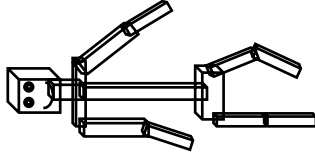
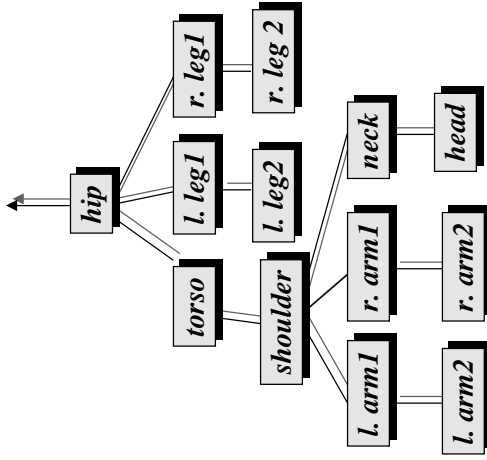


Hierarchical Modeling

- A node represents:
 - rotation(s)
 - geometric primitive(s)
 - Transformations



The root can be anywhere (hip)
Control for each joint angle, plus global position and orientation

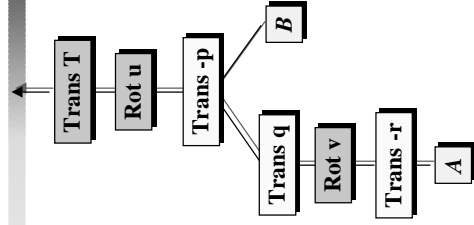
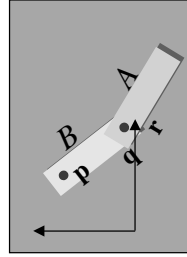


Relevant OpenGL Routines

- `glPushMatrix()`, `glPopMatrix()`
 - push and pop the stack. push leaves a copy of the current matrix on top of the stack
- `glLoadIdentity()`, `glLoadMatrixd(M)`
 - load the Identity matrix, or an arbitrary matrix, onto top of the stack
- `glMultMatrixd(M)`
 - multiply the matrix C on top of stack by M. $C = CM$
- `glOrtho(x0,y0,x1,y1,z0,z1)`
 - set up parallel projection matrix
- `glRotatef(theta,x,y,z)`, `glRotated(...)`
 - axis/angle rotate. "f" and "d" take floats and doubles, respectively
- `glTranslatef(x,y,z)`, `glScalef(x,y,z)`
 - translate, scale. (also exist in "d" versions.)

OpenGL Example

```
glLoadIdentity();
glOrtho(...);
glPushMatrix();
glTranslatef(Tx,Ty,0);
glRotatef(u,0,0,1);
glTranslatef(-px,-py,0);
glPushMatrix();
glTranslatef(qx,qy,0);
glRotatef(v,0,0,1);
glTranslatef(-rx,-ry,0);
Draw(A);
glPopMatrix();
Draw(B);
glPopMatrix();
```



Hierarchy methods

- Object Oriented
- Push matrix stack
 - Implies depth-first traversal
- Do type-specific transform
- Recurse on its children, and pops.

Interactive Applications

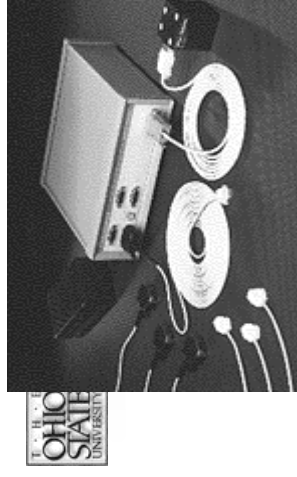
- How do we add interactive control?
 - Examiner => Object in hand
 - Fly-thru => In a virtual vehicle pod
 - Walk-thru => Constrained to stay on ground.
 - Move-to / re-center => Pick a location to fly to.
- Collision detection?
 - Can we pass thru objects like ghosts?

Interactive Applications

- What do we use to control the motion?
 - Mouse
 - One-button, two-button, three-button
 - What button does what?
 - Only when mouse is clicked down, released up, or continuously as the mouse moves?
 - Keyboard
 - Arrow keys?

