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Towards Building a Digital Library Service Metadata Model on the Semantic Web

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Abstract

In the current era of big data, digital library (DL) is migrating towards the directions of semantic exchanges and service interactions to facilitate DL users to search, share and reuse the digital resources in a more effective and efficient manner. This paper explores Semantic Web technologies for ontology-based modeling of DL service metadata across ubiquitous DLs, enabling to add semantics to DL services to address issues related to representation, cooperation and accessibility of services in or across the communities. In particular, the DL service metadata ontology addresses the dynamic behavior of a DL service by nesting the stateful changes, constraint rules and mapping rules to achieve the dynamic coherence for seamless service interoperability in the service lifecycle. The operation of the prototype system is demonstrated to validate the implementation of the proposed approach through access and visualization in a usage scenario.

Keywords: *Digital library, Ontology; Semantic Web; Service-oriented*

1. Introduction

With the explosive growth of library resources at a Web scale since 1990s, the digital libraries (DLs) have been widely developed all over the world to facilitate library users to search, share and reuse the DL resources effectively and efficiently. However, in the current era of big data, the vast amount of distributed, heterogeneous and dynamic DL resources and services in cross-community library collaborations still leads to the serious information overload problem. This stimulates the usage of Service-oriented architecture (SOA) and Semantic Web technology for next generation DL development based on pervasive and computing infrastructures [1] to enable its interoperability and interlinking with intelligent agents and realize effective communication, interoperation, integration and collaboration at the resource level of DL.

SOA can be defined as a system in which resources are made available to other participants in the network as independent services that are accessed in a standardized way [2]. While potential benefits of SOA are clear, it raises new challenges in the management of DL service metadata, in particular, in dealing with service interoperability. In SOA, each Web service has a WSDL (Web service description language) interface for service description and catogery selection. WSDL represents Web services by means of textual or categorical descriptions such as operation names and XML Schema data types at a syntactic level, but lacks a semantic level of expressivity for representing and classifying DL services, which is a prelude to the recently advocated DL intelligence. As a result, the existing DL service solutions for resource reuse based on WSDL may lead to poor precision, recall, scalability and compatibility.

The recent popularity of Semantic Web technology [3] has made possible the generation of the kind of shared knowledge concepts to alleviate the interoperability

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issues, by annotating Web services with generalized ontologies. The current paper explores Semantic Web technologies for ontology-based modeling of DL service metadata across ubiquitous virtual DLs via Unified Modeling Language (UML), through which, various DL services are annotated with OWL-based DL resource ontology and SWRL-based DL semantic rules, enabling to endow them with improved representation, cooperation and accessibility in or across the communities. On one hand, because a DL service tends to change through a series of different states via interactive service operations in its lifecycle, the DL service metadata ontology is proposed to nest the stateful changes to better address the service's dynamic behavior. On the other hand, because the execution of a DL service may produce different effects under different preconditions, the DL service metadata ontology is proposed to nest the constraint rules on the service preconditions and effects, also to better address the service's dynamic behavior. In addition, as heterogeneous DL services from different communities may be orchestrated to solve a complex problem in dynamic environment, the DL service metadata ontology is proposed to nest the mapping rules for mediating any mismatch between data, knowledge and Web services across different communities.

A prototype system leveraged by underlying DL resource and service ontologies is developed to help users to maintain ontologies, formulate queries and express conditions for finding DL services, *e.g.*, to help them map high-level requirement into unambiguous query trees. The operation of the prototype system is demonstrated to validate the implementation of the proposed approach for effective management of dynamic DL service metadata through access and visualization in a usage scenario.

2. Related Work

Service interoperability problem in the DL context has been addressed by some researchers through appropriate service description, modeling and integration.

The prevalent WSDL describes Web services as collections of operation names and XML Schema data types at a syntactic level, and has been widely used as a standardized interface to exchange multiple operation elements and XML documents. For example, Petinot *et al.* [4] developed a SOA for DLs, which is based on WSDL and allows for easy programatical access to all the specific functionalities offered by DL services, including full text search of documents and citations and citation-based document discovery. However WSDL is not suited for the creation of machine-understandable semantic descriptions of DL services, and doesn't address the semantic needs of DL service modeling. This inhibits the meaningful and seamless service interoperability in distributed DL environments.

