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A DROP HEURISTIC CONVERSION METHOD FOR EXTRACTING IRREGULAR NETWORK FOR DIGITAL ELEVATION MODELS

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ABSTRACT

The advantages and disadvantages of various DEMs have been discussed extensively and have been concluded that for many types of applications the Triangulated Irregular Network is better suited for approximating terrain surfaces because of its efficiency in data storage and its simple structure for accommodating irregular data points. While the U.S.G.S. grid DEM files are the most widely available digital elevation data, an efficient conversion algorithm between grid-based DEM and TIN models becomes more important as TIN models are increasingly more popular.

This paper first examines and compares several existing methods of converting grid DEMs to TIN models with a new method which uses a drop heuristic approach. The drop heuristic method may be used either to extract TINs from grid DEM or to reduce the size of an irregularly space point set.

INTRODUCTION

For representation of terrain, an efficient alternative to dense grids is the Triangulated Irregular Network (TIN) (Peucker et al. 1978), which represents a surface as a set of non-overlapping contiguous triangular facets, of irregular size and shape. In TIN models, a point consists of a set of triplets (x,y,z), where z is the dependent variable such as elevations. The independent variables (x,y) may form a uniformly spaced array or they may be irregularly distributed. TIN allows uneven sampling of points from non-regular surfaces and therefore reduces possible data redundancy. TIN is also more suitable for computations such as inter-visibility or extracting certain features of the surface because of its ease of updating and retrieval efficiency. However, most of the available digital elevation models (DEM), such as the U.S.G.S. grid DEM files, are in grid form and would need to be converted in order to construct TIN models. An efficient conversion method which selects points from grid DEMs to form a TIN model becomes more important as TIN models are increasingly more popular.

We briefly reviews several existing conversion methods for selecting points from grid DEMs to form TIN models in terms of their advantages and disadvantages. These methods include Peucker-Douglas' method (PD) (Peucker and Douglas 1975), Fowler-Little's method (FL) (Fowler and Little 1979), and Chen-Guevara's method (CG) (Chen and Guevara 1987). A drop heuristic method (DH) is then proposed and compared with the existing methods.

CONVERSION METHODS

Topographic surfaces are non-stationary (Pike and Rozema 1975) because the changes in relief variation of the terrain are not regular and vary from one land type to another. Approximating non-stationary surfaces by any global parametric approach becomes extremely complicate and therefore is excluded from discussion here.

The most important objective of any conversion method is to preserve as much terrain features as possible during the processes of selecting points from grid DEMs. Different criteria for point selection will result in various degree of approximations to the surface depicted by the original grid DEM. Consequently, accuracy can be considered as a property of the subset of points selected to represent the surface. Accuracy may be defined as some measures -average, median, or maximum- of the distribution of vertical deviations between the surface approximated by selected points and the surface depicted by the original DEM. The discussion about the existing conversion methods will be based on this concept of accuracy.

Peucker-Douglas' Algorithm

Peucker and Douglas (1975) proposed a method to detect pits, peaks, passes, ridges, ravines, and breaks from a given array of terrain elevation by local parallel processing. It attempted to extract global information through local operations of discrete elevation data. They assumed that the surface has a smooth neighborhood correlation - the surface is topographically well behaved - so that every point on a surface can be classified on the basis of an analysis of its neighbors.

For every point in a grid DEM, a 3 by 3 filter was used to construct a sequence of elevation differences between the point (located at the center) and its 8 neighbors in either a clockwise or counterclockwise order. The sequential pattern of sign changes or frequencies of the elevation differences associated with each point was then used to determine the terrain feature of the point. For example, if all elevation differences between a point and grid neighbors are all positive and exceed a pre-specified threshold, the center point may be classified as a peak (See Peucker and Douglas 1975 for details).

This method offers a feasible way of classifying terrain features of points in a grid DEM. However, it has very little use when applied to our problem as the method lacks clear definitions of thresholds in analysis of elevation differences (such as the case of peak points). In addition, the methods offers no clear criteria which can be used to determine the number of points needed to be selected from the original grid DEM.

