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A web-based application to support the interaction of spatial and semantic representation of knowledge

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Abstract. The visualization of semantic information provides new ways for knowledge acquisition and access, since it enables users to explore and understand the meaning of information, as well as to identify associations among data and connections to existing knowledge. Maps on the other hand are extensively used as symbolic representations of spatial reality. Lately, researchers have delved deeper into formalizing the connection between the map and the semantics it conveys using knowledge-based formalisms such as knowledge graphs, ontologies, and linked data. Semantic visualization techniques may also enrich maps with the knowledge immanent therein and support knowledge visualization and exploration.

The present paper describes the development of a web-based prototypical application that contains a spatial and a semantic component that interact. In addition to the representation of geospatial entities as cartographic features, the graph-based representation of semantic information is also implemented, to enable users to explore and understand the meaning and semantic relations between concepts and entities that appear on the map.

Keywords. semantic representation, spatial representation, ontologies, maps, geospatial semantics

1 Introduction

The integration, search, and retrieval of geospatial information pose major semantic challenges, especially in the context of the Semantic Web, since the lack of semantics may lead to misunderstanding the meaning of information (Decker et al. 2000; Fellah 2015; Huang and Harrie, 2020). Knowledge representation approaches are used to support the formalization, explication, and disambiguation of information. The visualization of semantic information (Nazemi et al., 2015) may also provide new ways for knowledge acquisition and access, since it enables users to explore and understand the meaning of data, as well as to identify associations among data and connections to existing knowledge.

On the other hand, maps are extensively used as symbolic representations of spatial reality. As a result of the arising of Web 2.0 and the development of web mapping technologies, geovisualizations and interactive maps today facilitate the perception of spatial entities and phenomena, as well as their interrelations and interactions in space and time.

Lately, knowledge-based formalisms such as knowledge graphs, ontologies, and linked data have been used to enrich geovisualization knowledge (Varanka and Usery, 2018; Huang and Harie, 2019), to create narrative maps (Mai et al., 2021) and to improve the interoperability across heterogeneous datasets, easing dataset publishing (Regalia et al., 2018). In this context, maps do not only consist in a representation of spatial data, but provide access to the knowledge that is immanent therein.

The present paper describes the development of a web-based prototypical application with a spatial and a semantic component that interact. In addition to the representation of geospatial entities as cartographic features, their semantic representation through ontologies is also implemented, to enable users to explore and understand the meaning and semantic relations between concepts and entities that appear on the map (Fig. 1). The implementation of the application is based on the Leaflet library, an open-source JavaScript library for interactive maps, and the D3 library, suitable for data visualization, but also for establishing the connection and interaction between spatial and semantic information.

The paper is organized as follows. Section 2 presents the related work regarding the formalization of map semantics using knowledge representation. Section 3 describes the design and functionality of the prototypical application for the representation and interaction of geospatial and semantic information. Finally, section 4 discusses conclusions and future work.

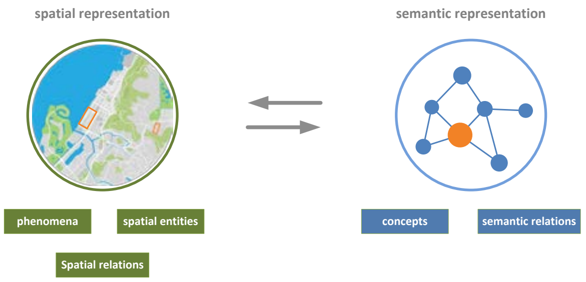

Figure 1. Interaction of spatial and semantic representation

2 Related work

Ontologies have been widely used to semantically formalize, integrate, and enrich spatial data. Ontologies have also been developed to formalize several aspects of cartographic knowledge, such as map generalization (Gould and Mackaness, 2016; Touya et al., 2014; Yan et al., 2017) and contour semantics (Hahmann and Usery, 2015).

Lately, researchers have delved deeper into formalizing the connection between the map and the semantics it conveys. Maps portray features which belong to classes or categories: a particular map feature is not described individually, but in the context of the category it belongs (Keates, 1996).

