EXPERT SYSTEMS APPLIED TO PROBLEMS IN GEOGRAPHIC INFORMATION SYSTEMS: INTRODUCTION, REVIEW AND PROSPECTS

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ABSTRACT

This paper discusses the nature of expert systems with special attention on construction of expert systems. We identify four major problem domains of geographic information systems in which expert system technology has been applied - map design, terrain/feature extraction, geographic database management, and geographic decision support systems. Efforts in each problem domain are critically reviewed. Considering the accomplishments and shortcomings of efforts to date, we suggest areas for future research. Two areas in particular need of further consideration are methods of knowledge acquisition, and formalization of both knowledge and uncertainty.

INTRODUCTION

In previous papers we introduced expert systems for land information systems (LIS) (Robinson et al 1986b), critically surveyed efforts related to expert systems for geographic information systems (GIS) and identified several research themes for developing expert system technology for GIS (Robinson et al, 1986c,d). In this paper we direct more attention to expert system construction. This topic was not presented in detail in previous papers and is typically ignored by those developing expert systems for applications in LIS, GIS and automated cartography. We then proceed to provide a critical update to our previous surveys (Robinson et al, 1986c,d). Considering trends in the field and the evolution of our thinking, we elaborate on various aspects of expert system research and development of particular importance to GIS.

One may think of expert systems as computer systems that advise on or help solve real-world problems requiring an expert's interpretation. They solve real-world problems using a model of expert human reasoning, reaching the same conclusions that the human expert would reach if faced with a comparable problem (Weiss and Kulikowski, 1984). For a more detailed introduction to expert systems readers are referred to Robinson et al (1986b).

CONSTRUCTING EXPERT SYSTEMS

Generally speaking, expert systems go through a number of stages that closely resemble classical systems analysis - identification, conceptualization, prototyping, creating user interfaces, testing and redefinition, and knowledgebase maintenance. Also, it has been observed that once the thrill of a prototype system and a fancy interface wears off, many projects come to an abrupt end as the expense of developing them further and maintaining them is assessed (Bobrow et al, 1986).

Identification

To identify problems amenable to solution through expert system technology, a critical mass might be one or two knowledge engineers and a group of experts. Five to ten test cases should be collected for later use. With distributed knowledge, the interview process should expose specializations and the degree of consensus in solution methods among the group of experts.

Conceptualization

Once the domain has been identified the next step is conceptualization and formalization of knowledge. Initial knowledge acquisition sessions should start with a single expert who can demonstrate by working through several examples. Having developed some sense of the problem the knowledge engineer can then begin to articulate in a semiformal language what is believed to be going on in the problemsolving sessions.

A useful next step is simulating the process of solving of one or more test cases. After several rounds of simulation by knowledge engineers critiquing by single expert, it is often useful to bring in other experts to help identify idiosyncracies and determine the multiplicity of problem-solving styles. In the Pride project (Mittal et al, 1985) knowledge acquisition sessions led to creation of a "design knowledge document." It outlined different stages of design, dependencies between stages, and provided a detailed rendering of various pieces of knowledge (rules, procedures, constraints, etc). Before the first line of code had been written the document had evolved to 20+ closely typed pages with 100+ pages of appendices. It reportedly played a crucial role in defining and verifying knowledge eventually incorporated into the Pride system. It was circulated among experts for comment, correction, and identification of omissions. Thus, it helped make explicit some of the knowledge that had been implicitly applied by experts.

User Interfaces

One of most important and time consuming stages in developing expert systems is creation of suitable user interface. Particularly one that matches what users of the noncomputer system have been accustomed to. Goal browsers are an artifact of the user interface unique to expert systems. These goal browsers can be used to lay out the expert system design process as a network of different goals and displays goal status during the construction stage. They also sometimes allow the user to edit, undo, advise and reexecute goals.

Testing and Redefinition

Once a prototype has reached the stage where it is possible to go through the initial test problems from beginning to end it becomes important to start testing the system with friendly users. This usually reveals new problems. Thus, it is common for a second or even a third version of a prototype may be developed. Feedback from solving real problems often forces reimplementation - a cycle characteristic of knowledge programming.

Knowledgebase Maintenance

After friendly users have tried the system a plan must be developed for a large software development project. The plan must provide for testing, development, transfer, and maintenance of the knowledgebase. A process must be put in place at user locations to help tune the user interface, and extend the knowledgebase as new problems are found and easier ways to interact with the system are suggested. When the plan is complete one can more easily evaluate the cost of resources required versus the value of solving problem.

SOME EFFORTS IN EXPERT SYSTEMS AND GIS

There have been a number of expert system efforts reported that are relevant to GIS problems. Table 1 illustrates the relationship between problem domains of geographic information systems and activities particularly applicable to expert system development. The problem domains are : (1) automated map design and generalization, (2) terrain/feature extraction, (3) geographic database management and (4) geographic decision support.

