ENQUIRY SYSTEMS FOR THE INTERROGATION OF INFRASTRUCTURE

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BIOGRAPHICAL SKETCH

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Note: The views expressed are not necessarily those of the Royal Australian Survey Corps. The paper stems from the results of personal experience and research by the author.

ABSTRACT

Up until now the major effort by organizations which encode data covering large geographic areas has been in the data base creation phase with relatively little effort on the use, or interrogation, of that data, particularly with respect to establishing enquiry systems of infrastructure. It seems that the next stage in development of systems will be in specialist enquiry systems, or expert systems - an expert system being defined as "a set or arrangement of things so related or connected as to form a unity or whole and being skillful and having training and knowledge in some special field". One important application of an expert system is the interrogation of infrastructure which is required for relief operations for natural disasters, search and rescue operations, and also for route planning and charting.

INTRODUCTION

The degree of automation in cartography has increased gradually over the past ten years. Many mapping organizations are now using computer-assisted procedures to produce their cartographic products at a quality that is now "acceptable for reproduction". Up until now the major effort by organizations which encode data covering large geographic areas has been in the data base creation phase with relatively little effort on the use, or interrogation, of that data, particularly which respect to establishing enquiry systems of infrastructure - infrastructure being the substructure or underlying foundation, and especially the basic installations, on which the continuance and growth of a community, state and country depends. It seems that the next stage in development of systems will be in specialist enquiry systems, or expert systems. The need for such systems is reflected in both the public and private sectors. Often quotes referring to the "need to have an integrated emergency management system which takes into account procedures, communications and transportation aspects" appear in newspapers following natural disasters (Governor Anthony Earl (State of Wisconsin) in The Capital Times of April 12, 1984). Clearly the Governor may not have in mind an expert system of the type discussed in this paper, but the concept is recognized, albiet at an elementary level. The private sector, when referring to expert systems are generally more precise as addressed by Bereisa and Baker (1983) when discussing the state of development in automotive navigation systems at Buick Motor Division, General Motors Corporation (Abstract only submitted to AUTO-CARTO 6).

This paper discusses a basic conceptual view of possible expert systems, discusses some characteristics of systems oriented toward infrastructure applications, examines components of an expert system, and considers relationships between various types of data, structure of information and implementation of algorithms by using a case study.

A CONCEPTUAL VIEW OF AN EXPERT SYSTEM

One of the dysfunctions in the development of automated cartography and geographic information systems up until now has been to draw a prospective user and the system designer closer together than, say, the relationship that existed between the user and the cartographer in traditional mapmaking. While this might seem an obvious benefit for any system, the dysfunction occurs in that all too frequently the "system designer" becomes the controlling operator with the "user" taking a subservient role - a point expressed by Bie (1983) who suggested that "autocartography has been technology-driven rather than resulting from user needs". There are innumerable articles and papers which support this notion - papers which describe in detail data input, editing, validating of data, and processing (often just to create valid data) procedures, and then briefly mention possible future applications of their systems. While such work has contributed greatly to our discipline, by addressing techniques, standards, and the like, as well as creating data bases from local project area to global coverage - a fundamental requirement for geographic information systems - the design of expert systems should be approached more directly from a user's perspective.

The development of expert systems should proceed with specific purposes and scopes clearly determined and defined, and at a level of sophistication that will serve the user adequately and efficiently. I am, however, concerned of uncertainty within the field of geographic information system development. While some authors have favoured research into expert systems (Smith 1984), others have been more pesimistic, noting that "few geographical problems command such attention" and query "on what topic do we really know what we are talking about in the sense of expert systems?" and "where is there a need for a daily (or at least frequent) use?" (Nystuen 1984 page 359).

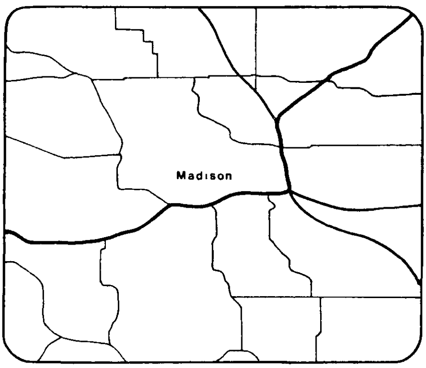
Perhaps the problem of conceptualizing expert systems has been caused by a lack of understanding of the role of cartography and an inadequacy of suitable definitions. It is not my intention to attempt to provide any sort of historical analysis of cartography, but rather to observe the direction the discipline has taken in recent years. This direction has been generally to add more "information" to cartographic products both directly and indirectly. Map symbolization and specification has been refined to enable more information to be printed directly onto the map. For example, tourist road maps contain road distances, rest areas, bus depots, highway interchange numbers, schematics of major roads with time, as well as distance, provided, and so on. Indirectly, much more information is provided in the form of leaflets, books, and so on, designed to accompany maps.

