AN INDIRECT GENERALIZATION OF CONTOUR LINES BASED ON DEM GENERALIZATION USING THE 3D DOUGLAS-PEUCKER ALGORITHM

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ABSTRACT:

In order to simplify the generalization of contour lines during the compilation of maps at smaller scales, an indirect method is put forward based on the generalization of the corresponding DEM first using the 3 dimensional Douglas-Peucker (3D D-P) algorithm before the final contour lines are derived. Preliminary experiments show that the Douglas-Peucker algorithm can be expanded to 3D and it is suitable for the global generalization of DEMs. Furthermore, the derived contour lines from the generalized DEMs can maintain the macro relief form while depress the micro geo-morphological vibration. It is concluded that the indirect generalization of contour lines based on the DEM generalization using 3D D-P algorithm is a promising way according to its speed and quality in the generalization.

INTRODUCTION OF THE DEVELOPMENT HISTORY FOR THE AUTOMATED GENERALIZATION OF CONTOUR LINES

To describe the relief forms on the earth's surface, contour lines have been used widely no matter for manual or computer assisted cartography (Hake and Grünreich, 1994). It is suitable for hydrologic analysis, simulation of relief forms, and cartographic display such as contour lines or layer tinting for the map readers and can even be a data basis for establishing a Digital Elevation Model (DEM) (Tang et al., 2005). Because of their measurability of the height of any point on a map, the contour lines are still a necessary part of topographic maps.

However, the methods of generalization of contour lines during the compilation of maps at smaller scales are usually quite complicated because while being simplified with topological coherence (Zhang et al., 2007), the generalized contour lines should reflect the main characteristics of the relief form. At least, the solution of this problem cannot rely on the simplification of the individual contour lines' figures although some good algorithms for simplifying the figures of the individual curves were suggested in 1970's. Since the end of 1970's, many scientists have suggested or designed the methods of automated group-wise generalization of the contour lines (Hentschel, 1979; Wu, 1982).

Until now, it seems to be a necessary and important step to search for the geo-morphological structural lines first which are implicitly described by the contour data. They act as the framework for organizing the bends of the contour lines. Only after these structural lines have been properly generalized, can one decide which valleys or ridges should be selected, merged and others deleted through maintaining or changing the local figures of the corresponding contour lines harmonically in groups (Fei, 1993; Wu, 1995; Ai, 2007). Obviously, the process of this kind of generalization of contour lines is rather complicated because it is a hard task to find out all the implicit geo-morphological structural lines which are hidden behind the local figures of the adjacent and nearby contour lines. Besides, one must organize nearly all the bends on the contour lines into various geo-morphological structural lines before the generalization of these structural lines is implemented. Finally, it is not an easy job to decide what the simplified figures of the contour lines in groups should be even if, say, a valley is to be deleted, since instead of the old bends, the proper new loci of the contour lines have to be decided by the geographical context of the vicinity, cartographically speaking.

Hence, it is a task for digital cartographers and GIS developers to look for a new method of generalization of contour lines for faster and better generalization results.

DEMS AND THE RELATIONSHIP BETWEEN CONTOUR LINES AND DEMS

A digital elevation model (DEM) can be seen as a kind of data with a certain format to describe the relief form of the earth's surface. The data about three dimensions of every point are necessary. It is widely used for extracting various relief parameters such as elevation, slope, slope aspect, roughness and so on, and can be used for sight analysis, generation of drainage basin structure, calculation of earthwork amount, automated hill shading map-making, etc (Zhou and Liu, 2006). It is also possible to expand the concept of DEM to various attribute amounts relevant to the earth's surface (Li and Zhu, 2000). Therefore, DEM has been widely used in a lot of fields. The data representation of DEM has many forms, among which are 3D randomly distributed point sets, regular square grids (RSG), arranged points on parallel profiles, points along contour lines, triangular irregular network (TIN), etc. (Hake et al., 2002).

From the above discussion, points along the contour lines can be regarded just as one of the DEM types. If a generic format of DEM is to be found to include all kinds of the above mentioned DEMs, that is none other than the 3D randomly distributed discrete points with or without constraints. All other types of DEMs can be seen as its special cases. Therefore, if the DEM with the format 3D randomly distributed discrete points can be generalized correctly, why can't the other types of DEMs, including the points along the contour lines? If contour lines are derived from the generalized DEM, could they reflect the simplified relief form while maintain the major geo-morphological structure? If so and only if so, could the indirect generalization of contour lines be feasible.

