

Virtual Workbench - A Non-Immersive Virtual Environment for Visualizing and Interacting with 3D Objects for Scientific Visualization

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ABSTRACT

The Virtual Workbench (VW) is a non-immersive virtual environment that allows users to view and interact with stereoscopic objects displayed on a workspace similar to a tabletop workspace used in day-to-day life. A VW is an ideal environment for collaborative work where several colleagues can gather around the table to study 3D virtual objects. The Virtual Reality laboratory at the Naval Research Laboratory has implemented the VW using a concept similar to what is reported in [1]. This paper investigates how the VW can be used as a non-immersive display device for understanding and interpreting complex objects encountered in the scientific visualization field. Different techniques for interacting with 3D visualization objects on the table and using VW as a display device for visualization are evaluated using several cases.

1. INTRODUCTION

Immersive virtual environments (VEs), such as Head Mounted Display (HMD) and CAVE systems, and non-immersive virtual environments, such as WALLs and Workbenches, are currently being used to incorporate virtual reality into scientific visualization [2,3,4,5]. Unlike monoscopic displays used for current visualization environments, these VEs provide an environment where 3D visualization objects can be viewed in their native three dimensions that gives the users an opportunity to gain a more complete understanding of these complex objects. In addition, the ability to manipulate the data in an intuitive manner, move through the virtual world, and move around these complex objects allows users to focus their attention on the data and away from the interface.

2. CURRENT VR DEVICES USED IN SCIENTIFIC VISUALIZATION

The scientific visualization field currently utilizes several VR systems. The most commonly used device is the HMD. Most HMDs available today are composed of two imaging screens, typically CRTs (Cathode Ray Tube) or LCD (Liquid Crystal Display) panels. Two imaging screens are placed directly in front of the users' eyes. Each imaging screen can be driven by separate video signal containing distinct left eye and right eye views. HMDs are

typically constructed to block the vision of the user's surrounding physical environment so that it creates a fully-immersed VE. Tracking of the HMD is typically accomplished by attaching an electromagnetic (or sonar, optical, etc.) position and orientation tracker to the top of the HMD. Various input devices ranging from simple buttons to complex datagloves are used for locomotion and interaction within a virtual environment. The simplicity of completely replacing the vision of a user makes HMD systems attractive, but the bulk and low resolution of most of today's HMDs limit their use in scientific visualization applications.

The BOOM (Binocular Omni-Orientation Monitor) is a full-color, high-resolution (1280x960 pixels), CRT-based, immersive display device. The BOOM is counterweighted on a free-standing platform to provide a weightless 6 degree of freedom display unit. The BOOM's CRT-based design provides higher resolution and brightness and better contrast when compared to LCD-based HMD systems. Tracking is accomplished through the same mechanical linkages that provide the counterweight feature. The BOOM's viewing unit consists of two handles for manipulating the view, and buttons on the handle allow users to issue commands for locomotion and interaction within the VE. BOOM systems provide the same basic interactivity as HMD systems with much better video images. Until HMDs can match the BOOMs resolution and high quality video images, the BOOM will be very important for scientific visualization.

The CAVE (CAVE Automatic Virtual Environment) is a surround-screen, surround sound, virtual reality device. Video output is rear projected onto the walls of the CAVE (except for 4-wall CAVES use front projection for the floor screen). Tracking devices track the head position of a user inside a CAVE, providing the data to produce correct stereo information for the scene. A user can explore the virtual world by physically moving around the CAVE and by utilizing a device called a "wand" (with a second tracker and buttons to issue commands). A CAVE system generates 2 views for each wall (one for each eye for stereoscopic viewing), thus the rendering requirements for generating an average scene at decent update rates is enormous (e.g. for a 3 wall cave, 2 eye points x 3 walls = 6 complete scene renderings). A CAVE also requires a large allocation of space for projector throw and mirror placement. Very few research organizations can afford to own and run a CAVE due to these huge resource requirements.

