Map automatic scale reduction by means of mathematical morphology

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Abstract

This paper deals with the use of mathematical morphology for the automatic smoothing of contours in the plotting of digital maps. Due to scale reduction this operation is normally performed by human experts, since it is essential not to flood the map with information and, at the same time, not to miss any important feature. If a regular zoom out is used, one has no control over the results. In digital cartography scale reduction needs to be made automatically, but with a certain degree of control over the results. The mathematical morphology operators of dilation and erosion permit scale reduction in a controlled way if an appropriate structuring element (shape and size) is chosen. Using a simple IBM-PC-XT based image processing system (SITIM) it was possible to test this method for two real cases, with promising results.

Introduction

As a map is reduced representation of a topographic surface, its scale determines the amount of information that can be shown. The consequence of scale reduction is generalization: the smaller the scale, the greater the degree of generalization. Automatic scale reduction is a difficult task to be performed, since essential features must be kept, but the amount of information displayed has to be limited. The role of an experienced cartographer is to choose the information to be depicted and to smooth out thematic lines. For example, a large scale map should present the big rivers and most of its tributaries while in a small scale one only the major tributaries should be drawn (Keates, 1973, 1982). Thus, a mathematical algorithm to automatically reduce the scale of a whole map still does not exist, due to the lack of non-subjective criteria to evaluate the output results (Thapa, 1988).

The objective of this work is to use the mathematical morphology (MM) operators dilation and erosion in order to automatically reduce the scale of contours, like the perimeter of a lake or a coast line. These features are very common on a map and the automation of this procedure could save a lot of time. Obviously, this is only a small step towards simplification, which is part of the solution of the complex generalization problem.

First, erosion and dilation will be described, as well as opening, which is a combination of the former two operations. Then, examples of the use of this technique to simplify features on a map are presented and some conclusions are drawn. The image processing system used was INPE's developed IBM-PC-XT based SITIM.

Dilation, erosion, and opening

Before describing the MM operations of dilation, erosion, and opening some general concepts have to be presented. An object IMAGE only has INFORMATION when the OBSERVER decides which PROPERTY of the object should be studied. On the observer's mind TO PERCEIVE an image is to transform it. Now it is possible to introduce the concept of STRUCTURING ELEMENT. A structuring element is another object, more simple, and smaller than the original object. Chosen by the observer, it interacts with the former object, changing it into a CARICATURE that contains only the PRINCIPAL CHARACTERISTICS of the original object. This caricature contains all relevant information needed to study the original object. Then, after the transformation by the structuring element, measurements can be done over more simple geometric structures, yielding useful information.

The mathematical definition of EROSION of an object X by a structuring element A is the set (Haralick et al., 1987):

$$X \ominus A = \{x : A_x \subseteq X\} \qquad (1)$$

The effect of erosion on an object is to reduce it, smoothing its perimeter. When the set X eroded its complementary set X^c is expanded. This operation is called dilation and is mathematically defined as (Haralick et al., 1987):

$$X^c \oplus A = (X \ominus A)^c \qquad (2)$$

or

$$X \oplus A = \{x : (A_x \cap X) \neq 0\} \qquad (3)$$

If X is eroded by A and then dilated by A, the resulting set is not the original set X, but a simplified version of it. Only the MORPHOLOGICAL ESSENTIAL PART of X stays (Barrera, 1987). This new set is called the opening XA of X by the structuring element A. Its mathematical definition is (Haralick et al., 1987):

$$XA = (X \ominus A) \oplus A \qquad (4)$$

If the structuring element has a regular shape, the opening may be viewed as a non-linear filter that smoothes the object's contours. This type of smoothing, neglecting the details that are smaller than the structuring element, is similar to the cartographer's task of simplification. Depending on the choice of the structuring element (shape and size), a map simplification may be attempted.

Methodology

This section describes the use of MM to simplify contours in cartography. In order to test the method two different regions were chosen: Ilha Grande, near Rio de Janeiro, and Santa Branca Reservoir, near São Paulo, both in Brazil. The original data were obtained from topographic maps made by the Brazilian Institute for Geography and Statistics (IBGE) and São Paulo State Energy Company (CESP) for the Santa Branca Reservoir map at 1:25,000.

