

The GeoWall: Low-cost Stereoscopic Visualization for Geoscience Research and Education

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Introduction

In 2001 the GeoWall project began with a question: Could we create an affordable (<\$10,000) version of our existing CAVE® hardware and software (www.evl.uic.edu/CAVE). Instead of relying on special-purpose hardware, we used off-the-shelf components including new projection technology, fast graphics cards and inexpensive computers to provide a stereo projection system that was more affordable than previous commercial solutions. A community of users interested in sharing software, visualizations, and experiences formed and led to over 500 GeoWalls being built. Five years later this collaboration between Computer Science and Geoscience has changed the way Geoscience research and education is done.

The reasons for creating the GeoWall are obvious. A good understanding of spatial relationships is a fundamental requirement in the Earth Sciences; Earth science data is typically 3D and time-dependent. The GeoWall allows people to visualize the structure and dynamics of the Earth in stereo to aid the understanding of spatial relationships. Making use of inexpensive polarized 3D glasses entire classrooms or conference audiences can share the 3D experience. Since the hardware is portable, it can travel as checked luggage on flights to remote sites making it easier to bring the visualizations to the audience.

The article will describe the GeoWall hardware and software and will talk about how the GeoWall Consortium was instrumental in creating a community of users in a variety of disciplines. The paper will then focus on several case studies of

how the GeoWall has been used in research and education. Finally it will describe our recent work in high-resolution tiled displays.

GeoWall Hardware and Software

At the beginning of the Geowall project in early 2001 there were several solutions using active stereo monitors and projectors, or converters to take active stereo and convert it for passive stereo use. This generally limited the exposure of researchers and students in the Geosciences to the occasional demonstration of advanced scientific visualization at a central computing facility.

Our prototype GeoWall hardware in 2001 was based off our earlier work on the CAVE and ImmersaDesk® but made use of off-the-shelf components: a PC with a dual-head graphics card, and two 1024x768 DLP projectors. Passive stereo was achieved with linear polarizing filters, glasses, and a polarization-preserving screen. The total cost of the hardware was under \$10,000. See Figure 1. A suggested set of components and vendors, as well as instructions for setting up the hardware, were made available on-line via the GeoWall Consortium web site (www.geowall.org).

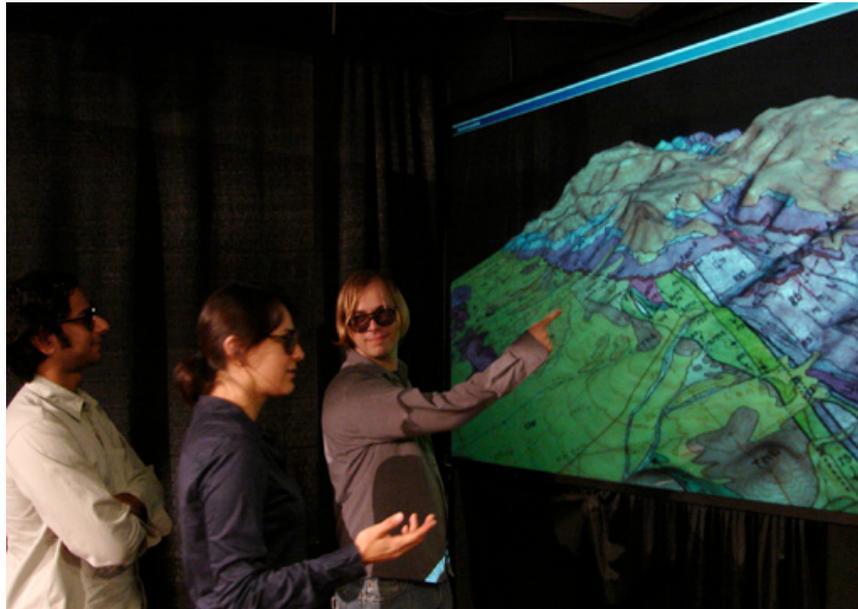


Figure 1: Students wear lightweight polarized glasses to view a stereoscopic GeoWall application showing the topography of Hickey Mountain, Arizona

The goal in creating the GeoWall and its associated software was to provide support for the most common work being done in the Geosciences. The combination of affordable, off-the-shelf hardware and ease of operation made the GeoWall into a popular investment at many Geoscience departments and

research facilities. It became attractive, and pretty easy, to travel with the GeoWall to give presentations: a complete GeoWall setup fits in the trunk of a car, and can be taken as checked luggage on airlines. Along with a setup time that is typically under 20 minutes, the GeoWall was getting seen and attracting more members to the GeoWall Consortium.

