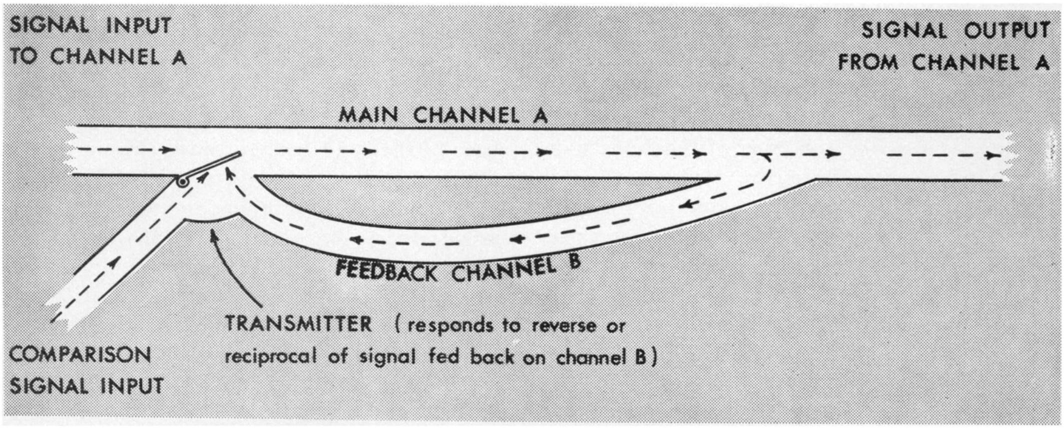

FIG. I–3. NEGATIVE FEEDBACK.

to carry out. It elicits compliance at the lower levels because the electrical or chemical form of the signal sets off a specific reaction. At higher levels the receiving system is likely to comply because it has learned that the transmitter is capable of evoking rewards or punishments from the suprasystem, depending on how the receiver responds.

13.2.3 Purpose and Goal. By the information input of its charter or genetic input, or by changes in behavior brought about by rewards and punishments from its suprasystem, a system develops a preferential hierarchy of values that gives rise to decision rules which determine its preference for one internal steady state value rather than another. This is its *purpose.* It is the comparison value which it matches to information received by negative feedback in order to determine whether the variable is being maintained at the appropriate steady state value. In this sense it is normative. The system then takes one alternative action rather than another because it appears most likely to maintain the steady state. When disturbed, this state is restored by the system by successive approximations, in order to relieve the strain of the disparity recognized internally between the feedback signal and the comparison signal. Any system may have multiple purposes simultaneously.

A system may also have an external *goal,* such as reaching a target in space, or developing a relationship with any other system in the environment. Or it may have several goals at the same time. Just as there is no question that a guided missile is zeroing in on a target, so there is no question that a rat in a maze is searching for the goal of food at its end or that the Greek people under Alexander the Great were seeking the goal of world conquest. As Ashby (1961, p. 6–7) notes, natural selection permits only those systems to continue which have goals that enable them to survive in their particular environments. The external goal may change constantly, as when a hunter chases a moving fox or a man searches for a wife by dating one girl after another, while the internal purpose remains the same.

A system's hierarchy of values determines its purposes as well as its goals. It is not difficult to distinguish purposes from goals, as the terms have been used: an amoeba has the purpose of maintaining adequate energy levels and therefore it has the goal of ingesting a bacterium; a boy has the purpose of keeping his body temperature in the proper range and so he has the goal of finding and putting on his sweater; Poland had the purpose in March 1939 of remaining uninvaded and autonomous and so she sought the goal of a political alliance with Britain and France in order to have assistance in keeping both Germany and Russia from crossing her borders.

13.2.4 Costs and Efficiency. All adjustment processes have their *costs,* in energy of nonliving or living systems, in material resources, in information (including in social systems a special form of information often conveyed on a marker of metal or paper money), or in time required for an action. Any of these may be scarce. (Time is a scarcity for mortal living systems.) Any of these is valued if it is essential for reducing strains. The costs of adjustment processes differ from one to another and from time to time. They may be immediate or delayed, short-term or long-term.

