Conflict Resolution in Map Generalization: A Cognitive Study

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ABSTRACT

The generalization of a single type of feature such as linear or areal feature has been addressed in digital cartography. In real world applications, generalization almost always involves more than one type of feature. Assuming different types of features are generalized separately, an important issue is how to resolve the conflicts among different types of generalized features when they are assembled back together. The cognitive process concerned with this type of conflict resolution is not well understood. This is one of the major obstacles for developing a knowledge-based system for map generalization. This paper attempts to explore the process of conflict resolution using a human subjects experiment, focusing on the resolution of conflicts between linear and areal features. The experiment is designed as follows. First, a number of areal features published in the literature and a linear feature are obtained. Second, the two types of features are generalized to a certain scale separately, and then are assembled back together. Third, the results before and after generalization are given to different subject independently, and each subject is asked to identify the conflicts between the linear and areal features, and to rank several suggested strategies for resolving the conflicts. Preliminary results suggest that the violation of topological relations is the major source of conflicts, and the best strategy to resolve the conflicts is to displace the generalized line locally.

INTRODUCTION

There have been extensive research efforts on the generalization of a single type of feature such as linear or areal feature, and significant results have been achieved (MacMaster, 1986, 1987, 1989; Muller, 1990; Buttenfield and McMaster, 1991; Muller and Wang, 1992; Zhan and Buttenfield, 1993). In recent years, attention has been paid to the development of more comprehensive map generalization system in order to facilitate real world applications which involve the generalization of various types of map features, namely, point, linear and areal features (for example, Brassel and Weibel, 1988; McMaster and Shea, 1988; Shea and MacMaster, 1989). Although some theoretical and conceptual models have been proposed for such a system (Mark, 1989, 1991; Armstrong and Bennet, 1990; Armstrong, 1991; Shea, 1991), no comprehensive operational map generalization system has been realized. One of the major difficulties for developing such a system is the lack of full understanding of map generalization processes involving more than one type of feature. What is, for example, the process for generalizing a map containing three types of features? How does an expert cartographer identify the conflicts among different types of generalized features? How are the conflicts resolved by a cartographic specialist? These are questions that should be addressed before a comprehensive map generalization can be fully realized.

This paper explores the human cognitive process for conflict resolution in map generalization through human subjects experiments. Here conflict is defined as the violation of spatial relations during map generalization. When different types of features are generalized separately, an important issue is how to resolve the conflicts among different types of features when they are assembled back together. The cognitive process concerned with this type of conflict resolution is not well understood, and remains as a major obstacle for fully automate the process of map generalization. We will focus on the process of identifying conflicts as well as the process for conflict resolution between linear and areal features in this discussion. We will first give a brief discussion of spatial relations and its connection with conflict resolution in map generalization.

SPATIAL RELATIONS AND CONFLICT RESOLUTION

The basic idea behind map generalization in most cases is easy to state: reduce the complexity of visual information in such a way as to retain important aspects and suppress unimportant ones. Some of the things to preserve are geometric, and McMaster (1987) has done an excellent job of evaluating various line generalization procedures, primarily according to geometric summary measures. But cartographers have also always be concerned with preserving the semantics of maps, especially spatial relations. To formalize this, it is necessary to provide formal definitions of spatial relations as well.

Recently, Max Egenhofer and his colleagues have developed new ways to characterize topological spatial relations. This approach is termed the '9 intersection' because it identifies an interior, a boundary, and an exterior for each entity, and then tests which of the 9 possible intersections (3 parts times 3 parts) are non-empty. The 9-intersection model was first proposed by Egenhofer and Herring (1991), and has been shown to have much more power to characterize spatial relations than had previous formal models of spatial relations (see Egenhofer et al., 1993). It has also been found to be closely related to the ways that people characterize and distinguish spatial relationships in language (Mark and Egenhofer, 1992; Mark and Egenhofer, under review).

The major concern of the present paper is how to preserve spatial relations between a line and some regions as both are generalized. For relations between a line (simple, unbranched) and a region (simple, connected region with no holes), Egenhofer and Herring (1991) found that 19 topologically-distinct spatial relations between such entities could be distinguished, depending on where the ends and the body of the line lie in relation to the parts of the region. Ideally, the topological spatial relation, as defined by the 9-intersection, should be the same after generalization as it was before. And if this is not possible, the spatial relation after generalization should be a 'conceptual neighbor' of the relation before.