In this context, Varanka and Usery (2018) focused on the concept and implementation of a map as a knowledge base to enable its interpretation by humans and machines and provide access to the inherent knowledge. In this perspective, the map is viewed as a synthesis of not only data and design principles, but also as an amalgamation of semantic propositions and logical categories that create a body of knowledge organized as a map.

Huang and Harrie (2020) developed a prototype that combines geospatial linked data with ontologies and semantic rules that formally represent knowledge regarding three key aspects of geovisualization: cartographic scale, data portrayal and geometry source. This knowledge-based approach aims to support inferences on the visualization of spatial data and provide rich semantics to users through a semantically enriched legend.

Hu et al. (2015) designed a prototypical linked-data-driven web portal to support semantic search for ArcGIS Online. The process is supported by an ontology based on the ArcGIS Online schema and used two semantic annotation systems for the semantic extraction of entities and classes from map metadata, titles and descriptions.

Mai et al. (2021) developed a set of knowledge graph-based GeoEnrichment toolboxes and proposed a modular ontology to formalize the map content and the geovisualization process for narrative cartography. They argue that by representing both the map content and the geovisualization process in Knowledge Graphs, the data acquisition and integration challenge, and the semantic challenge of conventional narrative cartography may be overcome.

Web-based tools for the exploration and visualization of linked geospatial data include Map4RDF and Sextant. Map4RDF is a mapping tool for the exploration, visualization, and interaction with RDF datasets enhanced with geometrical information (Leon et al. 2012). Sextant is a web-based tool for the visualization and exploration of linked spatio-temporal data and for the creation, sharing, and collaborative editing of spatio-temporal thematic maps (Nikoalou et al., 2015). Both use GeoSPARQL for modeling and querying the geometry of spatial data.

The present paper presents a prototypical web-based application in which an ontology represented as a semantic network enriches spatial data on land cover with semantic information to promote deeper understanding and reuse of map content. The visualization of the ontology as a semantic network constitutes an alternative semantic representation of the map content and functions supplementarily to the traditional map legend.

3 Application design

3.1 Spatial representation of information

The web application includes a spatial and a semantic component that interact. The spatial component consists of a map with OpenStreetMap tiles as a basemap layer that depicts our area of interest, the Greek island Andros, in which spatial entities are represented such as rivers, arable land, grassland areas, bush areas, and orchards. The open-source JavaScript library Leaflet is used to support interactivity and navigation functionalities such as zooming and panning on the map. Leaflet is also used to create a table of contents that contains the available layers that exist in the map and from which the user can select which one to activate. The data represented on the map are in GeoJSON format, which, in combination with Leaflet library, offers various functions such as filtering specific features, defining their style either for all or for some of their properties, as well as showing additional information of the elements through a pop-up window (Fig. 2).

3.2 Semantic representation of information

The web application also features a graph-based semantic representation of geospatial information. More specifically, the Environment Ontology (EnvO) (Buttigieg et al, 2016) is used to explicate the meaning of geospatial concepts and their-between semantic relations. EnvO is an expressive, machine-readable knowledge representation of environmental entities, such as ecosystems and environmental processes, used for data and metadata annotation. The ontology includes definitions of environmental concepts and various semantic relations, e.g., subclass-of, part-of, has-part, located-in, adjacent-to, continuous-with, etc. It also includes mappings to linked data sources, such as Wikipedia and other related ontologies and computational lexicons. Fig**.** 3 shows the graph view of the EnvO concept ‘water body’ with the associated concepts and their interrelations. The application includes a visualization of the ontology in the form of a semantic network, which was created as a graph layout, using the D3 library.

Figure 2. Pop up window with additional information about the selected element

3.3 Linking and interaction of spatial and semantic representation of geospatial knowledge

The linking and interaction of the spatial with the semantic component of the application is achieved through a series of functions developed using the JavaScript programming language.

Initially, after creating the map and inserting the spatial entities in GeoJSON format, functions provided by Leaflet library were created to support the connection and interactivity of the spatial representation with the graph-based semantic representation. By clicking on each spatial entity on the map, the user may explore the semantic information of the selected entity through the semantic network which appears on the right side of the application (Fig. 4).

