

A Land Use Identification and Visualization Tool Driven by OWL Ontologies

Jorge Gomes¹, Nuno Montenegro², Paulo Urbano¹, and José Duarte²

¹ LabMAg, Faculdade de Ciências da Universidade de Lisboa,

{jgomes, pub}@di.fc.ul.pt,

² Faculdade de Arquitectura - UTL

{nmontenegro, jduarte}@fa.utl.pt

Abstract. We present a software tool for urban planning, driven by semantic web ontologies. With this tool, the participants of the urban development process can semantically annotate an intervention site with knowledge about the use of the land. The tool provides the user as much flexibility as possible in the choice of the land use standard that will be used to perform the classifications. This flexibility is achieved by defining extensible ontologies in which the concrete standards can be built upon. This allows our tool to load external ontologies that define the taxonomy of the standard and the semantic relations between the land use categories. The loaded ontologies seamlessly integrate in the application, and are used through a friendly user interface. We also demonstrate how ontologies can be used to perform automatic categorizations and consistency checks in the geographical knowledge, aiding in the process of identifying the land uses of a site.

Keywords: urban planning, semantic web, ontologies, OWL, GIS

1 Introduction

Urban and regional planners usually develop long and short term plans to guarantee efficient management of land use and to promote the growth and revitalisation of urban, suburban, and rural communities. Before making plans for the development of these communities, planners study and report on the existing land use for business, residential, and community purposes. Our work aims to design and build a tool for the manipulation of land use knowledge, to assist the urban development process. It is targeted at district planning and the ultimate goal is to promote the generation of more sustainable urban environments. To achieve this goal is important to have reliable and up-to-date georeferenced information, firstly, in order to identify the requirements of the plan, and subsequently to establish appropriate recommendations.

We have designed 4CitySemantics, a software tool that aims at aiding in the city planning process, and heavily relies on semantic web technologies. The main objective of this tool is to provide the urban planners with a sharable semantic interpretation of a defined intervention site and surrounding areas. Besides visualizing the semantic information associated with georeferenced spatial

features, this tool provides the participants in the urban design process with the possibility to identify and classify semantically the urban areas subject to intervention.

The key principle behind the tool is to offer as much flexibility and customization as possible, in order to be able to integrate smoothly with different urban knowledge and different classification standards. Allowing the tool to work with any land use classification standard is paramount because there are many classification systems used in land use planning. Land use standards are usually defined by state regulations, and the urban planner is required to use the standards existing in the intervention zone. Semantic web technologies play the main role for attaining the desired flexibility. We defined base ontologies written in OWL 2, which can be extended as needed to describe the standards that the user wants in the tool. The tool will then interpret the knowledge present in those extensions using the semantic structure laid out by the base ontologies.

With 4CitySemantics users are able to 1) load a georeferenced map from a shapefile, 2) choose the intervention zone and define the surrounding region on the map; 3) define any other zones on the map as necessary; 4) load a land use standard from an OWL ontology; 5) visualize the standard and all the information associated with it; 6) classify the parcels on the map in accordance with that standard; and 7) query the map for the parcels classified with any land use categories, taking advantage of the reasoning capabilities.

2 Related Work

The use of ontologies has been a hot topic in urban planning [1], mostly for urban planning knowledge externalization, sharing, integration, and reuse. The main objective of the European COST C21 Action [2], known informally as *Towntology* was to “increase the knowledge and promote the use of ontologies in the domain of urban development, in the view of facilitating the communications between information systems, stakeholders and urban experts at a European level”.

In the context of *Towntology*, CityGML [3], an information model for the representation of 3D urban objects, was successfully integrated with OSM, a soft-mobility ontology, and with OTN, an Ontology of Transportation Networks [4], both developed in OWL. OSM could complement the soft-mobility aspects that were absent in OTN and CityGML was useful for visualization and communication. There were also cases of interoperability in the area of archeology [5] and air quality [6].

KnowledgeScapes [7] is a visualization tool that links spatial features in a spatial dataset to urban concepts expressed in an ontology. The users are able to browse and select concepts and the corresponding spatial features are highlighted. In comparison with 4CitySemantics, the ontologies in KnowledgeScapes are written using only RDF, with more limitations in terms of expressiveness and inference and the users are not able to annotate themselves the spatial data with semantic information, they can only visualize the selected spatial concepts.

