Hierarchies of Distinctions as Generators of System Theories

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This paper generates a variety of general-systems theoretic concepts and a range of systems theories using a minimal set of primitives. The notion of a *distinction* is taken as primitive and the natural hierarchy of distinctions becomes the primitive structure. A number of system theories are then analysed in terms of these primitives: Zadeh's *fuzzy sets theory;* Klir's *epistemological hierarchy* of system modeling; Popper's *3 worlds* theory of system types; Pask's *conversation theory* of system interaction; and Checkland's *soft systems theory*. A small number of types of distinction are shown to underly these theories and, taken in various combinations, to generate them.

1. The Need for General Systems Theory

The need for general systems theory (GST) today seems even greater than some 35 years ago when Bertalanffy (1950) wrote his seminal paper. In economics we are certain only that none of our theories apply any longer. Godet (1983) remarks:

> *"The deep crisis in industrialized countries is just beginning...this crisis was not only unforeseen, but is going to last and grow...The year 1973 marked the turning point at which the future ceased to resemble the past...Such breakdowns are associated with new behaviour patterns, so that models based on the data and relationships of the past are powerless as predictors."*

We have a variety of models that "account" for this discontinuity such as Toffler's (1980) "waves", Mensch's (1979) model of Kondratiev cycles in terms of generation interaction, and Beenstock's (1983) transition model. We have been through an era of the Club of Rome resource horizon to one where food and energy are seen as in surplus supply and pollution as controllable (Meadows, Richardson and Bruckmann, 1982).

Into this world of economic, and hence social and political uncertainty, we are introducing new technologies that give scope for discontinuity on a scale beyond imagination (Peccei, 1981). Genetic engineering enables us to take the little understood phenomena of life and change them in ways whose consequences are beyond our prediction (Cherfas, 1982). Fifth generation computing attempts to create artificial systems based on knowledge processing that emulate the processes of the human mind (Moto-oka, 1982).

Bertalanffy (1968, p.100) summarizes the rationale for GST as:

> *"Inclusion of the biological, behavioural and social sciences and modern technology necessitates generalization of basic concepts in science; this implies new categories of scientific thinking compared to those in traditional physics; amd models introduced for such purpose are interdisciplinary in nature."*

The omens of the 1950's and 60's have become the actualities of the 1980's and 90's. We need these new categories of scientific thinking as never before. The gap between theory and practice has closed and if our theories are inadequate our technologies may leave no modes of existence available to their creators.

In this paper we attempt to sketch out foundations for GST that would support the new categories of thinking demanded by social, economic and scientific developments. Much of what we have to say is necessarily abstract, but we are concerned to have as small a gap as possible between the abstractions of the theory and the intuitions of common sense. If GST is to have impact on the real problems of today then it must be comprehensible by all the people of today. We have to provide explanations of problems, and tools for their solution which are perceived as usable and are actually usable.

2. Mind and General Systems Theory

What is the essence of general systems theory? Bertalanffy's arguments suggest that it goes beyond the phenomenological consideration of analogies between sciences, of notions of, and about, systems that are somehow "general." The essence was captured by Jaspers (1931, p.11) in his consideration of *Man in the Modern Age*:

> *"Man not only exists but knows that he exists. In full awareness he studies his world and changes it to suit his purposes. He has learned how to interfere with 'natural causation', insofar as this is merely the unconscious repetition of immutable similars. He is not merely cognisable as extant but himself freely decides what shall exist. Man is mind, and the situation of man as man is a mental situation."*

Jaspers' emphasis on the mind in these terms is not an argument for idealism in the classical sense, but for neo-idealism in a technological world. Whereas science may present itself as the prophet of nature's laws, a predictor of events based on natural causation, it is inextricably wed to technology that has come to dominate nature and promulgate its laws, a predictor of events reified by its own decree.

When Bertalanffy argued for GST much of the physical world was already under the control of technology, but the biological and mental worlds remained naturalistic. Now genetic engineering and fifth generation computing are taking steps to bring the worlds of life and mind within the domain of technology. Thus we have a paradox, a truly self-referential puzzle. We are taking control of life and mind when we do not understand either. Yet we *are* life and mind, and by controlling them we may come to understand and control ourselves. The general theories that have so far escaped us and are necessary to our next stage of activity may arise out of that next stage of activity. We are in the midst of a dialectical situation where thesis and antithesis are clear, but the synthesis may form in many ways.

