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HISTORY AND APPLICATIONS

OF

INTERPRETIVE STRUCTURAL MODELING

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APPENDICES ATTACHED TO THIS MANUSCRIPT:
"Some Applications of Interpretive Structural Modeling (ISM)"
* "Bibliography on Applications of Structural Modeling (ISM)", November 25, 1978
*"Bibliography on Theory of Interpretive Structural Modeling (ISM)", November 25, 1978

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HISTORY AND APPLICATIONS OF INTERPRETIVE STRUCTURAL MODELING

John N. Warfield

It is a great pleasure to be here today, at the invitation of Professor George Abonyi, to present a history and applications of interpretive structural modeling at this meeting of the Canadian Operations Research Society.

I know this is a very sophisticated group of people. I suspect that there are people here who have never heard of interpretive structural modeling (ISM), and who will benefit from a very cursory description of it. However there is no need to go into all the theory since that is readily available in print, so I will simply present a little "familiarity" material and go on to treat the history and applications.

ISM is a computer-assisted learning process designed to help groups organize their knowledge or belief about some issue or problem. Its successful application relies on the availability of a skilful facilitator of the process. To understand how the process proceeds, it is useful to know a few basic ideas about the process.

Figure 1 introduces the basic concepts of the symbolic language that accompanies the process. While the participants do not need to know this language, it is very useful in explaining the process.

Suppose that some issue or problem has been analyzed for the purpose of finding a set of "elements". These will usually be statements in prose language, and you will see examples shortly. Each element in the set can be represented by the symbol s with an appropriate subscript. The ith element is designated s_i.

Suppose also that it is desired to explore how the elements of this set are related, in terms of a "contextual relation" represented symbolically by R.

It is then possible to imagine a whole family of statements of the form $s_i R s_j = x$. Such statements can be translated into prose as follows:

The statement:

The element (s_i) is related (through the contextual relation that has been specified) to the element (s_j) has the "truth value" x, where

x = 1 means that $s_i R s_j$ is true

x = 0 means that $s_i R s_j$ is false

In other words, for the set of all possible statements involving the elements and the contextual relation, there is postulated a set of binary numbers, one for each statement, such that if the statement is true the binary number is 1 and if the statement is false the binary number is 0.

A binary matrix can be constructed using the elements as indexes for the matrix, and using the truth values as the entries in the matrix. Figure 2 shows an example of such a matrix for a set having 3 elements.

Any square binary matrix that is indexed in the same way on its horizontal and vertical axes can also be associated with a unique digraph, where there is a path on the digraph from one element s_i to another element s_j if and only if $s_i R s_j$, with the uniqueness stemming from the side requirement that the number of edges be minimized.

Figure 2 shows such a digraph corresponding to the matrix shown in the figure.

Figure 3 shows a larger binary matrix arranged to make it possible to construct a suitable digraph by inspection. Figure 4 shows the associated digraph.

When the vertices of the digraph are replaced with boxes that contain the prose statements of the elements, and a side arrow is added to show the specific contextual relation, the result is an interpretive structural model. However we have begun to use the word "map" to represent such a model, to simplify the language.

Figure 5 shows two maps that illustrate interpretive structural models.

• AN ELEMENT	s
• THE i^{th} ELEMENT	s_i
• A CONTEXTUAL RELATION	R
• A STATEMENT	$s_i R s_j = x$
• THE STATEMENT IS TRUE	$x = 1$
• THE STATEMENT IS FALSE	$x = 0$ or $\bar{x} = 1$

