Applications

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GeoWall: Stereoscopic Visualization for Geoscience Research and Education

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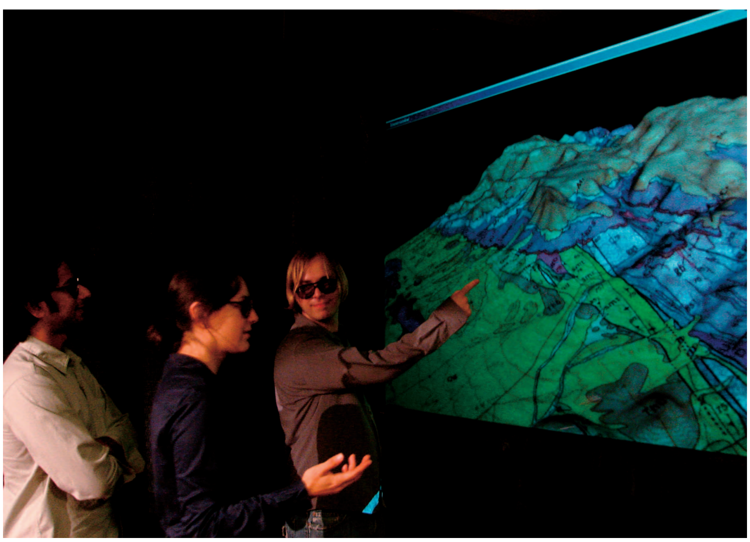
In 2001, the GeoWall project began with a question: Could we create an affordable (less than $10,000) version of our existing CAVE hardware and software (see http://www.evl.uic.edu/cave)? Instead of relying on special-purpose hardware, we used off-the-shelf components including new projection technology, 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 was formed, leading to the building of more than 500 GeoWalls. 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 lets people visualize the structure and dynamics of the Earth in stereo, aiding their 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, and has a setup time of less than 20 minutes—it's easy to bring visualizations to the audience.



(Courtesy Electronic Visualization Lab., Univ. of Illinois at Chicago and the GeoWall Consortium.)

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

In this article we describe the GeoWall hardware and software and discuss how the GeoWall Consortium was instrumental in creating a community of users in a variety of disciplines. Using case studies, we'll show how the GeoWall helped research and education. Finally, we will describe our recent work in high-resolution tiled displays.

GeoWall hardware and software

When the GeoWall project began, in early 2001, several expensive solutions existed that used active stereo monitors and projectors, or that could take active stereo and convert it for passive stereo use. This generally limited the exposure of geoscience researchers and students to the occasional demonstration of advanced scientific visualization at a central computing facility.

We based the prototype GeoWall hardware (see Figure 1) on our earlier work on the CAVE and ImmersaDesk, but use off-the-shelf components: a PC with a dual-head graphics card, and two $1,024 \times 768$-digital light processing projectors. We achieved passive stereo with linear polarizing filters, glasses, and a polarization-preserving screen. The total cost of the hardware was less than $10,000. We made available online a suggested set of components and vendors, as well as instructions for setting up the hardware—see the GeoWall Consortium Web site at http://www.geowall.org. The "GeoWall Components" sidebar lists the items needed for a GeoWall.

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) in front of the projectors polarize the light in different directions for each eye; the imagery is then projected onto a polarization-preserving screen. Users wear lightweight polarized glasses to view the imagery. Current GeoWall setups support both the side-by-side (horizontal span) stereo described

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previously and quad-buffered (clone mode) stereo (see Figure 2).

Our goal in creating the GeoWall and its associated software was to support the most common work 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 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—Viewer, ImmersaView, and Walkabout—and sample data sets (see Figure 3).

Viewer (see Figure 3a) 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 data set for the GeoWall shows stereo pairs taken along the bluffs of the Mississippi River in Minneapolis by Kent Kirkby, a geology professor at the University of Minnesota, who uses them to prepare his Earth science students for making field observations.

ImmersaView (see Figure 3b) is a 3D object viewer based on OpenInventor that uses Coin3D (see http://www.coin3d.org). ImmersaView can load a series of VRML models and let users rotate, move, and zoom in on these models, or play them as an animated sequence. A sample data set shows earthquake hypocenters (3D locations of earthquakes within the planet) along subduction zones in various parts of the world, making the 3D plate boundaries very obvious.

