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ABSTRACT

Concepts of general systems theory, cybernetics and the like may provide the methodology for communication theory to move from a level of technology to a level of pure science. It was the purpose of this paper to (1) demonstrate the necessity of applying systems theory to the construction of communication theory, (2) review relevant systems concepts and principles, and (3) specify the applicability of systems theory to communication theory development and specific methodological proposals. In part 1 the continuous nature of communicative phenomena is examined with particular attention being given to the notion of the mathematical function. Part 2 begins at a very basic systems level, i.e. the notion of wholes as compared with aggregates and relations. It continues with a discussion of open systems principles such as: equifinality, dynamic homeostatasis or the steady state, entrophy and ectrophy and Prigogine's equation. The concluding section considers the cybernetic notion of deviation amplifying mutual causation and the role of simulation in the construction of communication theory. (Author/LG)

A FUTURE OF COMMUNICATION THEORY:

SYSTEMS THEORY

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A FUTURE OF COMMUNICATION THEORY: SYSTEMS THEORY

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> In the history of Western science, atomistic and holistic ways of thinking have alternated. Early scientific thinking was holistic but speculative; modern science has reacted by being empirical but atomistic. Neither is free from error, the former because it replaces factual inquiry with faith and insight, the latter because it sacrifices coherence at the altar of facticity. We witness today...the shift toward holistic but rigorous theories. This means thinking of facts and events in the context of wholes forming integrated sets with their own properties and relationships. Looking at the world in terms of such sets of integrated relations constitutes the systems view (Laszlo, 1972, p. 19).

In communication research the necessity of a systems approach seems almost obvious; as noted by Redding (1970) communication study deals with complex, multi-dimensional phenomena characterized by high levels of fluidity, subtlety, and non-repetiveness imbedded in a complex maze of other interacting factors. Further, the corpus the communication researcher wants to understand stretches perversely across many fields of study in science and art; the head of the beast may lie in one discipline while the tail is in another (Thayer, 1967). Bertalanffy (1956, 1967) has proposed that unifying concepts, such as those of general systems theory, appear able to bridge fields traditionally subsumed under the title of science and humanities without obliterating the profound differences that do exist. Models, principles and laws exist that apply to generalized systems or their subclasses, without respect to the type of system considered, the nature of its elements, or the relations or "forces" between them.

The purpose of this paper is threefold: (a) to demonstrate the binding necessity of applying systems theory to the construction of communication theory (b) to review a few relevant systems concepts and principles and (c) to specify the applicability of systems theory to communication theory development and specific methodological proposals.

I

The question of "which came first the chicken or the egg" which epitomizes the category oriented conception of knowledge must be put into proper perspective (Rapoport, 1968). According to this view the content of knowledge is categories or classes; increase of knowledge is attained by recognizing finer divisions or subcategories. To ascertain causality the categorical view states that one event must have preceeded the other in time.

> The relative continium of evolutionary development reveals the meaninglessness of this question...For if we trace the chicken-egg cycle backward in time we shall gradually lose sight of both the chicken and the egg without being able to say when this happens, except by an arbitrary, hence inconclusive decision (Rapoport, 1968, p. 2).

The categorical view became obsolete with the introduction of the continium and with mathematical techniques for dealing with continuous data. Techniques are now available to solve simultaneous equations of the form $y = f(x)$; $x = f(y)$. From the categorical view, it might be said that neither x nor y could be determined. To illustrate this point, Rapoport uses the joke: "Where are you Joe? With Bill. And where are you Bill? With Joe. (p. 2)." Put into mathematical form with x representing the vector of Joe's position and y the vector of Bill's:

$$\begin{aligned} y &= x \\ x &= y \end{aligned} \qquad \text{(static)}$$

These equations generated from a categorical viewpoint have no unique solution. But the system:

$$\begin{aligned} y &= f(x) \\ x &= f(y) \end{aligned} \qquad \text{(dynamic)}$$

may well have a unique solution or at least a non-trivial class of solutions. If this is so, then the reasoning which says we must have x in order to determine y is misleading. This reasoning is fallacious because of the implication that knowledge of the value of one of the unknowns must preceed knowledge of the other in time. In this light it would perhaps be well advised for the communication researcher to take note of the mathematical function (an elementary systems tool). According to Rapoport,

> The mathematical function dispenses with the notion of causality entirely; and even though the mathematical physicist may on occasion lapse into conventional language and say that something has happened because of something else, in his professional reasoning, the idea of causality serves no useful purpose (pp. 3-4).

