Automatic Transformation of Different Levels of Detail in 3D GIS City Models in CityGML

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ABSTRACT

3D Geographic Information System (GIS) models are increasingly used for planning and analyses on a city level. Defining 3D GIS city models in different levels of detail (LoD) is often needed to browse and handle large models more efficiently. In this paper, a methodology framework for automatic transformation of different LoDs in CityGML is presented and illustrated. A new exterior shell extraction algorithm was developed from the Ray Tracing algorithm for classifying building surfaces as interior or exterior. A transformation framework among each LoD was developed based on the new exterior shell extraction algorithm. The transformation framework also includes an additional LoD called LoD3.5 that the authors proposed in this paper. The new LoD can satisfy the needs of applications which require information about interior rooms while maintaining a small data storage. The results show that the new exterior shell extraction algorithm can help achieve an automatic derivation of LoDs in CityGML.

Keywords: 3D GIS, CityGML, Level of Detail, Model Simplification, Ray Tracing, Schema Mapping, Shell Representation, Visualization

1. INTRODUCTION

3D city models require huge data storage as well as tremendous computational power for viewing and rendering, especially for large and detailed models. Due to the limited power of most computers, it is necessary to represent 3D GIS city models in different levels of detail (LoDs) to reduce model complexity and storage requirements for smooth and efficient visualization and analyses. As one walks through a 3D city model in the multi-LoD graphical user interface, the distances of objects change and thus the LoD representations of objects need to be modified accordingly. Therefore, automatic and fast transformation among LoDs of 3D GIS city models is needed, especially if the GIS models is derived from a detailed data source such as building information modeling (BIM). Automatic LoD transformation can also reduce the modeling ef-
forts and ensure model consistency if one is given a high LoD model and asked to prepare 3D city models of lower LoDs (Andujar, et al., 2010; Mao, et al., 2011).

Among all the common 3D GIS standards available nowadays, City Geography Markup Language (CityGML) has the most sophisticated definition about LoDs. CityGML is a common modeling language for 3D city objects launched by the Open Geospatial Consortium (OGC) in 2008. CityGML defines city objects such as buildings and infrastructure in terms of topographic object information, semantic information and appearance properties (Gröger & Plümer, 2012). Besides the pre-defined information in CityGML, users can create Application Domain Extensions (ADE) within CityGML schema to store information according to specific needs. The highly integrating and extensible schema of CityGML has made it a trend in 3D GIS city models for various applications (Kolbe, et al., 2005). CityGML also supports five distinct LoDs for buildings in city models ranging from 2.5-dimensional regional models (LoD0) to detailed 3D building models with interior information (LoD4). LoD4 models define the detailed information about buildings, even interior rooms and furniture. While some people create LoD4 CityGML models from scratch, LoD4 models could also be generated from various sources such as building information models (BIM) or laser scanning data (J. Benner, et al., 2005; Isikdag, et al., 2008; Isikdag & Zlatanova, 2009; van Berlo & de Laat, 2011; Cheng, et al., 2015).

The LoDs in CityGML contain many features such as building interiors and furniture that LoDs defined in other GIS schemas do not. CityGML defines five distinct LoDs for efficient visualization and data analysis (Gröger, et al., 2012). Different LoDs can be stored for the same object simultaneously, which provides different resolution for viewing and analysis. The different LoDs are demonstrated in Figure 1. The LoD0 definition was added to CityGML schema at version 2.0. A LoD0 model is essentially a 2D digital city model with a 3D representation of the terrain. Buildings in LoD0 are in the form of footprint or projection of roof edge polygons (T. Kolbe, 2009). LoD1 uses a block model which models a building by its bounding box with a flat roof. On the other hand, buildings in LoD2 add roof structures to the building blocks. Boundary surfaces of buildings with different properties are also available from LoD2. LoD3 buildings have detailed wall and roof structures. Openings (i.e. windows and doors) are also available in LoD3 models. LoD4 models complete the LoD3 models with interior building features such as rooms, interior doors, stairs and furniture (J Benner, et al., 2013). Although the official CityGML Encoding Standard gives descriptions about each LoD, no clear definitions were offered and therefore users often create models in different LoDs according to their own understanding. In addition, the CityGML Encoding Standard did not provide methods to transform between LoDs. Since this study aims to deal with 3D city models, only LoD1 to LoD4 models will be considered in Figure 1.

LoD requirements depend on the applications. For example, LoD2 models would often suffice for visualization purposes, whereas LoD4 models are more suitable for simulation purposes (Strzalka, et al., 2011). To support fast rendering in visualization and satisfy different application needs, transformation between different LoDs must be achieved. However, OGC does not provide detailed transformation methods, and no complete transformation between LoDs in CityGML has been reported so far. In addition, current generalization and transformation methods such as vertex clustering (Rossignac & Borrel, 1993) and edge collapse (Hoppe, et al., 1993) are unable to deal with complex 3D models with a large number of surfaces.

This paper aims to develop an automatic transformation framework between LoDs in CityGML for building models in 3D city models in GIS. An algorithm is proposed to extract the exterior shell of a building and simplify the LoD4 and LoD3 models for model generalization. In order to fulfill the large gap of data between LoD4 and LoD3 models, a new LoD is proposed for CityGML. The rest of this paper is structured as follows. Background information
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