# Towards Building a Semantic Grid for E-Government Applications

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***Abstract:*** - Nowadays, there is a growing number of e-government portals and solutions that provide integrated governmental e-services to the customers (citizens, enterprises or other public sectors). However, the administration and interoperability of distributed e-government nodes are faced with increasing challenges caused by the service-oriented modeling difficulties and ontological issues in distributed computing, resource integration and knowledge sharing over heterogeneous computing platforms. To overcome this, a Semantic Grid infrastructure is presented in this paper for distributed management of e-government resources across ubiquitous virtual governmental agencies. An ontology-based service-oriented approach to problem-solving in e-government is proposed in the Semantic Grid, enabling to provide, in an open, dynamic, loosely coupled and scalable manner, the service publication, discovery and reuse for connecting the customers and agencies of e-government services based on their semantic similarities in terms of problem-solving capabilities. The operation of the system is demonstrated using Protégé-2000, a widely accepted ontology modeling tool to validate the implementation of the proposed approach towards effective ontological maintenance.

*Key-Words:* - CSCW; E-government; Ontology; Semantic Grid; Semantic Web; Service-oriented

## 1 Introduction

Due to current trends in the public administrative fields towards highly specialized portal and solution providers cooperatively offering integrated governmental e-services to the customers (citizens, enterprises or other public sectors), there is an increased need for ubiquitous virtual governmental agencies to establish and maintain a Computer Supported Cooperative Work (CSCW) through effective communication, interoperation, integration and collaboration at the resource level. Although the current internet and World Wide Web (WWW) have given birth to the emerging concepts of e-government towards CSCW, the heterogeneity and incompatibility among distributed e-government resources is still a major obstacle to sharing and coordinated use of multiple governmental service provisions, which may be geographically dispersed over heterogeneous computing platforms due to their largely unplanned and unanticipated growth.

The development and maturing of Grid computing technology [1], in particular, its evolvement to an Open Grid Service Architecture (OGSA) [2] has promised to address the above challenge, by providing a pervasive infrastructure to support flexible, coherent deployment and reuse of diverse Grid services such as governmental service provisions residing in ubiquitous virtual governmental agencies. However, managing semantic interoperability in the Grid environment remains a bottleneck, which in turn limits its ability to support ontology-based, seamless service interoperability. The emerging Semantic Web [3] possesses a huge potential to address the ontological issues for solving semantic interoperability, by representing ontology into machine-processable languages such as Web Ontology Language (OWL) [4] and Semantic Web Rule Language (SWRL) [5].

Having realized the advantages of both emerging resource modeling techniques – Semantic Web for ontology-based modeling and Grid computing for service-oriented modeling, the recent popularity of

Semantic Grid [6] has renewed the computing advancements in building open, dynamic and adaptive systems, with a high degree of automation, which annotate the diverse Grid services with domain ontology and support the flexible coordination and collaboration on a global scale. The availability of semantically annotated Grid services has given various resources well-defined meaning, better promising the seamless service interoperability of autonomous, heterogeneous, distributed applications such as e-government applications.

Aiming at managing semantic interoperability of service-oriented e-government applications effectively, this paper describes a preliminary attempt at using Semantic Grid paradigm for distributed management of e-government resources across ubiquitous virtual governmental agencies through multi-layered integrated infrastructures consisting of resource layer, ontology layer, middleware layer, application service layer and portal layer. Web Ontology Language (OWL) [4] and Semantic Web Rule Language (SWRL) [5] are utilized to represent the e-government ontology for formally describing the basic concepts, relationships between concepts, and rules of thumb in the e-government applications. Web Ontology Language for Services (OWL-S) [7] is utilized to add semantics to governmental service provisions to endow them with semantic capabilities needed for their flexible, coherent deployment and reuse in e-government applications.

