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Grid Technologies for Virtual Control Laboratories

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Abstract—**In this paper, Grid technologies are introduced to build e-Learning environments for control education. Service-oriented Grids open new fields of applications, the Learning Grids. The learning services concept and their deployment through Grid technologies are excellent means to integrate virtual control laboratories into e-Learning environments for control education. An example application from a virtual laboratory demonstrates the advantages of a Grid over classical solutions.**

I. Introduction

The current generation of electronic learning (e-Learning) solutions has adopted the rather narrow pedagogic paradigm of information transfer, which features the teacher as someone who selects particular pieces of information and makes them available to students on the Web. However, there is no evidence that this approach to technology enhanced learning is in anyway effective. It has been adopted simply because it is an easy way to use the Web's facilities.

Remote or virtual laboratories with real or simulated experiments are becoming widely accepted in the control community for providing distance education and for augmenting traditional laboratories. From a pedagogical point of view, in this kind of environments the student has an active and central role in the learning process. Learning activities are inherently aimed at aiding the construction of knowledge and skills in the student, rather than the memorisation of information.

In keeping the student at the centre of the learning process, personalisation and individualisation become relevant aspects to be supported by technologies through the creation of the right context. The students can learn through direct experiences. So, the question remains – how do we provide better means for e-Learning environments combined with virtual laboratories while maintaining or improving the quality of learning by new information and communication technologies. A Learning Grid can contribute to the achievement of these objectives through the definition of the learning services concept and their deployment through Grid technologies.

Section II of this article introduces into the term Grid by presenting a general concept of Grid computing associated with its problems and the current state of technology and main standards. It describes the transition from the computational Grid towards the service-oriented Grid and the changes both in architecture and in philosophy. Then in Section III advantages of using Grid technologies in educational applications are discussed in detail. Finally, in Section IV a practical example of a Grid application with a virtual control laboratory and with collaborative experimenting is demonstrated. The article closes with Section V summarising technologies and their potential influence on education.

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II. What is the Grid?

Historically the term Grid has been used describing a worldwide communication infrastructure for clustered computers that allows seamless transparent access to data and computing power on demand in order to solve large-scale computational problems. A Grid costs a fraction of what a supercomputer costs. They are commonly known from engineering, science and commerce. Grid is also a new paradigm for the information technology. The well known World Wide Web will be succeeded by the upcoming World Wide Grid. The futurologists are promising that it will be possible to get large IT-resources "from a plug in the wall" without the necessity to know who provides the resources and where the resources are coming from. Nowadays such service-oriented Grids find applications in quite new areas not previously considered as the environments for a Grid. An example of such a new area is education. This is the topic mainly addressed in this article

A. Grid basics

From a general point of view, a Grid is considered as a collection of clustered computational machines, the nodes. In order to have a powerful supercomputer by a Grid the computational problem has to be split into slices and assigned to these nodes. Each node processes its slice individually and after the completion of its slice the results are put back together. Grid nodes do not need to be placed in one geographic location; moreover, machines collaborating in the Grid may have different architectures and operating systems. It is obvious that these nodes need to communicate with each other based on some standards. Therefore a vital topic of security is involved for the interchange of data between nodes. Depending on the application the data should be kept confidential and protected from undesired external changes. Also other issues must be addressed, e.g. redundancy of nodes, quality of service and scalability.

A Grid shows some limitations and has to fulfil some requirements. The Grid is applicable only for tasks that can be easily split into smaller slices and that do not require the characteristics of a real-time challenge. In order to reduce the complexity of a Grid, a special layer is introduced that is for gluing the nodes on a logical level. The software responsible for this task is commonly called middleware. Its spectrum ranges from execution environments responsible for the management of processes on nodes, to full development environments. What traditional Grids lack, are the standards on that they are built. In most cases when considering computational Grids, the methods of communication, the level of integrity between nodes and the architectures are each specially designed for a particular project.

B. Service oriented Grid

During recent years a new approach for building Grids has emerged. Instead of perceiving the Grid nodes only as computational elements of an infrastructure they became providers of services [1]. This shift, from strict computational capabilities to service suppliers, opens new fields of applications for Grids. The nodes, instead of only delivering their computational and storage capacity, are now regarded as providers of particular services. They may be parts of some code existing in multiple instances allowing the parallelization of the execution of an application. The nodes may offer individual services best suited to their own capabilities. Moreover, services developed for the usage in one application or Grid may be reused in new applications. The service-oriented approach has additional advantages. It introduces well-defined standards, allows the creation of searchable catalogues of services. Further details are described in Section II-C.

