Contour Simplification with Defined Spatial Accuracy

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Abstract

Contours of larger scale maps and datasets can be retrieved through selection process from master datasets or can be derived via using digital terrain elevation models. The Selection process of contours is not enough by itself for their display at varying scales. The contours should be simplified so as to have cartographically acceptable geometries for the target scale representation. There are lots of line simplification algorithms. For contour simplification, suitable algorithms should be applied or developed. In contour simplification, aiming cartographically acceptable geometric shapes or representing geometric shapes with minimum number of points should not only constitute the criteria. Furthermore, the simplified contours should bear some certain spatial accuracy.
Contours are indeed 3D geometry shapes. Their third dimension is concealed on their geometry. Horizontal positional changes in contours can cause some serious errors on their vertical positions. This may affect the analysis results made using this data. In this study, a methodology has been proposed to realize contour simplification within defined horizontal and vertical positional accuracy. The methodology utilizes error band contours which are derived from digital terrain elevation data for their usage in the simplification of contours within the defined vertical positional accuracy. Error band contours are derived for the heights that construct the vertical borders of the error bands. For the contour simplification being within the defined horizontal positional accuracy, simplification tolerance of line simplification algorithms or buffer polygons of contours can be used. As a result, contours are simplified within the defined spatial accuracy which is very crucial for the most of the analysis nowadays.

Keywords: Contour simplification, Spatial accuracy, TIN, Error bands, Topological errors

1. Introduction:

Line simplification is one of the cartographic processes vital for the display of geographic elements at varying scales (Itzhak et al., 2005). It constitutes an important step in map production systems, especially in the production of derived datasets from master datasets through generalization. Map generalization is a process of "information abstraction" rather than the "data compression", although two purposes have associations to each other. Real generalization operation should be intelligent action which considers object's geographical characteristics not simple geometrical properties (Tinghua, 2004).

Parallel to the advances in computer science, lots of line simplification algorithms have been developed. Most of the algorithms developed are for general purposes and possibly give different results. Some are superior in reduction of points in representing a line object where else some are superior in other aspects such as following the main shape of the original line more faithfully or showing better cartographic quality. In simplifying lines, a suitable simplification algorithm should be selected according to the characteristics of geographic object that the line represents.

A special attention has to be given in representing contours at varying scales. Line simplification process constitutes a critical step in this case. Terrain characteristics should be taken into account in the simplification process. Furthermore, the simplified contours should supply certain geometric accuracy. In this study, a special stress has been made on the geometric accuracy of the simplified contours and a methodology has been proposed for accomplishing the contour simplification within certain defined geometric accuracy.

2. Contour Simplification:

Contour simplification is a typical structure based generalization. As a special line representation, the contour contains a series of terrain characteristics such as valley distribution, ridge distribution, geomorphologic type and so on. Only when cartographers firstly assess the above properties correctly, could contour line simplification obtain satisfactory result. If the cartographer looks at each contour only as a single line with such geometric measures as distance, curvature, angularity, fractal dimension, the simplification result will deflect the terrain characteristics and terrain distribution. In some degree the real operation object in terrain generalization is not contour segment itself but the drainage network contained in the contour representation. After the judgment of small unimportant valley in the drainage system, the contour generalization is then to remove them through the elimination of bend group across series of adjacency contour lines (Tinghua, 2004). In this process, two key steps are required. One is to extract the drainage system from the contour lines and build the associations between the valley branch and the bend group of contour lines. Another is to analyze the structure of drainage system to decide which branch to be removed, and then to perform the geometric elimination of bends. So the contour generalization includes two aspects at both geographic and geometric levels. The previous focuses on the decision of importance of terrain characteristics by the analysis of drainage structure, and the latter the simplification of line (Tinghua, 2004). In the literature of contour generalization, many works have been conducted on the first and second questions, including White (1985), Weibel (1986), McMaster (1987), Brassel and Weibel (1988), Thapa (1988), Li (1988, 1995), Visvalingam and Williamson (1995), Li and Sui (2000), Gokgoz and Selcuk (2004), Gokgoz (2005), and Cetinkaya and et al. (2006).

