GeoScope: Full 3D Geospatial Information System Case Study

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Abstract Aiming at the integrative management and comprehensive applications of large-scale 3D geospatial information covering the full 3D space of a city, this paper briefly introduces the design and implementation of a full 3D GIS platform: GeoScope, which provides a professional solution for the massive full three-dimensional geospatial data integration, management, analysis, visualization, and applications. GeoScope is characterized by: (1) extendible software architecture based on the hierarchical message bus, facilitates multimodal integrative applications of 2D GIS and 3D GIS; (2) unified 3D city models, support multiscale semantic representation of outdoor & indoor and aboveground & underground 3D objects; (3) high-efficient 3D geospatial database engine, supports integrated management of massive 3D geospatial data for real-time applications; and (4) high-performance visualization engine exploiting the massively parallel computation architecture of modern GPUs, supports real-time realistic rendering of large-scale complicated 3D geospatial environments. The successful pilot application of GeoScope is also illustrated with the 3D city models of 8494 km² of the whole Wuhan City, the largest city in middle China.

Keywords 3D geospatial information system; 3D city models; database engine; visual analysis; levels of detail; semantic relationship

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Introduction

Cities are increasingly becoming centers of economic growth, people's lives, and geopolitical relations. Because of the limitation of nonrenewable land resource, more attention has been paid to the development of underground and aboveground urban spaces. It is therefore undeniable that the need for 3D geospatial information is increasing rapidly, especially in Architecture Engineering and Construction (AEC), as well as in 3D urban planning & development, in which modeling full 3D space including both aboveground and underground, outdoor and indoor environments are needed to provide an efficient total solution. At the same time, a 3D city model must...
also be increasingly independent from any application, i.e., the data management should not be coupled tightly with any software, so that the data and related software such as the database and visualization engines can be used for a variety of tasks.

However, there is still no ideal solution for such practical requirement. Currently, no standards exist for harmonization of geospatial information to include the (above and on) ground as well as underground objects. For example, the OGC standards CityGML still need thematic extensions, i.e., application domain extensions (ADE), for not only the subsurface geological and geotechnical objects, but also some above and on ground objects, such as the Subsurface ADE, GeoBIM ADE and Utility Networks ADE. In practice, more and more virtual globes designed for public user web-based or desktop applications are available, like Google Earth and Microsoft Bing Map, as well as SkylineGlobe (www.skylinesoft.com). Though these kinds of tools are widely used for 3D geospatial information visualization services, there are still more people trying to use these kinds of tools for professional purposes. The commercial 3D GIS software platforms for professional applications can be classified into three types: (1) the 3D enhancements of traditional 2D GIS, such as both ArcGlobe and ArcScene, which enable the creation and maintenance of Z-aware GIS features (http://www.arcgis.com/home/); the RealSpace GIS technology of SuperMap GIS 6R, which announced integrated 2D GIS with 3D GIS (http://www.supermap.com/). Such kinds of 3D extensions are useful for macroscopic landscape modeling or detailed limited area cityscape modeling. (2) 3D GIS developed from 3D modeling of geology and mining, like GoCad (http://www.gocad.org), which focused on the 3D subsurface modeling. (3) 3D GIS developed from a traditional 3D visualization engine, like VRCITY based on virtool (http://www.crystalcg.com/), which enables a clear three-dimensional visual experience for a local cityscape. The current situation of 3D city modeling is that the practical tasks still cannot be fulfilled by any kind of stand-alone 3D GIS software, due to the limitation of simple data models and structures and related operating functions performance issues. Hence, this situation stimulated the initiation of a full 3D geospatial information system, that integrates massive, heterogeneous geospatial information and georeferenced information to represent the 3D geometry, appearance, topology, and semantics of man-made objects and natural features.

The following sections introduce the design and implementation of a 3D GIS platform software, GeoScope, which proposes a full 3D data model and structure that explicitly represents the 3D geometry and topology as well as semantic hierarchy.

1 Unified 3D GIS models and extendible software architecture

According to object-oriented data modeling, geo-objects in a three-dimensional space can be defined as continuous fields and/or discrete features. Many initiatives have studied modeling the 3D concepts of geo-data in information models driven by applications such as facility management, urban planning, 3D cadastre, noise modeling, flooding, disaster and crisis management. The geographic world is complex; it does not follow the rules that are built into computer databases. Thus, the rules need to be complex when used to represent the geographic world. 3D topological and semantic structures, which are significant for description, analysis, visualization of the surface, and near-surface of the Earth, are not standardized in many GIS even the CityGML. Moreover, in order to ensure the high-performance operation of 3D GIS database, various traditional application-oriented 3D geospatial data models and structures have to be optimized and unified. As shown in Fig.1, the integrative 3D spatial data model is first proposed for the conceptual representation of a typical full 3D space in three layers: geometry, scale and semantics. The LoD (Levels of Detail) concept is one of the most significant characteristics of the unified 3D GIS model. To ensure spatial consistency between 3D models at different scales, three special level-detail-of-relations between objects and their geometry are defined as follows: simple aggregation (such as the LoD1 through LoD4 defined in CityGML), hierarchy aggregation and hybrid hierarchy aggregation. Therefore, we can consider the handling of large amounts of 3D GIS data in a more efficient pyramid index manner and/or the R-tree structure.
This conceptual model defines a unified framework of the full 3D space within the same 3D coordinates system and unified data structure, which supports various high-performance databases and 3D visualization engines. The unified 3D geometrical and topological data structure is designed as illustrated in Fig.2,
supporting standardized data access as well as operation of continuous or discrete 3D objects. This geometry model can support not only realistic visualization applications, but also complicated 3D spatial analysis including geometric measuring, topological and semantic analysis.

