Design and Implementation of 3D Model Database for General-Purpose 3D GIS

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Abstract To improve the reusability of three-dimensional (3D) models and simplify the complexity of natural scene reconstruction, this paper presents a 3D model database for universal 3D GIS. After the introduction of its extensible function architecture, accompanied by the conclusion of implicit spatial-temporal hierarchy of models in any reconstructed scene of 3D GIS for general purpose, several key issues are discussed in detail, such as the storage and management of 3D models and related retrieval and load method, as well as the interfaces for further on-demand development. Finally, the validity and feasibility of this model database are proved through its application in the development of 3D visualization system of railway operation.

Keywords 3D model database; 3D GIS; 3D modeling; CAD models

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Introduction

The accurate and efficient reconstruction of 3D virtual geographic environments has always been a focus of research in 3D GIS field. In general, most methods for rapid modeling can be divided into two categories: one is the use of existing geospatial techniques like LIDAR and digital photogrammetry to quickly acquire original 3D geospatial data, which is subsequently processed in a lot of complex editing work, while the other is based on interactive modeling from reusable computer-aided design (CAD) models, which may be extracted from constructed projects or imported from CAD modeling software.\cite{1-3}

Nowadays, the key to the promotion of the low efficiency of modeling in scene reconstruction for universal 3D GIS lies in the improvement on the reusability of existing models like 3D CAD models, just as 2D symbolization plays an important role in the enhancement of information communication and acceleration of mapping.\cite{4} Especially, there is an increasing trend of CAD’s combination with 3D GIS because of its powerful modeling and editing capabilities. For example, CAD models of individual buildings can be used to make up the shortage of measured survey and terrestrial photogrammetry, which may have difficulty in obtaining complete building information due to environmental restraints like occlusion between objects.\cite{5} Besides, CAD models can represent more complex structure, finer material features, and higher level of details of entities. Several popular formats of them and related introduction are listed in Table 1.
Table 1  Introduction of five popular formats of CAD models

| File format | Software / Program | Creator | Graphic information contained | Generality |
|-------------|--------------------|---------|-------------------------------|------------|
| DXF         | AutoCAD            | AutoDesk| Geometry; Color               | Good       |
| 3DS         | 3DSMAX             | AutoDesk| Geometry; Material; Texture; Lighting; Animation; Camera | Much better|
| FLT         | Multigen           | Multigen| Geometry; Material; Texture; Lighting; Animation; Camera | Much better|
| OBJ         | Wavefront          | Wavefront| Geometry; Material; Texture | Common     |
| WRL         | VRML              | Silicon Graphics| Geometry; Material; Texture; Lighting | Better     |

In practice, simple block models, derived from 2D map data in regular modeling, such as building extrusion without roof, are available from graphic designing and planning softwares like AutoCAD. Another type of model, mesh model, used widely in 3D scene visualization and spatial analysis, generally contains detailed geometrical and simple topological information.[6,7] Fig.1 shows a 3D mesh model in a 3DS format of a Chinese building.

Fig.1  3D solid and wireframe modes of a building

One proposal of integration of CAD to 3D GIS is to establish 3D model database based on library approach to meet the changing needs of model reuse for general-purpose 3D GIS.[2] Moreover, it is wise to enrich and enlarge the database in batches of modeling, recommended as the strategy of model collection. In this approach, the idea of reusability suggests the possibility for 3D models, especially complex and detailed models, to be completely extracted from reconstructed scenes and stored in an open data base, which other modelers can be allowed quick and easy access to for their own modeling need. This is greatly desirable and feasible, the moment Internet has permeated many fields of social development, where a number of various models are available now for free or for a fee.[9]

In this integration, there are several critical issues that needs to be considered: (1) Modelers have to link imported models with given attributes in GIS, for any dataset of GIS is composed of spatial data associated with nonspatial properties that original CAD models are lacking in. (2) The data amount of single CAD model in pursuit of high level of details is often fairly large, while GIS needs to deal with a lot of such entities at the same time. Then, it is considered desirable to simplify the original model or reorganize its storage structure of 3D graphic information for the balance among rendering efficiency, data scheduling, and graphic quality in 3D GIS.[2,8] (3) Most CAD models are independent in 3D GIS and cannot be used to present an object’s temporal behavior on which 4D GIS is given more and more attention to.

