

ON 3D GIS SPATIAL MODELING

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ABSTRACT:

3D city spatial data are the main research objects in GIS. 3D city spatial data have the characteristics of multi-object, heterogeneity and multi-structure. It could be classified referring to the geo-surface into three kinds: above-surface data, surface data and subsurface data. The current research on 3D city spatial information system is divided naturally into two different branch, 3D City GIS (3D CGIS) and 3D Geological Modeling (3DGM). The former emphasizes on the 3D visualization of buildings and the terrain of city, while the latter emphasizes on the visualization of geological bodies and structures.

3D Spatial Modeling is the key to 3D GIS, and is the basis of 3D GIS. All kinds of 3D spatial modeling methods are different with the difference of modeling objects. Based on the difference of spatial modeling objects, 3D spatial modeling methods are divided into two kinds, one is Geographical Spatial Modeling, and another is Geological Spatial Modeling. Geographical Spatial Models mainly include 3D FDS, n Tuple model, Simplified Spatial Model (SSM), Urban Data Model (UDM), OO3D model, etc. Geological Spatial Models mainly include 3D-TIN, Grid, TEN, Octree, Solid Model, GTP, etc. And some integrated models as TIN+CSG, TIN+Octree, TEN+Octree. With the contrast of all the 3D spatial modeling methods, this paper also present some key issues on 3D spatial data modeling.

1. PREFACE

GeoSpace is a continuous 3D space. It is one of the important issues in GIS to represent the geospace and its objects in 3D space. Current 3D GIS researches mainly focus on the spatial objects above-surface. With the rapid development of computer science and spatial information technology, the spatial data that GIS managed not only include the nature geographical data, but also extend to above-surface and subsurface natural and humanized (Fig 1). It is an important category in GIS to integrally study the description, representation and analysis of surface and subsurface spatial data.

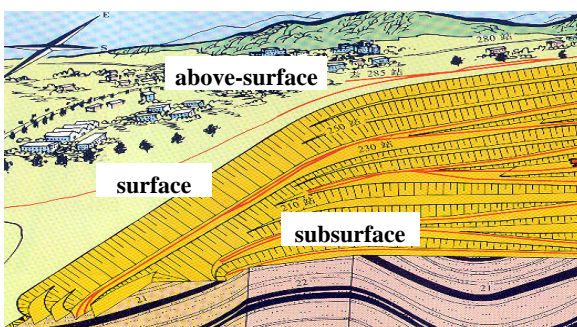


Fig 1 A typical skeleton of coalmines

City spatial information is the most complex data in geospace information, and they are representative on 3D GIS research. An investigation into user requirements for 3D city modeling in current 3D GIS mainly focused on the spatial objects above-surface, few or not on the subsurface objects. With the rapid development of urbanization, more and more issues were influenced directly or indirectly by city subsurface environment including city geology, hydrology, engineering geology and tunnels. It is demanded that much more study should focus on

the real 3D spatial information and on its integration. 3D GIS is an efficient method for acquisition, storing, managing, visualization and analyzing the integral information of surface and subsurface, and is an important platform for supporting the sustainable development research on urban. However, different 3D GIS modeling methods are usually used in separate domains. The presented models during the past decades are usually divided into above-surface, surface and subsurface modeling methods according to the spatial objects it modeled. And we call the space that above kinds of model described are Geographical Space and Geological Space. Usually, current 3D GIS describe the Geographical Space objects, while the Geological Space objects are represented in some geological software (Wu LX, 2003).

In a word, integral real 3D spatial data of city should contain Geographical Space and Geological Space data, and a real 3D GIS should describe and represent all of the spatial objects including Geographical Space and Geological Space. The basis of 3D GIS for digital city is to construct a new 3D data model for the integration of urban Geographical Space and Geological Space. According to the characteristics of geospace objects, it is classified into three kinds: geographical objects, surface objects and geological objects.

2. 3D SPATIAL DATA MODEL

Data model and data structure are the basic contents for spatial data organization, and they are the keys for GIS software development. Concept model is a core of spatial data model design, which is used to define some rules for representing attributes of spatial model. In 3D GIS modeling, Features' location and shape are in 3D space, and they have their own space. The main differences between 2D GIS model and 3D GIS model are that features' attribute of the former is the domain of spatial position and the changes of attribute are

following the change of geometric (position, shape, size). But 3D GIS modeling objects have their own attribute.

A modification of the 3D GIS models is that they allowing operations with body objects. Based on the spatial objects that 2D GIS defined (point, arc, face), the 3D GIS models add another object: body. Because of the extension in dimension, 3D GIS models have great difference in topology and geometric to 2D GIS models, such as the geological stratum as a face object, geological body and buildings as body object. So it is more complex to model in 3D GIS than in 2D GIS.

Many authors and researchers have studied on the 3D spatial modeling and presented kinds of 3D spatial data models. According to the different objects studied on, all the models are divided into two types: 3D Geographic spatial objects model and 3D Geological spatial objects model.

