



Conceptual design, data model and key techniques of “3D Assistant”

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Abstract: Conceptual design, data model and key techniques of “Geo-engineer 3D assistant”, an underground 3D GIS oriented to geology and mine application, were discussed. In particular, the importance of high-order smoothing triangular pieces to surface’s fine expression in geological modeling was emphasized. The contour mode is the most favorite mode of the three modes about surface expression: DEM, TIN and contour. Topology in underground 3D modeling with CAGD was compared. From the view of boundary and coboundary, which is soul of IS 19107 (Geographic information spatial schema), 3D underground topology was re-examined.

Key words: 3D assistant; true 3D; GIS; fine expression of surface; contour mode; 3D topology

1 Introduction

Geological 3D modeling is very different from 3D CAD and the orthodox 3D GIS (such as ArcGIS 3D module). It needs to overcome many special difficulties in technique. HOUDING [1] proposed the concept of three-dimensional geological modeling, distinguishing geological 3D modeling from general 3D modeling. MALLET [2] proposed a discrete smooth interpolation (DSI), the follow-up studied [3–4] made the theory of three-dimensional geological modeling become mature. LI et al [5–7] studied three-dimensional topology; WU et al [8] studied three-dimensional petroleum-reservoir description. MAO et al [9] introduced gray system theory into 3D geological modeling; PAN et al [10] studied the multi-resolution Octree model; QI et al [11], CHENG et al [12], WU et al [13], CHE et al [14] researched similar prism model, which was then extended to the general tri-prism modeling method. With the three-dimensional modeling of geological theory become matured, many softwares of underground three-dimensional modeling and GIS were developed. Some new products were

emerging and some were being planned.

“Geo-Engineer 3D assistant”, shorten as “3D assistant”, which was developed by the Chinese Academy of Surveying and Mapping as an underground true 3D GIS software, for geological exploration, mining, urban underground planning and management and environment conservation. The product was designed and developed in 2010. Now it has primary ability of constructing underground 3D model and 3D visualization. The authors are applying for software copyrights. In the near future, it will gradually become mature and a handy 3D assistant for the geological engineers. This paper discusses conceptual design, data models and key techniques about “3D assistant”. It is hoped to provide a reference for colleagues, and also to receive some advices for the products.

2 Family of 3D assistant

3D assistant product includes three parts of surface toolbox, development package and geo-exploration system. The main functions and major users of each part are listed in Table 1.

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Table 1 Conceptual design of 3D assistant product

No.	Product name	Main function	For major user
1	Surface toolbox	3D surface modeling, browsing, displaying and analyzing. The tool is similar to surfer.	Most of geology and mining engineer
2	Development package	Secondary development of components	Professional users who have ability of secondary development
3	Geo-Exploration system	3D geology modeling, fault modeling, reserve calculation, print all maps and tables.	Geological exploration users

2.1 Surface tool

The tool is mainly used for surface building, visualization and analysis based on a variety of three-dimensional data. According to a surveying of WANG et al [15], Surfer, produced by Golden Software Inc., is the most used tools in geographic spatial information mapping for geological engineer. Because of simple and rich in functions, it wins the majority of workers to learn and use. However, China needs own surface modeling tools. The authors plan to provide a surface modeling tool for Chinese geology and mine engineer. The software tool should have the following features:

1) Modeling 3D surface from various data sources of text file, Excel file, DBF file, MDB files and commonly used graphics files, such as shape file, E00 file, DXF file, Mif file, Vec file, and so on.

2) By grid, hypsometric tints, contour, TIN, plane, profile, perspective and other means to display, print out the three-dimensional surface.

3) Various 3D spatial measure means, including distance calculating, area measurement, slope calculating, orientation, angle and other measurements; spatial operations means, including overlay operation, buffer operation and profile operation; spatial analysis means, such as sunlight analysis, through visual analysis, connectivity analysis and adjacency analysis.

2.2 Development components

The development component is mainly for professional application software developers. Although there are many open-source 3D software resources, such as OSG, VTK, Ogre and GDAL and many charge development tools, such as skyline, AVS and IDL, the gate for the most professional software developers is still too high to entry the true 3D world. The more importance is that these resources often do not provide fault-expression function, which is fundamental for geological modeling. The authors wish to share experience and source code in developing 3D assistant with other professional software developers, to speed up the development of underground real three-dimensional GIS applications.