Walkabout (see Figure 3c) is a 3D terrain viewer that lets users walk over 3D terrain and apply various texture maps to the surface. A sample data set 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.

Based on these applications' success, and the growing number of members in the GeoWall Consortium, geoscience software vendors such as ESRI (see http://www.esri.com) began building GeoWall visualization modes into their software. The "Other Tools and Software Supporting GeoWall" sidebar (on the next page) lists some vendors that support GeoWall in geoscience and other fields.

GeoWall Consortium

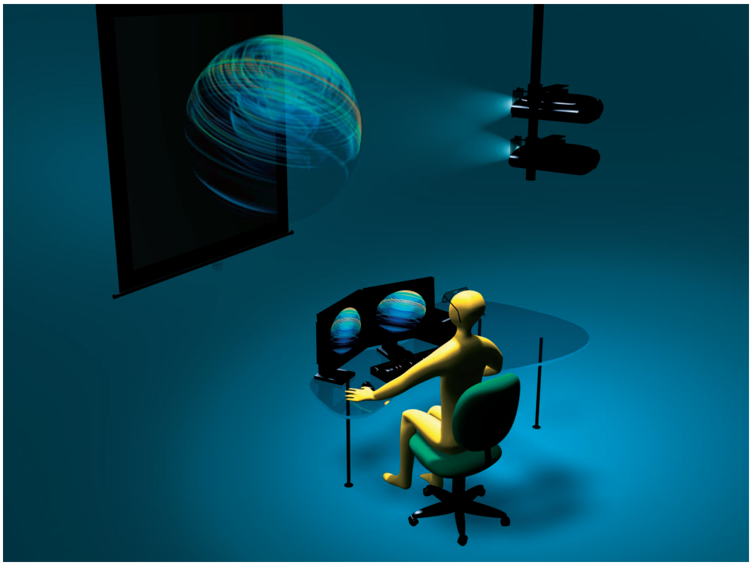
At the same time the GeoWall was introduced in 2001, we established the GeoWall Consortium. The consortium is a group of researchers and practitioners from different fields interested in supporting the GeoWall. It helps establish new GeoWall sites and provides a central resource for knowledge transfer and the sharing of modules and data sets. The consortium was given a big boost in 2002 when the National Science Foundation funded further work on the GeoWall through its Information Technology Research program.

The GeoWall Consortium was a key factor in the success of the GeoWall, creating a sense of community with shared goals. The consortium Web site and mailing lists gave all interested parties a central place to communicate and stay updated on the rapidly changing technology of CPUs, graphics cards, and projectors, and to react

GeoWall Components

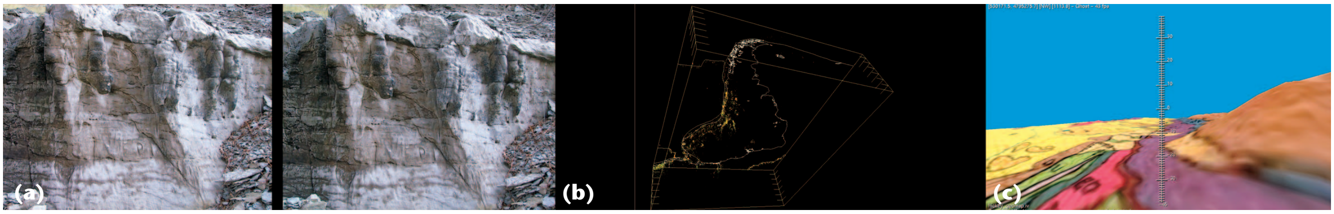
To build a classic GeoWall, you would need the following components:

- personal computer (with Windows, Linux, or Mac OS X),
- two digital light processing projectors,
- graphics card with two DVI or VGA outputs,
- polarizing filters to put in front of the projectors,
- polarization-preserving silver screen or rear-projection black screen, and
- polarized glasses—a $10 pair of plastic ones for repeated research lab use and a $1 pair of paper ones for one-time classroom or museum use.



(Courtesy Electronic Visualization Lab., Univ. of Illinois at Chicago and the GeoWall Consortium.)

2 The GeoWall uses two digital light processing projectors connected to the dual outputs of a PC-based graphics card to generate stereoscopic visuals.



(Courtesy Electronic Visualization Lab., Univ. of Illinois at Chicago and the GeoWall Consortium.)

