Immersive Analytics at the Electronic Visualization Laboratory

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Figure 1: EVL *Continuum* Space for Amplified Collaboration

ABSTRACT

September 2023 marked the 50th anniversary of the Electronic Visualization Laboratory (EVL). This paper summarizes EVL's efforts in Visual Data Science, with a focus on the many networked, immersive, collaborative visualization and virtual-reality (VR) systems and applications the Lab has developed and deployed, as well as lessons learned and future plans.

Index terms: Visualization, Virtual Reality, Visual Data Science, Collaboration

1 INTRODUCTION

Comprehensive research papers and references on EVL's early work, summarized in this article, are available in [2,1].

September 2023 marked the 50th anniversary of the Electronic Visualization Laboratory (EVL) at the University of Illinois Chicago (UIC). Since its founding in 1973, EVL has been developing tools and techniques for real-time, interactive visualizations—pillars of VR. In addition, EVL's culture is relevant to its successes, as it has always been an interdisciplinary lab that fosters teamwork, where each person's expertise contributes to the development of the necessary tools, hardware, system software, applications, and human interface models to solve problems.

EVL's introduction of the CAVE Automatic Virtual Environment in 1992 [5], the first widely replicated, projection-based, walk-in, VR system in the world, put EVL at the forefront of collaborative, immersive data exploration and analytics. Since then, EVL developed a wide range of immersive systems and technologies used for visualization and visual analysis tasks, such as PARIS, ImmersaDesk, CAVE2 [3], and SAGE2 [4]. These technologies helped pave the way for a resurgence in VR and led to the introduction of Immersive Analytics, which investigates how new interaction and display technologies can be used to support analytical reasoning by immersing the users in data.

Over the years, as multidisciplinary collaborations evolved and advanced scientific instruments and data resources were distributed globally, the need to access and share data and visualizations while working with colleagues, local and remote, synchronously and asynchronously, also became important fields of study.

This paper describes some of EVL's networked, immersive, collaborative visualization and VR systems and applications, as well as lessons learned and future plans.

2 VISION

Created in 1973 by computer scientist Tom DeFanti and artist and physicist Dan Sandin as a joint program between UIC's College of Engineering/Computer Science (CS) department and the School of Art & Design, EVL was the first Science + Art program in the

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country, leading to an MFA in Electronic Visualization or an MS or PhD in CS with a specialization in data visualization. The joint degree program ended in the mid-2000s when the College of Architecture, Design and the Arts reorganized. However, EVL continued its strong working relationship with the School of Design and recently, UIC became the first public university in the United States to offer a Computer Science + Design (CS+DES) undergraduate program leading to a Bachelor of Science in Computer Science and Design degree; the interdisciplinary program is based at EVL.

EVL's fundamental philosophy, still true today, comes from its founders. DeFanti believed in developing advanced visualization hardware and/or software systems for non-computer people, whether artists or astrophysicists. Sandin believed artists should use (or build) the most advanced technologies of their time to create their art and would often point out that Renaissance painters made their own paints. Further, DeFanti and Sandin both believed systems should be user-oriented (easy to use, easy to learn), low-cost, interactive, and real-time (to provide immediate feedback). While they recognized the benefits and stunning visual quality of state-of-the-art, high-performance computer-graphics systems coming to market in the 1970s, those systems were expensive and not easily accessible to most people.

Given EVL's *interdisciplinary collaboration* focus, their goal was not to have people in each discipline learn everything about another discipline, but to learn the vocabulary of other disciplines, thereby improving communications so people could work together on joint projects. Non-computer people acquired basic programming skills. Technical people learned aesthetics. And CS and Art students learned how domain scientists approached problem solving. In the 2000s, EVL professors Jason Leigh and Andy Johnson coined the term *immersive empathic design*, whereby EVL students got summer internships at domain scientists' facilities to immerse themselves in scientists' environments for on-site, hands-on experiences, observe how scientists solved problems, learn to be empathic, and determine how EVL's tools and techniques could design better systems to fit scientists' needs and expectations.

Today, EVL continues its focus on real-time interaction and interdisciplinary collaboration, though we use the term ***visual data science****,* which we define as real-time, interactive, multi-modal (visual, audio, haptic), networked, collaborative data visualization, high-performance computing and immersive environments to support analytical reasoning. EVL continues to use the most advanced tools of its time, form interdisciplinary teams, and create human interface models to tackle today's grand challenges. Because EVL takes a systems approach to problem solving, it is also a technology enabler and disruptor and has long been advancing high-performance computing and networking cyberinfrastructure.