The purpose of the present discussion of causality should not be construed as an attack on rationality or scientific determinism rather the intention is to point out that causality has a limited range of operation. Causal thinking has been used for such a long time and in certain fields with such success that it is considered <u>the</u> scientific thinking although it may well be a subvariety of it (Angyal, 1941). According to Bunge (1959) at least eight noncausal classes of scientific explanations can be identified.

The death blow to categorical, atomistic thinking is finally dealt by Brimermann's Limit. Brimermann has proposed (based on Heisenberg's uncertainty principle and Einstein's mass-energy relation) that there is a maximum rate at which matter can transmit information. Whether this matter comprises a human brain or a computer makes no difference. The actual value of this limit is 10^{47} bits per gram per second, which is admittedly a very large number. It must be kept in mind, however, that taking a ton of computer adds only three to the exponent, and taking tons of computer and decades of time increases the number of processable bits to only about 10^{70}. The fact that this limit imposes a serious problem can best be seen with an example. Ashby (1970) cites the simple case of a 20 x 20 panel of lights; each lamp may be lit or unlit. Since there are two possible conditions for each of the 400 lamps, the total number of combinations is given by 2^{400} or 10^{120}. Suppose the problem were to consider comparisons of these combinations, i.e. groupings of combinations, such as "what combinations look most like a cubist picture?" The number of dichotomies possible from 10^{120} combinations is $2^{10^{120}}$. To ask for a particular dichotomy requires the selection of one from this list, thus necessitating the processing of 10^{120} bits! (This quantity obviously greatly exceeds the limit.) Combinations of complex multi-dimensional systems could produce even larger numbers of possible combinations. Of course it would be absurd to proceed in scientific research by considering <u>all</u> possible combinations, but in social science the tremendous problem of deciding what to exclude becomes critical.

> It is on this basis that the method of 'model making' has the irrefutable claim as better than the study of raw facts. The model by replacing a system which would demand a transgression of Brimermann's limit, makes the study possible. From this point of view we transfer from system to model to <u>lose</u> information (Ashby, 1970, pp. 99-100).

In addressing this problem F. C. Frick has suggested that information theory is not a model of behavior or even of communicative behavior, rather a tool that may be used in the construction of such models. The concept of model building to lose information is not in contradiction to Angyal's (1941) concept of finding the superordinate system of the "<u>unitas multiplex</u>." In systems thinking the task is not to find relations between members but to find the superordinate system in which they are related. Similarly Kaplan (1964) writes of the far reaching implications of information theory and cybernetic models, "models of this kind are far more effective than philosophical dialects in freeing behavioral science from the stultification of both mechanistic materialism and mentalistic idealism (p. 292)."

The application of these concepts to knowledge seem to be a function of the level of study in which one engages. Pure science, says Feibleman (1972), consists of investigating nature by the experimental method in persuance of the "need to know." Applied science is the use of pure science for some practical end. Pure science, then, has the goal of the understanding of nature, i.e. explanation. Applied science seeks the control of nature. Time lags are not uncommon between pure and applied science. Feibleman cites the discovery of conic sections by Appolonius of Perga in the third century B. C. when they were of intellectual interest only. They were not applied to the problem of engineering until the seventeenth century.

The third level of science is technology which differs from applied science in that applied science is guided by hypotheses deduced from theory while technology uses a trial and error or experience-guided skilled approach. The results of pure science would produce pure theory while applied science would result in empirical laws. The extension of technology might be working principles. At what level is communication theory operating? In 1905 Einstein theoretically deduced that the amount of energy in one gram of matter was exactly 90 trillion joules; applied science and technology demonstrated the truth of this proposition 40 years later with the explosion of the first atomic bomb. Working from a level of technology this deduction would seem at best unlikely.

