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Full Length Research Paper

Semantic web services for implementing national spatial data infrastructures

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Either the business model or the requirements of "Sustainable Development" has rendered collaboration indispensable today. Spatial data infrastructures (SDIs) are widely accepted as the way of enabling collaboration among various parties. An SDI can be realized as an "interoperability infrastructure" which enables government, private sector, academia, and others involved to collaborate by allowing the usage of "data" and "services" of each other. Since there may be various parties involved, building and maintaining an SDI is an ambitious task. The two sub-infrastructures, "technological" and "institutional" ones of an SDI are need to be worked out. The interest of this work is to assess the potential of semantic web services (SWS) for the technological interoperability infrastructure of SDIs. For this aim, an SDI use case was implemented with SWS. It has been found that SWS are not mature enough yet for SDIs. However, they need to be researched further to be employed in the implementation of SDIs.

Key words: Spatial data infrastructures, semantic web services, interoperability, integrated coastal zone management.

INTRODUCTION

There are numerous definitions of SDI in the related literature. As one of the most concise explanation of the concept behind a national SDI, OMB (1992) defines the U.S. National Spatial Data Clearinghouse as "an electronic service providing access to documented spatial data and metadata from distributed data sources". Public and private sectors, local governments, universities, citizens and all others who somehow deal with spatial data that would be able to access the data available via the Clearinghouse. However, an SDI involves more than a clearinghouse.

In our view, an SDI has two "sub" interoperability infrastructures. These are "technological" and "institutional" ones. Technological interoperability infrastructure defines the Information and Communication Technologies (ICT) involved. Institutional interoperability infrastructure defines the rights and responsibilities of the stakeholders of an SDI. Institutional infrastructure will also define the rules and mechanisms for building and maintaining an SDI. Involved issues would be the ones related to collecting and updating of the data, quality assurance of the data, private sector role, pricing, value-added pricing, ownership, privacy, security of the data. The interest of this work is in the technological infrastructure. Therefore, from now on "interoperability" refers to technological interoperability.

Assuming an ICZM officer who wants to perform a "site-selection" for marine aquaculture in a geographical region, she would collect all the data needed from SDIs either local or national, in perhaps real-time and perform the application. Interoperability involves resolving heterogeneities in the definition and representation of the data and services. Definition may be different due to both content and context (semantics). For instance, concerning the "number of lanes" attribute of the "road" definitions of two different software systems, the attribute

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Abbreviation: SWS, Semantic web services; **SDIs,** spatial data infrastructures; **ICT,** information and communication technologies; **ICZM,** integrated coastal zone management; **SOA,** Service Oriented Architecture; **W3C,** world wide web consortium; **WSDL,** web services definition language.

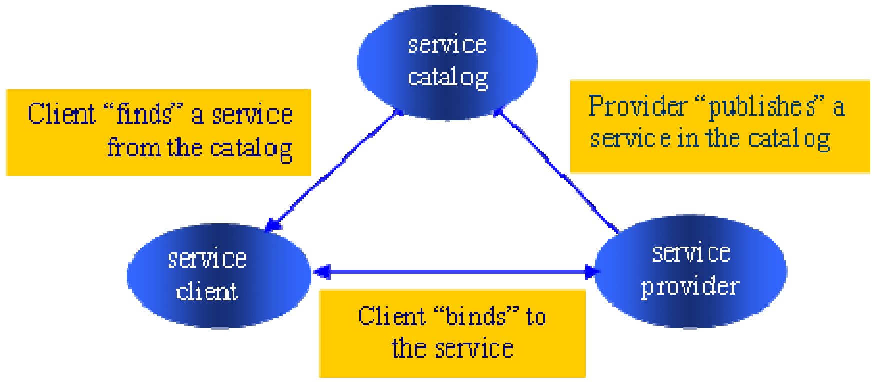

Figure 1. The vision of service oriented architecture (SOA).

may be totally missing in one of the systems, named differently (e.g. "nof-lanes" and "lanes") or represented differently in the two systems. Considering representation, the spatial data may be represented as in either "raster" or "vector" form. A "polygon", for instance, may be represented as a list of line segments or as a list of coordinates, both of which forming the polygon's boundary. Coordinates may be represented in different coordinate systems, in different units etc.

Building and maintaining of an SDI is an ambitious task. INSPIRE documentation (EC, 2004) may be perceived as a sign of the complexity of the task. Besides, there is not an accepted methodology for this task. At a general level it can be said that the two sub-infrastructures, "technological" and "institutional" ones of an SDI are need to be worked out. The interest of this work is the implementation of technological interoperability infrastructure.

There are two options for this implementation. The one is the prevalent, "syntactical" one and the other is the emerging "semantic" one. An SDI use case implementation of the syntactical option was already performed in an earlier work (Cömert and Akıncı, 2003) of the authors. Therefore, an SDI use case, related also to Integrated Coastal Zone Management (ICZM) has been chosen and implemented using SWS in this work.

