**TWO KINDS OF GENERAL THEORIES IN SYSTEMS SCIENCE**

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## ABSTRACT

A key tenet of the philosophy of science is that science progresses when a more general theory is formulated. That is, an aim of science is to explain as many phenomena as possible with as few statements as possible. This idea, that more general theories are preferred over more specialized theories, lies at the heart of systems science. But are there different ways in which a theory can be more general? Is there a tradeoff between universality and testability? Does increasing generalization lead to a loss of information and utility? An examination of several principles from systems theory and cybernetics suggests three conclusions: there are two types of general theories; general theories requires "domain specific knowledge" to make the connection between theory and experiment or between theory and practice; and theories which are more general than those formulated in the traditional disciplines can be effective at facilitating communication among disciplines.

## 1. INTRODUCTION

How does scientific knowledge develop? Is knowledge in systems science different from knowledge in other scientific fields? If it is different, in what way is it different? Are the systems sciences a revolution in one or more previous sciences, the addition of a new domain of inquiry, or a new type of inquiry lying perhaps between mathematics and the sciences?

Karl Popper claimed that science advances by conjectures and refutations, and he preferred bold conjectures to more modest conjectures. [1] Indeed a goal of science is parsimony in theories. The aim is to develop the smallest number of propositions to explain the largest number of phenomena. But Popper also maintained that theories should be falsifiable. Can a theory be too general? Is there a trade-off between the universality of a theory and its testability?

Identifying more general theories is important because it points to the more significant contributions in a field. An examination of key principles in cybernetics and systems theory suggests that two types of theories currently exist within the systems sciences. One type of general theory adds a new dimension which had previously been neglected or had been assumed to be insignificant. The second type of general theory is a more abstract version of previous theories. The first type of contribution is consistent with the correspondence principle, a principle in the philosophy of science which stipulates how to construct a more general theory. The second type of contribution does not advance a single discipline. Rather, it identifies the common structures among theories in several disciplines. These theories can be said to lie between mathematics and the existing sciences. Distinguishing these two types of more general theories tells us something about the way that science progresses and about the particular contribution of systems science.

## 2. THEORIES WHICH ADD A NEW DIMENSION

The correspondence principle can serve as a guide to the most significant developments in a scientific field. Weidner and Sells have defined the correspondence principle as follows: "Any new theory -- whatever its character or details -- must reduce to the well established theory to which it corresponds when the new theory is applied to the circumstances for which the less general theory is known to hold. This principle was first applied to the theory of atomic structure by Niels Bohr in 1923." [2] The correspondence principle provides a procedure for checking a new theory even before any experiments are made. For instance, relativity equations reduce to Newtonian formulations when velocities are much smaller than the speed of light. Wladislaw Krajewski has emphasized that the correspondence principle does not apply to all examples of more general theories, only to theories which add a new dimension. [3]

How can the correspondence principle be applied to general systems theory? What laws or theorems does it identify as being major contributions to the field? Two examples are provided below.

### 2.1. The Thermodynamics of Open Systems

Explaining the thermodynamics of living systems has been a concern of systems theorists since the early days of the field. Von Bertalanffy argued against the vitalists's notion that living systems violate the second law of thermodynamics. [4] The heat death of the

Universe was a subject dealt with by Norbert Wiener. [5] Ilya Prigogine and his colleagues have extended the work on the thermodynamics of open systems.

The main point is that the Clausius-Carnot inequality governing the variation of entropy during a time interval dt takes the form

$$dS = deS + diS \qquad diS > 0$$

where deS is the flow of entropy due to exchanges with the surroundings and diS is the entropy production due to irreversible processes inside the system such as diffusion, chemical reactions, heat conduction, and so on. For an isolated system deS is zero, and

$$dS = deS + diS \quad \text{reduces to} \quad dS = diS > 0. \text{ [6]}$$

In Prigogine's theory a closed system is a special case of an open system. In accord with the correspondence principle, a new dimension, deS, the flow of entropy through the system, has been added.

