UNIVERSITY OF ILLINOIS AT CHICAGO

CAVE
Backgrounder

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CAVE Backgrounder

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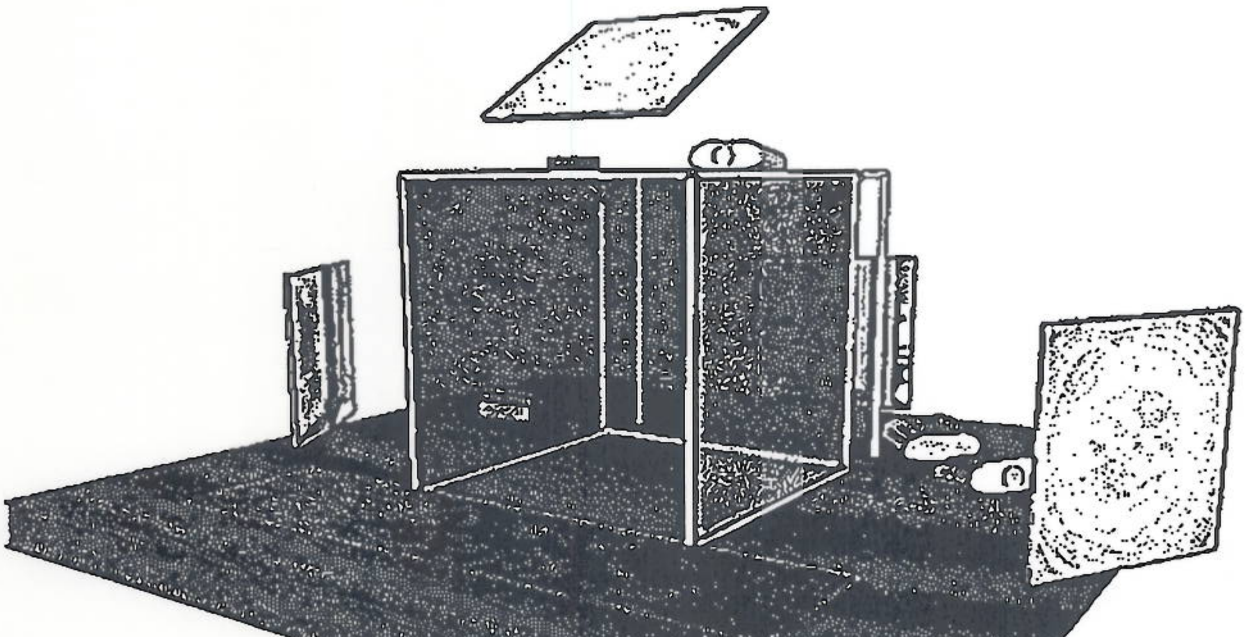

CAVE Automatic Virtual Environment

Electronic Visualization Laboratory
University of Illinois at Chicago

1. About the Electronic Visualization Laboratory

EVL advances research in computer graphics and interactive techniques through its unique interdisciplinary blend of engineering, science, and art; its students receive MS, PhD and MFA degrees through the UIC Electrical Engineering and Computer Science department and the UIC School of Art and Design. EVL's current research emphasis is virtual reality; however, faculty and students are also involved in a number of related cutting-edge problems: multimedia; scientific visualization; new methodologies for informal science and engineering education; paradigms for information display; algorithm optimization for parallel computing; sonification; and, abstract mathematical visualization.

Most recently recognized for its work in virtual reality with the introduction of the CAVE virtual reality theater in 1992, EVL has a history of innovative contributions to the computer graphics field since its inception in 1973. In the mid '70s, EVL created "Electronic Visualization Events," a series of public performances where images were computer generated and color processed in real time with musical accompaniment. Around the same time, EVL hardware and software were used to create the computer animation for the first "Star Wars" movie. In 1976, based on an idea by colleague Rich Sayre, EVL developed an inexpensive, light-weight glove to monitor hand movements; the Sayre Glove provided an effective method for multidimensional control, such as mimicking a set of sliders. Projects in the 1970s through mid-1980s centered on videogame technology, real-time animation on microcomputers, and interactive multimedia installations.

In the late '80s, the Lab began focusing on scientific visualization, developing and providing tools and techniques for research scientists and engineers. Continuing these efforts, EVL is now applying virtual environments to scientific computing. EVL promotes the use of these advanced technologies to academic, industrial, and government audiences, to make people aware that technology is key to America's leadership role, through installations at museums and professional conferences. In recent years, EVL has received major funding for its collaboration and outreach activities from NSF, ARPA, and the U.S. Department of Energy.

EVL's 1987 "The Interactive Image" is on permanent display at The Computer Museum in Boston and the St. Louis Science Center. EVL faculty, staff, and students organized the SIGGRAPH 92 "Showcase" event; Showcase featured 35 projects on workstations networked to onsite and remote supercomputers that illustrated interactive and collaborative scientific computing and visualization research, and marked the introduction of the CAVE. The Lab recently organized the SIGGRAPH 94 "VROOM" event, a major virtual-reality exhibition highlighting computational science and engineering applications. EVL is now focusing its efforts on soliciting and helping develop content for the Supercomputing 95 "NII Testbed" event, as well as leading that conference's unique "Information Architecture" and national infrastructure. Additionally, EVL has been, and continues to be, a major influence on the advancement of electronic art and entertainment; EVL alumni and artists are internationally recognized for interactive art installations, performance art pieces, and entertainment productions.

EVL contains state-of-the-art graphics workstations and a video editing suite, plus access to the SGI Power Challenge Array, CM-5, and Convex supercomputers at NCSA, and to the IBM SP-2 at Argonne National Laboratory.

2. The CAVE

2.1. CAVE General Description

Virtual reality may best be defined as the wide-field presentation of computer-generated, multi-sensory information that tracks a user in real time. In addition to the more well-known modes of virtual reality – head-mounted displays and boom-mounted displays – the Electronic Visualization Laboratory at the University of Illinois at Chicago recently introduced a third mode: a room constructed from large screens on which the graphics are projected on three walls and the floor.

The CAVE is a multi-person, room-sized, high-resolution, 3D video and audio environment. Graphics are rear projected in stereo onto three walls and the floor, and viewed with stereo glasses. As a viewer wearing a location sensor moves within its display boundaries, the correct perspective and stereo projections of the environment are updated, and the image moves with and surrounds the viewer. The other viewers in the CAVE are like passengers in a bus, along for the ride!

"CAVE," the name selected for the virtual reality theater, is both a recursive acronym (Cave Automatic Virtual Environment) and a reference to "The Simile of the Cave" found in Plato's "Republic," in which the philosopher explores the ideas of perception, reality, and illusion. Plato used the analogy of a person facing the back of a cave alive with shadows that are his/her only basis for ideas of what real objects are.

The CAVE premiered at the ACM SIGGRAPH 92 conference. It is achieving national recognition as an excellent virtual reality prototype and a compelling display environment for computational science and engineering data.

2.2. CAVE Motivation

Rather than having evolved from video games or flight simulation, the CAVE has its motivation rooted in scientific visualization and the SIGGRAPH 92 Showcase effort. The CAVE was designed to be a useful tool for scientific visualization. The Showcase event was an experiment; the Showcase chair, James E. George, and the Showcase committee advocated an evironment for computational scientists to interactively present their research at a major professional conference in a one-to-many format on high-end workstations attached to large projection screens. The CAVE was developed as a "virtual reality theater" with scientific content and projection that met the criteria of Showcase. The Showcase jury selected participants based on the content of their research and its suitability to projected presentation.

The challenge was attracting leading-edge computational scientists to use virtual reality. It had to help them get to scientific discoveries faster, without compromising the color, resolution, and flicker-free qualities they have come to expect using workstations. Scientists have been doing single-screen stereo graphics for more than 25 years; any virtual reality system had to successfully compete. Most important, the virtual reality display had to couple remote data sources, supercomputers, and scientific instrumentation in a functional way. In total, the virtual reality system had to offer a significant advantage to offset its packaging. The CAVE, which basically met all these criteria, had success attracting serious collaborators in the HPCC community.

To retain computational scientists as users, we have tried to match the virtual reality display to researchers' needs. Minimizing attachments and encumbrances have been goals, as has diminishing the effects of errors in the tracking and updating of data. Our overall motivation is to create a virtual reality display that is good enough to get scientists to get up from their chairs, out of their offices, over to another building, perhaps even to travel to another institution.

2.3. CAVE Design

The CAVE is a theater 10x10x9 feet, made up of three rear-projection screens for walls and a down-projection screen for the floor. Electrohome Marquis 8000 projectors throw full-color workstation fields (1024x768 stereo resolution) at 96Hz onto the screens, giving 2,000 x 2,000 linear pixel resolution to the surrounding composite image. Computer-controlled audio provides a sonification capability to multiple speakers. A user's head and hand are tracked with Polhemus or Ascension tethered electromagnetic sensors. Stereographics' LCD stereo shutter glasses are used to separate the alternate fields going to the eyes. A Silicon Graphics' Onyx with three Reality Engines is used to create the imagery that is projected onto three of the four walls. (Prior to the Onyx, we used four Silicon Graphics' Crimson Reality Engine workstations to create the imagery for four walls, plus a Silicon Graphics' Personal IRIS that served as a master controller for the system. All workstations then communicated via a ScramNet optical fiber network from Systran Corp.) The CAVE's theater area sits in a 30x20x13-foot light-tight room, provided that the projectors' optics are folded by mirrors.

