Designing multi-projector VR systems: from bits to bolts

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Abstract

Immersive multi-projection virtual environments are becoming affordable for many research centers, but existing solutions require several integration steps to be fully operational, which are highly complex and not publicly available. This tutorial presents the most recent techniques involved in multi-projection solutions, from projection to computer cluster software for large scale immersive VR environments. The hardware in these VR installations is an assembly of projectors, screens, speakers, computers and tracking devices. The tutorial will introduce hardware options, explaining their advantages and disadvantages. We will cover software design, available open source tools and middleware, and how to manage the complete solution, with tasks such as installing the computer cluster and configuring the 3D stereo graphical outputs. An introduction to tracking systems, explaining how electromagnetic and optical trackers work, will be also provided. At the end, we are going to present important design decisions in real cases: the project processes, problems encountered, good and bad points in each decision.

Sections

- Infrastructure
- I/O (Tracking and Audio)
- Clusters
- Cases

Section I: Infrastructure

Several technologies are available to implement a multi-projection facility. We are going to present some of these technologies and devices, and try to link them. An evaluation of the most common used projection techniques and their future is studied: What kinds of screens are available and the best use for each one, presenting calibration issues related to each technology and topology; details in site preparation, from air-conditioning to floor requirements. Control and automation is also mandatory in industrial VR facilities, therefore we will present the possible software techniques and how to integrate special hardware for it.

Displays Systems

ePaper - Flexible, full-color OLED (Sony)

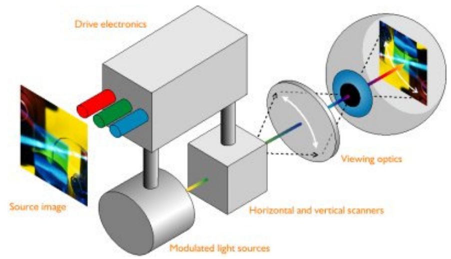
Personal Systems

- Desktop Display

- Domes

- Head-Mounted Displays

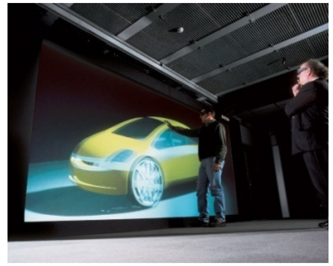
- Virtual Retinal Displays



Multi-user Displays

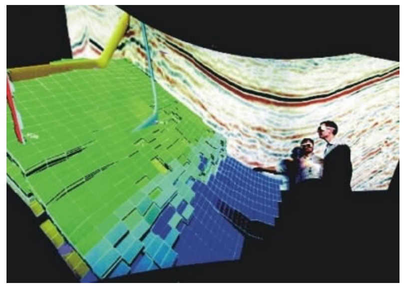
- Collaborative Desks

- Display Walls



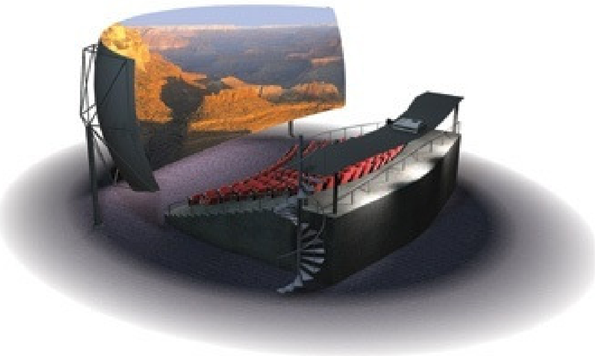
- Rectilinear Displays

- Wrap-around Screens

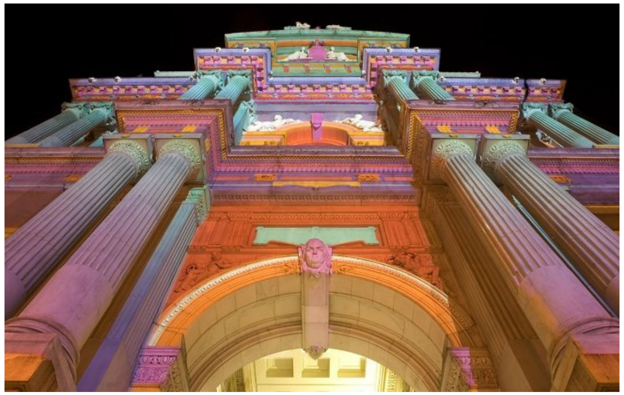


Crowd Displays

- Large-Scale Displays

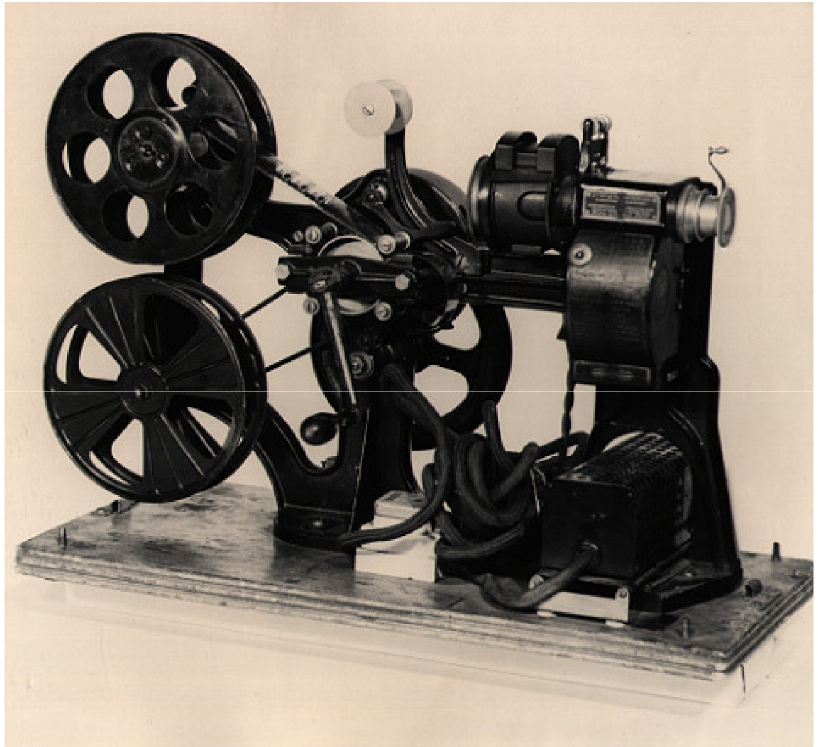


- Spatially Augmented Displays



Projection Technologies

- Several Solutions
- Several Parameters
  - Brightness
  - Contrast
  - Resolution
  - Refresh Rate



Brightness

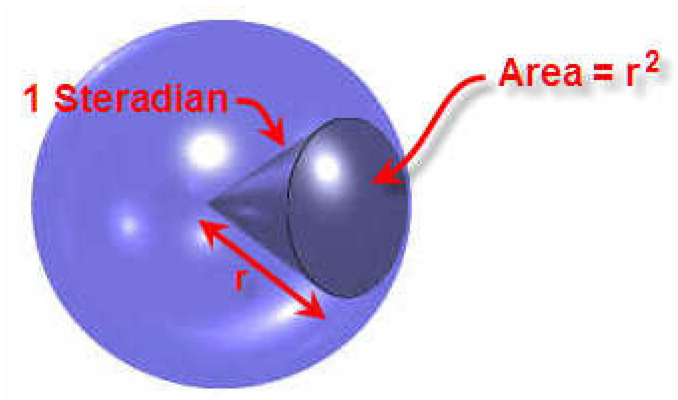
- What is Lumen?
- How to measure?
- How to choose?
- How to Choose the Brightness?

What is Lumen?

Lumen is the SI unit of luminous flux.

Formula : 1 lm = 1 cd·sr

*



How to measure?

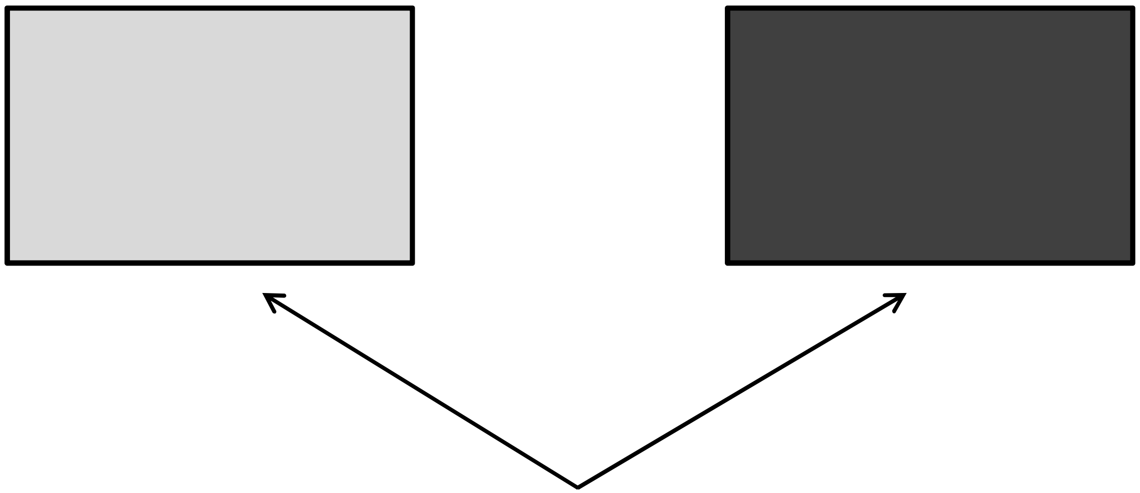
- Several ways
  - ANSI lumens
- Dividing a square meter image into 9 equal rectangles

How to Choose the Brightness ?