Fowler-Little's Method

Using concepts similar to Peucker and Douglas' algorithm, Fowler and Little (1975) proposed a two-phase method for selecting points from a raster grid DEM to construct TIN models. Their method begins with the entire collection of points in the grid DEM. The first phase of generating a TIN by this method is the extraction of the skeleton of "surface-specific" points and lines. Nodal features, such as peaks, pits, and passes, may be detected by procedures similar to what Peucker-Douglas suggested. As to linear features such as ridge and channel lines, additional operations are required. For each point in the grid, a 2 by 2 filter ([i,j], [i,j+1], [i+1,j], [i+1,j+1])is used to determine whether a point may be a candidate for linear terrain features (ridges or channels). The lowest of the four is recorded as not possibly being a "ridge" point, and the highest of the four is recorded as not possibly being a "channel" point. Candidates are connected to form ridge and channel lines. A horizontal tolerance has to be specified so that the number of points representing each linear terrain feature can be reduced by a line generalization procedure suggested by Douglas and Peucker (1973).

An initial triangulation is then constructed for the selected points. The second phase of the method compares the triangulated model of selected points with the grid model and introduces "support points" to reduce the maximum error below a specified tolerance. Grid points are inserted as "support points" to the triangulation at locations where the elevations differences between two surfaces approximated by the triangulation and the original grid DEM exceed certain pre-specified tolerances (vertical tolerance). The process stops when the triangulated surface is closer to the grid surface than the specified vertical tolerance level.

This methods selects points according to their terrain features and has an advantages of holding maximum error under a pre-specified level. The recursive procedures of adding support points may fit the approximated surface very closely to the original surface under a small tolerance. However, the result will be a much larger number of points. In addition, there appear to be no unique, clear criteria to decide a proper tolerance level in both vertical or horizontal cases. The advantage of this method is that a user can control the difference of elevation between the original and the converted surfaces, but the disadvantage is the trade-off of obtaining a larger size of data sets.

Chen-Guevara's Method

Another method for selecting points from a dense grid DEM relies on an estimate of the significance of each point in the grid (Chen and Guevara 1987). The significance is measured by calculating how well each point is approximated by its eight grid neighbors. For each pair of neighbors, the distance from the center point to the line connecting the neighbors is calculated; the shortest (perpendicular) distance is used instead of the simple vertical displacement, to compensate for the effect of different slopes. The (unweighed) average of the four distances is used as a measure of the significance of the central point. After calculating a significance for every point in the matrix, the least important points are discarded, based on either a pre-determined significance level or a desired number of points.

The concept of this method is straightforward and the procedures are faster than those of the two methods previously described. Another advantage of this method would be the flexibility of controlling either the size of the output point set or a pre-set level of significance by which points with higher significance are kept and those with lower significance are discarded. However, the selection is totally based on local information and offers no guarantee or attempt to the global fitness between the triangulated and the grid surfaces.

Summary

In summary, the three methods described above each have their advantages and disadvantages. A common property of all of these methods is that the solutions are dependent on pre-determined parameters: these are 2 tolerances in the case of Fowler-Little's method, and either a tolerance or a prescribed number of points in the case of Chen-Guevara's method.

These methods suggested that there may be two possible stopping rules when converting a dense grid to a TIN model:

1) a pre-set number of points to be selected and
2) a pre-set tolerance of difference of elevations between the original surface and the surface approximated by the converted TIN model (in this case, accuracy is measured by the maximum of the elevation difference).

While information loss must occur during the conversion process, it is not easy to choose one of the two possible stopping rules over the other (even in the case of Chen-Guevara's method). Ideally, one might prefer to have as small a tolerance as possible while the size of the data sets is also as small as possible. Unfortunately there exists no single solution to satisfy both requirements. Therefore, users will always have to find an appropriate middle ground between these two criteria for their own purposes.

THE DROP HEURISTIC METHOD

The purpose of a conversion method is to convert a dense grid DEM to a TIN model by properly selecting important points so that a surface approximated by the converted TIN model is as close to the surface of the original grid DEM as possible while the size of a converted data set is reduced to an acceptable level. An ideal conversion method should have the ability to select only those important points while minimizing the information loss.

