TOWARDS A CARTOGRAPHIC EXPERT SYSTEM

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ABSTRACT

The need for a significant improvement in the quality of cartographic output from geographic information systems has been identified elsewhere. It has been argued that encoding of cartographic knowledge into a cartographic expert system would be the most efficient means of achieving this aim. This paper summaries the initial steps to achieving this goal. It is suggested that the cartographic design process can be broken down into a number of distinct tasks: Preliminary inquiries, generalisation, symbol assignment, symbol placement and evaluation. Each of these, while more or less linked to the others, is a single self contained entity. All are considered, however, to be dependent on a well constructed hierarchical structure to the data. Such structures may be prepared for each different diagram-type to be tackled by the cartographic expert system, and may contain much ancillary information. These structures may be used as a basis for map evaluation and contain information relevant to the symbol assignment and placement tasks. The amount of explicitly stated knowledge suitable for incorporation within an expert system is evaluated and further cartographic and computing research goals to enable the implementation of the proposed expert system are identified. Initial research is progressing on the algorithms for map evaluation, and the identification of rule bases for symbolisation and placement.

INTRODUCTION

Several cartographers have identified the adverse effect of the advent of computers on the quality of cartographic products. Indeed Monmonier (1984, p389) refers to the creation of 'cartographic monstrosities with unprecented ease' (see also Jenks, 1976; Muller, 1983). The problem has been caused by scientists, lacking cartographic training, having access to facilities which can as easily create bad maps and diagrams as they can good ones. The problem is exacerbated when scientists have access to extensive databases, and particularly when they are producing maps from Geographic Information Systems (GIS) (Robinson and Jackson, 1985). It is possible to envisage a number of software solutions by which cartographic designs may be improved. Menu-based selection and editing of map components is feasible, but the preparation of diagrams of even modest complexity, would involve the user in examination of an excessive number of menus which would be very time consuming and not guarantee any improvement in the finished product. A system with dynamic menus, where the contents of each menu would depend on some number of pre-defined parameters, may improve both the product and production time. The selection of contents for the menus would, however, involve the encoding of cartographic knowledge in the software, which would therefore be an expert system. Mackaness et al. (in prep) have, however, suggested a more holistic, expert system approach to encoding cartographic knowledge. This contribution starts by briefly summarising the conceptual background to such a system, before going on to define the components of a cartographic expert system and briefly discuss the initial steps taken towards its fulfilment.

EXPERT SYSTEMS IN CARTOGRAPHY

Expert Systems (or intelligent knowledge based systems-IKBS) have been extensively reviewed in the specialist literature from which a number of keynote books can be referenced (Barr and Feigenbaum, 1982; Hayes-Roth et al., 1983).They have also been the subject of recent articles in the geographical and environmental science literature (Smith, 1984; Wilkinson and Fisher, 1984; Davis and Nanninga, 1985).

The success of any particular expert system is dependent on the system being applied to a clearly bounded domain of knowledge, and decisions within that domain being consequent on a pool of ascertainable facts. Some of the cartographic knowledge is readily accessible in journal articles, reference works and textbooks on cartographic practice, too numerous to list here. On many maps and diagrams specific types of data are shown by conventional symbols, e.g. the use of colour on many geological and soil maps is standardised, as are the symbols used in national topographic mapping programmes. Where convention does not cater, however, rules must be used to select possible outcomes, and decide between alternatives. Recovering this knowledge and formulating these rules will be a more complex task and will involve interrogation of willing subjects who are prepared to see, in the very long run, their own skills incorporated within a machine.