It was important to include a standard set of open source software viewers with each new GeoWall so users could start seeing their own data in 3D quickly. We provided three standard viewers and sample datasets. See Figure 2.

Viewer is a stereo image pair viewer. One of the easiest ways to get content onto the GeoWall is to take stereo pair photographs with a digital camera. A sample dataset shows stereo pairs taken along the bluffs of the Mississippi River in Minneapolis by Kent Kirkby, Geology professor at the University of Minnesota, who uses them to prepare his earth science students for making field observations.

ImmersaView is a 3D object viewer based on OpenInventor, using Coin3D (www.coin3d.org). ImmersaView can load up a series of VRML models and allow users to rotate, move, and zoom in on these models, or play them as an animated sequence. A sample dataset shows earthquake hypocenters (3D location of an earthquake within the planet) along subduction zones in various parts of the world making the 3D plate boundaries very obvious.

Walkabout is a 3D terrain viewer allowing users to walk over 3D terrain and apply various texture maps to the surface. A sample dataset shows the topography of Hickey Mountain, Arizona overlaid with a texture of a scanned and georeferenced paper geologic map allowing students to directly see the relationships between them.

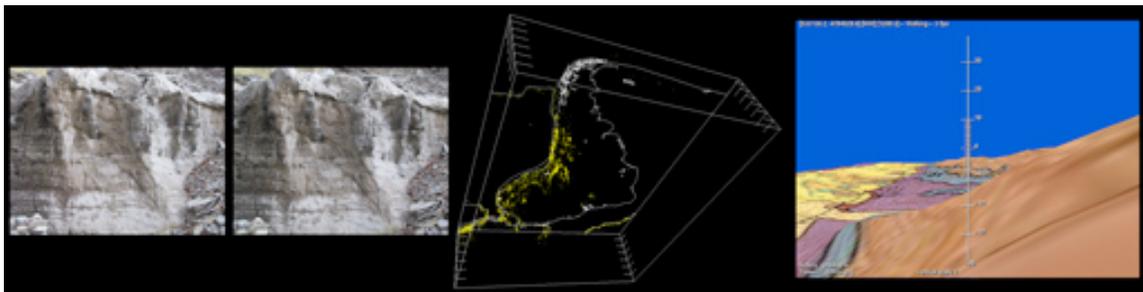


Figure 2: Three standard viewers were provided with the GeoWall: a stereo image pair viewer, a 3D object viewer, and a 3D Terrain viewer to give new members of the GeoWall Consortium a common starting point

Based on the success of these applications, and the growing number of members in the GeoWall Consortium, vendors of Geoscience software such as ESRI (www.esri.com) saw a demand and began building GeoWall visualization

modes into their software. Other existing visualization tools such as Fledermaus and iView3D from IVS 3D (<http://www.ivs3d.com/>) support the GeoWall. Software in other disciplines such as Vis5D (vis5d.sourceforge.net/) for general visualization, Partiview (haydenplanetarium.org/universe/partiview/) in astronomy and VMD (www.ks.uiuc.edu/Research/vmd/), Chime (www.mdl.com/chime/), and CrystalMaker (www.crystalmaker.com) in Chemistry also support the GeoWal.

GeoWall components sidebar

- modern personal computer (Windows, Linux, Mac OS X)
- 2 DLP projectors
- graphics card with 2 DVI or VGA outputs
- polarizing filters to put in front of the projectors
- polarization preserving silver screen or rear-projection black screen
- polarized glasses
 - < \$10 per pair plastic ones for repeated research lab use
 - < \$1 per pair paper ones for one-time classroom/museum use

The GeoWall uses a dual headed graphics card to drive a double-wide desktop. Imagery for the left eye is drawn on the left half of the desktop while imagery for the right eye is drawn on the right half of the desktop. The left half of the desktop is then sent to one projector while the right half is sent to the other. Polarizing filters (either linear or circular) are placed in front of the projectors to polarize the light in different directions for each eye and the imagery is then projected onto a polarization-preserving screen. The users wear light-weight polarized glasses to view the imagery. Current GeoWall setups support both the side-by-side (horizontal span) stereo described above and quad-buffered (clone mode) stereo. See Figure 3.

