EXPERT SYSTEMS IN COMPUTER CARTOGRAPHY

by

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EXPERT SYSTEMS IN COMPUTER CARTOGRAPHY

ABSTRACT: The purpose of this paper is to describe the application of expert system concepts to cartographic problems. Expert systems, a subfield of artificial intelligence, are computer programs based on knowledge and symbolic reasoning. The basic principles of expert systems will be explained. Areas of cartography that are most suitable for this new approach of computer-assisted cartography will be identified. Examples of cartographic expert systems will be discussed, problems identified, and future research efforts in the area of cartographic expert systems suggested.

INTRODUCTION

Technology has always had a strong impact on cartography. In particular, the new technology of computer-assisted cartography has had revolutionary effects. Many operations that were done slowly and labor intensively by hand can now be done by computer. It seems that, with computer assistance, the cartographic process has become easier and faster. The overall cartographic goal, however, is not just to make maps faster and cheaper, but to make maps that are more effective in communicating spatial and environmental concepts and information (Robinson *et al*. 1984, 51).

Despite recent advances, computer cartography is far from reaching complete automation of the conventional mapping process. For this reason Robinson *et al.* (1984, 48) suggest the use of the term 'computer-assisted' cartography rather than 'automated' cartography. Further automation therefore is one of the main goals of computer cartography research.

The use of computers in map making also changed the relationship between the cartographer and map user. Before the advancement of computer cartography, professional cartographers were responsible for the design, production, and reproduction of maps and plans. The map user for the most part had to be content with whatever printed maps were available. Today, it is possible for map users to create their own maps using digital computers, CRT displays, and plotting devices. The result is that knowledgeable map users can generate maps tailored to their specific needs. Computer mapping programs commonly used, however, still require a prior knowledge of cartography, especially in the areas of map design and cartographic objectives (Lai 1985). There is always the danger of misuse of computer mapping systems by individuals lacking fundamental cartographic expertise and/or access to guidance from a professional cartographer. This results in poorly designed maps which fail to communicate the cartographic message and are most likely misinterpreted. What is needed is a cartographic 'advisor'. Ideally, computers should be made 'smart' enough to detect mistakes and guide a map user, inexperienced in cartographic design, through the creation of meaningful maps.

The most promising approach toward better user generated maps and more automation in cartography comes from the application of Artificial Intelligence techniques to computer cartography. The approach taken is that of an Expert System in which knowledge and skills of one or more experts is embedded in a set of explicit rules. A cartographic expert system emulates an expert cartographer in a specific cartographic task.

The field of expert systems has been growing rapidly in recent years. Expert systems have been successfully implemented for a variety of tasks, such as medical diagnosis (Buchanan and Shortliffe 1984), mineral exploration (Gaschnig 1979), chemical structure elucidation (Lindsay et al. 1980), and computer-system configuration (McDermott 1982). Several expert system applications in the areas of mapping, charting and geodesy have also emerged very recently (Graklanoff 1985).

EXPERT SYSTEMS BACKGROUND

The Position of Expert Systems in the Field of Artificial Intelligence

Artificial Intelligence (AI) is an emerging technology that has recently attracted considerable publicity. Research in AI is focused on developing computational approaches to intelligent behavior. It has two goals:

1) making machines more useful, and

2) understanding human intelligence.

For computer cartography, we are primarily concerned with the first goal.

One model of AI has been called the 'onion model' (Nilsson 1981/82) (Figure 1). The inner ring depicts the basic elements from which the applications in the outer ring are composed. The basic elements of AI are heuristic search, knowledge representation, common sense reasoning and logic, and AI languages and tools (Gevarter 1984, 4).

Many AI programs search for solutions to problems. Commonly, these problems are too complex to do an exhaustive search for all possible solutions. Heuristic search is guided by empirical rules, also called 'rules of thumb' or 'heuristics', in order to reduce the search (Gevarter 1984, 4).

Knowledge representation can be viewed as the task of developing, maintaining, and using computer-interpretable formalisms for representing knowledge. AI research seeks representations that can be given a declarative interpretation, like those of mathematics, for expressing non-mathematical knowledge (Nilsson 1981/82).

Common sense is low level reasoning, based on a wealth of experience. How to represent common sense in a computer is a key issue in AI that is unlikely to be solved soon (Gevarter 1984, 5).

Specific high level languages, such as LISP and PROLOG, and software tools based on these languages have been

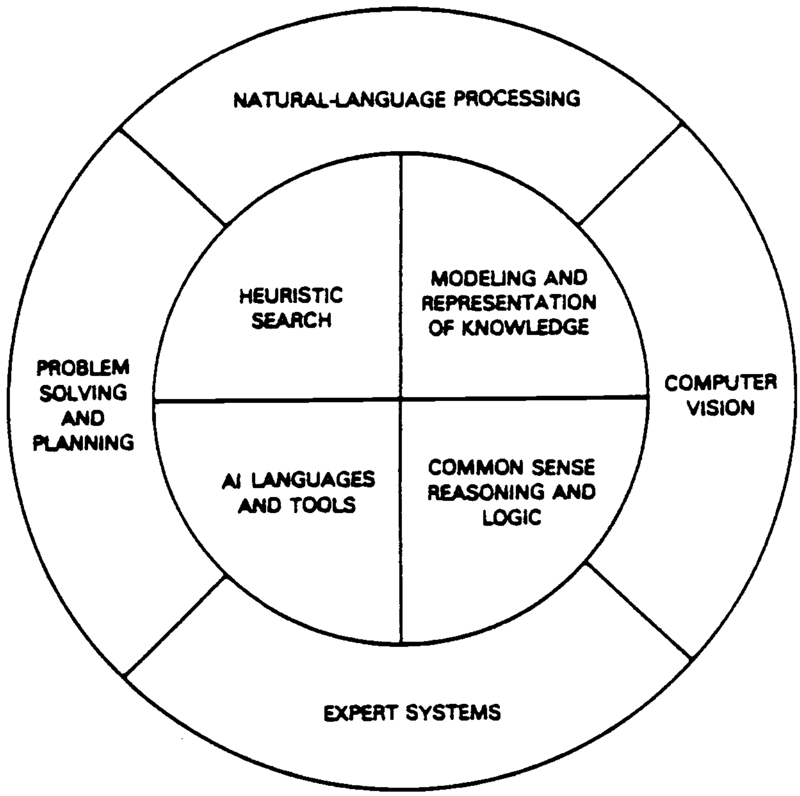

FIGURE 1. Elements of Artificial Intelligence
(Source: Gevarter 1984, 6)

developed for AI applications.

Based on these AI elements, Nilsson (1981/82) identified four principle AI applications:

Natural Language Processing is concerned with computer based speech understanding, text understanding and generation, and related problems.

Computer Vision is concerned with enabling a computer to see, and to identify and understand what it sees.

Problem Solving and Planning systems focus on intelligent problem solving techniques.

Expert Systems try to make a computer act as if it was an expert in some domain[1].

Definition and Characterization of Expert Systems

The attempt to define the term 'expert system' is complex. Many researchers use different definitions. Feigenbaum (1982, 1) gives a formal and general definition of an expert system:

> "An 'expert system' is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field."

