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A comparative study of the performance of manual generalization and automated generalizations of line features

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Abstract

This chapter presents the results of an empirical study of three different generalization procedures, namely, the traditional manual technique, Douglas-Peucker algorithm and an algorithm based on a natural principle. The performance of these three methods is compared for a small sample of linear features. The results suggest that the new method, derived from a natural principle (Li and Openshaw, 1990b), is surprisingly close to replicating the manual generalization process, at least in the example studies, and that it may well offer the basis for a new generation of automated line generalization procedures.

Introduction

Generalization is one of the fundamental processes in GIS (see Abler, 1987; Rhind, 1988). It occurs in many spatial data manipulations, especially those involving change in scale of map data and the overlay of map data sets acquired at different scales. A wide variety of algorithms have been developed (see McMaster, 1987, 1989; Nickerson, 1988). Unfortunately, most methods are based on algorithms which were developed for data reduction and then applied to line generalization. As a result, it has been concluded that the possibilities for an automated geometric solution to the line generalization problem is limited (Muller, 1990). However, it has been argued elsewhere by the authors (Li and Openshaw, 1990a) that there is a relatively straightforward natural principle that can be used to guide the generalization process and that algorithms based on this principle should perform better than data reduction algorithms in the generalization context. The purpose of this study is to measure the performance of a new automated line generalization procedure based on this principle (see Li and Openshaw, 1990b) and to compare it with both manual generalization and the widely used Douglas-Peucker algorithm (Douglas and Peucker, 1973).

The strategy involves digitizing some arbitrarily selected features from existing topographic maps at various scales and comparing the results of manual generalization with those produced by the two automated procedures. In the next section, a brief description of the test dataset is given. The third section outlines the measures of generalization effects that are used in this study, while the fourth compares the performance of the three different methods. The chapter finishes with some discussion and conclusions.

Description of test data set

A piece of river network with three line segments has been selected for this study as it provides a reasonable spread of complexity. There is nothing special about the choice. Figure 1 shows the three river segments digitized from four different map scales (1:25 000; 1:50 000; 1:250 000 and 1:625 000). The 1:10 000 scale is ignored because the 1:25 000 scale maps are basically the photographic reductions of the 1:10 000 scale maps and there is little extra to be gained from the digitizing effort. The selected features were digitized from OS topographic maps using ARC Digitizing System (ADS), which is part of ARC/INFO. Digitization was carefully performed to ensure that the line segments are recorded as accurately as possible in order to avoid too much information loss. It is not known what effects the data acquisition process has had on the subsequent analysis of generalization effects. It is probably small and in any case the effects are common to all methods.

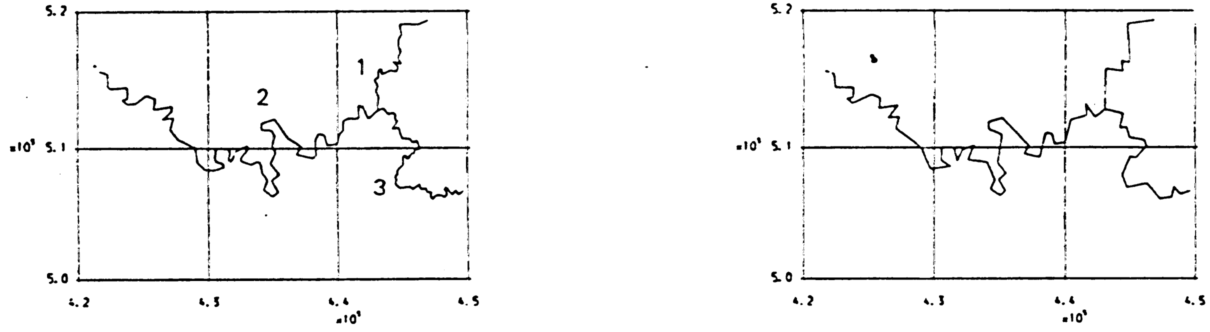
Some measures of generalization effects

In seeking to understand the effects of generalization on the characteristics of linear features, it is useful to have some numerical measures which can be used to compare the three generalization techniques. McMaster (1986) describes 30 possible measures. However, Visvalingam and Whyatt (1990) pointed out that many of these measures are "inappropriate, misleading and questionable". In this chapter the following two measures are used to quantify the effects of generalization on the characteristics of linear features. They are the sinuosity ratio, and an error level for measuring displacement of line segments.