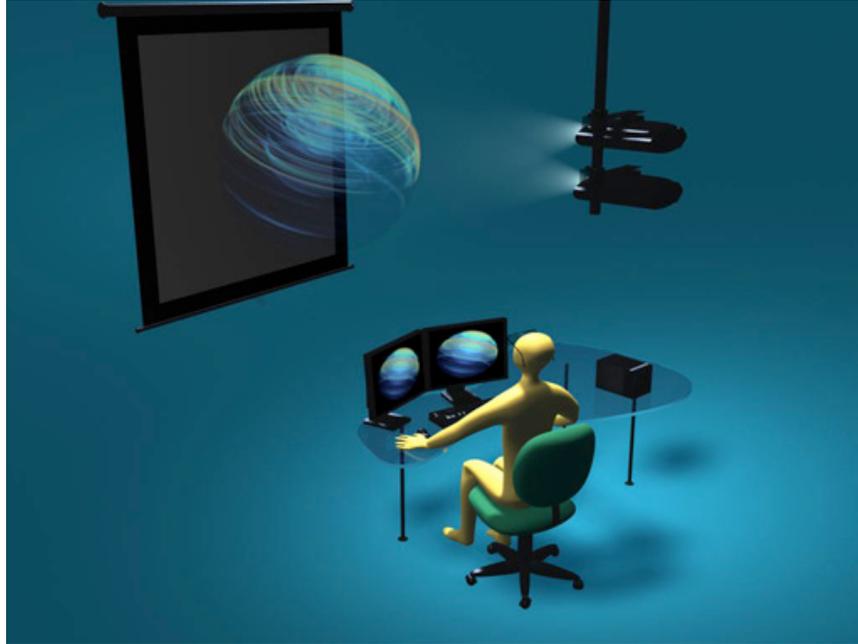


Figure 3: The GeoWall uses two DLP projectors connected to the dual outputs of a PC-based graphics card to generate stereoscopic visuals. Filters are attached to the projectors to polarize the light which is then projected onto a polarization-preserving screen. Viewers wear lightweight polarized glasses to correctly view the imagery in stereo.

The GeoWall Consortium

In 2001, at the same time the GeoWall was introduced, we established the GeoWall Consortium (www.geowall.org). The consortium is a group of researchers and practitioners from different fields interested in supporting the GeoWall. It helps establish new GeoWall sites and provides a central resource for knowledge transfer and the sharing of modules and datasets.. The consortium was given a big boost in 2002 when the National Science Foundation funded further work on the GeoWall through their ITR program.

The GeoWall Consortium was a key factor in the success of the GeoWall, creating a sense of community with shared goals. The consortium website and mailing lists gave all interested parties a central place to communicate and stay on top of the rapidly changing technology of CPUs, graphics cards and projectors, and react quickly when old products disappeared or new products appeared. In addition to this on-line presence we also held a yearly 'GeoWall Summit' meeting to get together face-to-face and see what was accomplished in the previous year. This allowed us to avoid duplicated effort and helped us build on each others' work. Other regular meetings took place at the Geological Society of America's Annual Meeting and the American Geophysical Union's Fall Meeting.

Case Studies

In this section we will present several first-person accounts of how various members of the GeoWall Consortium have made use of the GeoWall.

Paul Morin at the Department of Geology and GeoPhysics, University of Minnesota, Minneapolis, MN

Few students enrolled in Introductory Earth Science have any intention of continuing in earth science. These students would be better served if the curriculum was designed to be a 'concluding' science course, explicitly providing students with the knowledge needed to become better informed citizens. The University of Minnesota is attempting to develop a Midwestern model of an effective 'concluding' earth science course by integrating three essential approaches: use of regional case studies to increase student comprehension; a comprehensive evaluation of students' prior knowledge, misconceptions and post-instructional knowledge; and an ambitious use of visualization, primarily with GeoWall systems, to facilitate the students' use of maps and data sets, and level the classroom playing field with regard to spatial conceptualization.