Input Devices

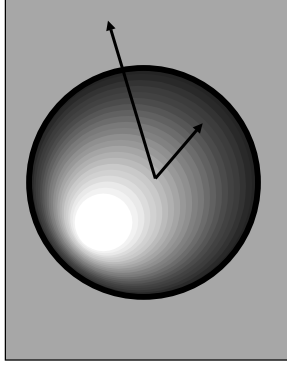
- Interactive user control devices
 - Mouse
 - 3D pointer - Polhemus, Microscribe, ...
 - Spaceball
 - Hand-held wand
 - Data Glove
 - Gesture
 - Custom



ALSO AVAILABLE
The Spaceball 2003 FLX

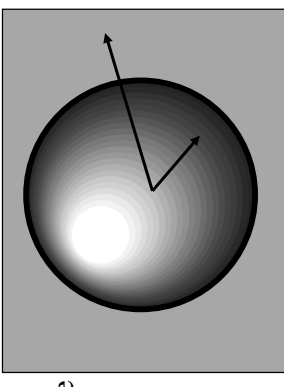
A Virtual Trackball

- A rather standard and easy-to-use interface.
- Examiner type of interaction.
- Consider a hemi-sphere over the image-plane.
- Each point in the image is projected onto the hemi-sphere.



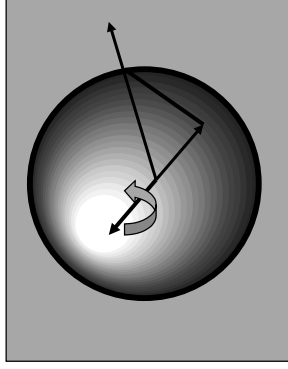
A Virtual Trackball

- Points inside the projection of the hemi-sphere are mapped up to the surface.
 - Determine distance from point (mouse position) to the image-plane center.
 - Scale such that points on the silhouette of the sphere have unit length.
 - Add the z-coordinate to normalize the vector.



A Virtual Trackball

- Do this for all points.
- Keep track of the last trackball (mouse) location and the current location.
- This is the direction we want the scene to move in.
- Take the direction perpendicular to this and use it as the axis of rotation.
- Use the distance between the two points to determine the rotation angle (or amount).

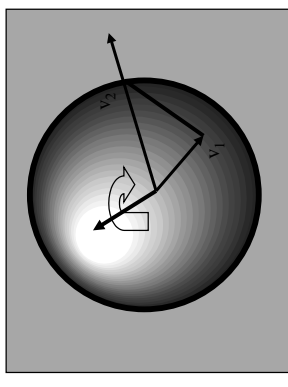


A Virtual Trackball

- Rotation axis:

$$\vec{u} = \vec{v}_1 \otimes \vec{v}_2$$

Where, v_1 and v_2 are the mouse points mapped to the sphere.





A Virtual Trackball

- Use `glRotatef(angle, ux, uy, uz)`
- Slight problem: We want the rotation to be the last operation performed.
- Easily fixed:
 - Read out the current `GL_MODELVIEW` matrix
 - Load the identity matrix
 - Rotate
 - Multiply by the saved `GL_MODELVIEW` matrix

Virtual Reality

Roger Crawfis



Virtual reality technology

- many definitions of virtual reality (VR), for example:
- "the creation of the effect of immersion in a computer-generated three-dimensional environment in which objects have spatial presence" [Bryson & Feiner, 1994]
- "things as opposed to pictures of things"
- interaction, not content
- many variations, desktop VR, fish tank VR, augmented reality



Related terminology

- virtual environment
- virtual world
- artificial reality
- augmented reality
- telepresence
- Teleoperation
- Collaborative Spaces



Performance requirements

- wide-field stereoscopic display fill's the user's field of view
- head-tracking supports the illusion that the user is looking around in an environment
- 3D computer graphics fills the environment with objects
- 3D interaction gives users the feeling that they are interacting with real objects
- overall frame rate must be > 10 frames/sec
- end-to-end delays must be < 0.1 sec for interactive control



The problem with VR is...

- that it is apparently simple
- NOT the unusual hardware
- many components must work together in real-time
- many criteria must be met
- unclear how to use the interface
- human factors issues not well understood



The evolution of VR

- 1960 Morton Heilig files patent to the US Patent Office
- **"Stereoscopic TV Apparatus for Individual Use"**
My invention generally speaking comprises the following elements: a hollow casing, a pair of optical units, a pair of television tube units, a pair of earphones and a pair of air discharge nozzles, all coacting to cause the user to comfortably see the images, hear the sound effects and to be sensitive to the air discharge of the said nozzles.
- 1960-70 Sutherland's head-mounted display
- 1984 NASA Ames VIVED project
- 1986-90 NASA Ames VIEW lab and VPI
- 1990-onwards VR community fully formed and flourishing...