Based on the shape analysis, Wang and Muller (1998) gave a method, called “bend simplify”, to simplify line through the bend detection and this algorithm is able to be used in contour simplification to remove the small bend corresponding to minor valley. Selection of appropriate tolerance used in line simplification is as much important as the simplification algorithm applied. Tolerance used in the line simplification algorithm will definitely affect the simplification results. Very suitable algorithm may give absurd results due to the usage of inappropriate tolerance. Moreover, using the same tolerance for the whole data encounters some undesired results. Smaller tolerance is desired for dense contours to avoid topological errors such as line-crossing and coincident lines, where else larger tolerance is preferred for the other parts of the area for the desired results.

Lee (2004) has introduced a new approach for the line simplification that takes into account topological errors created during simplification such as line-crossing and coincident lines. If any topological error is detected, then the involved line segments are marked and a reduced tolerance will be applied to re-simplify these segments. With the usage of this approach, larger tolerance can be used with the benefit of avoiding the topological errors in dense contours.

3. Geometric Accuracy in Contour Simplification:

With the increase in the usage of digital geographic datasets nowadays, the spatial accuracy of the generalized contours has been of high importance, even more so than within paper maps. It can seriously affect data within a GIS and hence the results of the analysis. Besides getting cartographically satisfied line shapes, the generalized contours should also supply some certain geometric accuracy restrictions.

Contours are defined as the intersections between the terrain surface and the leveling surfaces. A leveling surface contains the points of which heights are the same. Therefore contours are indeed 3D geometry shapes. Their third dimension is concealed on their geometric shapes. Positional changes of a contour in horizontal plane can cause some serious vertical positional changes, due to its shape. The magnitudes of vertical positional change depend highly on the slope of the terrain of the area of interest. In mountainous and hilly areas, small changes in their horizontal positions can cause serious vertical positional changes (Figure 1). The opposite is valid for flat or moderately slope areas. Consequently, the simplified contours should supply certain vertical positional accuracy besides horizontal positional accuracy.

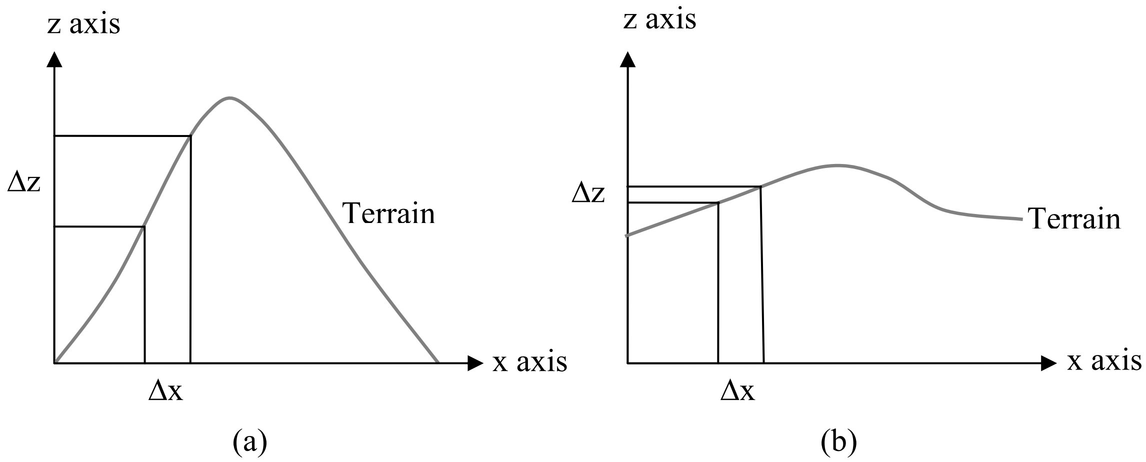


Figure 1: The effect of horizontal positional changes of contours on their vertical positional accuracy. Profile views of (a) Hilly ground and (b) moderately slope area.

Contour simplification with maximum horizontal positional changes being under certain values can be performed with the usage of appropriate simplification tolerance used in the algorithms, such as maximum distance, diameter of a circle, etc. This may not be possible for some line simplification algorithms that use parameters such as deviation angle, etc. In this case, buffer polygons of contours can be used for this purpose, which are created with a maximum horizontal positional change distance allowable. The contours can be simplified so as to be that the simplified geometries remain within the buffer polygons.

