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A General Strategy for Semantic Levels of Detail Visualization in Urban Environment

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Abstract

Applications based on urban environments are applied frequently in daily life which increases the needs for a high quality visualization result. It combines the urban environment and the special application-related topic together. The urban environment can be visualized with different scales, namely with different levels of detail to improve rendering and processing performance of the application. Visualization for the special topic, semantics, similarly is in need of a smart strategy to stay consistent with information density. This paper proposes a general strategy to handle semantic levels of detail visualization in urban environment. An example is given to illustrate how it is applied. Later, a mapping between urban environment levels of detail and semantic levels of detail is discussed. In the last part, the limitations of the general strategy are stated. And visualization issues for semantics are listed such as the proper visualization form and technique for a given semantic level of detail. This paper aims to bring about a wider discussion on semantic levels of detail visualization in urban environment.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications

1. Introduction

An urban environment based application is a combination of the urban environment itself and one or more special topics that interest users. The urban environment is represented through geometric features, which provides information about the location, shape and appearance of the urban environment. In order to improve rendering and processing performance of geometric features, geometric levels of detail are proposed in 3D computer graphics, which are always evaluated by the complexity of geometries. The visualization of the special topic, or to be more general, semantic information, needs a similar strategy to maintain information density and to better help users make decision-making choices.

2. Previous works

2.1. Levels of detail of geometric objects

Nowadays in the field of computer graphics, levels of detail (LoD) literally means the detail degree or complexity of a given 3D object as the distance between the viewpoint and the object varies, or according to other different standards besides distance such as object importance or object position. Hence **Geometric LoD** in this paper basically means the geometric complexity of a single object within the urban environment, dealing with appearances and structures.

2.2. Semantic visualization and its level of detail

Taking semantic aspects into consideration enables the possibility to improve accurate information management and knowledge sharing, as well as the reliability and performance of the visualization result [BOS10]. Recently, semantic visualization in 3D environment mainly focuses on assigning semantic meanings to geometric elements and then properly representing them in the environment.

[MSH08] constructed a scene-graph which combines visual models, semantic mark-up, interactive filtering skill and model styling all together. [HSBF09] tried to establish the link between 3D shape and its semantics to help reconstruction. [ARSF09] designed a multi-segmentation framework to assign semantic meanings to 3D object geometric features then visualize them accordingly. [PCS11] visualized three city bus lines in urban environment with a multi-layered structure, storing both semantic and geometric data.

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Although these works deal with semantic visualization in urban environment, they do not emphasize the importance of levels of detail for semantics. One example concerning semantic LoD can be found in [ZZTM10]. In their work, the trajectory of human activity is visualized at three levels, separately are event-based LoD, traffic-based LoD and location-based LoD. However, the results are visualized upon a 2D map which is not a strictly speaking urban environment. [ZH10] proposed a semantic-based conceptual model to solve the problems of integrated management of buildings and dynamic property rights in complex 3D built environments. However it is hard to extend to other topics.

In general, we use **Semantic LoD** (S-LoD) to describe the levels of detail for all the non-geometric features, attribute information or semantics that are to be visualized, either abstract datasets or concrete datasets.

2.3. Geometric-semantic combined LoD solution

The five LoDs proposed in CityGML (OGC), firstly appeared in 2006, are globally accepted as a geometric-semantic combined standard for urban environment, which now evolves towards CityGML2.0. It gives a common definition of the basic entities, attributes and relations of a 3D city model and differentiates five consecutive levels of detail where objects become more detailed regarding both geometry and semantic differentiation as LoD gets lower.

CityGML LoDs are defined for individual buildings as geometric LoD does, and it uses these geometric LoDs to represent the LoDs of the urban environment. However, the urban environment is composed of lots of urban objects, not all the urban objects can stay at the same geometric LoD. And the LoD of single buildings can not show how the overall urban environment is structured. Moreover, CityGML only gives general descriptions of a LoD, without a 'measurable' way to define that exact scope, especially with respect to semantics.

[GD09] defined different levels of abstract to represent the overall construction of 3D urban environment rather than focusing on single buildings. Similar to that, **Urban LoD** (U-LoD) is used in this paper to describe the structural details for the whole urban environment at a global view.

3. A general strategy for semantic LoD

For a given application, the content of semantics involved is highly related with the application purposes. Semantic types vary between temporal semantics and thematic semantics, according to different classification standards. The general semantic LoD strategy is based on the condition that semantics to be visualized in the urban environment are from only one domain. If there is more than one domain, the LoD solution for each domain can be generated separately with the general LoD strategy. Then they can be co-visualized together in the urban environment.

The main idea is that a more detailed level (lower LoD) enriches descriptions of the content from a higher LoD. While the information density remains consistent, a lower LoD can only enrich part of the semantics of the higher LoD, hence information for the non-enriched part will have to lose. The strategy is illustrated below in Figure 1.