MATERIALS AND METHODS

Materials

Web services and semantic web services

Web services (WS) have emerged as the most popular implementation (McGovern et al., 2003; Colan, 2004; Weerawarana et al., 2005) of a vision, called "Service Oriented Architecture" (SOA). The SOA vision is realized by a "publish-find-bind" pattern, in which service providers publish their services in service catalogs, service clients find required services from the catalog which points out the providers for "matching" services. Client then requests (bind) the actual service from the provider (Figure 1). If a single service cannot do the "job" for the client then a "service composition" is needed. In that case, a number services with perhaps different providers, are combined into a composite service.

World Wide Web Consortium (W3C), one of the main bodies for setting the standards for WS defines a Web Service as "a software application identified by a URI whose interfaces and binding are capable of being defined, described and discovered by XML artifacts and supports direct interactions with other software applications using XML based messages via internet-based protocols" (W3C, 2002). With a simplifying view, a web service can be perceived as a piece of program code accessible over the Web.

In the SOA vision client does not care about the heterogeneities of the provider as long as the client can communicate with, request data from, and use the code of the provider. This is what makes interoperability much easier to achieve than its traditional practice. There are contributors in this scene though. One of them is XML (extended markup language) which is the communication language of the architecture. The data, services, and communication messages are defined in XML. Therefore, the interoperability provided is sometimes called "consensus based interoperability". Concerning spatial data, it has not been possible to agree on a common data definition over the years. The consensus over a language provides a great degree of reusability. One example is the reusability of XML tools like XML parsers. Another example would be XSLT (Extensible Stylesheet Language Transformations) (W3C, 2007). In defining a transformation between two XML documents by an XSLT document, pre-existing XSLTs may be re-used to develop translators easily on demand. For the definition of Web services there is Web Services Definition Language (WSDL). WSDL is an XML based interface definition language. It defines the service interface, namely the types of input and output parameters and the binding details including the style of interaction. To be able to call a service the user must know its interface.

Finally, for cataloguing of Web services there are service catalogs like UDDI (Universal Description Discovery and Integration) (UDDI, 2004) and ebXML (electronic business using XML) catalogue service (OASIS, 2004). Web services are advertised in these catalogs according to the "information model" of the catalogue. Information models determine the "service metadata" which is indeed a sign of "semantic richness" of service definition. Concerning the geospatial data and services arena, the language of consensus to define data at the moment is GML (Geography Markup Language). GML is an XML based language to define the geometry of geographic objects. GML does not define geographic objects like roads or rivers. Geographic objects are defined through GML application schemas (Lake et al., 2004). Common application schemas may be developed over GML to make things easier in a certain domain. One such example is CSML (Climate Science Mark-up Language) which has been developed to cover the data definitions of five marine communities (Millard et al., 2005). Concerning the standard setting organizations in the area, there are two major bodies. One of them is Open Geospatial Consortium (OGC) and the other is International Standards Organization Technical Committee 211 (ISO TC211). OGC defines Web services like WMS (Web Map Service), WFS (Web Feature Service), CSW (Catalogue service Web) and some others which do not need to be listed here concerning the scope of this work. CSW employs either ebRIM (ebXML Registry Information Model) (OGC, 2004), or ISO TC211's 19115 for the data and 19119 for the services as its information model (OGC, 2005).

XML, GML, WSDL, UDDI, ebXML, and many others alike are all the provisions for the current, "syntactic" or "human oriented", Web. That is, human intervention is needed to interpret the meaning of "words" or "syntax". In other words, the "semantics" have to be reasoned by the human user. There are a number of problems with this approach. First of all, the discovery is difficult. Concerning the discovery from number systems, the user has to know either all the "semantics" (that is, meaning of schemas) of the systems or just "canonical semantics" (that is, meaning of a "common schema"). The former is the style of OGC Web services. In the case common schema, schema mappings have to be defined and maintained by human intervention. After somehow getting the discovery results the human user again has to know how to combine them into her system to perform the eventual task. This is very difficult on the side of user, time consuming and expensive in general. Besides, it is very difficult to scale when there are new semantics involved.

Due to these problems semantic web (SW) has been envisioned. SW is defined in (Lee et al., 2001) as ". Semantic Web is not a separate Web but an extension of the current one, in which information is given a well-defined meaning, better enabling computers and people to work in cooperation. In our view, SWS is meant for an environment where web services are discovered, composed, and executed automatically by the "machine" in performing a certain task. This vision necessitates "machine understandable" descriptions of both services and the data processed by these services. Ontologies, explicit specifications of conceptualizations (Gruber, 1995), are employed for machine understandable definitions. The envisioned through "semantic" or "machine understandable" definitions was also a great degree of reusability through shared ontologies over the web. Ideally, the human intervention would be needed only in defining the "concepts" via ontologies. However, this ideal point is not reached at the moment, and human intervention is still needed in the discovery and composition of web services. Due to the scope of the paper, the provisions for SW will briefly be explained in the implementation section below.