### 2.2. Second Order Cybernetics

In the case of second order cybernetics a new dimension has been added not just to a specific scientific field but to the scientific process itself. The new dimension is "the amount of attention paid to the observer." The previous conception of science was that observations were or should be independent of the characteristics of the observer. In recent years, however, a number of quite different disciplines have been converging on the idea that neglecting the role of the observer is no longer tenable. [7] In accord with the correspondence principle the new formulation reduces to the old formulation when the characteristics of the observer are disregarded. [8]

## 3. MORE ABSTRACT THEORIES

The second type of general theory in the systems sciences are theories which are more abstract than theories in the more specialized disciplines. These theories do not follow the correspondence principle. They do not define a new dimension. Rather, these theories identify the common features or structures of several more specific theories. They are not interdisciplinary theories but rather metadisciplinary theories. The primary contributor of theories of this kind to cybernetics and systems science was Ross Ashby. Ashby presented the case for a scientific approach to general systems theory as follows.

The method of considering all possible systems, regardless of whether they actually exist in the real world, has already been used, and shown its value, in many well established sciences...Much of its (physics) theory is concerned with objects that do not exist and never have existed: particles with mass but no volume, pulleys with no friction, springs with no mass, and so on. But to say that these entities do not exist does not mean that mathematical physics is mere fantasy. The mass-less spring, though it does not exist in the real world, is a most important concept; and a physicist who understands its theory is better equipped to deal with, say, the balance of a watch than one who has not mastered the theory.

I would suggest that a similar logical framework would be desirable as a part of general systems theory. The forms occurring in the real world are seldom an orderly or a complete set. If they are to be related to one another, and higher relations and laws investigated, a rigorous logic of systems must be developed, forming a structure on which all the real forms may find their natural places and their natural relations. [9]

### 3.1 The Law of Requisite Variety

The law of requisite variety was proposed by Ashby at least as early as 1952. There are basically two interpretations of it. 1) The amount of appropriate selection that can be performed is limited by the amount of information available. 2) For appropriate regulation the variety in the regulator must be equal to or greater than the variety in the system being regulated. Or, the greater the variety within a system, the greater its ability to reduce variety in its environment through regulation.

Shannon's tenth theorem relating to the suppression of noise is a special case of the law of requisite variety. Shannon's theorem states that the capacity of a correction channel places a limit on the amount of correction that may be made in a noisy channel. [10] Ashby's law is more general because it applies in all cases involving selection based on information, not simply in the case of a correction channel for a communication system.

The law of requisite variety has far-reaching implications in the practical world. The law suggests a way to calculate the appropriate size of a regulator, once the amount of variety that the regulator is to control has been specified. The regulator in question may be a computer, a person, a corporation or a federal agency. The law also suggests strategies for improving the effectiveness of regulation -- one can either reduce the variety in the system being regulated or increase the size of the regulator. [12] Although many disciplines assume the importance of communication and decision-making, the law of requisite variety proposes a quantitative relationship between the two.

### 3.2. A Theory of Adaptive Behavior

In 1952 Ross Ashby published Design for a Brain: The Origin of Adaptive Behavior. [11] His idea was that every adaptive mechanism (including organisms and organizations) must do two things -- handle day to day problems and periodically restructure itself. In the case of a manufacturing organization it must both produce the current product and periodically develop a new product or reorganize itself. An organization which can both successfully produce an existing product and develop a series of new products is likely to be adaptive. This theory provides a theoretical foundation for the various fields of management whether in business, government, education, health care, etc. It also provides a theoretical foundation for social and organizational learning.

