Towards Semantic Enablement for Spatial Data Infrastructures

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Abstract. Based on abstract reference models, the Open Geospatial Consortium (OGC) has established standards for the storage, retrieval, and processing of geographical information. These standards act as foundation for the implementation of concrete services and Spatial Data Infrastructures (SDI). Research on geo-semantics plays an increasing role to support complex queries and discovery across heterogeneous information sources, as well as for on-the-fly integration and semantic translation. So far, existing approaches only target individual solutions or focus on the Semantic Web, leaving the integration with SDI aside. What is missing is a common semantic enablement layer for Spatial Data Infrastructures which also integrates reasoning services from the Semantic Web. Focusing on Sensor Web Enablement (SWE) we outline how Spatial Data Infrastructures can benefit from such semantic enablement layer.

1 Motivation

Developing and deploying Spatial Data Infrastructures based on OGC services is attractive for two reasons. First, these services are well standardized and their implementations can be tested for conformity. Second, the OGC has defined a top-level interface standard called OWS Common [1] defining many aspects that are shared by multiple OGC Web services. Regular test-beds investigate, report on, and discuss the interoperability between specific services. Both points ease the integration of services into Spatial Data Infrastructures, make them more adaptable and reusable, as well as form the basis for their orchestration [2].

Services, however, are not built for their own sake but to encapsulate data or processing models. To exchange information between services, i.e., to make them interoperable, they have to share common schemas or define mappings between them. For instance, if one processing service requires a wind direction string as input and was developed with a *wind blows from* conceptualization in mind, a second service delivering wind information as strings but based on a *wind blows to* conceptualization can still act as input source [3]. The OGC standards guarantee interoperability on a syntactic level. Services can exchange information if they agree on names and data types for their inputs, outputs, and functions. Whether the information from one service can be interpreted in a meaningful way by another service is not covered. For instance, a Web Processing Service (WPS)

[4] can be used to compute the dispersion of a gas plume caused by a factory fire based on wind direction measurements delivered by a Sensor Observation Service (SOS) [5]. Both services need to share a common understanding of wind direction to generate meaningful results [3,6]; otherwise the simulated dispersion would point exactly in the opposite direction. Consequently, the challenge is to establish semantic interoperability, i.e., the ability of services to exchange information in a meaningful way with a minimum of human intervention [7][1].

2 Semantic Enablement Layer for OGC Services

Over the last years, work on geo-semantics has focused on several challenges towards establishing semantic interoperability between (OGC) services. This includes fundamental work on the role of ontologies in GIScience [8], the vision of semantic reference systems and grounding of geographical categories [9,10], semantics-based and context-aware retrieval of geographic information [11,12,13], as well as work on Semantic Geospatial Web services [14] and their chaining [15]. This research has lead to several new services and tools such as ConceptVISTA[2] for ontology creation and visualization, the SWING Concept Repository[3], the SIM-DL similarity server and Protégé plug-in[4], or the semantically-enabled Sensor Observation Service SemSOS [16]. In contrast to classical work on SDI, these new services do not share a common interface and hence are island solutions that lack a binding to each other and partially also to classical OGC services. For instance, the Pellet reasoner or the SIM-DL server can infer new information about geographic feature types, using the Description Logics Interface Group (DIG) protocol for communication and the Web Ontology Language (OWL) for knowledge representation. In contrast, OGC services such as the Web Feature Service (WFS) which could be chained with these reasoners use GetCapabilities requests and the Geographic Markup Language (GML). Semantics-based information retrieval, on-the-fly integration, and semantic translation all require a horizontal and vertical Semantic Enablement Layer (SEL) for OGC services.

Three challenges have to be considered: (1) How to link data encodings and service protocols to formal specifications stored within ontologies? (2) How to manage and maintain these ontologies? (3) How to incorporate reasoning services known from the Semantic Web?

1. Data encodings such as SensorML or service operations such as GetCapabilities describe the functionality and data offered by a specific OGC service. This includes sensor inputs and outputs in case of SensorML, and a list of contained geographic feature types in case of a Web Feature Service's capabilities document. In most cases, these descriptions only consist of plain-text

[1] This is still a working definition as it does not define when a combination of data is considered to be *meaningful*.