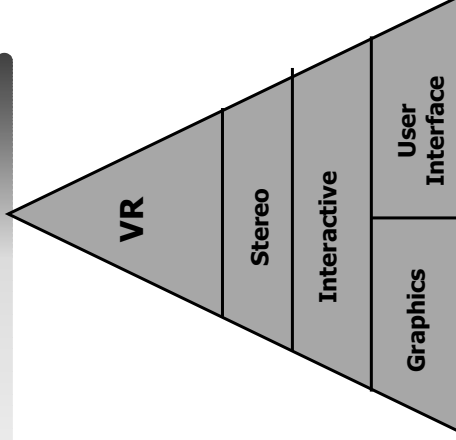


Degrees of immersion

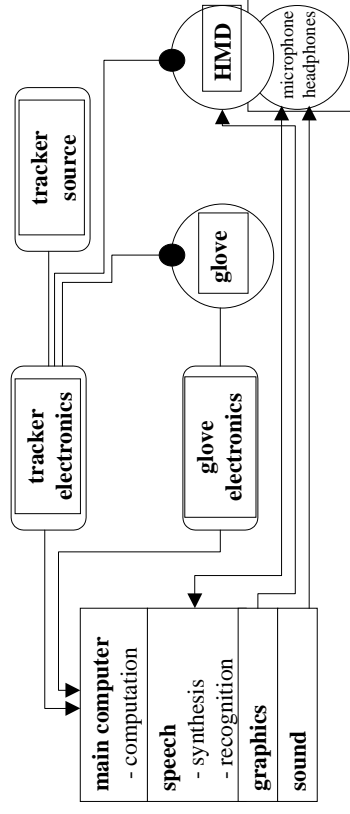
DISPLAY	INTERACTION	IMMERSION
colour	keyboard	
high resolution	2D Mouse	
Stereo	6D input device	
head tracking	6D tracking + buttons	
wide field of view	6D tracking + gloves	
head coupled	force tracking	
		High

Virtual Environments

- Immersive
- Interactive
- User Centered



Typical configuration



Patrick Olivier

Displays

- primary technology underlying immersion
- many aspects: colour, resolution, field of view...
- display paradigms:
 - stereo via two displays
 - stereo via one display images synchronised (eyewear)
 - CAVE: immersion via surrounding large screens
 - head tracking (fish tank VR)
 - head tracking head-mounted

Virtual Environments

- Display Technologies
 - HMD's - Head Mounted Displays
 - Large theater - Imax, Omnimax
 - Stereo displays
 - HUD's - Head's Up Displays
 - windshields
 - goggles
 - CAVE - Surround video projections





Tracking paradigms

- usually a sensor determines position and orientation relative to source (calibration renders position of source irrelevant)
- sensor detects a signal from the source in such a way that the position and orientation can be determined
- either the source or the sensor can be fixed
- numerous technologies: electromagnetic, ultrasonic, mechanical, video, inertial



What to track?

- head position and orientation
 - any significant body part
 - any articulations
- Other tracking technologies**
- passive stereo vision systems
 - marker systems (used in motion capture)
 - structured light methods (light stripe)
 - inertial tracking (using accelerometers)
 - eye tracking (commonly optical - corneal reflection)



Virtual Environments

- Interactive user navigation devices
 - Head tracker
 - Treadmill
 - Bicycle
 - Wheelchair
 - Boom
 - Video detection
- Anyone seen the new game at GameWorks?

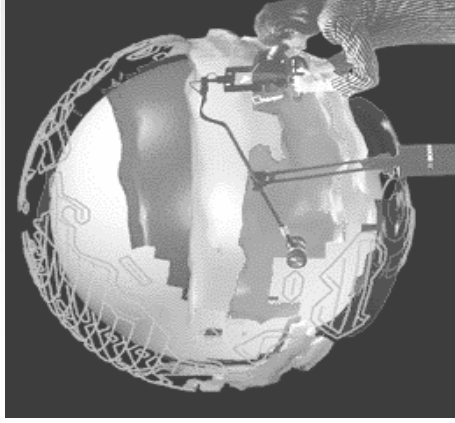


Virtual Environments

- Interactive user control devices
 - Mouse
 - 3D pointer - Polhemus, Microscribe, ...
 - Spaceball
 - Hand-held wand
 - Data Glove
 - Gesture
 - Custom



Fakespace BOOM 3C



Video Output

Full Color Stereo - or Monoscopic.