Brachman *et al.* (1983) define expert systems in more detail by using seven semi-independent dimensions:

1) Expertise - high level rules, the avoidance of blind search, and high performance;
2) Reasoning by symbolic manipulation;
3) Intelligence - fundamental domain principles and weak reasoning methods;
4) Difficulty or complexity;
5) Reformation - conversion from a description in lay

terms to a form suitable for expert-rule application;

6) Reasoning about self in various forms, especially for explanation;

7) Type of task.

These dimensions can be understood as linear axes along which systems could vary continuously. They represent ideal conditions, no existing expert system meets all seven of these dimensions (Brachman _et al_. 1983). For a better understanding of expert systems, these dimensions will be further described.

Expertise. The most important goal of an expert system is to achieve the high level of performance of a human expert for a specific task. The main criterion for this is that expert systems successfully solve the problem for which they are applied. Another criterion for expert behavior is the way in which a solution for a problem is derived. Experts find solutions by quickly eliminating many possible hypotheses; they avoid blind search.

Symbol Manipulation. In expert systems, knowledge is represented symbolically. The symbols are manipulated by qualitative reasoning techniques that relate items through judgmental rules, as well as through theoretical laws and definitions (Buchanan and Shortliffe 1984, 3).

Intelligence. The intelligence of an expert system depends on the scope of its basic principles and the quality of its general-purpose reasoning processes. The first deals with the coverage of the domain by the system. The latter is based on the accessibility of facts as well as on completeness of the inference structure. One of the serious shortcomings of today's expert systems is that they are only operational in a very narrow and highly specialized domain of expertise.

Complexity and Difficulty. The problems to be solved by an expert system have to be complicated enough to require an expert for their solution. This criterion is very difficult to quantify. The question is how to delimit a degree of problem complexity at which domains qualify for expertise.

Reformulation. A task that the field of expert systems development is just beginning to approach is taking a problem in some arbitrary initial form and converting it into a form appropriate for processing by expert rules.

Reasoning about Self. An expert system must be able to reason about its own processes. The most important aspect of self knowledge, often cited as a central feature of expert systems, is explanation. For the explanation of a result, an expert system must understand its own chain of reasoning. Explanation in expert systems is usually done by tracing the rules that have been used to solve a problem. Since knowledge is represented almost exclusively as high-level rules, explanation from basic domain principles is usually not achieved. However, not all expert systems must necessarily have the ability to explain a line of reasoning, for example if the result is self-explanatory.

Task. Different tasks can substantially change the architecture of a system. Comparison of expert systems and measurement of success depend on the type of task. Expert systems have been built to do interpretation, diagnosis, monitoring, prediction, instruction, planning, and design (Table 1).

Expert Systems Versus Conventional Computer Programs

An expert system differs from more conventional computer programs in several important ways. In a conventional computer program, knowledge and methods for knowledge utilization are intermixed. This makes it difficult to change the program. Expert systems, however, separate domain knowledge from the methods for applying the knowledge to a problem and so can be changed by simply adding, deleting, or changing rules in the knowledge-base (Duda and Gaschnig 1981, Gevarter 1984, 72).

Tasks that require perception, knowledge, reasoning and

Category	Problem Addressed
Interpretation	Inferring situation descriptions from sensor data
Prediction	Inferring likely consequences of given situations
Diagnosis	Inferring system malfunctions from observables
Design	Configuring objects under constraints
Planning	Designing actions
Monitoring	Comparing observations to plan vulnerabilities
Debugging	Prescribing remedies for malfunctions
Repair	Executing a plan to administer a prescribed remedy
Instruction	Diagnosing, debugging, and repairing student behavior
Control	Interpreting, predicting, repairing, and monitoring system behaviors

TABLE 1. Generic Categories of Expert Systems Applications (Source: Hayes-Roth et al. 1983)

judgment are amenable to expert system technology (Graklanoff 1985). Problems that can be solved using an algorithm[2] and involve a substantial amount of numerical or data-processing procedures are usually tackled with

Low Amenability to Expertizing		High Amenability to Expertizing
Expertise not Essential to Problem Solutions		Expertise Essential to Practical Problem Solutions
Knowledge is complete and exact.	Knowledge Exactness	Knowledge is ill-defined. Available data can be errorful and incomplete.
Problem/task is stable. Repetitive task instances are solved in same or highly similar manner.	Problem/task Stability	Problem/task situation is dynamic and unstable. Similar or same resolutions to successive task instances are typically not possible because of complex variances among successive states.
Problem/task is not time-sensitive Substantial time can be used for blind search methods.	Time Sensitivity	Problem/task is time perishable. Resolution must be achieved within imposed time constraints to avoid degradation, expense, extended negative experience, or extended loss of opportunity.
Availability of expertise is high. Expertise is relatively easy to achieve.	Availability of Human Expertise	Availability of expertise is sparse. Expertise is difficult and time consuming to achieve.
Knowledge-base and inference rules are fixed.	Stability of Knowledge-Base and Inference-Judgment Rules	Knowledge-base and inference rules continually change and expand.
Very low number of potential solutions.	Number of Potential Solutions	Very high number of potential solutions.

TABLE 2. Continuum of Problem/Task Amenability to Expertizing

(Source: Graklanoff 1985)

conventional computer programs. Between these two extremes lies a continuum along which tasks are more or less amenable to intelligent assistance. Graklanoff (1985) used six criteria to judge the degree to which a given task is amenable for assistance by expert systems (Table 2).

Components of a Rule-Based Expert System

The basic components of a rule-based expert system are a knowledge-base, an inference engine, and a working memory or global data base (Figure 2) (Gevarter 1984, 71). The actual implementation of an expert system can vary significantly from this general model, depending on the task of the system.

The knowledge-base contains rules, facts, and information about the problem that might be useful for finding a solution (Hayes-Roth _et al_. 1983). Commonly, the rules are represented as production rules, also referred to as 'Situation-Action' rules or IF-THEN rules (Gevarter 1984, 73).

The inference engine organizes and controls the steps taken by the system to solve the problem. It has complete control over the order of deduction and is the key to the system (Gondran 1986, 52). Commonly, IF-THEN rules are chained to form a line of reasoning. The basic cycle of the inference engine is shown in Figure 3.