FIGURE 1. SYMBOLIC ASSOCIATIONS

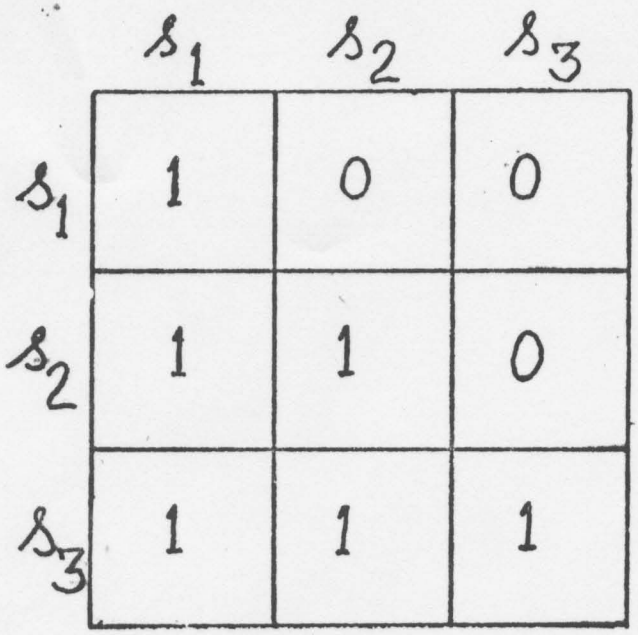
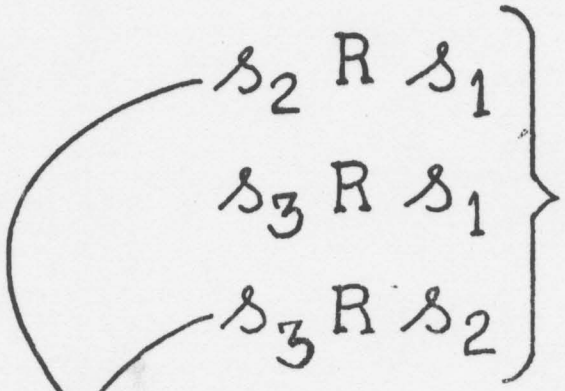
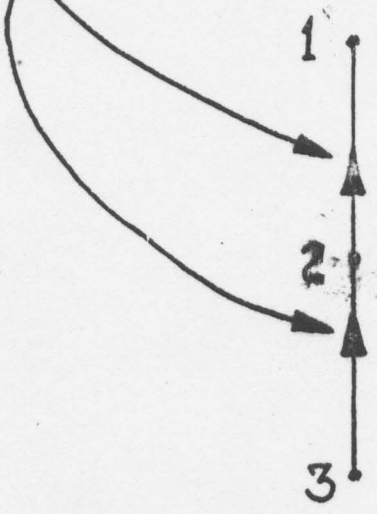


FIGURE 2.

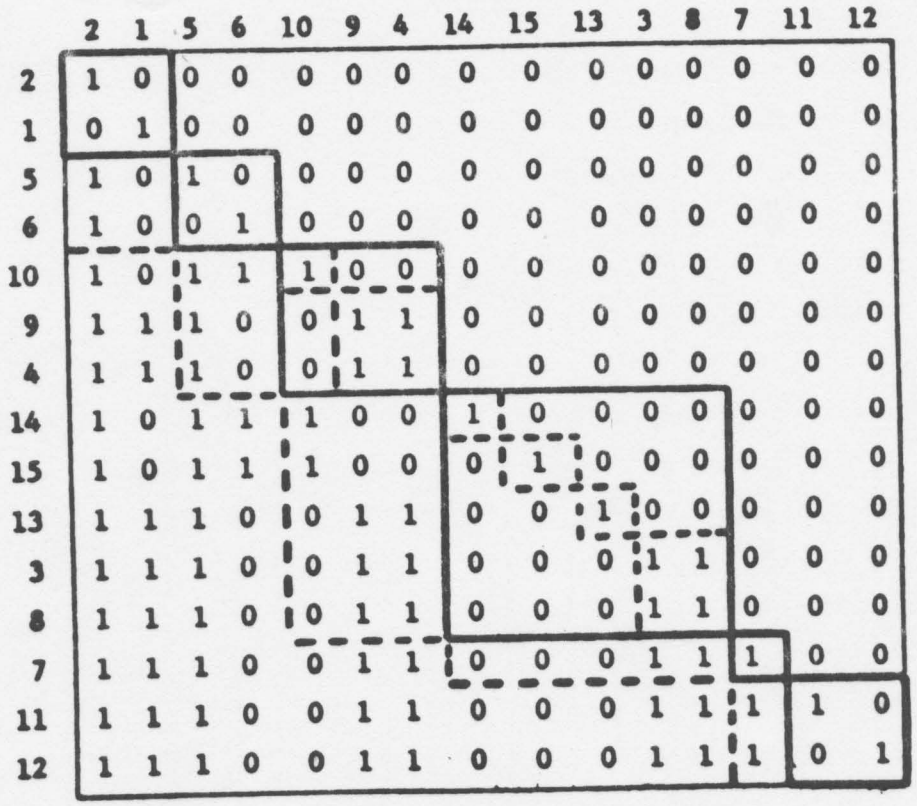
MATRIX, ALGEBRAIC DESCRIPTION, AND DIGRAPH DESCRIPTION