Sinuosity ratio and line length

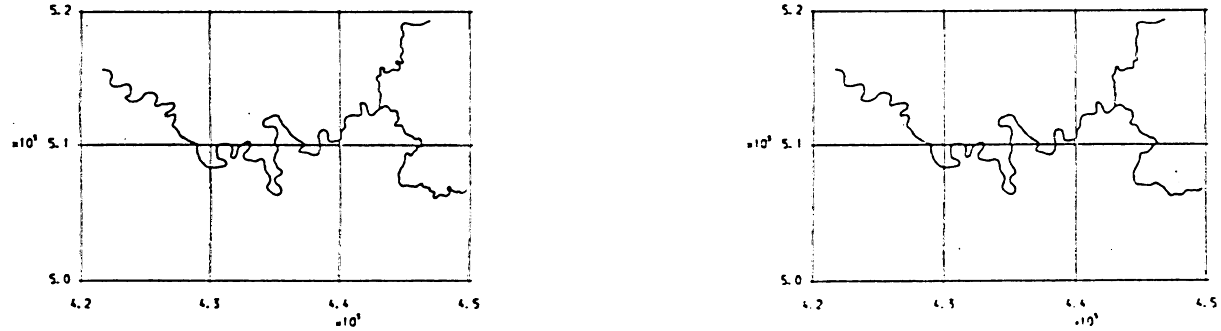
Sinuosity ratio is a statistic which is designed to measure the wandering or meandering of a linear features. It is defined as follows (Unwin, 1981):

$$S = \frac{\text{Observed line length}}{\text{Straight-line distance from origin to end}} \tag{1}$$



a) from 1:25 000 scale map

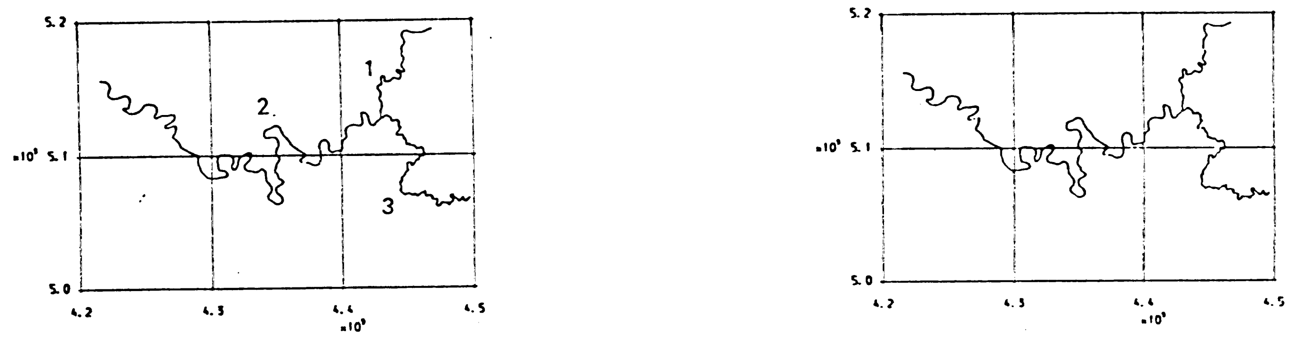
b) from 1:50 000 scale map



c) from 1:250 000 scale map

d) from 1:625 000 scale map

Figure 68.1. River segments digitized from various scale maps.



a) 1:250 000 scale by Douglas-Peucker algorithm

b) 1:625 000 scale by Douglas-Peucker algorithm

c) 1:250 000 scale by natural algorithm

d) 1:625 000 scale by natural algorithm

Figure 68.2. Examples of line generalization by automated techniques. (sequentially generalized from 1:25 000 to 1:50 000, then to the scale shown)

The larger the sinuosity ratio, the more complex or meandering the line. Sinuosity is not an absolute measure since the value of the ratio may vary with the positions of the two end points of a line segment. Nevertheless, it is a useful measure of the increase (or decrease) in line length due to generalization.

