Component based 3D GIS software design for the urban planning

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Abstract

An increasing number of users of GISs have been asking for 3D extensions for years. One popular approach for modeling 3D geo-features is to create 3D CAD model manually. In particular, manual 3D geo-feature modeling approach provides a high quality of visualization for 3D GIS features. However, this approach can be time consuming to generate 3D models being created manually and requires high costs.

The design philosophies of our proposed 3D GIS software components are interoperability, standardization, reusability, adaptability and performance. We introduce a novel-modeling concept; so-called, Rule-based modeling (RBD) that can model 3D geo-features using 2D profiles and 3D feature attributes. By using rule-based engine and model library, we are able to create 3D geo-features automatically. RBD component combines a synthetic modeler with efficient LOD (level-of-detail) control for real-time rendering.

In addition to, describing the details of our component, we present the comparison result between manual modeling and proposed rule-based modeling in terms of the following criteria: input data domain, interoperability, reusability and modeling cost.

1 Introduction

The 2D GIS which is based on two-dimensional map, is serviced in many fields related to client/server application as well as web-based services. However, current three-dimensional GIS(3D GIS) software is not entering practical step for reason of the lacking of 3D data construction, system analysis and development related.
The advantages of 3D GIS are providing various 3D spatial analysis operations, such as terrain surface analysis, visibility computation and geodesic shortest path computation. However, it is clear that much time and expenses are required to construct 3D dataset exactly. Therefore, it is the best way that we should use existing constructed 2D GIS data with minimum 3D attributes.

In this paper, we present the design method for scene modeler component that can do three-dimensional modeling by using the existing 2D-based GIS data. The problems can be summarized in three points: building 3D models, storing them, and providing an interface to visualize and manipulate them efficiently. To develop a three-dimensional GIS (3D GIS) software, it requires technologies of various research fields such as spatial data processing and analysis, remote sensing, computer graphics and virtual reality. In 3D GIS software, 3D geo-feature modeling and visualization are important portions of various GIS applications. Currently, it is in step to provide interoperability that is presented by international standard organizations, such as ISO(International Standard Organization) or OGC(Open GIS Consortium) in 3D GIS research fields. It requires the standardization researches related to 3D geometry model for 3D GIS.

We present design and analysis results of scene modeler component that can do modeling 3D models according to the level-of-detail requests at the 3D scene rendering phase.

2 Related Work

Recently, component-oriented programming is receiving increasing amounts of interest in the software engineering community. The goal is to create a collection of reusable components that can be used for component-based application development. Application development then becomes the selection, adaptation and composition of components rather than implementing the application from scratch [9, 4].

Bachmann et al[1] presented the Architecture Based Design (ABD) method. The ABD method provides structure in producing the conceptual architecture of a system. The ABD method is one example of how understanding of architecture and the influences that drive architecture design can be exploited to help the development process. They introduced the ABD method which is based on the functional decomposition, business requirement/realization and software template use.

Murer[10] introduced the method to motivate for a broader interdisciplinary discussion about components including technical aspects, but also organizational, social and even marketing aspects. He investigated these various aspects to develop the concept of a software engineering environment capable to face the outlined challenge. The primary mechanism for reuse in component architectures is component composition.

Outhred[11] indicated to the difficulty for programming for evolution or adaptation by using Microsoft's COM(Component Object Model) that is representative
component-based frameworks. Currently, it is not definitely defined the 3D GIS but the GIS system is developed according to each application goal [3]. Characteristics of representative 3D GIS software are constructing spatial information system, spatial analysis, visualization quality improvements and so on.

In the Figure 1, there are fundamental technologies for 3D GIS, such as database technology, legacy GIS system management, computer graphics, virtual reality, mobile applications and wearable computing technologies.

Figure 1: Fundamental technologies for 3D GIS

There are two approaches for constructing a 3D GIS system. One is a manual modeling approach that creates 3D model manually according to 2D vector map. The other is an automated modeling approach which can model 3D model automatically and uses minimum 3D attributes (i.e., building height, road width) and 2D vector map to build 3D model. Figure 2(a) shows the activity diagram for manual modeling approach. Manual modeling approach is composed of following steps: First, we create 3D models and their textures manually. Then, we map 3D models (e.g. buildings) to 2D vector map. Figure 2(b) shows the activity diagram for synthetic modeling approach which we proposed. This modeling approach also has two main processing steps. First, we collect 2D profile data from legacy GIS system. Then, we construct minimum attributes for creating 3D model such as height of building.