Aiming at the design of 3D model database for general-purpose 3D GIS and the solution of critical issues mentioned above, this paper presents its ability to import/export existing CAD models in popular formats, store similar models in form of specific groups, and thereby reuse them in different application that reduces a great deal of time investment in modeling. Section 1 gives the function architecture of this database and is followed by details of the storage and management of database in Section 2. The method of model retrieval and load is discussed in Section 3. At last, its implementation and application in railway visualization is illustrated.

1  Function architecture of 3D model database

1.1  Data hierarchy of models

3D models can be graphic or image models for the description of shapes, positions, orientations, and sizes of geographical entities, as well as the expression of aspects of their spatial-temporal distribution and dynamic changes.[4] It can be concluded in the following respects that most of them included in a complicated scene often form an implicit spatial and temporal hierarchy based on fundamental models.

- The distribution of independent models in accor-
dance with fixed rules in one piece of scene. Most of these rules can be parameterized. For example, a polygonal vegetation area may be covered by several types of trees and bushes of different sizes, distributed in regular rows and columns, or random positions with defined density to lighten inaccurate modeling workload (Fig.2).

The composition of submodels or component models in one whole model. Not only these submodels can just be grouped with different spatial positions, scales, and directions to compose an “assembly model” or a geometrically regular model like lofting, but also one gray model can be bind with corresponding texture submodels to enhance the realism of landscape (Figs. 3 and 4).

The combination of state models to present an object’s temporal behavior. In general, the types of objects’ behavior fall into two categories: definite behavior with known states in discrete time like turnout’s switch and uncertain behavior in response to real time events, such as collisions [10]. CAD models are generally stationary and thus applied more in former presentation. In a broad sense, the transition of levels of detail (LOD) can also be regarded as a type of behavior just influenced by human’s sight but not real world.

1.2 Function architecture

Considering the hierarchy stated above, the paper presents the function architecture of 3D model database for general-purpose 3D GIS (Fig.5). It mainly includes three parts: import and export, interactive visualization, and database management to be discussed in Section 2.

- Format conversion. As stated previously, it is necessary to simplify the model or reorganize 3D graphic information contained in CAD model. However, complete automated simplification is time-consuming. One feasible way is to store vertex’s properties in triangle-strip structure stored in user-defined format, which can greatly improve rendering efficiency in 3D GIS.

- Data encryption/decryption. To protect confidential model data from theft, users can choose to encrypt the model file and decrypt it in the proper time.

- Batch import/export. It relieves greatly the submission to database of a batch of models, such as a large file directory of classifiable model files by their names, to establish automatically a tree structure of
classification. On the contrary, users can also export a specific class of models ranging from formats or features to share with others.

- Perspective view. It is for browsing of model’s contents stored in converted files in solid or wireframe mode.
- Thumbnail preview. A model’s thumbnail in favor of later scanning is created at the time of its initial visualization, with its image data stored in model format or standard image format like jpg/jpeg. Besides, users can choose a proper vision angle in perspective view for thumbnail re-creation.
- Animation/exhibition. Smooth transitions of selected models for exhibition can be connected by simple rotation or other special animation effects like bounce. This is the same as a series of 2D pictures made into sliders smoothed by shutter or mosaic effect.

2 Database design

Considering the function architecture of this model database presented in Section 1, its storage structure can be divided into two parts: model files and information tables (Fig.6). The former may be a group of one whole directory and its subdirectories of imported models in original or converted files. The models’ given properties from manual attribute recording are stored in the attribute table, while their class and state information can be obtained from the class table and state table, recorded when each model’s category and state models’ package is customized. These tables can be efficiently established and queried in commercial database like SQL Server.

![Fig.6 Storage structure of database](image)

The detailed information of three tables is listed as follows (Tables 2, 3, and 4). They are linked by related fields. For example, if one model’s MID is known and other models in the same state package are wanted, users can fast retrieve the model from attribute table by MID and its linked SGID, which can be used to acquire other state models in state group.

### Table 2 Detailed structure of attribute table

| Field name | Field type | Field description |
|------------|------------|-------------------|
| MID        | INTEGER    | Model’s ID         |
| CID        | INTEGER    | ID of class the model belongs to |
| MNAME      | STRING     | Model’s name       |
| FORMAT     | INTEGER    | Format of model file |
| ATTRIS     | STRING     | Linked attribute   |
| SGID       | INTEGER    | ID of state group the model is packed in |

### Table 3 Detailed structure of class table

| Field name | Field type | Field description |
|------------|------------|-------------------|
| CID        | INTEGER    | Class ID           |
| CNAME      | INTEGER    | Class name         |
| SUBNUM     | INTEGER    | Number of included subclasses |
| SUBIDS     | BLOB       | Included subclasses’ ID datasets |

