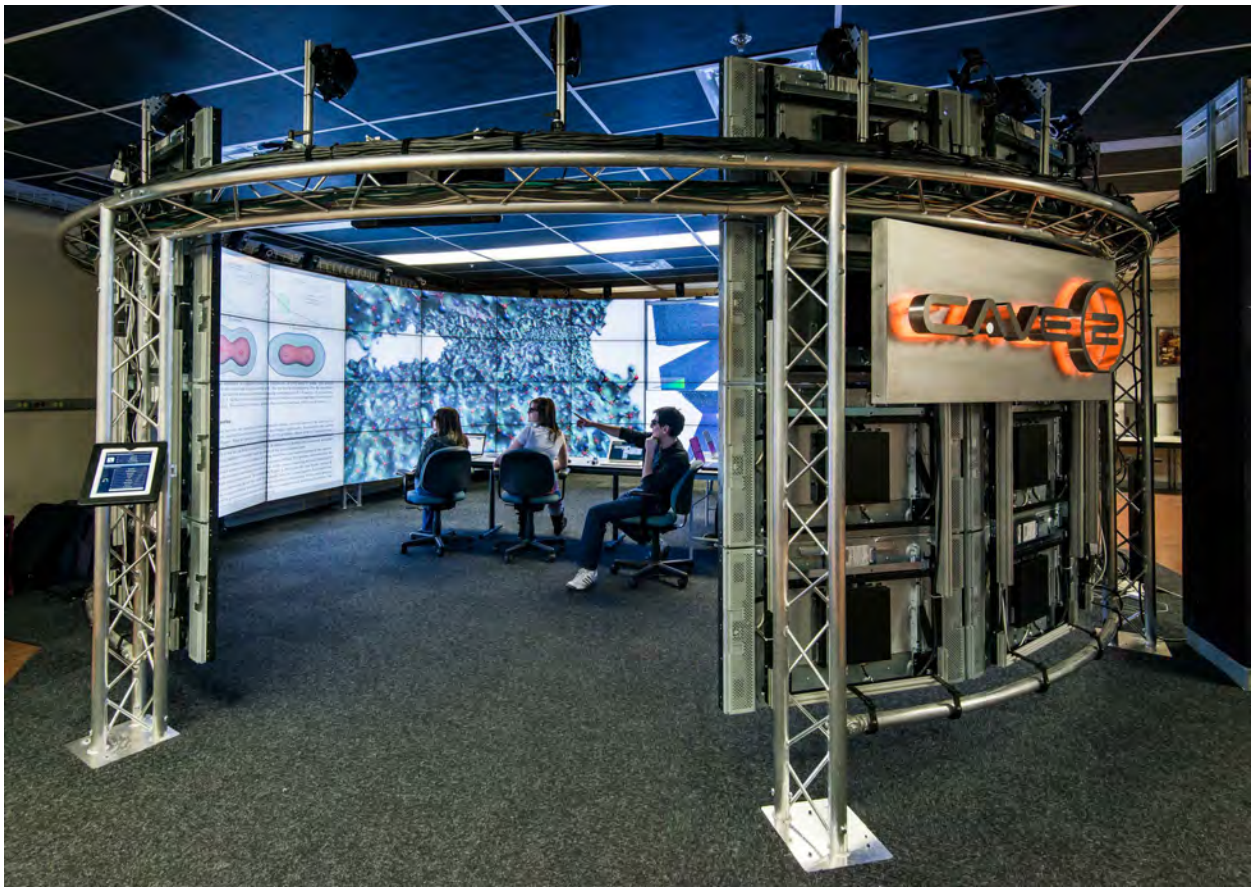
Construction of *Blaze* at the University of Illinois at Chicago:
A Shared, High-Performance, Visual Computer for Next-Generation Cyberinfrastructure – Accelerated Scientific, Engineering, Medical and Public Policy Research

Department of Energy Award DE-SC005067

For the period April 1, 2010 – September 30, 2013

http://www.evl.uic.edu/cave2



FINAL REPORT
Submitted February 17, 2014

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1. Accomplishments

1.A. Major Project Goals

The* Blaze *high-performance visual computing system serves the high-performance computing research and education needs of University of Illinois at Chicago (UIC). Blaze consists of a state-of-the-art, networked, computer cluster and ultra-high-resolution visualization system called CAVE2 that is currently not available anywhere in Illinois. This system is connected via a high-speed 100-Gigabit network to the State of Illinois' I-WIRE optical network, as well as to national and international high-speed networks, such as the Internet2, and the Global Lambda Integrated Facility. This enables Blaze to serve as an on-ramp to national cyberinfrastructure, such as the National Science Foundation's Blue Waters petascale computer at the National Center for Supercomputing Applications at the University of Illinois at Chicago and the Department of Energy's Argonne Leadership Computing Facility (ALCF) at Argonne National Laboratory.

DOE award # DE-SC005067, leveraged with NSF award #CNS-0959053 for "Development of the Next-Generation CAVE Virtual Environment (NG-CAVE)," enabled us to create a first-of-its-kind high-performance visual computing system. The UIC Electronic Visualization Laboratory (EVL) worked with two U.S. companies to advance their commercial products and maintain U.S. leadership in the global information technology economy. New applications are being enabled with the CAVE2/Blaze visual computing system that is advancing scientific research and education in the U.S. and globally, and help train the next-generation workforce. Details are provided in this final report.

The CAVE2™ Hybrid Reality Environment, developed by the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago (UIC), is a new type of 'digital lens' – a high-resolution computer display in which people can study phenomena too large, too small, too dangerous, too complex, or too distant to truly understand well. CAVE2 is a virtual reality display, providing people with an alternate reality – immersing them in three-dimensional (3D) worlds inside cyberspace and letting them intuitively interact with the data, change size and perspective, make observations – and ultimately gain insight and knowledge. In addition, CAVE2 enables both 2D and 3D datasets to be juxtaposed, creating hybrid information spaces to assist knowledge workers make sense of today's increasingly large and heterogeneous datasets.

Imagine being larger than a six-story building, being smaller than a molecule, standing inside train tracks to observe distortion as high-speed trains roar past, seeing neurons firing in the brain, or traveling to Mars. And, while exploring these cyberworlds of visual information, imagine accessing related data and documentation, whether diagrams, formulas, spreadsheets, or research documents. This is no longer science fiction – with the CAVE2, it's science fact.

INTELLECTUAL MERIT. Today, most professions rely on computers to generate, capture, filter, analyze and visualize data. Natural phenomena from global weather systems to chemical reactions at the atomic level can be simulated inside supercomputers, generating massive amounts of scientific data. Conversely, phenomena from particle accelerators to nuclear reactors to earthquakes are instrumented with sensors, capturing data at ever-increasing resolution. These troves of data are invaluable to scientists as they explore the raw information and evidence needed for new insights and discoveries. However, making those insights is an ever more complicated task, as the scale and complexity of data continue to grow at unprecedented rates.

Researchers from diverse disciplines, such as art, astronomy, cultural heritage, bioengineering, earth science, neuroscience, nursing, physics, psychiatry, rehabilitation, and structural engineering, are already using the CAVE2. It has application to many industries, government research laboratories and museums that utilize visual information technologies, such as aerospace, architecture, automotive design, agricultural engineering, climate modeling, energy, manufacturing, medicine, and pharmaceutical.

BROADER IMPACT. CAVE2 will enhance undergraduate and graduate research and education. It is already enabling UIC to work with domain scientists and computer scientists who are early adopters of this new instrumentation, and is providing UIC students with unprecedented opportunities to use, support, design, develop and deploy advanced technologies while "immersing" themselves in various application domains, producing demonstrable results – such that UIC partners are more productive and UIC students gain the skills necessary to get jobs upon graduation. UIC has worked with two companies – Planar Systems, Inc. and Mechdyne Corporation – to develop new flat-panel display technology and to commercialize CAVE2, respectively – which will advance all of science and engineering. CAVE2 will accelerate basic research and product development for industries, schools and research labs that invest in the technology, enabling the U.S. to maintain its competitiveness in the global marketplace and its leadership in high-performance computing. This benefits the Nation, and society as a whole.

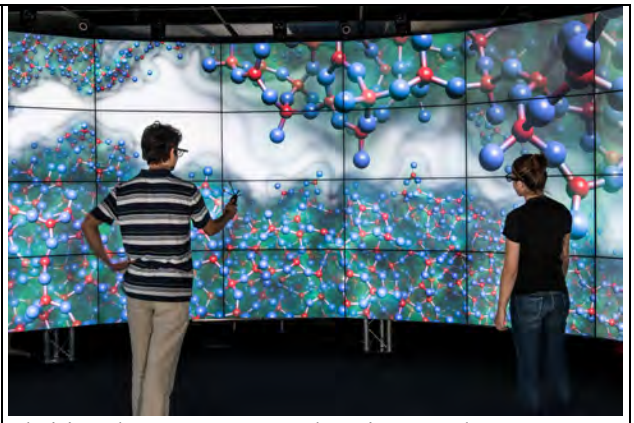
1.B. CAVE2 Application Development and Usage

One way to significantly measure Accomplishments is the number of applications and users the CAVE2 has attracted since its premiere in October 2012. Most of these applications use ***OmegaLib*** *software, also developed by EVL, to display the data in CAVE2, unless otherwise noted. Here are some examples.*

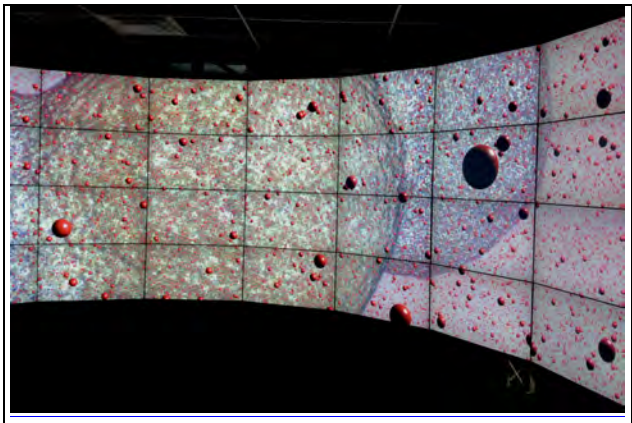
Thomas Marrinan, EVL research assistant and computer science PhD candidate, visualizes brain vasculature and cortical tissue in CAVE2. Specifically, the reconstruction of a patient's vessels and cortical tissue gathered from MRI data is supplemented with artificially generated microvasculature to simulate vessels below the resolution of imaging techniques in order to provide doctors with more information. EVL collaborated with the UIC Bioengineering Department's Laboratory for Product and Process Design and the University of Illinois Hospital & Health Sciences System's Department of Neurosurgery.

Connectome images represent streamlines depicting white matter fiber tracts in the brain derived from diffusion tensor images (DTI) obtained in an MRI scan. The fiber tracts are color-coded by their primary direction (green: front-back, red: left-right, blue: up-down). EVL collaborates with Olusola Ajilore, Department of Psychiatry, College of Medicine, University of Illinois Hospital & Health Sciences System.

Khairi Reda, an EVL research assistant and computer science PhD candidate, shows this visualization of a balls-and-sticks model of a molecular chemistry dataset to fellow students in the CAVE2. The clouds represent the density of electrons around atoms. Chemistry models and simulation data provided by Aslihan Sumer, Juliuis Jellineck and Michael Papka of the Argonne Leadership Computing Facility, Argonne National Lab.

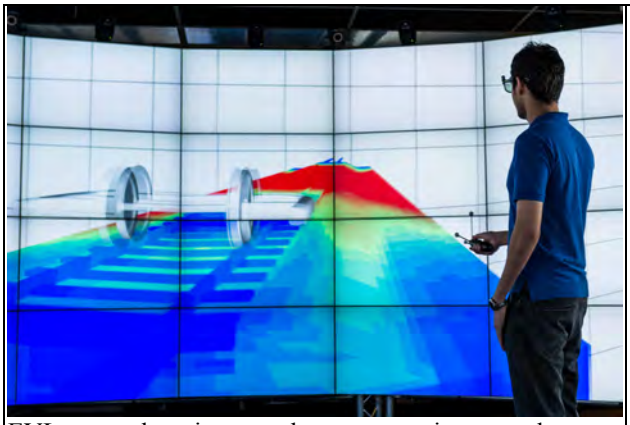


Khairi Reda, an EVL research assistant and computer science PhD candidate, flies through a close-up of a glass fissure computed in a 5-Million atom molecular dynamics nanoscale simulation. Visualization by Reda, Aaron Knoll and Michael Papka of the Argonne Leadership Computing Facility, Argonne National Lab. Simulation and data provided by Kenichi Nomura and Priya Vashishta of University of Southern California.

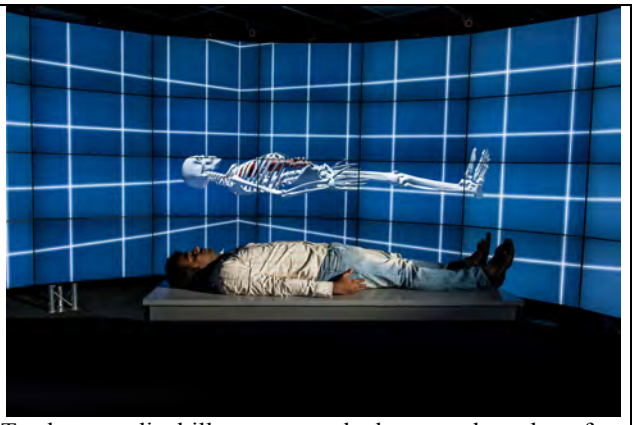


EVL student Khairi Reda visualized this simulation of the burning of three aluminum nanoparticles at very high temperatures (approximately 2000 C) in order to study their potential use in fuel cells. Simulation and data provided by Kenichi Nomura and Priya Vashishta of University of Southern California and Michael Papka of the Argonne Leadership Computing Facility, Argonne National Lab.

