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Grid Supported Learning Environment in Control Education

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Abstract: In this paper, Grid technologies are introduced to build e-learning environments for virtual control laboratories. 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. At the high end of this approach collaborative experimenting in a virtual scene is possible.

1. 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.

Remote or virtual laboratories with real or simulated experiments are becoming accepted in the engineering community for providing distance education and for augmenting traditional laboratories. Students have to modify instruments for a better understanding of the principle on which the plant operates. From a pedagogical point of view, in this kind of environments the student has an active and central role in the learning process. 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. 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.

The first section is an introduction into Grid computing and into the Virtual Control Laboratory (VCLab). The second describes the transition from computing to service-oriented Grid and describes its main properties. The third section is a case study of implementation of main features of the service-oriented Grid using VCLab as an example. The fourth section extends the case study on the area of collaborative learning in a Grid supported environment. The last section summarizes the results.

Grid

Historically the term Grid has been used describing a world-wide communication infrastructure for clustered computers, the nodes, that allows seamless transparent access to data and computing power on demand to solve large-scale computational problems. 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. Also other issues must be addressed, e.g. redundancy of nodes, quality of service and scalability.

Grids are commonly known from engineering, science and commerce. Nowadays a new type of Grids, the 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 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.

VCLab

The VCLab (Schmid, 1998) 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 laboratory 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. The software comprises the essential physical effects, but cannot claim to be an equivalent substitute of the real experiment; nonetheless it is capable enough to demonstrate the underlying principles. From the Learning Grid perspective, VCLab has in its repository the components and services necessary for building learning units in the control engineering domain.

2. SERVICE-ORIENTED LEARNING 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 (Foster et al., 2001). This shift, from strict computational capabilities to service suppliers, opens new fields of applications for Grids. The nodes 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.

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

2.1 Learning Objects (LOs) and Units of Learning (UoLs) 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 the following 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 (Fig. 3). 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. They take the form of UoLs. Each UoL is described by an ontology, which defines the set of concepts to be taught. Each concept corresponds to a Learning Object (LO) that constitutes the learning material. The ontology describes the order in which the LO will be delivered to achieve the teaching goal for a learner. Each UoL realizes a certain learning model, which is modelled by the ontology. The LOs represented by UoLs and combined with the learner specific requirements are being delivered personalized by a suitable IMS-LD player

2.2 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 representing learner's identity within the 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.

2.3 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.

2.4 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. Using information stored in learners profiles it is easy to contact fellow students having the same interest and being of the same level of understanding.

2.5 Virtual Organizations (VOs)

A main assumption of VOs is that resources offered by participants within the group can be shared (Vallés et al., 2003). 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.

3. VCLAB AS A GRID SUPPORTED VIRTUAL LABORATORY ENVIRONMENT

The Grid supported implementation of VCLab is an appropriate case study to present the introduced properties of service-oriented Grids in a practical manner to the control community.

3.1 Architectural perspective of the Grid implementation

In order to understand the benefits of the VCLab on the Grid, the architectural perspective of implementation and the interactions between the services are presented. Fig. 1 shows the services, on which the functionality of the VCLab is based and their interrelations with the elements of the Grid infrastructure. VCLab consists of two services, Computation and Simulation. Their operation is orchestrated by the Driver Service (Capuano et al., 2000), which implements that interface necessary for an e-learning application.
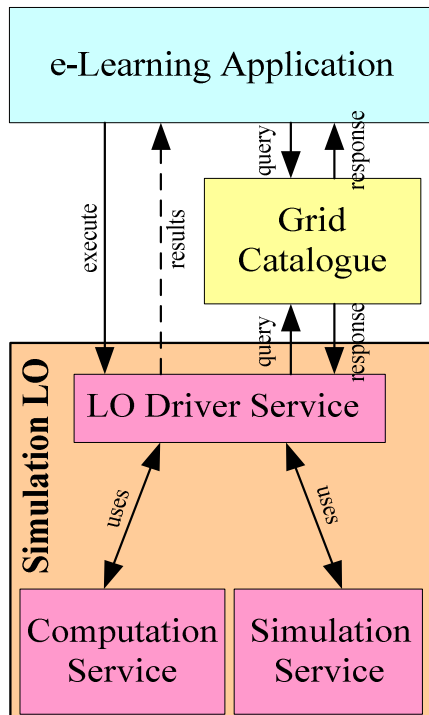

Fig. 1. VCLab Grid architecture

The Grid Catalogue plays a central role on the Grid, which contains the metadata describing both, the services incorporated within the Grid and the stored resources.

