UNIFIED REPRESENTATION OF THREE DIMENSIONAL CITY MODELS

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ABSTRACT:

Three-dimensional (3D) representation and visualization of city environments are employed in an increasing number of applications from the areas of urban planning, city marketing, tourism, facility management and emergency response. Presently, existing 3D city models are scattered over different public and private sections in different models, different data formats, and different levels of detail. Because of these heterogeneous condition, the integrated management and public application become more difficult. This paper briefly present a conceptual description of unified 3D city models based on classification of various applications and analysis of common requirements. It facilitates the immediate data access, integration of different 3D geoinformation with different levels of detail and further 3D visualization, spatial query and analysis.

1. INTRODUCTION

City is the most densely distributed district of population, economy, technology, infrastructure and information on Earth. Because of the particular intuition and rich information characteristic in three-dimensional (3D) representation, analysis and simulation, cybercity GIS and cityscape models are employed for urban information representation in an increasing number of applications. Such as the well-known applications in the fields of architecture, urban planning and communications, as well as the city and regional marketing, virtual tour, location based services (LBS), emergency response(Altmaier, 2003; Zhu & Lin, 2004). However, existing 3D city models (3DCMs) are scattered over different public and private sections in different models, different data formats, and different levels of detail. Due to limited data availability, missing 3D spatial analysis functions, diversity of formats and processing systems, and insufficient access mechanisms, the integrated management and public application become more difficult. Unlike the 2D GIS represents multidimensional spatio-temporal phenomena in a standardized style of map, 3D GIS is difficult to realize unified 3D abstraction and representation for the complexity of real-world and diversity of person's psychological perception. Generally, 3D representation with different emphases is the basic reason for 3D GIS imbalance development.

Since 1990s, the study on 3DCM focus on hybrid models, such as TIN-Octree model(Shi, 1996), TIN-CSG model(Li, 1998; Sun, 2000), Octree-TEN model(Li, 1998; Li, 1997) and object-oriented integrative 3D data model(Gong, 1997; Bian, 2000). The hybrid models facilitate spatial analysis, but need simultaneously to store the raster and vector data, and the transformation between raster and vector is also hard to keep consistency. Based on three basic geometric elements of node, segment and triangle, Shi (2003) proposes a conceptual data model to represent complex 3D objects, whereas he does not take into account object aggregation. Since Cambray(1993) presented three-tiered architecture description for urban man-made artifacts, many researchers have proposed solutions to model description with levels of detail, such as the real-time creation of 3D LoD model and management with R-tree structure(Gruber, 1997; Zlatanova, 2000). For LoD concept of 3DCMs, the intensive study is required. Coors(1998) only consideres the demand of visualization and the LoD representation for single object. Köninger(1998) proposes the abstraction levels and LoD mechanisms from urban design perspective. Kolbe(2003) proposes the geometric, topologic and thematic modeling of 3DCMs. As the object-relational database has the mechanism to organize the individual data into some kind of objects, some researchers study the LoD description methods aided by technique of database(Kofler, 1998; Li, 2000; Gröger, 2004).

The abstract model of the OpenGIS Consortium (OGC) represents spatial objects by features. Features are abstraction of real world objects with respect to phenomena(Herring, 2001). With the release of GML3 in early 2003 also 3D objects, triangulated irregular networks (TINs), 2.5D raster data as well as explicit topologic relations became representable(Cox, 2003). GML3 is an XML-based abstract format for the concrete specification of application specific spatial data formats, which can be extended and specialized to a specific application domain; and it explicitly supports simple and complex 3D geometry and topology. However, it still lack the representation of thematic aspects, attributes, and interrelationships of the graphical objects. Applications that employ OGC web services for 3D geo-visualization are rare up to now. Most likely this is due to the fact that no specification for a real 3D portrayal services has been released by the OGC yet. To bridge the gap between 3D visualization using OGC data services and the portrayal service WTS, the SIG 3D of the Geodata Infrastructure North Rhine-Westphalia(GDI NRW) in Germany is working on the specification of a new dedicated 3D portrayal

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service called Web 3D Service (W3DS). In order to demonstrate and evaluate the possibilities of W3DS, the “Pilot 3D” has been started within the initiative GDI NRW. 3DCMs for Cologne and Leverkusen are built up. The application scenario provides function of interactive route planning and online ticket services. An increasing number of municipalities show great interest in standard for 3DCM.