EVL research assistant and computer science PhD candidate Alessandro Febretti used OmegaLib software to quickly display 3D data representing the self-assembly of a ligated gold nanoparticle and proteins inside an ionic solution in the CAVE2. Data was provided by the Petr Král Research Group of the UIC Department of Chemistry and the Vincent M. Rotello Research Group at University of Massachusetts, Amherst.



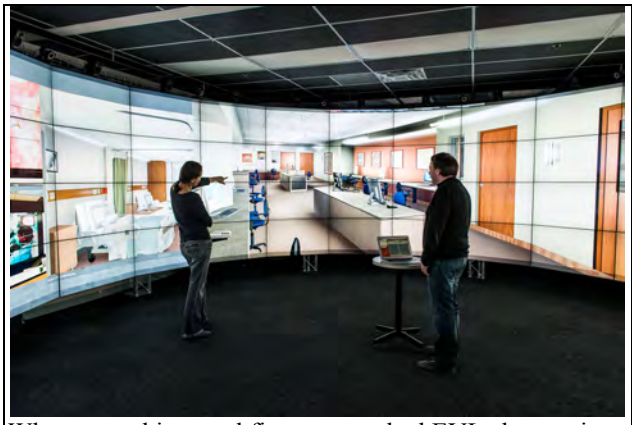
EVL research assistant and computer science graduate student Vaibhav Govilkar stands inside virtual train tracks in CAVE2 to observe distortion as high-speed trains roar past. This visualization of fundamental dynamics phenomena related to high-speed rail operations was done in collaboration with the National University Rail (NURail) Center – which consists of researchers at UIUC, UIC, MIT, Michigan Tech, University of Kentucky, University of Tennessee, Knoxville, and the Rose-Hulman Institute of Technology – and is funded by the U.S. Department of Transportation.



To show medical illustrators and educators the value of virtual-reality for medical training, EVL director Jason Leigh and research assistant and computer science PhD student Alessandro Febretti mocked up a 3D skeleton, complete with body organs, including the heart, lungs, and intestines, that students can manipulate on the walls of the CAVE2. Datasets were publicly available on the web. Another EVL student lies on a bench in front of the walls for added effect.

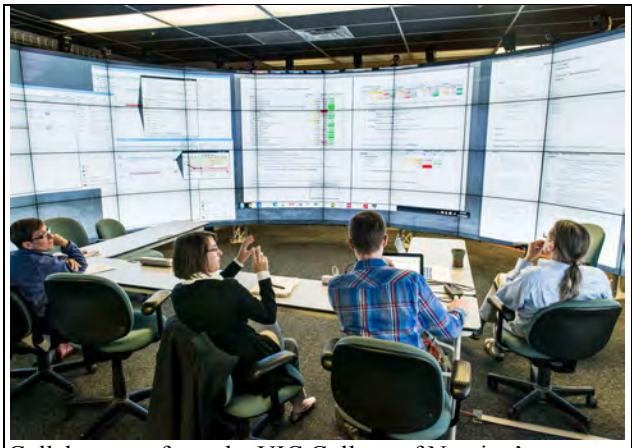
In an homage to "StarTrek," EVL research assistant and Computer Science graduate student Arthur Nishimoto has spent his spare time over the past two years creating 3D models of the starship Enterprise. Nishimoto created all interior room models, and ported the Enterprise's exterior model, developed by Dennis Baily and converted to Blender by Eric Clark, to the CAVE2.

EVL research assistant and PhD computer science student Victor Mateevitsi uses **Google Maps** and **SAGE** to display crime data overlaid on a map of Chicago. EVL is funded to work with the City of Chicago, with the goal of helping civic leaders and law enforcement make better decisions using data rather than hunches or politics.



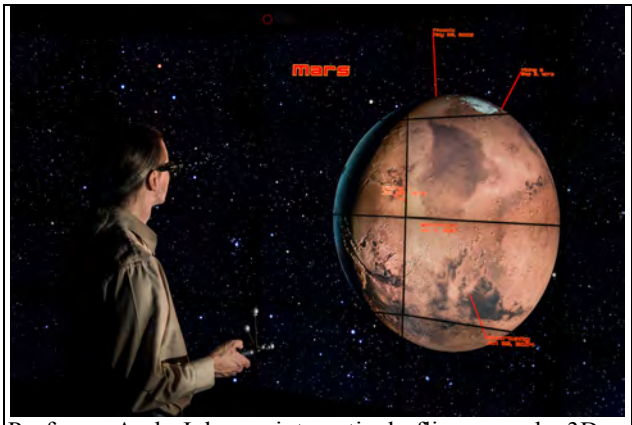
When an architectural firm approached EVL about using CAVE2 technology to show clients what a hospital floor might look so they could easily approve designs, EVL research assistant and computer science PhD candidate Sangyoon (James) Lee mocked up a scenario using a 3D model of a nurses' station and patient rooms available from the web. Here, two observers virtually walk the hospital corridor and enter the rooms. EVL **SAGE** was used to display several 3D models simultaneously in the CAVE2.

Here, EVL students Arthur Nishimoto and Sungwon Nam display a 3D representation of Mars created by EVL graduate Robert Kooima (using Mars data from the NASA Mars Global Surveyor and Viking missions and star data from the European Space Agency Hipparcos mission), along with several 2D images of the Mars Curiosity Rover (using data from the NASA Jet Propulsion Laboratory and Caltech). EVL **SAGE** is used to display the data in CAVE2.



Collaborators from the UIC College of Nursing's Department of Health Systems Science and EVL compare and discuss several prototype interfaces of a hospital patient plan of care system in the CAVE2 as part of the NIH grant "Describing, Contrasting, and Visualizing End-of-Life Care in the 21st Century." The CAVE2's large display space enables the collaborators to simultaneously see various prototype designs. EVL **SAGE** software is used to display multiple files in the CAVE2.

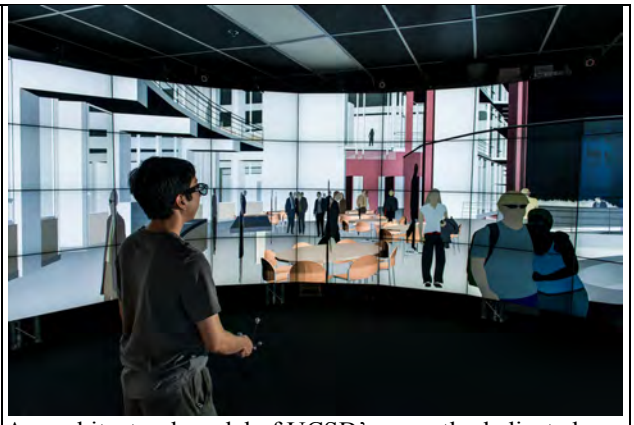
The NASA-funded SIMPLE project (Sub-ice Investigation of Marine and Planetary-analog Ecosystems) is a collaboration of UIC, Stone Aerospace, NASA Ames Research Center and Montana State University. This project is furthering biological research in terrestrial environments analogous to those found on other planets, to enable remote searches for, and identification of, life in extreme environments. By experimenting with using an autonomous underwater vehicle (AUV) to capture 3D biogeochemical information in the extreme environment of West Lake Bonney, a perennially ice-covered Antarctic dry valley lake in the McMurdo Dry Valleys of Antarctica, this project hopes to apply what it learns to planetary science, such as capturing and analyzing information about the water ice surface of Jupiter's moon, Europa. EVL **SAGE** software is used to display multiple files in the CAVE2.



Professor Andy Johnson interactively flies around a 3D representation of Mars in the CAVE2. The planet Mars was originally created by EVL graduate Robert Kooima with data from the NASA Mars Global Surveyor and Viking missions, and star data from the European Space Agency Hipparcos mission. Kooima's **Electro** software is used to display the 3D model in the CAVE2.

Individuals in the CAVE2 interactively fly through Earth's galaxy to observe constellations from different viewpoints. Data is from the European Space Agency's Tycho-2 catalog, which contains the positions and magnitudes of more than 2.5 million of the brightest stars collected by the star mapper of the Hipparcos satellite. EVL graduate Robert Kooima created this application; his **Electro** software is used to display it in the CAVE2.

As a demonstration of cultural heritage, EVL research assistant and computer science graduate student Arthur Nishimoto displays Medinet Habu, the Mortuary Temple of Ramesses III located on the West Bank of Luxor in Egypt, in the CAVE2. The 360-degree photographic image was taken by Tom DeFanti of Calit2/UCSD with the assistance of Adel Saad and Greg Wickham of King Abdullah University for Science and Technology in Saudi Arabia, using the CAVEcam camera developed by Dick Ainsworth, Dan Sandin, and Tom DeFanti. Images were stitched together by Dick Ainsworth. Calit2's **CalVR** software is used to display this 3D model in the CAVE2.



An architectural model of UCSD's recently dedicated Structural and Materials Engineering (SME) building is shown in the CAVE2 by EVL research assistant and computer science graduate student Arthur Nishimoto. The Graphics, Visualization and Virtual Reality Laboratory (GRAVITY) at the UCSD Jacobs School of Engineering produced the SME model. Calit2's **CalVR** software used to display this 3D model in the CAVE2.

CAVE2 displays a 3D model of a section of the rebar cage of the San Francisco-Oakland Bay Bridge created by American Bridge Company/Fluor Enterprises. A UCSD Structural Engineering student and UCSD computer science professor Jurgen Schulze ported to virtual reality. It is displayed with Calit2's **CalVR** software.

Artist and EVL co-director emeritus Dan Sandin ported his virtual-reality art work, "Particle Dreams," to CAVE2. It is displayed with Calit2's **CalVR** software.

Jonathan Fay, Microsoft Research, & Chris Laurel ported World Wide Telescope to CAVE2; it uses **Windows**.

In addition, EVL will be conducting classes in the CAVE2, in Fall 2013, to encourage faculty and students to use its hybrid environment for classroom discussion and projects. EVL has already conducted some classes and meetings, in the CAVE2, as shown here.

EVL director Jason Leigh held a weekly Tech Meeting in CAVE2 when it was first developed. Students push content onto the walls of CAVE2 using **SAGE**.

EVL professor Andy Johnson moved his Data Visualization class into CAVE2 for a day. Students push content onto the walls of CAVE2 using **SAGE**.

1.C. CAVE2 Publicity

1.C.1. CAVE2 Articles and Media Coverage

December 18, 2013. Al Jazeera America television station aired a science story on the NASA-funded ENDURANCE project and CAVE2: http://youtu.be/RB3UAEIEm1I

November 11, 2013. Think ING, a German engineering publication featured a story on CAVE2: https://www.think-ing.de/index.php?media=10934

October 14, 2013. Chicago Ideas Week provided CAVE2 tours. An article appeared in the Chicago Tribune: http://my.chicagotribune.com/#section/-1/article/p2p-77845730/

September 18, 2013. TechHive, a publication of PC World, published the article "The art of numbers: Who knew Big Data could look so cool?": http://www.techhive.com/article/2048715/the-art-of-numbers-who-knew-big-data-could-look-so-cool-.html

August 20, 2013. NSF "Science Nation" produced and published a print and video story on CAVE2: http://science360.gov/obj/video/f4a9db5d-e84c-44e4-a47c-00bd661c81c9/cave2-immerses-scientists-engineers-research-literally

August 13, 2013. The online Spanish publication "lainformacion.com" featured CAVE2: http://noticias.lainformacion.com/ciencia-y-tecnologia/ciencias-general/la-sala-de-realidad-virtual-que-puede-cambiar-la-ciencia_8TqJqCqNaMbwT1hfuSHYd6/

July 24, 2013. Illinois Science & Technology Coalition (ISTC) Catalyst, July 2013 issue, published the EdTech video (May 22, 2013), info@istcoalition.org

July 22, 2013. Mechdyne, the company that licensed CAVE2, created an informational video: http://youtu.be/uKeL0CXp54I

July 10, 2013. Mechdyne, the company that licensed CAVE2, created a promotional video: http://youtu.be/oNO7Yhg501A

May 22, 2013. "Visualizing Next-Generation Virtual Reality in Chicago" (video), EdTech: Focus on Higher Education, http://www.edtechmagazine.com/higher/video/visualizing-next-generation-virtual-reality-chicago

May 17, 2013. "How Much Would It Cost to Build the Starship Enterprise?," Gizmodo: http://gizmodo.com/how-much-would-it-cost-to-build-the-starship-enterprise-506174071

April 23, 2013. "CAVE2" (video and print), WTTW (PBS Chicago), "Chicago Tonight": http://chicagotonight.wttw.com/2013/04/23/cave2

April 2013. NSF FY 2014 Budget Request to Congress: http://www.nsf.gov/about/budget/fy2014/pdf/01_fy2014.pdf