Error level for displacement of line segments

It is usually assumed that, after undergoing a generalization process, some parts of the features presented on smaller scale maps have been displaced from their original positions.

Locational errors created by the generalization process can be measured using the so-called "vector displacement". This is widely used to reassure the performance of data reduction algorithms. However, there are some problems in its applications. If the vector displacement is to be measured, then one must consider (a) how to find the corresponding points on two different lines to generate the vector and (b) if those points on spikes should be taken into account. In this study, a relative measure, an approximate value at map scale, e.g. 0.25mm, termed "error level" is used instead of an absolute value (e.g. 95m in terms of ground distance). For example, if the scale to which a map is to be generalized is 1:620 000, then 0.25mm at this map scale represents a value of about 156m in ground distance. Additionally, only those typical errors, which could be local maximas but occur most frequently, are measured.

An empirical comparison of automated and manual generalization

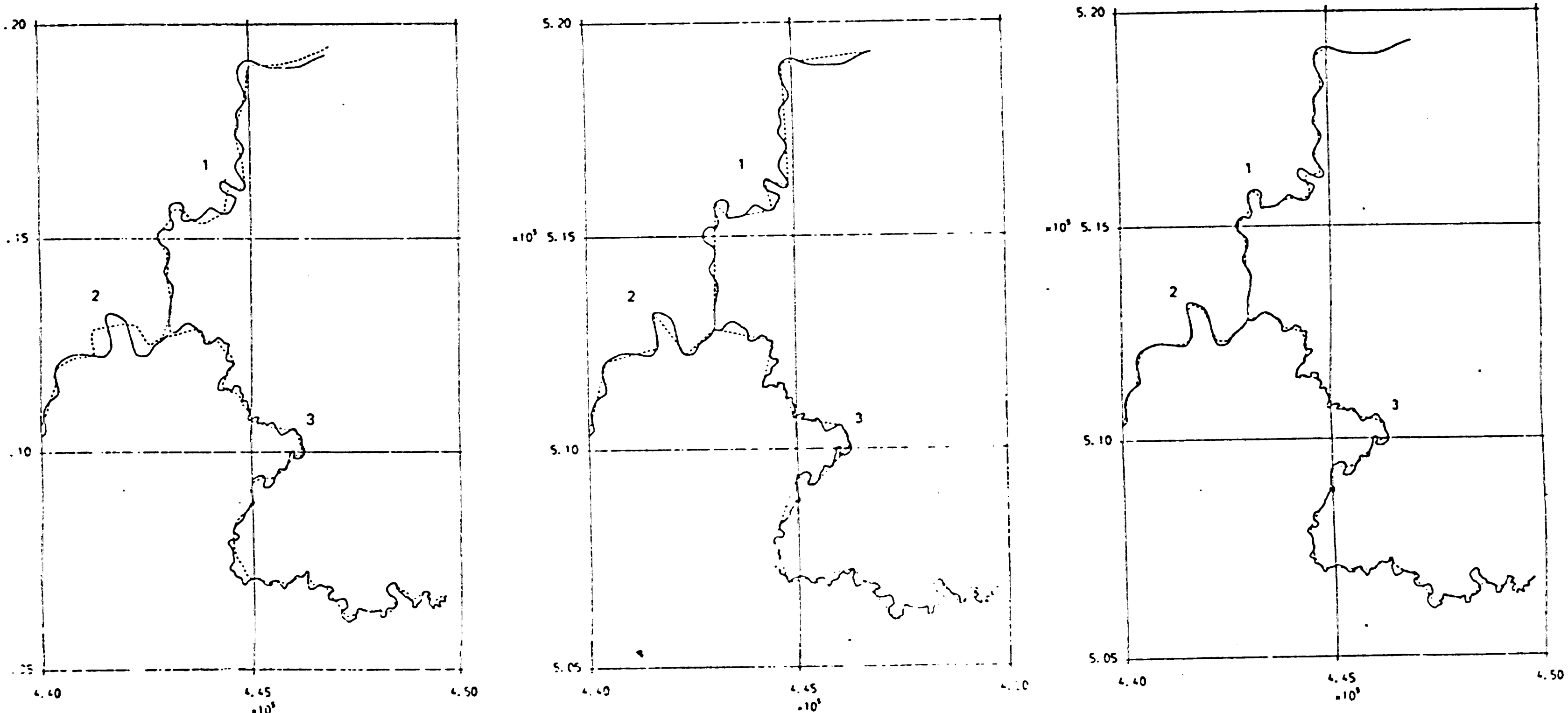
Two automated techniques are being tested here, the Douglas-Peucker algorithm and the new algorithm as recently developed by Li and Openshaw (1990b). The former is widely recognized as being the best among the existing algorithms for automated line generalization and it has been implemented in many GIS systems (e.g. ARC/INFO), while the latter is thought by the authors to be a very promising technique. The empirical results will test this conjecture.