Fortunately, the recent popularity of Semantic Web technology has provided a standardized way to describe Web services in a machine understandable manner which paves the path for semantic interoperability. In particular, the vision of Semantic Web service (SWS) was presented by Sycara *et al*. [5], which combines the growing SOA and Semantic Web, and facilitates maximal automation and dynamism in Web service discovery, selection, composition, negotiation, invocation, monitoring, management, recovery and compensation. DAML-S [6] and its updated version OWL-S [7] are the most salient service ontologies to describe Semantic Web services. They provide a core set of markup language constructs for describing the properties and capabilities of Web services in unambiguous and computer-interpretable form, and how to interact with them in a meaningful manner, which in turn provides a good basis for meaningful service interoperability. For example, Zhang and Yang [8] developed the Semantic Web service-based DL in the information grid environment to resolve the interoperability issues across DL systems. It implements service discovery for information retrieval with UDDI, describes Semantic Web services with OWL-S, and deploys and retrieves services through Apache LDAP. Qiu *et al.* [9] used the Semantic Web service paradigm based on both DAML-S and OWL-S to integrate distributed DL resources to realize the interoperation and automation of Web services, and ultimately form a centralized, unified DL system that supports semantic retrieval process of DL services. However, emphasizing on the technological aspects of a formal service ontology, DAML-S or OWL-S do not provide complete vocabulary sets for describing domain-specific DL services.

To alleviate the above disadvantage, few researchers have explored Semantic Web technologies for domain-specific DL service metadata modeling. For example, Hu and Zhao [10] proposed an ontology-based framework for knowledge service modeling in DL, and analyzed its service process. Using this framework, more efficient knowledge services can be provided by a DL for satisfying the customers' individual requirement about knowledge. Marinchev [11] defined a meta-description of DL services with formal Web Ontology Language (OWL) [12], and developed an algorithm to transform the DL data between its Web service form and the OWL instances.

However, the current Semantic Web-based DL service metadata ontology is still not widely used in practice because it has not adequately addressed the dynamic behavior of a DL service, which is necessary for seamless service interoperability, due to the lack of a comprehensive, yet flexible representation scheme that nests both the stateful changes via a series of interactive service operations, the constraint rules on the service preconditions and effects and the mapping rules for mediation across different communities.

3. Dynamic Modeling of DL Service Metadata on the Semantic Web

As both Semantic Web and Web service technologies can be used to alleviate the service interoperability issues in distributed DL environments, they are combined for utilization in the current work to deliver communities of users (*e.g.*, citizens, enterprises or other public sectors) a loosely coupled, distributed solution to facilitate their seamless access to heterogeneous DL resources through well-defined Semantic Web services in such environments.

3.1. Ontology-Based Service-Oriented Modeling via UML Class Diagram

Unlike traditional resource management practices that concentrate on the separate capabilities of involved resources, the Semantic Web services facilitate the capturing of the semantics of exchanged DL resources through ontology and service interaction so that diverse resources can be federated in a meaningful way and each individual resource management issue can be tackled in a much more coordinated way. Ontology is used to accommodate the dynamic differences in vocabularies and models in diverse DL activities, in particular, whenever a rigorous and unambiguous communication between human and machine, machine and machine, or human and human is necessary.

Referring to Figure 1, a dynamic modeling of DL service metadata via Unified Modeling Language (UML) class diagram is proposed on the Semantic Web to facilitate effective management of heterogeneous DL services.