This direction should be maintained - that is to provide more information - but should be more selective with respects to specific needs. For example, a person travelling along Interstate Highway I70 through Colorado is probably only interested in accomodation within close proximity to I70 and not all accomodation in the State of Colorado.

CHARACTERISTICS OF INFRASTRUCTURE ORIENTED SYSTEMS

The scope of infrastructure is extensive and in one way or another is used on a daily basis. Infrastructure can be examined from a place or city perspective and from an area or region perspective. Infrastructure includes information on population and administration, medical facilities, water supply, power supply, airfields, ports, railways, roads and telecommunications.

Analysis of this information is equally diverse. Applications might include service functions such as the supply of road maps, flight routes and times, and accomodation as provided by tourist information centres; county and state functions such as management of service facilities, planning logistics for natural disaster relief operations, or rerouting traffic for highway construction ; or national and international functions such as aeronautical and nautical route charting and offshore area determination. It would be an ambitious attempt to try to list all such facilities, functions and applications and the intention is not to do so, but to merely highlight the vast number of applications and to indicate some parts or roles that expert systems might play in the future management of these resources. More specifically, some of the roles might be to plan routes through road networks to provide tourists with route information or to determine the best path to route vehicles to provide relief and aid operations (Figure 1); or to plan aeronautical routes and to locate navigation aids; or to determine buffer or protection zones along a coastline for navigation purposes (Figure 2); or to plot a route around barriers of features (Williams 1980).



Route through Dane County, WI on US151

Figure 1

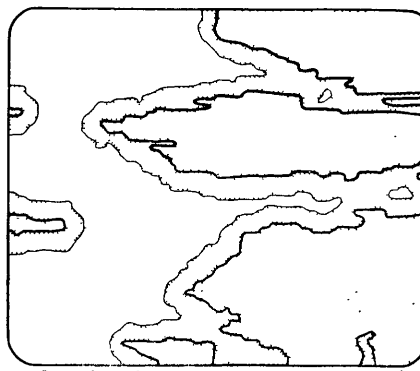

Bering Strait, AL (20 nautical miles)

Figure 2

In addition to type of infrastructure and the purpose of application, the geographic area of coverage has to be considered. Again this can be extensive in scope, ranging from local project area to global coverage. Thus a key characteristic of an expert system would be to manage information rationally with respect to area of coverage and application.

COMPONENTS OF AN EXPERT SYSTEM

Communication

The success of an enquiry (expert) system will depend upon its abitity to provide timely and reliable information. That is, a detailed and accurate response provided in two days time is of no value if the information is required by tomorrow. Likewise, too much information is often as bad as too little information. Thus an expert system should have an input system, or more accurately, a user communication module which should be able to interact during the information gathering process in order to increase or decrease the amount of information being provided. This interaction may be provided in a number of ways including by the use of menus, by question and answer, or by declarative statements

(Williams 1980). In any case, one of the functions of the communication module should be to validate the response, advise on the availability of certain information and to record a historical account of the task.

System response

In most discussions on systems, the processes performed by the system would be discussed at this stage and that followed by analysis of output. But with an expert system, it should be the final products that drive the intermediate stage and so this component should be examined next. The system output may be a visual display on a screen, a printed graphic or a text description and associated tables, with the precision of system response related to the intended use or user. For example, a person requiring general information on the route between Madison, Wisconsin and Green Bay, Wisconsin might be satisfied by a response which said to take Highway US151 and State Highway 26 to Oshkosh, a distance of 87 miles, and then Highway US41 to Green Bay, a further 56 miles, while another user requiring more detailed planning information, might need more specific details regarding road identification, intermediate distances, location of refuelling places and selected areas for accomodation, and yet another user, say a construction engineer, might require a detailed drawing and description of a particular road intersection. Therefore, the first user would probably be satisfied with a (text) statement, the second might require a route map annotated with selected information and accompanying guides, and the third might require high quality graphics and detailed information on terrain characteristics.

Information processing

In order to provide information as discussed above, adequate processors and related data bases are required. The number of "requests", and therefore algorithms to be analysed is a function of the actual requirements of an implemented system. For the analysis of infrastructure for search applications, algorithms are required for the determination of shortest, or best, paths in complex, or multi-level, networks such as road transportation systems; the determination of shortest paths between unrestricted nodes, those having no "physical links" but constrained by distance as the case of air navigation routes; and the determination of "proximity", "closest location", and associated features.