A new method which uses drop heuristic procedures to discard insignificant points from grid DEMs to construct TIN models was developed here with an objective of minimizing information loss during each attempt to discard a point. The drop heuristic method may be terminated by either a user-defined tolerance level of elevation differences or a user-defined number of points selected for TIN models. Unlike the Chen-Guevara's method which establishes the importance of a point from the elevations of its grid neighbors, the new algorithm defines the importance of a point as the difference between its real elevation and an elevation interpolated from the approximated TIN surface. The computation of this elevation difference is described in the following section of interpolation procedures.

Interpolation Procedures

The interpolation procedure is described in Figure 1. First, the points are expressed in two dimension (Figure 1a), assuming that point O is found to have Delaunay neighbors A, B, C, D, and E. The dashed lines connect point O and its Delaunay neighbors. If point O is removed, point A, B, C, D, and E will be connected by solid lines as the relationship of Delaunay neighbors would be re-defined by a new triangulation (solid lines).

The next step is to locate point O with one of the newly constructed triangles. In the case of Figure 1b, it would be triangle (BCE). Construct a vertical line in space passing through point O. This vertical line must intersect the plane of the triangle (BCE). The absolute value of the difference between the elevations of point O and the intersection point O' is then defined as the difference between the real and interpolated elevations of point O. In the case where the point falls right on one of the edges, the interpolation process is then just a sample linear interpolation.

The Algorithm

The drop heuristic method first includes all candidate points in the output point set and gradually drops those non-important points until a desired number of points is reached or no elevation differences are found to exceed a pre-set tolerance level. The importance of a point is defined by the difference between its real elevation and the elevation interpolated after it has been dropped and a new TIN using Delaunay triangles (Delaunay 1934, Lee and Schachter 1980, Tarvydas 1983, de Floriani et al. 1985) has been constructed. The larger the difference, the more important the point is. The Delaunay triangulation is used because of its ability to maximize the angles between edges of triangles in the network (Lawson 1972) and its convex outer boundary.

The drop heuristic starts by adding a diagonal edge connecting the upper right point and the lower left point of each grid cell. Two triangles are created for each grid cell and the whole network serves as an initial selected and connected as Delaunay triangles. Each vertex in the output point set is then evaluated to determine how well it is approximated. If the difference between the real and interpolated elevations for the point being evaluated is the smallest among all points being evaluated, the point is dropped from the output point set. The processes are repeated until a pre-determined number of points is reached or until no point is found to be associated with a difference of elevation which is smaller than a pre-determined tolerance.

More technically, the objective of the drop heuristic method may be summarised as follows:

> Given a grid DEM of n regularly spaced observation points and a pre-specified number of points of the output point set, or a difference threshold of elevation information loss, the objective is to select M points, where M « N, such that when the Delaunay triangulation of the M points is obtained, the interpolated elevations of the remaining N-M points are as close as possible to their observed values.

The algorithm which attempts to reach a solution close to optimum on this objective is as follows:

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0.  include all N points into the output point set
    initially;
1.  to each grid cell, add a diagonal line segment
    connecting the upper right and lower left corners
    to construct the initial Delaunay triangulation for
    the grid DEM;
2.  for every point in the output point set, test the
    following steps:
    a.  find its Delaunay neighbors;
    b.  reconstruct a Delaunay triangulation among the
        Delaunay neighbors without the tested point;
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    c. find out in which triangle the tested point is located;
    d. construct a vertical line passing through the tested point;
    e. compute the intersection of the vertical line and the plane of the triangle in which the tested point is located
    (the elevation of the intersection found is the estimated interpolation of the tested point);
    f. compute the absolute difference between the real and estimated elevations for the tested point;
3. drop the point which has the least absolute difference between its real and estimated elevations from the output point set;
4. add edges of newly generated Delaunay triangles into the existing triangulation;
5. check if the desired number of points is reached, if so, stop;
otherwise, go to step 2.

The drop heuristic algorithm was coded in FORTRAN and was tested on U.S.G.S. 7.5 minute quadrangle grid DEM files. The results are shown in Figure 2. The original grid DEMs are 350 by 500. The converted TINs were set to 200 points.

The primary advantage of the drop heuristic is that it attempts to minimize the information loss during each step. Whether the point is actually a peak, pit, pass, or a point on a linear topographic feature such as ridge, valley, or channel, it can only be dropped if it can be closely interpolated by a surface modeled without it.