Goals that inspired the CAVE engineering effort include:

a. The desire for higher-resolution color images and good surround vision without geometric distortion
b. Less sensitivity to head-rotation induced errors
c. The ability to mix virtual reality imagery with real devices (like one's hand, for instance)
d. The need to guide and teach others in a reasonable way in artificial worlds
e. The desire to couple to networked supercomputers and data sources for successive refinement

2.4. Virtual Reality Challenges that Influenced CAVE Design

Over the past two years, as we considered building the CAVE, there were several inherent problems with head-mounted virtual-reality technology to which we gave a great deal of thought:

a. Simplistic real-time walk-around imagery
b. Unacceptable resolution (the popular head-mounted displays offer resolution that is twice as bad as being legally blind)
c. Difficulty of sharing experiences between two or more people
d. Primitive color and lighting models
e. No capability for successive refinement of images
f. Too sensitive to rapid head movement
g. No easy integration with real control devices
h. Disorientation a common problem
i. Poor multi-sensory integration, including sound and touch

The CAVE provides us with these current capabilities and engineering results:

a. A viewer is presented with dynamically moving full-color images at 2,000 x 2,000 pixel resolution in stereo on the walls and floor. The images truly float in space allowing the viewer to walk around them.

b. The primary viewer's position is tracked so that the correct perspective view is generated in real time. Head rotation is used to subtly adjust the perspective, not swing the entire world as in head-mounted displays.

c. The primary viewer can navigate with a variety of intuitive navigational devices currently under test and construction. At interesting points, the viewer can freeze the viewpoint and automatically provide the computer-graphics system with enough time to fully render the image (called "successive refinement"). The viewer may still rotate his/her head to take in the entire refined scene and still achieve a good stereo effect without requiring recomputation. Interestingly enough, the image still tracks you somewhat, akin to how the full moon seems to follow you as you walk, an effect that is quite striking.

d. All viewers wearing LCD shutter glasses can see full 3D stereo projected into the room. In 3D movies or workstation stereo, objects must be kept near the center of the screen or behind the screen because the edges of the display cause the illusion to be destroyed for objects between the viewer and the screen (this is called "edge violation"). The CAVE edges are easy to keep out of view due to its wrap-around screens; projection into the room is not only possible but the best part.

e. Since all viewers can still see their hands, body, and feet, they do not need training to stay oriented in the virtual space. Disorientation common in head-mounted displays is not an issue with the CAVE, unless specifically induced. The 10'x10' CAVE allows groups of people, up to 12, to be led by a scientist/demonstrator to interesting places, a preservation of the teacher/student relationship not possible with head-mounted displays.

f. A MIDI synthesizer is connected via Ethernet/PC so, for example, sounds may be generated to alert the user or convey information in the frequency domain.

g. A second tracker is currently implemented on a 3D wand with buttons. We have the analog-to-digital boards to interface to other physical input devices.

2.5. CAVE Interactive Steering of Computer Simulations

Applications run in one of two modes: locally on the Onyx/CAVE and/or distributed between a backend computer and the Onyx/CAVE. In distributed computing mode, CAVE participants may "interactively steer" simulation codes. In local mode, CAVE participants either steer modest simulations or explore precomputed datasets.

Scientific simulation codes are typically large and complex. They require HPCC resources – scalable computers, vector processors, massive datastores, large memories, or high-speed networks – to run efficiently. Depending on the dataset and type of analysis scientists want to do, they set up their simulation codes to calculate greater detail, a different time step, or a different state defined by new parameters. In distributed mode, CAVE users explore/experience visualizations of datasets, identify an area they want to enhance, and then invoke simulation codes on the networked computers to compute new datasets. The backend machine generates new data, which is then transferred to the Onyx for rendering and display in the CAVE.

To date, the CAVE has been networked to several backend machines: Thinking Machine Corporation's CM-5, a Silicon Graphics Challenge Array, and an IBM SP-1 and SP-2.

3. CAVE Variations

3.1. The ImmersaDesk

We are developing ways to make the CAVE both smaller and more affordable. The "ImmersaDesk" is a drafting-table format virtual prototyping device. Using stereo glasses and sonic head and hand tracking, this projection-based system offers a type of virtual reality that is semi-immersive. Rather than surrounding the user with graphics and blocking out the real world, the ImmersaDesk features a 4x5-foot rear-projected screen at a 45-degree angle. The size and position of the screen give a sufficiently wide-angle view and the ability to look down as well as forward. The resolution is 1024 x 768 at 96Hz. It will also work in non-stereo mode at 1280 x 1024 at 60Hz.

We have learned from working with the CAVE that immersion is critical to achieving a workable virtual reality/prototyping system, and that immersion is dependent on being able to look forward and down at the display in such a way that the edges of the screen are not seen, or at least not prominent. Head-tracked stereo is important for virtual reality as well, although this can be easily achieved with a high-end workstation, desktop monitor and active stereo glasses. The ImmersaDesk allows the necessary wide angle of view and, because of its screen angle, the capability to portray forward and down views on one screen. Many researchers have developed stereo, even head-tracked monitor and projection-based wall virtual reality systems, but these do not allow down views and typically have narrow angles of view. It may sound simple, but putting the screen at an angle is extremely effective.

The ImmersaDesk is derivative of the CAVE system, being an excellent development environment for the CAVE, and also a stand-alone system. The ImmersaDesk prototype is 100% software compatible with the CAVE libraries and interfaces to software packages like Sense8's World ToolKit and SGI's Performer/Inventor, as well as visualization packages like AVS and IBM Data Explorer. Interfaces to industry standard CAD output files are also provided via these packages. The first ImmersaDesk is being built under contract for delivery to NIST for a factory planning experiment.

With proper video input boards, the incorporation of video-teleconferencing (VTC) with virtual-reality computer-generated material should be straightforward. Since the CAVE/ImmersaDesk libraries have been much used to view high-bandwidth supercomputer output, the VTC/networking features will also permit the interactive shared steering of computations and the querying of databases by a number of people. This neatly combines the best of video communications with the best of simulation computing and the high-end of virtual reality interactive 3D visualization.

Coping with network and simulation-induced latencies are a focus of current software efforts. Near-term research targets voice input, tactile and graphical input, recording of sessions, and compatibility with packages like Performer, AVS, Pro-Engineer, AutoCAD and others. Continued integration with Silicon Graphics' Power Challenge Array is planned.

3.2. The NII/Wall

We are also planning to make projection virtual reality available to large audiences by building a high-resolution (1600 x 2048) stereo screen called the "NII/Wall." A non-stereo PowerWall was developed by Paul Woodward's group at the Army High Performance Computer Research Center for the Silicon Graphics' booth at Supercomputing '94. Silicon Graphics is providing two Power Onyx systems (with upgrades to a future version of the Reality Engine) to EVL to develop the stereo version of this concept.

The NII/Wall will serve as a portal into large parallel computers located around the Nation so that scientists and engineers can interact with simulations being run on distributed clusters of shared-memory processors. Of particular interest to SGI, third-party software producers, and engineering end-users, of course, is the successful porting to and use of packages on the Power Challenge Array architecture. Companies in Chicago will access these developments via the NII/Wall.

The NII/Wall uses four Reality Engines spread across two Power Onyxes to achieve the high-resolution, high-intensity, passive-stereo image. One Onyx controls the top half of the screen and the other controls the bottom half (each at 1600 x 1024). Seamless matching of such images on a horizontal line will, of course, take detailed care. The top and bottom are each driven by two Reality Engines displaying polarized projected images for each eye. Throwaway polarized passive glasses (like the cardboard glasses used for viewing 3D movies) can be used by the audience instead of the active stereo glasses we use in the CAVE and ImmersaDesk systems. These $1,000 glasses are quite fragile and have proven to be a significant barrier to virtual reality uses in education, training and outreach. The NII/Wall is much more suited for audiences, and although it uses a lot of computers and projectors, the number of people it reaches per unit time is far greater than either the CAVE or the Immersadesk.

Clearly, the NII/Wall could be achieved with one dual-headed Onyx and two projectors at half the resolution, but Silicon Graphics wishes to develop to the higher standard. The NII/Wall achieves its immersion by wide-screen projection, but does not allow, unfortunately, a way to look down, a problem with any normal audience seating arrangement. (Note that the angle of Omnimax/ Imax theater seating addresses this problem by steeply pitched seating). We will experiment with large-area types of tracking, mindful of the fact that it is only possible to track one person at a time, not an audience. We anticipate certain uses of the NII/Wall in which high-resolution telepresence is the goal rather than audience participation. In any event, the goal of this endeavor is to optimize the display as best as possible for real-time high-resolution stereo graphics, given the constraints.

4. CAVE Research Focus and Timeline

EVL is currently involved in CAVE visualization and virtual-reality research and development. EVL, along with NCSA and Argonne National Laboratory, are jointly collaborating on CAVE supercomputing and networking research.

4.1. EVL Research Goals

EVL goals are:

a. To provide an infrastructure for computer scientists to work with computational scientists to collect, maintain, develop, distribute and evaluate virtual environment (VE) tools and techniques for scientific computing. VE tools and techniques include computer-based models, simulators, data libraries, programming libraries and user interfaces. The libraries and user interfaces encompass visual, auditory, tactile and motion-based information displays.

b. To provide researchers with access to the latest VE equipment to explore their data in highly immersive, highly interactive environments.

To accomplish its goals, EVL has partnered with NCSA and the Mathematics and Computer Science Division of Argonne National Laboratory (ANL), in a multi-year, ongoing effort to develop highly leveraged national collaborations at major professional conferences that emphasize HPCC technologies, virtual reality, and scientific visualization. The purpose is to encourage the development of teams, tools, hardware, system software, and human interface models on an accelerated schedule to enable national-scale, multi-site collaborations to facilitate solutions to National Challenge and Grand Challenge problems. New paradigms for networking and scalable computing interoperability and optimization will result, as well as methods for graphical user interaction.

