KECKCAVES: Enabling Interactive Visual Exploration in Virtual Reality for the Geosciences Louise H. Kellogg¹, Tony Bernardin², Magali I. Billen¹, Eric Cowgill¹, J. Crutchfield³, **Austin J. Elliott**¹, Bernd Hamann⁴, **Cara L. Harwood**¹, Oliver Kreylos², Dawn Sumner¹

OF AMERICA® T149 - DP4

- University of California Davis, Department of Geology 2 - University of California Davis, Institute for Data Analysis and Visualization 3 - University of California Davis, Department of Computer Science

UCDAVIS

DEPARTMENT OF GEOLOGY

KECKCAVES

UCDAVIS **COMPUTER SCIENCE**



The earth sciences increasingly rely on large and complex datasets obtained via major investments in data acquisition, modeling, and simulation. As a result, geoscience students must be prepared to understand, use, and develop cyberinfrastructure tools (CI) for analysis and interpretation of such data. Interactive visualization in a virtual reality environment provides a uniquely powerful method for interacting with complex data to build understanding of complex systems and concepts. At the Keck Center for Active Visualization in Earth Sciences (KeckCAVES), we have built a collaboration among computer scientists, geoscientists, and physicists to develop a suite of research tools for visualization and remote collaboration in such immersive environments. These methods are used for scientific problems as diverse as neotectonic mapping, mantle dynamics simulations, earthquake physics, and 3D reconstruction of microbialites. With support from an NSF CI-TEAM grant, we have incorporated these tools into a program for training, education, and mentoring the next generation of computer scientists and geoscientists.

What do we do?

Our CI program for education, training, and mentoring uses virtual reality in a 4-sided CAVE and other interactive immersive visualization environments, ranging from 3D screens to desktop and laptop computers. Our multidisciplinary teams develop CI tools, conduct research and education, and prepare instructional modules that are being integrated into the general education and geosciences and physics curriculum. The KeckCAVES is a magnet for students, and our program interests and educates a diverse student population in using, supporting, developing, and designing geoscience virtual reality tools. Through mentored research activities and focused courses, we provide geoscience, physics, applied mathematics, and computer science students with the background, tools, and sense of discovery that motivate them to become part of a well prepared CI workforce. In addition, by integrating the tools into immersive displays at the Tahoe Environmental Research Center (TERC) and by introducing visualization tools into undergraduate general science education, we expose thousands of people to the scientific use of virtual reality.



real or synthetic 3D objects of any scale in a virtual space where they can be manipulated through hands-on interaction.

KeckCAVES Facilities

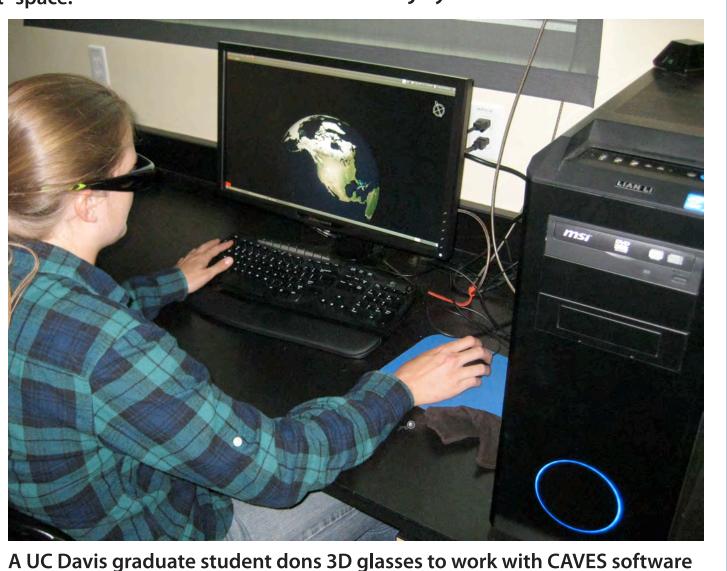


The KeckCAVES: A user perceives a seamless three-dimensional environment that can be explored by manipulating data within the 800 ft³ space

In addition to use in the CAVES facility itself, KeckCAVES software runs on any Linux or Mac OS computer, and so is perfectly suitable for individual or personal use.

