Semantic Grid-Based E-learning Architecture

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Abstract – This paper presents an architecture along with an implementation approach to build efficient e-learning applications.

In this architecture, e-learning infrastructure uses the Grid computing technology which chooses the best available resources for e-learning objects execution. An e-learning object is defined as the unit for structuring e-learning applications/courses. Furthermore, the infrastructure uses the Semantic Web to specify the learning objects requirements as well as the grid resources description.

A broker entity is developed within the architecture as a mediator who receives performance requirements of the learning object specified using the E-learning standard LOM and the available resources on the grid that are required to execute that object. The broker implements diverse scheduling algorithm to allow a flexible scheduling of resources needed by different E-learning applications.

The proposed architecture is expected to guarantee the optimum allocation of available Grid resource to satisfy the performance requirements of E-learning applications.


1. Introduction

Due to the explosive growth of the Internet and communication technologies, e-learning has become a common means of disseminating knowledge to learners who may come from an academic (e.g., schools, universities, etc.) or industrial (e.g., government institutes, private sector, etc.) domains.

The increasing reliance on such type of technology entails some new requirements. These requirements may relate directly to the nature of the learning material or to the specific preferences stated by the user. For example, a video clip may require a specific decoder and a minimum processing speed. On the other hand, the user may prefer to watch this video with special additional effects (e.g., 3D sound) that may impose further performance requirements.

Having learning material, which are usually represented by learning objects, bound to a specific computing system may limit the e-learning application’s scalability and availability because any system has its intrinsic computing capacity. To liberate learning objects from such computational constraints, we propose in this paper an architecture that is ultimately based on the Grid platform [1] with some augmentation of other supporting technologies, namely Semantic Web [2] [3] and Web Services. The Grid should help increase the availability of the required resources especially under stringent performance requirements. Using Semantic Web help establish a shared understanding between the performance requirements, as specified by the learning objects, and the performance metrics, as interpreted and managed by the Grid. Finally, Web Services can be used as a transparent interface that the e-learning application can use in order to deal with the Grid.

Figure 4 sketches the relationship between the different pieces in the proposed architecture. As shown, the e-learning application consists of a collection of learning materials represented by learning objects. In order to process and run these learning objects, the e-learning application submits them to an e-Learning Grid hoping that the prospective performance requirements imposed by the intrinsic characteristics of the learning object (LO) and the additional performance preferences of the user are fulfilled efficiently.

Along with the LO’s information, the e-learning application submits the overall performance requirements to a Grid broker for processing via a Web Service. A Grid broker is an entity responsible of interpreting the performance requirements of an e-learning object vis-à-vis the available resources at the grid infrastructure. To facilitate the transformation from the high-level description of performance requirements at the application level to the system-level of the Grid, ontologies maybe used to bridge the semantic gap associated with performance vocabulary.

In order to fulfill the desired performance criteria, the broker attempts allocating the appropriate Grid resources using some scheduling algorithms. The scheduling is performed in light of information obtained from the GRAM (Grid Resource Access Management) module of the Grid, which maintains runtime information about all Grid resources.

The rest of the paper is organized as follows: in section 2, we present the related works. Section 3 provides fundamentals of grid computing, semantic
web, e-learning grid and the relationship between them. Section 4 describes the main requirements for a grid based e-learning architecture we are proposing. In section 5, we present our grid based e-learning architecture and their components. Section 6, describes the implementation detail of our architecture. This includes the specification of E-learning user’s requirements as well as the specification of grid resources. Section 7 concludes the paper and states our future works.

2. Related Works

The research in the area of e-learning is very active. It has lead to the introduction of a standard which defines interoperable e-learning applications or courses. Interoperability is achieved through the use of a standard e-learning object, which is the unit of structuring e-learning applications [4] [5]. Consequently, it becomes easy to define an e-learning object and share it as a plug-in and play over the Internet. In this context, the efficiency of the e-learning systems is very crucial for the adoption of e-learning technology.

Related to our work is the work of Pankrastius et al. [6] who propose the use of the Grid computing system to increase the efficiency of e-learning applications. In their architecture, they propose to add a code to the learning object in order to register itself with a Grid computing broker, that is responsible to find suitable resources for the learning object. The learning object is then called a Grid learning object. However, it is not specified how the e-learning object requirements are specified by users in a modular, portable way.

In our work, we use the semantic web [2] and its ontology backbone concept to specify the performance requirements of e-learning applications and map them to resources requirements so that they can be used by the Grid computing functions. Those performance requirements are specified by the writer of the e-learning object.