Use case

In this work, an SDI use case, which is also related to ICZM, was implemented using SWS. In the use case, it is intended to show "conflict areas" of environmental resources use in a given geographical region. The region is "Torba Bay" area in Bodrum, Turkey. In choosing such a use case, we were inspired by a recent dispute where the Ministries of Tourism and Environment are against the Ministry of Agriculture who is in favor of the aquaculture farmers in Bodrum, one of the most popular touristic resorts in Turkey. The tourism sector and environmental authorities blame the cages for disrupting tourism and for causing environmental pollution, respectively. The local and central agricultural authorities object to the both claims. The case has been taken to the court by the farmers of the region who won the case in May 2007. It is our argument that if the sites of marine aquaculture had been determined scientifically as part of an ICZM program in the past this dispute might have been avoided today.

Indeed, two use cases were planned to be performed with SW services. In the first one, the purpose was to serve a map which would show "conflict areas" among the uses of marine aquaculture, water sports, environmentally protected areas, marinas, and beaches. The second use case is to perform a "site selection" for the best sites of marine aquaculture using SWS. Leaving the second one for further work, in this work an SWS implementation of the first use case was performed. Though the map served was not a conflict map but a site-selection map which was produced by the work of Bahar (2007). This does not bother the intention for the use case, which was "serving a pre-composed map over internet employing SWS". Instead of pre-composed map, a map produced by web services can also be served, which is a work planned for the future.

In both use cases, the user who is an IZCM officer should be able to use data and services of corresponding providers as in Figure 2. While orange color indicates local SDI, green color is for National SDI membership in the figure.

Methods

For the implementation of the use case, several SW services have been designed and developed. These web services are OMUGazetteerService, BboxCreationService, WMSWrapperService and MarineService, respectively. The "code-first" approach for the development of Web services was chosen and Eclipse WTP (Web Tools Platform)[1] was used as the service development environment. WSO_2[2] WSAS (Web Services Application Server) was used as the Web services deployment environment. WSO_2 WSAS is an application server for Web services. It has been built on Apache Axis2 which is the most popular Web services framework. Eclipse WTP and WSO_2 WSAS are open source products.

"OMUGazetteerService" is a gazetteer service implementation. It has an operation named "getLocation". The getLocation operation takes a city name and a county name as its input and returns a coordinate pair as its output. The returned coordinates are geographic coordinates that shows the latitude and longitude values of the required centre of population.

BboxCreationService has an operation named as *createBbox*. The *createBbox* operation takes geographic coordinates of a point as the input arguments and returns two X and Y coordinate pairs that represent a bounding box created around the input point. The *CreateBbox* operation performs two tasks. First, it transforms geographic coordinates to UTM coordinates. Second, it calculates bounding box coordinates.

WMSWrapperService is a client for an OGC Web Map Service (WMS). It enables the invocation of an OGC WMS service as a W3C Web service by using SOAP protocol. Users invoke the *WMSWrapperService* by using SOAP protocol, and then *WMSWrapperService* invokes the OGC WMS service via HTTP GET method behind the scene. *WMSWrapperService* has an operation named as *getMap*. The *getMap* operation takes bounding box coordinates as argument and returns a jpeg map as a result.

MarineService is an orchestrator which controls the cooperation of other web services to perform the use case scenario. It implements a service chaining. It takes input parameters from users and invokes the *OMUGazetteerService*, *BboxCreationService* and *WMSWrapperService*, respectively. The *MarineService* has an operation named as *getConflictAreas*. The *getConflictAreas* operation takes a city name and a county name as an argument and returns a map as a result. Returned map shows "conflict areas" among the uses of marine aquaculture, water sports, environmentally protected areas, marinas, and beaches. Figure 3 shows UML sequence diagram of service composition.