March 13, 2013. American Society for Engineering Education (ASEE), First Bell: http://mailview.custombriefings.com/mailview.aspx?m=2013031301asee&r=5866572-2c82

March 7, 2013. Commercial Integrator, "University of Illinois CAVE2 Project Redefines Immersive Video": http://www.commercialintegrator.com/article/university_of_illinois_cave2_project_redefines_immersive_video/P2

March 5, 2013. UIC NEWS, "Step into CAVE2 virtual world": http://news.uic.edu/step-into-a-virtual-world

March 5, 2013. Mechdyne, "Mechdyne Corporation Licenses CAVE2 Hybrid Reality Environment from the University of Illinois at Chicago": http://www.mechdyne.com/article.aspx?id=238&Mechdyne+Corporation+Licenses+CAVE2T+Hybrid+R

eality+Environment+from+the+University+of+Illinois+at+Chicago

March 2013. John Peddie Research, "S3D Market Opportunities" (mentions CAVE technology): http://jonpeddie.com/publications/s3d-market-opportunities/

March 2013. John Peddie Research, "Dynamics in SoC, GPU, and IP markets" (mentions CAVE technology): http://www.jonpeddie.com/publications/work_station_report/#TOC

February 28, 2013. Charlie Meyerson, "Chicago has a 'Project Batman' and it's hiring," WBEZ 91.5 (NPR radio blog): http://www.wbez.org/blogs/charlie-meyerson/2013-02/chicago-has-project-batman-and-its-hiring-105799; http://youtu.be/3wMpHZs0F7k

February 26, 2013. io9, "New virtual reality CAVE brings us one step closer to Star Trek's Holodeck": http://io9.com/5986569/new-virtual-reality-cave-brings-us-one-step-closer-to-star-treks-holodeck

February 25, 2013. Time, "CAVE2: Not a Star Trek Holodeck Yet, but Getting Closer": http://techland.time.com/2013/02/25/cave2-not-a-star-trek-holodeck-yet-but-getting-closer/#ixzz2OrdO3zDR

February 25, 2013. NSF: "International Team Targets Innovations in STEM Learning" (photo illustration): http://www.nsf.gov/news/news_summ.jsp?cntn_id=127063&WT.mc_id=USNSF_51&WT.mc_ev=click

February 20, 2013. Discovery Canada's "Daily Planet": http://watch.discoverychannel.ca/#clip869617

February 20, 2013. Associated Press[1], "Star Trek-style holodeck becomes reality as scientists invent 3D virtual reality system": http://bit.ly/XkTdjP

February 20, 2013. Associated Press[1], "A giant 3D experience for scientists": http://www.youtube.com/watch?v=aetwWTER4hE

February 20, 2013. Associated Press[Error! Bookmark not defined.], "Future science: Using 3D worlds to visualize data": http://bigstory.ap.org/article/future-science-using-3d-worlds-visualize-data

January 2013. EdTech: Focus on Higher Education, "University of Illinois at Chicago: Virtual Reality's CAVE Pioneer": http://www.edtechmagazine.com/higher/article/2013/01/university-illinois-chicago-virtual-realitys-cave-pioneer

January 2013. University of Illinois Hospital & Health Sciences System, "CAVE2 - Large Scale Next Generation Virtual Environment": http://hospital.uillinois.edu/About_UI_Health/Newsletter/2013-01/CAVE2_-_Virtual_Environment.html?utm_source=newsletter_jan&utm_medium=email&utm_content=CAVE2&utm_campaign=Jan_Newsletter

December 2012. UIC OVCR Annual Report 2011: http://www.evl.uic.edu/core.php?mod=4&type=4&indi=836

Winter 2012. UIC Alumni Magazine, "Discoveries Channeled": http://www.uiaa.org/uic/news/uicalumni/1212c.html

December 2012. University of Illinois President's Season's Greetings email: website no longer functional

December 14, 2012. NSF Science 360: http://news.science360.gov/archives/20121214

December 11, 2012. NSF, "State-of-the-Art Virtual Reality System Is Key to Medical Discovery": www.nsf.gov/news/news_summ.jsp?cntn_id=126209&WT.mc_id=USNSF_51&WT.mc_ev=click

November 28, 2012. Medill Reports, "Move Over, Holodeck":

[1] As of March 13, 2013, Associated Press print and video stories were picked up by 530 media outlets worldwide.

http://news.medill.northwestern.edu/chicago/news.aspx?id=211746&terms=mitch%20smith

November 7, 2012. NSF Science 360 (sidebar), "Today's Exclusive: CAVE2 – An Advanced Cyberworld For Data Exploration": http://news.science360.gov/archives/20121107/

November 1, 2012. Planar Systems case study, "University of Illinois": http://casestudies.planar.com/#vertical-markets/education/university-of-illinois

October 30, 2012. Medill Reports, "Move over NASA: Explore the surface of Mars with virtual reality": http://news.medill.northwestern.edu/chicago/news.aspx?id=209741

October 14, 2012. Chicago Ideas Week demonstrations. ABC News the CAVE2 as well as a brief interview with EVL director Jason Leigh: http://abclocal.go.com/wls/story?section=news/local&id=8839408

October 3, 2012. UIC NEWS, "Showcase for Innovation, Ideas": http://www.uic.edu/htbin/cgiwrap/bin/uicnews/articledetail.cgi?id=16698

October 3, 2012. EVL Web, "CAVE2™: An Advanced Cyberworld for Data Exploration": http://www.evl.uic.edu/core.php?mod=4&type=4&indi=824

May 2009. EVL Web, "CAVE2: Next-Generation Virtual-Reality and Visualization Hybrid Environment for Immersive Simulation and Information Analysis": http://www.evl.uic.edu/core.php?mod=4&type=1&indi=424

1.C.2. CAVE2 Videos

November 21, 2013. "EVL Graduates Mentor Spark Middle School Students 2013": http://youtu.be/Xorgyc7CPGg

November 12, 2013. "Particle Dreams In Spherical Harmonics": http://www.youtube.com/watch?v=rMRa92weadU

July 2013. "Immersive Visualization of Whole-Brain Tractography in CAVE2": http://youtu.be/8TGOo_EvvNU

February 28, 2013. Calit2 "Terminating the GLIF at UCSD": http://youtu.be/Ar7vmMIM7q8

December 2012. CAVE2 Documentary: http://youtu.be/yf0sllpZx3w

December 2012. CAVE2 Trailer #2: http://youtu.be/vK74PP4kHHM

October 7, 2012. ABC-TV Channel 7, Chicago: http://abclocal.go.com/wls/video?id=8839945&pid=8839408

October 1, 2012. CAVE2 Trailer #1: http://youtu.be/d5XDbzy7vuE

1.C.3. CAVE2 Presentations and Meetings

October 16, 2013. Jason Leigh gave a talk on CAVE2 and virtual reality to the Chinese Academy of Forestry, Beijing.

October 14, 2013. An informal opening of the CAVE2 at Monash University was held, with Jason Leigh and Maxine Brown in attendance. Leigh gave a CAVE2 presentation to interested faculty. Monash is also in discussions with EVL about future CAVE2-to-CAVE2 research collaborations.

August 15, 2013. Mechdyne hosted a symposium for its manufacturing customers, to introduce them to the CAVE2 technology; Jason Leigh, EVL director, is a keynote speaker followed by CAVE2 demonstrations.

June 4, 2013. Maxine Brown attended a UIC meeting with representatives of University of Technology, Sydney (Australia), who were interested in collaborating with UIC in the areas of Human Centered

Technology Design and Contemporary Design Practice. Brown discussed EVL's classroom of the future (Cyber-Commons) and CAVE2.

May 30-June 1, 2013. Jon Peddie, Russia COFES 2013, St. Petersburg, Russia: http://www.cofes.com/Events/COFESRussia2013/tabid/610/Default.aspx

May 25, 2012. Representatives from Chicago's Field Natural History Museum visited EVL to discuss possible collaborations and integrating EVL technologies into the Field Museum exhibits.

May 23, 2013. At a symposium in honor of Paul Wielinga, a long-time collaborator who was retiring from SURFsara (formerly SARA) in The Netherlands, Maxine Brown gave a remote presentation about visualization, virtual reality, collaborative spaces and EVL's many years of collaboration with SARA.

April 25-26 2013. Jon Peddie, RTT Excite 2013, Munich Germany: http://www.rtt.ag/en/events/rtt-excite-2013/overview/

April 22-25, 2013. Maxine Brown gave presentations on CAVE2 and SAGE at the DOE Computer Graphics Forum (DOECGF 2013), held in Portland, Oregon.

April 23-26 2013. Jon Peddie, FMX2013, Stuttgart Germany: www.fmx.de

April 22-28, 2013. Andy Johnson participated in the Big Data Week conference organized by the City of Chicago's Department of Innovations and Technology, and talked about the Batman project EVL is doing in the CAVE2.

April 17, 2013. Colleague Laurin Herr of CineGrid showed EVL technologies in his presentation at the Digital Entertainment Leadership Forum at Hong Kong Cyberport.

April 11-14 2013. Jon Peddie, COFES 2013, Scottsdale, Arizona: http://www.cofes.com/Events/COFES2013/tabid/592/Default.aspx

April 6, 2013. Colleague Laurin Herr of CineGrid showed EVL technologies in his presentation to the SMPTE Digital Cinema Technology Summit at the annual NAB conference in Las Vegas.

March 2, 2013. Jason Leigh presented at Media X's Augmented Decision Systems Concepts, Incentives, and Requirements Workshop, Stanford University.

February 26, 2013. Tom Schenk Jr., "Chicago has a 'Project Batman'," talked about CAVE2 at the OpenGov Chicago, <streamed live at http://youtu.be/3wMpHZs0F7k>

February 4-5, 2013. Alessandro Febretti presented the paper "CAVE2: A Hybrid Reality Environment for Immersive Simulation and Information Analysis" at the IS&T/SPIE Electronic Imaging, International Society for Optics and Photonics, San Francisco, CA.

February 2013. UIC Office of Sustainability and the Sustainability Strategic Thinking Advisory Committee, student intern did a Powerpoint presentation that included CAVE2 (to be posted online): http://www.uic.edu/sustainability/thinking/

January 29, 2013. Jason Leigh gave an EVL presentation at the first Fred Dech Memorial Lecture, University of Chicago Medical Center.

January 23, 2013. Jason Leigh gave an invited presentation on EVL research and development at the bi-annual meeting of the University of Illinois Board of Trustees. The UIC Chancellor's Office distributed 3D glasses to attendees as a giveaway, and encouraged trustees to visit EVL and tour CAVE2.

January 17, 2013. EVL collaborative research with Argonne National Laboratory that utilizes CAVE2 was referenced in the Argonne State of the Laboratory address: http://www.anl.gov/events/state-laboratory-address

November 13, 2012. At SC12, Maxine Brown and Luc Renambot met with Ed Seidel and Gabrielle Allen, currently at Skolkovo Institute of Science and Technology in Russia, to discuss future collaboration and technologies (including tiled display walls and CAVE2).

November 13-15, 2012. Maxine Brown and Luc Renambot attended SC12 and held a SAGE BOF that attracted ~50 national/international people. Renambot's gave an overview of SAGE extensions, and how it now runs in CAVE2. For information, see: www.sagecommons.org/sage-bof-session-at-sc12/

October 14-19, 2012. EVL PhD candidate Thomas Marrinan presented the poster "Whole-Brain Vascular Reconstruction, Simulation, and Visualization" at the IEEE VisWeek 2012 Conference in Seattle, Washington. The poster was awarded an Honorable Mention. This application was one of the first applications ported to CAVE2 when it was built.

1.C.4. CAVE2 Demonstrations, Tours and Meetings

November 20, 2013. Board members of the Illinois First Robotics toured CAVE2.

November 11, 2013. EVL participated in the UIC Computer Science Open House, and gave tour/demo to local minority high school students being recruited to UIC for college.

November 6, 2013. The UIC Physics 112 AstroLab class visited CAVE2 to see astronomy examples.

October 28, 2013. EVL was visited by a delegation from University of Electronic Science and Technology of China to learn more about EVL's activities, including CAVE2.

October 24, 2013. Michael Meyer, lead scientist for Mars Exploration Program at NASA Headquarters, visited UIC and EVL's CAVE2.

October 18, 2013. Peter Tan, UIC alum and President of BenQ Latin America Corporation, toured EVL.

October 14, 2013. EVL participated in the UIC Computer Science Open House, and gave tour/demo to local minority high school students being recruited to UIC for college.

October 14, 2013. EVL participated in Chicago Ideas Week and gave CAVE2 tours/demos.

August 15, 2013. Mechdyne is hosting a symposium for its manufacturing customers; Jason Leigh, EVL director, is a keynote speaker followed by CAVE2 demonstrations.

July 26, 2013. Representatives of the National Center for High-performance Computing (NCHC) in Taiwan visited EVL to introduce the new Center director, and to discuss ways to more closely collaborate. Attending were: Ce-Kuen Shieh (director), Li-Der Chou, Weicheng Huang, Li-Chi Ku (NCHC) and Chu-Sing Yang (National Cheng Kung University).

July 25, 2013. EVL did tour/demo for 18 children, grades 4-6, who are attending the Baker Demonstration School's summer program. The School has developed a pilot STEM program.

July 25, 2013. EVL did tour/demo for high school and middle school teachers attending UIC's Project Lead The Way (PLTW) summer program to study digital electronics and principles of engineering.