We present the synthetic modeling method that is based on automated modeling approach. We design the 3D scene modeler component that could level-of-detail (LOD) control [6, 7, 8] for facility models according to user's requests.

3 3D GIS software component design

3.1 Design philosophies

The design philosophies of our proposed 3D GIS software components are interoperability, standardization, reusability, adaptability and performance. The important parts of scene modeler component that considers in design phase are as following:

interoperability By designing and embodying a standardized data provider, we can solve the problem resulted from different aspect of data format and database
standardization The Geometry Model specified in the OpenGIS simple features specification with specialized zero-, one- and two-dimensional collection classes named MultiPoint, MultiLineString, MultiPolygon for modeling geometries corresponding to collections of Point, LineString and Polygons respectively. OGC(Open GIS Consortium) simple features spec. also proposed methods for testing spatial relations between geometric objects and methods that support spatial analysis[2]. We consider in standardization of three-dimensional geometric model as extending the two-dimensional geometric model proposed by OGC(Open GIS Consortium).

reusability We can improve the software reusability by constructing several core components for 3D GIS application such as data provider, data graph, scene graph and viewer component.

adaptability We design the scene modeler component to easily adapt in 3D GIS applications as well as various application fields such as CAD/CAM, computer graphics and virtual reality applications.

performance In simple features specification of the Open GIS Consortium[2], the Well-Known Binary (WKB) representation for Geometry provides a portable representation of a Geometry value as a contiguous stream of bytes. We also use WKB to store geometry information as in OGC simple features specification[2]. In addition to, we exploit the Level-Of-Detail (LOD) control method to improve performance for rendering three-dimensional objects.

3.2 Design elements

The major component design elements for developing 3D GIS software are data provider, data graph, LOD modeler, scene graph and world viewer which is ActiveX control form.
Figure 3 shows the component diagram of our proposed component architecture for 3D GIS software component system. The static modeler has several packages such as building modeler, road modeler, landscape modeler and natural resource modeler. Here, we call the LOD modeler and scene graph component as the scene modeler component.

3.3 Scene modeller component

The scene modeler component is composed of the scene graph package and LOD modeler package. The scene graph package creates the scene graph for 3D rendering by using given data in preprocessing step of 3D visualization. The LOD modeler package coarsens or fines the 3D geo-features (i.e. building, road) according to the request of user or client program.

We assume given input data set as 2D data with 3D additional attributes such as building height, road width. The major functionality of LOD modeler achieves three-dimensional modeling of various detailed geo-features rendering by using 2D geometric information and 3D additional attributes.

There are two important system elements to model the static LOD geo-feature model efficiently. One is the rule-based modeling engine and the other is the model library. For example, in case of a building, our proposed modeling system can create 3D polygonal model to process 2D profile geometry of a building and height attributes as an input by using the rule-based modeling engine and model library. Figure 4 shows an example of a result of synthetic modeling concept according to the LOD level $\tau$.

The scene modeler component is consisted of dynamic modeler package that manage dynamic three-dimensional scene by user interaction after the scene rendering performed and static modeler package that performs the rule-based mod-
eling according to user LOD requests. The *meta scene graph* can be defined in three-dimensional scene graph which is consisted of information from data graph only. First, the dynamic modeler composes a meta scene graph by using information about whole scene which is receiving from initial data graph component. Then system performs the refinement process of the scene graph, determines the LOD state according to user view parameter and requests to static modeler a relevant LOD model. Figure 5 describes these modeling activities of the dynamic modeler.

![Diagram of Dynamic Modeler](image)

**Figure 5: The Activity Diagram of Dynamic Modeler**

### 3.4 Rule-based modelling

We present a novel modeling concept so-called rule-based modeling that can model the 3D geometry model by using 2D profile and additional 3D attributes. The de-
tail system elements for the rule-based modeling are rule-based modeling engine, which creates geometry information by referring facilities attributes in modeling phase, and model library, which has preprocessed models and appearance data in order to create detailed model. The rule-based modeling engine is the reasoning engine that already defines geometry components and rules beforehand to model 3D facilities according to their classified features in GIS. The model library is composed of geometry components (i.e. window, roof, parapet) and appearance components (i.e. texture, terrain texture), which is constructed by the preprocessing phase. The data obtain from the model library are not exactly matched real-world original facilities, but it can a similar model. The data, which is provided by model library, don’t match exactly geometries and attributes of real-world models but the modeling engine can create similar models to real-world models. Moreover, the rule-based modeling engine includes the rule parameter database (RPD) that can edit rule. Table 1 shows an example of RPD according to LOD level.

