LINGUISTIC ASPECTS OF MAPS AND GEOGRAPHIC INFORMATION

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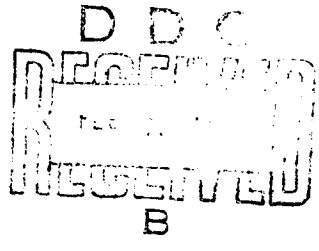

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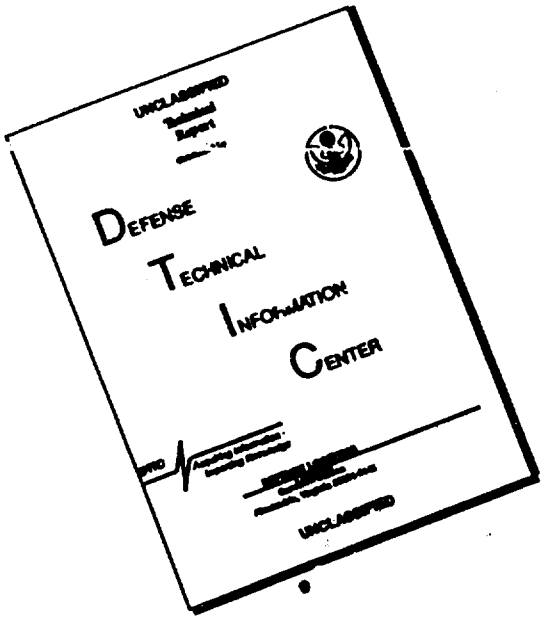

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LINGUISTIC ASPECTS OF MAPS AND GEOGRAPHIC INFORMATION

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ABSTRACT

The frequent reference by geographers and cartographers to "the language of maps" is made precise by clarifying ways in which maps and other formulations of geographic information constitute a language. Aspects of this language are identified, and emphasis is placed on the use of linguistic concepts for study of models of geographic information that are treated as components of a geographic information system. Some linguistic methods suitable for processing geographic information are identified and the selection of references provides a guide to the appropriate literature. Brief mention is made of some fundamental methodological and conceptual issues that have been resolved in completed and forthcoming journal articles.

INTRODUCTION

Though the making and use of maps is an old and highly skilled art, the formal study of maps and other cartographic models for storage and communication of geographic information has only recently attracted the interest of cartographers and geographers. The recent emphasis on automated methods for data processing and pattern analysis provides an impetus and motivation for formal investigations of the properties and structure of cartographic models that manipulate and communicate geographic information. Though there is an extensive literature on the design, construction and interpretation of maps, the cartographic literature has failed to develop concepts relevant to the design and operation of an information system capable of compilation, storage, selection, retrieval and analysis of locative and other geographic data. The purpose of this study is to identify a methodological framework that facilitates the description and analysis of properties of both geographic information and the models that express this information. The fundamental premise of this methodology is that there are special languages for manipulation and communication of geographic information, but the description and analysis of these languages may use profitably the concepts, tools and methods developed by linguists and logicians for study of a wide variety of natural and artificial languages.

The notion that maps comprise a language is not novel. While Ackermann [1957] is only one of many geographers to adopt this conceptualization of maps, his expression of this observation is particularly clear.

> There are four basic ways in which men communicate with one another.... Music is one, words another, numbers still another and finally what we might call graphic portrayal. Thus there is a language of words; there is a language of numbers or mathematics; and in a sense there is a language of graphic portrayal which includes sketching, photography, the architectural or engineering plan, and maps.... The map is a most important instrument of graphic portrayal.

Though the concept of language is not clarified in this and similar statements, the juxtaposition with the natural language of words and the artificial language of logic

and mathematics suggests the implication that maps have a structure that may be formulated as a linguistic system. Bunge [1968] and Harvey [1969] reach a similar conclusion.

My objective is to go beyond the bare observation that maps have a linguistic basis to clarify some of the ways in which maps and other formulations of geographic information constitute a language and then indicate how a linguistic approach contributes to description and analysis of the information content of a geographic information system.

