Multi-dimensional Ontology Model to Support Context-aware Systems

A Mobile Application to Search and Invoke Semantic Web Services

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***Abstract*— Computing has evolved in such a way that has left behind the limitation of being static and local, promoting the emergence of the new era of computing called Ubiquitous Computing. To maximize the use of this new computing platform, it is necessary to develop new and improved structures for knowledge and information representing, in order support the implementation of new intelligent searcher and recommendation systems. Thus, recommendations and search results will be fully based on contextual information and user profiles. This paper describes an architecture based on a multi-dimensional ontology model to represent mobile user contexts, Web services and application domains. A mobile application is also presented to show the benefits of this approach in a mobile computing environment.**

Keywords-mobile computing; ontologies; semantic Web services; context-aware systems.

I. INTRODUCTION

Computing has evolved in such a way that has left behind the limitation of being static and local, that is, not being able to easily carry computing resources from one place to another due to its large size and energy demand. Currently this limitation has been solved with the reduced size, weight and power consumption of computing devices, resulting in the emergence of mobile computers, enabling communications between mobile devices and people anywhere in the world [1]. The mobile computing has become a reality, thanks to the evolution of wireless communication technologies and the Internet. Mobile computing is rapidly gaining importance because there is an incremental daily demand for information access from anywhere and at any time with multiple purposes. Nowadays, information is distributed around the world in multiple servers and databases, therefore to discover and gather this information accurately in mobile devices represents a big computational challenge.

Web services (WS) [2] represent an important technological trend for distributing software resources around the world. WS are software component interfaces based on a set of XML-based standards, languages and protocols and are executed through the exchange of XML messages, allowing different applications to communicate across multiple platforms. WS enable reutilization of legacy software and integration of more complex systems which can be of major interest in mobile environments.

Currently, there is a trend towards digital convergence, so it is possible to access information (voice, video or data) with any mobile devices via the Internet, which allows use and consumption of Web services. Emergent technologies for mobile phones are expected to offer full support for the Web, all telephone devices will have Internet access (generation 4G) [3].

These advances in telecommunications in turn promote the increased use of mobile devices in everyday life, so that computing power is distributed throughout the environment, becoming an invisible and integral part of our lives. This situation gives rise to the new era of computing called Ubiquitous Computing, which is considered the third generation of computing [4]. The main goal of Ubiquitous Computing is to integrate computers and devices in a physical environment of users trying to fully exploit the services offered by this new computing paradigm.

To maximize the use of this new ubiquitous computing platform, it is necessary to develop new and improved structures for representing information and knowledge to support the implementation of new intelligent search and recommendation systems. Thus, recommendations and search results will be fully based on contextual information and user profiles. Context is defined as "any information that can be used to characterize the situation of a person, place, or object that is considered relevant to the interaction between a user and application" [5]. In this way, systems that are able to extract, interpret and use information from the environment are known as context-aware systems.

It is therefore necessary to create a solution capable of taking into account the distribution of information, user mobility and consequently the context information of the user, enabling access to Web services offered on the network.

The rest of the paper is organized as follows: Section II presents a motivation example; in Section III, related work is presented; in Section III, the multi-dimensional ontology model is described; in Section IV, a Web service semantic registry is presented; Section V, describes a context-aware mobile application; in Section VI, experiments and results are presented; and finally, in Section VII, conclusions are described.

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II. Motivating Example

To provide an example of the approach presented in this article, consider a mobile application that allows any user to connect to a public Semantic Web Service Registry (SWSR) to search for web services and invoke them as needed. During the registration of the mobile user, the SWSR obtains the mobile user data (full name, gender, birth date, occupation, mobile device brand, model, phone number, interest list and interest ranking). Once that the user is registered, the SWSR extracts the mobile user position (longitude and latitude data from the mobile device) every time when the user starts a session with the SWSR. Using all information, the SWSR creates an ontology instance of the user context, the mobile device and the user interests.

Using this application, any registered mobile user can search, select and invoke Web services according to his/her needs. Search of Web services starts when the user selects to view the list of Web services classified according to a given application domain. The Web service list is dynamically generated as a result of executing a query to the ontology model. The user has the option to search for Web services considering his geographical position at the time of the request. Once the user selects an application domain, the mobile application displays the interface, where the user can select from a list of recommend services based on the selected domain and user context. This recommendation is done through an inference rule, which is executed dynamically with user data. Let's assume that the user requested the address of any restaurant located at Lindavista district, as a result the mobile application returned a map location of a restaurant at Lindavista, recommended based on the users interests. The mobile application described in this work shows that the development of a multi-dimensional representation using ontologies and semantic Web services facilitates the generation of intelligent and dynamic recommendations of relevant services to end users. This result is mainly due to the incorporation of the user's context shaped by his interests and his geographical context.

This paper describes a multi-dimensional ontology model which represents three dimensions: user context information, Web services and application domain classifications. Using ontological representation enables semantic representation of concepts (classes), relations between concepts, individuals and inference rules to discover and produce new knowledge. In particular, the model reported in this paper allows the combination of different ontologies to offer a more complex representation of contextual variables and software resources. Using a multidimensional ontology modeling approach has the following benefits [6]:

a) Ontologies are managed as modules that can be expanded, reduced and maintained individually by their owners.
b) The multi-dimensional ontology model is itself another ontology, which imports ontologies as modules. In this multi-dimensional ontology model, an integrator defines semantic relationships across ontology modules regarding application interests.
c) Through the use of inference and query rules, the multi-dimensional ontology model can be used to answer questions traversing dimensions.