When a user is accessing a Grid application, it identifies the user and obtains his/hers profile. Then the application uses the Grid Catalogue to provide the list of the resources matching the learner queries and the profile. When the user chooses a UoL to work with, the e-learning application contacts the Grid Catalogue, which provides the list of services required to deliver the resource to the user. In the case of VCLab such a service is the Driver Service shown in Fig. 1, which implements a particular interface understood by the e-learning application. Such a driver service takes the control over the execution of the resource and requests the required services from the catalogue. In the VCLab case these are the Simulation and Computation Service within a Simulation LO.

This Grid architecture shows a high degree of separation of services during the implementation and favours the extensibility of the application itself. The e-learning application needs not to be aware of the services used by VCLab; it only needs to find a suitable driver for a particular LO to be delivered.

3.2 A Learning Model for Control Experiments

Achieving a successful integration is not only performed on a technological level, but also in regard to pedagogical aspects. For this purpose a generic model for the delivery of virtual scientific experiments has been developed, which can be applied to control experiments. This model splits a Unit of Learning (UoL) into four macro phases: Presentation, Practical Situation, Abstract Situation and Institutionalization phase, see Fig. 2.
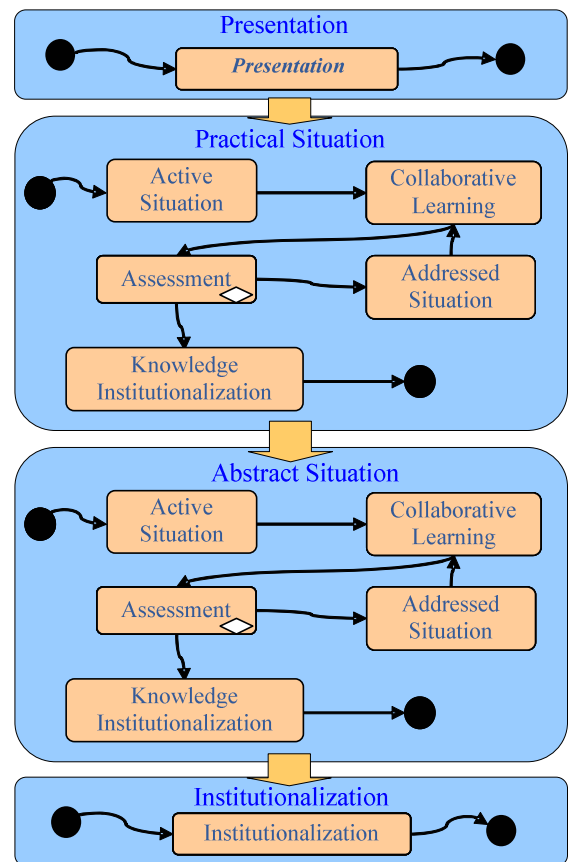

Fig. 2. Control experiment learning model

The phase of Presentation provides the description of the didactic experience that the learner is about to start. To such aim, the description of the different phases, the necessary information for the learner about the character and goals of the experiment and about the general reference regarding the operation of the software will be provided.

The Practical Situation represents the phase in which the learner live the concrete experience. Simulation and the presence of a collaborative environment are available in which the personal learners' experience can be mediated from the interaction with the other learners. This phase has an iterative character and consists of five micro phases:

Active Situation – A fascinating and interactive scene in 3D is proposed, inside of which the learner will be able to move and manipulate objects. Simulations are run by a series of controls that the learner can opportunely vary, modifying in real time the behaviour of the simulation, observing its response and actively gaining personal knowledge.

Collaborative Learning – During this phase the learner has the possibility to mediate the personal knowledge with the others, to compare the results, and finally use the synergy between personal and collective construction of knowledge.

