RESEARCH ON GEOGRAPHIC SPATIAL RELATIONS AND REASONING IN AUTOMATIC MAP DESIGN AND GENERALISATION*

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Abstract

Spatial relations have been investigated by cartographers, geographers, psychologists and computer scientists etc. The results coming out of this research build the base for the approach presented in this paper: The spatial relations are classified in local and global relations, which are important for spatial data handling in automatic map design and digitial generalisation. In this paper, cartographic label displacement and geometric cartographic line simplification which are based on spatial relations and spatial reasoning are analysed. In cartographic label displacement, the relations between cartographic features and their labels are mostly very complex; therefore a progressive method of spatial relation handling is used. For the purpose of an effective communication of geographic spatial information, the spatial knowledge in the graphic simplification process is also analysed.

Keywords: Geographic Spatial Reasoning, Geographic Spatial Relation, Geographic Spatial Knowledge, Automatic Cartographic Design, and Automatic Cartographic Generalisation

0 Introduction

Geographic spatial relations must be handled in all cartographic processes. Cartographers use rules of spatial cognitive and cartographic symbols to communicate geographic spatial knowledge. For this reason, cartographers must exactly express the geographic spatial relations using a set of predefined cartographic symbols. In a digital cartographic environment, computers and software must be trained to “know” and understand geographic spatial relations, and how map-readers use the spatial relations to acquire the spatial knowledge. Therefore, geographic spatial reasoning in map design and generalisation should be investigated carefully. The proposed paper presents some new viewpoints on this topic.

Cartographers, geographers, psychologists and computer scientists investigate spatial relations. This research is the base for the approach presented in this paper: The spatial relations are classified in local and global spatial relations. These are important for spatial data handling in automatic map design and digital generalisation. A map is an abstract spatial model of the geographical space, from which related

* This research is supported by NSF, No. 49971068; by National Excellent Young Teacher Fund; by Huo Yingdong Fund for Young Teacher in University; by the Swiss Confederation and by the Institute of Cartography at ETH Zurich.

spatial knowledge can be gained. Furthermore the spatial knowledge in maps is classified into local and global spatial knowledge. At the hand of the spatial reasoning and the geographic meaning of every kind of spatial relation, the way is discussed to gain the geographic spatial knowledge from elementary spatial relations. These spatial relations must be stored in a spatial database by means of additional distances and directions.

The spatial relations on a map may be changed during the cartographic generalisation, but the cartographer must consider the consistency of corresponding spatial relations between the two spatial data models. In this paper, different rules about the change of spatial relations between spatial multiscale models are described. The equivalent relations of different spatial relations between multi-scale spatial data models and the fuzziness in process of change of spatial relations are analysed, too. In automatic map design and generalisation, many data operations are connected to spatial relations and spatial reasoning.

1 Spatial Relation and Spatial Reasoning

Spatial relations are very important in mapping and cartographic data handling. The classifications of spatial relations have been investigated (Egenhofer/Franzosa, 1991). The spatial reasoning and its application in GIS and digital cartography belong to the main cartographic problems, like for example the acquirement of spatial knowledge, the nature in change between the different spatial relations in the process of digital cartographic design and digital map generalisation.

1.1 The Classification of Spatial Relations

Egenhofer / Franzosa (1991) have presented the classifications of spatial relations based on the set theory. In this paper, the classification of spatial relations is considered. This classification method is well suited for cartographic vector data handling. The elementary units of cartographic objects are points, line segments and areas symbols. All spatial relations can be deduced from these. Thus new spatial relations result from the combination of spatial relations of elementary units. Elementary spatial relations are relations between point and point, or between point and line segment. The spatial relations between two points could be either identical or separated. The spatial relations between a point and a line segment could be as follows.

(1) A point is beside the line segment (including that a point could be situated on the left or right half-plane or is on the extension of this line segment);
(2) A point is on a line segment;
(3) A point and the endpoints of line segment are identical.

The spatial relations between two line segments can be deduced from the spatial relations between two points and between a point and a line segment. The number of spatial relations between two line segments is 8 (Fig.1) (Guo, 1998). The spatial relations between two lines, between a line and a polygon and between two polygons, between a point and a line and between a point and a polygon can be deduced from the elementary units of spatial relations with the same method.