4.2. EVL/CAVE Research Scope of Work

EVL has defined the following research with respect to the CAVE:

a. **Hardware integration and development: Building a scalable workstation**
   1. Couple virtual environments (VE) to massively parallel processors, superworkstations, massive datastores, networks
   2. VE-to-VE tight coupling
   3. VE-to-VE transmission latency compensation

b. **System software architecture design**
   1. VE as a "scalable workstation" to the metacomputing environment
   2. Steer computations/ invoke programs on supercomputers
   3. Access massive datastores
   4. Collaborative environments (intraCAVE; interCAVE)

c. **Human/computer interaction and navigation**
   1. System-level software for interaction/navigation
   2. Modes of interaction/navigation
      - Graphical user interfaces
      - Voice recognition
      - Gesture recognition
      - Tactile feedback
      - Force feedback

- Motion control platforms

3. Modes of investigation
   - VE query formation
   - Navigation
   - Search key specification
   - Visualization annotations
   - Scripts
   - Retrieval
4. Synchronize all sensory and motor modalities
5. Adapt user interfaces so they work across VE platforms
6. Successive refinement

d. VE documentation

1. Session scripting, capture, edit, and replay tools

e. VE library and emulators

1. Develop emulators in OpenGL
2. Develop extensions to graphics libraries and toolkits to interface to VE devices (e.g., AVS, INVENTOR, NCSA Mosaic, PERFORMER, RENDERMAN, AutoCAD etc.)
3. Upgrade emulators and libraries to include volume visualization
4. Extend libraries to work with non-Cartesian data

f. Sound/sonification tools for data analysis

1. Create standards for an "open" audio library
2. Develop an audio library
   - Navigation tools
   - Localization tools
   - Sonification tools
   - Interaction tools
3. Develop auditory interfaces for scientific representation
4. Develop tool prototypes demonstrating use of VE sound libraries

g. Visualization applied to VE

1. Visualize very large datasets
2. Visualize volumetric datasets
3. Advanced rendering techniques (texturing, volume visualization, and lighting and shadows)

h. CAVE development

1. Design CAVE spaces larger than 10'x10'x10'
2. Develop more durable, cost-effective VE systems for use in informal education

i. VE tools

1. Virtual Director, Recorder, and Editor
2. Quantitative analysis tools
3. 3D user interface toolkit

4.3. CAVE Research and Development History and Projected Timeline

a. **1991**
   1. CAVE conceptualization and early tests

b. **1992**
   1. CAVE premiere at SIGGRAPH 92 Showcase
   2. Collaborations with computational scientists and engineers, applying virtual reality and scientific visualization to scientific problem solving (see Section 9: SIGGRAPH 92 Showcase and Section 10: Supercomputing 92)

c. **1993**
   1. CAVE enhancements
      - New CAVE configuration with SGI Onyx
      - CAVE-to-supercomputer prototyping, done jointly with NCSA
   2. CAVE standardization
      - Development of complete CAVE specifications for minimal space utilization with folded optics, stainless steel structure, sonification capability, and scalability
   3. CAVE duplication at multiple sites
      - EVL, NCSA, ARPA Enterprise, Argonne National Laboratory
   4. CAVE utilization
      - New collaborations with NCSA and Argonne researchers
      - New collaborations with industrial partners
   5 CAVE demonstration at Supercomputing 93
      - CAVE-to-CM5 prototype
      - Nine new applications in math, astrophysics (see Section 11: Supercomputing 93)
   6. National Call for Participation for SIGGRAPH 94 VROOM
      - A national search for new collaborators
      - Design and implementation of a major event at SIGGRAPH 94 for VR technology transfer and training to 7,000 attendees and 700 media representatives
   7. Online documentation of collaborative scientific research using NCSA Mosaic, with graphical extensions added to Mosaic to best communicate scientific visualizations.
   8. CAVE quantitative assessment studies

d. **1994**
   1. CAVE demonstrations at SIGGRAPH 94 (see Section 12: SIGGRAPH 94 VROOM)
   2. Call for Participation for Supercomputing 95 Information Architecture virtual reality, scientific visualization, and networking events (see Section 13: Supercomputing 95)
   3. Enhance CAVE sound libraries
   4. Purchase new equipment to enhance CAVE architecture
   5. CAVE quantitative assessment studies
   6. Work with EVL industrial partner General Motors Research to install a CAVE at their facility
   7. The conceptualization and development of desktop virtual reality: The ImmersaDesk
   8. The conceptualization and development of a large-screen stereo projection system: The NII/Wall

e. 1995

1. Continuing development of new scientific and engineering collaborations (To continue current collaborations and solicit new collaborations through the Supercomputing 95)
2. December 1995: Staging the Supercomputing 95 event
3. Purchase new equipment to enhance CAVE architecture
4. Develop and commercialize the ImmersaDesk
5. Develop the NII/Wall
6. CAVE quantitative assessment studies
7. Work with EVL industrial partner General Motors Research to install a CAVE at the EDS Virtual Reality Center

f. 1996

1. Continuing development of new scientific and engineering collaborations
2. Integrate motion control platform in the CAVE
3. Purchase new equipment to enhance CAVE architecture
4. CAVE quantitative assessment studies

g. 1997

1. Continue to develop new scientific and engineering collaborations
2. Fall 1997: Staging the Supercomputing 97 event
3. Purchase new equipment to enhance CAVE architecture
4. CAVE quantitative assessment studies

5. CAVE Deployment

CAVEs currently exist or are being installed at the following locations:

- Electronic Visualization Laboratory, University of Illinois at Chicago
- National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign
- Argonne National Laboratory
- ARPA Enterprise
- General Motors Research
- EDS Virtual Reality Center

Other EVL and NCSA industrial partners have expressed interest in building their own CAVEs.

6. CAVE Demonstrations

The CAVE has been demonstrated at the following conferences:

6.1. SIGGRAPH 92, Chicago

(see Section 9)

6.2. Supercomputing 92, Minneapolis

(see Section 10)

6.3. Radiological Society of North America (RSNA) 92, Chicago

6.4. National Association of Broadcasters (NAB) 93, Las Vegas

(done in cooperation with Silicon Graphics, Inc.)

6.5. Supercomputing 93, Portland

(see Section 11)

6.6. SIGGRAPH 94, Orlando

(see Section 12)

6.7. Supercomputing 95, San Diego

(see Section 13)

7. CAVE Applications Development Environments

There are several application development programming tools to simplify the task of designing, implementing, and testing a CAVE application. These tools are briefly mentioned here; for more specific information, refer to the CAVE User's Manual.

7.1. CAVE Library

The CAVE Library has all the functions necessary to create a CAVE program. It deals with the synchronization of all the CAVE devices, the synchronization of the walls, the calculations of the stereo transformation and many other CAVE-specific tasks.

7.2. CAVE Simulator

The CAVE simulator is a development tool for CAVE applications. The simulator is used to create the virtual environment, to place the objects in the space, to define and test any computation that takes place in the virtual experience, and to tune the application as much as possible before using the actual CAVE hardware. It is designed to run on any workstation that supports GL. At EVL, the CAVE simulator can be run on any of the SGI workstations (including the Personal Irises and the Indigos).

The simulator program is completely compatible with the CAVE program. If an application runs in the simulator, it will run exactly the same way in the CAVE.

7.3. CAVEviewer

CAVEviewer is a NCSA Mosaic viewer enhancement to EVL's CAVE Simulator for SGI workstations. It provides a Graphical User Interface (GUI), consisting of various buttons and pull-down menus, for real-time manipulation of CAVE application simulations. The CAVEviewer's GUI provides a means for non-experts/non-developers to conduct CAVE simulation viewing (in 3D and even tracked stereo), and exploration via NCSA Mosaic.

CAVEview was developed as a feasibility project only. For those interested in obtaining a copy, it is bundled with Mosaic-based SIGGRAPH 94 VROOM documentation and application programs, and is available via anonymous ftp from ftp.ncsa.uiuc.edu in the directory: /VR/VROOM. The file is 100MB compressed using the UNIX COMPRESS utility (approximately 350MB uncompressed).

8. CAVE Funding

Proposal:	A National Scale Distributed Computing Environment (a.k.a. Supercomputing '95 proposal)
Submitted:	1/95
PI:	T.A. DeFanti
Co-PIs:	M.D. Brown
Agency:	NSF, ARPA
Requested:	$884,275
Period:	6/95-5/98
Status:	Pending

Proposal:	Quantitative Assessment of Transfer of Training in the CAVE Virtual Environment and Its Relevance to the National Information Infrastructure (NII) (RENEWAL)
Submitted:	9/94
PI:	T. DeFanti
Co-PIs:	D.J. Sandin, R.V. Kenyon
Agency:	NSF
Requested:	$785,095
Period:	8/95-7/98
Status:	Pending

Proposal:	***Funding for NII/Wall development*** Silicon Power Station Program: NCSA/EVL/SGI Strategic Global Marketing Partnership
Submitted:	12/94
PI:	L. Smarr
Co-PIs:	T.A. DeFanti, M.D. Brown
Agency:	Silicon Graphics, Inc.
Funded:	Appx. $1,300,000 in equipment to EVL
Period:	1/95-1/96
Status:	Funded

Proposal:	***Funding for ImmersaDesk development*** Design, Construction and Delivery of an ImmersaDesk System for NIST
Submitted:	11/94
PI:	P. Banerjee
Co-PIs:	T.A. DeFanti
Agency:	NIST
Requested:	$170,671
Funded:	$170,671
Period:	12/94-9/95
Status:	Funded

Proposal:	Virtual Reality Alliance:Augmenting and Complementing NII MetaCenter Activities (MetaCenter Regional Alliance)
Submitted:	5/94
PI:	T. DeFanti
Agency:	NSF
Requested:	$1,500,000
Funded:	$1,285,736
Period:	10/94-9/97
Status:	Funded

Proposal:	National Information Infrastructure and Virtual Environments: Collaboration and Outreach (a.k.a., VROOM proposal)
Submitted:	12/1/93
PI:	T. DeFanti
Co-PIs:	D.J. Sandin, M.D. Brown
Agency:	NSF, ARPA, DOE, NASA
Requested:	$855,825
Funded:	$450,000
Period:	6/94-6/95
Status:	Funded

Proposal:	The High Performance Computing and Communications Visualization Project: Deployment (Amendment #1 to NSF CISE Research Infrastructure)
Submitted:	5/3/93
PI:	T. DeFanti
Co-PI:	M. Brown
Agency:	NSF/ARPA
Requested:	$598,338
Funded:	$598,338
Period:	9/93-1/95
Status:	Funded

Proposal:	NSF CISE Research Infrastructure (Note: 53% for virtual reality)
Submitted:	11/16/92
PI:	T. DeFanti
Co-PIs:	R. Grossman, T. Moher
Agency:	NSF
Requested:	$2,000,000
Funded:	$2,000,000
Period:	8/93-1/99
Status:	Funded

Proposal:	Prototyping and Quantitative Assessment of an Intuitive Virtual Reality Environment & Its Application to Grand Challenges to Computational Science
PI:	T. DeFanti
Co-PIs:	D. Sandin, R. Kenyon
Agency:	NSF
Requested:	$711,860
Funded:	$544,000
Period:	10/92-9/95
Status:	Funded

Proposal:	High-Performance Computing, Communications and Visualization (a.k.a. Showcase proposal)
PI:	T. DeFanti
Co-PIs:	L. Smarr, M. Brown
Agency:	NSF
Requested:	$822,274
Funded:	$402,000
Period:	8/92-1/94
Status:	Funded

Proposal:	Software Technology (NOTE: A part of this grant, funded by the State of Illinois for technology transfer of visualization to small businesses, was used by the Electronic Visualization Laboratory for CAVE development prior to the SIGGRAPH 92 conference.)
PI:	T. DeFanti
Co-PIs:	None
Agency:	State of Illinois
Funded:	$400,000
Period:	11/91-6/92
Status:	Funded

Proposal:	Showcase '92
PI:	T. DeFanti
Co-PIs:	None
Agency:	NSF
Funded:	$150,000
Period:	1/91-1/92
Status:	Funded

9. ACM SIGGRAPH 92 Showcase

CAVE Applications
Chicago, July 26-31, 1992

Molecular Dynamics of Membrane Protein and Receptor Protein Binding

This project uses computer graphics to develop an understanding of structural biology dynamical processes. The graphics illustrate the probable means by which cholera toxin transports an intact protein through a target cell's external membrane while intoxicating the cell. In this process, cholera toxin recognizes and binds an external membrane-bound receptor, triggering a dynamic change in the structure of the toxin and the membrane; a portion of the toxin and enzyme enter the cell.

