VISUALIZING CARTOGRAPHIC GENERALIZATION

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ABSTRACT

Map generalization is a complicated and not well-understood process. In order for users to go beyond the simple and arbitrary application of generalization operators, and accompanying tolerance values, to features in databases, visualization techniques must be designed to allow a better understanding of the effects. Through such visualization users can quickly understand, and adjust, their decisions. This paper proposes, given an existing framework of the generalization process in both vector and raster mode, a series of techniques for visualizing the outcome. Several graphic examples of such techniques are provided.

INTRODUCTION

As evidenced by the growing literature and number of conferences on the topic, interest in automated map generalization is rapidly growing. The reason for this increased attention to map generalization is obvious: with well-structured spatial databases now commonly available (such as TIGER), the creation of multiple representations from these master databases, and more complex types of spatial analyses, require sophisticated capability to generalize these data. Complete automated generalization remains one of the major unsolved problems in digital cartography and GIS.

Multiple operators for the generalization of digital databases have been developed and fully tested in both a vector and raster format (Rieger and Coulson, 1993). The model detailed by McMaster and Shea (1992) establishes a classification of both vector-based (point, line, and area), and raster-based (structural, numerical, numerical categorization, and categorical) operations. Vector-based generalization includes operations such as simplification, smoothing, enhancement, and displacement; sample raster operations include gap bridge, erode smooth, and aggregation. Unfortunately, for both types of operations, methods currently do not exist for visualizing the results of the generalization process. For instance, simplification involves filtering unnecessary coordinate data from the line; yet the user, other than through rather subjective visual comparisons and static geometric measures (McMaster, 1986), does not have analytical or visual methods for ascertaining the effect, or quality, of the simplification. In this paper methods are presented for visualizing the effect of several generalization processes. For instance, a common generalization practice would be the simultaneous application of simplification, smoothing, and displacement operations to features (McMaster, 1989). However, different algorithms and parameters might be applied to each feature with current interactive software. To visualize these processes, one approach might alter the *hue* of each feature with the operator, *saturation* with number of iterations, and *value* with tolerance level. Features that are both significantly simplified (=blue) and moderately smoothed (=red) would appear as a mixture of the colors, but with a higher blue content. Multiple iterations of an operation (i.e. smoothing) would increase (red) saturation. Other possible visual variables used to view generalization include size (parameter level) and texture (operation).

VISUALIZING VECTOR-MODE GENERALIZATION

Several frameworks for the organization of vector-based generalization operations have been presented. For this paper we will use the framework presented by McMaster and Shea (1992), which identifies the fundamental operations of *simplification, smoothing, aggregation, amalgamation, merge, collapse, refinement, typification, exaggeration, enhancement, and displacement.* To graphically understand the effects of a generalization process, a set of basic visual techniques must be established. For this purpose, we turn to the work of Bertin and the well-established visual variables. However, not all visual variables are appropriate, and addition visual methods must be designed. This may be seen more clearly with the operations of merge and simplification.

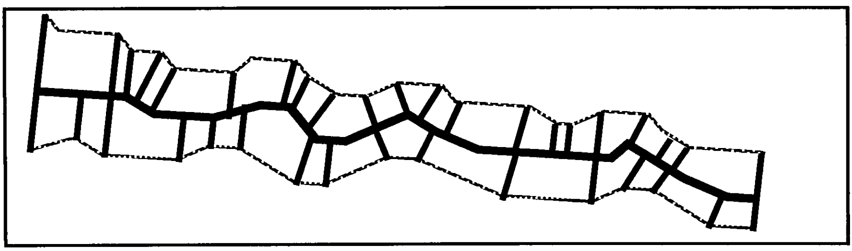

Figure 1. Visualization of operation merge.

Merge and Simplification

For the generalization operation **merge,** one simple approach for visualization involves creating a "millipede" graphic (Figure 1), where the legs depict distance to the original two boundaries that have been fused together.