How successfully systems accomplish their purposes can be determined if those purposes are known. A system's *efficiency,* then, can be determined as the ratio of the success of its performance to the costs involved. A system constantly makes economic decisions directed toward increasing its efficiency by improving performance and decreasing costs. How efficiently a system adjusts to its environment is determined by what strategies it employs in selecting adjustment processes and whether they satisfactorily reduce strains without being too costly. This decision process can be analyzed by game theory, a mathematical approach to economic decisions. This is a general theory concerning the best strategies for weighing "plays" against "pay-offs," for selecting actions which will increase profits while decreasing losses, increase rewards while decreasing punishments, improve adjustments of variables to appropriate steady state values, or attain goals while diminishing costs. Relevant information available to the decider can improve such decisions. Consequently such information is valuable. But there are costs to obtaining such information. A mathematical theory on how to calculate the value of relevant information in such decisions was developed by Hurley

(1963). This depends on such considerations as whether it is tactical (about a specific act) or strategic (about a policy for action); whether it is reliable or unreliable, overtly or secretly obtained, accurate, distorted, or erroneous.

14. HYPOTHESES

A large number of general hypotheses which apply to two or more levels can be stated about structure and process of living systems. These are propositions concerning cross-level formal identities which can be demonstrated empirically. A few out of many such hypotheses that could be stated are listed below. These are selected because they are referred to in the next article. Many of the hypotheses were suggested by the work of others, though usually the others thought of them as related to one level only and not as general systems hypotheses. It must be remembered that when they are applied to a specific system, allowance must be made for the disanalogies among systems. The variables involved show regular changes with level and type of system, and from one individual system of the same level and type to another. The hypotheses are numbered by the same procedure, distinguishing the various subsystems processing matter-energy and information and separating structure and process, which are employed in numbering the sections of the next article.

Hypothesis 1–1. In general, the more components a system has, the more echelons it has.

Hypothesis 1–2. In general, the more structurally different types of members or components a system has, the more segregation of functions there is.

Hypothesis 2–3. The more isolated a system is the more totipotential it must be.

Hypothesis 3.1.2.2–1. When the boundary (except those portions containing the openings for the ingestor or the extruder) of one living system, *A,* is crossed by another, smaller, living or nonliving system, *B,* of significant size, i.e., no smaller than the subsystems or subcomponents of *A,* more work must be expended than when *B* is transmitted over the same distance in space immediately inside or outside the boundary of *A.*

Hypothesis 3.2–1. An optimal mean temperature at which process is most efficient is maintained by a living system.

Hypothesis 3.2.2.2–1. The farther a specific matter-energy transmission passes along a distributor from the point of its input to it and toward the final point of its output from it, the more it is altered by lowering the concentration of the kinds of materials or energy it contains which are used by the system's subsystems and increasing the concentration of the products or wastes produced from it and output by those subsystems.

Hypothesis 3.2.2.2–2. In general, total entropy per unit cubic contents increases progressively along a distributor between the points of input and output.

Hypothesis 3.2.5.2–1. If process *A* applied to any form of matter-energy always precedes process *B* (as, for example, converting precedes producing), variations imposed on the rate of process *B* by variations in the rate of process *A* can be decreased by storing a supply (or "buffer inventory") of the outputs from process *A* between the components which carry out the two processes.

Hypothesis 3.3–1. Up to a maximum higher than yet obtained in any living system but less than 100 per cent, the larger the percentage of all matter-energy input that it consumes in information-processing controlling its various system processes, as opposed to matter-energy processing, the more likely the system is to survive.

Hypothesis 3.3.1.2–1. The frequency of the output signal of an input transducer increases as a power function of the intensity of its input, the form of the power function being $\psi = \kappa(\phi - \phi_0)^n$, where ψ is the frequency of the output signal, ϕ is the physical magnitude of the input energies, ϕ_0 is a constant, the physical magnitude of the minimum detectable or threshold input energies, k depends on the choice of measurement units, and the exponent n varies with different modalities of the transducer.

Hypothesis 3.3.3.2–1. In all channels $C = W \log_2 (1 + P/N)$. That is, the maximum capacity (in bits per second) of a channel is equal to its band width times the logarithm of (1 plus the ratio of the power of the signal to the power of the white Gaussian noise in the channel).

Hypothesis 3.3.3.2–2. There is always a constant systematic distortion between input and output of information in a channel.

