A 3d GIS's Spatial Data Model Based On Cell Complex

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ABSTRACT:

Based on cell complex theory, after analyzing the corresponding relationship among cell, cell complex and 3D spatial solid, a formal definition for 3D spatial solid is presented. Through analyzing the geometric constructing relationship between cell and cell complex, we induce element boundary define and adhesive relationship existed in 3D spatial object; analyse three kinds of non-manifold cases in three dimension, which are regarded as non-manifold adhesive relationship. And to express complicated 3D non-manifold solid and make sure the completeness and uniqueness of element topology information in model, relevant topological data structure is developed. Taking the surface and underground 3D space around University City region of Xianlin, Nanjing as the research object, a 3D model with complicated geological environment and man-made buildings is established based on the new presented 3D GIS data model, verifies the efficiency and application of the 3D GIS data model proposed in this paper.

1. INTRIDUCTION

Along with the advance of science and human's requirement, human activities have extended to underground space. Especially urban underground space is used as important resource for exploiting, such as subway, tunnel, air defence engineering, pipeline, underground parking and so on. So many projects in company with original geology body compose of complicated underground 3D space and change the geological characters such as bearing capacity, underground water flow field etc. To describe, manage, analyse and display so complex underground spatial objects, we should make use of 3D GIS. Recently researchers at home and abroad have some systemic researches which include corresponding theory and technology method of 3D GIS. Summing up these researches, it is a general way for 3D GIS research that taking spatial data model for key and massive spatial data management and maintenance for base and spatial analysis as well as visualization for application support. Thereinto, spatial data model is to simplify real world and pursue disperse model to express geographical object which can be treated with by computer. So it is the core issue of 3D GIS.

2. RELATED WORKE

Form 1990, many researchers presented a lot of 3D spatial data models which ware used in different applications. Molennaar M(Molenaar M, 1990)and Fristch D(Frirsch D, 1996)presented 3DFS, which was based on formal description. 3DFS defined four kinds of geometry element which are node, arc, edge, face and the topological relationship between the basal elements with the geometric objects of point, line, face and body. Also, it expressed the topological relationship between point and body, line and body, point and face clearly. M Pilouk(Pilouk M, Tempfli, Klaus, et al, 1994), Chen Xiaoyong(Chen X, Ikeda K, Yamakita K, et al, 1994)presented a delaunay tetrahedral spatial data model. Li Qingyuan(Li Qingyuan, 1997)presented a vector structure based on body partition which defined five group topological relationship and presented a method to establish topological relationships. Brown(B I M. 1998)used structured 3D regular grid, non-structured 3D irregular grid and irregular tetrahedron to establish geological models. Hou Enke(Hou Enke, Wu Lixin, 2002) presented an Object Oriented 3D body element topological data model, which is based on the study of the basal attribute of geological objects and the requirement of 3D geological modeling. Wu Lixin(Wu Lixin, Zhang Ruixin, Qi Yixin, et al, 2002; Wu Lixin, 2004), Cheng Penggen(Cheng Penggen, Gong Jianya, Shi Wenzhong, et al, 2004)respectively used Generalized Tri-Prism (GTP) or QTPV to establish geological model, described the 3D logistic model and established the topological relationship between basal elements. Wang Yanbing(Wang Yanbin, Wu Lixin, Shi Wenzhong, 2003)extended the GTP model, and introduced tetrahedron to the GTP model. Cheng Penggen(Cheng Penggen, Wang Chengrui, Gan Weijun, et al, 2005)presented a compound 3D data model which used triangulated irregular network to express stratum and use QTPV to describe the interior of stratum. To satisfy the need of underground real 3D compound modeling, Wu Lixin(Wu Lixin, Chen Xuexi, Che Defu, et al, 2007) presented a GTP-EM based on GTP by modifying and extending the GTP model.

These application-oriented 3D spatial data models can satisfy specific demand, however, there are also some obvious problems: 1) It is without universality for these application-oriented model which is hard to meet the different situation demand and multiple coupling area requirements; 2) It may have a lack of mathematical completeness and have redundance or lack of element topology relationship for application-oriented.

