Development of modular virtual lab for introductory computing courses

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***Abstract*—This paper describes the ongoing process of developing a virtual lab for different introductory computing courses based on the ACM-IEEE Computer Science Curricula. The laboratory is designed as a 3D virtual collaborative system with carefully developed instructional sequences covering different, often overlapping teaching subjects. The central object to every lab is a composite model of PC whose basic components are suitable for teaching computer architecture, programming, and operating systems courses. The same PC model is also used in conjunction with other composite 3D models of hardware for networking and net-centered courses. The 3D computing lab that we develop offers two advantages. First, composite component model it applies helps students gain a complete understanding of computing technology through interleaving problems viewed from different perspectives. Second, by following students' activities and progress, instructors can easily identify the most difficult teaching concepts and modify their syllabi accordingly.**

Keywords – computing education; virtual lab; 3D models; technology-enhanced learning

I. INTRODUCTION

It is widely recognized that better and more effective ways of presenting the discipline of computing are needed. As a consequence, an ongoing review of the corresponding curricula is necessary. Since computer science draws its foundations from a wide variety of disciplines, undergraduate computer science students must apply concepts from many different fields while facing the single most demanding task: learning to integrate theory and practice.

A joint group formed by ACM and the IEEE Computer Society established an ongoing review process that allows individual components of the curriculum to be periodically updated [1]. In designing our computer science curriculum we followed their recommendations, starting from computer architecture as the central course, followed by programming fundamentals, operating systems, networking and net-centric courses. We noticed that there are some teaching subjects that span various courses and blur the traditional distinction between different teaching areas. This was the leading idea in developing our 3D computing lab which is currently used as an auxiliary means for teaching different undergraduate courses. This approach is also in line with the announced 2013 curriculum trend of joining different, logically related courses and defining necessary prerequisites for following courses.

Our 3D learning environment has been conceived as a set of tightly related technological and pedagogical issues, having to be dealt with independently, but under a unifying approach. This dual approach to teaching computing will be reflected in this paper, in which we will describe how the initial idea is being brought into life.

Our 3D virtual computing lab (to which we will refer as 3DVirCSLab thereinafter) has been developed using Open Wonderland toolkit [2]. Its architecture serves as the common foundation for building an interactive classroom with integrated 3D objects. Design and implementation of 3DVirCSLab is based on component composition model [3]. Component composition technique can facilitate development of reconfigurable and evolutionary system, providing efficient modular structure.

The central, starting object in our 3D computing lab is a composite model of a PC which can be virtually disassembled so that different structural components (CPU, memory, storage units, and buses) can be visualized and manipulated in carefully designed assignments. 3D model of the PC, together with other 3D models of hardware components (routers, network interfaces, computer network, and cloud system) is further used as a component in networking and net-centered courses. By their nature, assignments are modular and allow for studying hardware at different levels. Also, the composite nature of the model and assignments is very well suited for studying software execution at different levels (CPU instruction set, assembly language, high-level programming language, virtual machines, and web services). The chosen toolkit also allowed us to seamlessly include the execution of different software simulators developed over the years in our 3D lab; among the most successful are interactive simulation of digital circuits and a networking simulator. Our intention is to prove that virtual worlds are valid and useful testbed for simulations.

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Typical classroom session is organized as a series of scheduled meetings in virtual space under the instructor's supervision. Although students can also freely join the classroom scene at any time and use its collaborative features, the instructor's presence has proven to be necessary for following students' progress and identifying the most difficult topics. Experience gathered from virtual class sessions is then used for adjusting syllabi, extending assignments to better cover the most difficult teaching subjects, and helping students get the deep understanding of the subject.

We proceed to explain some related work, in terms of similar solutions as well as motivational examples, in Section II. Section III presents more details on virtual worlds with the focus on Open Wonderland, which is the world of choice for the proposed implementation. Section IV describes the implemented 3DVirCSLab virtual classroom and experiments conducted in order to test the validity of the proposed approach. We conclude with the preliminary evaluation of the approach in Section V, and finally discuss future work and possible improvements in Section VI.

