The New Triangulation-Simplify Algorithm of TIN

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Abstract: Simplification of triangulation structure plays an important role in constructing three-dimensional modeling. In this paper, we study all of triangulation-simplify algorithm in use these days, and introduce an algorithm which is very useful in many areas, named TIN simplification based on Vertex Decimation, to actual simplification of three-dimensional terrain. For the huge data of three-dimensional terrain, authors introduce a new algorithm and make it more efficient.

Key Words: Triangulation Structure Model, TIN, Triangulation-Simplify Algorithm, Vertex Importance

1. Introduction

The GIS technology is more and more matured in recent years, it generally attributes the geometry characteristics of the primitive object with the polygon grid data model, and uses illumination, the texture technology to enhance the authenticity and the visual effect of the polygon grid simulation. As TIN (Triangulated Irregular Network) expresses one continual superficial fundamental mode in GIS, it has the variable resolution, the high precision, and can display the shape characteristics of the irregular landform, therefore it has the extremely widespread usage. Using TIN we can analyze and manage many kinds of geography information, including DTM; compute degree of slope and aspect, superficial area and superficial length; do visible analysis and vision zone analysis and so on.

In all methods of producing TIN, because the Delaunay net of triangular has characteristic of "the maximum minimum interior angle" [1,2], making triangulars which have the incisive interior angle not appear, so its performance in the terrain fitting aspect is most excellent, it also obtained the widespread application.

The complex Delaunay triangle net model can attribute geometry characteristics of terrain in a better way, but this needs the support of a high demonstration platform and then can achieve a certain speed of drawing, under the present hardware level some model data is radically unable to achieve acceptable drawing effect. For instance, the triangle net model magnitude which is obtained in highly data field approximately is 10^5 to 10^7, such magnanimous data set, to be demonstrated precisely needs expensive hardwares. On the other hand, although simple Delaunay triangle net model can obtain the higher drawing speed, it actually lacks vivid fidelity in the simulation of geometry characteristics of primitive object.

Therefore, the conflict between the ultra large scale of data and the existing poor hardware condition caused the inevitability of the triangular net simplification. Moreover, the detail level model (Level Of Detail, LOD) also bases on the triangular net simplification. Therefore the simplification of triangular net is an important part of three dimensional construction.

2. Introduction of Algorithm

The goal of triangular net simplification is that using approximate model to express triangular net model. The visible characteristics of primitive model are maintained as much as possible, but numbers of vertex are less than numbers in the primitive triangular net.

There are many algorithms for triangular net simplification, according to whether gradually increasing the detail in the simplification process from one initial thick grid or deleting geometry element from primitive grid we can get two kinds of simplification methods, one is called gradually thinning method, the other is geometry element deletion method. Geometry element deletion method is used mostly, and there are many algorithms of this kind. For example the method of vertex deletion, the method of side folding[3], the method of triangle folding and so on. The method of vertex deletion is used more often, it is easier to achieve, especially it suits the simplification of the terrain Delaunay triangular net.

Some concepts appear in the algorithm:

Concept 1: related triangle group of vertex. Regarding any vertex v_i in triangular net, the triangle set which shares one vertex with v_i is called the related triangle group of this vertex.

Concept 2: the average planes of vertexes. Supposing in the vertex v_i related triangle group each triangle normal line vector is n_k, the center is x_k, the area is a_k, then the planes that are structured by the definition of line vector and center beneath are called the average planes of the vertexes.

$$N = \frac{\sum n_k a_k}{\sum a_k}, n = \frac{N}{|N|}, x = \frac{\sum x_k a_k}{\sum a_k}$$

Concept 3: vertexes' importance. vertexes' importance is defined as the distance between a vertex and its average plane, namely :

Importance = distance between a vertex and its average plane = |n•(v-x) |

n: vertical vector of average plane

v: vertex vector

x: central point vector of average plane

The relation of triangles of neighboring levels in LOD model based on TIN is not simply one-to-many, but we can establish relations of one group to one group through the simplification. To realize the transformation between the LOD model levels, we can use the higher detail triangle group to replace the lower detail group. As figure 1 shows, the 4 triangles on the right side can be substituted by the 6 triangles on the left side.

According to the thought above, regarding one TIN grid net, traverse of all vertexes, delete the allowed vertexes and the next triangles, revises this vertex and deleting symbolizes of its surrounding vertexes, then take partial triangularization to the star-type polygon which remain. At the same time modify the vertex structure, and delete the primitive triangle group in the triangle chain table and create the new triangle group, then we can obtain the simplified grid net of next level. This process can repeatedly go on, until meet the request. In this way, we can obtain a series of LOD models.