In every discipline there are some critical skills that serve as conscious or unconscious 'gate-keepers' for progress in that field. In earth science, visualization and map interpretation is the critical restriction. So much of the information in earth science is encoded in maps, that students who are not innately predisposed to understanding them find it difficult to understand much of the course content and methodology. The GeoWall helps students of diverse backgrounds and abilities to understand map data and succeed in the course. For example, the GeoWall allows students in the lab sessions of our large introductory earth science courses to take the flat topographic maps on their desks and see them draped over the actual 3D terrain in stereo, to help them connect the 3D world and its representation on the maps. The GeoWalls not only help increase students' scientific literacy, but may also greatly increase the diversity of students who have a positive and enriching experience in their final science class. In 2006 almost 1/3 of undergraduate non-major Earth Science students in the US already use a GeoWall in their coursework.

Peter van Keken at the Department of Geological Sciences at the University of Michigan, Ann Arbor, MI

Since 1929, the Department of Geological Sciences at the University of Michigan has maintained the Camp Davis Field Station 30 miles south of Jackson, Wyoming in the Rocky Mountains. This ideal outdoor classroom offers some of the most scenic and interesting geology, history, and ecology in the entire Rocky

Mountain region. Students attending undergraduate courses in Geology, Environmental Science and the Humanities spend three to five weeks at the camp each summer.

The GeoWall doesn't replace going into the field; it helps the students get a better idea what they will see before they get there. To help prepare students for the trip we use IVS 3D's Fledermaus to show the geology and topography of the field area. We also show stereo pair photographs that have been taken on previous trips to show details of the area.

After the students have taken detailed measurements of the lithology and local structure, their data is interpreted within the broader regional context using 3D Landsat photography and ArcGIS views on the GeoWall. This approach provides the students with a deeper insight in the 3D and time-dependent processes that shaped the Rocky Mountain geology.

The GeoWall has augmented traditional techniques of providing context, which are generally limited to expensive and static 3D models of geology, and sketches on the blackboard. It is our experience that students get a much better understanding of the context of their field work in a shorter amount of time.

Mark SubbaRao and Doug Roberts at Adler Planetarium and Astronomy Museum, Chicago, IL

The Adler's Crown Milky Way 3D Theater, which contains a GeoWall, was the first theater in the country to show 3D images from the Mars Rover expedition, and half a million visitors have seen the images since they premiered. The two rovers, Spirit and Opportunity, arrived at Mars in January 2004. The Jet Propulsion Laboratory and NASA worked with an alliance of science centers to disseminate collections of imagery from the mission so the public could feel they were a part of the exploration of Mars. These two rovers have a large complement of cameras. Although all of the cameras are stereo capable, not all images are taken in this mode. However, approximately 10,000 to 20,000 of the 110,000 images taken by the Mars Rover expedition have been stereo images.

At the Adler, visitors to the Crown Milky Way 3D Theater pick up a pair of polarized glasses as they enter the small theater room. They then see a slide show of stereo Mars images from both of the rovers. As the mission progresses different sets slides are shown highlighting current findings. Occasionally Adler scientists "take over" the theater for live presentations on the Mars Rovers or other content such as galaxy flythroughs from the Sloan Digital Sky Survey.

The stereo mars images show undulations in the terrain not apparent in the monoscopic image, which has led many Adler visitors to comment that it was like

actually standing on the surface of Mars. For the same reason that the stereoscopic information is useful for the scientists and engineers in the Mars exploration program, it also provides for a much more compelling public display.

Brian Davis – SAIC, Contractor to the USGS Center for Earth Resources Observation and Science (EROS), Sioux Falls, SD

The EROS data center has used our GeoWall as a communications/outreach tool for our data, science, and scientists. Recently, fire science researchers at the USGS Center for Earth Resources and Observation Science (EROS) have used GeoWalls to visualize the output of predictive fire model simulations, in three and four dimensions, draped on elevation data provided by the USGS, and integrating raster layers of land-cover, climate, and forest fuels information from the LANDFIRE project (www.landfire.gov). The GeoWall is proving to be an invaluable visual communications tool for analysis and description of both fuels and fire conditions.

