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Semantic Representation of Complex Resource Requests for Service-oriented Architecture

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Abstract

Many open distributed systems across Internet such as those in grid computing and e-Commerce involve the requesting, allocation and maintenance of sorts of resources. The discovery of large amount of resources in different sites is an important issue for the design of these systems. The booming semantic Web technology provides a suitable infrastructure for the publishing, requesting and matchmaking of resources. This paper presents a generic representation for quantified resource requesting with Semantic Web. It allows the representation of complex resource descriptions such as containment hierarchies and disjoint constraints between them. A model-theoretic semantics for matchmaking with countable resources is given for this representation. A constraint-based technique for the matchmaking check with such representation is designed.

Keywords: *quantified resource, semantic Web, resource matchmaking, Service-oriented Architecture*

1. Introduction

A lot of distributed applications across Internet involve the requesting, allocation and maintenance of many sorts of and large amount of resources in different sites. In e-Commerce, for example, a customer may issue a request to a shop for a quantity of goods. A travel agent may book a number of airline tickets from an airline agent and a number of apartments from a hotel agent. In the field of grid computing, tasks may require for different types of computational resources of certain amounts, such as computers, their memories and disk space, and bandwidth with networks. Most of these Internet applications involve interactions between heterogeneous information sources and agents in open environments, in which the problem of interoperability between the heterogeneous sources is a big issue.

Semantic Web [1-3] is a booming technology to achieve semantic-level interoperability based on XML. It was motivated to have information sources machine-understandable and agent-sharable by means of annotating their content with common data model and shared ontology. Semantic Web is especially suitable for the task of resource discovery across Internet. First, ontology technology provides a means to conceptualize and manage different sorts of resources, and to specify resource advertisements and requests. Second, the employment of publicly standardized semantic Web specifications helps to achieve interoperability for the interaction between resource requesters, providers and brokers.

The main concern of this paper is the representation for quantified-resource matchmaking between resource advertisements and resource requests. Quantified resource requesting is mostly investigated in the field of grid computing [2, 3, 4, 5], whereas few works is known about quantified-resource matchmaking in the context of e-Commerce although it should have more extensive applications in the area and manifest more complex forms. Our work thus mainly focus on two extensions: one is to allow to advertise summarized resource descriptions, another is to allow more expressive queries for quantified resources.

2. Resources, Resource Advertisements, and Resource Requests

2.1. Resources

The term “resource” is extensively and freely used in information field without a widely-accepted accurate definition. We view resources as anything that is of certain degrees of utility

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and capacity to some competing processes. In the fields of computer sciences especially grid computing, typical resources include computers, memories, CPU time, disks, printers, network bandwidth, or even programs and data sources. In e-Commerce, typical resources include various sorts of goods, traffics, energy supplies, human resources, and etc. Resources as a whole can be classified along different dimensions according to features such as if a resource is consumptive, divisible, and sharable.

For the context of this paper, we are only concerned with classification based on the ways they are represented, advertised and queried. Since a resource can be either an individual, or a collection of individuals, or an amount of substances or energy, mainly we distinguish resources between resource elements which are individual resource items, and resource portions which may contain other resources. A resource portion is either countable in that it consists of a finite set of resource individuals, or uncountable such as water and fuel in that they are considered to be continuously divisible. Resource portions are main concern of this paper.

2.2. Resource Advertisements

To allow resource discovery across Web, we assume an open architecture in which resource owners advertise their resources in a public resource advertisement base, and resource requesters issue resource requests to the resource advertisement base for availability. It is impractical to register all the resource items in the resource advertisement base when the quantities of resources are so many. Rather it is reasonable to allow a summarized advertisement for each type of resources. For instance, a resource advertisement base might advertise that there are 50 computers in a LAN rather than list each of them. Furthermore we claim that it is useful to allow multi-view descriptions and hierarchical descriptions in resource advertisements.

For an example of multi-view description, it might be advertised that a laboratory has 5 servers and, at the same time, 20 computers installed with Unix. They are multi-view description in that they describe the same resource repository with different capacities. Hierarchical descriptions involve the representation of inclusive relations between different resource repositories and resources capacities. An example of hierarchical descriptions: “Computing Center has 2 labs, one lab has 40 PC-486s, the other has 30 PC-586s”. It is our objective to extend the existing approach with such multi-view descriptions and hierarchical descriptions.