July 25, 2013. EVL did tour/demo for students participating in the UIC Minority Engineering Recruitment & Retention Program.

July 24, 2013. EVL did demos for David Kohler, President and COO of Kohler Company.

July 24, 2013. Brazilian collaborators Tereza Cristina Carvalho and Fernando Redígolo from University of Sao Paulo visited EVL to discuss SAGE and tiled displays, and see the new CAVE2.

July 24, 2013. EVL hosted representatives from the University of the Sunshine Coast in Australia who are interested in building a CAVE2 in a new campus building. Visiting were John Bartlett, Selvan Pather, Patrea Andersen and Iona Beauly, as well as architect Ian Brewster.

July 12, 2013. EVL did tour/demo for students participating in the UIC Minority Engineering Recruitment & Retention Program.

July 8, 2013. EVL did tour/demo for high school and middle school teachers attending UIC's Project Lead The Way (PLTW) summer program to study 3D CAD.

July 8, 2013. Mechdyne brought its client PepsiCo for a CAVE2 demo.

July 3, 2013. Maria Roussou, an interaction and virtual-reality designer, researcher, educator, and consultant, and an Adjunct Lecturer at University of Athens, visited EVL to see its latest technologies.

June 25, 2013. EVL did CAVE2 and SAGE demonstrations for 250 visitors attending the U.S. Ignite conference in Chicago (shown in this photo).

June 20, 2013. EVL did CAVE2 and SAGE demonstrations for 15 students from Imam University, Saudi Arabia, who visited UIC for one week as part of a scientific trip to the U.S.

June 12, 2013. Mechdyne brought its client Experience Art & Design for a CAVE2 demo.

June 12, 2013. Eric Wernert of Indiana University visited EVL for a CAVE2 demo.

June 7, 2013. UIC Chancellor Paula Allen-Meares and University of Illinois Foundation board member Leon Loichle visited EVL for a CAVE2 demo.

June 6, 2013. Representatives from Boeing came to see CAVE2.

May 21, 2013. EVL hosted tour/demo for students from Chicago's Martin Luther King High School (shown in this photo). The students also got an overview of UIC from the College of Engineering's "Project Lead the Way" program that helps recruit high-school students to attend UIC.

May 20, 2013. Dieter Hartmann, Department of Physics & Astronomy, Clemson University, visited EVL to learn more about EVL's Cyber-Commons classroom and CAVE2.

May 16, 2013. Mechdyne visited EVL to learn more about CAVE2 and also about SAGE.

May 13-15, 2013. Robert Horn of the Human Science and Technology Advanced Research Institute (H-STAR) at Stanford University visited EVL to learn more about its advanced technologies.

May 13, 2013. EVL did a remote collaboration demo with Calit2 using SAGE and CAVE2, networked to Calit2's Vroom room. Larry Smarr had visitors Richard Wurman and ESRI (geographical mapping company). EVL showed various geoscience and mapping applications.

May 9, 2013. Rosie Foulke from Sensory Technologies visited EVL for tour/demo.

May 7, 2013. Guangxing Wang from Southern Illinois University at Carbondale and visitors from the Research Institute of Forest Resource Information Techniques, Chinese Academy of Forestry, Beijing, China (Hongbo Ju, Huaiqing Zhang, Wang Xiaohui and Zhao Fen) visited EVL for a CAVE2 tour/demo.

May 3, 2013. Brian Mitchell and Stuart Connell from GE Global Research visited EVL for a tour/demo.

April 30, 2013. EVL hosted a one-hour meeting of the UIC Office of Governmental Relations and Lewis-Burke group to discuss the White House's Brain Initiative, and to see CAVE2 brain demos.

April 29-30, 2013. The UIC Physics department's introductory Astronomy Class ("AstroLab"), brought 3 labs, each with 24 students, for one-hour CAVE2 experiences – focusing on astronomical applications (e.g., Mars, constellations, WorldWide Telescope).

April 26, 2013. Steve Ellis from NASA visited EVL for a tour/demo.

April 26, 2013. EVL did a presentation/tour for students from the Northwestern University Medill School of Journalism.

April 24, 2013. EVL hosted one of three Spring 2013 CAVE2 Open Houses to accommodate people interested in experiencing UIC's new Virtual Reality Environment. Approximately 180 people attended over a 3-hour period (this photo shows one group in the CAVE2).

April 23, 2013. Rebecca Muyal, a graduate student at the University of Manitoba in the Faculty of Architecture, is doing her thesis on evaluating the effectiveness of CAVEs in architecture. She came to evaluate CAVE2. (She will be visiting Brown University to see a CAVE.)

April 23, 2013. Several members of the UIC COE Industrial Advisory Board toured CAVE2: Andy Dunham (Baxter Healthcare Corp.), Scot Greenlee (Exelon Nuclear), Robert Hauck (GE Healthcare), Audra Karalius (formerly with Sara Lee), and John Regan (Illinois Ventures, LLC). In addition, Larry Hill, Assoc. VP for Research and National Labs at University of Chicago, along with several architects, visited to get technology ideas to incorporate in a new space that the University is building out.

April 18, 2013. Shinji Shimojo of Osaka University in Japan visited EVL to learn about EVL's Cyber-Commons and CAVE2 systems. Shimojo's group is a major SAGE user, and does many SAGE networked demonstrations with several PRAGMA institutions in Asia. Osaka's CyberMedia Center (CMC) is now a national supercomputing center and he wants to build a "Cyber-Commons" to provide more advanced networked visualization services. Also, the Osaka government recently built 4 buildings known as the Knowledge Capital, and he wants to install a CAVE2 in the "Science Lab" building.

April 5, 2013. Chris Kennedy, Chair of the University of Illinois Board of Trustees, visited EVL for tour/demos.

April 4, 2013. Margarete Jadamec, NSF Postdoctoral Research Fellow at Brown University, visited EVL for tour/demos.

April 3, 2013. EVL hosted one of three Spring 2013 CAVE2 Open Houses to accommodate people interested in experiencing UIC's new Virtual Reality Environment. Approximately 180 people attended over a 3-hour period.

March 28, 2013. Emily Wang, Department of Otolaryngology, Rush University Medical Center, visited EVL for a tour/demo of CAVE2.

March 28, 2013. Mechdyne visited EVL to see CAVE2.

March 25, 2013. Kenji Tanaka, Graduate School of Information Science and Technology, The University of Tokyo, visited EVL for a tour/demo of CAVE2.

March 21, 2013. Jessica Roeder and Joe Kochan, US Ignite, made a site visit to EVL to discuss CAVE2 demonstrations during the US Ignite conference, to be held in Chicago in June 2013.

March 20, 2013. Maureen Parks, University of Illinois Vice President of Human Resources, toured CAVE2 with her family.

March 11, 2013. Representatives of the UIC Computer Science Department, OVCR and OBFS, visited EVL and got a tour of CAVE2.

February 25, 2013. The 12th Annual ON*VECTOR International Photonics Workshop was held at Calit2/UCSD, sponsored by NTT Network Innovation Laboratories, and organized by Pacific Interface Inc. The highlight of the Workshop was Larry Smarr's presentation "Terminating the GLIF at UCSD,"

which was a SAGE collaborative session between Calit2/UCSD and EVL's CAVE2, using SAGE.

Larry Smarr SAGE presentation with EVL.


Calit2/EVL collaborative CalVR demo.

February 22, 2013. Philip Galanter, Department of Visualization, Texas A&M University, visited EVL.

February 21, 2013. Jonathan Fay of Microsoft Research and Chris Laurel visited EVL to work on putting World Wide Telescope (WWT) in the CAVE2

February 20, 2013. EVL hosted one of three Spring 2013 CAVE2 Open Houses to accommodate people interested in experiencing UIC's new Virtual Reality Environment. Approximately 150 people attended over a 3-hour period.

February 19, 2013. Jonathan Fay of Microsoft Research and Chris Laurel visited EVL to work on putting World Wide Telescope (WWT) in the CAVE2

February 18, 2013. EVL did tours/demos for the UIC Computer Science Open House, to recruit high-school children to attend UIC.

February 6, 2013. Rohit Varma, UIC Department of Ophthalmology and Visual Sciences, visited EVL and toured CAVE2.

February 6, 2013. Rajiv Ranaganathan of the Physical Medicine and Rehabilitation Department, Northwestern University visited EVL and toured CAVE2.

January 30, 2013. Christopher Kennedy, Jr. (son of Chris Kennedy, chair of Univ. of Illinois Board of Trustees) toured the CAVE2.

January 24, 2013. Thom Lendvay of University of Washington and Michael Scott of the UIC Mechanical Engineering Department toured CAVE2.

January 22, 2013. Northwestern University Medill School of Journalism graduate student Alan Yu visited EVL to interview Maxine Brown about StarLight and CAVE2.

January 14, 2013. Mechdyne visited EVL to see CAVE2.

December 21, 2012. Skidmore, Owings and Merrill and Argonne National Laboratory representatives toured CAVE2.

December 18, 2012. Human Capital Research Corporation (HCRC) visited EVL to learn about visualization technologies.

December 9, 2012. EVL did a live high-definition video tour of CAVE2 to the CineGrid audience in San Diego.

December 7, 2012. Maxine Brown and Andy Johnson hosted two visitors from Universidad Industrial de Santander, Colombia, South America. Laura Prada and her colleague were interested in developing tiled display walls running SAGE and in building a CAVE2.

December 3, 2012. EVL hosted tour/demo for a "Meet and Greet" event sponsored by the UIC Graduate

College's Recruiting Division, which encourages prospective applicants (specifically, McNair Scholars, students with strong academic performance and research work) to attend UIC for graduate school. The Meet and Greet events expose students to life as a UIC graduate student, provide a campus tour, and match prospective students with advisors to the College to which they are applying.

December 1, 2012. MidGraph (Midwest Computer Graphics Workshop) held reception and open house at EVL for approximately 60 people.

November 15, 2012. EVL hosted tour/demo for a "Meet and Greet" event sponsored by the UIC Graduate College's Recruiting Division, which encourages prospective applicants to attend UIC for graduate school.

November 12, 2012. EVL participated in the UIC Computer Science Open House, and gave tour/demo to local minority high school students being recruited to UIC for college.

November 2, 2012. Adler Planetarium came to see CAVE2 and discuss possible virtual-reality collaborations.

October 31, 2012. Matthew Bolton from UIC Mechanical Engineering Department visited EVL.

October 30-Nov 2, 2012. Northwestern Medill journalism student Mitch Smith visited EVL and subsequently wrote a news article about CAVE2.

October 29, 2012. Two classes from the School of the Art Institute and one class from UIC Art & Design toured EVL and saw SAGE and CAVE2 demos.

October 18, 2012. EVL hosted Sachiko Kamiyama of Mitsubishi Chemical Holdings, Inc. (MCH). She is a member of The Kaiteki Institute Company, the strategic think-tank of MCH. She visited EVL to analyze technologies and propose strategies to MCH and its subsidiaries. Accompanying her was Yukihisa Namiki, CEO of World Intellectual Property Holdings, who is a technology consultant for MCH.

October 17, 2012. Northwestern Medill journalism student Meghan Leach visited EVL to develop a news story about CAVE2.

October 12, 2012. Adler Planetarium came to see CAVE2 and discuss possible virtual-reality collaborations.

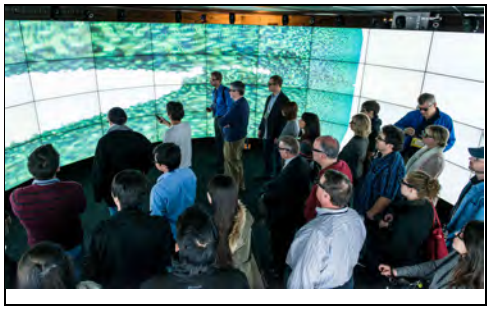
October 12, 2012. EVL did tour/demo for the UIC COE Industrial Advisory Board.

October 11, 2012. EVL hosted demos, including a CAVE2-to-StarCAVE demo between EVL in Chicago and Calit2/UCSD in San Diego, as part of the GLIF 12th Annual Global LambdaGrid Workshop. Virtual-reality images, 360-degree photographic panoramic CAVEcam images, and LiDAR scans were interactively shared between the CAVE2 at EVL and the NexCAVE and Vroom at Calit2 (photo shows GLIF attendees in CAVE2 with data being steered by Calit2).

October 9, 2012. Mechdyne visited EVL to see CAVE2.

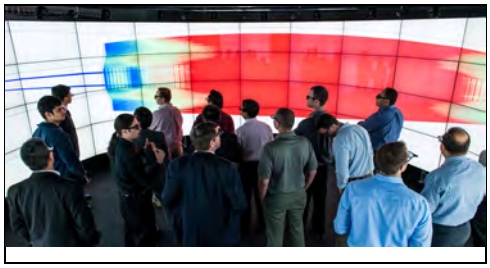
October 8, 2012: EVL did tour and SAGE and CAVE2 demos for UIC Computer Science Open House.

October 8, 2012. EVL did tour/demo as part of Chicago Ideas Week, and premiered CAVE2 (shown in this photo).



October 2, 2012. EVL participated in the UIC Computer Science Open House, and gave a presentation and technology demonstrations to local minority high school students being recruited to UIC for college.