The idea of using the semantic web for specifying an e-learning object is not new. It has been proposed by Stojanovic et al. to organize and offer e-learning materials in a semantic basis [7]. One of the objectives of the semantic web is to provide semantic descriptions which make sense to users and which are machine processable, and machine actionable, thus maximizing the potential for sharing and reuse. Web data are then described using the Resource Description Framework (RDF) [8] which is standard specifications for a metadata model. One of the main characteristics of the semantic web is the use ontology backbone. This ontology enables to describe characteristics of e-learning materials using semantic learning objects. Therefore, in our work we propose to use this ontology backbone to semantically describe and organize the performance requirements of e-learning objects. We then provide the mapping between the semantic performance requirements of the e-learning objects to grid-based resources which satisfy those requirements.


E-learning Grid is a "flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions, and resources – what we refer to as virtual organizations.", as defined by Ian Foster et al. [9]. [10] has also established a three point checklist for grid computing which enumerates in a good way the advantages of a grid system. The three point checklist define the grid as a system which "1) coordinates resources that are not subject to centralized control … 2) … using standard, open, general-purpose protocols and interfaces … 3) to deliver nontrivial qualities of service."

The Grid platform is meant to increase applications efficiency ([11], [12], and [13]) by taking care of underutilized resources and turning on the underlying infrastructure into a powerful enterprise. The underlying resources can be any of-the-shelves devices, such as personal computers, mobile phones and PDAs, sensor networks, etc. (see Figure 1). The Grid computing enables the access to these devices in a transparent and efficient way.

Figure 1. Large-Scale Grid Distributed Resources

The Grid platform is composed of a set of services which discover resources, monitor them and allocate them to users' applications. Users' applications are then monitored to ensure that their executions meet the performance requirements determined by the users at application's submission.

However, in order for the grid computing to be used in a large-scale environment, a standard should be defined. The Open Grid Forum [14], working toward this objective, has defined the Open Grid Services Architecture (OGSA), where protocols are defined toward the interoperability among grid services. The Grid components or services are then defined as web
services using standard languages and standard architectures, such as WSDL and SOAP. In this way, grid components are then published and discovered using the web services standard.

To facilitate the shareability of services components, the semantic web has naturally been proposed, therefore giving birth to the new definition of a semantic Grid [2] [3] In the same way as semantic web is important to web, the semantic grid is important to the grid, and the semantic-OGSA has been proposed [15] as reference architecture. The Semantic Grid is an extension of the current Grid in which information and services are given well-defined meaning through machine-processable descriptions which maximize the potential for sharing and reuse.

The semantic grid vision is a network of information sources with rich metadata. This approach is essential to achieve the full richness of the Grid vision, with a high degree of easy-to-use and seamless automation enabling flexible collaborations and computations on a global scale. Semantic Grid research group identified two areas of investigation that are Semantic in the Grid and Semantic on the Grid.

- Semantic in the Grid. It consists of the application of semantic web technologies inside grid middleware to achieve truly interoperable infrastructure. The Open Grid Services architecture is an example of application of Semantic in the Grid. The objective of this architecture is to make it easy to create dynamic “virtual organizations” by service integration [16].

- Semantic on the Grid. It uses semantic web technology to enhance publishing and linking scientific materials (e.g. e-learning materials). MyGrid is one of the successfully project which employs Semantic on top of the Grid. MyGrid is producing a virtual laboratory workbench to serve the life science community (www.mygrid.man.ac.uk).

The Semantic Grid is developed to fulfill these objectives:

- Provide information for linking services and providing the needed information management capabilities.
- A semantic web infrastructure as infrastructure for Grid computing applications.
- As discussed in the related work, e-learning applications use also the semantic web for structuring and describing e-learning objects. Our objective through this work is to provide an architecture that will use semantics and ontology on the Grid to offer high level support for managing grid resources and for developing complex applications (composition of e-learning objects and/or resources) that will benefit from the use of semantics. Our main goal is to develop an e-learning architecture that provides efficient support for e-learning applications.

4. Requirements

In this section we will not tackle on the importance of e-learning applications whose advantages are overviewed in [17]. However, we present the requirements we set when designing our Grid based E-learning architecture.

When considering the efficiency for an e-learning-based system, three important problems have to be considered:

- Sharable e-learning objects (transparency). Authors must be able to write e-learning objects that can be used by learners without necessarily the underlying system where the learning objects will be executed.
- Efficient execution of e-learning applications. This consists of satisfying the performance requirements of these applications for efficient execution. An e-learning application which uses a multimedia e-learning object for its execution has to require sufficient resource to guarantee an acceptable performance for a learner. This is very important as a lack of efficiency at runtime will destroy the objective of e-learning.
- Efficient construction of e-learning objects. This consists of proposing mechanisms to efficiently build learning material for learners. Nguyen proposed in [18] an adaptive approach for building a course using intelligent agents that help in choosing effectively adaptive course.