Figure 2 depicts the potential use of value in visualizing the effect of a **simplification** operation. Simplification is a basic data reduction technique, and is often confused with the broader process of generalization. Simplification algorithms do not modify, transform, or manipulate x-y coordinates, they simpy eliminate those coordinates not considered critical for retaining the characteristic shape of a feature. A visual technique, then, must impart the idea of information loss.

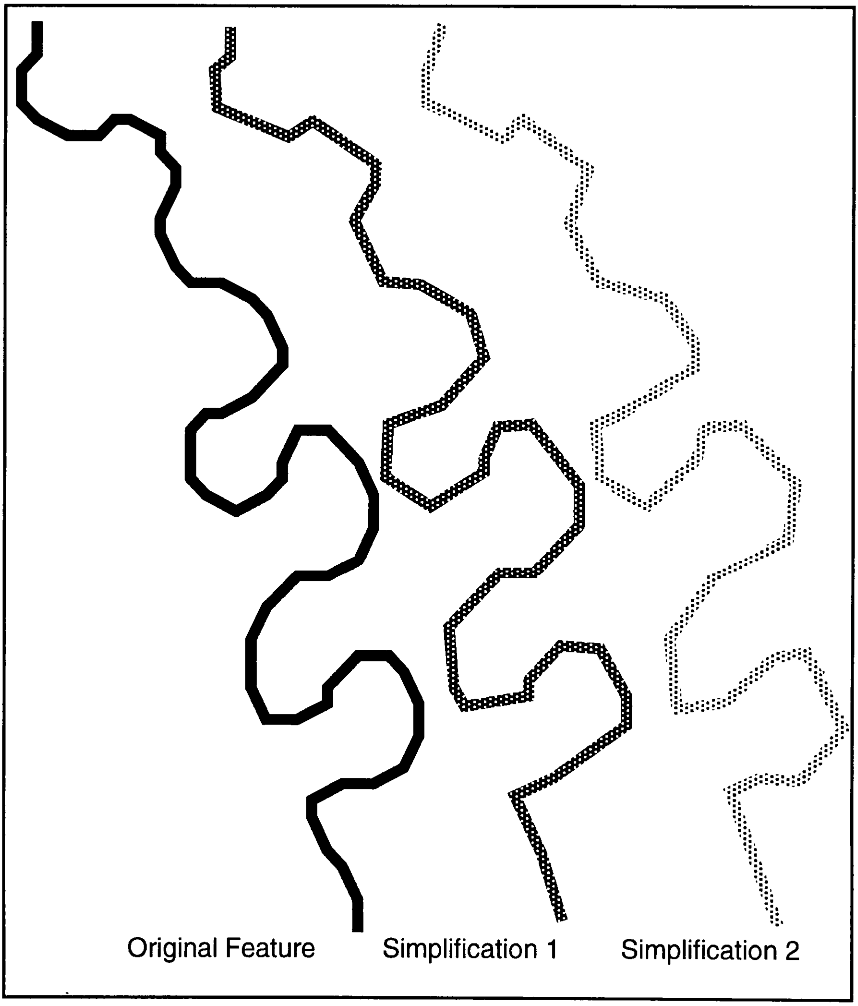

Figure 2. Use of value to depict increasing simplification

Here such visual variables such as size, value and saturation seem appropriate. This illustration uses value, where, as coordinates are eliminated through the process of simplification, the line begins to "fade", representing fewer coordinates along the line. Other visual techniques might include depicting the displacement vectors, or areas lost, through the application of a simplification operation. Such a technique is illustrated on Figure 3.

