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A Methodology Based on Ontology for Geo-Service Discovery

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Abstract: Due to popular use of internet and fast progress of communications technology, the researches related to GIS in environmental models is being focused to use Geospatial Information System (GIS) in a Service Oriented Architecture (SOA). In this architecture, the geo service requesters can access the provided geo-services through the communication network by using client/server method. Effectiveness of the method depends on the existence of interoperability especially at semantic level. Lack of semantic interoperability makes obstacles for automated discovery of geo-services. The current article proposes a methodology based on ontology for discovering field-based geo-services. An ontological structure including the ontology of measurement theory, the core ontology of geo services and the upper ontology supports semantic framework for this methodology. In the other words, these ontologies provide required knowledge for describing ontologies of provided and requested geo-services. Sample ontologies have been built to test the implementation of the proposed methodology for discovering geo-services. In this regard, a geo-service discovery application has been developed by this research in order to implement a prototype of the methodology.

Key words: Interoperability . geo-service . ontology . description logic . OWL language

INTRODUCTION

Due to spatial nature of most environmental problems, environmental scientists are interested applying GIS in order to solve these problems. Therefore, linking environmental models with GIS is currently a well established field of environmental and GIS researches. In the most of environmental problems, only a few numbers of geospatial functions of GIS are applicable. In a research work, it was argued that from 150 independent geospatial functions about 20 functions are usually used [1]. Further a function which may belong to an application and operate according to an algorithm, may not be applicable for another situation.

Therefore, with taking these and also growing of popular use of internet and fast progressing of communications technology into consideration, the researches in the field of linking environmental models and GIS is being focused to use GIS with a Service Oriented Architecture (SOA). In this architecture instead of using standalone GISs, network-based distributed services are used.

Web services as network-based distributed systems are self-contained, self-describing, modular applications that can be published, located and invoked across the Web. Web services perform functions, which can be anything from simple requests to complicated business processes. Once a Web service is deployed, other applications (and other Web services) can discover and invoke the deployed service [2]. Web service is accessible only through its interface, usually in request/reply manner [3]. Each web service includes one or more operations which operate on input data according to certain algorithms. Geo-services are a type of web services which contain geo-operations and operate on geospatial data.

Geo-services communicate with each other through exchanging messages in XML format in order to publish, discover and invoke them in a heterogeneous environment. The message can be exchanged in a standard manner according to a set of computer networking protocols including UDDI (Universal Description, Discovery and Integration), WSDL (Web Services Description Language) and SOAP (Simple Object Access Protocol) [4]. These set of protocols

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support the syntactic interoperability between geo-service requester geo-service provider and broker.

However, existence of semantic ambiguities in standard protocols makes barriers for automatic service discovery. For example, WSDL file provide the signature of the operations of the service, that is, the name, parameters and the types of parameters of the service. Trying to discover services by name may not be always very meaningful since a service name could be anything and in any language.

The current research pays attention to semantic ambiguities in the field-based geo-services and a methodology based on ontology proposes for discovering them. The ontology of measurement theory, the core ontology of geo-services and the upper ontology are state of the art and have developed and built during fulfillment of this research [5]. They support semantic framework for the methodology and provide required knowledge to describe semantic ambiguities of requested and provided geo-services.

The remaining part of this paper explains pervious and current researches related to linking GIS and environmental models. It discusses problem of semantic ambiguities in discovering field-based geo-services. The article focuses on ontology as a means for describing semantic ambiguities and briefly introduces the selected ontological language, which properly formalizes semantic ambiguities. The proposed methodology and its components are introduced as well. Further, it introduces the main proposed ontologies which support semantic framework, ontology management and matchmaker in the methodology. Then, it explains the implementation of a prototype for methodology. Finally the paper is concluded.

PERVIOUS WORKS

Currently, GIS and environmental models are linked in a standalone or client/server form. They may be tightly or loosely coupled or integrated with each other [21]. Tightly coupled systems lead to new standalone systems whose domain of application will be limited and a new integration must be achieved for each model/GIS combination. In the loosely coupled approach, standalone systems are separated and exchange data. In this case developer and user are confronted with tedious batch conversion tasks, import/export obstacles and barred access to distributed resource by heterogeneous processing environments and heterogeneous data [7]. These approaches suffer from lack of interoperability.

Distributed computing technologies such as COM (Component Object Model) in client/server architecture can be used to share GIS and models across various domains. However, tightly coupled relationship between client and server can not inherently take advantage of the existing World Wide Web (WWW) [4].

Some current researches focused on using open systems and object-oriented approaches for developing tools to integrate GIS and environmental models [8-10]. Feng and Sorokine identified that OpenGIS or ISO/TC 211 can be used to integrate GIS and hydrologic models [11]. But there remains a gap between what is provided in these specifications and what is needed for GIS hydrologic model integration. The semantic of parameters is a weakness of these approaches.

Due to the popular use of the Internet and the dramatic progress of communications and telecommunications technology, the paradigm of linking GIS and environmental models is shifting into increasingly distributed computing architecture based on loosely coupled web services [12-15]. Key to the interoperation of web services is the adoption of a set of enabling standard protocols that support syntactic rather than semantic interoperability.