THE MESSAGE



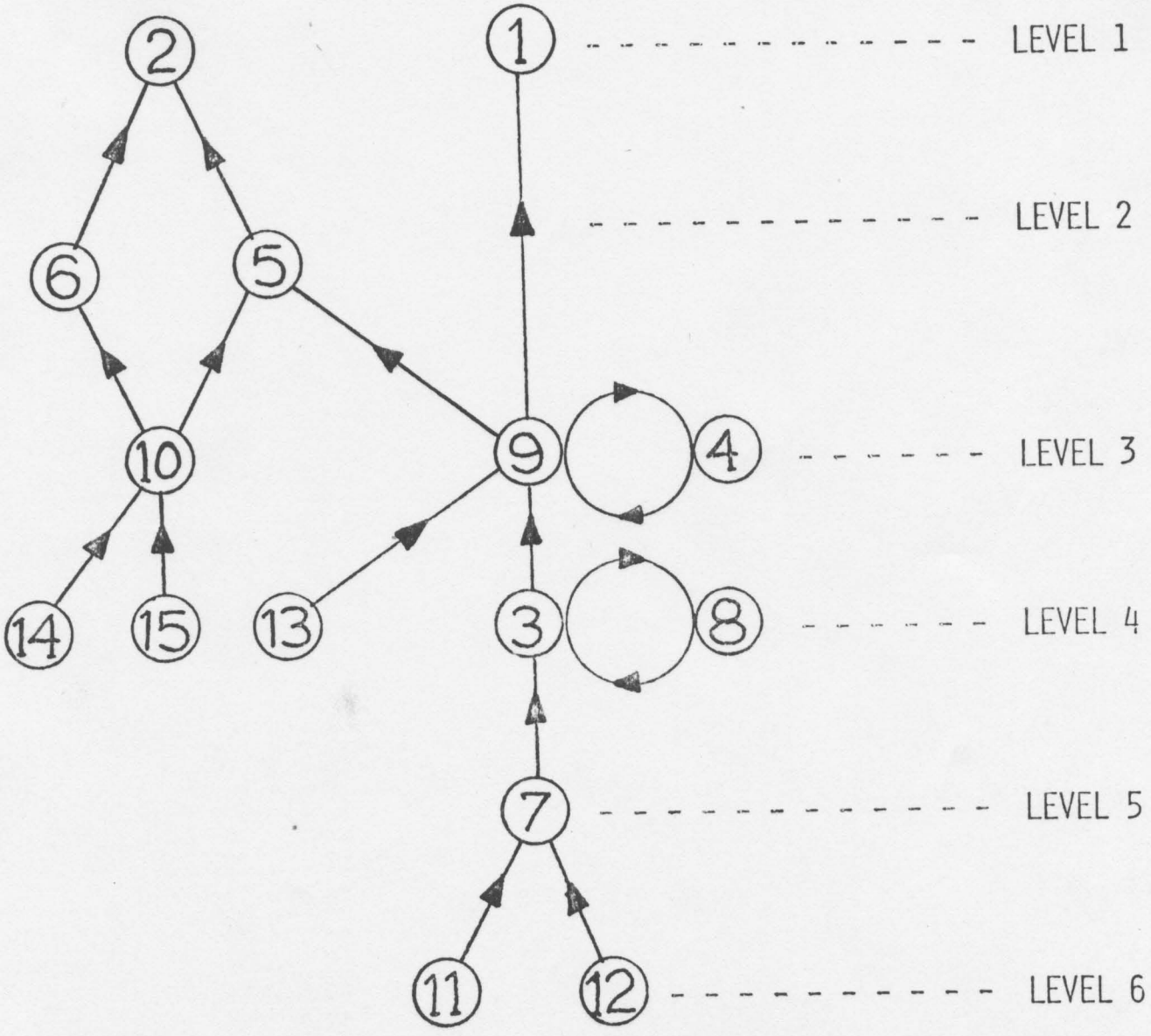
THE FRAMEWORK



	2	1	5	6	10	9	4	14	15	13	3	8	7	11	12
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
10	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0
9	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0
4	1	1	1	0	0	1	1	0	0	0	0	0	0	0	0
14	1	0	1	1	1	0	0	1	0	0	0	0	0	0	0
15	1	0	1	1	1	0	0	0	1	0	0	0	0	0	0
13	1	1	1	0	0	1	1	0	0	1	0	0	0	0	0
3	1	1	1	0	0	1	1	0	0	0	1	1	0	0	0
8	1	1	1	0	0	1	1	0	0	0	1	1	0	0	0
7	1	1	1	0	0	1	1	0	0	0	1	1	1	0	0
11	1	1	1	0	0	1	1	0	0	0	1	1	1	1	0
12	1	1	1	0	0	1	1	0	0	0	1	1	1	0	1