Jaspers' emphasis on the role of mind points to the source of the analogies between sciences that have formed the technical content of much of GST. All theories arise from the human mind and have in common those modes of thought established by education and convention. Bertalanffy (von Bertalanffy, 1967, p.93) quotes Heisenberg:

> *"in quantum physics, the object of research is not nature itself any more, but man's investigation of nature. At the end of physical research, man confronts himself alone."*

and notes:

> *"Every symbolic world, the latest and most abstract called science included, is a construct determined by innumerable factors of biological, anthropological, linguistic and historical nature. The only limiting condition is that the construct does not too much conflict with reality 'as is.'"*

Jaspers' point is that "as is" is increasingly under our control. In 1984 we do not have to be reminded that the Orwellian vision of the creation of reality through the media is close to being reality. However, the interaction between mind and reality, mediated by technology, goes far deeper than the cosmetics of political life. We think and the processes of our thinking are common to all the sciences, as well as other domains, and we act to validate our thinking and the processes of our actions are common to all the sciences, as well as other domains.

Bertalanffy's emphasis on the significance of open systems becomes most cogent when we realize that the most open system of all is that of our mind. What we have thought, we can think again. Where we have constructs, we can construct alternatives. Thus, another paradox arises.

GST should be intrinsically the source of its own demise. If we can trace the analogies between the sciences back to the processes of our minds, then we should be able to change those processes and hence the sciences deriving from them. In GST we may not be deriving the deeper underlying laws of nature, but rather giving ourselves greater control over the choices involved in reifying such laws.

This is a meta-systemic viewpoint based on neo-idealism that needs to be counter-balanced with one based on realism. These are not contradictory positions since either may readily account for the other: there is nothing to prevent the mind from inventing and validating the real world and the laws of nature; there is nothing to prevent nature from creating systems that exhibit all the phenomena of mind. GST should be able to provide foundations for both these positions. The foundations of GST itself should be derivable from either position. Scientific training has so long emphasized positive empiricism, however, that the links between the sciences deriving from the characteristics of the mind in imposing meaning on the world tend to be neglected.

In the remainder of this paper we sketch out a basis for GST that is based on a few primitive notions that are readily explained informally and yet able to be developed rigorously. We show how a number of major systems theories arise from this basis.

3. Making a Distinction

We have previously suggested (Gaines and Shaw, 1981) that the methodology of GST can be based on the concept of *making a distinction* that underlies Brown's (1969) logical calculus in *Laws of Form* and Kelly's (1955) psychological calculus in *Personal Construct Psychology*. The key feature of Brown's argument is captured in his statement:

> *"The theme of this book is that a universe comes into being when a space is severed or taken apart...By tracing the way we represent such a severance, we can begin to reconstruct, with an accuracy and coverage that appear almost uncanny, the basic forms underlying linguistic, mathematical, physical and biological science, and can begin to see how the familiar laws of our own experience follow inexorably from the original act of severance."*

It is this reconstruction of the basic forms underlying any culture from the distinctions made by those participating in it that we regard as the foundations of general system theory.

What Brown terms a distinction Kelly terms a *personal construct* and the key feature of his argument is captured in his statement:

> *"We assume that all of our present interpretations of the universe are subject to revision or replacement. This is a basic statement which has a bearing upon almost everything that we shall have to say later. We take the stand that there are always some alternative constructions available to choose among in dealing with the world. No one need paint himself into a corner; no one needs to be completely hemmed in by circumstances; no one needs to be a victim of his biography. We call this philosophical position constructive alternativism." (p.15)*

Our theoretical position is then the assumption that we may be able to account for the formal and psychological foundations of a culture, such as a scientific or technological discipline, through an analysis of the distinctions made. Our practical position is that we may be able to solve problems encountered in these cultures by making explicit the systems of distinctions underlying the problems and changing them appropriately.

We believe the concepts of *making distinctions* and *constructive alternativism* are sufficiently simple, explicable and intuitively clear, that they satisfy our requirement for a GST to be widely presented and understood. Thus our problem is to show that these primitives are adequate to support all that we would want from a GST. There are two approaches to this problem: first, to adumbrate the formal development of these primitives; second, to illustrate the derivation of existing system theories from them. The following section is concerned with this first problem and later sections outline the derivations.

