PS-GIS: Personalized and Semantics-Based Grid Information Services

Yue Kou, Ge Yu, Derong Shen
School of Information Sci. & Eng
Northeastern University
Shenyang 110004, China
0086-24-83687776
{kouyue, yuge, shenderong }@ise.neu.edu.cn

Dong Li
Business Software Division
Neusoft Group Ltd.
Shenyang 110179, China
0086-24-83662207
lidong@neusoft.com

Tiezheng Nie
School of Information Sci. & Eng
Northeastern University
Shenyang 110004, China
0086-24-83687776
nietiezheng@ise.neu.edu.cn

ABSTRACT

The emergence of grid as an infrastructure for sharing of large-scale resources increases the need for information services that allow an efficient management of resources. This paper proposes the Personalized and Semantics-based Grid Information Services (PS-GIS) that serve as information management units for service publishing, discovery and monitoring. We present the approach to personalization of service publishing and discovery by describing ranking the similar services to the same management region. By applying the ontology theory for characterizing semantic information, a semantics-based domain selection and service matching method is adopted. And also service description and storage mode of UDDI are extended without changing its inner implementation. Our experimental results show the benefits of PS-GIS in precision, recall and query response time when compared with various alternate strategies.

Categories and Subject Descriptors

H.3.3 [**Information Search and Retrieval**]: Information filtering, Retrieval model, Search process

General Terms

Management, Design, Experimentation, Theory.

Keywords

Grid, Information Service, Personalization, Virtual Organization, Ontology, Semantics, UDDI.

1. INTRODUCTION

Grid technologies enable large-scale sharing and coordinated use of networked resources [1]. CIMS-oriented Service Grid is becoming a new important trend of business area in supporting flexible enterprise composition and resource sharing [2]. However, owing to resource explosion on Internet [3], often the services we are looking for do not match our individual preferences, in other words they are not personalized to users' needs. In fact, among the large number of services only a small fragment will be relevant for the individual user or VO (Virtual Organization). In addition, besides the functional descriptions of services some non-functional information such as semantics description [4], QoS [5, 6] and constraints etc is even more important in the process of service discovery. If non-functional properties of services are ignored, the query results will not be accepted by clients with requirements of QoS, constraints and so on at runtime. And also some characteristics of services are dynamic-changed, it's crucial to monitor their changing to guarantee the accuracy of metadata. Therefore, if there are no practical measures of service publishing, discovery and monitoring, it is difficult to guarantee high precision, recall and efficiency. Then information services supporting flexible, efficient and scalable publishing, discovery and monitoring towards geography-dispersed resources are a vital part of grid system [7].

Thereby, this paper proposes the Personalized and Semantics-based Grid Information Services (PS-GIS) that serve as information management units for the publishing, discovery and monitoring of resources. The specific technical contributions detailed in this paper are the following.

– We present the approach to personalization of service publishing and discovery by constructing a rank model, which can cluster the similar services to the same management region based on the user's inputs. This rank model is built so as to select only the services which can most fit the preferences, the characteristics and the taste of the individual during service discovery.

– By applying the ontology theory for characterizing semantic information, a semantics-based domain selection and service matching method is adopted, which improves the operations of traditional UDDI [8] (Universal Description, Discovery & Integration). Based on the semantics the query range can be more complete and the query result can be more precise which benefits the improvement of query recall and precision.

– By means of adopting information extending, monitoring and feedback collecting, service description and storage mode of UDDI are extended without changing its inner implementation by introducing the extended repository.

The rest of this paper is organized as follows: Section 2 describes the related work while section 3 introduces the system architecture. We expatiate at the implementation strategy of PS-GIS in section 4. The experimental results are presented in Section 5. We conclude in Section 6 with a discussion of the future work.

INFOSCALE 2007, June 6-8, Suzhou, China

DOI 10.4108/infoscale.2007.933

2. RELATED WORK

Some related efforts for developing grid information services include: X.500 [9], LDAP [10], UDDI and MDS4 [11]. The working model and functionality of these technologies in comparison to PS-GIS are discussed below.

X.500 and LDAP are the most important directory service standards that are used to abstract information from a hierarchical organization. However, these standards aren't applicable to dynamic information updates frequently for grid system.

UDDI and MDS4 (Monitoring and Discovery System) are familiar information management technologies in existing grid system. UDDI specifications define a standard for enabling businesses to publish or discover services. Globus MDS4 is a tree hierarchical-based information management system where there is a single top-level information service that presents a uniform interface to clients to access data, while lower-level information providers collect the data. Once the provided data is changed, the top-level information service will be notified by the lower-level information providers. However, there are the following limitations in applying UDDI or MDS4 directly in grid system.