The basic control strategies may be backward reasoning,

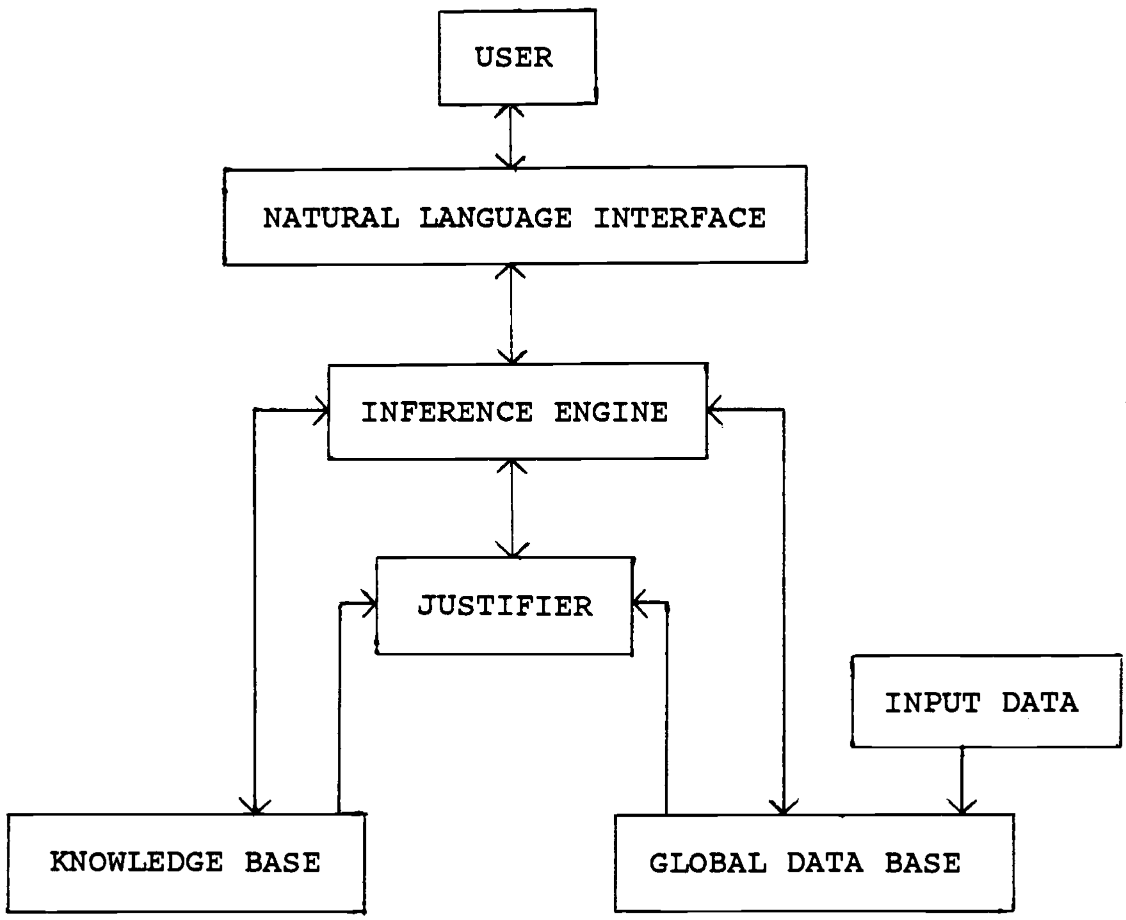

FIGURE 2. Structure of a Rule-Based Expert System (modified after Gevarter 1984, 72)

forward reasoning, or opportunistic reasoning. In the backward reasoning or goal driven model, the problem is solved from a goal toward an initial state (data) (Nii 1986a). The system matches the THEN part of a rule with the global data base and finds the applicable IF situation[3]. In the forward reasoning or data driven model, inference steps are applied from an initial state toward a goal (Nii 1986a). The system matches the IF part of a rule and executes the THEN part[4]. In an opportunistic reasoning model, either forward or backward reasoning steps are applied dependent upon which of the two is more 'opportune' at the time (Nii 1986a). Most expert systems employ either the backward or the forward reasoning model.

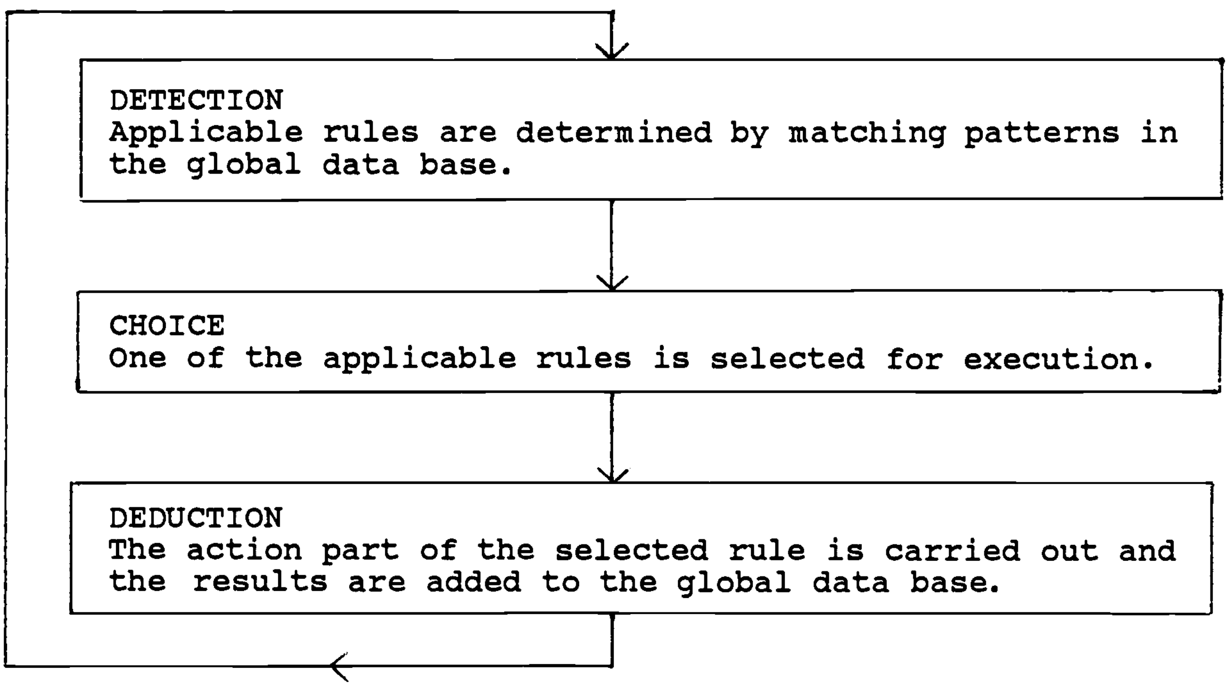

FIGURE 3. The Basic Cycle of the Inference Engine (modified after Gondran 1986, 52)

The global data base contains intermediate hypotheses and decisions made by the expert system.

Other desirable components of expert systems are a natural language interface and a justifier (Figure 2). The natural language interface allows the user to interact with the system in a problem-oriented language, usually some restricted version of English (Hayes-Roth et al. 1983). In some cases graphics or structure editors are used to interact with the user. The justifier explains the actions of the system to the user. For that purpose, it collects the rules that have been used to solve the problem and translates them into English for presentation to the user (Hayes-Roth et al. 1983).

Blackboard Systems

A blackboard system is an expert system that employs the opportunistic model of problem solving (Nii 1986a). Its structure is slightly different from a rule-based expert system (Figure 4).

The global data base is called the blackboard. Instead of a single knowledge-base, the blackboard system contains separate and independent knowledge sources. The knowledge sources are self activating and respond opportunistically to changes on the blackboard (Nii 1986a). They are represented as procedures, sets of rules, or logic assertions. The control modules determine the next thing to be processed - the focus of attention. The solution of a problem is built incrementally one step at a time.

The independent nature of the knowledge sources makes it easy to combine symbolic reasoning and numeric (algorithmic) computation (Nii 1986a). Numeric algorithms can be treated as separate knowledge sources. The integration of symbolic reasoning and numeric computation makes the blackboard structure especially suited for applications that involve a lot of numeric data processing, such as computer cartography. Blackboard systems, however, are expensive to build and to run.