[1] http://www.eclipse.org

[2] http://www.wso2.com

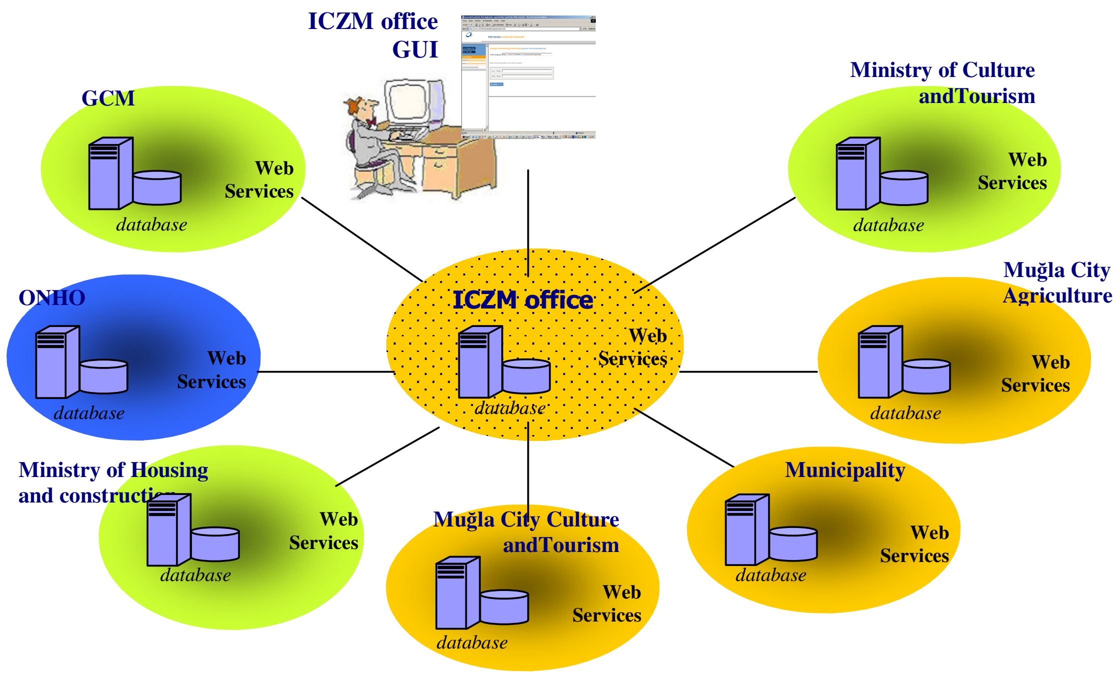

Figure 2. Local and national agencies involved in the use case.

Describing SW services

SW service descriptions were done in OWL-S (Ontology Web Language for Services). OWL-S is OWL based Web Service description language. OWL-S (Ontology web language for services) became W3C Standart in 2004. OWL-S provides automation of specific web services functions like service discovery, execution, composition and interoperability (W3C, 2004). Protege Ontology Editor was used for this task. Protege[3] is an open source ontology editor and knowledge base that is developed by Stanford University. Protege OWL-S Editor Plug-in[4] was also used to describe the services in the OWL-S language. Since one of the objectives of this work was to show that SWS are possible to implement, only two of the services were defined in OWL-S. These were OMUGazetteer service and BboxCreationService.

Publishing SW services

This is the publishing of service descriptions in the service catalog. OWL-S UDDI Matchmaker[5] was used which is the extension of UDDI service catalog with Matchmaker module (Figure 4). Thus, it is possible to search and publish services with their semantic capabilities in UDDI (Srinivasan et al., 2005). With the same justification employed in service description, only OMUGazetter Service and BboxCreation service and an additional GazetteerServicewere published in UDDI Matchmaker. The first two of these services were written by the authors while the last one is a service from http://www.serviceobjects.com[6]. It was wrapped in an OWL-S definition. Parts of these descriptions and the ontologies of their input and output parameters are illustrated in Figure 5.

[3] http://protege.stanford.edu/overview/
[4] http://owlseditor.semwebcentral.org/
[5] http://www.daml.ri.cmu.edu/matchmaker/
[6]http://ws.serviceobjects.com/gcr/GeoCoder.asmx?op=GetGeoLocationWorldwide

Semantic service discovery

Service discovery is meant for searching for the services of required qualities in the service catalog on the basis of services' "metadata". This is where semantic interoperability option differs from the syntactical one. While in the syntactical case a "keyword" based match is applied, in the semantic search a concept based match is employed on the basis of the concepts defined by the ontologies used. Thus, shortcomings of keyword based search are avoided. A keyword-based search can have low recall low precision (Bernstein and Klein, 2002). RacerPro[7] (Renamed ABox and Concept Expression Reasoner Professional) is used as the reasoner of OWL-S UDDI Matchmaker. The matching algorithm recognizes four degrees of match between two concepts. These are "exact", "plugin", "subsume" matches and "fail" if there is no match. Since these are explained in detail in Srinivasan et al. (2005), they will not be repeated here.

Semantic Service discovery performed in this work was the discovery of a gazetter service with respect to the user's query parameters which are input and output parameters of the service required. This discovery is illustrated in Figure 6. Matchmaker finds two gazetteer services and ranks them. These services are *OMUGazetteerService* and *GazetteerService* which had been published in the catalogue earlier. Ranking is performed whether the match is an "exact", "plug-in", or subsumes type of match as mentioned above. Since the query concepts of "point" and "city" fits exactly to the concepts of OMUGazetterService it was ranked higher.

In agreement with this ranking, the user prefers *OMUGazetteer Service* If they exists equally in ranked services then the user