For long lines that pass through the study area, such as those examined in this study, only those spatial relations with both ends of the line outside the region remain relevant. Of the 19 relations distinguished by the 9-intersection model, only 3 would meet this criterion, and these are differentiated by whether the line is entirely disjoint from the region; or the body of the line intersects with the interior of the region; or the body of the line just touches or is co-linear with the region's boundary. The performance of an algorithm, or the judgements of a cartographer, can be based in part upon whether the spatial relation changes among these categories from before to after the generalization operation(s). If subjects tend to preserve spatial relationships, then an algorithm or rule which does not should be modified, or a post-generalization displacement or geometric adjustment should be performed to re-establish the 'correct'

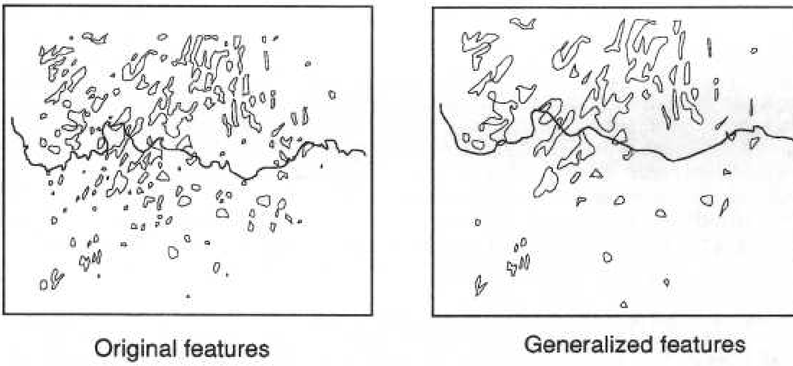

Figure 1. An example of the stimuli used for conflict identification

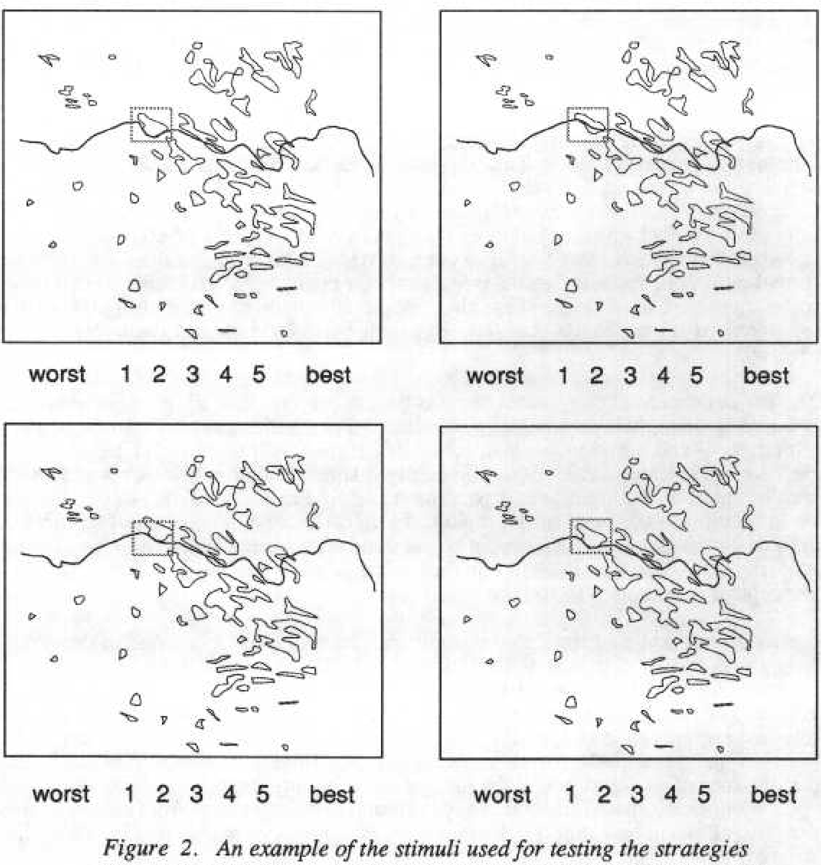

Figure 2. An example of the stimuli used for testing the strategies for conflict resolution. A subject is aksed to rank the results from the four strategies.

spatial relation. On the other hand, if some changes in topology bother the human subjects whereas others do not, rules could be developed to 'fix' only those cases which contradict the human tendencies. Moreover, some cartographers suggest that local displacement of the generalized line is probably the most common strategy for resolving conflicts between linear and area features. But more rigorous evidence is needed in order to support this intuition. We will now turn to discuss the experimental design.

