Emerging from the CAVE: Collaboration in Ultra High Resolution Environments
CAVEから示現：超高解像度環境におけるコラボレーション

Jason Leigh, Andrew Johnson, Luc Renambot, Dan Sandin, Tom DeFanti, Maxine Brown
Byungil Jeong, Ratko Jagodic, Cole Krumbholz, Dmitri Svistula, Hyejung Hur,
Robert Kooima, Tom Peterka, Jinghua Ge, Chris Falk

Electronic Visualization Laboratory, University of Illinois at Chicago, Illinois, USA

Low-cost computing, displays and networking is making it possible to create collaboration environments that are truly able to bridge distance. This paper describes EVL’s work since 1992 that has pursued the goal of creating collaboration environments that have been able to seamless merge high-resolution 2D information with 3D information incorporating a variety of viewing and interaction modalities.

1. Introduction

In 1992 EVL invented the CAVE [1]. The CAVE is a 10-foot cube of a room rear-projected with stereoscopic computer graphics. The net effect was that the viewer could see 3D objects in life size as if it were co-present with them in the room.

In 1995 EVL began conducting some of the earliest research in tele-immersion whereby participants in distantly located CAVEs could collaborate with one another linked by high-speed networks [2,6]. The goal was to be able to create an environment in which users could see and work with each other as well as with data. This research enabled tools such as VisualEyes which General Motors used to enable collaborative automobile interior design [3].

Since then EVL has considered numerous ways to more seamlessly merge both 2D and 3D spaces into digital "war rooms" or project rooms. Prior research in traditional paper-based war rooms have shown that in some cases, productivity among users was enhanced more than two-fold [4].

The challenge EVL wanted to address was to attempt to transfer these benefits into the digital realm, for not only users in the same physical space, but also teams of users distributed over distance.

2. The Continuum Digital “War Room”

The first of our attempts resulted in the development of the Continuum [5]. The Continuum is a digital project room comprising a number technologies: a digital whiteboard on which users can write notes; a multi-site AccessGrid video conferencing system; a passive stereo projection "GeoWall" system [7]; and a small 2x2 tiling of high resolution 21" LCD panels.

EVL conducted user experiments between two distributed Continuum spaces (one at EVL and one at the Technology Research Education and Commercialization Center in Dupage County, Illinois- a facility funded by the Office of Naval Research and operated by the National Center for Supercomputing Applications). These experiments had users engage in a number of tasks including information foraging, information visualization, and consensus formation.

Observations of users in the space indicated that:

- Users were able to perform tasks with greater parallelism by taking advantage of the multiple screens.
- By providing a pointer that could seamless travel from one screen to another, users wished that all the screens could be driven as one large unified desktop rather than separate desktops.
- When users were asked to perform the same tasks in traditional single-projector "powerpoint presentation" rooms, they felt "cramped."

These observations led us to consider how to build more seamless environments and with display resolution preferably approaching print quality.

3. The LambdaVision Tiled Ultra Resolution Display

EVL's LambdaVision is a 100 Megapixel 17-foot wide tiled display of LCDs driven by a cluster of 30 computers and networked with 20 Gigabits/s of bandwidth [8]. The "Lambda" in LambdaVision is a term used by networking

J. Leigh et al. “Emerging from the CAVE: Collaboration in Ultra High Resoluion Environments,” *First International Symposium on Universal Communication,* Kyoto, Japan, June 14-15, 2007.

researchers to describe a single wavelength of light in an optical network. LambdaVision exploits the hundreds of gigabits of bandwidth that were made cheaply available when the dot-com bubble burst in 2000. LambdaVision is connected to the Global Lambda Integrated Facility (GLIF) a worldwide research network that consists of multiple tens of gigabits of bandwidth (www.glif.is). Using GLIF LambdaVision is able to connect to distantly located Grid computing clusters and high-definition cameras that can generate images and stream them for display.