Students who use CAVES programs do so on a variety of systems, from personal laptops with a simple 2-button mouse to desktop computers, 3D desktop computers, and large-format

The software and instructions for downloading it are available on our website and wiki, www.keckcaves.org



on a 3D-enabled desktop computer.

six buttons and a joystick.

four-sided Mechdyne CAVE, an

DLP projectors.

immersive visualization environment

consisting of three 10' x 8' walls and a

10' x 8' floor. Stereoscopic images are

projected onto all four surfaces using

A wireless 3D position tracking

the position and orientation of a user's

head and allows him or her to interact

intuitive and efficient fashion using a

position-tracked handheld wand with

with the virtual environment in an

system synchronizes the 3D display with

Undergraduate Education in the Classroom Virtual environments are engaging and have been shown to gain and

hold students attention, which increases their motivation to learn.

Structural Geology

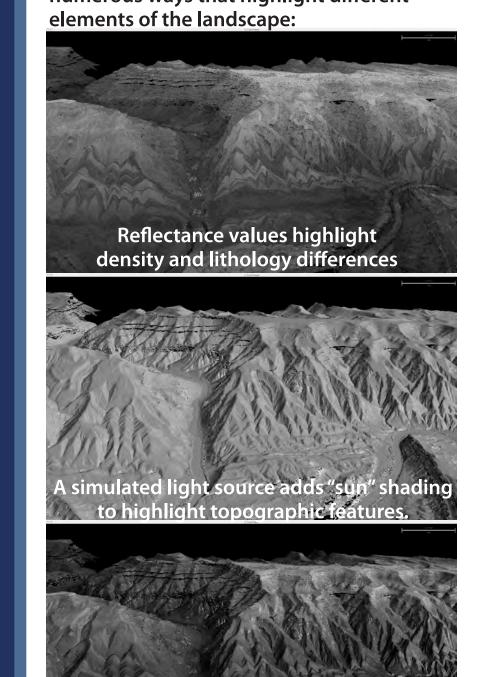


Geology is among the most visual of the sciences, so geology tudents benefit immensely from visualization in a 3D virtual reality environment. Students are expected to be able to visualize and mentally rotate objects in order to understand many key geologic concepts. However, research in geoscience education and cognitive science shows that not all students have equally developed spatial thinking skills. Incorporating 3D visualizations into teaching geology can remove barriers related to spatial thinking, and may help improve spatial ability.

3D visualizations allow direct perception of geologic concepts that cannot be manipulated or experienced in the real world such as

We developed laboratory modules designed for undergraduate structural geology curriculum using a self-discovery approach. The laboratory modules are structured to allow students to discover and articulate each concept from observations of synthetic data both on traditional maps and using the volume visualization software