An ontology-based service-oriented problem-solving in e-government is proposed in the Semantic Grid, enabling to provide, in an open, dynamic, loosely coupled and scalable manner, the service publication, discovery and reuse for connecting the customers and agencies of e-government services based on their semantic similarities in terms of problem-solving capabilities. Ontological query languages such as OWL-QL [8], and ontological inference engines such as Racer [9] and JESS [10] are used to implement the semantic matchingmaking process.

The operation of the system is demonstrated using Protégé-2000 [11], a widely accepted ontology modeling tool to validate the implementation of the proposed approach towards effective maintenance of e-government ontology.

## 2 Related Work

E-government applications on the distributed reasoning infrastructures such as Grid or Semantic Web, and more generally, on the Service-Oriented Architecture (SOA) or ontological architecture, have been the focus of some recent research.

Regarding e-government applications on the Grid or SOA, Silva & Senger [12] discussed the utilization of Grid computing platforms as an enabling infrastructure for e-government, e-commerce and e-business application. A set of Grid services that are fundamental for e-government applications, such as database access and integration and knowledge discovery services are identified. Terregov [13] is a European Union e-government project that adopts the principles of SOA based on interoperable components with dynamic support for finding e-government services. Terregov makes it possible for local, intermediate and regional administrations to deliver online a large variety of services in a straightforward and transparent manner regardless of the administrations actually involved in providing those services. Fu et al. [14] implemented a Grid-based e-government information portal as a ubiquitous communication channel between the government and its citizens, by taking Grid services as its basic units and applying publishing/subscribing mechanism to transport messages between servers. Maad & Coghlan [15] explored the potential of Grid infrastructure for e-government applications, by assessing the potential benefits of OGSA in meeting the critical success factors for e-government, which are identified as integration, knowledge management, personalization, and customer engagement.

Regarding e-government applications on the Semantic Web or ontogical architecture, another European Union e-government project Ontogov [16] adopts an ontology-enabled e-government service configuration strategy, enabling to test and validate a semantically enriched platform that will facilitate the consistent composition, re-configuration and evolution of e-government services. Tsampoulatidis et al. [17] described an ontology representation scheme for e-government systems based on Semantic Web language XML Topic Maps. This scheme supports the provision of various thematic services to the citizens guaranteeing independence of the knowledge between the actual sources of information and the data representation. Through ontological engineering, Brusa et al. [18] contributed to the semantic interoperability level required in back-office of e-government tasks, bringing about a situation where semantics associated to data is highly specific, complex and used from all government administration areas, and delivering more efficient integrated e-government services to the front-end users. Votis et al. [19] proposed an ontologically principled SOA on the

Semantic Web for the administration and integration of distributed nodes in an e-government network, by utilizing a two-level semantic mediator model to both provide an integrated descriptions of e-government entities and map actual information to them.

Notwithstanding the promising research results and implemented prototypes reported from existing research work for Grid or Semantic Web enabled e-government applications, there is still a major gap between these e-government systems and the vision of Semantic Grid to realize more integrated solutions that accelerate the convergence of Grid computing and Semantic Web technologies. Although the Semantic Grid infrastructure has been proposed for e-science and e-commerce applications such as our previous work on Semantic Grid-based e-design [20] and some proof-of-the-concept prototypes have been developed, to the best of the authors' knowledge, we are not aware of architectures that weave a Semantic Grid for e-government.

# 3 The Semantic Grid Infrastructure for E-Government Applications

Ubiquitous virtual governmental agencies can be connected into a distributed e-government network to offer integrated governmental e-services to the customers (citizens, enterprises or other public sectors), by establishing and maintaining a CSCW through effective communication, interoperation, integration and collaboration at the resource level. However, the inherent scale, complexity, heterogeneity and dynamism of distributed e-government resources, makes the effective capture, retrieval, reuse, sharing and exchange of resources a critical issue in e-government applications. As the essence of the Semantic Grid is to deal with interoperability problems in dynamic and open environments, and populate such environments with globally distributed but semantically enriched resources, it is utilized in this work to deliver agencies and customers a loosely coupled, distributed solution to facilitate their seamless access to distributed e-government resources in a virtual organization. Such an infrastructure is depicted in figure 1, which consists of five layers: resource layer, ontology layer, middleware layer, application service layer and portal layer.