The above-explained spatial relations are the spatial relations between elementary cartographic objects (point, line and polygon). In fact, there exist many other spatial relations in maps or in cartographic database, for example the traffic network, a group of contour lines, etc. The spatial relations within a map are mostly very complex; these express the geographic spatial knowledge by means of a group of cartographic objects, as for example, a group of contour lines. The cartographic objects can be classified into points, lines, areas, point groups, line groups and area groups (Guo, 1998). The cartographic spatial relations could be classified into local and global spatial relations. The local ones include the spatial relations between the elementary cartographic objects (points, lines and areas). The global spatial relations are the spatial relations between groups of cartographic objects. For example, the spatial relation between a road and a town, which may be represented by many polygons, or by other groups of cartographic objects. A group of contours is used for representing the relief.

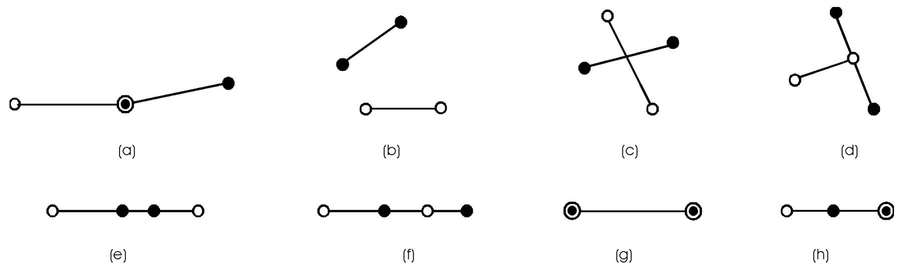
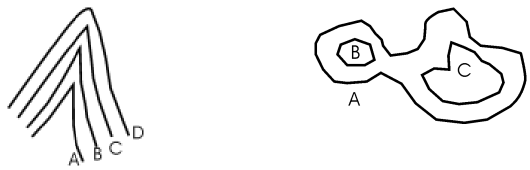


Fig.1 Spatial relations between two line segments

1.2 Spatial Reasoning and The Spatial Knowledge

The geographic spatial knowledge is the base for the communication of geographic spatial information (Chen 1990). In order to express existing geographic spatial knowledge on a map, the computers must consider the spatial knowledge of the cartographic database (Freksa/Mark, 1999). The spatial knowledge is a combination of the spatial relations and the attributes of the cartographic objects. According to the classification of spatial relations, the geographic spatial knowledge can be classified into local and global spatial knowledge. But this kind of spatial knowledge classification is relative. For example, there exist local and global spatial knowledge for a line, but the global spatial knowledge of a line is only the local spatial knowledge in a map or in a group of lines. In fig.1, a group of contours can represent the relief, but between two lines exit spatial relations, for example for line A and B in the fig.2 (a), and closed line A, B and C in the fig.2 (b). Evidently there are entire spatial relations in the group of contours, and in the entire feature of the relief, for example a tree structure of contours (Guo, 1998).



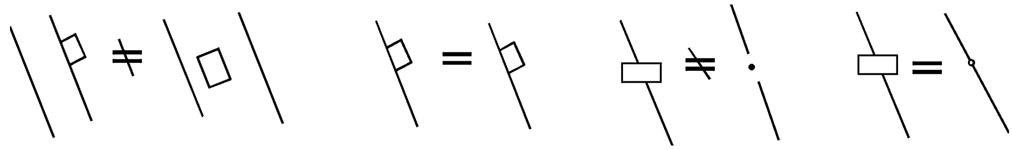
(a) (b)