The first problem is not an open issue. As pointed out previously, the use of standard e-learning object allows defining an object and sharing it as a plug-in and plays over the Internet.

The second problem is our main focus in our paper. The third problem is not our focus, although we believe that any e-learning mechanism that is used to build e-learning applications from e-learning objects can be easily integrated within our framework.

When designing this architecture for e-learning systems, we had the following requirements:

- Modularity. The description of performance specifications of e-learning objects should be separate from the e-learning application code.
- Administration of performance requirements. The performance needs of the e-learning objects can be removed, updated. In addition, there should be a possibility to add more requirements to an existing e-learning object.
- Portability. Our architecture is not specific to any language or platform. It can be implemented using standard tools and techniques.
- Human understandable and machine-processable. The specification of performance requirements of an e-learning object should be descriptive and semantic-based. This will allow maximizing the
sharing of the e-learning object among different users. In addition, the above specifications should be machine-processable.

5. Architectural Approach

E-learning, as defined by the National Assembly for Wales is "The use of electronic technology to support, enhance, or deliver learning". Nowadays, e-learning applications are being increasingly used in education and industry to support distance learning. Due to the explosive growth of the Internet and communication technologies, e-learning applications started to become more popular and common. Building such applications using the traditional P2P or client-server architectures put us before the following problems:

- Lack of an automated mechanism for managing e-learning resources. These resources are essentially handled in an ad hoc or manual manner.
- Poor performance as the e-learning system does not scale up well once the underlying finite resources start to be pushed to their limits.
- Poor scalability typically leads to limiting the learning scope and ability.
- Such simple architectures lack effective mechanisms that enable the user semantically search and navigate through the content of the e-learning system.

Our aim in this research is to propose a new architecture that integrates several technologies in order to overcome the problems stated above.

6. Grid-Based E-learning Architecture

The Architecture presented in the figure bellow describes a high level layered architecture of Semantic Grid for E-learning applications.

The architecture consists of three key layers. The first layer represents the base layer of the Grid infrastructure in which all distributed resources (computers, databases, servers, etc) are managed autonomously. The upper layers count on this layer for providing efficiency, computing, communication power, reliability, availability and security.

The Grid layer is enclosed by the mid layer of Semantics that provides descriptions for the Grid resources and the stored educational material. The Semantic Grid is made possible through the use of ontologies, schemas, and other types of metadata that describe the grid resources which will ease the utilization of these resources.

The top layer in the architecture represents the application layer (e-learning system) where the end user (learner) seeks knowledge and educational material. This layer exposes the e-learning resources (objects) and ontology to describe them. E-learning objects have diverse forms: multimedia object, text, web pages, etc. Through this layer, the learner deals with the e-learning system transparently with a high degree of search and navigational flexibility through the learning material, and with high efficiency and independence from managing the physical resources of the IT infrastructure. The ontology described in this layer is used to enable the learner to navigate through the learning contents and search them effectively.

We argue that this architecture, through its conceptual layers, is able of achieving the following goals:

- Enabling ubiquity in learning by automating the adaptation of learning material to resources and vice-versa.
- Facilitating the accessibility to learning repositories through interconnecting heterogeneous learning sources.
- Easing the dissemination of learning material by virtualizing and aggregating disparate IT/Educational elements.
- Expanding the learning scope and abilities, especially when the computing power and resource provisioning become no barriers.
- Extending the reachability of learning resources and materials to schools and all other training institutes with limited computing power and connectivity

6. Implementation Approach

As discussed previously in the architecture, a Grid learning object includes metadata which describes in a semantic way the performance requirements of the e-learning object. This is described using XML and standard languages so that to foster common understanding and sharability among learners. The semantic requirements are then mapped to requirements in terms of Grid resources. An e-learning application can then submit the e-learning object, along with its
specifications and identity to the Grid for further processing as shown in Figure 4.

Figure 3. Implementation Approach

The Grid infrastructure is composed of the following elements. Those elements are inspired from the standard definition of Grid computing environment and the Globus [19] [20] [21] implementation of the standard:

- Grid Resource Information Protocol (GRIP) service. This service is associated with every single resource in the Grid. It monitors the resource and reports on its configuration, its current load, and its local policy (e.g. cost). This service is part of what we call a local resource manager in the state-of-the-art of resource management. It is based on the Lightweight Directory Access Protocol (LDAP). It is part of the standard definition of the Grid Information Protocol.