GENERALIZING DEMS WITH A 3D D-P ALGORITHM AND THE BASIC IDEA OF THE INDIRECT GENERALIZATION OF CONTOUR LINES

With the development of data acquisition, WebGIS, multi-scaled GIS databases and the LOD models in the virtual reality technique, a number of methods about the generalization of DEM have been suggested responding to the need of reducing the data volume and accelerating the calculation or transmission of the relief data (Weber., 1982; Cai and Zheng, 2003; Wan and Zhu, 1999; Yang et al., 2005). But nearly all of them are based on the local operation, so the maintenance of the important feature points is not assured. Besides, the efficiencies of some algorithms are not satisfactory. Therefore, it is desirable to find a global and efficient method of DEM generalization.

In 1973 Douglas and Peucker put forward an algorithm for simplification of the curve's figures (Douglas and Peucker, 1973). This algorithm has become one of the most commonly used methods for simplification of curves in the software of GIS and digital cartography because of its excellent capability of always selecting the relatively important feature points out from the source data.

Recently, the essence of the well-known Douglas-Peucker (D-P) algorithm was inherited and it has been expanded from a two dimensional to a three dimensional approach, called the 3D Douglas-Peucker (3D D-P) algorithm (Fei *et al.*, 2006). And it has been applied to the generalization of DEM which is composed of 3D randomly distributed discrete points (He and Fei, 2008). The main idea of this algorithm is as follows: Firstly, a common origin and an initial base plane are determined or designated for the source points. All the rest 3D discrete points can be seen as the end points of different vectors starting from the common origin. The unordered 3D discrete points are sorted point-wisely starting from the anchor point and looking for the new point which has the nearest 3D distance with the most recently found point as the next and are put into a queue (Here the origin, anchor point and floating point determine the initial base plane). By doing this, different base planes for the source point groups have actually been formed using the changing current anchor vectors and floating vectors (see Figure 1). Then the potential 3D feature points which are the most significant with respect to the current base planes are extracted one by one.

The principle of the point selection is similar to that of the 2D D-P algorithm, i.e., amongst all the points between the current anchor point and the floating point, the point which has the maximal distance to the current base plane is chosen as the currently considered point. Only when the distance between the currently considered point and the current base plane is greater than a predefined threshold, will this point be selected, otherwise all the intervening points are deleted. Likewise, the selected point becomes the current floating point and similar recursive processes continue until all the potential points have been considered with respect to all base planes. In this way only the main geo-morphological feature points can be preserved for the study area. In order to heighten and balance the sensitivity of the 3D D-P algorithm, *n* origins and *n* sets of base planes can be used for each generalization (where *n* is an integer greater than one). In our experiments, *n* equals three. And the three intermediate results of the DEM generalization corresponding to each of the three origins and each of the three sets of base planes respectively are logically added as the temporary result. With the technique of automatic regulation of the thresholds, the most proper *n* thresholds can be determined to get the desired compression ratio for the final generalization result.

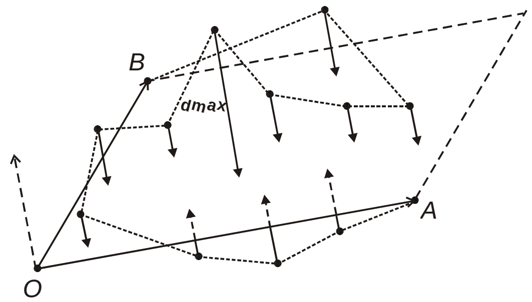


Figure 1. The first base plane and the ordered 3D discrete point set

Once the DEM, or the surface of the earth, has been generalized properly, one of its relief representations, say, the corresponding contour lines, must have also been properly generalized. This is the basic idea of this indirect generalization of contour lines.