Fig.2 The local and global spatial knowledge

1.3 The Change of Spatial Relations Between the Multi-Scale Spaces

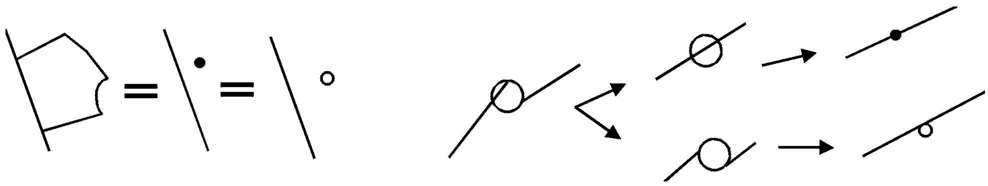
Map generalisation is one of the main problems in cartography and GIS. The same cartographic objects are represented in different detailed degree, according to the map scale. In the process of map generalisation the graph of map features must be simplified. The spatial relations should also be changed from a large to a small map scale representation. Therefore the change of spatial relations between a multi-scale representation should be investigated in map generalisation and the creation of a multi-scale cartographic database is necessary. The change of the consistency, fuzziness and equivalency of the existing spatial relations between two different map scales are to be considered in map generalisation and by the multi-scale spatial data handling (Guo, 1998).

The consistency of spatial relations means that the spatial relations on maps in different scales should be equal. The fuzziness of spatial relations is defined as the degree of the difference and the similarity between two spatial relations. The equivalency of spatial relations shows that the two different spatial relations possess the same meaning at a higher level (Guo, 1998). Fig.3(a) shows that the consistency of the spatial relation between a building and a road is not retained, but in fig.3(b), this relation is maintained. Fig.3(c) and (d) are similar with fig.3(a) and (b) respectively. Fig.4(a) shows that the distance from a building to a road is fuzzy, when the map scale is reduced. Fig.4(b) shows that the spatial relations between two lines and an area are abstracted, when the map scale is reduced. Fig.5 shows that the spatial relation between a line and a group of lines should be transformed into the spatial relation between a line and an area (or a point), when the map is generalised.



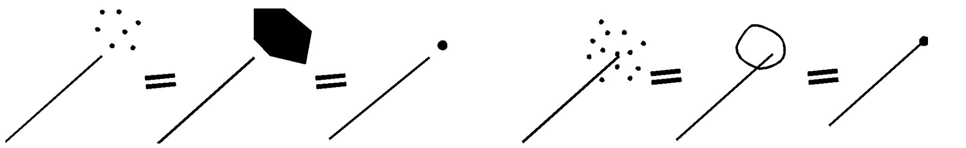
(a) (b) (c) (d)

Fig.3 The consistency and unconsistency of spatial relations



(a) (b)

Fig.4 The fuzziness of spatial relations



(a) (b)

Fig.5 The equivalence of spatial relations

2 Cartographic Label Placement

The label placement is still a time consuming task in the manual map production as well as also in automatic map making and GIS output generation (Zoraster, 1997), By means of spatial knowledge it is hoped to improve essentially the placement problem. The rules for label placement are well known (Imhof, 1975). In this test, the applied rules are as follows:

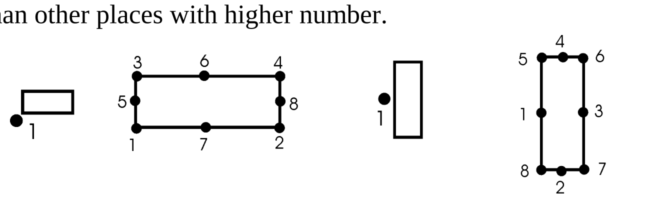
1). Labels should not overlap any other cartographic features.

2). Each label should not overlap any other labels.

3). The visual distance between the point feature and its label should be shorter in comparison with the other point features and their corresponding labels.

4). The places of point labels are not limited in a finite set, and different place of a label has different priority for label placement.

Fig.6 shows the typical label places for point features. The place of label with lower number is better than other places with higher number.



(a)Horizontal direction (b) Vertical direction

Fig.6 Typical label placement for point feature

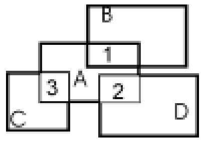


Fig.7 Intersection of rectangles

2.1 Determining the Least-Conflict Placement (The Greatest Probability Placement)

According to the least conflict of all rectangles, the first best typical label places for point features are identified. The size of the confilct can be evaluated with the quotion of the area of all rectangles and the area of its intersected parts. In fig.7, the rectangle A of a label intersects rectangles B, C and D, the conflict areas are rectangles 1,2 and 3. When the sum of the areas of conflict areas is minimal, this place of a label is selected. In fig.8 the result of selected typical label placement positions for the test data is represented.

