STUDY ON 3D MODELING AND VISUALIZATION IN GEOLOGICAL EXPLORATION ENGINEERING

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Commission II, WG II/4

KEY WORDS: Three-Dimensional, Geological Information System, Modeling, Visualization, Geological Exploration Engineering

ABSTRACT:

With the development of GIS, its applications concern with different domains, such as geography, mapping, urban, traffic, geology, mine, military and so on. 3D GIS is the research hotspots in the domains of city, geology, mine etc. 3D GIS in city has been developed more quickly, CyberCity, for example is a smart application of 3D GIS, but it is slow in subsurface engineering because of its complexity. In generally speaking, the key problems for developing 3DGIS are the researches on 3D modeling, visualization and interaction according to the practice situation. In this paper, taking the phenomena in geologic exploration engineering as the research objects, the authors discuss the three-dimensional geologic phenomena and data capture methods in section 2. A blended data model integrated vector and raster data is proposed in section 3. Tri-prism volume data structure is designed in section 4. The necessity of 3D visualization and its application in geologic exploration engineering are discussed, and some visualization examples are given in section 5. Several geologic bodies modeling techniques are presented in section 6. Lastly, some conclusions are given in section 7.

1. INTRODUCTION

With the rapid development of computer technologies, GIS, an efficiency tool to capture, handle, analyze, manage and visualize spatial geographic data, has taken place prodigious changes in processing data types, system functions, application domains and so on. For instance, the spatial data types expand from 2D to 3D, temporal-dimensional and multi-dimensional, GIS software from stand-alone to Client/Sever, Internet or World Wide Web. Currently, most of GIS software is successful in processing 2D or 2.5D spatial information, but it is weak in 3D domains. In fact, the real worlds, no matter surface or subsurface, are in real three-dimensional. It is urgent to develop 3D GISs for managing real world. In the field of geological exploration engineering, there has been much confuse and uncertainty associated with the interpretation and report of subsurface characterization data. A great deal of this is attributed to the lack of a suitable medium to properly represent and display the complex spatial and temporal information involved in subsurface investigation. Let geoscientist easily create high-impact 3D representations of complex characterization data and modeling result in a few time are the objectives of 3D GIS applying in geological exploration engineering. So the study on modeling and visualization is the core problems in developing 3D geology and mine GIS.

2. DATA CAPTURE AND PRESENTATION OF GEOLOGICAL PHENOMENON

In geological exploration engineering, there are many types of geological phenomenon need to be handling. According to their forming conditions, the geological phenomena can be classed into the natural geological and the exploration-engineering phenomenon. The former is the natural geological entities such as ore deposit, rock, stratum and its break line, gas gather point and so on, and they are irregular on the face and complex to describe. The later are the constructions, which have regular shape, such as silo, inclined well, borehole, exploring trough, laneway, pick cavity and so forth. For exploring and presenting the complex geological phenomena, geologists have made some exploration works, such as direct observation of outcrops in field, borehole, sap, seismism and so on. Most of the sampling points are discrete, but they are always arranged regularly. Boreholes, for example, are designed in different section. To obtain the complete description about the geological objects, the geologist must extrapolate and interpolate original sampling data. Most of the geological exploration information is three-dimensional, but they are presented on two-dimensional plan drawings or stored into archives, such as geologic exploration and drilling archives, borehole histogram, exploration line section plot, layers of laneway, general plan of geologic exploration engineering and so forth, due to the limit of technique condition before.

In fact, it is not easy, time consuming and costly to obtain true, credible and exact three-dimensional information. Generally speaking, the data of picking laneway root in design and really measurement, and the stratum data come from geologic exploration and pick engineering. Stratum and ore deposit are ″gray″ three-dimensional spatial entities, their describing data are not only fewer and abnormity but also biggish randomicity. Some of their data come from deducing and hypothesis. In a word, the 3-D geologic phenomena in geological exploration engineering are very complex.