Hypothesis 3.3.3.2–3. In a channel there is always a progressive degradation of information and decrease in negative entropy or increase in noise or entropy. The output information per unit time is always less than it was at the input.

Hypothesis 3.3.3.2–4. A system never completely compensates for the distortion in information flow in its channels.

Hypothesis 3.3.4.2–1. As a system matures it uses increasingly efficient codes, e.g., codes which require fewer binary digits or equivalent signals per input signal. These codes approach but never actually reach the theoretical minimum number of symbols required to transmit the information. Efficient codes also have the following characteristics:

(a) Simple symbols are used for the most frequent messages and more complex ones for the less frequent ones.

(b) The symbols are selected to minimize confusion among them.

(c) The symbols are chunked in long rather than short blocks.

(d) Limitations on the transmitter of the signal are taken into account. For example, if it transmits highly redundant signals, each one is not coded, but some of the redundancy is removed.

(e) Limitations on the receiver are taken into account. For example, distinctions to which the receiver cannot react are neglected.

Hypothesis 3.3.4.2–2. If a transmitter of information is putting out information coded to have H bits per symbol and a channel has a capacity (in bits per second) of C, then the channel cannot transmit at a rate faster than C/H symbols per second, though it is possible to encode the message so as to transmit at a rate of $C/H-\epsilon$ symbols per second, where ϵ is a positive fraction, less than one and usually small, of C.

Hypothesis 3.3.4.2–3. The quantity ϵ (see Hypothesis 3.3.4.2–2) decreases as a system matures and associates, gaining practice in coding information.

Hypothesis 3.3.4.2–4. If a transmitter with an information transmission rate (in bits per second) of R is transmitting over a noisy channel — and all living channels are noisy — with a capacity (in bits per second) of C, and if R is less than C, there is a code which can make the transmission almost free of errors, and as the system matures and associates, gaining practice, it gradually approaches such transmission.

Hypothesis 3.3.4.2–5. If a transmitter with an information transmission rate (in bits per second) of R is transmitting over a noisy channel with a capacity (in bits per second) of C, and if R is greater than C, there is no way to encode the message so that the equivocation (i.e., the uncertainty as to what signals the transmitter put into the channel which the receiver still has after he has received a message from the channel) is less than $R-C$, but there is a way to encode it so that the equivocation is $R-C+\epsilon$, where ϵ is a positive fraction, less than one and usually small, of C. Moreover, as a system matures and gains practice, it encodes in ways so as to decrease the size of ϵ.

Hypothesis 3.3.4.2–6. As the noise in a channel increases, a system encodes with increasing redundancy in order to reduce error in the transmission.

Hypothesis 3.3.4.2–7. If messages are so coded that they are transmitted twice, errors can be detected by comparing every part of the first message with every part of the second, but which of the two alternative transmissions is correct cannot be determined. If they are transmitted three times, they can be both detected and corrected, by accepting the alternative on which two of the three transmissions agree.

Hypothesis 3.3.4.2–9. As the amount of information in an input decreases (i.e., as it becomes more ambiguous), the input will more and more tend to be interpreted (or decoded) as required to reduce strains within the system.

Hypothesis 3.3.4.2–10. As the strength of a strain increases, information inputs will more and more be interpreted (or decoded) as required to reduce the strain.

Hypothesis 3.3.5.2–1. When a new information input, B, is associated, usually more than once, with a familiar one, A, that elicits a certain output, B sooner or later becomes capable of eliciting the same output as A.

Hypothesis 3.3.5.2–2. A system associates a given strain within it with motor acts which relieve it, so that such a strain comes to elicit the motor acts.

Hypothesis 3.3.5.2–3. A system does not form associations without (a) feedback as to whether the new output relieves strains or solves problems, and (b) reinforcement, i.e., strain reduction by the output.

Hypothesis 3.3.5.2–4. Associations established early in the life of a system are more permanent than those established later.

Hypothesis 3.3.5.2–5. In associating there is an optimal ratio of correct trials to error trials, depending on the probability that specific signals will regularly coincide in the system's environment. In most experimental environments and all natural environments this probability is less than 1, and if association were to occur with too few error trials, a system could not properly allow for probable future variations in the appearance of signals. Since the probability of the signals regularly coinciding also is nearly always greater than 0, if association occurs with too many error trials, the system cannot profit soon enough from past inputs.