MAPS AND GEOGRAPHIC INFORMATION SYSTEMS

For the present purposes it is adequate to view a geographic information system as any thing that functions like a map in communicating geographically ordered information to users of the system. A highly flexible geographic information system, designed to respond to a wide variety of user needs, has been partitioned by Thomas [1967] into the six component subsystems of data collection, data processing, archival and storage, communication and feedback, planning and control, and user. Though a formal discussion requires rather precise definitions of these subsystems and of geographically ordered information, for the present exploratory purposes it is more critical to amplify the implications of this functional definition. The interest is on things that function like a map because textual material and systems of equations, as well as sketches and drawings, communicate information about location and a wide variety of areal relations. When the stress is put on geographic information and its communication to users of the system, the structural parameters of elements of the system are significantly less critical considerations than the manner in which these elements contribute to the communication function. It is at this level that linguistic concepts are appropriate because they take into account the meaning of geographic information but are largely unaffected by the structure and form of alternative symbolic expressions of geographic information.

A functional approach is a departure from the classical study of maps that emphasizes structural properties of map symbols in terms of the selection of a projection, symbols and colors and the psychological effects upon map users of these and other structural attributes. Dornbach [1967] establishes the deficiencies in treating the map as a collection of isolated design problems and argues effectively the need to treat the map and the user as integral parts of an information system requiring that the geographer study the use-situation in its entirety. By requiring that maps satisfy user needs, Dornbach concludes that a map is an information system that must be functionally designed, and the design objectives are a map that transmits a specific set of facts to a specific community of users. It follows that the map of greatest value is one that approximates a one-to-one relationship with its visual schemata rather than with the earth's surface.

The stress upon effective communication by visual displays is largely a consequence of Dornbach's interest in a rigidly fixed system that provides a map of specified geographic information to a specified community of users. The more general situation, however, concerns an information system that provides a wider variety of geographic information to a more diverse group of users. While the design of maps that communicate geographic information to users remains an element of this more versatile, more flexible system, it is not possible either to ignore problems associated with the storage and processing subsystems or to assume that communication of geographic information is restricted to the map format. These subsystems, along with the user subsystem, involve high levels of handling and manipulation of geographic information. There is the transmittal and transformation of information within and between internal subsystems as well as communication with the users that provide and extract geographic information. Since, by definition, all communication is by languages, identification of the functions and properties of these languages is prerequisite to the successful design of a geographic information system.

While appropriate linguistic structures will encompass the language of maps, by focusing interest in things that function like maps, the need is for a methodology and concepts that are sufficiently general to permit description and analysis of varying types and forms of expressions of geographic information. The advantages that accrue from considering the handling and communication of this information within a system framework is that general systems theory provides criteria for examining the nature and value of information and for evaluating the performance properties and organizational components of the structure which contains and uses the information.

CONCEPT OF LANGUAGE

A *sign* is the smallest unit that *designates*, and that which is pointed out is called the *designation* of the sign. A *sign process* is an arrangement of signs that designates some thing. *Language* is an institutionalized collection of signs that have common designations to members of the community using these signs. The signs are produceable by members of this community and they may be combined in some ways, but not in other ways, to obtain sign processes which also have a common designation to the users.

Concepts and methods appropriate for the study of languages are provided by *semiotic*, the general theory of signs developed by Morris [1955], and its three major fields: *symbolic logic* - the study of formal and mathematical languages, *linguistics* - the study of communication between men, and *cybernetics* - the study of communication between man and machine or between machines. The dyadic relations between sign, designation and user subdivide these fields into three major divisions.

Pragmatics studies the relations between signs and users. This largely empirical field emphasizes the origin, uses and effects of signs in processes of communication.

Semantics studies the relations between signs and the designations of signs. The description or construction of a semantic system involves (a) classification of signs, (b) specification of rules of designation, (c) listing of rules of formation that

govern the arrangements of signs that may occur in sign processes, and (d) identification of rules of truth that establish when a sign process is true.