It is noted that both algorithms have some critical parameters that need to be set. In the Douglas-Peucker algorithm, the tolerable distance is set at 0.5mm at map scale. This is the value of maximum permissible displacement error due to generalization by the algorithm. There are three variants of the new algorithm and here the raster-vector (without overlap) version (see Li and Openshaw, 1990b) is selected with fuzzy raster size set at 0.7mm at map scale.

An intuitive comparison

The features selected for this study have been described previously. Figure 68.1, in fact, shows the generalization of these river features by manual techniques. Figures 68.2a and b show the generalization of the same line features by Douglas-Peucker algorithm from initial scale of 1:25 000 to both 1:250 000 and 1:625 000 scales, While Figures 68.2c and d show the same features but this time generalized by the new algorithm.

In Figure 68.1, it is obvious that river features become increasingly less complex with decreasing map scale. A visual comparison with Figure 68.2c and d and Figure 68.1 suggests that there is a high degree of similarity between the features generalized



a) By manual techniques b) By Douglas-Peucker algorithm c) By natural algorithm

Figure 68.3. Example for the errors generated by generalization between 1:25 000 scale and 1:625 000 scale

by manual techniques and the new algorithm. By contrast, there is less apparent visual similarity between the features generalized by Douglas-Peucker algorithm and those by manual techniques. Indeed, the features in Figure 68.2a and b seem to represent a destruction of the nature of those river features shown in Figure 68.1. This is an intuitive impression and some quantitative results may be desirable.

Change in sinuosity ratio

The sinuosity ratio provides some general information about the relative complexity of those line segments that have the end points at the same positions (coordinates). However, it proved difficult to match the end points when the same feature was digitized from different scale maps. This introduces some uncertainty into the results. Table 68.1 gives the results for both manual and automated generalization. Surprisingly, there is not much difference for the sinuosity factors between manual generalization and the automated generalization carried out by the two selected algorithms. In some cases, the results by Douglas-Peucker algorithm are more close to those by manual generalization while in other cases the natural algorithm produces results closer to those by manual generalization. One concludes that sinuosity ratio is not very sensitive to the different characteristics of the generalized features which are visually apparent in Figure 68.2.

Error level for displacement by manual generalization

Figure 68.3 (a, b, c) show examples of displacement errors generated by the three generalization techniques. In extreme cases, small features may have been completely destroyed.

In map accuracy specification, there is a tolerable error for a given scale of map. The value varies with country. The US specification which is most widely quoted states: "95 per cent of all well-defined cultural and drainage features shall be plotted on the map in correct horizontal coordinate position within 1/50 inch (0.5mm), at publication scale". Of course, this value represents the accumulated effects of all the errors that may have been introduced at different stages of the entire mapping and generalization processes. The errors created by generalization alone should be smaller than this quantity. It is interesting, then, to compare features at two different scales to obtain the error level due to generalization and to then investigate how much this contributes in percentage terms to the tolerable mapping error as a whole.

Through the overlay of two features digitized from two maps with different scales, the discrepancies can be inspected and measured if the differences are large enough. Table 68.2 lists the error levels that have been measured by overlaying the three river segments. It can be seen that typical levels of error introduced by manual generalization of linear features is within a band of 0.35mm at map scale. This suggests that errors due to generalization account for up to 70 per cent of the total error budget.