The OGC (Open Geospatial Consortium) produces specifications for interchanging information and geo-processing services between systems. In a consensus process OGC initiated standards about Web Processing Service (WPS), provide a common view on geo-processes ranging from complex such as modeling of climate change to simple, for instance, buffering [16]. WPS are easily accessible and flexible libraries of geo-processing algorithms in a web service environment. However, semantics of processes is missing in the WPS [17].

Few researchers address semantics interoperability of web services. The Adaptive and Composable E-emergency and Geographic Information Services (ACE-GIS) Project developed architecture for semantic interoperability in service composition and supplied components for semantic modeling and mapping [18]. ARION (Advanced Lightweight Architecture for Accessing Scientific Collections) is a European Commission project in the domain of ocean and meteorology aimed at developing a digital library that allows access to data and models over the WWW [19].

The Web-Ontology Working Group at the World Wide Web Consortium (W3C) has produced an ontology of service concepts that supplies a web service designer with a core set of markup language constructors for describing the properties and capabilities of a Web service [20]. But OWL-S (Ontology Web Language for Services) seems to lack a formal semantic framework behind. Some of the missing semantics is in the text of the document [21]. A specified limitation is that for each Service, only one

ServiceModel is expected to hold. This makes evaluating the relationship between a ServiceModel required by a requester and the one underlying the provider's system impossible [21]. In addition, OWL-S only allows defining parameter types for input or output parameters of geo-service by selecting a predefined type or a defined class. There is no possibility to describe other details of the input and output such as type of measurement or unit of measure.

PROBLEM DESCRIPTION

Geo-services in distributed computing architecture based on loosely coupled geo-services are distributed on different physical locations. Geo-services must be published, discovered and invoked in this architecture. These tasks can be fulfilled by performing communication and exchanging message between service requester, service provider and broker. The message can be exchanged in a standard manner according to a set of computer networking protocols including UDDI, WSDL and SOAP (Fig. 1).

These set of protocols, however, support the syntactic interoperability between geo-service requester (modeler) geo-service provider (GIS) and broker (publisher) rather than semantic interoperability. To request geo-services, the required knowledge can be extracted from their WSDL interfaces. But the extracted knowledge includes data type rather than unit of measure or measurement scale. In practice, "knowing the type of a data structure is not enough to understand the intent and meaning behind its use" [22].

For example an environmental modeler needs a geo-service which produces runoff rate in kilogram per square meter for his model. A discovered geo-service which is described with a WSDL file may satisfies the needs of modeler. In the WSDL file, it has been described that the output name of this geo-service is runoff volume and its data type is float. The environmental modeler can not be insured through the name and data type of the output that the discovered geo-service satisfies his need. He needs to know semantic details related to input and output of the geo-service such as unit of measure or measurement scale which is crucial for discovering appropriate geo-service.

The term "semantic" here refers to the meaning of an expression in a language [23, 24]. Expression can be single symbol (the "words" of a language) or symbol combinations. The meaning triangle defines the interaction between symbols or words, concepts and objects in the world (Fig. 2).

The meaning triangle illustrates the fact that the relationship between a word and an object is indirect and words cannot completely capture the real meaning of an object. The correct linkage is only accomplished when an agent interprets the word invoking a corresponding concept in a context picking out the intended interpretation and discarding others.

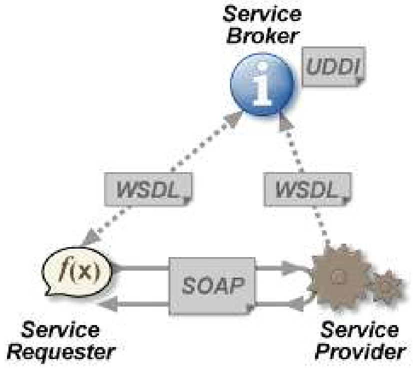


Fig.1: The basic model of service and the elements of Web services stack (http://en.wikipedia.org/wiki/Web_service)

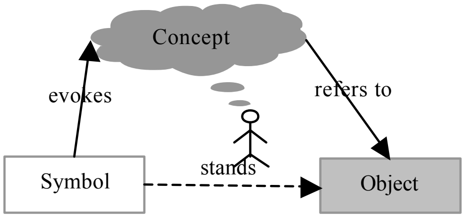


Fig.2: The Meaning Triangle [35]

With refer to meaning triangle, the semantic details belong to the geo-services can be constructed based on the real world conceptualization.

The nave people use prototypical objects such as mountain, building in order to conceptualize objects in the environment. In contrast, many scientists conceptualize the environment as fields [25-28]. The field-based approach treats the environment as a collection of fields. Each field defines the spatial variation of an attribute as a function from the set of locations to an attribute domain [29]. Patterns of temperature, population density, pH of the soil, soil type or tree-coverage fit neatly into this conceptualization.