2.3 Geo-exploration system

The software provides functions for mineral resources exploration in the geological recording, geological modeling, geology structural analysis, reserve calculation and digital geological report relatively strong and other professional functions.

Motivations of providing exploration system come from next three considerations. First, the Chinese Academy of Surveying & Mapping is under lead of the Ministry of Land and Resources, should be to provide three-dimensional geospatial information technology support for exploration of mineral resources; Second, the two collaborator of the software, China University of Mining & Technology Beijing (Institute of Earth Sciences and Surveying & Mapping) and Liaoning Technical University (Institute of surveying & mapping and Geographical Sciences) are advantage in resource exploration domain; Third, the professional software in mineral resources exploration are more immature relative to mine. So, it has more room for development.

3 Data model of 3D assistant

A software system function and scalability depends largely on its core module data model. Good data model can make software more easily implement complex functions, and the system has good scalability and performance robustness. This chapter describes the “3D assistant” of the data model framework.

Object oriented 3D vector boundary model is the foundation of “3D assistant” data model. It consists of point feature, curve feature, surface feature and solid feature, as shown in Fig. 1.

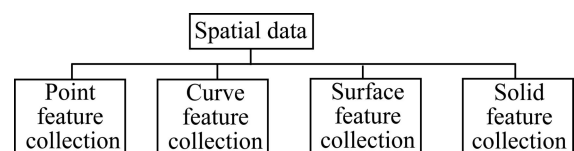


Fig. 1 Summary of vector boundary data model in “3D assistant”

3.1 Point feature

0-dimensional spatial object, which can not extend along any direction, such as observation points, the sampling points, drilling hole point, or even a building, a bridge, a village, a city in a certain scale, could be abstracted as a point feature. Point is expressed as the geometric elements of three-dimensional point (D3point).

3.2 Curve feature

1-dimensional spatial object could extend along one direction (the direction can turn), such as roads, rivers, fault outcrop line, intersection line of fault surface with stratum interface, drilling spatial path, a pipeline, a tunnel and so on. Geometric representation of curve feature could be classed into two-dimensional curve (D2curve) and three-dimensional curves (D3curve). A two-dimensional curve is a series of two-dimensional point, three-dimensional curve is a series of three-dimensional points. If points in a two-dimensional curve carry with same elevation attribute value, they become a contour in three-dimensional space.

3.3 Surface feature (Geosurface)

2-dimensional objects can expend along two directions, such as the stratum interface, unconformity interface, fault and so on. The geometric representation of surface feature is a collection of a number of isolated surfaces, because a geo-surface may be cut into several sub-surfaces by faults; Geometric representation of a surface is a collection of a number of (3 or more) three-dimensional points (D3point), connected to form three-dimensional triangular irregular network D3TIN. The D3TIN is constituted by the 3D vertices array (D3vertexes), edge array (D3edges), three-dimensional triangular array (D3triangles); Contour array (Contour) can be derived from a TIN. In the above mentioned, essence of a contour is a series of discrete two-dimensional points, which can form a two-dimensional triangulation network of restricted by the upper contour and the lower contour. Addition to geometry expression of stratum interface, unconformity and fault, surface is boundary expression of solid feature.

3.4 Solid feature (Geosolid)

3-dimensional object can be expanded along the X , Y , Z three directions, such as stratum, rock body, water body, building and so on. Geometry expression of solid feature is a collection of a number of separate geometric solids (Solid), since a geological body (for example, the body of a stratum) may be cut into a number of isolated bodies. The geometry expression of a solid boundary is a

shell, specified by a top of the interface, a bottom interface and a side torus (Cylinder). The side torus is formed by vertical triangulation between a top surface ring and bottom surface ring (Fig. 2(b)).