[7] http://www.racer-systems.com/

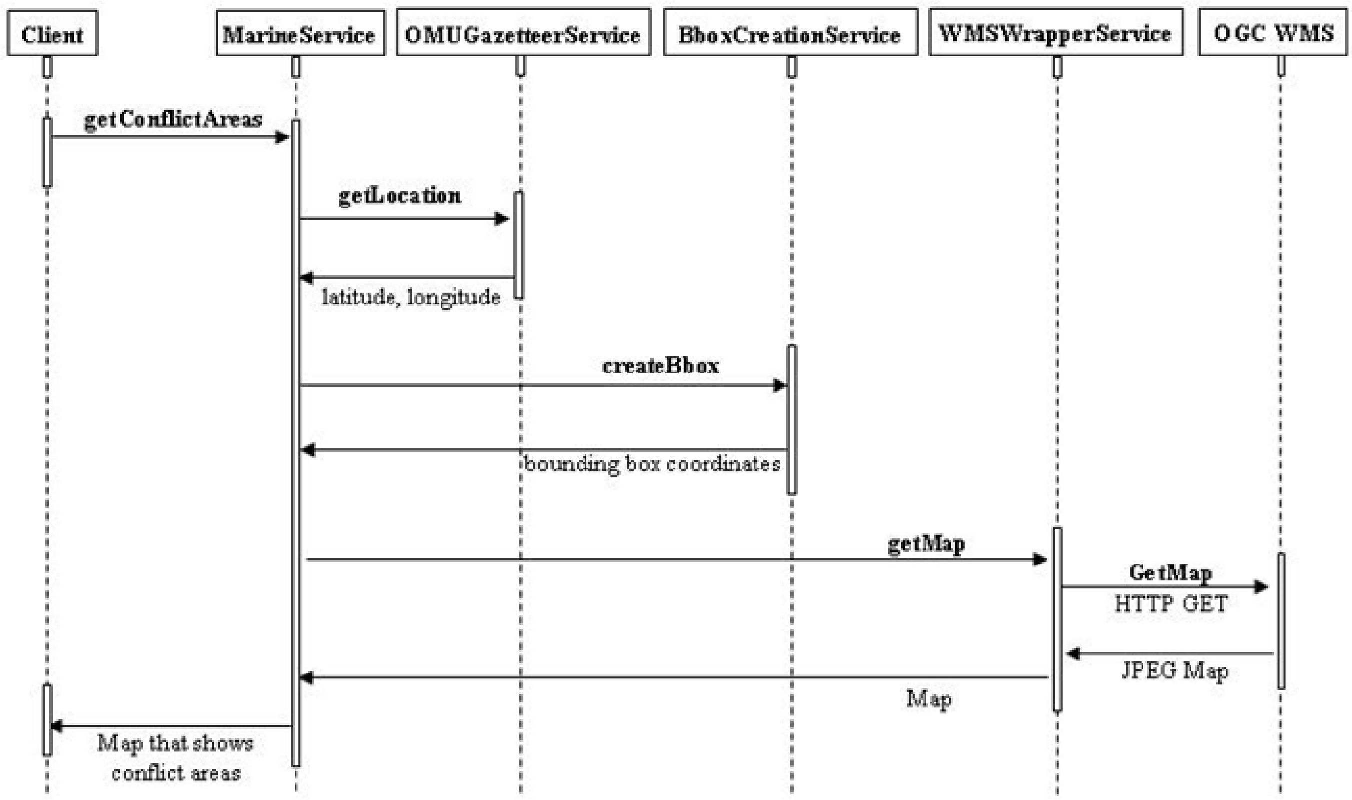

Figure 3. UML sequence diagram of service composition.

