AUTOMATIC RECOGNITION AND RESOLUTION OF SPATIAL CONFLICTS IN CARTOGRAPHIC SYMBOLISATION

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ABSTRACT

One of the fundamental stages of the map design process is that of assigning and positioning representative symbols on a map. This is achieved in most computer cartography systems by user selection of the symbols, followed by the positioning of those symbols on the features nominated. If the symbols interfere with each other at all, the user must intervene. This user intervention is most undesirable because the changes made may have undesirable repercussions for the rest of the map; thus the process of change can become iterative and therefore time consuming. The objective of the research reported here is to automate this element of the design stage. Where points or lines overlap with each other or with others of the same type, three possible solutions may be recognised: re-symbolisation, re-location, and generalisation. The main area of research to date has been in the development and implementation of algorithms that apply cartographic license (clarification of information by localised small movements of features). The simplest problem occurs when points are not confined by any other map feature. This paper illustrates the progressive complexity of algorithms required as the solution becomes constrained by the increasing proximity of other features and argues the need for a solution that optimally clarifys such local conflicts whilst ´blending´ with the map as a whole.

INTRODUCTION

The Need For Automated Map Design

The techniques for transferring spatial data into computers (digitisation) and methods of accessing data (via geographical information systems- GIS) are becoming increasingly advanced (Green et al. 1985). This is in response to growing demands for efficient methods of handling the ever increasing volumes of spatial data. Parallelling this demand, A.I. techniques are being introduced at the data storage level, in the form of knowledged based GIS -KBGIS (Smith and Pazner 1984; Peuquet 1984). KBGIS have arisen directly from a real need to store and interrogate data efficiently, in a format that enables fast access to both raster and vector data. However these systems make no decisions on how the data is used and reveal limited information about the data.

The main component missing from the computer mapping environment is a system to control the design stage. This design role is normally performed by the cartographer (in consultation with the user), indeed ´nowhere in any production process do the needs of the users influence the nature of the product more than in the design stage´ (Page and Wilson. 1978, p157). But with increased ease of access, the design stage is being carried out by scientists and general users with little or no cartographic skill. With easy manipulation and selection of symbols, unwittingly patterns in the data are often either enhanced or suppressed, enabling the creation of ´cartographic monstrosities with unprecedented ease´ (Monmonier 1984, p389).

Potential Solutions

It is argued that the ideal solution to this problem is a computer system that mimics the role of the human cartographic expert. The advantage is that it would enable researchers with no cartographic skills to display field data in a variety of ways using optimal spatial designs (Mackaness et al. 1985).

In order for a system to mimic a human, ideally it must have equivalent human attributes: these include cartographic knowledge, a method of articulating that knowledge, and an ability to reason. Such mimicry is possible using artificial intelligence (A.I) techniques to construct an expert system. Expert Systems have been extensively reviewed in specialist literature (for example, Barr and Feigenbaum, 1982) and have been shown to be of interesting potential in design (R1), diagnosis (MYCIN), and prognosis (PROSPECTOR).

Present research is concerned with developing a system for one aspect of computer-aided cartography - namely evaluating and resolving spatial conflicts in map design. As discussed below, the problems are sufficiently complex that heuristic knowledge based methods may be the only way of resolving some of the central problems in this process.

PROBLEMS IN AUTOMATING MAP DESIGN

The process of cartographic design is a complex, interactive process between the user and the cartographer (see Morrison, 1980). It will depend amongst other things, on the requirements and knowledge of the user, and the facilities and experience of the cartographer. The complex process of map design can be considered under five headings.

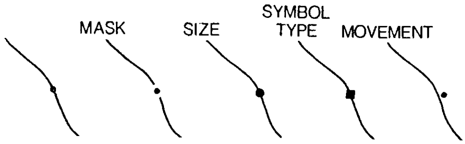
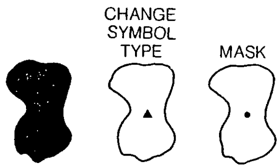
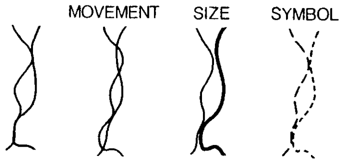
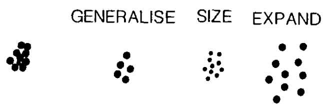
1. Gather from the user, information such as data to be displayed, map type, and map use.