Resolution

Up to 1280 x 1024 pixels per eye.

Optics

User interchangeable modules offer from 40 to 110 degrees horizontal FOV

Tracking

Opto-mechanical

Accuracy

0.015" at 30"

Latency

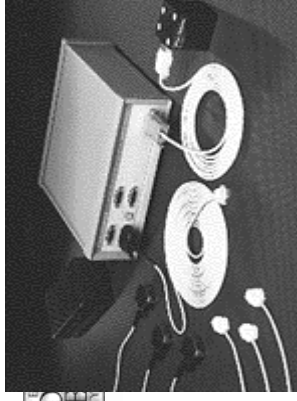
200ns

Sampling Frequency

>70Hz

Range

6' diameter horizontal circle (center 1 foot unavailable) 2.5' vertical.



ALSO AVAILABLE
The Spaceball 2003 FLX

Human factors of virtual reality

- Limits on motion frequencies:
 - head (5 Hz)
 - hand (10 Hz)
 - full body (5 Hz)
 - eye (100 Hz)

Human factors of virtual reality

- Limits on Vision (optical resolution):
 - angular size of the smallest object that can be resolved:
 - essentially the angular size of a colour pixel
 - measure as a linear size in minutes of arc
 - full moon is 30 minutes of arc across its diameter
 - human visual system can resolve 0.5 minutes of arc in the central visual field
 - 2-3 minutes of arc in the peripheral visual field

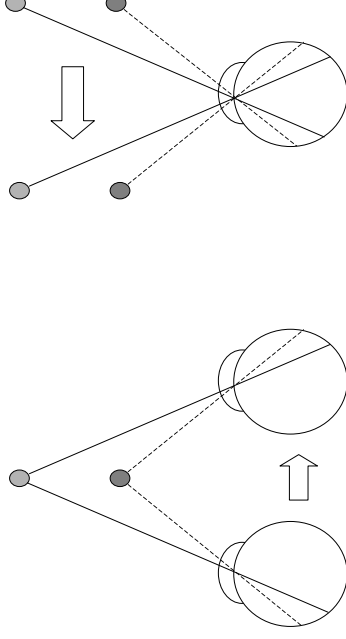
Cues to support the sense of immersion



- immersion: want to be in an environment that contains “things” and not looking at pictures
- spatial presence of virtual objects due to:
 - **spatial constancy**
 - 10 frames/sec minimum requirement
 - if your head moves and the scene doesn't it isn't VR
 - object behaviour (e.g. application of consistent physical laws)
 - **depth perception**
 - stereo
 - head motion parallax
 - many other depth cues
- wide field of view
 - environment seems to fill field of view (60° minimum threshold)



Motion parallax



Aspects of head-motion parallax

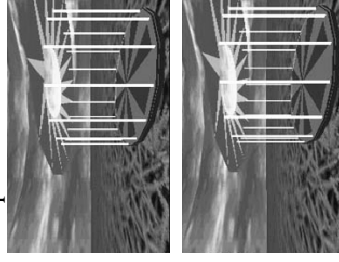


- due to change in visual scene as the head moves
- performed in a VR system by tracking the user's head and rendering the virtual scene from a moving point of view
- head-motion parallax is a monocular depth cue:
 - beyond 1m monocular cues dominate
 - within 1m binocular disparity and motion parallax is crucial
 - need 12 frames/sec for motion parallax



Stereopsis

- fusion of images from two eyes
- projected rays of same points in world different for each eye
- points in the world are visible to one eye and not another





Aspects of stereopsis

- People have different fusion capabilities (it is believed that as many as 20% have little capability)
- Effective out to 3-6m but critical < 1m
- Far-field, not that critical.



Virtual Environments

- Draw at 120Hz
- Track user position/orientation at 120Hz
- Provide Haptic feedback at > 200Hz
- User tracking > 10Hz



Augmented Reality

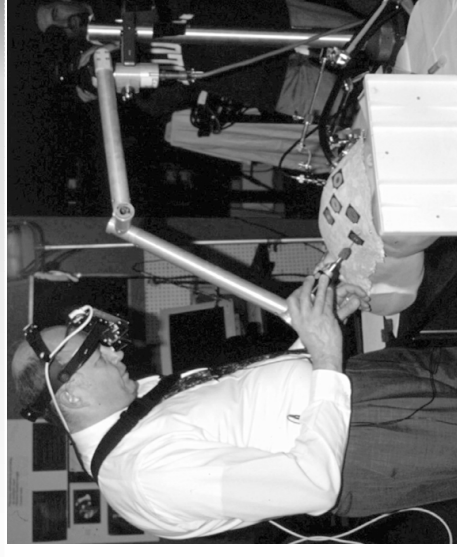
- Merged real imagery and computer generated imagery.
 - Video capture into visualization system
 - See-thru glasses