2.2 Progressive Label Placement based on Spatial Relations

Fig.8 shows the existing conflicts between rectangles. Intersecting rectangles are not acceptable. The spatial relations between these point features and rectangles serve as base for a progressive label placement process. To solving overlapping placement rectangles, a progressive reposition of the labels is used. A new label position will be determined according to the spatial relation between the two conflicting areas. If there exists a solution, then the program tries to resolve the next conflict. The new possibility of label reposition can be caused by the reposition of another labels, because the spatial relations have changed. This process is repeated until there are no new label reposition (Guo, 2001).

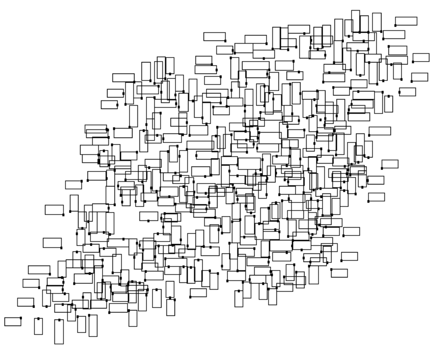


Fig.8 The conflict of rectangles

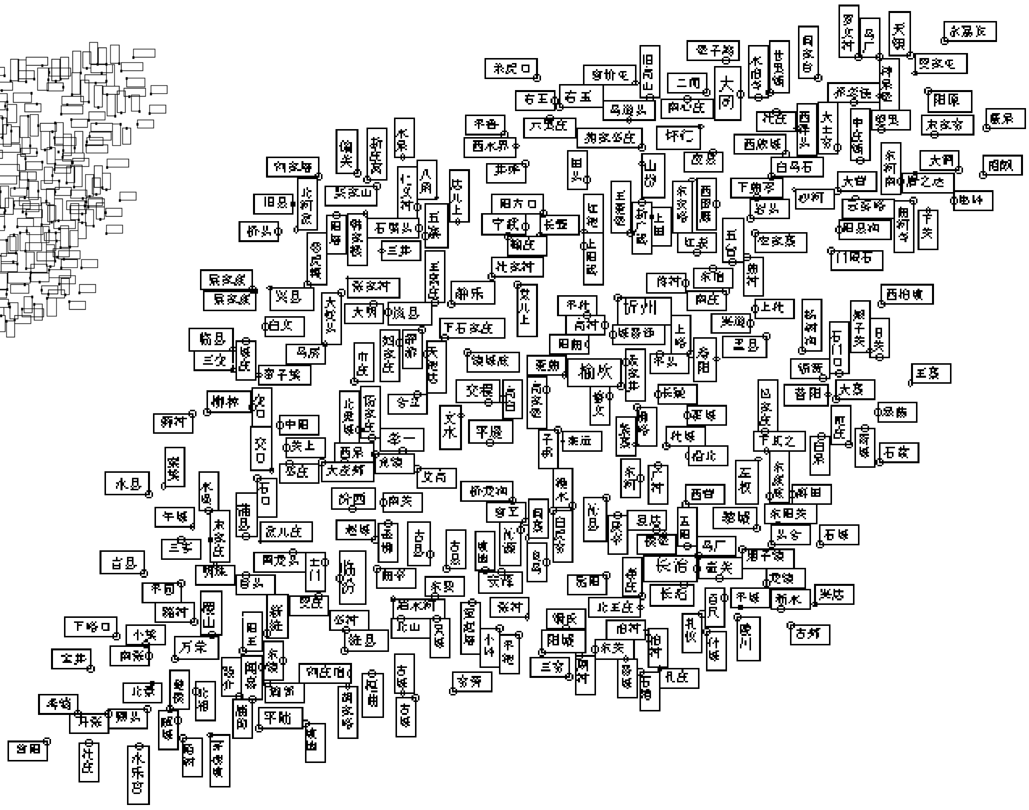


Fig.9 The result of the test data with IPM

There may be labels, that can not be placed due to some unfavourable situations at the moment, then some labels are eliminated. Figure 9 is the result of the label placement on the test data set.