III. Related Work

In the last years several projects concerning web services and mobile computing have been developed and reported. Of particular interest, are those related context-aware systems that incorporate multiple ontologies, use Web services for attending mobile user demands, incorporate a semantic Web service model and use reasoning and inference facilities for recommendations. This section presents an overview of these related work.

In 2004 Weißenberg et al. [7] presented FLAME2008, a platform for service customization through the use of information based on individual situations and personal demands of users. This proposal tries to determine the most appropriate set of web-based information and services through the semantic descriptions of situations and services. The main objective of FLAME2008 is to implement a Web-Based information system for large users groups and large service sets. In FLAME2008, services and information are sent to the mobile device, based on the current situation and profile of each user. The situation of user is obtained through the use of sensors and the information on user's profile. Ontologies are responsible of matching demands and offers. Offers are composed of situation, profiles and bound services for the situations. Description of situations and services are based on profiles, they contain a set of attributes characterizing the situation. The values for the attributes are instantiated by the ontology. Sensor data and user's profile are used to infer a demand. As a result, an ontology is created, where instances are used to construct a situation request profile semantically matched with all the situations known by the system. In this way a service request profile is constructed and matched against all the registered service profiles i.e. inferences are made on situations and services. Interests and preferences are specified in profiles. Besides of location, time and situation, the user's context history is considered in the personalization of services and the information delivered to the mobile device. In FLAME2008 contexts are handled in a dynamic way, they are obtained from information of sensors and help to identify the situation of user; under this perspective the parameters of the situation define the context, giving the possibility of having a large range of contexts.

Ontologies in FLAME2008 are structured in layers: upper ontologies, which are used for processing generic and abstract concepts; domain ontologies, used to model concepts form different application domains; task ontologies, which model service ontology and situation ontology; and application ontology. In particular, the service ontology adhering to the OWL-S specification defines services using: profile for advertising and finding services, process model for describing cooperation between services and grounding for the execution of services. The situation ontology is defined by user's context and profile, this ontology is composed of several sub-ontologies for all the different context dimensions.

In 2004 Sheshagiri et al. [8] presented myCampus, a project where users subscribe with a set of task-specific agents to develop different tasks. These agents require the knowledge of contextual attributes of users. The sources of contextual information are modeled as Semantic Web Services that can be automatically discovered by agents. The static knowledge about users is stored in the form of rules that map contextual attributes onto service invocations, in this way the ontology can identify and activate the resources in response to the context of the users' queries. Sources of contextual information are defined as Semantic Web Services; it means that every source has a profile with the description of its functional properties. The ontology makes use of rules for local and global service identification, to identify one or more relevant sources of contextual information. Service discovery is carried out through these profiles.

FLAME2008 and MyCampus were two of the first projects that incorporated a semantic Web service approach by using OWL-S. However, the main drawback of OWL-S model is that it makes difficult the automatic incorporation of existing Web services (legacy WSDL files) requiring their semantic extension with OWL-S.

In 2005 Gu et al. [9] presented SOCAM, one of the first ontology-based models to represent contexts; SOCAM includes person, location, and activity and computer entity. SOCAM is a middleware architecture for rapidly building context-aware services. It provides support for discovering, acquiring, interpreting and accessing context information. Although SOCAM uses the concept of services, these are not defined by standardized languages such as WSDL or OWL-S. Limiting the possibility of incorporating existing Web services from different vendors on different platforms.

In 2005 Kim et al. [10] described a framework to search products and services through the use of a real-time ontology mapping mechanism between heterogeneous ontologies and taxonomies. This proposal is based on Web services and Semantic Web and is composed of: service client, service providers and search agent. The service client installed on a mobile device allows the specification of a product and a search intention. When a search is specified the information from de GPS is automatically considered. If a response is produced the client service is responsible for communicating results to the user. The service client uses a specific ontology to store user's specific categories and attributes related to ontologies. The service provider component allows the description of products and services through the providers' ontologies. When products and services are published providers must specify the meta-data of documents, they are needed by the ontology to find the description of services.

The main component of this proposal is the Service Search Agent, it is responsible of harvest the service providers through the use of a semantic web robot. The information collected is integrated into the ontology of products and services. The search agent receives the search request from client; it searches for relevant service providers, evaluates the obtained results and recommends the most adequate services for the user. The search agent is composed of four main components: an information integrator it uses a semantic robot for collecting the category and attribute information about products and services from various providers. When the request from client arrives the location processor defines the range of regions to be searched according to the location of user. Then with the information on the client's request and his location the query generator generates the query for the products and services ontology. The last component is the service evaluation agent that evaluates the retrieved results according to the intent on the user's search and recommends the most relevant products and services. This framework has a disadvantage, it requires services providers to describe their services using their own ontologies, leaving aside the use of interoperable Web service description languages. Another disadvantage is that it does not incorporate the reasoning services for deducing and generating recommendations.

In 2008 Dickson et al. [11] presented the use of Multi-Agent Systems, Semantic Web and Ontologies (called MAIS) for the implementation of an ubiquitous touristic service. Their objective was to provide coordination and integration of information and service resources anytime anywhere and provisioning personalized assistance to tourists. In the MAIS architecture tourist inquiries are sent to an ontology, results are produced according to the requirements and preferences of users. Through the use of the ontology the system can propose tour plans, formulate itinerary plans and connections between transport routes. The ontology organizes tourism-related information and concepts allowing the interoperability through the use of a shared vocabulary and meaning of terms. In this way all the agents in the system have a common basis for searching, interpreting and reasoning. The ontology was populated by extracting information and services from Web pages, using Web crawlers. Moreover this proposal has a Matchmaking mechanism to select and compose the packages that better correspond to the needs and preferences defined in the tourist's profile.