University of North Carolina, Chapel Hill



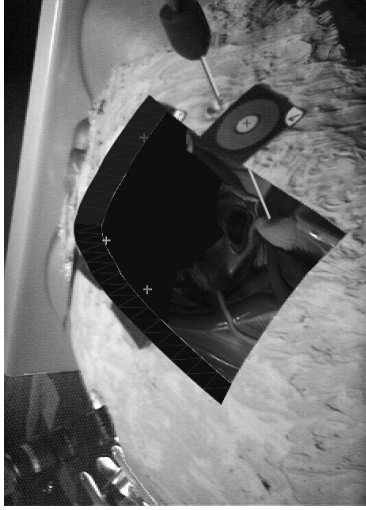
Augmented Reality



University of North Carolina, Chapel Hill



Augmented Reality



University of North Carolina, Chapel Hill

- Also useful for non-medical

- Mechanics drawing super-imposed over the actual machinery.
- Guided tours.

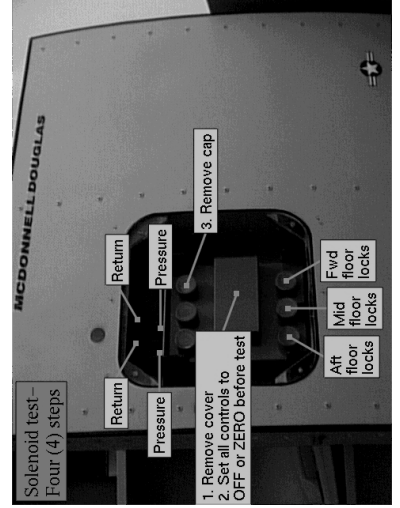


Augmented Reality



Augmented Reality

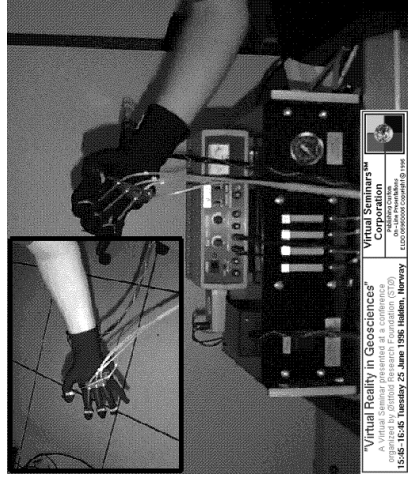
- Complex Instructional Manuals



Haptics

- Force feedback is needed at very fast rates.

- Gloves
 - force resistant
 - nerve stimulated



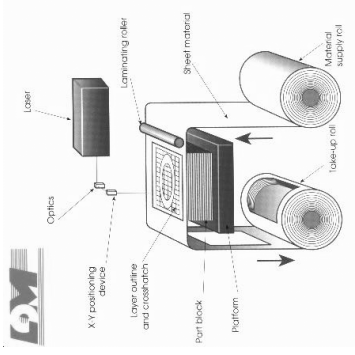


Rapid Prototyping

- Build real models of the visualizations
- Stereo Lithography
 - Laser etching
- Laminated Object Manufacturing
 - Laminated paper layer, then cut with laser