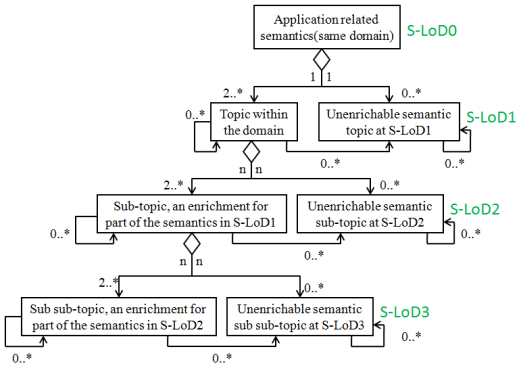

Figure 1: *General **S**emantics **LoD** strategy with four levels.*

- S-LoD0: this level is the overall information about the semantics to be visualized, comprehensive and general.
- S-LoD1: here the semantic objects are different topics within this domain. Two or more topics are needed to aggregate the overall semantics in S-LoD0. And it contains zero or more topics which can not be further enriched by a lower level. Objects at this level can have zero or more internal associations with each other. But they can only be aggregated into one S-LoD0 objects.
- S-LoD2: at this level, a sub-topic is the enrichment for part of the topic in S-LoD1. At least two sub-topics are essential. Each sub-topic can be aggregated into n>=1 topics in S-LoD1. And objects at this level can have zero or more internal relations with each other.
- S-LoD3: sub sub-topic here is an enrichment for part of a sub-topic from S-LoD2. Similarly, at least two sub sub-topics are needed and each can be aggregated into n>=1 sub-topics. Internal associations are possible.

Strategy here only illustrates four levels. According to the specific function needs of the application, more levels with detailed information can be structured based on this strategy.

3.1. An instance of tourism resources

Based on this general semantic LoD strategy, an simple example for the visualization of tourism resources is given to demonstrate how it can be applied. The semantic visualization is to help tourists make visiting plans or other types of decision-making choices concerning tourism, according to their personal interests. To implement in other semantic topics and domains, it is the same process. Below in Figure 2 is the tourism LoD (T-LoD) solution which has four levels:

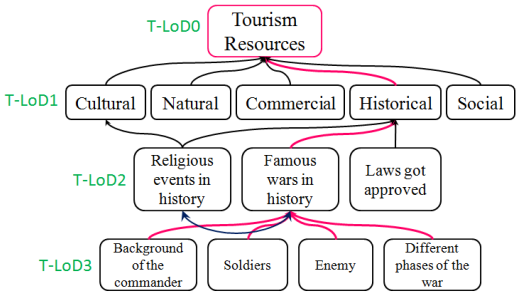

Figure 2: *Tourism resources **LoD** solution with 4 levels, constructed from the general S-LoD strategy.*

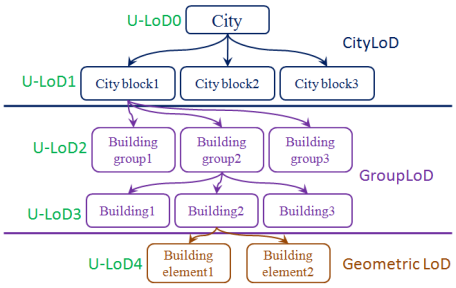

Figure 3: *Simple Urban **LoD** definition.*

- T-LoD0: semantics here comprehensively describe the overall tourism information within the urban environment, such as its population, history, international relations and most famous tourism landmarks.
- T-LoD1: five different topics are demonstrated here at this level, each of them enriches tourism information related to the topic, with more details. These five items in all aggregate into the tourism resources in T-LoD0.
- T-LoD2: take historical item in T-LoD1 as example, here it focuses on describing one single historical event. Details can be the location, time, result and influence of the event. For a religious event, it is a historical item, while it might have influence on the culture of that time, which meanwhile belongs to a cultural item. One internal relation is that a religious event in history resulted in a war.
- T-LoD3: the focus shifts to enrich semantic object in T-LoD2. For example, detailed information about the war command officer, soldiers, enemies and different phases of the war can be separately enriched with details.

3.2. Mapping semantic LoD and urban LoD

Definition for Urban LoD

Since semantics are visualized in the urban environment, which works as the urban background to embed semantics, so the levels of detail for urban environment can not be ignored. The definition of Urban LoDs can refer to [HMM12], which proposed a GroupLoD and a CityLoD strategy.

As illustrated in Figure 3, five urban LoDs are defined:

- U-LoD0 and U-LoD1 are from the idea of CityLoD. U-LoD0 is at city-scale level, which visualizes the whole city. U-LoD1 divided the city into different city blocks either by road networks or regional districts.
- U-LoD2 and U-LoD3 refer to the idea of GroupLoD. In U-LoD2, building groups within a block are emphasized and single buildings are the focuses in U-LoD3.
- U-LoD4 turns to the geometry details of one single building, which is the content of geometric LoD, such as the roofs, windows and doors defined in CityGML.

The mapping between U-LoDs and S-LoDs

After defining the contents of different levels of detail for both semantics and the urban environment, a mapping between these two is conducted. Taking the city of Nantes, France as example, an Urban LoD strategy and a Tourism LoD strategy are generated separately as illustrated in Figure 4 (next page), both containing three levels.