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 of 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, e.g. the learner has to deal with a set of equations describing the experiment.

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

3.3 Learner perspective of the Grid implementation

Implementing this learning model using the LO and UoL paradigm allows the building of a library of reusable learning units. Each object described by metadata is being easily catalogued and can even be dynamically bound for learning content delivery. Fig. 3 shows the screenshot of a learning session composed of several basic LOs. An active situation with a laboratory scene LO and an assessment LO with symbolic facilities and embedded Excel evaluation sheet LOs are in this example used for basic modelling of the dynamical behaviour and level control of small tubular tanks. An ontology used for building the UoL allows an easy navigation between the learning contents and assures their delivery in the right order according to the learning model from Fig. 2.
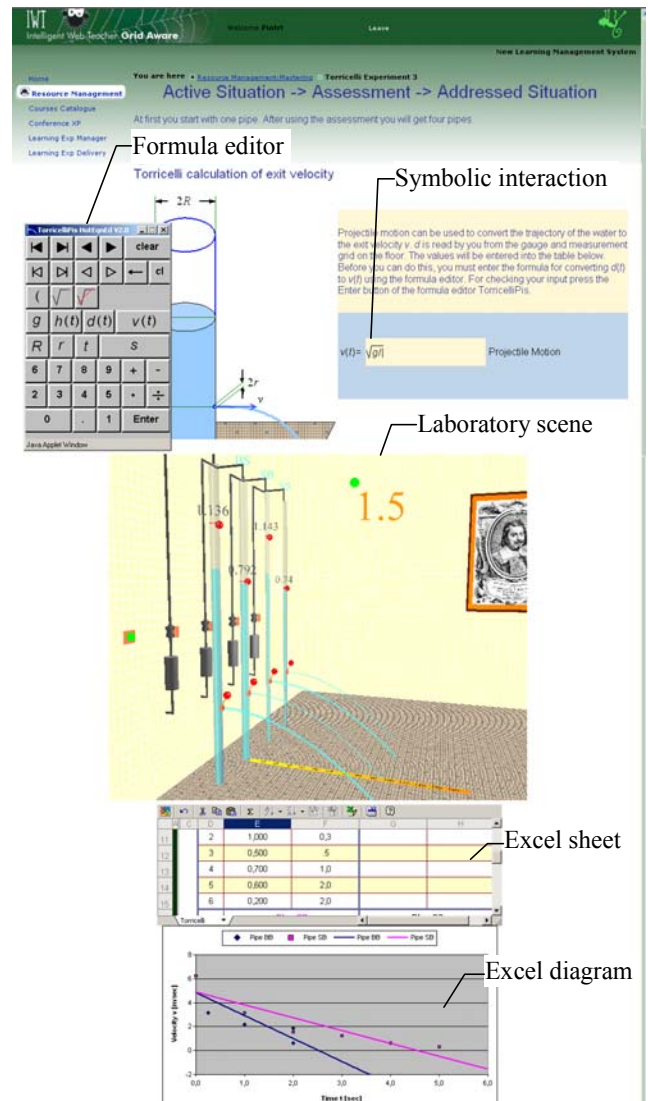

Fig. 3. Screenshot of VCLab learning session

From the learner perspective, the Grid implementation simplifies the delivery process of the resources, in the sense that it removes the burden on the user of possessing and handling demanding software and hardware. The required hardware is always accessible; the higher complexity of the resource is

compensated by the choice of a suited execution node, which is performed automatically by the Grid infrastructure. The software for calculations and simulations is also always up to date because it is located on the server. Because of the server-sided execution the delivered content may be richer in details. Each LO of a UoL being executed may run on a different server. Therefore, the UoL can contain several LOs executing in parallel, what would not be possible in case of a conventional client-sided execution model. This property is especially important in case of Collaborative Learning described in detail in the following section.

It is especially important that the Learning Grid offers a personalized approach of learning in form of an activity. The learner profile carried together with the requests to the Grid makes all experiences suited to the learners needs. The delivered content depends on the courses already taken and on the general advancement of the learner in a particular topic. Preferences, like language of content and its form: text, audio, video or their combination may be taken into account during delivery. As the progress made by the learner is hold in his/her profile, he/she may access the learning activities from any computer without caring for the synchronization of the context. The learner is not anymore bound to a particular workstation and his/hers profile follows him/her.