Hypothesis 3.3.6.2–1. The longer information is stored in memory, the harder it is to recall and the less likely it is to be correct, but the rate of loss is not regular over time.

Hypothesis 3.3.6.2–2. Information stored in the memory of a living system increasingly over time undergoes regular changes — e.g., omissions, errors or additions of noise, and distortions — resulting from processes of selection, reorganization with other stored information, interpretation, and entropic decay of organization.

Hypothesis 3.3.6.2–3. The removal from a system of information representing experience stored in the memory (as distinguished from the information constituting its template, whose removal is often fundamentally damaging or lethal) predictably alters stochastic measures of the system's subsequent behavior, and the degree of these changes increases as the amount removed is increased.

Hypothesis 3.3.7.2–1. Every adaptive decision is made in four stages: (a) Establishing the purpose or goal whose achievement is to be advanced by the decision; (b) analyzing the information relevant to the decision; (c) synthesizing a solution selecting the alternative action or actions most likely to lead to the purpose or goal; and (d) issuing a command signal to carry out the action or actions.

Hypothesis 3.3.7.2–13. Decisions overtly reflecting values of a system are made only at the highest echelon.

Hypothesis 3.3.7.2–14. A system which survives generally decides to employ the least costly adjustment to a threat or a strain produced by a stress first and increasingly more costly ones later.

Hypothesis 3.3.7.2–16. The deciders of a system's subsystems and components satisfice (i.e., make a sufficiently good approximation to accomplishment in order to survive in its particular environment) shorter-term goals than does the decider of the total system.

Hypothesis 3.3.7.2–17. A system cannot survive unless it makes decisions that maintain the functions of all its subsystems at a sufficiently high efficiency and their costs at a sufficiently low level that there are more than enough resources to keep it operating satisfactorily.

Hypothesis 3.3.7.2–18. Systems which survive make decisions enabling them to perform at an optimum efficiency for maximum physical power output, which is always less than maximum efficiency.

Hypothesis 5.1–1. As the information input to a single channel of a living system, measured in bits per second, increases, the information output, measured similarly, increases almost identically at first but gradually falls behind as it reaches a certain output rate, the channel capacity, which cannot be exceeded in the channel. The output then levels off at that rate and finally, as the information input rate continues to go up, the output decreases gradually toward zero as breakdown or the confusional state occurs under overload.

Hypothesis 5.1–2. Channels in living systems have adjustment processes which enable them to maintain stable, within a range, the similarity of the information output from them to the information input to them. The magnitude of these adjustment processes rises as information input rates increase up to and somewhat beyond the channel capacity. These adjustments enable the output rate to remain at or near channel capacity and then to decline gradually, rather than to fall precipitously to zero immediately whenever the information input rate exceeds the channel capacity.

Hypothesis 5.1–3. Among the limited number of adjustment processes which channels in living systems employ as information input rates increase are: omission, error, queuing, filtering, abstracting, multiple channels, escape, and chunking. (*Omission adjustment process* is failing to transmit certain randomly distributed signals. *Error adjustment process* is incorrectly transmitting certain randomly distributed signals. *Queuing adjustment process* is delaying transmission of a sequence of signals which is temporarily stored. *Filtering adjustment process* is giving priority in processing to certain classes of signals. *Abstracting adjustment process* is processing information with less than complete detail. *Multiple channels adjustment process* is simultaneously transmitting information over two or more parallel channels. *Escape process* is simultaneously transmitting information input. *Chunking adjustment process* is transmitting meaningful information in "chunks" of signals rather than symbol by symbol.) Each of these processes applies to random and nonrandom information inputs except chunking, which applies only to nonrandom inputs with repetitious patterning to a system that can associate (or learn). Each of these processes has a cost in some sort of decreased efficiency of information-processing.

Hypothesis 5.1–4. Higher level living systems in general have the emergent characteristics of more kinds and more complex combinations of adjustment processes than living systems at lower levels.

Hypothesis 5.1–5. As average information input rate increases, variation in output intensity increases.

