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COMPLEXITY: A SUBJECT OF INQUIRY

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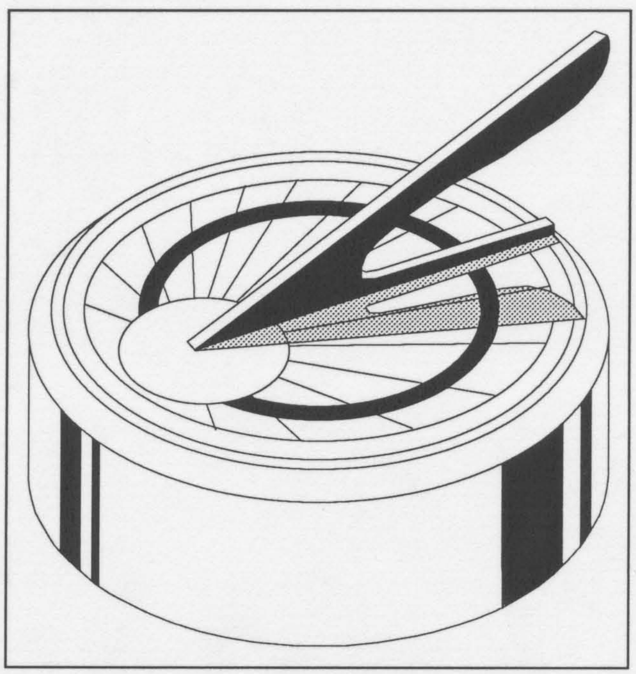

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When asked by George Klir to write a paper in which I would discuss my research results, I was very pleased to agree. George has been a stalwart in the field of general systems, holding to the goals originally enunciated by the founders of the Society for General Systems Research. His dedication to this area is strong and unique. He initiated the International Journal of Systems Science over two decades ago, and has consistently sought to expand and upgrade the literature of the field during this period, both through his own research and by providing publishing opportunities for others. If enough others would follow his example, the growth of this field and the implementation of what it could offer would provide major benefits to society. Not only was my affection for George Klir involved, but as it turned out, I was in the process of trying to find a way to communicate, in an overview way, the essence of a period of 25 years of research on complexity. George's suggestion not only crystallized the already-active intention to teach myself what I had been doing, but also provided a fine medium for me to try to convey the essences to others.

The Connection to Systems. While systems will be mentioned in this paper, and the concept of system design plays a key role in my work, connection to systems is downplayed in this paper, to avoid the implication that this is only a paper dealing with systems in the sense of the various systems societies. On the contrary, this work focuses on complexity as the major concept, and when I use the term "system", I use it in the sense defined by the American scientist J. Willard Gibbs: "...any portion of the material universe which we choose to separate in thought from the rest of the universe for the purpose of considering and discussing the various changes which may occur within it under various conditions". George Klir can remember, I am sure, a time when he collected from the systems community well over a hundred definitions of "system", and I believe he can tolerate my practice of using this one.

On Credibility. In considering what to include in this paper, and the style in which it should be written, I found myself confronting a situation that is not to my liking. Several years ago I was impressed when I read that a certain federal offical had, on the wall of his office, a sign that read: "Credibility is a non-renewable resource". I have tried to make this a strict guideline for my own writing. The standard mode of scientific contribution is to try to be as credible as possible, crediting sources not only of scientific knowledge applied in an author's work, but also crediting sources of inspiration that may have arisen simply from a well-turned piece of wisdom that arose without empirical backing.

On Writing Style for this Paper. Still, in this paper I am writing, I had to face up to the fact that if I chose to continue that tradition in this piece, I would have to use so much of the paper for referencing what was gleaned from writings of others (both living and dead) that the messages I wanted to convey would be lost in the cross-referencing. Therefore I elected in this piece to take advantage of my past attention to referencing and crediting, and to omit almost all reference to the works of others. Anyone who is dismayed by this can consult several annotated bibliographies, books, and papers. Not long ago I had occasion to tabulate the extent of this situation. I found that in the 25-year period of my research on complexity I had published 77 papers on complexity, made 56 presentations on this subject, produced heavily-indexed books and bibliographies[1] that integrated much of this work, and collectively had involved 1,978 pages, 1,003 references, 501 figures, and 187 tables. While these numbers say nothing much about the quality of what has been produced, I hold that they do entitle me to the luxury of following the strategy I set forth for writing this paper. Moreover, to compensate for the lack of appropriate citations, I make a blanket offer to any skeptical reader to respond to any reasonable queries or criticisms of what I have to say in the following.

Assertions, Conjectures, and Laws. Some time ago I observed that careful researchers would distinguish in their writing between such things as theorems and conjectures. A conjecture would be acceptable, if acknowledged as such, and if it were based on at least a modicum of evidence--not enough to settle the issue, but enough to warrant exposing it to a community of scholars. In pursuing this approach here, I designate key ideas as Assertions (made without proof, based on twenty-five years of research, integration, and aggregation), Conjectures (made to incite others to consider them and pursue ways of validating or invalidating them) and Laws of Complexity (which I feel have been tested enough to warrant designation as such, being tested not only in the empirical domains of action, but through correlation with the highest-quality thinking of the highest-quality philosophers).

Assertion 1. *Most of what is presently called "science" has yet to meet the appropriate criteria for using that title.*

I found that I could not write this paper, without recognizing this Assertion, and that I had to be responsive to it, in order to proceed. For this purpose, I discuss first "science and the fixing of belief". This allows me then to discuss "science and complexity", in which I note that complexity is an attribute--and that if significant knowledge can be gathered about that attribute, a science of complexity can make a very broad set of contributions to the many areas or fields that have the attribute of being complex. Some of these areas are so closely linked to complexity (I call them "proximity factors") that the study of complexity is mostly a study of attributes of these factors, including ways to describe the proximity factors, and ways to work with these factors toward a general improvement in human capacity to deal with complexity.

Assertion 2. *Most of the literature that discusses the proximity factors of complexity is relatively useless in investigating complexity, because it relates to the proximity factors at a scale that is far too small. The utility of components of such literature is tested by determining whether the components can be extended into large-scale thinking. I have coined the concept "open at scale" to describe methods, concepts, etc., that are not inherently scale-limited.*

This view leads to a discussion of "constrained extraction", in which screening of literature for relevance to complexity is critical to taking advantage of any scholastic inheritance.

Assertion 3. *The 17 Laws of Complexity discovered so far (by a combination of literature screening, empirical research, and correlation of philosophy with these) are likely to stand up against many forms of exploration, and are likely to provide significant guidance for major improvements in the areas of the proximity factors.*

With this view in mind, the laws of complexity are structured in a matrix showing the proximity factors to which they appear now to have the most relevance.

While the ***specific*** contributions of others to these Laws and to the proximity factors are not identified in this paper, Table 2 does show a triadic connection involving certain authors, certain proximity factors, and related Laws of Complexity.

