Three-Dimensional Spatial Information Visualization In Geologic Exploration Engineering

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Abstract: Visualization is the important means of understanding and explaining the geologic phenomena from the bore huge data sources. In this paper, taking the geologic exploration engineering as research objects, the authors discuss the three-dimensional geologic phenomena, propose a blended data model integrated vector and raster data, analyze the necessity and technique route of visualization, and several techniques for geologic exploration engineering visualization and modeling are proposed.

Keywords: Three-Dimensional, Data Model, Visualization, Geologic Exploration Engineering

1 Introduction

Along with the deep study of geographic information system, its applications concern with different domains, such as geography, mapping, urban, traffic, geology, mine, military and so on. Especially, the rapid development of computer technologies, geographic information system, an efficiency tool to capture, handle, analyze, manage and visualize spatial geographic data, has taken place prodigious changes in data types, functions, application patterns and so on. 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, operation methods from command to interactive graphic interface. The visualization forms have taken place great changes from conventional static map to multimedia electronic map or atlas which including voice, image, text, texture and animation. The users are not only interested in conventional static map, electronic atlas; but also they are more interested in visualization, dynamic analysis and dynamic simulation. Complicated static map, in spite of being in paper or on screen, cannot be suitable for the user's needs. They hope that they can use a dynamic, visual and interactive software environment to handle, analyze and display the spatial information. The study of spatial information visualization should include 2D, 2.5D, 3D graphics and animation. Geologic exploration engineering is a real three-dimensional space. Generally, geologic exploration information is displayed by means of topographic and geologic map, geologic profile chart, level chart etc. These methods cannot present the three-dimensional information in efficiency, convenience and truth. It is difficult to implement real three-dimensional handling, such as cutting sections, three dimensional query and analysis. In this paper, taking the phenomena in geologic exploration engineering as the examples, the authors discuss the three-dimensional geologic phenomena in section 2, propose a blended data model integrated vector and raster data in section 3, introduce visualization in scientific computing and its application in geologic exploration engineering in section 4, and several techniques for geologic exploration engineering visualization and modeling are proposed in section 5. Lastly, some conclusions are given in section 6.

2 Spatial Object Description of Geological Exploration Engineering

To prove up and research the character and space distribution of geologic objects, people have done all kinds of geologic exploration. In geologic exploration engineering, different archives and drawing, 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 are obtained. These archives and drawings are three-dimensional data, and are drawn into two-dimensional plan due to the limit of technique. 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 body 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. According to the forming conditions, the 3-D phenomena can be divided into the natural geological phenomenon and the exploration-engineering phenomenon. The former is the natural geological entities such as ore body, rock, stratum and its break line, gas gather point, and so on. The later are the constructions such as silo, inclined well, borehole, exploring trough, laneway, pick cavity, and so forth. The natural geological entities are irregular on the face and complex to describe. The exploration engineering phenomena have more regular shape.

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.

Different three-dimensional geologic phenomena have different description methodology. Scientists have made in-depth research and obtained delectable schemes to describe geologic objects. For instance, the shape of an ore body is an irregular close curved surface and we can describe it by using DEMs of the top and bottom surfaces. The ore body 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.

3 Three-Dimensional Data Model in Geologic exploration Engineering

For an information system, the data model determines its data structure and process function on the data. To visualize the information of geologic exploration engineering effectively, one of the key technique is that how to store, process and denote the spatial information of underground three-dimensional objects. Some data models have been come forth, 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 data description format, data structure can be divided into raster-based and vector-based. 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 the object-oriented data models, an entity, no matter how complex it is, can be described by using an object. The relationship among objects can be established by object identify. It supports not only changing record in size but also aggregation objects. It is the ideal model to describe 3-D spatial objects, therefore, when designing 3-D spatial data model, object-oriented data model integrated vector and raster data can be adopted.