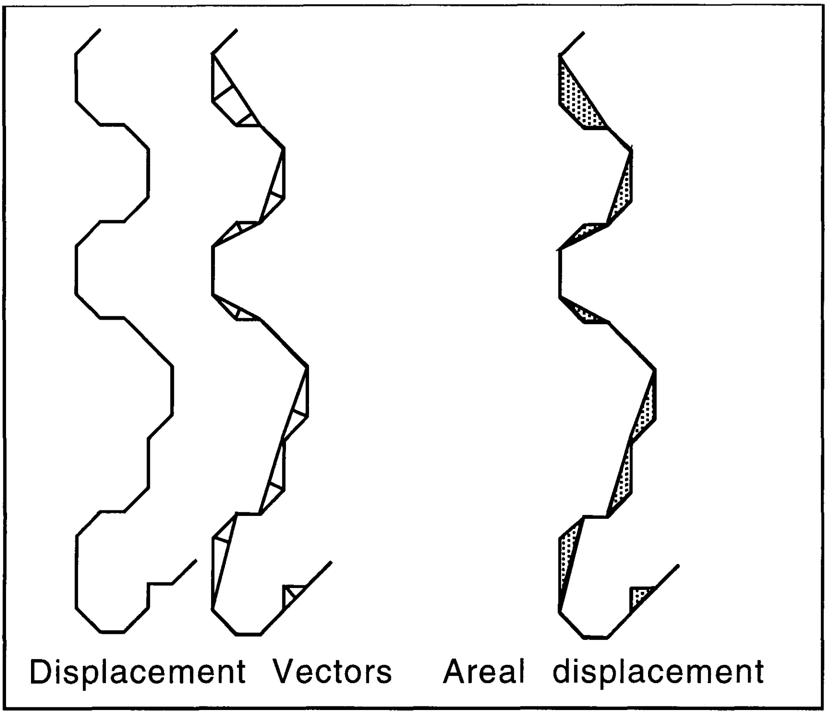

Figure 3. Visualization of displacement vectors and areal displacement for the operation of simplification.

Amalgamation

A series of visual techniques for depicting the generalization operation of **amalgamation** are also possible. Amalgamation involves the fusing together of polygonal features--such as a series of lakes, islands, or even closely-related forest stands--due to scale reduction. By fusing the features together, the intervening feature space is lost. It is this change in the ratio of feature **a** to feature **b**, as well as a sense of the original configuration of features, that is of interest to the user. One potential technique (Figure 4) involves the creation of a spider diagram that connects the multiple centroids of the original set of polygonal features and the centroid of the newly generated amalgamated polygon, thus illustrating the general complexity of the process. Another technique involves the application of value, where those regions of the lost category are emphasized, giving a sense of area change. Similar techniques could be applied to the process of **aggregation**, where a series of point features are fused into an areal feature, normally represented by an enclosing boundary.