Not only is the choice of the presented content affected, but also the overall quality of service. The right selection of the nodes for operation on an appropriate geographical location with respect to the learner results in faster response times. This is particularly important in case of animation, e.g. for real time experiments.

Equipping the nodes with different kind of services allows a better user balancing and scalability. It is common that the enrolment to particular courses changes over time and even during semesters. The Grid can adapt itself automatically to the demand for services.

4. COLLABORATIVE LEARING IN GRID ENVIRONMENT

An important aspect of learning in virtual environments is Collaborative Learning, which is a micro phase in the control experiment learning model of Fig. 2. It is actually a scenario in which learning activities may benefit mostly from the Learning Grid. It is hard to implement rich collaborative environments capable of running several simultaneous experiments and supporting several groups of learners working together in parallel using the classical server centred approach. Even fastest server would very soon reach its limit in case of a large amount of simple simulations or in case of executing several complex ones. Distributed services on the Grid remove these bottlenecks.

4.1 Architectural perspective of Grid supported Collaborative Learning

Collaborative e-learning applications start the execution querying the Grid Catalogue for a driver service that can perform collaborative experimenting, see Fig. 4. The catalogue pro-

vides this application with the node hosting the service, which is suited for it and which can sustain the amount of potential users and embedded experiments offered by the environment. The corresponding Driver Service takes over the execution. It contacts the Grid Catalogue for instantiating the other Driver Services for the embedded Simulation LOs. A good granulation of the solution can be observed, mimicking the property of a conventional Grid of splitting the tasks in small slices and assigning them to nodes spread on a Grid.

For each instantiation of the Collaboration LO its supporting Simulation LOs may be delivered from different hosts depending on the current state of the Grid and on the availability of the hosts. From the learners perspective there is no difference in learning experience what is assured by the quality of service constraints.
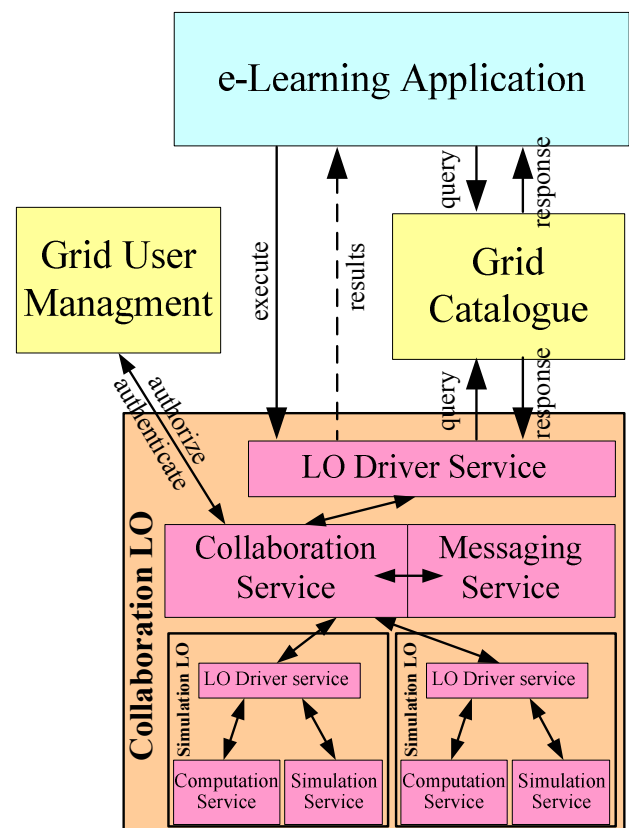

Fig. 4. Collaborative environment execution architecture

The Collaboration Service benefits from the authentication and authorization facilities of the Grid infrastructure by the Grid User Management. Looking up the profile of the learner it may determine his/hers role within the environment.