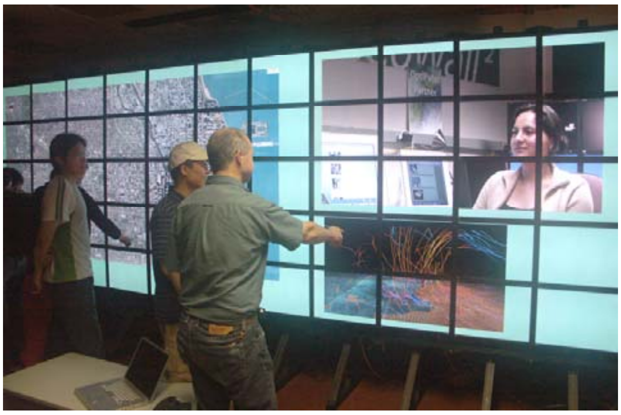

Fig. 1. The LambdaVision

4. SAGE: the Multi-User, Multi-Tasking, Multi-Tile Operating System

Traditionally applications developed for tiled displays used the entire wall to display a single visualization. This made the walls essentially a "single tasking" environment like MS-DOS.

EVL's Scalable Adaptive Graphics Environment (SAGE) sought to overcome this by turning the entire wall into a unified frame buffer onto which content from distributed clusters (either local area or wide area) could be streamed [9]. SAGE can therefore show multiple concurrently running applications at the same time on multiple windows on the wall. SAGE allows multiple users to simultaneously move and resize the windows as if it were a multi-user multi-tasking operating system.

The ability to support multiple simultaneous interactions is important because as the screens grow to envelope entire rooms, one cannot expect only one operator at a time to control the space. As was found in our Continuum experiments, providing multiple users with the ability to simultaneously interact with the environment increases the possibility for concurrent work.

In SAGE, when a user moves a window from one portion of a wall to another, complex pixel routing is conducted that seamlessly redirects the pixels over the network from one set of compute clusters to another. High speed gigabit networks provide sufficient bandwidth to make this degree of interactivity possible.

In order to enable multiple collaborating displays to see the same content, EVL is developing VisualCasting [9]. VisualCasting uses a scalable cluster to intelligently broadcast pixels to multiple tiled displays of differing configuration. All participating sites can resize their windows in their own way. VisualCasting ensures that the streamed images properly matches the window sizes.

5. The Varrier and Dynallax Autostereo Display

While LambdaVision provided the ability to display 2D content at exquisite resolution, another challenge came in trying to develop a compatible technology capable of displaying 3D stereoscopic content.

The Varrier is a tiled display manufactured (by EVL) to include a black line screen (barrier) in front of it. By interleaving the left and right eye images into vertical strips, and aligning them with the gaps in the barrier based on a viewers point-of-view, it is able to generate a stereoscopic image that can be seen without requiring the viewer to wear specialized glasses [10].

The Dynallax was an improvement over the Varrier that used a dynamic barrier screen, rather than a static screen. The Dynallax was built by laying a (preferably) monochromatic LCD panel on top of the standard color LCD panel. The barrier is therefore drawn by changing the front LCD panel, while the computer imagery is drawn on the rear LCD panel [11].

Fig. 2. The Varrier

A dynamic line screen offers several significant benefits:

- the width of the lines and the separation of the lines can be adjusted based on the viewer's distance to the screen as well as to accommodate multiple simultaneous viewers, and viewpoints- limited only by the total resolution of the LCD panel.
- sub-regions of the dynamic line screen can be turned on or off under software control to enable both monoscopic and autostereoscopic sub-windows to appear within the same display. This means that viewers can, for the first time ever, conveniently look at 2D content using the full native resolution of the display screen, and 3D stereoscopic content, without being encumbered by specialized glasses.

6. The LambdaTable- Working on Table Tops

Thus far the emphasis has been on working on walls. In 2005 EVL began conducting research in table-top displays. This came from a realization that it was only in the last 25 years that people began working on vertically oriented computer screens. This was largely because the types of disembodied user-interfaces (such as keyboards and mice) were only comfortable to use and therefore practical on vertically oriented display. On the other-hand mankind has been working on flat horizontal surfaces for more than a millennium using direct interaction techniques- such as with their hands, pencils, paper notes and diagrams.

The LambdaTable [12] sought to take advantage of low-cost emerging high-resolution displays to develop a table-top display that provided sufficient resolution to display print information and intuitive direct interaction. We believe that this is the last missing pieces in making our digital war rooms complete.