- First, they provide little support for personalization applied to publishing and discovery of services to satisfying different users' preferences.
- Second, they are restricted to keyword search because of lacking the support of semantic information. Thus the supply side and demand side can not agree on the comprehension of concepts easily.
- Third, they can not describe extensive metadata such as QoS, constraints and relation between services, so it doesn't support service publishing and discovery with non-functional information.

Therefore, it is necessary to perform some improvements or extensions based on the existing information management technologies. There have been some solutions introduced to provide better metadata management by extending UDDI specifications with QoS or other capabilities, e.g., WSLA [12, 13], WSOL [14] and DAML-S [15] etc. For instance, Ran S. [16] proposes a new Web services discovery model with QoS support by changing the inner implementation of UDDI. This approach aims at expressing user's actual needs better which improves the query precision. Al-Ali R.J. [17] extends the service abstraction in the OGSA for QoS properties. Gwyduk Y. [18] presents a QoS model supporting non-functional properties of the Web service so as to satisfy the constraints of users. However, most current methods are either limited within a specific QoS model, or lack of semantic supports, or negligent of the evaluation of service reliability to identify whether the published qualities are consistent with the monitored real world status.

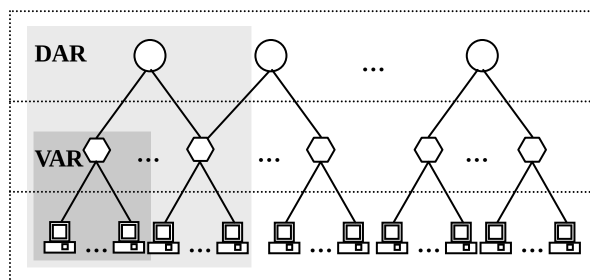
As for PS-GIS, services possessing certain similarities are ranked to the same region corresponding to the specific group of users' personal preferences. We adopt a semantic-based domain selection and service matching method applying the ontology theory for characterizing semantic information. Without changing UDDI's inner implementation, service description and storage mode of UDDI are improved based on WSLA (Web Service Level Agreement) and OWL [19] (Web Ontology Language) with non-functional information support. By means of establishing an evaluation mechanism based on the monitored and feedback information, service reliability is calculated to enhance the availability of service remarkably.

3. SYSTEM ARCHITECTURE

In this section, we first describe the rank model of services in grid environment. And then the major components of PS-GIS and the extended service descriptions will be introduced.

3.1 Rank Model of Grid Services

In spite of the rapid increasing of grid service amount, only a small fragment will be relevant for the individual user or organization. Tailoring information services to individuals is personalization that can be applied in the process of publishing and discovery of resources. So if services possessing certain similarities can be ranked to the same region corresponding to a specific group of users' personal preferences, the probability that these users' requests being satisfied in this group will be much higher. Thus we divide the whole service space into several domains first, and then in each of them services and users with similar characteristics are organized into the same VO and are provided centralized management. Domain and VO are considered as information management units which are responsible for metadata access, retrieval and storage. In this way, the range of query is reduced and the resource search efficiency is improved consequentially.



DCP: Domain Cluster Point **VCP**: VO Cluster Point
RS: Resource Service **DAR**: Domain Autonomy Region
VAR: VO Autonomy Region

Figure 1. Rank model of grid services.

As illustrated in Figure 1, the whole service space is divided into three ranks on logic: RS (Resource Service), VCP (VO Cluster Point) and DCP (Domain Cluster Point). This rank model enables users or VOs to customize their request environment with a specific template to suit their personalized preferences.

- RS represents service providers, requesters or the base services with simple operations. Resources and users with similar characteristics are organized into the same VO that performs centralized management to them.
- VCP is used to describe the VO it represents and is in charge of recording the information and characters of RSs in the corresponding VAR (VO Autonomy Region) to provide uniform accesses for dynamic and static information.

– DCP is used to manage the information of all VCPs registered in its DAR (Domain Autonomy Region). Compared with VCP, DCP has some additional abilities such as query forward besides the support in accessing, retrieving and storing information.

The major advantages of this rank model comprise: (1) By dividing services into different domains and VOs in advance, query request can be located directly to the space of relative domain or VO. (2) Some specific templates can be defined on VCPs or DCPs, by which users' personal preferences can be taken into account during service publishing and discovery. (3) Service reliability can be calculated based on the monitored and feedback information aggregated by VCP. And it can supply powerful evidence for selecting top-quality services as results. (4) It's impossible to produce bottlenecks between domains because they're distributed completely. The system is scalable to sustain the increase of users and applications.