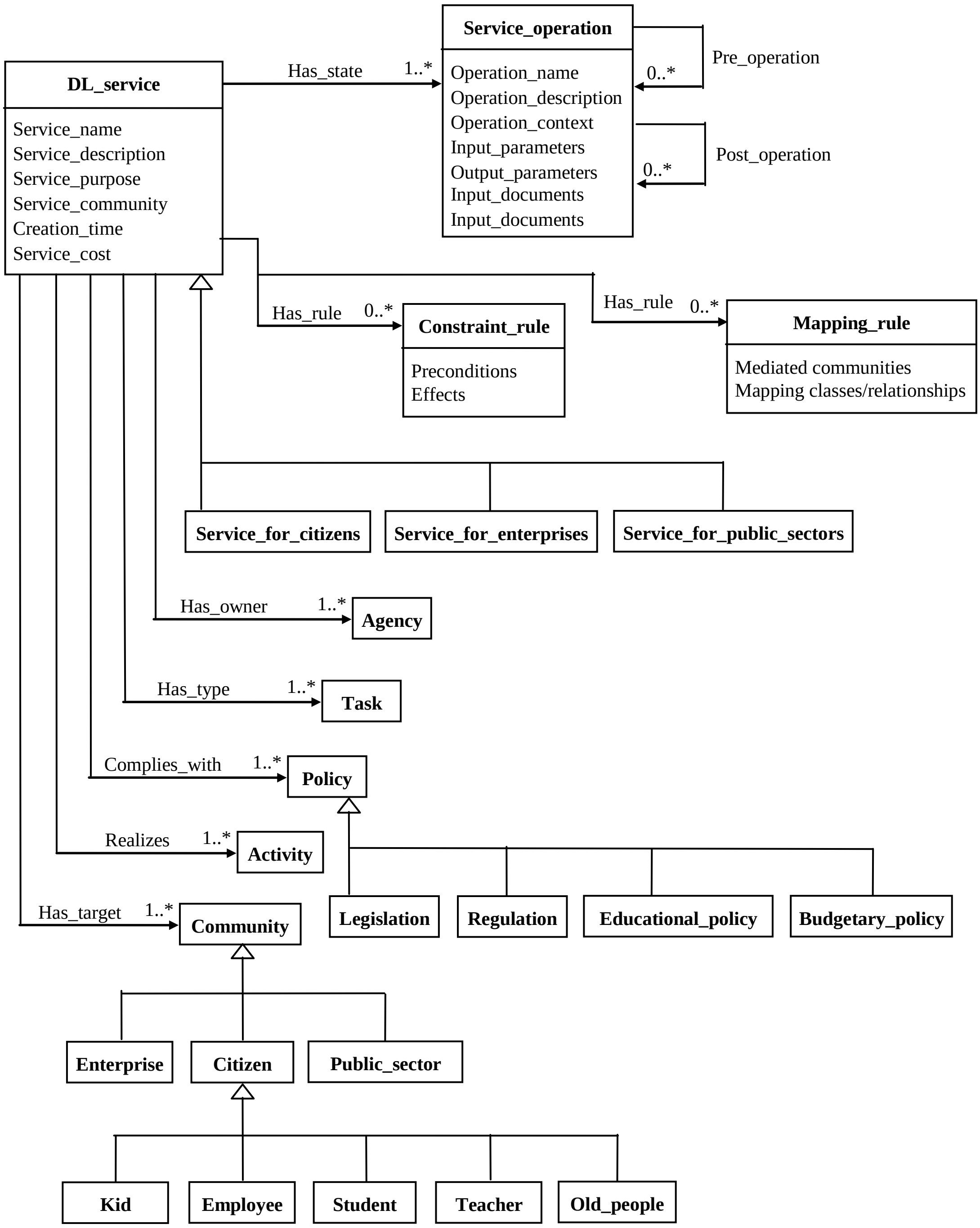

Figure 1. Dynamic Modeling of DL Service Metadata with UML Class Diagram

The DL service metadata ontology is built with the formal representation language OWL that is the most expressive semantic markup language up to date on the Semantic Web, starting from a set of inter-related top-level concepts that adequately support the rigorous and unambiguous description of DL service provisions across ubiquitous virtual communities of libraries. The top-level OWL concepts include DL service, agency, task, policy, activity, community, service operation, constraint rule, and mapping rule, each of which can be further specialized into optimal number of lower-level sub-concepts to represent the domain as accurately as possible. For example, the DL service class can be specialized into Service for citizens, Service for enterprises and Service for public sectors classes through ontological inheritance. The Policy class can be specialized into Legislation, Regulation, Educational policy and Budgetary policy classes. The Community class can be specialized into Citizen, Enterprise and Public sector classes. The Citizen can be further specialized into Kid, Old people, Student, Teacher, and Employee classes.