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Also, some researchers try to research the 3D spatial data model and topological relationship from the spatial topological property. From the view of topology, the space of 3D GIS is only a metric space. A metric *d* from metric space **R** can get **R** related topology which is defined metric topology from *d*. Therefore, every metric space is the topological space. But on the other side, the topological space may not be a metric space. Consequently, 3D spatial entity and their topological relationship can be defined in 3D topological space. Simon Pigot et al(Simon P, 1992)extended the theory of 2D topological cell, and studied the definition and description of 3D spatial entity and their topological property and presented the 3D topological spatial cell theory. In this theory, any space is defined as a 3-manifold space, and there is one or more connective or separated *k*-manifold ($0 \leqslant k \leqslant 3$) for every spatial entity. Meanwhile, they introduced topological property of manifold to spatial entities, and used it to descript topological property of spatial entities, such as connectivity, directionality, identity and so on. Based on this theory, Chen jun, Guo wei(Guo Wei, Chen Jun, 1997; Chen Jun, Guo Wei, 1998)presented a 3D spatial entities definition domain, separated the 3D spatial objects into four spatial entity types which are point entity, line entity, face entity, body entity by the dimension of spatial entity. This method commendably utilizes the relationships among the topological property of orientable *k*- pseudomanifold , compact and connective *k*-pseudomanifold and *k*- complex with nicer simplex structure. Therefore, it has much more integrality and strictness. Based on the theory of simple complex, M.Breuning(Breunig M, 1999)presented a method to combine 3D GIS spatial data models, and developed a prototype system which was called GeoToolKit.

3D data model based on the theory of simple complex has a favourable mathematical base, which can express most of natural and artificial objects, but also has some drawbacks. 1) There are some limitation to express natural phenomenon, it can just express regular solid without free fault, interlayer etc. 2) This model can not unify wire frame, surface and solid model. However, the same geographical object may need different model in different application and distinct geographical object may also need various models in the same application. 3) The theory foundation is simple complex which limits that the basic elements for constructing model are simple entity object (triangle and tetrahedron etc.) which can not satisfy intricate practical need. 4) It lacks the completeness and uniqueness research for topological expression among elements. The shortcoming may result in topological information redundances or loss.

3. Formal definition for 3D spatial solid based on cell Complex

In the theory of cell complex, an *n*-cell homeomorphic to an opened sphere of $\mathbf{R}^n$ in Euler space and its boundary is defined by a lower dimension cell with a certain number. Corresponding to the entities of Euler space, 0-cell can be regarded as a point, 1-cell can be regarded as a segment, 2-cell can be regarded as a face, and 3-cell can be regarded as a region. Every cell object is defined by its exterior, interior and boundary. A cell complex in $\mathbf{E}^n$ is a limited $\mathbf{E}^n$ cell set K, $K = \bigcup\{\alpha : \alpha \ is \ a \ cell\}$. If α and β are different cells of *K*, then $\alpha \cap \beta = \varnothing$. A cell complex in $\mathbf{E}^3$ is a limited set adhesive by 0-cell, 1-cell, 2-cell and 3-cell. To a cell complex *X*, its *n*-cell framework X_n is defined by a consistent set of *k*-cell ($k \leq n$). Compared to the theory of simple complex, cell complex can be used to represent a more generic topological space, and simple complex is an specific type of cell complex.

Based on the theory of cell complex, the basic entity in E3 can be defined as:

- Vertex entity: a vertex entity corresponds to the 0-cell.
- Edge entity: an edge entity corresponds to the 1-cell, and its boundary is defined by vertex entity.
- Face entity: a face entity corresponds to the 2-cell, and its boundary is defined by edge entity. The set of edge entities belonging to boundary make up of a loop and there may be more then one boundaries for a face entity.
- Region entity: a region entity corresponds to the 3-cell, and its boundary is defined by face entity. The set of face entities belonging to boundary make up of a shell and there may be more then one shell for a region entity.