Assertion 4. *Many individuals and groups who are currently involved in research on areas that are complex are likely to find that their research can be greatly enhanced, if they will take the work reported here into their thinking, and strive to advance this work along lines indicated in a section called "Research Directions".*

Assertion 5. *The functional areas of system description and system design can be greatly enhanced by applying the results of the work reported here.*

Major Results. One of my intentions in reviewing the past 25 years of my research on complexity was to try to identify and highlight what might be called "major results". At the end of this paper, I present my own analysis of what these major results are, along with some of the rationale for designating them by this title.

Science and Fixing of Belief

It is customary for investigations in physical science to revolve around substantive topics: topics that are describable by nouns rather than adjectives, topics that lend themselves to quantitative measurement validated by comparison with internationally accepted standards, topics that possess the property of being tangible, topics that lend themselves to investigation in the confined space of a laboratory.

If the bevy of attributes just set forth were mandatory for all science, the development of social sciences would generally be impossible. But the world needs high-quality understanding of its societies, and if the approach to such understanding cannot be scientific, then some other unknown concept would be sought (perhaps in vain) to try to bring discipline to what are now called (without reference to clearly-defined criteria) the "social sciences".

Light is often shed upon deep questions by philosophers. The question "what is science?" has occupied quite a few philosophers. Of those who dealt with this question, none has been more insightful than "America's greatest thinker", Charles Sanders Peirce. His concept of science largely springs from the following question: "How is belief fixed?"
In approaching this fundamental question, Peirce, who was himself an excellent physical scientist, involved in highly accurate physical measurements, concluded that there were four components to the answer to this question. The four methods of fixing belief were:

- Authority
- Tenacity
- Metaphysics
- Science

In elaborating on these four methods, Peirce did not accept "received doctrine" (i.e., authority), as his understanding of science. Instead, he developed the concept of science as he saw it had to be developed, in order to merit its presence in a set of categories of how belief is fixed.

Authority. The first method of fixing belief, authority, is well known in history. In many instances, whole populations were subjected to the authoritarian views of individuals who set forth the bases for human thought and behavior. The method of fixing belief by authority is not limited to powerful dictators, but is present wherever unquestioning acceptance of ideas marks individual behavior. So Kant was led to define "enlightenment" as "man's release from his self-imposed tutelage". ***Absence of questioning of received doctrine offers the foundation for fixing belief by authority.***

Tenacity. The second method of fixing belief, tenacity, has to do with the time dimension of belief. Through tenacity beliefs, once attained, are maintained and reinforced, by an unwillingness to entertain the thought that previously-accepted beliefs could be mistaken. ***Tenacity is a protector of "intellectual turf", a built-in mindguard, working against correction of what might be long-held misbelief.***

Metaphysics. In speaking of fellow philosophers, Peirce talked of "seminary philoophers" and "laboratory philosophers". The seminary philosopher arrived at belief through mental operations in which seemingly logical connections are made involving concepts often viewed as intangible. ***But the primary characteristic of the metaphysician that distinguishes the metaphysical approach from the scientific mode of fixing belief is the indifference of the metaphysician to any attempt to validate beliefs through external observation or experiment.***

Science. A key concept in Peirce's philosophy of science is that of human "fallibility". Taking for granted that the human is fallible, Peirce arrived at his view that science is a social phenomenon, taking its characteristics from what is understood about human beings. If the human is fallible, then authority is automatically subject to question, tenacity of belief is an attribute without proper foundation, and metaphysics is never to be trusted simply because of its origins. But there is nothing magical about science that shields it unerringly from fallibility either. ***What distinguishes science from the other three modes of fixing belief is the notion that every idea, no matter of what origin, is to be viewed as possibly arising from fallibility and, consequently, subject to continuing, never-ending assessment by a "community of scholars"***. In the absence of such a community, science loses all significance. Notably, the precise method of scrutiny is not specified in Peirce's philosophy of science, which is broad enough to encompass all forms of human inquiry in which two beliefs play a decisive role: (a) humans who present knowledge as "scientific" are fallible and (b) the social system accommodates dedicated communities who constantly assess tentatively accepted "science" to invalidate it or to re-validate it as new information arises. What is the "laboratory" where scientific scrutiny takes place? Nuclear weapons testing and nuclear power plants testify to the expansion of the laboratory [often stereotyped as a laboratory (room) where strange white-coated persons carry out mysterious experiments] into the broader world of atolls, deserts, and nuclear power plants, hence into all of Earth. Space exploration has begun to extend the laboratory into the entire universe.

Science and Complexity

In 1968 I began a study of complexity, which I have continued to this day. Complexity is not substantive, not measurable against any standard, not even well-defined, perhaps. Yet, being an attribute, the study of complexity might be applicable to a very broad class of situations, where components of the situation might be regarded as "complex" and, thereby, might make the situation itself complex.

Becoming known to the author around 1972, the Peirce concepts of how belief is fixed immediately posed the challenge of how beliefs about complexity would be fixed. It seemed immediately clear that the study of complexity had to be scientific. But since complexity is intangible, not measurable against any accepted standard, how could its study become scientific? A review of the literature in the early 1970s found almost nothing that dealt head-on with complexity. If there were no literature on a subject, if the subject itself were intangible, and if no mode of measurement were available, what could be done to focus a study of complexity, and how might results of its study gain any credibility?

In academic life, the concept of "proximity disciplines" has meaning as follows: some areas of study are "close" to other areas of study. For example, the study of economics involves the study of human behavior, which is an area of considerable importance in psychology, biology, sociology, and anthropology, and even (perhaps) history. While the academic community tends to see the world of knowledge as partitioned by its disciplines, the study of complexity can hardly accept as a basic tenet that complexity is merely "interdisciplinary", i.e., involving only several disciplines. However the modified concept of "proximity areas of knowledge" seems to have merit with respect to complexity. As mentioned previously, complexity is an attribute, and if it is to have any significance it must be found in those areas to which that attribute applies.

Proximity Factors. To augment the mere concept of complexity, a search for "proximity factors" can be initiated. The objective is to identify those concepts that serve as a source of enlightenment with respect to complexity.

The Human Being. We can imagine that if every occurrence in the history of the universe were perfectly understandable, and if every desired feature could be humanly conceived and constructed according to a perfect plan so as to modify the universe in the future, the concept of complexity would be irrelevant to anything. ***In the first instance, complexity arises out of the readily observable, repetitious inability of human beings to comprehend certain occurrences in the universe; and of the readily observable and ubiquitous inability of human beings to conceive and construct highly-effective means of providing satisfactory remedies for perceived harmful events in that universe.*** In short, complexity is meaningful only when connected to the human being; and then when that connection involves human effort to comprehend or to design. But comprehension is also an attribute, and we would do well to try to replace it with something more tangible.