Unfortunately, (or fortunately) the methodology of social science differs significantly from that of physical science. In social science the methods of controlled laboratory experiment, mathematical theory, qualitative experiment, "are necessary but by no means adequate (Rapoport, 1969, p. 183)." Rapoport argues that an added dimension, a value dimension, is operating in social science and cannot be ignored. Since social scientists are able to establish empirical laws through normative statistics, statistics becomes the "inductive technology" of social science. (The term technology implies the construction of principles not theory.) The role of the laboratory experiment is primarily heuristic in nature, behavioral experiments being primarily an aid to conceptualization. A danger arises as the "inductive technology," the mathematics becomes more refined; there is a tendency to select problems which fit the available tools rather than to develop the tools needed for new problems. The second danger lies in the confusion between method and substance. Chomsky states the <u>reductio ad absurdum</u> of this case when he states that "to call psychology a behavioral science is like calling physics meter reading (Searle, 1972, p. 16)." In summary Rapoport states,

> The social scientist should be familiar with the creative products of humanity, and he must be sensitive to values. He cannot build scientific theory from imagination and empathy, but imagination and empathy will help him in his groping for concepts and variables, foundations on which significant social theory can be built while such groping goes on. The social scientist must work in a 'milieu' of 'permanent revolution' (p. 186).

Our consideration has thus far been somewhat abstract, <u>i.e.</u> shifts in ways of "thinking," considerations of "pure science." Monge (1972) argues from a practical viewpoint:

> The scientific model of theory construction...is based upon assumptions which often cannot be met by researchers in the field. Thus theory construction in the future should abandon the covering law model in favor of the systems paradigm, which provides for a slightly less powerful form of explanation, but one whose assumptions can more realistically be met...the adoption of this theoretical strategy will cause us to focus on a new set of variables and employ a new set of techniques which will significantly increase the ability of communications scientists to understand, predict, control, and explain the phenomenon of communication (p. 15).

The shift to systems thinking will be by no means simple; a seeming different philosophic base will perhaps be required before the transition can be effected. Categorical thinking is so firmly rooted a habit that the change to system thinking will be as difficult as the transition from a three-dimensional to a four-dimensional geometry (Angyal, 1941). This shift must be made, however, if communication research is to proceed from the level of technology to the level of pure science.

II

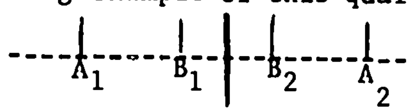
> The tendency to study systems as an entity rather than a conglomeration of parts is consistent with the tendency in contemporary science no longer to isolate phenomena in narrowly confined contexts, but rather to open interaction for examination and to examine larger and larger slices of nature (Ackoff, 1959, p. 145).

To insure that the shift to systems thinking is not merely seen as a new method of dealing with many relations, our examination of systems principles will begin at a very basic level, the structure of wholes.

A "holistic" approach was utilized by Angyal in 1941 to solve the most difficult problem faced by personality psychologists, i.e., the integration of part processes in the total organism. As an example of "whole" consideration, the simple system formed by the intersection of two straight lines is given. By examining the characteristics of either or both lines, one cannot deduce the nature of the "whole" formed. A new element has been created namely, the angle. While the lines might be measured in centimeters the angle would be measured in degrees, a new unit of measurement. "The whole is more than the sum of its parts" seems clearly illustrated. Summation, however, should not even be considered. The result of summation is an aggregate. More precisely put, "Aggregation and whole formation are processes of an entirely different order (Angyal, 1941, p. 257)." Wholes cannot, therefore, be compared to aggregates at all. "In an aggregate it is significant that parts are added; in a system it is significant that parts are arranged (p. 256)." To understand the logic of systems it is useful to compare them to relations.

1. A relation requires two and only two members between which a relation is established; complex relations are always reducible to pairs of relata. A system is not a complex relation. A linear system cannot be described in terms of the relation of its segments.
2. Relata enter into relationship because of immanent qualities (color, size, shape, etc.). The members of a system do not become elements because of immanent qualities, rather by their distribution or organization within the system. It makes no difference whether dots, crosses, or stars are used to show a linear system, the position is what matters.
3. The role of the dimensional domain differs for systems and relations. For relations it serves the purpose of disjunction only. In a system it not only separates the parts but takes part in the formation of the system. "A system is the distribution of its members in a dimensional domain (p. 249)."

