Designing and Evaluating 3D Knowledge Visualization Techniques for Urban Planning

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Semantic enrichment of 3D city models for sustainable urban development
Visualization of enriched 3D city models

Depending on the type of information

Air flow
Visualization of enriched 3D city models

Depending on the type of information
Visualization of enriched 3D city models

Depending on tasks and context of use

- Find the most polluted area
- Find the exact pollutant value of the most polluted area

Pollutant concentration represented by solids
Visualization of enriched 3D city models

Depending on tasks and context of use

Find the area associated to the largest number of pedestrians

Find the exact value of this area

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Visualization of enriched 3D city models

Depending on tasks and context of use

Find the most polluted areas at bird’s eye view

Find the most polluted areas at pedestrian level

Pollutant concentration represented by solids
Visualization of enriched 3D city models

Depending on tasks and context of use

Context: LOD >= 3

Intervisibility aspects
Visualization of enriched 3D city models

Complex tasks can imply to visualize more than one dataset => the selected visualization techniques must be compatible (can be used together without any occlusion or other problem)

An example of two potentially incompatible techniques
Selection of appropriate visualization techniques

According to different criteria:

- **information** to visualize
- **task(s)** to perform
- **context** of use
- **compatibility** with already selected visualization techniques
Objectives

• Creation of a knowledge base of visualization techniques in 3D urban environment
  – conceptualization of the domain → ontology O3DVT
  – representation of existing visualization techniques -> knowledge base
  – representation of known uses and evaluations

• usable for:
  – selection of techniques
  – evaluation of (in)compatibilities
Ontological work

• What is a visualization technique for 3D city models?

• What is the use or the evaluation of a technique?

• Aspects to cover
  – input : describes the information to visualize
  – output : describes the output rendering
  – usage/evaluation : context, task, data
    => level of usability
Starting points

Brodlie & Noor (2007) Top Level Visualization Ontology (TLVO)  
data, processus and visualization products

Amar et al., (2005) 
low level tasks for visualizing information

Tyndiuk (2005)  
context from two reference frames : viewpoint and movement.

GML – Geography markup language (geometric objects)  
CityGML – urban objects  
Wordnet – lexical database
Global structure of the ontology O3DVT

- Visualization Technique
- Data Description
  - Lexical issues (WordNet)
  - Data Type
- Output Rendering
- Geometric Objects (GML)
- City Objects (CityGML)
- Evaluation
  - Context of use
  - Visualization Tasks

Evaluates:

Visualization Technique
Data description representation

\[(x, y, z) \rightarrow \text{real number}\]

\[(x, y, r) \rightarrow \text{integer number}\]

\[(x, y, z) \rightarrow (v_x, v_y, v_z)\]
Data semantics representation

Information type: **pollutant concentration**

The balls represent the average pollution value of small volumes organized according to a grid =>

Coverage: **3D region associated to a grid**
Data description representation
Output rendering representation

Pollutant concentration levels represented by solids positioned at 1 meter above terrain level

Output shapes: colored spheres

Output location: a 3D space contained in a surface
Output rendering representation

Visualization Technique
  outputLocation

OutputLocation

ObjectAttached
  objectType
  objectRelation

CityObject

3DSpace
  containedIn

SpatialRelation

SpatialObject

OutputShape
colored : boolean
textured : boolean

PointRepresentation
CurveRepresentation
SurfaceRepresentation
SolidObject
  ...Box
  ...Sphere
  ...Cone

TextRepresentation
  ...RichText

TopologicalRelation
  ...
ProjectiveRelation
  ...
MetricRelation
  ...
task: **estimate** the highest pollutant value

Context: user at **bird’s eye view** manipulating the scene model that can be seen on any type of display model referring to “Place du Marché, Carouge, Switzerland”
Usage representation

- Visualization Technique
- Usage
- Context
  - viewpoint
  - spatialConfiguration
  - displayType
  - navigationSpace
- Task
- Usage
- CityModel
  - geoName
  - LOD
  - modelURL
- SpatialObject
  - MultiPoint
  - MultiCurve
  - MultiSurface
  - MultiSolid
  - Grid
- ReadValue
  - ReadText
  - Estimate
  - Find...
  - Compare ...

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Implementation of the knowledge base

1. Translate the UML conceptual schema into OWL definitions:
   => provides the basic vocabulary used to define the techniques

2. Represent formally the visualization techniques in OWL

```owl
VisualizationTechnique
   and (outputlocation some (3DSpace containedIn some Surface))
   and (outputshape some Sphere)
   and (datadescription some(DataDescription
      and (coverage some (3DRegion containedIn some Grid))
      and (datatype some RealNumberType)
      and (informationType some (concept some wn:pollutant
         and concept some wn:concentration)))))
```
Implementation of the knowledge base

1. Translate the UML conceptual schema into OWL definitions:

- UML class or association class $\rightarrow$ OWL class
- UML simple association $\rightarrow$ OWL object property (+ some, only, min, or max constructs to represent number constraints)
- UML attribute (integer, string, boolean valued) $\rightarrow$ OWL datatype property
- UML subclasses $\rightarrow$ OWL subClassOf axioms

$\Rightarrow$ provides the basic vocabulary used to define the visualization techniques
Implementation of the knowledge base

2. Represent formally the visualization techniques in OWL

```
VisualizationTechnique
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    and (datatype some RealNumberType)
    and (informationType some
      (concept some wn:pollutant
        and concept some wn:concentration))))
```
Querying the knowledge base

Find techniques to display rich text (text + images) on panels

Query (class expression)

VisualizationTechnique and datadescription some (DataDescription and datatype some RichTextType) and (outputshape value RichTextPanel)

Query results

Sub classes (0)

Instances (5)

⇒ Very expressive query language
   Uses logical inference
   Handles incomplete information
Querying the knowledge base

Find techniques for the estimation of pollutant concentration with a navigation context above the scene (birds eye view) or in the scene (at pedestrian level)
Incompatibilities between techniques

Defined by rules expressed in SWRL language, such as:

Visualization_Technique(?t1), Visualization_Technique(?t2),
Rendering condition → PossibleCompatibility(?t1, ?t2)

Visualization_Technique(?t1), Visualization_Technique(?t2),
Rendering condition → Incompatibility(?t1, ?t2)
Validation of the ontology

According two axes:

- **Coverage** of the 3D visualization techniques domain
  => Currently about 40 techniques issued from the litterature are represented in the knowledge base

- **Adequacy** for the intended application
  => it is effectively possible with O3DVT:
     - to find 3D visualization techniques according to complex research criteria
     - to detect incompatibilities between techniques

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Conclusion and future work

With O3DVT we propose:

• a detailed and organized description of 3D visualization techniques (usually not explicitly described even widely used) and of their usage or evaluation
• a formalized implementation as an ontology and a knowledge base

In a near future we plan:

• to populate the ontology with more 3D visualization techniques, in particular with techniques not explicitly described but widely used in the 3D GIS domain
• to populate the evaluation part essentially with uses (more frequently found than formal evaluations)

• An interesting application of O3DVT should be:
  – Its implementation in a 3D GIS
    => automatic selection of visualisation techniques