A COMMUNICATION MODEL FOR THE DESIGN OF A COMPUTER-ASSISTED CARTOGRAPHIC SYSTEM

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ABSTRACT

This paper explores some fundamental considerations for the design of a general, computer-assisted cartographic system. While many researchers have examined how to convey environmental models by means of maps, little is known about the cartographer as percipient of the variety of source used in cartography today or of how that input is transformed into the cartographer's product. The input differs in significant ways from traditional source and from the map the cartographer is making. The paper addresses capabilities which might be used to support a cartographer developing a map or chart using a variety of source materials and computer assistance.

In order to prescribe design options and system capabilities for computer-assisted cartographic systems, we must better understand how a cartographer develops his or her own model of the environment and of the information to be represented, along with the processes she or he uses to transform the model into a product. Such information must inform our specification of retrieval, manipulation, display, storage, and data representation facilities that are needed in computer-assisted cartographic systems and of the ways those capabilities must interact. The paper presents a model for looking at the cartographer at work and discusses considerations for the design of a computer-assisted cartographic system.

INTRODUCTION

Computer technology is changing the cartographer's work environment in several significant ways. Cartographers are making new kinds of products which may be used by other cartographers or by "user systems" such as planning support systems, simulators and automatic piloting devices. As technology enables users to exploit more accurate and precise information, their requirements are becoming more stringent. Cartographers are using new tools in order to respond to such requirements. Computers afford capabilities for making more accurate and precise products as dictated by user requirements. With increasingly demanding currency requirements, we can foresee the time when some classes of maps will require updates based on real-time analysis of new data. Such a requirement will also require perusal of large volumes of source materials in very short times.

Cartographers are employing a widening range of source materials, including such materials as new kinds of soft copy maps and imagery, data bases of textual information, such as surveyors' field notes, and digital data bases of terrain, cultural, and landscape features.

Automated systems are performing many mechanical tasks, such as drawing grids and contour lines, that currently occupy large amounts of the cartographer's time. In addition to allowing the cartographer to focus on product content, such systems have the advantage of permitting cartographers to preview and edit the results prior to plotting. Computers make available means of viewing and manipulating source materials and intermediate products in ways that were heretofore impractical or impossible.

In this paper we address ways of expanding computer assistance to cartographers to support the higher order cognitive activities that a cartographer must perform. Such capabilities will permit development and maintenance of higher quality products with decreased production time.

FOCUS

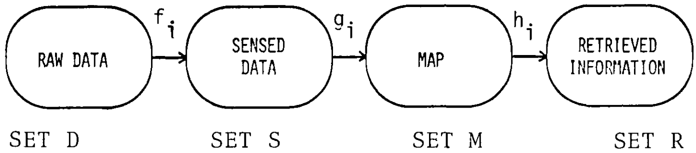
We are interested in the making of reference maps in a production environment in which professional cartographers design new product lines as well as designing and constructing maps to specification. In such an environment a single instance of the production process may result in multiple products or in inputs to multiple products.

We see the cartographic process consisting of two related kinds of mental and physical activities. In this paper we refer to them as the generation and selection of information content, e.g. the name and location of a city, and the portrayal or representation of that content, e.g., the symbol used to locate a city and the typography used for its name. The portrayal part of cartography has been studied in considerable detail. Portrayal consists of selecting the most appropriate means of depicting information as well as of implementing the portrayal of specific facts. In the past, much of the cartographer's craft has consisted of meticulous execution of essentially mechanical actions to depict information. Technology now affords automated support for some of the more mechanical tasks. It affords considerably less for the other part of the cartographer's job, the generation and selection of information and the construction of new knowledge. Such activities are being increasingly recognized as an important part of cartography. Reasons for such a change of emphasis include the relegation of some portrayal tasks to automated systems, increasing demands for completeness and timeliness, increasing volumes of available, often conflicting, source inputs, and the absence of direct experience by the cartographer of the milieu to be portrayed.