Even some practices in model design, data production and quality control for 3DCMs are available, but the abstract and formal description for 3D city is still the critical issue to be solved. Based on the worldwide interviews carried out in 1999, the European Organization for Experimental Photogrammetric Research found that the 3DCM data content mainly consists of building, vegetation, transportation networks, public infrastructure and telecommunication. The building, traffic and vegatation are considered as the most important content(Fuchs, 1996). Danahy(1997) also considered that urban landscape, vegation and building are the most important ground objects. Indeed, a general strategy for transparently integrating vast amounts of data with multiple data types and multiple LODs has not put forward so far. The lack of unified data model has become the obstacle of development of 3DCM.

2. 3DCM APPLICATION CHARACTERISTCS

2.1 Application Classification

Many practical application show that data content definition of 3DCM application are based on the direction of application. Based on the worldwide interviews, Batty et al. (2001; 2002) have defined twelve different categories of application including emergency response, urban planning, telecommunication, architecture design, Facilities management, and so on. More general classification is also put forward (Bourdakis, 1998; Shiode, 2001). Traditional categories of 3DCM application usually depend on the function of application, but the classification are random and can’t be unified. Different group have great difference in understanding the details, and the application type are changing ceaselessly. Compared with the application of 2D spatial data, the application of 3DCM is a communicative process that relies on the encoded meanings that can be transferred from creators and organizers of information to users and receivers of the same information(Zhu & Lin, 2004).

The description of 3DCM for various applications should have different characteristics distinctively. For instance, the geo-visualization applications stress the display of real-world realistically and authentically, whereas analysis applications aim at the representation of real-world abstractively and compactly. Based on the study of different application characteristcs of 3DCM, three different categories can be defined as: (1) realistic visualization applications, (2) 3D spatial searching and path navigation applications, and (3) decsion making support applicaitons.

■ Realistic visualization applications

The 3D realistic visualization provides us some insights about the relationaship between virtual scenery and real world. The photorealistic 3DCMs convenient the observers to understand the city because they can more rapidly recognize the special element and adjust their sight according to spatial position and scale. Photorealistic models serve as an excellent base to represent entire man-made objects, realistic details and texture. Realated applications includthe urban designing & planning, environment simulation, visual impact assessment, tourism & game, education, and so on.

■ 3D spatial searching and path navigation applications

It should be noted that there is a great difference between pursuing realism and a recognisable virtual environment (VE). As the 3D spatial searching and path navigation applications, it is not necessary to imitate the reality and to create the realistic VE at such personal scale is still not feasible.The most important aspect of such application of exploring and navigating in a VE (both immersive and non-immersive) is orienting oneself. It is significant to be able to identify certain street or building. Therefore, the 3DCM must be more recognisable. Such applications take scenery structure and landmarks as the main content. Typical applications include location based services, emergency response services, etc.

■ Decsion making support applicaitons

The 3DCM applications clearly vary from one another. Among infrastructure such as water, sewerage, and electricity provision as well as road and rail network all require detailed 2D and 3D data for their improvement and maintenance. For example, the analysis of sight-lines for mobile and fixed communications is crucial in environments dominated by high buildings to secure a clear reception of signals. There are two necessary conditions for these applications, i.e. the analysis model and the 3DCM meetting certain applicational standards. Typical applications include the study of transmission of wireless signal, real estate analysis, market and economy forecast, etc.