4. Formal Foundations

In considering the formal foundations of GST based on the notion of a distinction, it is instructive to develop the contrast with the usual foundations based on mathematics. GST, as the study of the underlying foundations of the sciences, may itself be seen as a science of knowledge. A philosophical dictionary definition of "knowledge" is that it is "apprehended truth" and that "certain knowledge is more than opinion, less than truth" (Runes, 1960, p.161). Knowledge stands between opinion which is in the domain of psychology (the study of mental phenomena) and truth which is the domain of logic (the study of truth preserving inferences); the underlying discipline is epistemology (the study of truth ascription).

It would be reasonable to suppose that psychology and logic would be closely related aspects of a science of knowledge. Until recent times this was so, but, in the late nineteenth century, psychology and logic diverged and an attempt was made to set up a system of logic that stood alone, independent of any processes of human reasoning. The divergence stemmed from attempts to establish formal foundations for mathematics, particularly those of Frege (1884) and Husserl (1891). The stimulus for Frege's work was to re-establish irrevocably the position that mathematics was *a priori* (independent of experience) and *analytic* (based on inferences in which the conclusion is part of the premise), in contradiction to Mill's (1875) position that arithmetic is not *a priori* but empirical and induced from experience, and Kant's (1781) position that it is *a priori* but synthetic and made known through experience.

Husserl's work shows the arguments most strongly because, in response to Frege's (1894) critical review of his 1891 book, he became concerned with the role of psychology in logic and formulated the basis of pure logic clearly demarcated from processes of the mind (Husserl, 1900). In his discussion and the distinctions he makes Husserl generates a model of relationships between logic, psychology and knowledge which underlies the development of modern epistemology (Mohanty, 1982). Similarly, Frege generated a notion of pure logical inference that underlies the development of modern formal logic (Kneale and Kneale, 1962).

These considerations suggest that in seeking foundations for GST we should regard with some suspicion formal logics developed as foundations for mathematics and deliberately disregarding psychological considerations. There are also many technical problems with standard predicate calculus (SPC): in the foundations of set theory (Martin, 1970); relevance of implication (Anderson, Belnap and Dunn, 1975); ontology of existence (Schock, 1968); and extension beyond first order predicates (Kneale and Kneale, 1962). GST would most naturally treat SPC as a system derived from the constructs underlying the extreme position of developing mathematics independently of the mathematician and should be able to account for the problems that arise. It seems unlikely that such an approach could lead to foundations for GST itself.

The problem that Russell noted in Frege's logical foundations for mathematics was that the axiom of comprehension (Fraenkel, Bar-Hillel and Lévy, 1973), that every predicate defines a set, leads to a violation of the law of contradiction, that a statement and its negation cannot both be asserted. Russell's theory of types (Copi, 1971) attempts to resolve this by restricting the application of this axiom, but in so doing makes extremely complex what had been a simple and intuitive theory. Fitch (1952) has argued for unrestricted predication as a primitive of any logical system adequate to represent the whole gamut of human knowledge, and Kelly's psychology and Brown's logic may both be seen as based on this primitive.

In set-theoretic terms Brown and Kelly take the axiom of comprehension as *a priori* and derive all other concepts from this. This is not the standard and familiar approach, and this makes it very misleading to translate their discussions into logic and set theory. They are defining a basis of knowledge which is prior to both and from which these theories must be derived. The key questions are: to what does a construct apply; what is it that is distinguished? We fall into a trap if we have any answer based on other knowledge, particularly the obvious ones of logic and set theory. The proper answer is that what is distinguished is defined only by being distinguished; it requires an auxiliary ontological postulate to reify this by assuming some entity is thus defined.

We have suggested elsewhere (Gaines, 1980) that what is distinguished is a *system* and that this notion is a sufficient definition for a system. A system is what is distinguished as a system and in this lies the essence of systems theory. To distinguish some entity is a necessary and sufficient criterion for its being a system and this is uniquely true for systems. This definition may appear too weak in that it does not involve the expected properties of a system. The Oxford English Dictionary notes that a system is "a group, set or aggregate of things, natural or artificial, forming a connected or complex whole." However, these are properties that derive from our definition: a set of things is treated as distinct from another and it is this which gives it coherence; it is also this which increases its complexity by giving it one more characteristic than it had before, that it has now been distinguished.

Thus, the notion of a distinction leads naturally to that of a system and the axiom of comprehension is equivalent to the assumption that all distinctions define systems.