Archival Representation. Let us say that we demand evidence of comprehension in the form of archival representation, i.e., documentation, writings or analyses that might come from fallible sources; such that a community of scholars could investigate the documentation, writing, or analyses, and invalidate or re-validate in the light of a variety of factors. And while some instances of complexity might be short-term, it seems necessary to allow for the possibility that a prolonged period of time might be required to obtain an adequate representation of a complex situation, whereupon the term "archival" seems appropriate without being unduly limiting. In short-term instances, this term might be considered as a synonym for "high-quality".

Language. The familiar may, nonetheless, be worthy of deep concern. Any evidence of human comprehension will only be presented through communication to other human beings, and the overriding vehicle for such presentation is language (not, however, limited only to prose). It is not enough, when studying complexity, to note in passing that it will be discussed in linguistic terms. The mere fact that complexity is inherent in human difficulty suggests that the difficulty flows through directly to language. ***While the prevalence of language as a means for revealing thought about the past is clear, one must also note that any attempt to create newly-designed resolutions of complex situations may involve the creative, inventive use of language simply to make possible the development of a "linguistic domain" which can be shared by all those human beings who are involved in the considerations.***

Organizations. Matters that are complex can almost certainly be taken as matters where a single individual cannot, acting alone, even describe accurately the situation being considered; and/or where a single individual acting alone lacks the resources required to mount a program of action to resolve some complex situation. Because of these commonplace features, ***the presence of the human being evolves in our thinking into the presence of organizations; those creations of human beings established specifically to make possible joint action in***

understanding complex situations and, hopefully, of conceiving and carrying out actions to modify features of those situations.

Groups. When organizations come into view as action arenas involving complexity, it becomes equally clear that only fractional components of those organizations will be involved with a given complexity in a given time period. These fractional components are not individuals, but rather they are collections of individuals, called groups. ***It is groups within organizations who may strive to grapple with the linguistic demands of complex situations to be able to describe these situations to archival standards, and to be able to create conceptual initiatives to help resolve those situations.***

Formal Logic. Many of the domains of simplicity or domains of understanding have long been supported by an underlying logic. Many of the areas of human activity involve logic long since developed and carried forward in space and time, being masked or hidden in established behavioral modes. But no such heritage is available for complex situations. Therefore one must recognize that the logic of a complex situation is yet to be discovered, and, until it is, there will be no basis for its gradual evolution into the good, gray, domain of the routine. ***Moreover, because the logic will undoubtedly be more complex than what is normally assimilated, we can expect that the assistance of technology in grappling with, uncovering, and designing the logic will be required as a predecessor to routinization; if the latter is even possible.***

The nature and formal requirements of logic were presented by two authors independently in the year 1847. These authors, George Boole and Augustus de Morgan, were both in the United Kingdom, and today's formal logic, as applied to analyze complex issues, involves the merging of the algebra of Boole and the Theory of Relations of de Morgan; both being subsequently enhanced significantly by Charles Sanders Peirce and, more recently, by Frank Harary (1967) and by John N. Warfield (1974).

Numerical Quantification of Parameters. In addition to the logic of complex situations, one must consider the numerical quantification of some aspects of those situations. In designing responses to complexity, numerical quantification of some aspects of design will almost always be required. ***What is most important about numerical quantification is that it not be prematurely imposed***. It can surely be deferred until at least some (and, preferably, all available) aspects of the qualitative logic of the situation are in hand.

Working Environment. It is generally understood that whenever some aspects of life require recourse to an organization, and whenever some form of production is anticipated, it is appropriate to consider carefully the design of an appropriate working environment. ***Such an environment is intended to eliminate obstacles to carrying out whatever form of work is required, and to provide necessary enhancements to enable and support the form of work that is to be carried out.***

So far this common understanding has been frequently overlooked when complexity is involved. If it ***has*** been overlooked, one will find complex situations being worked with by groups in facilities that were designed and constructed for some much simpler, more ordinary, purpose. If it ***has not*** been overlooked, one will still find complex situations being worked with by groups in facilities that have been constructed without regard to the full panoply of obstacles and/or enhancements that are possible; the facility having been constructed to sell some kind of product such as the facility itself or technology that has been mindlessly introduced into that facility.

Group Process. Given that complexity normally involves the organization as a context, and a working environment in that organization as a site for group effort, it seems evident that the process used by the group will be critical to developing appropriate understanding of complex situations or issues. It also seems clear that, since the group is brought together to overcome individual limitations, the process applied in the working environment should have certain attributes. It should facilitate emergence of each individual group member's understanding as part of the resource of the group. Likewise, it should facilitate the collective learning of the group in assessing each individual member's contribution. It should also facilitate the development of the formal logic underlying the description, diagnosis, and prescription concerning the complex issue in a form that lends itself to archival representation. Because of the extensive amount of information typically associated with complex situations or issues, the process should be very sensitive to the display needs of group members, to keep before them the large amounts of information and the interpretation and organization of that information for ready access as a resource while the group process proceeds. ***In short, the group process should be carefully designed with a panoply of purposes in mind, in order that the group can be effective in working with complexity.***

Computing Machinery. The human being, as a member of a group, connected to an organization, striving to work with a complex situation or issue, finds available a powerful resource in today's computing machinery. These machines are, themselves, based in formal logic and, while this logic often appears to the user as though the machine were doing calculation with everyday numbers, this is merely an artifact of the "human interface" or the "gui" (graphical user interface) provided by the manufacturer of the machine.

Algorithms for formalizing structural thinking can reside in the computer, and make possible group interaction for Socratic instruction (learners responding to questions), leading to interpretable "maps" of complex situations or issues.

Beyond the strictly logic aspects of complexity, the computing machine can also serve its more common functions of assisting with the quantification and computations required, especially in design situations.

Connecting Proximity Factors to Science. Having identified ten proximity factors to complexity [the human being, archival representation, language, organizations, groups, formal logic, numerical quantification of parameters, working environment, group process, and computing machinery], it becomes possible to assess the availability of scientific knowledge for the study of complexity through an assessment of the scientific knowledge attached to these proximity factors. It is conceivable that proximity factors can contribute significant scientific understanding to complexity itself, viewed as an attribute that involves them.

Constrained Extractions

At first glance, it might appear that the legacy of knowledge from study of the proximity factors would furnish a large territory from which to make credible the study of complexity. But this point of view must be severely constrained. To illustrate the point, consider how easy it is for most free-standing human beings on Earth to jump one centimeter off the floor; and how impossible it is for those same human being to jump 10 meters off the same floor. ***The basic idea is one of scale.***

Screening on Scale. The concept of scale must be kept in mind constantly in assessing relevance of inherited knowledge or received doctrine to a study of complexity.
Most university courses develop understanding and skills in working with ***small-scale issues and situations*** and evaluate student performance on such small-scale issues. Larger scale issues are dealt with by authority, tenacity, and metaphysics, but hardly by science. Evaluation of student performance on large-scale issues is almost entirely absent. The proud possessor of university degrees is often well-informed and talented at small scale. The same individual, when confronted with large scale should expect to begin from scratch, and enter a world full of confusion and challenge. Worst of all, many of the beliefs attained at small scale must often either be discarded or radically reconceptualized in order to be harmonious with more global contexts; creating a very difficult learning situation for the individual who is striving to expand thought processes into the realm of the complex.

