Improving Student Learning in Computer Science Courses by Using Virtual OpenCL Laboratory*

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Abstract - Laboratory experience is an essential factor for engineering and science education. Virtual laboratories are widely used by universities and research institutions in various kinds of academic sectors. However, general virtual laboratories always have some weakness for computer graphics which its experiment needs to be done in high performance computers. In the assessment of a graduate computer graphics course, the authors find out the choke point of virtual laboratories when it handles computer graphics tasks. Also, this paper proposes a novel architecture of virtual laboratories by adopting Xen VGA Passthrough and virtual OpenCL technologies in order to break the bottleneck.

Index Terms - Virtual laboratory, computer graphics, Xen VGA Passthrough, Virtual OpenCL.

1. Introduction

In advanced computer science education, an excellent laboratory environment plays a critical role in students learning and researching. And it is fully known that in times of rapid development of both software and hardware, modern computer science laboratories not only operate with a wide range of software applications under different operating systems, but deal with a huge number of data concurrently. Although it is in dire need of building a High Performance Lab (HPL) in the university, but costly setup and maintenance spending make it difficult to provide satisfactory HPL at the universities because of limited budgets. Fortunately there is always a way out. Virtual laboratory concept has been put forward to stand up to these challenges. Instead of installing software on diverse computers, it is possible to install those applications on server clustering using Virtual Machine software. Virtual Lab Platform (VLP) that consists of several high-end servers and virtualization technologies, allows users to perform experiments on real systems via remote access and the data processing and analyzing applications can be running on it. Thereby, laboratory resources can be shared among a larger community to geographically distributed users while without physically needing to visit the lab. So, the use of VLP not merely reduces the equipment cost in scientific research and teaching, but also solved the problem of lack of laboratories or laboratory devices.

While Virtual Lab Platform (VLP) is beneficial from an economic and flexible point of view, it is not ascertained that it can achieve the most important goal that is high performance. In this paper, an assessment study is presented that explores this question in the context of a graduate course in computer graphics. In particular, the contributions of this paper are:

i. An assessment methodology that can be used to quantify student learning in lectures and labs,

ii. detailed assessment results from a graduate graphics course that uses VLP for computer graphics experiments, and

iii. proposes a new VLP architecture based on Virtual-OpenCL (VCL) technology.

The rest of the paper is organized as follows. Section 2 discusses related work. Section 3 introduces the VLP and how it is used in the context of the evaluated course. The assessment methodology is described in Section 4. And finally a novel architecture virtual laboratory proposed in section 5.

2. Related Work

The advantage of laboratory experience in higher education (and other fields) has obviously been known for a long time[1]. One of the main goals of the laboratory is for students to obtain experience in the theory and practice of experimentation[2]. Such experimental skills are considered of great importance in the computer science[3]. Therefore, it is crucial that laboratories teach students how to deal with the theory learned in class under realistic environments.

Numerous virtual laboratories, such as the Open Computer Laboratory (OCL) [4], had been proposed in order to solve inflexible management problems of realistic laboratories and access by providing comfortable use and remote access to an experimental facility. By using OCL, not only the fully elastic operational spaces can be provided for end users, and also the control of terminal management can be implemented by the management personnel of computer laboratories. The use of remote access to educational resources has been explored in the distance education domain [5]. [6]. Besides virtual laboratories mentioned above, some virtual laboratories, which aim for realism but do not adopt a central shared resource, have been designed for various application domains (e.g., thermodynamics [7], civil engineering [8], geotechnical engineering [9], and cell biology [10]).

The virtual laboratory which is used in this study is the OCL that has been specifically designed for computer science education [4]. While there are some extra virtual laboratory

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facilities for computer science, they are mainly designed for research and are thus more complex to use. The discussion of OCL features and functionality in this paper is limited to a very brief overview. Instead, the focus of this paper is on the weakness of the OCL and, sequentially, proposes a totally innovative architecture to improve the performance of VLP.

While virtual laboratories have been used in various domains, the number of assessment studies is seldom. Yarbrough and Gilbert have studied the effectiveness of multimedia-based laboratory experiments for civil engineers [8], however, their assessment relies on self-reported perception of learning by students. Wyatt *et al*. have assessed student use of a virtual geotechnical laboratory [9], but they were not able to relate this information to student learning. Kinnari *et al.* have evaluated a networking laboratory qualitatively with student surveys [11].

3. Virtual Laboratory Platform

To provide the necessary background, this section, firstly, takes a brief look at why laboratory components are important in computer graphics education and how OCL fits into this picture.

A. Computer Graphics Education

Computer graphics is prevalent today. Computer imagery is found on television, in newspapers, for example in weather reports, or for instance in all kinds of medical investigation and surgical procedures. A well-constructed graph can present complex statistics in a form that is easier to understand and interpret. Many powerful tools have been developed to visualize data. Computer generated imagery can be categorized into several different types: two dimensional (2D), three dimensional (3D), and animated graphics. As technology has improved, 3D technology have become more common, but 2D are still widely used.