CONCLUSION

The Fowler-Little's method has the advantage of capturing linear topographic features. The associated disadvantage of the method is that there is not a clear and definite criterion to define a proper tolerance for the method. The Chen-Guevara's method focuses more on local variations rather than topographic features of larger scale such as ridge or channel lines. Its advantage is that the method is fast and less complicated.

The advantages of the drop heuristic method is that it may be applied to either a grid DEM or any set of irregularly spaced points. In addition, it may be used together with any other conversion method just for the purpose of reducing the number of points. The criteria used by this method is directly based on the differences between the approximated and the original surfaces during each step. Finally, the method also provides the flexibility of using either a pre-set number of output point set or a pre-set of threshold of elevation differences as stopping rule so that various applications can adapt whichever stopping rule that is suitable.

REFERENCES

Chen, Z-T. and J. A. Guevara, 1987, "Systematic selection of very important points (VIP) from a digital terrain model for constructing triangular irregular networks". AUTO-CARTO 8, ACSM, Baltimore, MD, pp. 50-56.

De Floriani, L., B. Falcidieno, and C. Pienovi, 1985, "Delaunay-based representation of surface defined over arbitrarily shaped domain". Computer Graphics, Vision and Image Processing, Vol. 32, pp. 127-140.

Delaunay, B., 1934, "Sur la sphere vide". Bulletin of the Academy of Sciences of the USSR, Classe Sci. Mat. Nat., pp.793-800.

Douglas, D. and T. K. Peucker, 1973, "Algorithms for the reduction of the number of points required to represent a digitized line or its caricature". The Canadian Cartographer, Vol. 10, No. 2, pp. 112-122.

Fowler, R. J. and J. J. Little, 1979, "Automated extraction of irregular network digital terrain models". Computer Graphics, Vol. 13, No. 2, pp. 199-207.

Lawson, C. L., 1972, "Generation of a triangular grid with application to contour plotting". California Institute of Technology, Jet Propulsion Laboratory, Technical Memorandum No. 229.

Lee, D. T. and B. J. Schachter, 1980, "Two algorithms for constructing a Delaunay triangulation". International Journal of Computer and Information Science, Vol. 9, pp. 219-242.

Peucker, T. and D. Douglas, 1975, "Detection of surface-specific points by local parallel processing of discrete terrain elevation data". Computer Graphics, Visions and Image Processing, Vol. 4, pp. 375-87.

Peucker, T., K. Fowler, J. Little, and D. Mark, 1978, "The Triangulated irregular network". In Proceedings of the DTM Symposium. ASP-ACSM, St. Louis, Missouri, pp. 24-31.

Pike, R. J. and W. J. Rozema, 1975, "Spectral analysis of landforms". Annals of the Association of American Geographers, Vol. 65, No. 4, pp.449-516.

Tarvydas, , 1983, "Terrain approximation by triangular facets". Proceedings, AUTO-CARTO VI, Ottawa.

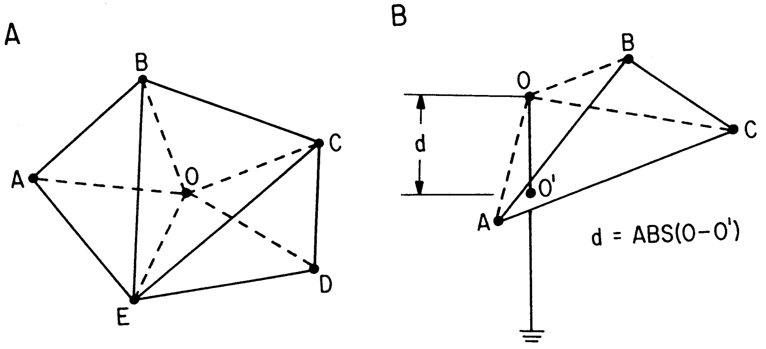

Figure 1 (a)-(b)