D3 library offers features to load data described in JSON format and display them in various ways. It requires a well-defined structure of the JSON object, and in our case, the creation of the semantic network in the form of a D3 graph with nodes and links. To achieve this, a subset of the EnvO ontology was converted into json files, with the proper structure for D3 library, that constitute the graph-based semantic information. Afterwards, each JSON file was inserted in the map and functions that define the format of the graph, nodes, and links, as well as their labels were created to enable users to have a parallel representation of spatial and semantic information.

The semantic network shows the concept that the spatial entity belongs to, as well the relationships of the selected concept with other concepts in the ontology which are illustrated with a legend. For example, the concept ‘area of cropland’ is associated with an IS-A relation to the concept ‘vegetated area’, with a PART-OF relation to the concept ‘cropland ecosystem’ and with an ADJACENT-TO relation to the concept ‘atmospheric boundary layer’.

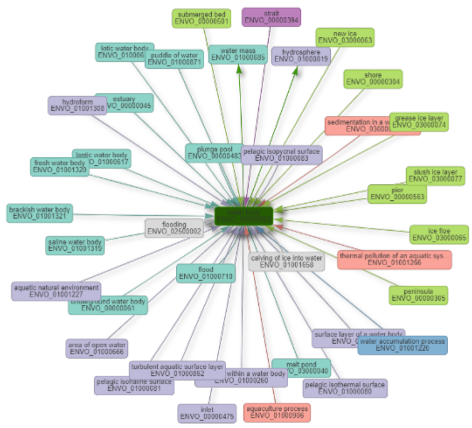

Figure 3. Graph view of the EnvO concept ‘water body’ with the associated concepts and their interrelations (https://www.ebi.ac.uk/ols/ontologies/envo/terms/graph?iri=http://purl.obolibrary.org/obo/ENVO_00000063)

If the relation between the concepts is the same, then the links and the corresponding nodes have the same color. For example, in Fig. 5 the IS-A relations have blue color. The arrows of each link indicate the direction of the relationship. By clicking on a concept of the semantic network, its definition also appears (Fig. 5).

3.4 Data and Software Availability

The prototypical application is available at http://cybercarto.ntua.gr/annotation/. To implement this application several tools have been used, such as those described in the above sections. For the spatial data, we have used synthetic data from Corine Land Cover for the island of Andros. The EnvO ontology is available publicly online at https://obofoundry.org/ontology/envo.html. All JSON files used for implementing the application and supporting this publication, are available on figshare and are accessible via the following DOI: https://doi.org/10.6084/m9.figshare.19635288.v1.

4 Conclusions

Maps portray not only spatial features but also the categories in which those features belong. Categorization is a fundamental cognitive process for human thinking and learning. The formal representation of the semantics of these categories may deepen the understanding and enable the reuse of map content. Ontologies and other knowledge representation formalisms have been used to formalize the semantics of spatial information and support knowledge representation and integration. Semantic visualization techniques may provide an alternative way to enable users explore knowledge, comprehend the meaning of spatial concepts and discover their associations with other concepts.