This new Grid philosophy allows perceiving it in analogy to the commonly known concept of power grids, where the consumer is not aware where and how the power is exactly produced. He only receives the final product with a defined quality. In case of a pure computational Grid, the client receives the computational power not knowing where it comes from and what the resources are. But this power is limited to particular clients. When it comes to a service-oriented grid, the user receives the functionality he needs with the desired quality of service.

Fig. 1 presents basic interactions between elements of a service-oriented Grid. Services published into a Grid Registry are queried and then instantiated depending on the user request. Mainly for sake of efficiency the client's communication with the service is direct but may also be virtualized

C. Technology and standards

The realization of service-oriented Grids needs clear standards to have that interoperability of Grid elements and their reuse in other applications. The two main organizations involved in standardization of Grid technologies are the Global Grid Forum (GGF) [2] favouring the family of the Open Grid Services Architecture (OGSA) [3] standards and to some degree the competing Organization for the Advancement of Structured Information Standards (OASIS) [4] promoting the Web Services – Resource Framework (WSRF) [5] standards.

Both organizations adopt the currently widely recognized Web Services and their extensions as their building blocks. These families of standards differ in the depth of the middleware integration, in the choice of the platform and in the programmatic languages of the implementation. But their general approach towards the Grid is the same.

The main functionalities delivered by the middleware of a service-oriented Grid are:

Location – allows the determination, whether the required service exists and at which locations it is accessible

Instantiation – allows the instantiation of the service on that host, which matches the capabilities required for the service running with a given quality of service.

Orchestration – allows the dynamical composition of more complex services.

In the example shown later in this article the middleware called GrASP [6] is used, which was developed in an EU funded project. It follows the OASIS recommendations based on the implementation of the WSRF called WSRF.NET, which uses Microsoft's .NET Framework as the implementation environment [7].

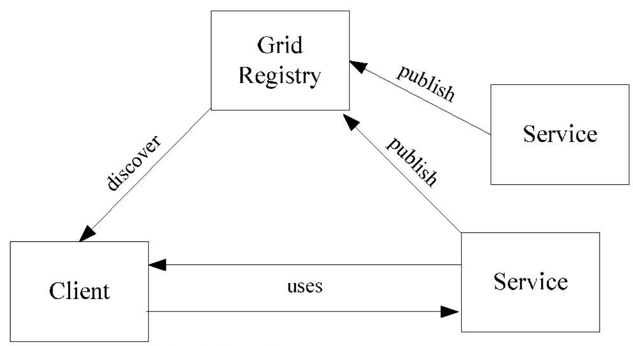

Fig. 1. Structure of a Grid environment.

III. Learning Grids

Grids yield significant benefits to applications. The question to be answered here is what advantages may yield a Grid particularly to educational systems.

A. Learning Objects (LOs) in a Grid environment

In the concept of using LOs the learning content is split into reusable elements. These elements are used to build complex learning resources. In the world of service-oriented Grids the LOs are becoming fully functional services with their own user interface. They are independently interoperable blocks, which may be used as they are, or, moreover, are reused to build new more complex blocks using other Grid services, e.g. orchestration. LOs themselves can be nested. For illustration consider a complex LO example. Delivering a nested LO for a real-time experiment several components are necessary and each of them is implemented as a separate LO. The required components would be: the LO rendering the experiment environment, the LO displaying an

Excel worksheet for evaluating results and optionally a scope LO displaying the experiment signal histories. These components would be embedded into another LO, therefore constituting a new composed unit called e.g.: Experimenting LO, which itself could be nested in a more general LO. Due to the well-defined Grid standards like Web Services, the learning courses can be built from LOs delivered by different Grid services. The Grid techniques offer the capabilities of cataloguing and easy managing LOs by using metadata. Metadata for describing LOs and ontologies for the semantic modelling of the learning domain can be used to build and execute distributed learning applications on a Learning Grid.

B. *Collaboration and communities*

The use of a common platform allows a better collaboration, both in sense of interpersonal communication for collaborative learning, as well as collaboration between applications existing within the Grid. A Learning Grid is a natural environment for its participants to create virtual learning communities. All participants belong to the same community of Grid users sharing the same tools, creating and sustaining professional relationships through time.

