3D LOCAL NON-UNIFORM FIELD MODEL BASED ON 3D VECTOR MODEL FRAME

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Commission II, WG II/1, 2, 6, 7

KEY WORDS: 3D, Local non-uniform, Field model, Vector model, Volume function, Analytic model, Local raster model

ABSTRACT:

This paper proposes a model, which is called '3D (Three Dimension) local non-uniform field model based on 3D vector model frame', which integrate '3D volume function analytical model' and '3D local raster model' into the frame of '3D vector boundary model', to express 3D object and local non-uniform attribute data field. In the model, the authors adopt 3D vector boundary model as basic frame, then partition solid objects interested by user and construct volume function, i.e. represent local non-uniformity attribute data field inside the solid objects by '3D volume function analytic model'. 3D volume function analytic model could be visualized by 'slice up' method, or be translated into 3D local raster data model for visualization. In this way, it can integrate vector representation, analytic expression, and raster representation into a unified 3D model. The paper proposes that there two topological view in GIS, one topological view is based on boundary and coboundary, another topological view is based on point-set theory. In dealing with surface feature or boundary surface of solid feature, the author advise using '3D TIN partition along surface' and 'double cubic B-B(Bernstein-Bézier) triangle surface piece smooth connection', which are widely used in 3D CAD and 3D geometry modeling. With the help of these techniques, it can deal with nearly vertical surface, and make surface representation more approximate to natural surface than 'plane TIN partition' and 'small triangle plane' in traditional geo-science. This 3D data model could be used in geology, mining, environment, oceanography and aerography.

1. INTRODUCTION

Geo-Information Science needs to express two types of information, one is objects, another is fields – some attribute fields. In this way, GIS (Geo-Information System) has developed two types of data model, i.e. vector model and raster model. The first targets to express object. The second targets to express field.

3D GIS (Three Dimensional Geo-Information System) is also same. Geo-Information Science requires 3D GIS to be able to express objects of point, curve, surface, solid and their composite entity conveniently. In many cases, it is also required to be able to express non-uniformity field – some kinds of attribute fields inside solid object. But in most cases, people mainly pay attention to non-uniformity attribute field of interesting spatial objects (such as mineral content in ore body), i.e. local non-uniformity attribute field. But for background, it is enough to express its boundary.

There are three modeling approaches in 3D world. The first, 3D vector model can conveniently express 3D objects, but it is difficulty to express non-uniformity field inside solid, surface and curve. The second, 3D raster model can express non-uniformity field of solid, surface and curve, but it is very inefficient to express objects. The third, 3D analytical model is also can express object and non-uniformity field. 3D vector model and 3D raster model have been studied thoroughly (Molenaar,1992; Fritsch,1992; Rongxin,1994; Xiaoyong,1994; Qing 2004). There are a few research works for 3D analytical

model (Qingyuan, 1998; Jianhua, 2001). There are some researches for vector-raster mix model (Jianya, 1997; Fuling, 2000) and vector-raster integrate model (Deren 1997, Qingquan 1998; Peijun, 2001).

This paper proposes a model, which is called '3D local non-uniform field model based on 3D vector frame', which integrate volume function analytical model and 3D local raster model in the frame of 3D vector border model.

The model intends to be used in mining, geology and environment, oceanography and aerography.

2. 3D VECTOR BOUNDARY FRAME

2.1 3D Vector Model

3D vector model is also called 3D vector boundary model or 3D vector representation. In geology and mining application, the all-important is able to describe stratum, fault, drill and laneway. So 3D vector model is very suitable for geology and mining application.

In 3D vector model, the real world is abstracted as a set of 3D objects, including four types of basic primitive (0D object -- point object, 1D object--curve object, 2D object -- surface object and 3D object -- solid object) and composite objects, which are made up of objects with one or more basic primitives.