From the preceding discussion, it can be seen that the cartographic design process can be identified as fulfilling all the criteria for expert system viability. Indeed, Monmonier (1985, p388) hints at the use of expert systems in map design, and Smith (1984, p155) explicitly states that it is a suitable area for expert system application. In the long run, totally automated map production systems can be envisaged, which would digitise map data, select data for display, design the form of the display, and finally draw the resulting diagram. Smith (1984) has, however, pointed out the over-optimism of researchers in artificial intelligence, when their predictions are compared with their delivery. Systems conducting all these cartographic functions are certainly far in the future, and may not even be desirable. Following the suggestions of Robinson and Jackson (1985), the present researchers have set themselves the more modest goal of designing an expert system to provide automated on-line assistance to scientists and others interactively displaying spatial data from GIS. In effect the system will be an expert cartographic front-end for a GIS to assist the user in map production. MAPAID has been suggested by Robinson and Jackson (1985) as a name for this system, and will be used henceforward in this paper to distinguish the short term research objective from longer term possibilities.

MODELLING MAP PRODUCTION FOR AUTOMATION

For the purposes of the MAPAID development, three human roles can be identified in the map production process:

1. the user defines the data to be mapped, and the reason for generating the map;

2. the cartographer selects a map type suitable for the most efficient communication of the data to the specified audience (map users), and prepares an appropriate design; and

3. the cartographic draughtsman executes the design.

The work described here is concerned with the second stage. This stage can itself be broken down into four seperate components which are discussed at length by Mackaness et al. (in prep).

1. The preliminary task is to gather information from the user such as data to be displayed, map type, definition of output.

2. To make decisions on levels of generalisation such as the acceptable levels of visual clutter and which base data to include.

3. Having identified the data categories to be mapped, symbols can be assigned.

4. The spatial conflicts must then be resolved. This can be acheived by various means: generalisation, change of symbols and/or their size and/or small movements of the position of the symbol.

5. The final stage of the expert system is to evaluate the map to 'measure' it's effectiveness.

Present research reported in the remainder of this paper is concerned with the issues of the symbol assignment problem.

The Search Process

Generation of a good map design via an expert system is effectively a search problem, choosing the design that satisfies the largest number of constraints. The aim is to find the solution in the most efficient way (see for example Charniak and McDermott, 1985). This can be done either by the application of a systematic unguided search procedure (which may be slow to converge to the optimum solution) or by the application of heuristics to constrain the search procedure, thus reaching the desired goal more quickly. Any search problem necessarily involves the definition of three main components:

1. Goal state description
   A quantitative description of a permissible map design from a cartographic angle. This will involve the definition of acceptable and unacceptable levels of spatial complexity.

2. Goal test function
   Functions are required to evaluate intermediate map designs to assess how near the map is to the optimum goal state.

3. Distance Evaluator
   This is a function that determines the degree of success that the system has had in reaching the optimum goal.

In practice each of these three components must be expressed in appropriate quantitative definitions and algorithms related to visual quality.

The central difficulty of automating the map design process is in quantifying these tasks, which are presently performed by the cartographer. This is essentially a cartographic problem, not a computer one. In this project we have restricted our 'design process' to a limited set of functions, primarliy because these relate to concise mathematical algorithmic methods for map evaluation.

When a cartographer is assigning symbols he is viewing the map, both as a whole, at the macro level, (to determine if the map will be balanced or display the appropriate message), and at a micro level to determine if the symbol will 'fit' (will not be obscured, or overshadow other data). The evaluation tasks taking place are complex and ill defined (see Muller 1983); 'most often in cartographic design the overall appearance of the map results from chance' (Morrison, 1980).

Initial Spatial Investigation

The first stage is to assess the total amount of data that the user hopes to include in the map. One method of imitating this viewing process is to spatially investigate the data to determine

a)the total number of point feature codes (fcs) and the number of times they occur.

b)the total number of line fcs and the number of times they occur.

c)the total number of area fcs and the number of times they occur.

d)the total number of fcs on the map.

Symbol Assignment

The initial assignment of symbols to fcs in view of the above information (using appropriate conventions) can then take place. A map must convey a theme; one reason for the existence of convention is to generate maps that are easily recognisable (without recourse to the key) and to aid in interpretation of special data against a backdrop of base data;

A look up table of conventions will include a list of possible choices for any one fc, and some abstract symbols for fc's that do not have a convention.

