Issues Integrating Remote Laboratories into Virtual Worlds

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Laboratory work in education has long been recognised as providing real benefits to students. Increasingly, remotely accessible laboratories are being used for laboratory work in the sciences and engineering, providing students with remote access to real equipment while delivering additional benefits to institutions. There is an increasing focus on how these labs may improve laboratory learning outcomes. One potential enhancement, resulting from their mediated interface, is the ability to add contextual information to a laboratory activity. Virtual worlds have been identified as a rich environment for providing contextual information. However, the reported examples of real equipment laboratories integrated into a virtual world are specific to the laboratory. This paper describes a more generic approach to interfacing a virtual world, Open Wonderland, to laboratories which use the MIT iLabs platform. The paper reports on the issues involved in the interface and the strengths and limitations of this system.

Keywords: Interoperability, Laboratory, Remote, Virtual World.

Introduction

Remote laboratories are increasingly in use throughout the world providing students remote access to real equipment (Lowe, Murray, Lindsay, Liu, & Bright, 1986). These labs are mediated through a computer interface, providing an opportunity for educators to manipulate the environment in which students perform labs. It has been argued previously that adding domain specific contextual information to a laboratory activity has the potential to improve students understanding of how the laboratory relates to the real world (Machet, Lowe, & Gütl, 2012). Three-dimensional virtual worlds have the facility to provide an environment for adding contextual information while preserving the authentic experience of working on real equipment.

This paper presents a technical solution for remote laboratory integration into a virtual world, specifically an iLabs based lab incorporated into Open Wonderland. The paper describes the state of virtual world and remote laboratory integration in the literature, presents an overview of the iLabs architecture and the development environment for Open Wonderland and describes the system we are aiming to develop. Alternative solutions are described and the final solution for interfacing the iLabs components and Open Wonderland platform is presented. Design issues that affect the selection of the solution and the relative merits of the chosen approach are discussed, and conclusions are drawn and suggestions made for future work.

Background

There is currently no single standard for the development of remote laboratories. Rather, there are a number of different architectures that have been developed to meet various pedagogic needs, diverse philosophical approaches, and specific technical laboratory requirements. In addition to single use remote labs, there are a

number of platforms that have been developed to provide students with access to a variety of laboratories, such as Labshare's Sahara platform, or MIT's iLabs platform.

For the research reported here, the iLabs platform has been selected for the initial work as there has already been some development into providing new interfaces into the iLabs experiments (Payne & Schulz, 2013). Additionally it is hoped that developing a solution for a widely used remote lab platform will allow the integrated system to be expanded for use with a number of different labs for future work.

There are a number of affordances of virtual worlds described in the literature, such as the ability to collaborate, which are advantageous to remote access laboratory work (Dalgarno & Lee, 2010). One such affordance is the ability to contextualise an activity by providing additional information in the form of the virtual world surrounding. This has been used in teaching in a number of laboratories, where activities within the immersive virtual world are part of a story that provides the user with contextual information to be used in completing the activity and applying the knowledge to areas outside the scope of the lab activity (Pringle & Henderleiter, 1999). Examples such as Puget Sound laboratory (Windschitl, Winn, Education, Box, & Wa, 2000) and Virtual Chocolate Factory (Back, Kimber, Rieffel, & Dunnigan, 2010) use custom developed virtual worlds, while other lab activities have been set in existing virtual worlds such as Open Wonderland and Second Life ("Circuit WarZ," 2010; Scheucher, Bailey, Gütl, & Harward, 2009).

Research into which virtual world best meets educational requirements does not provide a stand-out candidate for all learning in virtual worlds; rather this depends on the nature of the learning activity and which virtual world affordances are being exploited. While no platform meets all of the requirements for the integration a remote lab into a virtual world, a few such as Open Wonderland, Second Life and Open Sim could all be argued to be suitable (Kaplan & Yankelovich, 2011; Smith, 2009). Previous investigation has led to the selection of Open Wonderland for this project primarily because it is open source, cross-platform, requires no proprietary software development and importantly supports multiple language plug-ins and application sharing so existing remote lab interfaces can be easily re-used (Machet & Lowe, 2012).