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2.2 Boundary and Coboundary

Boundary and coboundary is a pair of very important concepts in vector data model (ISO 19107. 2001). Boundary represents the limit of an object, describing the transition between an object and the rest of its domain of discourse. Dimension of an object boundary is less one dimension than the object. Coboundary is a set of topological primitives of higher one dimension than associated with a particular object, such that this object is in each of their boundaries. For example, boundary of 3D solid is 2D surfaces, and the solid is a coboundary of the surfaces. Boundary of a 2D surface is 1D Edges and the surface is a coboundary of the edges. Boundary of 1D edge is 0D two nodes and the edge is a coboundary of the nodes. For coherence, it is defined that boundary of 0D point is null.

By the authors view, there are two topological views in GIS. One topological view is based on Boundary and coboundary; another topological view is based on point-set topology. The first is mainly used in spatial data organization, such as 2D topological relation in Arc/Info product and the six groups topological relation, which were given by authors (Qingyuan 2002). The second topological view can be used in check about two spatial objects. The second view can be represented by 4-intersection model and 9-intersection model (Engenhofer, 1991,1994; Clementini, 1994, 1996).

2.3 3D Object Representation

A point object is represented as a 3D point, a line object is represented as two boundary nodes and a series of pattern points (between two pattern points, may straight line connected or spline curve connected), 3D surface object is represented as boundary rings (one out boundary ring and n inner boundary ring, n is large or equal 0, a ring is composed of some oriented edges) and pattern net, which is composed of some pattern curves (these pattern lines, may be straight line or spline curve). Representation of 3D solid object is crucial to 3D Vector GIS. The basic requirement of 3D solid object is its boundary representation.

2.4 Elaborate Representation of Surface

In 3D GIS, 2D object — surface is not only 2D object, but also boundary composition of solid object. Surface representation is crucial to 3D GIS. DEM is a widely used technique in 2.5D GIS. But in 3D GIS, it is often needed to represent nearly vertical or vertical surfaces. TIN is often used in 2.5D/3D GIS. In traditional 2.5D GIS, TIN is often tessellated by small plane pieces. The authors consider that in 3D GIS it is necessary to elaborate representation to surface.

In 3D CAD (Computer Aided Design) or 3D geometry model, TIN is often tessellated by small pieces surface, especially double cubic B-B (Bernstein – Bézier) triangle pieces with smooth connection (Farin, 1986, 1993). The surface function expresses below:

$$P(u, v, w) = \sum_{i=0}^{3} \sum_{j=0}^{3-i} V_{i,j,k} B^3_{i,j,k}(u, v, w) \qquad (1)$$

Here is meaning in expression (1):

1. $P(u, v, w)$ is surface function value, $u, v, w \in [0,1]$ is weight coordinates (area coordinates) of moving point in triangle surface.

2. $B^3_{i,j,k}(u, v, w) = 3!/(i!j!k!)*u^i v^j w^k$ is Bernstein base polynomial, and $i+j+k=3$.

3. $V_{i,j,k}$ are control vertexes (sampling points).

De Casteljau iteration algorithm can be used to iterative lower power in (1) by linear interpolation (De, 1959,1963).

2.5 Shortages of 3D Vector Model

Although 3D vector model can express 3D solid easy, there are some shortages for it.

1. It is difficulty to express attribute change in solid interior by 3D vector model. In many cases, it is needed to describe the non-uniformity inside solid object.

2. Algorithms of some spatial operations, such as buffer analysis, overlay analysis and intersection, are very complicated.

3. ANALYTIC EXPRESSION OF NON-UNIFORM FIELD OF SOLID OBJECT INTERIOR

3.1 Introduction

For many 3D applications, representation of non-uniform field inside solid object is important. 3D vector model is insufficient in this aspect. 3D raster model and 3D analytic model can be used to express non-uniformity of solid object.

2D raster model has been used in 2D GIS widely. 3D raster model has also been used in 3DGIS and 3D GMS (Geoscience Modeling System). There are many researches about 3D raster model, but research for 3D analytic model is nearly vacancy.

