Immersive Displays for Education Using CaveUT

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Abstract: Educators can now build large-scale immersive virtual reality (VR) displays using common electronics and *CaveUT* (http://PublicVR.org/ut/CaveUT.html). CaveUT is an open-source freeware modification to the graphically intensive video game, Unreal Tournament. The resulting software platform can support VR applications with a wide range of visual content, animation, code modifications, and networked virtual environments for collaborative learning. An immersive display is most useful when a wide-angle interior view of the displayed material is revealing. This is the case in our example application, the Virtual Audubon Exhibit. Sensory immersion can also convey a sense of *presence* or "being there" which enhances engagement with the material, if properly handled. Building your own immersive display with CaveUT requires as little as $2500 per screen of common electronics and hardware. Our goal is to give the reader a sensible basis for deciding weather and how to build his or her own immersive display.

Introduction

Educators have long been interested in virtual reality (VR) because it provides a unique way for students to interact with things they cannot normally see such as a molecule or an ancient artifact. This is already possible with simple visualizations, or *Desktop* VR. *Immersive* VR, however, allows the user to see things from the inside, seeing relationships not readily apparent in a desktop view. CaveUT provides educators with a low-cost way to build multiscreen immersive displays, like the Virtual Theater (Fig. 1), for as little as $2500, using standard hardware and electronics. Many applications for educational VR have been developed and are readily available on the Internet However, the CaveUT platform also provides tools which allow people with little experience in software development to create compelling VR applications. In this article we will first discuss the value of immersive VR for education. Then we will describe as example of VR software: the Virtual Audubon Project, an educational tool developed by a student as a learning project. Finally, we will describe the practical requirements for building an immersive display and the educational opportunities it affords.

Education and Immersive VR

Before we describe the costs and methods for building immersive displays, we will discuss the educational value of doing so. First, we will definite virtual reality (VR) and present its educational advantages. Then, we will look at the particular advantages and limitations of the type of *immersive* virtual reality CaveUT supports.

A VR application (1) has a three-dimensional virtual world which appears to exist independently from the user (2) this virtual world responds to the user's actions in some way, at minimum by letting the user navigate within it, and (3) the interface creates the illusion of *presence* in the user--the feeling that s/he is *there* in the virtual world (Zeltzer 1992). In recent years, educators have relaxed their view of the third requirement to include desktop interfaces which act as a "window" into a virtual world. Therefore, we need a new term, *Immersive* Virtual Reality (IVR), to refer to VR which employs a sensorially immersive display. Some displays are clearly immersive (i.e. a six-walled cube, rear-projected on every side) and some are clearly not (i.e. a standard monitor), while there is a continuum of displays in between. Arbitrarily, we call a display *immersive* if it fills more than half of the user's total view.

VR allows the user to interact with models of things they could not see in the real world (Roussos et al. 1999) and places or things may be inaccessible because of their microscopic or macroscopic scale, such as molecules, galaxies or weather systems. They may be physically inaccessible, such as the surface of the moon. They may be no longer extant, for example the Temple of Isis at Pompeii. They may even be imagined or proposed, such as colony on Mars. They may be dangerous or too expensive to be used in a classroom. They may even be theoretical or abstract (Winn 2003b)(Jackson 2000)(Youngblut 1998) An example is Global Change World (Winn 2001 et al.)(Winn et al. 2003a) which allows the learner to manipulate major environmental factors in a model of Puget Sound (Washington, USA) and to travel through virtual time to see the results.