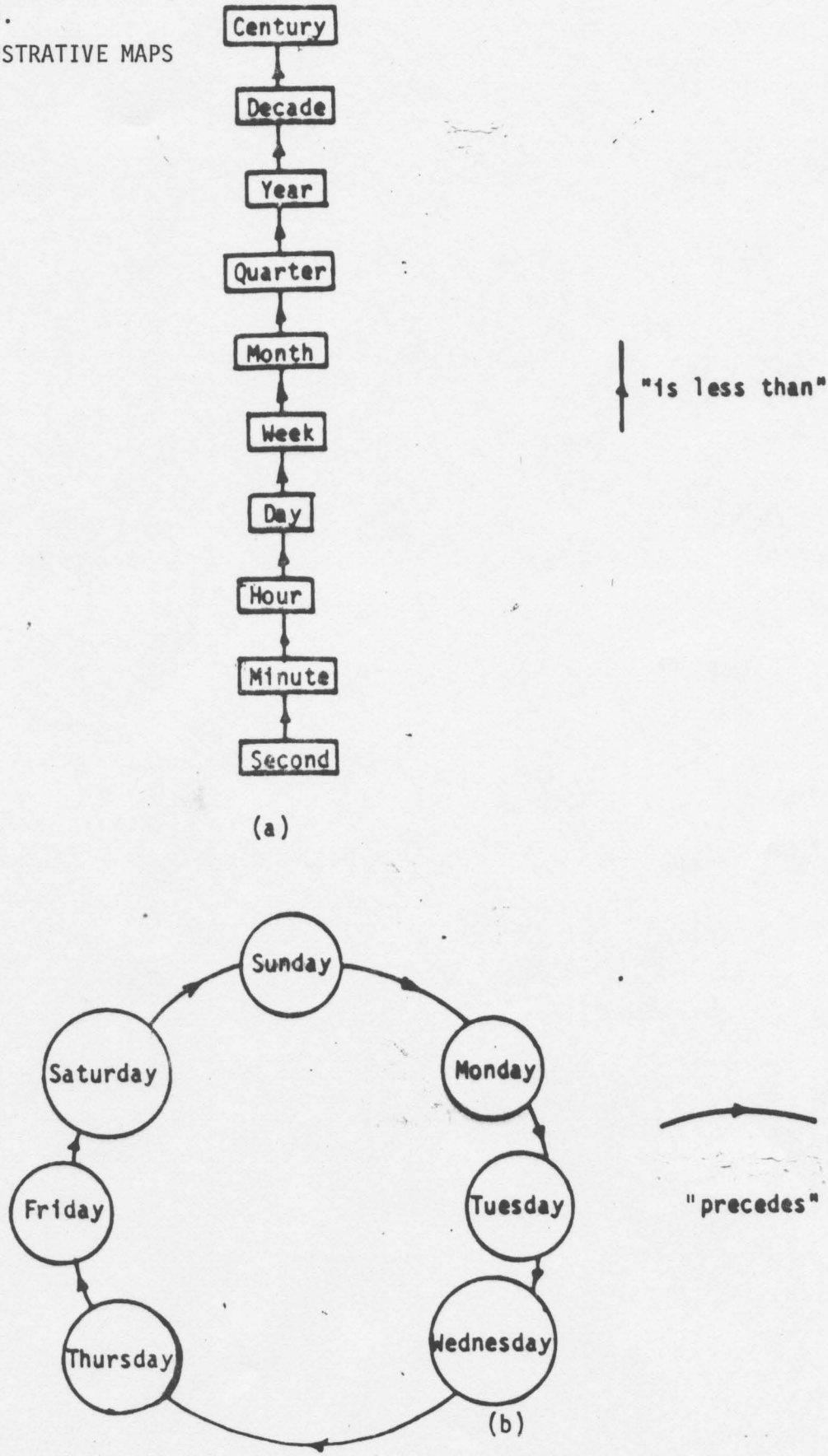
FIGURE 3. A BINARY MATRIX ARRANGED TO FACILITATE DRAWING THE CORRESPONDING MULTILEVEL MAP

FIGURE 4. DIGRAPH OF THE MATRIX SHOWN IN FIGURE 3



DIGRAPH OF MATRIX

FIGURE 5.
TWO ILLUSTRATIVE MAPS



Such maps are particularly useful when there is a large element set, and when there is a substantial amount of interrelation among the elements.

One can imagine that there are at least four competing modes for showing a large set of interrelationships. These are illustrated in Figure 6. In this Figure, one sees four different ways to say the same thing. One uses a prose sentence, one uses a "graphics sentence", one uses a set theory expression, and one uses Venn diagrams.

When there are many interrelationships, only the graphics sentence concept allows for a continuing ease of readability. The other three modes become quite difficult to interpret, especially for lay persons concerned with policymaking.

Figure 7 shows the keys to "map reading". These are easily learned, and provide the essential knowledge to use the structures that result from the ISM process.

The types of structures that can arise from the use of ISM are shown in Figure 8. We have used the ISM ideas to portray these structural types in relation to one another. The most general type of structure is the multilevel map. Others are special cases of this. A multilevel map was presented in Figure 4, and it has the property that any elements that are mutually related always lie at the same level in the multilevel map.