The authors think that 3D analytic model can play more important role in expressing inner non-uniformity of solid, and volume function is the core of 3D analytic model.

3.2 3D Analytic Expression

3D analytic expression is volume function: $V = f(x, y, z)$, (Qingyuan, 1998; Lixin, 2003). Here, V is a kind of attribute value, such as density or content of metal ore; f is a function mapping relation; (x, y, z) is a 3D spatial coordinates. Volume function is also called 4D super surface. It is different from 3D surface function: $Z = f(x, y)$.

Analytic model can accurately express attribute value of non-uniform field. It needs fewer memory resources, and is less compute-consuming. It can ensure uniqueness and geometry invariance of spatial object.

3.3 Some Argument about 3D Analytic Expression

There are following opinions on 3D analytic expression. (Jianhua, 2001):

1. Parameterised coordinates are local thus it can't be used to build spatial index in spatial databases.

2. In 3D GIS spatial entities are more complicated than entities in 2D. So it is difficulty to express the attribute field with a single mathematical function.

3. Similar with in 2D GIS, analytic model can't play main role in 3D GIS.

The authors agree on above opinions partially. Analytic model do has above shortages, but it also has some advantageous characteristics that 3D raster model and vector model can't provide. Especially in case of sparse underground sampling and non-linear attribute value changes, it will be more reasonable to calculate attribute value of raster nodes by constructed non-linear volume function. In 2D GIS, analytic model do not play important role. The reasons can be concluded as follows. Firstly, with the help of remote sensing and photogrammetry, specified attribute value can acquired quickly at low-cost. Secondly, it is unimportant and even unnecessary to represent non-uniformity field of area interior. Thirdly, it is still very difficult to approximate a complicated field surface by uniform approximate function. But in geology and mining, underground sampling is very spare for high cost. It is very significant to represent interior non-uniformity field of solid entity by volume function. The value of volume function can be adopted as value on raster node in 3D raster model. In this sense, the authors believe that analytic model based on volume function integrating with 3D vector model and 3D raster model can partially solve the sparse-sampling problem as well as approximate authentic attribute value of solid entity better in the real world.

3.4 Volume Expression by Partition Solid Domain

Given a studying 3-D space, it is nearly impossible to use one analytic expression to represent 3D attribute field, just as it is impossible to represent a complicated natural surface or curve with one analytic expression. But it is possible to express attribute local changes with partitioned volume functions, just as it is possible to represent any complicated free surface or curve with partitioned analytic function by spline patch or spline curve section

Precondition of fitting 3D volume function is 3D volume partitioning. There are two approaches to partition the 3D volume. The first approach can be divided into 2 steps. General tri-prism partition is the first step that extends 2D triangle irregular network (TIN) by adopting drill as additional edge. Then tetrahedron partition is the second step that dissect the one tri-prism into two tetrahedrons (Lixin, 2003). Another approach is direct tetrahedron partition (Xiaoyong, 1994; Hanguo, 1995).

3.5 Tri-Cubic B-B Volume Function Fit

After solid partitioned, how dose fit volume analytic expression from tetrahedron solid domain? A possible method will be an extension of 2D triangle domain B-B (Bernstein-Bézier) surface by constructing B-B volume function in which independent variables are tetrahedron volume weighted coordinates. The expression is below:

$$P(t, u, v, w) = \sum_{l=0}^{3} \sum_{i=0}^{3-l} \sum_{j=0}^{3-l-i} B^3_{l,i,j,k}(t, u, v, w) * V_{l, i, j, k} \quad (2)$$

Here:

1. $P(t, u, v, w)$ is volume function value (attributive variable), $t, u, v, w \in [0,1]$ is weighted coordinates (volume coordinates) of moving point in tetrahedron.
2. $B^3_{l, i, j, k}(t, u, v, w) = 3!/(l!\ i!\ j!\ k!)*t^l\ u^i\ v^j\ w^k$ is Bernstein base polynomial, and $l + i + j + k = 3$;
3. $V_{l, i, j, k}$ is control vertexes (such as sampling point).

