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Shell Model Representation as a Substitute of LoD3 for 3D Modeling in CityGML

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Abstract The OGC standard for 3D city modeling is widely used in an increasing number of applications. It defines five consecutive Levels of Detail (LoD0 to LoD4 with increasing accuracy and structural complexity), in which LoD3 includes all exterior appearances and geometrical details and subsequently requires much storage space. A new LoD is introduced as shell model with the exterior shell of the LoD3 model and the opening objects like windows, doors as well as smaller façade objects are projected onto walls. In this paper, a user survey is presented. The results of this survey show that the shell model can give users almost the same visual impression as the LoD3 model. Furthermore, algorithms are developed to extract the shell model from LoD3 model. Experiments show that this shell model can reduce up to 90% storage of the original LoD3 model. Therefore, on one hand it can be used as a substitute for a LoD3 model for the visualization on small displays. On the other hand, it can be treated as a sub-level of detail (SLoD3) in CityGML, since it retains almost the same amount of information but requires much less storage space.

Keywords shell model; 3D building; CityGML; generalization; user survey

CLC number P208

Introduction

Level of Detail (LoD) is a technique used to improve the performance and quality of 3D object representation in computer graphics. It follows a simple fundamental rationale: when a 3D scene is rendered, it is optically sufficient and computationally efficient to use a less detailed representation for small, distant, or unimportant portions of the scene.¹ James H. Clark introduced this concept for the first time in an issue of communications of the ACM.² Thereafter, numerous LoD frameworks have been proposed. Among others, discrete LoD, continuous LoD, view-dependent LoD and hierarchical LoD have been widely applied for various purposes.³ The last three frameworks are tailored for run-time rendering, while the discrete LoD requires a preprocessing stage before creating individual LoD models. The advantages and disadvantages of each framework make them useful for different applications.

Although LoD is uniformly defined as a number of milestones along the scale space when taking the scale space as a linear continuum, there are no agreed
LoDs for 3D buildings because LoD frameworks are normally established according to the spatial accuracy, the semantic precision, and the complexity of buildings required for different applications.\[4\]

CityGML defines a standard for the ontology of buildings at LoDs.\[5\] Its description comprises a categorization from LoD1 to LoD4, ranging from the coarsest block model to individual buildings with all their architectural details together with interiors, stairs and furniture.

Originally, the LoDs in CityGML are defined according to varying requirements of applications on the one hand and the diversity of data sources and registration techniques on the other.\[6, 7\] Therefore, they might not include all representative milestones in the scale space of 3D buildings. For example, windows, doors, balcony, etc., are vital architectural features that are important for visual impression. However, they are removed during the transition from LoD3 to LoD2 model. This means the leap from LoD3 to LoD2 is too great and there should be at least some intermediate LoDs between them, so that a gentle transition along the scale space can be reached with respect to the visual impression of users.

In our work, two additional LoDs are introduced between LoD3 and LoD2 defined in CityGML. They are termed as sub LoDs or SLoDs.

- SLoD3 = exterior shell of the LoD3 model, whereby the opening objects like windows, doors as well as smaller façade objects are projected onto walls.
- SLoD2 = exterior shell after generalization of features on roof and walls.

In line with the LoDs defined in CityGML, SLoD3 and SLoD2 models can be regarded as exterior shells of the LoD3 building model. In this paper we discuss the substitutability of the SLoD3 model for LoD3 buildings on the base of investigation about visual distance perception and depth perception. At the same time, a user survey was conducted to find out how similar the SLoD3 model is to the LoD3 model with respect to the visual impression. Moreover, a set of algorithms was developed for extracting SLoD3 buildings from LoD3 buildings.

The rest of the paper is structured as follows: Section 1 describes the LoD3 modelling in CityGML at first and then discusses the feasibility of the substitutability of LoD3 by SLoD3; Section 2 presents the user survey; Section 3 is dedicated to the algorithm of extracting SLoD3 from LoD3 model; In Section 4 the implementation and experimental results are shown; The last Section summarizes the conducted work.