Symbol Evaluation

This will involve determining how much area is taken up by the various types of symbols, identifying symbol conflicts and resolving them (application of cartographic license, alternative symbols, size change etc.).

At a micro level, symbols must be distinguishable from their surroundings. A symbol will be indistinguishable if the background area is too similar in tone (or colour). As this conflict is spatial the system must determine which points and lines lie within each polygon. This is a simple point-in-polygon search. When a fc is assigned a symbol, the expert system would look at the tones of all polygons in which that fc occured, to see if the symbol is distinguishable.

Groups of symbols should not be so clustered that they obscure one another. One can have clustering made up of different fc points (and lines) and fc's of the same type. In order to resolve clustered data, one must first construct an algorithm that identifies the clusters. When considering an appropriate algorithm, one must realize that the resolution of symbol proximity problems must take into account the number of points clustered. If just two points overlap, then there is clearly an optimum vector of separation. This vector is defined as the line of minimum movement in order to seperate the symbols. If twenty points are in a cluster (say) then the separation of one pair may well make the conflict between other points worse. With this in mind two algorithms are proposed. The first is cluster analysis which determines how many points constitute a cluster and records the actual separation. The separation distance must be known so that the system can determine by just how much a group need be separated in order to resolve the conflict. The vector of separation is determined by first calculating the centroid of the cluster. The separation takes place parallel to rays extending from the centroid (a sort of big bang principle).

Spatial Evaluation

A map must 'look right' and therefore a formula is needed to determine how balanced a map is looking at each stage of symbol assignment. A formulae can be derived from Yoeli's statements on free map area. 'The number of symbols which can be placed on a map sheet can be expressed by the ratio of free space area/area of the symbol. Free map area is defined as the area of map which is not occupied by any other linear or point symbol of the same colour as the shown symbol.' (Yoeli, p90). The general equation for freeMapArea (FMA) is given as equation 1.

$$FMA_{points} = (totalMapArea - \sum_{1}^{nfc} S.\ sOcc)\ /\ totalArea * 100 \quad (1)$$

nfc - all types of feature codes.
S - area of symbol.
sOcc - number of occurences of that symbol.

The FMA can be calculated for indivdual fc, single data types, particular tones, or as an indication of visual content for the map as a whole. At any one stage during map design the system will calculate the free-map-area for particular colours and types of symbols. The thresholds of these values will depend on map type, audience and size of finished product, and on the spatial properties of the data (for example symbols used to show an even distribution may not be appropriate for showing a clustered distribution). If the thresholds are exceeded, then the expert system must decide on one or some of the factors that can be altered to reduce the threshold. There are various alternatives: reduce size of symbols, reduce amount of base data, or re-group data.

This work was seen as an essential prerequisite to constructing the expert system. It was felt that present data processing systems did not cater for such requirements. The expert system presently under construction is 'object orientated'. Inother words, it's actions are determined by the spatial properties of the objects under investigation (in this case spatial map data). In order to evaluate the map situation at any one stage, a production system must first calculate the spatial relationships between points, lines, and areas.

Required Functions

Let us now consider the type of mathematical interpretations that are required. The list below shows the type of functions required, the reason for needing it, and the possible solutions that the expert system might consider, should the function report true.

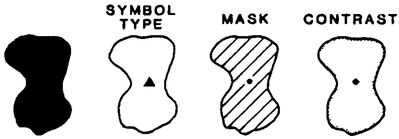
The Rule Base

It is the rule base which determines the interpretation of the spatial analysis (or gives meaning to the mathematical values). The rule base presently consists of about 50 rules concerning the definition of the components of a map, and the juxtaposition of symbols on a map. These rules have been gleaned from published literature. Though far from complete, it is expected that the final number may easily exceed 400. The objective when defining these rules is to enable the generation of the maximum number of potential permutations with the minimum number of rules. The rule base (which has yet to be configured into an expert system framework), consists of premises and assertions.