3 System Architecture

In 4CitySemantics, knowledge regarding geographical features and land use classification taxonomy are represented using OWL 2. The knowledge is separated from the tool, and so it is fully independent of any land use standard, as long as it is represented as an ontology. Designing a system where the user can define its own concepts, which our tool should be able to correctly interpret them, raises some challenges: In one hand, it must be given enough liberty for the user to define its own concepts, allowing rich descriptions and fully supporting the OWL 2 semantics. On the other hand, the application must be able to bring into play these foreign concepts, imposing some (preferably minimal) restrictions to the user in the construction of the ontology.

The compromise between these goals is achieved through a small set of concepts that are defined in non-modifiable ontologies in which the tool relies. We call these ontologies the skeleton ontologies, because they are the common ground where different ontologies will be built upon. To create an extension ontology defining a concrete land use, the user must extend the concepts of the `LandUseSkeleton` ontology, with all the expressiveness he wants, as long as the connection points between the ontologies are kept, so the tool can interpret it. The land use skeleton ontology can be viewed as a schema for the definition of a land use, which itself is also a schema. The extension provided by the user together with the skeletons provided by the application form the T-Box of the knowledge base. They define the schema that is used to assert information about the parcels of the map.

The semantic information will target geographical features from a map (loaded via a shapefile), so there must be some correspondence between the map and the ontology individuals. This is specified in the `CoreGIS` ontology, that defines the classes `Feature` and `Zone` and some properties related to them. A geographical feature is any element in the map, which may be a polygon, line or point. A zone is an aggregate of geographical features. For each geographical feature present in the map, there will be a corresponding OWL individual of the class `Feature`, linked to the map by the identifier of the feature. The ontologies are not intended to replace the shapefile, just complement it with semantic information, so it is not necessary to express the features geometry in the ontologies.

The semantic information created in the tool is stored in a separate OWL ontology respective to the current project. This ontology is representative of the A-Box. It can be used to 1) perform future modifications and additions to the information by opening the ontology in the tool 2) share the information, exploiting the advantages offered by the Semantic Web. The articulation of all the ontologies described in this section is summed up in Figure 1.

The tool provides a friendly user interface for the loaded land use ontology and the georeferenced map. The user can annotate semantic information about the map parcels without worrying about the implementation details of the ontologies. If it is already built an ontology representing the desired land use, the participants of the urban planning process can use the tool without even understanding OWL – and simultaneously take advantage of it.

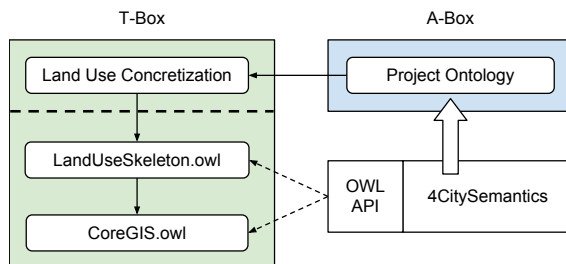


Fig. 1. The ontology modularity that allows the tool to use any land use system. The solid arrows represent ontology imports. The dashed arrows represent the dependencies of the application.

4CitySemantics is developed in Java 7 over Netbeans Rich Client Platform¹. The ontologies are read using the OWL API², and the reasoning throughout the application (which will be detailed later) is provided by the Pellet Reasoner³. The ontologies were built using Protégé 4.1⁴. The georeferenced maps are loaded and manipulated in the application with GeoTools⁵.

4 Land Use Ontologies

In this section we describe the skeleton ontology that allows any land use standard to be used in the application. An extension of this skeleton will be exemplified with the LBCS⁶ ontology, that was developed in previous work [8]. We also present how the application uses reasoning to offer the users relevant advantages in this domain.

4.1 Land Use Taxonomy

Through the study of multiple land use standards we identified a few common characteristics that formed the skeleton ontology, which is the common ground where the actual land uses will be built upon. Namely, we found that each land use category has an identifier (code), a color for visual identification in maps, a title and a description. To cope with these necessities, it was created a `LandUseCategory` class and data properties for the color (`hasColor`) and identifier (`hasIdentifier`), both with `String` as range.

The land use standards typically show some degree of hierarchic organization, so the land use categories should be represented as classes in order to map the

¹ Generic framework for Swing applications – <http://platform.netbeans.org>

² Java API for manipulating OWL Ontologies – <http://owlapi.sourceforge.net>

³ An OWL2 DL reasoner – <http://clarkparsia.com/pellet>

⁴ Open source ontology editor supporting OWL2 – <http://protege.stanford.edu>

⁵ Open-source Java GIS Toolkit – <http://geotools.org>

⁶ Land Based Classification Standards – <http://www.planning.org/lbcs>

hierarchy of land use categories. To assert information about the categories, namely through the `hasColor` and `hasIdentifier` properties, it should be used punning. Punning⁷ is a form of meta-modeling supported by OWL 2 that makes possible to use a class in places where an individual was expected (among other possibilities). This is achieved in the ontology by declaring an individual with the same IRI (name) as the class that is being punned. While the object shares the same IRI, depending on its context, it is evaluated by an OWL reasoner as a different thing (class or individual).