Because cell complex is the composite object assembled with adhesive relationship of the lower dimension cell, any complicated solid objects in 3D space can be composed of four basic solid objects above by adhering. There are three adhering relationships among point, line and face in 3D space considering non-manifold cases.

4. 3D spatial data model based on cell complex

Based on the formal definition of three dimensional solid objects with cell complex theory, three dimensional solid is composed of 0-3 dimensional cell complexes by adhering. And the cell is defined by its boundary. Therefore, the basic elements in 3D spatial data model are point, line, face and volume which correspond to 0-3 dimensional cell complex. The elements are defined by its boundary. The basic relationships among elements are boundary-definition relationship (I am whose boundary and who is my boundary), and adhering relationship (I adhere to whom and who adheres to me).

Based on above definitions, it is possible to define four basal elements which are vertex, edge, face and region; two boundary elements which are loop and shell which are boundaries of face entity and region entity respectively; three adhesive entities of vertexUse, edgeUse and faceUse. Supposing X_0 is a set of all vertexes, X_1 which is similar to the wire frame model is a set of all edges, X_2 which is similar to the facial model is a set of all faces, and X_3 which is similar to the entity model is a set of all entities. The UML diagram of this 3D spatial data model can be expressed as figure 1:

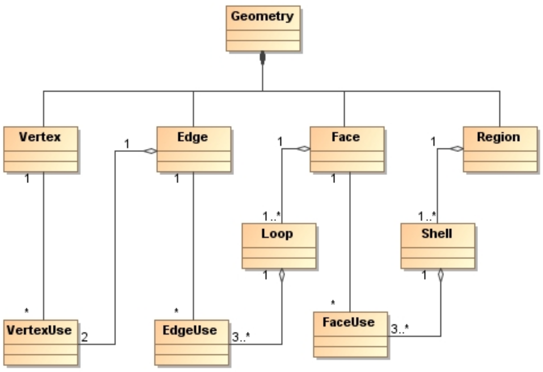

Figure 1. 3D spatial data model based on the principle of cell complex

Thus, the new presented 3D GIS data model based on cell complex theory is constructed. Any geometry is just composed by the cell complex hierarchy. This data model unifies wire frame, surface and volumetric model through 0-3 dimensional cell. In this model, basic unit is 0-3 dimensional cell which is not restricted as simplex and can express any related dimensional geometric objects which get over the drawback that 3D spatial data model based on simple complex. After the construction relationship analysis of cell and cell complex, we deduce that there are boundary definition and adhering relationship among elements in the 3D spatial data model which makes sure the topological information completeness and uniqueness without redundance or loss for each element in model. And we also analyse three non-manifold adhering relationships in 3D space, which insures the correct expression of non-manifold solid.

5. Application example analysis

Taking the surface and underground 3D space around University City region of Xianlin, Nanjing as the research object, a 3D model with complicated geological environment and man-made buildings is established based on the new presented 3D GIS data model (Fig.2). In Figure 3, we express DEM data for surface model, stratum data for solid model and bore data for wire frame model and construct regional 3D geological model. Figure 3 illustrates different geology objects in the same scene being displayed in the form of wire frame model, surface model and solid model. Based on the topological information among elements in the model, set operation between 3D spatial objects are implemented, and corresponding geology analysis such as palisade map constructing (Figure 4), virtual digging (Figure 5) and tunnel analysis (Figure 6) are realized. These application instances verifies the effectiveness and practicability of 3D spatial data model proposed in this paper.