The WALL is another commonly used device for creating non-immersive VEs. Stereoscopic scenes generated from the computer is projected onto a vertical screen. Many users can simultaneously see stereoscopic scenes on the screen by wearing special glasses (active or passive). This device is commonly used for displaying data for a large group of people and interaction with 3D objects are rarely done since standing in front of the screen can obstruct the view of the audience.

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3. CURRENT VR APPLICATIONS IN SCIENTIFIC VISUALIZATION

CAVEs have been widely used for creating VEs that allow users to be completely surrounded by virtual objects. Unlike HMDs or BOOM displays, CAVEs can blend real objects (e.g. participants) with virtual objects. Thus, the viewers can experience virtual objects and real physical objects simultaneously in the same environment. In [2], the authors compiled a detailed report on using CAVEs for visualizing data from several different areas of science including architectural walk-throughs, exploration of fractals, and exploration of galaxy data. In this study, the authors provide a thorough description of how scientists were able to use the CAVE to experience a strong sense of immersion and participation within the VE.

The Virtual Windtunnel, as reported in [3], describes a technique to interactively interrogate particle traces of an unsteady flow field. A BOOM was used for the display and a tracked data glove was used to inject seed particles into a virtual flow field thus allowing users to visualize time-dependent particle tracers for the simulation. The ability to use one's hand to directly interact with the flow field within the VE is a very powerful technique.

The authors in [4] report an atomic scale teleoperation system that uses an HMD and a force-feedback manipulator arm to interface with a Scanning Tunneling Microscope (STM). In this VE, users can visualize STM data and apply modifications to the atomic surface in real-time. The material surface under study had to be sampled and graphically reconstructed for the user at human scale, a magnification on the order of 10^{10} . In this environment, the authors created a 3D virtual world for users to see, feel and manipulate matter at the nanometer scale. A WALL was used as a secondary display for the audience.

The Responsive Workbench as a Virtual Work Environment was reported in [1,5]. In these case studies, the authors propose the Workbench for visualizing blood flow in a heart and implementing a "Virtual Windtunnel" for visualizing fluid flow around solid bodies. In both of these cases, the VE was used by the scientist for manipulating the modeled environment in addition to visualizing static and dynamic objects and data.

A general purpose VE module for the Application Visualization System (AVS) [6] was reported in [7]. Any 3D visualization objects generated from AVS networks can be visualized using a tracked HMD. Viewing 3D visualization objects generated using AVS (e.g. isosurfaces, streamlines) in an immersive 3D environment proved to enhance the users perception of the 3D nature and characteristics of the objects. This module was used in visualizing exhaust plume flow around a heliport on a large ship. Pilots are susceptible to dangerous encounters if they fly into the path of the ship smoke stack plume due to large velocity fluctuations within the airwake. Results from a numerical model of the airwake from the smoke stack were visualized in a HMD with the ship in the background. This VE was used to understand the behavior of the airwake (direction and the magnitude of the velocity field) above the ship and near the helicopter landing deck. In this case, using the HMD is ideal for navigation through or around objects but it does not create a collaborative environment such as what is available with the Virtual Workbench (VW).

All of the related work described above provides new and innovative devices and methods for using VEs for scientific visualization. This paper investigates the application and appropriateness of the VW as a tool for interacting with 3D visualization objects. In this paper we first provide a general description of how the VW is implemented. We then discuss several visualization cases each utilizing different visualization and interaction techniques, for the purpose of evaluating the VW as an aid for interpreting complex data.

4. VIRTUAL WORKBENCH

Currently the viewing plane(s) for a user in a VE created using a HMD, CAVE, Wall, or BOOM is located vertically in front of the user. Although these implementations provide a good immersive environment for some tasks, such as virtual walk-throughs, they fail to create a cooperative workspace such as a conference table, where a group of people can gather around a table to study an architectural plan (note that these objects lie on a horizontal plane). Also, these VEs are ineffective for certain applications where a user does not wish to be immersed in data, but rather would like to be in a natural environment (with the company of other colleagues for the purpose of collaboration) with the virtual scene created in front of the user. An example of such an application would be presurgical planning or medical training application. A surgeon does not wish to be immersed with the patient. Rather, we believe he wants to be in a normal operating room environment and have the virtual patient in front of him atop a virtual operating table. We see that the VW as an ideal device for creating such collaborative environments.