2.3. Resource Requests

While complex resources are common in e-Commerce, the issue has not been addressed in existing grid-oriented resource request languages [2, 3]. Although complex resources could be represented as composition of atomic ones with logic connectives, e.g., using logical conjunction to express two portion of resource as a whole such as “9 PCs and 2 workstations”. Such approach may cause confusion when two portions of resources are not disjoint. For instance, “3 professors and 2 female teachers” may denote a set of 3, 4, or 5 teachers depending on the number of female professors in the set. Sometimes such description needs to be clarified with clearer alternatives such as “3 professors plus, in addition, 2 female teachers” or “3 professors including 2 women ” which imply respectively the use of exclusive-joining and inclusion between resource portions. Below is a more complex example illustrating the usage of resource exclusive-joining and inclusion:

CS department of Beijing Institute of Technology(BIT) might select a group of senior scholars as the doctorial thesis-defense committee members for A PhD student whose thesis is about the combination of grid and agent. The requirements for the committee members might be specified based on university-policy as follows:

(a) There must be 7 scholars who are all computer-science professors in Beijing.
(b) At least 4 of them must be out of BIT.
(c) At least 3 are experts in grid
(d) At least 3 are experts in agent
(e) In addition, a secretary for the defense should be selected who must be department teacher with PhD degree in computer science.

This human resource requirement shows how a complex resource request could be composed of simpler ones with joining, exclusive joining, and inclusion. Both (a) and (e) should be included but they should be disjoint. Groups corresponding to (b), (c), and (d) may not be disjoint, and all these 3 groups are included in group corresponding to (a). Later we will show how such requests would be formulated in our representation.

3. Complex Resource Representation Based on Semantic Web
3.1. Resource Ontology

In our framework, different forms of resources, including resource repositories, resource portions, and resource items, are uniformly modeled as resource objects. The reason is to gain representational uniformity and simplicity for reasoning with the hierarchical relation. First, we assume a root class ResourceObject for all the resource objects, and its 2 subclasses ResourceElement and ResourcePortion. In class ResourcePortion 2 roles include and disjoint are defined which denote respectively the containment and disjoint relation between two resources. In description-logic style these are written as as:

ResourceElement $\subset$ ResourceObject

ResourcePortion $\subset$ ResourceObject $\cap$ ($\forall$ include ResourceObject) $\cap$ ($\forall$ disjoint ResourceObject)

For our purpose of quantified resource matchmaking, class QtPortion are especially defined which inherits ResourcePortion and additionally defines 2 roles quantity and elementClass which respectively denote how many and what type of resources elements are declared.

QtPortion $\subset$ ResourcePortion $\cap$ (=1 quantity Number) $\cap$ ($\geq$1 elementClass Class)

Here the value of attribute elementClass is in itself a description-logic class constructor which must be a subclass of ResourceElemens. QtPortion is divided into two subclasses DQtPortion for discrete portions and CQtPortion for continuous portions. ResourceElement is also divided into two subclasses DResourceElement and CResourceElement. In addition to these resource-related concepts, the ontology also includes assertions regarding the properties of these concepts. For example, “For QtPortion r1 and QtPortion r2, if the elementClass of r1 elementClass of r2 are disjoint, then disjoint(r1, r2) is true” This might be represented as a RuleML rule in the logic layer of semantic Web infrastructure.xx

3.2. Representation of Quantified Resource Advertisement with RDF

In our framework, a resource advertisement base declares a set of resource object instances linked with role include. A resource advertisement base is represented as a set of RDF statements which are subject-predicate-object triples.

(1) University BIT has 100 classrooms ;
(2) 70 of (1) are multi-media enabled .
(3) 40 of (1) are large ones that can hold 200 students;
(4) 50 of (1) are middle ones that can hold 100 students;
(5) 10 of (1) are small that hold 50 students;
(6) All large classrooms are multi-media enabled;

For such advertisement, part of predicate-form RDF statements are as follows:

advertise(r0): isa(r0, DQtPortion); elementClass(r0, Classroom); quantity(r0, 100);
isa(r1, DQtPortion); include(r0, r1); elementClass(r1, MediaClassroom); quantity(r1, 70);
isa(r2, DQtPortion); include(r0, r2); elementClass(r2, LargeClassroom); quantity(r2, 40);
…

Where MediaClassroom is assumed to be defined in the ontology as the subclasses of Classroom and subsumes LargeClassroom3.3 Resource request specifications.