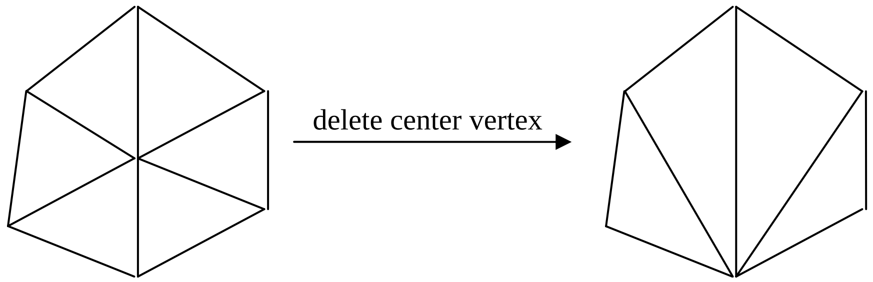

Fig.1 scheme of vertex deletion

3. Algorithm

Practically, data set is very big, and we often need to simulate the three dimension scene of field on PC machine, so the efficiency of simplification requests especially high. The actual DEM data is the regular grid data, therefore we can construct regular triangular net very simply in the preliminary test, then gradually simplify until it can meets the requirements.

The algorithm condition of judgment of vertex deletion is: Importance is smaller than one threshold value which is defined in advance.

The determination condition allows designers to design for different TIN model, in order to emphasize the usability of the algorithm, we divide the simplification process into 5 levels, and reconsider the setting of the importance threshold value of each level.

Suppose the threshold values of 5 levels are C0, C1, C2, C3 and C4. C0 is the smallest importance value of all the vertexes in the original model, this model is the very original model, namely:

$C0 = \min \{ Ipi \}$; (C0 is not equal to zero, Ipi is the importance of vertex)

In order to make sure the establishment and dynamic demonstration of the LOD model, we have to make sure that the variation of simplification model is uniform, and that the smallest importance values of all level vertexes conform to equation relation, namely:

$C0/C1 = C1/C2 = C2/C3 = C3/C4 = r$; $(r<1)$

C4 should be smaller than the maximum importance value of all vertexes.

Namely: $C4 < \max\{ Ipi \}$;

Value determination of r or C1 is determined by tests. It is appropriate to keep simplification efficiency about 10% at each time. At the same time we must make sure the final erroneous value is smaller than the scope assigned; Of course, we also can determine r value though the precision which assigned by the user.

4. The Realization of the Algorithm

Before each simplification, it is necessary to recompute every vertex's importance, and the method is

allocating the vertex importance which is deleted in last simplification to surrounding vertexes, that is, importance of vertex is no longer fixed, it will change dynamically along with the vertex deletion.
There's another work, re-produces the TIN model. In this TIN model, it does not include the deleted vertexes or triangles, but adds new triangles to re-constructed topology relations of TIN. This work guarantees no disturbance that vertex deletion last time generates and influences the simplification this time, and controls the error through only one parameter named importance.
Trims all improved thought, designs algorithm flow chart as figure 2.

1) the initialization of the triangular net simplification
   Re-compute the importance of existing vertexes;
   Re-constructs the topology relations of TIN.