In 2009 Amel Bouzeghoub et al. [12] presented a context aware semantic recommender system. Recommendations are based on a multidimensional ontology which models persons, buildings, events and available resources. The recommender system was implemented for mobile users in a campus environment. Recommendations are proactively generated considering user context, geographic position and recommendation logs. Authors suggest that context is a multi-dimensional space, where each dimension is represented as a specific ontology. In particular, the set of ontologies incorporated into the multi-dimensional space are: domain ontology, user ontology, activity ontology, location ontology, and time ontology.

In 2009 Cadenas et al. [13] described mIO, an ontology network to represent knowledge related to context. The mIO ontology consists of a core ontology which interlinks different ontology modules needed for modeling context. They introduce the concept of modularization for ontologies, to allow using only the modules that are involved in a given case, instead of using the whole ontology network. Their ontology network contains ten modular ontologies: User, Role, Environment, Location, Time, Service, Provider, Device, Interface and Network. Authors also propose using context logs for better recommendation results.

Despite the use of an ontological model in Dickson [11], Bouzeghoub [12], and Cadenas [13] projects, their main drawback is that they do not incorporate semantic Web service representation and reasoning.

In 2009 Sousa [14] presented ICAS, an architecture that allows creation of context aware services, and SeCoM, a semantic model to represent contexts. Authors present a study case applied to a university campus, where the objective is to identify pedagogic characteristics of documents and persons. SeCoM model consists of six main ontologies and six supporting ontologies. Main ontologies are: Actor ontology, Time ontology, Temporal Event ontology, Space ontology, Spatial Event ontology, Device ontology, and Activity ontology. Secondary ontologies are: Contact ontology, Relationship ontology, Role ontology, Project ontology, Document ontology and Knowledge ontology. Inference is based on user preferences, user context, and user interests to identify relevant services. In this approach, services are classified in categories, adding preconditions and post conditions for each service, allowing search and selection of services by comparing input and output compatibilities. This work also maintains action logs, which are used for recommendation.

In 2009, Woerndl and Hristov [15] described an approach for personal information management in mobile devices, using a recommender system based on ontologies. The system recommends documents and articles considering time and location context and the user personal ontology. Authors implemented a PDA Semantic Desktop (SeMoDesk). Recommendations are obtained from the interest of a user in a topic or document, considering user schedule and location. SeMoDesk is a desktop application for mobile devices, for this reason has some limitations regarding the ontology model and does not support semantic Web service invocations.

In 2009 Liiv [16] describe SMARTMUSEUM, a platform for recommendations in the cultural domain of a museum. SMARTMUSEUM uses a combined approach based on rules, collaboration and content personalization, where content is semantically enabled by an ontology. Recommendations are about cultural objects allocated in the museum and content related with those objects. User profile includes abilities and interests of user, and a log of visited places.

In 2010, Gómez-Pérez presented SEEMP [17] a project aiming at facilitating employment services in Europe. SEEMP consists of an ontology network which describes employs and employees from human resource perspective. SEEMP reference ontology consists of the following ontologies: Job Seeker Ontology, Job Offer Ontology, Compensation Ontology, Driving License Ontology, Economic Activity Ontology, Occupation Ontology, Education Ontology, Geography Ontology, Labour Regulatory Ontology, Language Ontology, Skill Ontology, Competence Ontology, and Time Ontology.

These reported proposals are based on similar technological mechanisms, such as context-awareness, incorporating multiple ontologies (multi-dimensional space), use Web services for attending mobile user demands, incorporate a semantic Web service model and use reasoning and inference facilities for recommendations. However, the main difference between related work and the approach described in this paper, is the implementation of a multi-dimensional ontology model with adaptable and extendible ontology modules; and the incorporation of a semantic Web service representation capable of acquiring legacy WSDL files. As a result, the approach reported in this paper offers an innovative contribution for dynamic and changing mobile environments.

IV. MULTI-DIMENSIONAL ONTOLOGY MODEL

The core solution of this work consists of a multi-dimensional ontology model, for which the following design objectives were established:

a) Build a model capable of representing multiple dimensions with changing attributes.
b) Design the model using a semantic formalism which allows the description of classes (concepts), class hierarchies, semantic relationships between those concepts, and axioms.
c) Design and implement dimensions as self-contained ontologies to enable modularization. Modularization of ontologies in turn facilitate individual ontology maintenance, update and expansion.
d) Design the model to allow the integration of multi-dimensional ontology models to face and solve multi-disciplinary problems.

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e) Enable the definition of query functions to extract information using any number of dimensions and any number of attributes.
f) Enable the definition of inference rules which allow the generation of new semantic connections between concepts across all dimensions.
g) Enable automated inclusion of pure WSDL service descriptions into a ontological representation of services. Without imposing Web service providers a new requirement for augmenting their services with very specific models such as OWL-S.

In order to achieve the afore-mentioned design objectives, a multi-dimensional space model was implemented with ontologies. OWL [18] was chosen as the ontological language, because it is based on description logics (DL) allowing the description of concepts and semantic relations between concepts. For inference rules definition, SWRL was selected, because it is fully compatible and importable into OWL ontologies, so through a set SWRL rules new semantic relations can be deduced logically. To query the model, SQWRL [19] was used. SQWRL (**S**emantic **Q**uery-enhanced **W**eb **R**ule **L**anguage) is built based on the well known SWRL which allow extensions by built-ins. SQWRL defines a set of built-ins operators that can be used to construct more specialized functions for querying ontologies. The multi-dimensional ontology model consists of three dimensions: the *user context*, the *application domain* and the set of available *services*; each of these dimensions define multiple and changing attributes. For instance, to model the interest of the user, it is necessary to consider a wide range of possibilities, depending on the subject of interest.