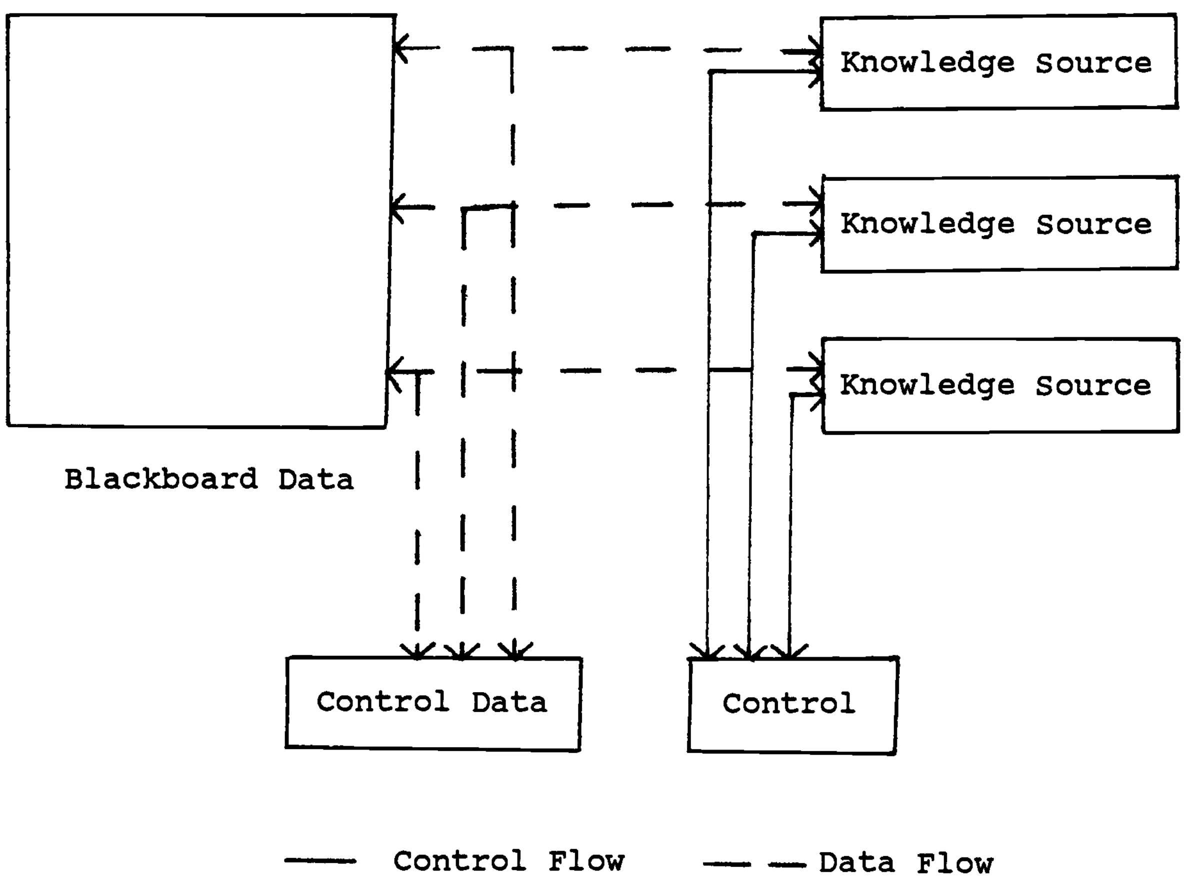

FIGURE 4. The Blackboard System
(modified after Nii 1986a)

THE POTENTIAL FOR EXPERT SYSTEMS IN CARTOGRAPHY

The subject matter of cartography seems to be complex enough to qualify for the expert systems approach. Expertise is necessary to produce well designed and effective maps. This is especially true for computer generated maps, as can easily be seen when comparing computer maps created by an expert cartographer with maps created by an inexperienced layman. Although expert systems are intended to substitute for human experts, it is for several reasons unlikely that they will replace all cartographers (Robinson and Jackson 1985):

1) It is unlikely that human experts could formalize all their knowledge to fit into a computer usable form;
2) Cartography is an evolving field. Cartographers would still be needed to do research (even if it was only to update cartographic expert systems);
3) Cartography involves artistic elements which are still impossible to capture in an automated system.

In the following, several areas of cartography that could benefit from expert systems concepts are discussed.

Map Design

Map design problems seem to be highly suited for expert system techniques. There is a wealth of knowledge and rules about various aspects of map design. However, the overall knowledge of map design processes is still incomplete and much research is needed in this direction. There are usually many possible solutions for a map design task.

One problem of knowledge acquisition[5], the problem of disagreeing experts, applies especially to map design. Most likely, different 'experts' have different opinions of the quality of a specific map design. The lack of a systematic and generally accepted methodology for cartographic assessment is a problem that needs urgently to be addressed by the cartographic community (Fisher and Mackaness 1987).

Map design fits in the category of design problems that have been identified to be amenable to expert systems applications (Table 1). Expert systems have been developed for the map design tasks of name placement (Freeman and Ahn 1984, Pfefferkorn et al. 1985), and map generalization (Nickerson and Freeman 1986).

Cartographic Production

Many processes are involved in producing a cartographic product. Graklanoff (1985) sent out questionnaires to experts in the field, to assess which cartographic production processes are suitable for expertizing. Processes that are mainly mechanical, such as plate making, negative preparation, engraving, and press printing were rated low on their amenability to expertizing. These processes are more suited for conventional computer programs and for the application of other artificial intelligence areas, such as robotics. Production processes that require human decision making, such as source evaluation, source selection, compilation planning, and feature selection were rated to have a high amenability for expert system concepts. The latter processes fit into the generic expert system applications category of planning (Table 1).

Cartographic Education and Training

Computer aided instruction is playing an increasingly important role at all levels of education. With the help of expert systems, intelligent tutoring systems can be constructed. With intelligent computer aided tutoring systems, it becomes possible to keep records of what the student knows, the logic of teaching can be generalized, and models of student knowledge can be inferred from student behavior and used as a basis for tutoring (Buchanan and Shortliffe 1984, 455). For these reasons, expert systems will have a major impact on the teaching of cartography.

Digital Data Base Applications

Many tasks dealing with digital map data could be done using expert systems. Heivly (1986) built an expert system for edge-joining USGS 1:2 million scale digital maps to create a multi-regional data base. Similarly, map overlay processes and the combination of different data sets could be done with expert sytems (Robinson and Jackson 1985).

The area on the interface between computer cartography and geographic information systems is a prime candidate for exploitation by expert systems. The increasing complexity and diversity of systems requires increased knowledge by users of these data bases and information systems. Several researchers are already active in this area (Bouille 1984, Smith and Pazner 1984, Peuquet 1984).

EXAMPLES OF CARTOGRAPHIC EXPERT SYSTEMS

Several cartographic expert systems have been built in the last five years. Most of them are based on production rules, but experiments with other representations have also been undertaken. Unfortunately, no system has yet been built using the blackboard architecture, although this approach seems well suited for cartographic applications. This might result from the fact that the blackboard system idea is very new and still under development.

Cartographic expert systems perform a variety of tasks, such as map feature labeling, map generalization, consultation for cartographic decision making, and edge-joining of digital map data (Table 3). Some of these systems will be discussed in the following sections.