Hypothesis 5.1–6. As average information input rate increases, the average processing time increases.

Hypothesis 5.1–7. As average information input rate increases, variation in processing time increases.

Hypothesis 5.1–8. As average information input rate increases, the percentage of internal channel capacity used in nontask communication increases.

Hypothesis 5.1–9. As average intensity of input increases, up to a point average processing time decreases.

Hypothesis 5.1–10. As average input intensity increases, use of the omission adjustment process decreases.

Hypothesis 5.1–11. As input priority increases, average output rate increases. (Input priority is the probability that a given message will be preferentially transmitted before other messages.)

Hypothesis 5.1–12. As input priority increases, average processing time decreases.

Hypothesis 5.1–13. As the size of the input ensemble increases, the average processing time increases.

Hypothesis 5.1–14. As the size of the input ensemble increases, the use of all adjustment processes increases.

Hypothesis 5.1–15. As the size of the output ensemble increases, the channel capacity increases.

Hypothesis 5.1–16. As the size of the output ensemble increases, the total processing time increases.

Hypothesis 5.1–17. As the size of the output ensemble increases, the processing time per symbol decreases.

Hypothesis 5.1–18. As average information input rate increases, the costs measured in energy (ergs per bit); utiles (e.g., cents per bit); time (seconds per bit); or duration of the state of the system (seconds before the state changes) remain more or less constant for a period of time and then finally increase rapidly, near the point where the performance curve begins to decrease from the maximum because the system is overloaded.

Hypothesis 5.1–19. As the percentage of total resources to meet costs (as defined in Hypothesis 5.1–18) runs out, average output rate decreases.

Hypothesis 5.1–20. As the percentage of total resources to meet costs runs out, average output intensity decreases.

Hypothesis 5.1–21. As the percentage of resources to meet costs runs out, the size of the ensemble decreases.

Hypothesis 5.1–22. As the percentage of resources to meet costs runs out, output range decreases.

Hypothesis 5.1–23. As the percentage of resources to meet costs runs out, average processing time increases.

Hypothesis 5.1–24. As the percentage of resources to meet costs runs out, use of omission, error, queuing, filtering, abstracting, multiple channels, and escape adjustment processes increases.

Hypothesis 5.1–32. The queuing adjustment process is employed more frequently the higher the peaks of information input overlap until such time as the length of the queue is greater than the local, short-term memory capacity of the system, and then the use of this adjustment falls off rapidly in a confusional state.

Hypothesis 5.1–33. As a corollary of the above, the effectiveness of the queuing adjustment process is positively correlated with the amount of local, short-term memory capacity.

Hypothesis 5.1–42. A minimum rate of information input to a system must be maintained for it to function normally.

Hypothesis 5.2–1. As stress increases, it first improves system output performance above ordinary levels and then worsens it. What is extreme stress for one subsystem may be only moderate stress for the total system.

Hypothesis 5.2–2. The greater a threat or stress upon a system, the more components of it are involved in adjusting to it. When no further components with new adjustment processes are available, the system function collapses.

Hypothesis 5.2–4. The range of stability of a system for a specific variable under lack strain is a monotonically increasing function of the amount of storage of the input, and under excess strain, it is a monotonically increasing function of the rate of output.

Hypothesis 5.2–5. There is an inertia to the matter-energy and information-processing variables which a system maintains in steady state, so that change in their ranges of stability is much less disruptive of system controls if it is undertaken gradually.

Hypothesis 5.2–7. When a barrier stands between a system under strain and a goal which can relieve that strain, the system ordinarily uses the adjustment processes of removing the barrier, circumventing it, or otherwise mastering it. If these efforts fail, less adaptive adjustments may be tried, including: (a) attacking the barrier by energic or informational transmissions; (b) displacing aggression to another innocent but more vulnerable nearby system; (c) reverting to primitive, nonadaptive behavior; (d) adopting rigid, nonadaptive behavior; and (e) escaping from the situation.

Hypothesis 5.2–20. The decider of a system must resolve conflicts among other subsystems, which signal their demands for autonomy, and the suprasystem, which signals commands for compliance.