EXPERIMENTS OF THE DEM GENERALIZATION AND THE INDIRECT GENERALIZATION OF CONTOUR LINES

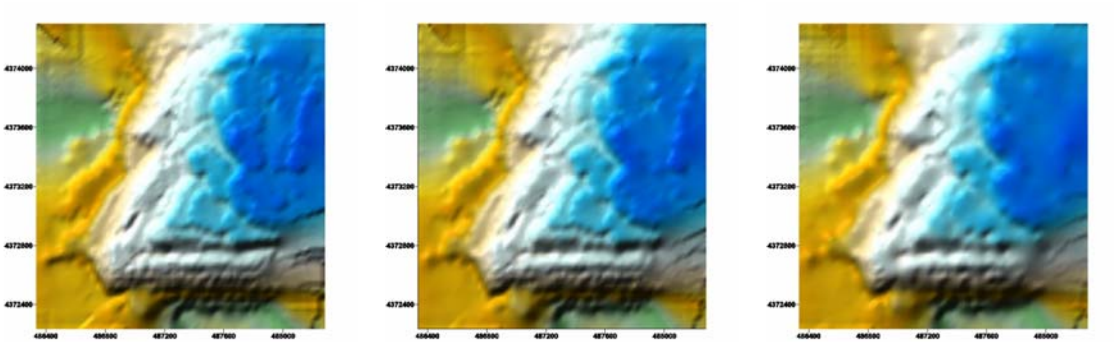
In this paper, three experiments are introduced. The source data for these experiments are: A and B. Data A is composed of 3134 points in the format of 3D randomly distributed discrete points; and data B consists of 15 521 points in the format of points along different contour lines. The experiments introduced in this paper are all based on a micro-computer with following hardware and software configuration: the Intel double-core CPU of Pentium 4 with the main frequency of 3.0 GHz/s, the main memory with 1 GB, the operation system Windows XP, and the programming language C#.

1.1 Experiment 1

Figure 2 shows the results of point-wise DEM generalization using the 3D D-P algorithm from the source data A and they are illustrated through the hill shading method by the software Surfer 8.0.

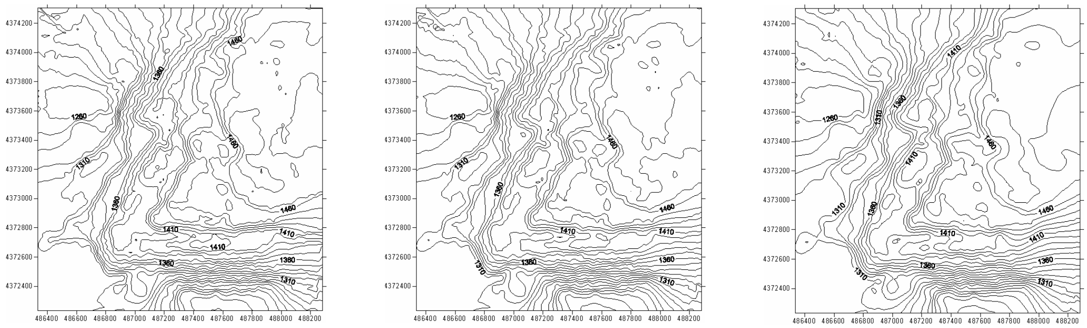
Figure 3 shows the results of point-wise DEM generalization using the 3D D-P algorithm from the source data A and they are illustrated with the contour lines. For the sake of comparison, no contour lines of the generalized results are removed in the figures of this paper.

Table 1 describes the parameters of the above mentioned point-wise DEM generalizations and their time cost.



Hill shading from 3134 points of source DEM data — Hill shading from point-wisely generalized DEM (1568 points left) — Hill shading from point-wisely generalized DEM (784 points left)

Figure 2. Hill shadings from the results of point-wise DEM generalization by 3D D-P algorithm



Contour lines from 3134 points of source DEM data — Contour lines from point-wisely generalized DEM (1568 points left) — Contour lines from point-wisely generalized DEM (784 points left)

Figure 3. Contour lines from the results of point-wise DEM generalization by 3D D-P algorithm