EVL works with computer scientists, artists, designers, and domain scientists in academia, industry, government labs, and nonprofits (e.g., museums). Its inventions are open source, and some have been commercialized. EVL builds and supports user communities on a global scale. Most importantly, EVL amplifies its core research mission with its educational mission, applied to all workforce dimensions—education, training, advancement, and mentoring—for undergraduate and graduate students, collaborators, and the public.

3 Culture and Facilities

EVL is housed in the CS department. EVL's *family* consists of CS visualization, Human Computer Interaction (HCI), and High-Performance Computing (HPC) faculty, domain science collaborators from other departments, and technical and administrative staff. All write grants to support the Lab and teach classes using the Lab's advanced technologies and inventions. All participate in weekly Tech Meetings where students give updates on their research projects. Newcomers are welcome, and those who get involved become family members.

In its current location, EVL has 7,000 sq. ft. of contiguous space with large and small rooms. An open floor plan has faculty, staff, students, VR/visualization systems, computers, display walls, whiteboards, desks, chairs, and tables all coexisting, though an internal calendar lets people reserve a machine or room as needed. The *main lab* is where new technologies, such as the CAVE and now CAVE2, live, with nearby tables and chairs for developers to sit and test their codes. Continuum, a large room with new and mature technologies, is used for meetings, classes, and art/design performances. A large machine room houses high-performance computers and networks, keeping work areas quiet and cool, but is close by in case a machine needs rebooting. A kitchen, reception area, offices, meeting rooms, rooms with desks for 15 graduate students, and rotating spaces for undergraduate students complete the layout. This *free form* layout is deliberate and integral to EVL's culture of fostering interdisciplinary teams, open communications, meaningful collaborations, and immediate access to technology, all while preparing students for real-world experiences.

In 1992, EVL introduced the *CAVE (CAVE Automatic Virtual Environment)*, a multi-person, room-sized, walk-in, projection-based, high-resolution video and audio VR system, at the ACM SIGGRAPH 1992 conference. In 1994, EVL developed a smaller, single-screen, portable, and more affordable VR display, the *ImmersaDesk. PARIS (Personal Augmented Reality Immersive System)* [8]*,* designed in 1998, was similar in size to the ImmersaDesk but had a translucent rear-projection screen and a half-silvered mirror, creating a projection-based, augmented-reality, desktop display where a user's hands were integrated with the virtual space and provided the primary means of interaction, using a hand + haptic device.

Rapidly UIC researchers complained that access to EVL's CAVE was difficult; if it wasn't being used for campus demos, then it was used for software development and therefore unstable. In response, EVL acquired additional space and built a second CAVE in 1998, funded by the UIC College of Engineering. The original CAVE was then devoted to development, and the new CAVE became a *production-ready* system for demos and contract work. Keeping devices *demo-ready* while doing ongoing development remains a challenge to this day.

By 2004, UCSD and EVL were lead institutions on the NSF-funded OptIPuter project (a distributed computer with storage, computing, and visualization resources connected over optical networks) [7]. EVL researchers observed how scientists from UCSD Scripps Institution of Oceanography and UCSD National Center for Microscopy and Imaging Research worked with big data.

This inspired EVL to begin developing *SAGE (Scalable Adaptive Graphics Environment)* as the OptIPuter's visualization middleware. The domain scientists needed large displays to view ultra-high-resolution images, such as earthquake images and brain electron microscope images, but some images were too big to fit on a tiled display, so they needed to be able to dynamically pan and zoom through them. They also wanted to open windows with related movies, images and/or text for context; to have multiple users simultaneously interact with those windows using their laptops; to share content to the display; and to move pointers on the screen to focus attention. Since its inception, SAGE continues to evolve and today, people use SAGE to collaborate with other users via laptops, desktops, and/or high-resolution displays worldwide for research, meetings and classes.

In 2008, EVL built *Cyber-Commons,* a technology-enhanced virtual *project room* that supported local and distance collaboration

and group-oriented problem solving. It consisted of a large, tiled display wall with a touch-sensitive surface that formed a nearly cinematic classroom blackboard. Using SAGE2 (second-generation SAGE), anyone with a laptop or tablet could simultaneously display very large images and/or simultaneously juxtapose more information, and better spatially organize, see and infer relationships among the data.

EVL introduced the *CAVE2 Hybrid Reality Environment* in 2012. A *n*ext-generation, large-scale, VR environment, it is a hybrid system that combines the benefits of scalable-resolution display walls (e.g., Cyber-Commons controlled by SAGE2) and large-scale VR systems (e.g., the classic CAVE) to create a seamless 2D/3D environment that supports both information-rich analysis as well as VR simulation exploration at a resolution matching human visual acuity.