2.1 Geographical Space Objects Modeling

Geographical Space objects mainly refer to the constructions on the ground, such as buildings, bridges and towers. The concept of a 2D GIS introduced by Molenaar in 1989 as "Formal Data Structure", and extended to comprise 3D

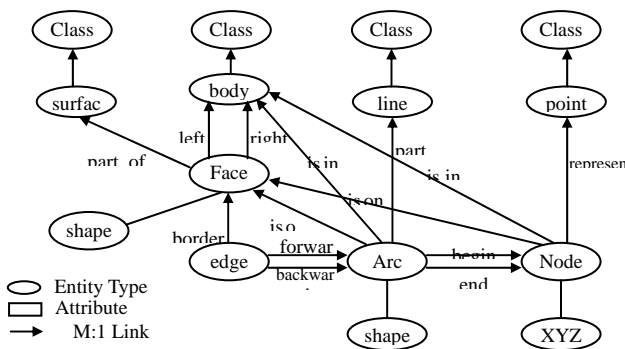


Fig.2 3D Formal Data Structure

information and texture of 3D Formal Data Structure (3D FDS) in 1992. The model comprised of four elementary objects (point, line, surface, body), four primitives (node, arc, edge, face). The topology, which has is-in and is-on of 3D FDS, is distinctly expressed including: point and body, arc and body, node and face, arc and face (Fig.2).

Based on 3D FDS, such models as n-couple model, Simplified Spatial Model (SSM), Urban Data Model (UDM), Object-Oriented 3D Data Model (OO3D Model) are presented.

2.2 Geological Space Objects Modeling

The subsurface objects mainly refer to humanized engineering body such as tunnel, subway and cave, and natural geological body such as stratum, faults and ore body. The modeling of geological body is included in this paper. The geological body modeling is also called three-dimensional geological modeling (3DGM). Usually, geological models are divided into three kinds: surface model, solid model and integrate model. They including: TIN model, Grid model, block model, tetrahedral network model (TEN), pyramid model, wireframe model, B-Rep model, Multi-DEM model, CSG model, Octree model, GTP Model, TEN+Octree, TIN+Octree, and so on. All of these

model are used to describe the occurrence of geological body and to calculate the possible reserves (Houlding S 1994). Here we introduced some typical models.

1. TEN : TEN was introduced by Pilouk to overcome some difficulties of 3D FDS in modeling objects with indiscernible boundaries. According to the definitions, TEN has four constructive objects (tetrahedron, triangle, edge, node). The topological relationship is given by the adjacency of spatial objects. A body object is composed of tetrahedrons, a surface object of triangles, a line object of arcs and a point object of nodes.

TEN model is appropriate for representing irregularities in the real world, such as terrain, soil, geological objects, etc. Since the model uses the simplex-complex concept, TEN can be expected to cover the scope of possible topological relations in 3D space (see Fig.3). While algorithms for constrained triangulation are discussed in the literature, the 3D construction of 3D constrained tetrahedrons is still under research.

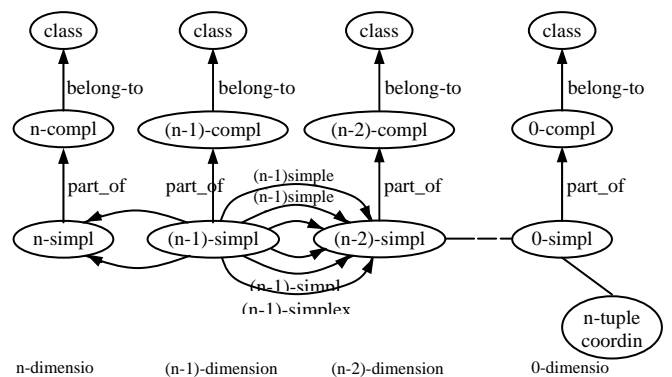


Fig.3 TEN: n-dimensional conceptual model

2. General tri-prism (GTP) model : GTP model of broad suitability is proposed (Qi A W, Wu LX 2002; Wu LX 2004). The GTP is comprised of six primitives as node, TIN-edge, side-edge, TIN-face, side-face and GTP. Besides, three intermediary diagonal lines in each GTP component are temporary applied for spatial operations. Six groups of topological relations between the six primitives are carefully designed for geo-spatial inquiry and geo-spatial analysis.

GTP model makes use of the up and down triangles of GTP to express the geological stratum, and expresses the spatial relation among the stratum by use of the side face of GTP. Fig 4 shows that the wide lines represent the drill holes. The GTP is combined by two unparallel triangles and three irregular side faces, which might be uncoplaner for the unparallel drill holes. Tri-prism is one of the special cases of GTP in condition that the drill holes are parallel, and a GTP will degrade into a tetrahedron or a pyramid respectively in condition that one triangle face or one size-edge shrink to a point. Hence, the GTP is so called.

It is obvious that the GTP model can efficiently make use of the drill hole data that sampling each interface point to identify different geological strata. GTP model can not only model the strata in real 3D, but also represent the layer interfaces of strata by means of the collection of TIN faces.

