# A STRATEGY TO BUILD A SEAMLESS MULTI-SCALE TIN-DEM DATABASE

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**ABSTRACT:**

With the development of 3D GIS, the visualization of the earth's surface is more and more important. In order to improve the efficiency and the precise of the terrain visualization, it is essential to build a seamless multi-scale database. At present, building a global seamless multi-scale database is a challenge to many scholars. This paper discusses the strategy to build a seamless multi-scale terrain model database. Though triangulated irregular network has a lot of advantage in the terrain representation, there are several bottlenecks to solve. In this paper, it describes the technology of constructing the Delaunay Triangular and the data structure. Storage, integration and update strategy is also given.

## 1 INTRODUCTION

How to represent the earth's surface is a basic problem of the geographic and the spatial information science. With the development of the digital earth, how to represent the spatial information of the earth has been the subject of extensive research in recent years. Digital Elevation Model (DEM for short) of the global terrain is an important component of the digital earth. Unfortunately, the present models are only suit for a local area. As for global area, there are no proper models and algorithms. A seamless DEM database can be a solution to the problem. It is a challenge to many scholars and it will be discussed in this paper.

DEM was brought out for auto-engineering of highway originally in the late 1950's. It is the digital expression of the earth's surface, including both spatial and property information. After a half century, there have been kinds of methods to model the terrain, including physical models and digital models. Digital models can be modeled by mathematics and geometrics. Kinds of functions are the mainly mathematics description, while the geometrics methods are described by points, lines and areas. Grid, Contours and Triangulated Irregular Network (TIN for short) are the three primary geometric models for terrain representation.

Comparing to the other models, TIN model has a lot of advantages in the expression of the terrain information as the unit of the model is the triangle. First, it is not only suit for regular distributed data points, but also suit for irregular distributed data points, while grid model is only suit for regular distributed data points. Generally speaking, the data points acquired from the field work don't distribute regularly. TIN model offers a more flexible model. Second, because the earth's surface is seldom absolutely flat, the data density is changing with the different terrain complexity. Grid model use the regular square meshes to represent the earth's surface, while TIN use the irregular triangle meshes. TIN model can reduce the redundance data of Grid model and especially excel at the regions where the terrain is complicated and changes sharply. Third, the precision of the TIN model is higher than other models on the terrain representation. Therefore, it does better in the precision and the efficiency of calculating the elevation than contours model. Having so many advantages, TIN-DEM has been applied in hydrography and highway engineering successfully in recent years.

Every coin has two sides. The disadvantages of TIN model are obvious, which limit the applying of the TIN model. First, complexity of the data structure makes it difficult to manage TIN data expediently and record the topologic relationships. And it is also hard to find a data structure that can manage all kinds of TIN data properly. Second, it takes a good while to generate the TIN meshes when there are millions of points. Though there are many algorithms to produce DEM based on the TIN model, few algorithms are high efficient. Third, nowadays especially in China, due to the main formats of the final DEM products are still based on Grid model and contours model, their middle product (TIN) is abandoned. It is a waste of time and money. What's more, the update procedure of these products is inefficient and costly. As for TIN-DEM, it needs geographical feature lines and some other constrained edges to update the triangular meshes. The algorithm of the update process has to be optimized, too.

In order to build a global seamless multi-scale TIN-DEM database, finding solutions to these disadvantages is highly important. This paper will discuss the possible solutions, including the TIN generation algorithms and the corresponding data structure, storage, integration and update solutions.

## 2 ALGORITHMS AND DATA STRUCTURE

The well-known Delaunay triangulation and its duality, Voronoi diagram, are becoming increasingly important and have found extensive applications in various fields (Aurenhammer F., 1991). It optimizes the minimal interior angle of constructed triangles, which makes it convenient for different engineering applications. In this paper, we use Delaunay triangulation.