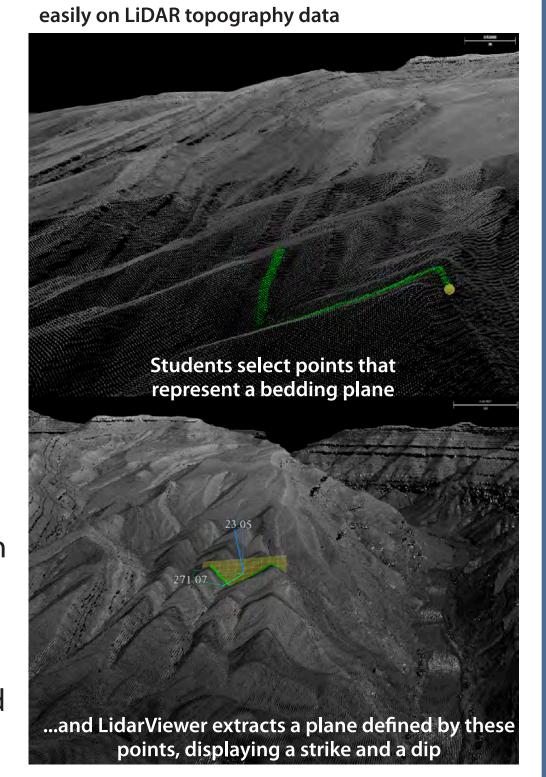
An undergraduate (Jessie Saunders) put together all the data sets used for the exercise, then made 3DVisualizer so we can put this activity out on the web. The 3DVisualizer software is freely available from KeckCAVES (keckcaves.org), and the exercise and its synthetic data will be available from the website soon!



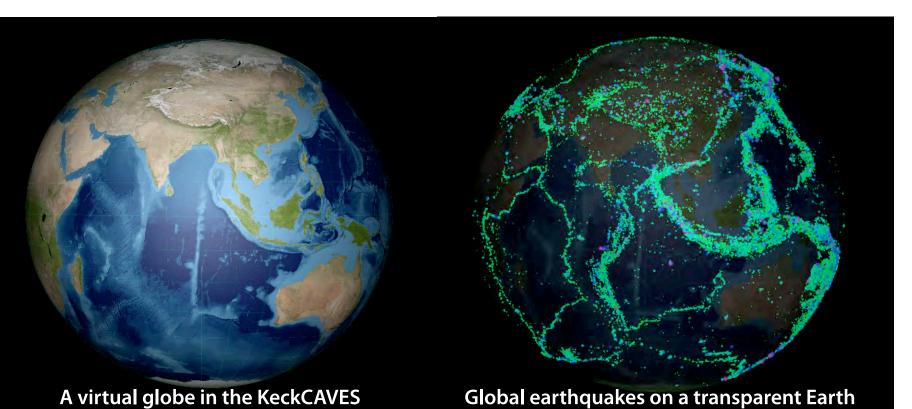
Students also use topographic data to map rock units, measure strike and dip, and explore real world examples of the interaction between bedding and topography, without having to leave the classroom.

Using 3D point clouds that represent topographic data, students select features to measure and use LidarViewer's geometric primitive extraction function to define bedding planes, fault lines, stream channels, and other basic geological features.

Interacting with and handling the three-dimensional data with ease, students gain perspectives of a landscape that are otherwise difficult or impossible to obtain. Structural geology students can conduct a structural "three-point-problem" to define the dip of a bed through illuminating interaction.



Earthquake Visualization



The simplest application to show students in the CAVE is a rtual globe containing a century of global earthquake locations plotted at true depth. EarthquakeViewer helps new users learn to navigate in the CAVE while opening up the structure of the planet to them. The earthquake locations reveal tectonic plate boundaries and fault dynamics, and prompt discussions about how we know what the interior of the Earth is like.

We generate movies in EarthquakeViewer for outreach and use in education modules in large-enrollment general education geoscience classes targeting students who are not majoring in STEM (Science, Technology, Engineering, and Mathematics) fields.



the deep earthquake hypocenters that define the subducting Pacific plate.

Graduate Education: Immersive Research



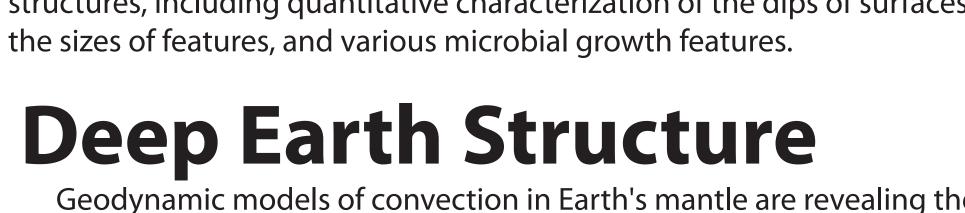
Graduate students explore topographic survey data they collected to analyze fault slip during the 4 April 2010 M7.2 earthquake in northern Baja California. CAVES software is an integral tool in this ongoing research.