A field-based geo-service takes as input one or more fields and returns a resultant field. In the other words, geo-operations are mappings or transformations applied to the fields in order to derive new field.

With refer to the latter example, modeler may select the wrong geo-service due to the fact that there are implicit details and semantic ambiguities in the descriptions of modeler's request and provided geo-service. Semantic ambiguity may arise since the symbol used for output of requested geo-service (runoff rate) is not exactly the same as provided geo-service (runoff volume). Further, the unit of measure (e.g. runoff rate in kg m^{-1} and runoff volume in l m^{-1}) is absence in description of geo-service's input and output. In general, semantic ambiguity and implicit details in field based geo-services may arise due to difference in input and output name, discrepancy in type of measurement and lack of unit of measure. The next section introduces an ontology as specific artifact for expressing semantic ambiguities and implicit details.

DESCRIPTION OF SEMANTIC AMBIGUTIES AND IMPLICIT DETAILS BY ONTOLOGIES

Conceptualization is a description of (a piece of) reality as perceived and organized by an agent, independently of the vocabulary used and the actual occurrence of a specific situation [30]. “An ontology is a specification of a conceptualization” [31]. An ontology is a specific artifact designed with the purpose of expressing the intended meaning of a vocabulary in terms of the nature and structure of the entities it refers to [30]. It typically contains two distinct parts: Names for important concepts and background knowledge/constraints in the domain [32].

To describe the details of field-based geo-services, an ontology language is needed that introduces concepts, properties of concepts, relationships between concepts and constraints.

Description Logics (DLs): DLs are a well-known family of knowledge representation formalisms. They are subsets of First Order Logic (FOL) [33] and based on the notion of concepts (unary predicates, classes, or types) and roles (binary relations or properties). They are mainly characterized by constructors that allow complex concepts and roles to be built from atomic ones [34]. Constructors determine the expressive power of DLs.

The language $\mathcal{AL}$ (Attributive Language) is a minimal DL that is of practical interest, because complex descriptions can be built from atomic concepts or roles inductively with concept constructors. [34].

For example, *female* and *person* are atomic concepts. Then an $\mathcal{AL}$ concept describing that a female is a person is:

$$female \subseteq person$$

If it is supposed that *hasChild* is an atomic role, for instance, the concept denoting those persons whose children are female can be represented as follows:

$$Person \cap \forall\ hasChild.Female$$

Where, ∀ is "all value restriction" and states that x is an instance of ∀R.C if all objects related to x via R are instances of C.

Using top concept (T), for instance, those persons that have at least a child can be represented as:

$$Person \cap \exists hasChild.T$$

where ∃ denotes "some value restriction" and states that for an object x to be instance of ∃R.C, there has to exist an object, say y, which belongs to C and is related via R to x [32].

These restrictions make constrains on R along with C concept as its filler. The expressive power of the $\mathcal{AL}$ language is restricted and not sufficient to describe geo-service concepts. In the $\mathcal{AL}$ language, for instance, T is only used as filler for existential quantification and the following complex statements can not be expressed.

$$\begin{array}{l}
Operation \cap (requires.input) \geq 1 \cap yields.output = 1 \\
\forall das : played - by \cdot (pcr : precipitation - rain - fall \\
-value \cup pcr : land\ -\mathrm{cover}- value \cup pcr : DEM \\
\exists cogs : requires \cdot requested - runoff\ - input \\
\ni cogs : has - m - unimth : Meter
\end{array}$$

To describe these expressions, a DL language which supports cardinality restriction, *hasValue* restriction, full existential quantification (∃R.C) and union (C∪D) in addition to $\mathcal{AL}$ constructors is needed for this research.

A DL-based system describes the relation between concept and role expressions [34]. It is a collection of definitions for role and concept, or a set of axioms that restricts the models for the ontology [34]. It is composed of a set of statements of the forms:

$$C \equiv D\ (R \equiv S) \qquad (1)$$

$$C \subseteq D\ (R \subseteq S) \qquad (2)$$

Where C, D are concepts (and R, S are roles). The statement (1) is a concept definition and asserts that the concept expressions C and R are equivalent. It introduces a new concept in terms of other previously defined concepts. For example, a spatio-temopral-particular is defined as a perdurant, endurant, or quality by the following equivalence:

$$spatio - temporal\text{ - }particular \equiv perdurant \cup endurant \cup quality$$

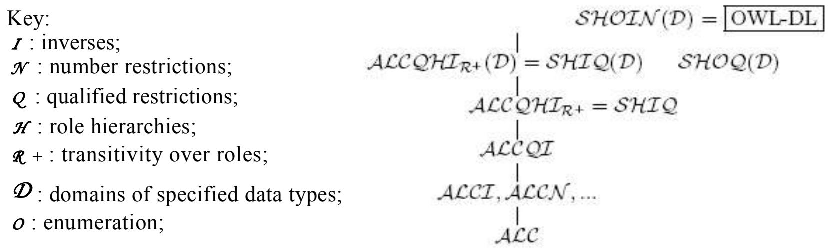


Fig. 3: Expressivity hierarchy for description logics [37]

The statement (2) is a (general) concept inclusion axiom (GCI) and asserts that concept expression C is more specific than (or included in) expression R. It constructs a taxonomic tree. For example field-data is a geo-data can be declared as:

$$field - data \subseteq geo - data$$

A DL based system also contains assertional knowledge that is specific to the individuals of the domain of discourse usually called membership assertions. For example,

$$Unit - of - measure\ (KilogramPerSquareMeter)$$

is a concept assertion and states that the individual KilogramPerSquareMeter is a unit-of-measure. Similarly,

$$has - measurement - uni\ (DEM,\ Meter)$$

is a role assertion and specifies that DEM has Meter as a unit [34].