We submit that cartography as a discipline is becoming more oriented toward comprehending, evaluating and assimilating information, and synthesizing new knowledge, thus more of a cognitive activity than ever before. As a consequence, we would expect to see changes in the education of future cartographers and changes in the tools available to the cartographer.

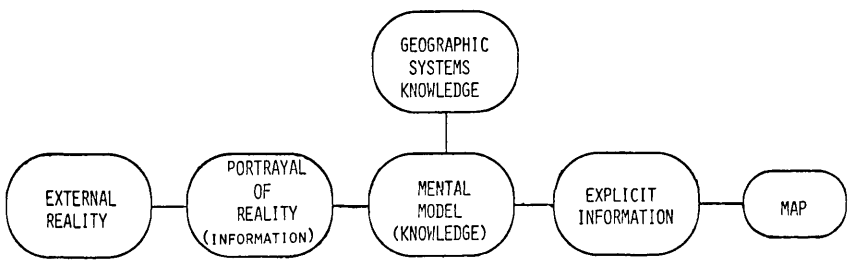
MODELS OF CARTOGRAPHY AS COMMUNICATION

A widely accepted model of the cartographer's system looks something like the one below. (We have adapted this model from Morrison (1978)).



According to the model the cartographer serves as a mediator between reality and the map user. The cartographer's role in the traditional model is often defined to be that of transmitter of information. We want to explore in greater detail the relationships of sets D, S, M, and functions f_i and g_i.

We propose a model in which nodes correspond to information objects and arcs represent mental or physical processes. The cartographer is the agent directing information flow and the generator of new or transformed information.



The node labelled "External Reality" corresponds to the milieu the cartographer's product is intended to represent. The node labelled "Portrayal of Reality" corresponds to the information available in materials the cartographer uses as input.

The cartographer brings to this task a body of knowledge about systems in the world at large. Cartographers deal with ecological systems, economic systems, transportation systems, drainage systems, cultural systems and many others. In order to evaluate information for correctness and for relevance to the intended use and to determine the optimal portrayal of the information in the final product, cartographers must consider the interdependencies among system components. In this paper we refer to such knowledge as "Geographic Systems Knowledge."

The cartographer's "Mental Model" of the milieu of interest includes an ever-expanding body of "unformulated" or tacit knowledge (Robinson and Petchenik, 1976). Drawing upon the work of Polany and others, they define tacit knowledge as "the nonverbal, non-imaged conception of meaning. . .which is held to be true and known." Such knowledge acts as a transformer and as a filter for all perceptions and externalizations by the cartographer.

The cartographer articulates explicit statements of portions of the mental model, which can be examined, manipulated and revised, either alone or in conjunction with other "Explicit Information". The actions result in an expanded and revised body of tacit knowledge as well as in a growing body of externalized information.

There are various categories of explicit information. They include imprecise information that constitutes a skeleton to which new information is added. It can be made more precise without requiring a major revision of one's tacit knowledge. One example of such information is a rough sketch of the most pronounced geographic features of an area. The second kind of explicit information is information about something that has a relatively broad scope of influence, such as general information about climate or density of population, or changes that have affected a large part of an area, for example, information that was once cultivated is being allowed to revert to wilderness or that an area is recently developed for a particular use. Another kind of explicit knowledge is detail, which is distinguished by its relatively small impact on the total area as known to the percipient.

Finally, we would like to mention the susceptibility to change of an isolated "piece" of information, as another criterion for categorizing explicit knowledge. Susceptibility to change depends upon various things, particularly the source of data and its impact on the percipient's overall sense of the area. Control is a kind of explicit information that is not very susceptible to change, as is information about the general direction of flow of a river. On the other hand, conflicting data that are extracted or derived from different sources are highly susceptible to change and interpretation by the cartographer. In fact, the "revision" of such data to be consistent with less changeable information is a significant part of the cartographer's job. Explicit information may be either spatial or logical-mathematical in character. It may be stored in any number of forms, residing in the cartographer's mind or externalized in any number of ways.