- Depends on several factors:
  - Ambient light
  - Screen size
  - Stereoscopy
  - Subject

Contrast

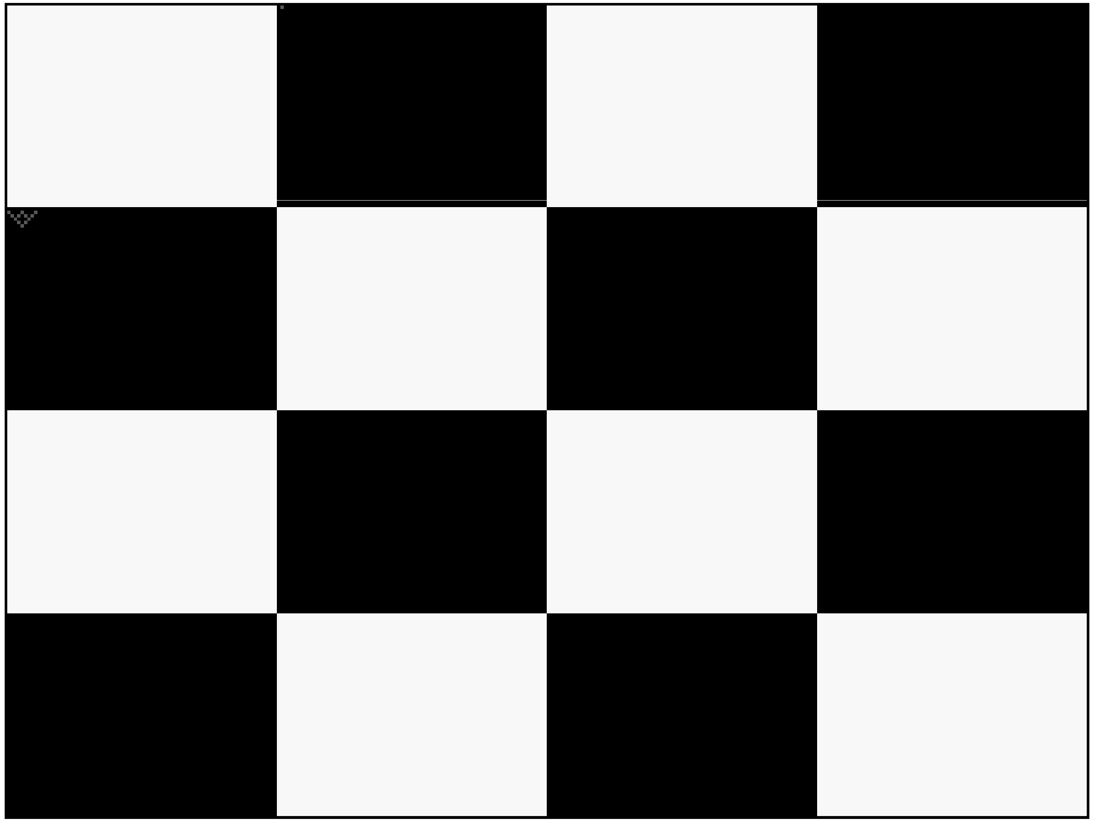
- Expressed as a ratio between the brightest and darkest areas of the image.



500,000:1

Contrast

- On/Off contrast   X ANSI contrast



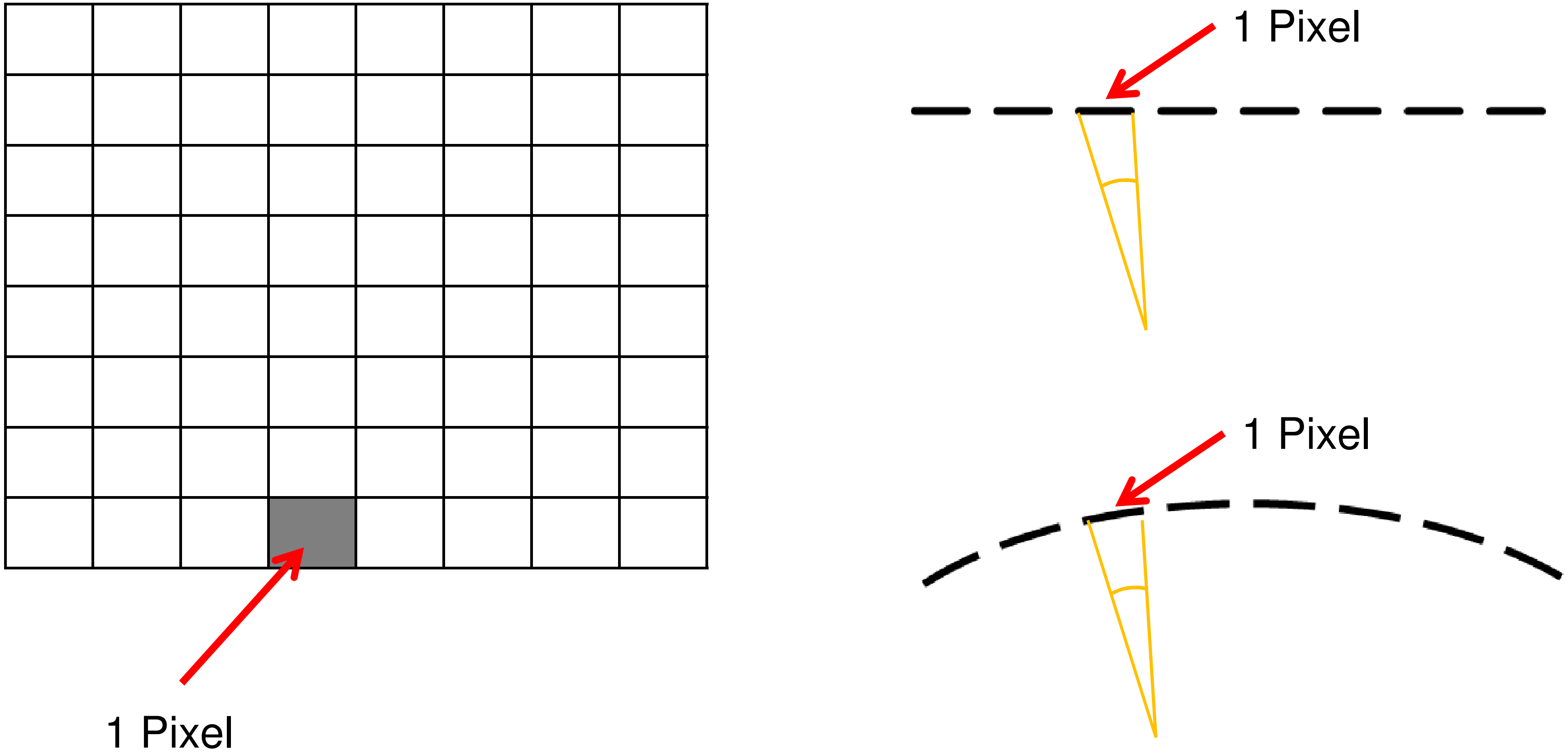
Dynamic Iris

- A dynamic iris is a device built into some projectors that sits between the lamp and the lens. Many times per second, the projector evaluates the overall brightness of the image being projected at the moment, and then opens or closes the iris to allow more or less light through.

Resolution

Standard	**Resolution** (*pixel dimensions)*	**Aspect Ratio**	**Pixels**
VGA	640x480	4:3	307,200
SVGA	800x600	4:3	480,000
XGA	1024x768	4:3	786,432
SXGA	1280x1024	5:4	1,310,720
SXGA+	1400x1050	4:3	1,470,000
WUXGA	1920×1200	16:10	2,304,000

Angular Resolution



Scan Rate / Display Frequence

- Frequence:
  - Bandwidth (MHz)
  - Horizontal frequency range (KHz)
  - Vertical frequency range (Hz)
- Some projectors compress or change the source frequency.

Common Projection Technologies

- CRT

Brightness : about 250 lumens
Contrast : about 2500:1
Resolution : about 2500x2048 pixels
Scan : about 180Hz

- LCD

Brightness : about 6500 lumens
Contrast : about 130:1
Resolution : about 1024x768 pixels
Scan : about 120Hz

- DLP

Brightness : about 14000 lumens
Contrast : about 1500:1
Resolution : about 1400x1050 pixels
Scan : about 120Hz

- LCOS

Brightness : about 10000 lumens
Contrast : about 10,000:1
Resolution : about 4096x2160 pixels
Scan : about 120Hz

* Approximated values

CRT (Cathode Ray Tubes)

- Based on 3 independent tubes (Red, Green, Blue)
- Advantages: calibration flexibility, high refresh rate (> 120MHz), anti-aliasing
- Disadvantages: low brightness, noise signals

LCD (Liquid Crystal Displays)

- Based on liquid crystal technologies
- Disadvantages: low refresh rates usually < 80MHz, low geometric calibration control, aliasing (door effect), need accurate positioning, short live cycle
- Advantages: low cost, compact, high contrast, just one lens.

DLP (Digital Lighting Processing)

- Based on Digital Micromirror Devices - DMD
- Advantages: high brightness, just one lens
- Disadvantages: low refresh rate (maximum 120Hz), low calibration control, aliasing, positioning

LCOS (Liquid Crystal On Silicon)

- Based on reflexive liquid crystal
- Disadvantages: low refresh rate < 80MHz, low calibration control, positioning
- Advantages: high resolution, high brightness, high contrast.

Other Points to Evaluate

- Aspect Ratio
- Color and Geometric Aligment
- Weight
- Data and video inputs
- Powered Lens
  - Lens Shift
  - Zoom Lens

Lens

- Short throw, Fish Eye x Tele(photo) zoom
- Motorized x Fixed
- Focal length

- Zoom throw ratio

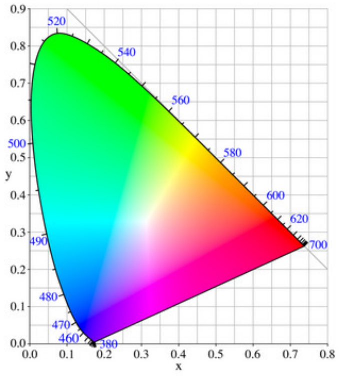
Throw Distance = Screen Width X Lens Throw Ratio

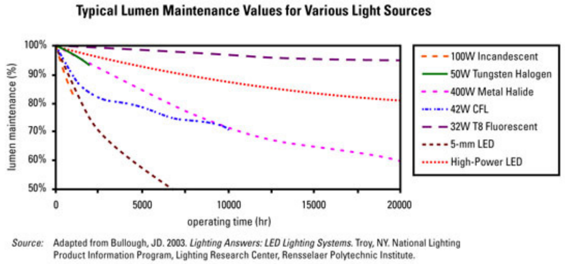
1.3:1 - 5m (500cm) = Horizontal 384cm

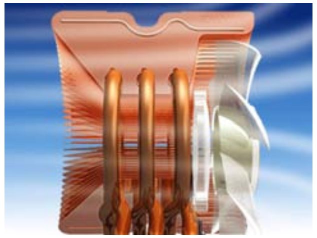
0.8:1 - 5m (500cm) = Horizontal 625cm

Lamps Characteristics

- Well suited spectrum;
- Long life;
  - over 10 000 h.
- Lumen maintenance;
- noisy cooling solutions.