Screening on Context. A second screening on received doctrine involves ***the basic idea of context***. Many topics dealt with in education are treated without clear identification of relevant context. If the context were provided, many subjects would be seen as relevant only to such narrow contexts as to raise questions about their inclusion in any time-limited, resource-limited learning experience. Possibly even some entire schools of universities might be abolished, or restricted to a minor departmental existence, if significant context were made a requirement for formal offerings.

Screening on Failures and Environments. Examples of failures in large-scale situations may have value in motivating people to learn more about complexity, but experience suggests that such motivation will generally not be felt unless the individual begins to see large-scale failures as collections of situations with a common attribute; and not merely as isolated instances of uncorrelated situations. An explosion at Chernobyl and waste of huge sums of money in trying to design an untestable new and larger computer chip may not appear as correlated events unless the impact of complexity is seen as being held in common by such incidents.

Screening on All Three Factors. In perusing the proximity literature for clues as to how to deal with complexity, matters of both scale and context are involved in constraining the extraction from this literature. Mathematical methods that are only useful for solving problems with a few variables are of interest only to the extent that they may be miniscule components of much larger situations. On the other hand, a paper from psychology that reveals human scale limitations in information processing is very relevant. In striving to find materials relevant to learning to work with complexity, the literature may be most useful in furnishing three types of revelations: (a) identification of concepts that are ***valuable in large-scale, unrestricted contexts*** (b) identification of ***limitations*** on individual, group, and organizational capabilities to rise to the encompassing context involved in working with large-scale issues and (c) examples of ***failures and environments*** in which those failures occurred.
Keeping Track of the Sources. In studying complexity, much investigation of literature was carried out from 1968 to the present (*see* End Note 1). Many publications were indexed to keep records on what was examined to construct knowledge about complexity. Some literature was cited not because it represented a contribution to advancing the knowledge of how to deal with complexity but, rather, sharply exemplified myopic unawareness of the importance of issues of scale and context, while claiming broad applicability.

Laws of Complexity.

Moving forward in time from the early days in which a strategy for studying complexity evolved to the immediate present, the question arises: "What have been the major products (if any) of the more-than-quarter-century of study of complexity?" By striving to identify these major products, an arena for evaluatory dialog can be opened, which can invoke intermediate points along the way from the early work to the present, without demanding a complete history and chronology of the intermediate events.

Beginning around 1980, a portfolio of Laws of Complexity was gradually created. Initially a group of three was set forth, but over time additions were made until it is now possible to state ***seventeen such Laws***. Laws of Complexity attach to the attribute, but can be presented in relation to the proximity areas identified earlier in this paper as being intimately related with complexity. An initial overview is offered through Table 1.

Arraying Laws of Complexity for Focus and Functional Relevance. The reader can see in Table 1 that the Laws are placed in a two-dimensional array, of which one dimension deals with ***the individual, groups, organizations, and process***: four of the ten proximity factors discussed previously in this paper. The other dimension of the array involves ***purpose pinpointed to four specific functions***, without which investigation of complexity lacks connection to human interests. The four functions listed are: ***description, diagnosis, prescription, and implementation***. One working group might be content simply to describe a complex situation, without regard to placing judgments about what factors are at work in that situation that are thought to warrant change. But another group might be interested in covering sequentially all four functions: first finding a description of a complex system, then ferreting out what seems to be unsatisfactory in that situation (in the form of a diagnosis), then designing an integrated pattern of change in the situation (i.e., writing a prescription) and, finally, implementing that prescription in practice.

What Table 1 is aimed at revealing is which Laws are particularly (though not exclusively) relevant to which cells in the matrix; in order that an individual who is interested in assessing the origins or applicability of the Laws will have a suggested starting point.

Along similarly purposeful lines, Table 2 seeks to show the connection of proximity factors to contributions arising from particular investigator-authors that are relevant to or even definitive with respect to particular Laws.

FOCUS →→→→→ FUNCTION ↓↓↓↓↓↓	INDIVIDUAL	GROUP	ORGANIZATION	PROCESS
DESCRIPTION	■ Limits ■ Triadic Compatibility	■ Limits ■ Uncorrelated Extremes	■ Limits ■ Organizational Linguistics	■ Limits ■ Triadic Necessity and Sufficiency ■ Universal Priors
DIAGNOSIS		■ Inherent Conflict ■ Structural Under-Conceptualization ■ Diverse Beliefs	■ Forced Substitution ■ Precluded Resolution	■ Success & Failure ■ Universal Priors
PRESCRIPTION	■ Requisite Parsimony ■ Requisite Saliency	■ Requisite Variety		
IMPLEMENTATION				■ Gradation ■ Validation

TABLE 1. LAWS OF COMPLEXITY, STRUCTURED VERTICALLY BY FUNCTION AND HORIZONTALLY BY FOCUS

TABLE 2. RELATION OF PROXIMITY FACTORS TO LAWS OF COMPLEXITY, AS MEDIATED BY WORKS FROM VARIOUS FIELDS AND AUTHORS

Proximity Factor	Fields and Authors	Related Laws
Human Being	*Economics*: K. Boulding *Philosophy:* J. Deely, C. S. Peirce *Psychology*: R. F. Bales, W. Bennis, G. A. Miller, H. A. Simon *Systems*: G. Vickers	• Limits • Requisite Parsimony • Requisite Saliency • Triadic Compatibility
Archival Representation	*Mathematics*: F. Harary, K. Kuratowski, F. Zwicky	• Organizational Linguistics • Underconceptualization
Language	*Chemistry*: A. Lavoisier *Mathematics*: K. Gödel, D. Hilbert, G. Leibniz *Music*: W. Mozart, L. von Beethoven, and others *Philosophy*, C. S. Peirce	• Organizational Linguistics • Underconceptualization
Organizations	*Economics*: S. Beer, K. Boulding, A. Downs *Philosophy*: R. Ackoff *Sociology*: A. Etzioni, C. Kluckhohn	• Limits • Organizational Linguistics • Requisite Parsimony • Requisite Saliency