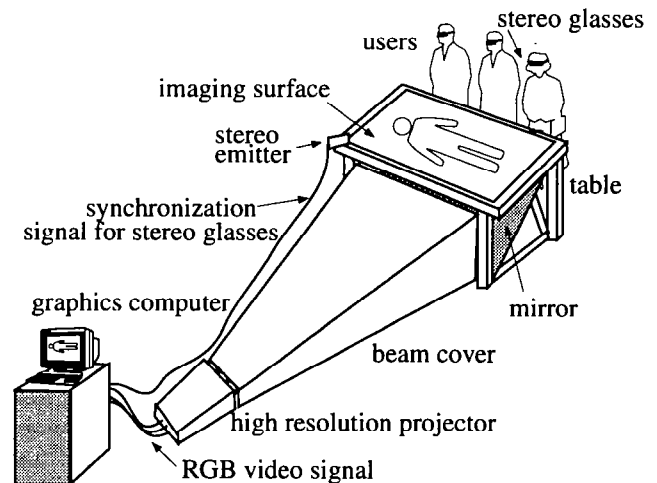


Figure 1. Schematic diagram for the NRL Virtual Workbench.

As shown in Figure 1, the VW is created using a high resolution projection system, a mirror, and a table with an imaging surface. The scene for the virtual environment is created on a high-performance graphics computer using a standard graphics library. Separate left and right eye views are generated using conventional graphics techniques and sent to the projector at 120 Hz. Users stand in front of the table wearing active stereo glasses. These glasses have the capability of turning on and off the left and right eye lens in sync with the projection of left and right eye images. This produces the illusion of the projection of a stereoscopic image in front of or behind the imaging surface.

One major advantage of using the VW for creating VEs is that it can simulate the viewing volume to appear on top or below the tabletop. This feature is achieved by manipulating the eye-separation and the convergence plane of the stereoscopic views. A good example of an application that requires the virtual objects to appear on top of the table is the Virtual Operating Table where the virtual body appears to lay on top of the table. Ocean data visualization is an example where it is more appropriate to position the virtual ocean floor below the tabletop.

We have added a variety of interaction techniques for the NRL VW. Gesture recognition is done using tracked gloves that can detect the pinching of the thumb and one of the index, middle, or ring fingers. The NRL VW allows the user to use one or two gloves depending on the particular interaction requirements for a

given application. Speech recognition is also used as an interface method using a commercially available speech recognition system. Audio feedback is used to provide simple feedback to the user on the success or failure of input commands. Head tracking (when necessary) is implemented by mounting a tracker on a set of earphones that user can optionally wear.

The VW generates an environment very close to a real world tabletop working environment. The complex and bulky interface devices usually associated with VR, such as HMDs, are not needed. The VW is unique among VR devices in facilitating cooperative work at a reasonable fabrication cost because the user is in a natural environment and can see other users.

5. CASE STUDIES

5.1 Real-Time Square Jet Simulator

The purpose of this case study is to use the VW for displaying and interacting with visualization objects generated using results from a numerical simulation of an axially excited free square jet [8]. The numerical model solves the unsteady compressible transport equations with an ideal-gas equation of state and appropriate inflow/outflow boundary conditions. As reported in [9], the numerical simulation was converted into a module that runs in real-time on a supercomputer. Selected flow variables are sent over (when requested) to the local workstation for display.

Standard visualization techniques from AVS were used for generating different visualization objects. The nature of our modular implementation allowed us to visualize the data generated using various visualization techniques (3D arrows, isosurfaces, particle advection, streamlines, etc.). Considering the length of the paper, we will address two interacting techniques in detail for this case study.