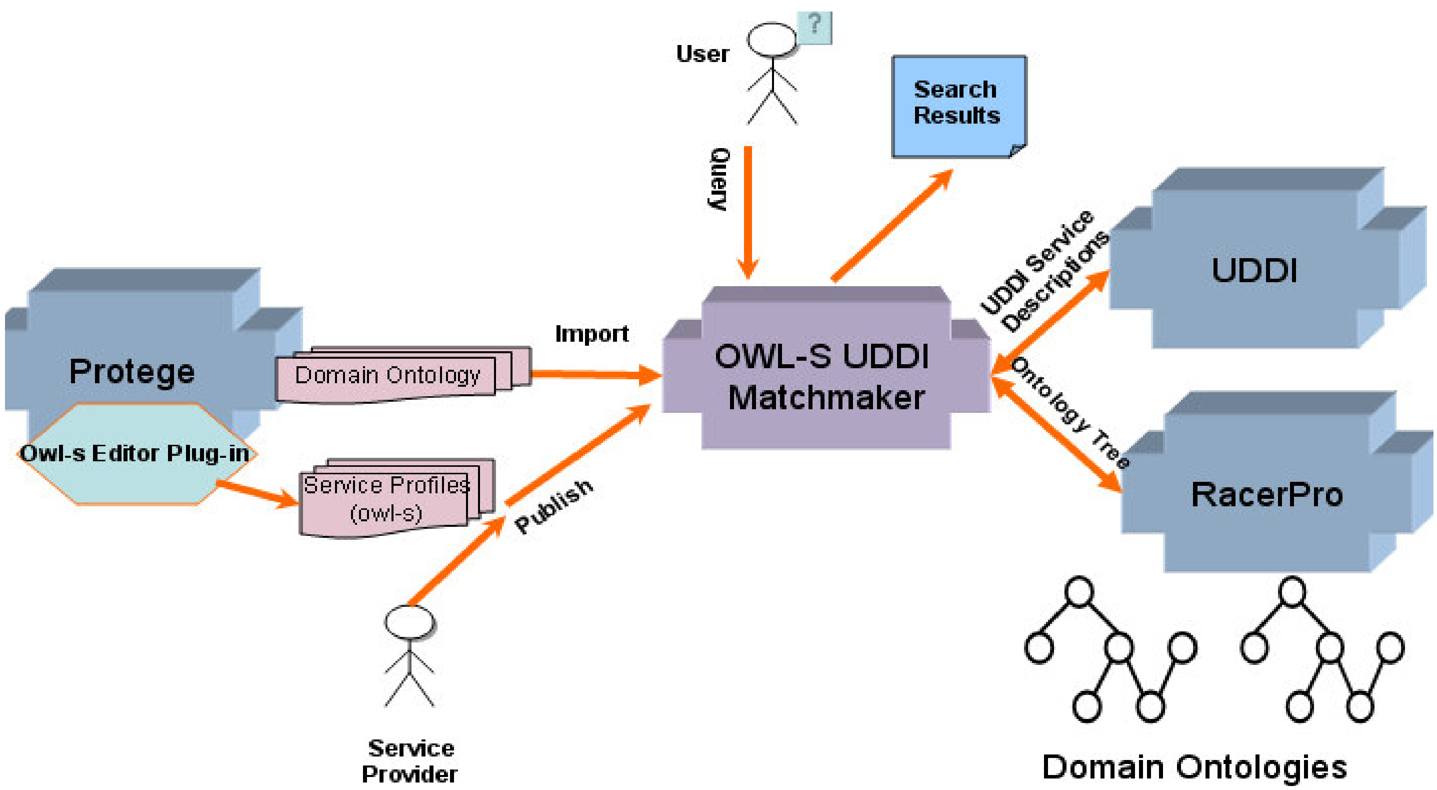

Figure 4. OWL-S UDDI Matchmaker architecture.

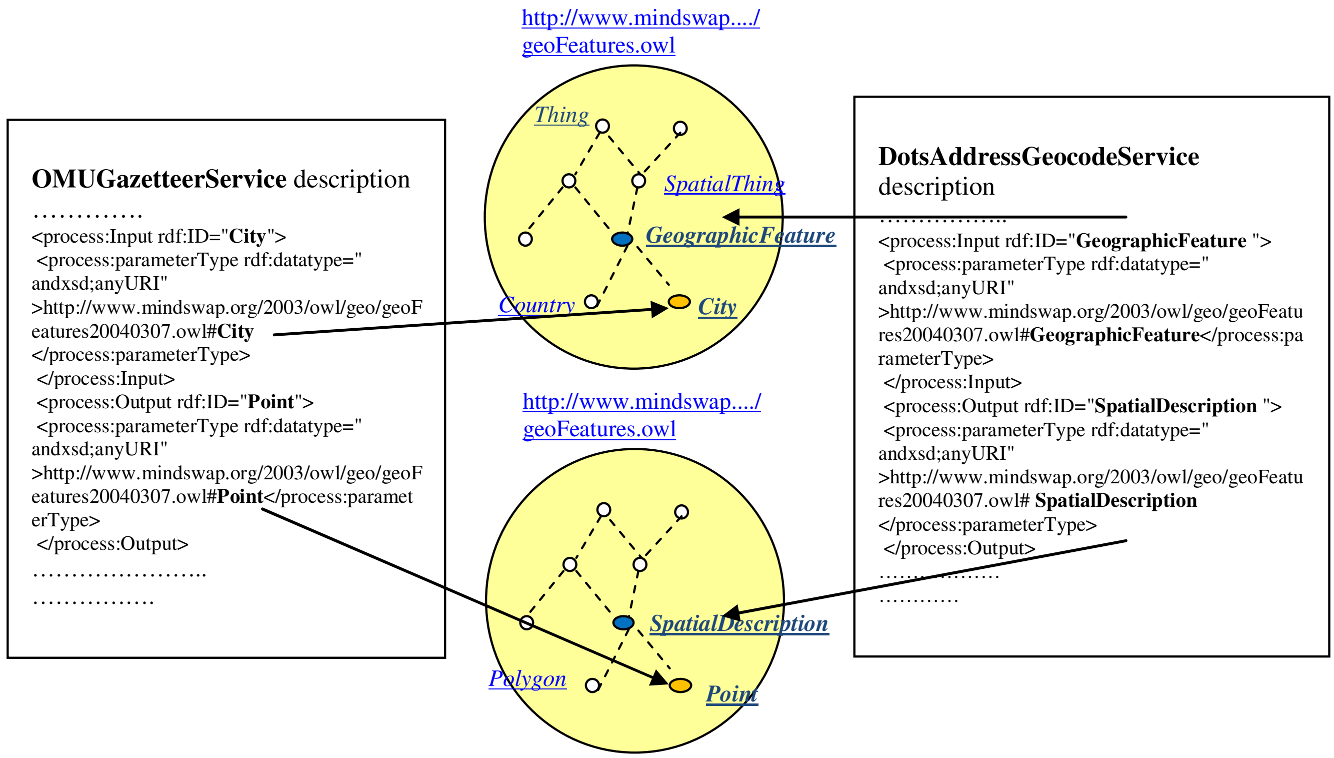

Figure 5. Parts of the two gazetteer service descriptions and the ontology concepts of their input and output parameters.