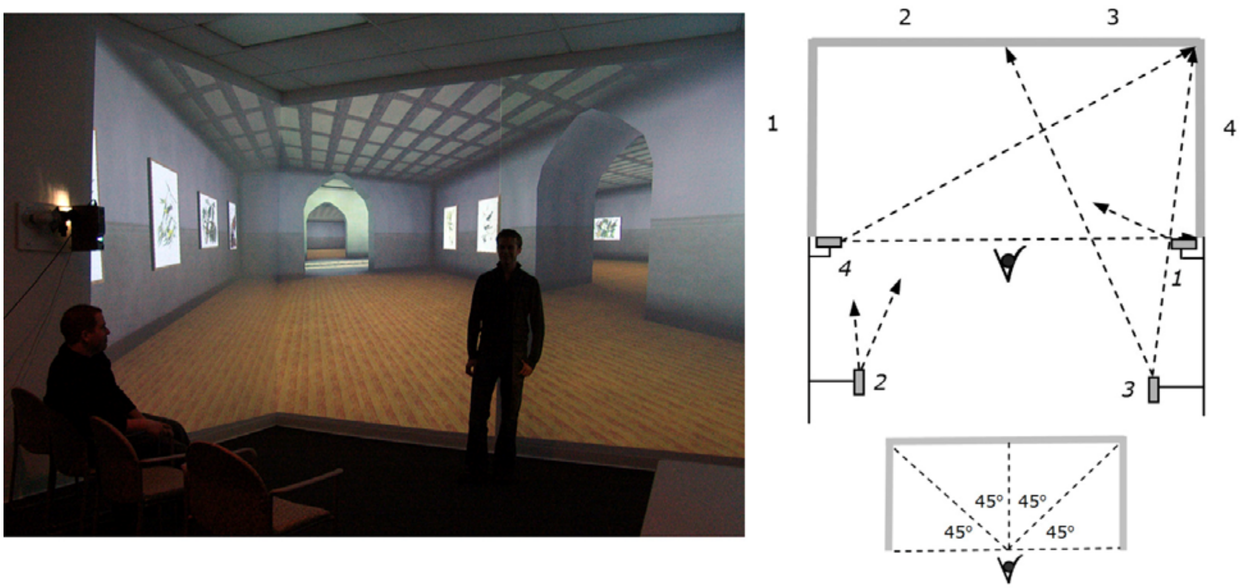

Figure 1: *(left)* Seethaler's Virtual Audubon Exhibit in the Virtual Theater, an immersive display based on CaveUT at the School of Information Sciences, University of Pittsburgh, USA. *(upper right)* A schematic of the theater showing the placement of the projectors and the parts of the walls they illuminate. Not all of the projection beams are shown fully, to reduce visual clutter. *(lower right)* Diagram of the viewer's field of view for each screen, used to determine perspective effects.

VR can also illustrate subjects and processes that are difficult to express in other media. For example, topics with a strong spatial component, such as architecture, are better expressed in VR rather than two dimensional media such as a blackboard or a printed page. For architecture, Immersive VR has the added advantage of letting the viewer see the inside of a virtual structure Also, VR is a good way to interface with simulations of dynamic systems such as ocean currents, planetary motion, changes in electrostatic fields, movement of nutrients in a food web and the social behavior in a troop of gorillas. The behavior of such systems are often nonlinear, being “...an emergent property of an entire system of factors, mutually influencing each other, that change unpredictably over time" (Winn 2003b). VR simulations are particularly useful for modeling natural systems.

There is a consensus in the literature that the sense of “presence” afforded by VR-based learning application can enhance learning (Dede 1999 et al.)(Salzman et al. 1998)(Winn 1997 et al.)(Winn et al. 2001). Another feature of VR is that the relatively large number of display dimensions and potential methods of interaction (Bowman 2002) allows VR applications to communicate a lot of information quickly to the user and to receive complex input from him or her. Students can safely make mistakes in a virtual environment, creating more opportunities for educational design In addition, students and educators can collaborate over great distances using a networked virtual environment (Cobb 2002)(Dede 2004)(Bruckman 2002)(Andrews 2002)(Räihä, 1997). Finally, is popular and tends to be well received by educators and students (Antonietti 2000).

The advantages described above are available in “desktop” VR. But immersive VR The sensory immersion afforded by Immersive VR usually results in a sense of presence or “being there” and therefore engagement. However, this is useful only to the extent that it focuses the student on what s/he is supposed to be learning. Therefore the information design of the application is crucial--it must take advantage of the egocentric views of the virtual world which immersion can provide. (Salzman et al. 1998) For example, an egocentric view of a virtual Egyptian temple (Jacobson 2005b) allows the user to be perceptually inside of it. As with most religious architecture, the temple is very information-rich with meaning attached to all aspects of its design, and it was meant to be "read" by an observer on the inside. An egocentric view allows the user to not only see the symbolism in the temple more efficiently, but in their appropriate context and spatial relationships, all of which are meaningful. The egocentric view provided by a *desktop* VR application (3D world in a window) is certainly useful, but a very wide-angle immersive display is better.