We developed a suite of VR modules for incorporating tracking in the AVS 3D viewer. These modules provide appropriate data structures to track different 3D objects within the viewer. For example, for head tracking the whole view, we can attach the camera object to a tracker.

We implemented data probing as the first interaction technique for this test case. The standard probing technique provides a 3D geometric shape showing the location of the probe point within the data volume. This allows the user to move this object around the data volume to probe field values. One of the difficulties encountered in data probing using 2D computer displays is translating along the third axis. (The first two translations are done parallel to the vertical and horizontal sides of the viewing window.) This is attributed to the fact that the scene is displayed in monoscopic mode and translation along the third axis needs to be performed using an additional key command such as Shift. This process could be very cumbersome. We overcome this difficulty by attaching the probe object to a tracked glove. This, along with the stereoscopic view on the table allowed us to move the hand around without difficulty to query data values.

For the next interaction technique we used the VE created by the VW to interrogate the velocity field using a particle advection technique. The standard particle advector module from AVS provides a 3D object for selecting seed positions for releasing particles. We attached this object to the hand tracked glove for navigating through the 3D volume. We were able to move the hand around the data volume and push a trigger button to start the advection. Particles advect along the velocity field leaving trajectories behind (Figure 3). This created a VE where we can navigate around the virtual volume to repeatedly advect particles to study the velocity field of the flow system.

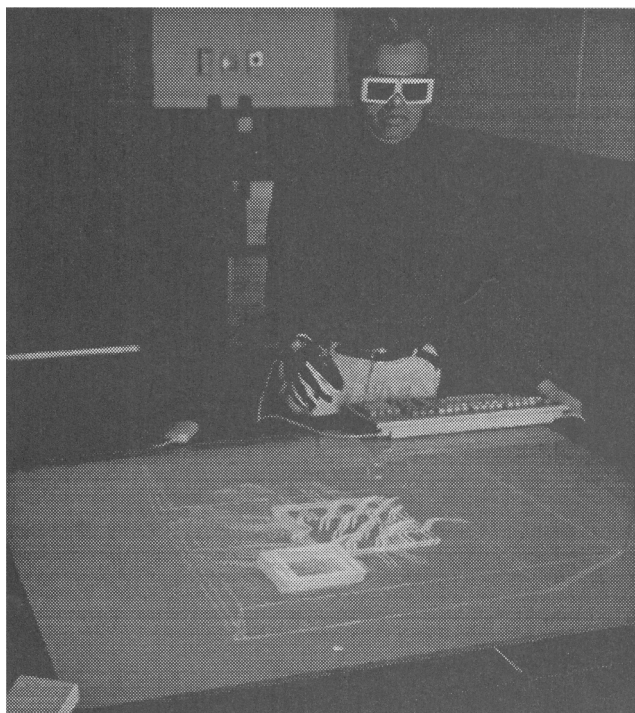


Figure 2. Using tracked hand to release particles in the flow field.

5.2 Molecular Docking

In this study we are attempting to create a VE for interacting with two 3D objects that represent the surface of two molecules using two handed gestures. Our intention is to allow users to grab molecules from the tabletop and use their hands to find the best orientation that fits the molecules' surfaces. (In the past, chemists had to use cumbersome mouse or keyboard commands to perform this kind of manipulation.)

We create the VE that simulates the viewing volume of the scene slightly above the table top to give the impression that two molecules are laying on top of the table. Interaction with the molecules with two hands are achieved by wearing two tracked gloves. (Two geometric objects that resemble hand were used to provide visual cues for showing the hand position in relation to the VE.) When a tracker position is within the boundary of a molecule, the user can send a signal using a switch (mounted on the fingers of the glove) to attach a molecule to a hand. This technique is used to attach each molecule into the left and right hand and the user can manipulate the orientation of each molecule to find good fits between the two objects.