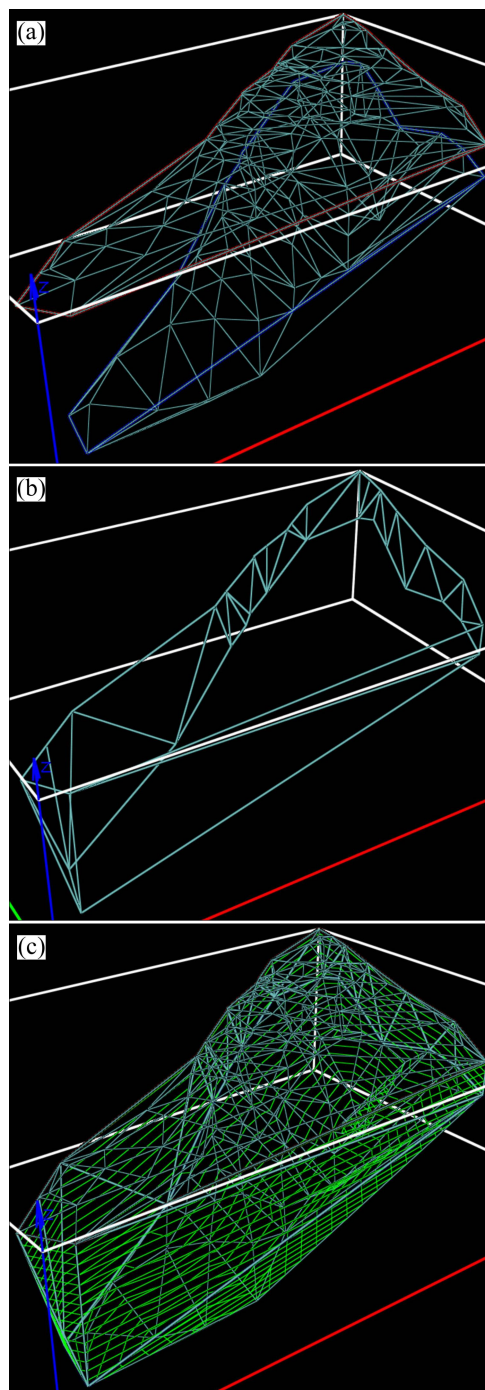


Fig. 2 Constitution of solid boundary shell: (a) TIN of Topsurface and Bottomsurface; (b) TIN of Cylinder; (c) TIN+contour of Topsurface, Bottomsurface and Cylinder

In the above data structure, a geosurface is composed of several surfaces, and a geosolid is composed of several solids, so it can support expression of underground geological model with faults cutting.

4 Discussion on key techniques

In a software system, many techniques are involved. Here, only several key techniques are discussed.

4.1 Fine expression of surface

Surface expression technique in CAGD (computer-aided geometric design), 3D GIS (three-dimensional geographic information system), 3D GMS (three-dimensional geological modeling systems) play a very important role. Surface expression of both three-dimensional surface features directly, but also the boundary of a solid feature. A continuous piecewise smooth triangle patches to express the free surface has a long history in the CAGD, and also has a lot more mature approach [16–18]. In the traditional 3D GIS, which application mainly oriented to expression of terrain and buildings, it is rarely to use small triangle surface pieces to represent a nature surfaces, but small triangle planes is enough. With the expansion of 3D GIS application domains from the ground to underground, many problems, which never encountered on the ground, become acute and sharp in the underground. Among the problems in underground, surface expression method is one. On the ground, due to ground-based observations can be sampled intensively, and most of the building shape are regular, collection of small triangle planes to express surface is fully able to meet application accuracy requirements. But underground, costly sampling makes sampling sparse, such as the distance varies from tens of

meters of geological drilling, as far as several hundred meters or even kilometers. This sparse sampling, if still using the traditional collection of the small plane piece to represent of geology interfaces, such as stratum interface, unconformity interface and fault, it will be less accuracy than that of the application required. Therefore, according to the geological drilling sampled data to construct continuous and smooth surface with collection of piecewise triangle surface patch becomes a task of developers in underground 3D GIS. Although surface expression of higher order triangle surface piece along mosaic patches have been a lot of maturity in the field of CAGD method [16–18], but most of these methods are not as familiar to geo-science workers. “3D assistant” has a new attempt in fine expression of the geological surface. High order smooth triangular piece method, which is widely used in the CAGD field, is introduced into underground 3D GIS.

From smoothness of contour, it can be seen that after using the technique of a high-order triangle surface piece smooth stitching triangular patch, the expression precision of surface has been improved significantly.