1 Feasibility study of the shell model representation

LoD3 models in CityGML denote architectural models with detailed wall and roof structures, balconies, bays and projections.\[8\] As mentioned in the introduction, the facade of a building of LoD3 can be semantically differentiated (Fig. 1(a)). Furthermore, the openings such as doors and windows are represented as thematic objects. If a building of LoD3 is observed more closely, it can be found that every component, e.g., wall is represented as a cuboid (multi surface) instead of a planar surface (see Fig. 1(b)). This means that at least six polygons are required in order to model a simple wall without any opening objects in LoD3. As a result, a single building in LoD3 needs a rather large storage space. Therefore, modelling all the buildings in a district or even the whole city leads to enormous storage space.

Hypothesis: If a facade is represented by using a planar surface instead of a group of cuboids, the storage space can be reduced at least 5/6. In our work, the model composed of several planar surfaces of the original LoD3 model is called the SLoD3 (Sub-Level of Detail 3) model. However, the question arises: can the facade modelled by a planar surface give us the same visual impression as the one in real LoD3 (modelled by a set of cuboids)?
differ in the representation of building details in the depth direction. In other words, the LoD3 model represents building elements with their thickness and the architectural details can be differentiated in the depth direction, while SLoD3 model does not represent building elements with their thickness and the architectural details are differentiated in the horizontal and vertical direction. This kind of difference can be noticed only when the building is observed very closely. It will disappear when we have a certain distance to the target objects, for example, when the 3D building models are viewed on a small display (like PDA etc.) or a group of buildings have to be shown in the same view field on a monitor.

Actually, this is a perceptual phenomena associated to perceived layout. It is known as the anisotropy of visual space which describes a pattern of perceived dimensions of the layout in which horizontal layouts are perceived accurately or slightly overestimated, while vertical layouts and depth are perceptually undershot. Levin & Haber (1993) explain this phenomenon by using the visual angle between stimuli and observer’s eyes; the frontoparallel distances present larger visual angles than depth distances. In one word, eye-to-object distances have little value in shape perception when the viewing distances are large relative to the object depths.

As a matter of fact, this kind of optical illusion could also be found in our real world. In order to conduct the renovation work for a building without influencing its exterior appearance, its facade is painted on a planar cloth which hangs in front of the building. The painted facade can be viewed as the exterior shell of the facade. It keeps all the spatial details, thus gives pedestrians a similar visual impression.

Therefore, the question raised in the hypothesis might be answered as follows: yes, the SLoD3 models can give the same visual impression as the LoD3 models. In order to verify this argument, a user survey has been conducted which will be presented in the next section.

2 The user survey about the shell model representation

The user survey focused on the analysis of visual similarity between LoD3 models and SLoD3 models. Five SLoD3 buildings were extracted from their LoD3 models. Seven facades were selected for the user survey because they consist of many opening objects like windows and doors. Every pair of facades (viewed in LandXplorer) was captured as an image almost from the same viewpoint, as shown in Fig. 4. Note: For every pair of building façades, the left one is modelled in LoD3 while the right one is in SLoD3 extracted from the corresponding LoD3 building. For the 4th pair of façade, the upper façade is associated to LoD3 model while the nether façade represents the SLoD3 model.

These façade pairs are visually coded and the participants did not know which façades were modelled in LoD3 and which were extracted from them. The question was phrased for every façade pair as “how similar do you find these two facades?” There were four options survey participants could select from for similarity: (a) over 90%, (b) 80%-90%, (c) 70%-80%, and (d) less than 70%.

The user survey was conducted in October/November at three different universities. The participants
were: (1) 15 master students with the age range from 22 to 28 at the Technical University of Munich, (2) 14 Ph.D. students with the age range from 27 to 35 at the Technical University of Munich, and (3) 260 undergraduate students with the age range from 17 to 20 at the Nanjing Normal University. The background of all of the participants was geodesy and geoinformatics.

The results of the user survey are summarized in Table 1.