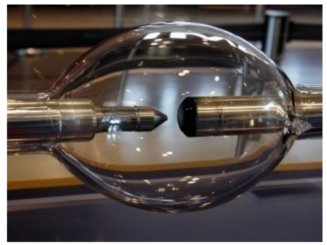


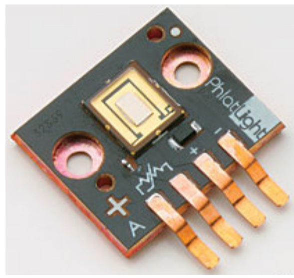




Lamps

- Incandescent
- Arc-lamps or Gas discharge
  - Metal halide lamps
  - UHP - Ultra-High Performance
  - EHP - Ultra-High Efficiency
  - Xenon arc lamps
- LED - light-emitting diode



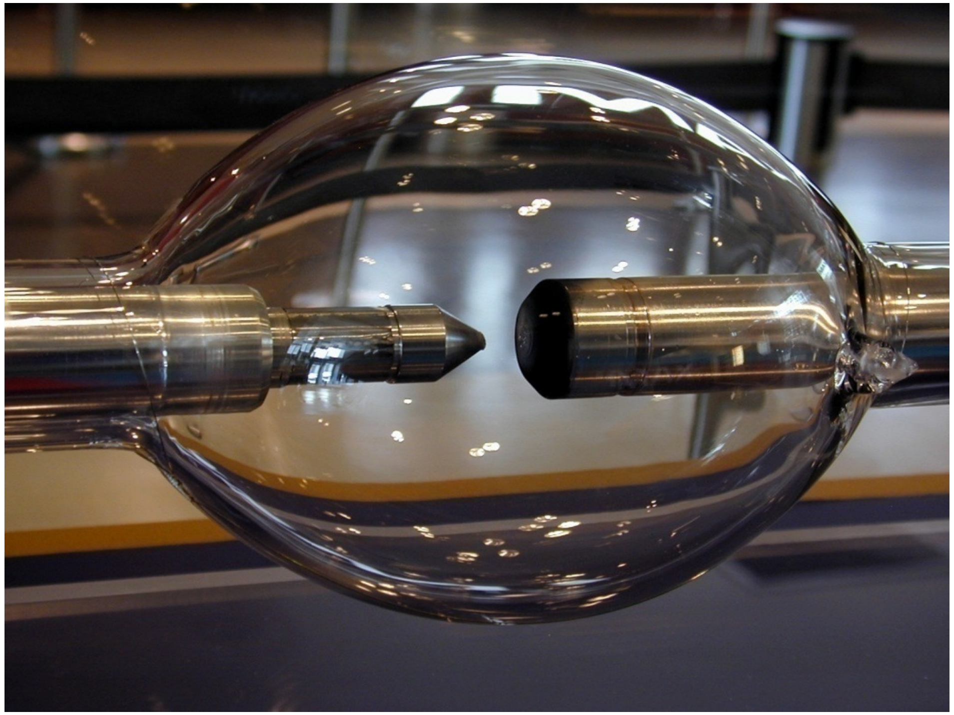


UHP / UHE

- The Hg pressure inside the lamp has to be higher than 200 bar to allow for good color quality and high efficiency. This requires bulb temperatures above 1190K at the coldest spot inside the lamp.
- At the same time the hottest parts of the quartz envelope have to stay cold enough (*<1400 K)*

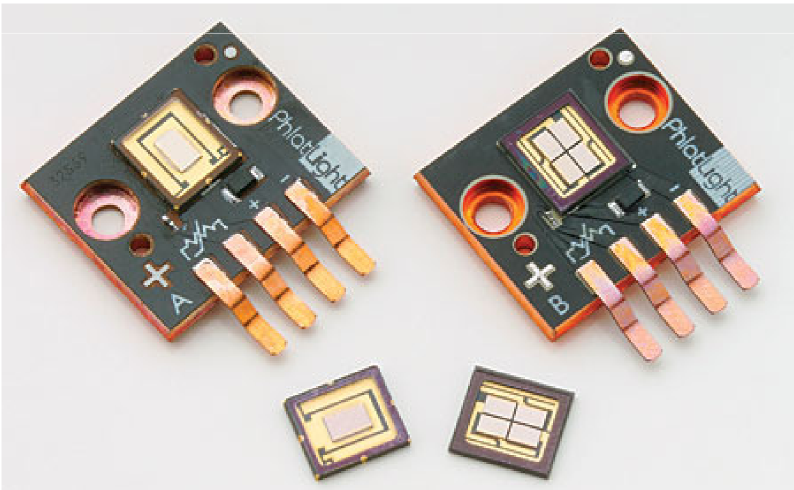
Xenon Lamp

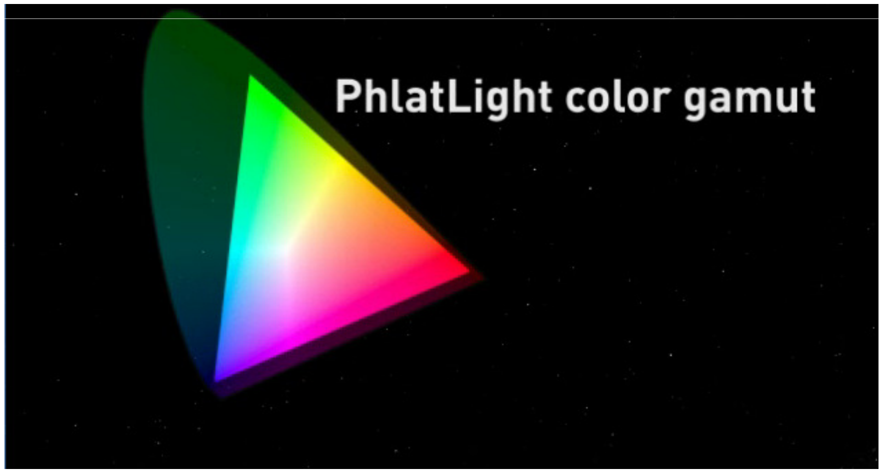
- 15 kW Xenon short-arc lamp



LED light

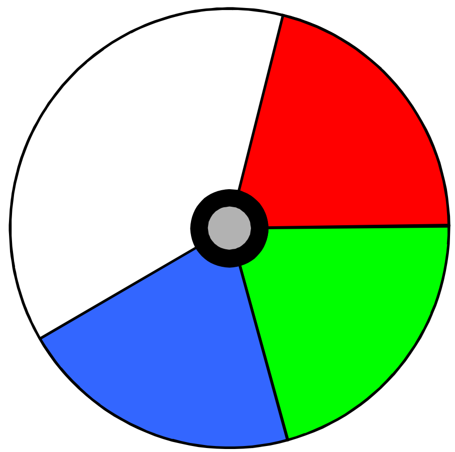
- Phlatlight - PHotonic LATtice (Samsung)





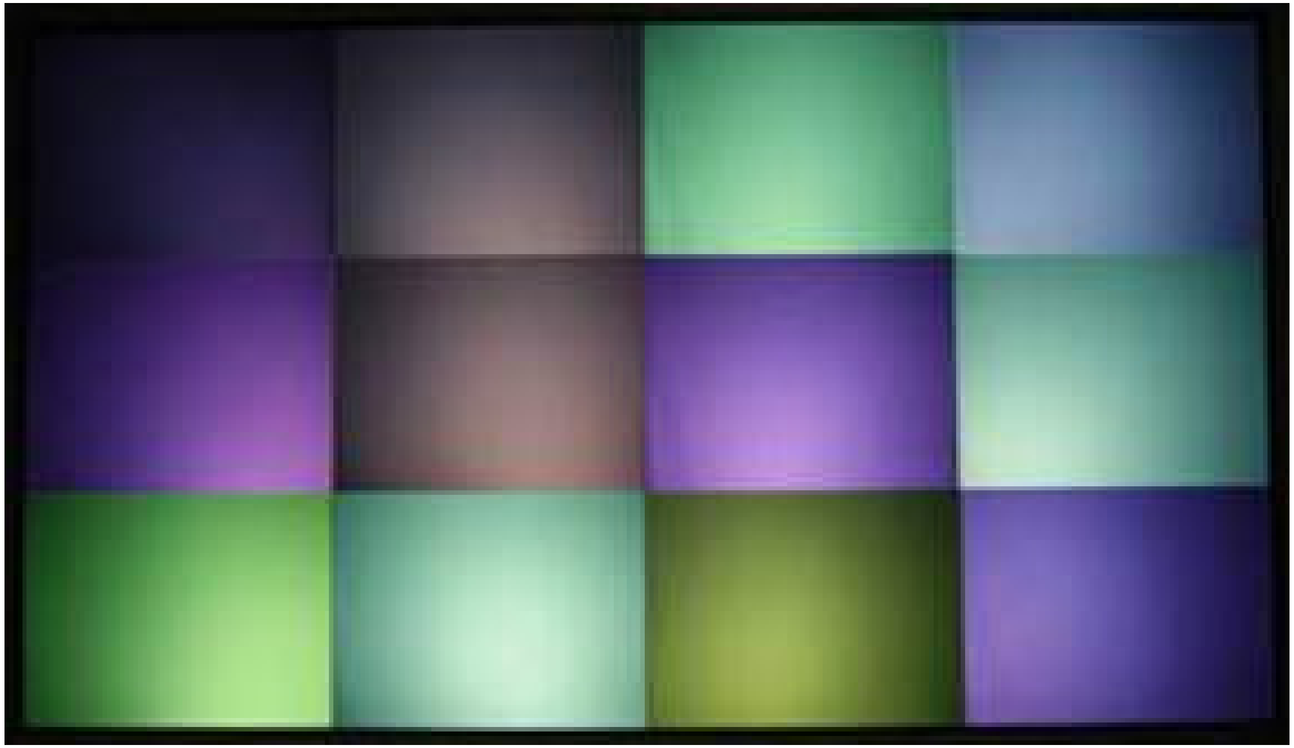
Problem Tackled

- Color wheel
- Color filters can vary
- Screens prism effect
- High gain screen
- Age differently