The DL service is defined to hide the complexities associated with management of geographically distributed DL resources by wrapping up them as Web services based on the underlying DL resource ontology, for making usage of them as transparent and meaningful as possible from the users' point of view. Basic syntactic DL service profile includes service name, service description, service purpose, service community, creation time and service cost.

To enhance the DL service metadata ontology with a semantic level of expressivity for representing domain-specific DL service metadata, it is annotated with OWL-based DL resource ontology in the present work. For example, the DL service associates with the Agency, Task, Policy, Activity and Community through Has owner, Has type, Complies with, Realizes and Has target associations respectively.

On the other hand, the execution of a DL service may behave differently in response to multiple service interoperations in the service lifecycle, as it tends to change through a series of different states via interactive service operations in its lifecycle. Therefore, to enhance the DL service metadata ontology with dynamic behavior, it is annotated by nesting the stateful changes via a series of interactive service operations, resulting in assured state coherence for seamless service interoperability in the service lifecycle. For example, the DL service associates with the Service operation through Has state association. Basic service operation profile includes operation name, operation description, operation context, input parameters, output parameters, input documents and output documents. The Service operation further associates with the other Service operation through Pre-operation and Post-operation associations to establish the operation-operation dependency.

In addition, the execution of a DL service may produce different effects under different preconditions, hence the DL service metadata ontology is also annotated by nesting the constraint rules on the service preconditions and effects, resulting in assured constraint coherence for seamless service interoperability in the service lifecycle. For example, the DL service associates with the Constraint rule through has rule association. A constraint rule includes the corresponding service preconditions and effects, in other words, the preconditions satisfied only result in the corresponding effects in the same constraint rule after service execution. The constraint rule is formalized using SWRL [13] that is the most expressive semantic rule language up to date on the Semantic Web. SWRL allows users to formulate the corresponding service preconditions and effects in the form of IF-THEN formats expressed in terms of OWL concepts. Below is an example of constraint rules associated with a DL service.

The constraint rule example shown in the below SWRL equation (1) specifies, if the precondition "a book delivery service is offered to a widowed old people whose age is over 70" is satisfied, then the execution of the service results in the effect "free service charge".

$$Book\_delivery\_service(?x) \wedge Has\_target(?x, ?a) \wedge Old\_people(?a) \wedge Widowed\ (?a) \wedge Age(?a, ?b) \wedge swrlb{:}greaterThan(?b, 70) \rightarrow Service\_cost\ (?x, 0) \quad (1)$$

In dynamic, distributed DL environment, we cannot assume that data, knowledge and Web services across different communities are both centralized and compatible, hence the DL service metadata ontology is also annotated by nesting the mapping rules for mediation across different communities, resulting in assured cross-community coherence for seamless service interoperability in the service lifecycle. For example, the DL service associates with the Mapping rule through has rule association. A mapping rule includes the mediated communities and mapping ontology classes/relationships, in other words, the cooperative communities satisfied will result in the mapping ontology classes or relationships to resolve mismatch across communities after service execution. The mapping ontology classes/relationships can be extracted from existing cross-domain multi-ontology systems [14-15]. The mapping rule is also formalized using SWRL. Below is an example of mapping rules associated with a DL service.