The simplification tolerance or buffer polygons mentioned above can not be used for assuring vertical positional changes being under certain values. For this purpose, error band contours derived from digital terrain elevation models or from triangulated irregular networks can be used. Error band contours can be derived for the heights that construct the vertical borders of the error bands and can be used for this aim. Similar approach defined by Lee (2004) can be applied. At first, simplification with the specified tolerance can be applied to the contours and the line-crossings with the error band contours can be checked. If any is detected, then the involved line segments can be marked and a reduced tolerance will be applied to re-simplify these segments.

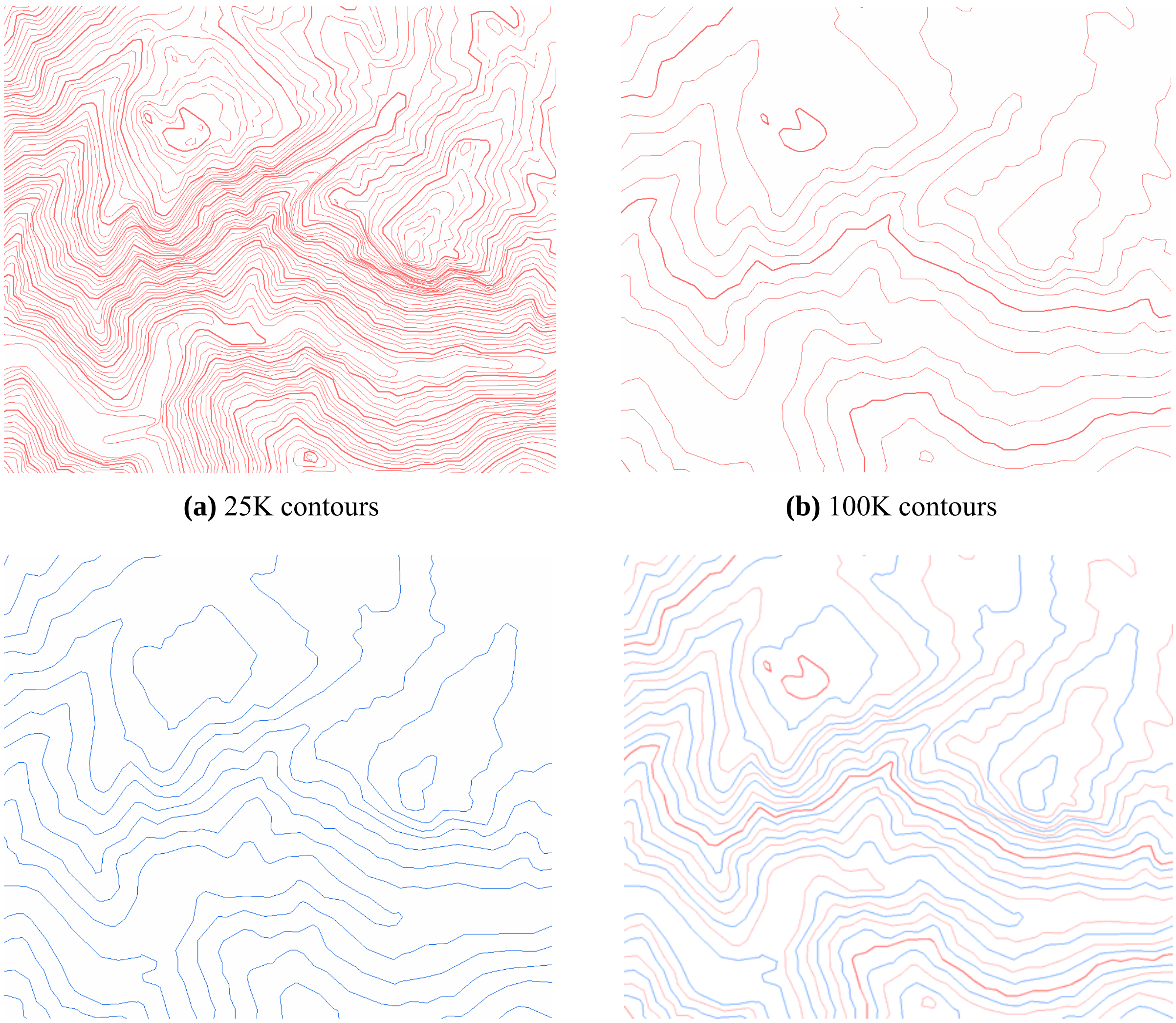
As a result, maximum horizontal positional changes of contours can be ensured being under defined accuracy by choosing appropriate simplification tolerance. And maximum vertical positional changes of contours can be ensured being within defined accuracy by maintaining simplified contours not crossing the derived error band contours. Furthermore, selecting maximum vertical error tolerance smaller than the half of the contour interval will automatically avoid topological errors like line-crossings in the simplified contours. Any line simplification algorithm can be used with this approach. The result of contour simplification will produce cartographically satisfied geometric shapes besides ensuring simplified lines being within defined horizontal and vertical spatial accuracy.