These algorithms are required to be processed in a multi-level environment and so the structure of the information and management of the information has to be designed accordingly. However, there are usually constraints on the type of structures that can be represented by various data base management systems. Most data base management systems will only support structures that satisfy certain properties required by the data base management system. The most common manner of characterizing structures is either as hierarchical or network structures. In a hierarchical structure each record type can at most have one owner. With a network structure more than one owner is allowed for each record type (Hawrysczkiewycz 1976). The interrogation of infrastructure requires retrieval and processing of information at both local and global areas of coverage and, so, a hybrid system of list, hierarchical, and network data structures incorporated into an appropriate relational model is required.

System knowledge
Some of the processes are deterministic while others may only provide estimates and so a portion of the data base and some algorithms could constitute a form of "system knowledge". This introduces the concepts of "knowledge" and "experience". Knowledge can be viewed as data including relationships, and deterministic procedures and techniques for providing finite answers. Experience can be viewed as those procedures and estimates that are "likely" to provide "reasonable" responses based on experience; for example, it is likely that the route between two cities is likely to be shorter using the Interstate Highway system than, say, the County road system.

In order to examine these components more closely, a case study is used. The study is concerned with the analysis of road networks in a multi-level configuration.

CASE STUDY

A case study is used to demonstrate the notions of knowledge and experience and the type of data structures required to perform queries on infrastructure type information. The case study specifically addresses the "shortest route through road networks" problem and processes data across regions down to the level of local roads, by using complex node structures, and a hydrid system of hierarchical, network and relational data structures.

Suppose one wishes to determine the shortest route in a road network between two terminal places or nodes. Then an algorithm (Figure 3) permits the analysis of a graph to produce a path in a network. Raphael (1976) suggests that, with heuristic algorithms, the success of the operation depends upon the "estimator"; that is the ability to efficiently determine the most likely distance to the terminal node from the present position.

As this process contains an "experience" operation, the "estimator", or factor by which the direct distance between a node and the terminal point is multiplied, can be modified by observing the current relationship, for example the class of link (road) currently being processed. Futher, because of the irregularity of road patterns, a route determined between an origin node and a terminal node may not necessarily be the same as a route determined from the terminal node and the origin node, and so an "experience" operation would be to determine both routes and select the shorter.

```
GRAPH PATH (Origin, Destination)
IF    <Origin = Destination)
THEN  <trace path to goal off "closed" list>
ELSE  <generate successors to Origin>
      <determine estimated distance to Destination as the
       summation of distance travelled and direct distance>
      <place node on "open" list>
      <select node from "open" list with lowest value>
      <place node on "closed" list>
      <GRAPH PATH (selected node, Destination)>
```

Figure 3

However, if one wishes to determine the route between a local road junction in the Township of Arena, County of Iowa and State of Wisconsin to a road junction in the County of Winnebago, State of Wisconsin, then the determination is required through a multi-level network. In this study the following relationships have been established: (1) <u>same base unit</u>, where origin and terminal nodes are in the same network, whether it be Town, County, or State; (2) <u>adjoining</u> units, for example adjacent Counties; and (3) <u>hierarchical areas</u>, for example a Township within a County. Figure 4 is a recursive algorithm to determine a route through a multi-level network and Figures 5, 6, 7 and 8 show a graphical representation of a solution.

```
PLAN PATH (Origin, Terminus)
IF    <same base unit>
THEN  <process unit>
ELSE
    IF    <unit on same level>
    THEN
        IF    <adjoining units>
        THEN  <determine transition point>
               <process adjoining units>
        ELSE  <locate exit from each unit>
               <process lower order units>
               <PLAN PATH (with exit points)>
    ELSE
        IF    <hierarchical areas>
        THEN  <determine transition point>
               <process lower order unit>
               <PLAN PATH (point to terminal)>
        ELSE  <locate exit from each unit>
               <process lower order units>
               <PLAN PATH (with exit points)>
```

Figure 4

It can be seen that with this hierarchical approach, it is possible that important parts of a route will be processed at too high a level for practical use. For example, the City of Madison appears as a single node on the state level data base. This situation can be remedied by defining certain key nodes as <u>complex</u>, or <u>special</u>, nodes whereby directories (part of the knowledge base) permit the evaluation of a node with input and output links to the determination on a lower order data level. This principle can be extended recursively to include such features as highway interchanges, such as I90/I94. Similarly, links may become complex links at a lower order as is the case for a divided highway and so may be directed. Further, links may be temporarily "non-operational" due to, say, flooding and so may be obstructed.