### 2.1 Delaunay Triangulation

Let S be a set of non-collinear points in the plane. Triangulation T(s) is the maximal division of a plane into a set of triangles with the restriction that each triangle edge, except those defining the convex hull of S, is shared by two adjacent triangles. A Delaunay triangulation DT(s) is a unique triangulation constructed on S such that a circum circle of any triangle does not contain any other point from S. This condition, frequently also considered as an empty circle property, optimizes triangulation according to the minimal inner angle of the triangles. Triangles from DT(s) considered as Delaunay triangles (or legal triangles) and their circum circles as Delaunay circles. Figure 1 shows an example of non-Delaunay and Delaunay triangulation.

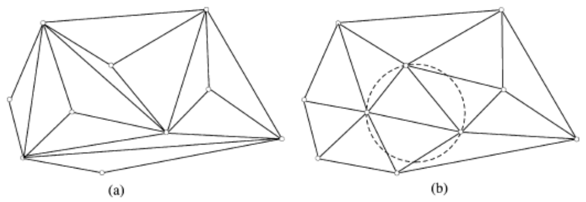


Figure1. Non-Delaunay (a) and Delaunay (b) triangulation

In 1977, Lawson (Lawson CL, 1977) showed that any triangulation T(s) can be transformed into DT(s) by applying the empty circle test on all pairs of triangles. If the empty circle property is violated, the common edges of the two triangles are swapped. The Delaunay triangulation is obtained when this procedure is recursively applied on all inner edges of the triangulation. This procedure is known as a Lawson's local optimization shortly named also legalization or LOP (de Berg M, van Kreveld M, Overmars M, Schwarzkopf O, 1997).

### 2.2 Algorithms

There are many Delaunay triangulation algorithms. Su and Drysdale (Peter Su and Robert L. Scot Drysdale, 1995) classified the algorithms into five groups: incremental insertion algorithms, gift-wrapping algorithms, divide and conquer algorithms, convex hull based algorithms, and sweep-line algorithms. Some of these algorithms are surveyed and evaluated by Fortune (Ding-Zhu Du and Frank Hwang ,1992) and Su and Drysdale. Their results indicate a rough parity in speed among the incremental insertion algorithm of Lawson (Lawson CL, 1977)], the divide and conquer algorithm of Lee and Schachter, and the sweep-line algorithm of Fortune.

Due to the Delaunay triangulation algorithms have reached maturity and the performance of these algorithms can satisfy the practical purpose, this paper adopts the following two algorithms for different purposes: the incremental insertion algorithm, the divide and conquer algorithm.

When the points data haven't been generated the TIN, the divide and conquer algorithm is used to construct the TIN.

Dwyer (R.A.Dwyer, 1987) showed that a simple modification of this algorithm runs in O ( $n \log \log n$ ) expected time on uniformly distributed points. Dwyer's algorithm splits the set of sites into vertical strips with $\sqrt{n / \log n}$ points per strip, constructs the DT of each strip by merging along horizontal lines, and then merges the strips together along vertical lines. His experiments indicate that in practice this algorithm runs in linear expected time. Another version of this algorithm, due to Katajainen and Koppinen (J. Katajainen and M. Koppinen, 1987), merges square buckets together in a "quad-tree" order. They show that this algorithm runs in linear expected time for uniformly distributed sites. In fact, their experiments show that the performance of this algorithm is nearly identical to Dwyer's. in this paper we use the Dwyer's divide and conquer algorithm.

While there have been several generated local TINs to be integrated or new points to be added to the present network, incremental insertion algorithm is used.

The incremental algorithm perhaps is simplest algorithm for constructing the Delaunay triangulation. The algorithm adds points to the network one by one and updates the network after each point is added. They have two basic steps. The first, Locate, finds the triangle containing the new point. (The algorithm is made simpler by assuming that the point is enclosed within large triangle.) The second, Update, updates the network
.

The bottleneck of the algorithm is the Locate routine. All of the algorithms perform Update using an approach similar to that in Guibas and Stolfi (L. Guibas and J. Stolfi, 1985). They start at a random edge in the current network and walk across the network in the direction of the new point until the correct triangle is found. The basic step is to perform a CCW orientation step against an edge of a triangle to see if the point lies on the correct side of that edge. If not, the algorithm crosses to the other triangle that shares that edge. If so, it steps to the next edge around the triangle. When the point is on the correct side of all three edges in a triangle it has been located.