Name	Task	Author
AUTONAP	Automated Map Labeling	Freeman and Ahn 1984
ACES	Automated Map Labeling	Pfefferkorn et al. 1985
MAPEX	Automated Map Generalization	Nickerson and Freeman 1986
MAP-AID	Automated Map Design	Robinson and Jackson 1985
Cartographer's Advisor	Map Design Consultation	Bossler et al. 1987
---	Map Design Consultation	Bossler et al. 1987
---	Map Design Consultation	Muller et al. 1986
---	Edge-Joining of Digital Map Data	Heivly 1986

TABLE 3. Cartographic Expert Systems

AUTONAP

AUTONAP is an expert system for automatic map name placement for point, line, and area features (Freeman and Ahn 1984). The goal of map annotation is to achieve an unambiguous and aesthetically pleasing placement of the feature names. It is especially difficult to reach the goal of being aesthetically pleasing. Experienced cartographers accomplish this quite well, but it is difficult to formulate rules about how exactly they do it.

A rule-based approach is taken to implement the system.

The knowledge-base contains heuristic name placement rules based on cartographic conventions. Some of these rules are listed in the Appendix. These rules trigger numeric algorithms that perform the name placement procedures. As more experience with the system is gained and higher standards of aesthetic quality can be set, new rules will be added to the knowledge-base.

A hierarchy is established for the annotation of area, point, and line features. Area features are annotated first, since they have the smallest degree of freedom: area names must be spread from one end of the area to the other, following the general shape of the area. Point features have the next highest priority, since point names have to be placed close to the point to which they refer. Line features can be labeled last, since their name can be placed anywhere along the line. This hierarchy requires backtracking, if, for example, the constraints of point feature name placement forces a change in the placement of area feature names. This backtracking is not presently provided for in AUTONAP.

The AUTONAP system has been implemented and experiments have been conducted to:

1) test the validity of the rule-base chosen;
2) identify special situation problems, not covered by standard rules;
3) devise additional rules; and

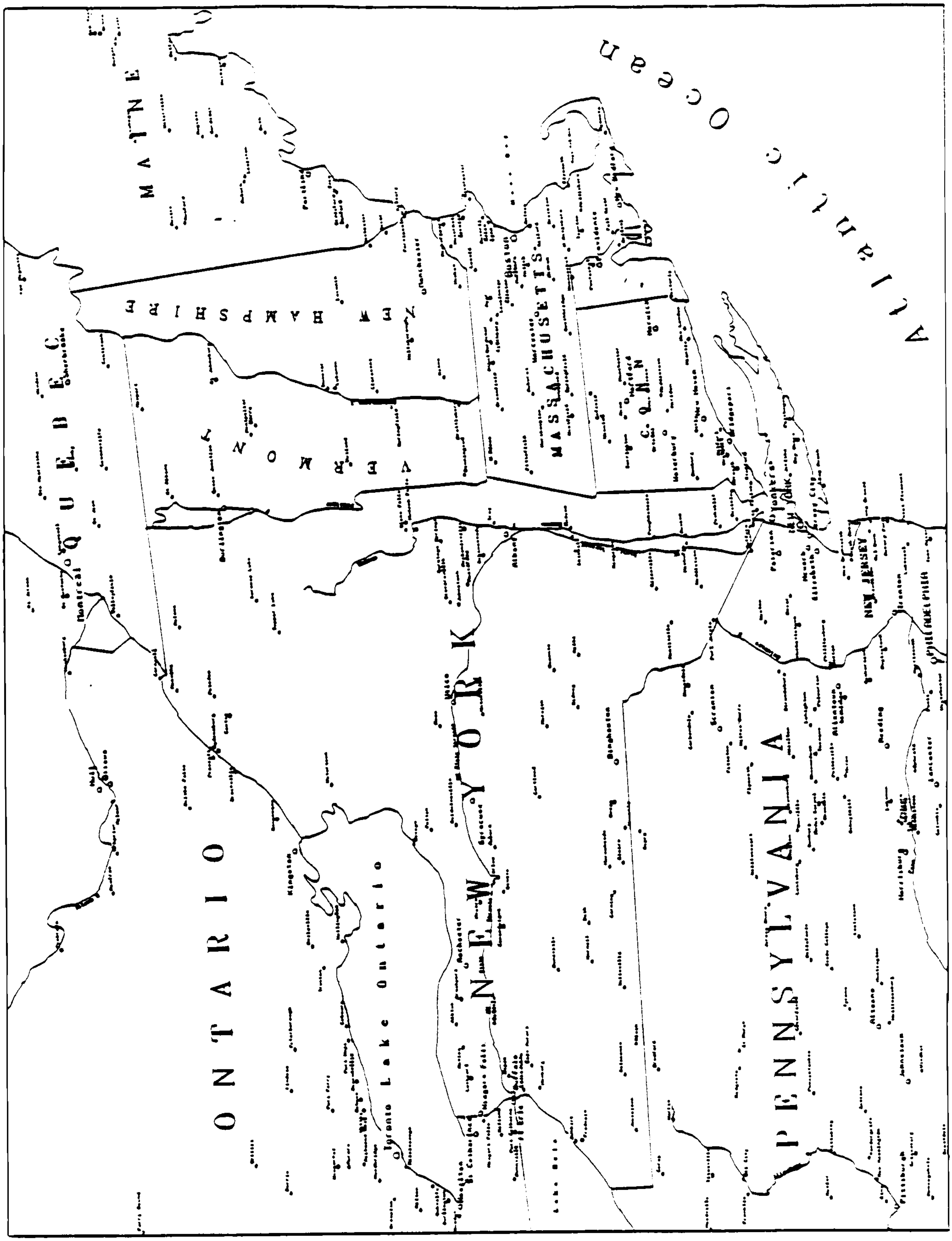

FIGURE 5. Fully Automated Area, Line, and Point Feature Name Placement by AUTONAP (Freeman and Ahn 1984)

4) generally evaluate the entire approach.

The aesthetic level of an experienced human cartographer is not yet achieved by the system, but at this stage of development map placements have been produced that are free of ambiguities, avoid overlap, and satisfy standard cartographic requirements (Figure 5). AUTONAP has been called one of the most successful cartographic expert systems to date (Robinson and Frank 1987).

<u>ACES</u>

The task of ACES is, like that of AUTONAP, the labeling of maps (Pfefferkorn <u>et</u> <u>al</u>. 1985). The system is still in a developmental stage and is currently able to perform moderately complex map labeling tasks. The labeling hierarchy of area, point, and line features is the same as in AUTONAP.

The knowledge of ACES is represented in three ways: mapnode description, interaction graph, and decision or design tree. Mapnodes are the features of the map to be labeled. Mapnode descriptions are mapnode attributes, such as location, type, label text, and possible label positions. This information is used to develop an interaction graph which consists of pointers that connect mapnodes whose influence rectangles overlap. The decision tree controls the search behavior of the system. It contains information about strategies that have already been tried and where the search for a solution can be continued. The labeling process is performed iteratively until all feature classes are placed. Features that could not be labeled successfully are identified and remedial processing is taken after all classes have been processed.

MAPEX

The task of MAPEX is map generalization (Nickerson and Freeman 1986). The system addresses the problems of line feature generalization, feature combination, feature deletion, feature simplification, interference detection, feature displacement, and displacement propagation. Rules are used as high-level controllers for low-level algorithmic procedures that are required for the map generalization process. The higher level of the rules is completely separated from the lower level tasks of geometric manipulation of the map data (Figure 6).