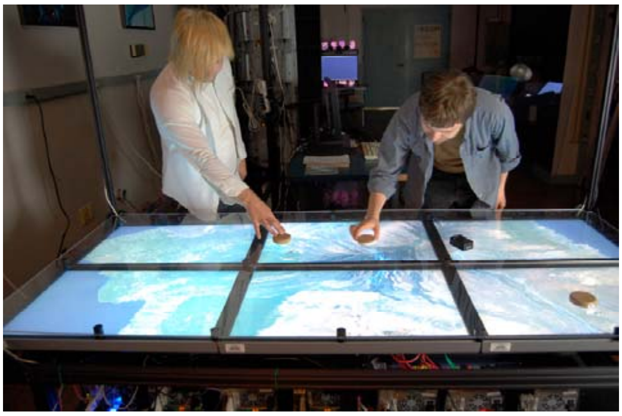

Fig. 3. The LambdaTable

The LambdaTable uses a small cluster of computers to drive six 30" 4 megapixel LCD panels and an array of infra-red cameras to track infra-red objects that are used to manipulate the information on the table. In total LambdaTable provides 24 Megapixels of resolution. A touch screen overlay can also be used, however the current generation of touch screen technologies (e.g. SmartTech) that will work on LCD panels can only support two simultaneously touches at a time without becoming confused. NYU's Multi-Touch screen using FTIR (frustrated total internal reflection), while suitable for rear-projected table-top displays, which are typically low resolution (about 1 megapixel), cannot be used for LCD flat panels because the LCD panels occlude the cameras that are needed to detect the FTIR touches. Needed, are LCD flat panels where each pixel display element is also a camera element.

7. The Next-Generation Context Aware Virtual Environment (NG-CAVE)

The Next-Generation Context Aware Virtual Environment (NG-CAVE) seeks to combine all these capabilities into a single unified environment. An artist's concept of the NG-CAVE is shown in Fig. 4.

Still in the design stage, NG-CAVE harnesses the experience EVL has gained from developing the LambdaVision, Dynallax, and LambdaTable technologies. The NG-CAVE will consist of walls that are covered entirely with flat panel Dynallax screens to enable the display of both 2D and 3D autostereoscopic content. Some form of touch screen overlay will be placed over all the walls to enable direct manipulation. An array of cameras will be embedded within the mullions (borders) of the LCD panels to enable direct eye-contact during video conferencing as well as an opportunity to stitch together a single panoramic view of the environment that can be VisualCasted. The cameras can also be used to enable image-based interaction techniques so that users can manipulate 3D data using gestures. An array of speakers will be placed behind the tiles so that when an application window, such as a video conferencing window, is moved from one part of a wall to another, the sound will appear to travel seamlessly across the walls and follow the window. Lastly, intelligent middleware and applications must be developed to coordinate all these systems into a coherent and easy-to-use environment.

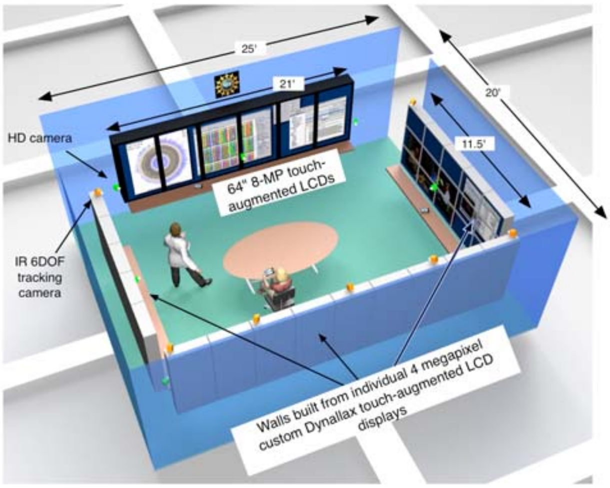

Fig. 4. The Next-Generation CAVE.