4. In a relation the connectedness between relata is a direct one; in a system parts are related in reference to their position in the system. "The parts are not considered separately but with respect to a superordinate more inclusive factor (p. 250)." Geometric symmetry provides an interesting example of this quality.



If the one dimensional figures above are to be made to coincide, it cannot be done in a one dimensional space, i.e. A1 with A2 and B1 with B2. To make them coincide they must be rotated in a second dimension with respect to their "axis of symmetry." Similarly two dimensional objects require three dimensions, etc. Symmetry is used here to demonstrate relation of parts to a "superordinate whole" a kind of system "connectedness."

To organize wholes or aggregates models seem advantageous. A machine model of the organism has many difficulties as evidenced by the non-applicability of the second law of thermodynamics. A living organism is maintained by a constant exchange of components with its environment; metabolism is a characteristic of living organisms (systems). This problem is solved by calling living systems open systems (Bertalanffy, 1940). According to Bertalanffy (1968), "an open system is defined as a system in exchange of matter with its environment, presenting import and export, building up and breaking down of its material components (p. 141)."

Katz and Kahn (1966) have summarized the characteristics of open systems in nine categories. This system with expansion is given:
1. Importation of energy. Open systems import energy from the environment as can be evidenced by metabolism. Further, the personality according to Katz and Kahn is dependent upon the external world for stimulation. They cite studies of social deprivation (Spitz, 1945), sensory deprivation (Solomon, 1961), and Koehler's (1944, 1947) continual stimulation which demonstrate that personality is indeed dependent upon the external world for stimulation.
2. Through-put. Open systems transform energy available to them. The body metabolizes glucose to yield heat and energy.
3. Exportation. Open systems must export some product into the environment, whether it be metabolic wastes of organisms or raw goods in terms of an organization.
4. Cyclic characteristics. The discovery of the systemic cycle may be the discovery of the system principle.
5. Negative entropy (negentropy). To survive open systems must stop the increase of entropy, to do this they import negentropy. They do this by storing energy and maintaining the steady state.
6. Feedback and information. The open system employs feedback schemes as self regulation, resulting in correction for deviation. This feedback can be considered a simple form of information.
7. The steady state and dynamic homeostasis. "Under certain conditions open systems approach a time independent state, the so called steady state (Fliessgleichgewich after von Bertalanffy, 1942). The steady

state is maintained in distance to true equilibrium and therefore is capable of doing work; as it is in the case of living systems in contrast to systems in equilibrium (p. 142)." The system remains constant in spite of the continual importation and exportation process (body temperature, blood ph). Maintenance of the steady state is accomplished thru feedback loops known as regulators (Bertalanffy, 1962). Homeostasis is achieved according to Canon (1932) by, "the ensemble of organic regulators which act to maintain the steady state...(p. 6)." With respect to psychological organization, Kretch and Crutchfield (1948) have said that, "cognitive structures will react to influences in such a way as to absorb them with minimal change in existing cognitive integration (p. 97)."

While metabolic regulation is the simplest application of the steady state according to Katz and Kahn (1966), "the basic principle is the preservation of the character of the system (p. 97)." Although this principle is easily and intuitively understood, it must be considered of prime importance. Laws of equilibrium do not apply to systems which do not seek equilibrium. Further, a system in equilibrium does not expend energy; it is at rest, a balanced state. An open system at rest must expend energy to maintain the steady state.

8. Differentiation. Open systems tend toward increased differentiation specialization and elaboration. Evolution has led to complex highly differentiated organisms. "The growth of personality proceeds from primitive, crude organizations of mental functions to hierarchically structured and well differentiated systems of beliefs and values (Katz & Kahn, 1966, p. 99)."