The following section briefly discusses selection of OWL-DL as a DL language to describe the proposed ontologies of this research.

Web Ontology Language (OWL): OWL is a standard for ontologies on the Semantic Web from the World Wide Web Consortium (W3C). It is built on top of RDF (Resource Description Frame) (OWL semantically extends RDF(S) (Resource Description Frame Scheme)), with its predecessor language DAML+OIL (DARPA Agent Markup Language + Ontology Interface Layer) [35].

OWL language is classified into OWL-Lite, OWL-DL and OWL-full sublanguages. OWL-Lite has simple constraint features and does not support cardinality restriction. On the other hand OWL-full has maximum expressiveness and the syntactic freedom of RDF with no computational guarantees. In addition, no reasoning software will be able to support every feature of OWL-Full [36].

While OWL-DL supports those users who want the maximum expressiveness without losing computational completeness (all entailments are guaranteed to be computed) and decidability (all computations will finish in finite time) of reasoning systems. Technically OWL-DL is an extended logical language based on $\mathcal{ALC}$ (Fig. 3). It is equivalent to $\mathcal{SHOIN}(\mathcal{D})$ [37] which is an $\mathcal{ALC}$ extended with transitive roles [38], role hierarchies (equivalently, inclusion axioms between roles), nominals (classes whose extension is a single individual) [39], unqualified number restrictions, inverses and datatypes (Fig. 3) [40]. A detailed discussion of OWL is, however, beyond the scope of this article. For further details refer to [35, 41].

OWL-DL with number or cardinality restrictions, full existential quantification and union constructor has been selected to formalize geo-services expressions.

PROPOSED METHODOLOGY FOR GEO-SERVICE DISCOVERY

The proposed architecture for geo-service discovery generally consists of an ontology management, a matchmaker and a semantic framework supported by the ontology of measurement theory, the core ontology of geo-services and the upper ontology.

Ontology management is a database mounted on a server and performs tasks of registering the ontology's specification of provided geo-service. The procedure of registering a service consists of storing the Uniform Resource Indicator (URI) of service's ontology, the name of geo-service and geo-service provider into the database. An ontology of provided geo-service has a URI by which it is possible to access to ontology. For example the URI of the upper ontology is as follow: http://www.ncc.org.ir/ontologies/UpperOnt.owl

Ontology management also supports searching the database based on query of the requester and uploading the appropriate ontologies of provided geo-services to the matchmaker server. DL reseaoner installed on the matchmaker server is the inference engine of the architecture which establishes reasoning between ontologies of requested and provided geo-services.