3 The Progressive Graphic Simplification of Contours

The graphic line simplification influences the spatial relations. In paragraph 1, the characteristics of the spatial relation changes were presented. Now, we focus on the graphic simplification of contours. Only with a group of contour lines the topographic terrain can be represented well. Therefore a group of contour lines should be generalised together. But it is not necessary sometimes to obtain complete topographic characteristic lines, because contour lines represent a topographic surface with discrete digital data. If the map scale is reduced, a topographic surface can be only represented with a group of contour lines as a cartographic symbol. In this paper, the authors try to get the “sudden change” results with a “progressive change” method. This method is an extension of the progressive graphic simplification method (Guo, 1998).

3.1 The Establishment of the Spatial Relations of Contour Lines

First the continuity of contour lines is established. Then the spatial relations of the contour lines are determined. Contour lines should be continuous, but they are often broken. In order to satisfy this continuity, the discontinuous contour lines must be connected with line segments. The contour lines should be detected, for example contours broken on a cliff. Thus all contour lines and other lines, which have been found in the map, can form a lot of polygons. Based on these contour lines, the neighbor relations of contour lines can be determined.

In order to establish the spatial relations of contour lines, numerous rules should be considered. All these rules could be classified into mathematic rules and into mapping rules for the topographic representation. Based on these rules, a tree structure of the contour relationships can be established automatically (Guo, 1998).

3.2 Local Topographic Characteristics

The local topographic characteristics include : hilltops, depressions, ridge lines, ravine lines etc. We can decide by means of a tree structure, if closed curves represent the hilltop or depression. There will be a saddle between the two parallel and neighbored contour lines that were encircled in another neighboring contour line. For example, fig.10 (b) shows the corresponding tree structure of contours in fig.10 (a), and there exists a saddle between two closed contours B and C. Rivers are ravine lines, which intersect the contour lines. The other topographic characteristic lines can be easily found.

(a) A saddle (b) A tree structure of contours in left (a)

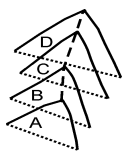
Fig.10 A tree structure of contours and a topographic characteric

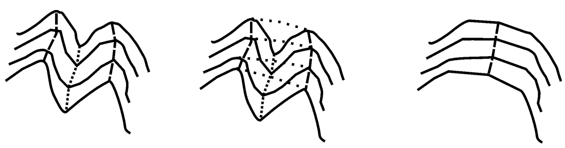
3.3 Progressive Simplification of Contour Lines

The progressive simplification is a linear process. The main idea is to acquire a result of contour lines generalisation through an iteration of progressive changes. It is very important to consider the the spatial relations among contours, especially those of potential intersections. Therefore the progressive graphic simplification used for line features must be adjusted. For this purpose the following steps are necessary (Guo, 1998).

1) The closed convex contour are processed in the same way as the ordinary closed linear features;
2) The parts without related characteristic lines of every contour line are handled first with progressive line simplification (Guo, 1998).
3) If bends are related to terrain characteristic lines, then the terrain characteristic lines and related points should be ranked according to their importance, for example the length of a characteristic line and the important degree of a characteristic point on a bend. In a progressive simplification of contour graphics, the processing is carried out according to characteristic lines importance from low to high. If equal importance is encountered, valley lines are preferential.

Characteristic lines are related with the bends of contour lines. These relationships between the characteristic lines and the related bends have been stored. In fig.11, bend A, B, C and D are related with a characteristic line, the average area of these bends can be calculated. The bends with the least-average area can be searched from these relationships,. If this average area is smaller than the given threshold, then the characteristic lines and related bends on the relevant contour lines are eliminated.