The architecture depicted in Figure 1 shows the multi-dimensional ontology model and mobile applications which exploit the information modeled and represented in the ontological model. Representing multiple dimensions of semantic information using Web-based ontologies is a promising trend from the area of knowledge representation that has proven good results. An important benefit of using multi-dimensional ontologies is the feasibility of maintaining each ontology and the possibility of exchanging and extending parts of the model.

In the following sub-sections each ontology is briefly described:

A. *User Context Ontology*

The user can define his context through the use of his mobile device. First the user must define his profile; the application for user's profile definition has been implemented with the *Framework JSF* and the *PrimeFaces* components. The first step in the profile definition is to specify the name, birth date, sex, and occupation of user. This information it is stocked into the users context ontology (Figure 2).

After the user supplies the information for profile creation a connection with the users context ontology is established and a primary list of interests is generated for the user. In this list the user can select the services where he is interested. Every item in the list has a level of interest property, which is used to assign a weight to the item. This weight means the level of interest of user on that service and he can change it through the mobile device.

The user context ontology represents the semantic information of the user context, incorporating his general data, occupation, interests and information from the mobile device used to interact with the system. In particular, the information required is related to its geographical position. Figure 2 shows classes of the *User Context* ontology, which are described next.

Interest, this class defines a hierarchy of concepts of interest to the user; *Interest Record*, this class represents the interaction between users and their reported interests (*interest level* defines a property that that takes values in a range from 1 to 10, indicating the level of interest that a user has in a given period of time over a specific concept), when the individuals for the *Interest* class are created they are assigned with an interest level of five, that is an intermediate value (see *inference rule* 1) that can be changed by the user. *User*, describes the general user characteristics represented by user name, date of birth and gender; *Occupation*, occupation defines a job or profession of the user, *Device*, describes the characteristics of the mobile device of the user; *Position*, defines the geographic coordinates of latitude and longitude obtained through the mobile device.

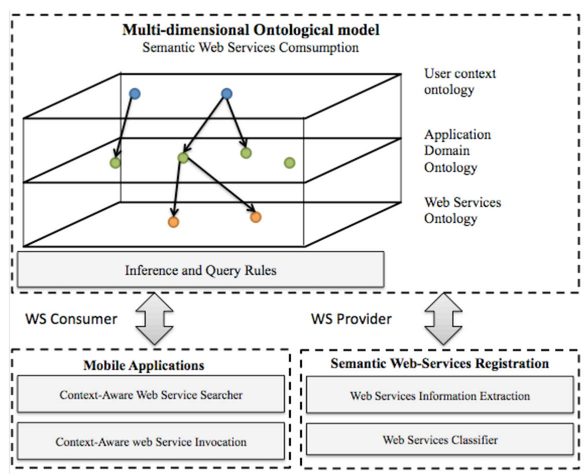

Figure 1. General architecture

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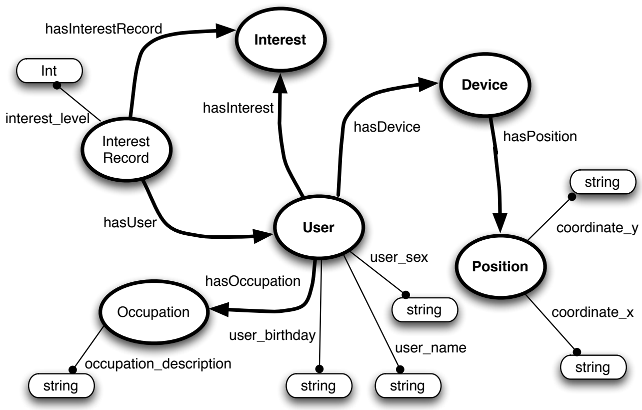

Figure 2. User Context Ontology

B. *Web Service Ontology*

The Web services ontology shown in Figure 3 shows the common components that any Web service describes. This ontology is populated automatically when a service provider is registered in the system and publishes Web service interfaces using WSDL files. This ontology allows Web services to be semantically annotated with more functional information. This ontology consists of the following classes: *Provider*, defines the individual Web services published by supplier name, password, email and a URL; *Service* defines a Web service provider entered by using a service name and a access URL, *Type*, defines complex data types used within the service using a type name, a base class and a boolean flag that determines if a data type is comparable with geographical longitude and latitude, *Operations*, defines the operations defined in the service description; *Variable* defines the input and output values of an operation, in addition to describing the components of a complex data type; *Value* samples, defines a set of values that can be used as a reference for assigning value a given input variable.