Proximity Factor	Fields and Authors	Related Laws
Groups	*Psychology:* I. Janis, B. W. Tuckman *Sociology:* C. Argyris	• Diverse Beliefs • Inherent Conflict
Formal Logic	*Philosophy/Mathematics:* R. Ashby, I. M. Bochenski, G. Boole, A. De Morgan, F. Harary, J. Hartmanis, K. Kuratowski, C. S. Peirce, B. Russell, P. Suppes, A. N. Whitehead	• Limits • Organizational Linguistics • Requisite Variety • Triadic Necessity & Sufficiency • Uncorrelated Extremes • Universal Priors
Quantification of Parameters	*Physics:* G. Friedman, J. W. Gibbs *Psychology:* J. Piaget	• Limits • Relative Saliency
Working Environment	*Law/Policy Science:* H. Lasswell	• Requisite Parsimony • Success & Failure
Group Process	*Psychology:* A. Delbecq, M. Osborne, A. H. Van de Ven	• Uncorrelated Extremes

Research Directions

The research being described here was pursued through a multi-faceted strategy, because of the necessity ultimately to integrate a variety of types of information. The strategy involved the following components:

- Aggressive literature study in both (a) academic literature and (b) the print media
- Direct experimental observations
- External consultations
- Direct development of needed science and methods of practice
- Extensive cooperation with unsolicited requesters
- Visiting researchers
- Targeted forays to solicit academic collaboration
- Highly-varied direct practice and extensive documentation
- Overview analysis

These components of strategy will be discussed from the perspective of what was sought and what was achieved or not achieved, in light of the desire for a successful long-term outcome.

Aggressive Literature Study. Because complexity was the object of study, it was felt that literature study had to take on an encyclopedic character, seeking aggressively to discover what had been thought about and what had been tested, especially in regard to the identified proximity factors. It was felt that the majority of relevant knowledge would be found in various academic publications, including some that delved deeply into history. On the other hand it was felt that it would be essential as a reality check to begin to keep a log of major catastrophes or disasters, both physical and economic, in order to begin to decipher the aspects of those situations that might indicate the ubiquitous presence of complexity, and the consequences of that presence. Studies of this type began in 1968, continue to the present day, and should be continued into the future--especially the studies of media events indicative of significant failures and disasters, as this will help build the documentary basis for defining complexity more precisely.

These studies contributed significantly to results as follows:

- Illumination of intellectual limitations on the individual human being, contributing to the conceptualization of the Law of Limits, the Law of Triadic Compatibility, the Law of Requisite Parsimony, and making evident the requirement for group collaborative efforts in dealing with complexity
- Identification of the set of Universal Priors to all science, contributing to the Law of Universal Priors
- Formulation of the Law of Success and Failure
- Contributing, along with results obtained from outcomes arising from Highly-Varied Direct Practice, to the Law of Structural Underconceptualization
- Providing the necessary foundations that enabled the Interpretive Structural Modeling process to be conceived, developed, and applied
- Providing the necessary foundations for the Law of Requisite Saliency
- Demonstrating the appropriateness of the Law of Gradation
- Demonstrating the appropriateness of the Law of Validation
- Illustrating regularly and profusely the vast amount of misconception blanketing the thought processes of human beings and suffocating organizations, caused largely by projecting concepts that are appropriate for small-scale situations into large-scale situations where the dysfunctionality cannot be overstated
- Demonstrating clearly the shortcomings of higher education which, so far, has failed to make the necessary distinctions for purposes of reorganizing higher education in order to develop graduates who understand how to cope with complexity
- Demonstrating repeatedly the lack of foresight and lack of proper infrastructure in society for preventing large-scale disasters, for carrying out and implementing appropriate sociotechnical systems designs, and for responding adequately to large-scale crises in all societal sectors

Direct Experimental Observations. While reading offers a powerful means of arriving at insights on complexity, it cannot take the place of direct experimental observations. Very early in the program of study on complexity, it was decided to set up a situation that would allow for a period of experimental observation of a group of people who were willing to accept a complex challenge to work together in a constructive mode.

This work began with the establishment, in the early 1970s, of the "Large City Design Team", a group of multi-disciplinary professionals coming together in a common setting from various organizations; and having broad, deep, and complementary experience in the area of urban design. Motivation for this team was provided by the extensive disturbances taking place in the United States while the team was at work. At that time several major movements were taking place at the same time, including the anti-Vietnam War movement, the Civil Rights movement (accompanied by numerous marches and arson in major cities), and a huge amount of misdirected "underground", inflammatory information dissemination. In the same time period, the concept of "new towns" was in vogue in both the United States and Europe, with some U. S. legislation promoting the idea in various formats. As a result of the latter, the project not only allowed for learning more about how to describe what might be called a "well city", as opposed to a "sick city", but also opened up an opportunity to formulate, for the first time, a theoretical approach to designing a large new city based upon the aggregated knowledge and wisdom of persons expert in various facets of urban design.

After observing this team in action for two years, the following conclusions were reached:

- The team got nowhere
- When the team finally became demoralized with its own incompetence to produce useful product, it degenerated into making a set of separate reports in specialized areas that lacked coherence or cohesion as a body of knowledge
- When measured against the approach developed by the Greek architect, Constantin Doxiadis, it was clear that Doxiadis was well ahead of any team conceptualization
- It was crystal clear that several factors had major impact in preventing the team from making progress: the lack of any systematic way to aggregate and organize their thinking on this large-scale subject; the inability of the team to find a way to manage its own processes; the negative impact of having social scientists on the team (it being thought originally that these individuals would help bring what was known about individual and group behavior to improved team interaction, only to find that the social scientists were the worst offenders in terms of team interaction); the lack of development of any commonly-held vision of any aspect of the work; continued questioning of why the project was being supported, and whether the support would be withdrawn; and the absence of significant enthusiasm on the part of middle managers in the organization supporting the work, which helped damage the morale and participation of internal staff members
- It was appropriate to seek outside consultation to help analyze the nature of the team's difficulties

External Consultations. The Menninger Clinic in Topeka, Kansas, was recognized internationally as a major psychiatric consulting institution, having extensive experience in working with individuals that suffered from mental conditions. Representatives of this firm were engaged to review the work of the Large City Design Team. The essence of their conclusions were as follows:

There are basically two kinds of people on this team: the Convergers and the Divergers. The Convergers are primarily engineers and physical scientists. They want to arrive at a solution before they comprehend the situation and its scope. The Divergers are primarily social scientists. They are motivated to engage in endless dialog, never moving in the direction of convergence, but rather continually expanding the scope of the discussions into new areas in which they have singular interests. It is very likely that a team of this type could, if they so desired, work indefinitely and never arrive at any constructive design for a large city.

Direct Development of Needed Science and Methods of Practice. As a result of the experiences and consultation just described, it was decided to begin the long road to development of a needed science of complexity, and methods of practice. It was further decided that the science of complexity should place a heavy focus upon the practice of large-scale system design, and that it should reflect the observed need to lay the basis for and support the development of methods of practice that would enable people from a variety of backgrounds to work together productively on large-scale tasks.

