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Ten years of Immersive VR Installations - Past, Present, and Future

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Abstract

Virtual Reality (VR) has found application in many fields including art history, education, research, and smart industry. Immersive 3D screens, large-scale displays, and CAVE systems are time-tested VR installations in research and scientific visualization. In this paper, we present learnings and insights from ten years of operating and maintaining a visualization center with large-scale immersive displays and installations. Our report focuses on the installations themselves as well as the various developments of the center over time. In addition, we discuss the advantages, challenges, and future development of a location-based VR center.

Keywords: Virtual Reality, Large-scale Displays, Scientific Visualization, Visualization Center, Stereoscopic 3D, CAVE, Powerwall

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality; Human-centered computing—Human computer interaction (HCI)—Interaction devices—Displays and imagers;

1 Introduction

Virtual Reality (VR) has found application in many different fields [6, 7] and has proven to be a useful tool in research and scientific visualization (SciViz) [1]. SciViz is the art of interpreting data for many scientific problems [1], many fields have accepted it as key to insight and understanding of complex data. For SciVis, it offers numerous opportunities for viewing data [1] and helps to understand the results of simulations [12]. Bryson et al. define VR for SciVis to include head-tracking and stereoscopic output while requiring a high-performance computer graphics system and a method for user input. These requirements are shared between head-mounted displays (HMDs) and large-scale installations like a CAVE [2]. In comparison to HMDs, large-scale installations may provide advantages like the ability to collaborate with other researchers in the room and higher quality displays, but do come with challenges.

While HMDs are more common and provide advantages such as being affordable and transportable, this paper focuses on large-scale immersive displays. One type of these large-scale displays are CAVEs or CAVE systems. The original CAVE built by Cruz-Neira et al. can be described as one of the most iconic [2]: it is a room-scale cube that uses rear projection onto the walls to display a virtual world and a top projection for the floor. A major advantage of this system was the ability to collaborate in person, a small group of people could be in the installation at a time. There are different types of CAVEs too [8]. A majority of CAVEs today use back projection to generate the immersive space.

In this paper we share our experiences and findings from operating a visualization center equipped with large-scale installations and focusing on SciViz over 10 years. We discuss the lessons learnt and how the hard- and software changed according to the requirements over the years.

2 The Visualization Center

The center features two large-scale displays: a Powerwall and a CAVE. Both installations are driven by a cluster of graphics workstations.

The Powerwall consists of a rear-projected planar screen with a size of $6\ m \times 3.15\ m$ and two projectors with a resolution of 4096×2160 *pixels*. It can display stereoscopic content at a frequency of 60 fps per eye using passive stereo with polarization filters. An optical tracking system is provided for interaction. Cinema-like seating enables the Powerwall to provide high-resolution interactive visualizations for medium-sized groups up to 21 researchers.

The 5-sided CAVE is designed primarily as a single-user system, but may be entered by up to 5 users to encourage scientific discussion. The walls with a size of $2.7\ m \times 2.7\ m$ are rear-projected using 2 active-stereo projectors per wall, resulting in a resolution of 1920×1920 *pixels* per wall and a total of 10 projectors for the CAVE. The optical tracking system features four cameras mounted in the upper corners of the CAVE.

Our report covers the ten years of operations, starting from 2012 that has been broken down into three phases.

2.1 Phase 1: 2012 - 2014

The team had prior experiences running a smaller projection device (a so-called "Holobench" [11]). Part of their task in this phase was to collect experience running larger more complex installations.

In regard to software used during this phase, the focus was on operating commercial software solutions, to provide a stable service. Two proprietary, commercial products were mainly used: RTT Deltagen[1] (now: 3DExcite Deltagen), and Amira[2].

In parallel, the scene graph library OpenSG [9] (with an additional tool to manage distributed rendering, the CAVE Scene Manager [3], developed by Adrian Haffegee [5]) was installed and adapted as a base for custom application development.