Architecture

iLabs
The iLabs platform is a remote laboratory sharing platform developed at MIT with the aim of sharing laboratory resources in various geographical locations with students and institutions across the world. The aim was to develop a scalable system that provided for easy deployment of new labs (Harward et al., 2008). iLabs at a basic level consists of a Lab Client which provides the interface through which the user creates and submits an experiment specification, and a Lab Server which handles the validation and submission of an experiment from the Lab Client via the Service Broker and runs the experiment on the equipment. Messaging between the Lab Server and the Lab Client are passed through a Service Broker using SOAP calls. (Payne & Schulz, 2013).

Open Wonderland
Open Wonderland is an open source virtual world developed by Project Open Wonderland. Among the main goals of the Open Wonderland developers was the provision of an extensible toolkit based on open standards to enable easy development (Kaplan & Yankelovich, 2011). Open Wonderland has a modular client-server architecture developed in the open source Java programming language.

The Wonderland toolkit allows developers to extend Open Wonderland at a number of different "extension points". A common extension is new *object types* referred to as *cells* which can have client-side and server-side behaviours. Open Wonderland provides the infrastructure to create and add new modules, where new cell types can be developed and compiled. There are also a number of existing modules in the Open Wonderland Module Warehouse that can be used, such as video streaming. Currently there is no SOAP module for Open Wonderland, but there are a number of solutions for external communication, such as a module that provides an example of a RESTful API to a web service (Flores, 2011).

Integrated System
The integrated system will need to be developed to interface Open Wonderland to the iLabs Lab Server so that students who are within the Open Wonderland world can access the remote laboratory controls and execute the lab. This means that the Lab Client and Service Broker functionality of the iLabs system must be implemented for use within Open Wonderland.

A solution will need to be found for how this Lab Client and Service Broker functionality can be developed in Open Wonderland using Open Wonderlands scripting, cell behavior and add-on modules, or accessed from within Open Wonderland using existing functionality such as X11 application sharing or a VNC viewer. Effectively, Open Wonderland would appear to any iLabs Lab Server as a generic Service Broker.

Lessons

Solution Alternatives

In order to interface between Open Wonderland and iLabs, we can look at the solutions from the point of view of the level of integration of iLabs Lab Client and Service Broker functionality into Open Wonderland. In this case, in increasing order of integration the following solutions are proposed:

1. **External functionality**. The Lab Client and Service Broker functionality can be realised externally to Open Wonderland. Access to the Lab Client will then be through either the Open Wonderland VNC viewer module capability, or X11 application sharing, depending on the nature of the interface. This solution would require a small amount of development in Open Wonderland and make use of existing components in iLabs and Open Wonderland; however the integration of the control interface within the contextual elements to be added to the virtual world would be limited. Additionally, this system would be most affected by latency in external communication. Scheucher 's (2009) integration of an iLabs based force on a dipole laboratory into Open Wonderland provides an example of this type of integration using a VNC viewer to access the Lab Client which was a LabView interface to the force on dipole equipment.

2. **Partially integrated functionality.** A second option would be the development of the Lab Client functionality within Open Wonderland so that all laboratory controls are developed within Open Wonderland. In this case, the Open Wonderland Lab Client would communicate with a modified Service Broker through exiting communication channels (for example dedicated sockets or the Open Wonderland RESTful API). The Service Broker functionality would sit outside of Open Wonderland and be modified to accept information from the Open Wonderland Lab Client. This option requires significant development but is based on the ability to use tested Open Wonderland interfaces to external services. This solution will allow new labs to be implemented in Open Wonderland requiring only Lab Client development and providing the ability to re-use the new Service Broker.

3. **Wholly integrated functionality.** As a third wholly integrated option, both the Lab Client and Service Broker functionality would sit within Open Wonderland. In this case, the Lab Client controls would be implemented in Open Wonderland, and inputs from this would be used to provide information for the SOAP interface to the Lab Server. The SOAP client would need to be developed as a module for Open Wonderland. This option allows the most integration of components within the virtual world. It eliminates the need for a separate Service Broker, but also requires a large amount of development (particularly the SOAP module for Open Wonderland) and the solution will be more specific to the laboratory, requiring additional re-work for future lab integration.