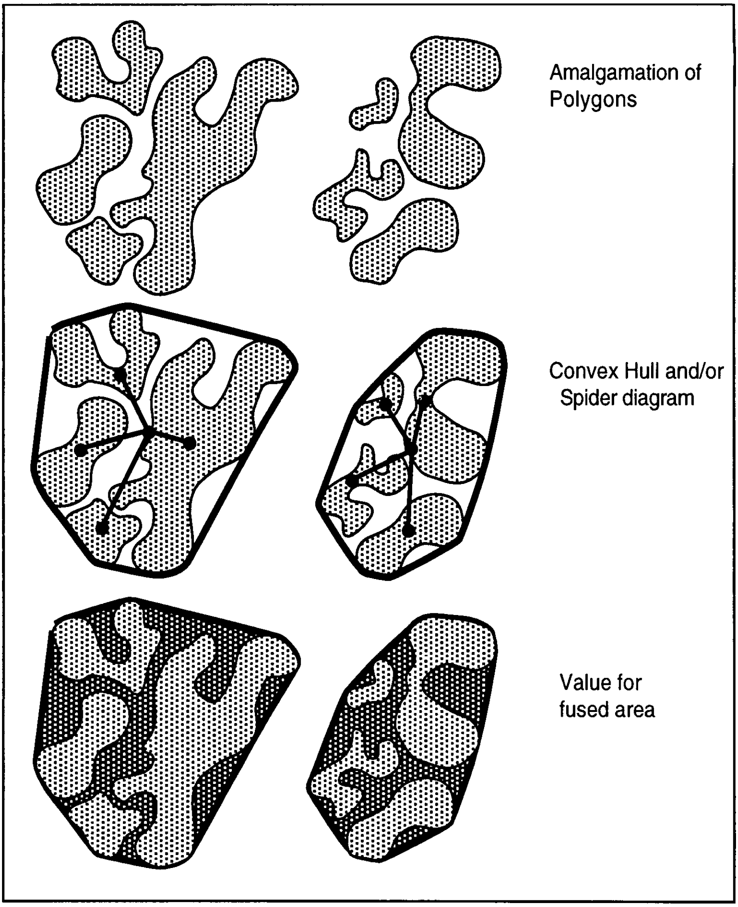

Figure 4. Visualization techniques for amalgamation

Smoothing

Possible techiques for the generalization operation of **smoothing** involve display of both displacement, as with simplification using displacement vectors and area, and changes in the angularity and curvilinearity of the feature. In this case changes in the value (Figure 5) of a linear feature represent decreasing angularity or curvilinearity. Another possible visual technique is to connect the inflection points of the curve in order to give a sense of how rapidly the curve is changing. Many short segments would indicate a more complicated line.

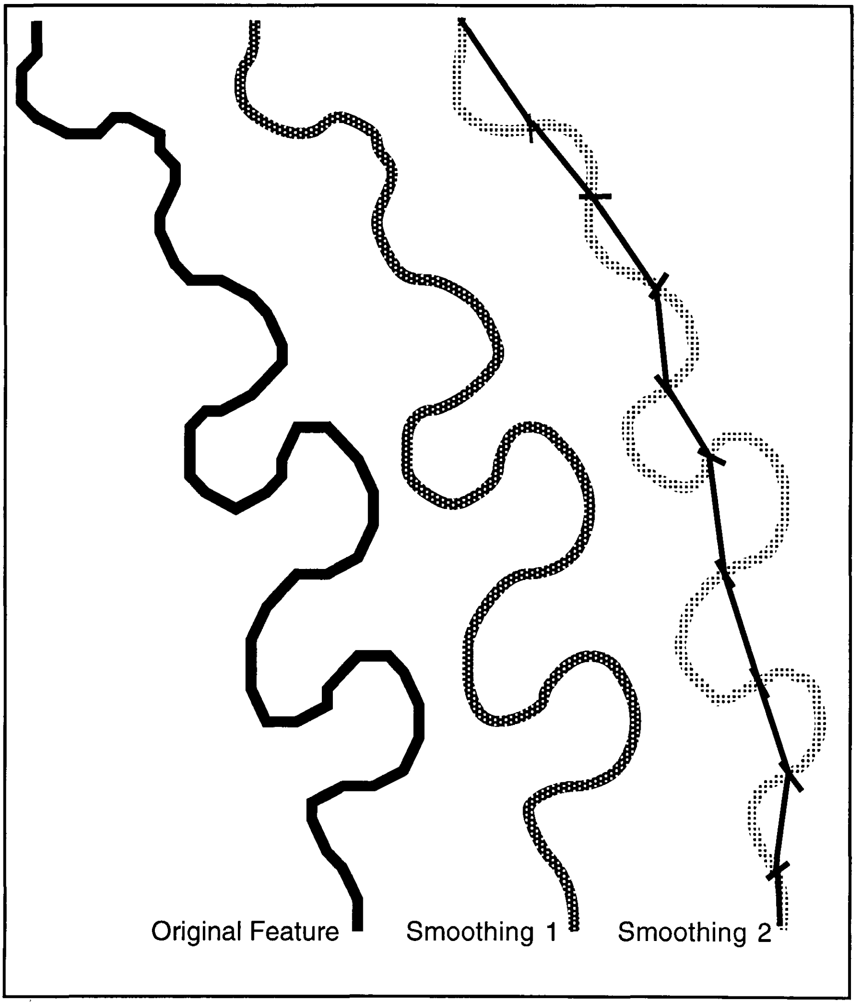

Figure 5. Techniques for visualizing angularity /curvilinearity changes resulting from smoothing.

VISUALIZING RASTER-MODE GENERALIZATION

Raster-Mode Generalization

A model developed by McMaster and Monmonier (1989) identified four basic classes of raster-mode generalization operators. The four fundamental categories developed in this framework included: (1) structural, (2) numerical, (3) numerical categorization, and (4) categorical generalization. Schylberg (1993) modified this framework to include a category of object-based raster generalization. A summary of these methods is provided in the original paper, and are outlined below.