3 Three standard applications come with the GeoWall: (a) a stereo image pair viewer, (b) a 3D object viewer, and (c) a 3D terrain viewer to give new members of the GeoWall Consortium a common starting point.

Other Tools and Software Supporting GeoWall

Based on GeoWall's success, software vendors began supporting the tool for geoscience as well as other disciplines. These tools include the following:

- IVS 3D's Fledermaus and iView3D (see http://www.ivs3d.com/) for Earth science;
- Vis5D (see http://vis5d.sourceforge.net/) for general visualization;
- Partiview (see http://haydenplanetarium.org/universe/partiview/) for astronomy; and
- Visual Molecular Dynamics (see http://www.ks.uiuc.edu/Research/vmd/), Elsevier MDL's Chime (see http://www.mdl.com/chime/), and CrystalMaker Software's CrystalMaker (see http://www.crystalmaker.com) for chemistry.

quickly when old products disappeared or new products appeared. In addition to this online presence, we also held a yearly GeoWall summit to meet face-to-face and review the accomplishments of the previous year. This allowed us to avoid duplicated effort, and helped us build on each other's 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: Department of Geology and Geophysics, University of Minnesota

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 postinstructional knowledge; and
- an ambitious use of visualization, primarily with GeoWall systems, to facilitate the students' use of maps and data sets and to level the classroom playing field with regard to spatial conceptualization.

In every discipline there are some critical skills that serve as conscious or unconscious gatekeepers 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 understand map data and succeed in the course. For example, the GeoWall allows students in the lab sessions at the University of Minnesota's 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 might also greatly increase the diversity of students who have a positive and enriching experience in their final science class. In 2006, more than one-third of undergraduate nonmajor Earth science students in the US already use a GeoWall in their coursework.

Peter van Keken: Department of Geological Sciences, University of Michigan

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.

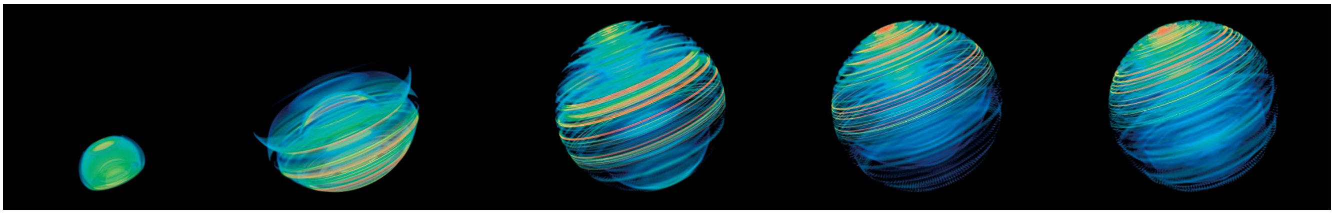
The GeoWall doesn't replace going into the field; it helps the students get a better idea of what they will see before they get there. To help prepare students for the trip, the Department of Geological Sciences uses IVS 3D's Fledermaus to show the field area's geology and topography. We also show stereo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

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 blackboard sketches. It is our experience in the department 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: Adler Planetarium and Astronomy Museum

The Adler's Crown Milky Way 3D Theater, which contains a GeoWall, was the first theater in the US to show 3D images from the Mars Rover expedition. 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 imagery from the mission so the public could feel they were a part of the Mars exploration. 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



(Courtesy Electronic Visualization Lab., Univ. of Illinois at Chicago and the GeoWall Consortium.)

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 letting scientists review simulation results in stereo.

20,000 of the 110,000 images taken by the Mars Rover expedition are 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 taken from both of the rovers. As the mission progresses, different sets of 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 they actually felt as if they were standing on the Mars surface. 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: contractor, USGS Center for Earth Resources Observation and Science

The United States Geological Survey (USGS) Center for Earth Resources and Observation Science (EROS) has used GeoWall as a communications and outreach tool for our data, science, and scientists. Recently, EROS fire science researchers used GeoWalls to visualize in 3D and 4D the output of predictive fire model simulations, draped on USGS elevation data and integrating raster layers of land cover, climate, and forest fuel information from the Landfire project (see http://www.landfire.gov). The GeoWall is proving an invaluable visual communications tool for analysis and description of both fuels and fire conditions.