### Table 4 Detailed structure of state table

| Field name | Field type | Field Description |
|------------|------------|-------------------|
| SGID       | INTEGER    | ID of state group |
| SGNAME     | STRING     | Name of state group |
| SDESC      | STRING     | State description |
| MIDS       | BLOB       | packed models’ ID dataset |

3 Model retrieval and load method

Currently, most of 3D model databases provide the function of text-based model search for key words in filenames, formats, attributes and so on, which cannot work in some cases, such as when objects are not annotated or annotated with unspecified or derivative keywords. Therefore, the content-based multimedia retrieval method is emerging for models’ shapes analysis as well as automatic classification and identification. The 3D model search engines adopting this technique allow the input of 2D sketches or photos instead of text (Fig.7), which accord with user’s direct impression of objects. One of its important procedures is to establish 2D and 3D geometrical shape feature index from feature extraction and match them according to similarity measurement. However, it is not appropriate in practice for the efficiency of its search for a batch of models instead of a single model cannot meet the needs of retrieval and load in large-scale scene reconstruction.
In pursue of fast and automatic retrieval to make model load easy, the further-development interfaces of the 3D model database are given in the paper, including export/import interface, fuzzy query-by-text interface, and interactive selection interface. For example, developers are suggested first to design their own text files for configuration of models’ geometrical and attribute information and then submit them to the database, waiting for the corresponding result set of models from automatic search by key words through query interface. Afterward, the pattern for interactive selection of satisfactory models from the result set can also be customized via selection interface. Next, all selected models need to be loaded to the scene from the database by export/import interface and grouped in different ways described in Section 1. Suppose the real-time simulation of water pipe. Followed by each valve’s correct placement and orientation in stationary modeling, its on-off state model package can be retrieved to guide its open/ close behavior. The whole application process stated above is expressed in Fig.8.

4 The implementation and application

This research was undertaken in a 1024 Mb RAM 2.26 GHz Inter Pentium PC with an ATI MOBILITY FireGL 3200 graphics card. The operation system is Windows XP, and three information tables mentioned in Section 2 are stored in Microsoft Office Access 2003. The import and export interface (input and output interfaces) supports the conversion from formats of 3DS, DXF, and WRL to SUP, which adopts strip storage of vertices. Its file structure is listed in Fig.9.

| File header | ID of Format version | Scope of all models’ boxes | Origin coordinates |
|-------------|----------------------|-----------------------------|--------------------|
| File body   | Num of models        | Scope of each model’s box   |                     |
|             | Num of vertices      | List of vertices’ coordinates|                   |
|             | Num of normal vectors| List of normal vectors      |                     |
|             | Num of texture coordinates| List of texture coordinates|                |
|             | Num of material      | List of each material’s data|                    |
|             | Num of lights        | List of each light’s parameters|                |

The main UI of this 3D model database is designed consistent with resource manager in Windows, which can be easily familiarized by the majority of users (Fig.10). It is divided into a tree view for classification, a list view for thumbnails, two perspective views in solid and wireframe mode, and an attribute editing view.

In the development of 3D visualization system of railway operation, the model database was successfully applied in modeling work. In general, the models contained in railway scene can be classified into several types as follows:

**Lofting models.** In general, loft function only re-
quires a section surface to scan along a path to construct a model. Here, sections of railway bed (including rail), bridge body, and tunnel are quickly retrieved from the database through query interface (Fig. 11(a)).

**Independent models.** Turnout, intersecting crossover, and signal lamp fall into this category (Fig. 11(b)). Their positions are all obtained from the configuration file, while the orientations need to be computed. For example, the signal lamp’s orientation is equated to the closest railway for their parallelism. Besides, their behavior needs to be considered. Compared with two kinds of a turnout’s state, an intersecting crossover contains eight as each of its four nodes may be open or closed.

**Parameterized models.** The catenary system near the railway station can be regarded as a composition of two poles and many units distributed along the line between the poles (Fig. 11(c)). In a similar way, a bridge is held up by a number of piers at fixed intervals parallel with the bridge body.

## 5 Conclusion

The main research contributions are (1) extensible function architecture in support of spatial-temporal hierarchy of models and (2) fast and automatic load method from the database to the scene with the help of further-development interfaces. Such kind of 3D model database would become more and more important in the modeling of 3D GIS.

![Fig. 11 Models in the railway scene](image-url)

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