The first category, structural generalization, redefines the framework of the raster matrix, normally through a transformation of the cell-to-area relationship. The second, numerical raster generalization, also known as spatial filtering, manipulates the complexity of the image by smoothing deviations, or reducing the variance of the matrix, enhancing edges, or sharpening edges, as well as a variety of specific operations, such as those used to extract specific terrain classes. The third, numerical categorization, involves the classification of digital images using standard techniques from digital image processing in order to produce a classified 'categorical' output matrix. In the last category, purely categorical generalization techniques must reduce the spatial complexity through the consideration of the number or weighting of the attribute categories within the moving kernel. Such methods are intrinsically more difficult since the assignment of new values, based on nominal-level information, is a more subjective process.

As with vector-mode operations, a series of techniques for visualizing the effect of raster-mode generalization have been developed. For example, one may superimpose a set of original grid lines on a structurally modified image to display resolution change. For categorical generalization, one may use a saturation mask in order to show the effects of aggregation or erode smoothing, where the cells that have been modified are more saturated and those unchanged are less.

Other visual techniques can be applied to visualize the effects of generalization in raster mode. For instance, one common method used to generalize raster images involves the aggregation of cells into larger units (Figure 6). In this example each two x two matrix of cells is aggregated into one larger cell. The three **A**s and 1 **B** in the upper left portion of the matrix are aggregated to an **A** in the generalized version. However, some of the new cells are "stronger" than others in that the dominance of the original attributes varies. In this example, the three **A**s and one **B** represent a three-cell dominance. In the upper right area of the image, a four-cell dominance of the original category **D** is found. The integer dominance value can be represented with a value, texture, or saturation in a third image design to visualize the strength in any cell. The method here involves the use of value. The darker values represent those cells where, in the original image, greater numbers of the dominant cell were found. Such a technique would allow the user to differentiate those regions on the image where large blocks of cells were relatively homogenious versus those regions with a high spatial variance.

Additionally, by using only one image color could be effectively used to display the original categories, with saturation or value applied to represent the actual dominance value.

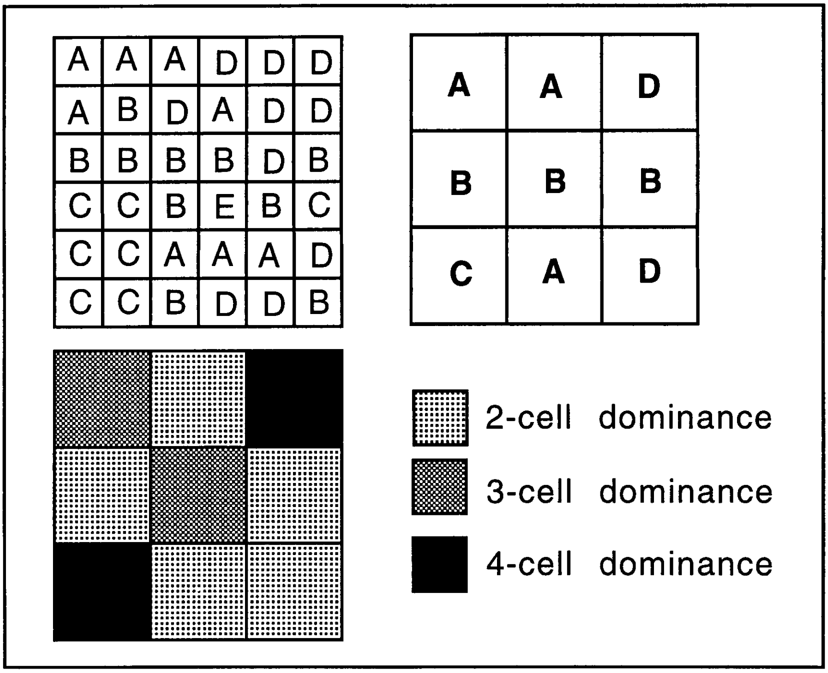

Figure 6. Method for depicting quality of cell aggregation.

