Multidimensional Ontology Model to Support Context-Aware Systems

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Abstract

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. This situation gives rise to the new era of computing called Ubiquitous Computing, where it is necessary to develop new and improved structures for knowledge and information representation and exchange, in order to support the implementation of intelligent and context-aware systems. Thus 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.

Introduction

Computing has evolved in such a way that has left behind the limitation of being static, heavy and local. This limitation has been resolved with the emergence of mobile computing devices which are smaller, lighter and have low power requirements, enabling communications between mobile devices and people anywhere in the world (Park and Adachi 2007). 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.

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 (Weiser 1999). 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.

The emergence of mobile computing technology, distributed information around the world across multiple servers and databases, and the incremented demand for opportune and personalized information from anywhere, has created a significant need for the development of more and smarter mobile applications that help to discover and gather this information accurately.

Current advancements in the area of knowledge representation have promoted the design and implementation of ontologies as a core solution for information and knowledge discovery through reasoning and inference mechanisms. On the other hand, progress in research on and development of intelligent infrastructures for Web services represent the enabling technology that facilitates the interoperability of multiple mobile applications across multiplatform.

Web services (WS)[1] 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 that 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.

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" (Blefari-

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

Melazzi, Casalicchio, and Salsano 2007). 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.

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. Any registered mobile user can search, select and invoke Web services according to his/her needs.

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.

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. Using a multidimensional ontology modeling approach has the following benefits (Horridge et al. 2012):

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.

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.

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 works.

In 2004 Weißenberg et al. (Weißenberg, Voisard, and Gartmann 2004) 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.

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. (Sheshagiri, Sadeh, and Gandon 2004) 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 Kim et al. (Kim, Lee, and Choi 2005) 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.

In 2008 Dickson et al. (Dickson et al. 2008) 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.

In 2009 Amel Bouzeghoub et al. (Bouzeghoub, Ngoc, and Krug 2009) 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, Woerndl and Hristov (Woerndl and Hristov 2009) 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.

Shen and Cheng (Shen and shen 2011) propose the use of semantic web technologies and context to implement a context-based access control mechanism. An otology is used to represent the context and a framework is proposed to handle the information of context through an inference engine. Control access policies are represented as rules for the ontologies. Four types of contexts are proposed : subject context for specific subject-related contexts, object context for object-related information used to characterize the context of object (creation and status), context transactions for current and historic transactions, and environment context for operatriona, technical and situational environment at transaction activation.

Deravaju and hoh (Deravaju and Hoh 2008) Propose a middleware for the integration of context aware services and the information from several sources in a pervasive environment. The main objective of this proposal is to allow the development of context-aware services by defining a set of functionalities that translate the raw information from sensors into knowledge for actuators and software. Contextual information is modeled through a framework composed of three layers: the upper layer ontology provides definitions for general-purpose terms upon which domain ontologies can be constructed. The mi-level ontology holds context entities representation it acts as a traducer for the upper-layer ontology and the lower-layer one. The lower-layer ontology contains a collection od domain specific ontologies for context-aware applications.

Resende et. al. (resende et al. 2009) propose a mobile context-aware geographic information system based on ontologies. The aim is to propose an architecture for the development of context-aware GIS mobile applications through the integration of context sensitive mobile systems and GIS applications, the main components of this project are: a mobile GIS application to manipulate geo-spatial data, a set of web services to manage communications and supply information to the users a set of ontologies for modeling the context and a geographical database that manages geospatial data.

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.

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.
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 (Bechhofer 2012) 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[2] was used. SQWRL (Semantic Query-enhanced Web Rule Language) 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.

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

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

User Context Ontology

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.

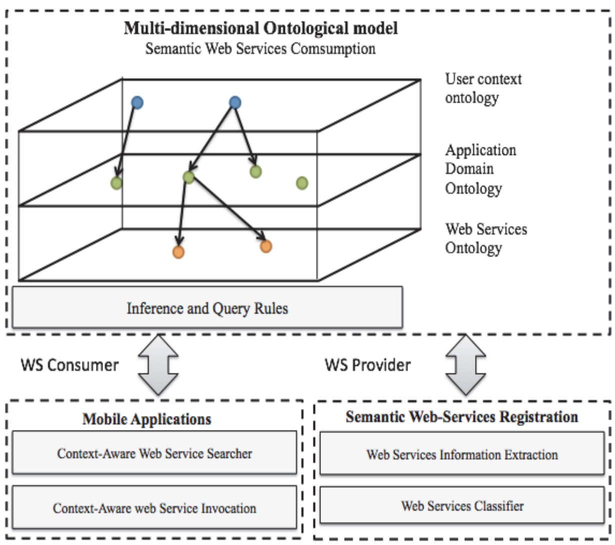

Figure 1. General Architecture

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.

Web Service Ontology

The Web service 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.