This application was developed using Georgia Tech's Simple Virtual Environment Library (SVE) [10]. Tracking capabilities were extended to incorporate the two handed grabbing feature. Molecular surfaces were generated (data kindly provided by Michael Pique, Scrips Institute, La Jolla, CA) using a stand-alone program for loading into the application as two polygonal surfaces.

We found that VE created in this case provide a comfortable environment for visualizing and interacting with molecules. Attaching molecules to each hand along with the stereoscopic view on top of the table provided a natural environment for manipulating 3D shapes.

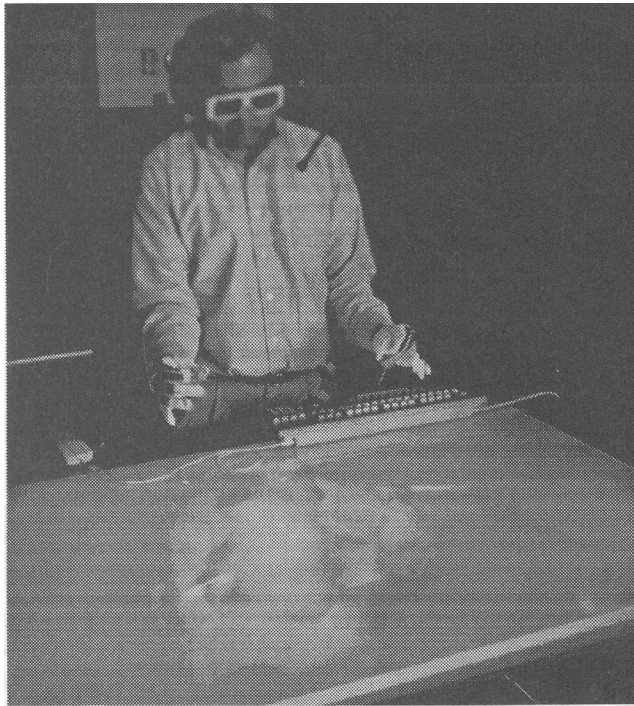


Figure 3. Two handed gesture interaction for manipulating molecules.

5.3 Visualizing Simulated Flow Past a Tuna

The purpose of this study is to use the VW for visualizing fluid flow past a tuna fish for understanding the biomechanics and the hydrodynamics of the tuna's body. Tuna fish have been characterized as cruising specialists that have adapted to long distance steady swimming, thus understanding the flow can lead to new methods for designing long-range underwater vehicles for the Navy. Numerical simulation is used to compute unsteady flow past a tuna to understand the time variation of the pressure distribution over the surface of the cardinal fin and the body [11].

The simulation is an ideal case for positioning the viewing volume of the scene under the tabletop. This creates a VE that simulates a view similar to the environment where tuna swim. For visualization, time dependent unstructured cell data was loaded into AVS. Pressure distribution for the tuna's body was generated using standard visualization techniques. To visualize the changes in the pressure distribution, the geometric objects generated using time dependent data were animated.

5.4 Visualizing Unsteady Flow above DDG51 Destroyer

This study involves visualizing airwake and exhaust gas trajectories over a complex ship superstructure. Previous numerical studies have shown that the region over the helicopter landing deck has rapid velocity fluctuations that can cause dangerous encounters for the helicopter pilots. This study used a numerical simulation to compute the unsteady flow around the superstructure [12].

Our intention in using the VW for visualizing results from this simulation is to create a VE similar to the real life environment that helicopter pilots see when they attempt to land on a ship. One major advantage in the VE compared to the real life scene is that the users at the VW are able to see the air-wake (generated using appropriate visualization techniques).