3.3. Resource Request Specifications

While resource advertisements specifies a set of resource instances, a resource request specifies a pattern of resource objects that is to be matched against the declared resource advertisements. As pattern resource request generalizes resource advertisement by introducing pattern variables (prefixed with ‘?’ in below) as well as constraints between them. For example, the request of example (5) in section 2.3 can be formulated as follows:

Request (?X, ?Y, ?Z1,?Z2, ?Z3):
disjoint(?X,?Y);isa(?X,DQtPortion);quantity(?X,7);
elementClass(?X,Scholar[major:computer-science, title:professor, location: Beijing]);

isa(?Y,Teacher);institute(?Y, bit); department(?Y,cs_dept); degree(?Y, phd_cs);
include(?X, ?Z1); isa(?Z1,DQtPortion);quantity(?Z1, 4); elementClas(?Z1, Scholar[institute ≠bit]) ;
include(?X,?Z2); isa(?Z2,DQtPortion);quantity(?Z2, 3); elementClass(?Z2, Scholar[expertise : grid]);
include(?X, ?Z3); isa(?Z3, DqtPortion);quantity(?Z3,3); elementClass(?Z3,Scholar[expertise: agent])

In the request specification, RDF-triples are written as binary predicate form, and a frame-like syntax is adopted to denote a specialization of class with role constraints.

4. A Semantic Model for Resource Matchmaking

The problem of quantified resource matchmaking with our representation can be formulated as follows: Given a resource advertisement base specified in form as presented in section 3.2, and a resource request specified in form as presented in section 3.3, how can we decide if the request is satisfied with the resource advertisements as a whole, i.e., if the sorts and the amounts of resources specified in a resource request is available in the collection of resources specified in a resource advertisement base? To clearly define the problem, a formal semantics for the representation is necessary.

Definition 1: A resource matchmaking specification is a triple (O1, O2, A, Q) where

- O1 is an ontology, called base ontology, which consists of a hierarchy of first-order classes together with their respective roles;
- O2 is an ontology based on O1 consisting of a hierarchy of second-order classes with root DQtPortion, which has roles elementClass, quantity, disjoint and inclusion as described in previous section.
- A is an advertisement base formed as advertise(r): Tr which publish resource r with a RDF description denoting its hierarchical composition with role inclusion .

Q is a resource request formed as request(X): with a finite set X of resource variables and a finite set of constraints Cx between the variables.

The following question is, given a resource matchmaking specification and an allocation of it, what does mean by “The resource request is satisfiable with the resource advertisement”. A semantic formalization of our quantified resource representation is thus necessary.

Definition 2. Given a resource matchmaking specification R=(O1, O2, A, Q), an interpretation of R is a triple I =(U, E, [.]), where U is a set of individuals, E⊂ U is the set of all individuals of resource items, [.]I is a mapping from any expression in R to a set-theoretic construct over U such that

1) For a class name c in O1, [c] I ∈ power(U), especially [ResourceElement] I = E; for an role r in O1, [r] I∈ power(U×U).
2) For any class c, subclass c1 of c, and instance a of c in R, [c1]I⊂[c]I ; [a] I ∈ [c] I.
3) The conventional description logic constructors as well as subsumption relation in O1 are the same as those of conventional description logic;
4) [DQtPortion]I=power(E); [quantity]I is a function in power2(E) → N, such that for any x ∈ power(E), [quantity]I(x) = |x|, i.e., the number of elements in x; [elementClass]I is a function in power2(E) × power2(E), such that, for any x, y ∈ power(E) , (x, y) ∈ [elementClass]I iff x ⊂ y ; [include]I ∈ power2(E) × power2(E), such that for any x, y ∈ power(E), (x, y) ∈ [include] I iff x ⊃ y ; [disjoint]I ∈ power2(E) × power2(E), such that for any x, y ∈ power(E), (x, y) ∈ [disjoint] I iff x ∩y =ϕ
5) For A≡advertise(r): Tr , [A] I = ∪ {[r]I } such that [Tr]I is true}
6) For Q ≡ ? request(X1, …, Xn) : C, [Q] I ∈ power2(E) and

[Q] I ={ [X1] I,V ∪…∪[Xn] I,V | for all valuation V of variables {X1, …, Xn} such that [C] I,V is true}

With this interpretation, we can define some semantic properties of a resource matchmaking specification. First, an advertisement must reflect the true containment relation between two portions of resources.