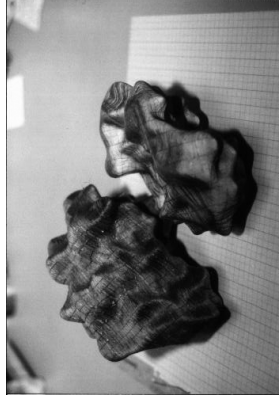


Laminated Object Manufacturing

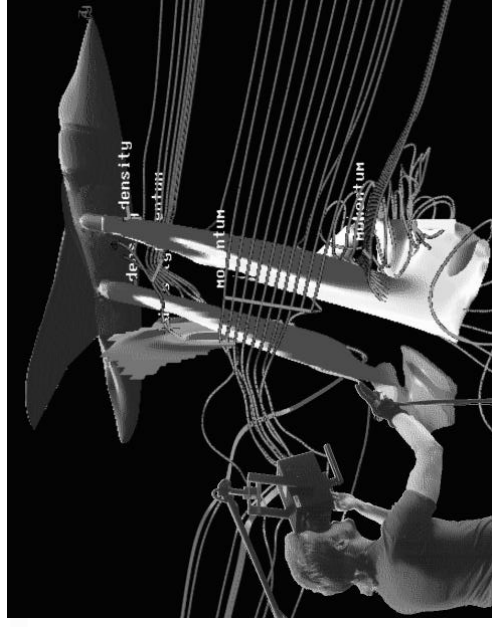


Laminated Object Manufacturing

- Molecular Docking



NASA's Virtual Wind Tunnel



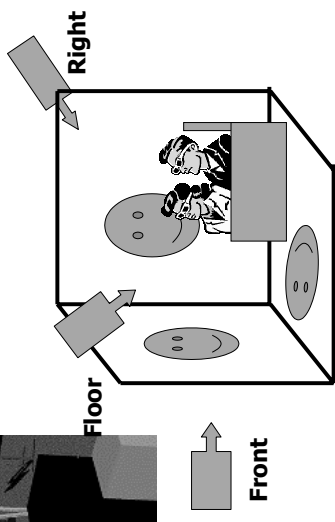
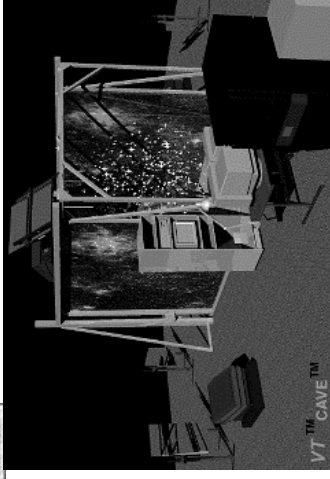


The CAVE Architecture

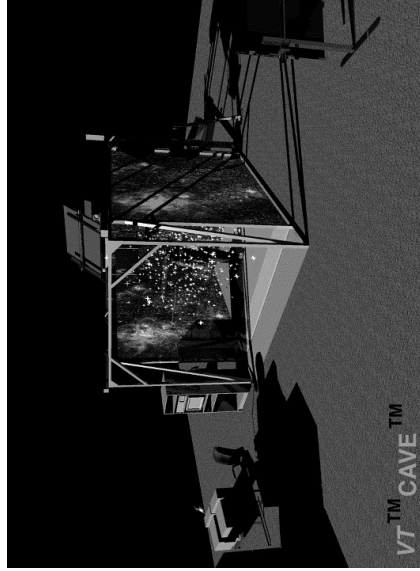
- Four projection screens
- Four graphics rendering engines
- Stereo glasses
- Head-tracking of one user
- Hand held wand for input



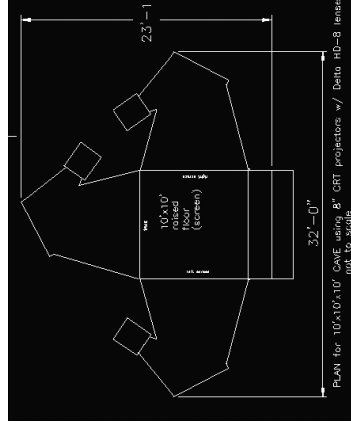
The CAVE Architecture



The CAVE

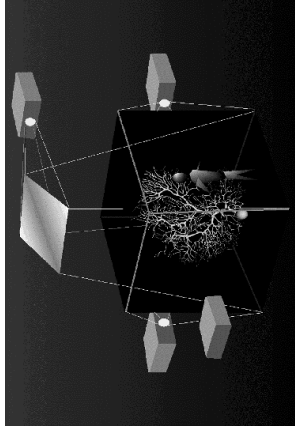


The CAVE





The CAVE



The CAVE Architecture

- Several people can view at once
- The projections are only correct for one person.
- Laser's synch the stereo displays with Liquid Crystal shutter glasses on each viewer.



The CAVE Architecture

- Benefits
 - Eye movement problems are avoided!!!
 - User's orientation does not matter.
 - Can see and examine real people and objects within the room



The CAVE Architecture

- Problems
 - The light intensity on each projector varies
 - Precise alignment of the projectors is necessary for a smooth seam.
 - Viewing does not change for the other viewers.
 - Expensive.



Single Projector Systems



- ImmersaDesk
- Responsive Workbench



Responsive Workbench



Making VR Work

- To ensure latency, many of the visualization techniques need to be streamlined or pre-computed.
- Examples, pre-computed iso-contours, precomputed stream lines and particle traces.