C. *Scalability*

An outstanding advantage of a Learning Grid environment opposed to the traditional approach is the approximately linear scalability inherited from its predecessor, the computing Grid. When the number of students enrolled to a particular course gets larger, more instances of a particular service will be created on the hosts within the Grid. When additional hosts are needed they do not have to belong to the same university or run the same operating system as long the services are implementing the same interface.

D. *Personalization*

A very important feature of a Learning Grid is the fact that it can deliver learning contents from heterogeneous resources in a unified fashion and personalized according to the profile of the learner. The following procedure is in analogy to the power grid. A learner with a well-defined profile introduces himself to the Learning Grid and requests some contents relevant to his learning needs. The Learning Grid starts here to find the best suitable service for the learner's needs. This would match closely as possible the user's profile taking in account the user's location, language skills, level of advancement in selected topic, preferred form of delivering content, etc.

E. *Virtual Organizations (VOs)*

One of the main advantages of the new Grid technologies is their capability to integrate heterogeneous environments to an abstract entity. This property can be used to group resources of different universities to build a VO, e.g. a virtual university. Such an approach would allow specialization of universities in concrete areas and sharing the best offer with other universities.

IV. A Practical Example of a Learning Grid Application

A. *The European Learning GRID Infrastructure (ELeGI)*

In order to make the Learning Grid available for control education it is necessary to have both, a repository of LOs related to control education and a Grid framework including a course management system. The EU funded ELeGI project is one of the projects involved in bringing the power of a Grid to the educational domain. The main project goal is the development and demonstration of new learning scenarios, which opens the Grid approach for distance learning. The following two components are used to illustrate the concept of a Learning Grid.

B. *Virtual Control Laboratory (VCLab)*

The VCLab [8] has been originally developed as a tool to support students in control system design using professional design and simulations of automation processes. It uses a 3D virtual user environment to recreate and to visualize experimenting plants. One can interact with a displayed scene in a similar fashion like with real devices. The dynamical behaviour of the plant is generated by a simulator driven by simulation models. From the Learning Grid perspective, VCLab has in its repository the components and services necessary for building LOs in the control engineering domain.

C. *Intelligent Web Teacher (IWT)*

The IWT [9] is a course management platform including a Web portal offering functionalities allowing the management of contents and courses, the collaboration and administration. It is an extensible platform, which runs self-composed LOs and embeds them into developed courses.

In IWT LOs from external suppliers can be integrated using a driver concept. Such external LOs are self-contained objects with a well-defined logical function and a full user interface. Analogical to device drivers, these drivers can be executed on behalf of particular resources handled by them. In this concept the learning contents have to be defined for which every type of resource has a driver associated with it. These drivers are Grid services with a well known interface. Therefore they can be managed by the IWT portal, both with associated portlets, which are the essential parts of the LOs.

Because IWT is built on the GrASP middleware IWT is also a Grid framework that delivers both, basic Learning Grid functionalities and its own services, which can be reused by objects being integrated using the portal.

D. *Integrating VCLab into IWT*

The VCLab components are integrated as LOs into the IWT framework by using drivers as described in Section IV-A. The procedure of the instantiation of VCLab components as LOs is presented in Fig. 2. When the learner decides to take part in a course that uses VCLab resources, the portal receives a request to create the instance of the particular LO. The portal combines the original request with data with-

Assessment – This micro phase marks the transition from action to opinion by giving the learners a variety of questions to judge the current validity of the learning process. If the output is not adequate a possibility is offered to enter in a facilitated didactic situation, which leads to the phase of the *Addressed Situation*. The learner can enter again into the phase of *Active Situation* or *Collaborative Learning* in order fill own gaps. This ends in a further assessment with a loop back if not successful. Otherwise the phase of *Knowledge Institutionalization* is entered.

Addressed Situation – This optional phase, to which learners may be redirected in case an unsuccessful Assessment may provide an altered version of the *Active Situation* and give additional hints which should allow a facilitated understanding of the experiment.

Knowledge Institutionalization – It is the last micro phase of the *Practical Situation* when the knowledge validity is shown to the learner with a correct solution and a list of concepts which should be known after completing this activity.