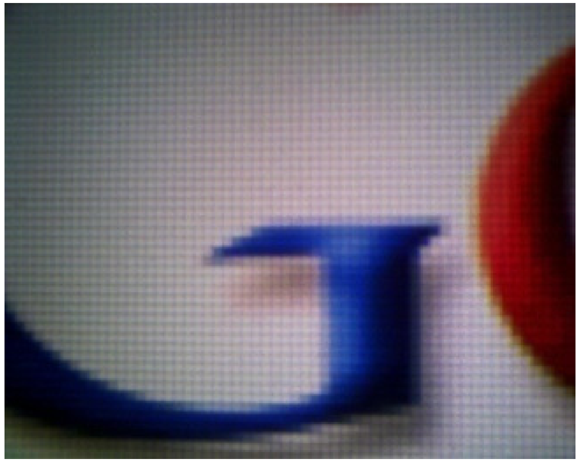
Color sample

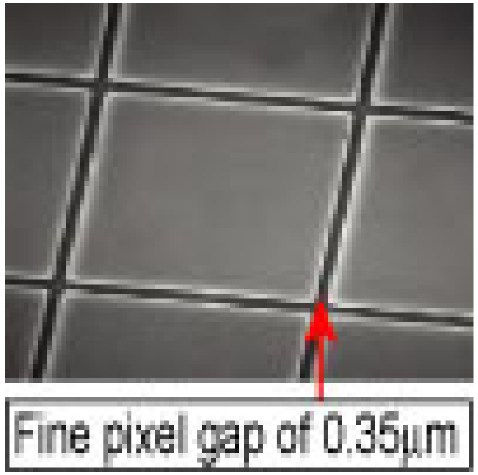
- Low exposure
- Due to color wheel cycle



Problems

- Screen door effect or Fixed Pattern Noise
- rainbow effect can appear around bright on-screen objects.





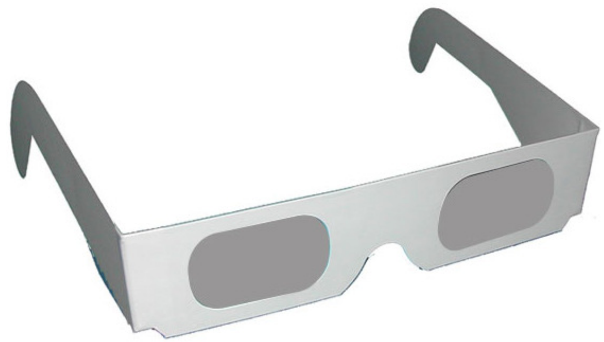
D-ILA

Stereoscopy

- Shutter Glasses (active)
  - Electronic controls
- Passive Filters
  - Anaglyph (red x blue)
  - Linear & Circular Polarization
  - Difraction
  - Infitec
- HMDs (Head Mounted Displays)
- Auto-steroscopy

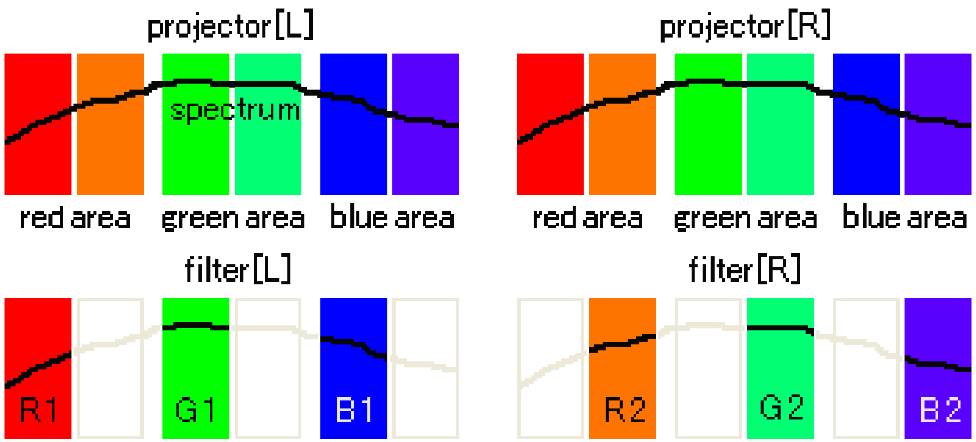
Passive Stereoscopy

- Anagliph;
- Polarization (linear and circular);
- Auto-stereoscopic;
- INFITEC Polarization.



Infitec

- Split the color spectrum
- All colors are presented
- Reduce Brightness
- Good Separation



Active Stereoscopy

- Shutters (active);
  - Do not need screens to maintain polarization
  - Needs high frequence video sources
    - Ideally 120Hz
  - Needs bateries

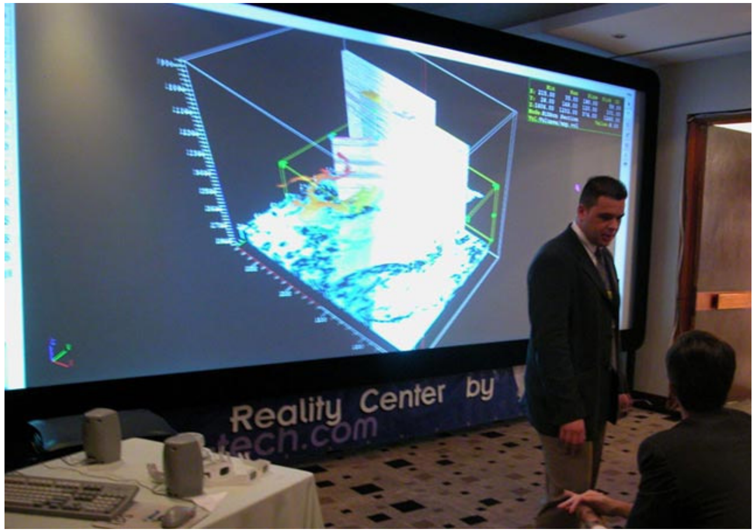
Projection and Screen Geometries

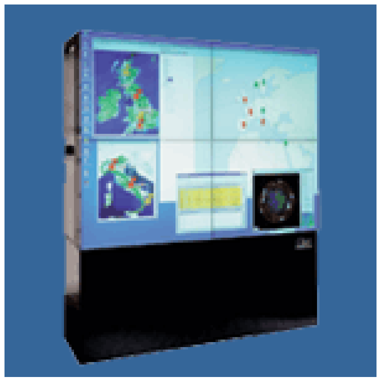
- Planes (PowerWall, InfinityWall, Panorama,etc)
- CAVEs
- Irregular (Workbenchs)

- Cilindric, Conics, Torus
- Spherics
- Domes

Plane - Display Wall

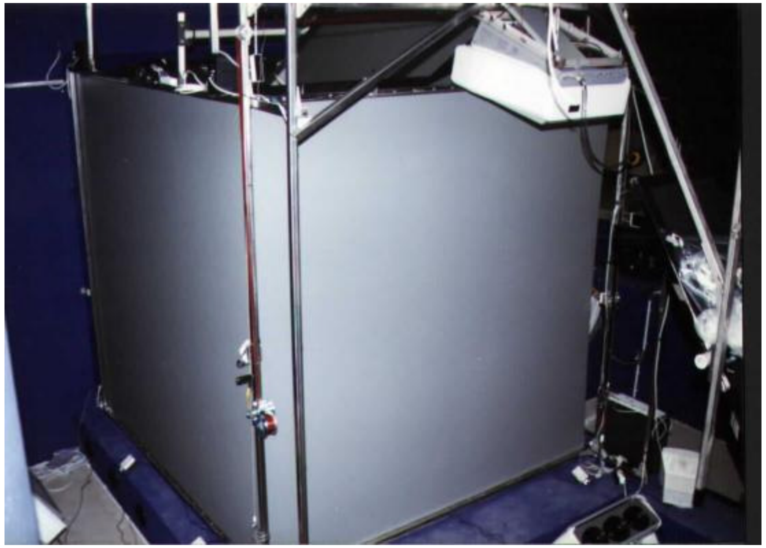
- Simple solution
- Similar to a big monitor
- Application Port simpler
- Less Immersive
- Medium Audience
- Large Market Choice