2.2 Practical Requirements

■ Object-oriented representation and description

The unified 3D city models aim at creating better information processing enviroment in multi-dimensional space. 3D city models abstract all kinds of related objects as unified and formalized object in essence. The process and principle conform with the rule of urban enviroment cognition. Representing concepts as objects not only is convenient in consolidating our view on "concepts", such a representation can be readily implemented using an object oriented language.

■ Convenient to realtime rendering

with respect to virtual landscape and virtual city, B-rep models are convenient to decompose geographical phenomenon into bodies, faces, edges and vertices. B-rep models also facilitate the geometric description of complex spatial entities in urban areas. The triangle facet based models ensure the correct and quick display using 3D rendering engine of OpenGL and/or DirectX. Despite the complex data structure and the data update difficulties, B-rep methods provides a total topological decomposition and would be the favourite for 3D city modelling.

■ Representation with multiple levels-of-detail

While the real world is assumed unique, the way represented depends on the intended use. Thus, different applications that share interest in the same real-world phenomena may have different perceptions and therefore require different representations. Traditionally, the main advantage of LoDs is usful for the dynamic visualization of large scale of cityscape. Efficient analysis is another important reason of using LoD in a multifunctional 3D GIS.

■ CAD and GIS Integration

There is a growing tendency to integrate CAD and GIS in many applications. This can be explained by the fact that CAD and GIS systems provide information of the same real-world objects. Architecture, construction and engineering (AEC) designers are the major providers of large-scale 3D models with high degree of accuracy and details. AEC software provides all kinds of primitives to design and visualize the 3D models.

- Meetting the requirements of spatial query and analysis

Guided by application, 3DCM is used to support the geo-related decision-making. Most of the 3D spatial analysis function is extended from that of 2D GIS. Queries and analysis can be performed on 3D models to understand spatial distribution and relationships of specific geographic areas. Basic functions include shortest path computation, surface area and volume computation, 3D network analysis, etc. There are increasing demands for applying physical and chemical model to offer some value-added services, such as hydrological analysis, line-of-sight analysis, sunlight and shadows analysis, landscape analysis, spatial statistical analysis. In addition, it is important that developping some new methods for knowledge discovery with the help of spatial attribute data and other thematic data.

3. UNIFIED ABSTRACTION AND REPRESENTATION FOR THREE DIMENSIONAL CITY MODELS

The unified representation of city models strive for illustrating intrinsic or indispensable properties of three dimensional city. A conceptual unified description of 3D city based on classification of various applications and analysis for common requirements is proposed. The conceptual models provide theoretical proof for automatic data understanding and analysis, facilitating the consistency of spatial information acquisition and process.

3.1 Spatial Object Types

Based on the cognitive theory, spatial phenomenon is classified into two types: feature entity and Fields. Coverage (fields) is an association between a geometric description of entities and a set of attributes in OpenGIS specification. Compared with natural objects, the urban man-made objects are relatively regular in the terms of shape, distribution, and structure. This makes it possible for data model to abstract and represent urban spatial objects with some primary geometric elements. As shown in Figure 1, the point object, curve object, surface object, volume object, group object, LoD object, DEM and Texture object are then employed as the eight basic objects to describe urban spatial entities. The 3D spatial objects and the relationship between geometric element and object types are defined as below:

- DEM and Texture object are a representation of the continuous spatial phenomenon such as landscape surface and various geological layers.
- 3D point object, the cube object, has the simplest spatial extension (the 3D position, the azimuth and the box size) and sometimes special attributes such as CAD models in 3DS format. In the Cybercity, the tree models, the street lamp models, and any elaborate 3D CAD models are usually identified as 3D point objects with special attributes.
- 3D curve object, built up of connected line segments as a 3D points string, is mostly used to describe the pipelines and communication/electric power lines. The pipelines possess extensions in aperture size and are visualized as an assembly of cylinders and joint-elbows.
- The 3D surface object is composed of one or more facet primitives such as TIN or convex polygon. Lake and road surfaces and green land are represented as surface objects.
- The 3D volume object is bordered by special facets: for instance, the building is composed of the wall, the roof and the bottom. In the cybercity, there are two classes of body objects: one is the simple solid, namely the primitive entities such as the cube, the cylinder, the sphere, and so on. The other is the more complicated solid usually composed of series of primitive entities.
- The group object is a representation of different entities treated as an integral whole logically. For example, a campus consists of trees(point object), road(curve object), track and field playground (surface object) and buildings(volume object). Therefore, these different entities can be considered as group object.
- The LoD object is a multiscale representation for the objects mentioned above. The multiscale representation is one significant feature of the unified 3DCM. LoD models stand for a sequence of models with various resolutions and quality for the same object in a scenery. Each level of detail may include 2D vector, 2D texture images, DEM and 3D models.

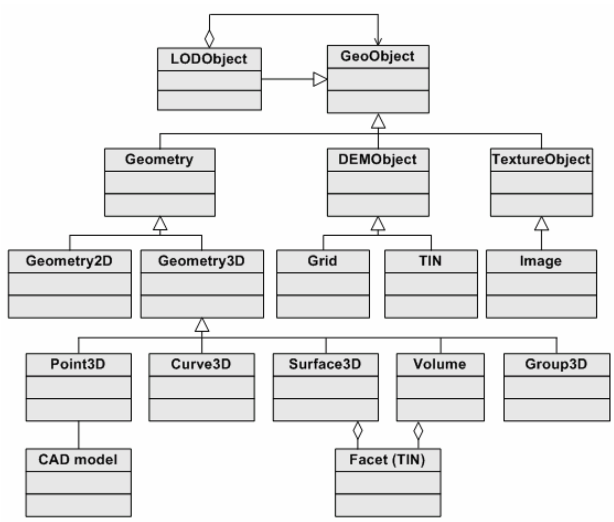

Figure 1. Conceptual description for unified 3D city models

3.2 Spatial Object Properties

3D city models provide attribute feature definition of 3D object. Because of extension in three dimensional space, 3D city models become even more complex and various in describing urban spacial characteristics. Traditional description such as position, size, shape in 2D space can not characterize the features of 3D object integrallty. Spatial object properties of 3D city model should describe from both spatial characteristic and visual characteristic. Spatial characteristic reveal the geometric structure of 3D city models and facilitate the model management and services in a mode of partition, category, or hierarchy. The 3D city model data emphasize more visualized representation and the visual characteristic reveal the psychological and esthetical characteristic of 3D city model. According to the characteristic of 3D city model object in application and practice, we define spatial object properties including geometric descriptions, material properities, textural properties, resolution, thematic information, model recognition, integrity and consistency.

- 3DCM for realistic visualization

Visual quality evaluation based reality criterion was used as the most important criteria for 3D city models. Reality criterion rely not only on the data content, but also on the rendering process. Such as the data integrality, detailed geometric precision, degree of reality for texture and orthoimage, as well as the enviroment mapping, shadow and scenery illumination.

- 3DCM for location and navigation

For location and navigation applications, the 3D city model provides an observer with definite sensory cues for orienting oneself. The core task of route guidance is to recognise the ground objects and to judge the spatial relationship. The 3DCM data content of location and navigation applications depends upon the principle of landmark design and reality criterion. Landmarks include the path, boundary, region, node and distinctive buildings. The degree of abstract for each object depends upon the weight of recognizable significance.

- 3DCM for analysis

The spatial analysis consist of morphology, relationship and action description for spatial object. For example, visibility analysis, sunlight and shadows analysis are the fundamental analytical methods in urban planning and design. The visibility analysis employes geometric characteristic of buildings and landscape, the law of sun movement should be fully considered in sunlight and shadows analysis. There is a significant interest in such models from telecommunications companies who require 3D urban morphologies to determine the ideal allocation for base stations. The simulation of high frequency wave propagation needs the 3DCM with high solutions, and vice versa.