HISTORY

I have tried to trace some of the history of interpretive structural modeling back to its mathematical ancestors. Figure 9 shows my own classification of the history into five periods. The early period involved the development of the basic components, including graph theory, mathematical logic, and matrices. Then there was a period of mathematical development of these components, involving the work of Peirce with Boolean matrices, Whitehead and Russell with the algebra of relations, Weiner's conceptual development of the interpretation of the binary relation, and Kuratowski's interpretation of crossings in drawing graphs.

There was a period when the ideas apparently had not jelled sufficiently to be used explicitly, but were nevertheless used

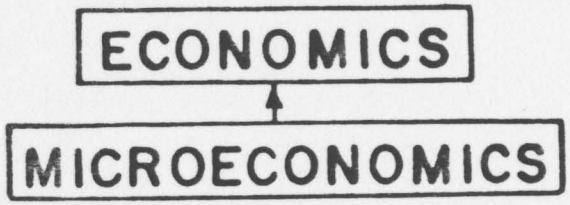
1. MICROECONOMICS IS INCLUDED IN ECONOMICS	A PROSE SENTENCE
2. 	A GRAPHICS SENTENCE
3. ECONOMICS = A MICROECONOMICS = B $B \subset A$	A SET THEORY MODEL
4. 	A VENN DIAGRAM MODEL

FIGURE 6. ALTERNATIVE WAYS TO PORTRAY A STATEMENT

FIGURE 7. KEYS TO "MAP READING"

- This little piece of structure is a "sentence" represented in graphical form:

- You can translate the graphical form into prose if you know the 3 "parts"
- The GENERAL FORM of the graphical sentence is