Town of PULASKI

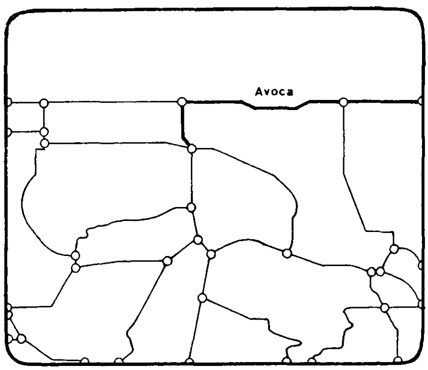


Figure 5

County of IOWA

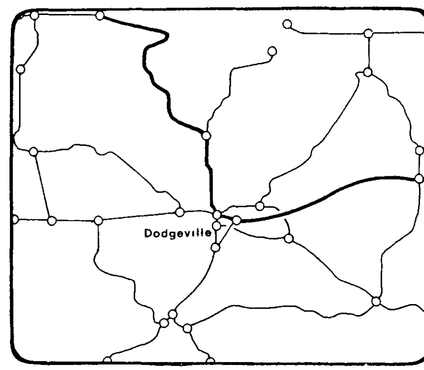


Figure 6

State of WISCONSIN

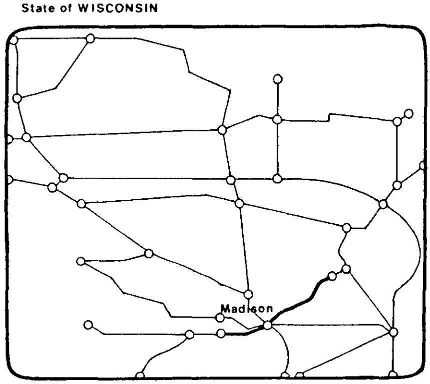


Figure 7

County of WINNEBAGO

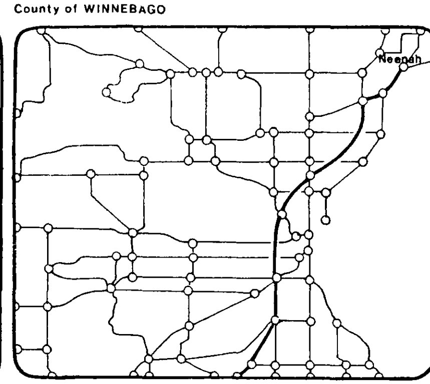


Figure 8

Measurement and reference

While it would be desirable to have a homogeneous data base with respect to area of coverage and coordinate system, this is neither practical nor possible - practical in the sense of having to transfer innumerable maps plans, and documents currently available to a common reference system; and possible in the sense that while data up to County level could be on planar system, State and Country level data bases should be on a spherical system. Thus an expert system should be able to detect deficiencies in the data base as well as transforming between data sets.

Data base structure

The term, data structure, has been used by many authors, often with slightly different connotations. Generally the term is used to describe data format types, for example vector, raster, string, polygon and so on and associated relationships such as topological structure. Information is data that has been processed to obtain specific results of relationships and increases knowledge of the recipient (Burch and Strater 1974). With respect to expert systems, the design phase should be viewed from the higher perceptual level and so the analysis should be of data base structure, or information structure. The case study emphasized the relationships of information. Figure 9 describes the data base structure.

```
                DATA BASE STRUCTURE FOR ROUTE SELECTION SYSTEM
                ----------------------------------------------
The following definition describes the structure of the data base using
Backus notation:

<file title>     ::= <system address> <base area code> (<area code>) <file type>

<system address> ::= {system disk drive} | {network address}

<base area code> ::= {US} | <other>
<other>          ::= {CA} | {UK} | {AU} | ....

<area code>      ::= {null} | <sub-unit code> <area code>
<sub-unit code>  ::= <state> | <county> | <town> | <special>        [#1
<state>          ::= {AL} | ... | {CA} | ... | {WI} | ... | {WY}
<county>         ::= ... | {DA} | ... | {IO} | ... | {WI} | ...
<town>           ::= ... | {AR} | ... | {DO} | ... | {PU} | ...
<special>        ::= {town subdivision} | {complex interchange} | ...

<file type>      ::= <directory code> | <data code>
<directory code> ::= <@> | <&> | <+> | <%>
<@>              ::= {directory of data available}
<&>              ::= {directory file of adjacent areas}
<+>              ::= {directory file of inter-level nodes}
<%>              ::= {directory file of intra-level nodes}
<data code>      ::= <n> | <n#> | <n'>
<n>              ::= {feature e.g. 1=boundaries, 2=roads, etc}
<n#>             ::= {data file of network nodes for feature "n"}
<n'>             ::= {data file of network links for feature "n"}

Note [#1         ::= sub-unit codes are in hierarchical order
```

Figure 9

CONCLUSION

The case study provided evidence that processing of multi-level networks is feasible. However, the study also highlighted the need for further research into experience and estimation operations, and techniques for converting experience information into knowledge information, although intuitively if particular routes are used regularly then this knowledge could be incorporated into directories.

This research indicates that enquiry systems for the interrogation of infrastructure are feasible and such systems will be demanded as digital data becomes freely available.

NOTE

All figures were redrawn and simplified for reproduction purposes from output produced by author-developed software.

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