Hypothesis 5.2–24. Conflicts among various sorts of alternatives are resolved by a system in different ways:

(1) Between two mutually exclusive positive goals, i.e., goals which elicit approach behavior, resolution is difficult if they appear to be of equal value, but choice is usually made quickly without much vacillation.

(2) With goals that are positive and negative at the same time, approach occurs until the system is near, then avoidance or movement from the goal occurs, and the system tends to vacillate for a time fairly near but not at the goal.

(3) Between two mutually exclusive negative goals, the system vacillates from one to the other but tends not to make a decision.

Hypothesis 5.4.1–1. The rate of increase in the number of components of a young system rises exponentially until it reaches a maximum, but this growth rate may be altered by several factors.

Hypothesis 5.4.1–2. Growing systems develop in the direction of: (a) more differentiation of subsystems; (b) more decentralization of decision-making; (c) more interdependence of subsystems; (d) more elaborate adjustment processes; (e) sharper subsystem boundaries; (f) increased differential sensitivity to inputs; and (g) more elaborate and patterned outputs.

Hypothesis 5.4.1–4. If the rate of information input into a system falls below a specific lower limit, normal growth of the system is impossible.

Hypothesis 5.4.3–4. Decentralization of decision-making in general increases the speed and accuracy of decisions which reduce local strains.

Hypothesis 5.4.3–5. As decentralization increases, echelons or components of the system's decider increasingly make decisions without the benefit of relevant information existing elsewhere in the system.

Hypothesis 5.4.3–6. The more decentralized a system's deciding is, the more likely is there to be discordant information in various echelons or components of its decider.

Hypothesis 5.5–1. The farther away a component is from the point of trauma to a system, the less pathological is its posttraumatic function, and particularly the less does the trauma disturb its role in the system's hierarchical processes.

Hypothesis 5.6–1. If a system's negative feedback discontinues and is not restored by that system or by another on which it becomes parasitic or symbiotic, it decomposes into multiple components and its suprasystem assumes control of them.

15. CONCLUSIONS

This analysis of living systems uses concepts of thermodynamics, information theory, cybernetics, and systems engineering, as well as the classical concepts appropriate to each level. The purpose is to produce a description of living structure and process in terms of input and output, flows through systems, steady states, and feedbacks, which will clarify and unify the facts of life. The approach generates hypotheses relevant to single individuals, types, and levels of living systems, or relevant across individuals, types, and levels. These hypotheses can be confirmed, disconfirmed, or evaluated by experiments and other empirical evidence.

NOTES

(1) Christie, Luce, and Macy (1952) call the physical form which the communication takes the "symbol design," and the information itself the "symbol contents."

(2) Bertalanffy (1956, p. 3) suggests that systems can be defined much as I define them, as "sets of elements standing in interaction." And he says that this definition is not so vague and general as to be valueless. He believes these systems can be specified by families of differential equations.

(3) Rothstein (1958, p. 34–36) deals with the constraints among units of organized systems in terms of entropy and communication as information processing:

"What do we mean by an organization? First of all an organization presupposes the existence of parts, which, considered in their totality, constitute the organization. The parts must interact. Were there no communication between them, there would be no organization, for we would merely have a collection of individual elements isolated from each other. Each element must be associated with its own set of alternatives. Were there no freedom to choose from a set of alternatives, the corresponding element would be a static, passive cog rather than an active unit. We suggest the following general characterization of organization. Consider a set of elements, each associated with its own set of alternatives. We now define a complexion as a particular set of alternatives. There are, of course, as many complexions as there are ways of selecting a representative from each set of alternatives. The set of complexions then has an entropy which is merely the sum of the entropies of the individual sets of alternatives so long as the elements do not interact. Complexion entropy is a maximum for independent elements. Maximal entropy, i.e., zero coupling, will be said to constitute the condition of zero organization."

Ashby (1962, p. 255–257) also deals with this. He says, speaking of what "organization" means as it is applied to systems, "The hard core of the concept is, in my opinion, that of 'conditionality.' As soon as the relation between two entities A and B becomes conditional on C's value or state then a necessary component of 'organization' is present. Thus *the theory of organization is partly co-extensive with the theory of functions of more than one variable.*"

He goes on to ask when a system is not a system or is not organized: "The converse of 'conditional on,' is 'not conditional on,' so the converse of 'organization' must therefore be, as the mathematical theory shows as clearly, the concept of 'reducibility.' (It is also called 'separability.') This occurs, in mathematical forms, when what looks like a function of several variables (perhaps very many) proves on closer examination to have parts whose actions are *not* conditional on the values of the other parts. It occurs in mechanical forms, in hardware, when what looks like one machine proves to be composed of two (or more) sub-machines, each of which is acting independently of the others. . . .