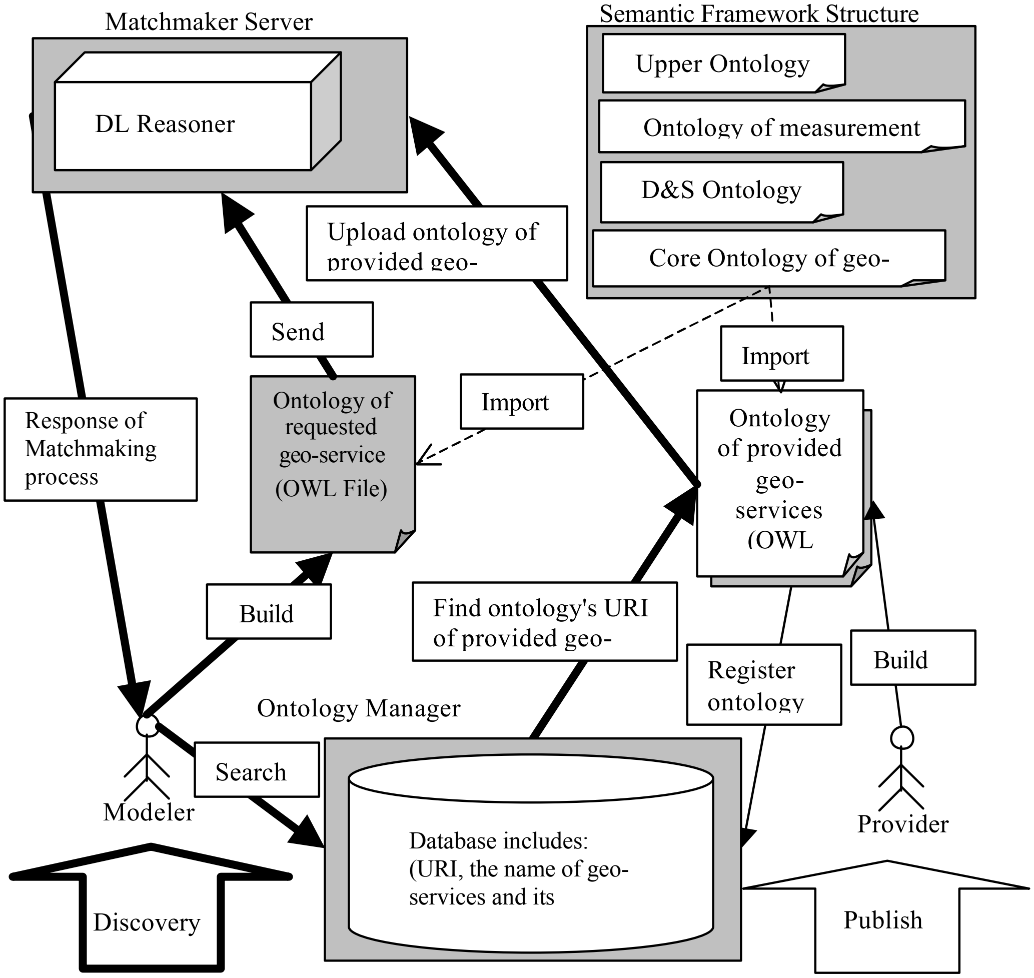


Fig. 4: Architecture of methodology based on ontology to discover appropriate geo-services

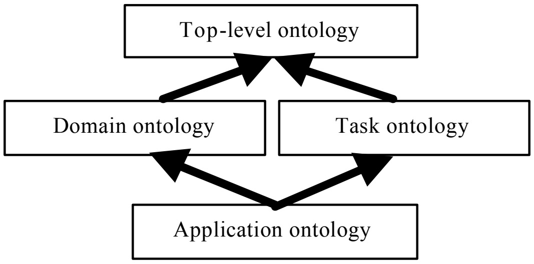


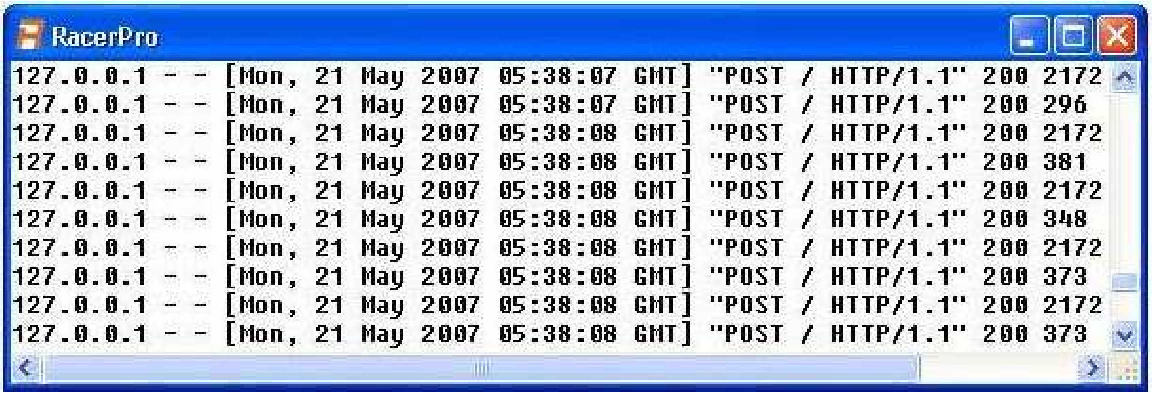
Fig. 5: Kinds of ontologies. Thick arrows represent specialization relationships from [42]

Figure 4 shows the architecture of the geo-service discovery based on ontology.

Main proposed ontologies for supporting semantic framework: Semantic framework for describing requested and provided geo-services are supported by a set of main ontologies to enhance geo-service discovery. This set of main ontologies is included the upper ontology, the ontology of the measurement theory and the core ontology of geo-services which have been developed by this research. They can be classified according to their levels of dependence on a particular task or point of view which follow the illustrated diagram in Fig. 5. According to the diagram it can be distinguished between top-level, domain, task and application ontologies.

In order to match between ontologies of requested and provided geo-services at the application level, there must be an agreement between GIS and environmental modelers about basic and general concepts. This agreement is achieved by means of these main ontologies.