### 3.3. Self-organizing Systems

The idea of self-organization was stated succinctly by Ashby. "Every isolated determinant dynamic system obeying unchanging laws will develop 'organisms' that are adapted to their 'environments'." He explains the theorem as follows:

The argument is simple enough in principle. We start with the fact that systems in general go to equilibrium. Now most of a system's states are non-equilibrial (if we exclude the extreme case of a system in neutral equilibrium). So in going from any state to one of the equilibria, the system is going from a larger number of states to a smaller. In this way it is performing a selection, in the purely objective sense that is rejects some states, by leaving them, and retains some other state, by sticking to it. Thus, as every determinate system goes to equilibrium, so does it select. We have heard AD NAUSEAM the dictum that a machine cannot select; the truth is just the opposite: every machine, as it goes to equilibrium, performs the corresponding act of selection. [13]

It is important to note that the system that is organizing itself is a closed system. Both organisms and environments are present within "the system." If the original system is not very complex, the "organisms" and "environments" that evolve will be simple and uninteresting. However, if the original system contains considerable variety, for example, a community or an ecosystem, the organisms and environments that evolve can be quite complex.

Basically two processes are involved in self-organization -- the creation of new entities and the selection of appropriate entities. Ashby tended to emphasize the very general nature of selection whereas Von Foerster emphasized the creation of new entities. [14]

The principle of self-organization constitutes a more general theory that encompasses Darwin's theory of natural selection, learning theory, and theories of political and economic development. In Darwin's theory the environment determines which species are best able to survive in a particular ecological niche. "The dead shall not breed." In learning theory the environment -- whether parents, school or culture -- rewards appropriate behavior and does not reward inappropriate behavior. In politics candidates that appeal to the largest number of voters are elected. In market economies companies that produce a consistently high return on investment are the most likely to survive.

## 4. THE NEED FOR DOMAIN SPECIFIC KNOWLEDGE

How scientific progress requires not only more general theories but also testable theories. The demand that theories be useful is one way of obtaining falsifiability. Theories which add a new dimension require that new procedures be developed. New procedures which lead to new or improved results lend empirical weight to a theory and provide instances of the failure of falsification.

In the case of more abstract theories, there is a need for "domain specific knowledge" to operationalize the more general theory. More abstract theories are very helpful in identifying the similarities among theories in two or more fields, but simply knowing the abstract theory is not sufficient. If one wants to apply cybernetics to the design of computers, one must know electrical engineering. And if one wants to apply cybernetics to the management of a business firm, one must know a lot about business and finance. Hence, for people interested only in one particular domain, a more general theory may not seem to be very useful. This remoteness of abstract theories from the domain of application and the existence of more readily applicable descriptions, helps to explain why systems science has not more rapidly become institutionalized on university campuses.

## 5. AN IMPLICATION FOR THE STRUCTURE OF UNIVERSITIES

The correspondence principle is a fairly well-known idea in the philosophy of science. It defines a way of making an important contribution to a specific field of science, or, in the case of second order cybernetics, to all of science. However, the second type of general theory has received less attention in the philosophy of science. Perhaps the principal contributor of these theories has been the systems science community.

There is an important implication of this second type of general theory. The original purpose of general systems theory was to help people in different disciplines learn from one another. Kenneth Boulding described the intention in this way.

> We had no illusions that we could find the general theory of practically everything. We all respected the disciplines and the discipline that went with them. We also were disturbed about their isolation and anxious to induce a little intellectual voyeurism into the intellectual community, to encourage people to look into other people's disciplines, even if only through the window. One of my own interests at the time was the hope that out of this might come economies in teaching. The students met many of the same concepts, often under different names in different disciplines, where they had to learn them all over again, and I hoped that if we could find structures of theory which were common to a number of different disciplines, this would make it easier for the disciplines to be learned and to interact. [15]

Has systems science achieved this purpose? If it has, there are important implications for the structure of universities. That is, if systems science contributes to the productivity of the more specialized disciplines, or facilitates communication among people in different disciplines, then education and research on a university campus would seem to be enhanced by having a systems science program.

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