"Map" represents the end products of the cartographer's activity, a subset of the body of the cartographer-generated explicit information. The selection and extraction processes are inevitably influenced by the cartographer's tacit knowledge (Robinson and Petchenik, 1976) as may be all of the activities that result in the portrayal of the information. The portrayal process, however, is outside the scope of this paper.

The model delineates the types of knowledge and information cartographers deal with. Computer systems that store, manipulate, inter-relate, and display such classes of information can be powerful tools for the next generation of cartographers. The benefits cartographers realize from such systems will also depend on the power and appropriateness of the interfaces available to the cartographer.

The processes represented by the arcs in our model, are less well understood than the types of information discussed above; however, there is research on cognition and related subjects which might help us understand the processes involved.

ROLES FOR COMPUTERS

Computers can help cartographers utilize the information and knowledge identified in the model above. We now explore some examples of the assistance computer systems might provide. A better understanding of the mental operations used to construct a mental model and the body of explicit information from which the final product is extracted will no doubt result in definition of operators that have not yet been proposed for automated systems.

The ability of an automated system to portray reality is limited by the kinds of data it can store. There are today a variety of kinds of systems for storing various kinds of digital data, including cellular data, linear data, and character data. Cellular data includes single and multiple related frame imagery and raster-scanned maps,digital elevation data and surrogate travel. Linear data includes digital representations of features, such as roads, rivers, boundaries, with assoicated length and direction. Character data ranges from free form text data bases to highly structured data bases, which may include much descriptive information about data stored in other formats. Most systems in operation today utilize only one of the kinds of data listed above; moreover, the data must be in a system or sensor specific physical schema and in a system-imposed logical schema. More advanced systems will be able to store multiple kinds of data (Hagan, 1982), and perhaps to select and retrieve non-digital data such as microfiche.

The choice of source materials available to the cartographer is limited by our ability to move data from one system to another. Standard data formats and standard data structures enhance the economic feasibility of doing so. The National Committee for Digital Cartographic Data Standards is addressing standards for spatial data. Other standards activities, such as those of ANSI/SPARC and the International Standards Organization are working on other standards issues.

The ability to store data is only useful when the relevant source can be readily identified, selected and retrieved. It is currently too expensive to index source materials manually. Automated indexing capabilities require the ability for the system to derive and encode attributes of imagery and other source materials. Decision aids to support source selection can be extended beyond boolean algebra and text search capabilities to include heuristics. Sophisticated decision support systems that incorporate heuristic search are becoming available to other professional groups and warrant investigation for their applicability to the source selection problem.

The cartographer's mental model consists of both tacit and explicit knowledge. A cartographer constructs a mental model on the basis of his or her own organization and manipulation of various information inputs. A computer assisted cartographic system can make available a variety of operations to view, rearrange, and transform information. The cartographer must be able to use such operations in a manner that fits his own cognitive style. As the cartographer performs different kinds of mental activities at different times during construction of the mental model, he/she may use different kinds of assistance. Construction of the mental model depends upon availability of source materials that are not used for direct transfer of data to a working manuscript. Such materials may present a broader view of the area or a more detailed depiction than the final product.

There is evidence that people tend to form a holistic first impression of anything new before examining details. A cartographer starting production of a large-scale map, for example, may look at a small scale map in order to get a feel for the area. Other capabilities to support construction of the initial mental model included three-dimensional perspective displays, fly-through and other forms of surrogate travel, and rapid sequence projection of user-selected images, such as thirty Landsat scenes over the same area to provide a survey of seasonal changes. (The system must perform transformations so that images are displayed to the same projection and scale.)

As the cartographer proceeds to more detailed analysis of the area other operations might be used, such as overlays of geographic and image material. The system might highlight or suppress information based on various user-specified criteria, which might include operators currently available. For example, a cartographer might wish to highlight or suppress roads that are not cleared of snow.

Technology to support such operations is currently available. For example, flight simulators provide both three-dimensional views and fly-throughs. Image processing systems can identify differences between two images of the same area. Medical experts are using displays of CAT scan data from various perspectives. A deeper understanding of the mental processes used in cartography may uncover the need for new operations and types of displays to support practitioners.