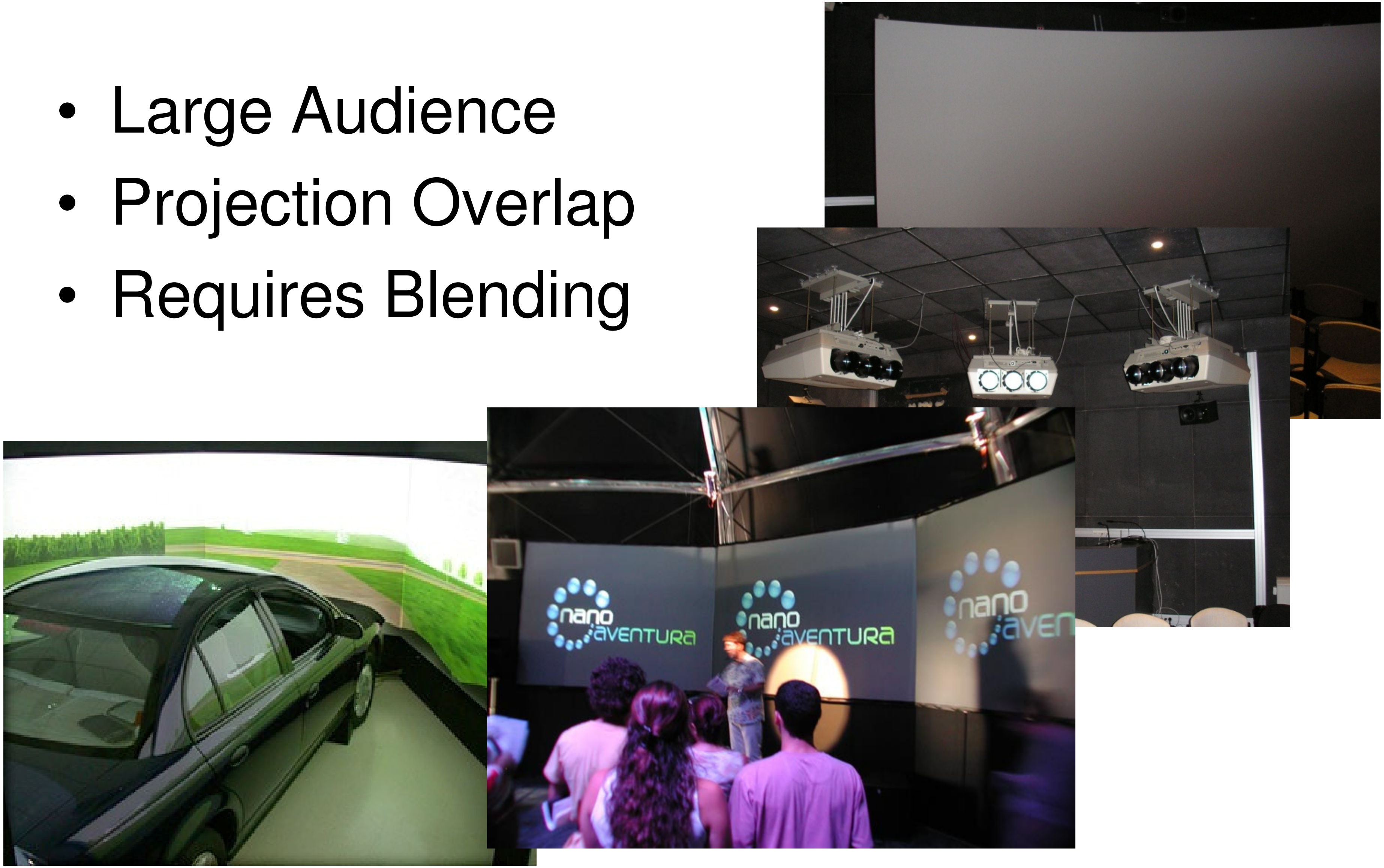
CAVEs

- Famous solution
- Highly Immersive
- Different types:
  - 4, 5 or 6 sides
- One User



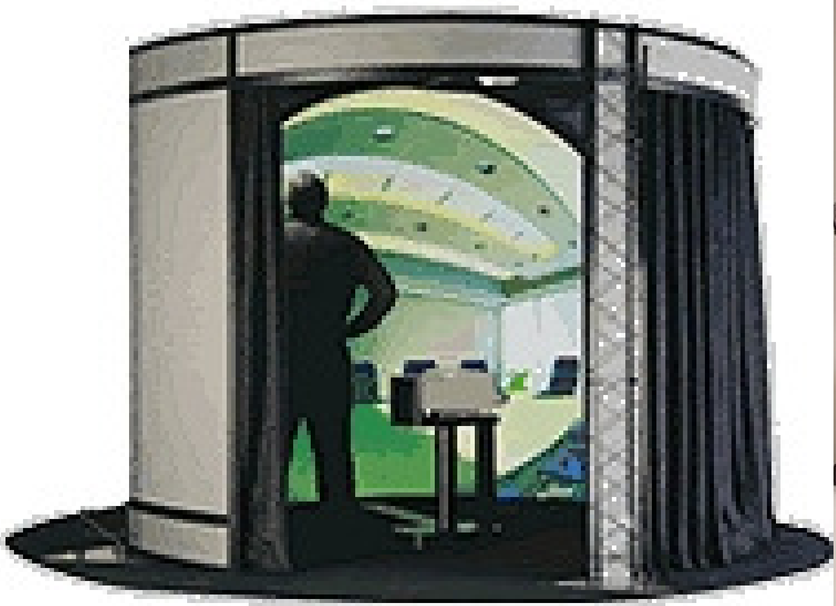
Cylindrical

- Large Audience
- Projection Overlap
- Requires Blending



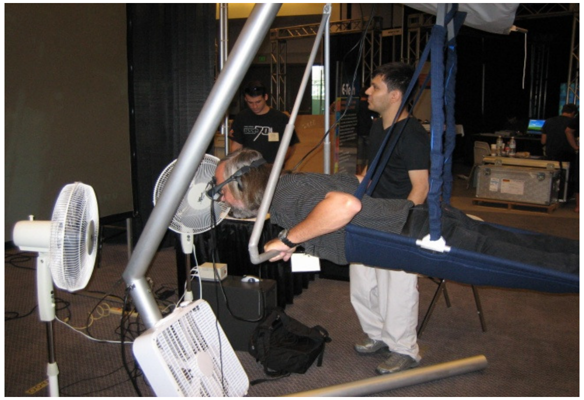
Spherical

- Large Field of View
- Deformation Correction



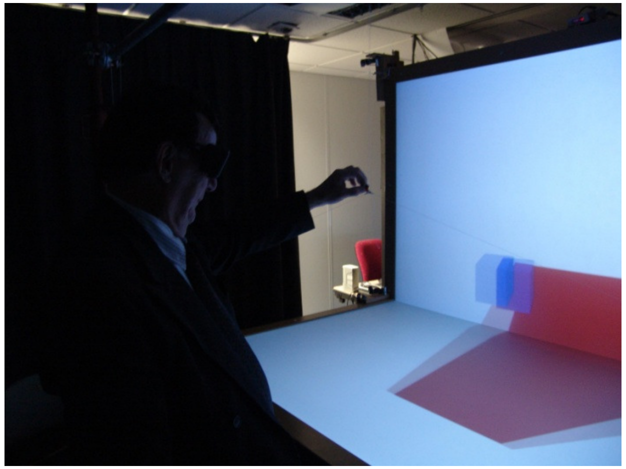
Alternative Solutions

Hang-glider



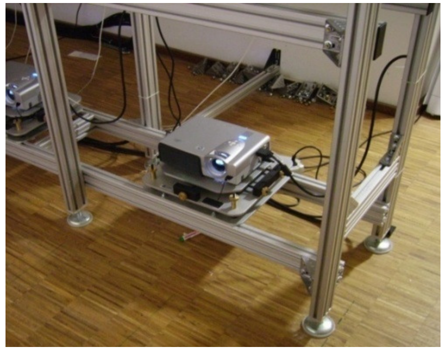
Thorus

WorkBench

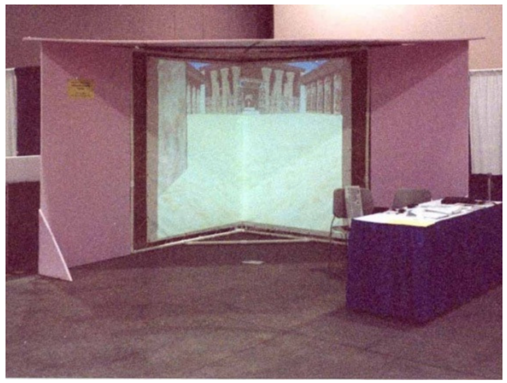


Multi-Projector Structure


- Screen Frames
- Projector Mount and Arrays
- Possible Materials
  - Wood
  - Aluminum
  - Plastic Pipes
    (http://planetjeff.net/ut/CUTCave.html)

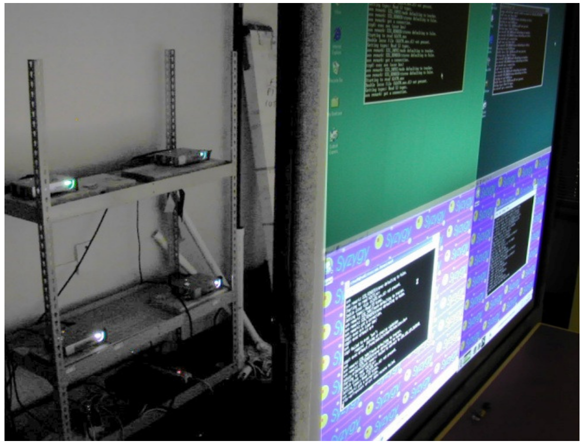



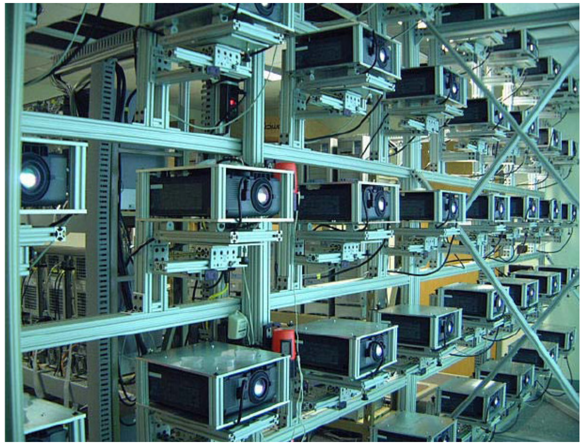
- Special Cares
  - Weight
  - Magnetic Interference
  - Vibrations

Projector Arrays

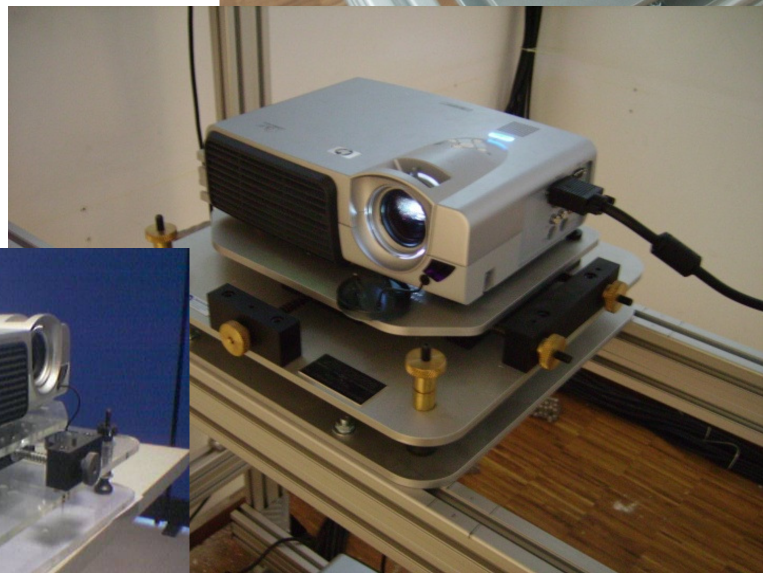
- Aluminum Frames
- Scalable and Modular
- Stereo or Mono Bays
- 6 DOF projector mounts