4. Application :

In this study, contour simplification within defined spatial accuracy has been realized with an application. In the application, it is aimed to produce simplified contours for 100K scale topographic maps, using 25K scale contours which constitute the elevation data of master dataset.

Figure 2a shows original 25K scale contours with 10m contour interval. Contour interval for the 100K scale topographic maps is 50m and can be retrieved through selection process from 25K scale contours (Figure 2b). Contour selection process is not enough for their usage in 100K scale topographic maps. Contours should be simplified with appropriate algorithms to reach their cartographically acceptable graphic shapes. And the simplified contours should bear some certain horizontal and vertical positional accuracy.

Triangulated Irregular Network (TIN) of the area of interest was created using all available data of master dataset besides 25K scale contours, and error band contours were derived through it (Figure 2c). 25m was chosen for the maximum vertical positional change, which is the half of the 100K scale contour interval. The 100K scale contours with the error band contours derived are depicted on Figure 2d. The error band contours shows the vertical borders of the simplification process.



(a) 25K contours

(b) 100K contours

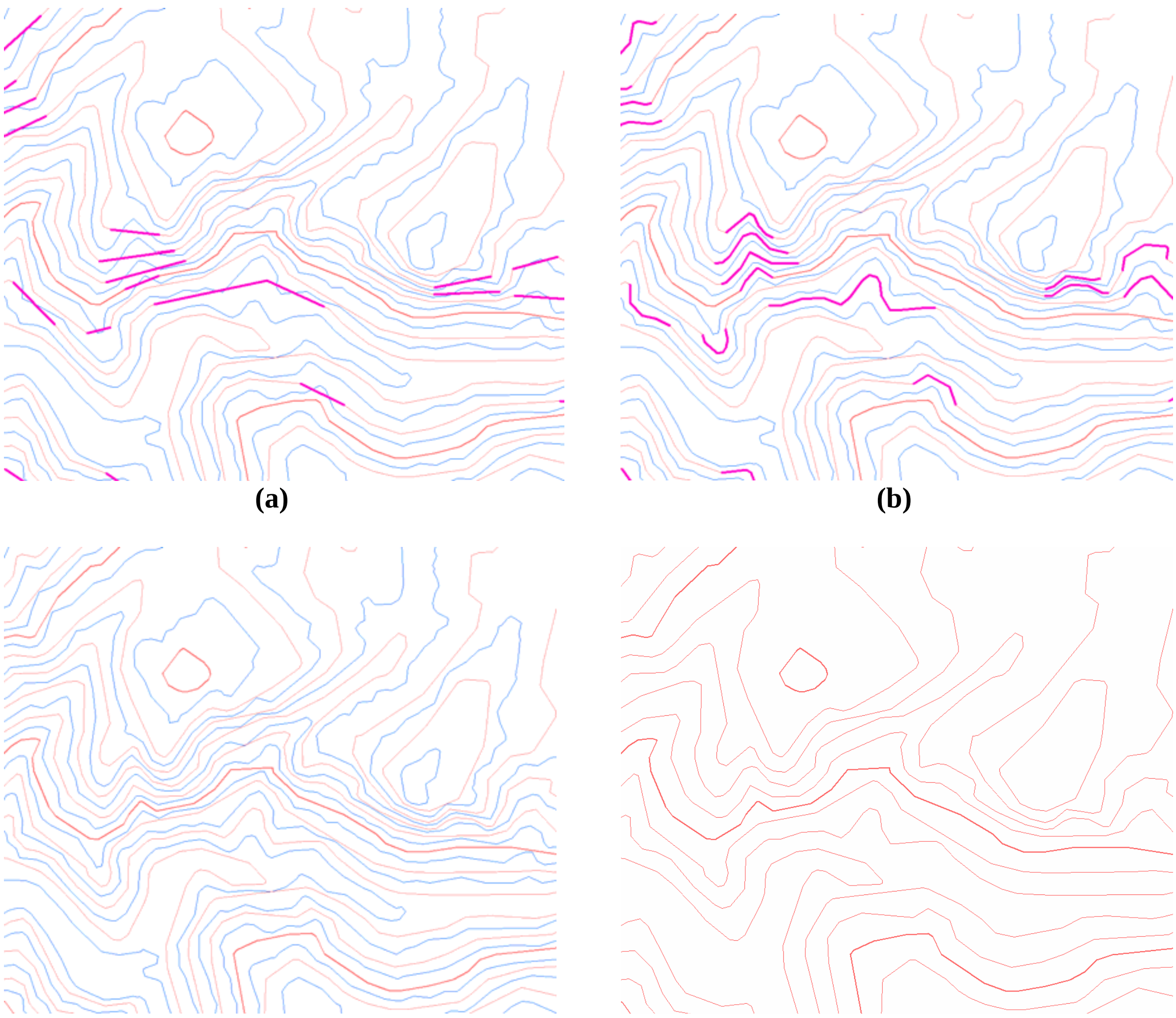
(c) Error band contours

(d) 100K contours and error band contours

Figure 2: 100K scale contours with their error band contours

Method developed by Wang and Muller (1998) was used for the simplification algorithm in this study. At first, contours were simplified with a 160m tolerance. Then, line-crossings with the error band contours were checked and the involved line segments were marked (Figure 3a). The involved line segments were depicted in purple colors in Figure 3a. A reduced tolerance was then applied to re-simplify these segments (Figure 3b). For the reduced tolerance, half of the previously used tolerance is used for this study. The iteration for