Definition 3. Let R=(O1, O2, A, Q) be a resource matchmaking specification, I be an interpretation of R. I is inadmissible with respect to A iff [A]I is undefined; otherwise I is admissible with respect to A. A is invalid iff all interpretations of R is inadmissible with respect to A; otherwise A is valid.An invalid resource advertisement description is illegal because it makes no sense. It is important to be able to check the validness via syntactic inference. An immediate observation is that if A contains an include-clause DQtPortion[quantity: n1, elementClass: c1] include DQt Portion [quantity: n2, element Class: c2], and n1 < n2 or c1 $\cap$c2 =ϕ then A is invalid.

Definition 4: Let R=(O1, O2, A, Q) be a valid resource matchmaking specification, I be an admissible interpretation of R. Q is satisfied with A in I iff there exists x$\in$[Q] I such that x $\subset$ [A]I. Q is satisfied with A iff for all interpretation I of R, Q is satisfied with A in I. Q is unsatisfiable with A iff for all interpretation I of R, Q is not satisfied with A in I.

We thus established a semantic account for the satisfaction of resource request with resource advertisements.

5. Implementation and Application

5.1. Resource Matchmaking as Object Constraint Satisfaction

To implement the matchmaking between a complex resource request and a resource advertisement, we take the matchmaking problem as one of object constraint satisfaction (OCS)[8-10]. The variables of an OCS are resource variables in the resource request which ranged over instances of Dqt Portion; the constraints are role constraints in the resource request. The domains of the constraint variables consist of DqtPortion instances generated by joining finite number of sub-portions of resource portions in the resource advertisements. For the allocation to be operable, we stipulate that all the sub-portions are from among a set of mutually disjoint resource portions. To make the idea clearer, we give the following definition:

Definition 5: Let R=(O1, O2, A, Q) be a valid resource matchmaking specification. VQ and CQ are respectively the resource variable set and query constraint of Q. And A quota out of A is a set of pairs α={s1/r1, …, sn/rn }here r1, …,rn are nodes in A, which satisfied following conditions:

(a) s1, …, sn are respectively sub-portions of r1, …,rn in that include(ri, si) holds for each i.;
(b) s1, …, sn are mutually disjoint ,i.e., disjoint(si, sj) holds for each i and j.
(c) the quantity of si is determined.

For each subset R of { s1, …, sn }, let JR be a new instance of DqtPortion by joining all the resource portions of R in following way:

(1) the quantity value of JR is the sum of those of all the resource portions of R
(2) the elementClass value of JR is the DL-union of those of all the resource portions of R
(3) the set of include values of JR is R
(4) the set of disjoint values of JR is the intersection of those of all resource portions of R

An assignment of Q with quota α is a mapping λ which maps each resource variable in Q to a subset S of { s1, …, sn }. λ is an allocation of A to Q iff when each resource variable X in Q is replaced in CQ by Jλ[X], the instantiated constraint is satisfied with A as defined in definition 4.

A resource matchmaking algorithm based on this idea thus need to find one or more mutually disjoint sub-portions of advertised resource portions that satisfied the constraint of the request. The constraint-solving algorithm is currently under development.

5.2. Application Background

The research aims at resource management in an ongoing multi-agent education management system for college. The multi-agent system consists of two set of agents [11]. One is a set of resource agents , such as estate agents, human resource agents, and textbook agents, which provide services of resource requesting, booking, and allocation. The other set of agents are task agents, such as department clerks, which perform task planning, scheduling, monitoring and execution. The requesting and allocation of resource are important parts in the interaction between the task agents and resource agents [12]. Despite the diversity of various sorts of resources, the behaviors of the resource agents are quite similar. Thus a generic framework for resource modeling is necessary.

6. Conclusion

In this paper we proposed a representation for quantified resource matchmaking with a number of novel features. First it allows the representation of complex resource requests and advertisements with quantified resource quota, containment hierarchies and disjointness constraints. This enhance the flexibility and expressiveness of the representation. To give an accurate definition of the resource matchmaking with such representation, a semantic theory is established. Second it is semantic-Web-oriented in that the representation follows conventions of RDF and semantic Web ontology. In addition, the resource-servicing architecture with summarized resource advertisement repository cooperating with resource-requesting agents is in line with the spirit of semantic Web and is suitable for wide range of e-commerce applications.

The future work include the development of efficient algorithms for the matchmaking with this representation.

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