The Design of a Retinal Resolution Fully Immersive VR Display

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ABSTRACT

We present the design of Brown University's new Cave, which is expected to be fully operational in February 2014. With one arc-minute resolution, 3.8 π steradians of visual surround, head-tracked stereo, and an almost seamless screen, this Cave offers advances to the state-of-the-art virtual reality experience. This improvement is achieved with the installation of 69 high-resolution long throw projectors, a cylindrical screen with conical ceiling, and a 135 square foot rear-projection floor. Though Caves have been around for over 20 years, they have remained impractical for many potential uses due to their limited resolution, brightness, and overall immersion. Brown's new Cave aims to bridge this gap.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality;

1 INTRODUCTION

For many, the Star Trek Holodeck represents the ultimate virtual environment. The fictional Holodeck can instantly create any virtual environment, support several users without 3D glasses, create tangible objects such as chairs and platforms, and create avatars with convincing artificial-intelligence personalities. Holodeck-like virtual environments are still decades away.

The CAVE (cave automatic virtual environment) was invented at the University of Illinois Electronic Visualization Lab in 1992 [1]. In the two decades since, Caves have evolved dramatically and are one of the best virtual environments currently available. They provide better resolution than head-mounted displays and induce less motion sickness, though they remain essentially single-user environments.

Subjects performing biological data exploration tasks qualitatively prefer and quantitatively perform better in a Cave system than with a flat virtual reality wall (Fishtank VR) or on a Desktop [3]. However, users of Brown's old Cave, where these experiments were conducted, requested brighter, higher-contrast imagery, and a larger working space [4]. Clearly, the Cave needed improvement. Researchers in almost every field use visualizations of their data. For the most part, these representations are currently constrained to two dimensions. Brown's new Cave is designed with these scientists in mind.

Caves have evolved from the initial cube shape [1] to systems such as the polygonal approximation of a cylinder LCD screen-based CAVE2 [5], the third-generation StarCave with its tilted trapezoidal walls [2], or any number of other state-of-the-art designs currently implemented around the world.

Brown University's new Cave is an experimental cylindrical Cave with a rear projection acrylic floor and a conical partial ceiling; these display surfaces are lit by 69 HD projectors. The light from opposing walls limits the contrast ratio of all Caves, but rear projection provides better contrast than front projection. With 69 projectors, precision alignment of the projectors would have been practically unworkable; instead, we rely on camera-based blending and alignment, using software from Scalable Displays Technologies in Cambridge, MA. The use of camera-based blending software in a head-tracked immersive environment is one of several unusual defining features of this Cave.

The new Cave is in its final construction stage, with all the components in place with the exception of the screen[1]. Once the screen is installed, the Cave will be physically complete. The software component of this installation has been tested and is fully functional with a four projector system on a fraction of cylindrical screen, and thus we should have a functioning Cave in February.

Figure 1: Artist's rendering of the new Cave based on CAD drawings (The front part of the screen, the doors, is omitted in this image).

2 GOALS AND DESIGN

The alterations from the old Cave to the new Cave are advances toward a closer imitation of reality–toward a suspension of disbelief. First, the field of view is nearly complete: close to 4 π steradians, with a blind spot of size 0.2 π steradians above and behind the user's head when facing forward. Second, our goal was to reach retinal resolution, sufficient brightness, and sufficient contrast to match or nearly match human visual abilities. Third, we come closer to seamlessness, having no mullions, minimizing corners, and blending smoothly between projected regions. And last, we offer a 3-dimensional experience with head-tracked stereo.

To reach all these goals, the new Cave had to be a complex system. In the sections below, we discuss some of the design decisions that were made.

2.1 Projectors

Brown's new Cave uses 69 long-throw projectors provided by Delta Electronics, Inc., each with 1920x1080 pixels at 120Hz with alternating-eye stereo capability. This renders about 140 million

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[1] the screen is due to arrive from the machine shop in late January 2014

IEEE Virtual Reality 2014
29 March - 2 April, Minneapolis, Minnesota, USA
978-1-4799-2871-2/14/$31.00 ©2014 IEEE