Along with the computer graphics technique application in geologic domain, people use computer to process all kinds of geologic data and draw different two-dimensional plots presenting geologic information. 2D techniques have been used by geologists for many years in the form of software for computer graphics, image processing, and more recently, as Geographic Information System (GIS). 2D display representations include surfaces, multiple layers, fence diagrams, and stereo image. It takes some time and visualization skill to organize the information and built a mental picture of the geological spatial scene according to these 2D plots. Although these 2D processes are excellent tools for storing, manipulating and combining surfaces, but geologists require 3D capability for most applications. The development in computer graphics have provided a better environment in which automated techniques for analysis and display of geological information in three dimensional and can be used solve complex geologic problems.

3. THREE-DIMENSIONAL DATA MODEL ANALYSIS

Modeling geological bodies and exploration engineering according to the original sampling data is the key for data management, data handling and visualization. There are many conventional methods of modeling 3D objects in geological domain, such as data models based on vector, data models based on raster, data models based on integrated vector and raster data, and object-oriented data models. In geometry, 3-D data structures can be classified into surface-based and volume-based representations. In the view of data description format, data structure can be divided into raster-based and vector-based. Different three-dimensional geologic phenomena have different description methodology. Geologist have made in-depth research and obtained delectable schemes to describe geologic objects. For instance, the shape of an ore deposit is an irregular close curved surface and we can describe it by using DEMs of the top and bottom surfaces. The ore deposit grade spatial distribution can be presented by using 3-D trend surface. Stratum interface can be presented by using Digital Elevation Model (DEM). Laneway consists of regular columns or consecutive sections. We have to measure the horizontal sections in turn to describe the pick cavity. The borehole can be presented by using spatial coordinates of borehole center curve.

Since it is difficult to describe spatial entities efficiently by using only one data structure, the common view is to adopt integrated data model. Object-oriented technology has come into fashion in computer science and technology. In geological exploration engineering domain, we can use object-oriented methodology to design 3-D data model. In geometry, the geological entities can be divided into point, line, surface and body. But according to management they can be divided into different management units, for instance, mine, mine lot, mineral deposit and ore deposit. A management unit can be regarded as a complex object that consists of various of entities, such as regular body, column, irregular body, surface entities, line entities, arc, point entities and so on. Regular body can be presented by CSG, Octree and Vaxtixel, Column by continue sections, Irregular body by DEM, Tri-Prism Volume and irregular tetrahedron network. Surface entities consist of boundary arcs enclosing curve surface, DEMs constructing curve surface and sections. Arcs constitute line entities, and so on.

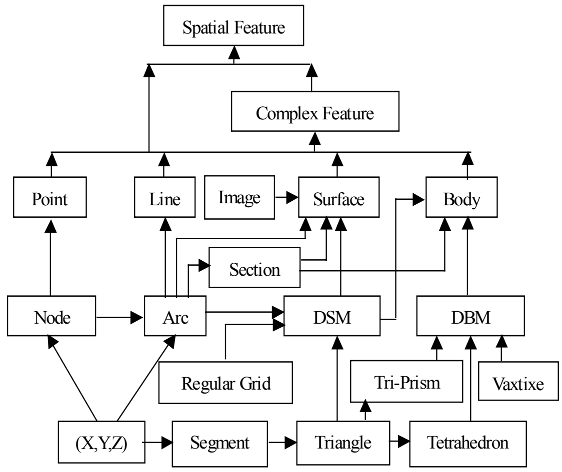

Figure 1. Object-oriented blended data model with integrated vector and raster

Figure 1 is an object-oriented blended data model that integrates vector and raster data structures and it is suitable to Geological Exploration Engineering. This data model involves many spatial object classes. When applying this model, we should consider the complexity and capture style of geological entities and select different data structure.

4. TRI-PRISM VOLUME STRUCTRUE DESIGN

Tri-Prism Volume (TPV) is a data structure based on volume element. Geologic body can be considered a body that is consisted of multi-stratum. In general, the stratum can be presented be surface model such as TIN but it? difficult to build a 3D stratum model based on surface model. TPV structure can solve this problem, because it not only can describable both surface and interior of the 3D entities such as stratum and ore deposit, but also represent complex geological tectonic, for instance, faultage, buckle, hollow. Tri-prism volume graph is showed in figure 2. Tri-prism volume has six vertexes.