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Cosmic Explorer

The Cosmic Explorer is motivated by Carn the PBS series "Cosmos," in which he explores the far corners of the universe. In this implementation, the user explores the formation of the universe, the generation of astrophysical jets, and colliding galaxies by means of numerical simulations and virtual reality technology. This application demonstrates human-oriented paradigms for examining large sets of data that contain spatial and temporal information. By allowing a human to explore these databases as they might explore a physical place, a user can take advantage of human experience rather than technological prowess to comprehend the data.

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Virtual Molecular Reality

This project demonstrates the interaction between a virtual reality system and a molecular dynamics program running on a supercomputer. The programs are capable of simulating very fast macromolecular assemblies for studies in structural biology. The new generation of parallel machines allows one to simulate the response of biological macromolecules to small structural perturbations, administered through the virtual reality system, within a short time, even for molecules of a few thousand atoms.

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Graphical Planning for Brain Surgery

This presentation includes demonstrations of brain surgery planning software that currently is being clinically tested. The procedure employs a 3D localizer as a means of interactively transferring spatial relationships from MRI-derived 3D anatomical models directly onto the patients.

The Showcase presentation allows participants to interactively manipulate the localizer around a plastic model of a human head (or a live volunteer) and get immediate feedback in the form of a stereoscopic model.

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Fractal Exploratorium

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The Snowstorm

This project visualizes 3D vector fields with several techniques: short vectors attached to 3D lattice points, linear tracers, isopotential curves, etc. Of special interest is a large number of particles flowing through the field whose velocity is proportional to field strength. Examples are selected from the Lorenz Attractor, steepest descent algorithm, and more. Additionally, attendees can create their own 3D fields by combing a virtual space with a wand.

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The Virtual Embryo

Real-time interactive 3D visualization of the anatomy of a 7-week-old human embryo is demonstrated in a virtual reality environment. Distributed processing allows dynamic manipulation of voxel-based and surface-based representations of embryonic morphology extracted from a database at the National Museum for Health and Medicine. This work enables researchers to extract new information about various aspects of human development by re-examining existing collections of specimens with visualizaton and analysis tools.

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Kuwaiti Oil Fires

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10. ACM/IEEE Supercomputing 92

CAVE Applications
Minneapolis, November 1992

Molecular Dynamics of Membrane Protein and Receptor Protein Binding

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Visualization of the Molecular Mechanism of Cancer

The oncogene product protein p21 regulates the growth of cells by its interaction with the molecule guanosine triphosphate (GTP). Single point mutations in the genetic DNA code for this protein can result in changes in the molecular structure of p21 that can lead to uncontrolled cellular growth and cancer.

Molecular dynamics simulations can be used to study the behavior of p21 and thereby obtain insights into its mode of action. Such computational methods can also be used to design drugs that could counteract the harmful effects of the genetic mutations that alter the normal function of this protein.

This virtual reality visualization depicts the motions and interactions of the atoms of p21, its GTP substrate, and water molecules in the vicinity of the protein's primary site of action during 12 picoseconds of its lifetime.

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Modeling of Piezoelectric Crystal Resonators

Piezoelectric crystals are an important component in electronic appliances such as computers, cellular phones, and pagers. To be useful, these crystals must resonate in a particular vibrational mode at a specified frequency over a wide range of temperatures. To reduce product development time, engineers need to be able to model the behavior of piezoelectric crystals. In the past year, extensive collaboration between Argonne and Motorola has resulted in the development of algorithms and prototype software to model these crystals on massively parallel architectures such as the Intel DELTA.

The project has two major components: (1) the development of a new finite element for modeling piezoelectric crystals, and (2) the development of scalable parallel algorithms for the sparse linear algebra computations. Our prototype implementation has been able to solve problems with over 500,000 degrees of freedom at speeds of 2.5 gigaflops on the Intel DELTA. Visualization allows us to see the shape of the deformed crystal and the vibration mode shapes modeled.

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Modeling Superconductors on Massively Parallel Computers

The recent discovery of high-temperature superconductors has generated considerable interest in the modeling of these materials. High-temperature superconductors have tremendous industrial potential, but for many applications the currently available materials have several undesirable physical properties. Through a better understanding of this class of superconductors, it is hoped that materials with more desirable physical traits can be found.

Formally, these newly discovered materials are classified as layered type-II superconductors. Layered superconductors are composed of thin, 2D superconducting sheets alternating with thicker insulating layers. Type-II superconductors are characterized by their ability to remain superconducting in a so-called mixed state. In this state, which exists between a lower and upper critical applied magnetic field, denoted by H(c1) and H(c2) respectively, these materials allow magnetic flux lines to penetrate the bulk of the material. This phenomenon is possible because of the formation of compensating vortex currents around these magnetic flux lines, which shield the remaining superconducting regions from the effect of the magnetic field.

We use an extension of the Ginzburg-Landau theory developed by Lawrence and Doniach to predict vortex structure and configurations. To accurately model such systems we must use a full 3D model with millions of unknowns. To successfully solve such large systems, we have had to use a combination of highly efficient algorithms and massively parallel computing.

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Full Configuration Interaction on the Intel Delta

In this demonstration, we are looking at a visualization of the communication pattern of a theoretical chemistry application on the Intel DELTA. The DELTA is a mesh-connected parallel supercomputer with 512 i860 processors. The computation being performed here is a Full Configuration Interaction computation on 128 processors. The communication pattern is difficult to predict, and the tool PADL, developed at Argonne National laboratory, enables us to study it in detail.

As processors request needed data from other processors, bottlenecks may result if there is too great a concentration of communication traffic on a small number of processors. During this computation, we can see bottlenecks develop, but they are of relatively short duration. During most of the computation, the arrows are sparsely distributed, indicating that the parallel algorithm is performing as originally envisioned.

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Cosmic Explorer

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Mapping Cognitive Function with Subdural Electrodes and Registration of Cerebral Evoked Potentials on 3D MRI

This process first maps the cortical areas associated with such cognitive processes as language, attention, and memory onto 3D images of the brain surface created from MRIs. It then determines whether measurements from passive recordings of the electrocorticogram during cognitive tasks can be used as objective measures to localize cognitive functions onto the cortical surface. Anatomically precise maps of cortical function allow a more quantitative evaluation of individual differences due to the influence of handedness, gender, and plasticity on cortical organization.

The experimental design also provides an opportunity to examine the patterns of electrophysiologic covariance between cortical electrodes, to test hypotheses that suggest that cognitive functions are organized as parallel processes distributed throughout the brain. It is hoped that these maps have the practical effect of improving surgical outcome while also increasing our understanding about how cognitive processes are organized within the human brain.

During neurosurgical procedures involving frontal or parietal cortex it is imperative to identify the critical motor, sensory, and speech areas so that they may be spared. Neurosurgeons often find it necessary to map these areas during surgery, because there is great variability in the cortical functional organization between people. Having this information available before surgery would allow the surgeon to confidently plan the best approach for cortical resections.

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The Snowstorm

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Realistic Modeling of Brain Structures with Remote Interaction Between Simulations of the Inferior Olive and the Cerebellum

Interactions between realistic neuronal simulations in different locations along with a listening post at the concurrent First Annual Computation and Neural Systems Meeting in San Francisco illustrate a novel use of the network. A simulation of the mammalian inferior olive on a workstation at SIGGRAPH and a simultaneous simulation of a cerebellar Purkinje cell on the Intel Delta at Caltech allows the Chicago demonstrator to provide an electrical stimulation of the inferior olive which initiates an action potential over the network to the Purkinje cell at Caltech.

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Kuwaiti Oil Fires

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CAVE Sound (general description)

CAVE sound is determined either aesthetically or algorithmically for each of the above projects. For the majority of demonstrations, an appropriate set of sounds, previously sampled and stored, is triggered by a particular graphical application as it is loaded into the CAVE workstations. Other demonstrations rely on "sonification," a data-driven technique where the same data that drives the graphics drives the sound.

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11. ACM/IEEE Supercomputing 93

Experiential Science in The Virtual Reality Theater
CAVE Applications
Portland, November 1993

Interactive Steering of Supercomputer Simulations!

Some of the applications demonstrated at Supercomputing 93 run in two modes: locally on the SGI/CAVE, or distributed between the CM-5 and the SGI/CAVE. In local mode, CAVE participants explore precomputed datasets. When distributed computing mode is enabled, CAVE participants may "interactively steer" their simulation codes on the CM-5.

This ability enables CAVE users to explore/experience visualizations of precomputed datasets, identify an area they want to enhance, and then invoke simulation codes on the networked supercomputer to compute new datasets. The CM-5 generates new data, which is then transferred to the SGI workstations for rendering and display in the CAVE.

Scientific simulation codes are typically large and complex, and require high-performance computing resources – whether massively parallel processors, vector processors, massive datastores, large memories, or high-speed networks – to run efficiently. Depending on the dataset and the type of analysis that scientists want to do, they set up their simulation codes to calculate greater detail, a different time step or a different state defined by new parameters. In some instances, codes can be executed locally but take longer to run, so a supercomputer is used to provide faster interaction.