Developing Content for Immersive Virtual Reality

CaveUT (Jacobson & Lewis 2005a)(Jacobson 2005c) is open-sourced freeware which adds an immersive VR interface to the graphically advanced computer game, Unreal Tournament.

The game's advanced graphics capabilities allow the Unreal version of the temple to have a high degree of detail and employ advanced lighting effects. Performance is good, allowing the student and/or instructor to interact smoothly with the material. The large community of *Unreal Tournament* gamers and researchers produces a great deal of artistic content, animation, and code modifications for the game engine. CaveUT developers can use most such content, in pieces or in whole applications, and benefit from the *Unreal* development community's support and cooperation.

Unreal Tournament supports multiplayer games networked over the internet, where each player drives a humanoid avatar. In a networked game, users can speak to each other through a built-in voice-over-ip protocol and each player can command his avatar to perform the actions it is capable of. This creates many opportunities for collaborative instructional design. Finally, the game's extensive authoring support makes constructivist learning exercises possible, where students might add content to the virtual world or make interesting avatar for themselves.

An example of student-made content for CaveUT is the Virtual Audubon Exhibit (Fig. 1) developed at the University of Pittsburgh's School of Information Science. Lyle Seethaller, a graduate student, produced it as a semester project in approximately 100 hours. He had no prior experience in Unreal Tournament, 3D modeling or digital artwork. The process itself was educational (constructionist) and the result is a useful educational tool in itself.

The Virtual Audubon Exhibit allows the viewer to "walk" through the virtual exhibit and view virtual images of prints of wildlife based on watercolors by James Audubon. Audubon tried to make his images of birds the same size as the birds themselves, and the pages of his famous book "Birds of America" were 27 by 40 inches. The virtual prints appear life-size to the viewer in the Virtual Theater, which preserves their intended. The virtual museum where the virtual exhibit is located affords the same opportunities for thematic layout as in a real museum, except that the layout of the space is infinitely changeable

Hardware Design

The designer must determine the number and placement of the projection surfaces (e.g. screens) for the initial installation. They can be front-projected (Fig. 1), rear-projected (Fig. 2), large flat monitors or some combination More screens can be added later, so we recommend starting with a simple configuration. If space is lacking, mirrors can be used to bend the projection beams (Jacobson et al. 2001), but this can be difficult and will always degrade the image to some extent. Each screen will require one projector and one standard PC with a good video card. An additional computer hosts the server and acts as the operator console. The server connects to the clients through an Ethernet switch and the appropriate cables.

CaveUT supports up to 32 screens, which can be placed in any orientation to the viewer. The software will adjust the perspective correction on each screen to provide a unified view across all screens, (Figures 13) They do not have to be contiguous. For example, a driving simulator could be configured with two screens for the front windshield, two for the back, one each for the side windows and a small one for the rear-view mirror. Finally, the CaveUT documentation includes detailed instructions for building a portable semi-immersive display, the V-Cave (Jacobson 2005c).

There are many possible configurations of CaveUT. A CaveUT display can begin simply and expand gradually into a more advanced facility, such as the SAS-Cube (Cavazza 2004)(ALTERNE 2005), which supports stereographic imaging and spatial tracking The simplest, cheapest and easiest configuration is the stationary *V-Cave* (Fig. 3) which uses two plain walls and the projectors resting on bookshelves. The MiniCave pictured in Figures 1 and 2 has three projectors which are turned on their sides, so that each projection screen can be taller than it is wide. In the MiniCave's design diagram (Fig. 3), notice how the projection beam of each projector is lopsided. That is the result of a simple keystone correction built into all standard LCD/DLP projectors. There is no relationship between the length and shape of the projection beam and the view angles for the display, which in the MiniCave is simply sixty degrees for each screen. The view angles for a screen are determined by the perspective correction in the image, which is entirely independent of how the image got onto the screen.