## 3.1 Resource layer

The resource layer includes various kinds of computational resources (such as supercomputers, workstations, clusters and visualization servers), network resources (such as various routers, buffers and printers), storage resources (such as storage controllers, disk arrays, tape libraries, disk drives and tape drives), modeling resources (such as statistical modeling software, functional modeling software and process modeling software), collaborative support resources (such as various online consultation, live presentation and visual conferencing tools), knowledge resources (such as governmental strategies, initiatives, policies and standards) and data resources (such as files, relational and XML databases). These resources are often located geographically and virtually, supplied across multiple agencies and represented in heterogeneous formats with little semantics on their sources and usage, hence resulting in significant interoperability challenges.

## 3.2 Ontology layer

Unlike traditional resource management practices that concentrate on separate capabilities of involved resources, the proposed infrastructure captures the semantics of exchanged e-government resources in its ontology layer 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 differences in vocabularies and models in all domains of human life and work including e-government activities, in particular, whenever a rigorous and unambiguous communication between human and machine, machine and machine, or human and human is necessary.

The e-government ontology is built with the formal representation language OWL [4] and SWRL [5] that are the most expressive semantic markup languages 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 governmental service provisions across ubiquitous virtual governmental agencies.

The top-level OWL concepts include task, agency, enterprise, citizen, activity, process, issue, legislation, responsibility, right, rule and service, each of which is further specialized into optimal number of lower-level sub-concepts to represent the domain as accurately as possible.