Cartographer's Advisor

Cartographer's Advisor is being developed by the National Ocean Service (NOS) Charting and Geodetic Services (Bossler *et al*. 1987). Its task is cartographic decision making concerning the questions: whether an item of information should be applied to a chart, how it should be symbolized, and where the symbol should be placed. At present, the Cartographer's Advisor is a stand-alone system used for

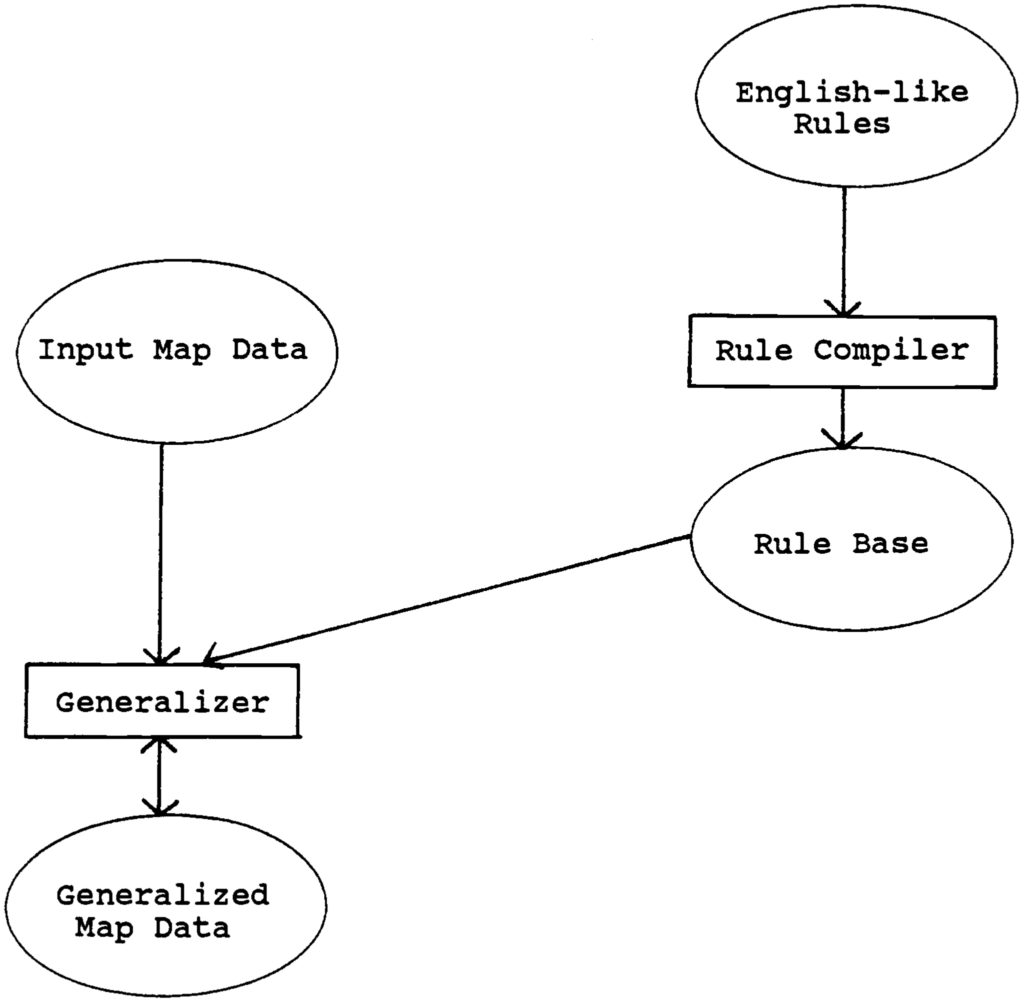

FIGURE 6. Diagram of the MAPEX System
(Source: Nickerson and Freeman 1986)

consulting individual cartographers. Eventually, the system will be integrated with existing cartographic workstations.

For a proof of the concept, a prototype system was designed for the task of shipwreck representation. The system contains 85 rules based on NOS standards and procedures[6]. At this stage, the Cartographer's Advisor can evaluate the proper representation of shipwrecks from information commonly supplied in source documents.

The Cartographer's Advisor incorporates explanation facilities (Figure 7). The user can ask 'why' a piece of information is requested and 'how' a certain representation was selected. For explanations, the system backs up the inference chain and displays the rules that were used in an English-like version.

A false fact table contains a collection of discarded alternatives used to improve system efficiency.

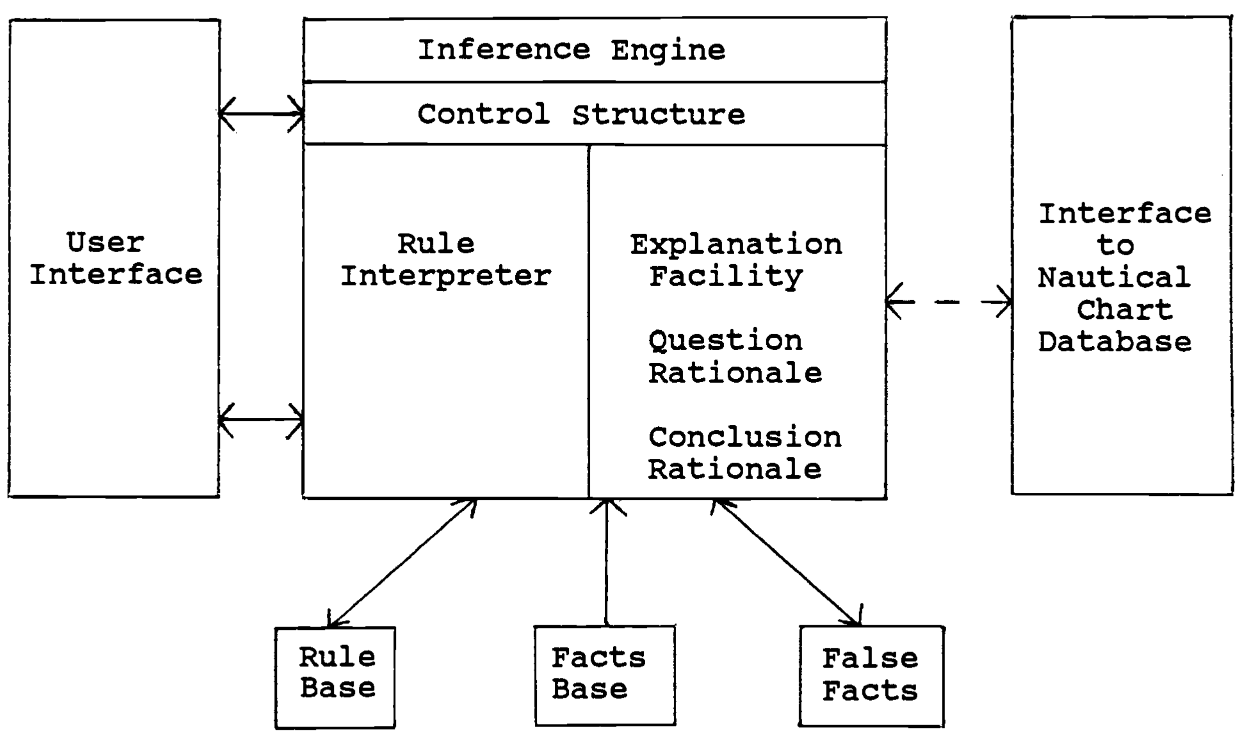

FIGURE 7. Organization of the Cartographer's Advisor (Source: Bossler et al. 1987)

MAP-AID

The MAP-AID system is currently being developed at the Thematic Information Service of the Natural Environment Research Council in the United Kingdom (Robinson and Jackson 1985). The task of MAP-AID is map design. The system consists of three basic components: the expert system, data base systems, and graphics packages (Figure 8).