4.2 Unique advantage of contour way in surface expression

There are three typically ways in surface expression: 1) DEM (digital elevation matrix); 2) TIN (triangulated irregular network) with elevation in vertexes, and 3) contour. These three presentation forms are interchangeable. Traditional paper topographic maps are based on the contour way, geological engineers are familiar with use

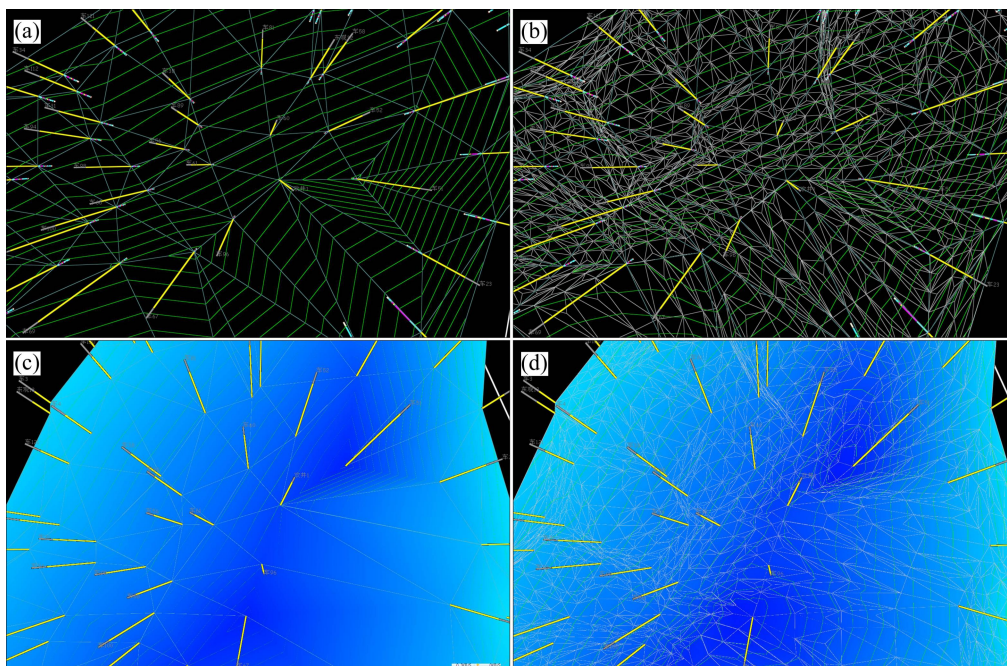


Fig. 3 Comparison of basic triangle plane pieces and high-order triangle surface pieces: (a) Contour based on basic triangle plane pieces; (b) Contours based on high-order triangle surface piece; (c) Drawing basic triangle plane pieces; (d) Drawing high-order triangle surface pieces

of this method. With the emergence of digital methods, surveying & mapping community become prefer DEM way. This can be confirmed by the fact that most of terrain data are provided in DEM way from the National Bureau of Surveying & Mapping. Indeed, DEM has the advantage of data structure regular, similar to the image data, and easy to translated to regular triangle net (as long as linking the diagonal of rectangular grid along one direction, grid mesh network can be transformed into regular triangle mesh network, which can be viewed as a special case of TIN), and contour. TIN with elevation is fond by computer graphics programmers mainly, because the surface is drawn finally with spatial triangular facets.

It is stressed here is that geological engineers more favorite contour way than other ways. This is because, in DEM and TIN ways, for geological engineers, the surface morphology is “implicit”, even through the computer three-dimensional visualization methods (for example, by 3D grid or height-setting-color) to be able seen the surface (such as terrain) of the ups and downs, but if the geological engineer want to modify the surface shape, without knowing where to start. In the contour-based surface presentation way, shape of the surface is presented by horizontal position of the contours. So shape of a surface is “explicit” and “revisable”. The geology engineer can directly modify surface shape through “drag” a contour in a plane map. This is why engineers like contour surface expression rather than DEM or TIN surface expression.

Although contour way of surface presentation looks like a series of curves (which can be smooth or unsmooth), essentially they are controlled by a series of discrete points. Modifying a contour shape, in essence, is “dragging” these “points” in the horizontal position.

It is easy to constrain triangulating these points in adjacent contours, but TIN formed by triangulating the points in contours is different from TIN formed by triangulation original sampling point. They are finer than original TIN. It adds a lot of data.

The contour to modify the shape of surface for engineer, transformed into the triangle piece to OpenGL rendering easily, so it is a good surface expression way.

4.3 Surface presentation technology routes in 3D Assistant

“3D assistant” takes this technology routes in the expression of surface: 1) Triangulating the original sample points to build the basic TIN; 2) Tracing basic TIN to construct basic contours series; 3) If being needed, fitting the high order triangle surface for the basic TIN, every basic triangle is split into 28 small triangle pieces by adding 18 attachment points (3 points for every edge, 9 points inner the triangle), triangulation the inserted attachment point to form high-order TIN; 4) Tracing

high-order TIN to construct high-order contours series. Triangulation based on the new generation of contour smoothing fine lines.