When the urban environment is at U-LoD0, the global view of Nantes is visualized. Tourism semantics should be the general information about Nantes.

At U-LoD1, Nantes is divided as city center and other parts. For city center, we can visualize the overall descriptions of tourism resources within this block. While the main tourism focus for the city center might be commercial items such as hotels and restaurants, then semantics visualized can be enriched descriptions only about commercial items. In this way, urban object in U-LoD1 can have a local semantic LoD strategy similar to the structure of T-LoD0 and T-LoD1.

For U-LoD2, the city center of Nantes is divided into three building groups. Similarly as analysis for U-LoD1, the choice for visualized semantics can generate a local LoD strategy as illustrated in the bottom of Figure 4.

For Nantes Cathedral, semantics can be detailed overall information at the local T-LoD0. If a user is interested in the historical items and he already knew some general stuff of the Cathedral from T-LoD0, he wants to have more details on historical events, here semantics provided can be contents from local T-LoD1. In a more extreme case, he is eager to know detailed information about a main role in a historical event, he can set the rule to choose his interests concerning that so semantics visualized can stay at local T-LoD2. A more perceptive result for the analysis is given in Table 1:

Given U-LoD	Available local T-LoD
U-LoD0	local T-LoD0
U-LoD1	local T-LoD0, local T-LoD1
U-LoD2	local T-LoD0, local T-LoD1, local T-LoD2

Table 1: *Matching result of Figure 4*

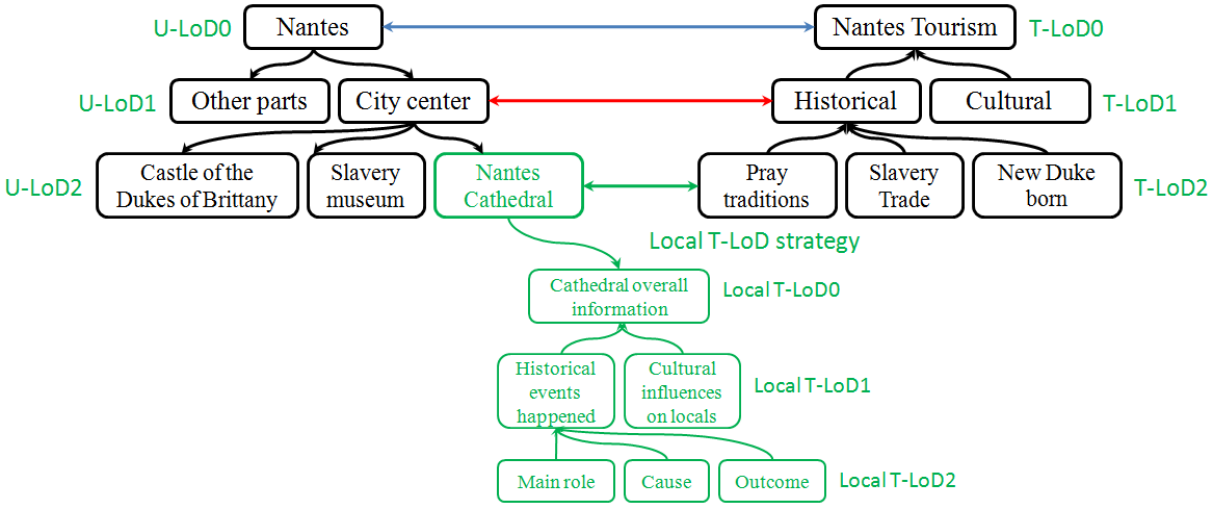

Figure 4: *A simple example of correlating urban LoD and semantic LoD.*

It shows that when Urban LoD is given, semantics visualized can be contents of a local LoD at the same level as the corresponding U-LoD, or of higher local LoD levels.

4. Discussion

This paper discusses how to deal with semantic levels of detail visualization in urban environment. A general semantic LoD strategy is given, which can be instantiated and modified according to the specific field of semantics. A simple example with tourism resources is given and a mapping between urban levels of detail and the tourism resources levels of detail is discussed. The purpose of this paper is to bring about a wider discussion on semantic levels of detail visualization in urban environment.

The general LoD strategy is to generate a LoD solution by enriching semantic descriptions for a higher LoD. However, at which degree can lower semantics be treated as an 'enrichment' is hard to define. There is no standard to state the clear borderline between two semantic LoDs. And a LoD strategy with many levels does not necessarily means it is a good solution for semantic visualization. A guideline is needed concerning at what degree a LoD strategy is 'enough'.

Visualization issues: this paper only discusses problems of the LoD strategy at a conceptual level. When it comes to the final visualization process, technical issues might be:

- Visualization forms: semantics can be represented through texts, symbols, pictures, textures, audios, videos, simple shapes or 3D objects. For a given semantic LoD, which form(s) is (are) proper?
- Visualization techniques: where exactly to place semantics and how they interact with urban environment as semantic LoD changes?
- Legibility, information diversity: this is the optimization of semantic LoD visualization. We can not just visualize semantics, but have to take into consideration the legibility and information diversity of them.

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