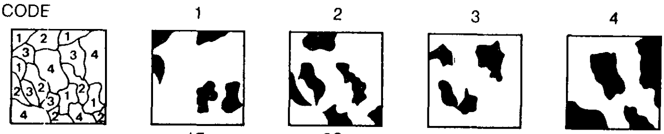
2. To make decisions on levels of generalisation such as the acceptable levels of visual clutter and which base data to include.

3. Symbols can be assigned depending on the data categories to be mapped.

4. The spatial conflicts must be identified and resolved. This can be achieved by various means: generalisation, change of symbols and/or their size and/or relocation.

5. The final stage of the expert system would be to evaluate the map by measuring it´s effectiveness.

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?	Contiguous lines can obscure information.		
4)For any points, are they clustered?	Points must not obscure one another.		
5)Number of and distance between points in cluster.	If large number then spatial separation method must not be used.		
6)Identify optimum centroid of cluster.	To spread points without destroying local spatial integrity.		
7)With area of polygon and number of occurrences, calculate free map area.	FMA used to evaluate complexity of maps, and use of symbols.		



	1	2	3	4	
FMA	17	25	19	39	100
NO. OF OCCURENCES	5	6	4	4	19
MEAN Fc SIZE (FMA/occ.)	3.4	4.2	4.8	9.8	

Figure 1 Evaluative Functions, Problems and Solutions

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. This contribution is a start in that direction and is based around a discussion of algorithms for identifying and resolving spatial conflicts.

ALGORITHM DEVELOPMENT OF EVALUATIVE TECHNIQUES

Optimising the design of a map includes aspects such as balance, clarity, and contrast. These aspects are governed by factors such as scale, content, and the size of the finished product. Techniques are required to evaluate the data spatially in order to determine the nature of the conflict, and having considered the possible solutions, to resolve that conflict. Figure 1 shows some types of evaluating techniques required. It demonstrates the type of conflict they will detect and shows possible solutions to the conflicts, from which an expert system might choose the optimum, given the constraints relating to those offending elements.

It is worth stressing that any conflict in a map is essentially a spatial problem. A monochrome example will be used to demonstrate this: let us suppose a map contains areas symbolised using the same tone area fill as a point symbol, such that any symbol falling within that area will be indistinguishable. A conflict will only occur if there are point symbols that must be represented within those areas. Otherwise there is no conflict.

Conflicts can also occur when there is a change of scale. Suppose a large pictorial symbol (a flag on a pole) is used to show the holes on a golf course. If the golf complex is large (or the number of holes few) then the use of pictorial symbols is satisfactory. If however there are a group of holes clustered together, or the map is produced at a smaller size then spatial conflicts will occur. Two facts should be apparent from the above illustrations; the first is that the database containing the information must be based on spatial proximity; no one item can be changed without due consideration of its impact on the rest of the map. Secondly, in order for an optimum solution to a conflict to be found, any one point (line or polygon) must ´know´ about its local environment and what other data lie in its immediate vicinity (it´s property list).

Spatial Proximity Data Base (SPDB)

Most cartographic data are digitised and stored in vector format. A great deal of research has been done on storing such information in such a form as to enable fast retrieval (specified according to area or feature - fc) from an efficient and compact storage space. The GIS requirements for a design, where the system (not the user) must identify the conflict, are however quite different.

The format and accuracy of both the data, and the database determine (to a large degree) the efficiency and ability of a system to determine and resolve spatial conflict. The structure of the database must enable the system to efficiently determine both the property list of any one feature, and the proposed symbol that will be used to represent that feature. A database based on spatial proximity was investigated by Matsuyama and coworkers (1984). The system must first search the database for spatial conflicts, and identify the components of each conflict. Identification of those components would not just include measuring the Euclidean distance between each, but also parameters such as the degree of enclosure (the amount by which a group of features are enclosed by a line).