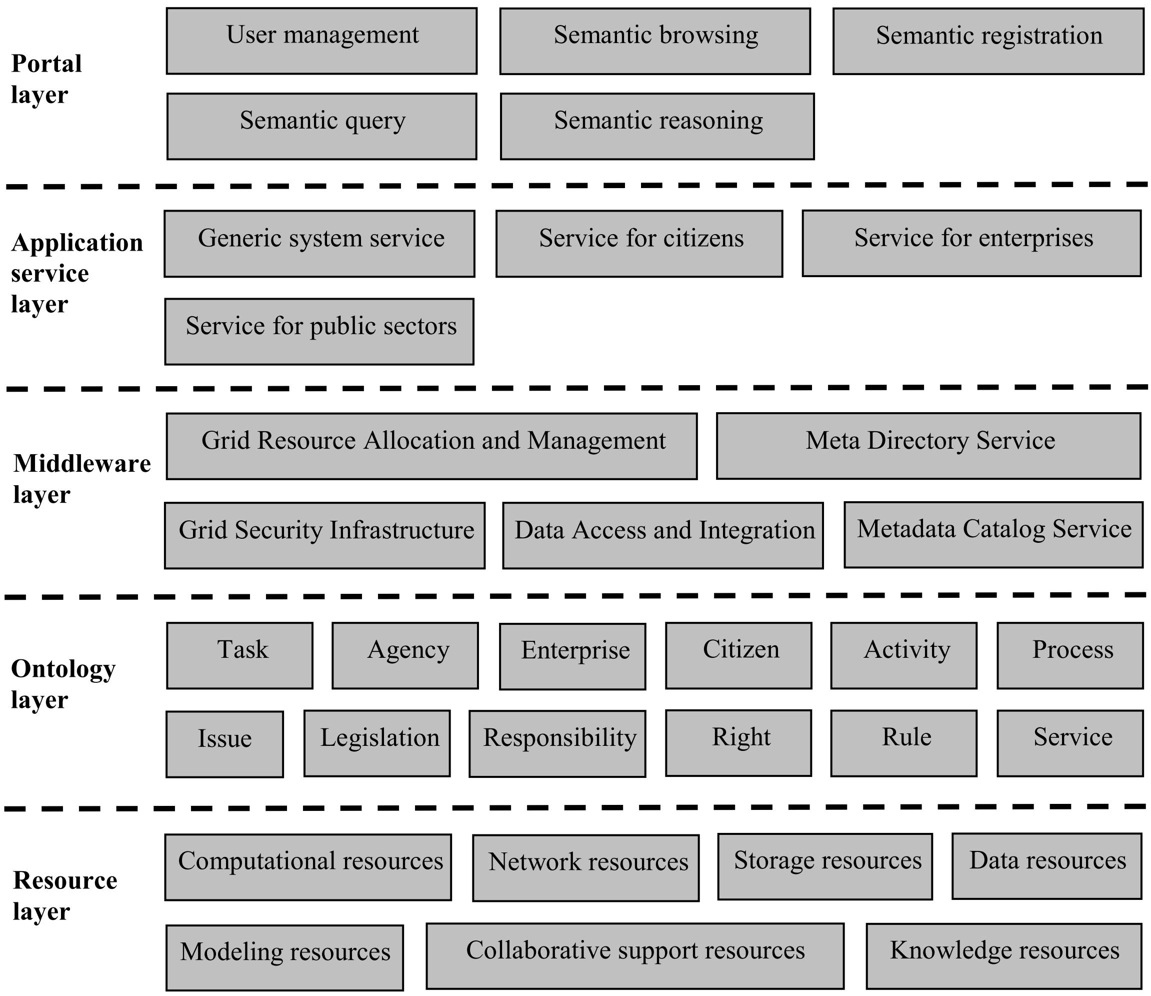


Figure 1. The Semantic Grid Infrastructure for e-government applications

SWRL allows users to formulate horn-like rules in the form of IF-THEN formats expressed in terms of OWL concepts. The rules are used to infer new OWL concepts from existing OWL concepts. For example, the following rule in SWRL, retrieves all persons in the ontology who is married, over 25 years old and live in Hangzhou, together with their ages:

*Person(?p) ^ Married(?p) ^ hasAge(?p, ?a) ^ swrlb:greaterThan(?a, 25) ^ liveIn(?p, Hangzhou) →query:select(?p, ?a)*

## 3.3 Middleware layer

As Grid and its corresponding OGSA provide a pervasive infrastructure to support coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations (VO) [2], the Grid middleware layer is used to underlie the e-government platform, in which, each governmental agency acts as an participating VO. The Globus Toolkit 4.0 (GT4) [21] has become the *de facto* standard in the Grid world as the open source middleware of various Grid applications. It is a combination of core services, libraries, interfaces and protocols, such as Grid Resource Allocation and Management (GRAM) [22], Meta Directory Service (MDS) [23], Grid Security Infrastructure (GSI) [24], Data Access and Integration (DAI) [25] and Metadata Catalog Service (MCS) [26]. These components lower the complexities and technical thresholds associated with management of geographically distributed resources by wrapping up them as Grid services for making usage of them as transparent as possible from the users' point of view.

## 3.4 Application service layer

The development of applications will be facilitated by a set of Grid enabled application-level e-government services such as generic system services, services for citizens, services for enterprises and services for public sectors, which are produced by wrapping up various e-government resources through Grid middleware. Web Service Description Langauge (WSDL) and Web Ontology Language for Services (OWL-S) [7] are two widely accepted service description languages in the e-commerce community to describe Web or Grid services. WSDL describes services as collections of operation names and XML Schema data type at the syntactic level. OWL-S describes services as collections of control constructs of problem-solving capabilities at the semantic level. To endow the e-governmental service provisions with semantic capabilities needed for their flexible, coherent deployment and reuse in e-government applications, WSDL is enriched by adding semantic information with OWL-S service ontology. As OWL-S service ontology does not provide complete vocabulary sets for describing specific Grid services in various application domains, the domain-specific terms and concepts used in OWL-S to describe Grid services are defined in domain resource ontology, i.e., distributed e-government ontology.