September 16, 2012. EVL did tour/demo for the National University Rail Center (NURail) Workshop, which was held at UIC. EVL receives funding to do visualization, so attendees got to stand inside virtual train tracks in the CAVE2 System and observe distortion as high-speed trains roar past (shown in this photo).



August 29, 2012. EVL did demonstrations for Timothy S. Kroecker, Corporate Development Officer of the Air Force Research Laboratory, Information Directorate, located in Rome, NY. He was visiting UIC to recruit and promote collaboration with members of the UIC College of Engineering.

July 31, 2012. EVL did tour/demo for UIC Project Lead The Way High-School Teacher Workshop (shown in this photo).

June 25, 2012. Anwar Osseyran and Sander Ruiter of the SARA supercomputing center in The Netherlands were in Chicago to visit NCSA, but stopped by EVL to learn about our latest technologies. SARA built a CAVE almost 20 years ago, and Osseyran got to see the new CAVE2 structure as it was being built.

May 8, 2012. Maria Roussou, an interaction and virtual-reality designer, researcher, educator, and consultant, and an Adjunct Lecturer at University of Athens, visited EVL to see its latest technologies.

May 8, 2012. University of Birmingham (U.K.) professors Richard Clay and Henry Chapman visited EVL.

1.C.5. Other Meetings Related to CAVE2

April 6, 2013. Lance Long of EVL attended the National Association of Broadcasters (NAB) exhibition in Las Vegas.

February 15, 2013. Jason Leigh, Andy Johnson and Maxine Brown attended the Urban Sciences Research Coordination Network Workshop in Chicago, organized by University of Chicago's Urban Center for Computation and Data (UrbanCCD).

June 13-14, 2012. EVL attended Infocomm 2012 in Las Vegas to learn more about state-of-the-art mono and stereo panel displays.

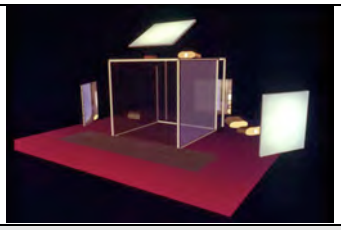
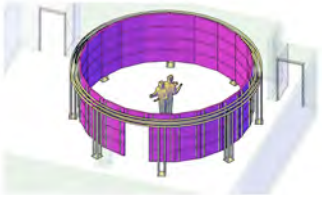
May 1-2, 2012. Maxine Brown participated in an NSF MRI Panel at NSF in Arlington, VA.

1.D. CAVE2 System

1.D.1. Comparison with the Original CAVE

CAVE2 is the world's first flat-panel-based, high-resolution CAVE (Cave Automatic Virtual Environment). It was developed by the UIC Electronic Visualization Laboratory (EVL) in October 2012 and commercialized by Mechdyne Corp in January 2013. EVL introduced the original CAVE in 1992 and commercialized it in 1994.

The CAVE2 is approximately 24 feet in diameter and 8 feet tall, and consists of 72 near-seamless passive-stereo off-axis-optimized 3D LCD panels, a 36-node high-performance computer cluster, a 20-speaker surround audio system, a 10-camera optical tracking system and an 80Gbps connection to the outside world. CAVE2 provides users with a 320-degree panoramic environment for displaying information at 37 Megapixels in 3D or 74 Megapixels in 2D with a horizontal visual acuity of 20/20 – almost 10 times the 3D resolution of the original CAVE for half the cost. This comparison chart shows the improvements between the CAVE2 and the original CAVE.

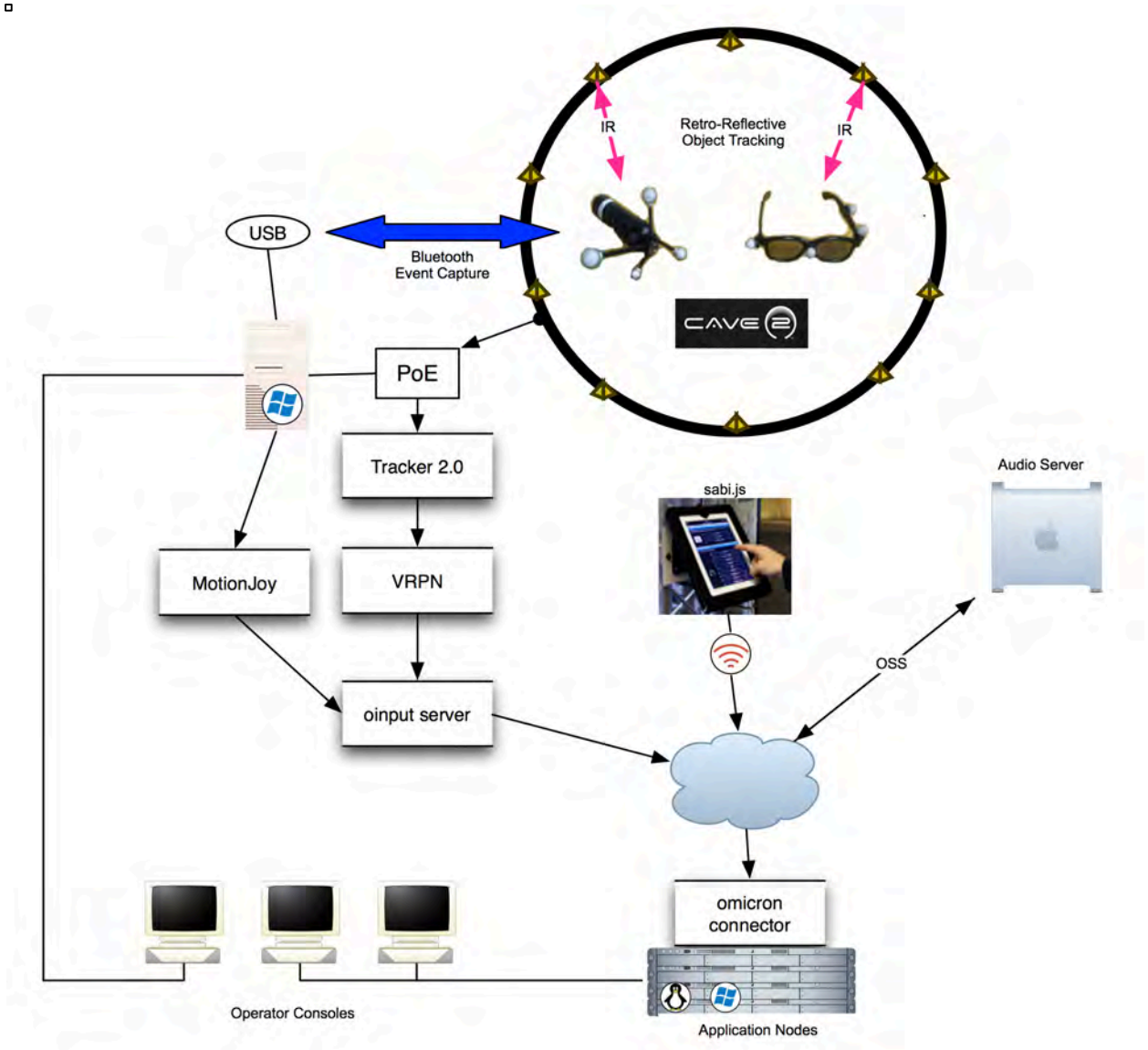
Image			
	CAVE	**CAVE2**	**Improvement**
Year	1992	2012	20 years
Size–Footprint	~30'x30' room with ~15' ceiling (CAVE 10'x10')	~30'x30' room with ~9' ceiling	Same
Virtual Reality Environment– Cubic feet	1,000 cu.ft. (10L x 10W x 10H)	3,167 cu.ft. (pi x radius 12ft.^{2} x 7H)	3X
Projection vs 3D LCD	4 Projectors	72 LCDs	n/a
Stereo Resolution (Megapixels)	2.6 (1280 x 512 x 4)	36 (1,366 x 736 x 72 / 2)	13X
Visual Acuity	20/110	20/20	–
Brightness (lumens)	4000 (1000 x 4)	266,400 (3,700 lumen x 72)	66.6X
Contrast Ratio	< 500:1	3,000:1	6X
Bulb life (hours)	2000 per projector	50,000 per LCD	25X
Display cost per stereo Megapixel	$35,000 (Electrohome Marquee 8000) base cost of projector is $23,000[2]	$14,000	2.5X
Processor	4x100 MHz MIPS R4000	36 x 2.9 GHz 16-core Xeon E5-2690	4,176X
Graphics	SGI Crimson VGXT	Nvidia GTX 680 2GB RAM	
Memory	256M	36 x 64GB	9000X
Storage	3.2GB	36 x 2TB	22,500X
3D Tracking	Tethered	Wireless	
Networking	10Mb/s	80Gb/s	8000X
Total Cost	$2M in today's dollars	$926K	50% cost

[2] http://www.curtpalme.com/PJSpecs_Electrohome.shtm

1.D.2. CAVE2 Environment

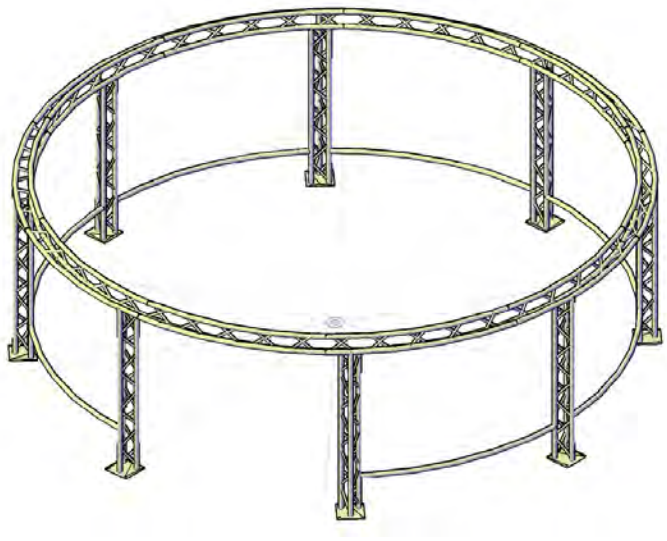
EVL upgraded both its showcase room and its server room with additional air conditioning and power to support CAVE2. The physical environment of the room presented some challenges; notably, the detrimental reflectivity and acoustic effects of the hard flooring, white porous ceiling tiles, and the CAVE2's large polygonal LCD glass surfaces. We installed high-sound-absorption, black acoustic ceiling and carpet tiles to mitigate the reflection of acoustic waves and the reflection of light emitted from the LCD displays. The carpet was made of partially recycled fiber, a textured product rated for high traffic and low maintenance. We also designed a logo and had signage created – brushed-finish, stainless-steel letters with backlit illumination, as shown in this photo.

The following sections will describe all the components of the CAVE2. Here is a block diagram.



1.D.3. CAVE2 Structure and Cabling

CAVE2 has a circular truss constructed of 10 equal arc segments with 8 legs and 7 lower truss chords. Each of the 72 display modules required one power cable, one video cable, and one network cable connecting the module to its corresponding quad controller/power supply/compute node. Varying lengths were ordered to accommodate the required runs around the CAVE2 cylinder and minimize bulk at the endpoints. Audio cables wired each speaker to the audio rack. Two remote consoles for the Windows and Linux head-nodes, located at the CAVE2 operator's bench just outside the perimeter, were also connected. A USB key for convenient model data loading into the Linux head-node was connected via a long USB 2.0 extension that terminates near an iPad control tablet at the CAVE2 entrance.

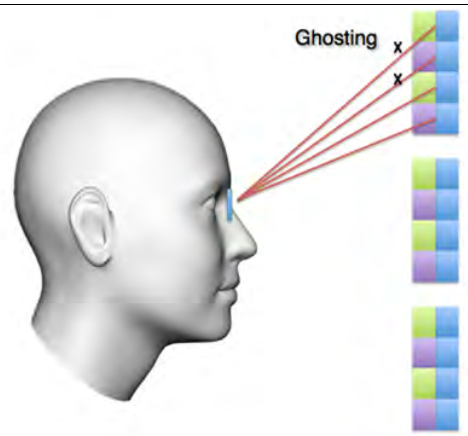


CAVE2 truss

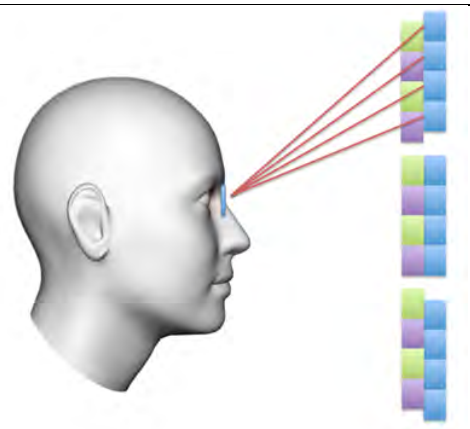
CAVE2 completed rack assembly

1.D.4. CAVE2 Displays

CAVE2 has 72 displays (18 columns x 4 rows) of interlaced passive-stereo displays arranged in ~6.7m diameter cylinder. The two middle rows consist of Planar's Clarity Matrix LX46L-3D 46" commercially available displays – which EVL partnered with Planar to design and develop; for more information, see Section 1.F.1. The top and bottom rows are custom-designed displays – also co-designed by EVL and Planar – in which the X-pol passive-stereo filters are offset to accommodate off-axis viewing, as illustrated in the diagram below.



Normal polarizer registration.



Shifted (-/+) polarizer registration for top and bottom rows.