II. RELATED WORK

Work [4] describes importance of serious virtual worlds due to their use for education, business collaboration and art. Reference [5] describes the possible application of the composite component models in education, but without interactivity and actual implementation. A survey of different educational applications of Open Wonderland in education is presented by the founder of the Open Wonderland project in [6]. Chapter from the book [7] presents a case study of the use of a Virtual World environment in UK Higher Education and reports on the activities in a project to create a culturally sensitive virtual world to support language learning.

Reference [8] reports initial efforts in integrating physics simulation into 3D virtual world, and illustrates one possible use of Wonderland in engineering education. Paper [9] follows this track by describing a complete integration of wireless sensor network simulation into the Wonderland.

Reference [10] focuses on Collaborative Virtual Learning Environments, examining the state of the art in both open source and proprietary software. We used this survey to decide on the toolkit to use for our virtual classroom implementation.

While composite component model found many applications in graph theory, mathematics, and software design, we were not able to find any report of its use for educational purposes. The implementation of this approach in a virtual classroom allows users to see information organized into levels and to walk through 3D models of components to gain better understanding of the subject, as we will describe in sections to follow.

III. THE CHOICE OF 3D PLATFORM: OPEN WONDERLAND

The decision to use Open Wonderland as the platform for developing 3DVirCSLab was based upon several fulfilled conditions which distinguish it from similar solutions such as OpenSim.

- the platform is free and open-source;
- it has a highly modular architecture;
- we can use it as a case study of open-source design in our Java programming courses;
- we can use it in computer graphics assignments such as adding 3D objects and creating object hierarchy;
- it has a fairly active user community.

Open Wonderland is Java open source toolkit for creating collaborative 3D virtual and mixed-reality worlds. It supports audio conferencing, desktop application sharing, and integration with external data sources. Open Wonderland provides a rich set of objects for creating environments, and supports shared software applications, such as word processors, web browsers, and document-presentation tools. For example, one or several users can draw on a virtual whiteboard and view PDF documents and presentations. A user, represented by an avatar, can communicate through the avatar to others in the virtual scene by using a headset or by the use of a dedicated chat window for text messages. The scene generated by an Open Wonderland client can be viewed from a first-person or several third-person perspectives.

Open Wonderland is not a virtual world as such, but rather a toolkit for building virtual worlds and, as opposed to Second Life, it falls into the category of business oriented virtual worlds [4].

3D objects in Wonderland have a well-defined life cycle that includes the ability to save them for storage and reuse. Open Wonderland has a modular structure that enables extensibility and flexibility. Modules are pieces of Java code that envelope a feature or a functionality that can be plugged in into a core Wonderland project. This means that the focus was on developing tools for business collaboration such as file sharing and voice communication. On the other hand, it is far less sophisticated regarding the tools for creating content inworld, and it is limited to importing models built in external 3D modeling tools. Despite this limitation, Open Wonderland is chosen due to its modularity that provides flexibility and extensibility.

IV. COMPOSITE COMPONENT MODEL APPLIED IN VIRTUAL LABORATORY FOR COMPUTER SCIENCE COURSES

The starting point in defining the 3D computer science lab is to import basic 3D objects-components (referred to as cells in Wonderland), which have both rendering and functional component. The library of basic components is then further extended by introducing new compositions. This process implies relating and combining new 3D objects (3D composition components) into levels, as well as adding new functionalities and tools. Interactivity functionality is then added to each object; the procedure is repeated until the highest level of composition is reached.