Why 3D is important? If one is an expert in predictive forest fire model simulations, then the GeoWall visualizations are overkill. However, how do you tell your story to a land manager, politician, or a member of the general public? For sharing that complex 3D and 4D information in a context that non-experts and novices can understand, a visual communications tool is much more effective. More and more scientists are using our Showcase Visualization Lab and our GeoWall systems to present their data, research, and science.

The GeoWall has also been used to show leading edge earth science research to numerous audiences, including the Governor of South Dakota, the entire South Dakota congressional delegation, and all under-secretaries of the US Department of the Interior. In the Fall of 2003, I represented the Department of the Interior at GIS Day, held at the EPA headquarters in Washington D.C, which was the first time that ArcScene was demonstrated on a GeoWall. In 2004, I represented the U.S. Geological Survey at the 20th annual Committee on Earth Observation Satellites meeting in Beijing, China, where I demonstrated the GeoWall and USGS research.

Peter van Keken at the Department of Geological Sciences at the University of Michigan, Ann Arbor, MI

Modeling the dynamics and structure of the Earth's interior now routinely involves massively distributed computational techniques, making it feasible to study time-dependent processes in the 3D Earth. We generated global seismic wave propagation data using the SPEC3D software package from the Theoretical & Computational Seismology group at the California Institute of Technology.

Simulating one hour of the 1994 earthquake in Bolivia using 24 2.5 Ghz Pentium 4 PCs took over 20 hours to compute.

We then extracted 169 frames from the simulation to create an animated stereoscopic visualization. The combination of the new wave propagation modeling with volume rendering has provided unprecedented views of seismic waves into the Earth interior. The strong heterogeneity and spherical shape of the Earth causes a multitude of refractions and reflections of seismic energy that within a short amount of time provide a very complicated picture. The 3D-time visualization is essential to make sense of the development; it allows a very natural view into the seismic wave complications, such as the conversion of seismic energy from transverse to longitudinal waves at deep interfaces, and the development of torsional normal modes. See Figure 4.

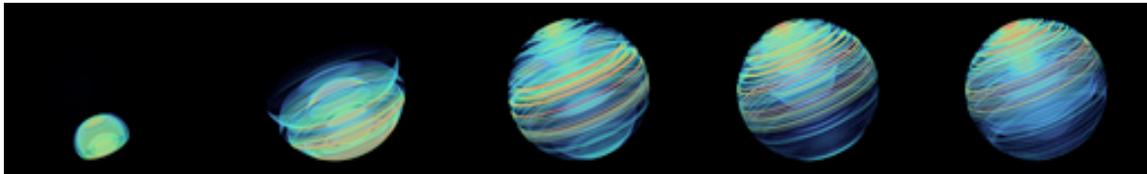


Figure 4: Time series animation from the simulation of the 1994 Bolivia earthquake. A stereo version of this animated movie can be shown on the GeoWall allowing scientists to review the results of the simulation in stereo.

The Need for High Resolution

While GeoWalls are currently being built with high-resolution (1920x1080) projectors, there is a need for much higher resolution. To address this more directly we developed the PC-cluster based GeoWall-2 in 2003. The GeoWall-2 consisted of 15 LCD panels tiled in a 5x3 array with a total resolution of 8000 x 3600 pixels, driven by 8 high-end PCs as either a vertical display or as a table. One of the first GeoWall-2s was delivered to the EROS data center at the United States Geological Survey in 2004. Applications include visualization for the National Map Mission where 133 US cities are being photographed at 1 foot per pixel resolution, leading to images of 365,000 by 365,000 pixels. Single displays can show context or detail but tiled displays are needed to show both simultaneously.

While this same cluster of computers could be used to drive an array of projectors, we chose to use LCD panels for the GeoWall 2. The advantages include more resolution for less money with LCD panels, and simpler alignment and colour correction. More importantly for casual usage, the lifetime of an LCD panel is roughly 20,000 to 30,000 hours (three years) while projectors have lifetimes of only 2,000 hours and high bulb replacement costs. This allows us to leave the GeoWall 2 on all the time for easy use. The obvious disadvantage of using LCD panels is the borders of the panels. We continue to 'draw' imagery

underneath the borders so looking at the display is similar to looking through a set of French windows, and geoscientists tell us that they get used to this quite quickly. See Figure 5.