The mapping rule example shown in the below SWRL equation (2) specifies, if "two cooperating communities Library and Citizen center" is satisfied, then the execution of the service results in the consequent "mapping Old people (in Library community) and Senior citizen (in Citizen center community) classes".

$$DL\_service(?x) \wedge Service\_community\ (?x\ Library) \wedge Has\_target(?x, ?a) \wedge Old\_people(?a) \wedge DL\_service(?y) \wedge Service\_community\ (?y\ Citizen\_center) \wedge Has\_target(?y, ?b) \wedge Senior\_citizen(?b) \rightarrow Mapping\ (?a,?b) \quad (2)$$

In summary, the DL service metadata ontology can be formally expressed using SHIQ, which is a description logic of OWL:

$$DL\_service \equiv (\geq 1\ Has\_owner.Agency) \cap (\geq 1\ Has\_type.Task) \cap (\geq 1\ Complies\_with.Policy) \cap (\geq 1\ Realizes.Activity) \cap (\geq 1\ Has\_target.Community) \cap (\geq 1\ Has\_state.Service\_operation\ ((\geq 0\ Pre\_operation.Service\_operation) \cap (\geq 0\ Post\_operation.Service\_operation))) \cap (\geq 0\ Has\_rule.Constraint\_rule) \cap (\geq 0\ Has\_rule.Mapping\_rule) \quad (3)$$

The above ontology-based service annotation shows that the represented DL service can be a complex service that has at least one owner, one type, one community and one state, complies with at least one policy, realizes at least one activity, has zero or at least one constraint rule and one mapping rule, using "AND" relationships. A service operation associates with zero or at least one other service operation using "AND" relationships. A constraint rule has corresponding service preconditions and effects using SWRL. A mapping rule mediates any mismatch across communities using SWRL. However, lower level details about service operations such as input documents, output documents, *etc.* are not considered at this point and will be explored in our future work.

3.2. An Illustrative Example of Ontology-Based Representation in OWL Format

As an example of the semantic annotation to DL services, Figure 2 shows the representative snippets of OWL source codes of a DL service named Interlibrary book delivery service, which are displayed using Internet Explorer's XML parser.


```
<rdf:RDF
      xmlns:rdf=http://www.w3.org/1999/02/22-rdf-syntax-ns#
      xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
      xmlns:owl="http://www.w3.org/2002/07/owl#"
      xmlns:xsd="http://www.w3.org/2000/10/XMLschema.xsd#"          1
      xmlns:DLresource=http://zufe.edu.cn/dllab/DLresource.owl#
      xmlns:DLservice=http://zufe.edu.cn/dllab/DLservice.owl#>
      ……
      <DLservice:DL_service rdf:ID="Interlibrary_book_delivery-ZUFE">
            <DLservice:Service_name>Interlibrary_book_delivery_service</DLservice:Service_name>
            <DLservice:Service_description>This DL service is used for ordering interlibrary book and
                        dispatching  it to citizens</DLservice:Service_description>
            <DLservice:Service_purpose>Book_delivery<DLservice:Service_purpose>          2
            <DLservice:Service_community>Library<DLservice:Service_community>
            <DLservice:Creation_time>09-03-2007<DLservice:Creation_time>
            <DLservice:Has_owner rdf:resource="http://www.zufe.edu.cn/library#Library of Zhejiang
                        University of Finance and Economics"/>
            <DLservice:Has_type rdf:resource="DLresource#Book_delivery"/>
            <DLservice:Complies_with rdf:resource="DLresource#Regulation"/>          3
            <DLservice:Realizes rdf:resource="DLresource#Book_delivery"/>
            <DLservice:Has_target rdf:resource="DLresource#Citizen"/>
            <DLservice:Has_state>
                  <DLservice:Service_operation rdf:ID＝"Service_operation-1">
                        <DLservice:Operation_name>Check_eligibility</DLservice:Operation_name>
                        ……
                  </DLservice:Service_operation>
                  <DLservice:Service_operation rdf:ID＝"Service_operation-2">
                        <DLservice:Operation_name>Order_book</DLservice: Operation_name>
                        <DLservice:Operation_description>This service operation is used for ordering
                                    favourite book online</DLservice: Operation_description>
                        <DLservice:Operation_context>Before_order</DLservice: Operation_context>          4
                        <DLservice:Input_parameters>……</DLservice:Input_parameters>
                        <DLservice:Out_parameters>……</DLservice:Out_parameters>
                        <DLservice:Pre_operation rdf:resource="DLservice#Check_eligibility"/>
                        ……
                  </DLservice:Service_operation>
                  <DLservice:Service_operation rdf:ID＝"Service_operation-3">
                        <DLservice:Operation_name>Dispatch_book</DLservice:Operation_name>
                        ……
            </DLservice:Has_state>
            <DLservice:Has_rule rdf:resource="DLresource#Constraint_rule"/>          5
            <DLservice:Has_rule rdf:resource="DLresource#Mapping_rule"/>
      </DLservice:DL_service>
      ……
</rdf:RDF>
```