Example 1 – Ilha Grande

Two maps from IBGE were used to gather the original data, one at 1:50,000 and the other at 1:250,000. The coast line of Ilha Grande was digitized by means of a Geographic Information System (GIS) developed at INPE. Resulting vector data were rasterized and binarized. The binary image from the 1:50,000 scale map was then processed by means of several opening operators. The basic structuring elements for erosion and dilation were 3x3 squares. The SQUARE OPENING filters 3x3, 5x5, 7x7, and 10x10, obtained by successive application of erosion and dilation, yielded 3x3, 5x5, 7x7, and 10x10 matrices in which all elements are ones. The advantage of this setup is small computational cost associated. Of course other structuring elements of more complex shapes could have been used. It is suggested further tests with different structuring elements.

Promising results were obtained with this simple procedure. This can be seen from figure 1, which depicts counterclockwise, from top left: original data from 1:50,000; original set operated by a 5x5 opening; original set operated by a 7x7 opening; original set operated by a 10x10 opening; and original data from 1:250,000.

Figure 1 – Ilha Grande, Brazil. The top images were digitized from maps, the bottom ones were automatically generated by MM opening operators.

It is not easy to visually differentiate the five images because the island shore line is 'well-behaved'. A closer look shows a continuous smoothing from the original map at 1:50,000 to the original map at 1:250,000. In order to have some quantitative measurements, the areas (pixel count) of the individual images were computed. The results are on table 1.

TABLE 1 – ILHA GRANDE AREAS (PIXEL: 23m)

IMAGE	AREA (PIXEL COUNT)
Original from 1:50,000	52,182
Filter 3x3	52,165
Filter 5x5	52,014
Filter 7x7	51,918
Filter 10x10	51,669
Original from 1:250,000	55,625

Example 2 – Santa Branca Reservoir

A more complex feature was chosen this time: a reservoir in Santa Branca, São Paulo. The original data was taken from an IBGE map (1:250,000) and from a CESP map (1:25,000). Original data were digitized, rasterized, and binarized on INPE's GIS.

The same MM operators – 3x3, 5x5, 7x7, and 10x10 openings – were used, with the same structuring elements – square matrices with all elements equal to 1. The results, depicted on figure 2 deserve a longer discussion. Again, there is much room for new tests and improvements, with the choice of other structuring elements.

Now the smoothing due to scale reduction is readily visible. Scale change is ten to one. In addition, reservoir level changes with the rainfall and the 1: 25,000 map was obtained from aerial photographs taken on the dry season, while the 1:250,000 map shows an average level situation, what makes a certain difference. Even so, the results are encouraging, as seen from the sequence of figures 3, 4, 5, and 6.

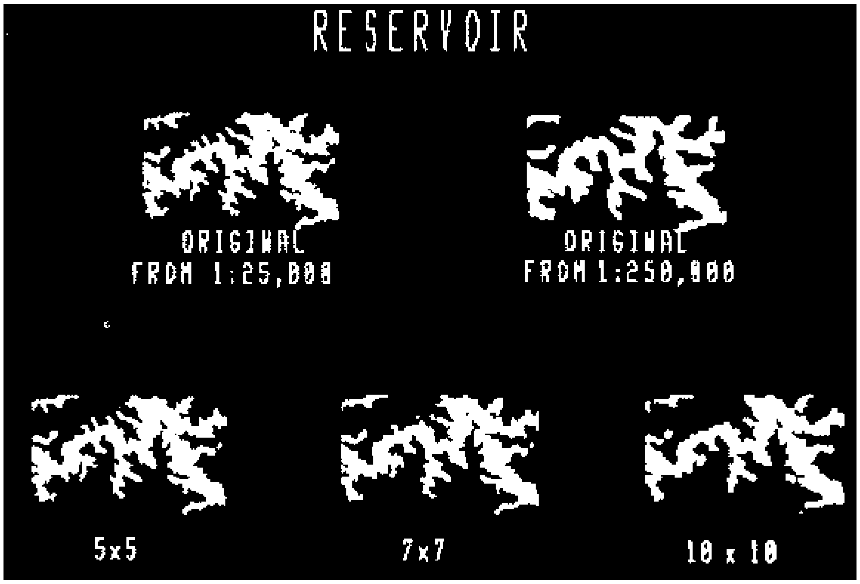

Figure 2 – Reservoir in Santa Branca. The top images are the digitized original data. The MM filtered images appear at the bottom.