CAVE experiences enable researchers to interactively explore their scientific domains, play "what if" games by modifying their codes, and view the resulting visualizations in close-to-real-time. Virtual reality is recognized as an "intelligent user interface" to the emerging National Information Infrastructure, that will enable computational scientists and engineers to access HPCC enabling technologies and that will put the "human in the loop" for timely data analysis and understanding.

Evolution of Shape and Sound via Genetic Programming

The ideas of genetic evolution combine with computer science and art to create aesthetically pleasing shapes and sounds. A *gene* is a symbolic mathematical expression that determines the unique geometric shape and musical sound of an object in this virtual world.

CAVE participants rotate, mutate or marry objects to other objects of the same generation, or request the system to recalculate the objects in high-resolution mode (which affects the computer's response time).

The CAVE enables participants to explore these genetic lifeforms, both visually and aurally, in a true 3D environment. This research employs a new algorithm for genetic evolution, recognizes shape and sound as integral components of its lifeforms, algorithmically generates shapes and sounds based on a user's selection criteria, and displays the lifeforms in a surround-screen, surround-sound environment.

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Blowing Snow

Blowing Snow is a simplified simulation of wind interacting with the person who is being tracked inside the CAVE. CAVE participants control wind direction and velocity. Particles *(snowflakes)* from the upwind direction bounce off the person being tracked; vortices develop downwind from the person being tracked. Wind sounds are affected by user input; sound volume is tied to wind velocity and sound localization is tied to wind direction.

This CAVE experience is actually an experiment to determine how visible the flow patterns are when thousands of tracing particles are introduced. Virtual reality's excellent 3D characteristics enable the use of large numbers of particles, which would probably be self-obscuring in a normal 2D display environment. This display technique will eventually be used to visualize results of computational fluid dynamics (CFD) calculations on supercomputers.

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Topological Surface Deformation*

This program uses free-form deformations (FFDs) to study the topology of mathematical surfaces. Topology is the study of the characteristics of mathematical surfaces, such as their number of sides, edges or holes. Deforming a surface changes its shape, but not its characteristics; an edge remains an edge, and a hole remains a hole, no matter how distorted the edge or hole appears. The claim of topologists that a donut (torus) and a coffee cup are topologically equivalent is one of the deformations demonstrated in the CAVE.

CAVE participants interactively manipulate a grid-like control structure to specify a deformation. The CM-5 recomputes the surface's shape; results are sent to the SGI workstations to be rendered and then displayed in the CAVE. The deformation algorithm was adapted from the literature (Sederberg and Parry, 1986). The program also allows a series of deformations to be recorded and later played back in the CAVE for review.

The CAVE's immersive virtual environment enables participants to walk around mathematical shapes, step through complex surfaces, or move a surface through itself. Virtual reality encourages users to see shapes from a new perspective – from the inside, looking out – and to explore and manipulate complex surfaces in order to better understand them.

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Mathenautics: Three-Eighths of Thurston's Eight-Fold Way

Mathematicians study the behavior of lines and curves on the surfaces of different shapes, such as a sphere and a donut-shaped torus. While these bodies are 3D, their surfaces are 2D manifolds. Examples of 2D manifolds that are not surfaces of 3D bodies are the plane, the saddle and the Moebius band. With an accompanying geometry, mathematicians can measure distances, angles and areas in these 2-spaces. Different 2-spaces admit different geometries. On a plane in 3-space, the three angles of a triangle always add up to 180 degrees, whereas on a sphere, this sum is always greater than 180 degrees. Inside the hole of a torus, on the part of the surface facing the center, this sum is always less than 180 degrees, whereas outside, on the part facing away, it is always greater than 180 degrees.

If, unlike the torus, the geometry is to be uniform over an entire space, then for surfaces, there are only *three* different geometries possible:

- the familiar Euclidean (the geometry of the surface of a plane)
- the spherical (the geometry of the surface of a sphere)
- the hyperbolic (the geometry at the center of a saddle)

Mathematician William Thurston conjectured in 1980 that, for 3D manifolds, there are *eight* different uniform geometries – his *eight-fold way*. People are used to seeing 2-spaces from the outside, as illustrations that appear in math texts. The CAVE enables participants to see 3-spaces for three of Thurston's eight geometries from the inside, as inhabitants might see them.

Three different 3-spaces can be visited in the CAVE: Euclidean, spherical and hyperbolic. Each is represented by packing, or *tiling*, the space by repeating a simple shape. Two instances of Euclidean 3-space can be visited: one is tiled by cubes; the other, nicknamed *Escher space* because of its resemblance to Escher's "Relativity," is tiled by staircases. The spherical and hyperbolic 3-spaces are tiled by dodecahedra, but in distinctly different ways.

Non-Euclidean geometries, historically taught and appreciated solely in the abstract, may now be *lived in* and *experienced* through the use of the CAVE. The main thrust of this application is to test virtual reality as an educational tool in a significant context, one that is not simply derivative of previous techniques, but which uses the virtual reality medium to its potential.

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The Fluid Universe: Formation of Structures After the Big Bang

The physics of fluid flow coupled with gravity is of crucial importance to the understanding of many astrophysical phenomena. In this application, CAVE participants stand inside the universe and experience the evolution of the largest structures observed to date as they form around them; data was precomputed on NCSA's Convex C3880. Starting around the time of the Big Bang, about 15 billion years ago, participants follow the evolution of the nearly homogeneous gas as it fragments and collapses under its own self gravity. By following the evolution of density isosurfaces, we see that the amount of gas at high density (within the surfaces) increases with time. At the end of the simulation, the density distribution looks similar to that seen in observational surveys.

The virtual reality experiences provided by the CAVE are enabling researchers to better discern the overall 3D shape (or morphology) of these density filaments, particularly as their shapes evolve over time. Specifically, scientists have been surprised by the speed with which large density filaments move with respect to their size.

Scientists are already asking for more visualization features (some of them limited by machine speed), such as: the ability to view larger datasets, generate multiple 2D cross-sectional slices of a data volume, interactively change isosurface thresholds, and do volume rendering.

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The Fluid Universe: Rayleigh-Taylor Instability in Fluid Flow*

This interactive simulation of the Rayleigh-Taylor instability shows what happens when a heavier fluid lies on top of a lighter fluid. The gravitational force causes the heavier liquid to form fluid *fingers* that flow down into the lighter liquid, causing mixing and turbulence. There are many astrophysical objects that show this kind of behavior, such as the remnants of giant explosions called supernova and the atmospheres of some stars.

CAVE participants interactively set some simulation parameters, such as the angle at which the fluids flow or the density of the heavier liquid, and then invoke simulation code on the CM-5 to compute the flow over time. Viewers see a progression of images as the system calculates and displays frames of an ongoing time series.

To date, scientists viewing this application in the CAVE have achieved a better understanding of the *texture* (or 3morphology) of the data produced by the simulations. Specifically, the evolution of small eddies on the sides of the large Rayleigh-Taylor *finger* were very interesting to observe.

Additional visualization features – such as those requested for the previous example, The Fluid Universe: Formation of Structures After the Big Bang – are also of interest to astrophysicists studying fluid dynamics.

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Spacetime Splashes: Catching the Wave of Einstein's Equations*

Einstein's theory of gravity, known as general relativity, is a complex set of nonlinear partial differential equations. We have developed full 3D code to solve these equations for the gravitational field. This demonstration shows gravitational waves propagating through spacetime according to Einstein's equations for the gravitational field. The waves are disturbances in the gravitational field that travel at the speed of light. The simulation computes the evolution of various components of the waves.

Gravitational wave components are represented in the CAVE as opaque and semi-transparent surfaces. Participants watch as waves propagate through a volumetric gravitational field over time, or interact with the volume: move the volume up or down to see what's below or above, respectively; navigate through the volume; or, define and display subvolumes. A special mode enables participants to interact with the CM-5 to control physical parameters of the simulation (e.g., the amplitude of a wave, the shape of a wave, etc.).

Astrophysicists are interested in applying virtual reality and scientific visualization to spacetime simulations to help them better understand and interpret numerical studies of black holes, gravitational waves, and the Einstein Equations for the gravitational field.

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Distributed VIS-5D for Large Atmospheric Simulations

A simulation of Hurricane Gilbert, using VIS-5D software, lets CAVE participants stand inside the hurricane, experiencing such phenomena as wind direction, wind speed and temperature. Summer heat builds up over Earth's tropical oceans, and hurricanes are nature's way of getting that heat to the top of the atmosphere where it can be radiated back into space.

With VIS-5D, CAVE participants explore datasets, which were precomputed on NCAR's CRAY YMP, that portray the development of a heat bridge from the ocean surface to the top of the atmosphere. They also explore the resulting violent winds by releasing streamers into the air flow, by slicing through the wind vector field, by examining a volume rendering of wind speed, and by creating isosurfaces of temperature. Hurricanes are very complex phenomena, and the interactivity of VIS-5D and the CAVE help researchers understand that complexity.

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Endless Turbulence

Strong turbulence is at the heart of supersonic fluid flows, and accurately modeling this turbulence over a wide range of length scales is one of computing's Grand Challenges. CAVE participants stand inside a 3D patch of fluid through which shock waves have passed. The flow was precomputed on the AHPCRC 512-node CM-5, producing over 210 GByte of compressed data. The flow in this patch was computed at a 512x512x512 resolution, or an eighth of a billion zones, using the Piecewise Parabolic Method (PPM) developed by Paul Woodward and David Porter.

As the shocks decay into vortex sheets, sheets into vortex tubes, and tubes into noise, participants observe in detail the formation and decay of turbulent structures. Using the CAVE's input controls, participants can move through the large volume or view time steps of the structures' formation. Virtual reality offers a unique way for researchers to navigate through the morass of data.