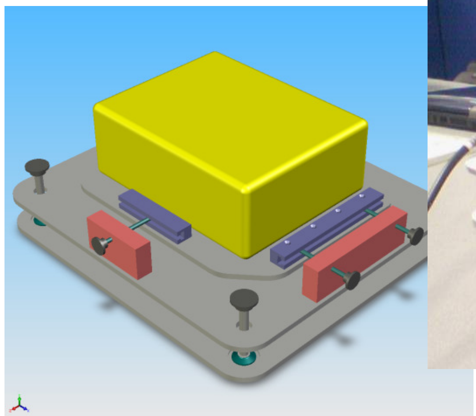




Projector Mounts

- 6 DOF projector mounts
- Sub-millimeter control
- Absorb Vibration

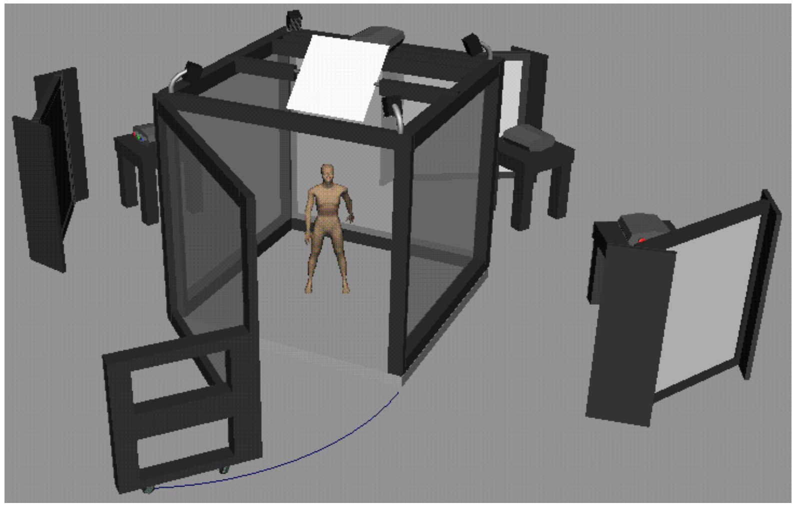




Planar Mirrors

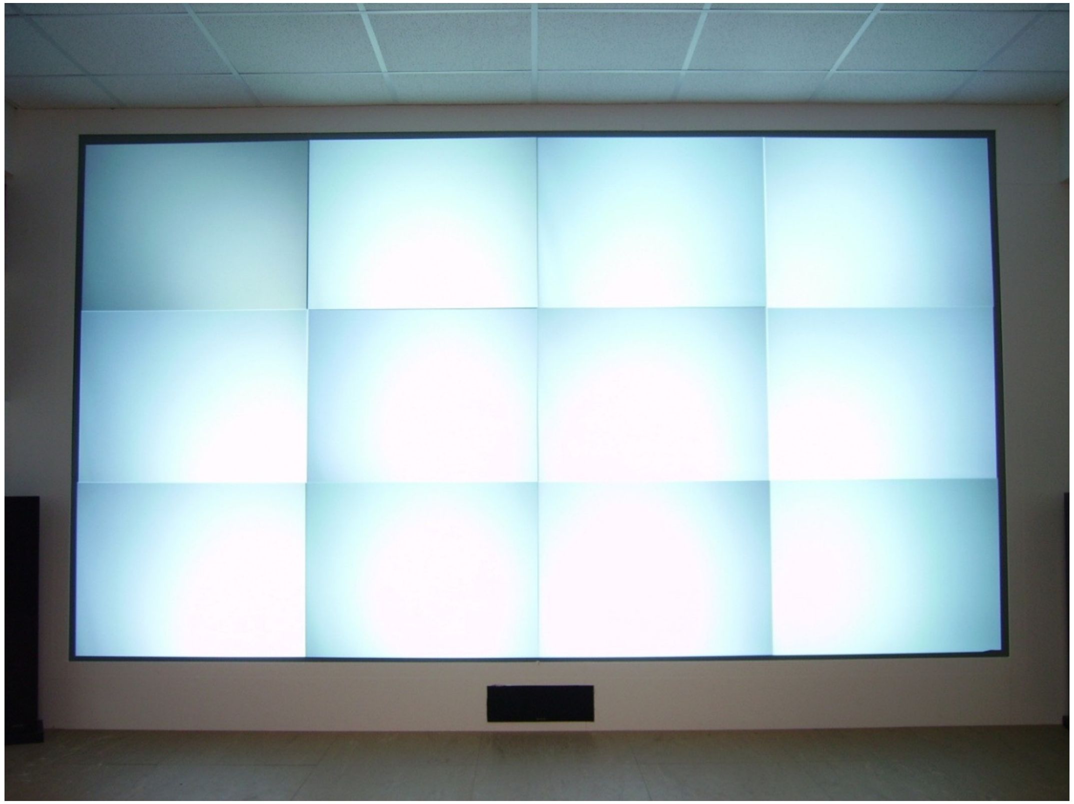
- Complementing Projector Mount
- Shorter Projection Distance
- *WorkBench*

- Front Surface Mirrors/First Surface Mirror
  - **for Polarized Light**
  - Frontal reflection
- Reflection over 99.99%
- **Plastic Substrates**



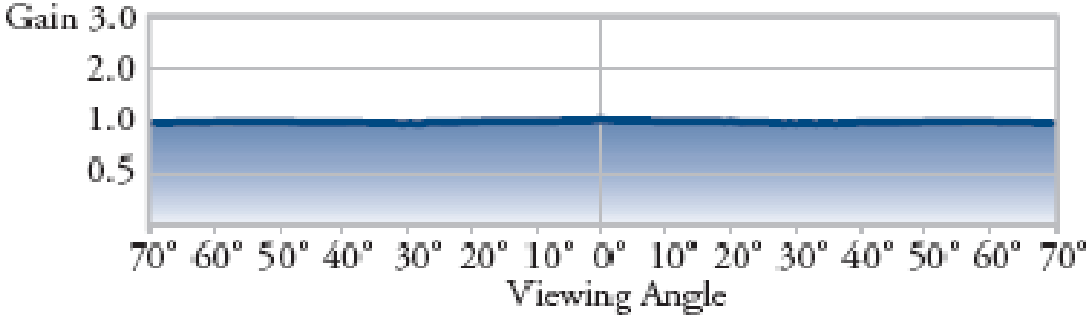
Projection Issue: Homogeneous Brightness and Hot Spots

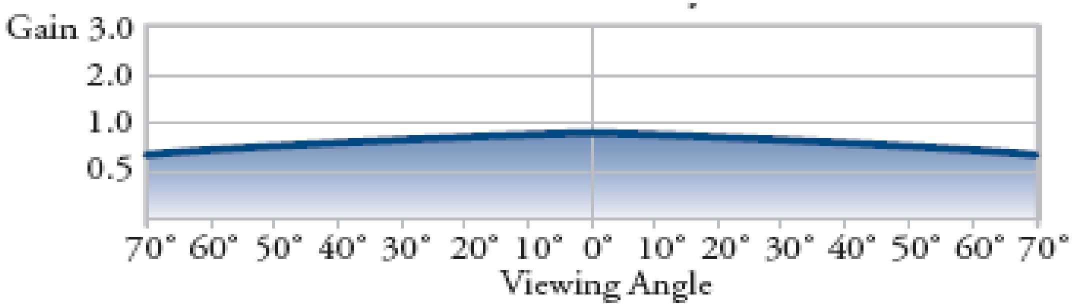
- Oblique Light rays vs Viewing Direction
- Translucent Screen
- Bulb source



Projection Issue: Viewing Angle

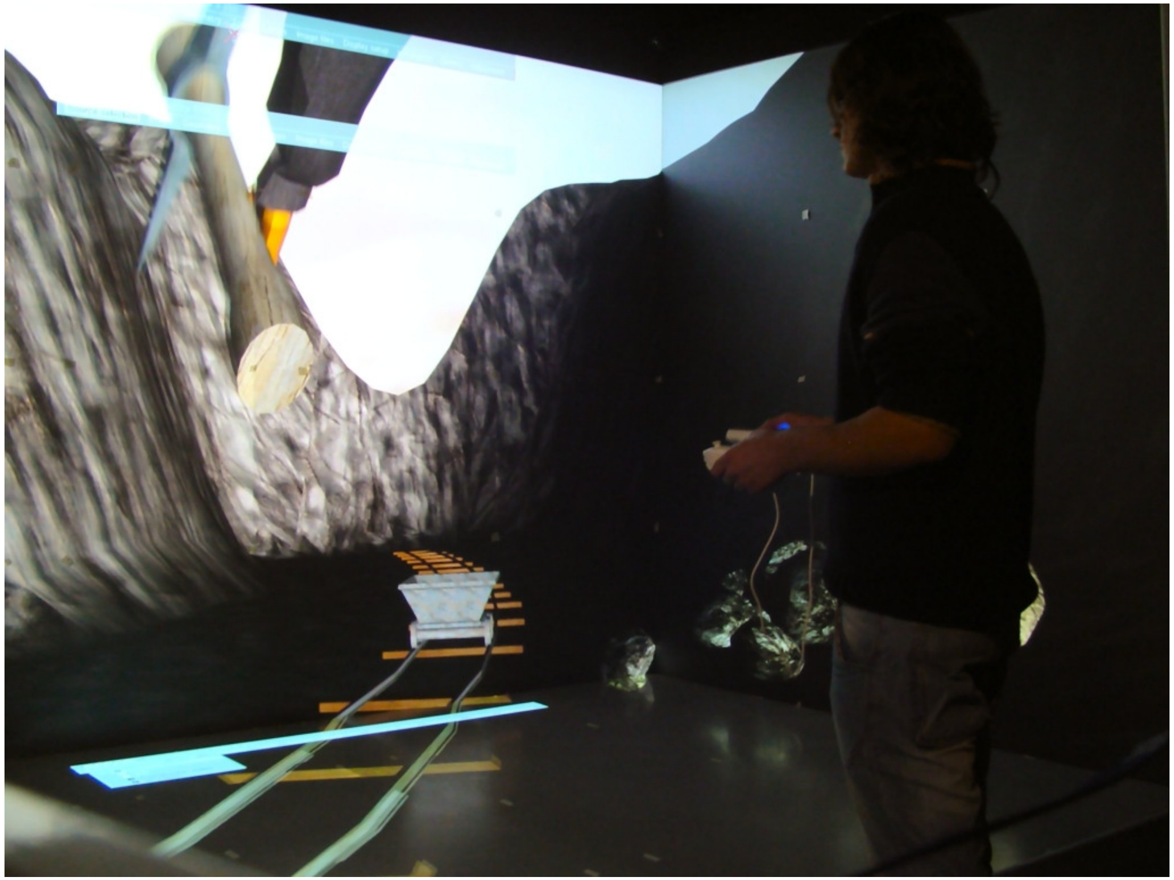
- Screens with gain usually have a narrow field if view, losing brightness when viewed from an angle
- Flexible or Rigid Screen





