3D Hilbert Space Filling Curves in 3D City Modeling for Faster Spatial Queries

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ABSTRACT

The advantages of three dimensional (3D) city models can be seen in various applications including photogrammetry, urban and regional planning, computer games, etc. They expand the visualization and analysis capabilities of Geographic Information Systems on cities, and they can be developed using web standards. However, these 3D city models consume much more storage compared to two dimensional (2D) spatial data. They involve extra geometrical and topological information together with semantic data. Without a proper spatial data clustering method and its corresponding spatial data access method, retrieving portions of and especially searching these 3D city models, will not be done optimally. Even though current developments are based on an open data model allotted by the Open Geospatial Consortium (OGC) called CityGML, its XML-based structure makes it challenging to cluster the 3D urban objects. In this research, the authors propose an opponent data constellation technique of space-filling curves (3D Hilbert curves) for 3D city model data representation. Unlike previous methods, that try to project 3D or n-dimensional data down to 2D or 3D using Principal Component Analysis (PCA) or Hilbert mappings, in this research, they extend the Hilbert space-filling curve to one higher dimension for 3D city model data implementations. The query performance was tested for single object, nearest neighbor and range search queries using a CityGML dataset of 1,000 building blocks and the results are presented in this paper. The advantages of implementing space-filling curves in 3D city modeling will improve data retrieval time by means of optimized 3D adjacency, nearest neighbor information and 3D indexing. The Hilbert mapping, which maps a sub-interval of the ([0,1]) interval to the corresponding portion of the d-dimensional Hilbert’s curve, preserves the Lebesgue measure and is Lipschitz continuous. Depending on the applications, several alternatives are possible in order to cluster spatial data together in the third dimension compared to its clustering in 2D.

Keywords: 3D Adjacency, 3D City Modeling, 3D Indexing, 3D Spatial Data Management, 3D Space Filling Curves

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1. INTRODUCTION

3D spatial city models in different applications require different analyses and purposes. It is not an immense exertion if it just meant for 3D object visualization (see van Lammeren, Houtkamp, Colijn, Hilferink, and Bouwman (2010) and Nichol, Wong, and Wang (2010)). In most critical applications, information retrieval time is important (see Dash, Steinle, Singh, and Bhr (2004) and Tomaszewski (2011)). Without a proper procedure of storing 3D spatial data, queries for each object or the nearest neighbor or range search queries will reduce the time efficiency of processing and information retrieval. Meanwhile for mobile applications, displaying all 3D objects in a single display consume a lot of processing-memory allocation and will decelerate device performance. Alternatively, by knowing which 3D objects are within a certain radius or distance from the current location or especially within some query window would be a useful implementation for mobile application display, which requires windowing.

On the other hand, 3D (spatial and semantic) data consume more disk storage compared to 2D data. Requesting 3D spatial data from servers requires step by step memory disk searching and would be a hassle if the information was stored in different servers in different agencies throughout a country. Yet, again, 3D spatial data with proper data constellation will boost the retrieval time and optimize the processing procedure.

Therefore, in this paper, a new method of storing 3D spatial city models is presented. It is useful for various applications and improves data retrieval time by providing 3D adjacency, nearest neighbor information and 3D indexing. The advantages of implementing the space-filling curve in 3D city model will be explained as a new method of organizing 3D data in an opponent arrangement.

This paper is organized as follows. In Section 2, we review the recent trends in 3D Geoinformation Sciences related to 3D spatial queries (especially single object searches, range queries and nearest neighbors). In Section 3, we review the CityGML standard. Then, we review space-filling curves and we introduce our own 3D Hilbert space-filling curve implementation in Section 4. Finally, we present the analysis and results of these above mentioned 3D spatial queries in Section 5 and conclude this paper in Section 6.

2. TRENDS IN 3D GEOINFORMATION SCIENCES

Visualization of three dimensional (3D) objects becomes more widespread in developments (see Behley, and Steinhage, (2009), Jin and Bian (2006) and Liu, and Fang (2009)). This can be seen from the demand in 3D based applications (see Freitas, Sousa, and Coelho (2010) and Zhang, Fang, and Jing (2009)). Visualization of 3D objects can support a more realistic view as in the real environment than the two-dimensional (2D) visualization. 3D view of a building model is more realistic compared to 2D floor plan of a building in a navigation application.

In commercial software development, private companies are competing in developing tools that are capable of managing 3D cities. ESRI (CityEngine), Bentley (Bentley’s Map V8i) and Google (Google Earth) offer users the capability to create, visualize and measure 3D cities in their products (Jazayeri, 2012).

Since quite a number of 3D city model formats are available, there is a need for standardizing the 3D city model format for various applications. City Geography Markup Language (CityGML) is an example of an exchange standard format for 3D city models (see Figure 1). It consists of different Levels of Details (LOD); LOD0, LOD1, LOD2 and LOD3. Different LODs reflect different 3D spatial information details. The higher the LOD, more object detail and geometry is included. This common information model is the first standard related to 3D city models (Jazayeri, 2012).

Users want to visualize and analyze their 3D city models (see Over, Schilling, Neubauer, and Zipf (2010) and Mao, Ban, and Harrie
Relating Transportation Quality Indicators to Economic Conditions in the South-Central U.S.
www.igi-global.com/article/relating-transportation-quality-indicators-economic/55370?camid=4v1a