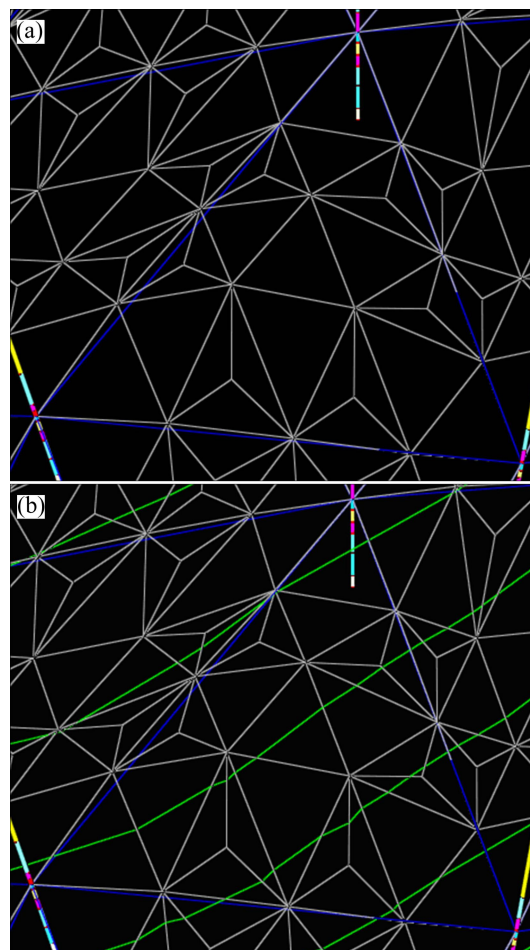


Fig. 4 Basic triangle and high-order triangle and contours: (a) A basic triangle split to 28 small triangle; (b) Fine high-order surface contours

Thus, 3D assistant can present a surface in two modes: 1) cursory mode, it can draw easily fastly cursory surface form (by draw basic plane pieces); 2) fine mode, it can draw a surface in fine and smooth shape, (when drawing, still in small triangle plane in OpenGL, but every basic triangle plane is replaced by 28 smaller triangle plane pieces).

“3D assistant” user can modify surface shape by dragging the control points on a contour in a plane map or by drag points in intersection curve of surface with profile in a profile map. So, it is possible to modification a surface shape linkage in plane map, profile map and three-dimensional surface.

4.4 3D GIS topology for geological applications

In the traditional 3D GIS, topology is optional, if so, that is the main expression of TIN’s nodes, edges and triangle. This is because there is few traditional 3D GIS

to express solid. In CAGD, which mainly oriented to application in machine parts, product design, architectural design, focuses on relationship of entities constituent of point, line, surface and solid, but it has a big difference from topology used in underground 3D GIS. LI [5] discussed topology four different aspects in underground 3D GIS with 3DCAGD. The most critical difference is that in 3DCAGD, the surface is only physical boundary, rather than interface between the two solids, so, it is only one side of surface with polyhedron. This conduces that an edge can only have two adjacent surfaces. But underground 3D GIS emphasis on “surface” is the interface between the two solid, and thus as the side of the boundary surface it has more than two adjacent surfaces. For example, intersection of a fault plane with a coal layer (in coal geology and mining geology, called it “broken coal intersection line”), there are three sides adjacent surface (including sub-surface). Underground 3D GIS application concerns the solid and surface, the relationship between the solid and the solid, so for every surface, it should be concerned about their “positive neighboring solid” and “negative neighboring solid”. LI [5–7] has proposed that with five or six groups of relationship to describe the relationship of node, edge, ring, face, shell and solid. “Introducing interface, splitting solid” as a method of construction three-dimensional topology relationship and a concept of “one surface with three layers” had been proposed in his works. These works may be somewhat immature. But it was really an independent research, and had some reference value for underground 3D GIS.

Geographic Information Working Group of International Standardization Organization (ISO TC211) published an International Standard of “Geographic Information Spatial Schema” [19] in 2003. The most foundation standard in the series of geographic information standards is considered. Many of its concepts are gradually penetrating into the global geographic information workers, recognized by peers for the majority. China has adopted the international standard as a national standard [20]. The first author of this paper has luck to participate in this work. Name and dimension of geometry and topological object are listed in Table 2.