1.D.5. CAVE2 Computer Cluster System and Networking

EVL leveraged DOE funding for "Blaze," Jason Leigh, PI, to provide computational support for CAVE2.

The CAVE2 cluster consists of 36 nodes (one per two displays), 1 Linux control node, 1 Windows control node, and a storage server. The nodes are mounted in three equipment racks in the adjacent air-conditioned machine room.

The cluster supports dual booting of Linux (SUSE) and Windows (Win 7). The Linux kernel is booted via PXE from the storage server, mounting local root and NFS storage locations. Network booting ensures each node is kernel-version-synchronized with PXE, replacing the need for GRUB to control boot device. Windows is installed locally and selectable via the PXE local boot option. The storage server is used as the cluster repository, giving us more flexibility to explore multiple OS use cases and remote dynamic storage models for tiled display software. The CAVE2 cluster and storage server are 80Gbps connected to StarLight, where they connect to other regional, national and international networks.

1.D.6. CAVE2 Motion Tracking and Interaction Devices

CAVE2 uses an optical motion tracking system consisting of 10 Vicon Bonita infrared cameras mounted to the circular truss and positioned above the displays to cover the entire volume of the CAVE2 environment. Retro-reflective markers are mounted in unique patterns on various objects (e.g., glasses and controllers), identified and registered into tracker memory. In use, the tracker recognizes and separately tracks those objects; i.e., the position and orientation of a user's stereo glasses (head) and navigation controller (hand) in six degrees of freedom. This allows for multiple controllers, users and yet-to-be-enabled devices to interact in the CAVE2 space independently, subject to the functionality the application may grant them. (For a list of current interaction devices, see Omicron, Section 1.E.2.)

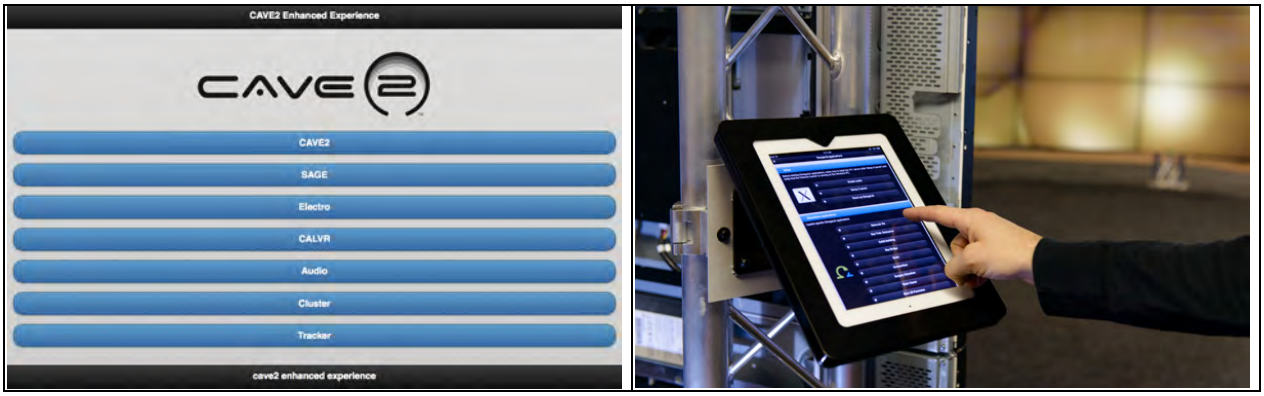
The primary user devices are the common Playstation Move controller and typical 3D cinema passive-stereo glasses. Retro-reflective balls are attached in unique patterns for the tracking system to identify each object and continuously track its position (x, y, z) and orientation (pitch, yaw, roll) in 3D space, as shown in this photo. The Playstation controller's Bluetooth communicates joystick and button events to CAVE2 applications.

1.D.7. CAVE2 Audio Hardware

The CAVE2 audio system is composed of 22 separate audio channels providing localized audio for visual content. A speaker is mounted at the top of each column of displays and oriented towards the viewer. The result is a full ring of audio shaped as a hypothetical cylinder centered within CAVE2, with a diameter and height matching the 3D viewing range of an average viewer. The subwoofers are located outside the CAVE2 cylinder on the floor, offset 90 degrees from the center of the visual environment. The CAVE2 sound server, a Mac Pro computer, runs the OmegaSound Audio Library (see Section 1.E.8).

1.D.8. CAVE2 Web Controller

A web-based graphical interface to control booting/OS/application selection, along with display and audio controls, is implemented on an iPad tablet mounted at the CAVE2 entrance. The web interface is also accessible from any mobile browser (e.g., tablet, phone, laptop).



1.E. CAVE2 Software

1.E.1. Operating System Environments

CAVE2 supports both Linux and Windows operating environments. Most CAVE2 middleware runs under Linux, but World Wide Telescope, an application developed by Microsoft Research, requires Windows.

1.E.2. Omicron User Interaction Library

Omicron was initially written to support OmegaDesk, an instrument funded by NSF MRI CNS-0821121, with software development funded by the UIC Vice Chancellor for Research Areas of Excellence Award for "Development of Railroad Research and Education at UIC." We have since made Omicron general purpose and extensible to support SAGE, OmegaLib and CalVR.

Omicron <https://code.google.com/p/omicron-sdk/> is a Software Development Kit (SDK) written in C++ that handles input from a number of novel input devices, and is designed for use on multiple visualization and virtual-reality displays**.** Some of the devices currently supported are:

- All motion capture systems supporting the VRPN protocol (e.g., the Vicon tracking cameras)
- NaturalPoint trackers (TrackIR, Optitrack)
- Wii controllers
- Xbox 360 controllers
- Microsoft Kinect (multiple Kinects supported)
- SAGE pointer connections
- PQLabs multi-touch overlays
- iPad touch interfaces and dynamic GUIs
- Thinkgear brainwave interfaces

Omicron input support can be integrated into C++ applications as a static library, or can be run as a standalone input server, streaming input data to multiple applications. Omicron comes with client-side interfaces for programs written in Unity, Processing and C++.

1.E.3. OmegaLib Middleware

Principal funding for OmegaLib came from NSF MRI "Development of OmegaDesk," Jason Leigh, PI, Award # CNS-0821121, 2008-2013.

OmegaLib <http://code.google.com/p/omegalib> is C++ middleware that is being designed to ease the development of applications on virtual-reality and immersive systems. Its main features are:

- Support for hybrid systems, presenting 2D and 3D content on the same display surface
- A C++ and Python API: Applications can be developed as standalone executables in C++ or as scripts in Python. OmegaLib also supports mixed native/script applications with user-defined C++ modules that can be exposed to Python through a simple declarative interface.

- Run-time application switching: applications can be reloaded or swapped without restarting the system.
- Display system scalability: OmegaLib runs on desktop machines, multi-GPU workstations driving tiled displays, and cluster systems such as the 36-machine, 72-display CAVE2.
- Web interface control and pixel streaming to HTML5 clients
- Experimental SAGE integration
- A customizable 2D/3D widgets library
- Support for a wide range of input peripherals through the Omicron toolkit
- Extendable integration with third-party high-level toolkits, such as VTK and Open Scene Graph.
- Sound playback through the OmegaSound Audio Library (see Section 1.E.8). OmegaLib takes care of synchronizing sound assets between the application and sound machines of a virtual-reality installation. The sound server is scalable (it runs on laptop stereo speakers or on the 22-channel CAVE2 audio system) and can be customized using OmegaSound.

Altough OmegaLib is designed for CAVE2, it can be used to develop applications on standard desktop systems, leveraging the power of multiple GPU units when available. The OmegaLib source distribution includes all required main dependencies and builds out-of-the-box on Windows, Linux (32- and 64-bit) and OSX 10.7 or higher.

1.E.4. SAGE Collaboration Middleware

Principal funding for SAGE comes from NSF STCI "OptIPlanet Cyber-Mashup," Jason Leigh, PI, award # OCI-0943559, 2009-2013.

CAVE2 is a hybrid environment that can display both 2D and 3D images at the same time. SAGE is being enhanced to support both 2D and 3D windows.

SAGE (Scalable Adaptive Graphics Environment, <http://www.sagecommons.org>) is unique in that it supports distance collaboration among multiple endpoints equipped with tiled display walls connected via high-speed networks. Users can simultaneously share ultra-high-resolution scientific visualizations with remote collaborators while communicating with them via multi-point high-definition video and audio streamed to the displays.

SAGE is cross-platform, open-source middleware that provides users with a common operating environment, or framework, to access, display and share a variety of data-intensive information – whether digital cinema animations, high-resolution images, high-definition video-teleconferencing, presentation slides, documents, spreadsheets or laptop screens – in a variety of resolutions and formats, from multiple sources, to one or more tiled display walls, with the same ease that the Web affords for accessing lower-resolution objects today. To make tiled display walls easier to use, SAGE also provides automated assistance to users to organize information, especially as the quantity of content grows.

1.E.5. CalVR Middleware

CalVR is being developed by the UCSD/Calit2's Immersive Visualization Laboratory (IVL). Given the EVL/IVL collaboration, EVL ported several Calit2-developed applications to CAVE2 (see Section 1.B).

CalVR <http://ivl.calit2.net/wiki/index.php/CalVR> is open source and royalty free, for non-profit use. CalVR contains the typical virtual-reality functionality of middleware such as CAVElib, COVISE, VRUI or FreeVR, and also supports nonstandard virtual-reality systems, such as auto-stereoscopic displays and multi-user viewing and interaction support. CalVR is object oriented and written in C++. Functionality can be added through a simple plug-in system, which allows compiling new modules separately from the main code. CalVR has built-in navigation algorithms, a 3D menu system, and support for a variety of 3D display and tracking systems, as well as support for collaborative work at different sites.

1.E.6. Electro Middleware

Electro was developed by EVL PhD graduate Robert Kooima, and several legacy applications developed

while he was an EVL student have been ported to CAVE2.

Electro <http://csc.lsu.edu/~kooima/electro/electro.html> is an application development environment designed for use on cluster-driven tiled displays, virtual-reality systems, and desktop workstations. Electro is based on the MPI process model and is bound to the Lua programming language. With support for 3D graphics, 2D graphics, audio, networking, and input handling, Electro provides an easy-to-use scripting system for interactive applications spanning multiple hosts and a variety of displays.

1.E.7. Google Earth

Google Earth <http://www.google.com/earth/index.html> has been downloaded to CAVE2 and runs under Linux. EVL has a funded research project with the City of Chicago that utilizes Google Earth.

1.E.8. OmegaSound Audio Library

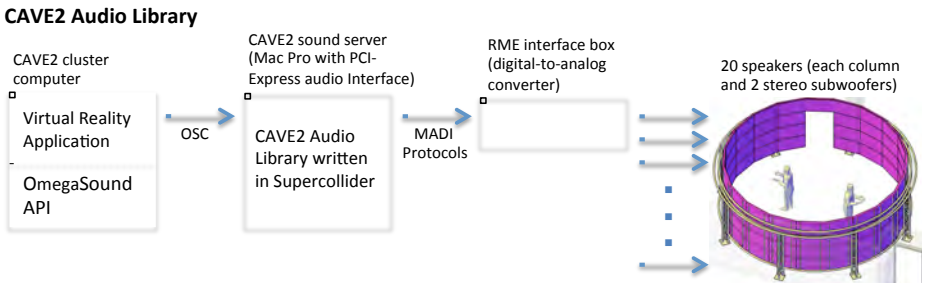
OmegaSound <http://docs.google.com/document/d/1DHKHlHZoXKkgnG1hAGNgZvb8HnGk3vC3HNXc5ZmZPqs/edit>, is an audio library written in SuperCollider <http://en.wikipedia.org/wiki/SuperCollider>, an open source programming environment for real-time audio synthesis and algorithmic composition. Notably, SuperCollider supports spatialized (i.e., localized) audio through a technique known as 2D Ambisonics. The CAVE2 Sound Server is controlled through Open Sound Control (OSC) messages.

One of the primary goals at the onset of CAVE2 audio software development was to develop a simple set of commands that interact with the sound server in order to facilitate playback and positioning of audio objects in virtual space. Individuals developing for CAVE2 access these commands via a C++ API.

The OmegaSound API abstracts many of the features necessary for interacting with the CAVE2 Sound Server (e.g., position of sound object relative to listener, location in virtual space), as well as formatting and sending OSC network messages. The result is a very simple set of commands to play, stop, or update sounds in virtual space. Ultimately, it will be capable of real-time audio synthesis, but now has the following basic functionality:

- Playback of mono audio samples
- Positioning of samples in virtual space
- Updating samples (e.g., location)
- Matching size of sound object to that of corresponding visual object
- Playback of ambient stereo or mono sources
- Application of reverb to sound objects, with controls for wetness/dryness and overall effect

The components of the audio library, hardware and software, are shown in the following diagram.



1.F. Significant Results

1.F.1. Commercialization

When the UIC Electronic Visualization Laboratory (EVL) received NSF funding in 2010 to build CAVE2, the 3D display screens we wanted to use were not commercially available; specifically, state-of-

the-art 3D flat-panel display screens had thick borders that made them inappropriate for 3D collaboration spaces, as thick borders obscure the information being displayed while thin borders do not. EVL partnered with U.S. company Planar Systems, Inc., to design and build the desired display screen, providing EVL with the needed technology, and Planar with a new product to market.