"The treatment of 'conditionality' (whether by functions of many variables, by correlation analysis, by uncertainty analysis, or by other ways) makes us realize that the essential idea is that there is first a product space — that of the possibilities — within which some sub-set of points indicates the actualities. This way of looking at 'conditionality' makes us realize that it is related to that of 'communication;' and it is, of course, quite plausible that we should define parts as being 'organized' when 'communication' (in some generalized sense) occurs between them. (Again the natural converse is that of independence, which represents non-communication.)

"Now 'communication' from A to B necessarily implies some constraint, some correlation between what happens at A and what at B. If, for a given event at A, all possible events may occur at B, then there is no communication from A to B and no constraint over the possible (A, B) couples that can occur. Thus the presence of 'organization' between variables is equivalent to the existence of a constraint in product-space of the possibilities."

(4) In Cervinka (1948) the author very precisely distinguishes, at the group level, between a concrete system, which he calls a "socius," that is a single person in a group together with all his relationships, and a "groupoid," an abstracted system, which is a pattern of attachments of a single kind of relation selected by an observer, which interrelates a set of people.

(5) This definition is consistent with the usage of Weiss (1958, p. 140). Murray (1959, p. 24) prefers the word "configuration" for an instantaneous spatial arrangement of subsystems or components of a system (or "entity," in his terms) and "structure" for an enduring arrangement. He distinguishes these clearly from an "integration" of recurrent temporal relations of component processes, a patterning of temporal variables.

(6) This concept is not a product of our times. It developed long ago. For instance, in the middle of the Nineteenth Century, Virchow (1862) wrote that the scope of the life sciences must include the cellular, tissue, organism, and social levels of living organization. In modern times the concept of hierarchical levels of systems is, of course, basic to the thought of Bertalanffy (1956, p. 7) and other general systems theorists. Even some scientists not explicitly of such persuasion, who have perhaps been skeptical in the past, recognize value in such an approach. For example, Simon (1962, p. 467–468) writes: "A number of proposals have been advanced in recent years for the development of 'general systems theory' which, abstracting from properties peculiar to physical, biological, or social systems, would be applicable to all of them. We might well feel that, while the goal is laudable, systems of such diverse kinds could hardly be expected to have any nontrivial properties in common. Metaphor and analogy can be helpful, or they can be misleading. All depends on whether the similarities the metaphor captures are significant or superficial.

"It may not be entirely vain, however, to search for common properties among diverse kinds of complex systems. The ideas that go by the name of cybernetics constitute, if not a theory, at least a point of view that has been proving fruitful over a wide range of applications. It has been useful to look at the behavior of adaptive systems in terms of the concepts of feedback and homeostasis, and to analyze adaptiveness in terms of the theory of selective information. The ideas of feedback and information provide a frame of reference for viewing a wide range of situations, just as do the ideas of evolution, of relativism, of axiomatic method, and of operationalism."

He goes on to assert that "hierarchic systems have some common properties that are independent of their specific content. . . .

"By a hierarchic system, or hierarchy, I mean a system that is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until we reach some lowest level of elementary subsystem. In most systems in nature, it is somewhat arbitrary as to where we leave off the partitioning, and what subsystems we take as elementary. Physics makes much use of the concept of 'elementary particle' although particles have a disconcerting tendency not to remain elementary very long. Only a couple of generations ago, the atoms themselves were elementary particles; today, to the nuclear physicist they are complex systems. For certain purposes of astronomy, whole stars, or even galaxies, can be regarded as elementary subsystems. In one kind of biological research, a cell may be treated as an elementary subsystem; in another, a protein molecule; in still another, an amino acid residue.

"Just why a scientist has a right to treat as elementary a subsystem that is in fact exceedingly complex is one of the questions we shall take up. For the moment, we shall accept the fact that scientists do this all the time, and that if they are careful scientists they usually get away with it."