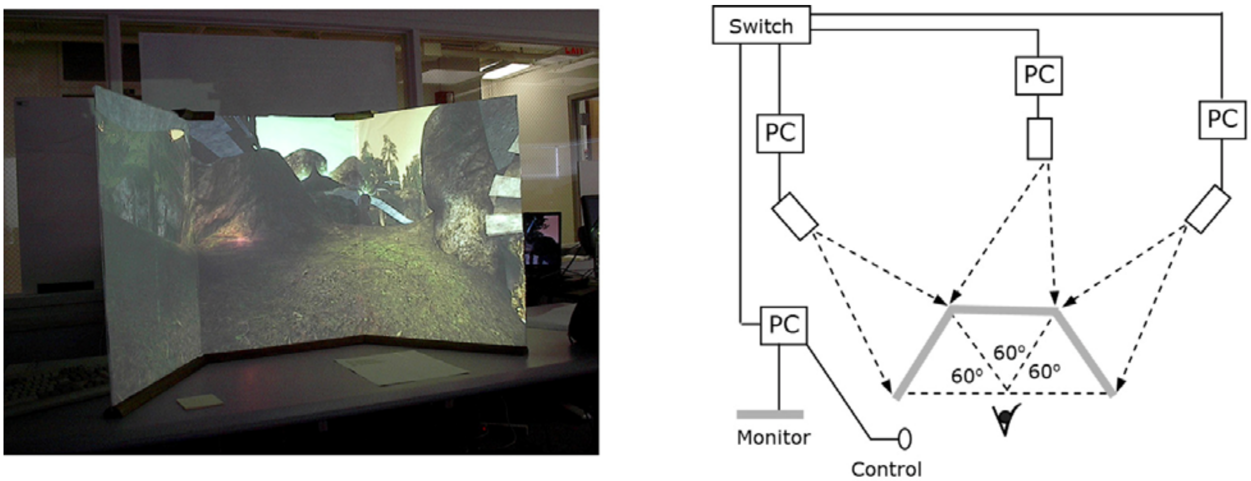

Figure 2: *(left) T*he MiniCave, desktop-sized immersive display intended for a seated observer. *(right)* An overhead-view schematic of the MiniCave.

For the MiniCave, the keystone correction makes no difference, but it can be used to make other designs possible. In the Virtual Theater uses 4 projectors, (Fig. 1)P projectors one and four can be placed on the edge of the display and still cover the part of opposite wall that they need to. If their projection beams were symmetric (not lopsided) each one would have to be placed in the middle of the other's projection area, which would be nearly useless. Another display which can use CaveUT is the BNAVE, (Jacobson 2001 et al.)(Jacobson 2005c) which depends on the keystone correction for each projector to fit the projection beams into the tight space for which it was built.

Hardware Requirements

This section details of the hardware that is required to make an immersive display. Each screen requires a digital projector, a PC with a good video card, and Ethernet cables. Altogether, there will cost about $1900-2500 per screen, depending on the type of projector purchased. In addition, you will need a PC to serve as a console/server, am Ethernet switch, and probably a game controller (joysticks and game pads, etc.) compatible with Unreal Tournament. These should cost about $1200 altogether

The screens for the front-projected display can be any clean flat white surface, such as the walls of the room where the Virtual Theater (Fig. 1). The stationary V-Cave (Fig. 3) was only temporary and the walls were actually fifty-percent grey. It worked because bright projectors can overwhelm color problems and even blemishes on the projection surface. However, the surface must be absolutely flat and smooth. If the regular walls are not available or inappropriate, simple ones can be made from high-quality plywood or thick pieces of rigid insulating foam board. The portable V-Cave uses vinyl banner material suspended from a frame of PVC pipe (Jacobson 2005c).

Rear-projection screens can be made from many kinds of translucent material. For example, the screens of the Mini-cave (Fig. 2) are planes of clear Plexiglas, each one backed with a cut-out section of a plastic table-cloth. The table-cloth material stops just the right amount of light so that the image appears on it, but lets enough through so that the image can be seen on both sides. Alternative materials are low-quality white shower curtains and professional quality rear-projection material (approx $10/sqare foot).

Each screen requires an ordinary (LCD or DLP) digital projector, available through the mass market. Desirable features are (1) VGA resolution (800x600 pixels, $800+ US) projectors will do, but XGA (1024x768 pixels, $1500+ US) look better, especially with the virtual environments students are likely to make. There are virtual worlds available with Unreal Tournament designed to look good at lower levels of detail, but that requires some artistic skill and rules out fine detail. (2) Designing the display and managing the projectors is much easier if they are identical. Each projector should be physically small (under ten pounds), especially if you intend to mount it on a wall or a tripod. In addition, Large projectors cannot be turned sideways because there is a significant danger that they will overheat. (3) Whenever possible, get a projector with an adjustable keystone correction, preferably in both the horizontal and vertical dimensions. (4) The *throw-distance* of a projector is the ratio of the its distance from the screen, to the size of the image on the screen. A short throw distance is usually better, allowing the projectors to be nearer to the screens and thus reducing the room needed for the display. The designer must know the projectors' throw distances before s/he can design the display.