They are a collection of axioms and constraints that restrict general and domain specific concepts and relationships about geo-services. In fact, general concepts and domain specific concepts which are used in ontologies of provided and requested geo-services have been described in one of these ontologies.



```
127.0.0.1 - - [Mon, 21 May 2007 05:38:07 GMT] "POST / HTTP/1.1" 200 2172
127.0.0.1 - - [Mon, 21 May 2007 05:38:07 GMT] "POST / HTTP/1.1" 200 296
127.0.0.1 - - [Mon, 21 May 2007 05:38:08 GMT] "POST / HTTP/1.1" 200 2172
127.0.0.1 - - [Mon, 21 May 2007 05:38:08 GMT] "POST / HTTP/1.1" 200 381
127.0.0.1 - - [Mon, 21 May 2007 05:38:08 GMT] "POST / HTTP/1.1" 200 2172
127.0.0.1 - - [Mon, 21 May 2007 05:38:08 GMT] "POST / HTTP/1.1" 200 348
127.0.0.1 - - [Mon, 21 May 2007 05:38:08 GMT] "POST / HTTP/1.1" 200 2172
127.0.0.1 - - [Mon, 21 May 2007 05:38:08 GMT] "POST / HTTP/1.1" 200 373
127.0.0.1 - - [Mon, 21 May 2007 05:38:08 GMT] "POST / HTTP/1.1" 200 2172
127.0.0.1 - - [Mon, 21 May 2007 05:38:08 GMT] "POST / HTTP/1.1" 200 373
```

Fig. 6: RacerPro inference engine

The upper ontology contains the descriptions of quantitative and qualitative aspects of a field property as well as its value in order to be used to state field-based geospatial data. On the other hand, the concepts in the ontology of measurement theory and the core ontology of geo-services must be aligned with general concepts of the upper ontology. Alignment to an upper ontology means relating the concepts and relations of an ontology to the basic categories of human cognition investigated by philosophy, linguistics or psychology [21]. Thus, the existing upper ontologies have been studied and the DOLCE that belongs to the WonderWeb project Foundational Ontology Library (WFOL) [43] has been selected as framework. This ontology has been modified in order to include the general concepts related to field-based geo-services.

The ontology of measurement theory at the domain level describes concepts related to the measurement scale and the unit of measure that are crucial for field-based geo-service discovery.

The core ontology of geo-services contains geo-service's concepts which are required to describe the properties and capabilities of geo-services. It includes concepts such as geo-service, geo-operation and service profile. These domain-specific concepts can be used to describe the semantic of input and output of a field-based geo-service.

Ontology management: The Protégé [44] version 3.2.1 Build 365 along with its OWL editor plug-in version 3.2.1 Build 365 [45-47] have been selected and extensively used for building and editing main ontologies and requested and provided ontologies of sample geo-services in this research. Protégé is an open source ontology editor that supports OWL-based ontology development and inference. Protégé is java-based and is extensible via plug-ins [48]. OWL in Protégé is provided through a plug-in; OWLViz [49] is another plug-in of Protégé which has been used for ontology inspection and documentation.

Matchmaker: A DL reasoner called RacerPro [50] (stands for Renamed Assertion Box and Concept Expression Reasoner Professional) version 1.8.1 has been utilized to perform matching and computed degree of matching between requested and provided ontologies of sample geo-services in this research (Fig. 6).

RacerPro is a knowledge representation system that can be used for reasoning with ontologies. RacerPro implements the description logic $\mathcal{SHIQ}$ [50] (Fig. 2). It can directly read OWL-DL documents and represent them in DL knowledge bases [51, 52].

The functions of RacerPro can be called through a LISP interface but RacerPro also acts as a server, providing these functions through a TCP interface and an HTTP based standard DIG interface for connecting client programs.

Similarity between the requested and provided ontologies of sample geo-services is measured by matching service-profile, geo-service and geo-operation concepts in these ontologies in order to discover appropriate geo-service.

In this regard, the next section explains an application for discovery of geo-services which have been developed by this research. Further, it explains building the requested and provided ontologies of sample geo-services and determining and representing the similarity of them by the application.

A PROTOTYPE OF THE METHODOLOGY

An application associated with a user interface has been developed to compute and illustrate the degree of matchmaking between corresponding concepts. This application is called geo-service finder and written in

Fig. 7: Snapshots of the geo-service finder

Java language by utilizing Java packages of the Protégé in order to access to the model of OWL ontology and RacerPro reasoner using DIG interface. Figure 7 illustrates its menus and items which are available through the user interface of the application.

Building Service-profile, Geo-service and Geo-operation Concepts: Suppose a modeler requests a geo-service in order to compute runoff rate and there is a provided geo-service in order to compute runoff volume. The following subsections discusses about building the service-profile, the geo-operation and the geo-service concepts in order to describe these geo-services.

Requested Geo-Service: The service-profile and the geo-service concepts for the requested runoff rate geo-service can be described as follows:

$$requested-runoff-profile \equiv cogs:service-profile \cap \exists cogs:describes \cdot requested-runoff-service$$
$$requested-runoff-service \equiv cogs:geo-service \cap \exists cogs:part-by \cdot requested-runoff-operation \cap$$
$$\forall cogs:part-by \cdot requested-runoff-operation$$

The geo-operation concept can be stated as follow:

$$requested-runoff-operation \equiv cogs:geo-operation \cap$$
$$\exists cogs:requires \cdot requested-runoff-input \cap \exists cogs:yields \cdot requested-runoff-output$$