3.3 Recursive LoD Aggregation

The LoD concept is one of the most significant feature of the unified 3D city models. To ensure spatial consistency between 3D models at different scales, three special level-detail-of-relations between features and their geometry are defined as follows: simple aggregation, hierarchy aggregation and hybrid hierarchy aggregation. The simple aggregation is that one object has a simple representation in all LoD. For example, a building has a simple block in LoD1, as a textured object with simple roof in LoD2 and as a highly detailed object with complex roof shape, detaild windows, entrances and ledges in LoD3. Hierarchy aggregation is that objects which are identifiable in one LoD are merged together in a less detailed LoD. The hybrid aggregation is that a LoD-aggregation combining both simple aggregation and hierarchy aggregation, as shown in Figure 2. Therefore, we can consider the handling of large amounts of 3D city models in the pyramid index manner and the R-tree structure. To give LoD object a appropriate definition, we should take into account such factors as shape identification, structure definition, consistency, balance between geometry and texture. Shape identification and structure definition are two important factors for LoD definition. The former can satisfy the demand for geographical object identification. The latter can ensure consistency of data definition and data representation, which is the base of data representation standardization.

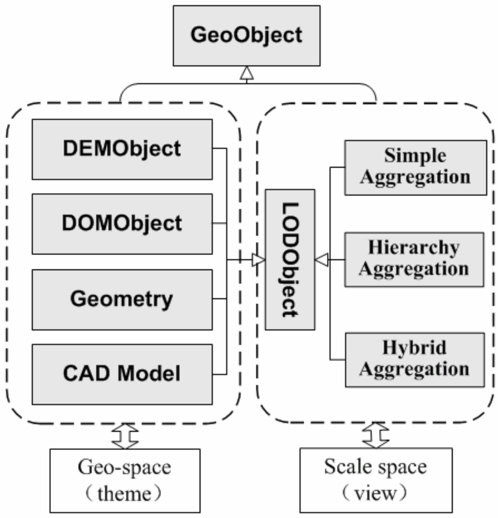

Figure 2. Recursive LoD aggregation

4. CONCLUSION

This paper briefly present a conceptual description for unified 3D city models based on the classification of various applications and analysis of common requirements. The unified three dimensional city models provide a compatible framework to represent multiple source and multiscale data. Besides support for interactive and dynamic 3D visualization, further query and spatial analysis and other GIS operations, it facilitates the immediate data access, integration of different three dimensional geo-information with different levels of detail, including raster data like the digital elevation model (DEM), the digital orthoimage, texture images and vector data like 3D building models. The abstract model of 3D city we proposed is compatible with OGC specification, but is easier to extend. All of these work lay a solid foundation for the consistency of spatial information acquisition and process, and for transparently integrating vast amounts of spatial data with multiple data types and multiple resolutions.

REFERENCES

Altmaier A, Kolbe T H., 2003. Applications and Solutions for Interoperable 3d Geo-Visualization. Fritsch D, Eds. Proceedings of the Photogrammetric Week 2003. Stuttgart: Wichmann Verlag.

Batty M, Chapman D, Evans S, et al., 2000. Visualizing the City: Communicating Urban Design to Planners and Decision-Makers[EB/OL]. http://www.casa.ucl.ac.uk/ /working_papers/paper26.pdf.

Batty M, Smith A., 2002. Virtuality and cities: Definitions, geographies, designs. In:Peter Fisher and David(Eds.), Virtual Reality in Geography, Taylor & Francis, London, pp. 270-291.

Bian Fu-ling, Fu Zhong-liang, Hu Zi-feng, 2000. An Object-oriented Integrative 3D Data Model. Journal of Wuhan Technical University of Surveying and Mapping, 25(4), pp.295-297.

Bourdakis V. Utilising Urban Virtual Environments. Proceedings of Europ IA98, Paris, 1998.

Cambray B., 1993. 3D modelling in a geographical database. Proceedings of the 11th International Conference on Computer-Assisted Cartography, Minneapolis, USA, pp. 338-347.