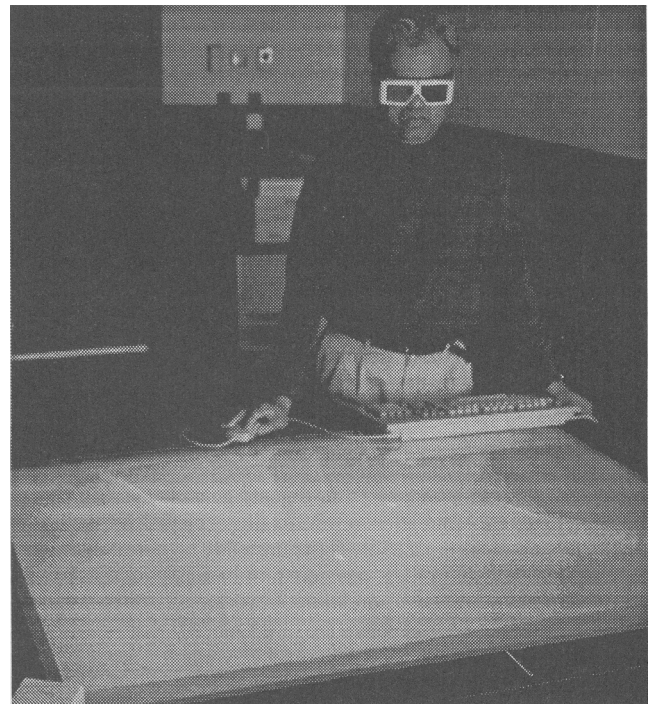


Figure 4. Visualizing pressure distribution on the tuna's body.

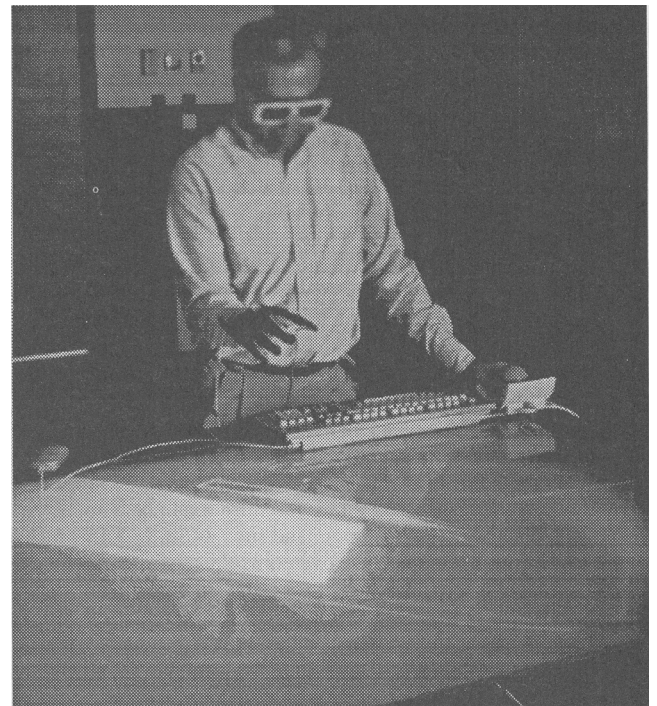


Figure 5. Using tracked hand to interrogate the velocity field with streamline visualization.

For this study we created two VEs for visualizing and interacting with the data. First we wanted to take advantage of the display of the VW to visualize time dependent temperature variations of the flow field above the helicopter landing area. Time dependent temperature data was loaded into AVS as a 4D field (time axis as the fourth axis) and time-axis orthogonal slicing in data space was performed to animate the data. The temperature profile was dis-

played using isosurfaces. We were able to use the VW to create a convenient environment for visualizing the time dependent behavior of the temperature and for understanding the dynamic nature of the flow field above the ship.

We also created another VE similar to the Virtual Windtunnel as reported in [4]. We constructed the view with the ship in the background and placed the simulated data volume with the velocity field for an instant of time. Then we used the standard streamline module to generate streamlines by attaching a seed position object to the tracked hand. With the stereoscopic view, moving the tracked hand around for creating streamlines at different positions within the volume was visually comfortable and easy to use.