3-D spatial objects in geological exploration engineering can be divided into point, line, surface and body in geometry. But according to management they can be divided into different management units, for instance, mine, mine lot, mineral deposit and ore body. 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, Column by continue sections, Irregular body by DEM, Vaxtixel and irregular tetrahedron network. Surface entities consist of boundary arcs enclosing curve surface, DEMs constructing curve surface and sections. Arcs constitute line entities. Arc entities are described by node points and interior points, and the point entities by coordinate pairs.

In a certain spatial region, an ore deposit, for example, can be assembled a complex object.In the view of object-oriented technology, the entities mentioned above could be classified into different object classes, and based on them we could generalize a superclass named spatial feature class. According to the different geometry features and the present method we can design the spatial objects into different classes, which are the basic of designing data model. We proposed an object-oriented blended data model that integrates vector and raster data structures and it is suitable to Geological Exploration Engineering. See Figure 1. This data model involves many spatial objects. When applying this model, we should consider the complexity and capture style of spatial objects to select different data structure for present the objects. We can create the relationship among the objects by using the object identifiers.

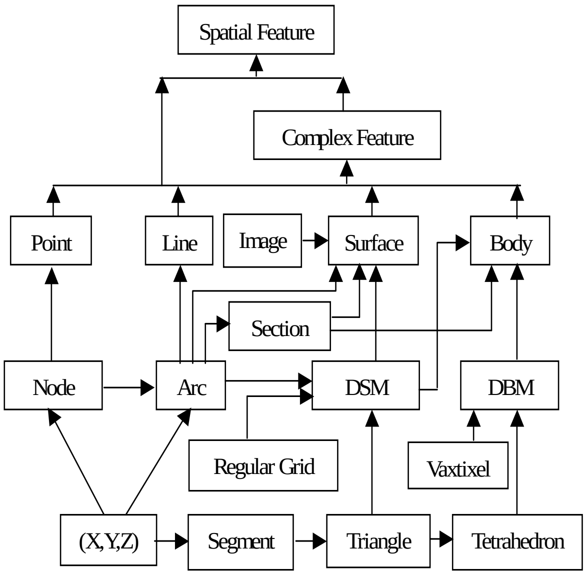

Fig.1 Object-Oriented Blended Data Model with Integrated Vector and Raster

4 Visualization in Scientific Computing and Its Application in Geologic Exploration Engineering

4.1 Visualization in Scientific Computing

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, geologic exploration, hydrodynamics and limited element analysis and so forth. It is a hotspot for applying Visualization in Scientific Computing (VSC) to 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. The requirement of the exploitation and management of natural resources, environment protecting and engineering design accelerates the development of three-dimensional visualization and animation image technique. In different research domains, the three-dimensional spatial data type, data location distributing and relationship are different, but the visualization flows are similar. The main process of three-dimensional spatial data visualization is shown in Figure 2.

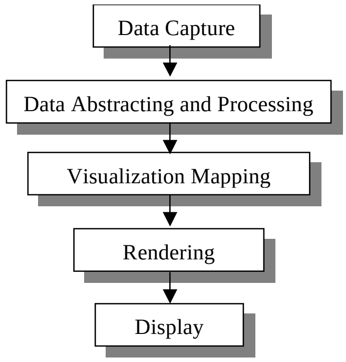

Fig. 2 Visualization Flow Graph

4.2 Visualization Example in Geologic Exploration Engineering

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, user can change the visual angle and view reelingly 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. This information provides science proof for geologic detail exploration, mine design and mining. Some visualization examples in geologic exploration engineering show in Figure 3 to Figure 6. Figure 3 to Figure 5 cite from EVS, http://ctech.com.

5 Several Techniques of Geologic Exploration Engineering Visualization

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 underground spatial objects. The data processing method is different for different data source. The key issue of visualization is spatial model construction.

5.1 Interpolating of Spatial Solid Data

Ore body component (grade) information is a typical spatial three-dimensional solid data. The direct measurement about an ore body grade information is discrete and fewer. Ore body 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.