A cluster analysis program has been written which uses least squares as a measure of distance between cases and average linkage to estimate the position of groups of cases in relation to other groups or individual cases (see Mather, 1976). The least squares method gives a Euclidean distance by finding the square root of the sum of the squares of the difference between the variable scores (x, y) of each pair of symbols. Average linkage has been selected as a reasonable method of clustering, because it attributes importance to the group rather than to extreme individuals. The program determines which items are clustered, how they are clustered (number of cases at each cluster level) and records clusters containing 'offending' points, where 'offending' is defined as points which are within a minimum distance of their neighbour. The array of points in Figure 2 are analysed and the results are pictorially shown in Figures 3. Figure 4 shows the 'spatial dendrogram' generated by the cluster analysis program. Such a 'tree' can be envisaged as diagramatically representing the database; as one moves down the tree, the system can automatically identify clusters, their components and proximity.

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Points  2 and  3 are  0.22 apart with  2 points in the cluster at level 1.
Points 10 and 11 are  0.28 apart with  2 points in the cluster at level 2.
Points  2 and  4 are  0.36 apart with  3 points in the cluster at level 3.
Points  6 and  7 are  0.45 apart with  2 points in the cluster at level 4.

   4 offenders recorded.


Number of symbols:    20
Number of variables:   2

        Cluster Analysis Tree Diagram
        =============================
Dendrogram of the distance similarity matrix -NNA.DAT