[2] http://www.geovista.psu.edu/ConceptVISTA/

[3] http://purl.org/net/concepts/

[4] http://sim-dl.sourceforge.net

or syntactic data type definitions in GML. A first step towards semantic enablement is to annotate these elements of the General Feature Model [17]. Semantic annotation links them to the according classes specified within ontologies. Recently, Maué et al. [18] proposed a methodology for the annotation of OGC services.

2. While annotations establish the links to classes and relations in ontologies, these ontologies need to be stored and managed in repositories. Typically, ontology repositories act as an interface offering access and URL resolution as well as auxiliary services for querying, visualizing, versioning, and comparing the stored definitions[5]. With regards to SDIs built on OGC services, a decomposition of the functionality into separate services would be more appropriate (comparable to the separation of WFS and WMS). In conformity with Lieberman et al. [19] and Stock et al. [20], we argue that such a Web Ontology Service (WOS) should be considered as a profile of the OGC Catalogue Service [21]. A WOS could store definitions from multiple domains ranging from geographic feature types over types of observations, to sensor types. In case of the gas plume example, a particular WOS could store feature types such as *factory*, *natural reserve*, and *inhabited place*, as well as sensor types such as *anemometer*. By providing access to the formal specifications, a WOS supports a semantic mapping between sensor outputs and the properties of features of interest when registering new sensors or adding their observations to a Sensor Observation Service [6]. Additionally, a WOS can be used as semantically-enabled catalogue to facilitate information retrieval beyond simple keyword search [11,12].
3. While a WOS encapsulates the ontology, a second service should encapsulate the reasoning components developed as core parts of the Semantic (Geospatial) Web. Reasoning services are not restricted to subsumption reasoning, but include non-standard inference such as finding the most specific concept, least common subsumer, similarity reasoning [11], as well as context-aware instantiation based on SWRL rules and built-ins [13]. We argue that such a Web Reasoning Service (WRS) should be developed as a profile of the Web Processing Service specification [4]. With respect to Sensor Web Enablement, a WRS could be used to discover appropriate sensors using a feature of interest as query [6]. For instance, a semantically-enabled SDI could automatically choose and register sonic anemometers if the user is interested in data on the dispersion of a gas plume. In case of semantics-based retrieval of feature types [12], the WRS would give the necessary reasoning power to the Web Ontology Service.

Defining ontology repositories and reasoning services as profiles of existing OGC services instead of creating new services from scratch facilitates the integration with existing SDI technologies and simplifies service orchestration. As WRS and WOS have to follow the OWS Common specification, a major challenge is the mapping between the protocols and representation languages used

[5] Examples of repositories and collaborative tools include work by the Open Ontology Repository Initiative, the NeON Cupboard, OwlSight, Web Protégé, or OWLDiff.

on the Semantic Web and the OGC world. For instance, since the WRS should encapsulate Semantic Web reasoners and make them accessible for SDIs, it has to map in both directions between *DIG tells and asks* calls on the one side and GetCapabilities request and GML on the other side[6].

3 Outlook

In this paper, we outlined the need for a Semantic Enablement Layer for OGC Web services. We argued that such a layer is a prerequisite for semantics-based information retrieval tailored to the user's context, translation, the orchestration of sensors and Web services, and finally semantic interoperability. Three steps towards establishing a SEL have been identified. First, data encodings and service protocols have to be linked to formal specifications stored in ontologies. Second, a service has to be established for managing and maintaining these ontologies. Third, a service has to encapsulate Semantic Web reasoners to integrate them into SDIs. While we focused on introducing the need for and components of the Semantic Enablement Layer, the reference implementation of the WOS and WRS is part of the 52°*North* semantics community[7]. Currently, our work on the WRS focuses on the encapsulation of the SIM-DL similarity server to make it accessible for OGC services such as the WFS. A semantic annotation API is developed in the *sapience* project[8].

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[6] If the WRS should also encapsulate other ontology languages and their reasoning services, such as WSML and IRIS, it has to implement additional mappings.

[7] http://www.52north.org/semantics

[8] http://purl.org/net/sapience/docs/

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