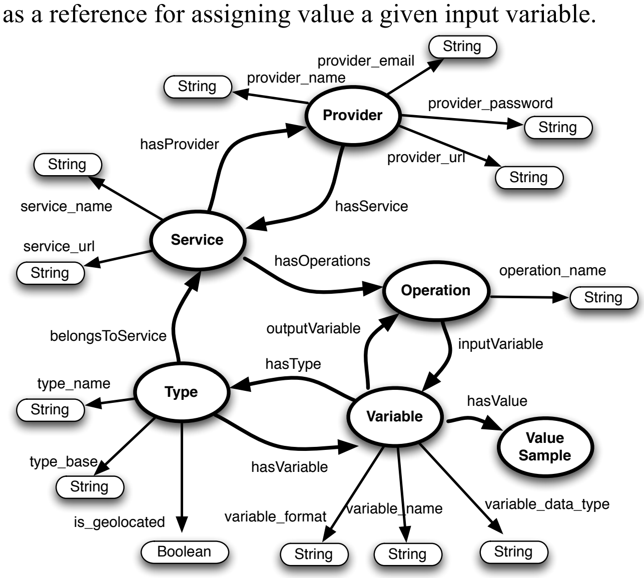

Figure 3. Web Service Ontology

C. *Application Domain Ontology*

The application domain ontology (Figure 4) defines a class hierarchy for classifying Web services according with a taxonomy of concepts related to various domains of interest to the user and applications that consume Web services. Through this ontology it is possible to find intersections between services functionalities and users' interests. This ontology can be continuously updating and adapting to new user requirements and new service providers offers.

The application domain ontology defines the class *Domain*, that defines a classification of possible fields of application of Web services and user interests.

D. *Integrating the Multi-dimensional Ontology*

This ontology imports all the definitions, concepts and semantic relations from the user context ontology, the Web service ontology and the application domain ontology.

In order to semantically relate the three models and produce new knowledge from them, it is important to establish semantic relationships between the concepts. However, these relationships are not defined arbitrarily, relations are decided based on a particular intention. In this case, the objective of putting the three ontological models together is to find related information with the user domain of interest and the Web service application domain. Therefore, the following relations are defined into the multi-dimensional ontology model:

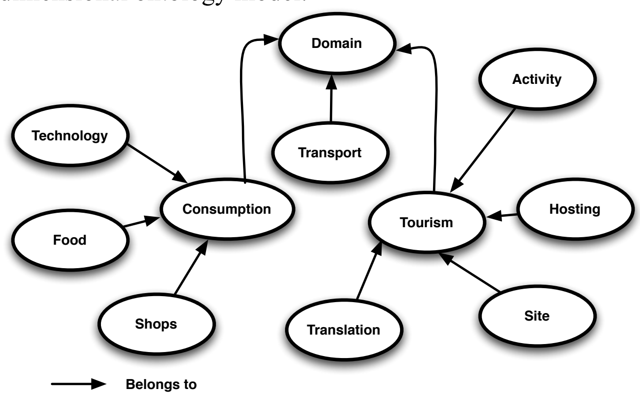

Figure 4. Application Domain Ontology

Based on the user context ontology internal relation *hasOccupation* (meaning: a user has a job or profession) the external relation *hasLevel* (meaning: an occupation has socioeconomical level) links the *Occupation* class with *Level* class from the application domain ontology. The semantic relation *interestHasDomain* (meaning: interest has an application domain) between the *Interest* class from the user context ontology and the *Domain* class from the application domain ontology correlates the user interest with application domains.

The semantic relation *serviceHasLevel* (meaning: a Web service has a socioeconomical level) correlates the *Service* class from the Web service ontology with the with *Level* class from the application domain ontology. And the semantic relation *serviceHasDomain* (meaning: a Web

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service has an application domain) correlates the *Service* class from the Web service ontology with the with *Domain* class from the application domain ontology, enabling with these relations to annotate semantically Web service definitions. Annotated Web services facilitate other service-related tasks such as Web service discovery and Web service matchmaking.

Finally, among an important semantic relation is the *userHasRecommendation* (meaning: a user has a context-based recommendation to consume a specific Web service). This relation enables the final user to get recommendations based on his/her interests and context. Figure 5 shows all semantic relationships between the three ontological models.

E. Inference and Query Rules

In order to discover and produce new semantic relations between individuals from the multi-dimensional ontology population, a set of inference rules are defined and executed.

Inference Rule 1. If a user *u*, is related to an interest *i*, through a record of interest *x*, and also the interest *i* has an application domain *d*, and service *s* also has the same domain *d* and the interest level *n* of the user *u* is greater than 5; then the inference engine makes the recommendation of the service *s* to the user *u*.

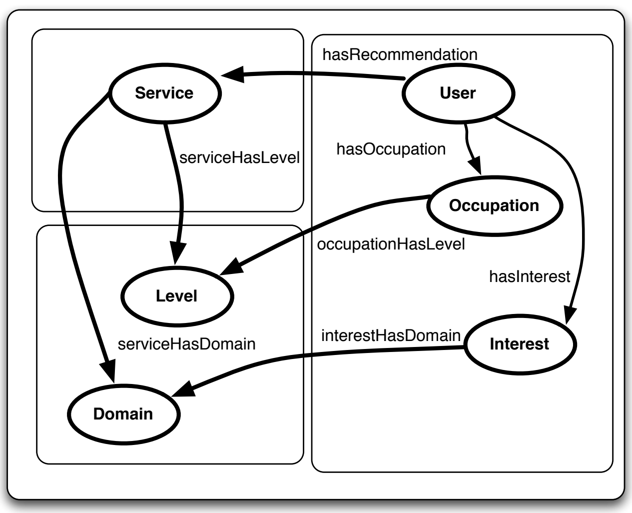

Figure 5. Multi-dimensional Ontology Model

contexto:Usuario(?u) ^ contexto:Intereses(?i) ^
dominios:Dominio(?d) ^ servicios:Servicio(?s) ^
contexto:RegistroInteres(?x) ^ contexto:tieneUsuario(?x, ?u) ^
contexto:tieneInteresesRegistrados(?x, ?i) ^ (1)
interesTieneDominio(?i, ?d) ^ servicioTieneDominio(?s, ?d) ^
contexto:nivel_interes(?x, ?n) ^ swrlb:greaterThan(?n, 5) ->
tieneRecomendacion(?u, ?s)

To facilitate external applications to query and search over the concepts and relations, a set of query rules are also defined and included into this multi-dimensional ontology.