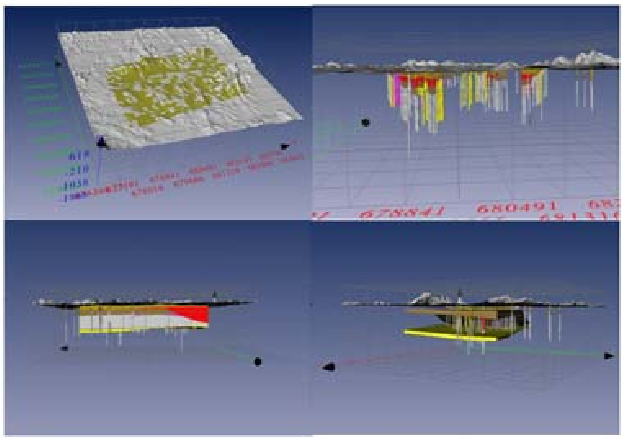

Figure 2. 3D geometric model of University City region of Xianlin, Nanjing

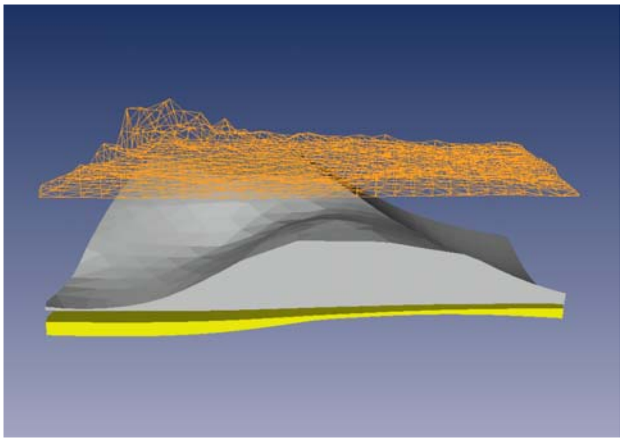

Figure 3. uniform of wireframe, surface and volumtric

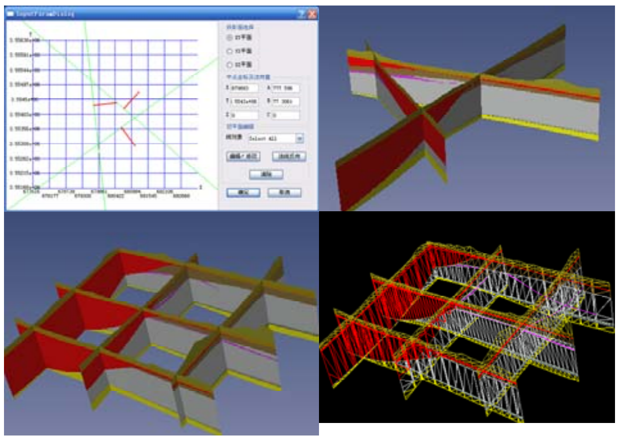

Figure 4. virtual slices and fences

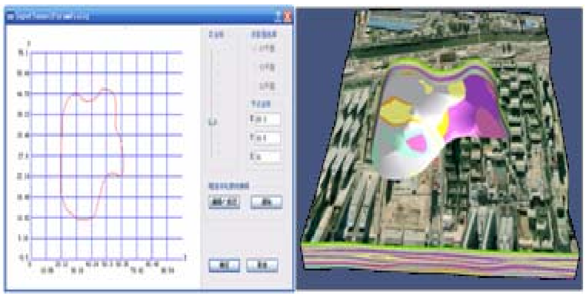

Figure 5. result of virtual digging

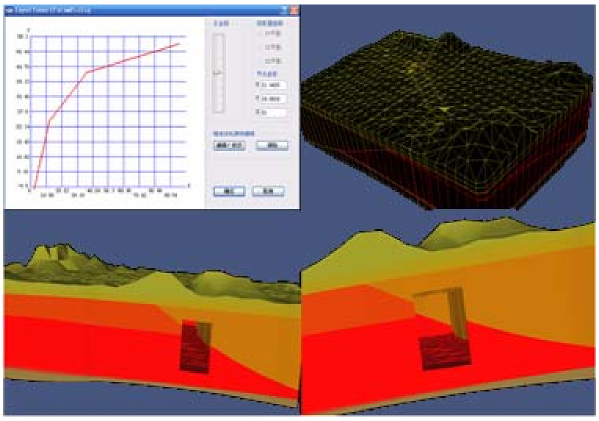

Figure 6. result of virtual tunnel excavation

6. CONCLUSIONS

In this paper, based on cell complex theory, we analyse topological characters and correlation of point, line, face and solid entity, and propose a 3D spatial data model. The model can express non-manifold solid object and has a better ability to express 3D solid with complicated construction. It can also unify wire frame model, surface model and volumetric model, which can satisfy the demand that the same geographical object may have a different expression in different application as well as different geographical objects may have different expression in the same application. Furthermore, it can be more freely to express 3D spatial objects without the limitation that basic elements must be simplex in traditional based 3D spatial data model based on simple complex theory. After the analysis of the adhering relationship between cell and cell complex, we can make sure that topological relationship among elements in model bears completeness and uniqueness. Lastly, prototype experiment based on practical data are fulfilled which validates the effectiveness and practicability of the 3D spatial data model proposed in this paper.

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REFRENCE

B I M., 1998. A Generic System for Integrated Modelling of Multi-Dimensional Spatial Data. Physics and Chemistry of the Earth, 23(3), pp. 285-2873.

Breunig M., 1999. An approach to the integration of spatial data and systems for a 3D geo-information system. Computers & Geosciences, 25(1),pp. 39-48.

Chen Jun, Guo Wei., 1998. A 3D Topological ER Model Based on Space Partitioning . Acta Geodaetica et Cartographica Sinica, 27(04),pp. 308-317.

Chen X., Ikeda K., Yamakita K., et al., 1994. Raster Algorithms for Generating Delaunay Tetrahedral Tessellations, International Archives of Photogrammetry and Remote Sensing 30, pp. 125-131.