The *Abstract Situation* macro phase is to extrapolate from the previously context an abstract model. It consists of the same micro phases as the *Practical Situation* and its execution is governed by the same rules. But instead of the simulation of a concrete case the activities will be set up on a greater interaction between theory and practice to induce the learner to test knowledge in order to achieve new goals. For example instead of a 3D scene in the *Active Situation*, the learner has to deal with a set of differential equations describing the experiment.

Finally the macro phase of *Institutionalization* provides the means for organizing and formalizing the acquired knowledge.

F. *The IMS-LD Specification*

Each of the macro phases from Section IV-E is delivered as a single LO or as a series of LOs. All together they constitute a Unit of Learning (UoL). For being used by IWT they must be compatible with the IMS Learning Design (IMS-LD) [10] specification. The main aim of this specification in the context of the delivery of resources is to provide standardized methods of modelling the learning content, in this case LOs. It introduces an abstract layer over the technological aspects of resources in which authors can create their learning content in pedagogical instead of technical terms. This specification describes the recipients of a particular resource, the resource requirements in the sense of services required for executions, and the dependencies between resources. Commonly the XML language was chosen to describe IMS-LD objects, which need so-called IMS-LD players responsible for the LO delivery. In the case of IWT, the CopperCore Engine [11] is used. The player loads the UoL prepared as an IMS content package, which contains the learning design description composed with the resources it describes.

All these properties of the IMS-LD specification make it very suitable for application in building a Learning Grid. IMS-LD compatible objects are reusable, based on well accepted standards which make them easily applicable in such heterogeneous environments like a Learning Grid.

G. *Example of an IWT session using VCLab LOs*

A section of an active learning session using IWT with LOs from VCLab is shown in Fig. 4. A web browser is used and the screenshot shows a section from the beginning of a composed active situation LO. Other sections, like assessment and addressed situation are not shown here. The example is taken from a simple UoL of learning Torricelli's law.

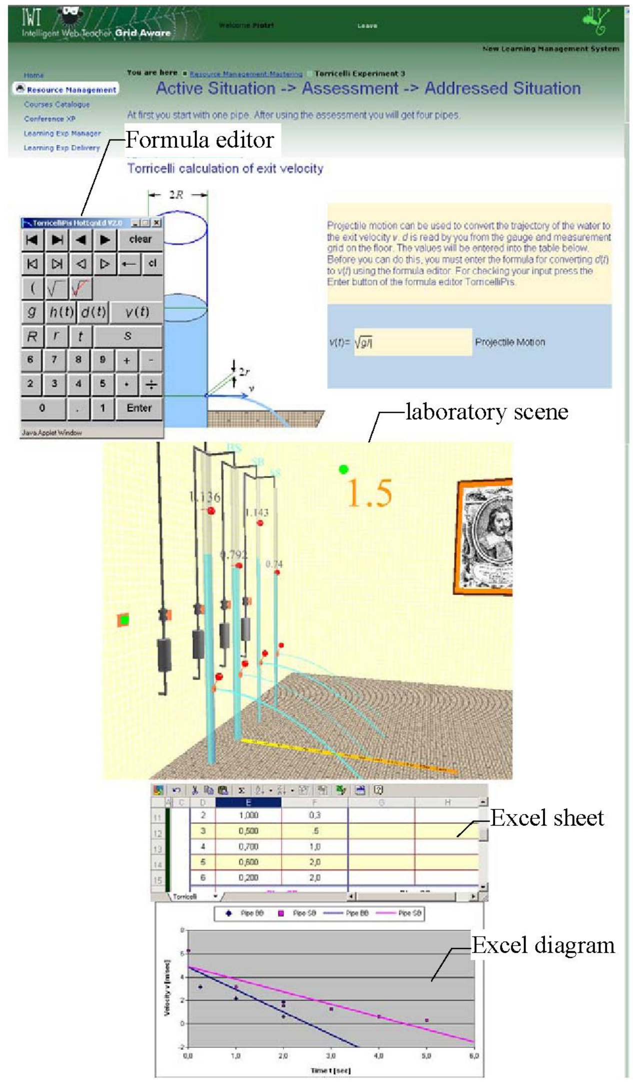

Fig. 4. Screen shot section of an IWT session.

The middle part contains the animated 3D laboratory scene LO, where four pipes of different diameter can be filled by pumps with water to a given height. In the lower part of these pipes outlet valves of different diameter can be opened to let the water flow to the floor. The learner interacts with the experiment using this scene. Measurements are taken using a tape measure and a measurement grid on the floor and using a watch clock at the top of the scene. The