### 3.5 Portal layer

The above four interactive layers make it possible to integrate heterogeneous, distributed e-government resources across virtual governmental agencies, enabling simplified access to diverse resources and dynamic coordination of sophisticated e-government processes. However, the practical value of an e-government system developed is largely determined by the user friendliness of its information portal, hence the appropriate deployment of Grid portal through a portal layer that simplifies the use of underlying Grid services for the end users has become popular. The portal layer seeks to foster collaborative development and usage of Grid technology by configuring, exposing and archiving Grid technologies through context-based interfaces, so that users can interact with the portal through an intuitive interface for user management, semantic browsing, semantic registration, semantic query, semantic reasoning, etc.

## 4 An Ontology-based Service-oriented Approach to Problem-solving in E-government

Problem-solving in e-government often involves searching, discovering and retrieving various e-government resources manually or automatically to realize a particular task or worklist. In the Semantic Grid infrastructure of e-government applications, various resources are represented and exposed as semantically annotated Grid services. Therefore, an ontology-based service-oriented approach to problem-solving in e-government is proposed, enabling to provide, in an open, dynamic, loosely coupled and scalable manner, the service publication, discovery and reuse for connecting the customers and agencies of e-government services based on their semantic similarities in terms of problem-solving capabilities. A general view towards the ontology-based service-oriented approach to problem-solving in e-government is depicted in figure 2.

Ubiquitous virtual governmental agencies can be connected into a distributed e-government network to offer integrated governmental e-services to the customers (citizens, enterprises or other public sectors). Each e-government node has a Grid portal for service providers such as agencies to publish Grid services or service requesters such as citizens, enterprises and other public sectors to retrieve wanted Grid services.

Once a Grid service is semantically annotated in the Semantic Grid, both its syntactic and semantic information can be advertised in a distributed semantic service registry, which has extended the traditional UDDI (Universal Description, Discovery and Integration) service registry to support semantic descriptions of heterogeneous Grid services for large scale resource integration. The limitations of the UDDI service registry are clear in a large scale distributed environment due to the lack of unambiguous semantics, fault tolerance and scalability. The proposed semantic service registry consists of a UDDI service repository, an OWL-S service repository and a semantic service mapping mechanism between both repositories.

The UDDI service repository is used to register each Grid service about its syntactic capabilities, while the OWL-S service repository is used to register each Grid service about its semantic capabilities. A domain resource ontology repository, i.e., e-government ontology is used to further provide rich semantics for describing specific Grid services in e-government domains, e.g., defining the concepts used in domain-specific OWL-S service repository. To support semantically enhanced service queries, the semantic service mapping mechanism between the UDDI service repository and OWL-S service repository also needs to be built to make each Grid service registered syntactically in the UDDI service repository have a corresponding semantic description in the OWL-S service repository.

The service matchmaking mechanism receives the request of the wanted Grid service specification in OWL-S format, which may be generated by analyzing the structure of original WSDL specification using WSDL parser. Then a semantically enhanced search in the OWL-S service repository of the semantic service registry is conducted for the matching semantic service description. Service capabilities, requested or published, consist of functional properties such as inputs, outputs, preconditions and results, and non-functional properties such as service name, service category, service classification and service parameters. These capabilities are semantically matched based on certain rules of similarity between two distinct ontological instances, as described by Paolucci et al. [27]. After the matching service in the OWL-S service repository is found, the target Grid service in the UDDI service repository can be retrieved via the semantic service mapping mechanism between the UDDI service repository and OWL-S service repository, and returned for invocation.