5.5 Interacting with Molecular Dynamics Simulations

The purpose of this study is to use the VW for interacting with visualization objects generated from a molecular dynamics simulation. The numerical simulation performs non-equilibrium molecular dynamics in an effort to understand the momentum transfer and associated motion between an atom and its surroundings in sheared dilute atomic mixtures. The numerical simulation is converted into a real-time simulation that sends the coordinates of the atoms to the visualization platform.

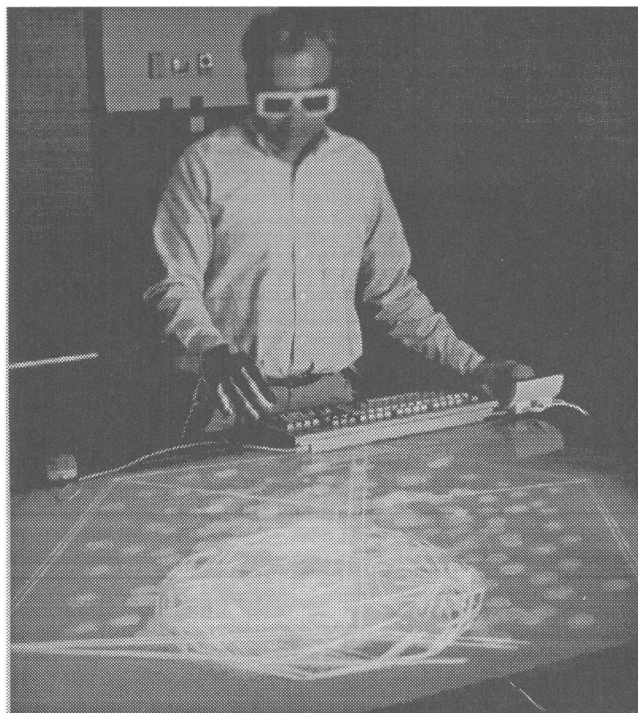


Figure 6. Tracked hand is used to select an atom defining a spherical sub-domain.

In the past, we used many regular interaction techniques (visualizing cluster of atoms, generating a trajectory for a selected atom, or displaying the dipole moment, etc.) with molecular dynamics data. In all of these cases we had to use a mouse to select atoms displayed on the monoscopic display. In an environment such as this, it is very difficult to select atoms in the back of the display.

The VE created using VW allowed us to overcome these problems. First, stereoscopic view gave us an excellent view of all atoms and the tracked glove enabled us to select atoms in 3 dimensions with much less difficulty.

6. CONCLUSIONS

We have shown that VEs created using a VW provide excellent environments for visualizing and interacting with 3D objects for scientific visualization. A VW creates a nice environment for collaboration with other users. The Interaction techniques we have implemented overcome many of the difficulties associated with regular computer workspaces.

Using visual programming environment such as AVS proved to be useful due to the modularity and flexibility of the system. For example, one of the difficulties we have frequently encountered was that the number of polygons for geometric objects such as isosurfaces are very high (30-70k triangles). This in turn caused update rate delays in the stereoscopic view due to the high rendering requirements. We were, however, able to exploit the modularity of AVS to downsize or crop the data to reduce the number of polygons in the geometric objects.

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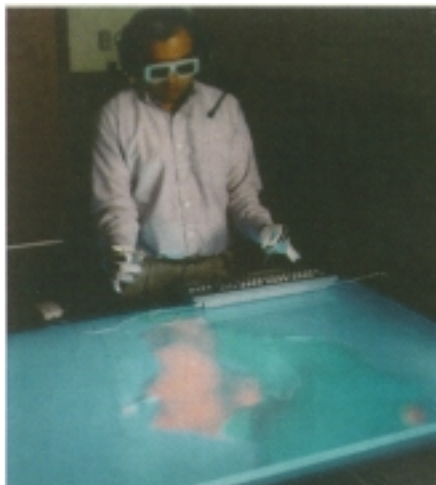


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