Cheng Penggen, Gong Jianya, Shi Wenzhong, et al. 2004., Geological Object Modeling Based on Quasi Tri-prism Volume and Its Application. Geomatics and Information Science of Wuhan University, 29(07), pp. 602-607.

Cheng Penggen, Wang Chengrui, Gan Weijun, et al., 2005. A Hybrid 3D Data Model Based on Multi-DEMs and QTPVs and Its Application in Geological Modeling. Journal of Jilin University(Earth Science Edition), 35(06), pp. 806-881.

Frirsch D., 1996. Three-Dimensional Geographic Information Systems - Status And Prospects. International Archives of Photogrammetry and Remote Sensing, 31, pp. 215–221.

Guo Wei, Chen Jun., 1997. Formal Framework of 3D Spatial Features and Topological Property Based on Manifold Topology. Journal of Wuhan Technical University of Surveying and Mapping, 22(03), pp. 202-206.

Hou Enke, Wu Lixin., 2002. An Object-oriented Three-dimensional Topological Data Model Based on Component for Geology Modeling. Geomatics and Information Science of Wuhan University, 27(05), pp. 467-472.

Li Qingyuan., 1997. 3D GIS Topologic Relation and Dynamic Construction. Acta Geodaetica et Cartographica Sinica, 26(03), pp. 235-240.

Molenaar M., 1990. A formal data structure for 3D vector maps. Proceedings of EGIS'90, Amsterdam, The Netherlands, pp. 770–781.

Pilouk M., Tempfli, Klaus, et al., 1994. A Tetrahedron-based 3D Vector Data Model for Geoinformation. pp. 129-140.

Simon P., 1992. A Topological Model for a 3D Spatial Information System. Proceedings of 5th International Symposium on Spatial Data Handling, Charleston: McGraw Hill, 1(2), pp. 344-360.

Wang Yanbin, Wu Lixin, Shi Wenzhong. 2003., Apply Tetrahedrons to GTP Model and Resulted Spatial Model Improvement. Geography and Geoinformation Sience, 19(5), pp. 16-19.

Wu Lixin, Chen Xuexi, Che Defu, et al., 2007. A GTP-based Entity Model for Underground Real 3D Integral Representation. Geomatics and Information Science of Wuhan University, 32(04), pp. 331-335.

Wu Lixin, Zhang Ruixin, Qi Yixin, et al., 2002. 3D Geoscience Modelling and Virtual Mine System. Acta Geodaetica et Cartographica Sinica, 31(01), pp. 28-33.

Wu Lixin., 2004. Some Issues on Ture Three-Dimensional Geosciencs Modeling. Geomatics World, 02(03), pp. 13-18.