5. Fuzzy Sets Theory

Developing a formalism for distinctions and systems based on the preceeding arguments is not easy. First, we have to avoid the use of logical or set-theoretic notations leading us to import results from our current mathematical culture that are no longer valid or meaningful. Second, we have to generate a number of further basic notions before we can even begin to have a notion. Brown (1969) attempts to overcome the first problem by using a new notation that is simple and intuitive yet powerful enough to make the required statements. His notation is important but runs into many problems (Kohout and Pinkava, 1980), as probably will any alternative. He does not adequately address the second problem, particularly in importing the notion of a name as a further primitive. The concepts of names and the uniqueness of named individuals are key constructions from distinctions and need very careful treatment.

In the literature the nonstandard developments of Lesniewski's *mereology* (Luschei, 1962), Curry and Feys' (1958) *combinatory logic*, and Schock's (1968) *concept theory*, address some of these basic problems. We are experimenting with a number of approaches and expect to report them at later meetings. For the purposes of this paper we will next focus on the other objective of bridging from the primitives to existing system theories.

One very interesting link is that from logics with unrestricted predication to Zadeh's (1965) *fuzzy sets theory*. It has been hypothesized that the axiom of comprehension might be consistent in a set theory based on a nonstandard logic, but only in recent years has this result been proved. Maydole (1975) showed that most contenders for an alternative logic led to inconsistencies in set theory, but left open the question of Lukasiewicz infinitely valued logic. White (1979) proved that this logic supports a set theory in which the axiom of comprehension is consistent. It was just this logic that Zadeh had taken as a basis for fuzzy sets theory.

The links from Brown's calculus of distinctions to Lukasiewicz logic had already been established. Varela (1975) used the calculus to analyse self-referential systems using a construction based on Russell's paradox which gave a 3-valued logic. Gaines (1976) used a recursive form of this construction to generate the infinite valued Lukasiewicz logic and Gaines (1983) shows that the axioms encompass modal, probability and fuzzy logics. The axioms are taken first as defining a non-truth-functional *standard uncertainty logic*: fuzzy logic is then derived by adding the constraint that the logic be truth functional; and probability logic is derived by the alternative constraint that the law of contradiction apply. Figure 1 shows the relationships between the various logics that may be derived from the Lukasiewicz axioms for a system of distinctions.

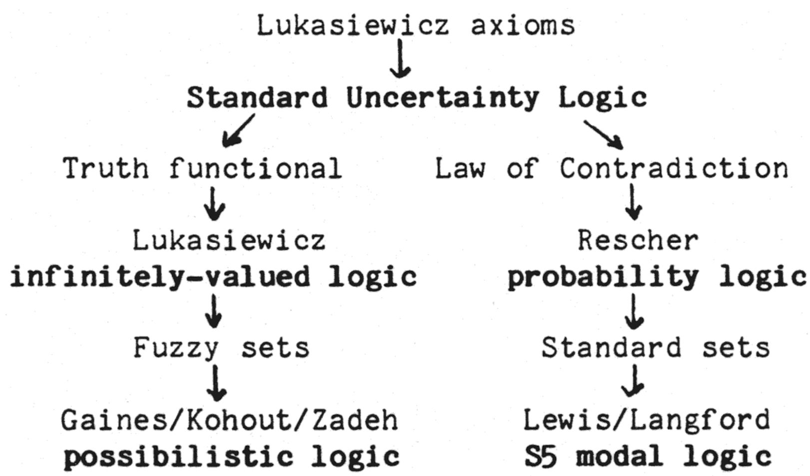

Figure 1 Logics generated from distinctions

6. Epistemological Hierarchy

Distinctions are not just static partitions of experience. They may be operations: actions in psychological terms; processes in computational terms. This is evident in Klir's (1976; 1985) hierarchy of modeling shown in Figure 2. The loop from events through distinctions up through the modeling hierarchy and then down again to predictions and actions characterizes what Shaw (1980) has termed the *personal scientist*. Klir developed this structure for work on symbolic modeling and Gaines (1977) has shown that it leads to general knowledge acquisition algorithms.

The hierarchy does not introduce any additional primitives beyond that of making a distinction. The levels of the hierarchy are the results of distinctions that we make. Thus the source system is distinguished as those distinctions that the particular personal scientist makes; it is a distinction about distinctions defining the construct system of an individual. The data system is distinguished as those distinctions that have been made about a particular event; again a distinction about distinctions defining an event. The generative system is distinguished as a set of distinctions that also defines an event; these are model-generated rather than event-generated.