Why is 3D important? If you are 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 complex 3D and 4D information in a context that nonexperts and novices can understand, a visual communications tool is quite effective. More and more scientists are using the EROS Showcase Visualization Laboratory and our GeoWall systems to present their data, research, and science.

Peter van Keken: Department of Geological Sciences, University of Michigan

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. In our department, we generated global seismic wave propagation data using the SPECFEM3D software package from the Theoretical and Computational Seismology group at the California Institute of Technology. Simulating 1 hour of the 1994 earthquake in Bolivia using twenty-four 2.5-GHz Pentium 4 PCs took more than 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 Earth's interior. The strong heterogeneity and spherical shape of Earth causes a multitude of refractions and reflections of seismic energy that within a short amount of time provide a complicated picture. The 3D time visualization is essential to make sense of the developments; it allows a 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).

The need for high resolution

While GeoWalls are currently built with high-resolution (1,920 × 1,080) 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 5 × 3 array with a total resolution of 8,000 × 3,600 pixels arranged as either a vertical display or as a table, driven by eight high-end PCs. One of the first GeoWall-2s was delivered to the EROS data center at the USGS 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 × 365,000 pixels. Single displays can show context or detail, but we need tiled displays to show both simultaneously.

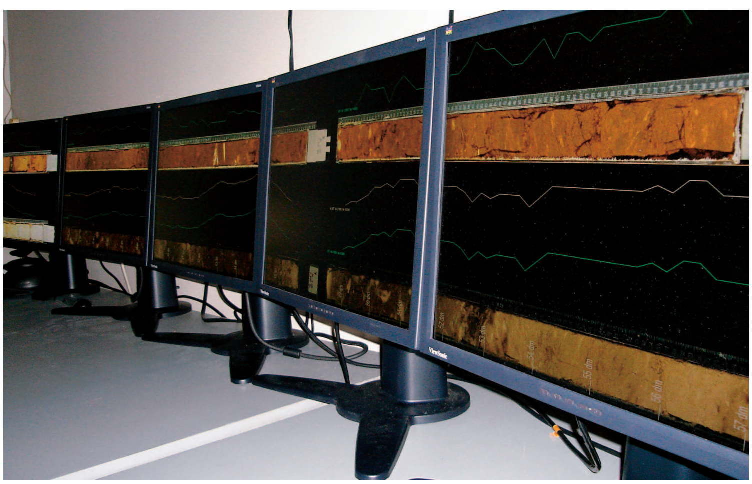
While this same cluster of computers could drive an array of projectors, we chose to use LCD panels for the GeoWall-2. The advantages include more resolution for less money, and simpler alignment and color correction. More importantly for casual use, an LCD panel's lifetime is roughly 20,000 to 30,000 hours (three years) while projectors have lifetimes of only 2,000 hours and require expensive bulb replacement. This allows us to leave the GeoWall-2 on all the time for easy use. The obvious disadvantage of using LCD panels is the panel borders. We continue to draw imagery underneath the borders, so looking at the display is similar to looking through a set of French

(Courtesy Electronic Visualization Lab., Univ. of Illinois at Chicago and the GeoWall Consortium.)

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

(Courtesy Electronic Visualization Lab., Univ. of Illinois at Chicago and the GeoWall Consortium.)

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



(Courtesy Electronic Visualization Lab., Univ. of Illinois at Chicago and the GeoWall Consortium.)

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

windows, and geoscientists tell us that they get used to this quite quickly (see Figure 5).

Whereas the classic GeoWall is a single PC, the GeoWall-2 is a cluster of PCs and could be difficult to manage as a network. To solve this problem we created an entry-level GeoWall-2, the Personal Geowall-2, whose components cost about the same as the original classic GeoWall. The PG2 is a single PC typically driving either six LCD tiles, or four LCD tiles and a classic GeoWall (see Figure 6). PG2 systems in 2006 are also being built with four Apple or Dell 30-inch displays giving 5,120 × 3,200 resolution from a small shuttle PC.

One of our current uses for the PG2 is Corelyzer, 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 over 200 dpi, we need high-resolution displays to visualize the core in multiple levels of detail. Corelyzer is a collaborative project between the Electronic Visualization Laboratory at the University of Illinois at Chicago, the US 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, the National Science Foundation funded Corelyzer.

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 more than 500 by the middle of 2005.

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. ■

Acknowledgments

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