  A is related to B
- The arrow stands for the specific relationship

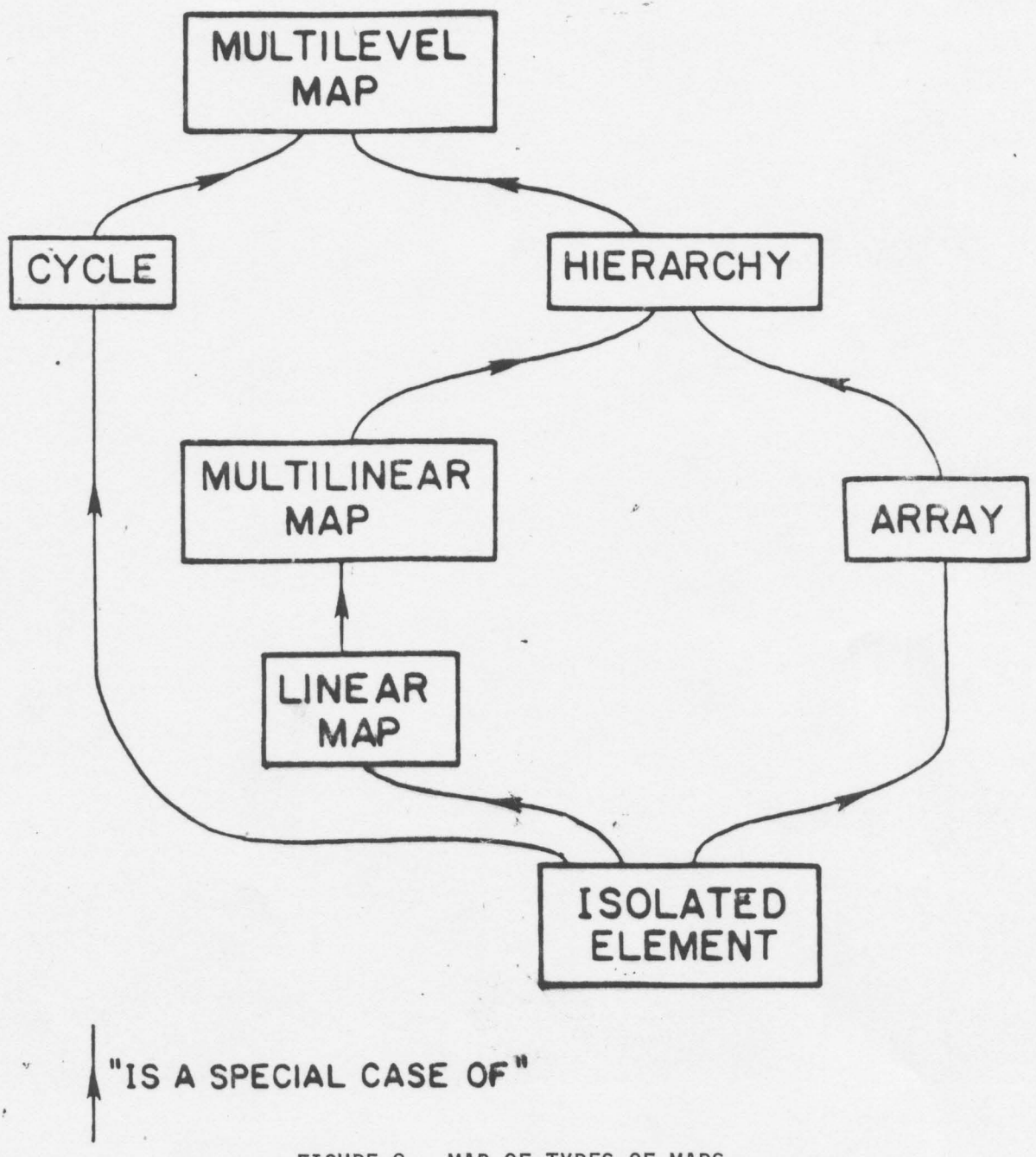


FIGURE 8. MAP OF TYPES OF MAPS

FIG. 9 PERIODS OF DEVELOPMENT AND APPLICATION OF INTERPRETIVE STRUCTURAL MODELING

1. The Early Period: Conceptions of Components (1736-1858)

   1736 - Euler - Graph Theory
   1847 - Boole - Mathematical Logic
   1858 - Cayley - Matrix

2. The Period of Mathematical Development of Components (1858-1930)

   1870 - Peirce
   1910-1913 - Whitehead and Russell
   1914 - Weiner
   1930 - Kuratowski

3. The Period of Intuitive Application (1930-1960)

   1934 - Black - Feedback Amplifier
   1938 - Shannon - Switching Theory
   1940's - Wiener - Cybernetics
   1950's - Ford and Fulkerson - Flow Problems
   1951 - Mason - Signal Flow
   1953 - Newell and Montrol - Ferromagnetism
   1957 - March and Simon - Organizations
   1958 - Churchman and Ackoff - Preference Analysis

4. The Period of Popularization (1960-1975)

   1960's - Harary
   1964 - Gore - Administrative Decision-Making
   1966 - Alexander - Architecture
   1967 - Hartmanis and Stearns - Sequential Machines

5. The Period of Widespread Application in Many Fields (1975-)

intuitively by numerous individuals concerned with various applications. This period included the development of the idea of feedback and its applications in various fields, and also it included various studies of preference in decision making.

The popularization of the use of digraph-like structures to portray rather complex phenomena began to occur in a limited way in the third period, but got a sharp impetus in the 1960's through the work of Frank Harary and others. The important idea of partitions on sets, which was useful in developing the idea of levels and descriptive subsets, was elaborated by Hartmanis and Stearns in their study of sequential machines.

All these events provided background for the development of the ISM process. The latter took place in a period of about six years, extending from 1968 through 1973. This involved a rather thorough analysis of what was necessary to allow people to work together effectively in pooling their knowledge, and what was needed to allow this pooled knowledge to be organized so that it could be portrayed and further studied and amended as needed.

THE ISM PROCESS

As presently used, the ISM process involves putting the element set into a computer, along with the selected contextual relation. The computer then poses individual questions to the group via a television screen. The group discusses each question, and arrives at a majority opinion or concensus. The group response is entered in the computer, and a new question is raised. This continues until the structure is completely defined by the set of responses. Each time a response is obtained, the computer makes inferences about other possible questions, and chooses as the next question the one that has the highest likelihood of yielding the maximum information. This cuts down substantially on the number of questions to be asked.

Inference is based on the hypothesis that the contextual relation is transitive. Some argue that this is a shortcoming of the process, and that the process should be expanded to include intransitive relations as well. Such an argument overlooks the central idea that if there is no transitivity there is seldom any reason to use a **transitive** structure (a digraph) as a fundamental basis for a model.

Also it is not at all clear that there exists a class of applications where methodology can provide significant assistance in developing a model, but where there is no transitivity to tap in the relationships among the elements of the problem.

In any case, the extensive applications that have been made of the ISM process to date, in a wide variety of fields, attest to its utility in those applications for which it was intended.

APPLICATIONS

The first application of the computer-assisted ISM process took place at the Kettering Foundation in Dayton, Ohio, in 1974. It dealt with the relationship among a set of variables having to do with the development of inner cities. Since that time, numerous applications have been made in many locations.

The Appendix to this paper lists most of the applications that have been made, and provides a bibliography of theory and applications.

Additional applications are in progress at the present time.

ISM has also been used in a way where it is coupled to other methodologies, including the nominal group technique (which is a good way to elicit the set of elements from a group, to be used later in structuring them). A videotape of one such application has been developed through The Academy for Contemporary Problems in Columbus, Ohio. This tape illustrates application to the problem of the City Council of Kent, Ohio, of reducing the municipal budget.