9. Equifinality. An open system is capable of reaching the same end state despite initial conditions. According to Bertalanffy (1956) it was the notion of equifinality which caused Driesch to embrace vitalism. How could a normal sea urchin be generated from only one half an ovum? To Driesch this contradicted the laws of physics and could only be attributed to a vitalistic soul-like factor. In physics or chemistry the final state of a reaction must be a direct relation to the initial conditions. All initial concentrations of chemicals will have an effect on the final concentration. Open systems on the other hand, may arrive at the same end by a variety of paths. Bertalanffy (1968) points out, "It can be shown, however, that open systems, insofar as they attain a steady state, must show equifinality. So the supposed violation of physical laws disappears (p. 40)."

Many of these examples of open systems characteristics are typified in an example of Koehler (1938) when he considers the case of a very simple open system-a candle, more precisely the flame. The candle could be considered with respect a larger system and including its intakes and outputs would allow closure (create a closed system). Considered as interacting freely with its environment, however, the flame can be seen to have inputs and outputs being transformed by the system. This process results in a steady state for the flame. An amount of energy has been stored in the base of the candle to reduce entropy. The equifinal nature of the flame is perhaps demonstrated by the fact that the flame will burn at the same temperature despite the initi[illegible] [illegible]perature used to start it.

It has been seen that due to the nature of open systems traditional laws of physics are inadequate to describe them. In obvious contrast to the second law, open systems, i.e. organisms, develop toward increased states of complexity. Evolution seems in clear contradiction to the second law. It was demonstrated by Maxwell's sorting demon (1872) that the second law did not apply to all systems. More recent theorists have attributed this distinction to the fact that open systems can import negentropy (Brillouin, 1964) or ectrophy (Bertalanffy, 1950). Writing in 1950, Bertalanffy cites Prigogine's equation (1946) as expressing the total change due to entropy for closed systems:

$$dS = d_eS + d_iS$$

d_eS denotes the change due to import, d_iS the change of entropy due to irreversible processes in the system. d_iS must be positive by the second law, but d_eS may be positive or negative (import of entropy or negentropy). Thus the total entropy can be negative (if d_eS is large) or positive. The second law then, is not violated for the system and its environment, although strictly speaking, it does not hold for the open system alone. Many considerations of this nature are discussed under the area of general systems theory.

> General Systems Theory is a term which has come to describe a level of theoretical model-building which lies somewhere between the highly generalized construction of pure mathematics and the specific theories of the specialized disciplines (Boulding, 1956, p. 3).

The aims of general systems theory (GST) have been stated by Bertalanffy (1968).

> (1) There is a tendency of integration in the sciences, natural and social.
> (2) Such integration seems to be centered in a general theory of systems.
> (3) Such theory may be an important means for aiming at exact theory in the non-physical fields of science.
> (4) Developing unifying principles running 'vertically' through the universe of the individual sciences, this theory brings us nearer to the goal of the unity of science.
> (5) This can lead to a much needed integration in scientific education (p. 38).

Bertalanffy, a theoretical biologist, had intended to present the concepts of general systems as early as 1937, but the intellectual climate was not favorable. It was not until the end of World War II that the atmosphere was ready for GST. For in the course of the war, developments of complex systems, e.g. ballistic missiles, demonstrated the need of systems approaches. A missile required the co-ordination of electronic, mechanical, aeronautical, and chemical engineers; an understanding of the entire system was beyond any single individual's grasp. It was not coincidental that von Neumann and Morgenstein's game theory (1947), and Shannon and Weaver's information theory (1949) appeared at approximately the same time. Cybernetics (Weiner, 1948) similarly made its appearance also at this time.

> A consequence of the existence of general systems principles is the appearance of structural similarities or isomorphisms in different fields. There are correspondences in the principles that govern behavior of entities that are, intrinsically, widely different (Bertalanffy, 1968, p. 33).

As an example, Bertalanffy points to an exponential law of growth. This law applies to certain bacteria, to populations of bacteria, to populations of animals and humans, and to the progress of science as measured by the number of publications. The difference in entities is obvious and so are the causal relations, yet the law is the same. "Similarly there are equations which describe competition of animal and plant species in nature which seem to work in fields of chemistry and economics as well (p. 33)." The similarity may lie in the fact that all are systems.