During this phase, the workstations were run as dual boot systems providing Windows (Windows 7) and Linux (SLES): Windows was required to run RTT Deltagen, which was the preferred viewer in phase 1 and only available for Windows. Linux was considered due to the less restrictive licensing and the cost of commercial

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[1] `https://www.3ds.com`
[2] `https://www.thermofisher.com/`
[3] `http://dev.invrs.org/documents/14`

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software solutions, making the exploration of open source software like OpenSG an important consideration for future developments.

More than 50% of the projects were realized with RTT Deltagen in phase 1, followed by AmiraVR. Here, the team and users were restricted to available functions and limited interactions of commercial software. With time customized applications were desired. This could only be achieved by in-house development which led to a change in the approach in phase 2.

2.2 Phase 2: 2014 - 2017

By 2014 requirements from the growing user base, like custom data formats, extremely large datasets or specialized visualizations, caused a move away from commercial software solutions that could no longer meet the increasing demands. Custom visualizations were created using third-party libraries like OpenSG or Equalizer [3], but even those proved to be limiting. In order to fully accommodate the users' requirements, two custom libraries were created in-house: one to provide a simple synchronization mechanism for multi-display installations and cluster-rendering, and the other to load, manage and render large-scale datasets. These two libraries allowed to tailor the visualizations to the users' datasets and their visualization needs. As these libraries were extended and adapted depending on various project requirements, they eventually became the software predominantly used for visualization and the use of other third-party libraries was phased out.

In this phase, development focus shifted to the Linux operating system. Windows was considered a legacy option only used for continued support of phase 1 projects. By 2017 game engines had already been used for scientific applications [4] and we decided to explore game engines for easier workflows, higher-quality visuals, and faster development times. This eventually lead to another switch in software and workflows which defined the third phase.

2.3 Phase 3: Since 2017

In 2017, game engines surged in the field of VR, even though they had been used for scientific visualizations previously [4]. Phase 3 is marked by the introduction of Unreal Engine 4 (UE4). With the development of the nDisplay plugin[4], it was possible to use UE4 for a CAVE and a Powerwall display setup, which only required the addition of tracking via VRPN [10]. This not only facilitated a more flexible workflow in regards to lighting, visualizations, target systems, and interactions, but also a higher visual quality and faster development times. The higher visual appeal enables the visualizations to not only serve purely scientific purposes, but to also serve for science communication to help convey information to non-researchers. Development of our custom libraries from phase 2 was discontinued.

To reduce considerable overhead in maintenance, phase 3 limited the operating system to Linux and discontinued support of previous Windows projects. We recreated and rebuilt several visualizations from various fields with the new Game-Engine-based workflow.

During phase 3, we acquired an additional Powerwall, based on LED technology. Due to its functional similarity to our projection-based Powerwall and the flexibility of UE4, we can export for all three installations as well as HMDs using our current workflow.

3 Discussion and Conclusion

With regard to display technologies, we have been working for ten years with projector-based systems with our CAVE and Powerwall and two with our LED-based display. We see several advantages of the LED technology, so we follow developments with this technology closely. The advantages include reduced maintenance, easier serviceability, very good brightness, and good color reproduction among other things. On the downside, there are issues like dissipation of heat, which could lead to high temperatures in an enclosed space like a CAVE, and smaller defects like dead pixels being common. Overall, we consider LEDs and the prospect of an LED CAVE, to be the next phase of our center.

Creating visualizations for different science domains gave the team experience in handling various types and sizes of data. The introduction of game engines allows for a focus primarily on the user experience as well as the visual quality of the visualizations. Further, compared to phase 1, the visualization process has been sped up significantly. It is now possible to simultaneously create experiences for CAVE, Powerwall, and HMDs with little rework.

The future of location-based visualization centers with large-scale immersive displays will be in close collaboration with prevalent, transportable VR hardware like HMDs. These centers offer a unique opportunity for researchers as well as a broader audience and play an important role for research and science communication.

[4] `https://docs.unrealengine.com/4.27/en-US/WorkingWithMedia/IntegratingMedia/nDisplay/QuickStart/`

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