We note a number of reported efforts in Table 1 that we do not discuss here. Some have been discussed in our previous papers, such as MAP-AID (Robinson and Jackson, 1985), ACES (Pfefferkorn et al, 1985), and ACRONYM (Brooks, 1983), while others are not reported in sufficient detail or have been abandoned recently, such as CES (Muller et al, 1986). Here we limit our discussion to a select group of efforts relevant to the exploitation of expert system technology to improve state-of-the-art in GIS and LIS.

Map Design

MAPEX is a rule-based system for automatic generalization of cartographic products (Nickerson and Freeman, 1986). This system was designed to work with USGS 1:24,000 DLG data being generalized to 1:250,000. Like other efforts in this field, there as no effort to extract expertise from human experts in map generalization. However, a significant contribution of this effort has been the formalization of the problem of generalization within a rule-based framework and the identification of existing rules and generation of rules-of-thumb. It is worthy of note that MAPEX was developed at the same institution that developed AUTONAP.

Table 1. Some Expert System Efforts Relevant to GIS Problem Domains.

Problem Domain	Expert System Effort
Map Design	
General	MAP-AID, MAPEX, CES
Name Placement	AUTONAP, ACES
Terrain/Feature Extraction	Palmer, ACRONYM, FES, CERBERUS, MAPS, SPAM
Geographic Database Management	LOBSTER, SRAS, KBGIS-I, KBGIS-II, ORBI, Wu
Geographic Decision Support	TS-Prolog, URBYS, DeMers GEODEX

AUTONAP (Ahn, 1984; Freeman and Ahn, 1984) is perhaps the most successful name placement expert system developed to date. This system emulates an expert cartographer in the task of placing feature names on a geographic map. However, like MAPEX there was no reported effort in extracting knowledge from an expert in name placement.

Terrain/Feature Extraction

Palmer (1984) showed how logic programming can be used as the basis of an expert system for analysis of terrain features. Using a triangular tesselation he represented nodes with their elevation, segments and triangles as first-order predicates. Then using Prolog to conduct symbolic analyses he demonstrated how valleys, streams, and ridges could be detected using the procedural knowledge encoded in a knowledge base and using Prolog control mechanisms. This work was subsequently extented by Frank et al (1986) to illustrate how physical geographic definitions might be formalized using logic programming methods.

FES is a Forestry Expert System (Goldberg et al, 1984) used expressly to analyze multi-temporal Landsat data for classification of landcover and landcover change of interest to foresters. Using a multi-temporal Landsat image database, production rules are applied in two phases. First production rules are used that involve change detection inference coupled with a reliability measure. The second phase generates decision rules regarding the current state of the image. The control structure of FES has been described as a "feedforward" system without backtracking.

CERBERUS was developed initially at NASA for the purpose of performing unsupervised classification of Landsat mulitspectral data (Engle 1985). It is data-driven rather than goal-driven. This FORTRAN-based system is currently being sold for $ 1750 through Cosmic as a knowledgebased system for experimenting with expert systems (Digital Review, 1986: 188).

Geographic Database Management

ORBI is an example of an expert system implemented in Prolog. It was developed to keep track of environmental resources for the country of Portugal. There are aspects of a classification system for environmental data and a decision-support system for resource planning. ORBI provides (1) a natural language parser for Portuguese that supports pronouns, ellipses, and other transformations, (2) menu handler for fixed-format input, (3) an explanation facility that keeps track of the steps in a deduction and shows them on request, and (4) help facilities that explain what is in the database, the kinds of deductions that are possible, and the kinds of vocabulary and syntax that may be used (Pereira et al, 1982). It remains one of the most impressive accomplishments todate.

LOBSTER (Frank, 1984), like ORBI, is based on the logic programming paradigm. It is a new implementation of a task previously solved using a traditional programming approach, namely a query language for a geographic database (Frank ,1982). It serves as an intelligent user interface to a spatial database managment system using the network data model rather than the relational model. It is felt that the flexibility in building the interface using a Prolog-like language was significant.

Smith and Pazner (1984) reported a prototype KBGIS that makes extensive use of several vintage methods drawn from the field of artificial intelligence. The objective of this system appears to have been to illustrate the use of techniques of artificial intelligence for search and simple learning on a spatial database. However, like so many other efforts, the last significant publication on this KBGIS reports it is under complete revision (Smith and Pazner, 1984).

Glick et al (1985) provide a more comprehensive design for a KBGIS using what they call hybrid knowledge representation. In contrast to Smith and Pazner (1984), who chose data structures that fit easily into the scheme of discrimination nets, Glick et al (1985) chose to use a variety of representation methods. Also reported is the use of a frame-based semantic net to represent the "meaning" of geographical objects and their interrelationships provides the capability to incorporate new entities, attributes, and relationships into the KBGIS.

Wu and Franklin (1987) describe an algorithm for polygon overlay that is implemented in Prolog. We include this work because of the importance of the polygon overlay problem to geographic database management and their use of Prolog to formalize the process of polygon overlay. This work in consistent with our suggestion that increased formalization of geographic knowledge be pursued (Robinson et al, 1986 a,b,c).