Syntactics studies the formal relations between signs by abstracting signs from both users and designations. The formulation of a syntactic calculus uses a classification of signs for the identification of *formation rules* that determine the permissible arrangements of signs, and these permissible sign processes are called *expressions* of the calculus. The syntactic calculus also identifies *transformation rules* that determine expressions that are logical consequences of other expressions.

The specification of a geographic information system incorporates pragmatic, semantic and syntactic dimensions of the languages used for communication between subsystems, for manipulation of geographic information within subsystems and for control of the entire system. Semiotic does not, however, identify many of the linguistic concepts that are prerequisite to handling, communicating and displaying geographic information. These limitations are not surprising; while this theory has been developed largely for sign processes composed of a serial arrangement of signs, such as natural language or the formal languages of logic and mathematics, sign processes that designate geographic information, such as maps and other cartographic models, do not restrict signs to a serial order. If a cartographic model utilizes a language, in the sense that it seems to make use of such basic linguistic concepts as sign, expression and syntax, the language clearly differs in quite important respects from conventional languages. Its distinguishing properties include the concepts of neighborhood and juxtaposition, which are not simple generalizations of the concatenation of conventional linguistic structure. While the serial order of language is commonly contained within the ordering concepts of 'before' and 'after,' the ordering of map symbols is multidirectional. Though the many similarities between the structures of maps and languages may suggest that cartographic models utilize a language that may be studied in terms of language concepts, at the same time the basic differences suggest that cartographic models are based upon a language

whose structure can be organized only by concepts of order that are more elaborate than 'before' and 'after.' The structure that holds between and among map symbols of a cartographic model is called a two dimensional language.

It must be emphasized that the language of maps is only one linguistic component of a geographic information system. In addition to a language for the generation and analysis of maps, there is need for a textual or discoursive language allowing for discussion of aspects of maps. These aspects include description of relations between maps or parts of a map, commands for manipulation on maps and queries about map properties. Dacey [1967] considers elements of a discoursive language for spatial relations and Narasimhan [1969] has an interesting examination of these two linguistic components for interaction and adaptive systems dealing with visual data.

TWO DIMENSIONAL LANGUAGES

Whether storage and manipulation is in terms of numeric or alphabetic symbols or in terms of stylized map symbols, the domain of geographic information is inherently two dimensional and a geographic information system must be able to handle, describe, interpret and, probably, analyze this two dimensional structure. A two dimensional structure does not necessarily require a two dimensional method of analysis, though it is rather firmly established that conventional approaches fail to give acceptable solutions to many two dimensional problems. For example, Unger [1958] notes that "...there are certain tasks, which might be termed spatial problems, at which digital computers are relatively inept.... Pattern recognition is another area in which present-day machines cannot match the performance of the designers." While the study of two dimensional data sets may simply require bigger and faster machines, a premise of my research effort is that the analysis of the two dimensional structure of geographic information requires the development of two dimensional languages.

The notion of a two dimensional language needs to be clarified. The basic units of the language are signs, and an allowable arrangement of signs constitutes an expression in that language. Two dimensional languages are distinguished by reference

to the ordering concepts of before, between and after: a language is called two dimensional when the arrangement of signs is such that, given the locations of two signs, the location of a third sign in the expression is not accurately described as before, between or after the two given signs. That is, the locations of the signs in an expression of a two dimensional language do not exhibit the characteristic serial ordering of all ordinary and most formal languages; instead, the locations have a multidirectional ordering in a two dimensional space. An expression in a two dimensional language is called a picture or figure. A map is a collection of particular kinds of pictures.