re-simplifying the contours goes till no contours intersect the error band contours. After the second iteration, no line-crossings were encountered for this example shown in Figure 3b. The results of the contour simplification are shown in Figure 3c and 3d. Figure 3c shows the simplified contours together with error band contours. No line-crossings among contours and the error band contours means that all contours are simplified within the defined vertical accuracy. A visual comparison of the simplification results with original contours is depicted on Figure 4.

As a result, contours were simplified within the defined vertical positional accuracy. And maximum horizontal positional accuracy was determined by the simplification tolerance used in the algorithm. In other words, the simplification tolerance plays a role in determining the borders of the simplified contours for flat areas. So do error band contours for mountainous areas. At the end, simplified contours were obtained within the defined spatial accuracy.



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

Figure 3: Contour simplification within error band contours

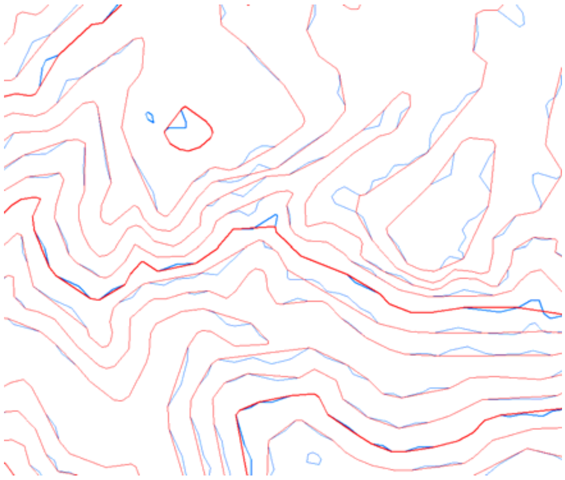


Figure 4: Visual comparison of the simplification results with original contours

5. Conclusion and Recommendations:

Contour simplification constitutes an important process in the production of larger scale topographic maps or derived datasets from master dataset through generalization. Lots of simplification algorithms have been developed and many studies have been carried on contour simplification. Contours are indeed 3D geometry shapes. Their third dimension is concealed on their geometric shapes. So, horizontal positional changes of contours due to line simplification can cause some serious vertical positional changes. Nowadays, the accuracy of data used in GIS is of high importance and can directly affect the analysis results. Therefore a special care has to be given for the spatial accuracy of simplified contours due to their third dimension.