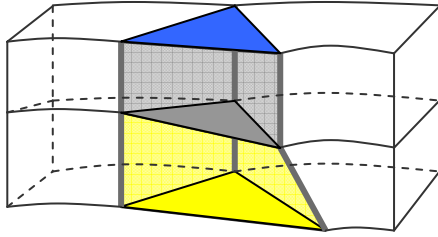


Fig 4 The principle of GTP model based on unparallel drill holes

3. Integrated model: There are four objects of point, line, face and body in 3D GIS that body is added on the basis of 2D GIS. Because of the complex description of 3D objects, it is difficult to describe spatial objects using single model. Many researchers presented integrated models for special spatial description. For example, Li Qingquan (1998) presented TIN + CSG, Octree + TEN, and vector-grid integrated model. TIN+CSG are used for 3D urban description. TIN is used to represent terrain and CSG to buildings. Octree+TEN mainly used in geology, mine. Octree + TEN are fit for geological construction with fault. Shi Wenzhong (1996) presented TIN + Octree that mainly used for 3D City. TIN represent surface of 3D spatial objects, and Octree express inside of 3D objects. Pointer links TIN and Octree. And so on.

3. COMPARISON OF GEOGRAPHICAL MODEL AND GEOLOGICAL MODEL

3D GIS data modeling is the basis of 3D GIS, but all above the models are not universal. This paper compared all of these models in geometry, primitive, using field and their advantage and disadvantage in order to giving some advices (Table 1).

4. CONCLUSIONS

With the rapid development of urban, the city space extends from surface to subsurface rapidly. 3D city spatial data have the characteristics of heterogeneity, multi-object, multi-scale and multi-structure. According to the different objects studied on, all the models are divided into two types: 3D Geographic spatial objects model and 3D Geological spatial objects model. It is one of the direction of 3D GIS by compared all of these models in geometry, primitive, using field and their advantage and disadvantage. Currently, two issues are firstly resolved for 3D GIS, one is to integrated geographical and geological objects, another is representation of topology of 3D objects which is the basis of spatial query and analysis.

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Table 1 Comparison of 3D spatial data model

Type	Name	Author/Date	Using	Primitive	Entity object	Model base	Advantage	Disadvantage
Geographical model	3DFDS	Molenaar 1990	3D city model	Node, Arc, Face, Edge	Point, Line, Surface, Body	Single value map	Easy make the adjacency between spatial and non spatial objects	Difficult to express complex spatial objects
	n Tuple model	Pigot 1992	Geology, complex buildings	0-3 Cell	0-3-Tuple Cell Complex	n-manifold	Topological expression, easy maintenance	Difficult to express complex spatial objects
	SSM	Zlatanova 2000	Web-oriented, visualization, query	Node, Planar face	Point, Line, Surface, Body	Simplex concept	Abstract primitives easily, small storage	Update dynamically and modify are complex, constructive objects are multi-values
	UDM	Coors 2003	City visulization	Node, Triangle	Point, Line, Surface, Body	Triangulation	Abstract primitives easily, small storage, facial visualize	Update dynamically and modify are complex
	OO3D	Shi Wenzhong, Yang bisheng 2002	City visulization	Node, Segment, Triangle	Point, Line, Surface, Volume	OO modeling	Complex object, LOD, Visualization	Indistinct Topology, little 3D spatial analysis function
Geological model	3D-TIN	Abdul 2000	Geology, terrain	Node, Line, Surface, Solid	Point, Line, Surface, Body	Single value map/FDS	Facial visualization	No attribute in object
	Grid		terrain	Square, rectangle		Surface divide	Facial visualization	Massive data
	TEN	Pilouk 1996	Geo-information, pollution cloud	Node, Arc, Triangle, Tetrahedron	Point, Line, Surface, Body	Simplex concept	Facial visualization, complex body and face	Difficult to visualize complex objects, great storage
	Octree	Hunter 1978	CAD/CAM, geology, sea	cube		Body divide	Simple structure, inside spatial attribute trans-formation expression	Difficult to express geological objects' geometrical boundary, Massive data, data redundancy
	Solid Model	Simon Houlding 1994	Geology, mine	component	Geological object's boundary	3-couple	Fit for Complex structure inside expression	Great manual work
	GTP ^[20]	Wu LiXin 2004	Geological engineering	Node, Line (TIN-L, side-L), Face (TIN-F, Side-F), GTP, diagonal	Point, Line, Surface, Body	Body divide	Topology completely, 3D expression of geology, based on drill hole data	Difficult to visualization of complex geological object
Integrated model	TIN+CSG	Li Qingquan, 1998	3D city model	Node, Segment, Triangle	Point, Line, Surface, Body, DEM	Surface divide	Two models integrate in a user windows	Difficult to express the complex geological object, such as fault, fold, fissure
	TIN+Octree	Shi Wenzhong, 1996	3D city model, geological engineering	Node, Segment, Triangle, Octree		TIN express surface, Octree express inside	Topology expression, query easily	Octree data changed with the change of TIN, easily disturbed by the pointer
	TEN+Octree	Li Qingquan, Li Deren	geological engineering	Octree, TEN		Octree express whole, TEN express part	Improve the precision of objects, reduce data storage	Difficult to build topology of spatial objects