Of course, these values also include some errors caused by map distortion and digitization. However, they do provide some information about the approximate total error levels. The largest error for the second river segment is created by cartographic exaggeration and/or displacement. If this part is excluded, then the error level is more or less the same as those of the other two. It may be interesting to note that the error level for the third river segment is no higher than the other two although this segment looks much more complex. That is, the error level due to generalization for more complex line segments is not necessarily higher than that in other segments. In fact, the error distribution for the complex lines is even more homogeneous.

Table 68.1. Sinuosity factors for features at various scales using different generalization methods

To Scale	From Scale	Segment	Manual	Douglas-Peucker	Natural
1: 50 000	1: 25 000	No. 1	1.668	1.650	1.667
		No. 2	2.620	2.606	2.627
		No. 3	2.511	2.544	2.604
1:250 000	1: 50 000	No. 1	1.535	1.593	1.592
		No. 2	2,534	2.513	2.561
		No. 3	2.232	2.163	2.079
	AG: 1:50K	No. 1	—	1.585	1.603
		No. 2	—	2,518	2.569
		No. 3	—	2.225	2.073
1:625 000	1:250 000	No. 1	1.330	1.372	1.354
		No. 2	2.316	2.342	2.356
		No. 3	1.800	1.826	1.715
	AG 1:250K	No. 1	—	1.442	1.427
		No. 2	—	2,429	2.219
		No. 3	—	1.9834	1.696

Note: In this table, 'AG' under the heading of 'from scale' means the automated generalized map.

Table 68.2. Error levels for displacement by manual generalization

From:	1:25 000						1:50 000				1:250 000	
To:	1:50 000		1:250 000		1:625 000		1:250 000		1:625 000		1:625 000	
error:	Max	Typi	Max	Typi	Max	Typi	Max	Typi	Max	Typi	Max	Typi
River No. 1	s	s	0.80	0.30	0.45	0.25	0.80	0.30	0.45	0.25	0.45	0.25
River No. 2	s	s	1.30	0.30	0.65	0.30	1.30	0.30	0.65	0.30	0.65	0.30
River No. 3	s	s	0.80	0.30	0.45	0.25	0.80	0.30	0.45	0.25	0.65	0.25

Note: 'S' denotes the errors are too small to be measured by inspection;
'Max' denotes the largest error (mm at map scale);
'Typi' means typical error level (mm at map scale)

For the Douglas-Peucker algorithm, the maximum error is controlled by the parameter given. It might be expected that the error level between successive scales (e.g. between 1:50 000 and 1:250 000) for Douglas-Peucker algorithm will be about 0.25mm at map scale, for a given tolerable distance of 0.5mm at map scale. It is also expected that the resulting error level by the natural algorithm will be smaller than 0.35mm at map scale for the fuzzy raster size of 0.7mm at map scale. It is also very important to investigate the error level between a given scale and other larger scale maps. For example, if the error level between 1:50 000 scale map and the generalized 1:250 000 scale map is 0.3mm at map scale, the error level between the 1:25 000 scale base map and the generalized 1:250 000 scale map could be quite different.

Table 68.3 shows the results for the error level generated by both the Douglas-Peucker algorithm and the natural algorithm. The symbol "D" in this table means "generalized by Douglas-Peucker algorithm from the immediate larger scale map which was digitized" and "DD" means the map was generalized from the immediate larger scale map which was already generalized by Douglas-Peucker algorithm. The "N" and "NN" have very similar meanings for the natural algorithm. From this table, it can be found that the actual errors for Douglas-Peucker algorithm are much larger than expected and much greater than the results for manual generalization.

Table 68.3 also shows the error levels generated by the natural algorithm. The errors introduced by this algorithm are very similar to those of the manual generalization procedure and smaller in many cases. In particular, the generalized 1:250 000 and 1:625 000 scale maps so accurately match the main shape of the original 1:25 000 scale map that the error levels are very small.

Change in fourier spectrum

The dataset used to generate these results has been very simplistic. However, the natural principle has also been applied to the somewhat more complex and perhaps more realistic geographical feature. If the coastline shown in Figure 68.4a is considered, then the Douglas-Peucker algorithm completely fails to produce a line which has any similarity to that produced manually (see Figure 68.4c) while the natural algorithm will still be capable of producing a very desirable result (see Figure 68.4d). If these findings are supported by further study, then it only remains to discover how best to implement this new method in a form suitable for application in both GIS software and, perhaps in graphics display hardware.