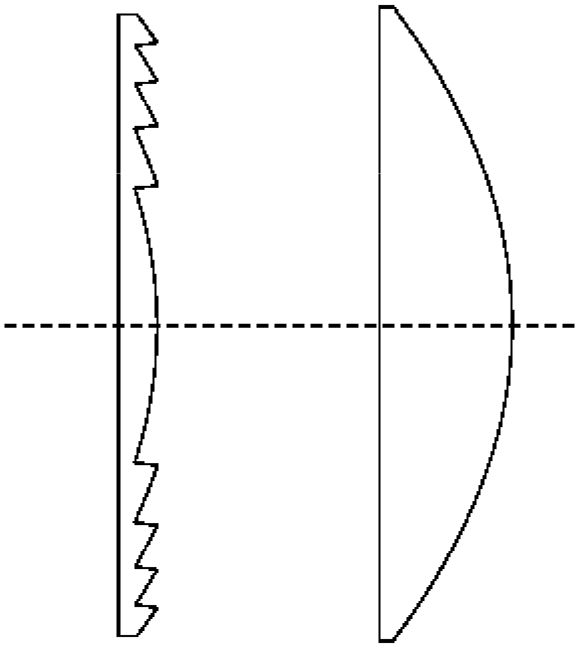
Projection Issue: Inter-reflection

- Cave: Light from other screens



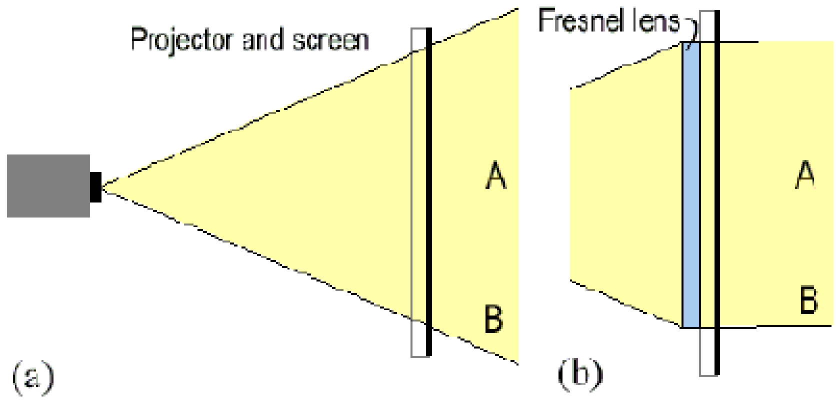
Redirecting Light: Fresnel Lens

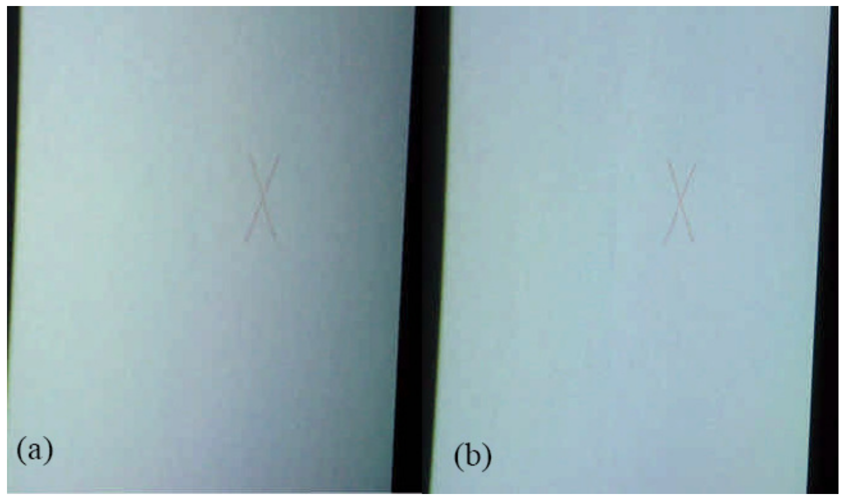
- To guarantee constant angle between viewing direction and protected light rays



How to use Fresnel Lens

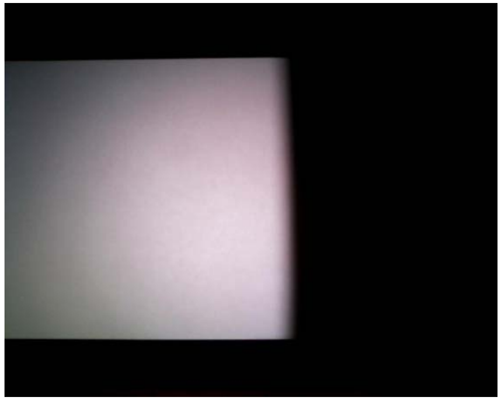
- Correct Projector rays
- Lens Size = Tile Size
- Minimum Space between tile > 0



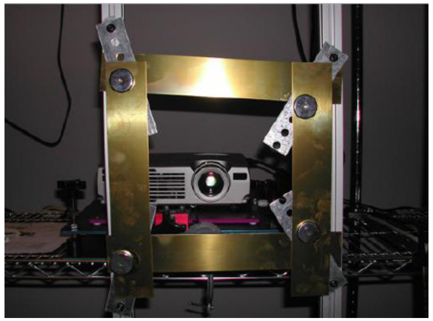


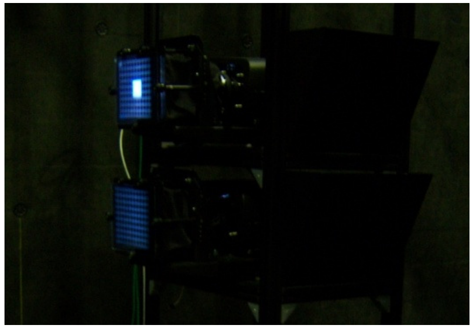
Stone, "Color and Brightness Appearance Issues in Tiled Displays",2001

Edge-blending



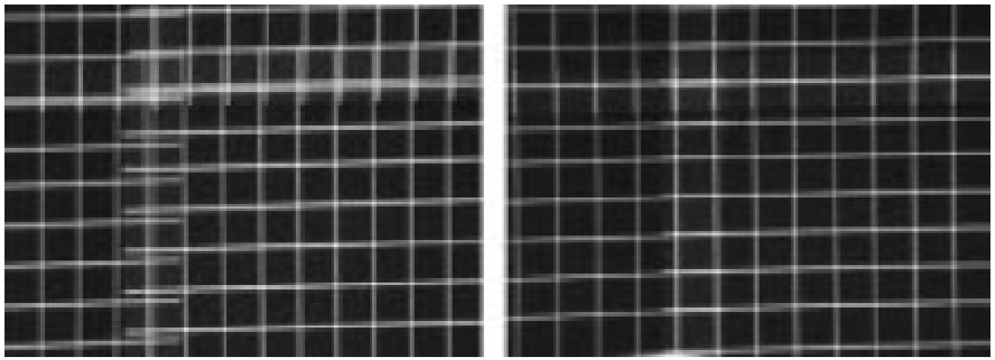
- Seamless edge blending
- Light Leak
- Small Overlap
- Almost aligned Scenarios
- Solutions:
  - Physical
  - Software Mask
  - Hardware Projector





Geometry Calibration and Warping

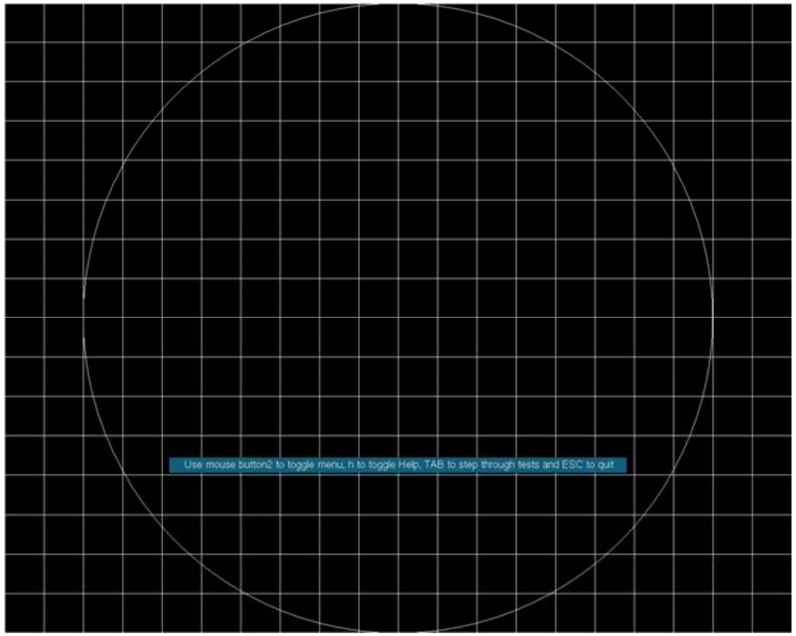
- Inter Projector Calibration
- Remove Seams
- Falloff Correction