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* **These applications run in distributed computing mode between the CM-5 and the SGI/CAVE, enabling participants to interactively steer the simulations.**

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CAVE video documentation manager: Dana Plepys, EVL

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CAVE Research

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12. ACM SIGGRAPH 94

VROOM: The Virtual Reality Room
CAVE Applications
Orlando, 24-29 July 1994

DETOUR: Brain Deconstruction Ahead

This autobiographical account by artist Rita Addison describes perceptual changes she experienced subsequent to her head injury in a car accident. DETOUR uses computer brain models and medical imaging to demonstrate anatomical trauma. In the final section, Addison's pre-accident photographic art is reconfigured to simulate the perceptual damage she sustained.

A virtual reality experience can be a powerful way to evoke and stretch empathic capabilities. Whether it is used in collaborative medical evaluations or to educate medical professionals, students, patients, and families, virtual reality technology is a unique and invaluable tool for communication.

Category
Medical Imaging

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Interactive Molecular Modeling Using Real-Time Molecular Dynamics Simulations and Virtual Reality Computer Graphics

Using real-time interactive molecular modeling and molecular dynamics simulations, this project demonstrates the docking of a drug molecule to its molecular receptor. A molecular modeler guides a drug molecule into the active site of a protein, receiving real-time feedback from a molecular dynamics simulation running on an IBM SP-1 parallel computer. The molecular system is displayed and manipulated in the CAVE virtual reality environment.

Using virtual reality, drug designers can interact visually, aurally, and (ultimately) tactilely with molecular models. This environment is enhanced via feedback and input into a simulation that represents the realistic atomic interaction between molecules. Accurate and efficient methods of investigating the recognition and binding of drugs to their biomolecular targets will significantly enhance the drug discovery process.

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Biochemistry

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Simulation of a Grinding Process in Virtual Reality

Simulation of a grinding process in the CAVE enables users to explore a commonly used manufacturing process from an entirely new vantage point. An operator performs the simple task of grinding a component by controlling the motion of three axes of the table with the wand. When the wheel is in contact with a part on the table, heat is generated and material is ground away. This produces internal stress and heat flow in the part, wheel, and table. The temperature and stresses are computed in real time on an IBM SP-1 and selectively displayed on the various components as the simulation unfolds. Sound is generated by monitoring the surface motions predicted by the model. Materials ablated by the grinding are ejected as small particles and displayed as sparks.

Analysis of this simple manufacturing process involves solving complex equations at speeds that exceed the perceived event. Real-time interaction between an operator and a *virtual* machine provides new insight into how to interact with the real machine. It also enhances our ability to model physical processes and generate more realistic simulations.

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Engineering

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Interactive Adaptive Mesh Refinement

Adaptive mesh refinement/derefinement techniques have been shown to be very successful in reducing the computational and storage requirements for solving many partial differential equations. This project focuses on the Rivara bisection technique, which is suitable for use on unstructured triangular meshes such as those used in finite-element calculations.

Virtual reality demonstrates the realization of interactive adaptive mesh refinement. A user indicates the areas of the mesh to be refined using a 3D wand in the virtual space. This interaction is especially desirable in three dimensions, where users are immersed inside the mesh to locate interior regions that require refinement.

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Algorithms

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Visualization of Casting Process in Foundries

This application models the pouring of a fluidity spiral used to measure the distance metal can flow in a channel before being stopped by solidificaion. The gray iron at 1395 degrees C is poured into the mold for two seconds and flows down the spiral arm turning to mush at 1215 degrees C and solidifying at 1150 degrees C. The casting then continues to lose heat to the mold until solidification is complete.

The calculations were performed using the Casting Process Simulator (CaPS), robust multidimensional time-dependent computer code that uses a finite-volume formulation in solving mass, momentum, and energy equations and performs mold filling and solidification.

Category
Engineering

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Phase and Amplitude Maps of the Electric Organ Discharge of the Weakly Electric Fish, Apteronotus Leptorhynchus (Brown Ghost)

This demonstration models the Apteronotus Leptorhynchus (commonly known as the Brown Ghost). It displays simulated data of the electric fields emitted by the fish, as well as how the fields are distorted by an object placed in the surrounding water.

The purpose of this fish simulation is to establish an understanding of how emissions are generated by the real fish. Since humans do not have an electric sense, it is difficult to comprehend how fish electric fields "feel." Alternative techniques, such as virtual reality, must be used to acquire some of that sensation. The results will help us understand how this fish uses phase and amplitude information from the electric organ discharge for electrolocation and communication.

Category
Neuroscience

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Using Virtual Reality for Machine Design

Caterpillar, Inc. uses virtual reality as a tool for interactively evaluating new machine designs. Using virtual reality, the operator of a virtual machine can test alternative machine designs while driving through a virtual proving ground, or can perform a loading cycle to fill a truck with soil. Hydraulically-actuated tools can be assessed with various hydraulic systems.

Using a virtual-reality system enables engineers and designers to get a "feel" for their machine designs very early in the design stage, helping them evaluate many different designs in shorter periods of time than possible using conventional methods.

Category
Engineering

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Acetylcholinesterase: Nature's Vacuum Cleaner

This research focuses on the electrostatic forces generated by Acetylcholinesterase, an enzyme that plays a key role in the human nervous system. Neurotransmitter molecules (acetylcholine) are drawn down a long tunnel and into a "reactive-site" cavern deep within the enzyme where they are cleaved into component parts for reuse. By literally voyaging into the enzyme along a route similar to that taken by neurotransmitter molecules, researchers gain a unique vantage point from which to examine the electrostatic field and other computed probes of enzyme activity. An immersive display also is a unique medium for helping nonspecialists understand a sequence of chemical events that would otherwise be difficult to convey.

Improved understanding of the actual forces and dynamics at work in the acetylcholinesterase process should enable design of novel inhibitor molecules that have therapeutic value.

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Visualization of Climate Data Over the Western United States

Many climatologists are interested in understanding energy transport in the atmosphere due to wind and precipitation. To achieve this goal, they must be able to observe anomalies and patterns, and they must be able to visualize cause-and-effect relationships implied by earth science data. Since these data either measure or simulate actual physical phenomena that humans sense in everyday life, it is natural to visualize this information in a way that emulates or complements our experience. A thesis currently being investigated is that immersion in a virtual world that models the one we live in may enable scientists to better understand the Earths's dynamic climatic processes.

This demonstration represents output from a regional climate model for the western United States. Data from the model are compared with actual measurements to help gauge the validity of the model.

Category
Earth Science

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Simulation of Light and Sound Distribution in an Environment

One application of virtual reality is imitation of the real world. Using virtual reality, the optic and acoustic behaviors of an environment can be experienced directly, and modifications can be evaluated immediately. In this demonstration, light and sound distribution in different room types is simulated. Simulation parameters and room properties can be modified interactively, and the resulting optic and acoustic energy distributions can be visualized.

Category
Algorithms (lighting, acoustics)

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Virtual Environments for Automotive Design

Viewers walk around, then sit inside a car made only of light. The viewer is able to change color schemes and move illumination sources around by hand. The scenes are composed of ray-traced imagery and dynamically-rendered geometric surfaces.

Evaluation of early interior design concepts is usually done by building full-sized physical mock-ups, which require time and expense. The virtual mock-up has the potential to replace many early physical prototypes, and provide flexibility in altering and viewing the concept, which is not possible with a physical part. Virtual environments can facilitate decisions regarding aesthetic, engineering, safety, and ergonomic criteria.

Category
Computer-Aided Design

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Knotted Spheres in the Fourth Dimension

Computer graphics simulations of virtual worlds help us develop intuition about objects we can never experience in real life. This demonstration exactly simulates interaction with images of complicated 4D structures as they would be experienced by an individual actually living in the fourth dimension and seeing with 4D light. The distinguishing feature of this virtual 4D world is that it produces holistic images that reveal global, rather than local, properties of the objects depicted.

Knotted Spheres in the Fourth Dimension exhibits real-time interaction with "knotted spheres" (knotted two-manifolds embedded in 4D space). A typical approach to visualizing such a surface is to project it into 3D and view it with 3D lighting, but this omits nearly all of the interesting 4D information about the structure. Instead, this system uses a fast approximation to volume rendering volume images of projected 4D objects with true 4D lighting and occlusion, enabling viewers to interact with and pick out important mathematical features of this class of objects.

Category
Mathematics

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The Onset of Turbulence in a Shear Flow Over a Flat Plate

Smooth, laminar flow over a flat plate eventually becomes turbulent. The transition to turbulence generally occurs on a scale that is too small and too fast for an observer to appreciate in an empirical experiment. This application lets the user track the development of a turbulent spot (from a numerical simulation) at a size and speed that are comprehensible.

Category
Fluid Mechanics

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CitySpace

CitySpace is an educational networking project that invites students to build a virtual city model made up of 3D objects and images from sites around the world. The CitySpace project strives to present a learning model based on collaboration, simulation, visualization, and wide-area digital networking. The project is intended for integration into project-based curricula and is designed for self-managing groups of students, mentors, teachers, and resource administrators. The model relies on a flexible, open, high-speed network based on client-server technology, widespread access to desktop digital media production tools, and efficient utilization of high-end computational resources.

Category
Collaborative networked visualization

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Three-Dimensional Terminal Viewer (3DTV)

Impaired visibility conditions caused by nightfall or precipitation can preclude aviation system users from obtaining the visual cues often helpful in detecting aviation weather hazards. Other aviation weather hazards cannot be detected by the naked eye. 3DTV was developed to study the value of real-time 3D visualization of derived weather hazards, such as microbursts, wind gust fronts, and heavy precipitation regions, to the aviation community. It provides a virtual environment that allows users to have a more intuitive understanding of the aviation weather hazard situation within the terminal area, and to promote effective communication between users through a shared and heightened situational awareness.

Algorithms, fed by real-time sensors such as Doppler weather radars, extract aviation weather hazards and allow the creation of a virtual world derived from physical phenomena. The system uses icons and surfaces to present an unobscured view of weather hazards to the target audience: air traffic managers, flow control specialists, and pilots.

Category
Atmospheric Science

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Scientific Visualization of Gyrofluid Tokamak Turbulence Simulation

High-performance algorithms for simulating and visualizing 3D plasma turbulence in magnetic fusion experiments have been developed as an aid in the development of more accurate predictive models of plasma transport and the design of future experiments. This work is part of the Numerical Tokamak Project, a national consortium of efforts using the most powerful supercomputers in the world to develop and use such numerical models. Virtual reality represents a "next step" in the development of a visualization system already in use by collaborators in the Numerical Tokamak Project.