At the time, this partnership between academia and industry resulted in a commercially available display technology far superior than what was available from foreign competitors. Planar introduced its new 3D display product in January 2012, which EVL then purchased to build a 6x3 3D tiled display wall in its Cyber-Commons classroom, which was used to begin prototyping CAVE2 software capabilities.

Large-scale displays enable people to work together, visualize designs and data, and derive and communicate insights quicker. Enterprises that have long awaited this type of technology include agricultural companies, health technology companies, pharmaceutical firms, the military, oil and gas exploration companies, architectural firms, and film and video game producers.

For Cyber-Commons classroom's 3-row configuration, with many viewers in sitting positions, vertical view angles are not severe, so viewers have comfortable ghost-free passive-stereo performance. For CAVE2, however, for viewers to get an immersive experience, they can walk around the environment and stand close to the displays which are arranged in 18 columns x 4 rows, creating walls that are 8-feet high; this experience, however, creates "ghosting" (distorted viewing), as the off-axis vertical viewing angles of displays on the top and bottom rows are off axis. EVL, again in partnership with Planar and Arisawa, developed customized displays in which the passive-stereo micropolarization filters on the surface of the LCD display is shifted (or offset) to enable viewers to see more of the "correct" pixel row and less of the "incorrect" or ghost producing adjacent pixel row. These customized displays were put along the top and bottom rows of CAVE2, increasing the low-ghost viewing range so that viewers can move closer to the CAVE2 display walls without exceeding the critical ghost angle. (See Section 1.D.4.)

CAVE2 provides users with a 320-degree panoramic environment for displaying information at 37 Megapixels in 3D or 74 Megapixels in 2D with a horizontal visual acuity of 20/20 — almost 10 times the 3D resolution of the original CAVE. The ultra-thin displays are tiled edge-to-edge in an 18-wide by 4-high (18x4) configuration that provides an almost seamless, color-matched digital surround. It is approximately 24 feet in diameter and consists of 72 46" Planar displays – the middle two rows use Planar's commercial displays and the top and bottom rows use Planar's customized displays. In addition, CAVE2 is driven by a 37-node high-performance computer cluster, a 20-speaker surround audio system, a 10-camera optical tracking system, and an 80-Gigabit/second connection to the outside world.

The technology used to build the Cyber-Commons 3D tiled display wall and CAVE2 – 3D ultra-thin border, flat-panel displays – was developed by EVL in partnership with Planar Systems, an Oregon-based company. This collaboration proved mutually beneficial, as EVL got customized technology that surpassed what was commercially available, and Planar got a new product to market.

Planar introduced its new 3D display product – named the Clarity™ Matrix 3D LCD video wall – at the Integrated Systems Europe (ISE) conference, held in Amsterdam, January 31 - February 2, 2012. In February, 2012, Planar published a UIC/EVL case study to promote the Cyber-Commons 3D display; see:

http://casestudies.planar.com/#vertical-markets/education/university-of-iillinois
http://casestudies.planar.com/content/project/pdfs/22/Installation-Profile-University-Illinois-Chicago-1-12.pdf (PDF download)

On November 1, 2012, Planar Systems, Inc. published a case study to promote the CAVE2 system, announced October 3, 2012, which uses both the abovementioned commercial displays as well as custom-built displays. To read Planar's UIC CAVE2 system profile (November 1, 2012), see:
http://casestudies.planar.com/#vertical-markets/education/university-of-illinois
http://casestudies.planar.com/content/project/pdfs/51/Installation-Profile-Illinois-CAVE2.pdf (PDF download)

EVL's work with Planar represents technology transfer at its best, as it has been a true partnership between academia and industry, resulting in new commercially available display technologies. Jason Leigh was quoted in the case study: "Planar...is unique in that they will custom-build a display wall that meets your interests. And they'll work with you doing it; sharing knowledge and solving problems in partnership. No other company has worked with us in this manner, and as a result, the experience has been more positive than we could have imagined."

In January 2013, Mechdyne Corporation licensed the CAVE2, and continues the strong working relationship that began in 1994 when Mechdyne licensed the EVL-designed original CAVE technology. Mechdyne has already sold one system to Monash University (Australia), and has serious interest from several other academic institutions, as well as some of its commercial customers.

Since its premiere, UIC researchers from diverse disciplines such as art, astronomy, cultural heritage, bioengineering, earth science, neuroscience, nursing, physics, psychiatry, rehabilitation, and structural engineering, are already using CAVE2. It has application to industries, government research laboratories and museums that utilize visual information technologies, such as aerospace, architecture, automotive design, agricultural engineering, climate modeling, energy, manufacturing, medicine, and pharmaceutical. This clearly benefits the Nation, enabling the U.S. to maintain its leadership position in high-performance computing and in contributing advancements to complex global issues – whether the environment, health, homeland security, or the economy, to name a few – which benefits society as a whole.

UIC licensed the CAVE2 Hybrid Reality Environment to Mechdyne Corporation in January of 2013, continuing the strong working relationship that began in 1994 when Mechdyne licensed the EVL-designed original CAVE technology. According to Kurt Hoffmeister, VP of Engineering and Product Development for Mechdyne, "One of the biggest benefits offered by the CAVE2 system is its versatility. The system can be integrated to provide the resolution and clarity that matches human visual acuity, for an entirely new level of immersive and collaborative experience."

Mechdyne's press release:
http://www.mechdyne.com/article.aspx?id=238&Mechdyne+Corporation+Licenses+CAVE2+Hybrid+Reality+Environment+from+the+University+of+Illinois+at+Chicago

Mechdyne makes photos available:
http://www.mechdyne.com/cave2-images.aspx

Mechdyne's CAVE2™ product web page:
http://www.mechdyne.com/cave2.aspx

Mechdyne's Manufacturing Symposium, titled "Utilizing Visualization Technologies to Achieve Product Design Excellence," to be held in Chicago on August 15, 2013. Jason Leigh, EVL director, is one of the keynote speakers. Attendees will also get tours of CAVE2:
http://www.mechdyne.com/filesimages/news%20and%20events/mechdyne_event_invitation.pdf

1.F.2. Key Outcomes or Other Achievements

The CAVE2 is a Hybrid Reality Environment, and blurs the line between immersive virtual-reality and traditional tiled display wall environments. CAVE2 is the culmination of EVL's 20+ years of experience and expertise developing immersive environments (the CAVE in 1992) and tiled display walls (LambdaVision in 2004). It combines the best attributes of both, and provides a unique panoramic 2D/3D environment that supports stunning immersive visuals with information-rich analysis.

The original CAVE, which is still sold today, relies on projectors. The original CAVE had limited resolution and poor contrast ratio; modern high-end projectors have greatly improved the picture quality. However, the CAVE's reliance on projectors and its enclosed nature limit its use to purposely built, dimly lit spaces, making it difficult to integrate in office environments. This has hindered its adoption in

everyday scientific workflows and limited it to opportunistic use. Furthermore, the cost of the modern high-resolution CAVE remains prohibitively high.

Scalable LCD tiled display walls, a modern-day platform for large-scale data visualization, are constructed by tiling multiple LCD monitors to form a contiguous display surface. LCD display technology is advancing rapidly while its cost is decreasing. Thin-bezel LCD panels are becoming more common and several manufacturers have recently introduced thin-bezel panels capable of stereoscopic 3D. Tiled display walls often span entire rooms, creating ultra-high-resolution display surfaces on which a variety of datasets can be juxtaposed for analysis and correlation. Scientists can also use them to visualize very large datasets at their native resolution, providing both detail and context. Knowledge workers and scientists have successfully integrated large LCD display walls into everyday workflows. Compared to CAVEs, LCD walls provide superior image quality and resolution. The monitors are easily calibrated (with far less effort than projector-based setups) and provide consistent color and luminance across the display surface, which in turn improves color perception in visualizations.

Both CAVEs and large display walls have distinct qualities that make them effective at visualizing different classes of data. CAVEs are extremely effective for visualizing 3D spatial datasets but are far less suited for 2D information visualization applications. Large, high-resolution display walls excel at visualizing abstract and multivariate 2D datasets, but are less suited for 3D data compared to CAVEs, as they do not provide the same degree of immersion, and often lack the ability to utilize stereoscopy. CAVE2 merges both these technologies – CAVEs and large LCD walls – and leverages their strengths.

The Hybrid Reality Environment is unique. It combines five main characteristics: (1) a large, high-resolution display that closely matches human visual acuity; (2) support for stereoscopic depth; (3) support for intuitive interaction interfaces, from keyboard and mouse to speech recognition, touch-screens and motion detectors; (4) space to encourage multiple co-located individuals to collaborate and analyze and interpret data; and, (5) software layer that leverages the hardware to simultaneously juxtapose multiple related datasets and utilize a variety 2D/3D visualization and interaction modalities. These characteristics synergize capabilities of virtual reality and high-resolution tiled displays, giving rise to a qualitatively distinct visualization environment that combines the best of both worlds. The fusion of these two formerly separate modalities results in environments that are capable of rendering large volumes of data while catering to different data classes' distinct visualization and interaction requirements.

There's solid empirical evidence backing the benefit of immersion in data exploration and analysis scenarios. One major contribution of a Hybrid Reality Environment is the transformation of traditional tiled display walls into highly immersive systems, incorporating head tracking, six-degree-of-freedom input devices, and in some cases a panoramic field of view. In particular, head tracking coupled with motion parallax cues helps people understand spatial relationships by leveraging the natural capacity for spatial cognition. This ultimately enhances user performance in visual data analysis tasks and improves visualization's scalability.

Traditional virtual-reality environments tend to be enclosed and somewhat isolating. Hybrid Reality Environments, on the other hand, provide large and open spaces, allowing for a greater degree of physical navigation, such as walking up to the display surface to see details. Embodied navigation is superior to virtual navigation, particularly when dealing with large data volumes. Hybrid Reality Environments are also more suitable for collaboration than traditional CAVEs, which can fit only a few standing individuals. In contrast, 20 individuals can comfortably stand in CAVE2 or it can be transformed into an immersive meeting room with seating for approximately 12 people, making it suitable for long-term use. Using LCD displays instead of projectors also results in cooler, quieter, and more comfortable workspaces.

Moreover, EVL partnered with Oregon-based Planar Systems, Inc., a display manufacturer, to produce a thin-bezel, stereo-capable flat-panel display, which ultimately resulted in Planar having a commercial product that was far superior to foreign competitors. Furthermore, EVL and Planar co-developed custom

displays for the top and bottom rows the CAVE2.

In January 2013, UIC licensed CAVE2 to Mechdyne, a small company, headquartered in Iowa, that is one of the world's leading providers of innovative visual information technologies, continuing the strong working relationship that began in 1994 when Mechdyne licensed the EVL-designed original CAVE technology. They have already sold a CAVE2 to Monash University in Australia, and have major interest from Osaka University (Japan), University of the Sunshine Coast (Australia), and the Chinese Academy of Forestry (China) as well as several of their commercial customers.

1.G. Opportunities Provided for Training and Professional Development

The development of CAVE2 is enhancing undergraduate and graduate research and education. UIC faculty, staff and graduate and undergraduate students were involved with the design and evaluation of CAVE2, facilitating greater advances than a single-investigator effort could afford. And, CAVE2 is now enabling UIC to work with domain scientists and computer scientists, who are early adopters of this new instrumentation, and to provide UIC students with unprecedented opportunities to use, support, design, develop and deploy advanced technologies while "immersing" themselves in various application domains, producing demonstrable results – such that UIC partners are more productive and UIC students gain the skills necessary to get jobs upon graduation.

1.H. How have Results been Disseminated to Communities of Interest?

As EVL develops MRI prototypes, we involve other collaborators, extending the research to partners on the UIC campus, nationally (museums, UCSD California Institute for Telecommunications and Information Technology, NCSA Great Lakes Consortium for Petascale Computing partners, DOE/SciDAC), and internationally (via StarLight, IRNC TransLight/StarLight, PRAGMA and GLIF). All the people working on display-related projects are involved in furthering research; either in their respective disciplines or by helping us better understand the limitations and future directions of our activities. It is clearly our students who benefit most, and are in high demand by the commercial sector for jobs in R&D when they graduate.

Since it's introduction in October 2012, the CAVE2 has been used by UIC domain scientists from such diverse disciplines, such as art, astronomy, cultural heritage, bioengineering, earth science, neuroscience, nursing, physics, psychiatry, rehabilitation, and structural engineering. A great deal of publicity is being generated – by NSF, Associated Press, PBS, Time, to name a few media institutions – to inform the public about this unique cyberinfrastructure instrument. In addition, EVL has created promotional materials, made available via the web, YouTube, journal articles, social media (e.g., Facebook, Twitter), and numerous conference presentations and demonstrations.

EVL participates in a number of UIC recruitment, retention, outreach, and broader participation programs and gives laboratory tours and technology demonstrations to: high-school students, teachers and visitors; the UIC "Bring Your Daughters to Work" day; the annual Engineering Open House; and, local chapters of the Society of Women Engineers (SWE), the Association for Computing Machinery (ACM), among others. We also provide video, PowerPoint slides, and other promotional material to collaborators to give presentations at education conferences, government briefings, art conferences, etc.

EVL has also commercialized the CAVE2, and its commercialization partner Mechdyne is disseminating information to its commercial customers. In fact, Mechdyne will be holding a symposium in downtown Chicago on August 15 to introduce its manufacturing customers to the new CAVE2 technology; Jason Leigh, EVL director, will give a keynote and CAVE2 demos will be provided.