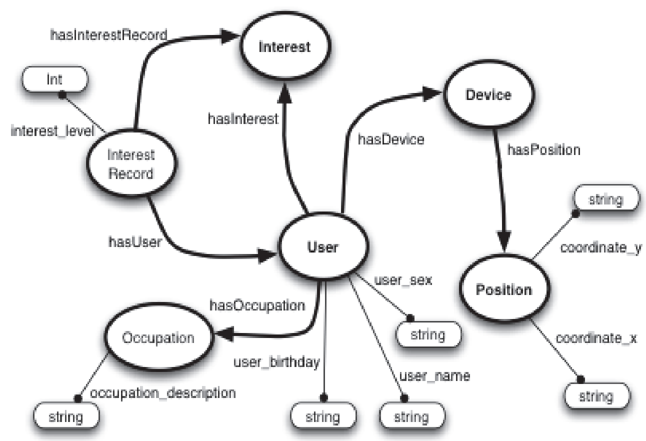

Figure 2. User Context Ontology

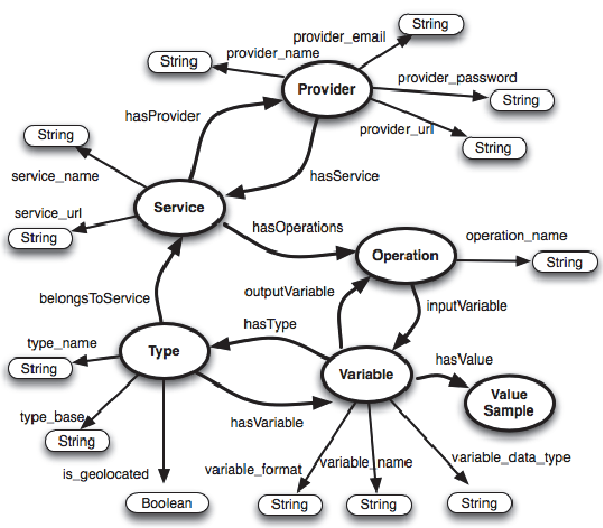

Figure 3. Web Services Ontology

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.

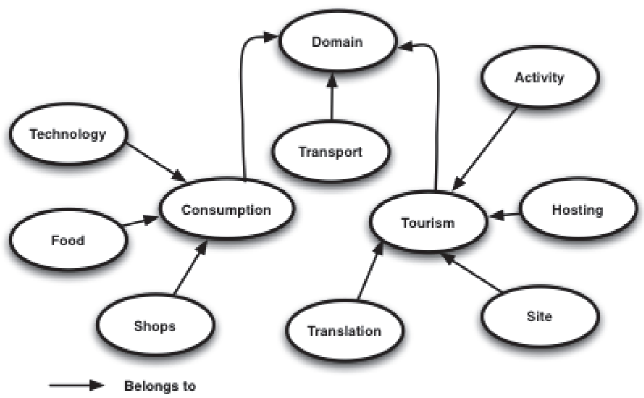

Figure 4. Application Domain Ontology

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 socio-economical 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 socio-economical 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 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.

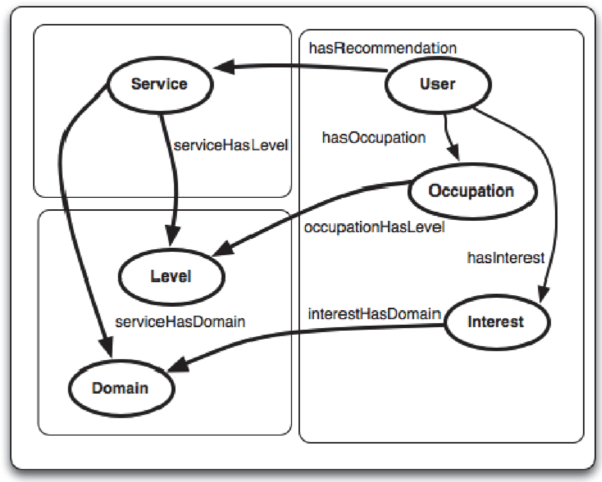

Figure5. Multi-dimensional Ontology Model

Rule-based Service Recommendation

To evaluate the ontological model, a rule-based service recommendation was implemented to search for Web services wisely. This application is intended to identify the characteristics of user profile and context, correlate them with Web services that may be of interest according to the application domain and through the implementation of a set of logical inference rules, produce recommendations that are context-aware.

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*.

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) ^
servicios:url_servicio(?s, ?url) ->
sqwrl:select(?s, ?nombre, ?url, ?d) (2)

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) ^
contexto:numero_telefono_dispositivo(?dispositivo, ?tel) ->
sqwrl:select(?dispositivo, ?marca, ?modelo, ?tel) (3)

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

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

Performance Analysis

Performance analysis of service-related tasks is an important issue whenever these tasks are based on ontological representation. In particular, in this paper the following service tasks are of performance concern:

Ontology population. This is the most time consuming task because for each service instance treated requires the execution of two operations: service parsing and service ontology recording. Which means that for each service, the parser extracts its operation names and respective input and output parameters, and then records all instances into their ontology classes. Obviously, the more service instances are treated the more time is needed. However, this particular time-consuming task is not considered as critical, because it is executed only once per service set. Even more, when new service instances are to be recorded into the same ontology, they are first validated for non redundancy, therefore only new different services are allocated. Ontology population is a time-consuming task, but is not a frequent task.

Service search. In a traditional implementation approach this tasks would require traversing the entire ontology T-Box and A-Box to find particular class instances, relation instances or individuals. However, in this paper the use of a rule language enhanced with querying constructs (SWRL) allows the definition and execution of rule-based search. A rule-based querying mechanism offers improved performance, as it filters only the necessary class, relations, axioms and individuals needed for the execution of each rule.

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.

Conclusions

This paper describes a multi-dimensional ontology model which incorporates 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.

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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