The match between the model-generated and event-generated distinctions that determines the degree of approximation of the model to the world; this is a distinction about distinctions among distinctions that defines goodness of fit.

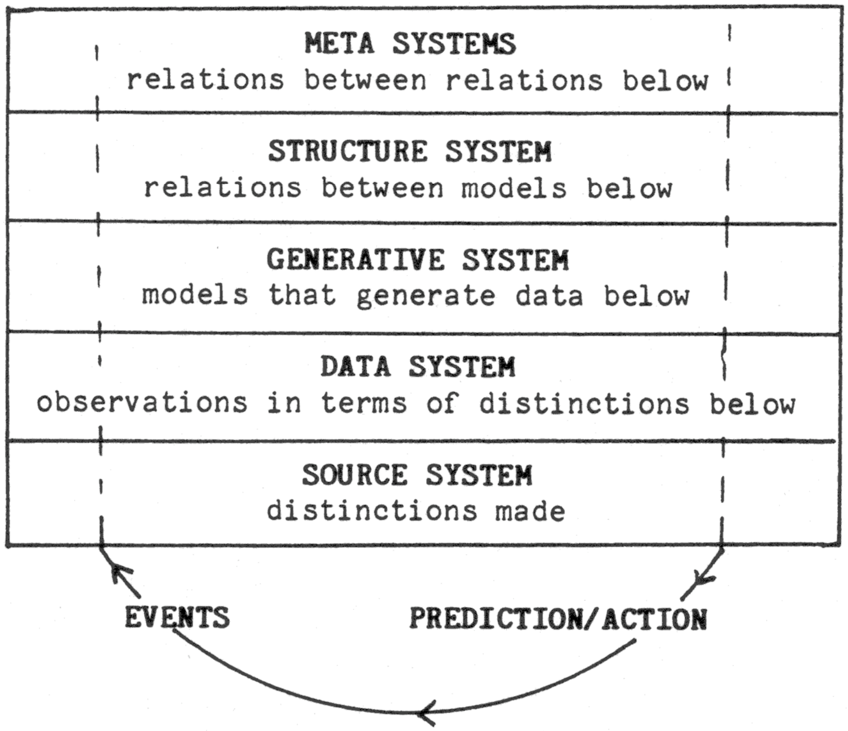

Figure 2 Epistemological hierarchy

A modeling schema results from distinctions about distinctions at each level in the hierarchy. In prediction the key distinction is whether a level accounts for the information flowing through it and we may term this distinction one of *surprise* (Gaines, 1977). Surprise goes in opposition to the degree of membership of a predicted event to an actual event and the expected surprise is a form of entropy. Surprise at the lowest level of the hierarchy corresponds to distinctions being inadequate to capture events; surprise at the next level to inadequate variety to experience events; at the next to inadequate approximation to predict events; at the next to inadequate complexity to explain events; and at the next to inadequate comprehensiveness to account for events.

7. Worlds and Conversations

Pask's (1975) *conversation theory* is an outstanding attempt to develop a GST encompassing a wide variety of physical, mental and social phenomena. He defines *cybernetics* as a form of system theory:

> *"primarily concerned with establishing isomorphisms...The basic mode of argument and development involves analogy...The analogy expressed or represented in the language employed to account for events is a metaphor. In this sense, cybernetics is the science or art of manipulating defensible metaphors..."*

Conversation theory is concerned with how metaphors are used to replicate analogies between individuals. Pask's notions of conversation, language and individual are sufficiently widened for the theory to encompass all aspects of knowledge acquisition and processing as such replication; conversations with nature model experience of the physical world and conversations with oneself model the restructuring of information at one level into knowledge at a higher level.

We have noted previously (Gaines and Shaw, 1981) that Popper's (1968) notion of 3 worlds is a basis for a systemic analysis of the relations between physical, mental and abstract systems. In using this to analyze the concept of a *knowledge environment* we have given a derivation of Popper's 3 worlds that leads to operational definitions of the various constructs that Pask considers in conversation theory (Gaines and Shaw, 1983). The form of the argument is shown in Figure 3.