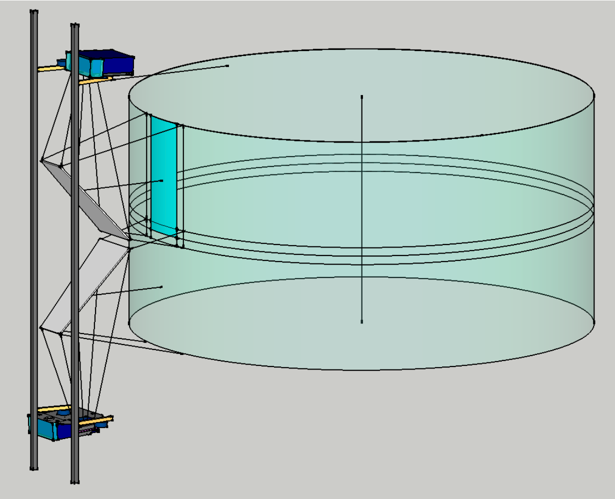

Figure 2: Light paths from the wall projectors onto the wall mirrors, then onto the screen, illustrating the increased throw gained by adding mirrors.

pixels, but accounting for about 30 % overlap of projection regions and blending, users will see about 80 million pixels. In particular, this achieves 37 DPI (dots per inch) on the main wall, giving us a 1 arc-minute resolution for a viewer eight feet from the wall. Also noteworthy, these projectors produce 3000 lumens in economy mode and have a typical contrast ratio of 1800:1. We chose to install long-throw projectors, requiring mirrors to fold the optics, since long throw projectors minimize vignetting and provide the deep depth of field needed for the curved screen (see Figure 2).

2.2 Screen and Floor

Our Cave screen is made of a flat floor, cylindrical wall, and conical ceiling. The screen offers 3.8 π steradians of surround, with only a piece of ceiling missing, where the cone is cut off above the curved screen doors. The curved screens minimize the number and total length of seams in the user's field of view, bringing us closer to seamlessness than a cubical Cave or an LCD panel Cave. This Cave is the first to implement a conical screen. The screen is made of polycarbonate with micron diffusion particles, a high-contrast material. The new Cave is entirely rear-projected, including the floor. The floor below the screen is made of a single 4" thick slab of acrylic, 16' by 12' in size, to be both weight-bearing, rigid, and not interfere with the light paths (see Figure 3).

2.3 Computing Cluster

We will run our projectors on a Colfax International computer cluster and, including the display lag of the projectors, we should achieve a total latency roughly equivalent to those of our baseline alternatives.

2.4 Software Needs

There are two primary issues that we handle with software: *warping* and *blending*. Having cylindrical and conical components to our screen, we must warp the light coming from the projector to make the image appear straight when projected onto the curved surface. To create a smooth image across adjacent projection regions, we have to blend the images from each projector. To manage these tasks, we use software from Scalable Display Technologies.

3 APPLICATIONS OF BROWN'S NEW CAVE

Several different applications that are run in Brown's old Cave will be transferred to the New Cave as soon as it is activated: terrain visualization, volume rendering, four-dimensional mathematical object viewing, and CavePainting (painting in three dimensions), to name a few. Given the interest of Brown researchers in the new Cave project, we expect to be collaboratively developing many new scientific applications for the Cave in the coming years.

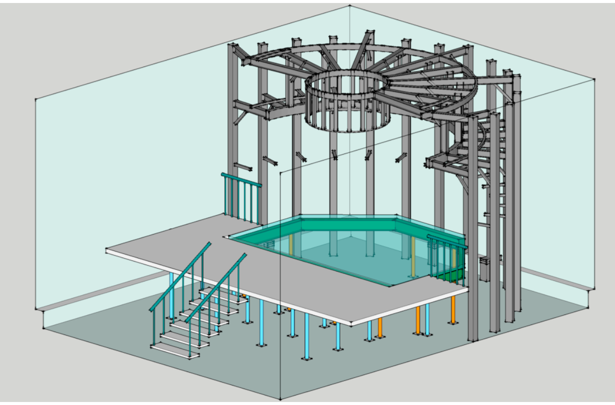

Figure 3: The aluminum superstructure of the new Cave, and the acrylic floor (in green).

4 CONCLUSION

Brown's new Cave accomplishes most of our goals. It will achieve retinal display resolution and increased brightness and contrast. The field of view still contains one blind spot, but we expect that will have little effect to the user because of its position. We will now be able to test a number of hypotheses about the value of various parameters of Caves in general, such as resolution, contrast, field of view, and mullions, to guide future directions of research in this field.

ACKNOWLEDGEMENTS

The authors wish to thank the Center for Computing and Visualization at Brown. This work was supported in part by grant OCI-09-23393 from NSF.

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