3.2 Component Functions

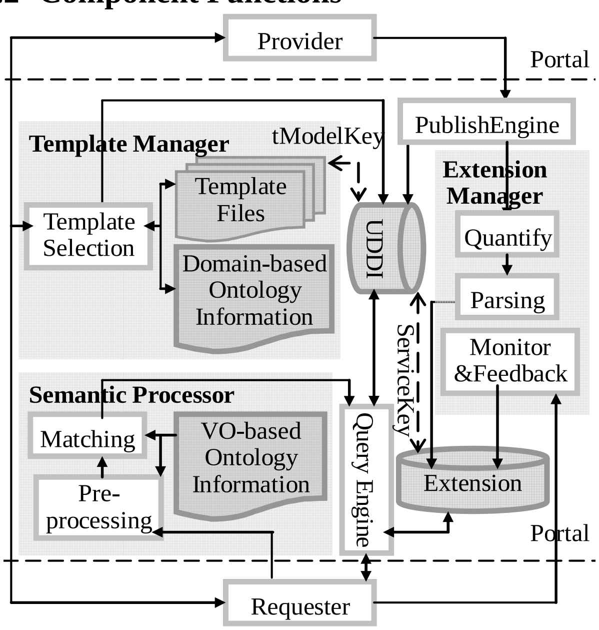


Figure 2. System architecture.

As introduced in section 3.1, VCP and DCP are the core of the rank model. They can aggregate or access both dynamic and static information of one or more sources flexibly. The major components of them are illustrated in Figure 2. Owing to adding some non-functional information, both services' characteristics and users' requests can be better expressed. Furthermore, semantic information can be used to perform domain selection and service matching intelligently, which facilitates the resource search efficiency. The detail component functions will be introduced as follows.

– **Template Manager**

Because services of the same application type are similar in characteristics appealing to a certain crowd's preferences, template manager can define some template files for personalization in advance. The mapping relations between template files and services in UDDI are established through tModelKey. During publishing or discovery, the user can select a certain application-specific template to describe the published information or query request. There are two ways to identify a template: If the user can determine the domain of his service or request, direct template selection will be performed himself. Otherwise, by applying ontology theory to deduce intelligently, the system will determine a domain and recommend the corresponding template to the user. For example, as illustrated in Figure 3, within the Travel domain services can be classified into some VOs such as TicketBooking, RoomBooking etc, each of which can be described with a specific template including the style of QoS and constraints.

```
<gpdl:VOs>
  <gpdl:VO name="ticketBooking" qos="ticketBooking"
desc="TicketBooking">
    <gpdl:filter>
      <gpdl:parameter name="TrafficWay" type="CheckBox">
        <gpdl:argument value="Airway"/>
        <gpdl:argument value="Railway"/>
        <gpdl:argument value="Navigation"/>
      </gpdl:parameter>
      …
    </gpdl:filter>
  </gpdl:VO>
  …
</gpdl:VOs>
…
<gpdl:qualities>
  <gpdl:quality name="ticketBooking" method="range">
    <gpdl:parameter name="Cost" type="float" unit="RMB"
dataSource="provider">
      <gpdl:constraint min="10" max="100.0"/>
    </gpdl:parameter>
  </gpdl:quality>
  …
</gpdl:qualities>
```

Figure 3. Fragment of travel domain template file.

– **Semantic Processor**

This process proceeds in four steps: segmentation, standardization, filtering and extending. Then both the supply side and demand side will agree on the comprehension of concepts and thus, the recall can be improved by intelligent deductions. With the preprocessed request, services which best meet user's requests can be found by employing semantic information to calculate the matching degree.

– **Extension Manager**

Based on quantitative and qualitative standards in WSLA, extension manager is used to make quantified processing for QoS information by changing its quantitative description to qualitative description in order to maintain the consistency with the qualitative request. Then QoS and constraints in XML format will be parsed into a series of operations in DB. In addition, during the running of service, requester can monitor service performance such as response time, error rate etc, which can be used to calculate service reliability through monitoring and feeding back in order to maintain high availability of services.

– **Query Engine**

Query engine is used to execute base query with some optimizing measures performed in this process. It can obtain service information with the same ServiceKey from UDDI and the extended repository that are used to store base registry information and extended parts respectively.

– **Domain-based/VO-based Ontology Information**

```
<owl:Ontology rdf:about="#TicketBooking">
  …
</owl:Ontology>
<owl:serviceset>
  <owl:service rdf:id="#TicketQuotation">
    …
  </owl:service>
  …
</owl:serviceset>
<owl:propertyset>
  <owl:objectproperty rdf:id="#unit price">
    <owl:samepropertyas>
      <owl:objectproperty rdf:about="#unit cost"/>
    </owl:samepropertyas>
    <rdfs:subpropertyof>
      <owl:objectproperty rdf:about="#price"/>
    </rdfs:subpropertyof>
    …
    <rdfs:domain>
      <owl:service rdf:about="#TicketQuotation"/>
        …
    </rdfs:domain>
  </owl:objectproperty>
</owl:propertyset>
```

Figure 4. Fragment of a VO-based ontology instance.