Figure 5: The GeoWall-2 addresses the need for high-resolution interactive imagery utilizing an array of LCD panels driven by a cluster of PCs.

Whereas the 'classic' GeoWall was a single PC, the GeoWall-2 was a cluster of PCs, and could be hard to manage. To solve this problem we created an entry-level GeoWall-2 called the Personal Geowall-2, or PG2, whose components cost about the same as the original 'classic' GeoWall. The PG2 is a single PC typically driving either 6 LCD tiles or 4 LCD tiles along with a 'classic' GeoWall. See Figure 6. PG2 systems in 2006 are also being built with 4 Apple or Dell 30" displays giving 5120 x 3200 resolution from a small shuttle PC.



Figure 6: The Personal GeoWall-2 uses a single PC to drive both a 'classic' GeoWall and a small 2x2 tile display, giving the user a way to see both stereoscopic content and high-resolution content simultaneously on a single PC

One of our current uses for the PG2 is CoreWall, which displays sections from one or more cores along with discrete data streams and nested images to provide a data fusion environment for the description of sediment cores. As the imagery of these cores is taken at 1200 dpi, high-resolution displays are needed to visualize the core in at multiple levels of detail. CoreWall is a collaborative project between the Electronic Visualization Laboratory at the University of Illinois at Chicago, the U.S. National Lacustrine Core Repository at the University of Minnesota, and the Integrated Ocean Drilling Program through the Joint Oceanographic Institutions in Washington, D.C. See Figure 7. In 2006 it was funded by the National Science Foundation.

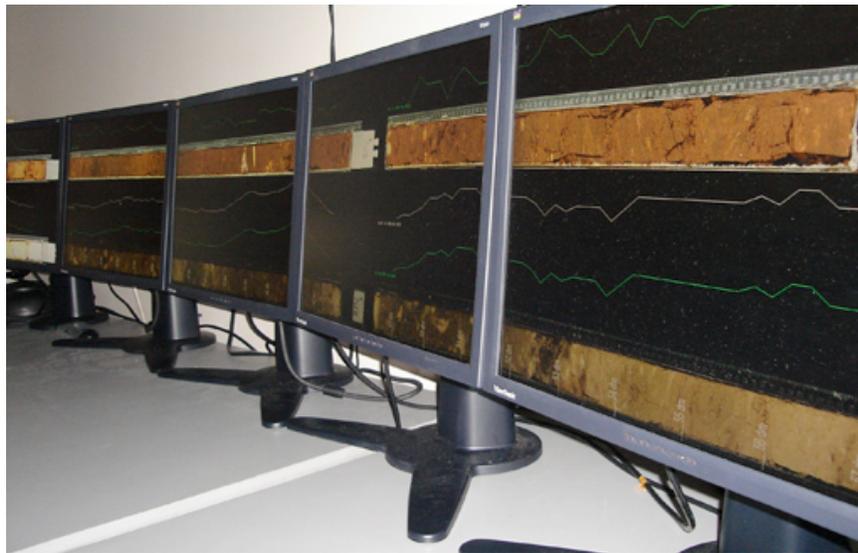


Figure 7: CoreWall uses a Personal GeoWall 2 to drive six LCD panels for viewing and interacting with high-resolution lake and ocean core data.

Conclusions

The GeoWall project has been successful because it addressed a common and important need in the Geoscience community. It took advantage of recent advances in computer graphics and processing power coupled with price-drops in projector hardware to create a visualization tool that geoscientists could afford. It gave them the hardware and software tools to support their existing way of working while sparking innovation in the use and extension of those tools.

The GeoWall Consortium was instrumental in the growth of GeoWall sites from the handful of early adopters in the first year to over 500 by the middle of 2005. A common website gave us a single point to distribute information and mailing lists

allowed users to stay on top of new developments. The yearly face-to-face meetings augmented these virtual communities and allowed us to develop a real sense of community and encouraged more casual collaborations

Our current work is now focused on satisfying the need for high-resolution visualization in the Geoscience community and we will be applying the lessons learned here to that effort.

Acknowledgements

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