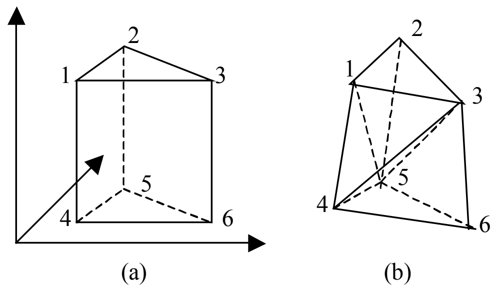

Figure 2. Tri-prism volume

When using TIN to modeling stratum, the horizontal coordinates of corresponding triangles in the top-bottom layers can be designed into the same, and the three edges are vertical and parallel with each other, see figure 2(a). In general, the corresponding points between top-bottom could not have the same horizontal coordinates because when using the point of intersection of drilling cut the stratum directly, and the side face will not be plane and should be parted into two triangle further, see figure 2(b). Vertex 1, 2, 3, 4, 5 and 6 compose a TPV and they may have the same 3D coordinates, for example, vertex 1 and 4 may be the same point but they are considered as different vertexes, see figure 3. The extrusive advantage of TPV is that a geological body, no matter how complex it is, it can be described by using TPVs in different size and shape, so TPV data structure is more simpler than the blend data structure, such as Octree-TEN. There are five kinds of partition methods (Tang, 1999), for instance, figure 3(d) is one of the methods and it is parted into a, b, c, d and e 5 TPVs. Figure 4 shows a frame graph about a part of TPV model.

To describe TPV we have designed a data structure, which is comprised of six kinds of elements, which are vertexes, TIN-sides, edge-sides, TIN-trangles, side face triangles or quadrangle and TPV. Each kind of elements can be designed into a class according to objected-oriented method. Figure 5 is a 3D stratum described by TPV structure, and figure 6 is a fence graph about the same region. The further work is how attach the spatial attribute into the TPV efficiently.