Domain-based/VO-based ontology information is used to describe domain/VO applying the ontology language OWL to define characteristic properties of them and relationships of these properties including synonymy, opposition, hierarchy etc. For example, the fragment of a VO-based ontology instance about travel is shown in Figure 4. The VO named TicketBooking is constituted with services relative to booking tickets such as ticket quotation and ticket deliver which are described by properties such as unit price, ticket name etc.

3.3 Extended Service Descriptions

How to describe a service to facilitate a precise and efficient service matching is vital. However, only little information such as service name, base description and access point are provided by UDDI. It lacks of non-functional service descriptions, which results in some limitations during service publishing and discovery. Thus, service descriptions of traditional UDDI should be improved by extending to it some non-functional information as follows.

QoS: It's used to describe the ability of a service to satisfy a requester, with which system can make some general analyses and select one with best performance. In our mechanism, there are two methods to obtain QoS information: on the one hand, service provider provides some qualities parameters such as service cost and response time during publishing. On the other hand, according to the third part's monitoring or user's feedbacks, the statistical qualities such as error rate and service reliability can be calculated.

Constraints: As one of the criterions for filtering query results, constraints are used to make a further restriction on services with equivalent function. Query results can be constrained within a geographical range, a time phase, a specific environment and so on.

Service relations: For practical application, users are not often satisfied with the single matching of service but asking for the collaboration among multi-services. Furthermore, once an exception occurs, some compensate services need to be invoked to perform resuming. Therefore, some kinds of service relations should be defined. Our system supports three relations: equivalent, composite and compensate, all of which can be defined by negotiations among providers in advance. For example, the relation between invoice service and transportation service can be defined as composite relation.

4. IMPLEMENTATION STRATEGY OF PS-GIS

In order to improve the traditional UDDI-based service publishing and discovery, some extensions are made. The major improvements can be summarized below: First, by performing the technique of template management, an appropriate domain will be selected directly by user or deduced applying ontology by system automatically. Then according to the identified template the corresponding extended information in a specific form will be published to maintain higher precision and efficiency of query. Second, we extend the traditional service description and storage mode of UDDI by adding an extended repository to store constraints, QoS etc, based on which query results can be refined better. Third, instead of adopting UDDI's single keyword-based search, ontology theory is applied to describe semantic information to obtain a uniform understanding between provider and consumer in concepts. Finally, by comparing the actual quality parameters in service running with the registry information published previously, reliability will be calculated to maintain higher availability.

In general, the functions of grid information services include: service publishing, discovery and monitoring. The interactions among these components can be illustrated in Figure 5.

4.1 Grid Service Publishing

Aiming at the published information conforming to a certain template, grid service publishing will be finished through the following operations such as template identification, information quantifying, parsing etc. The process of grid service publishing proceeds mainly in four steps:

Step 1: Having finished checking user's identity, the portal admits the user to input some base descriptions and specify the relative services of the published one.

Step 2: Based on user's inputs, a suitable VCP will be located and user can provide the extended information with the VCP-specific template furthermore. In detail, a direct location will be performed if the user can confirm the VCP himself. Otherwise, template manager will analyze the user's inputs and recommend a VCP to him.

Step 3: Extension manager quantifies the QoS information and parses the extended information from the XML format to a series of operations in DB.

Step 4: On the specific VCP, publish engine publish the base descriptions into UDDI with the service's tModel pointing to the identified template. Then add the non-functional information to the extended repository together with a ServiceKey produced just now to establish mapping relations between the extended repository and UDDI.