In 2016, the success of CAVE2 as a highly mediated meeting room led to the reinvention and renovation of *Cyber-Commons,* renamed *Continuum*, with upgraded technologies. In 2019, Continuum was upgraded to be a highly instrumented, sensor-enriched smart space, consisting of a large, touch-enabled, 2D tiled display wall and a separate, smaller, tracked 3D passive stereo wall (Figure 1). Continuum has ceiling-mounted microphones, cameras, lighting control, and optical tracking throughout the room's footprint in support of research and user studies. As with CAVE2, SAGE2 (and now SAGE3) is the underpinning middleware driving the displays and user interactions. Continuum is in continual use for CS and Design courses and weekly meetings. Other campus units use it for meetings and to showcase EVL's visualization and collaboration technologies to campus visitors.

4 Community

EVL has a long history of both organizing events and participating in events at major conferences, such as ACM SIGGRAPH and IEEE/ACM Supercomputing (SC), and at Global Lambda Integrated Facility (GLIF) workshops. These venues present opportunities to promote EVL's new technologies and achievements to the research communities with whom EVL is involved (VR, scientific visualization, advanced networking), and to attract both new collaborators and new users of its inventions.

International Grid (iGrid) events started in 1998 and continued in 2000, 2002, and 2005, as community-driven biennial events coordinated with the GLIF organization to accelerate the use of multiple 10-Gbps international and national networks, to advance scientific research, and to educate decision makers, academics, and industry researchers on the benefits of optical networks. iGrid events featured application demonstrations from international participants, as well as symposiums, panels, and classes on applications, middleware, and underlying cyberinfrastructure.

EVL continually investigates new computer technologies and has a strong working knowledge of GPUs, given all the computers it has purchased over the years to drive its visualization and VR displays (everything from mini-supercomputers to clusters to PCs). EVL's computers interface with both UIC's academic network and its research network. High-speed networking continues to be of significant benefit to researchers—to collaborate over distance, share data, and have real-time access to big data and remote computational resources. With NSF funding, UIC upgraded its campus's research network to 100 Gbps, a 10-fold increase over the previous decade, and deployed 100 Gbps into EVL where it connects to its many devices, including CAVE2.

Among EVL's early post-pandemic experiences was welcoming visitors to an experimental, multi-user, immersive, theatrical performance developed by EVL/Design's Daria Tsoupikova in collaboration with Chicago's Goodman Theatre and director Jo Cattell, called "*Hummingbird*" [6]. *Hummingbird* showed how VR can be an artistic, storytelling medium integrated into live performance, expanding upon traditional live theatre (Figure 2). It used EVL's CAVE2, Continuum, and Head Mounted Displays (HMDs), in which several participants and a principal actor wore HMDs to participate in a collaborative, narrative performance that takes place partly in the real world and partly in VR.

5 Major Outcomes

EVL undergraduate and graduate students have won multiple Best Paper and Honorable Research Awards, NSF Graduate Research Fellowship Awards and nominations, UIC Chancellor's Undergraduate Research Awards, UIC Engineering Dean's Scholar Fellowship Award, Doctoral Colloquium selections at premier conferences, Fullbright grants, and Computing Research Association fellowships. EVL students receive excellent jobs upon graduation. A common phrase upon graduation is "No one ever leaves EVL." Fostering a sense of family, community, and inclusion has been an important part of EVL's overall success. EVL makes every effort to stay in touch with its graduates. EVL attends many conferences, such as SIGGRAPH, SC, and IEEE Vis, where former students reunite. Alumni frequently visit EVL, give talks about their careers, and learn about EVL's latest innovations—and some adopt them for their jobs. Maintaining these relationships provides for a close-knit network and support system for all graduates.

EVL, as a technology enabler and disruptor, maintains a multimillion-dollar research facility. EVL has a track record of working with industry partners to help them be more competitive in the global marketplace, by either working with them to commercialize EVL inventions or educating them on how their commercial products can be re-engineered to meet the needs of the academic research and education market.

EVL's software (including *SAGE, CAVE2 Simulator,* etc.) is available for download from GitHub as open source for non-commercial use. For commercial use, UIC's Office of Technology Management brokers software and hardware licensing agreements with interested companies. EVL has had a longstanding licensing relationship with Mechdyne, who commercialized the CAVE in the 1990s, the ImmersaDesk in 1994 (first Fakespace and then later Mechdyne), and the CAVE2 in 2013. Finally, select EVL faculty and students have received patents for their inventions.

