Building Virtual Knowledge Graphs from CityGML Data

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Summary: *In this work, we show how to expose CityGML data as a Virtual Knowledge Graph (VKG). We use 3DCityDB to store the CityGML data, and Ontop to build the VKG. We demonstrate the work-flow using the models of the main campus of Technical University of Munich.*

Introduction

3D city models have been increasingly employed for advanced visualization and analysis tasks in various LBS applications, including indoor navigation and emergency rescue (Sun et al., 2020), and virtual and augmented reality (Santana et al., 2017). A widely adopted standard for the representation and exchange of 3D city models is *CityGML* (City Geography Markup Language) by Open Geospatial Consortium (OGC). It defines the three-dimensional geometry, topology, semantics, and appearance of the most relevant topographic objects in urban or regional contexts. Specifically, the representation of semantic and topological properties distinguishes CityGML from pure graphical 3D city models and enables thematic and topological queries and analyses.

One objective of CityGML is to inter-relate the 3D city information with other data to create a more complete representation of the urban landscape (Kutzner et al., 2020). However, this has not been exploited much in the research community. In this work, we tackle this problem by using semantic web technologies, and move urban data into *Knowledge Graphs (KGs)*. Thanks to the flexibility of the graph structure of KGs, multiple KGs can be easily integrated when they use vocabularies shared through ontologies. Many studies proposed geo-ontologies and so-called *GeoKGs* to represent domain knowledge and support geospatial data integration. Most of these works integrate the geodata sources by converting and materializing the original data as an RDF graph, and then storing such graph in an RDF store (Vinasco-Alvarez et al., 2020). Due to the resulting duplication of data, this way of proceeding can be expensive, especially when data sets are large or change frequently.

To overcome the challenges posed by materialization of the RDF graph, a different approach has been proposed, called *Virtual Knowledge Graph (VKG)* (Xiao et al., 2019). VKG is a popular paradigm that enables end users to access data sources through an ontology, which is semantically linked to the data sources by means of a *mapping*. Such mapping is expressed in the R2RML language standardized by the W3C. Thus, the ontology and mapping together, called a *VKG Specification*, expose the underlying data source as a virtual RDF graph, and make it accessible at query time using the standard W3C query language SPARQL. Using knowledge representation and automated reasoning techniques, a VKG system will then reason about the ontology and mapping and reformulate the SPARQL queries in terms of queries that can be directly evaluated at the data sources. This makes it possible to avoid the high cost of materialization. Such VKGs can be used in several application areas for LBS, such as dynamic semantic integration of urban information, and smart queries for PoI recommendations in routing algorithms.

Methodology

We proposed a framework called *CityGML VKG* as illustrated in Fig.1. We store the CityGML data into a relational database, and create a VKG specification (i.e., an ontology and a mapping). Then we use the popular VKG system *Ontop* (Calvanese et al., 2017) to expose the CityGML data as a VKG, which can be queried using the standard SPARQL query langauge.

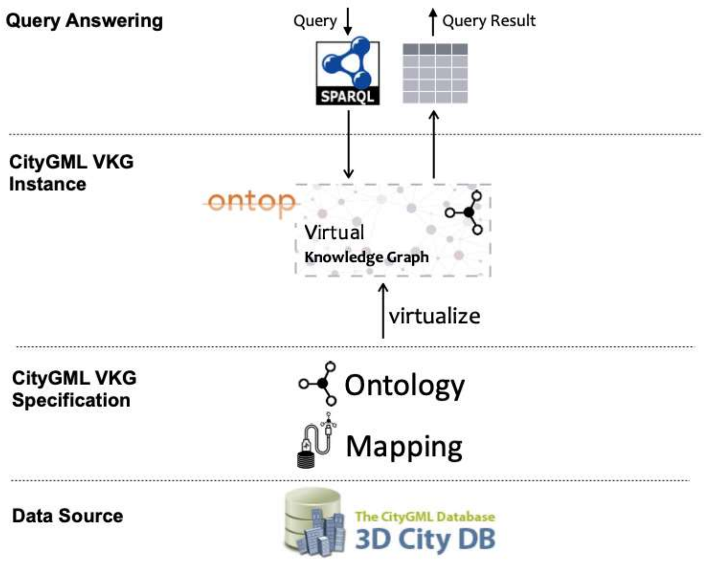

Fig. 1: Framework of CityGML VKG

Test data

We use the CityGML data of the main campus of Technical University of Munich as the test data (Fig 2). We make use of the 3DCityDB project, which implements the standard SQL encoding of CityGML, and import the sample data to 3DCityDB using PostgreSQL as a backend.