The calculate-runoff-input concept only needs DEM, land cover value and precipitation rain fall value as input data sets, thus, an open world assumption (OWA) [32] is used to describe it as follow:

$$requested-runoff-input \equiv cogs:input \cap \exists das:played-by \cdot DEM \cap$$
$$\exists das:played-by \cdot land-cover-value \cap \exists das:played-by \cdot precipitation-rain-fall-value \cap$$
$$\forall das:played-by \cdot (precipitation-rain-fall-value \cup land-cover-value \cup DEM)$$

The open world assumption means that it cannot be assumed something doesn't exist until it is explicitly stated that it does not exist. In other words, because something hasn't been stated to be true, it cannot be assumed to be false. The output of the requested geo-service is also described as follow:

$$requested-runoff-output \equiv cogs:output \cap \exists das:played-by \cdot runoff-volume \cap$$
$$\forall das:played-by \cdot runoff-volume$$

The following statements describe the geospatial data sets for requested geo-service:

$$DEM \equiv cogs:field-data \cap \ni cogs:has-m-unimth:Meter \cap \exists cogs:representsmth:height$$
$$precipitation-rain-fall-value \equiv cogs:field-data \cap \ni cogs:has-m-unimth:Millimeter \cap$$
$$\exists cogs:representsmth:precipitation-rain-fallland-cover-value \equiv cogs:field-data \cap$$
$$\exists cogs:representsmth:land-coverrunoff-volume \equiv cogs:field-data \cap$$
$$\ni cogs:has-m-unimth:LiterPerSquareMeter \cap \exists cogs:representsmth:runoff$$

Where the concepts in the core ontology of geo-service, the D&S ontology and the ontology of measurement theory are respectively identified by "cogs", "das", "mth" tags.

Provided geo-services: The service-profile, the geo-operation and the geo-service concepts for the provided geo-service can be described as follows:

$$\begin{aligned}&pcr:calculate-runoff-profile \equiv cogs:service-profile \cap \exists cogs:describes \cdot pcr:calculate-runoff-service\\&pcr:calculate-runoff-service \equiv cogs:geo-service \cap \exists cogs:part-by \cdot pcr:calculate-runoff-operation \cap\\&\forall cogs:part-by \cdot pcr:calculate-runoff-operation\; pcr:calculate-runoff-operation \equiv cogs:geo-operation \cap\\&\exists cogs:requires \cdot pcr:calculate-runoff-input \cap \exists cogs:yields \cdot pcr:calculate-runoff-output\end{aligned}$$

Where the concepts in the ontology of the provided geo-service is identified by "pcr"tag.
The calculate-runoff-input concept is described as follow by using an open world assumption as well:

$$\begin{aligned}&pcr:calculate-runoff-input \equiv cogs:input \cap \exists das:played-by \cdot pcr:DEM \cap\\&\exists das:played-by \cdot pcr:land-cover-value \cap \exists das:played-by \cdot pcr:precipitation-rain-fall-value \cap\\&\forall das:played-by \cdot (pcr:precipitation-rain-fall-value \cup pcr:land-cover-value \cup pcr:DEM)\end{aligned}$$

The calculate-runoff-output concept for the provided geo-service is stated as follow:

$$\begin{aligned}&pcr:calculate-runoff-output \equiv cogs:output \cap \exists das:played-by \cdot pcr:runoff-volume \cap\\&\forall das:played-by \cdot pcr:runoff-volume\end{aligned}$$

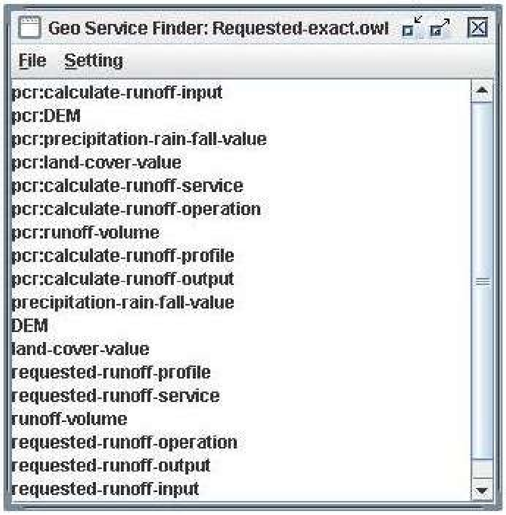
The following statements describe the geospatial data sets for provided geo-service:

$$\begin{aligned}&pcr:DEM \equiv cogs:field-data \cap \ni cogs:has-m-unit.mth:Meter \cap \exists cogs:represents.mth:height\\&pcr:precipitation-rain-fall-value \equiv cogs:field-data \cap \ni cogs:has-m-unit.mth:Millimeter \cap\\&\exists cogs:represents.mth:precipitation-rain-fall\; pcr:land-cover-value \equiv cogs:field-data \cap\\&\exists cogs:represents.mth:land-cover\; pcr:runoff-volume \equiv cogs:field-data \cap\\&\ni cogs:has-m-unit.mth:LiterPerSquareMeter \cap \exists cogs:represents.mth:runoff\end{aligned}$$

Calculating Similarity between Requested and Provided geo-services: The sample ontologies which have been developed in pervious sections can be loaded in geo-service finder application and Fig. 8 illustrates their concepts.