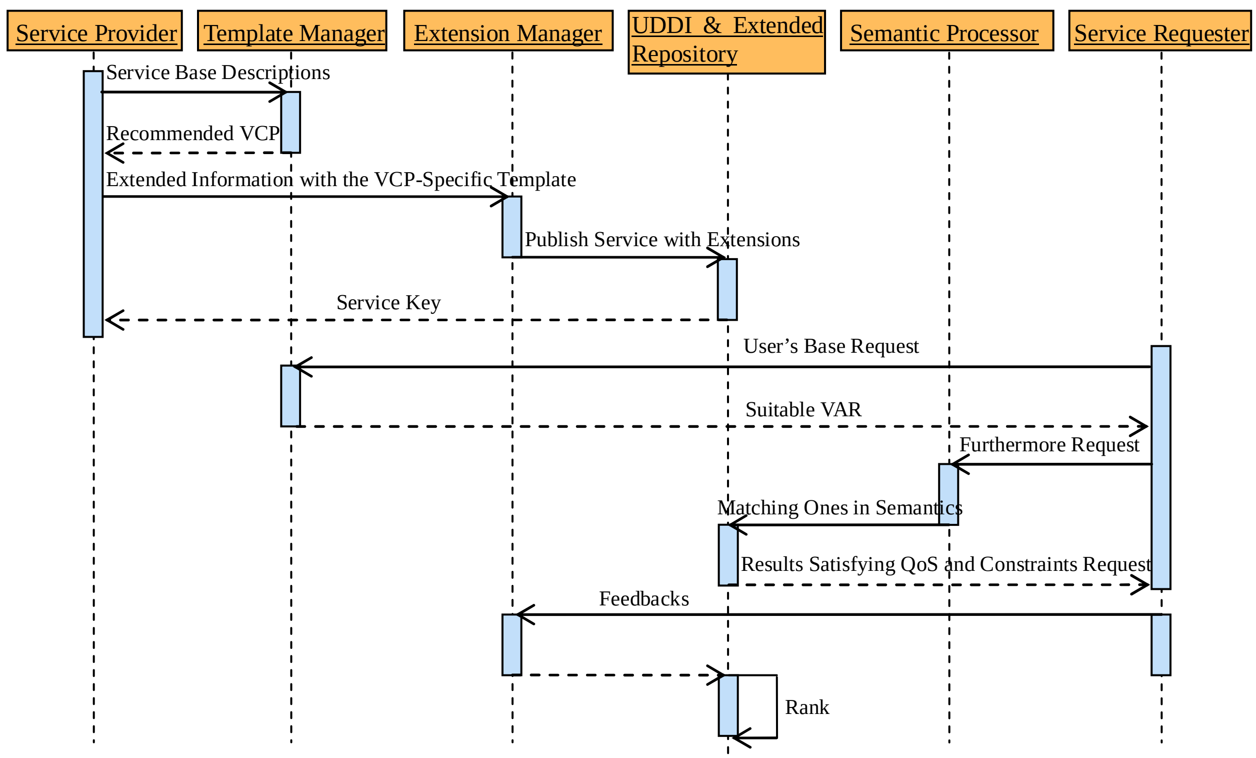


Figure 5. Interaction between the components.

4.2 Grid Service Discovery

Discovery strategy aims at facilitating system to find the most satisfying services with better performance intelligently, that is, the results should be the best matching ones to demands of users in function. The process of discovery is as follows:

Step 1: Having finished checking user's identity, the portal admits the user to input his base request and send it to his corresponding VCP.

Step 2: Template manager analyzes these descriptions and identifies whether they can be satisfied within the VCP. If so, User describes his requests further with the VCP-specific template. Otherwise, the query range will be enlarged from VAR to DAR or the whole services space in which some forwards may be needed to locate a suitable VAR.

Step 3: Based on ontology information, semantic processor retrieves the best matching services upon user's demands within the range of located VAR.

Step 4: Add further constraints to these candidate services using the extended descriptions and select those meeting the user's constraint conditions. According to QoS information and service reliability, the most excellent ones are returned to the requester.

4.3 Grid Service Monitoring

Because of resource's states are dynamic-changed in grid, it's necessary to monitor how characteristics vary over time. What is more, during service runtime reliability is used to measure whether the published qualities of services are consistent with the monitored real world status. Monitor and feedback collector uses standard OGSA notification mechanisms for subscription, notification and updating of dynamic service data. Its functions consist of two aspects: On the one hand, it is responsible for monitoring the dynamic-changed information, i.e., resource's states. On the other hand, it is used to collect query feedbacks from the third part or requester to calculate the service reliability as one of the reasons during consequent service discovery. Here the latter is the emphasis of our research in the paper. The reliability of service can be calculated as following steps.

$$\text{Reliability}=\sigma(\vec{P},\vec{Q})=\sum_{i=1}^{n}(p_i * q_i)/[\sqrt{\sum_{i=1}^{n}p_i^2} * \sqrt{\sum_{i=1}^{n}q_i^2}] \quad (1)$$

Step 1: Based on the uniform scoring standard, the published qualities and users' feedbacks are quantified into the form of scores (between 0 and 1) and represented by the vector P and Q respectively. Each dimension in vector P or Q (represented as pi or qi) is the score of a property to measure the qualities of service.

Step 2: Extend these vectors to have the same number of elements, that is, compensate each score of the lacking properties in P and Q by the score 0.

Step 3: The similarity distance between P and Q is estimated by the cosine similarity measure as shown in the formula 1, namely reliability.

For example, as for a ticket quotation service, there are three dimensions in vector P which is used to represent the performance, price and attitude with the scores of 0.8, 0.9 and 0.9 respectively. Vector Q has three dimensions representing the performance, price and network with the scores of 0.6, 0.9 and 0.5. Then after step 2, P and Q are extended with the form of (0.8, 0.9, 0.9, 0) and (0.6, 0.9, 0, 0.5) respectively. Based on the cosine similarity formula, the reliability of the ticket quotation service is 72%.