  1    --------!
               !
  2    -!      !
        !-!    +---!
  3    -! +----!   !
          !        +--!
  4    ---!        !  !
                   !  !
 10    --!         !  +-!
         +---------!  ! !
 11    --!            ! +-!
                      ! ! !
  5    -------------! ! ! !
                    ! ! ! !
  6    ----!        +-! ! !
           +--------!   ! !
  7    ----!            ! !
                        ! !
  8    ---------!       ! !
                +-------! !
  9    ---------!         !
                          !
 12    -------!           !
              +--------!  !
 13    -------!        !  !
                       !  !
 14    -----------!    !  !
                  !    !  !
 15    -----!     !--! +-!!
            +-----!  ! ! !!
 16    -----!        !-! +!
                     !   !
 17    ----------!   !   !
                 +---!   !
 18    ----------!       !
                         !
 19    ------!           !
             +-----------!
 20    ------!
```

Figure 4 Output from the cluster analysis algorithm

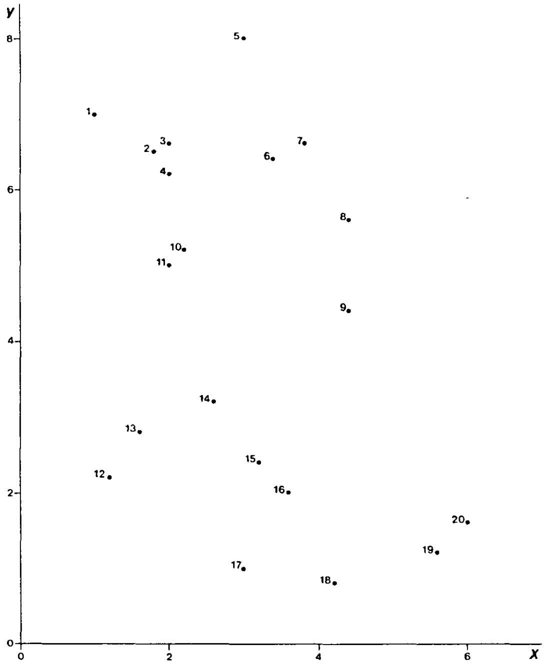

Figure 2 Randomly generated points

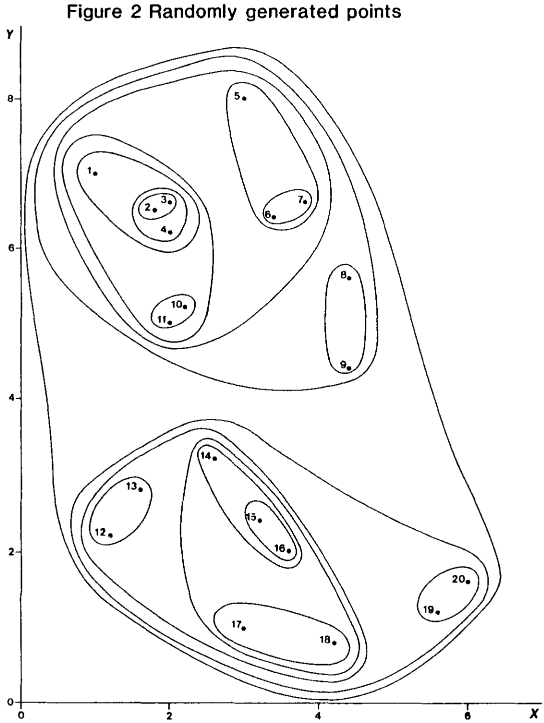

Figure 3 Clustering levels derived from cluster analysis algorithm

Proportional Radial Enlargement

As previously identified, there are a number of possible methods for resolving the problem of clustered data (Figure 1). One of those methods is to locally separate the points. It is not possible to separate the data by considering pairs of points, since the solution by movement of one pair, may infringe on adjoining data. Thus cluster analysis is used to determine how many points make up the clustered data. Any algorithm used to resolve clusters must satisfy the following objectives:

1. Their local spatial relationship much be preserved. Within the group of clustered points, the relative position of a point in relation to any other point must remain the same.

2. Whilst clarifying such information, the points must be moved a minimum distance in order to conserve spatial integrity. The amount of movement is determined by the initial proximity of points, and the size of the intended symbol.

One method that maintains ´shape´ is proportional radial enlargement; this involves selecting a centre and moving all the points away from the centre a distance, d, such that d is proportional to the original distance from the centre to that point. Where no other infringing data exist, the centre can be taken as the centroid of all the points (having equal ´mass´ or importance). The centroid, by definition will automatically gravitate towards the most dense part of the cluster, thus moving the majority of points the least amount. The shape of the group is preserved regardless of the position of the centre of radial enlargement (law of similar triangles). Figure 5 shows three such enlargements, each with different centres of enlargement. In Figure 5a the centre is the centroid of the points. Figure 5b shows another group of expanded points. Again the centre is taken as the centroid of the group. Some of the points now lie on the other side of the line. This is cartographically unacceptable; one solution is to alter the position of the centre. This could be done by altering the ´masses´ of selected points, which would effectively change the position of the centroid.

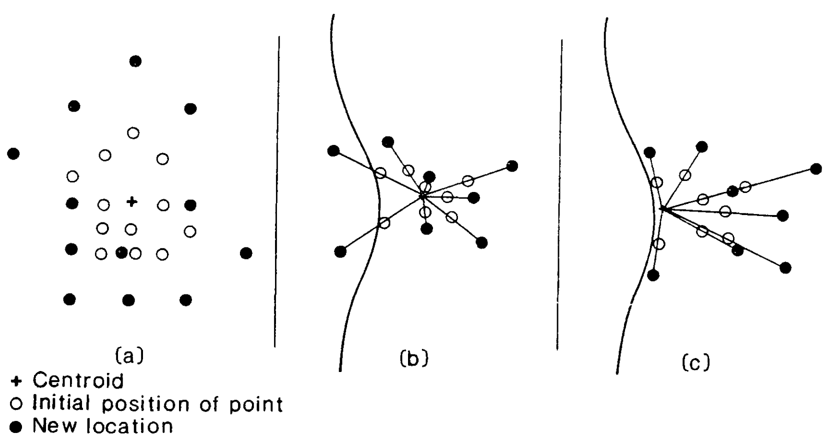

Figure 5 Radial Enlargement of Groups of points.

In all these cases the positions relative to each other are not compromised. There are however worst case situations where this solution is not appropriate (see figure 6), and alternative solutions (such as generalisation) must be considered.

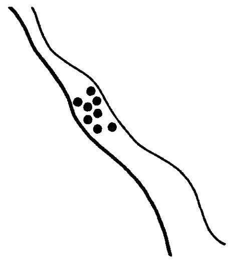

Figure 6 Worst Case