6 Lessons Learned

Here are some reflections from Prof. Emeritus Andy Johnson, formerly EVL Director of Research and Interim Director:

- Keep your friends close and your hardware ('toys') closer. Having everyone co-located with the equipment they use makes so many things simpler.
- Flexibility is important. Having a varied, but overlapping, research portfolio helps attract new funding, faculty members, and students, as research topics evolve over time.
- Use the tools you develop regularly to work out the bugs and keep the tools current.
- Family is important and EVL is like a family. Faculty, staff, and students all have desks and access to meeting rooms and a common kitchen area with an espresso machine. Having faculty and students casually talk with one another at different stages in their careers and learn how they are coping with issues gives a strong sense of continuity and a path forward.
- Evolution is good. Given the rapid pace with which technology ages and watching students and staff move on, plan to regularly update or replace computers, display screens, and software, prioritizing need and available funding. For example, the lifespan of a large display at EVL is typically 10 years before newer technology is available to support the Lab's evolving research focus.

- Create tools and techniques that help people, in collaboration with those being helped.
- Being affiliated with at least one academic department is important. EVL's affiliation with the CS department provides for a steady stream of new students and access to other faculty members who may have interesting new problems to solve or the knowledge to help solve new problems.
- Pursue your *passion projects* as they can lead to new research directions. Opportunities come from the strangest projects!
- The research lab must provide researchers and students with better infrastructure than at home, or why expect them to come into the lab to work?
- There is value in making simulators available so users can code from anywhere, but then come into the laboratory to test, especially when the resource, like the CAVE2, is a unique system and not easily shared among many users simultaneously.
- Diversity across multiple dimensions is good. EVL has worked with people of all ages, genders, races, disabilities, and scientific domains and with the public. Computer graphics/visualization appeals to students with a diversity of talents too, from interests in science and math to the arts – art, music, dance, audio, singing, acting, and so on.
- Understand the importance of *showtime.* The tech must work! Use conference demonstrations, museum exhibits, lab tours, and end-of-semester project demonstrations to harden the hardware and software and bring work to a form where it can be shown and used by others. Then use these demonstrations to meet new people, get feedback, and discover new problems to work on.
- It is important to get your work out of the lab and into the hands of actual users (scientists, students, museum goers, conference attendees).
- Live the dream. If you don't have the future you were promised in the sci-fi movies you watched as a child, then build that future with your friends!

7 Future

The world needs immersive, room-scale technologies for data analytics. Users are now accustomed to large flat-screen TVs and wide desktop monitors with high fidelity to support their work. New display technologies can aid researchers who collaborate on complex problems—studying one large image or visualizing multiple data representations with supporting information.

Experience has shown that for 3D data, room-scale stereoscopic displays, HMDs, smartphones, and tablets should all be integrated into larger, collaborative spaces, as it is still the only way to truly investigate data in depth. Integrating AR, VR, AI and HPC into spaces can release analysts from being tethered to their laptops and phones, enabling them to privately view personal data in addition to data being shared in the larger collaborative space. Further, integrating these modalities with voice and AI assistance will provide interesting research opportunities for *immersive* spaces. While we wait for wearable technology to improve, *immersive* visualization rooms outfitted with state-of-the-art tracking lets us prototype that future.

Though original CAVE projects involved one to a few domain scientists, the trend over the years has been towards projects with larger and larger groups, many featuring complementary expertise. Due to their cost and relative rarity, high-resolution immersive analytics spaces are increasingly being used by multiple groups under either a *time-share* or a *space-share* model. Under *space-share* models, modern spaces should accommodate seamlessly large group meetings (30–50 people) and/or multiple, simultaneous, small group meetings (5–10 people). Immersive analytics tasks require the ability to link representations together, to quickly annotate, and to brainstorm as a group, as though standing together at a whiteboard. Under *time-share* models, users should be able to quickly add new information to the conversation, to save the state of a session, to bring it back the next day or next year, and to be able to copy information from the public displays back to their personal displays.

EVL wants to aggressively pursue emerging opportunities. EVL sees many opportunities, so includes new CS faculty hires with knowledge of visualization, computer vision, HPC, and smart cities who want to be affiliated with EVL.

UIC's CS department will move into a new state-of-the-art building in 2025. EVL received NSF-funding to design and deploy *DOCC (Data Observation and Computation Collaboratory),* an immersive, AI-based, data analytics space for the new building that will be readily accessible to all CS faculty and students (Figure 3). It will embody Visual Data Science, with high-speed networking, AI supernodes, large displays, active 3D stereo displays, and all the support needed for a living laboratory.

Figure 2: *Hummingbird* in EVL's Continuum room

Figure 3: An EVL CAD Rendering of the DOCC Space

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