Query Rule 2. This rule allows to search for services related with a specific Web service provider.

dominios:Dominio(?d) ^ servicios:Servicio(?s) ^
servicios:tieneProveedor(?s, ?prov) ^
servicioTieneDominio(?s, ?d) ^
servicios:nombre_servicio(?s, ?nombre) ^ (2)
servicios:url_servicio(?s, ?url) ->
sqwrl:select(?s, ?nombre, ?url, ?d)

Query Rule 3. This rule allows obtaining information about a particular user device.

contexto:Dispositivo(?dispositivo) ^
contexto:tieneDispositivo(?u, ?dispositivo) ^
contexto:marca_dispositivo(?dispositivo, ?marca) ^
contexto:modelo_dispositivo(?dispositivo, ?modelo) ^ (3)
contexto:numero_telefono_dispositivo(?dispositivo, ?tel) ->
sqwrl:select(?dispositivo, ?marca, ?modelo, ?tel)

Query Rule 4. This rule obtains the interest level of a given user, with respect to the interest defined in the ontology.

contexto:RegistroInteres(?r) ^
contexto:tieneInteresesRegistrados(?r, ?i) ^
contexto:tieneUsuario(?r, ?u) ^ (4)
contexto:nivel_interes(?r, ?nivel) ->
sqwrl:select(?r, ?i, ?nivel)

This multi-dimensional ontology can be enhanced by defining more inference and query rules to extract interesting information across dimensions.

Reasoning performance depends on the number of axioms and population of ontologies. In particular, in the multi-dimensional model reported in this paper, each ontology is maintained consistent by manually running checks periodically. So far, the number of individuals and axioms in ontologies remain low, so performance problems with reasoning tasks have not been faced. However, it is highly likely that when the number of Web services grows scaling problems will arise. To cope with this problem, there is the plan to manage interchangeable service ontologies.

In the case of rule-based reasoning, until now, no performance problems have been faced, this is mainly because the model uses few inference rules, most of the rules are query-rules, which consume less resources.

V. WEB SERVICE SEMANTIC REGISTRY APPLICATION

In order to populate, modify and query the multi-dimensional ontology model described in Section III, a *Web Service Semantic Registry* (WSSR) was implemented (see Figure 6).

Figure 6 shows the use case diagram of the WSSR application. This application interacts with two main actors: the Web service provider and the ontology manager. The former is the person responsible for registering provider data and Web services. The ontology manager is a sub-system which offers administrative functions, such as: automatic Web service parsing, to extract relevant Web service data; automatic Web service recording into the ontology; automatic link between application domains and context; and execution of inference rules to produce recommendations for Web service consumption.

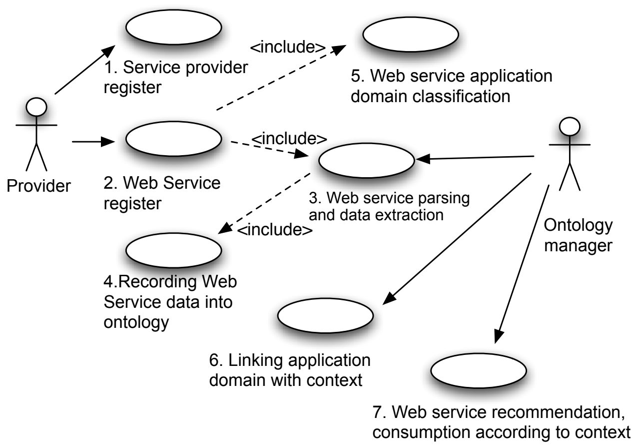

Figure 6. Use cases and associations of WSSR application

The WSSR was implemented as a Web application to enable Web service providers around the world to access the system and perform any of the following tasks: registration of new Web service providers, publication of Web services, semantic classification of Web services, and Web service lists. In this section these functionalities are described.

A. Registration of Web Service Providers

To gain access to the WSSR and make use of the registry functions, service providers must be registered first. Every new service provider is required to enter the following data: full name, URL of provider´s website and email address. He is also asked to create a username and password to access his account. All this information is stored in the multi-dimensional ontology model. In this study case, a total of 45 different Web service providers were registered in the ontology. In turn, each of these providers published different Web services.

B. Registering Web Services

The application for Web services registration, requires the provider to enter the URL of the WSDL file. The application connects to the specified URL, parsers the WSDL file to extract the relevant Web service information.

Registering Web services is an automated procedure which is executed through the following tasks:

1. *Data types information extraction*, this task consists of retrieving XML-Schemas from the WSDL file to obtain detailed information of complex and simple data types defined in the Web service interface.
2. *Extraction of service name and operations*, this task gets the name attribute of the service tag and the names of service operations. It also reads the elements that describe input and output parameters of each service operation.
3. *Registration of Web service information* in the web services ontology, this task creates a new individual instance in the *Service* class, using the specified URL and service name as data type attributes. It also establishes a semantic relation between the registered service and its corresponding provider using the *hasProvider* and *hasService* relations.
4. *Registration of parameters individuals* for complex data types into the *Parameter* class, establishing a new semantic relation between the new service instance and its parameters.
5. *Registration of operations individuals* in the class *Operation*, establishing respective semantic links with input and output parameters and parameters samples. Furthermore entity relationships are created among those individuals. There is a particular case when the return data type of a service operation is classified as geographically locatable. With this data type, it is possible to display the results on a map.