In a situation where spatial integrity was not important, (for example in a map showing train or bus routes) a high amount of total movement would be acceptable. In a map where spatial integrity was crucial then alternative methods must be used to clarify the data, such as a change of scale.

However when proportional radial enlargement is used, there is a loss of spatial integrity between the localised clustered features and the rest of the map (global features). One method used that is a compromise between the conservation of local spatial integrity and global/local blending is to use Gaussian distributions (optimally fitted to each expansion of points) to determine the ratio of movement. Thus the ratio of movement gradually decays towards the fringes of the cluster. Figure 7 compares two expansions. Figure 7a is a radial enlargement by a fixed factor of enlargement k, such that the distance of movement is proportional to the original distance from the centroid to the point. In Figure 7b the Gaussian decay curve is used to determine the value k, which decays to 0 as the distance from the centroid tends to infinity.

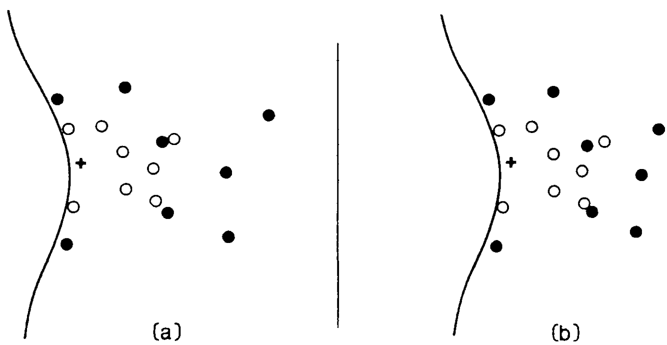

Figure 7 Proportional and Gaussian Radial Enlargements

Map Evaluation

At all stages there would be a need to evaluate the success of the design. Various parameters must be measured such as the total amount of movement of objects, changes in base data and re-symbolisation. The thresholds of these parameters will depend on map type, audience (those who will use the map) 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 an expert system might be used to decide on one or some of the factors that can be altered to reduce the threshold. These various alternatives include the reduction of symbol size and/or base data, and generalisation.

CONCLUSION

A human cartographer must first be able to identify conflicts in map design, and have at his disposal methods of resolving those conflicts. An essential prerequisite for a cartographic expert system must be equivalent methods for identifying and resolving spatial conflicts.

It is apparent that the solution to any spatial conflict involves first identifying the amount and types of data that lie in the immediate vicinity. Methods for efficiently searching the database for conflicts will depend on the format of the database. Only once the components of the conflicts have been identified can an optimum choice be made from the ´possible solutions´ (see Figure 1).

The approach outlined in this paper differs from other attempts to automate map design in that it views the problem of map complexity as a whole, not as a set of sequential design stages. No cartographer makes a map by selecting the data, symbolising, placing, adding text and finally drawing the key; rather they modify their decisions during the design, both at the global level (in deciding the maximum acceptable information content) and at a local level (where information is obscured because it is clustered together). If expert systems are to draw maps (and not just technical drawings) then they must have the equivalent cartographic senses; eyes with which to discern, knowledge with which to make decisions, and an inference system that enables it to change decisions during the design phase.

If a quantitative model can be developed that can optimally resolve clusters of points, it should be feasible to extend the method to include the similar types of problems found in line labelling and text placement situations. Further research is required specifically to algorithmically determine the degree of contiguity between lines (the amount of overlap), and calculate a value for the degree of enclosure. Alternative methods for resolving worst case clusters must also be identified (see figure 6).

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