De Casteljau iteration can be used to iterative lower power in (2) by linear interpolation (De, 1959,1963).

The key of 3D volume function construction is to keep boundary continuity between of two solids. Function and one order differential should be continuous. There will be a long journey to implement 3D analytic expression as well as 3D volume function transition naturally. But it will be proved to be a good method in geology modeling.

4. LOCAL 3D RASTER MODEL

4.1 Global 3D Raster Model

3D raster model has been used to represent non-uniformity of solid object interior for a long time. It is the simplest way to represent non-uniformity field inside 3D objects yet, though it spends a lot of diskette storage and computer memories.

In standard 3D raster model, every 3D cubic voxel stores one attribute value. It is easy to be calculated, located and analysed especially for several complex spatial operations such as buffer analysis, overlay analysis. It is also easy for 3D visualization and cutting sections. 3D sections (including vertical section--profile, horizontal sections and incline sections) are the best way to demonstrate its non-uniformity inside solid objects. The advantages of standard 3D raster model are simple, steady and robust. Based on standard 3D raster model, a lot of variants such as octree, linear octree, and 3D run length code etc have been developed. The authors call standard 3D raster model as well as its variants as global 3D raster model, because their raster unit are spreading in whole studying space.
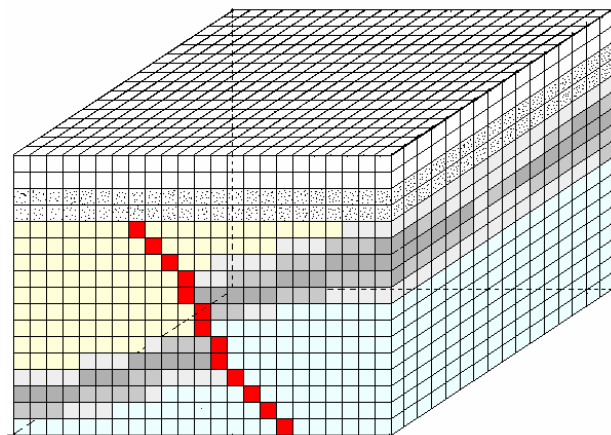

Figure 1. One of global 3D raster model—standard 3D raster model (the whole space is rasterized.)

Figure 1 is a 3D underground model represented as standard 3D raster model. The red cubic units represent a fault. Cubic units in other different colours represent different stratums. The top white colour units represent the overground space.

4.2 Shortages of Global 3D Raster Model

Following shortages in global 3D raster model can be identified.

1. It is a kind of field-based representation thus is difficulty to represent objects directly. To locate a specified object, whole memory units will be accessed.

2   It is inefficient to represent curve and surface objects.
3   In most of the global raster model lots of storage space are wasted to represent solid objects in which interior are uniform or their non-uniformity is not paid attention to according to user request.
4   It is difficult for some spatial analysis such as net analysis, adjacent analysis as well as spatial object inquiry.

4.3   Local 3D Raster Model

The paper proposes a new concept of 'Local 3D Raster Model'. The model is based on 3D vector boundary model. On-demanding representation of non-uniformity inside solid object is emphasized. In fact, representation of the whole 3D space by cubic voxel is storage-consuming and not necessary, especially curve and surface representation by cubic voxel need to be avoided for reason of low efficiency. For non-uniformity field inside solid objects specified by user request as well as solid objects that their changes can be described in details, local raster representation will be used. Vector model will be used to represent curves and surfaces. Other background solid objects that user won't care for will be viewed as uniform solid.
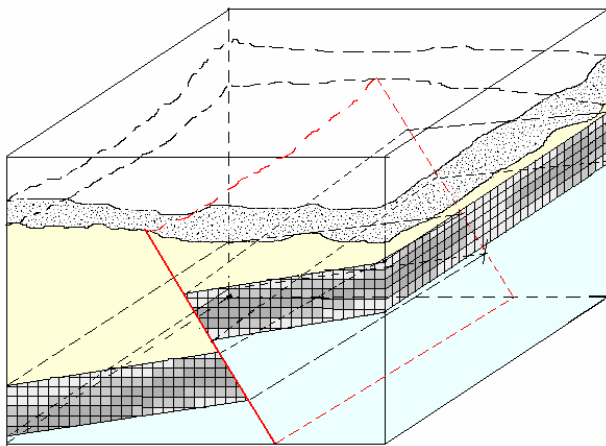