Collaborative experimenting using VCLab is based on a collaborative enhanced virtual laboratory scene. The communication between the collaborating learners is based on two different types of information channels supported by the Collaboration Service. There is the 3D scene with the learner avatars, from where the participants can see and hear what the experimenting colleague is currently doing and to which gestures can be submitted as reactions. The other type of in-

formation channel is more classical. The Collaboration Service uses the Messaging Service. On default it is a textual chat, which may be replaced by binding another service to it providing audio or even video capabilities. This possibility is drawn from the architectural flexibility of the Grid.

2.3 The Learner perspective of Grid supported Collaboration Learning

The VCLab collaboration environment supports the full control experiment learning model from Fig. 2. It contains a 3D virtual scene including embedded experiments, see Fig. 5. Participants of this virtual environment can be students of different universities participating simultaneously in the Learning Grid. They are represented by avatars and they communicate by means as shown above.

One important aspect of defining collaboration in e-learning is the definition of roles of participants and the assignment of these roles to them. The VCLab models four distinct roles within the collaboration environment. These roles are Author, Tutor, Learner and Experimental Plant. The Author does not directly take part in the collaboration activities. Its tasks are, preparing the environment by means of defining experiments, tasks for learners, instructions, designing graphics and so on. The Tutor is a privileged participant of the collaboration activities. Its tasks are to provide the content to learners, to monitor their progress, to supervise experiments, to give hints, explanations and advice, to answer learners' questions, which may occur during the learning process. The Experimental Plant represents the modelled knowledge, which learners should gain during experimenting with it.

The learner role is described by a learner model. The learner is allowed to interact with the experiment in active (master learner) and in passive mode. An experimenting group may have a tutor and must have one student who is the master. The master is actively experimenting while the others are passive. The master's role can be passed to each of the participants to control the plant.
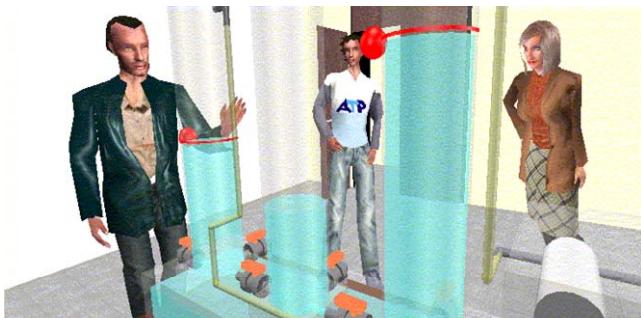

Fig. 5. Screenshot of a collaborative activity

Such a virtual meeting place could be the seed of creating a virtual learning community within a VO.

Another feature of this environment is that besides simultaneously running different experiments, a learner can dynamically plant its own experiment into the environment that he/she is working on. So it can be observed by fellow students and by the tutor. The Tutor can take over the control

and make a demonstration, which changes will be reflected in the original learner experiment. After leaving the collaboration micro phase, the learner may continue its session regarding to the learning model. This example of dynamical binding is only possible due to the dynamic nature of the Grid.

5. CONSLUSIONS

Learning Grids contribute to the achievements of the objectives given in the introductory chapter to this article through the definition of the learning services concept and their deployment through Grid technologies. Learning services will be consumed in dynamic virtual communities based on communications and collaborations where learners, through direct experiences, create and share their knowledge in a contextualised and personalised way. This way of learning using Grid resources can become now more open to learners in the control engineering domain. From the 3D visual representation the learner can get the information about the plant more effectively than only from 2D scopes or only from a textual representation. The presented solution is complete and may be regarded as a proof of the concept for a Learning Grid.

The topic that is equally important but not discussed here is the authoring of the content of the Grid supported Virtual Environments. VCLab provides a set of graphical authoring tools, which are self Grid applications. They create 3D scenes, simulation models, the composition of them with supporting elements like Java applets, HTML text, and automating it with online assessments to produce addressed situations. Also the creation of collaborative environments is supported by composing previously created experiments with static elements of the environment and defining the roles of participants.

The application of Grid technologies in education is of course a much wider topic than presented in this article and by the practical example of a virtual control laboratory. Nonetheless the most important aspects of utilizing service-oriented Grids in distance learning for control education are presented.

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