Another visual technique for the raster-mode process involves the computation of a change matrix. In Figure 7 the right-hand land use / land cover matrix has been generated from the left-hand matrix using a simple modal filter. As a result of the application of the modal filter, a series of changes are made to the cells. The lower-left matrix numerically depicts these results where, for instance, in three instances category **A** was changed to category **D**. As with the previous example, these numerical results can be converted to a visualization where value is used to illustrate lower and higher changes.

A series of techniques may also be designed for *numerical* raster generalization, such as image processing and terrain modeling. The result of any generalization process on these data, such as low- and high-pass filtering, will be a numerical difference between the old and new image. To visualize change, a three-dimensional surface might be created and, due to the potential complexity, smoothed. Of course a third matrix, using an appropriate visual technique, could also be created, as described above.

With the use of color, actual numerical differences between the new and old cells could be displayed with value and the variance of the differences around a cell could be represented with saturation. For terrain models, this would allow for the display of changes in both elevation (value) and slope simultaneously.

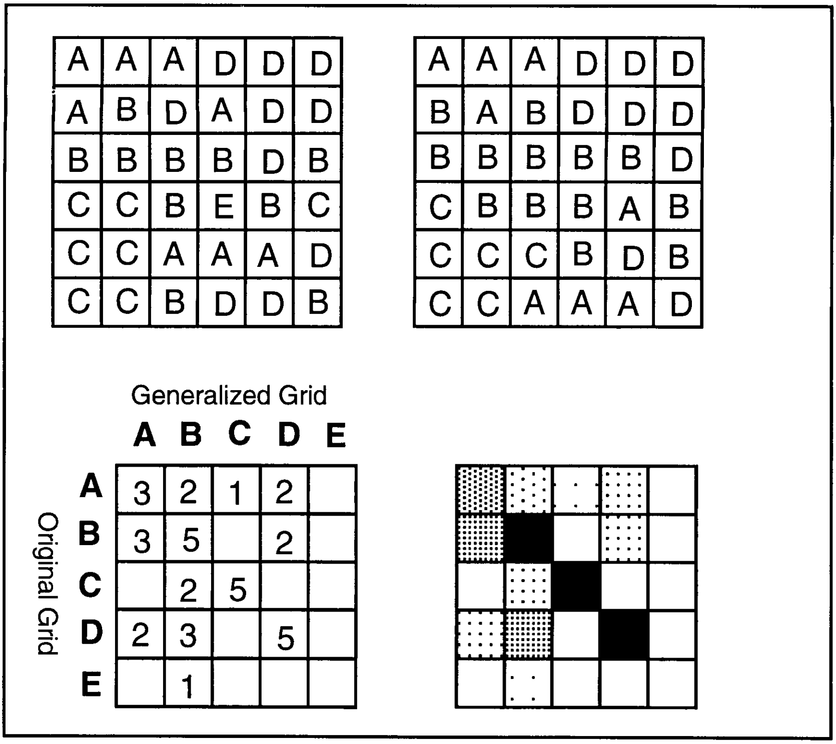

Figure 7. Method for visualizing category change on raster images.

SUMMARY

Research into automated generalization is now at a stage where, given recent progress, we can look beyond the actual operations and begin to focus on the resulting feature changes--the quality of the generalization. This will involve the design and implementation of appropriate visualization techniques, the integration of these techniques into existing interfaces for generalization, and user testing. Although we propose a preliminary set of methods in this paper, a more thorough set of techniques must be developed to cover all aspects of the process. Our work includes this further development as well as the creation of a conceptual framework for visualizing generalization based on existing frameworks of the process.

Perhaps one of the more important questions involves user-interface design. Several papers have reported on user interface design for generalization (McMaster, 1995; McMaster and Chang, 1993; and McMaster and Mark, 1991), but none have addressed the need for integrating visualization techniques. After generalization, the user must be provided through the interface with multiple options for viewing, and thus analyzing, the effect of the process. Given that many interfaces for generalization are in the design stage, it is timely to consider the integration of such visualization methods before such interface design is finalized.

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