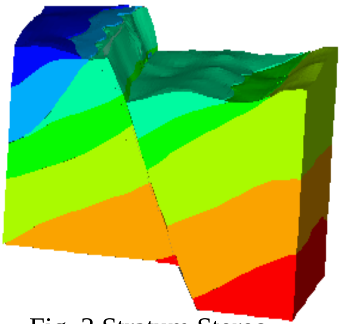

Fig. 3 Stratum Stereo

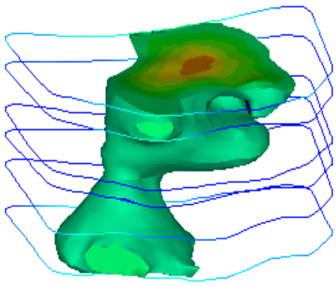

Fig. 4 Ore Body Isosurface

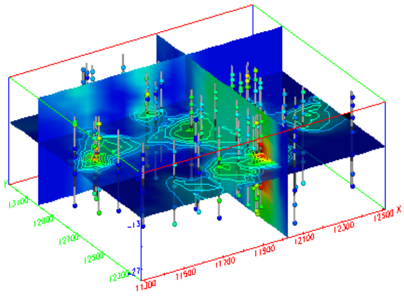

Fig. 5 Fence Diagram

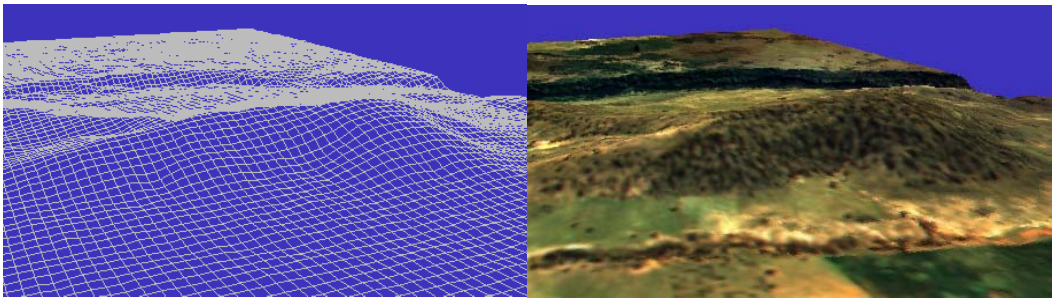

Fig. 6 DEM Framework and Landscape of

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 a ore body 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

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

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:

$$\sum_{i=1}^{n} \lambda_i = 1 \tag{2}$$

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

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).

5.2 Geologic Objects Surface Model Construct

5.2.1 Large Region Geologic Body Surface Model Construct

Obviously, large region geologic body drives at the stratum and the big layer ore body. Modeling these geologic bodies, Digital Elevation Terrain Model (DEM) can be used. There are two types of algorithm 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 weighed average method, for example, is a regular algorithm. The later has the advantages of high efficiency storage, data structure simpleness, representing the irregular terrain surface and linearity features correctly, 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, roof and bottom surface of ore body and be used to modeling geologic objects body. Currently, there is three accepted and adopted algorithms of constructing TIN: divide-conquer, incremental insertion and triangulation growth. The two formers are more popular. Divide-conquer algorithm has high time efficiency but occupies more EMS memory. Incremental insertion algorithm has low time efficiency and occupies less EMS memory. Wu proposes compound algorithm, which takes the advantages of divide-conquer and incremental insertion algorithm. The basic processes are shown in Figure 7. Compound algorithm is more suitable for modeling stratum and big layer ore body.