The direct development that began in the early 1970s had produced, among other things, the following outcomes (around the approximate time indicated):

- Development of the Interpretive Structural Modeling (ISM) Process (1973)
- Development of main-frame Computer software to support ISM through the Scanning Method (1974)
- Conduct of the first two ISM-supported application tests with groups at the Kettering Foundation (considering transportation planning in Dayton, Ohio); and in Cedar Falls, Iowa (with the City Council)
- Incorporation of the Nominal Group Technique into the group practices being studied and tested (1976)
- Publication of a book summarizing progress to date (1976), with sponsorship of Battelle Memorial Institute (Societal Systems: Planning, Policy, and Complexity)
- Development of theory on how to improve significantly the representation of knowledge patterns produced using ISM (1977) with sponsorship from the National Science Foundation
- Development of main-frame computer software to support ISM through the Bordering Method (1978) with sponsorship from the Office of Environmental Education
- Invention of the Options Field and Options Profile Methods (1979) with sponsorship from the Office of Environmental Education
- Conduct of numerous sponsored test applications of the developing practice in a variety of locations on a variety of topics, but without a dedicated facility for doing the work (1976-80)
- Design of the first dedicated facility in which to carry out the work, with initial construction related to this design at the University of Northern Iowa (1980) and the University of Virginia (1982), the latter being done under the heading "Center for Interactive Management", a part of the School of Engineering and Applied Science
- Conduct of extensive sponsored work with the U. S. Forest Service and the Virginia Department of Forestry, using the new facility (1982-1983), and off-site work with the Southwest Fisheries Science Center in La Jolla, California, using a temporary facility (1982-1983), with collaboration of Mr. David J. Mackett, who subsequently constructed a dedicated facility there
- Incorporation of the Tradeoff Analyis Method into the group practices being studied and tested, this coming from the U. S. Forest Service (1984)
- Closing of the Center for Interactive Management at the University of Virginia, due to internicine warfare between a dean and a provost over who controlled a chemistry supply room (1984)
- Reopening of the Center for Interactive Management at George Mason University (1984), with a newly-constructed, dedicated facility for doing the work
- Development of the first PC-based, DOS-based ISM software (1987)
- Continued buildup and testing of concepts of Interactive Management with a variety of sponsors at George Mason University (1984-1989)
- Closing of the Center for Interactive Management at George Mason University through administrative actions, giving the specially-designed facility to a newly-approved, community-college PH D program advocated by the Senior Vice President (1990)--and later giving the space over to house a language teaching laboratory (1993)
- Publication of the book A Science of Generic Design: Managing Complexity Through Systems Design, (1990), with a Second Edition to follow in 1994.
- Publication of the book: A Handbook of Interactive Management (1994)

Numerous other significant events occurred during this time period, which will be indicated in following sections.

Extensive Cooperation with Unsolicited Requesters. It was evident at the outset of the research program being described, that it would be impractical to test results obtained from the work without extensive cooperation of persons who, at that time, were unknown, but who would hopefully become interested in the work and apply it in their own situations.

The dilemma of trying to locate such people was very severe, matching the lack of research publications on complexity encountered at the outset. Accordingly, it was decided to publish and disseminate as much as possible on what was being done in the hope that persons would notice what was being done and show interest in cooperation or collaboration.

This point of view proved to be an accurate one. During the period 1974-1994, interest has been exhibited in quite a few quarters, and major efforts have been made to sustain and enhance this interest. Among key events occuring during the period are the following:

- Giving dozens of lectures on requested subjects both domestically and abroad, trying to take advantage of every opportunity
- Dr. Alexander Christakis became aware of ISM, decided that it was very relevant to what he had been working on for several years, and began to pioneer its applications in complex situations--something that he continues to do in a small business in Pennsylvania (1973)
- Dr. Raymond Fitz of the University of Dayton, Dr. Robert J. Waller of the University of Northern Iowa, and Dr. Carl Moore of Kent State University pioneered early applications of ISM to a variety of complex issues (1974)
- Persons in Japan began to test and apply the ISM methodology virtually as soon as it became available. In 1978, at a meeting of the IEEE Systems, Man, and Cybernetics in Tokyo, eight papers on the subject were presented by Japanese authors. The Hitachi Research Laboratory described their special-purpose facility design in which they had initiated the use of magnetic wall boards for display purposes: an innovation which was incorporated into the first design of a special-purpose situation room for Interactive Management. Researchers at Sony and Fujitsu published related papers in various journals, largely having to do with educational applications and with modes of computer development and representation of patterns of complex situations. Early applications to education were carried out at the University of Queensland, in Australia, and in India through Tata Consultancy Services.
- Professor Ross Janes, from London, City University, spent a year at the newly-developed Center for Interactive Management on a Fulbright Award, and returned to City University to establish the Interactive Management Unit (1980-81)
- IBM Corporation became interested and developed mainframe ISM software at their Rio de Janeiro location which they made available to the University of São Paulo, where Dr. Robert W. House had collaborated with Dean Ruy Leme and James T. C. Wright to initiate the use of ISM in Brazilian applications, involving such subjects as design of the alcohol fuel program, enhancing management of soybean farming activities, and upgrading operations at the Port of Santos (1980 onward)
- Developing a relationship with the Americans for Indian Opportunity, through La Donna Harris, that would evolve into a prolonged set of projects through the activities of Professor Benjamin Broome (1987 onward)
- Developing a strong relationship with the Defense Systems Management College, Fort Belvoir, Virginia, which produced eventually a redesign of the defense acquisition system, in response to many complaints about this system, largely through the work of Professor Henry Alberts and his colleagues (1987- onward)

- Making available the DOS-based PC ISM software to persons who wished to apply it (1987-onward)
- Spawning the firm Christakis, Whitehouse, and Associates in Pennsylvania, dedicated to the practice of Interactive Management, which has established a strong reputation in the ethical drug domain with pharmaceutical firms and with the U. S. Food and Drug Administration
- Developing a strong relationship with the Instituto Tecnologico y de Estudios Superiores de Monterrey (Nuevo Leon, Mexico) through interaction with A. Roxana Cárdenas who began and continues to play a major role in the evolution of this work in applications in Mexico (1989 onward)
- Developing a strong relationship with the Ford Motor Company, Ford Research Laboratory, through the efforts of Scott M. Staley, Ph. D., P. E., leading to transfer of the Interactive Management technology to Ford over a three-year period (1992-1994)
- Watching the introduction of Interactive Management into the National Railroad Passenger Corporation through the leadership of Mr. Kenneth S. McIlvoy, and noting the advances being made in that firm through cultural change and enhanced quality of operations (1992-1994)
- Developing and testing (with support from the Defense Systems Management College and the Ford Motor Company) a Windows version of software suitable for use in Interactive Management (1993-1994)
- Noting, throughout this period, that several individuals have undertaken to capitalize on various components of the work, without honoring its theory and prescriptions for practice

Visiting Researchers. Several visiting researchers have been accommodated during sabbatical leaves or for periods ranging from six weeks to over a year; including visitors from China, Greece, India (2), Mexico, and Venezuela. Of these, Judge John Kapelouzos made a significant contribution to the development of the Law of Uncorrelated Extremes, while Roxana Cárdenas contributed heavily to the archival documentation and to extended teaching and development of applications in Mexican society.