Table 2 shows the areas, in pixel counts, obtained from the original binary digitized images at the two different scales, as well as the areas of the filtered images.

TABLE 2 – RESERVOIR AREAS (PIXEL: 9m)

IMAGE	AREA (PIXEL COUNT)
Original from 1:25,000	75,315
Filter 3x3	74,887
Filter 5x5	73,577
Filter 7x7	71,546
Filter 10x10	67,878
Original from 1:250,000	81,621

Figure 3 – Reservoir original data from the 1:25,000 scale map.

Figure 4 – Reservoir data operated by a 7x7 opening.

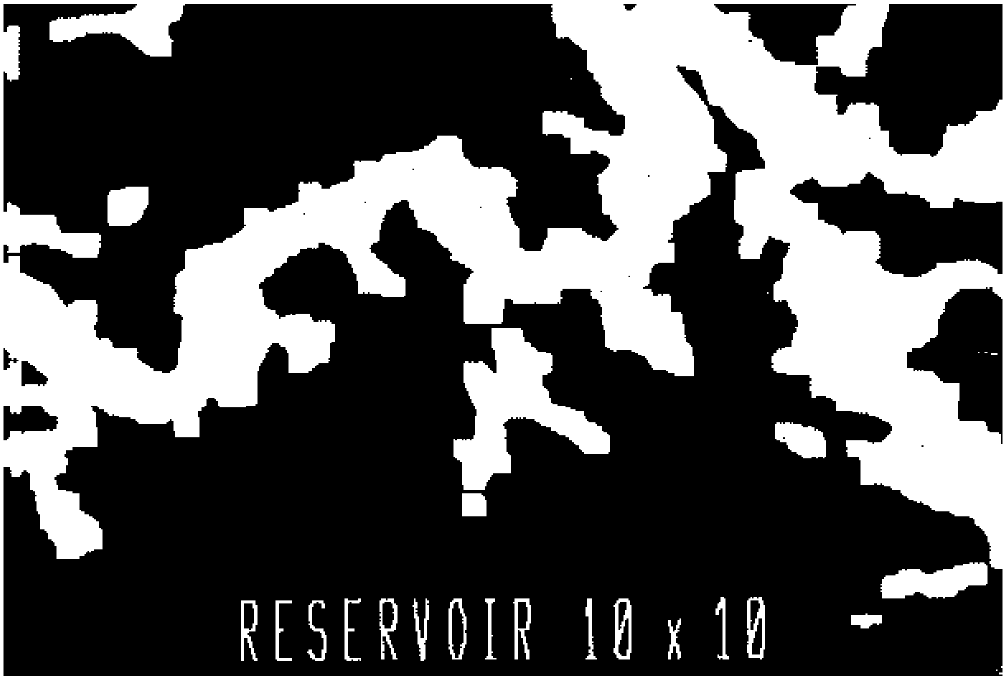

Figure 5 – Reservoir data operated by a 10x10 opening.

Figure 6 – Reservoir data taken from the 1:250,000 scale map.

Conclusion

The use of MM operators to simplify maps is a promising technique. There is still much work to be done, but the results already obtained show that this research area provides a possible solution. A closer look at the reservoir example may point out interesting features to be explored.

Figure 3 is an enlarged view of the reservoir from the 1:25,000 scale map. Figure 4 is the original image operated by a 7x7 filter. From the cartographer point of view it is the best approximation for the reduced scale representation at 1:250,000. Note that some portions of the figure tend to split. On figure 5, obtained by means of a 10x10 filter, note that the splitting has increased but smoothing approaches the one made by the cartographer at 1:250,000. Finally, figure 6 is an enlargement of the original data digitized from the 1:250,000 scale map.

It should be noted that the simplification made by the cartographer in both examples is not perfect either. They tend to increase the relative area of the regions due to smoothing, while the MM operations tend to reduce that area. In order to keep a constant area, a further dilation was tried at the end of the process, but the results were not acceptable, for the shapes of the regions have changed in an uncontrolled way.

The Ilha Grande results were of excellent quality, while the more complex region of the Santa Branca reservoir has to be viewed with caution. For the future it is suggested that other structuring elements be used as well as other MM operations.

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