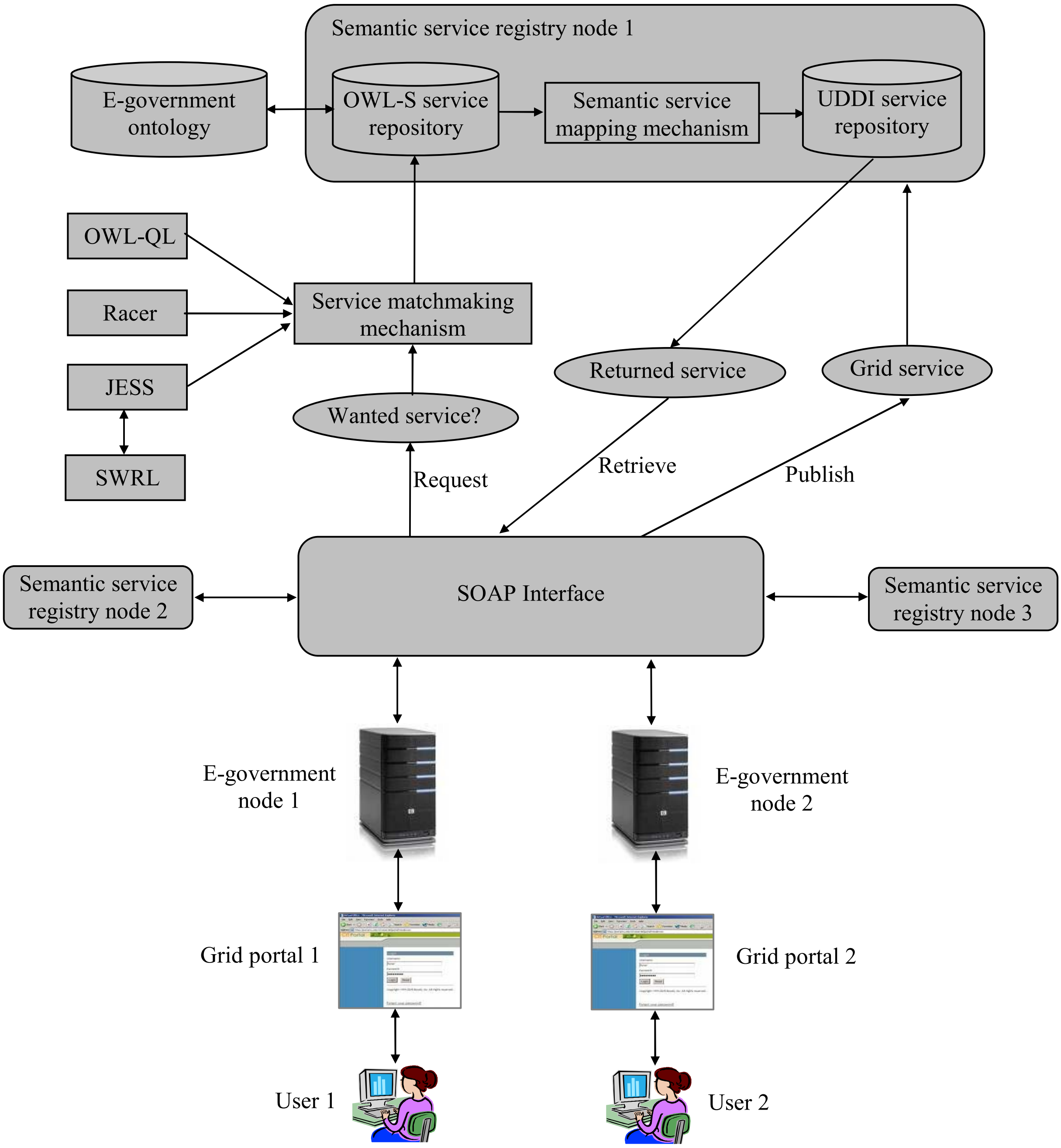


Figure 2. An ontology-based service-oriented approach to problem-solving in e-government

Ontological search engines such as OWL-QL [8], and ontological inference engines such as Racer [9] and JESS (Java Expert System Shell) [10] are used to control the whole process of service discovery and matchmaking. The OWL-QL provides ontology-based query to the e-government concepts, their properties and relationships in the underlying ontology repository. The Racer engine provides reasoning capabilities over various knowledge entities in the ontology repository, e.g., by performing common ontological operations such as terminological and assertion reasoning, subsumption checking, navigating concept hierarchies, and so on. As a rule-based engine and scripting environment written entirely in Sun's Java language, the JESS engine performs primitive reasoning with e-government rules that are formulated in the form of IF-THEN formats in SWRL, where the OWL concepts are mapped to JESS facts in the working memory. The JESS engine, coupled with SWRL, provides a rich rule-based reasoning facility for the distributed e-government environments and solves the semantic interoperability among the multitude of current rule-based e-government applications over heterogeneous computing platforms.