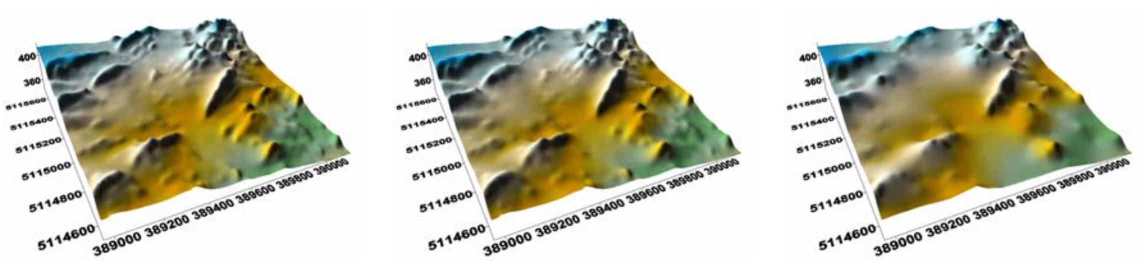
Method of generalization	Number of source points	Compression ratio	No. of points after generalization	Time consumed (seconds)	Initial threshold for three sub-processes
Point-wise, strict sorting	3134	50%	1568	7.188	20
	3134	25%	784	5.625	20

Table 1. Parameters of DEM generalization by 3D D-P algorithm

1.2 Experiment 2

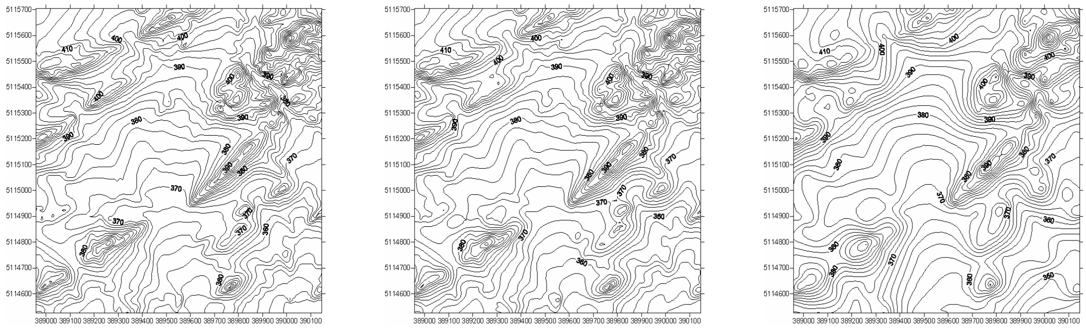
Figure 4 shows the results of point-wise DEM generalization using the 3D D-P algorithm from the source data B and are illustrated via the block diagrams with hill shadings.

Figure 5 shows the results of point-wise DEM generalization using the 3D D-P algorithm from the source data B and they are illustrated by the contour lines.



Hill shading from 15 521 points of source DEM data — Hill shading from point-wisely generalized DEM (3105 points left) — Hill shading from point-wisely generalized DEM (620 points left)

Figure 4. Block diagrams with hill shadings from point-wisely generalized DEM by 3D D-P algorithm



Contour lines from 15 521 points of source DEM data | Contour lines from point-wisely generalized DEM (3105 points left) | Contour lines from point-wisely generalized DEM (620 points left)

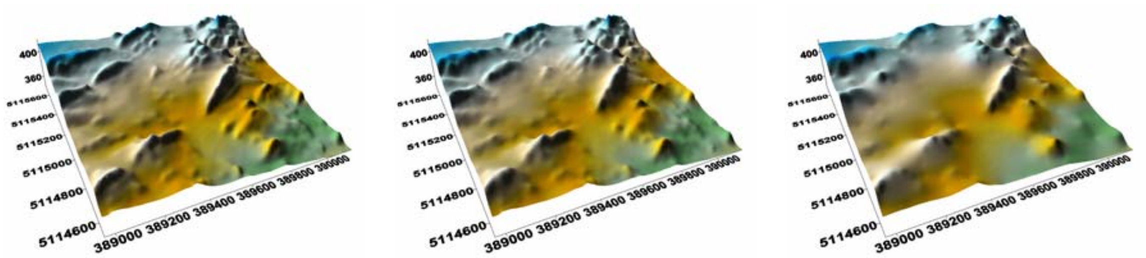
Figure 5. Contour lines from the results of point-wise DEM generalization by 3D D-P algorithm

1.3 Experiment 3

Although DEMs with different data formats can all be seen as the 3D randomly distributed discrete points, every generalization process can be a little bit different in order to fully utilize the specific characteristics of the source data and to speed up the process as much as possible. For example, if the source data are in the format of points along contour lines, there are two possible ways to line up the points from the source data, i.e. in addition to the above mentioned method of sorting and generalizing the source data point-wisely, generalizing the DEM line-wisely is also possible. That means, only the line-wise sorting by the nearest 3D distance between the last point of a contour line and the first point of another new contour is necessary and within a contour line all the points just keep their original orders. Normally, this small improvement can greatly accelerate the process, and the good generalization results remain untouched. Figure 6 shows the results of line-wise DEM generalization using the 3D D-P algorithm from the source data B and are illustrated via the block diagrams with hill shadings.