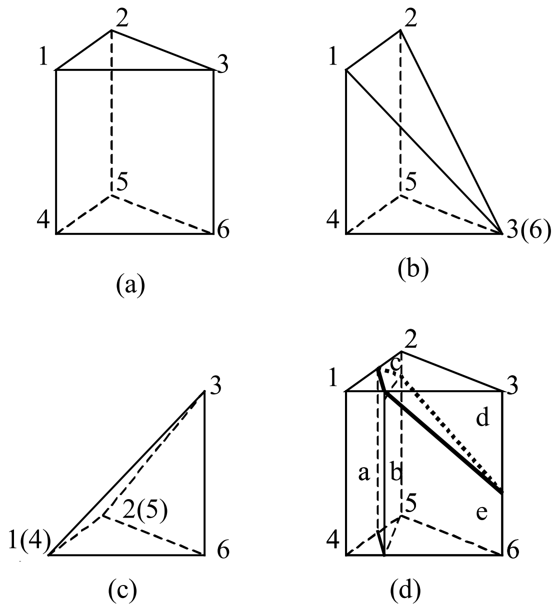

Figure 3. Special situation and partition of TPV

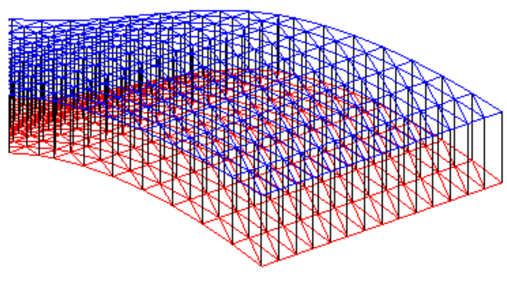

Figure 4. A frame graph of TPV

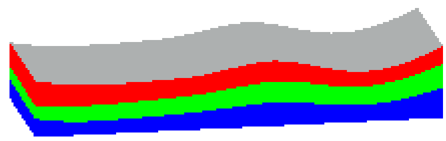

Figure 5. 3-D stratum model described by TPV

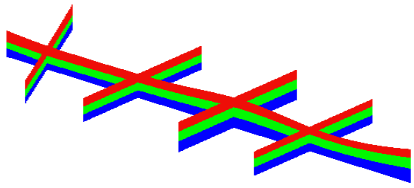

Figure 6. Fence graph of 3D stratum

5. 3D VISUALIZATION AND ITS APPLICATION IN GEOLOGICAL EXPLORATION ENGINEERING

Visualization in Scientific Computing (VSC) is a theory and technique, which transform the data created in the course of scientific computing and computing result into graph and image and display on screen by using the computer graphics and image processing technique. It hands together the technology of graphics generating, image processing and human-computer interactive. Its main function is to generate graphics from complex multi-dimensional data. VSC application domain deals with nature science and engineering technique, such as medicine, weather, geological exploration, hydrodynamics and limited element analysis and so forth. It has become a hotspot in Geographic Information System (GIS). VSC is an effective and efficient method for promoting the capability of processing and visualizing the spatial-temporal geo-referenced data. The three-dimensional image generated in the course of visualizing is very important for understanding and imagining the geography world and it′s changing.

3D visualization is very essential for interactive operation of geological data in most of the application, which provides the windows and the tools for mine design, exploration, mine management and ore quantity calculation. In the geologic exploration field, by using the visualization technology, from the large seism prospecting data, borehole survey data and geologic exploration data we can construct the pleasing stratum, mine and grade distribution in the mine, display their spatial range and the direction, and display all parameters and their relationship by different colors. By using the three-dimensional visualization technique, geologist can change the viewpoint and view-angle of every part of the spatial object, process and display the relief and stratum having bluff and faultage. Thereby the professional can explain the originally data and gained some important information, i.e. whether the mineral resource is existed, the location and reserves of the mineral resource. All these provide science proof and direct information in aspect of geologic detail exploration, mine design and mining, and also provide communication to non-geologists, governor and decision-maker of nature resources. Figure 5, 6 and 7 are visualization examples in geologic exploration engineering.

Virtual Reality (VR) is a computer graphic technology that can be used to emulate the real word in three dimension. Through the use of Virtual Reality Modeling Language (VRML), geologists can integrate GIS, VR and the Internet, and disseminate 3D geologic spatial data over the World Wide Web. The further development of visualization in geological exploration engineering is the application of VR.

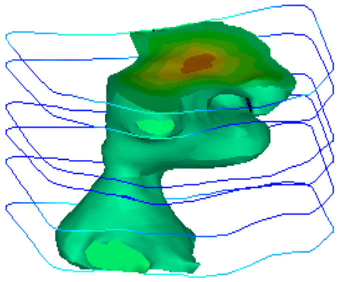

Figure 7. Ore deposit isosurface (from EVS)

6. MODLING TECHNIQUES OF GEOLOGICAL OBJECTS

Generally, it is not able to obtain complete, continuous information in geologic exploration engineering. The information source available to geologists includes direct observation of outcrops, mines or cores, and indirect geophysical measurements. Each of these sources provides information for only a point, a profile, or a surface. Using this information, the geologist must extrapolate and interpolate to construct a complete model of subsurface spatial objects. The data processing methods are different for different data sources.

6.1 Interior Modeling of Geologic Objects

Ore deposit grade information is a typical spatial three-dimensional solid data. The observation of an ore deposit grade information is discrete and fewer. Ore deposit component spatial distribution can be modeled by regular three-dimensional grid. To get the grade data of grid node, the discrete original grade measurement data must be interpolated into grid node. There are some interpolation methods, such as distance reverse ratio weighted method, triangle partition method and co-kriging method in geologic statistics and so on.

The co-kriging interpolation is popular and a slippage weighted average method, i.e. giving a weight factor to every known measurement points in research region and estimate the grade of the unknown point in this region by using weighted average method or linearity combination. Based on the spatial distribution feature, the weight factors are calculated considering the demand of best linear unbiased. Suppose {Z (x) | x ∈ A} is an ore deposit component parameter distributing in a spatial region A, and is considered a random field. According to the measurement values {Z (x_i) | i =1,2,…,n}, we can construct a linearity equation

$$Z^*(x) = \sum_{i=1}^{n} \lambda_i \bullet Z(x_i) \qquad (1)$$

Where λ_i (i= 1, 2, …, n) is weighting factor, $x_1, x_2, \ldots, x_n$ is a group of observation points and $Z(x_1), Z(x_2), \ldots, Z(x_n)$ are the measurement values.