Figure 2. Local 3D raster model (ore body is rasterized only.)

In figure 2, the red line is fault line. The loose deposit, stratum, ore and fault are represented by vector model; only interior of ore solid is represented by local 3D raster model in detail.

5.   INTEGRATING ANALYTIC MODEL AND RASTER MODEL INTO 3D VECTOR BOUNDARY FRAME

5.1   Introduction

Local 3D raster model can represent non-uniformity inside solid objects, if their interior attribute change can be described in detail. But till now, interpolations of attribute value by Kriging method and distance backward weight method are still popular. In many cases, points selection in the two methods are crucial and different point set can result in distinct outcome. Lately there are some research works on improve the quality of points selection such as D. Shepard's standard method and 3D Voronoi partition, but it is still not reasonable sometimes. By partitioning solid domain, volume function method will more reasonable than the two methods in calculation of attribute value in above-mentioned framework. But the fitted volume

function is not generic. It is necessary to combine 3D analytic expression with 3D raster model.

5.2   Translation from 3D Analysis Expression to 3D Raster Model

3D raster model is simple, steady and robust. 3D analytic model should be translated into 3D raster model (global 3D raster model or local 3D raster model). The method of translating 3D analytic model into 3D raster model is pretty simple. Attribute value of each cubic voxel can be calculated by 3D analytic volume function using centre of cubic voxel as parameters.

6.   CONCLUSIONS AND FUTURE WORKS

6.1   Conclusions

In the paper, a novel 3D model is proposed. The guiding methodologies are integration of several existing 3D models and on-demand rasterization of non-uniform field inside solid objects. Several conclusions are emphasized as follows:
1   In 3D GIS, 3D vector boundary model is still playing foundational role.
2   In many applications, it is need to represent local non-uniformity inside solid object.
3   3D analytic model based on 3D volume function will play more important role in representation of non-uniformity inside solid object. Tri-Cubic B-B volume function is a possible solution.
4   Local 3D raster model is based on 3D vector boundary model and is on-demanding according to user request.
5   3D volume analytic model should be translated into 3D raster model.

6.2   Future Works

Future works relative to this paper may contain several aspects:
1   3D model platform with topological relations according to the above discussion will be developed.
2   Approaches to fit the volume function as well as to construct the local 3D raster model will be explored.
3   Validation and comparison mechanisms should be established to test the differences between existing 3D models and the feasibility of our model utilizing the authentic data from the field of geology or mining.

7.   REFERENCES

Clementini E., Di Felice P., 1994，A Comparison of Methods for Representing Topological Relationships, Information Sciences 80, pp1-34,.

Clementini, E., Di Felice, P.,1996, A Model for Representing Topological Relationships Between Complex Geometric Features in Spatial Databases, Information Sciences 90(1-4): pp121-136

De Casteljau, P., Outillage Methods Calcul, Andre Citroen Automobile, SA, Paris, 1959.