4. Conclusions

We envision that as the cost of displays, computing, storage, and networking continue to decrease, and that if display technologies continue to increase in size, we will be able to eventually "wallpaper" homes, offices and meeting rooms with seamless displays. Much research is needed to make the hardware and software technologies seamless. New user-interaction paradigms are needed to work in these environments. The creation of such environments will enable new classes of applications spanning science, engineering, education, art and entertainment. Already we are seeing considerable interest in forward thinking display, computing and networking companies in the US and Japan that are interested in realizing such a capability. EVL is also working with science museums in the US to enable the general public to be able to experience these environments. The Adler Planetarium has already adopted EVL's tiled display model, and the Minnesota Science Museum is building a LambdaTable.

Acknowledgments

This research is supported in part by TRECC/NCSA/Office of Naval Research, General Motors Research, Nippon Telephone and Telegraph, and the National Science Foundation Awards CNS 0703916 , 0420477; ANI 0225642.

References

[1] C. Cruz-Neira, D. Sandin, T. DeFanti, R. Kenyon, J. Hart, "The CAVE®: Audio Visual Experience Automatic Virtual Environment," *Communications of the ACM*, June 1992.

[2] J. Leigh, A. Johnson, C. Vasilakis, T. DeFanti, "Multi-perspective Collaborative Design in Persistent Networked Virtual Environments," *Proc. IEEE VRAIS*. 1996.

[3] M. Smith, R., Pawlicki, R. R., Leigh, J., Brown, D. A., "Collaborative VisualEyes," *Proc. of 4th International Immersive Projection Technology Workshop*, Ames, Iowa, June 19-20, 2000.

[4] S. Teasley, L. Covi, M. Krishnan, and J. Olson, "How does radical collocation help a team succeed?," *Proc. CSCW'00* (Philadelphia, Dec. 2-6), ACM Press, New York, 2000, pp. 339-346.

[5] J. Leigh, A. Johnson, K. Park, A. Nayak, R. Singh, and V. Chowdry, "Amplified Collaboration Environments," *VizGrid Symposium*, Tokyo, November 2002 <www.vizgrid.org>.

[6] J. Leigh, A. Johnson, T. DeFanti, et. al., "A Review of Tele-Immersive Applications in the CAVE® Research Network," *Proc. IEEE VR `99*, Houston, TX, March 13-17, 1999.

[7] A. Johnson, J. Leigh, P. Morin, P. Van Keken, "GeoWall: Stereoscopic Visualization for Geoscience Research and Education," *IEEE Computer Graphics and Applications*, Vol. 26, No. 6, 2006, pp. 10-14.

[8] L. Renambot, A. Johnson, J. Leigh, "Techniques for Building Cost-Effective Ultra-high-resolution Visualization Instruments," *NSF CISE/CNS Infrastructure Experience Workshop 2005*, <www.cs.uiuc.edu/events/expwork-2005/Luc_Renambot_Abstract.pdf>.

[9] B. Jeong, L. Renambot, R. Jagodic, R. Singh, J. Aguilera, A. Johnson, J. Leigh, "High-Performance Dynamic Graphics Streaming for Scalable Adaptive Graphics Environment," *ACM/IEEE Supercomputing 2006*, November 11-17, 2006.

[10] D. Sandin, T. Margolis, G. Dawe, J. Leigh, T. DeFanti, "The Varrier auto-stereographic display," *Proc. SPIE*, 4297, No. 25, 2001.

[11] T. Peterka, R. Kooima, J. Girado, J. Ge, D. Sandin, A. Johnson, J. Leigh, J. Schulze, T. DeFanti, "Dynallax: Solid State Dynamic Barrier Autostereoscopic VR Display," *Proc. IEEE VR*, 2007.

[12] C. Krumbholz, J. Leigh, A. Johnson, L. Renambot, R. Kooima, "Lambda Table: High Resolution Tiled Display Table for Interacting with Large Visualizations," *Workshop for Advanced Collaborative Environments (WACE)* Redmond, Washington, 09/08/2005 - 09/09/2005.

J. Leigh et al. "Emerging from the CAVE: Collaboration in Ultra High Resoluion Environments," *First International Symposium on Universal Communication*, Kyoto, Japan, June 14-15, 2007.