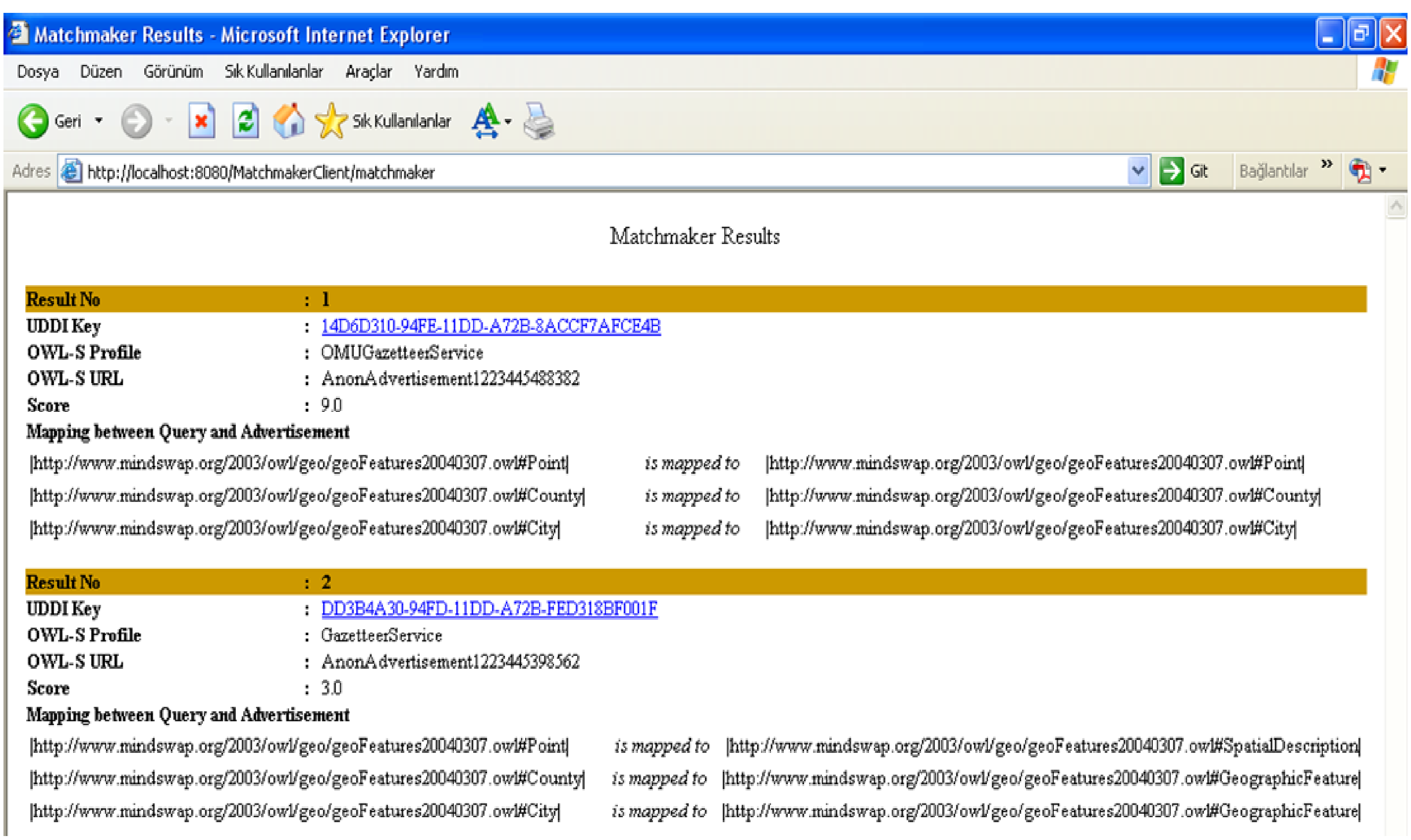

Figure 6. Discovery of gazetteer service in OWL-SUDDI Matchmaker.

should select services with respect to QoS (Quality of Services) parameters of services with their demo URLs or there should be a tool for this. OWL-S UDDI Matchmaker does not have this support yet.

Determining domain ontologies

This is the stage determining the ontologies that will define the concepts needed for service definitions. There are two options here. The one is to develop ontologies from scratch. And the other is to re-use the ontologies already existing on the Web. The second option requires ontology evaluation to determine the most suitable ontologies to be used and it is currently an active research topic. As two of the literature in the area (Alani and Brewster, 2006) proposes AKTiveRank, a prototype system for ranking ontologies. (Tartir and Arpinar, 2007) presents OntoQA, a tool that evaluates ontologies related to a certain set of terms and then ranks them according a set of metrics. Leaving a thorough evaluation for future work, mainly on the basis of availability and the containment of the concepts searched, a number of existing ontologies were used in this work.

The re-used ontologies are: *GeoFeatures Ontology*[8]: This ontology is a "domain level" ontology (Guarino, 1997) containing geographic feature classes and associated properties. It is developed for MINDSWAP project (Maryland Information and Network Dynamics Semantic Web Agents Project). Used for the descriptions of "point" and "city" concepts. *Space Ontology*[9]: This ontology is a top level ontology, developed in 2004 for Sweet Project. Used for the description of "BoundingBox" concept. GeoFeatures ontology does not contain a "BoundingBox" concept. *CreateMap Ontology*[10]: This ontology is an "application ontology" (Guarino, 1997) developed for ACE-GIS Project in 2004 by MUSIL (Muenster Semantic Interoperability Lab). Used for the description of "SRS" (Spatial reference system) and "Map" (GeoReferencedImage) concepts.