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Fusion Physics/ Energy Research

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Sounds from Chaos in Chua's Circuit

To exhibit chaotic behavior, an autonomous electronic circuit must contain at least one nonlinear element, one locally active resistor, and three energy storage elements. Chua's circuit is the simplest electronic circuit that contains these elements, and it is the only physical system for which the presence of chaos has been proven mathematically. It has become a paradigm for the study of chaos due to its universal chaotic properties, its simple circuit design, its ease of construction, and its rich variety of over 40 attractors.

Chua's circuit produces many types of signals, from sine-like periodic patterns to unpredictable noise-like patterns. These continuous signals can be generated in the human auditory range and displayed as sound using an amplifier and speakers or headphones. Sometimes, the sound resembles familiar musical tones. Other times, it produces novel sounds that contain both pitched and noise characteristics. By listening to the sound, observers can study fine details of a chaotic attractor. A composer could also organize the sounds into a musical presentation.

The unique aspect of the display of this study in virtual space is the simultaneous presentation of control space (manifold) and output phase space of the circuit. As users navigate the manifold surface, they receive immediate feedback by observing the phase display of the signal as well as changing acoustic responses.

Category
Algorithms (auditory display); Mathematics

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The Fluid Universe: Rayleigh-Taylor Instability in Fluid Flow

This interactive simulation of Rayleigh-Taylor instability shows what happens when a heavier fluid lies on top of a lighter fluid. The gravitational force causes the heavier liquid to form "fluid fingers" that flow down into the lighter liquid, causing mixing and turbulence. There are many astrophysical objects that show this kind of behavior, such as the remnants of giant explosions called supernova and the atmospheres of some stars.

Scientists viewing this application in the CAVE have achieved a better understanding of the texture (or morphology) of the data produced by the simulations. Specifically, the evolution of small eddies on the sides of the large Rayleigh-Taylor finger were very interesting to observe.

Category
Astrophysics

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Post-Euclidean Walkabout

This real-time interactive CAVE application takes you on a visit to the post-Euclidean geometry of Gauss, Riemann, Klein, Poincare, and Thurston. Here you can walk into a rectangular dodecahedron, a shape which is possible only in negatively curved hyperbolic space. With a wand, you can summon and play with the snail-shaped 3D shadows of soap films in positively curved elliptic space. You can see how to sew the edges of hyperbolic octagons together into the surface of a 2-holed donut. The CAVE becomes a spaceship you can navigate with the wand, as it glides through the phantasmic shapes that populate the 3-sphere.

The purpose of this project is to perfect persuasive visual and sonic environments in which to exhibit geometrical wonders and their startling metamorphoses, which interest research geometers. Convincing visualization of multi-dimensional, time-varying geometrical structures is equally useful in applied and pure mathematics.

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Mathematics

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Stepping Into Alpha Shapes

A finite set of points in 3D space and a real-parameter "alpha" uniquely define a simplicial complex, consisting of vertices, edges, triangles, and tetrahedra embedded in space: the "alpha complex" of the points. The "alpha shape" is the geometric object defined as the union of the elements of the complex. By varying the values of alpha, the system can create crude or fine shapes – from convex hulls to detailed structures containing cavities that may join to form tunnels and voids. Several graphical interaction techniques, as well as the use of sound synthesis, enable users to explore alpha complexes with meaningful visual and auditory cues. Alpha shapes have application in geometric modeling, grid generation, protein structure analysis, and medical image analysis.

The alpha-shape software constructs a geometric object with detailed and possibly quite complicated features on the outside and inside. The CAVE enables the immersive visual inspection of features. The audio experience is made possible through the real-time sound synthesis reflecting the detailed structure of the alpha shape.

Category
Geometric Modeling

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Virtual Breadcrumbs: A Tracking Tool for Biological Imaging

Virtual Breadcrumbs is an immersive virtual environment tool for tracking complex biological structures in a volumetric dataset. Through a combined volume and solid-model rendering visualization interface, it allows users to walk along the highly convoluted and twisted path of a fiber folding in three dimensions while simultaneously building a model of the fiber track. The tool is demonstrated with several medical and biological volumetric datasets. For example, it tracks chromatin fibers through the nucleus, cytoskeleton fibers through the cytoplasm, and neurons within brain slices from microscopic datasets.

The ability to track the structure of biological objects through a 3D volume is an important problem in biological and medical image analysis. It is also a difficult problem, because the need for continuous reorientation of the 3D viewing geometry causes spatial disorientation. The CAVE solves the problem and generates better tools for scientific investigation by providing a unique immersive environment for 3D biological image analysis.

Category
Medical Imaging

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Spacetime Splashes: Catching the Wave of Einstein's Equations

Astrophysicists are interested in applying virtual reality and scientific visualization to spacetime simulations to help them better understand and interpret numerical studies of black holes, gravitational waves, and the Einstein equations for the gravitational field.

Einstein's theory of gravity, known as general relativity, is a complex set of nonlinear partial differential equations. We have developed full 3D codes to solve these equations for the gravitational field. The demonstration shows gravitational waves propagating through spacetime according to Einstein's equations for the gravitational field. The waves are disturbances in the gravitational field that travel at the speed of light. The simulation computes the evolution of various components of the waves.

Category
Astrophysics

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The Development of Tornadoes with Storms and Along Gust Fronts

This demonstration is derived from current investigations of the processes involved in tornado genesis along thunderstorm outflow boundaries. The massively parallel CM-5 and CM-2 supercomputers are being used to numerically simulate the local environments that support these tornadoes. Rendered isosurfaces, such as temperature surfaces, give a tangible representation of the outflow leading-edge structure and key instabilities that may be present. Trajectories launched near these instabilities yield valuable information about the flow regime present at the outflow leading edge.

Category
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A Walk Through Chesapeake Bay

Unlike the atmosphere, the world's oceans are opaque, and processes that occur beneath the sea surface cannot be directly viewed. What little we "see" is inferred from measurements made with remote sensing instruments. Though it can be useful, this approach limits the ability of scientists (and the general public) to experience the many and varied processes that occur in marine environments. Now, with recent advances in computing and visualization, individuals can experience the environment beneath the sea surface in a visualization framework that is familiar to them. A visualization approach also allows many processes to be integrated, so that interaction of complex oceanic systems can be demonstrated (e.g., circulation and ecosystem dynamics).

Freshwater input is a primary forcing function for the circulation of estuarine systems such as the Chesapeake Bay. This first effort to focus on visualizing the input of freshwater to the Chesapeake Bay allows study of the effects of the Susquehanna, Potomac, and James Rivers, among others, on the salinity and hence the density structure of the Bay in a 3D time-dependent framework. This study combines bottom bathymetry, river discharge, hydrographic (temperature and salinity) datasets, and tidal datasets for the Chesapeake Bay, as well as circulation distributions from a numerical circulation model constructed for the Bay.

Category
Oceanography

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3D Hydrodynamic Model of the Heart

This computational model of the heart treats the heart wall as a set of fibers immersed in fluid and responding to both fluid forces and tension forces. The fluid, in turn, experiences a force field in the neighborhood of the fibers that prevents flow through the gaps in the fiber network, allowing the heart to pump the fluid. The anatomy modeled is that of a hog heart, for comparison with experimental data.

The main goal of this virtual reality project is investigational. The hope is that it will help clarify the relevance of virtual reality to this type of study.

Category
Biomedicine

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Real-Time Graphics Techniques Using IRIS Performer

Whether used as a training simulator or as an architectural design tool, most visual simulations try to achieve a sense of immersion for better usability and training value.

These virtual environments demonstrate various techniques in real-time computer graphics using IRIS Performer, a performance-oriented, multiprocessing 3D graphics toolkit. The techniques include level-of-detail control for frame-rate constancy, view culling, texture mapping, detail texturing, pre-computed animation sequences, billboard polygons, and morphing. The scenarios include a drive through a town, a walk through a radiosity-solved architectural model, and, a demonstration of real-time shadow generation using projected texturing.

Category
Algorithms

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Acknowledgments
Thanks to the rest of the IRIS Performer team: Sharon Fischler, Michael Jones, Allan Schaffer, Chris Tanner, and Craig "Crusty" Phillips (emeritus); to Maryann Simmons for many a midsummer night's coding; to Wes Hoffman of Paradigm Simulation for creating the town database; to Lightscape Technologies for the radiosity solution; and to Software Systems for the Multigen modeler.

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Virtual Exploration of a Florida Thunderstorm Using the SciAn Visualization Package

Raw and analyzed data from a variety of sources, as well as simulation, are used to explore a storm system in central Florida. The purpose of this research is to better understand the relationships among the co-evolving wind, water, and electric fields, with the goal of improving numeric models of storm systems and improving forecasts of precipitation, lightning, tornadoes, and downbursts.

Exploring the data in a virtual environment gives a better overall understanding of the structure of the storm than is possible with static or animated images on a flat screen. The ability to interact with the data in an inherently 3D space allows more natural exploration of the properties of the data. Merging an immersive environment with natural 3D interaction allows conventional visualization techniques, such as isosurfaces and streamlines, to function as extensions of the user's hands and senses.

Category
Atmospheric Science

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Collaborators in the CaPE Convection and Precipitation Electrification Experiment

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Stepping Into Reality

This team's current work is focused on embedding real (stair stepper) and computer-generated forces (mechanized and infantry) into a distributed interactive simulation. A virtual environment version of this work produced through stealth imaging is portrayed using the CAVE environment. An individual on the stair stepper can view the virtual environment, move around in it, and interact with other simulation entities by firing a weapon. As a feedback mechanism from the virtual terrain, the stair stepper provides a closer sense of reality.

Category
Situational Training

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Parallel Real-Time Radiosity

This application demonstrates how parallel architectures are being used to render scenes in real time or close-to-real-time using physically based lighting models (in particular, "radiosity"). For VROOM, the application visualizes Argonne West's Breeder Reactor model database and other interior room scenes.

Virtual reality is helping to determine which components of global illumination models are important to provide users with a level of realism beyond standard lighting models. Implementing the algorithms for radiosity and other physically based techniques in virtual reality helps focus the work on the areas that are most in need of improvement – for example, performance enhancements using parallel architectures, better modeling of the physics of light transport, human perception issues, and other areas.