4.4 Implementation of the Prototype System

In the system, we use JDK1.4.2, Jbuilder X, Apache Tomcat 5.0 and some support packages including UDDI4J, Dom4J and Xerces etc during system development. Our implementation uses the Globus Toolkit 3 for the grid service development. On the base of IBM WebSphere UDDI, our prototype of PS-GIS has been implemented.

For instance, as a part of PS-GIS, the process of service publishing conforming to a certain template is illustrated in Figure 6. Travel domain and TicketBooking VO type determine a VCP-specific template which includes some extended information such as traffic way, cabin rate and cost etc.

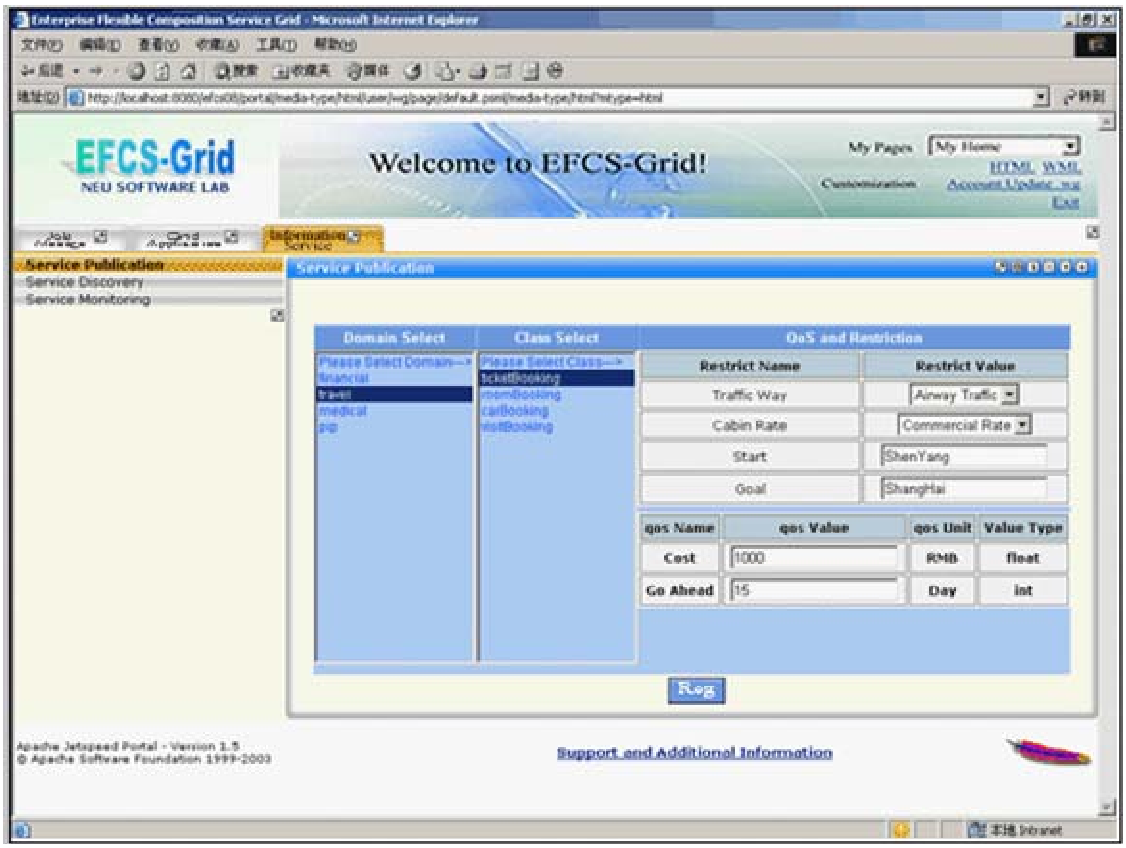


Figure 6. Service publishing in system prototype.

5. EXPERIMENTAL EVALUATION

In this section, the results of our experiments to evaluate the proposed approaches will be shown. Two service sets that consist of 50 services and 500 services respectively are used. We evaluate precision, recall and query response time of PS-GIS when compared with various alternate strategies for the same problem. Since the experimental results for both service sets have similar trends, due to limitation we mainly report the results for the latter service set.

5.1 Precision and Recall

The major factors that affect query quality are precision and recall [20], which are the quantization of relativity between search results and user request. Precision is defined as the ratio of the number of relevant services retrieved to the whole retrieved number. Recall is defined as the ratio of the number of relevant services retrieved to the number of all relevant services in system. To estimate the performance, the precision and recall of service discovery as the following four cases are compared.

– Query1: UDDI's single keyword-based search.

– Query2: semantics-based search by extending UDDI.

– Query3: search with QoS and constraints support by extending UDDI.