To create an ontology describing a land use standard, the user has to import the skeleton ontology, create subclasses of the `LandUseCategory` class, associate them with proper annotations for label and description, and fill the color and identifier properties using punning in the classes. We can see an example of this in Figure 2. Additionally, if there is already an ontology describing a land use standard, it can be linked with the skeleton, by declaring the existing categories as subclasses of `LandUseCategory` and defining relations between the existing properties and the ones from the skeleton (e.g. equivalent properties).

To show the land use taxonomy in the user interface (Figure 3), the application retrieves the subclasses of `LandUseCategory` and the respective properties in the punned individuals. The categories are displayed with all the information available. The user can select any of these land use categories and associate them with geographical features through a friendly user interface. The geographical features are associated to land use categories by the object property `hasLandUseCategory` (Feature \rightarrow LandUseCategory). When the user classifies some features, the expression `hasLandUseCategory some C`, where C is the selected category, is added as a type to the corresponding OWL instances of the geographical features selected in the map.

4.2 Advantages Offered by the Reasoning Capabilities

The most popular GIS software tools, such as GRASS GIS⁸ or Quantum GIS⁹, rely on relational databases to represent the information associated with the map parcels, including the land use. In these tools, the information is not semantically related, and so the user has the burden of, for example, maintain the integrity of the information, or develop more complex queries to deal with the relations between the categories. Our tool takes advantage of reasoning over the ontologies and can overcome some of these difficulties. It is important to note that the direct representation of the land use taxonomy (in the previous section) is only the tip of the iceberg. The land use ontology can also contain axioms defining any other relations between the concepts. These axioms will be used by the reasoner and will affect the actions of the user in the tool. This raises interesting possibilities in this domain, some of which will be presented next.

⁷ Metamodeling in Domain Ontologies – http://techwiki.openstructs.org/index.php/Metamodeling_in_Domain_Ontologies

⁸ GRASS GIS – <http://grass.fbk.eu>

⁹ Quantum GIS – <http://www.qgis.org>

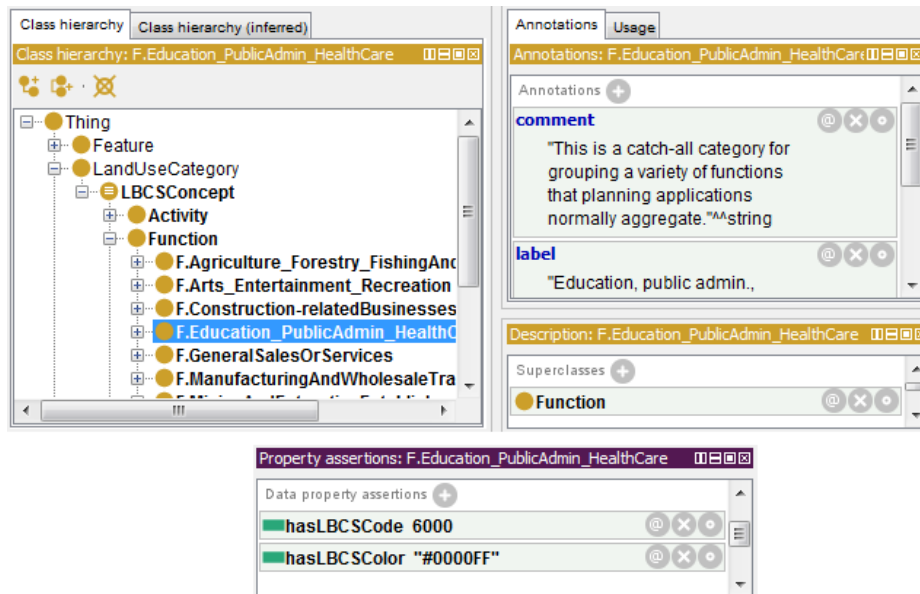


Fig. 2. A screenshot of Protégé, showing the LBCS ontology [8], extending the land use skeleton ontology. The classes (left) in bold belong to the LBCS ontology, the others belong to the LandUseSkeleton and CoreGIS ontology. The bottom image shows the data properties assertions that are made in the punned individual of the selected class.