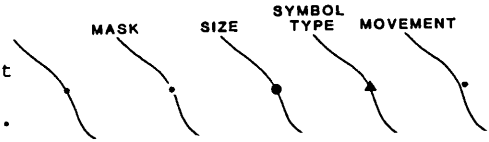
These rules not only define conflicts, but also provide guidance on resolution, and thus confine the choice of symbols to any one fc. Thus the selection of any one fc is guided by the knowledge of the cartographic expert system. Once all the fc's have a symbol then the map can be drawn and offered to the user as a potential solution. This then is the present objective of the research. At a later stage, the system could be developed so as to accept criticism from the user and to reselect symbols according to new constraints derived from the user.

FUNCTION REQUIRED	REASON FOR INVESTIGATION	POTENTIAL PROBLEM	POSSIBLE SOLUTIONS

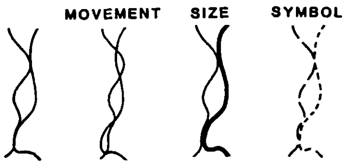
1) Is a point on a line? — Points must not be obscured by lines.



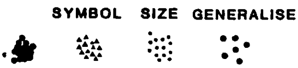
2) Is a point in polygon? — Points must not be obscured by polygon symbol.



3) For any two lines, how much segment overlap is there? — Line must not be obscured by line.

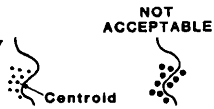


4) For any point fc, are they clustered? — Points must not obscure one another.

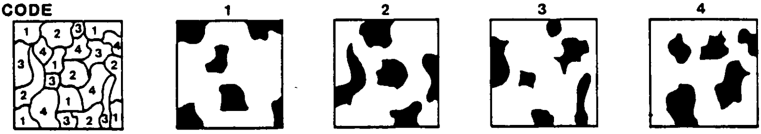


5) Total number of points in cluster? — If large number then spatial seperation method must not be used.

6) Centroid of the cluster? — To determine mean proximety of potential interference from lines and areas.



7) With area of polygon and number of occurences, calculate free map area. — FMA used to evaluate complexity of maps, and use of symbols.



FEATURE CODE	1	2	3	4	
FMA	18	27	36	19	100%
NO. OF OCCURENCES	9	6	5	6	26
MEAN Fc SIZE (FMA/OCC.)	2%	4.5%	7.2%	3.2%	

8) Number of different fcs for lines.
9) Number of different fcs for points.
— To determine FMA for points and lines, and thus derive a value of total map complexity.

CONCLUSION

The system proposed above is seen primarily as having a role in assisting non-cartographic users to access spatial databases to construct their own well designed maps. As spatial databases become more standardised and more openly available through network systems, there is likely to be a growing need for expert systems of this type. Certainly the growth in integrated geo-information systems and 'mobile' information systems displaying multiple overlaid data sets is likely to be an additional factor necessitating the development of cartographic expert systems generally. The present authors believe that the development of a cartographic expert system is a natural development in computer-assisted cartography. The object of this paper has been to emphasise the essential components and prerequisites of a cartographic expert system. While a simple system, to prepare a small subset of maps may be developed relatively rapidly, to achieve the sublety of an human cartographer, much knowledge engineering is required, and many fundamental issues of cartography require further research.

Although not all have been discussed in detail, it is possible to identify a number of specific theoretical and implementation tasks which need to be addressed before the implementation of a cartographic expert system can progress.

1. Elicitation of cartographic conventions.

2. Investigation of non-conventional rules for use in a rule base for generalisation, symbolisation and placement.

3. Quantification of visual 'noise', spatial clutter and aesthetic acceptability to enable the expert system to accept or reject candidate designs.

4. Define a suitable framework in which the expert systems can work, and develope software structures and rule-bases to encode information acquired in (1), (2) and (3) above.

5. Implementation of algorithms and data structures for efficiently constraining the search space to allow rapid generation of designs.

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