According to co-kriging, in the region A, for any unknown point x∈A, Z*(x) can be used to forecast Z (x). In the condition of best linear unbiased estimation, i.e. E[Z*(x) - Z(x)] = 0 and $E[(Z^*(x) - Z(x))^2]$ = min, there are follow equations:

$$\sum_{i=1}^{n} \lambda_i = 1 \qquad (2)$$

$$\sum_{i=1}^{n} C(x_i - x_j) \bullet \lambda_i - \mu = C(x - x_j), i, j = 1,2,\ldots, n \qquad (3)$$

Formula (2), (3) are the co-kriging equations. By solving the co-kriging equations, we can get the weight factor λ i = （i =1,2,…,n）. Thus any spatial point expectation values can be calculated by using formula (1).

6.2 Surface Modeling of Geologic Objects

6.2.1 Large Region Geologic Body Surface Modeling

Obviously, large region geologic body means the stratum and the big layer ore deposit. Modeling these geologic bodies, Digital Elevation Terrain Model (DEM) can be used. There are two types of methods to construct DEM, i.e. regular grid and Triangle Irregular Network (TIN). The former topologic relationship is simple, algorithm easy to implement and storage convenient, but occupy large DMS memory. The later has the advantages of high efficiency storage, simple data structure, correct to represent the irregular terrain surface and linearity features, easy to update and suitable different density data. But it is complex and difficult to implement the algorithm. TIN has obvious advantage in represent stratum surface, top-bottom surfaces of ore deposit and be used to modeling geologic objects body in large region.

6.2.2 Small Region Geologic Body Surface Modeling

For some small size ore deposit, which shape like lens and potato, it is difficult to model them by using the conventional TIN modeling. For the purpose of exploring the ore deposit distribution, the borehole usually set down along a certain exploration section. Thus creating the TIN of an ore deposit, a rule that adjacent section points meet the ore maybe allow link, must be abided. This case is similar to the case of constructing the earth′s surface model by using adjacent contours. In this case, the projection is vertical plane but not the horizontal plane. As show in figure 9. Suppose adjacent vertical profile A and B, the points meeting the ore deposit is arranged into loop P and Q by some algorithms such as ore deposit boundary extrapolating and convex generating. These two boundary represent by point sequences p_i, i=0, 1, …, m-1 and q_j, j=0, 1, …, n-1. The target is producing a set of triangular faces between loop P and Q. There are some algorithms to construct triangular faces between two loops, such as whole search solution, heuristic method based on local calculation together with decision-making. No matter which schemes, they all have a common characteristic is that obeying formula of the shortest paths or the maximal volume. Because the former (whole search solution) needs to carry on search in whole points, so its running efficiency is not high. The later based on local calculation, and the calculation work is small and fast.

To illustrate the basic theories of producing triangular faces consider an example: assume two loops, P and Q, as show in Figure 9. Suppose the point q_j in loop Q is the nearest point p_i in P. Initially, point p_i and q_j are connected to form the base of the first triangle. The 2 edges of the triangle are created by connecting the shortest diagonal between the adjacent loop P and Q i.e. $q_j \rightarrow p_{i+1}$. This segment is the base of the next triangle whose edges are also created by connecting the shortest diagonal between the adjacent loop P and Q: $q_j \rightarrow p_{i+2}$ or $q_{j+1} \rightarrow p_{i+1}$. This process continues until the loops are triangulated.