– Query4: semantics-based search with QoS and constraints support by extending UDDI.

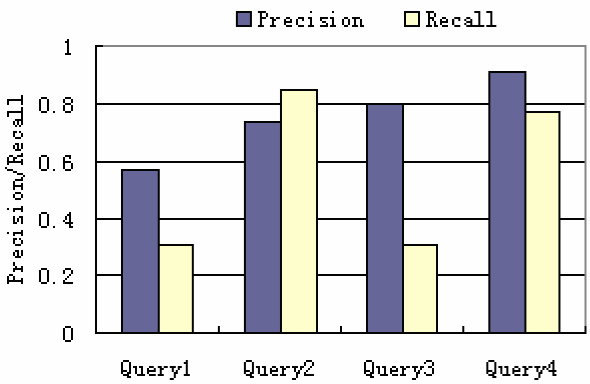


Figure 7. Comparison of different query methods in precision and recall.

Just as Figure 7, because UDDI is restricted to keyword search, both the precision and recall are lower in Query1. As to Query2, some semantics are introduced to perform segmentation, standardization, filtering and extending to user's request, so most relevant services can be retrieved and the recall is improved obviously. From the aspect of user's request, Query3 can be implemented within a smaller range by VAR location and template identification in advance. And its query results can be refined continuously by means of QoS, constrains and so on to maintain higher precision. According to the strategy presented in this paper, Query4 integrates the advantages of Query2 and Query3 since not only semantics is used to enlarge the retrieval range, but also some extended descriptions are supported to satisfy user's request further.

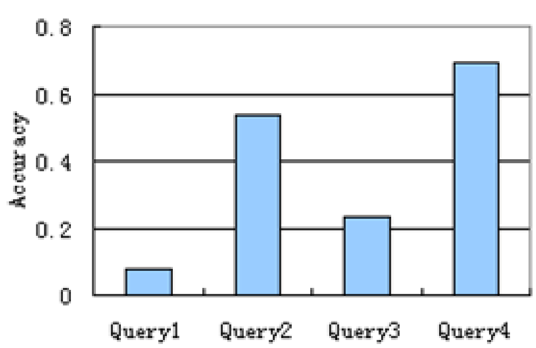


Figure 8. Comparison of different query methods in accuracy.

As illustrated in Formula 2, we introduce a comprehensive index Accuracy to measure the query performance based on precision and recall. Just as Figure 8, via compared with various alternate strategies, our approach acquires higher Accuracy performing on both of the service sets.

$$Accuracy = Recall * (2 - 1/Precision) \quad (2)$$

5.2 Advantages of the VCP-Specific Template Identification

Attentively, the improvement of precision and recall is at the expense of the increase of semantic process time. As illustrated in Figure 9, the more attributes inputted by users, the longer time spending on semantic analyzing and matching will be required. However, via template identification in advance, the published service or user's request can be located to the relative VAR and supplied in the VCP-specific style. The probability of user's request being met in this VAR will be higher and the query range is reduced accordingly. On the contrary, without template identification the query request may possibly be forwarded among DCP until the appropriate domain is identified, which results in excessive query time cost. So with template identification our approach is superior to the other method without identification in query response time.

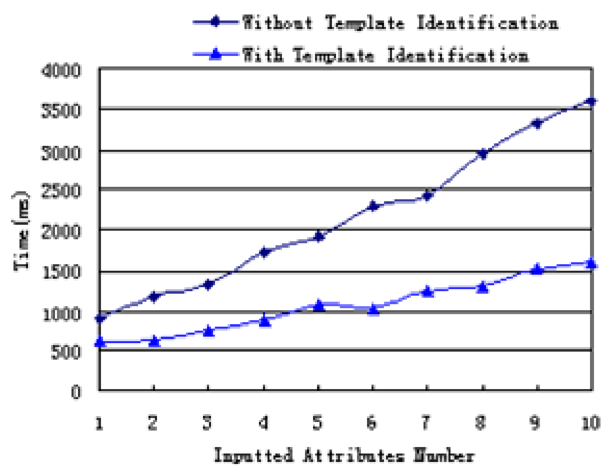


Figure 9. Query response time with different number of attributes inputted by users.

6. CONCLUSION

In this paper we apply the project EFCS (Enterprise Flexible Composition Services) as background and develop an in-depth research into grid information service management technology. Currently accomplished work comprises:

– Rank the similar services to the same management region to implement personalized service publishing and discovery.

– Propose an intelligent semantics-based domain selection and service matching method by applying the ontology theory to improve the operations of traditional UDDI.

– Extend and improve the service description and storage mode of UDDI to support publishing and discovery with the extended information such as QoS, constraints and service relations.

– Establish an evaluation mechanism based on the monitored and feedback information to calculate service reliability.