Earth surface dynamics

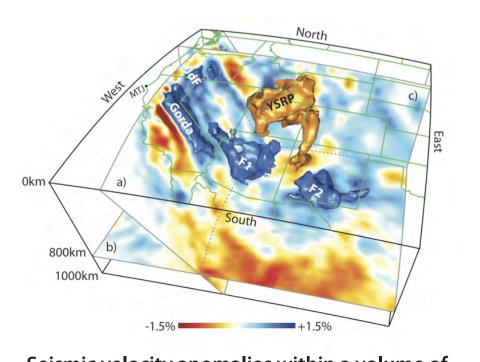
processes using the KeckCAVES. LidarViewer is a cyberinfrastructure tool developed by a student-faculty team to visualize and interpret very large 3D point clouds resulting from high-resolution topographic laser scans of the ground, buildings, trees, and other objects. Users can select points to identify specific objects, and fit geometric shapes (planes, cylinders, spheres, etc.) to extract quantitative information about the size, shape, and orientation of structures. LidarViewer was used extensively by geoscience students to investigate the 2010 Haiti and El Mayor-Cucapah earthquakes, and by computer science students as a platform for developing feature-extraction algorithms. LidarViewer is being used by students to study levee stability, flood planes, landslides, and the San Andreas fault.

Signatures of Life in Rocks

Graduate and undergraduate students alike use the KeckCAVES 3DVisualizer to explore the interiors of solid rock specimens. Ancient rocks precipitated by microbial mats (microbialites) reveal the signatures of microscopic life preserved in the rock record. We reconstruct their geometry by cutting serial sections of the rocks, scanning each surface, and reconstructing a 3D virtual representation of the microbialite from the scans. These models can be compared to x-ray tomography of modern microbialites. These methods allow investigations of intricate 3D structures, including quantitative characterization of the dips of surfaces, the sizes of features, and various microbial growth features.

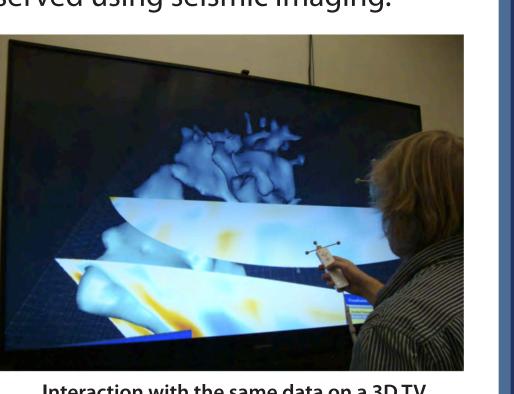


Geodynamic models of convection in Earth's mantle are revealing the processes governing plate tectonics, mountain building, volcanism, and the thermal history of our planet. Seismic tomography is used to see into Earth's interior to identify the thermo-chemical structures that lie deep beneath our feet. We use 3DVisualizer to investigate and analyze flow fields generated from geodynamics simulations and structures observed using seismic imaging.



the mantle represented as slices and isosurfaces

The same data being viewed in immersive 3D in the CAVES room.



The CAVE displays the inside of a scanned rock specimen.