The standard uses two important concepts of spatial object boundary and coboundary to express the concept of topological relations in the traditional GIS. A boundary is a set that present the limit of an entity, coboundary is a set of topological primitives of higher topological dimension associated with a particular topological object, such that this topological object is in

Table 2 Geometry and topological object in different dimensions

Dimension	Geometry object	Topological object
0	Point	Node
1	Curve	Edge
2	Surface	Face
3	Solid	[Topological] Solid

each of their boundaries. The boundary of a spatial object is lower one-dimensional than the object. The coboundary is higher one dimension than the spatial object associated with it. If a spatial object A is in boundary of spatial object B, B is coboundary of A. For example, if a node A is on the boundary of an edge B, the edge B is the coboundary of node A. Again, an edge A is in the boundary ring of surface B, the surface B is coboundary of edge A; surface A is on the boundary of solid B, the solid B is coboundary of surface B.

In the three-dimensional case, coboundary of a node is a number of edges, boundary of an edge is a start node and an end node; coboundary of a edge is a number of surfaces (note: In the 2-dimensional planar case, the coboundary has at most two faces. In the full topology case, there are precisely 2, one directed face having a positive “+” orientation and the associated face lying to the left of the edge, and the other directed face having a negative “−” orientation, and the associated face lying to the right of the edge), boundary of surface are one out-boundary ring and some inner-boundary rings, which are composed of edges. Coboundary of a surface has at most two solids, in the full topology case, there are precisely 2, one solid associated to its positive side, and the other associated to its negative side. The boundary of solid is one out-boundary shell and some (0–n) inner-boundary shells, which are composed of surfaces. With the concept of boundary and coboundary, the topology relationship of underground 3D GIS has been reviewed. Here are four groups modified for LI earlier exposition:

- 1) Node—an array of associated edges (coboundary);
- 2) Edge—the start node (boundary)—the end node (boundary)—an array of associated faces (coboundary);
- 3) Face—an array of edges (boundary)—the positive adjacent solid (coboundary)—the negative adjacent solid (coboundary);
- 4) Solid—an array of faces (boundary).

The four group relationships also could be expressed as Table 3.

Table 3 Four group topological relationships by boundary and coboundary

Topological Object		Boundary		Coboundary	
Name	Dimension	Name	Dimension	Name	Dimension
Node	0	null	−1	Edge	1
Edge	1	Start node, end node	0	Face	2
Face	2	Edge	1	Solid	3
Solid	3	Face	2	null	4 (if exist)

Boundary of 0-dimensional object (node) is empty (null), coboundary of solid in three-dimensional space is empty (null). If the adding relation “ring—an array of edges” and, “shell—an array of faces”, they are six group relationship of LI Qing-yuan had expressed

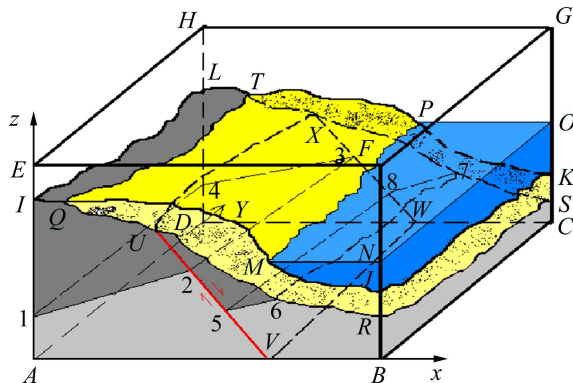


Fig. 5 Topology relationship of nodes, edges, faces, and solids for geological model

5 Conclusions

- 1) High-order piece fine expression to surface is necessary in geology and mine application.
 - 2) Contour is the most suitable mode for geology and mine engineers among all surface expression modes.
 - 3) Concepts of boundary and co-boundary, which comes from IS 19107, are very powerful thought tools for dealing with 3D topological relationship in 3D geo-modeling.
- Though, the underground modeling and GIS software have shown increasing trend, many key techniques which have been warring programmer still block in there. Some problems which looks like being solved, but still need to find a good solution. Underground 3D GIS is less mature than over ground. Especially for fault cutting model and expression attribute ununiformity inside of solid feature, still no satisfactory solution in geology application domain.

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