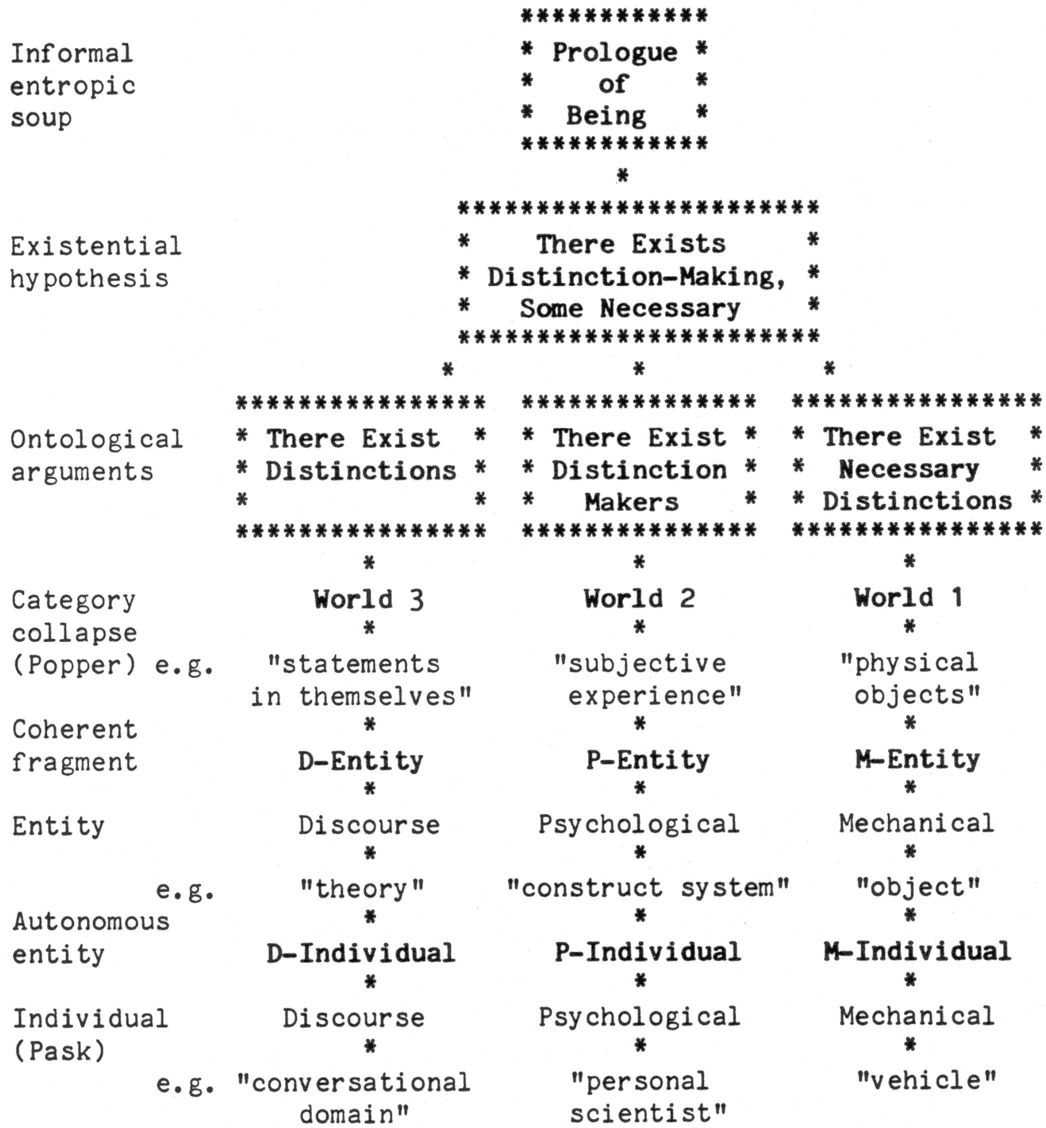

Figure 3 Derivation of Popper's Worlds & Pask's Conversation Theory

Out of some initial *prologue of being* we assume there is formed a fundamental postulate:

FP There exists distinction-making, some necessary.

This traps us (through ontological fallacies) into:

W3 There exist distinctions -- world 3.

W2 There exist distinction makers -- world 2.

W1 There exists a source for necessary distinctions -- world 1.