The study of computer graphics is a sub-field of computer science which studies methods for digitally synthesizing and manipulating visual content. Regardless of the fact that the term often refers to three-dimensional computer graphics, it also encompasses two-dimensional graphics and image processing. As an academic discipline, computer graphics courses are mainly about the manipulation of graphical and geometric information using computational techniques. It focuses on the mathematical and computational foundations of image generation and processing rather than purely aesthetic issues. Computer graphics is often differentiated from the field of visualization, despite the fact that the two fields have numerous similarities.

B. Virtual Laboratory

Due to the requirement for practical knowledge of OpenCV and OpenAL, frequent experiment is in need of be a part of computer graphics courses. In general, these laboratories always consist of high-performance hardware and Professional graphics cards in a lab room for hands-on exercises. While hardware labs are completely truthful, they are difficult to use, costly to set up, and time-consuming to maintain. From the above, not to mention undergraduate students, it is even unrealistic to allocate these costly high performance devices for all the graduate student. Therefore, it is quite natural of taking the benefit of a virtual laboratory platform to solve this shortage of resources problem. Considering that superior performance of realistic devices are probably the most notable quality of a computer graphics laboratory when it comes to student learning, maybe the shortcomings of VLP are significant. The pros and cons between Hardware Lab and Virtual Lab are shown in Table I.

Table I. Comparison of laboratory types used in computer networks education

	Realistic lab	**Virtual Lab**
High realism	Yes	No
Ease of use	Yes	Yes
Low cost	No	Yes
Ease of maintenance	No	Yes

C. Open Computer Laboratory

This paper concentrates on one particular instance of a virtual laboratory, the OCL. This laboratory has been designed in the principle of the Virtual Desktop Infrastructure (VDI) and Server-based Computing (SBC). The principle of the VDI-based virtual desktop infrastructure solution is "a dedicated virtual machine is prepared for each user on the server side and also the operating systems and a variety of applications that users need are deployed, and then the complete virtual machine desktops are delivered to remote users through the desktop display agreements". The foundation of such a solution lies in server virtualization. The principle of the SBC-based virtual desktop solution is "application software in a remote server is installed uniformly, and then users can access and operate server desktops and related applications through establishing a dialogue with server, but the dialogue between different users is isolated from each other".

In such a solution, a virtualization layer is inserted between the operating system event layer and the application software layer, and therefore the close tightly coupled relationship between the two layers is weakened, making the running of application not to be limited by the driving of the local operating system events. Moreover, user's virtual desktop has the ability to implement the isolation performance and security, and simultaneously owns the additional advantages of server virtualization technology, and therefore the quality of service can be guaranteed[4].

4. Assessment Methodology

To benchmark the performance of OCL in the computer graphics course, this paper uses a multifaceted approach to come to a conclusion about that.

A. Assessed Course

In the study of learning with a virtual laboratory, student learning is assessed throughout a course which uses OCL in the laboratory. This course is "OpenCV Application and

Implementation" taught by the author in spring 2013 at the Jiangsu University of Science and Technology. It is a graduate course that is required for the doctoral program and is also taken by professional master's degree students. Thereby, forty graduates participate in the experiment. In the future, these students would be either engineers or researchers in the computer graphics area.

The course consists of 36 lectures, 18 homework assignments, and 6 lab assignments. Lab assignment topics and related computer graphics concepts were taught to students before experiments. In each lab, OCL was used to set up and perform experiments and get measurement data.

B. *Assessing the Realistic Laboratory and Open Computer Laboratory*

In a typical OpenCV experiment, it can be expected that a new topic is first covered in lecture and then practised in more detail using high performance devices in the realistic laboratory. In order to find out the differences between the realistic laboratory and the OCL, Let us divide forty graduate students into two groups. Students in Group One did the experiment in the realistic laboratory, and Group Two did the experiment in the OCL. The realistic laboratory consists of thirty high-performance Dell Precision T3600 desktop workstations, and two-thirds were used in the study. The OCL runs on four dedicate high-performance IBM System X3650 M3 servers. To do a fair evaluation between these two kinds of laboratories, the proposed assessment methodology evaluates effect of the experiment three times.

i. First assessment: Test the time consuming in doing image transformation on the most famous picture Lenna.

ii. Second assessment: Test the time consuming in doing signature matching on the gallery that contains one hundred natural scenes dataset downloaded from the website of Standford Vision Lab.

iii. Third assessment: Do the test on the Virtual Reality Modeling effect.

C. *Assessment Results*

In each assessment, students were asked to use the same development tools to do the experiment in the given environment in case the error introduced by different tools. The benchmark result is shown in Figure 1.

During the benchmark progress, the evaluator firstly figured out the mean value of the results of all the experiment done in the same lab environment, and then set the default values shown in the figure of the realistic lab in all assessments at 100 percent, finally, compared the mean values of three assessments respectively, and then work out the figure values of the OCL.

D. *Analysis Results*

First of all, it is almost the same that the benchmark results of the realistic lab and the OCL in assessment one. Because image transform operations are low system resources consumption, each high-performance computer can be responsive to the operator rapidly. The performance loss of the OCL in assessment one ought to be in surplus communication expended between the server and the clients and doing twenty times repetitive tasks simultaneously only in one server. Fortunately, the loss is acceptable.