Figure 2. Representative Snippets of the OWL Source Codes of a DL Service Example

The first few lines in the OWL source codes marked portion 1 contain the namespace information and have the URI references. DLresource and DLservice are namespaces of DL resource ontology and DL service ontology respectively. The contents marked portion

2 define the basic syntactic service profiles including service name, service description, service purpose, service community, and creation time. The contents marked portion 3 define the service's semantic relationships with the agency, task, policy, activity and target.

The contents marked portion 4 define the service's stateful changes via a few of interactive service operations, including Check eligibility, Order book and Dispatch book. The service operation Order book has a pre-operation Check eligibility, as means that the citizen needs to execute the Check eligibility operation first before invoking the Order book operation. The contents marked portion 5 define the service's constraint rules and mapping rules, which are formalized in previous equations (1) and (2) using SWRL respectively in the last sub-section.

4. Querying DL Service Metadata via UML Activity Diagram

The ontology-based representation of DL service metadata makes it possible for semantic query engines to reason about the required DL services automatically to facilitate knowledge reuse. Corresponding to OWL used for formal representation of DL service metadata, a semantic query language SPARQL [16] is used to express queries across diverse metadata sources built in the ontology models, whether the metadata is stored natively or viewed as ontology models via middleware. SPARQL contains capabilities for querying required and optional graph patterns along with their conjunctions and disjunctions.

Referring to the UML activity diagram shown in Figure 3, when a user wants to search for a DL service in the DL service metadata repository, he or she first formulates query in natural languages, which is then transformed into the SPARQL format by the SPARQL converter by using concepts of the DL resource ontology corresponding to the selected community. Then the semantic query is conducted in the DL service metadata repository based on the SPARQL. Jena [17] provides a programmatic environment for SPARQL and includes a rule-based inference engine, which is used to execute the SWRL-based constraint rules and mapping rules involved in the DL services. The semantic query compares the query in SPARQL format with semantic service advertisements in the DL service metadata repository to make semantic match by calculating similarity scores for potential service pairs, and returns the most appropriate advertised services as SPARQL query results. An improved semantic matchmaking methodology for retrieving the required semantic services based on the formal specification of service capabilities has been proposed in our previous work [18] and won't be repeated here for conciseness. Finally, the result interpreter transforms the SPARQL query results into the final retrieved results in natural language that's much user readable.