The essence of the cartographer's contribution lies in the identification and representation, directly or indirectly, of numerous relationships within a geographical system. Cartographers are particularly concerned with spatial and geographical relationships; however, they must also use and understand economic and cultural system attributes and their implications. Geographic system knowledge in an automated system can be used in several ways, most notably to identify apparent inconsistencies or anomalies that become evident only upon examination of data in the context of the system under study, to constrain operations initiated by the automated system or by the cartographer, to generate inferences and other kinds of information, to identify new relationships among individual data items, and to solicit information from outside the system.

System knowledge is sometimes made explicit in various forms of rules that are stored and used by computer systems. Researchers in artificial intelligence have implemented a number of systems that store and use system knowledge. Generally, knowledge based systems focus on a rather narrowly defined topic, such as medical diagnosis or molecular structures.

Cartographers draw upon a wide body of general knowledge about the world, rather than upon a specific body of well-defined and detailed information. It is important to be able to define the scope of statements of system knowledge, using a wide range of variables, including historical and geographic factors. Such capabilities would allow the cartographer to have the system invoke statements about a particular area of interest, such as a reminder that the soil composition in the area supports only certain kinds of vegetation, which in imagery looks like other vegetation that is more familiar to the cartographer.

Geographic system knowledge might be most useful to cartographers as a guide and an alerting system in which the system calls the cartographer's attention to potential inconsistencies or gaps in stored information, and the cartographer directs the system on when and how to resolve the conflict. Cartographers might use such capabilities to assist in collecting and compiling the body of interrelated information that is the basis for producing a map. The working cartographer needs to be able to define statements of geographic system knowledge and to delete or modify tentative statements that she or he finds useful to test and examine during the compilation of explicit information. Geographic system rules could also be used to save and make available for later use general statements about a milieu that constitute a part of the cartographer's mental model.

A cartographer's working product is a part of the explicit information in the model above. It can take many forms, ranging from rough sketches which may be discarded to precisely plotted manuscripts. If the working product is stored in an automated system, the cartographer can manipulate and display it quickly. The system can generate displays of the information that cartographers using traditional methods do not have time to prepare.

The cartographer can insert information not already stored in the system and modify stored data using either graphic or alphanumeric representation. Data can be specified on displayed materials, extracted, transformed, and moved into the body of explicit information the cartographer is using. In many cases transferred data consists of one or more pieces of specific information, such as the course of a river. It is desirable to be able to add other kinds of explicit geographic information, including distribution patterns, such as density of certain vegetation of soil types, and generalizations, such as the eventual destination of rivers in an area. The system must also accommodate information concerning portrayal of the data and information about the origin and accuracy of the data and the confidence the cartographer has in it. All of the presentation options mentioned for exploitation of source materials are needed for use with explicit data. In addition, the cartographer needs to work with the data using various projections.

In order to examine and verify or revise the information a cartographer needs to be able to select portions of explicit information on the basis of boolean operations on any of the data stored; in order to exploit the data in the system, a cartographer also needs aggregate operators, spatial operators and operators to apply geographic system rules to specified portions of the data to do such things as identify gaps in the data or inconsistencies of various sorts. Work on the definition of spatial operators is proceeding in this forum and others. Considerable work remains to be done on the use of geographic system rules in conjunction with geographic system data. Such capabilities are need for transforming or deriving data for display as well as for selection.

CONCLUSIONS

The shift of emphasis in cartographers' work should see a corresponding expansion of the information support available in computer assistance. Users of computer assisted cartographic systems need to be able to treat geographic systems as systems, rather than as collections of independent pieces of information. The functionality available in computer-assisted cartographic systems should reflect the mental activities they are intended to support. In order to design more appropriate computer assistance, system designers need a model of the cartographic process that identifies the mental operations involved.

Implemented systems will be unobtrusive aids to cartographers only if they provide the functionality required and an interface appropriate to the user population and to the work environment.

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