Simulated experiments indicate that owing to the personalized service publishing and discovery, the query can be performed in a small range, which shortens the query response time. Based on semantics, the recall and precision of query have been increased remarkably. By means of extending service description such as QoS and calculating service reliability, the availability of services is improved effectively. Next we will make a further research on the equilibrium of resource distribution, the efficiency of service discovery and the intelligence of matching.

7. ACKNOWLEDGEMENTS

This work was supported in part by the National Science Foundation (60673139, 60473073 and 60573090), National High-Tech Development Program (2003AA414210) and the National Ministry of Education Project of China (GFA060448).

8. REFERENCES

[1] Foster, I., Kesselman, C. The Grid: Blueprint for a Future Computing Infrastructure. Morgan Kaufmann, USA, (1999), 259-278.

[2] Foster, I., Kesselman, C., Nick, J., Tuecke, S. The Physiology of the Grid: An Open Grid Services Architecture for Distributed Systems Integration. http://www.globus.org /ogsa/, 2002.

[3] Gong, L. Peer-to-Peer Networks in Action. IEEE Internet Computing, 5(1) (2002), 37-39.

[4] Studer, R. The Semantic Web: Suppliers and Customers. In *Proceedings of the 5th International Semantic Web Conference (ISWC '06)* (Athens, Nov 5-9, 2006), LNCS, 2006, 995-996.

[5] Al-Ali, R., Hafid, A., Rana, O., Walker, D. An Approach for QoS Adaptation in Service-Oriented Grids. Concurrency Comput. Pract. Exper., 16(5) (2004), 401-412.

[6] Taher, L., Basha; R., El Khatib, H. Establishing Association Between QoS Properties in Service Oriented Architecture. In *Proceedings of International Conference on Next Generation Web Services Practices* (South Korea, Aug 22-26, 2005), IEEE Computer Society, 2006.

[7] Fitzgerald, S., Foster, I., Kesselman, C., Von Laszewski, G., Smith, W., Tuecke, S. A Directory Service for Configuring High-Performance Distributed Computations. In *Proceedings of the 6th IEEE International Symposium on High Performance Distributed Computing* (USA, Aug 5-8, 1997), IEEE Computer Society, 1997, 365-375.

[8] Bellwood, T., Luc, C., Ehnebuske, D. UDDI Version 3.0 Specification. http://www.uddi.org/pubs/UDDI-V3.00-Published-20020719.pdf, 2002.

[9] Recommendation X.500, Information Technology-Open System Interconnection-The Directory: Overview of Concepts. Models and Services, ITU-T, 1995.

[10] Howes, T.A., Smith, M.C. A Scalable, Deployable Directory Service Framework for the Internet. CITI Technical Report, 1995.

[11] Monitoring & Discovery System (MDS4). http://www. golbus.org/toolkit/mds, 2005.

[12] Ludwig, H., Keller, A., Dan, A. Web Service Level Agreement (WSLA) Language Specification. http://www. research.ibm.com/wsla, 2003.

[13] Ludwig, A., Braun, P., Kowalczyk, R. A Framework for Automated Negotiation of Service Level Agreements in Services Grids. In *Proceedings of Business Process Management Workshops (BPM '05)* (Nancy, France, Sept 5, 2005), Springer-Verlag, 2005, 89-101.

[14] Tosic, V., Pagurek, B., Patel, K. WSOL – A Language for the Formal Specification of Classes of Service for Web Services. In *Proceedings of ICWS '03* (USA, June, 2003), CSREA Press, 2003, 375-381.

[15] DAML-S: Semantic Markup for Web Services. In *Proceedings of the International Semantic Web Workshop (SWWS '01)*, 2001, 411-430.

[16] RAN, S. A Model for Web Services Discovery with QoS. ACM SIGCOM Exchanges, 4(1) (2003), 1-10.

[17] Al-Ali, R.J., Rana, O.F., Walker, D.W. Jha, S., Sohail, S. G-QoSM: Grid Service Discovery Using QoS Properties. Computing and Informatics, 21(4) (2002), 363-382.

[18] Gwyduk, Y., Taewoong, Y., Dugki, M. A QoS Model and Testing Mechanism for Quality-driven Web Service Selection. In *Proceedings of SEUS/WCCIA* (South Korea, April 27-28, 2006), IEEE Computer Society, 2006.

[19] Brickley, D., Guha, R.V. RDF Vocabulary Description Language 1.0: RDF Schema. http://www.w3.org/TR/2004/ REC-rdf-schema-20040210/, 2004.

[20] Aslam, J.A., Yilmaz, Emine. A Geometric Interpretatin and Analysis of R-Precision. In *Proceedings of the 14th ACM International Conference on Information and Knowledge Management (CIKM '05)* (Germany, Oct 31-Nov 5, 2005), ACM Press, 2005, 664-671.