### 2.3 Data structure

A triangular mesh generator rests on the efficiency of its triangulation algorithms and data structures, so the following pseudo code algorithm illustrates the data structures of vertex, edge and triangle.

```
Definition of vertex:
Struct Vertex
{
   double x;                    //the coordinate of the vertex
   double y;                    //the coordinate of the vertex
   double z;                    //the coordinate of the vertex
};
Definition of Edge:
Struct Edge
{
      int nEdgID;        //the ID of the edge
      double startpoint; //the start vertex of the edge
      double endpoint;   /the end vertex of the edge
};
Definition of Triangle:
Struct Triangle
{
      int nTriID;                //the ID of the triangle
      struct Vertex *mPtriangle;    //three vertexes of the triangle
};
//store the vertexes
CTypedPtrList <Vertex> NewAddVertex;
//store the edges
CTypedPtrList <Edge> NewEdge:
//store the triangles
CTypedPtrList <Triangle> NewAddTriangle;
```

## 3 STORAGE STRATEGY

How to store the huge seamless TIN-DEM data in the relational database management system (RDBMS in short) has a great impact on the efficiency of the index and the visualization. In this paper we store the data block by block divided by regular regions. The adjacent regions store the common vertexes and triangular meshes as virtual vertexes and edges. Every block has its serial number. Then we can evoke the data stored in the RDBMS through the index of the serial number. These could build a more efficient database based on the triangulated irregular network model and will be helpful for the integration of the multi-scaled DBMS.

Quaternary Triangular Mesh (QTM for short) is a proper strategy to store, index and visualize the data. The surface of the earth can be divided and subdivided by the triangular mesh as the following Fig (Figure 2 and Figure 3).

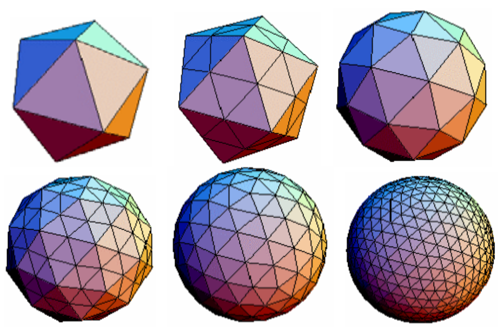

Figure2. The Global Division and Subdivision of the triangular mesh

Figure3. The Hierarchical Subdivision of the triangular mesh

According to the approach of global division and subdivision above, the data of the QTM method can be organized as the Figure 4 illustrates. The left figure is when the direction of the triangular mesh on the ellipsoidal is up while the right one is the opposite. So every block has it own index.

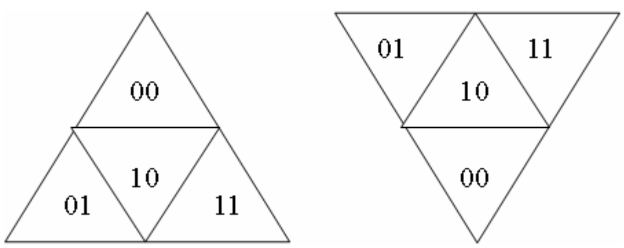


Figure4. Data organization based on the hierarchical subdivision

## 4 INTEGRATION AND UPDATE

Due to the storage strategy above, the data is stored in the DBMS block by block. So when it comes to the visualization, a logical seamless database could be formed including the geometry information and property information. Because the adjacent regions store the common vertexes and triangular meshes as virtual vertexes and edges, we can use these virtual vertexes and edges with the divide and conquer algorithm to finish the integration between the adjacent regions.
Figure 5 illustrates a case.