Targeted Forays to Solicit Academic Collaboration. In view of the satisfaction deriving from the interest shown in this work, it was decided to try to promote this work into American universities, by contacting selected individuals who had already expressed significant interest in the complexities involved in large-scale systems. Several of these individuals were beneficiaries of sponsorship by governmental financing agencies over several years, and the intent was to try to get them to study, incorporate, and extend the work being done; or to suggest improvements in it.

Of all the activities carried out during the period 1968-1994, this was the only one that can be called an unqualified failure. Despite offering to be fully cooperative, and in the face of extensive documentation of theoretical work and successful project activities, it has become clear that the overwhelming response of the American higher education establishment ranges from complete indifference to immediate rejection. Considering the potential importance of the acquisition by American university graduates of the ability to manage such presently ill-fated activities as the design of health-care systems, retirement systems, and other key sociotechnical systems that have become major parts of our social existence, the ability of the American university to ignore such matters is a matter of amazement and consternation. In spite of past failures, one recognizes that America is subject to many fads, and one can imagine the possibility that some key triggering event might catapult this work into the category of the currently popular fad, in which case it might take root in spite of everything.

Highly-Varied Direct Practice and Extensive Documentation. That there has been a highly-varied **direct** practice of the ideas resulting from the long period of research activity, i.e., practice carried out by the author and his colleagues as opposed to practice carried out elsewhere, will be evident from examining the library-held resources that incorporate many reports of such activity along with videotapes of entire practice sessions ranging up to 4 days of continuous Interactive Management workshop activity. Resources such as this have been available for quite a few years to any scholars who take a serious interest in such matters.

Overview Analysis. As this work attains what might be called the first plateau of its evolution, it has seemed essential to analyze what has gone on from an overview perspective. As part of this, one would highlight matters previously discussed in this paper. As another part of this, one would strive to decide which are the most significant of the outcomes from a scientific perspective, and why. That is to say, if we follow Kant's concept that enlightenment is man's release from self-imposed tutelage, what might have been discovered that warrants lasting attention, because of its potential for contributing to human enlightenment? The remainder of this article will be dedicated to my response to that question.

Science of Description

It has become evident that it is necessary to construct a "science of description" in order to make it possible to deal constructively with complex systems. Such a science will help to overcome the seemingly human tendency to avoid describing a system while, at the same time, striving to correct its deficiencies. It is also necessary to have such a science to support the strong need to design sociotechnical systems for the benefit of society, as opposed to simply legislating them into existence.

Conjecture 1. *The foundations of a science of description are available in the modern conceptualization of the science of semiotics, following the lines set forth by Charles Sanders Pierce in the 19th century.*

Conjecture 2. *The "geographical space" in which to couch such representations will consist of the distributive lattice (from mathematics); a space that is readily compatible with computer operations of various kinds. In situations where this space proves inadequate, it will be necessary to extend set theory to encompass the so-called "proionic systems", i.e., those systems where identity is lost and new elements emerge.*

Conjecture 3. *The concept "dimensionality" will play a major role in a science of descriptions, and will be used with the Field and Profile concepts arising in the Science of Generic Design and in applications of Interactive Management.*

Various articles can be consulted for elaboration of some of the basic ideas related to dimensionality[2].

The foregoing ideas concerning a science of description are supported by all the experiences to date in the research on complexity.

Science of Design

A significant outcome from the research on complexity is the science of generic design, first published in book form 1990, and being published in a Second Edition in 1994 by the Iowa State University Press.

This science carries over what has been learned about complexity into the domain of large-system design theory, supported heavily by the aggressive and selective findings from the literature and from media-publicized disasters. The science is organized around a development of this research called the "Domain of Science Model". This model is a graphical representation of a desirable organization of scientific knowledge and a desirable evolution of the knowledge to be organized. Consequently the Foundations, Theory, and Methodology of the science of generic design are distinctly reported, allowing a most favorable environment for discovery of the impact of human fallibility in its development, and providing a ready-made basis for testing and improvement.

Incorporated in the book are numerous instances of applications, along with various adjuncts that provide data on applications. Also included is a Postscript which, among other things, responds to referee comments on the manuscript, in order to illuminate further the science and its responsiveness to the Universal Priors.

Seven Organizational Design Levels. In institutional or organizational projects, where large-system design is practiced, it has proved helpful to discuss seven levels of activity. The odd-numbered levels relate to creativity and conceptualization concerning the major outcomes sought, and the even-numbered levels distinguish interfaces (often given short attention). Budgets often are limited to odd-level budgets, when it is just as important to have even-level budgets. The seven levels are:

- **Level 1:** *The Situation.* This is the overview level, where top-level managers are supposed to be determining and communicating high-level strategy; but where all too often, as I learned from observing much practice of Interactive Management, this level is only dealt with by the equivalent of "metaphor salespersons", while top-level managers are otherwise occupied in interfering with or micromanaging what is going on at lower levels.

- **Level 2:** *The Interface* Between the Situation and Level 3.

- **Level 3:** *The System Level.* This is the level in which the organization engages in system design for the purpose of being able to produce and sell products to customers. This level greatly needs strategic guidance, for the purpose of providing the core bases for decision making on system designs, and subsystem attributes.

- **Level 4.** *The Interface* Between the System and Level 5.

- **Level 5.** *The Subsystem Level.* In practice, there may be several subsystem levels, each more specific than the one above it; but this can be determined on the spot.

- **Level 6.** *The Interface* Between the Subsystem Level and Level 7.

- **Level 7.** *The Component Level.* This is the level involving the minimal functional components of the system designed to produce results within the continuing and evolving Situation at Level 1.

While linear, hierarchical structures are seldom advocated, this one may be appropriate in organizations whose level of sophistication has not yet extended to even-level budgeting.

One advantage of this structural description is that several large organizations who do large system designs have been able to compare what they do at the different levels, revealing the kind of serious deficiencies at the Situation Level mentioned above, and providing supporting evidence of the lack of even-level budgeting within their organizations.

Organizational Patterns. Every change in a relationship (whether it be the emergence of a new relationship, the disappearance of an old relationship, or the modification of a continuing relationship) within an organization is reflected in a change in one or more organizational patterns. It is the practice in organizations that these patterns shall almost never be visible, and that if they play a part in organizational decision-making their role shall be inherent (and thus obscured) in the intuitive processes involved in the decision-making.