Interpolation procedures in drop heuristic method

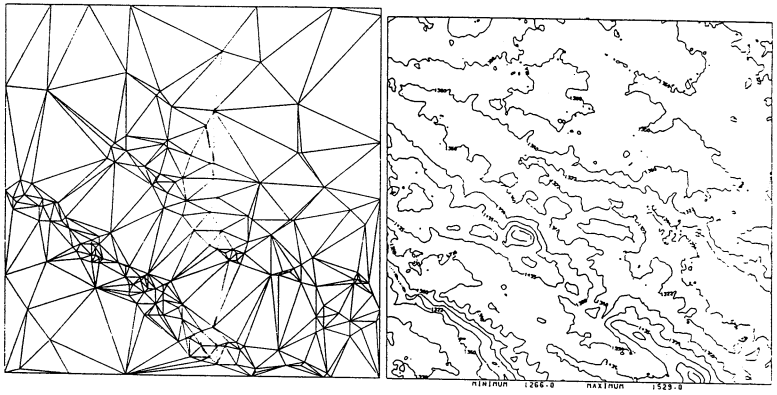

Figure 2(a) Krone Ranch, MO. N47°07'30" W112°15'00"

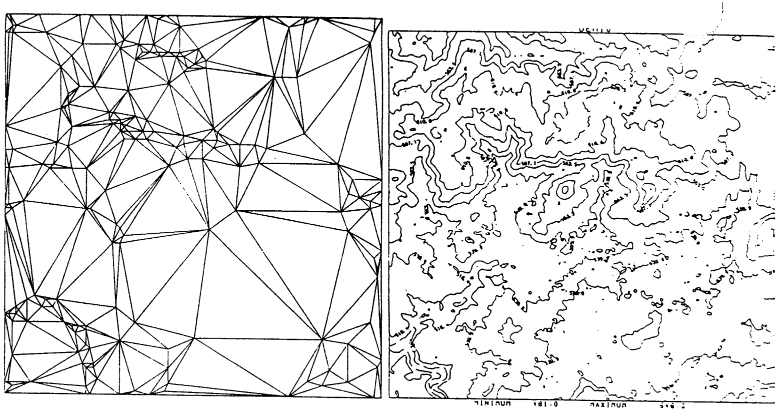

Figure 2(b) Herbert Domain, TN. N35°45'00" W85°15'00"

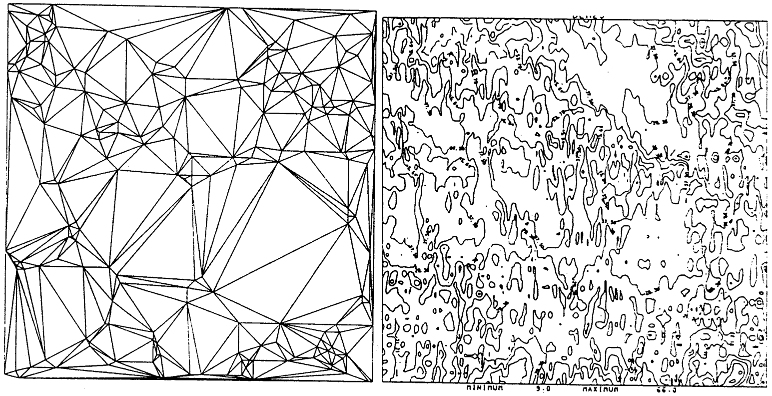

Figure 2(c) Benndale SW, MS. N30°37'30" W88°52'30"

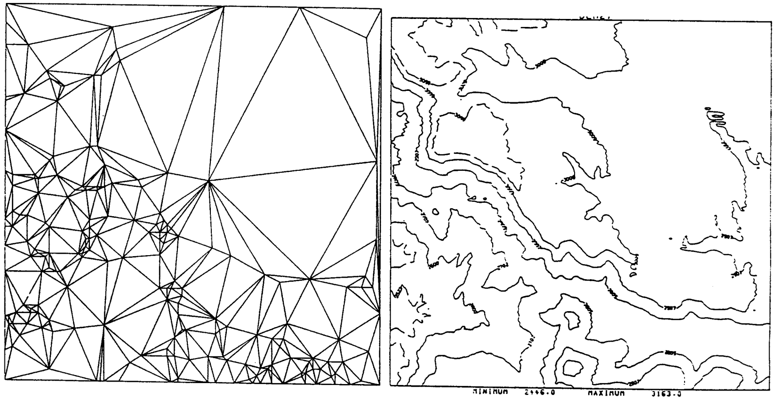

Figure 2(d) Cedar Break SE, UT. N37°30'00" W112°52'30"