The need for two dimensional languages has been recognized by other workers concerned with description and analysis of a wide variety of pictorial sources. Narasimhan [1964] forcefully stated the case that arises in the general problem of pattern recognition:

> ...it is much more appropriate to view the so-called pattern recognition problem as really the problem of pattern analysis and description, and emphasize that the aim of any adequate recognition procedure should not be merely to arrive at a "yes," "no," or "don't know" decision but to produce a structured description of the input picture. It is our contention that no model can hope to accomplish this in any satisfactory way unless it has built into it, in some sense, a generative grammar for the class of patterns it is set up to analyze and recognize.

The need for two dimensional languages has been recognized by workers in several diverse areas, including studies of bubble chamber photographs (McCormick and Narasimhan [1962]), schematics and diagrams in patent applications (Kirsch [1964]), images of cells and neurons (Ledley [1966]), while my work is motivated by maps and returns from remote sensors. Because of basic similarities in the structure of these two dimensional sources, the recognition of a similar method of analysis is probably not surprising.

Though there is considerable interest in linguistic analysis of pictorial sources, it has proven more difficult actually to construct such a language than to argue the

need. One model available for descriptive analysis of two dimensional languages is an extension of the context-free, phrase structure language or immediate constituent analysis developed, primarily, by Chomsky [1962, 1965] for syntactic description of languages having a serial structure. The application of this model to two dimensional languages requires construction of a set of rules that generates an arrangement of signs that forms a picture. The syntactic description of the language identifies the formation rules that govern the arrangement of signs that form pictures in the language and the transformation rules that give the conditions under which one or more pictures may be transformed into other pictures.

This model has recently been used to construct several languages that permit syntactic analysis of pictures, but the descriptive schemes are usually linear, as with the languages surveyed by Miller and Shaw [1968], and thereby restricted to line pictures and graphs. An exception is the language developed by Kirsch [1964] for syntactic description of triangles. Dacey [1970] extended the domain of this language to a wider variety of polygonal figures, while the two dimensional language in Dacey [1971a] includes formation and simple transformation rules for a class of polygons that can be decomposed into non-overlapping right triangles and rectangles.

These applications establish the use of two-dimensional languages to construct pictures. Because these are pictures of a single object or a collection of independently generated objects, these applications fail to indicate the ways in which two-dimensional languages facilitate the syntactic analysis of patterns and compages that comprise maps and other displays of geographic information. A fundamental step in this direction is the construction by Dacey [1971c] of a two-dimensional language which will generate the classical patterns on a strip, as they are defined, Coxeter [1961], in the geometric study of pattern. In principle, this basic language can be extended to generate the classical, two-dimensional crystallographic patterns, though the statement of the language would be quite complex. The important aspect of Dacey's language for strip patterns is the

demonstration that nontrivial patterns can be generated by a two-dimensional language. While strip patterns are exceedingly simple relative to the patterns displayed on even the most bland map, it has been established that two-dimensional languages permit the syntactic analysis of pictures composed of structurally related objects.

At this very early stage of development, it is difficult to assess the significance and intrinsic merit of the available languages. In fact, Clowes [1969] contends that these languages should be regarded as a variety of "two-dimensional" Turing machine rather than as a grammar. However, Betak [1971] has shown that Dacey's language for simple polygons is a grammar in the sense of context-free grammars defined by Miller and Chomsky [1963]. This means that the conventional theory of languages subsumes the two-dimensional picture languages, and has the important consequence that many basic concepts of conventional, serial language may be adapted to the study of two-dimensional languages. As one step in this direction, Betak [1970] has used syntactic measures of complexity to analyze the two-dimensional complexity of the linguistic models for polygons.