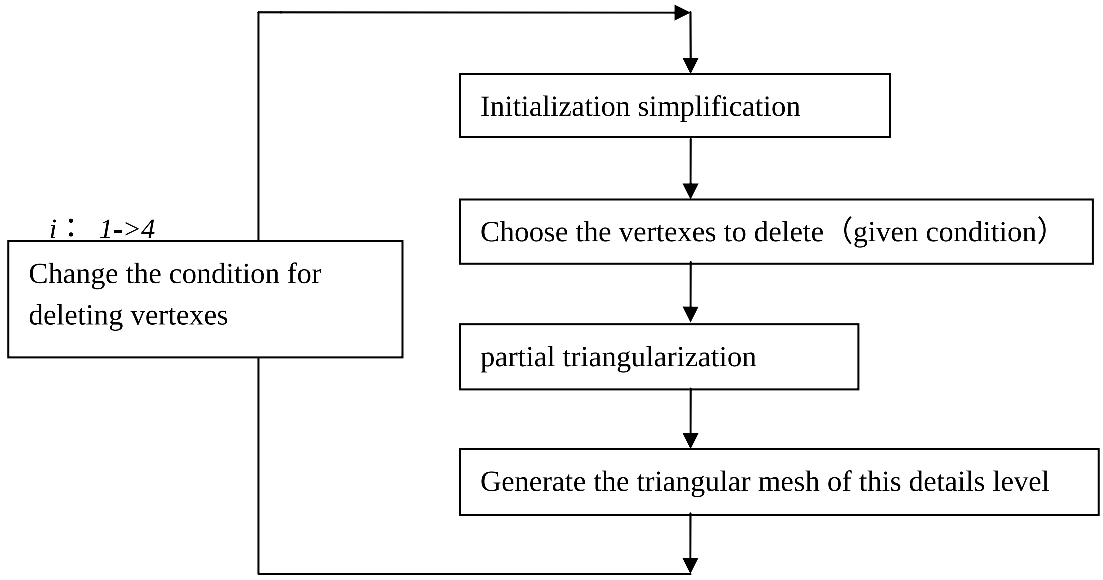

Fig.2 algorithm process chart

2) chooses the vertexes to delete
   According to the importance threshold rules discussed above, we can determine the importance threshold of this details level;
   Traverse all vertexes, and put all vertexes that satisfy such condition:
   Ip < Ci; (Ip is vertex importance, Ci is the importance threshold value of this detail level) into a linked list (VertexList).
3) partial triangularization
   Traverse the linked list VertexList, take out a vertex, set the deletion symbolizes of the vertex, and set deletion symbols of all surrounding triangle;
   The polygon cavity after the deletion of triangle vertexes.
4) Generate TIN of the detail level
   Set detail level symbolizes of all vertexes and triangles that have not be deleted, generates TIN of this level.

5. experimental results

5.1 statistics result

Statistics result of vertex deletion in simplified process is showed in table 1.

The DEM model that experiment adopts includes 63246 vertexes in all, in the experiment process, under different ranks, according to condition of the importance which produced, this algorithm would delete vertexes by level, and establish TIN model of different rank, to the most simplified level it deletes 33666 vertexes altogether, and the efficiency is 53.23%.

Table 1 simplified statistics result

Simplification order	The number of deletion
1	3473
2	5817
3	12997
4	11379

5.2 the algorithm simplified model elevation error

Stochastically extracts 12 points, calculates the relative original model elevation (H) error of these points separately in the algorithm model with the biggest simplification, namely:

$$ERROR = H_{new} - H$$

note: These 12 points were all deleted in the simplified model. We also calculated the relative error for a convenience comparison:

Error (%) = ERROR / H

Error analysis data as table 2 shows.

It is not difficult to deduce from the data of the table that the error between the simplified algorithm model and the original one completely conforms to the item requirement, the algorithm error is allowed. But the efficiency of algorithm manifested enormous superiority, which suits applications of high requests of simplification efficiency. After using the simplified model, we may show extremely smooth demonstration of bigger scale DEM model on the popular microcomputer. Moreover, under the control of importance, there is more vertex deletion in a smoother area, but in regions that terrain changes tremendous, the corresponding vertex removals are less.

Table 2 Algorithms models elevation error

Project	altitude		error	
	Primitive model(m)	new(m)	absolute(m)	relative (%)
2034	1078.00	1075.67	2.33	0.22

5284	1334.00	1332.99	1.01	0.08
12568	1254.00	1265.72	11.72	0.93
25079	1174.00	1174.00	0.00	0.00
29405	1134.00	1140.67	6.67	0.59
33658	1234.00	1220.67	13.33	1.08
37275	1054.00	1046.61	7.39	0.70
40748	1054.00	1054.00	0.00	0.00
45374	1233.00	1236.78	3.78	0.31
56281	1114.00	1128.93	14.93	1.34
61176	1134.00	1134.00	0.00	0.00
14785	1274.00	1274.00	0.00	0.00
Average error			5.10	0.44

5.3 the effect of simplified chart

Figure 3 is the primitive TIN model line graph, the vertexes are very crowded, and the effect of demonstration is very good, the mountain chains and the rivers' outlines are very clear.