Category
Algorithms

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The Virtual Eye

This project demonstrates the design of an anatomically realistic computer model of a human eye in a virtual environment. Users are able to explore and interact with the eye's components to discover their characteristics. The model will eventually be used to educate students on the eye's geometry and will allow them to simulate common presurgical procedures.

Category
Medical Imaging

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JASON Interactive Mapper

The JASON is an underwater remotely operated vehicle operated by the Woods Hole Oceanographic Institute. This virtual reality demonstration re-enacts the exploration of hydrothermal vents in the Guaymas Basin near Baja California. CAVE participants watch the JASON as it collects bathymetry data, temperature data, and high-resolution still images, and transmits a "live feed" from its video cameras (pre-recorded, in this case, for presentation purposes).

With a virtual reality interface, users are able to visit this normally inaccessible region via telepresence. After they watch the JASON explore the vents, they construct a 3D map from what they have seen, physically placing icons that represent observed objects and events into the virtual environment.

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Oceanography

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Evolution of Behavior in a Simulated Environment

This application enables CAVE users to view and interact with the behavior of various animats, virtual animals that exhibit behaviors similar to those of natural animals, such as predators, scavengers, or gatherers. The user interacts with the animats by giving distinct behaviors rewards or penalties that affect the life of the animat and its future generations. The fundamental notion of the application is based on the field of Artificial Life, the study of living organisms through artificial means.

Virtual reality enhances this simulation by providing users with immediate feedback on various behaviors. Behaviors should be easily recognizable and users should be able to determine if the behaviors are similar to what is expected. The visual feedback is different from traditional text-based results.

Category
Artificial Life

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Getting Physical in Four Dimensions

The goal of this application is to provide a more intuitive understanding of hyperspace. It enables users to physically interact with objects in four dimensions.

A series of classical 4D objects is projected into the 3D CAVE through simultaneous projection of both 3D slices and perspective projection. There is also a mode that enables the user to directly draw 4D surfaces of revolution by drawing a 3D curve. The user controls both the 4D projection point and the 3D viewing point, in addition to rotation and translation, in four dimensions.

A sub-cultural goal of this project is to enable users to develop an intuitive understanding of hyper-dimensional worlds. Human beings have learned about the 3D world in which we live by manipulating objects within it. In this project, the goal is to let people directly manipulate 4D objects in four dimensions. Previously, 4D objects were projected into three dimensions and then into two dimensions for viewing. Virtual reality allows a much more 3D environment, minimizing the effects of 3D-to-2D projections. It also creates a more physical interface to the 4D objects and their projections and transformations, which gives participants better intuitive insight into four dimensions.

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Mathematics

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Virtual Director

Virtual Director provides a user-friendly, virtual-reality method to control camera motion for instant playback or animation recording. The Virtual Director shown in VROOM is a camera motion-control application using the CAVE to control and play back users' input in real time. Stored camera-motion data can be used to control various computer-generated imagery cameras (e.g., Wavefront, AVS, Renderman, etc.). This demonstration also includes an astronomical simulation of colliding galaxies that has been fully rendered in batch mode with this kind of camera motion control in mind. The galactic data were simulated using a supercomputer and visualized with Wavefront.

Historically, controlling camera motion has been one of the most clumsy aspects of computer animation. When camera motion is recorded and played back using virtual reality, the control mechanism is much more user-friendly and "natural" for novice users than attempting camera control with traditional methods. Virtual reality facilitates the real-time interface for camera motion viewing, recording, and playback. This application is robust and can be applied to various 3D imaging settings as well as scientific datasets.

Category
Algorithms (animation production and recording)

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Topological Surface Deformation

The CAVE's immersive virtual environment enables participants to walk around mathematical shapes, step through complex surfaces, or move a surface through itself. Virtual reality encourages users to see shapes from a new perspective – from the inside, looking out – and to explore and manipulate complex surfaces in order to better understand them.

Topology is the study of the characteristics of mathematical surfaces, such as their number of sides, edges, or holes. This program uses free-form deformations to study the topology of mathematical surfaces. Deforming a surface changes its shape, but not its characteristics; an edge remains an edge, and a hole remains a hole, no matter how distorted the edge or hole appears. The claim of topologists that a donut (torus) and a coffee cup are topologically equivalent is one of the deformations demonstrated in this program.

Category
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Virtual Reality for Parallel Computer System Performance Analysis

Recording and analyzing the dynamics of application programs, system software, and hardware interactions are the keys to understanding and tuning the performance of massively parallel systems. Because massively parallel systems contain hundreds or thousands of processors, each potentially with 5-10 dynamic performance metrics drawn from multiple system levels, the performance data occupy a very sparsely populated, high-dimensional space. Understanding the dynamic "shape" of multiple performance data metrics in a high-dimensional space is only possible if one can examine multiple projections of this space.

The ultimate goal of this performance data immersion project is performance optimization and control of massively parallel systems. Not only does data immersion allow one to quickly grasp the relationships among large numbers of performance metrics, but by causally tying a metaphor in the virtual environment to a performance data source in the system or application code, it also allows the observer to intuitively realize real-time, adaptive control of system or application performance.

Category
Performance Analysis

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Computational Modeling for Crash-Worthiness of Electric Vehicles Using Nonlinear Finite Element Methods

This project uses transient nonlinear finite element analysis to model the crash-worthiness of a vehicle modified from gasoline to electric power. The modification changes the dynamic structural response of the vehicle during a collision, and designers must ensure occupant safety as the vehicle components undergo plastic deformation. Finite element models allow investigation of the deformed geometry and buckling patterns of the vehicle over a series of time steps. They also permit examination of key response quantities such as effective stress and effective plastic strain.

Category
Engineering

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The SIGGRAPH 94 Daily Weather Forecast

Interactive 3D visualization has proved its value for finding and understanding problems with numerical simulations of the atmosphere. Scientists are able to scan through large simulations quickly, looking for problems, and then trace back through simulated time to find the root causes of those problems by comparing different model fields and looking at the geometry of those fields from various angles.

This project demonstrates the current two-day forecast of Florida weather, made with the UW-NMS modeling system and visualized using the VIS-5D software. Virtual reality is used to present the high spatial and temporal resolution of numerical weather forecasts.

Category
Atmospheric Science

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The SANDBOX: Scientists Accessing Necessary Data Based on eXperimentation

Scientific databases contain enormous amounts of data collected through experimentation. They are accessed by investigators from many disciplines, most of whom are unfamiliar with databases and their associated query languages. Using the SANDBOX, an investigator places virtual instruments into a virtual reenactment of the original experiment and collects data from the scientific database in much the same way that the original data were collected.

This prototype of the SANDBOX allows an investigator to access parts of NASA's FIFE scientific database, which contains data from ground experiments, airborn instruments, and satellite photographs for developing ways to measure surface climatology from satellite information.

Category
Earth Science

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Acknowledgments
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13. Supercomputing 95
Call for Participation: NII Testbed (excerpt)

The NII Testbed provides a venue for interactive 2D and 3D demonstrations of National Challenges and Grand Challenges – remotely computed in a scientist's numerical laboratory and then transmitted over high-speed networks for presentation in San Diego. In keeping with Supercomputing conferences' emphasis on showcasing the most up-to-date networking technology in operation, consider this the Gigabit Challenge! Submissions will be coordinated with the conference's *High-Performance Computing Challenge* event, and people submitting to other, more presentation-oriented events, such as papers, panels, and workshops, are encouraged to submit to the NII Testbed as well. We are looking for applications that will run collaborations and simulations over the vBNS and gigabit testbeds to the San Diego Convention Center, with emphasis on remote, real-time supercomputing, very large data stores, remote instrumentation, and collaboration. Specifically, we are soliciting:

- Visualization/graphics presented in a large, single-screen projection environment. (Note: Stereo 3D with passive polarizing glasses may be provided if there are applications that can use them.)

- Virtual reality demonstrated in a CAVE, which will be available onsite (or any other virtual reality devices that people want to provide) with particular interest in telepresence and VR-to-VR.

- High-end networks and their applications – all experimental networking technology is of interest, and early notice of intent is necessary so we can coordinate funding and pair the technologies with killer applications well in advance of show time.

Connection to the Internet and vBNS is assumed. Also of interest are the CASA testbed, wireless Ethernet, HIPPI extenders, and innovative applications of the Internet/vBNS.

The jury, knowledgeable about technology and high-end applications, will proactively develop linkages between proposals and resources. For accepted proposals, pre-conference test facilities will be negotiated for demonstration development at participating sites. Assistance with virtual reality and large-screen visualizations, high-speed networking usage, sonification, parallel computing, and so on, will be provided as funding permits.

Applications of the National Information Infrastructure (NII) in manufacturing, health care, education and lifelong learning, and environmental studies, as well as computational science and engineering research, are encouraged.

All NII Testbed participants must document their work for access over the WWW with Mosaic; documentation must be made available during and after the conference.

Authors of accepted proposals will be notified of acceptance by April 1, 1995.

DISCLAIMER: The NII Testbed requires funding assistance from sources external to the conference, and may be canceled if such assistance is not forthcoming. The response to this call for participation will help us substantiate the proposals to equipment companies and government agencies for support.

<u>How to Submit a Proposal to the NII Testbed</u>

Deadline: February 14, 1995 (all formats).

These same instructions are also available via anonymous ftp from nii@sc95.sdsc.edu, (or send e-mail to tom@eecs.uic.edu).

Proposals must include the following information (proposals are expected to be short – one to two pages in length):

1. Contact person's name, affiliation, mailing address, phone number, fax number, and e-mail address.

2. Descriptive title.

3. Names and addresses of all collaborators.

4. Indicate one or more of the categories to which you are submitting:
   ___ Large, single-screen projection environment
   ___ Virtual reality using the CAVE
   ___ Virtual reality using contributor's equipment
   ___ High-end networking application

5. A 200-word summary describing your application and its significance.

6. Equipment needs:
   a. Do you intend to utilize the networks and equipment that will be provided?
   b. Will you provide/lend your own equipment?
   c. What additional hardware/software needs do you have?

Email submissions are encouraged. Submit a proposal in PostScript, ASCII, provide a WWW address, OR mail or fax one printed copy of your proposal by February 14, 1995, to:

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