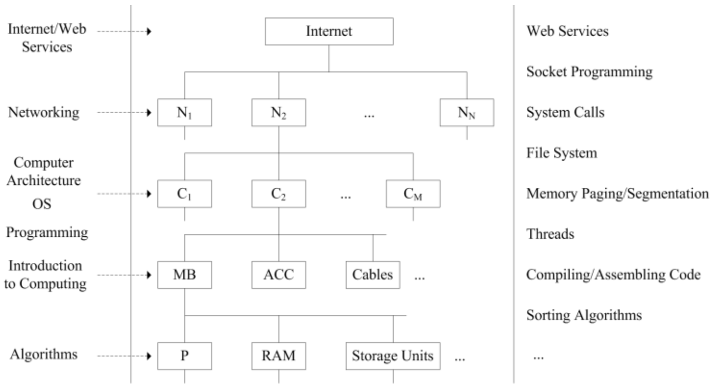

Figure 1: Diagram illustrating the idea of composing components in 3D Computer Lab.

The library allows the user to move through different levels, to display different components of the same level, and to "disassemble" each composition to its constituent parts. Disassembling can continue down to the basic component. At the same time, every component is a part of higher level composition, and can be used for defining new compositions of objects. This approach allows for easy navigation through different levels of the model, which has been the starting idea in developing virtual educational model we describe. The model itself is scalable and adaptable to different uses and applications. Graph in Figure 1 describes the composite component model applied in our 3D virtual computing lab (3DVirCSLab).
Levels, or composites of 3D cells form a hierarchy, which is then used by instructors for creating sub scenes designed for different assignments. Figure 2 shows the initial scene presented to a student entering the classroom. After choosing the assignment to attend on the left-side pane, the avatar walks through Wonderland portal component to arrive directly to the assignment sub scene. By rearranging the scene graph instructors can define new sub scenes, and drag components to different levels.
The idea of component composite model is implemented in Wonderland by attaching portal capability to every 3D object (cell). By clicking on the composite component, the student is teleported to a different part of the scene where the component is disassembled, according to the scene graph model. Knowledge about the certain PC component can be further developed by studying components of the same scene level, but also by teleporting to the sublevel. Modified Wonderland authentication module creates a log file which follows the complete learning steps for each student.
3D objects in a particular assignment are defined by tutorials which contain lesson slides, animations, simulations. Knowledge of a certain subject can be extended by studying components at the current level, level below or above. Log file follows the learning process of every student. By analyzing the log file for a particular student, the instructor can identify his learning pattern, and decide to change modules (i.e. merge or split cell groups in a scene graph, extend the assignments vith new content, or add new scenes). Also, since students see he same lesson track at the same time, it is easier to cooperate ın misunderstood concepts.

Figure 2: Entering virtual computer science classroom scene in Wonderland.

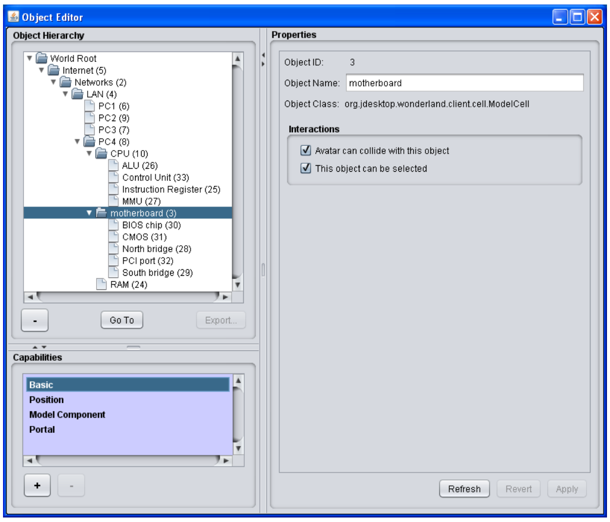

Figure 3: Virtual classroom scene graph showing composite component model applied in Wonderland. Basic components are organized into different levels; users can drag and drop to rearrange the scene graph.