EXPERIMENTAL DESIGN

In order to obtain the data for the experiment, a number of areal features published in the literature and a linear feature from real world data were obtained. Then, the linear feature was overlaid with the areal features in several different ways in order to obtain a number of possible spatial relations between the linear feature and the areal features before they are generalized. The two types of features were further generalized to a certain scale separately, and then assembled back together. The areal features and their generalized versions are from Muller and Wang (1992). The linear feature is from Zhan and Buttenfield (1993). The subjects used in the experiment were graduate students at the Department of Geography, State University of New York at Buffalo. All of them had some training in cartography and/or GIS.

The experiment consisted of two parts. Part I was intended to test the process of identifying conflicts between linear and areal features. Part II was used to test what strategies a person is most likely use to resolve the conflicts.

The following written general instructions were used at the beginning of the experiment in order to give the subjects some basic background information about the experiment.

> *"There are two versions of map features used in the experiment: the original one and the generalized one. Each of them has a linear feature and a number of polygonal features. The linear feature and the polygonal features are generalized first, and then assembled back together. It is assumed that the polygonal features and linear features are 'correctly' generalized, and our goal here is only to resolve the conflicts between the linear features and the polygonal features."*

The following written instructions were given to the subjects in Part I of the experiment, followed by two diagrams showing features before and after generalization. Figure 1 is one example of the diagrams.

> *"Each figure on the following pages shows a version of original features and a version of generalized features. Please identify (circle) the conflicts (anything that you do not feel is right)* ***between the linear features and the polygonal features*** *in the generalized features (lower portion of the diagram)."*

At the end of Part I, a subject was asked to "(Please) describe in writing how you found the conflicts."

In Part II of the experiment, the following written instructions were given to the subjects first.

> *"Each figure on the following pages shows a number of suggested strategies for resolving the conflicts* ***between the linear features and the polygonal features*** *in the generalized features. Please rank (choose a number between 1 and 5) the suggested strategies for the conflict resolution. Please use the relevant version of original*

features as reference if necessary."

Then two groups of diagrams are presented to a subject. Figure 2 is one example of the diagrams in the first group. The spatial relations between the linear and areal features are the same, but conflict to be resolved in each diagram is different. The first group consists of 3 diagrams, and the second is composed of 2 diagrams. The original features (before generalization) for each group was provided to a subject for reference purpose. In each diagram, results of conflict resolution by four suggested strategies were presented to a subject. These four strategies are: (a) modifying the geometry of the linear feature locally, (b) modifying the geometry of the areal feature locally, (c) displacing the linear feature locally, (d) modifying the geometry of the linear feature and the geometry of the areal feature locally. The subject was asked to rank the result of each of the suggested strategies. At the end of Part II, each subject was asked to "(Please) describe in writing how you would resolved the conflicts, if you think you could do better than any of the examples (use a drawing if necessary)." The results of the experiment are discussed in the following section. So far we have obtained results from seven subjects.

RESULTS

Number of conflicts identified

The number of conflicts identified by the subjects varies widely. For the first diagram, the number varies from 1 to 5 with the mean of 3. For the second diagram as shown in Figure 1, the mean is 3.4, the highest number of conflicts identified is 6, and one subject identified no conflicts. This implies that conflict identification is very subjective.

Another interesting question is what type of violation of spatial relations is considered a conflict. There are general agreements among the conflicts identified by the subjects. In the first diagram of Part I, six subjects agree on one conflict, and another two conflicts were also identified by four subjects. In the second diagram as shown in Figure 1, two conflicts were identified by five subjects, and one conflict is identified by four subjects. The results of conflict identification are summarized in Figure 3 for the diagram shown in Figure 1.