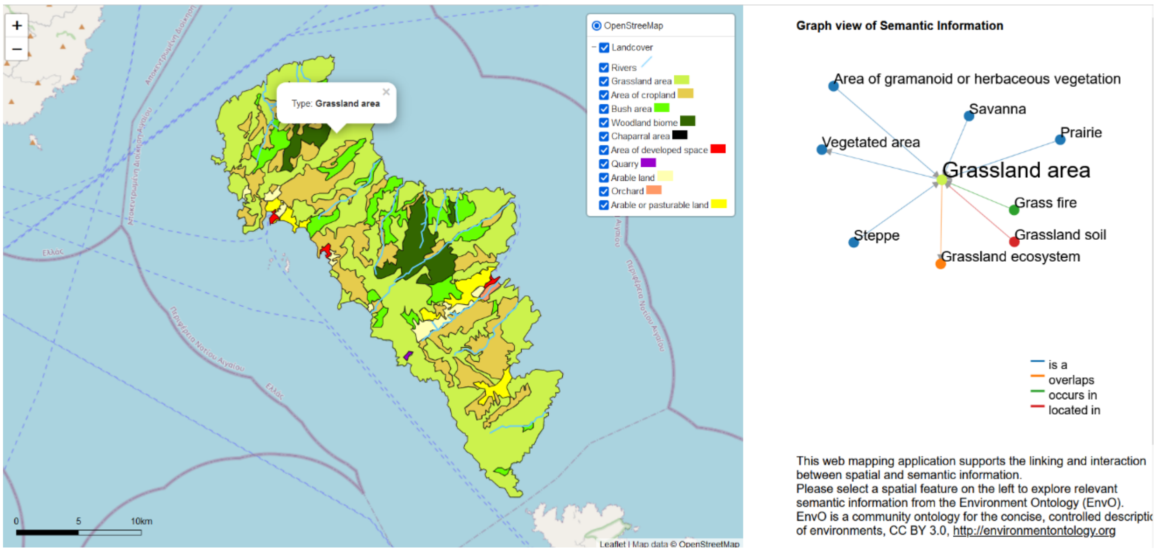

Figure 4. The parallel visualization of the concept "grassland" with its spatial manifestation (left) and its semantic network (right)

The present paper described the development of a web-

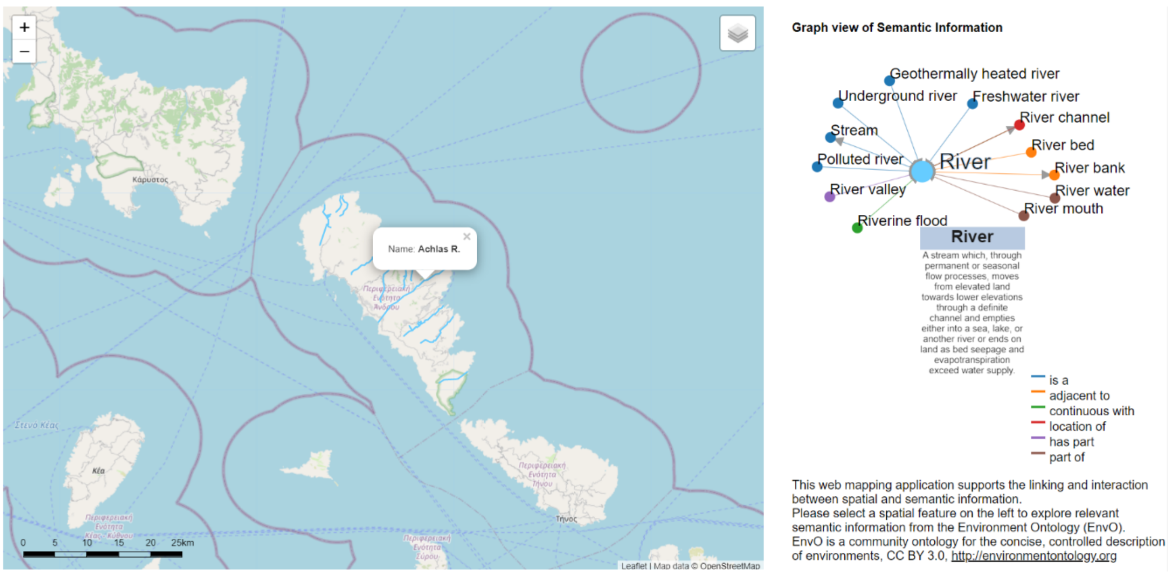

Figure 5. The spatial element 'river' with its semantic network. By clicking on the concept its definition appears

based prototypical application that enables the linking and interaction of spatial and semantic representation of knowledge. The semantic representation is achieved through a graph-based visualization of ontological knowledge that acts as the semantic legend of the developed application.

The enrichment of the application with additional spatial and semantic information (e.g., by displaying associated instances to visualize the relationship between concepts and instances) and interaction capabilities could further enable the user to gain a deeper understanding of the knowledge immanent in the map through the graph-based semantic visualization. However, the empirical evaluation of the application by users of different levels of expertise is an important step to investigate the complexity of such a visual representation and the degree to which users are able to successfully interact with the spatial and semantic components.

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