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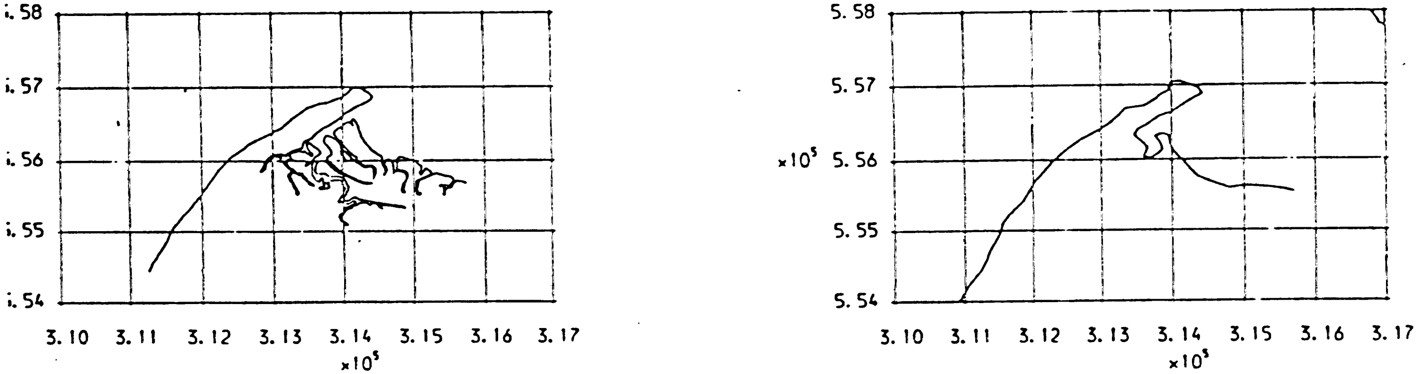
Concluding remarks

This chapter presents some results about the generalization for line features via three different methods. The results are important for three reasons. First, they show that the widely used Douglas-Peucker algorithm should be used for data reduction rather than line generalization; although both are clearly related and may not be separable activities. Indeed, if data reduction largely destroys the characteristics of a feature, then it can hardly be a useful cartographic function. Second, displacement of vectors due to manual generalization can itself account for around two-thirds of feature displacement permitted by some map accuracy standards. Tests showed that while the natural principle produced similar levels of displacement error to manual methods the Douglas-Peucker method typically produced higher levels of error than both.

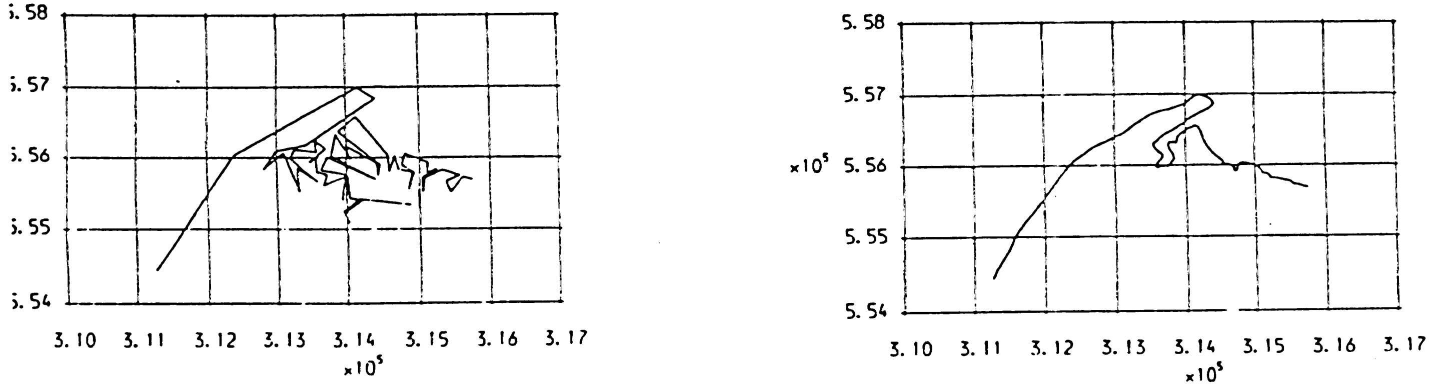
Table 68.3. Error level generated by automated algorithms