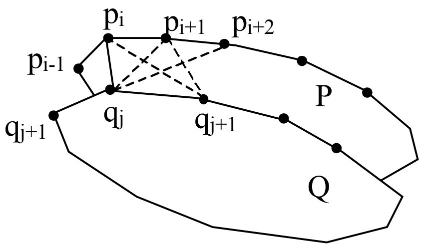

Figure 9. Shortest span model of surface triangulation

6.3 Adaptive Surface Triangulation

Because the sample points of geologic objects are sparser, abnormal and not symmetric, the TIN of the geologic body surface model, constructed by using the original sample points, is rougher and not sufficient for representing the surface shape of the geologic object. The original TIN should be subdivided by using a certain algorithms.

Adaptive surface triangulation of curve surface includes two parts: subdivide criterion and subdivide rule. Subdivide criterion is usually presented by using the maximal curvature of curve surface. It is time consuming to calculate directly the maximal curvature of curve surface. The curvature is usually estimated in practice. Suppose the unit outer normal vectors of triangular vertexes are N_1, N_2 and N_3, as show in Figure 10. They can be obtained by calculating the average normal vector of surfaces adjacent to the vertex. Each pair of outer normal vectors must be satisfied with $(1 - N_i \bullet N_j) < \varepsilon$, $i \neq j$, and $i, j \in (1, 2, 3)$. ε is the curvature tolerance and be used to adjust the density of triangular mesh, and assume 1.0×10^{-2} – 1.0×10^{-4}. Subdivide process is follow: checking each triangle curvature, subdividing the triangle which is not satisfied with the tolerance and modifying the adjacent relationship among triangles until all the triangles are satisfied with the tolerance. The subdivide method has three cases, as show in Figure 11.

Case 1. If three edges of a triangle are not satisfied with the curvature tolerance, then subdividing the original triangle into four triangles, as show in Figure 11(a).

Case 2. If there are two edges of a triangle, for example edge (A, B) and (B, C), are not satisfied with the curvature tolerance, then subdividing the original triangle into three triangles, as show in Figure 11(b).

Case 3. If there are one edge of a triangle, for example edge (A, B), are not satisfied with the curvature tolerance, then subdividing the original triangle into two triangles, as show in Figure 11(c).

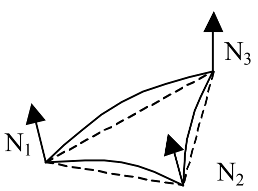

Figure 10. Triangle Curve Surface and the Normal Vector

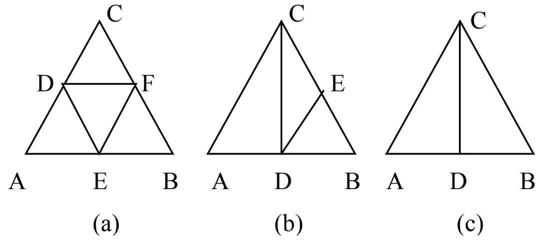

Figure 11. Three Cases of Subdividing

7. CONCLUSIONS

Most information in geologic exploration engineering is real three-dimensional, so let geoscientist easily create high-impact 3D representations of complex characterization data and modeling result in a few time are the objectives of 3D GIS applying in geological exploration engineering. 3DGIS provides good tools for geologists in analyzing and managing subsurface complex spatial data, communicating with non-geologists, and making scientific decision of nature resources. The key techniques of 3DGIS are the data modeling and visualization. Because the complexity of geologic bodies, it is difficult to describe spatial entities efficiently by using only one data structure. An integration data model should be adopted according to different geologic objects. Tri-prism volume structure can describe not only the interior distribution of grade of ore deposit but also the surface of ore deposit. Different geologic bodies should adopted different modeling methods according to the shape of bodies, data capture methods, objective of modeling and so on. Except for using computer graphics algorithms, some special algorithms must be studied for modeling 3D geologic objects. Visualization of geologic bodies is important, for implementing this purpose, good 3D graphics library, such as OpenGL, and graphics accelerator card are necessary for improving abilities of visualizing and interacting to 3D geological model. Through the use of VRML, geologists can integrate GIS, VR and the Internet, and disseminate 3D geologic information over the World Wide Web. The further development of 3DGIS applying in geological exploration engineering is to integrate GIS, VR and the Internet.

ACKNOWLEDGEMENTS

This research paper was Funded By Open Research Fund Program of LIESMARS (WKL (01) 0302).

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