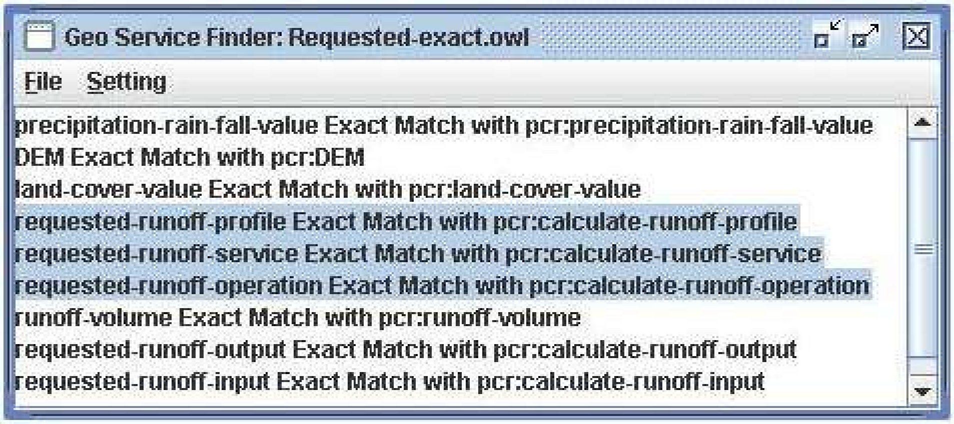
Their similarities are determined by accessing functionalities of the RacerPro inference engine through the application. In this regard, the application can be connected to RacerPro by using DIG (DL Implementation Group) interface. The result of inference between concepts in the ontologies of requested and provided geo-services is illustrated in Fig. 9.

It shows that the provided geo-service exactly matches with the requested geo-service. The following statements describe the matching between calculate-runoff-profile and requested-runoff-profile concepts, calculate-runoff-service and requested-runoff-service concepts and calculate-runoff-operation and requested-runoff-operation concepts:



pcr:calculate-runoff-input
pcr:DEM
pcr:precipitation-rain-fall-value
pcr:land-cover-value
pcr:calculate-runoff-service
pcr:calculate-runoff-operation
pcr:runoff-volume
pcr:calculate-runoff-profile
pcr:calculate-runoff-output
precipitation-rain-fall-value
DEM
land-cover-value
requested-runoff-profile
requested-runoff-service
runoff-volume
requested-runoff-operation
requested-runoff-output
requested-runoff-input

Fig. 8: The ontologies of sample requested and provided geo-services in the geo-service finder application



```
precipitation-rain-fall-value Exact Match with pcr:precipitation-rain-fall-value
DEM Exact Match with pcr:DEM
land-cover-value Exact Match with pcr:land-cover-value
requested-runoff-profile Exact Match with pcr:calculate-runoff-profile
requested-runoff-service Exact Match with pcr:calculate-runoff-service
requested-runoff-operation Exact Match with pcr:calculate-runoff-operation
runoff-volume Exact Match with pcr:runoff-volume
requested-runoff-output Exact Match with pcr:calculate-runoff-output
requested-runoff-input Exact Match with pcr:calculate-runoff-input
```

Fig. 9: The result of inference between correspondence concepts performed by the geo-service finder application

$$requested - runoff - profile \equiv pcr : calculate - runoff - profile$$
$$requested - runoff - service \equiv pcr : calculate - runoff - service$$
$$requested - runoff - operation \equiv pcr : calculate - runoff - operationa$$

In this case, the requested runoff geo-service is exactly the same as the calculate runoff geo-service. For modelers it means that the input and output of the requested geo-service is the same as the input and output of calculate runoff service. Therefore the calculate runoff service satisfies the needs of modeler.

CONCLUSION AND DISCUSSION

This article discussed that semantic ambiguities and implicit details are obstacles when discovering appropriate geo-services. Describing semantic ambiguities are crucial to precisely discover a geo-service. The ontology of measurement theory, the core ontology of geo-services and the upper ontology have been developed by this research to support a semantic framework for geo-service discovery. In fact, general concepts and domain specific concepts which are used in ontologies of provided and requested geo-services have been described in these ontologies.

It is briefly discussed that OWL-DL language is an appropriate DL language to formally describe the ontologies which have been developed by this research.

The article proposed a methodology for discovering geo-services. The architecture of this methodology and its components has been briefly discussed. An application in Java language developed to implement methodology for discovering appropriate geo-service and tested by sample ontologies of requested and provided geo-services.

As consequence, main ontologies including the ontology of measurement theory, the core ontology of geo-services and the upper ontology enhanced the semantic framework of the methodology and increased precision of discovery.

In this research, it has been paid attention to discovery of geo-services based on description of the input and output of geo-services. But the other parameters such as signature of geo-services may be also applicable in order to promote the description of geo-services. This can be considered as new direction for continuing this research.

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