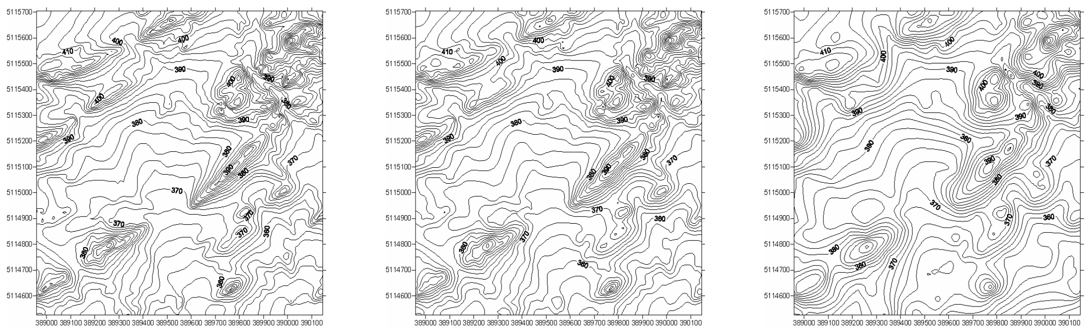
Figure 7 shows the results of line-wise DEM generalization using the 3D D-P algorithm from the source data B and are illustrated by the contour lines.

Table 2 illustrates the parameters of the point-wise and the line-wise DEM generalizations and the benefits from full use of the format characteristics of the source data for Experiment 2 and 3.



Hill shading from 15 521 points of source DEM data | Hill shading from line-wisely generalized DEM (3104 points left) | Hill shading from line-wisely generalized DEM (620 points left)

Figure 6. Block diagrams with hill shadings from line-wisely generalized DEM by 3D D-P algorithm



Contour lines from 15 521 points of source DEM data | Contour lines from line-wisely generalized DEM (3104 points left) | Contour lines from line-wisely generalized DEM (620 points left)

Figure 7. Contour lines from the results of line-wise DEM generalization by 3D D-P algorithm

Method of generalization	Number of source points	Compression ratio	No. of points after generalization	Time consumed (seconds)	Initial threshold for three sub-processes
Point-wise, strict sorting	15 521	20%	3105	86.297	20
	15 521	4%	620	82.563	20
Line-wise, less sorting	15 521	20%	3104	13.359	20
	15 521	4%	620	9.594	20

Table 2. Parameters of slightly different DEM generalizations by 3D D-P algorithm

CONCLUSIONS AND PROSPECTS

Through the preliminary study, the following conclusions and prospects can be made:

a) The 2D Douglas- Peucker algorithm can be expanded to the 3D, and can be applied to the global generalization of DEMs;

b) The automated generalization of DEMs by 3D D-P algorithm has a high speed and good results, and it is also proper for the generalization of DEM with huge volume of data if such techniques as avoiding or reducing the point sorting and partitioning of the source data are used;

c) It is not necessary to extract and apply the implicit geo-morphological structure lines in the process of this indirect generalization of contour lines, nevertheless, the indirectly generalized contour lines seems to have good cartographic quality in that the dominant geo-morphological structures have well been maintained while the minor relief forms, naturally depressed;

d) It is demanded that the result of generalization of water system and the indirectly generalized contour lines be harmonically registered by each other. Therefore, the assurance measures have to be worked out;

e) It would be ideal to have a mathematical criterion to evaluate the result of generalized DEM, so as to reach the best generalization result through intelligent regulation of the parameters for the generalization procedure;

f) It is necessary and practical to calculate the information amount of the correct contour line representation for a certain geo-morphologic type, a certain area, and a certain mapping scale, and use the calculated information amount for the final contour representation to regulate the degree of the generalization of the source DEM before the indirect generalization of contour lines can fully automatically meet the requirements of the cartographic norms or, possibly, of their improved variation.

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