Using this facility, a set of 20 Web services were registered in the WSSR. Figure 7 shows the Web interface listing deployed Web services. These Web services are related with transportation, hotel reservation, flight booking, tours, and general offers. Table 2 shows a classification of implemented Web services.

Table 1 Implemented Web Services

Transport	**Hotel Booking**	**Flight Booking**	**Tours**	**Restaurant**
Metro	Fiesta Inn	Aviacsa	Travelocity	Sanborns
Metrobús	Fiesta Americana	Aeroméxico	Turissste	Chili´s
Tren suburbano	Crowne Plaza	Volaris	Turística 2000	Sam´s Club
	Emporio	Inter Jet		Toks
	Sheraton			Steren

C. Web Services Classification

Once the provider has registered his Web services (one at a time), he must classify them, this is done by using the classification tool of the WSSR application, where the provider of web services has to select an application domain, a sub-domain and a type from the domain ontology to. It is also necessary to define a socioeconomic level, depending on the target market where the provider wants to offer his Web services. Classification of services is extremely important because if a service is not classified, it will not be possible to link it with any consumer request. It is also important to note that this classification can be extended or even exchanged with another application domain or domains if required. Currently domain-based classification of Web services is done semi-automatically. However, one of future extensions of this work is to implement fully automated classification of published Web services.

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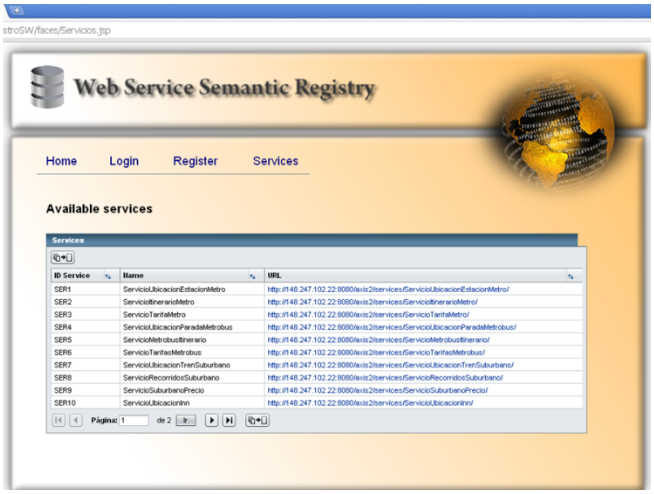

Figure 7. Web service semantic registry showing deployed services

VI. CONTEXT-AWARE MOBILE APPLICATION

To evaluate the proposed model, a mobile application was implemented. This mobile application allows any user to register into the WSSR to search for web services and invoke them as requested. This section describes the mobile application modules implemented.

A. *Mobile user registration*

All new mobile users are requested to register into the system before making use of its facilities. This registration task is executed as follows:

a) *Obtaining mobile user data*, this task requires the user to interact with the mobile application to enter the following data: full name, gender, birth date, occupation, mobile device (brand, model and phone number), interest list and interest ranking.

b) *Extracting mobile user position*, this task is executed as many times as the user logins the system through the mobile application. Therefore, position is the dynamic value which encapsulates longitude and latitude data from the mobile device.

c) *Registration of mobile user data and context*, this task registers a new user individual into the user context ontology. Also a new individual is created into the ontology to represent the mobile device characteristics. Occupation is established as a semantic relation between the user individual and the occupation class. The list of interests is also recorded in the ontology with their respective semantic associations with the user. Figure 8 shows the graphical user interface of the mobile application.

B. *Web Services Search and Invocation*

Search, selection and consumption of Web services are among the most demanded application tasks related with Web services. This functionality was implemented in the mobile application (see Figure 9). Search of Web services starts when the user selects to view the list of Web services classified according to their application domain. The classified Web service list is dynamically generated as a result of executing a query to the ontology model. The user has the option to search for Web services considering his geographical position at the time of the request.

Figure 8. User registers interests in the mobile application

Once the user selects an application domain, it displays the interface, where the user can select from a list of recommend services based on the selected domain and user context. This recommendation is done through an inference rule, which is executed dynamically with user data.

Figure 9. Search, selection and invocation of Web Services

Figure 9 shows the result of invocating a location Web service. In particular, in this case the user requested the address of any restaurant located at Lindavista district, as a result the mobile application returned a map location of a restaurant at Lindavista, recommended based on the users interests.

The mobile application described in this work shows that the development of a multi-dimensional representation using ontologies and semantic Web services facilitates the generation of intelligent and dynamic recommendations of relevant services to end users. This result is mainly due to the incorporation of the user's context shaped by his interests and his geographical context.

VII. CONCLUSIONS

This paper describes a multi-dimensional ontology model which incorporates the user context information, semantic Web services interface modeling and application domain classifications. The work reported in this paper incorporates various technological paradigms, such as: semantic Web services, mobile computing and ontologies. The main objective of integrating these technologies was to support the development of more complex and intelligent mobile context-aware applications.

In this paper we reported the implementation of a mobile-based architecture for the use of Semantic Web Services trough a multi-dimensional ontology. We present the initial results. Performance results are going to be obtained once the automatic mechanism for populating the ontologies from web pages is finished.