APPENDIX

SOME APPLICATIONS OF INTERPRETIVE STRUCTURAL MODELING

John N. Warfield

SOME APPLICATIONS OF INTERPRETIVE STRUCTURAL MODELING

John N. Warfield

INTRODUCTION

Interpretive structural modeling (ISM) was introduced in 1974 [1]. It is a learning process involving computer assistance, which makes it possible for groups of people to work together efficiently to structure their collective knowledge, preference, or insight concerning some issue of mutual interest or concern. Normally the issue is sufficiently complex that bounded rationality makes it very difficult to deal with systematically without the kind of cognitive assistance that is designed into the ISM process and facilitated by capable leadership.

Numerous applications of ISM have been made at various locations, with varied leadership. Many of these applications are identified and their salient features are reported in scattered locations, preventing easy access to the reports or results. Some of them have never been documented in the literature. Frequently the failure to document results stems from inadequate time due to the pressure under which the issue is being considered. At other times, propriety or discretion suggest that the results should not be made public, at least for a time.

There has been a need for a readily available compilation of at least some minimal descriptions of applications. This paper attempts to fill this need. Where applications are mentioned that the author has had no personal contact with, efforts have been made to assure accuracy, but if the author has made any errors in the presentation, or committed errors of omission, it is inadvertent and corrections are earnestly solicited.

CLASSIFICATION OF APPLICATIONS

Consideration has been given to ways of classifying the applications. It was felt that several different classification methods should be used, to satisfy different requirements.

Who Was Served?

The matter of who was served by the application of ISM is important as a means of identifying the particular application, since this is one of the few ways of uniquely specifying an application. In all but a very few of the applications, it is possible to identify who was served. In those cases where it is not possible to identify them (in this paper), the reason is in every case one of industrial proprietary considerations.

Usually the answer to "who was served?" can be given as an organization, although for practical purposes it may have been just a few people within the organization. In general, this question is answered according to who considered the issue being explored to be of particular importance to them.

Kind of Structure?

Structures are usually classified according to the nature of the contextual relation among the elements being structured [2]. The general rule is to do so unless clarity is enhanced by disregarding this mode of classification. Most applications lend themselves to this kind of description.

Kind of Organization

While the identification of who was served partly defines circumstances under which the application took place, it is thought that it is also helpful to identify the kind of organization that is involved. Usually this is identified as either a government agency at the federal, regional, state, or local level, or as a corporation or university. Occasionally the exercise involves only a temporary group brought together for some particular purpose.

Theme of Exercise

The applications may often be classified according to the theme of the exercise. This description usually discusses what was important to the participants, i.e., what was the topic that was being structured.

How the Elements Were Obtained

The mode of obtaining the elements that were chosen as the basis for the ISM process is often of interest. However it is not always known how the elements were obtained. Three common ways of arriving at elements are (a) brainwriting [2], (b) nominal group technique [3], and (c) content analysis of written material.

While many would also be interested in knowing how the contextual relation was chosen, there are no well-identified, standard ways of choosing a contextual relation. One could categorize the applications according to which specific contextual relation was used, but it is not clear that this would have any special merit.

TABULATING THE APPLICATIONS

The applications have been tabulated, as shown in Table 1. The classifications mentioned in the preceding section have been used for the tabulation. Where a question mark appears in the Table, it signifies that the information is not available to the author. Many of the applications did not involve the author personally, and have become known to the author by a variety of means, including correspondence, conference publications, reports available to a very limited distribution, or conversation accompanied by a partial written description.

The question of whether to mention names of the persons involved in each application was decided in the negative. However in deference to this decision, the alternative was selected of presenting a bibliography for each application for those instances where something is accessible in print from a known source that relates to the application.

TABLE 1

APPLICATIONS OF INTERPRETIVE STRUCTURAL MODELING

WHO WAS SERVED?	KIND OF STRUCTURE?	KIND OF ORGANIZATION?	THEME OF EXERCISE	ORIGIN OF ELEMENTS	REFERENCE(S)
A Board of the U.S. National Research Council	Intent Structure	Quasi-Federal	Engineering Manpower Education and Policy	Content Analysis	
Office of Environmental Education, Department of Health, Education, and Welfare	Intent Structure	Federal	Objectives of the Office	Content Analysis of Laws and Regulations	
Areawide Planning Districts in Louisiana	Intent Structure	State	Objectives for future development	Brainwriting	[4,5]
Rapides Area Planning Commission in Louisiana	Intent Structure	Regional	Transportation Planning	Unknown	[5]
Central Ohio Transit Authority	Intent Structure	Local	Transportation Planning	Brainwriting	
Franklin University	Intent Structure	University	Objectives of the University	Brainwriting	
Humanities Department, University of Virginia	Intent Structure	University Department	Objectives of the Department	?	