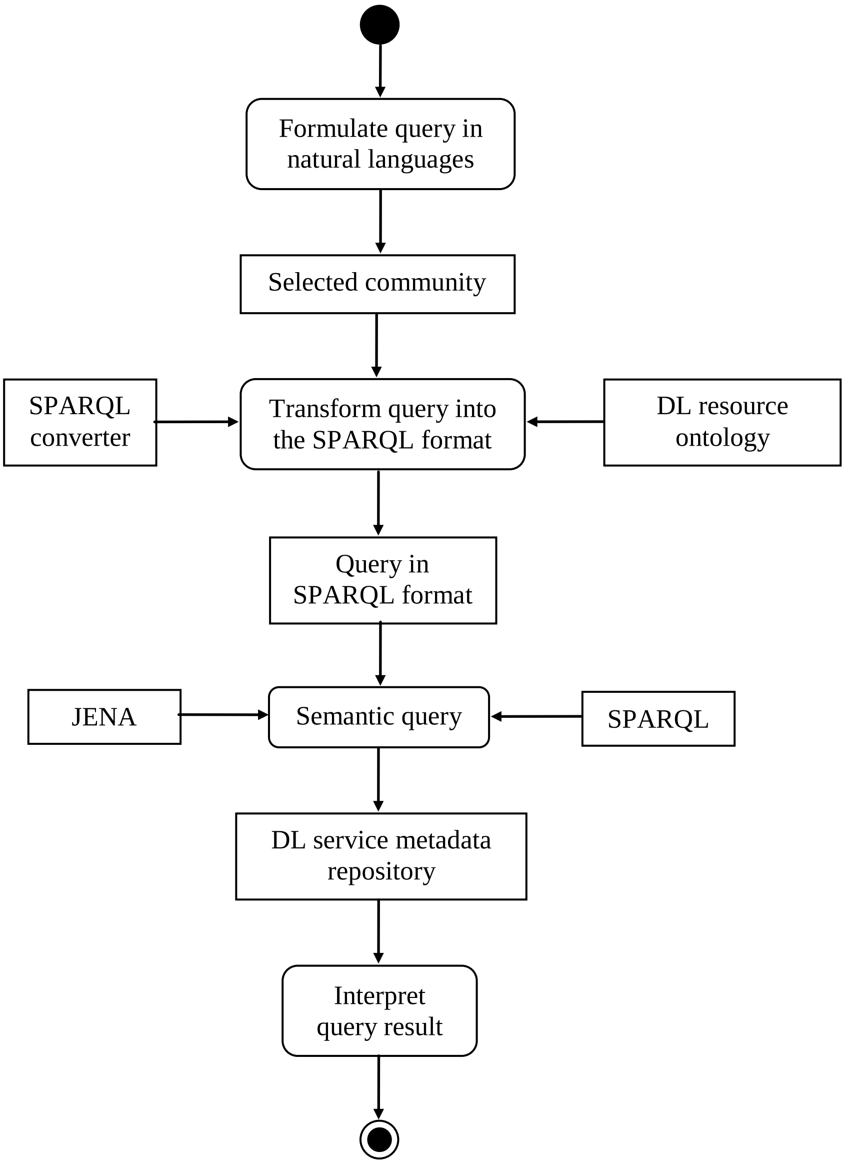

Figure 3. UML Activity Diagram for Semantic Query

5. System Operation for Effective Ontological Maintenance and Semantic Query

In this section the authors will study a case for ontological maintenance and semantic query to DL service metadata so as to test the practicality of the proposed approach. The prototype system is developed with high extensibility to facilitate future addition of new ontologies across DLs. Because the front-end of traditional search engine is not suitable for ontology-based service management, a user-friendly semantics-oriented front-end is developed to help users to maintain ontologies, formulate queries and express conditions for finding DL services. Various graphical user interfaces such as query trees, concept trees, property tables, relationship tables and query results are used.

Figure 4 shows the graphical user interface for ontological maintenance and semantic query in the prototype system. The left window displays the tree view of hierarchical DL resource and service ontologies.