A and B are the TIN-DEM products used to integrate a seamless TIN. A1/B8, A7/B1, A2/B9, A6/B4, A3/B10, A4/B11, A5/B12 are the common vertexes of the two blocks. When the any one of them is first chosen, the other one will search the common vertexes and edges and find the polygon that consists of these common vertexes and edges. In the polygon it will use LOP to optimize the triangular meshes. Then the integrated TIN is generated.

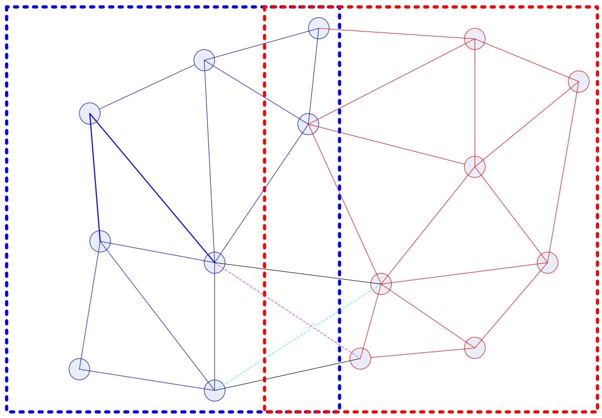

Figure5. Integration between two regions

We can build the pyramid of TIN-DEM automatically by selecting the sample points at certain grade, so are the layers of existing multi-scale seamless TIN DEMs. Thus, the update of the database can be finished in the large scale TIN-DEM. The other scale TIN-DEMs could update correspondingly. When some new geographical feature points or edges are appended, it uses the incremental algorithm to update of the data.

## 5 EXPERIMENT AND CONCLUSIONS

There is an experiment to test the strategy. The proposed strategy was implemented in C++ language on Windows XP operation system platform. Figure 6 is the data that selected to construct the TIN. Figure 7 shows the constructed triangular meshes. Figure 8 is the visualization system base on the strategy.

Figure6. Data selected to construct the TIN

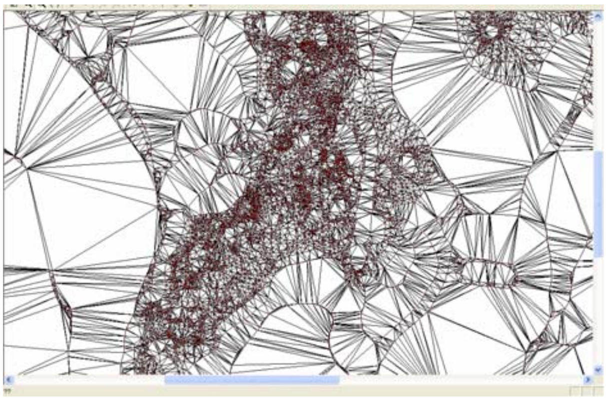

Figure7. The constructed triangular meshes

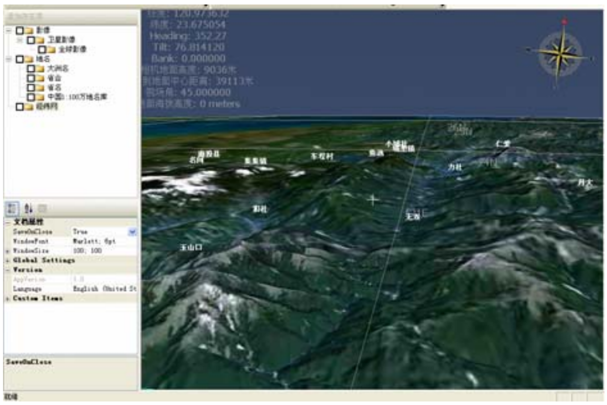

Figure8. The visualization system

Building seamless multi-scale database is an interesting research in 3D GIS. The strategy in this paper is an approach worth further studying and putting it into implementation. In 3D GIS, the precise of the vertexes elevation is an important factor in the quality of terrain model. And the spreading error of the sample points also has influence on the precise of terrain model. When the data is stored and updated in DBMS, it couldn't ensure the validity of the data. So the future work will focus on evaluating the precision of the generated TIN, the spreading of the error and the validity of storage.

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