It is only in recent times that the luxury of having a choice of whether to make visible organizational patterns or to leave them unarticulated has become available. Because modern technology, applied to manage complexity, has made feasible the discovery and articulation of organizational patterns, the question now comes to the fore of whether this choice that was previously made automatically by infeasibility should now be made deliberately by responsible managers.

There is abundant evidence that the failure of management to choose to make visible organizational patterns can be equated to a choice to assure that major decisions will be based on highly inadequate foundations. The Law of Diverse Beliefs and the Law of Inherent Conflict, both being founded in strong empirical evidence, provide a solid basis for the Law of Forced Substitution and the Law of Precluded Resolution.

Based in the discovery called "Spreadthink", which is at the base of the Law of Diverse Beliefs and the Law of Inherent Conflict, it becomes clear that neither individuals nor groups can formulate adequate patterns without the aid of supportive facilitation and technology, and in the absence of these patterns no basis can exist for making a carefully considered decision on major issues. Then the extreme pressures placed on high-level executives to make decisions in the absence of proper foundation produces the forced substitution of decisions not based in organizational patterns in view of the absence of them, and virtually guarantees that resolution of the complexities will be precluded.

Conclusions: Major Results

Over a quarter century of research on complexity has produced significant archival literature revealing the existence of a science of generic design applicable to the management of complexity, substituting meticulously designed systems for ad hoc legislations.

Extensive testing of an intermittent management system called Interactive Management has shown conclusively that this system is adequate to enable the science of generic design to be appropriately applied to the management of complexity.

Wherever complexity is found, Spreadthink is found, and until the disabling effects of Spreadthink are overcome by appropriate relational work using Interpretive Structural Modeling, the organizational patterns needed to understand complex systems in the organization will be absent; assuring the continuance of difficulties and the avoidance of appropriate resolutions of complex issues.

Because of the availability of computer systems to serve in processing large amounts of critical information, it is now feasible to fill out the system of roles needed in hierarchical organizations, so that organizational coherence can be achieved at all levels. Among the outcomes are great individual satisfaction in filling institutional roles, as well as great team satisfaction in observing how the individuals' endeavors contribute to overall success of the organization.

The nature of leadership roles changes from the older role of proposing special types of system changes from the top to those at lower levels. Now the nature of leadership roles is to concentrate *not* on specific system types, but instead on f*acilitating the capability of the organization to conquer complexity.* High-level leadership now must concentrate on attributes, rather than on substantives. Give the organization the attributes that it requires to deal with the attributes of complexity, and all of the details at all of the various levels can unfold in the organization, with appropriately identified functional roles. But if high-level leadership fails to exercise its responsibility to enable other organizational levels to manage complexity, the entire organization will suffer interminably or die.

The challenge that stands ahead is to expand the science of generic design and the practice of Interactive Management in the direction of supporting the structural thinking with sensible numerical assignments--a practice that will be much more valuable than trying to overlay numerical assignments on inadequate patterns.

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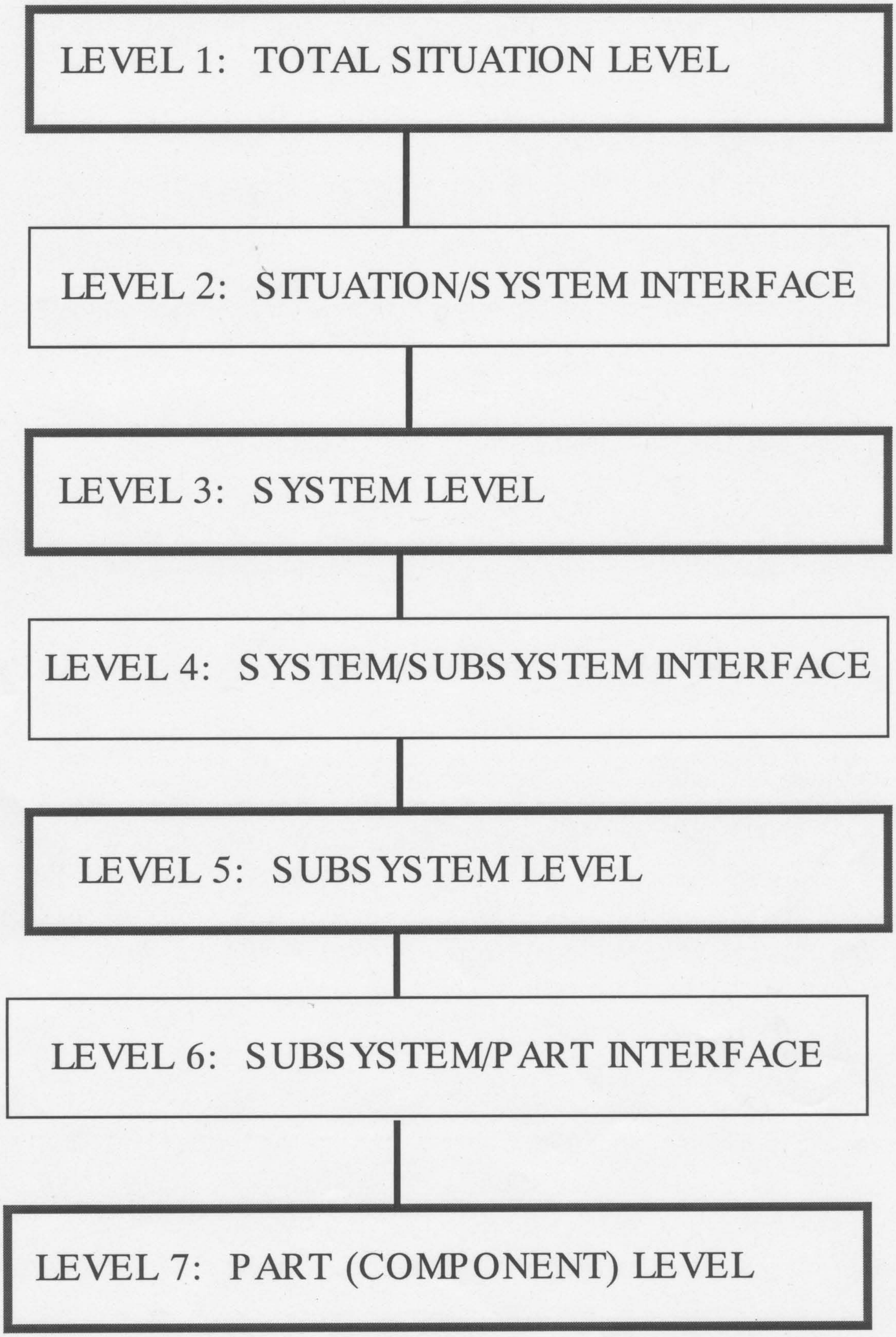

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