- Grid Resource Registration Protocol (GRRP) service. This service is associated with each single resource in the Grid. It registers load information and state in a global directory managed by the Grid Index Information Server. This service is also part of a local resource manager.

- Grid Resource Access and Management (GRAM) service. This service functions at a single resource level. It processes requests for resources. It allocates the required resources for the e-learning objects and monitors and controls those e-learning objects. It also reports on the status of the e-learning objects during execution on the target resource.

- Broker service. This service manages a global state in the Grid. It is responsible for scheduling and allocating the Grid Learning Objects received by the Grid. The Broker contacts the Grid Index Information Server to obtain information about the current status of the resources. Consequently, the Broker maps the performance requirements of the Grid e-learning objects to the best available Grid resources. The Broker can also implement a wide range of scheduling algorithms. The Broker should use efficient scheduling algorithms to satisfy e-learners requirements for performance.

Our implementation uses Globus as a Grid infrastructure. However, Globus does not include a Broker implementing a standard web service interface or better a semantic-based web service interface. Condor-G, DRM Broker, and Nimrod-G are projects implementing a Broker whose scheduling algorithms are economic-based. However, those projects do not provide neither a semantic web implementation, nor a wide selection of scheduling algorithms so that to investigate the different scheduling algorithms which are needed for e-learning applications. It is necessary to implement the Broker as a standard web semantic interface for ease of use and sharability. In addition, we would like to have the possibility of an on-the-fly plug-in and play of different types of scheduling algorithms. Some applications may have a better performance with a certain scheduling and allocation algorithms. For all these reasons, we opt to implementing our Grid Broker using Globus toolkit.

6.1 E-learning user and application related technical requirements specifications

We proposed performance related user ontology to support universal performance requirements specification of the learning object. An existing standard called LOM (Learning Object Metadata) has been developed in [22] to describe a learning object and similar digital resources used to support learning. The purpose of learning object metadata is to support the reusability of learning objects, to aid discoverability, and to facilitate their interoperability, usually in the context of online learning management systems. Our ontology will extend the LOM description to support performance specification of the user as well as the intrinsic learning application requirements. We introduced under the category “Technical” of the LOM specification the specification of user/application requirements. The Technical category groups the technical requirements and technical characteristics of the learning object. Under the sub-element requirements, two sub elements basically were added: (1) user requirements and (2) intrinsic application requirements (e.g. specific codec, etc.).
describes an example of performance ontology described within the LOM specification.

6.2. Grid-Based E-learning Specifications

We describe a set of requirements in terms of grid’s resources required for the execution of a given e-learning application. We classify computation resources into CPU, Memory, Bandwidth, etc. These are often the required resources for most of E-learning objects. The figure below presents an example of specification description of e-learning multimedia object. We have used XML language to specify these requirements and we have followed a standard XML representation of these resources requirements.

Table 2. Grid Resource Specifications for a Multimedia E-learning application

We classified the required resources to efficiently use, execute a multimedia application into (1) available network bandwidth, (2) the speed of CPU on which the multimedia application will be executed, and (3) the memory size available on computer in which the application will be executed. These might be extended to cover other resource properties depending on the type of the E-learning objects consumed. Each resource is named and has a value that enclose the unit and the threshold value that can be either maximum or minimum value. The work “ALL” in the description above means that all the specified resources have to be

Table 1. LOM document extended with user/application requirements
satisfied in order to use the multimedia service. In other cases, only one of the specified resources has to be fulfilled and in this case we use the operator “Exactly One” instead of the operator ALL.

7. Conclusion and Perspectives

In this paper, we presented Grid based e-learning architecture along with an implementation to design and build efficient, human friendly and shareable e-learning applications.

Efficiency is ensured using the Grid computing technology, which select the best available resources for the execution of e-learning objects that compose an e-learning application. Human friendly, shareable and machine processeable e-learning objects are ensured using the semantic web concept and its ontology backbone using specifications languages thus ensuring modularity, portability and making the e-learning objects definitions easier and clearer.

This work currently goes on. The main objective is to implement a full semantic-based e-learning Grid on top of Globus infrastructure. We are working on the implementation of the broker component and the communication with the E-learning objects and other Grid components (GRAM, and the Grid index information server). We are working to extend the specification of E-learning object’s requirements to includes classes of E-learning objects of the same application. We are also working on the implementation of the scheduling algorithms that can satisfy those requirements for all potential classes of learners.

8. References