TABLE 1 (CONTINUED)

WHO WAS SERVED?	KIND OF STRUCTURE?	KIND OF ORGANIZATION?	THEME OF EXERCISE	ORIGIN OF ELEMENTS	REFERENCE(S)
U. S. Department of Interior, Office of Coal Technology	Intent Structure	Federal	Objectives for Fossil Fuel R&D Program	?	
State of Ohio Environmental Protection Agency	Intent Structure	State	Objectives set forth in legislation	Content Analysis of Legislation	[6]
Urban Roundtable	Intent Structure	Temporary	National Urban Policy	Brainwriting	
Battelle Institute Development	Intent Structure	Not-for-Profit Institute	Staff Development	?	[7]
Sociology	Intent Structure	Discipline	Objectives of sociology	Content Analysis	[8]
Cedar Falls, Ia. City Council	Priority Structure	Local Government	Priorities on projects in city 5-year plan	Selected by City Council	[9]
Kent, Ohio City Council	Priority Structure	Local Government	Budget cutting priorities	Selected by City Council	
Neighborhood Group of Citizens	Priority Structure	Temporary	Ways to make the neighborhood safer	?	

TABLE 1 (CONTINUED)

WHO WAS SERVED?	KIND OF STRUCTURE?	KIND OF ORGANIZATION?	THEME OF EXERCISE	ORIGIN OF ELEMENTS	REFERENCE(S)
Mexican Peasants	Priority Structure	Temporary	Barriers to transfer of methane generator technology	Mexican Peasants	[10]
Corporation	Priority Structure	Private	Relative desirability of transportation projects	Brainwriting	
Australian Education System	Priority Structure	State	Activities for in-service teacher training	Questionnaire	[11]
Louisiana Planning Office	Priority Structure	State	Coastal Zone Management	?	[5]
Office of Science, Technology, and Environmental Policy, State of Louisiana	Priority Structure	State	Obstacles to Investment in LANDSAT (satellite) Access System	?	[5]
Chromalloy Corporation	Priority Structure	Corporation	Future markets	?	[5]
PLANALSUCAR, Brazilian Planning Agency	Priority structure	Federal	Agency activities	Brainwriting	[12]
Urban Studies Institute, State of Louisiana	Priority Structure	State	Energy resources	?	[5]

TABLE 1 (CONTINUED)

WHO WAS SERVED?	KIND OF STRUCTURE?	KIND OF ORGANIZATION?	THEME OF EXERCISE	ORIGIN OF ELEMENTS	REFERENCE(S)
Dayton, Ohio City Planning Commission	Priority Structure	Local	Factors in the improvement of Dayton	?	
Grantees of the National Science Foundation	Enhancement Structure	Temporary	Factors in enhancing technology assessment	Questionnaire	[13]
Corporation	Enhancement Structure	Corporation	Factors that enhance the forecasting and quality of technical accomplishments in product development programs	?	
Indefinite	Enhancement Structure	Research Team	Factors enhancing the renovation of the Sahel region of Africa	?	[14/15]
Interagency Futures Research Committee	Enhancement Structure	Federal	Societal trends affecting the future of American governance	?	
Corporation	Process Model	Corporation	Planning procedure for development of a system	?	
Students at Univ. of Queensland, Australia	Process Model	University	Structured course for self-paced learning of FORTRAN IV computer language	?	
Office of Environmental Education Dept. of HEW	Normative Process Model	Federal	Environmental Education System	Content Analysis	[16]

TABLE 1 (CONTINUED)

WHO WAS SERVED?	KIND OF STRUCTURE?	KIND OF ORGANIZATION?	THEME OF EXERCISE	ORIGIN OF ELEMENTS	REFERENCE(S)
Modelers	Mathematical Interdependence Structure	Disciplinary	Understanding and solving econometric models	Content Analysis	[17]
Teachers	Intensity Structure	Education	Relative intensity of learning disabilities in individual children	Theory of learning disability	[18]
High School Students	Energy Flow Structure, Preference Structure	High School	Food Web, Relative Quality of Life in Developing Nations	?	
U. S. Coast Guard	Enhancement Structure	Federal	Improving personnel practices	Nominal Group Technique, used by participants	

COMMENTS

This paper has been prepared for persons who are already knowledgeable about the ISM process, but are not aware of the various applications. Other readers who may be interested in the process will find references in the literature. To serve all readers, a bibliography is appended that was prepared for another purpose. This bibliography includes the references mentioned in this paper, along with other references to applications not mentioned in the paper, and also includes references to the theory of the process.

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