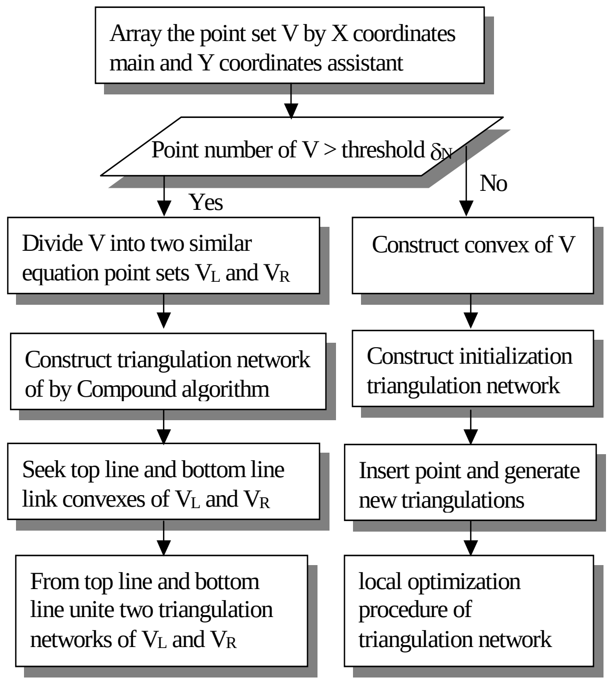

Fig. 7 Flow Graph of Compound Algorithm Creating TIN

5.2.2 Small Region Geologic Body Surface Model Construct

For some small size ore body, which shape like lens and potato, it is difficult to model them by using the method described in section 5.2.1. For the purpose of exploring the ore body distribution, the borehole usually set down along a certain exploration line. Thus creating the TIN of an ore body, 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 8. Suppose adjacent vertical profile A and B, the points meeting the ore body is arranged into loop P and Q by some algorithms such as ore body 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, the calculate work is small and more fast.

To illustrate the basic theories of producing triangular faces consider an example: assume two loops, P and Q, as show in Figure 8. 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.

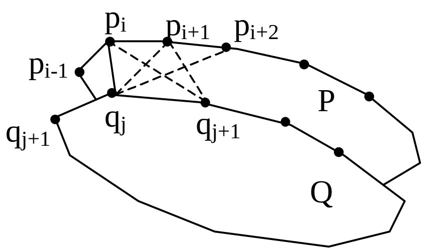

Fig. 8 Shortest Span Model of Surface Triangulation

5.3 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 9. 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 $1.0\times10^{-2} - 1.0\times10^{-4}$. 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 10.

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 10(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 10(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

10(c).

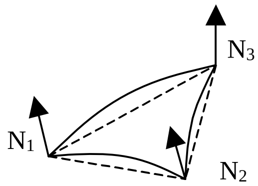

Fig. 9 Triangle Curve Surface and the Normal Vector

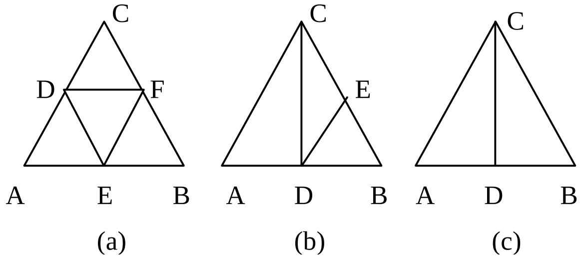

Fig. 10 Three Cases of Subdividing

6 Conclusions

Visualization technology has been widely used in different domains. Most of information in geologic exploration engineering is real three-dimensional. Visualization technology provides good tools for geologists. Using these tools, geologists can analyze and manage complex spatial data, communicate to non-geologists and provide scientific proof for governor and decision-maker of nature resources. Visualization of geologic exploration engineering information needs good data models and data structures. Blended data models integrated vector and raster is good method to describe geologic objects. Except for using computer graphics algorithms, some special algorithms must be studied for constructing special geologic objects. Good 3D graphics library, such as OpenGL, and graphics accelerator card are necessary for improving abilities of visualizing and interacting to 3D model. On the other hand, Virtual Reality Modeling Language (VRML) offers geologists the potential to disseminate 3D geologic spatial data over the World Wide Web. This is the future development direction of visualization of information of geologic exploration engineering.

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