Team Learning: Students and Faculty **Geothermal Systems and Resources**



students at UC Davis took advantage of the KeckCAVES' variety of 3D display capabilities and spurred the development of a software package that integrates terrain, 3D volumes, well logs, and 2D cross-sections to give a robust synthesis of available geologic, geophysical, and hydrologic data. The results of this effort earned

A graduate student explores temperature them first place in the Department of Energy's isosurfaces and compares them to a published cross-section in the CAVE. National Geothermal Student Competition. Geothermal research bridges

disciplines in the Earth sciences and is a burgeoning field for geoscientists of the 21st century. 3D Visualizer and associated CAVES programs allow students and researchers to see and work with 3D data volumes integrated with spatial data of many other formats. Using 3D Visualizer allows the student to virtually bring the material up or down to human scale, whether it's a planet-sized object or a rock that s in the palm of your hand.

KeckCAVES software developed specifically for geothermal exploration integrates data from various sources and in various formats. Terrain, interpolated temperature volumes, well logged lithology, geophysical profiles, and published interpretted geologic cross-sections are combined for direct comparison in 3D space.

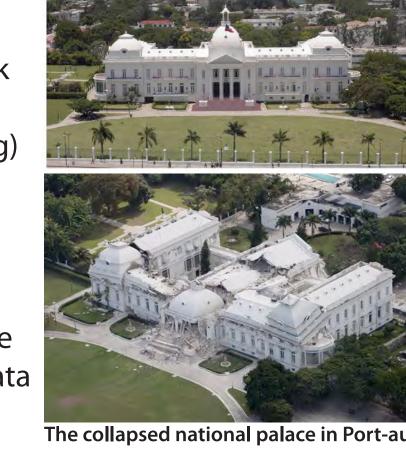
Earthquake Hazards

After the 12 January 2010 M7.0 earthquake in Haiti, the World Bank requested rapid imaging using LiDAR (Light detection and ranging) technology to assess the damage.

Data were collected by the Rochester Institute of Technology coordinated by the USGS.

Researchers at the USGS invited the KeckCAVES to help interpret the data using our scientific visualization

Crusta, displaying satellite imagery and high-resolution topography collected in the days immediately after the quake. UC Davis students and faculty responded by assembling a rapid scientific response team to process, analyze, and interpret the data. The team mapped the fault, investigated the history of seismicity in Haiti, learned why a geologic response is important after a natural disaster, and continued development of the CI tools Crusta and LidarViewer in response to the scientific questions that arose. The HET project represented a milestone in our philosophy of engaging students in research and co-developing cyberinfrastructure tools to solve scientific projects. Projects were led by the student participants. Just nine months after the earthquake, geology and computer science students presented their work at the GSA and AGU national meetings, and developed a web site to share results: haiti.geology.ucdavis.edu



Remote Collaboration

Teams are developing low-cost teleimmersion technology to enable interaction between people at different locations. Harnessing the 3D capabilities of common modern technology, researchers with the KeckCAVES have developed a method of embedding CAVES users dynamically into the 3D space their data occupy, and displaying both users and data for remote users. By enabling students at different institutions to work on shared datasets, we

will facilitate research and teaching collaboration while students gain knowledge and insight into the behavior of VR and immersive visualization.



More information can be found at www.keckcaves.org or on our YouTube channel: spelunkerucd

Public Education

TERC: Tahoe Environmental Research Center



Visitors to the Tahoe Environmental Research Center gather in and visualizations of various geoscience-related information relevant to the Lake Tahoe region. Here they view the lake isplayed with a digital terrain model including colored lake-floor bathymetry and a satellite imagery of the surroundings.

The Otellini Visualization Lab, located at the prestigious Tahoe Environmental Research Center (TERC), is a state-of-the-art facility and the centerpiece of TERC's efforts to both understand the complexities of Lake Tahoe and to educate and inspire the next generation of scientists and engineers. This public science education lab is a computer simulation and visualization laboratory which utilizes

state-of-the-art numerical simulation and visualization resources developed at the KeckCAVES and collaborating nstitutions. KeckCAVES provides visualizations of scientific data to provide students and the public with a

better understanding of complex environmental issues affecting Lake Tahoe and the region.

napshot of a 3D visualization showing the results of a computer simulation of a historic tsunami in Lake Tahoe.