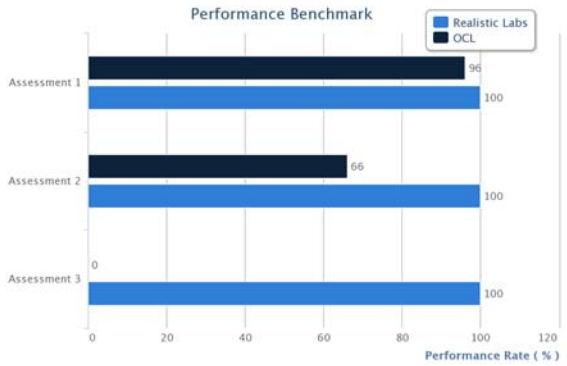

Figure 1. Benchmark on the realistic lab and the OCL

The next, it is sadly that the result of assessment two is worse. The reason is that signature matching requires much more system resources consumption than image transform, especially in the condition of dataset growing. Hence, the CPU resources of the OCL were exhausted even handled only one signature matching task, so needless to say twenty tasks. Another reason is that, in the OCL, the CPUs not only do complex calculation, but also be responsible for process scheduling

In the end, the deadly worst result happened in assessment three. The OCL could not finish the tasks. That's because the OCL is based on virtualization technology. All the resources used by users in the OCL are virtual. The virtual CPU, virtual GPU, and etc. each of them only has some elementary functions compared to a realistic one. Virtual Reality Modeling is an advanced feature of controlling the GPU, so to do Virtual Reality Modeling experiment in the OCL is impossible.

5. Virtual OpenCL Laboratory

A. *Virtual OpenCL Technology*

VCL can be used to build powerful parallel GPU based clusters from low-cost multi-core hosting nodes that can utilize cluster-wide (CPU and GPU) resources transparently. The main features of VCL are:

- Can run unmodified OpenCL applications.
- Applications can utilize cluster-wide GPU devices.
- Transparent selection of devices.
- Applications can be started on any hosting-computer, including workstations without GPU devices.
- Supports multiple applications on the same cluster.
- Runs on Linux clusters.

B. *XenVGAPassthrough*

Xen 4.0.0 is the first version to support VGA graphics adapter passthrough to Xen HVM (fully virtualized) guests. This means you can give HVM guest full and direct control of the graphics adapter, making it possible to have high

performance full 3D and video acceleration in a virtual machine. Xen VGA passthrough requires IOMMU (Intel VT-d) support from the motherboard chipset, from the motherboard BIOS and from Xen. Xen 4.0.0 supports VGA passthrough of the primary graphics adapter (the one that gets initialized and is used when you power-on the computer) only. VGA passthrough of secondary graphics adapters currently requires additional extra patches to Xen.

C. *VLP Baesd on VOL*

The principal idea of the new architecture of virtual laboratories is achieved by adopting both Xen VGA Passthrough and virtual OpenCL technology. The structure chart is shown in Figure 2.

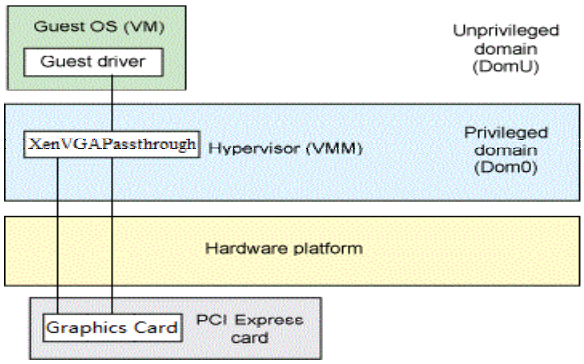

Figure 2. Diagram of the VLP uses the graphics card

By absorbing Xen VGA Passthrough and virtual OpenCL technologies into the component set of virtual laboratories will sharply improve it performances. It is important to emphasize that the virtual OpenCL technology is the key point in achieving high performance. Because if only utilizes the Xen VGA Passthrough technology, the virtual laboratory just could access the primary graphics card. That would mean if several users did tasks in the virtual laboratory, just only one graphics card could be used. This would be disastrous for the users. However, it is evitable by adopting the virtual OpenCL technology together since the virtual OpenCL provides the function to utilize cluster-wide resources (GPU) transparently. SO we call it Virtual OpenCL Laboratory (VOL). In this virtual laboratory, CPUs only are responsible for logic operations, while GPUs undertake complex computing.

D. *Assess the new virtual laboratory*

The assessment methodology used is the same as in section 4. The benchmark results are shown in Figure 3. The tremendous improvement of the new virtual laboratory is benefited from the combination of Xen VGA Passthrough and virtual OpenCL technologies. It is equivalent to utilize 4 graphics cards during the experiments, while a desktop workstation just has one high performance graphics card.

Figure 3. Benchmark on the realistic lab and the VCL

6. Conclusion

From the above, the virtual laboratory based on virtual OpenCL, called Virtual OpenCL Laboratory (VOL), solves the low performance problem of virtual laboratories. However, how to optimize the VOL for much more high performance is the next challenge.

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