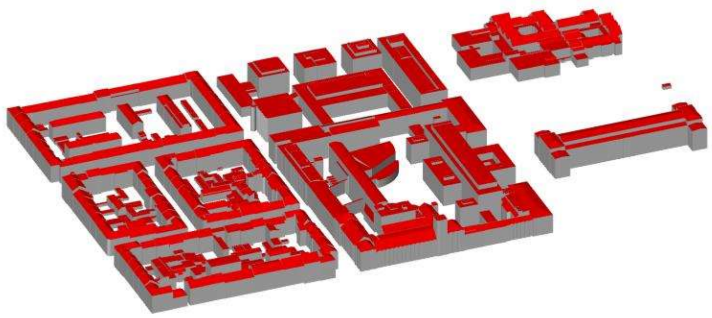

Fig. 2: The main campus of Technical University of Munich

Virtual Knowledge Graph Creation

We adopt the CityGML ontology[1] created by the University of Geneva, shown in the left part

[1] http://cui.unige.ch/isi/onto//citygml2.0.owl

of Fig. 3. We have developed a suitable R2RML mapping (the right part of Fig. 3) to 3DCityDB using the ontology editor Protégé with the Ontop plugin.

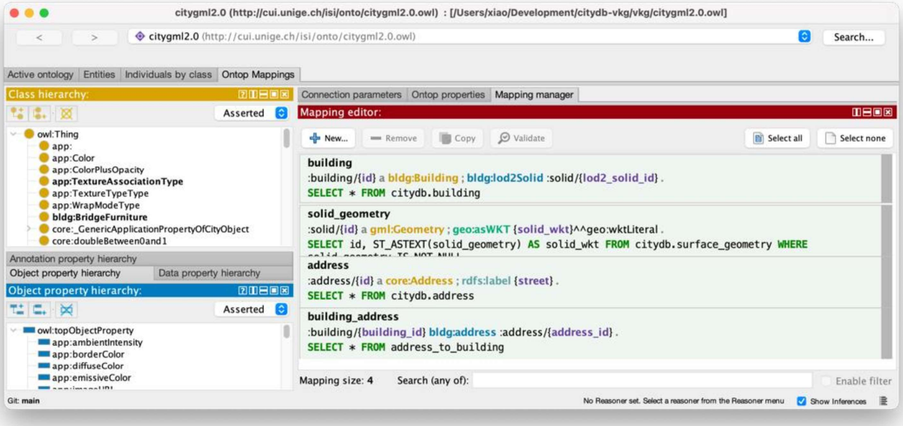

Fig. 3: The ontology and mapping editor in Protégé with the Ontop Plugin

Example Query

We show one example query in Fig 4, which retrieves all the buildings, together with their addresses and the LOD 2 solids. When evaluating this query, Ontop translates it into a SQL query, and sends it to the 3DCityDB backend.

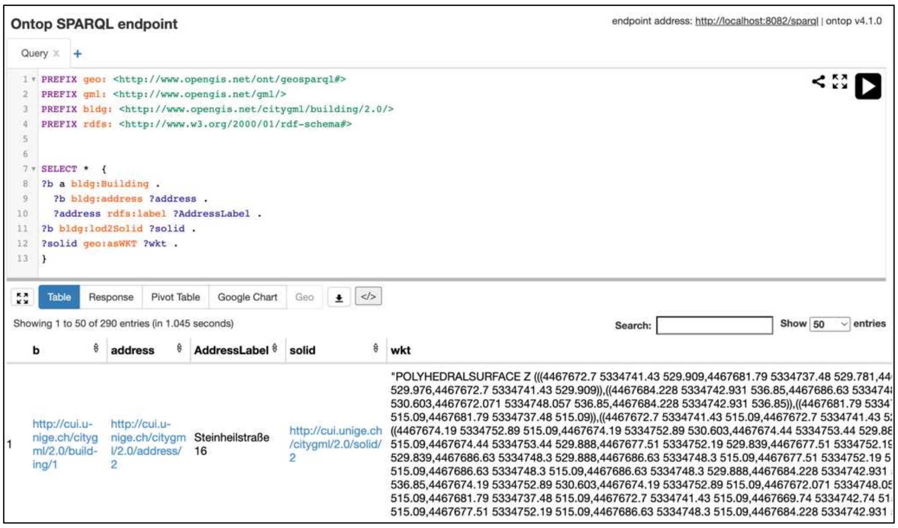

Fig. 4: An example SPARQL query evaluated in the SPARQL endpoint of Ontop

Conclusions

We have developed a proof-of-concept system for exposing CityGML data as a VKG. In the future, we will extend the coverage of the mapping, intregrate other datasets into the VKG, and apply the technology in LBS applications.

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