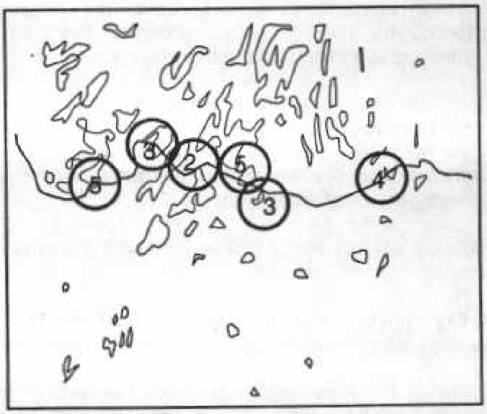

Figure 3. Number of subjects identifying it as conflict.

The process of identifying conflicts

It is clear from the subjects' written comments that the general process is to follow the linear feature and compare the spatial relations between the linear feature and the areal features in the versions before and after generalization. This suggests that relevant algorithm should try to mimic this process. All subjects wrote down the reasons why a conflict is identified. The reasons are all related to the violation of spatial relations between the linear features and the areal features after generalization as indicated in Section 2. In addition to the spatial relations, some subjects suggest that finer distinctions should be made, such as the distance between the linear feature and the areal features in the original maps must also be preserved proportionally in the generalized ones.

The best strategy

Five conflicts are used in Part II of the experiment. The results of conflict resolution of the five conflicts by four different strategies are evaluated by the subjects. The average score of the results by the four strategies is depicted in Figure 4. It can be seen from Figure 4 that the results by the strategy of "displacing the line locally" receives the highest score, 4.7. Thus it can be considered as the most recommended strategy. This is consistent with the general linguistic principle that linear features are normally located relative to areal features (rather than the other way around), and that the areal features are less movable. The results by the strategy of "modifying the areal feature locally" receives the lowest average score, 2.9, which may not be used at all. These results are in conformance with the general intuition. However, the other two strategies can not be excluded as evidenced in this experiment. The strategy of "modifying the geometry of the linear feature locally" is scored 4.0, and the strategy of "modifying the geometry of the linear feature and the geometry of the areal feature locally" got a score of 3.9. But the issue of which strategy to be used under what condition remains to be investigated.

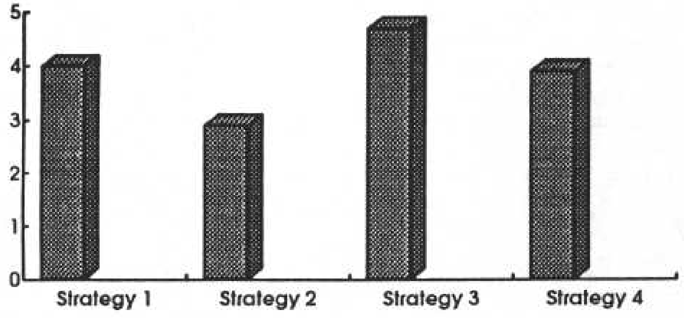

Figure 4. Mean scores of different conflict resolution strategies. Strategy 1: modifying the geometry of the linear feature locally, Strategy 2: modifying the geometry of the areal feature locally, Strategy 3: displacing the linear feature locally, Strategy 4: modifying the geometry of the linear feature and the geometry of the areal feature locally.

SUMMARY AND FUTURE WORK

Preliminary results clearly suggest that the conflicts arising in map generalization (violation of topological relations in this study) should be resolved, and among the four suggested strategies for resolving the conflicts, the results of displacing the generalized line locally received the highest rank. Although more experiments are needed in order to draw more rigorous conclusions on this, existing algorithms or rules should be modified in order to facilitate conflict resolution when more than one type of feature is involved during generalization.

Clearly, the experiment should be run using subjects with more cartographic generalization expertise, and should be repeated with larger samples. As the linear features and the areal features are taken out of context, the semantics of these features are not considered in this paper. The influence of the semantics on the identification of conflicts and on the strategies for conflict resolution is worth investigating.

For an automatic procedure for conflict resolution to be effective, it must accommodate the following issues: the identification of the conflicts, and the resolution of the conflicts. Either of these issues alone could be a challenging task, for instance, areal features before or after generalization can be completely different in the digital environment; to identify the conflicts, the procedure must be able to 'recognize' the corresponding objects in the original and generalized versions of features.

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