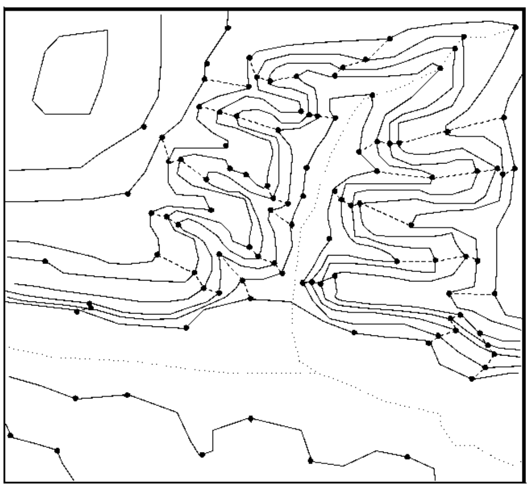


(a) (b) (c)

Fig.11 Related bends

Fig.12 The adjusted characteristic line after deleting bends

After deleting bends, the local corresponding characteristic points should be regenerated, and the neighbored characteristic lines are adjusted according to this conditions. In fig.13, the process of contours generalisation is from (a), (b) to (c). Fig12 (a) is a original contours graph. If the bend with smallest area is larger than the given threshold, the process stops. The ridge lines and the related bends are handled with the same method. Fig.13 shows the result of generalization on a test data set.



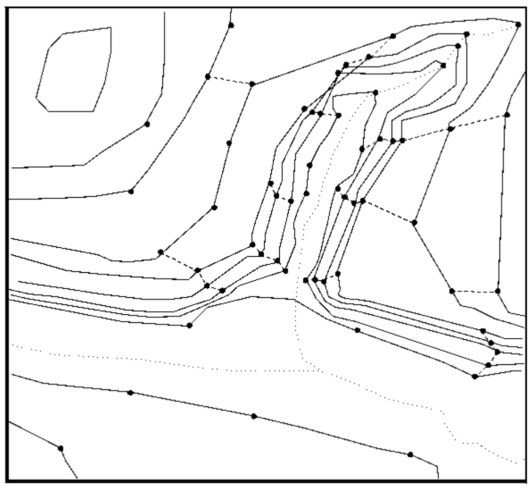


Fig.13 (a) Characteristic points and lines

Fig.13 (b)The result of progressive generalization

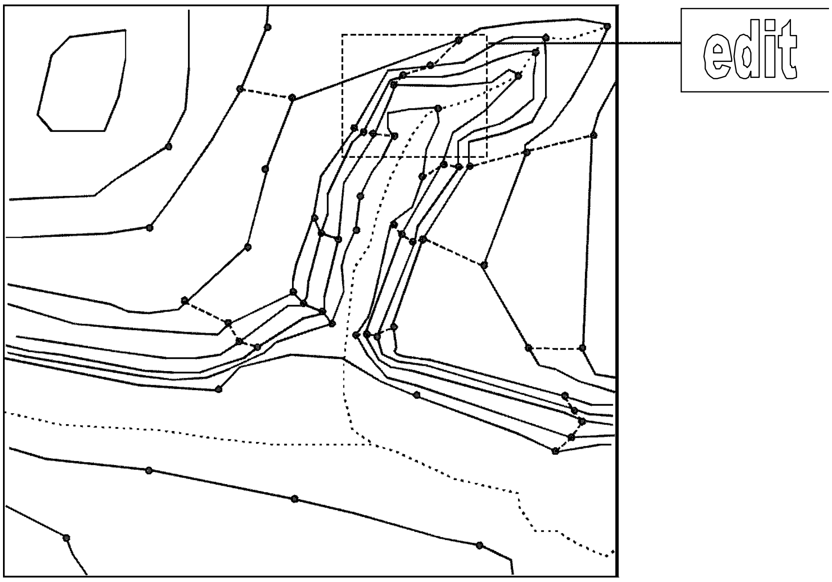


Fig.13 (c) The result of the intersecting data handling, after manual editing
Fig.13 The process of progressive contours generalization

4. Discussion

The spatial relations and spatial knowledge are a very important factor in the field of geographic spatial data handling. The aim of spatial reasoning is the acquisition of geographic spatial knowledge. How to find this spatial knowledge from the cartographic data base, and how to store, to manage and to use these spatial knowledge, is the main task in automatic map design and generalization. In this paper, only the characteristics of spatial relations are discussed, further on the application of spatial relations in label placement and graphic simplification is investigated in detail. In map design and generalization, spatial knowledge and spatial reasoning can be used for generating maps with a high graphic quality.

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