De Casteljau, P., Coubes er Poles Andre Citeroen Automobile, SA, Paris, 1963

Deren Li, Qingquan Li,1997,Study on a Hybrid Data Structure in 3D GIS, ACTA Vol.26, No.2, pp128-133

Egenhofer, M.F. and Franzosa,1991, Point Set Topological Spatial Relations, International Journal of Geographical Information Systems, vol 5, no 2, pp161-174

Egenhofer M.J., Clementini E., Di Felice, P., 1994 Topological relations between regions with holes, International Journal of Geographical Information Systems, vol 8, no 2, pp129-142

Farin,G., 1993, Cuvers and Surfaces for Computer Aided Geometric Design: A practical Guide, Academic Press

Farin,G.,1986, Triangle Bernstein Bezier Patch, CAGD, Vol.3, pp.83-187

Fritsch D., and Pfannenestein A.,1992, Integration of DTM data structures into GIS data Models. In: International Archives of Photogrammetry and Remote Sensing, Washington, USA, (PartB3), (XXIX), pp 497～503

Fuling BIAN, et.al., 2000, An Object Oriented Integrative 3D Data Model, Jounral of Wuhan Technical University of Surveying and Mappng, Vol.25 (4), pp294-298.

ISO TC 211,2001,Spatial Schema, ISO 19107

Hanguo CUI, et al, 1995, Algorithms for Automatic Generation and Dynamic Modification of Three-Dimensional Delaunay Triangulation, Journal of Engineering Graphics, No.2, pp1-7

Jianya GONG, Zhongguo XIA, 1997, An Integrated Data Model in Three Dimensional GIS, Jounral of Wuhan Technical University of Surveying and Mappng, Vol 22(1), pp7-15.

Jianhua WAN, Changgui ZHU, 2001, Geometry Expression for Spatial Object in 3D-GIS[J], MINE SURVEYING (1) pp 16-19

Jun CHEN, Wei Guo, 1998, A Matrix for Describing Topological Relationships Between 3D Spatial Features, Journal of Wuhan Technical University of Surveying and Mapping, Vol .23.No.4, pp359-363

Lixin WU, Wenzhong SHI, 2003, Geography and Geo-Information Science, Spatial Modeling Technologies for 3D GIS and 3D GMS, pp5-11

Lixin WU et al, 2003, 3D Geo-science Modelling Based on Generalized Tri-Prism(GTP) Model[J], Computers & Geoscience 2003 (special issue).

Molenaar M., 1992, A Topology for 3D Vector Map, ITC Journal, No.1, pp25-33

Peijun DO, et al, 2001, 3DGIS Data Structure and Visualization Based on Mine Properties, Journal of China University of Mining & Technology, Vol.30,No.3 pp238-241

Qingquan LI Deren Li, 1998, Research on the Conceptual Frame of the Integration of 3D Spatial Data Model, ACTA, Vol.27, No.4, pp325-330

Qingyuan LI, et.al., 1989, 3D Body Interpolation and Application in 3D GIS, Proceedings of International Conference on Modeling Geographical and Environment System with Geographical Information System, Hong Kong, China, pp826-829

Qingyuan LI, et al, 2002, Boundary Coboundary Six Groups Topology and 'One Face with Three Layers' in 3D GIS, IAPRS, Vol XXXIV, Part2, Commission II, Xian, 20-23, pp265-270

Qing ZHU, 2004, Surveying of Three Dimensional GIS Technologies, GEO MATICS WORLD, Vol.2,No.3, pp8-12

Rongxin LI, 1994, Data Structures and Application Issues in 3D Geographic Information Systems. GEOMATIC, Vol.48(3), pp 209～224

Xiaoyong C., IKEDA K., 1994, Three-dimensional Modeling of GIS Based on Delaunay Tetrahedral Tessellations. In:International Archives of Photogrammetry and Remote Sensing, Munich, Germany, 30:132～139

Xiaoyong C., IKEDA K., 1994, Raster Algorithms for Generating Delaunay Tetrahedral Tessellations, In: International Archives of Photogrammetry and Remote Sensing, Munich, Germany, 30:124～131

Yangbing WANG, et al, 2003, Apply Tetrahedrons to GTP Model Improvement, Geography and Geo-Information Science Vol.19, No.5, pp15-19

8. ACKNOWLEDGEMENT