Figure 3 shows the 3DVirCSLab scene graph with 3D objects forming the composite component hierarchy in Wonderland. This scene graph shows the spatial relationships between objects. The world (Internet) contains Network objects, which contains Computer objects, and so on.
For example, the Computer object (cell in Wonderland) might consist of the following data:

- a 3D model, which is data about what Computer looks like (its geometric shape)
- position - where Computer is located in the scene
- scale – Computer dimensions inside the scene
- behavior – Computer interactivity and communication

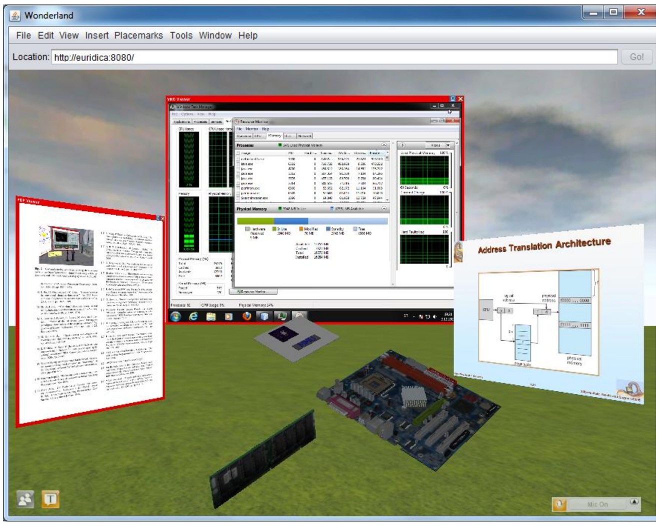

Figure 4: An example memory pagination assignment displaying 3D components for computer architecture and operating systems view.

Figure 4 displays an example of memory pagination assignment with cells useful both for computer architecture and operating systems view. A typical 3DVirCSLab scene has the tutorial explanation attached to it as a tooltip (for this purpose we use the Sticky Note module). Components which are part of the scene, but not yet integrated into Open Wonderland as modules (such as Windows Task Manager displaying memory usage and pagination from Figure 4) are presented as panels via the graphical sharing desktop system Virtual Networking Computer (VNC) module and are running remotely on a different machine.

The scene from Figure 4 uses the composite 3D model of motherboard, processor, and memory. Every component is used for teleporting to other assignments; the instructor can add other content by using modules already available in Wonderland scene (the most common ones are the PDF presenter and whiteboard).

It is also relatively simple to include the execution of the third-party 2D Java applications, as we did with sensor network simulator illustrated in Figure 5. Students using the simulator can experiment setting different parameters of the protocol and follow the animation.

I. PRELIMINARY EVALUATION

Researchers have proven both the effectiveness of collaborative learning as an educational practice and the use of computers in aiding the acquisition of higher level cognitive and problem solving abilities. Combining collaborative learning with composite component approach exhibit many advantages compared to traditional teaching methods, although not directly assessable and measurable. For starters, we noticed increased student motivation and the willingness to experiment in a unique environment. A game like design of the classroom keeps students' interest even though they are physically remote. Students and instructors who used the 3DVirCSLab as an auxiliary means in teaching and studying both agree on the additional value of virtual environments as an educational tool, fulfilling needs for an environment for remote communication and collaboration.

Figure 5: Wireless sensor networks simulator included as a module in virtual computer science classroom scene in Wonderland.

As far as the drawbacks, the initial setup of the virtual classroom requires investments in the hardware required to run a Wonderland server. On the other hand, Wonderland is completely free software, based on open source technology and sharing of resources. The instructors can include the existing teaching material into scenes; the additional effort is required only when there is no direct 3D representation of the concepts to be taught. Our experience shows however that the common impression of instructors is that benefits of using the 3D classroom by far exceed the efforts put into its creation.

II. CONCLUSIONS ANS FUTURE WORK

In this paper, we have attempted to describe the ongoing process of developing a virtual lab for different introductory computing courses. Until now, much of the research effort was put into testing different modules and adding functionality to the existing ones (i.e. portal, integration of 2D Java apps). We plan to implement some new assignments to get as much feedback from users as possible. However, we feel that the integration effort, with the discussion of choices taken, is already worth reporting. Another line of development might include combining a more sophisticated existing simulation tool with a virtual world.

We are also planning to evaluate the different scene layouts which will take into account student's cognitive process, relevant features, and entertainment. Through such a study we can polish the design of 3DVirCSLab and generate new guidelines for educators.

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