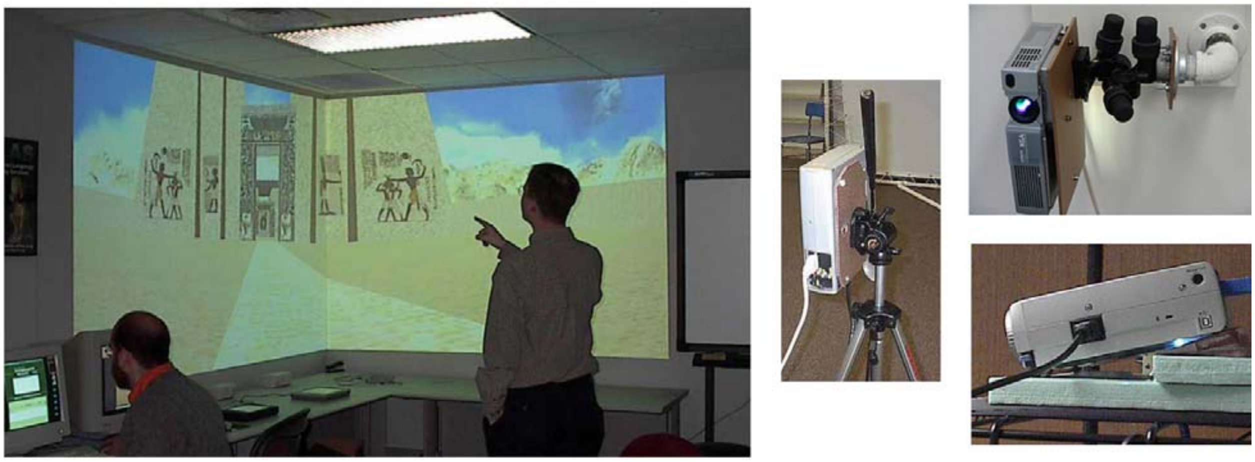

Figure 3: *(left)* A stationary *V-Cave*, the simplest possible (semi) immersive display. *(right)* Different ways to mount the projectors for various CaveUT displays.

Projectors can be mounted in a variety of ways (Fig. 3), but we strongly recommend getting a high quality ($300+) mount with the ability to make fine adjustments on at least two Euclidian axies (Fig.). We strongly advise against ball-and-socket mounts, because they are very difficult to adjust and few can hold a projector sideways.

Each projector is attached to a standard PC with a good video card, for a total cost of approximately $900 US. Generally, the PC should be somewhat better than the standard recommendations for Unreal Tournament (Epic 2005). All of the PCs must use a video card with good OpenGL support to function with CaveUT. We have had good luck with cards based on NVIDIA's geForce chipsets (NVIDIA 2005). Generally, it is best to make all of the computers identical. If necessary, the server/operator machine can be a little slower than the rest, as long as the display resolution for its Unreal Tournament installation can be reduced enough to keep its performance good.

All of the computers can be connected through a standard Ethernet switch ($40 US) and Ethernet cables (cost varies). A wireless switch is easier to set up, but more expensive and vulnerable to electrostatic interference. The console/server computer will need a simple monitor, keyboard, mouse and speakers. Finally, the display will need some kind of controller that is comfortable for the user. For a desktop display like the MiniCave, the usual keyboard and mouse controls are fine, but awkward at best in a display where the user is standing. A display based on CaveUT can employ any game controller (joysticks and game pads, etc.) compatible with Unreal Tournament. We recommend that developers experiment with these controllers to find what is appropriate for their applications.

Conclusion

We believe that immersive virtual reality is a useful educational tool, and new technologies like CaveUT have now made it affordable. We hope this will foster a larger and more diverse community of educators and researchers interested in it, which will many good things. CaveUT is available for all uses, public and private, at http://PublicVR.org/ut/CaveUT.html. Please feel free to contact us if you have any questions.

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