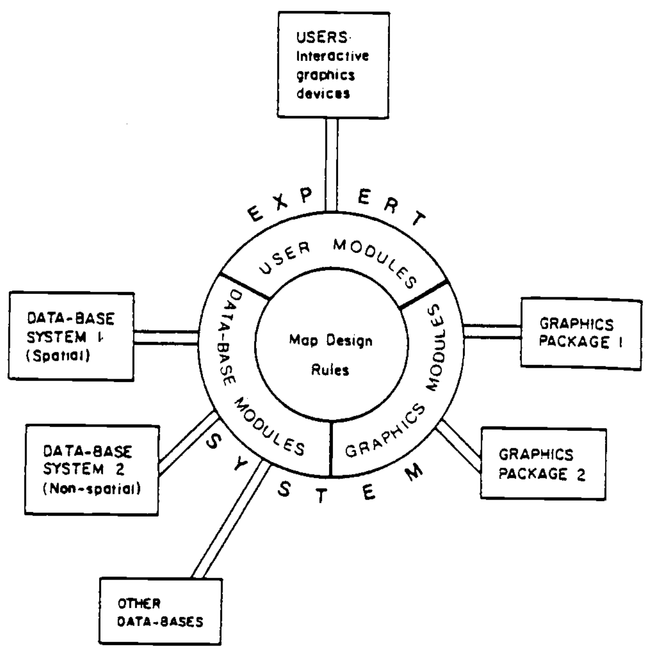

FIGURE 8. Structure of the MAP-AID System
(Source: Robinson and Jackson 1985)

The expert system part of MAP-AID is divided into four sections: the map design rule-base, user modules, data base modules (one per data base), and graphics package modules (one per package). The core of the system contains the map design rule-base with cartographic conventions covering the relative importance of different features and rules about acceptable combinations of features. For communication with the surrounding modules, a uniform set of standard interface procedures is defined.

The modules comprise interfaces to the external systems (user, data base, or graphics package). The user module operates as a natural language interface and converts the user input into a format suitable for processing. Similarly, it translates input requests from the system into English-style questions. The data base modules handle queries asked by the system core: they generate queries in the syntax of the data base system,issue them, receive the response, decode it, and act accordingly. The graphics package modules interact with the graphics packages that perform the graphics procedures requested by the core of the system.

Results about the performance of the MAP-AID system are not available yet. It seems that the conception of the system is very general. For actually implementing the system it will have to be built incrementally, starting with a single map design task and adding others at a later time.

DISCUSSION

Several cartographic expert systems have been introduced. All of them are still under development and more effort is necessary to produce production quality systems. The experimental systems prove, however, that there is much potential for the application of expert systems in cartography. Far from being 'ideal' expert systems, the discussed systems incorporate basic expert system principles. Areas that need further research are those of knowledge acquisition, knowledge representation, and explanation.

Knowledge acquisition is one of the most important steps in building expert systems, since the performance of the system depends on the quality and quantity of the incorporated knowledge (Buchanan et al. 1983). Robinson and Frank (1987) noted that there is little concern for the processes of knowledge acquisition and representation in cartographic expert systems: knowledge is generally taken from published literature, little effort has been made to extract expertise from human experts. However, the acquisition of intuitive and experiental knowledge from cartographic experts, including all the little tricks they use, is indispensable for the creation of a good expert system. It is also important to recognize that knowledge acquisition has to continue after the system has been implemented (Gardels 1987).

Future development of cartographic expert sytems depends on more rigorous approaches to the representation of cartographic knowledge. Efforts are needed to formalize cartographic knowledge for representation in expert systems. One method for structuring cartographic knowledge has been suggested by Eastman (1987). What needs to be done is to incorporate the structure of cartographic knowledge into expert systems.

One of the central ideas of expert systems, the idea of explaining its reasoning steps has not yet played a major role in cartographic expert systems. Explanations should definitely be incorporated in cartographic consulting systems and computer aided cartographic instruction systems. For fully automated cartographic expert systems that produce a map as output, a well designed map may suffice as 'explanation' in itself. However, the explanation of map design steps taken by the system would help system developers to refine the cartographic rule-base.

CONCLUSION

The cartographic world is becoming increasingly more difficult with the advancement of more and more complicated computer cartography systems. Map users who create their own maps with these systems need advice in order to create meaningful maps. There are also desires in the field to more fully automate the cartographic process. This, however, is not possible without incorporating the little tricks and rules of thumb that human cartographers use into computer programs.

Help for the solution of both of these problems comes from the rapidly developing field of artificial intelligence, more specifically from the field of expert systems. Especially, the areas of map design and computer aided cartographic instruction can take advantage of the new expert systems technologies. Expert systems can be employed in map design to fully automate complex design procedures, such as map labeling and map generalization, or to create map design consulting systems. Computer aided cartographic instruction could profit from intelligent systems that have the knowledge of an expert cartographer and are able to adjust to the strengths and weaknesses of individual students.

Although there is still much research needed, the potential for expert sytems in computer cartography has been recognized and the advancement of the art and science of cartography can be anticipated.

FOOTNOTES

1. Domain refers to a particular area of discourse, for example cartography.

2. An algorithm is a procedure that is guaranteed either to find the correct solution to a problem in a finite time or tell you there is no solution (Buchanan and Shortliffe 1984, 3).

3. An example for backward reasoning is:

Find out about C	(Goal)
IF B, THEN C	(Rule 2)
IF A, THEN B	(Rule 1)
=> IF A, THEN C	(Implicit Rule)
Question: Is A true?	(Data)

4. An example for forward reasoning is:

IF A, THEN B	(Rule 1)
IF B, THEN C	(Rule 2)
A	(Data)
=> C	(Conclusion)

5. Knowledge acquisition is the process of extracting knowledge from an expert and transferring it to the expert system (Buchanan _et_ _al_. 1983).