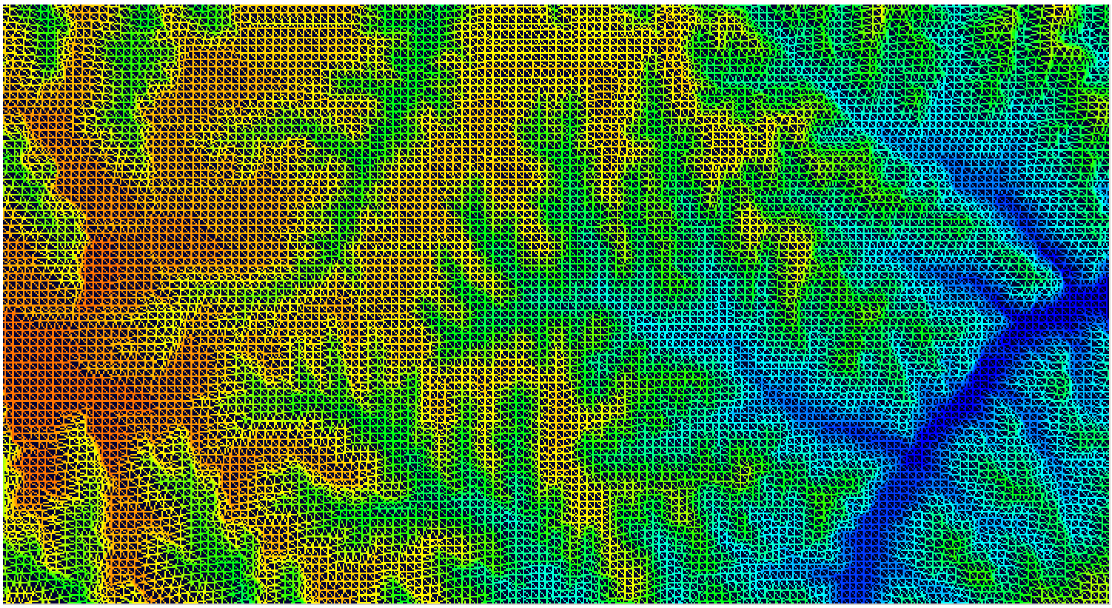

Fig. 3 primitive TIN model graph

Figure 4 is the striation graph of the final simplification algorithm, the number of the vertex reduces by more than 53%, It has already allowed the extremely smooth operation carried on the popular microcomputer, like the flight, rotating model and so on, but the mountain chains and the outlines of rivers had not changed fuzzily. Although it is inevitable to lose more model details, but terrain elevation errors are in control, and this does not affect the browsing and the examination of the model. It can be very fast to search terrain characteristics. So this kind of simplification model suits the condition very well. But if we have to carry on a work that needs very high precision such as morphometry, we may adjust the LOD level, so as to demonstrate more precise topographical model, which facilitates normal work.

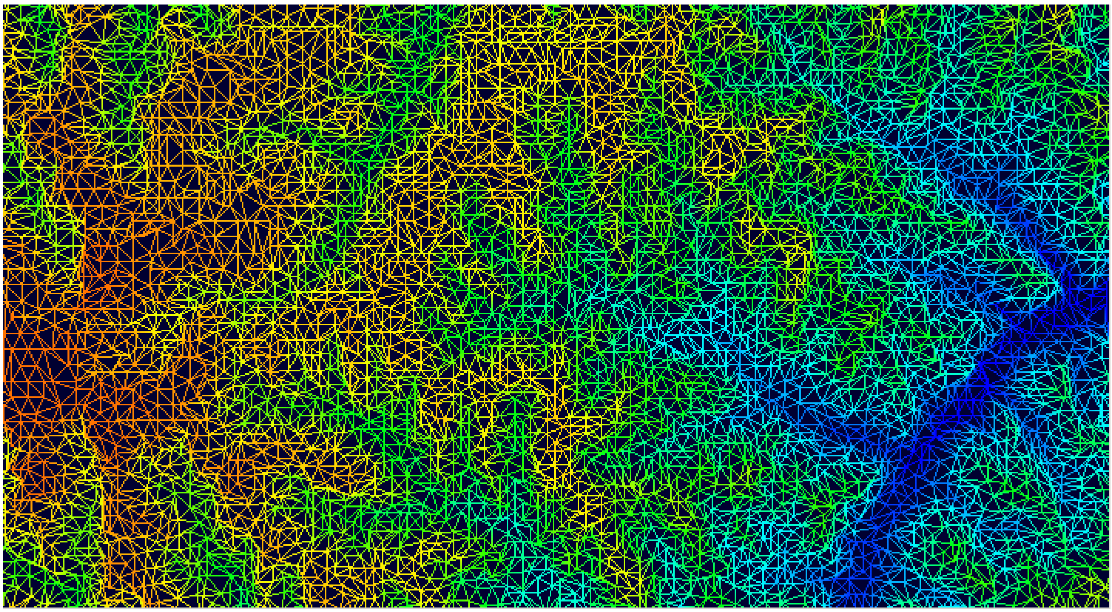

Fig. 4 the TIN model graph after algorithm simplification

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