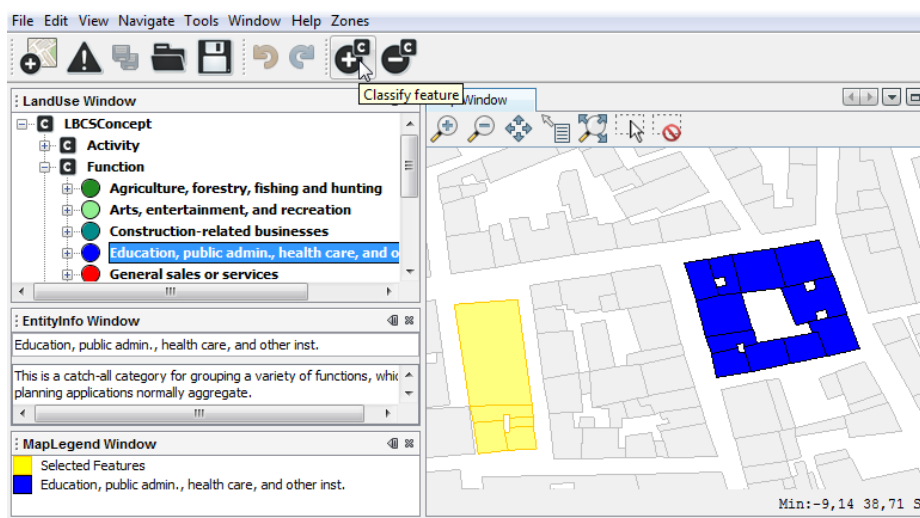


Fig. 3. A screenshot of the tool. One land use category is selected (left), displaying in the map (right) the features with that category. It shows some features selected in the map (in yellow), and the user classifying them with the selected category. For the selected category, it is shown the respective color, full name and description (left).

Finding the features with the selected category The most obvious use of reasoning is to find which features are directly or indirectly categorized with a given category. This is achieved by asking the reasoner for the instances of `hasLandUseCategory some C`, where `C` is the category. Note that this scheme deals perfectly with hierarchically organized land use categories, for example if we asked for Educational Services, we would also obtain features categorized with College, High School, etc. The features belonging to the selected category are then coloured in the map according to the `hasColor` property of its category.

It is also possible to conceive more general queries, such as asking for all the features that have a defined Function (using the example of LBCS, Figure 2). This highlights in the map features with many different and disjoint sub-categories. Each of these features is coloured according to the color of its sub-category, resulting in a multi-colour map, useful for land use analysis.

Automatic categorization (inference) Automatic categorization of some geographical features can be achieved through the use of equivalent classes axioms. We could for example state that all the features that have both the category `ResidenceFunction` and `PrivateOwnership` should be categorized (are equivalent to) as `PrivateResidential`. These equivalences can be anything else, including universal and quantifier restrictions, and expressions that are not related to the land use standard itself, but some other property of the geographical feature. This scheme can also be used to make correspondences between categories of different land use systems.

Consistency checks Through the creation of some equivalent (defined) classes and disjoint axioms it is also possible to express some restrictions and incompatibilities that will allow a more robust and error free classification. For example, we can express that a School cannot also be a Hospital by specifying that the classes `SchoolFeature` (equivalent to `hasLandUseCategory some School`) and `HospitalFeature` (equivalent to `hasLandUseCategory some Hospital`) are disjoint. Whenever the user classifies geographical features in the application, the consistency is checked by the reasoner. If the ontology becomes inconsistent, that classification is immediately removed in order to revert the ontology to a consistent state. The features that were the cause of the inconsistency are also highlighted on the map, so the user can understand its error.

5 Conclusion

We have presented 4CitySemantics, a tool for urban planning based on semantic web ontologies. Using the tool, the participants in the urban development process may semantically annotate the intervention site with knowledge about the use of the land. We show that ontologies can be useful when dealing with this type of information and can offer some advantages over the more traditional tools, for example the inference and consistency checks offered by the reasoning.

We have shown how extensible OWL ontologies can be used to create a flexible application, which adapts its behaviour based on an ontology that is provided by the user. Despite using external ontologies, the application can integrate seamlessly with them, and provides a user interface that hides the implementation details of the ontologies. Following this principle, 4CitySemantics was designed to be independent of urban semantic standards, being easily adaptable to different standards.

The development of the tool was followed closely by urban planning architects, the target of our application, and people familiar with geographic information systems. It was also presented to people outside of the project. The users considered the tool very interesting, and stressed that the possibility of using any land use standard was important. Despite some initial scepticism from the users familiar with the traditional GIS tools, they were pleased by the reasoning capabilities offered in 4CitySemantics. It could effectively tackle problems they had when working with the traditional tools, for example when dealing with hierarchical land use taxonomies.

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