Based on the unified 3D GIS model, an extendible and high-availability software architecture based on the hierarchical message bus (Fig.3) is designed to facilitate the flexible loading or unloading of GIS functions, as well as multimodal integrative applications of 2D GIS and 3D GIS. Especially, this architecture enables the loose couple of 3D geospatial data and GIS functions, which could maximize the usefulness of a 3D GIS.

![Hierarchical message bus-based software architecture](image)

**Fig.3** Hierarchical message bus-based software architecture

### 2 3D geospatial database engine

In order to support a variety of 3D application tasks, a high-efficiency data management—indeed from any application—urgently requires a 3D geospatial database engine (SDE). The SDE is an engine layer residing between the database and the GIS functionality (query, analysis and visualization). As shown in Fig.4, this engine provides three kinds of data management system modes: stand-alone files system, RDBMS-based database system and parallel databases system. The high-efficiency of the SDE relies heavily on key technologies such as the hierarchical 3D spatial index, multilevel caches, multi-thread dispatch and asynchronous communication and transmission. The core issue of SDE is the consideration of the distinctive data granularity diversity of various 3D object entities through the whole pipeline of data processing, from the disk storage to CPU cache and GPU frame buffer. Based on the analysis of data granularity and structure differences among the disk storage, memory management and rendering cache, a new data organization method is proposed to unify the granularity and structure in...
disk, memory, and display cache, which facilitates more efficient storage management and dynamic dispatching of large volumes of 3D geospatial data.

Based on this database, a precise synthetic environment and high-performance 3D geospatial analysis functions are developed for exploiting the inside (utilities, furniture, elevators, walls, doors, windows, and structural details), outside (aerial utilities, full city blocks of 3D detail, road access), and under (underground pipeline, subway) the full 3D space. There are three kinds of functions including (1) fundamental 3D algorithm, like intersection, point set query, discretization algorithm and Boolean operation. (2) general analysis functions, like 3D metrical operators, network analysis and statistic analysis. (3) spatial decision support functions, like suitability evaluation, sunlight analysis, geologic analysis, visual analysis (Fig. 5).

![3D geospatial database engine](image)

**Fig. 4** 3D geospatial database engine

**Fig. 5** 3D viewshed analysis result

### 3D visualization engine

Interactive 3D visualization is an essential function of 3D GIS, the performance of 3D GIS is also the decisive factor in successful applications. As shown in Fig. 5, the interactive 3D visual analysis is required to see the results. The real-time response of analytical computing results rendering is usually necessary. For such kind of real-time applications, a high-performance visualization engine exploiting the massively parallel computation architecture of modern GPUs was developed to support real-time realistic rendering of large-scale complicated 3D geospatial environments.

As shown in Fig. 6, this engine consists of three functional modules: efficient out-of-core data manager, data optimizer with accelerating algorithms, and renderer with advanced GPU shader. Each module runs in separate threads to exploit the power of multi-core CPUs. Thus, complicated real-time shadow generation of large-scale environments and transparency render could be realized by means of this visualization engine.

### 4 Pilot applications in urban planning management

As shown in Fig. 7, full 3D GIS could provide a total solution for more efficient data sharing and better data integrity across the entire lifecycle with a
comprehensive approach to create a sustainable world that balances economic and engineering demands with environmental and social needs. Based on such kinds of multidimensional visualization platforms, spatial decision-making support tools and spatial imagination and communication tools, urban planning and design at a city-wide scale can be finished more scientifically with high efficiency. In the meantime, a 3D GIS development, a comprehensive data production standard named “Technical specification for three dimensional city modeling” was compiled and issued on Nov. 17, 2010.

Based on a solid technical foundation, the Wuhan city 3D GIS covering the whole city area of 8494km², has been established and widely used for more than 200 projects, including examination and approval of construction schemes, urban planning, population management, house property management, and so on. Fig. 8 shows local 3D city models with good geometric accuracy and fidelity. A typical case proves that the application of 3D GIS could dramatically improve the efficiency of decision making over traditional 2D
GIS applications from several weeks to several days.

Fig. 8 A screenshot of 3D city models of Wuhan, China

5 Conclusion and future work

The full 3D geospatial environment is complex. The above-mentioned GIS platform GeoScope provides just the kind of scientific solution that supports a variety of applications with 3D representation, such as urban planning and design, facility management and maintenance, crisis management, and so on, at the scale of the whole city. Further development of GeoScope will enhance its distributed geocollaboration performance, as well as extend the integrative representation of dynamic 3D spatio-temporal phenomena, i.e., to support the creation of parallel computer mapping of the real world. Of course, building a parallel and augmented virtual geographic environment still faces great challenges in creating a fully automated, real-time and accurate 3D data acquisition, seamless and interoperable massive database management system.

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