Digitized Map	Generalized Map	River seg 1		River seg 2		River seg 3	
		Max	Typi	Max	Typi	Max	Typi
1: 25 000	D 1: 50 000	0.50	0.30	0.50	0.35	0.50	0.30
	D 1:250 000	0.50	0.30	0.62	0.37	0.50	0.37
	D 1:625 000	0.50	0.30	0.55	0.35	0.62	0.37
	DD 1:250 000	0.50	0.30	0.55	0.35	0.50	0.30
	DD 1:625 000	0.50	0.30	0.50	0.35	0.50	0.30
1: 50 000	D 1: 50 000	0.50	0.25	0.50	0.37	0.50	0.30
	D 1:250 000	0.50	0.25	0.50	0.37	0.50	0.35
	D 1:625 000	0.50	0.25	0.57	0.30	0.62	0.35
	DD 1:250 000	0.58	0.35	0.58	0.37	0.58	0.35
	DD 1:625 000	0.50	0.25	0.50	0.30	0.50	0.30
1:250 000	D 1:250 000	0.74	0.30	1.23	0.37	0.74	0.37
	D 1:625 000	0.50	0.25	0.50	0.30	0.50	0.35
	DD 1:250 000	0.70	0.25	1.23	0.40	0.68	0.30
	DD 1:625 000	0.50	0.25	0.57	0.25	0.74	0.25
1:625 000	D 1:625 000	0.50	0.25	0.57	0.25	0.52	0.35
	DD 1:625 000	0.50	0.25	0.62	0.25	0.42	0.25
1: 25 000	N 1: 50 000	s	s	s	s	s	s
	N 1:250 000	0.20	s	0.31	0.10	0.49	0.20
	N 1:625 000	0.74	0.25	0.62	0.25	0.49	0.27
	NN 1:250 000	0.18	s	0.25	s	0.50	0.25
	NN 1:625 000	0.42	0.15	0.49	0.15	0.62	0.25
1: 50 000	N 1: 50 000	0.30	0.15	0.50	0.15	0.30	0.15
	N 1:250 000	0.15	s	0.20	s	0.43	0.15
	N 1:625 000	0.74	0.25	0.65	0.25	0.50	0.35
	NN 1:250 000	0.20	s	0.20	s	0.60	0.30
	NN 1:625 000	0.42	0.15	0.49	0.15	0.62	0.25
1:250 000	N 1:250 000	0.76	0.10	1.00	0.25	0.69	0.20
	N 1:625 000	0.54	0.10	0.37	0.10	0.49	0.20
	NN 1:250 000	0.69	0.15	0.95	0.35	0.70	0.25
	NN 1:625 000	0.40	0.20	0.44	0.20	0.61	0.25
1:625 000	N 1:625 000	0.55	0.25	0.55	0.25	0.50	0.20
	NN 1:625 000	0.35	0.25	0.69	0.25	0.61	0.20

Note: 's' denotes the errors are too small to be measured by inspection;
'Max denotes the largest error (mm at map scale);
'Typi' means typical error level (mm at top scale).