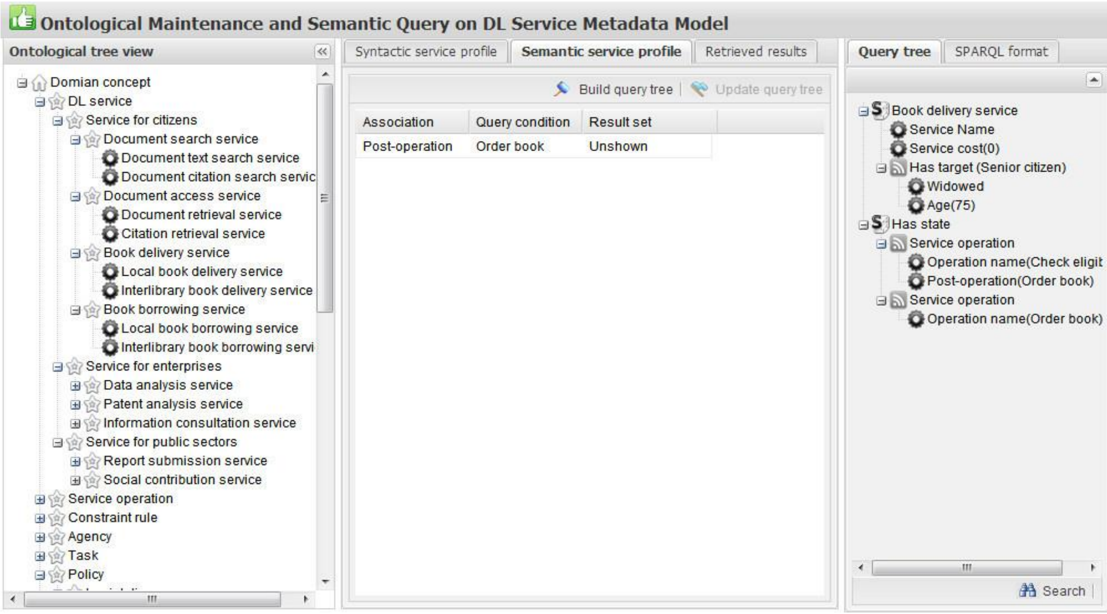

Figure 4. Graphic User Interface for Ontological Maintenance and Semantic Query in the Prototype System

Let's illustrate a semantic query example for DL service. A widowed 75-year-old lady in citizen center is looking for a free book delivery service that can order and dispatch book for her after checking her eligibility. This service query can be decomposed into the following conditions to facilitate semantic analysis:

1) Condition 1: It is a Free book delivery service, *i.e.*, its service cost is 0;
2) Condition 2: It targets the community: Widowed senior citizen whose age is 75 (Note that the lady inputs the targeted community as "senior citizen", a term that respectfully refers to the old people in a local citizen center);
3) Condition 3: Its state includes two service operations: Check eligibility and Order book. The former precedes the latter.

Click at the "Search" button at the bottom of the right window (Figure 4), then all the matching search results containing service name, service cost, service community and URL will be retrieved in the "Retrieved results" tab automatically (not shown here for conciseness). The representative snippets of the OWL source codes of the first matching DL service are shown in Figure 2. It shows that an advertised Book delivery service instance "Interlibrary_book_delivery-ZUFE" targeting Old people is semantically matched with the service requirement, because of the below reasons:

1) The advertised service is a sub-class of the requested Book delivery service.
2) Though the advertised target Old people is different from the requested Senior citizen, the involved mapping rule equation (2) in the sub-Section 3.2 is executed to map two classes Old people and Senior citizen to resolve data mismatch after the rule antecedent "two cooperating communities Library and Citizen center" is satisfied.
3) Though the advertised service doesn't show that its service cost is 0 directly, its involved constraint rule shown in the rule equation (1) in the sub-section 3.1 is executed to result in the service effect "free service charge" after the service precondition "a book delivery service is offered to a widowed old people whose age is over 70" is satisfied by the requested community Widowed senior citizen whose age is 75 (Senior citizen is mapped to Old people that is a subclass of Citizen).
4) The advertized service has states including service operations Check eligibility and Order book, which match states of the service request respectively.

6. Conclusion

This paper has presented Semantic Web technologies for dynamic modeling of DL service metadata across ubiquitous virtual communities of libraries. A new computational model that includes an ontological basis and semantic service representation is proposed to model heterogeneous DL services effectively and handle complex queries with assured semantic consistence, state coherence, constraint coherence and cross-community coherence, so as to achieve seamless service interoperability in the service lifecycle.

The approach allows not only to develop, deliver and integrate more efficient DL services but also to bring the possibility of easy manipulation through the user-friendly semantics-oriented front-end. The operation of the prototype system is demonstrated to validate the implementation of the proposed approach for effective management of DL service metadata through access and visualization in the usage scenario. Although the transition of the current prototype system into a real world operational DL system needs our future work on development of a stable and robust Semantic Web service-based DL infrastructure, our current work has built the semantic, service and organizational interoperability standards of DL infrastructure.

Acknowledgments

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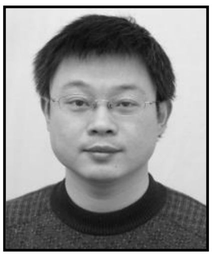

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