2. Products Produced by this Project

2.A. Publications

Khairi Reda, Alessandro Febretti, Aaron Knoll, Jillian Aurisano, Jason Leigh, Andrew Johnson, Michael Papka, Mark Hereld, "Visualizing Large, Heterogeneous Data in Hybrid-Reality Environments," Computer Graphics and Applications, IEEE, Volume 33, Issue 4, July-August 2013, pp. 38-48, http://dx.doi.org/10.1109/MCG.2013.37

Larry Smarr, "Terminating the GLIF at UCSD" (video), ON*VECTOR Workshop, Calit2/UCSD, San Diego, YouTube, February 28, 2013, http://youtu.be/Ar7vmMIM7q8

A. Febretti, A. Nishimoto, T. Thigpen, J. Talandis, L. Long, J.D. Pirtle, T. Peterka, A. Verlo, M. Brown, D. Plepys, D. Sandin, L. Renambot, A. Johnson, J. Leigh, "CAVE2: A Hybrid Reality Environment for Immersive Simulation and Information Analysis," Proceedings of SPIE Volume 8649, The Engineering Reality of Virtual Reality 2013 (editors Margaret Dolinsky and Ian E. McDowall), March 4, 2013, pp. 864903, http://dx.doi.org/10.1117/12.2005484

Jason Leigh, Andrew Johnson, Luc Renambot, Tom Peterka, Byungil Jeong, Daniel J. Sandin, Jonas Talandis, Ratko Jagodic, Sungwon Nam, Hyejung Hur, Yiwen Sun, "Scalable Resolution Display Walls," Proceedings of the IEEE, Volume 101, Issue 1, January 2013, pp. 115-129, http://dx.doi.org/10.1109/JPROC.2012.2191609

Thomas Marrinan, Ian Gould, Chih-Yang Hsu, Andreas Linninger, "Whole-Brain Vascular Reconstruction, Simulation, and Visualization" (poster), IEEE VisWeek 2012, Seattle, Washington, October 14-19, 2012, http://www.evl.uic.edu/core.php?mod=4&type=4&indi=830 (The poster was awarded an Honorable Mention.)

2.B. Inventions, Patent Applications, and/or Licenses

2.B.1. Patent

Patent Abstract: N/A
Patent Title: System and Methods for Visualizing Information
Patent Number (optional): 61/658,759
Country: U.S.
Application Date: 2012-06-12
Patent Status: Pending
Date Issued (optional): N/A

2.B.2. License

License Title: Non-Exclusive License Agreement (CAVE2)
License Status: Active
Application Date: 2012-06-12
Date Issued: December 2012
License Assignees: Mechdyne Corporation

2.B.3. Trademarks

CAVE2 system name and logo trademark application numbers:
85/653,106
85/653,119
85/842,632 (logo)
85/842,658 (logo)

UIC shares the trademarks by licensing them to commercial companies.

2.C. Websites

CAVE2
http://www.evl.uic.edu/cave2
This website provides general information about CAVE2.

3. Participants & Other Collaborating Organizations Involved

3.A. Individuals Who Worked on the Project

Participant's Name(s)	Project Role(s)	Nearest Person Month Worked
Andy Johnson[8]	Principal Investigator	1
Jason Leigh[8]	Co-Principal Investigator	1
Maxine Brown[9]	Co-Principal Investigator	1
Tom Peterka[3]	Co-Principal Investigator	1
Lance Long[1]	Other Professional	3
Luc Renambot[2]	Co-Investigator	1
Daniel J. Sandin[3]	Co-Investigator	1
Alan Verlo[4]	Other Professional	1
Jonas Talandis[5]	Other Professional	3
JD Pirtle[6]	Other Professional	3
Alessandro Febretti[7]	Graduate Student	5
Arthur Nishimoto[7]	Graduate Student	6

1: Computer systems architect (Funding: Matching funds, other grants, discretionary funds)
2: Software infrastructure architect
3: 3D stereo expert
4: Network systems architect
5: Structural design engineer
6: Audio design architect
7: Software development
8: Intellectual leader and co-architect
9: Publicity and documentation

3.B. Other Organizations Involved as Partners

Planar Systems, Inc.
Planar Systems, Inc. <www.planarsystems.com>, a U.S. company headquartered in Oregon, is a global leader of specialty display technology providing hardware and software solutions for the world's most demanding environments. UIC has a non-disclosure with Planar to develop passive-stereo displays.

Mechdyne Corp.
Mechdyne Corp. <http://www.mechdyne.com/>, a U.S. small company headquartered in Iowa, is one of the world's leading providers of innovative visual information technologies. UIC licensed the CAVE2 technology to Mechdyne.

3.C. Other Collaborators

Arisawa
Arisawa <www.arisawa.co.jp> is a Japanese company that manufactures the micopolarization (Xpol) screens used by companies such as JVC to create passive-stereo displays. UIC/EVL used Arisawa's Xpol material to design better passive-stereo displays in partnership with Planar Systems.

4. Impact

4.A. CAVE2 Impact on the Development of the Principal Discipline(s)

The CAVE2 Hybrid Reality Environment is the culmination of EVL's 20+ years of experience and expertise developing immersive environments and tiled display walls. It is a new type of 'digital lens' – a high-resolution computer display in which domain scientists can study phenomena too large, too small, too dangerous, too complex, or too distant to truly understand well.

CAVE2 will provide domain scientists with an alternate reality – immersing them in three-dimensional (3D) worlds inside cyberspace and letting them intuitively interact with the data, change size and perspective, make observations – and ultimately gain insight and knowledge. Also, CAVE2 enables both 2D and 3D datasets to be juxtaposed, creating hybrid information spaces to assist knowledge workers make sense of today's increasingly large and heterogeneous datasets.

CAVE2 will enable computer scientists to study a wide range of new problems at the intersection of human-computer interaction, virtual reality, computer graphics, high-performance computing, high-speed networking, and computer-supported cooperative work, with the goal of providing better ways to help knowledge workers manage scale and complexity in their research.

4.B. CAVE2 Impact on Other Disciplines

Many research scientists regard advanced virtual-reality instruments as the lenses of a "telescope" or "microscope," enabling them to view their datasets that reside in cyberspace. Today, all science is e-science: computers capture, filter, analyze and visualize data from instruments and simulations. We envision many disciplines will benefit from this technology, ranging from science and engineering to art and design to biomedical science. For example: in Geoscience, the 3D capability of the wall will make it convenient to show geologic structures which are 3D and often abstract, such as rock faces, topographic maps, or 3D point clouds of earthquake hypocenters. In Art and Design, it can be used to show both high-resolution 2D designs as well as 3D designs, such as architectural designs or products. In Biomedical science and education, anatomy students can see both 2D images from Xrays as well as a 3D structures of organs, and chemists can see 3D molecular and protein structures.

Domain scientists from diverse disciplines, such as art, astronomy, cultural heritage, bioengineering, earth science, neuroscience, nursing, physics, psychiatry, rehabilitation, and structural engineering, are already using the CAVE2. It has application to many industries, government research laboratories and museums that utilize visual information technologies, such as aerospace, architecture, automotive design, agricultural engineering, climate modeling, energy, manufacturing, medicine, and pharmaceutical. This clearly benefits the Nation, enabling the U.S. to maintain its leadership position in high-performance computing and in contributing advancements to complex global issues – whether the environment, health, homeland security, or the economy, to name a few – which, in turn, benefits society as a whole.

EVL has longstanding partnerships with a number of leading scientific research and education organizations – computer-science communities (UCSD California Institute for Telecommunications and Information Technology, King Abdullah University for Science and Technology), domain-science communities (University of Minnesota's Antarctic Geospatial Information Center), government laboratories (Argonne National Laboratory), museums (Science Museum of Minnesota, Adler Planetarium), and corporate research (Planar, Sharp Labs of America) – who have built many of our prior visualization systems, and have provided us with feedback on new requirements based on their evolving scientific needs. We truly believe we can transform their workflows by providing them with new and more intuitive ways of interacting with their data, and that CAVE2 will be of benefit to large-scale collaboratories of discipline scientists in need of advanced cyberinfrastructure.

4.C. CAVE2 Impact on the Development of Human Resources

The design of next-generation virtual-reality instrumentation provides opportunities for research, teaching and mentoring in computer science and engineering research areas. There was clearly a critical mass of UIC faculty, staff and students involved with the design and evaluation of new interactive active-, passive- and auto-stereo displays, facilitating greater advances than a single-investigator effort could afford. In particular, several undergraduate and graduate students were involved in the design and development of this MRI's hardware and software, under the supervision of faculty and staff. In particular, EVL has received generous NSF REU support in the past, and a number of undergraduates opted to remain in school and pursue graduate degrees.

EVL has literally built a worldwide community eager for advanced visualization and virtual-reality instruments by not only developing the hardware, but providing highly usable software libraries and exemplary applications. Specifically, EVL collaborators include partners on the UIC campus, nationally (museums, UCSD California Institute for Telecommunications and Information Technology, NCSA Great Lakes Consortium for Petascale Computing partners, DOE/SciDAC), and internationally (via StarLight, IRNC TransLight/StarLight, PRAGMA and GLIF). All the people working on display-related projects are involved in furthering research; either in their respective disciplines or by helping EVL better understand the limitations and future directions of our activities.

EVL's display hardware and collaboration software enables collaborative, shared access to international information. Our primary goal has been to dissolve the international barriers to advanced scientific collaborations as a model for future seamless connectivity. Our research partners are aggressively pushing forward on the technology and human factors of transoceanic, multi-cultural communication.

Also, as mentioned above (see Section 1.H), EVL is involved in numerous UIC campus recruitment and outreach activities, and showcases its technologies to entice high school students to attend college.

4.D. CAVE2 Impact on Physical Resources that Form Infrastructure

Today, all science is e-science: computers capture, filter, analyze and visualize data from instruments and simulations. To help researchers cope with the scale and complexity of their data as it continues to grow at unprecedented rates, and to assist with data analysis and insight, the CAVE2 provides researchers with new and more intuitive ways of interacting with their data.

The CAVE2 will transform scientific workflows. It is an advanced end-user instrument that can connect collaboratories of discipline scientists to global cyberinfrastructure in order to interact with their data and with one another. It will impact physical infrastructure – as it provides a unique room-sized hybrid reality environment and workspace, connected via high-performance networks to global R&E networks – which has heretofore not been available, just as the original CAVE technology transformed how scientists interacted with their data 20 years ago.

4.E. CAVE2 Impact on Institutional Resources that Form Infrastructure

The CAVE2 Hybrid Reality Environment is a new type of 'digital lens' – a high-resolution computer display that will transform the workflow practices of global collaboratories of discipline scientists, by enabling them to interact with one or more scientific visualizations of heterogeneous datasets, change size and perspective, make observations – and ultimately gain insight and knowledge. Today, most professions rely on computers to generate, capture, filter, analyze and visualize data. Natural phenomena from global weather systems to chemical reactions at the atomic level can be simulated inside supercomputers, generating massive amounts of scientific data. Conversely, phenomena from particle accelerators to nuclear reactors to earthquakes are instrumented with sensors, capturing data at ever-increasing resolution. These troves of data are invaluable to scientists as they explore the raw information and evidence needed for new insights and discoveries. However, making those insights is an ever more complicated task, as the scale and complexity of data continue to grow at unprecedented rates.

4.F. CAVE2 Impact on Information Resources that Form Infrastructure

Large-scale computational facilities are an essential part of global science and engineering cyberinfrastructure, and supporting them is a major responsibility of NSF. Facilities may be centralized (e.g, Blue Waters, Large Hadron Collider) or distributed (e.g., XSEDE). CAVE2 enables global collaboratories of scientists to access unique information resources (i.e., big data stores) and download and/or share data for analysis and insight.

4.G. CAVE2 Impact on Technology Transfer

CAVE2 helps maintain UIC's and the Nation's intellectual leadership in advanced display technologies by providing American industry with the fundamental knowledge needed to create next-generation products for the marketplace. For this MRI, EVL partnered with Planar, a U.S. company, to develop advanced 3D passive-stereo displays, which ultimately became a commercial product. EVL also partnered with Mechdyne, a U.S. company, and licensed the CAVE2 technology.

More importantly, CAVE2 has application to many industries, government research laboratories and museums that utilize visual information technologies, such as aerospace, architecture, automotive design, agricultural engineering, climate modeling, energy, manufacturing, medicine, and pharmaceutical. From fundamental research to product design and rapid prototyping, these industries will utilize this technology to maintain a competitive edge in today's global marketplace.

4.H. CAVE2 Impact on Society Beyond Science and Technology

The CAVE2 has the potential to assist virtual organizations of computer scientists and computational scientists accelerate solutions to issues of global importance, such as climate change, energy, homeland security, the economy, etc. The CAVE2 has the potential to assist industry maintain a competitive edge in today's global marketplace. And, the CAVE2, because of its unique hybrid 2D/3D design, can present multiple, dynamic, heterogeneous datasets in a coordinated fashion to help explain complex subject matter to policy makers and the general public. Advanced visualization and virtual-reality cyberinfrastructure will impact the way researchers deal with the scale and complexity of their data, will impact industrial product design and development, will provide more intuitive ways to present information to decision makers, will enhance education and training, and will help explain complex subject matter to the general public.