Leake (1961, p. 2076) sees value in the concept of levels for contemporary theory about biological organization. He writes:

"Life begins with complex macromolecules such as genes and viruses, and here the principles of physics and chemistry directly apply. Macromolecules may be organized and integrated with many other chemical materials to form cells, which at Virchow's time were thought to be the basic units of life. Cells, however, may be organized into tissues or organs, with specific integrations serving their specific functions. These tissues and organs may further be integrated into organisms, constituting individuals such as human beings. Human beings, and indeed many other organisms, are capable of further integration and organization into societies. These societies in turn may be integrated with a more or less limited ecological environment."

The view is also well stated by de Chardin (1959, p. 43-44):

"The existence of 'system' in the world is at once obvious to every observer of nature, no matter whom.

"The arrangement of the parts of the universe has always been a source of amazement to men. But this disposition proves itself more and more astonishing as, every day, our science is able to make a more precise and penetrating study of the facts. The farther and more deeply we penetrate into matter, by means of increasingly powerful methods, the more we are confounded by the interdependence of its parts. Each element of the cosmos is positively woven from all the others; from beneath itself by the mysterious phenomenon of 'composition,' which makes it subsistent throughout the apex of an organized whole; and from above through the influence of unities of a higher order which incorporate and dominate it from their own ends.

"It is impossible to cut into this network, to isolate a portion without it becoming frayed and unravelled at all its edges.

"All around us, as far as the eye can see, the universe holds together, and only one way of considering it is really possible, that is, to take it as a whole, in one piece."

Kaplan (1957, p. 12) has applied the concept of a hierarchy of systems to international relations: "The same variables will be used at different system levels. The international system is the most inclusive system treated by this book. National and supranational systems are subsystems of the international system. They may, however, be treated separately as systems, in which case inputs from the international system would function as parameters. This holds also for subsystems of nation states and even for personality systems."

The Panel on Basic Research and Graduate Education of the President's Science Advisory Committee of the United States in 1960 appeared also to recognize value in a general systems approach (Seaborg, 1960, p. 1810). They wrote: "we suggest that there is great promise in such an emerging subject as a general study of complex systems in action, within which such very large questions as the communication sciences, cognition, and large parts of biology itself might conceivably be treated as special cases."

A textbook of psychology has been written which embodies a conceptualization of a hierarchy of living systems like that I advance in the present work. (Coleman, 1960).

A recent presidential address of the Association of American Medical Colleges included a passage emphasizing the desirability of synthesizing the medical curriculum around the concept of the relations among levels of living systems. Hubbard (1967, p. 1079) wrote: "For the medical student . . . the significance of descriptions at the molecular and submolecular level must be presented in the context of their relationship to the more complex organizations of these same living systems at the level of the organ, the individual, and the family group."

And there is widespread scientific and popular implicit recognition of hierarchical levels of living systems. As one instance out of many, six banners in one of the halls of the United Nations Palais des Nations in Geneva depict six levels of social organization. They say: Family, Village, Clan, Medieval State, Nation, and Federation.

(7) Herbst (1957, p. 28) makes it clear that one should make the level of reference explicit. He says that often, in writing on group research, for instance, an author will change his level of reference from the leader (organism) to the group and back to a group member (organism) again without explicitly referring to the change. This produces confusing conceptual ambiguity.

(8) Illustrative of the similarities between the approach outlined here and current thinking about electronic system design is the following statement by Goode (1960, p. 15) concerning the need to identify the level of reference:

"Confusion . . . arises from consideration of the level of design. System design may be done:

"1) At the *set* level: that is, a radar, an ignition system, a navigation set. Any of these may be designed on a system engineering basis, given a need and the necessary analysis of requirements.

"2) At the *set of sets* level: thus an airplane, a telephone exchange, a missile system, each is itself a set of sets and is subject to system design.

"3) At the *set of sets of sets* level: thus an over-all weapon system, a telephone system, an air traffic system, represent such sets of sets of sets."

In a similar analysis Malcolm (1963, p. 4–5) distinguishes eight hierarchical levels in a large weapon system: system, subsystem, component, assembly, subassembly, unit, unit component, and part.

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