6. An example rule from the Cartographer's Advisor follows:

```
IF    the location of the wreck is L
      and the wreck is visible
      and the wreck location lies within a spoil area
      and the wreck is not of value as a landmark
THEN  the wreck is not applied
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REFERENCES

Bossler, J.D., D.L. Pendleton, G.F. Swetnam, R.L. Vitalo, C.R. Schwarz, S. Alper, and H.P. Danley. 1987. Knowledge-Based Systems for Cartography: Progress and Opportunity. Submitted to The American Cartographer.

Bouille, F. 1984. Architecture of a Geographic Structured Expert System. Proceedings of the International Symposium on Spatial Data Handling, Zurich, Switzerland, pp. 520-543.

Brachman, R.J., S. Amarel, C. Engelman, R.S. Engelmore, E.A. Feigenbaum, and D.E. Wilkins. 1983. What are Expert Systems? In Hayes-Roth, F., D.A. Waterman, and D.B. Lenat (Eds.). Building Expert Systems. Addison-Wesley Publishing Co., Reading, MA, pp. 31-57.

Buchanan, B.G., B. Barstow, R. Bechtal, J. Bennett, W. Clancey, C. Kulikowski, T. Mitchell, and D.A. Waterman. 1983. Constructing an Expert System. In Hayes-Roth, F., D.A. Waterman, and D.B. Lenat (Eds.). Building Expert Systems. Addison-Wesley Publishing Co., Reading, MA, pp. 127-167.

Buchanan, B.G., and E.H. Shortliffe (Eds.). 1984. Rule-Based Expert-Systems. The MYCIN Experiments of the Stanford Heuristic Programming Project. Addison-Wesley Publishing Co., Reading, MA.

Duda, R.O., and J.G. Gaschnig. 1981. Knowledge-Based Expert Systems Come of Age. Byte, Vol. 6, No. 9, pp. 238-281.

Eastman, J.R. 1987. Graphic Syntax and Expert Systems for Map Design. ASPRS-ACSM Annual Convention. Technical Papers, Vol. 4, Baltimore, MD, pp. 87-96.

Feigenbaum, E.A. 1982. Knowledge Engineering for the 1980's. Computer Science Department, Stanford University, CA.

Fisher, P.F., and W.A. Mackaness. 1987. Are Cartographic Expert Systems Possible? Proceedings, AUTO-CARTO 8, Baltimore, MD, pp. 530-534.

Freeman, H., and J. Ahn. 1984. AUTONAP - An Expert System for Automatic Name Placement. Proceedings of the International Symposium on Spatial Data Handling, Zurich, Switzerland, pp. 544-569.

Gardels, K.D. 1987. The Expert Geographic Knowledge System Applying Rules to Geographic Information. Proceedings, AUTO-CARTO 8, Baltimore, MD, pp. 520-529.

Gaschnig, J.G. 1979. Preliminary Performance Analysis of the PROSPECTOR Consultant System for Mineral Exploration. Proceedings of the 6th International Joint Conference on Artificial Intelligence, Tokyo, Japan, pp. 308-310.

Gevarter, W.B. 1984. Artificial Intelligence, Expert Systems, Computer Vision, and Natural Language Processing. Noyes Publications, Park Ridge, NJ.

Gondran, M. 1986. Introduction to Expert Systems. McGraw-Hill Book Co., London, U.K.

Graklanoff, G.J. 1985. Expert System Technology Applied to Cartographic Processes-- Considerations and Possibilities. ACSM-ASPRS Fall Convention. Technical Papers, Indianapolis, IN, pp. 613-624.

Hayes-Roth, F., D.A. Waterman, and D.B. Lenat. 1983. An Overview of Expert Systems. In Hayes-Roth, F., D.A. Waterman, and D.B. Lenat (Eds.). Building Expert Systems. Addison-Wesley Publishing Co., Reading, MA, pp. 3-29.

Heivly, C.G. 1986. Using Expert Systems Concepts to fix USGS Digital Boundaries. Proceedings of the Second International Symposium on Spatial Data Handling, Seattle, WA, pp. 572-582.

Lai, P.-C. 1985. Mis-Application of Automated Mapping, An Assessment. Proceedings, AUTO-CARTO 7, Washington, DC, pp. 322-326.

Lindsay, R.K., B.G. Buchanan, E.A. Feigenbaum, and J. Lederberg. 1980. Applications of Artificial Intelligence for Organic Chemistry: The DENDRAL Project. McGraw Hill, New York, NY.

McDermott, J. 1982. R1: A Rule-Based Configurer of Computer Systems. Artificial Intelligence 19, pp. 39-88.

Muller, J.-C., R.D. Johnson, and L.R. Vanzella. 1986. A Knowledge-Based Approach for Developing Cartographic Expertise. Proceedings of the Second International Symposium on Spatial Data Handling, Seattle, WA, pp. 557-571.

Nickerson, B.G., and H. Freeman. 1986. Development of a Rule-Based System for Automatic Map Generalization. Proceedings of the Second International Symposium on Spatial Data Handling, Seattle, WA, pp. 537-556.

Nii, H.P. 1986a. Blackboard Systems: The Blackboard Model of Problem Solving and the Evolution of Blackboard Architectures. The AI Magazine, Vol. 7, No. 2, pp. 38-53.

Nii, H.P. 1986b. Blackboard Systems: Blackboard Application Systems, Blackboard Systems from a Knowledge Engineering Perspective. The AI Magazine, Vol. 7, No. 3, pp. 82-106.

Nilsson, N.J. 1981/82. Artificial Intelligence: Engineering, Science, or Slogan? The AI Magazine, Vol. 3, No. 1, pp. 2-9.

Peuquet, D.J. 1984. Data Structures for a Knowledge-Based Geographic Information System. Proceedings of the International Symposium on Spatial Data Handling, Zurich, Switzerland, pp. 372-391.

Pfefferkorn, C., D. Burr, D. Harrison,D. Heckman, C. Oresky, and J. Rothermel. 1985. ACES: A Cartographic Expert System. Proceedings, AUTO-CARTO 7, Washington, DC, pp. 399-407.

Robinson, A.H., R.D. Sale, J.L. Morrison, and P.C. Muehrcke. 1984. Elements of Cartography. 5th ed., John Wiley and Sons, New York, NY.

Robinson, G., and M. Jackson. 1985. Expert Systems in Map Design. Proceedings, AUTO-CARTO 7, Washington, DC, pp. 430-439.

Robinson, V.B., and Frank, A.U. 1987. Expert Systems Applied to Problems in Geographic Information Systems: Introduction, Review, and Prospects. Proceedings, AUTO-CARTO 8, Baltimore, MD, pp. 510-519.

Smith, T.R., and M. Pazner. 1984. Knowledge-Based Control of Search and Learning in a Large-Scale GIS. Proceedings of the International Symposium on Spatial Data Handling, Zurich, Switzerland, pp. 498-519.

APPENDIX

The following are some of the key rules that are used in the AUTONAP system (Freeman and Ahn 1984):

General Rules

(1) A name should not overlap another name or a point feature. If a name does overlap a line feature or a boundary of an area feature, the line, not the name should be interrupted.

(2) Names should not be evenly dispersed nor be densely clustered.

Area Feature Rules

(1) The name of an area feature should span the entire area and conform to the general shape of the feature, leaving about one and one-half letter spaces at both ends. However, if there is no significant difference between this placement and horizontal placement of an area name, then preference should be given to horizontal placement.

(2) Non-horizontal-placed names should not be straight, but curved. The arcs should not be greater than 60 degrees.

(3) A name that reads away from the horizontal is preferred over a name that reads toward the horizontal.

Line Feature Rules

(1) The label for a line feature should conform to the

curvature of the line.

(2) Complicated and extreme curvatures should be avoided.

(3) Line feature labels should not be spread out, but may be repeated at reasonable intervals along the line.

(4) For horizontal line features, the names should be placed above the line. For vertical line features, there are two cases: If the line feature lies in the left half of the map, the name should be placed on the left side of the line to read upward. Otherwise, it should be placed on the right side of the line to read downward.

(5) One should avoid placing a name near an endpoint of a line feature.

Point Feature Rules

(1) The label for a point feature should be horizontal (usually east-west) and parallel to one of the map boundaries.

(2) Point feature labels,like line feature labels, should not be spread out.

(3) A point feature label should be close to the point feature to which it refers, though some minimum distance must be maintained.

(4) Since the English language has many more ascenders than descenders, name labels that are above the point feature are preferred to name labels that are below the data item.

(5) Although the best possible position of a point label is open to debate, placement somewhat above and to the right to the point is generally preferred.