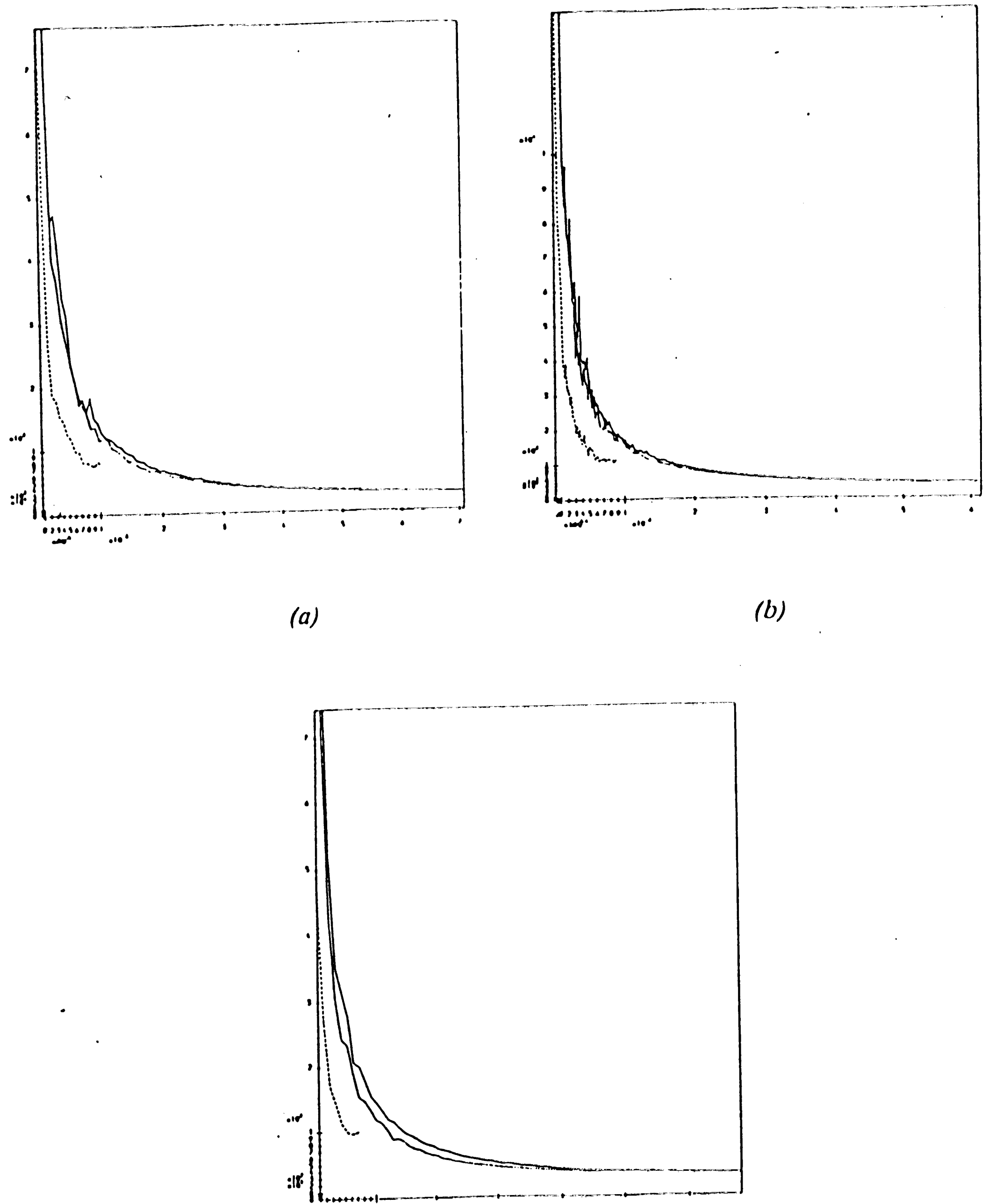


a) Digitized from 1:50 000 scale map *b) Generalized to 1:250 000 scale manually*



c) Generalized to 1:250 000 scale by Douglas-Peucker algorithm *d) Generalized to 1:250 000 scale by the natural algorithm*

Figure 68.4. Generalization of a piece of coastline by different methods



(a)

(b)

(c)

Figure 68.5: Frequency spectra for the river segments generalized by different techniques (for 1:625 000 scale). a) to c) for river segment 1 to 3

top mid bottom

a: manual; b: natural algorithm; c: Douglas-Peucker algorithm

Third, it appears that the natural principle for automated generalization can produce results very similar to those produced by manual cartographic procedures and works effectively even on very sinuous lines which are typical of geographic features. These potentially important findings suggest that this method deserves closer scrutiny.

Of course, the magnitude of the errors introduced by these algorithms may be affected by the criteria being used. In order to provide a more comprehensive comparison, the frequency spectra are also examined. Figure 68.5 shows the examples of the spectra of the same features but generalized by three different methods. It can be seen that the spectra for both manual generalization and by the natural algorithm are very close together in all three cases, while Douglas-Peucker results are quite different. This again supports the view that the ones generalized by Douglas-Peucker algorithm have a very different nature and characteristics.

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