The use of multi-dimensional models implemented with ontologies offers significant advantages: the ability to exchange, expand, extend and maintain the individual ontologies. An example is the application domain ontology, which can be interchanged as needed to adapt to new application needs.

The incorporation and exploitation of Web services through ontological models is a clear trend that promises to improve the automatic selection and invocation of legacy and new Web services.

All these technologies together (Web services and ontologies) are key facilitators for the wise management of context-based systems based on mobile computing.

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REFERENCES

[1] Y. Park and F. Adachi (eds.), Enhanced Radio Access Technologies for Next Generation Mobile Communication, pp. 1–37. 2007 Springer.

[2] Mobile Web Initiative. The Web and Mobile Devices. 2010. http://www.w3.org/Mobile/. March 2012

[3] K. Chen and J. de Marca, Mobile Wimax Wiley 2008.

[4] M. Weiser "The Computer for the 21st Century", ACM Mobile Computing and Communication Review, vol. 3, issue 3, pp. 3-11, 1999, doi: 10.1145/329124.329126

[5] N. Blefari-Melazzi, E. Casalicchio, and S. Salsano, "Context-aware Service Discovery in Mobile Heterogeneous Enviroments", Proc. IEEE Mobile and Wireless Communications Summit, 2007, 16th IST, septembre 2007 pp. 1-5, Budapest, doi: 10.1109/ISTMWC.2007.4299226

[6] M. Horridge, H. Knublauch, A. Rector, R. Stevens, and Ch. Wro, A Practical Guide To Building OWL Ontologies Using The Protégé-OWL Plugin and CO-ODE Tools, Edition 1.0, The University Of Manchester, March 2012

[7] N. Weißenberg, A. Voisard, and R. Gartmann "Using Ontologies in Personalized Mobile Applications", Proceedings of the 12th annual ACM international workshop on Geographic Information Systems (GIS 04), November 2004, pp. 2-11, doi: 10.1145/1032222.1032225

[8] M. Sheshagiri, N. Sadeh, and F. Gandon "Using Semantic Web Services for Context-Aware Applications", Proceedings of Mobisys2004 Workshop on Context Awareness, June 2004.

[9] T. Gu, H. Pung, and D. Zhang, "A service-oriented middleware for building context-aware services", Journal of Network and Computer Applications, vol. 28, issue 1, january 2005, pp. 1-18, doi: 10.1016/j.jnca.2004.06.002.

[10] W. Kim, S. Lee, and D. Choi "Semantic Web Based Intelligent Product and Service Search Framework for Location-Based Services", Lecture Notes in Computer Science Springer, Computational Science and Its Applications (ICCSA 2005) Part IV, may 2005, pp. 103-112, Singapore, doi: 10.1007/11424925_13

[11] K. Dickson, W. Chiu, T. Yves, F. Yueh, L. Ho-fung. C. Patrick, and K. Hung "Towards ubiquitous tourist service coordination and process integration: A collaborative travel agent system architecture with semantic web services" ACM Information Systems Frontiers, Volume 11, Number 3, July 2008, pp. 241-256, Bradford, UK., doi: 10.1007/s10796-008-9087-2

[12] A. Bouzeghoub, K. Ngoc, and L. Krug, "Situation-Aware Adaptive Recommendation to Assist Mobile Users in a Campus Environment", Proceedings IEEE International Conference on Advanced Information Networking and Applications (AINA-09), May 2009, pp. 503-509, doi: /10.1109/AINA.2009.120

[13] A. Cadenas, C. Ruiz, I. Larizgoitia, R. Garcia, C. Lamsfus, I. Vázquez, M. González, D. Martín, and M. Poveda, "Context Management in Mobile Environments: a Semantic Approach" ACM Proceedings of 1st Workshop on Context, Information and Ontologies, CIAO 2009, June 2009, Heraklion, Grecia, doi: 10.1145/1552262.1552264

[14] P. Sousa, E. Carrapatoso, B. Fonseca, M. Campos, and R. Bulcão-Neto, "Composition of context aware mobile services using a semantic context model", International Journal On Advances in Software, volume 2, numbers 2 and 3, December 2009, pp. 275-287.

[15] W. Woerndl and A. Hristov, "Recommending Resources in Mobile Personal Information Management", IEEE Proceedings of the Third International Conference on Digital Society, (ICDS 2009), February 2009, pp. 149-154, doi: 10.1109/ICDS.2009.21.

[16] I. Liiv, T. Tammet, T. Ruotsalo, and A. Kuusik, "Personalized Context-Aware Recommendations in SMARTMUSEUM: Combining Semantics with Statistics," IEEE Procedings of Third International Conference on Advances in Semantic, October 2009, pp. 50-55, 2009, doi: 10.1109/SEMAPRO.2009.25.

[17] M.C. Suárez-Figueroa, A. Gómez-Pérez, and B. Villazón-Terrazas, "How to Write and Use the Ontology Requirements Specification Document", ACM Procedings Confederated International Conferences, CoopIS, DOA, IS, and ODBASE 2009 on On the Move to Meaningful Internet Systems: Part II OTM'09, November 1009, pp. 966-982, 10.1007/978-3-642-05151-7_16

[18] S. Bechhofer, M. Dean, F. Van Harmelen, J. Hendler, I. Horrocks, D. McGuinness, P. Patel-Schneider, G. Schreiber, and L. Stein,: OWL Web Ontology Language Reference, W3C Proposed Recommendation. http://www.w3.org/TR/owl-ref/. March,2012.

[19] Semantic Query-Enhanced Web Rule Language. http://protege.cim3.net/cgibin/wiki.pl?SQWRL March 2012