Coors V., Flick S., 1998. Integrating Levels of Detail in a Web-based 3D-GIS. Proceedings of the 6th ACM Symposium on Geographic Information Systems (ACM GIS 98), Washington D.C., USA.

Cox S., Daisy P, Lake R, et al., 2003. OpenGIS Geography Markup Language (GML3). Implementation Specification Version 3.00, OGC Doc. No. 02-023r4.

Danahy J., 1997. A Set of Visualisation data needs in Urban Environmental Planning and Design for Photogrammetric Data. Proceedings of Ascona Workshop'97- Automatic Extraction of Man-Made Objects from Aerial and Space Images, Monte Verita, Switzerland, pp. 357-365.

Fuchs C., 1996. OEEPE study on 3D-city models. Proceedings of the Workshop on 3D-City Models(Oct. 1996), Bonn, Germany.

Gong Jian-ya, Xia Zong-guo, 1997. An Integrated Data Model in Three Dimensional GIS. Journal of Wuhan Technical University of Surveying and Mapping, 22 (1), pp.7-15.

Gröger G, Reuter M., 2004. Representation of A 3-D City Model in Spatial Oject-relational Databases (Jul. 2004). XXth ISPRS Congress 2004, Istanbul, Turkey.

Gruber M, Kofler M, Leberl F., 1997. Managing large 3D urban data base contents supporting photo-texture and levels of detail. Proceedings of the Ascona Workshop '97: Automatic Extraction of Man-made objects from Aerial and Space Images. Basel: Birkhäuser Verlag, pp. 377-386.

Herring J., 2001. The OpenGIS Abstract Specification, Topic1: Feature Geometry (ISO 19107 Spatial Schema). Version 5.OGC Document Number 01-101.

Köninger A, Bartel S., 1998. 3D-GIS for Urban Purposes. Geoinformatica, 2(1), pp. 79-103.

Kofler M, 1998. R-tree for Visualizing and Organizing Large 3D GIS Database[D]. Graz University of Technology, Austria.

Kolbe T H, Gröger G., 2003. Towards unified 3D city models. Proceedings of the ISPRS Commission IV Joint Workshop on Challenges in Geospatial Analysis, Integration and Visualization II, Stuttgart, Germany.

Li De-ren, Li Qing-quan, 1997. Study on A Hybrid Data Structure in 3D GIS. Acta Geodaetica et Cartographica Sinica, 26 (2), pp. 128-133.

Li Qing-quan, Li De-ren, 1998. Research on the Conceptual Frame of the Integration of 3D Spatial Data Model. Acta Geodaetica et Cartographica Sinica, 27(4), pp. 325-330.

Li Jun, Jing Ning, Sun mao-yin, 2000. Visualization with Level of Detail at Multi-Scale in 3D GIS. Computer Science, 27(9), pp. 82-85.

Shi Wen-zhong, 1996. A Hybrid Model for 3D GIS. Geoinfomatics, (1), pp. 400-409.

Shi Wen-zhong, Yang Bi-sheng, Li Qing-quan, 2003. An object-oriented data model for complex objects in 3D geographic information systems. International Journal of Geographic Information Science, 17 (5), pp. 411-430.

Shiode N., 2001. 3D urban models: recent developments in the digital modelling of urban environments in three-dimensions. GeoJournal, 52 (3), pp. 263-269.

Sun Min, Chen Jun, Zhang Xue-zhuang, 2000. A 3DCM Data Model Based on Surface Partition. Acta Geodaetica et Cartographica Sinica, 29(3), pp. 257-265.

Zhu Qing, Lin Hui, 2004. CyberCity Geographic Information System. Wuhan: Wuhan University Press, pp. 199-203.

Zlatanova S., 2000. 3D GIS for urban development[D]. Enschede: The International Institute for Aerospace Survey and Earth Sciences (ITC), The Netherlands.

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