RESEARCH OBJECTIVES AND ACCOMPLISHMENTS

It is useful to distinguish two classes of problems that confront the continued development of two-dimensional languages and their adaptation to the needs of geographic information systems. One class of problems was initially identified by Kirsch [1964] in the context of syntactic analysis of pictures. These problems involve the development of concepts and procedures appropriate for the definition of picture primitives, the expression of picture syntax, the generalization of the notion of concatenation to two dimensions, the manner of describing spatial relations that obtain between expressions that are components of complex pictures and, probably the most critical problem, the procedures for conducting syntactic analysis of pictures. Currently completed research has been primarily directed to this

class of problems. The studies by Dacey [1970, 1971a] provide partial solutions to problems involving the expression of picture syntax within a linguistic context and the two-dimensional generalization of the notion of concatenation. Although less progress has been achieved, the studies by Dacey [1971c] and Betak [1970, 1971] provide methods for the description of the spatial relations that obtain between components of complex pictures and, at an admittedly elementary level, identify procedures appropriate for conducting syntactic analysis of pictures.

The other class of problems concern, at one level, the semantic and syntactic properties of geographic information and, at another level, the manner of conducting syntactic analysis of maps and other displays of geographic information. While Thomas [1967] and Dacey [1967, 1971c] structured these aspects of geographic information within the context of a geographic information system, the attempts have not been notably successful. A somewhat more successful formulation is described in a forthcoming study by Dacey [1971d] that treats the use of maps and map information in the context of an adaptive, interactive geographic information system that is a specialization of Narasimhan's [1969] broadly defined information system. This study largely concerns the adaptation of linguistic principles to the structure of an information system but the emphasis is upon general theoretical principles rather than operational details.

It is difficult to evaluate the merits and utility of the completed research. It is clear that present theoretical work is far removed from the practical task of designing operating systems that are capable of providing structured descriptions of the pictorial information displayed on even the simplest of maps. In this sense, the completed research has failed in the initially identified objectives of constructing a two-dimensional syntax having a sufficiently rich structure to permit the performance of basic operations on simplified maps and charts, such as producing one map from another by changing the scale or to produce a map containing a specified class of geographic information from a larger body of information.

One possible explanation for this failure is that a linguistic approach is inappropriate to the study of the geographic information contained on maps. In this case, there is need to reexamine the basic conceptual approach and search for more productive ways to approach the study of maps and map structure. An alternative explanation is that the initially stated objectives were overly ambitious and failed to recognize the extreme logical and linguistic problems that confront the development of two-dimensional language structures. This latter explanation is accepted for several reasons. While progress has been slow, the current research effort has not produced negative evidence that casts doubt upon the validity of the motivating principles enunciated in the first pages of this report. Also, neither the present work nor other published studies have indicated discovery of more promising or potentially more productive approaches to the study of either pictorial or map information. Moreover, as already indicated, the research of the past year has yielded positive results that hold promise of eventual adaptation to map structures. As contributions to this objective, the present work has constructed languages that are capable of producing pictures of objects and pictures of objects that form well defined patterns. In addition, the feasibility of conducting syntactic analysis of these languages was demonstrated.

SUMMARY

To summarize, the following are the major results obtained from the current research effort.

Dacey's [1970] language for polygons was substantially modified by Dacey [1971a] so as to identify a relatively simple two-dimensional language that has the capability of producing pictures of polygons having highly complex configurations.

It was shown by Betak [1971] that the polygonal languages satisfy the conditions of a context-free grammar. Moreover, it was established that it is possible to conduct a syntactic analysis of these languages that is capable of yielding measures

of their two-dimensional complexity.

The basic linguistic structure of the polygonal languages was adapted by Dacey [1971c] as the basis for a language that is capable of producing any pattern defined by the periodic repetition of a motif along a strip, and the structure of this language is sufficiently rich that it could be adapted to the generation of any pattern that is obtained by the periodic repetition of a motif in two-dimensional space.

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13. ABSTRACT

The frequent reference by geographers and cartographers to "the language of maps" is made precise by clarifying ways in which maps and other formulations of geographic information constitute a language. Aspects of this language are identified, and emphasis is placed on the use of linguistic concepts for study of models of geographic information that are treated as components of a geographic information system. Some linguistic methods suitable for processing geographic information are identified and the selection of references provides a guide to the appropriate literature. Brief mention is made of some fundamental methodological and conceptual issues that have been resolved in completed and forthcoming journal articles.