In this study, an approach has been introduced to realize contour simplification within defined spatial accuracy. This approach can be utilized with any simplification methods. This is a major advantage. The methodology utilizes error band contours which are derived from digital terrain elevation data for their usage in the simplification of contour within the defined vertical positional accuracy. For the contour simplification being within the defined horizontal positional accuracy, simplification tolerance of line simplification algorithms or buffer polygons of contours can be used. As a result, the desired simplified shapes of contours can be obtained within defined spatial accuracy by using any simplification algorithm.

6. Reference:

Brassel, K.E., Weibel, R., 1988. A Review and Conceptual Framework of Automated Map Generalization, *International Journal Geographic Information Systems*, **2**, 229-44.

Douglas, D.H., Peuker, T.K., 1973. Algorithms for the Reduction of the Number of Points Required to Represent a Line or its Caricature, *The Canadian Cartographer*, **10**, 112-122.

Cetinkaya, B., Toz, G., Maras, H. 2006. Derivation of Ridge Lines using D8 Method for the usage in Contour Simplification, *Fifth International Symposium Turkish-German Joint Days*, Berlin, Germany.

Gökgöz, T., 2005. Generalization of Contours Using Deviation Angles and Error Bands, *The Cartographic Journal*, **42**, 45-156.

Gökgöz, T., Selçuk, M., 2004. A New Approach For The Simplification Of Contours, *Cartographica*, **39**, Winter 2004.

Itzhak, E., Yoeli, P., Doysther, Y., 2005. Analytic Generalization of Topographic Data and Terrain Models, *22nd ICA International Cartographic Conference*, A Coruna, Spain.

Lee, D., 2004. Geographic and Cartographic Context in Generalization, *ICA/EuroSDR Workshop on Generalisation and Multiple Representation*, Leicester, UK.

Li, Z., 1988. An Algorithm for Compressing Digital Contour Data, *The Cartographic Journal*, **25**, 143-46.

Li, Z., 1995. An Examination of Algorithms for the Detection of Critical Point on Digital Cartographic Lines, *The Cartographic Journal*, **32**, 121-25.

Li, Z., Sui, H., 2000. An Integrated Technique for Automated Generalization of Contour Maps, The Cartographic Journal, **37**, 29-37.

McMaster, R.B., 1987. Automated Line Generalization, *Cartographica*, **24**, 74-111.

Thapa, K., 1988. A Review of Critical Points Detection and Line Generalization Algorithms, *Surveying and Mapping*, **48**, 185-205.

Tinghua, A., 2004. A Generalization of Contour Line Based on the Extraction and Analysis of Drainage System, *20th ISPRS Congress*, İstanbul, Türkiye.

Visvalingam, M., Williamson, P.J., 1995. Simplification and Generalization of Large Scale Data for Roads: A Comparison of Two Filtering Algorithms, *Cartography and Geographic Information Systems*, **22**, 264-75.

Wang Z., 1996. Manual versus Automated Line Generalization, GIS/LIS 96 Proceedings, p.94-106.

Wang, Z., Muller, J.C., 1998. Line Generalization Based on Analysis of Shape, Cartography and Geographic Information Systems, 25, pp 3-15.

Weibel, R., 1986. Automated Cartographic Generalization, in A Selected Bibliography on Spatial Data Handling: Data Structures, Generalization and Three-Dimensional Mapping, ed. by Sieber, R. and Brassel, K. E., pp. 20–35, Geoprocessing Series 6, Geographisches Institut der Universitat Zurich, Zurich.

White, E.R., 1985. Assessment of Line-Generalization Algorithms Using Characteristic Points, *The American Cartographer*, **12**, 17-27.