For given input (a) with an example of Figure 4, the rule based modeler can create a simple extrusion of input data according to 2D profile geometry and additional 3D attributes (story of building, height). After get modeling rules according to facility features in rule-based modeling engine, modeler performs the three-dimensional synthetic modeling to create a detailed model. The equation (1) denotes the creation process of synthetic model for the rule-based modeling where $S_{x,y,z}$ denotes geometry information of the model, $P_{x,y}$ denotes the 2D profile and $R_{x,y,z}(\tau)$ denotes the geometry information obtain through performing the rule-based modeling at specific LOD level $\tau$.

$$S_{x,y,z} = P_{x,y} + R_{x,y,z}(\tau)$$  \hspace{1cm} (1)

The static modeler is the package which performs the rule-based modeling. As shown in Figure 6, the static modeler package creates a LOD model obtained from performing iterative modeling procedures by using a 2D profile and a requested LOD level value.

<table>
<thead>
<tr>
<th>LOD level</th>
<th>Modeling elements</th>
<th>Model library references</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOD 1</td>
<td>SE</td>
<td>None</td>
</tr>
<tr>
<td>LOD 2</td>
<td>EB, R</td>
<td>RT</td>
</tr>
<tr>
<td>LOD 3</td>
<td>EB, R, W, P</td>
<td>WT</td>
</tr>
<tr>
<td>....</td>
<td>....</td>
<td>....</td>
</tr>
<tr>
<td>LOD n</td>
<td>EB, R, W,P, ....</td>
<td>RDT,WDT, ....</td>
</tr>
</tbody>
</table>

Table 1: An Example of RPD according to LOD level. (SE:simple extrusion, EB:extrusion body, P:parapet, R:roof, RT:roof texture, WT:window texture, RDT:roof detail texture, WDT:window detail texture)
4 Component analysis

The comparison criteria of modeling schemes, such as manual modeling, synthetic modeling (rule-based modeling), are input data, manual CAD object modeling, interoperability, reusability, initial modeling cost and so on. Table 2 and 3 show comparison results between manual modeling scheme and our proposed synthetic modeling scheme according to above criteria. Figure 7 shows an result of synthetic modeling according to the 2D map(a).

5 Conclusion

We have presented the synthetic modeling approach so called rule-based modeling which can perform the modeling procedure for automatic 3D facility modeling such as buildings, roads and so on. We also have proposed the scene modeler component design method which can model 3D geometric objects by using 2D profile and additional 3D attributes according to user LOD requests. Our proposed scene modeler component is better than manual modeling schemes in terms of several criteria such as component reusability, automated modeling, interoperability, initial data construction costs and system performances. We have presented the analysis results of proposed scene modeler component that can various models according to LOD level by several comparison criteria. In addition to, our proposed approach are useful to urban planning applications.

We have demonstrated techniques for designing the scene modeler component. Possible ideas for future work include:

Improvement to synthetic model quality Since we use automated synthetic modeling approach, we might have intermediate quality of generated model. Therefore, we should improve the visual quality of synthetic model through better mod-
Management Information Systems

Manual modeling

Interoperability not supported (depends on data format)

Reusability difficult to reuse

Initial cost big cost to build initial 3D manual modeling data set

Advantages The visual quality of 3D model is fairly high and realistic due to use manual modeling data set.

Disadvantages It requires big cost to initial manual modeling for 3D CAD data. The CAD data size is too huge to manage.

Table 2: The analysis result of manual modeling.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Synthetic modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input data</td>
<td>2D vector map + minimum attributes for 3D modeling</td>
</tr>
<tr>
<td>Manual modeling</td>
<td>not required</td>
</tr>
<tr>
<td>Interoperability</td>
<td>supported</td>
</tr>
<tr>
<td>Reusability</td>
<td>easy to reuse</td>
</tr>
<tr>
<td>Initial cost</td>
<td>cost to build an client application S/W</td>
</tr>
<tr>
<td>Advantages</td>
<td>support to the automatic modeling by using legacy GIS data set and 3D additional attributes. minimize cost for modeling due to not required manual modeling. can provide real-time 3D visualization large data. is useful to related to urban planning applications.</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>It requires additional modeling S/W for providing realistic modeling.</td>
</tr>
</tbody>
</table>

Table 3: The analysis result of synthetic modeling approach.
eling algorithms.

**New applications** An extension of our proposed scene modeler component could enable a class of next-generation applications such as car navigation system, fire-house management system.

![2D map](image1.png) ![synthetic modeling result](image2.png)

(a) 2D map  (b) synthetic modeling result

**Figure 7:** 2D map and its synthetic modeling result

**References**