Some Grid services may reside locally to an e-government node and others remotely. Similarly, some Grid services may be registered locally to a semantic service registry node and others remotely. The Grid portals help to redirect the users to the preferred e-government node or semantic service registry node intelligently. Collaboration among e-government nodes, semantic service registry nodes and Grid portals is performed using SOAP (Simple Object Access Protocol) [28], which is an XML/HTTP based protocol for accessing services, objects and ontologies in a platform-independent manner. In particular, the use of OWL-S in conjunction with SOAP offers great flexibility to the Grid portal programmers for setting out the encoding, semantics and pragmatics of the communicating messages.

## 5 System Operation for Effective Ontological Maintenance

To demonstrate the feasibility of the proposed approach for e-government applications, in particular, for effective maintenance of e-government ontology, a Java-based software prototype is implemented in the network environment that includes below machines: 1) Application server: 4 CPU, 3.3G Frequency, 4GB Memory, 72GB SCSI HD, Redhat Linux 11.0, JBoss 5.0; and 2) DB server: 4CPU, 3.3G Frequency, 4GB Memory, 72GB SCSI HD, Redhat Linux 11.0, My SQL 5.0.

Globus Toolkit 4.1 (GT4.1) is employed to realize the semantic service registry, and various Grid services are deployed on the GT4.1 container. The Grid portals are implemented on JSP and JavaBeans. The integrated ontological reasoning tools including OWL-QL, Racer, JESS and SWRL are used to reason about concepts and their properties as well as the relationships between concepts. Diverse domain resource ontologies including OWL concepts, OWL-S service ontology and SWRL rules, can be loaded and used to build and explore the Semantic Grid.

Figure 3 shows the graphical user interface for ontology maintenance, using Protégé-2000 [11] that's developed by Stanford University, in conjunction with its *OWLViz* and *SWRL* plug-ins. Left and right windows respectively display the tree and graphical views of hierarchical e-government ontology. The top-level OWL concepts include *Task*, *Agency*, *Enterprise*, *Citizen*, *Activity*, *Process*, *Issue*, *Legislation*, *Responsibility*, *Right*, *Rule* and *Service*. The *Rule* class is specialized into *swrl:Imp* (for representing a single SWRL rule), *swrl:AtomList* (for representing a list of rule atoms), *swrl:Atom* (for representing a rule atom), *swrl:Builtin* (for describing built-ins), and *swrl:Variable* (for representing a variable). The concepts and properties to define SWRL rules are pre-defined using OWL. The general *Service* class is specialized into *Generic system service*, *Service for citizens*, *Service for enterprises* and *Service for public sectors*. Similarly, the *Service for citizens* is specialized into *Personal document service*, *Job search service*, *Learning service*, *Library service*, *Income tax service*, *Social care service* and *Housing service*. The *Housing service* is further specialized into *Alert service*, *Payment service*, *Financial plan service*, *Legal service*, *Loan service*, etc.