Table 1 indicates that: (1) more than 60 percent of participants found that the SLoD3 façades are very similar (>90% of similarity) to the LOD3 facades with respect to the visual impression, and (2) more than 90% of participants found that the SLoD3 façades are similar (>80% of similarity) to the LoD3 facades the LoD3 facades with respect to the visual impression.

| Facade pair | Similarity (%) |
|-------------|----------------|
|             | >90 | 80-90 | 70-80 | <70 |
| a           | 188 | 78   | 19    | 4   |
| b           | 191 | 78   | 15    | 5   |
| c           | 191 | 84   | 11    | 3   |
| d           | 221 | 50   | 14    | 4   |
| e           | 174 | 94   | 18    | 3   |
| f           | 176 | 92   | 19    | 2   |
| g           | 188 | 84   | 12    | 5   |

Fig.4  The seven pairs of facades used in the user survey
impression. This suggests that SLoD3 buildings can give users a very similar visual impression in comparison to the LoD3 buildings.

3 The storage space requirement of shell models

In this work, SLoD3 models were extracted using the similar algorithms that were developed in our previous work.[12] The algorithms have been implemented using Matlab (version Matlab 7.4). The platform is a PC with Intel(R) Core (TM)2 Duo CPU, E8400 @ 3.00GHz, 2.00GB RAM, and Microsoft Windows 7 Professional x86 (32bit). The program has been tested on a number of 3D buildings modelled in LoD3 by CityGML. The average computing time is about 0.04 s for a single building.

Depending on how complex a building is constructed, the required storage of CityGML file can be reduced to 20% of the original storage. For our work, we selected nine example buildings which are constructed with many windows and doors, as well as with very detailed architectural features. These buildings are obtained from the test bed “3D Ettenheim” in Germany. They were modelled in LoD3 by CityGML. Their SLoD3 models are extracted using the developed algorithm. Table 2 shows that the storage space has been substantially reduced, if the SLoD3 model is extracted from the original LoD3 model.

| Building | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|----------|---|---|---|---|---|---|---|---|---|
| LoD3     | 1051 516 2865 1019 810 584 1168 983 4073 |
| SLoD3    | 128 57 354 124 88 58 118 103 470 |
| Reduced percentages(%) | 88 89 88 88 89 90 90 90 88 |

4 Conclusion

This paper presents a user survey for the shell model representation, in order to find out whether the shell model can give users the same visual impression as its original LoD3 model during visualization. The total sample included 289 students from the Technische Universität München and the Nanjing Normal University that participated in the user survey. The results of this survey show that more than 90% of the user survey participants found that the shell model gives them a very similar visual impression as the original LoD3 model.

In addition, a set of algorithms were developed to extract the exterior shell of 3D buildings from their LoD3 models. The proposed algorithms are implemented and tested on a number of 3D buildings modelled in LoD3 by CityGML. The experiments show that shell models can be derived from LoD3 models very efficiently. Theoretically, it can reduce at least about 83% of the storage space of 3D buildings, because in the shell model representing every building component only one plan is enough, while a cuboid is required in the LoD3 model. Our experiments show that the approach can reduce about 90% of the storage space of 3D buildings.

Furthermore, the shell model can preserve the amount of information as much as possible. This has been verified by the user survey as far as the visual impression is concerned windows and doors are projected onto the corresponding plane of walls. These are still modelled as opening objects and their semantics are therefore retained in the CityGML. Additionally, shells of walls and roofs are extracted separately, to preserve their semantics after the extraction.

According to the user survey, we can state that, although shell models cannot replace the LoD3 models in CityGML for all the cases, nevertheless they give users the same visual impression as the LoD3 models when one observes them at a certain distance. Also, the shell model can be used as a substitute for a LoD3 model for visualization on small displays, because (1) they give users the same visual impression and (2) the shell model reduces the storage space substantially, and speeds up the transmission, and computation while visualizing.

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Notes to Contributors

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- ★ Geodynamic
- ★ Physical geo-surveying
- ★ GPS
- ★ Geo-surveying
- ★ Engineering surveying
- ★ RS
- ★ Photogrammetry
- ★ Mapping apparatus
- ★ Cartology
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