SRAS (Robinson et al, 1986d) is a spatial relations acquisition station. It is concerned with acquiring representations of natural language concepts to be used in subsequent queries of a geographic database. This is an mixed-initiative, question-and-answer system that chooses questions based on anticipated user response and its effect on the representation of the NL concept. It is one of the very few efforts in acquiring representations from 'experts' rather than developing rule-bases. Another unique feature of this effort is its recent concern with the composition of multiperson concepts for subsequent use in expert systems (Robinson and Wong, 1987).

Geographic Decision Support

Barath and Futo (1984) describe a system for comparing requirements of economic sectors and social factors. This goal-directed system is based on TS-Prolog. TS-Prolog is Prolog extended to allow for parallel processes and system simulation. Even though a simple example is presented, it is not clear whether the system is capable of using existing databases. This system also remains at the level of experimental applications, primarily funded by the Ministry of Industry of Hungary. Finally, like most of the above systems, the user interface has been given scant attention.

URBYS (Tani, 1986) is an expert system to aid in territorial planning and analysis of urban areas. Although there is recognition of the need for formalizing planning knowledge, it is nunclear whether the rigors of expert system construction will be followed in the elaboration of URBYS. Its organization is characteristic of the hybrid systems. Rather significantly, there is no formal provision for knowledge acquisition. It is left to the "expert" to change the rules and/or facts.

GEODEX (Chandra and Goran, 1986) was built to assist planners in evaluating site suitability for landuse activities. Its rules are drawn informally from a landuse planner. Using rules in its knowledgebase, GEODEX operates in a forward-chaining fashion applying site constraints drawn from the knowledgebase. There is mention of a capability of backtracking should the constraints prove so restrictive over the geographic database that no sites satisfy the constraints. As with most other systems, GEODEX is still under development.

DeMers (1986) reports an effort to develop a strategy for acquiring knowledge from landuse experts for use in the Land Evaluation and Site Assessment system. DeMers (1986) did not link knowledge acquisition to a formal method of knowledge representation, therefore little distinguishes this study from a multitude of other planning studies.

FUTURE PROSPECTS AND RESEARCH NEEDS

Robinson et al (1986a,c) suggest that many of the areas of past efforts will continue to be areas of research. For example, the map design problem will continue to be a focus of expert system development activity. However, it will increasingly make use of spatial databases. Given the research priorities of major funding agencies in the United States, terrain/feature extraction will continue as a very active area of expert system development. Geographic database management is quite a broad field and has implications for all the other research fields. Use of logic programming appears to be one of the more predominant trends which suggests that deductive geographic databases may become available soon. Much future work in spatial data error analysis, data capture and storage, and data transfer will be conducted within the context of this research theme. Development of spatially distributed databases containing data from a wide-variety of sources will encourage development of expert systems that navigate through a distributed system, combine contents of different databases, determine reliability of information, and maintain semantic variations.

Formalizing Knowledge

What is most notable about the efforts currently underway or proposed is that there is little concern for the process of knowledge acquisition and representation. Future developments of demand formalization of knowledge domains previously left partially formalized. These domains include cartographic design, terrain analysis, geomorphological feature extraction, extraction of natural and man-made features. This includes formalizing the process of knowledge acquisition and representation, something lacking in almost all of recent systems.

Formalizing Uncertainty

Much recent research in the field of artificial intelligence and expert systems concerns one of the byproducts of knowledge formalization - the formalization of uncertainty (Lesmo et al, 1985). It is clear that as progress is made in expert system development the importance of managing uncertainty will increase. For example, FES (Goldberg et al, 1984) included a reliability measure, Shine (1985) has reviewed the utility of Bayesian, Fuzzy, and Belief logics in feature extraction systems, and Robinson (1986) has reviewed the implications of fuzzy logic for geographic databases.

CONCLUDING COMMENTS

Given current computing infrastructure, expert systems are likely, over the near-term, to remain largely research/experimental systems. Developments are most likely to follow those already emerging. Prototypes will play an extremely important role in the future of this field. Prototypes based on a formal language of artificial intelligence will not only bring practical results but, more importantly, formally explore some of geography's less formalized areas. However, we feel that little will be contributed unless these prototypes are based on a rigorous approach to knowledge acquisition and representation. Thus, we feel that attempting to build a prototype expert system could be justified just on the amount of insight gained in the process of building it.

Recently Bobrow et al (1986) suggested that problems known to require a predominance of commonsense knowledge, english-language understanding, complicated geometric/spatial models, complex causal/temporal relations, or the understanding human intentions are not good candidates for current state-of-the-art expert systems. Most if not all of these problems are central to development of practical geographic expert systems. Thus, we suggest that there is much basic research to be done before practical geographic expert systems become a reality.

ACKNOWLEDGEMENTS

We would like to acknowledge partial support of a research grant from PSC-CUNY and National Science Foundation Grants IST-8412406 and IST-8609123.

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