Proposed Solution

The second option (with an integrated Lab Client, external modified Service Broker) has been selected as a basis for this research, as it provides a compromise between a generic solution that can be used with any laboratory, and a specific solution that allows all the features of the lab control to be well integrated into the Open Wonderland environment. Additionally, it is a compromise between being able to re-use existing code (such as already developed laboratory interfaces and the existing Service Broker) and a customised solution.

> **Lesson 1:** Bounded extensibility of the integrated solution is achieved through limiting the amount of laboratory specific development. New laboratories will require new in-world control interface development.

Development for this solution is made up of three parts: The Lab Client functionality within Open Wonderland, the interface between the Open Wonderland Lab Client and the new Service Broker, and the development of the modified Service Broker as illustrated in Figure 1.
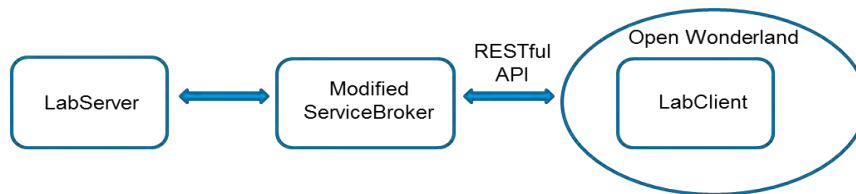
Figure 1: Proposed solution architecture

The Lab Client will consist of the experiment interface that the user will see when conducting the experiment. The interface controls will be developed 'in-world' and be integrated with the contextual elements in the virtual world. The interface will include a video feed of the laboratory for establishing the reality of the equipment. The Lab Client will need to pass the correct experiment information to the Service Broker which can then interface to the Lab Server.

> **Lesson 2:** Coherent integration of the laboratory control interface into the virtual world requires redevelopment of the control interfaces. The result will be that additional development effort will result in a logically presented control interface and improved latency.

The Service Broker functionality in this case will be to provide the authentication information known to the Lab Server in order to execute the lab. Development will require the modification of a Service Broker to accept the new format of inputs from Open Wonderland (using a RESTful interface).

> **Lesson 3:** External communication from the virtual world can be achieved through a suitably defined RESTful interface. Information from the virtual world can be communicated to an external web service, and the responses can be used to manipulate elements within the virtual world. This interface component will be useful in integrating future labs.

This option eliminates the need for a SOAP module to be developed for Open Wonderland, and makes use of existing external communication capabilities.

Discussion and Conclusions

The solution proposed here involves developing Lab Client functionality within Open Wonderland and a modified external Service Broker. The solution will require a significant amount of development but it does make use of existing components of the iLabs and Open Wonderland platforms such as the available Open Wonderland external communication module. The modified Service Broker and ServiceBrokerAPI functionality proposed will be available for re-use if new labs are included in Open Wonderland in the future.

This solution is an improvement over the using a VNC viewer (or X11 application sharing) to visualise a Lab Client outside of Open Wonderland, as there will be less latency between avatar actions and the control interface if the control is developed within Open Wonderland. However, the solution will require redevelopment of a control interface that already exists in many cases. An advantage of the chosen solution is the ability to integrate the control interface better into the virtual world, rather than being limited to the VNC viewer cell.

This paper has presented a technical solution for the integration of iLabs functionality into Open Wonderland. It offers a realisable solution that presents a reasonable compromise between re-use of existing components, development effort, extensibility and customisation. The solution proposed here allows for the development of a new remote laboratory environment that has the potential to be used for further research and learning.

The next steps in this research are to implement this solution and determine whether the integrated virtual world and remote laboratory system meets the functional requirements for future research to be carried out, particularly into the possible effects of adding contextual information to laboratories. Future work in this area could involve extending research into a number of different remote laboratories and laboratory learning outcomes, such as the effects of collaboration on remote laboratory learning outcomes.

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