III

If communication theory is to approach a level analogous to pure science in the physical sciences, a categorical viewpoint or technological viewpoint is inadequate. This has been demonstrated by the fact that working from such a level would demand a transgression of Brimermann's limit. While the first consideration to be made is a shift in thinking, i.e. to systems thinking, this is obviously by no means adequate. A corresponding shift in methodology would seem in order. Developments which address this need include: information theory, game theory, decision theory, topology theory or relational mathematics including network and graph theory, factor analysis, cybernetics, and general systems theory in the narrow sense deriving principles of organized wholes (Bertalanffy, 1968). In examining these developments one cannot fail to notice the isomorphy of concepts, laws and principles between various fields. Brillouin (1950) has suggested that measurement of information is in reality measurement of negentropy. Shannon and Weaver (1949) have thus begun to link the second law of thermodynamics to communication through The Mathematical Theory of Communication. Weiner (1948, 1951) has continued this notion with increased attention being given to the control aspect of communication.

A particularly interesting notion of cybernetics is that attention has thus far been concerned with "deviation attenuating mutual causal relations (Maruyama, 1963, p. 304)" and that attention must be given to "deviation amplifying mutual causal relationships (p. 304)." Deviation attenuating (or counteracting) loops or processes are also known as morphostasis, while deviation amplification is known as morphogenesis. Further synonymous terms have been found in Milsum (1968): Boulding's "disequilibrating feedback," and Milsum's "positive feedback or positively connected loop" have the same meaning as deviation amplifying mutual causal loop, while Boulding's "equilibrating feedback" and Milsum's "negative feedback or negatively connected loop" share the meaning of deviation counteracting mutual causal loop.

These mutual interaction loops are easily understood with an example of Milsum (1968) which he calls a "discreet time double subsystem model (p. 24)." The terms "vicious circle" and "turning the other cheek" characterize our intuitive understanding of the dynamics of mutual causation loops.

> Consider two systems A and B, say Archibald and Bertram, who interact mutually...let us suppose that Archibald upsets an amicable equilibrium by slapping Bertram upon the cheek...Bertram then returns the compliment with a strength multiplied by K_b... The factor K_b is henceforth called the gain and may amplify the slap if greater than one or attenuate it if less than one (p. 24-5).

Milsum from this situation generates a series of equations which show that a "vicious circle" will be started if the gain is greater than one. However, if the gain factor is less than one the rate of slapping will decay to zero.

Similar examples in economics are given by Maruyama (1963), whereby the rich stay rich and the poor stay poor (morphostasis) or the rich get richer and the poor get poorer (morphogenesis). If these processes are a communicative phenomena, it would seem to follow that the theory of their operation would be an appropriate consideration of communication theory.

The most promising technique likely to produce results significant to the construction of communication theory at this time is perhaps the notion of computer simulation (Krippendorff, 1970, 1972). In communication the researcher is dealing obviously with open systems; at present mathematical techniques for dealing with open systems are almost completely lacking. The non-applicability of the second law has already been seen. The critical consideration is then to artificially apply closure (that is, to close the open system and synthetically create a closed system). Special problems are then imposed in the creation of boundaries; in dealing with continuous phenomena how are the boundaries to be other than a mere arbitrary, hence imprecise, imposition? According to Angyal (1941) the superordinate system will be in the N + 1 dimension; it does not logically follow that N + 2 or N + 3 level boundaries would reveal the desired superordinate system principle. Working within a simulation a variation of boundaries (or any other variable for that matter) is possible.

In summary, the communication researcher of the future will of necessity develop use of the notion of the mathematical function. He will keep in mind that human communication involves open rather than closed systems; this will render a study of general system theory essential. It will be kept in mind that equilibrium which applies to closed systems is drastically different from the dynamic homeostasis or steady state of open systems, as well as the fact that open systems exhibit equifinality. Further, relational thinking is inadequate to describe these systems as is thinking in terms of aggregates rather than wholes. Finally, communication researchers will make a greater attempt to escape from a level of technology and make possible a true discipline of communication science.

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