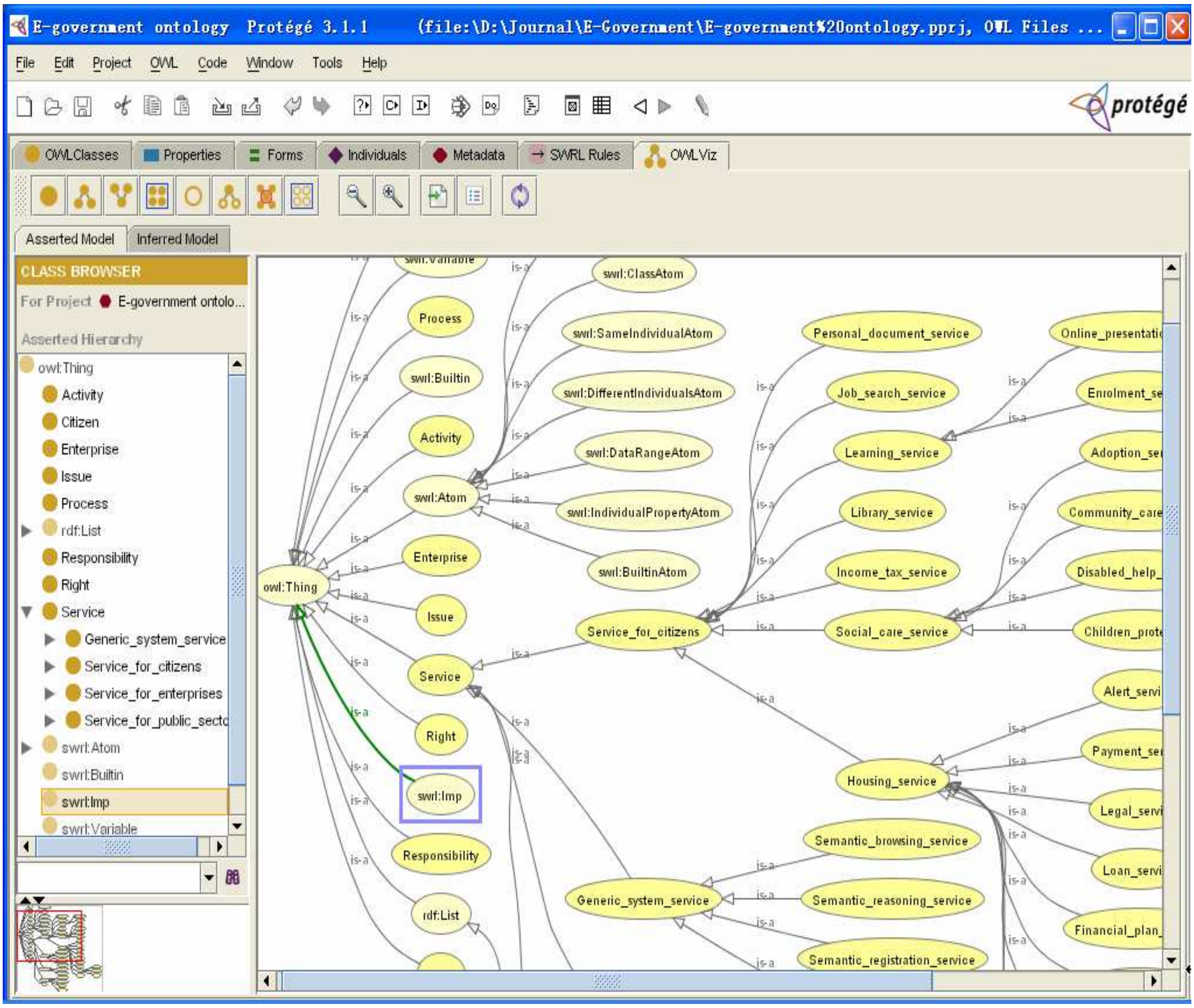


Figure 3. Graphic user interface for maintenance of e-government ontology

## 6 Conclusion

This paper has presented a Semantic Grid infrastructure to support distributed e-government applications across ubiquitous virtual governmental agencies. The work contributes to the semantic interoperability required in service-oriented e-government applications, bringing about a functional solution where the semantics associated to governmental service provisions are highly dynamic, seamless, and shared among distributed e-government nodes. The ontology-based service-oriented approach to problem-solving in e-government has been explored to enable the full integration of various ontological reasoning tools such as OWL-QL, Racer, JESS and SWRL in the Semantic Grid to provide, in an open, loosely coupled and scalable manner, the service publication, discovery and reuse for connecting the customers and agencies of e-government services based on their semantic similarities in terms of problem-solving capabilities. The operation of the system is also presented to validate the implementation of the proposed approach towards effective ontological maintenance.

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