RESULTS

Related work

As mentioned above, the current technological implementation option for SDIs is of the syntactical nature. Employed in this option are mainly the standards of well known bodies like Open Geospatial Consortium (OGC), International Standards Organization, Technical Committee 211 (ISO TC/211), World Wide Web Consortium (W3C), and Organization for the Advancement of Structured Information Standards (OASIS). Nevertheless, there is a difference in the philosophies of web services of OGC and W3C, which are predominant organizations as mentioned above.

The philosophical difference deserves to be addressed in detail in a separate work. It suffices here is to say that in the OGC way one searches for data, in the W3C way one searches for the services that either serve data or perform some other task. In the OGC style, "performing the task" is the job of client after importing the data using OGC services. In addition, in the OGC way, the client searches for the data in an interactive, in a sense in a "diologue" based mode. The client first asks about the server's schema to be able to write a "filter" (query) to import the needed data from the server. And then at the client, the data is translated into the client's schema. This is an interactive style where the user (the client) interferes with the operation.

Whereas, in the W3C style, once a number of services are composed into a more complex service to carry out in a certain task then, there would be no user intervention at run-time; once the composed service is initiated, it performs its task all by itself. In other words, OGC services were not designed for web services composition but rather for enabling the exchange of data via a standard way.

SWS are a highly active research area at the moment. There are works at both non-spatial and spatial data arenas. One of the highlighting works in the spatial area is that of Lemmens (2006). Although, the implementation here looks similar to that work, it is different in the way that WMS is the final service of the service composition in Lemmens (2006) but in this work it does not have to be. Since WMS has been wrapped as a WSDL service, it can be involved in any order in a service composition. The point here is related to the philosophical difference between OGC and W3C web services.

FINDINGS AND FUTURE DIRECTIONS

A SWS implementation of a SDI use case was effected in this work. The main goal was to get acquainted with the "cutting-edge" SWS technologies and SWS foundations and thus, to identify issues in implementing SDIs with SWS. Although, this work was able to concentrate more on whether SWSs were achievable, it has also identified a number of key issues for implementing NSDIs with SWS. In general, further work is needed in many areas for viable implementations of SDIs with SWS.

Besides achieving a SWS implementation, this work is also contributive for both pointing out and providing the remedy for the philosophical difference in the realizations of web services of the two fundamental standardization bodies in the area, namely OGC and W3C.

One of the findings is the fact that, although, there are technologies to implement SWS at the moment, they are not mature enough yet. One of the signs of immaturity of SWS technologies is the fact that, there is not a complete SW service development, deployment, execution and management environment in place. Various software components need to be used for each task. As experienced in this work as well, this makes the developing real world applications very difficult. Although, WSMX (Web Service Modelling execution environment) is claimed (Herold, 2008) to be a complete SWS development and execution environment, it has to be tested in the real world *scenarios*. Another sign of immaturity has been experienced during

[8] http://www.mindswap.org/2003/owl/geo/geoFeatures20040307.owl
[9] http://sweet.jpl.nasa.gov/ontology/space.owl
[10] http://musil.uni-muenster.de/onto/ACE/A_CreateMap.owl

the use case implementation. This was the fact that the software tools used were not “user-friendly”. Therefore, it has not been easy to resolve some error messages during the implementation.

A major concern related to SWS is the performance issue. There are many ongoing researches on the issue such as (Srinivasan et al., 2005) it is also presents some results on the performance issue. With 50 published services and 30 concepts in the ontologies of each, the query response time becomes around one millisecond which seems acceptable. Research is needed to determine the corresponding figures in an SDI environment.

This study has also identified some open issues concerning implementing SDIs with SWS. For instance, “how much semantics would be needed in an SDI environment?”, “how should we handle performance issues?, “what should be the overall architecture?”, “are there sufficient software tools to practically implement SDIs with SWS?” these are some of the issues which need to be studied further. The “how much semantics is needed for SDIs?” question is important from many respects such as the performance issue and some other aspects like the migration from existing syntactical implementations to semantic ones. Speculating on the issue, we argue that the semantics needed within the context of SDIs may be much easier to deal with than the ones needed in an artificial intelligence context like natural language processing. It would be useful to set aside the semantic requirements of SDIs for that respect. Therefore, this is another area where future work is planned.

Finally, a point of justification of SWSs for SDIs needs to be set aside. In other words, the need for SWSs for SDIs is to be justified while there are already syntactical web services implementations in place, which is the more realistic option at the moment. There are plenty of work at the syntactical web services front concerning spatial data and SDIs. A sound justification for SWS in the context of SDIs is missing in the related literature as well. Therefore, it deserves a separate research. The justification of this work then, is the need for determining the potentials and the open issues of a strong trend of web technologies, SWS, in implementing SDIs. Nevertheless, this work was able to concentrate more on whether SWSs were achievable leaving the detailed assessments for further work.

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