The distinctions that lead to these definitions of *worlds* are categorically dissimilar. However, if we compound our ontological fallacies with those of category collapse we can consider analogous phenomena within the the three worlds. An *entity* is defined to be a coherent fragment of a world, and an *individual* is defined to be an autonomous entity. Pask's M-Individuals are "living organizations" (Varela, 1979) in world 1; his P-Individuals are "personal scientists" (Shaw, 1980; Shaw and Gaines, 1981) in world 2; and his "conversational domains" are D-Individuals in world 3 (D for discourse).

These definitions can be formalized by noting that: an entity is a distinguished part of a world; a coherent entity is one that is relatively stable in that the relations of its parts one with another are more stable than with those outside it; an autonomous entity is one which is relatively uncontrollable in that the relations of its parts to those outside it are less stable than the relations of parts outside it with one another. Stability can be formalized in relation to pairs of distinctions in opposition except for unstable entities, and opposition can be formalized as pairs of distinctions distinguished by never both marking the same entity. These concepts are the basis of Pask's sub-theories of uncertainty and value, process and stability.

Individuals under these definitions are autopoietic unities in worlds 1, 2 and 3, and the worlds correspond to the different forms of autopoiesis noted by Varela (1981). Maturana's (1975) original biological autopoiesis is essentially in world 1. Zeleny's (1977) social autopoiesis is in world 2. Pask's (1981) organizational closure is autopoiesis in world 3. Life operates in all three worlds and is autopoietic in all three.

8. Soft Systems Theory

Checkland's (1981) *soft systems analysis* is a powerful tool for practical applications of GST which may be seen as based on the elicitation of the key distinctions underlying a problem. These results in *root definitions* of relevant systems that provide the formal framework for a problem analysis. His approach emphasizes the pluralism of systems analysis, constructive alternativism, that it is important to examine the problem from a number of viewpoints. These viewpoints form a hierarchy to which Checkland gives the mnemonic CATWOE (Figure 4).

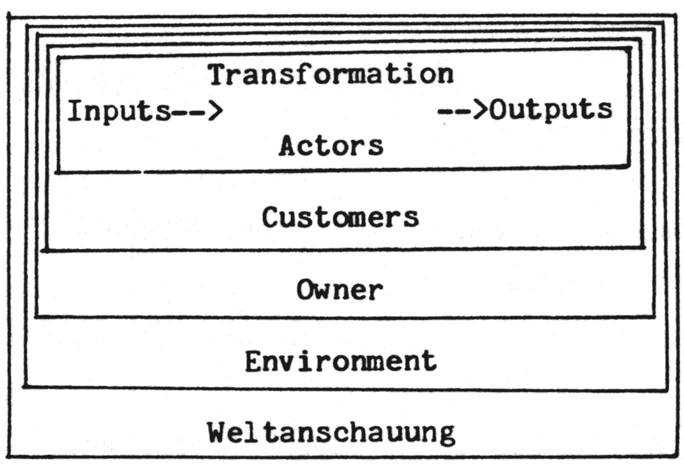

Figure 4 Root Definitions of Relevant Systems

The system is defined through a *Transformation* carried out by people who are the *Actors* within it; it affects beneficially or adversely other people who are its *Customers* and there is some agency with power of existence over it who is its *Owner*; it has to exist within outside constraints forming its *Environment* and the whole activity of system definition takes place within an ethos or *Weltanschauung* that affects our views of it.

The distinction of *agency*, that we introduced as *distinction makers* accounting for Popper's World 2, is central to Checkland's analysis. It is combined with the distinction of necessity to generate further distinctions between those agents responsible for the system transformation, those only affected by it, and those with power of existence over it. These refine the notion of agency and structure the problem. The environment is defined as a higher necessity above that of the owner and the Weltanschauung as one still higher encompassing the problem analysis itself.

9. Conclusions

It has become fashionable to note that GST is concerned with *systems thinking* and that the notion of a general theory of systems is not a feasible one. It is possible to regard the concepts discussed in this paper as leading to a mode of thinking and the systems analyses of Pask and Checkland so how powerful a tool this can be. Commencing with the basic notion of a *distinction*, postulating that there is an entity distinguished, a *system*, leads to the new categories of scientific thinking for which Bertalanffy called. However, we suspect that there is sufficient richness and coherence in the developments described, and the capability to encompass such a variety of natural and man-made phenomena, that it will be possible to build a GST that justifies the name. We hope this paper will interest others in joining us in the attempt.

Acknowledgements

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