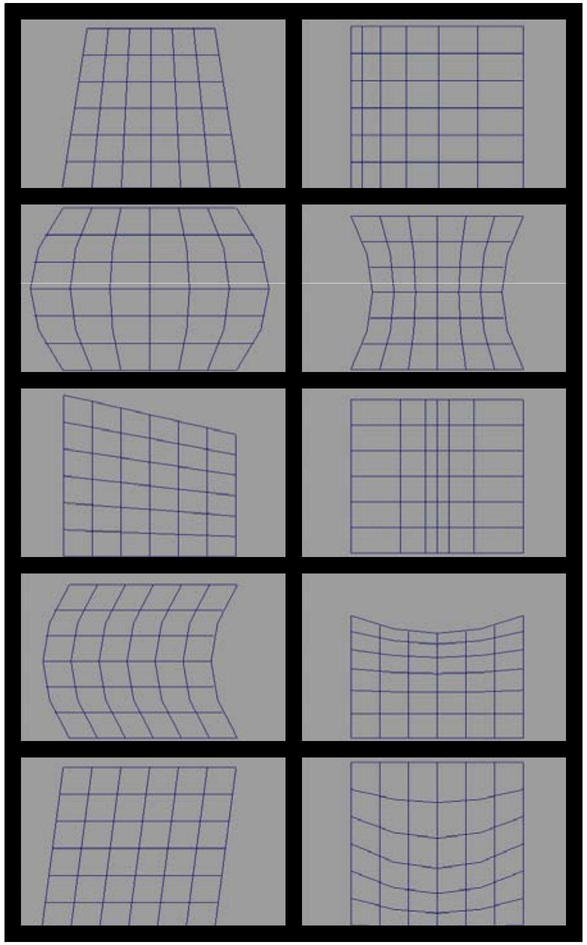


- Popular Technique:
  - Camera based Projector Registering
  - 2D Warping Map (Mesh)
  - Intensity Correction (Alpha-> Seams area)

Geometric Calibration

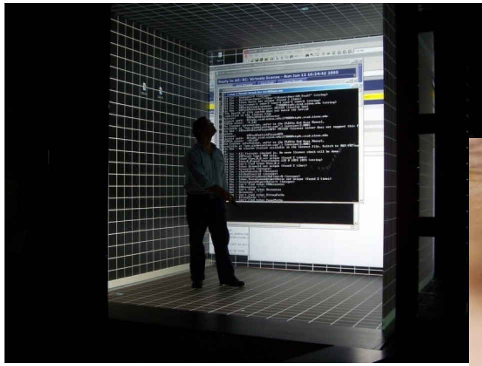
- Projector Registering
- Pattern Lines or Circle Dots
- Lens Distortion





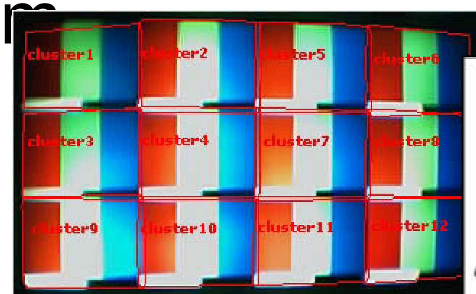
How to achieve the calibration color

- Eye



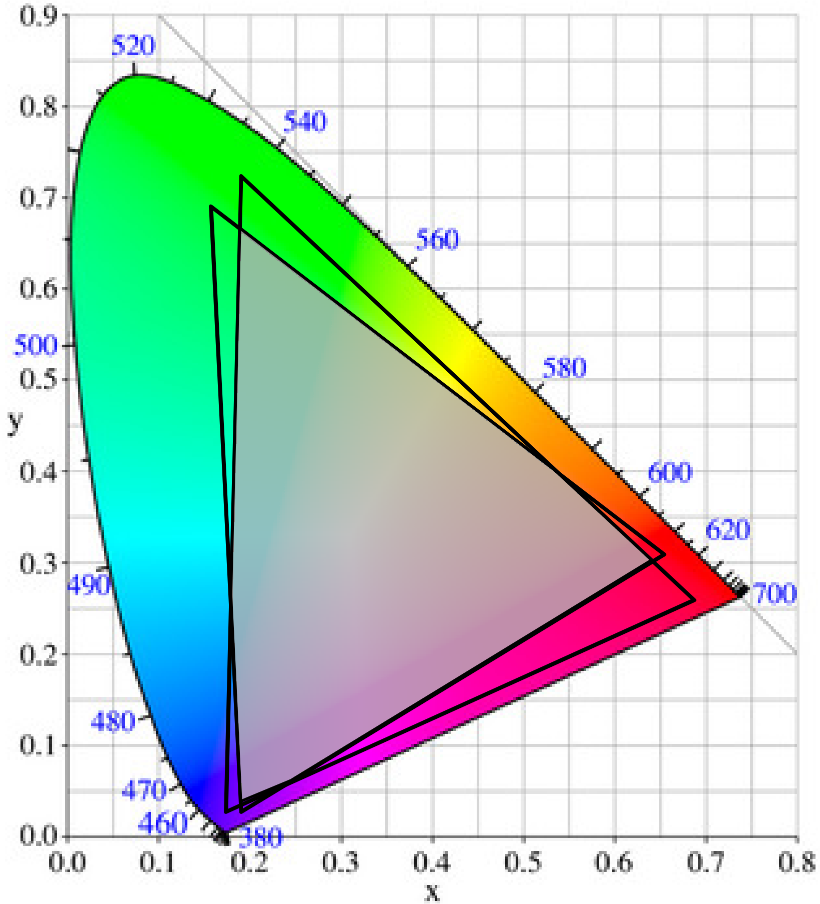

- Spectroradiometer


- Digital Camera or Webcam



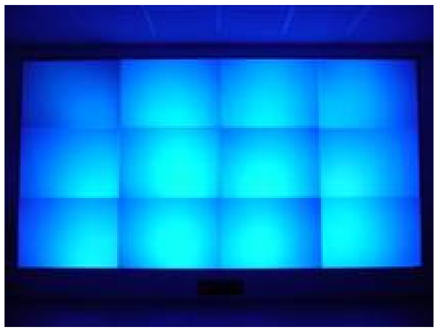
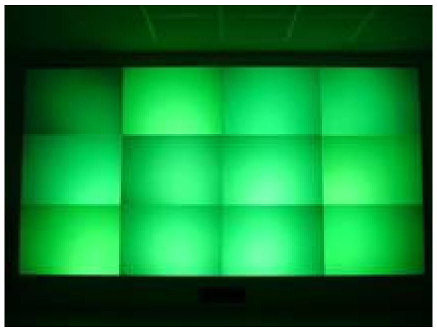
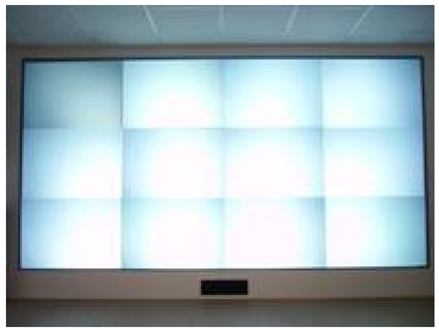
Color calibration

- Find a common gamut
- Change gamma curve in the graphic card
- Final
  - Color Lookup Table
  - Can be applied via PShader
  - Already support by cluster scenegraph such as OpenSG



Color Calibration

- Hot spot created by the camera
- Not aligned with projection direction
- No linear response to input
- Luminance more perceptive than chrominance

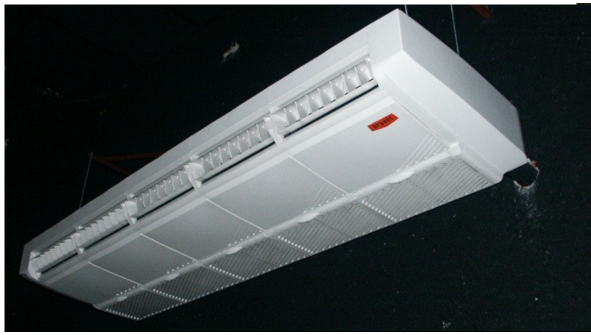





Color Calibration

- Test card / Test pattern
- Vectorscope
- SMPTE Color Bars 16x9
- Usefull for Calibration evaluation

Site preparation

- Cooling System
  - Stable Temperature
  - Particle Clean

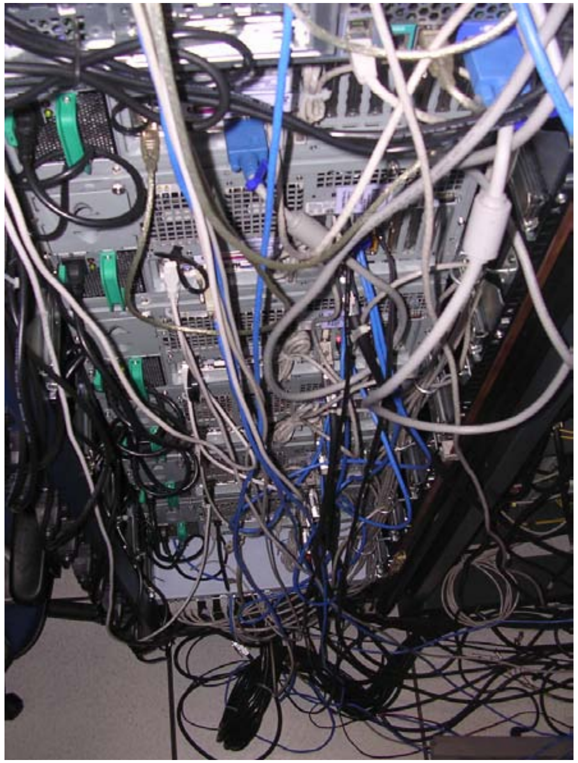
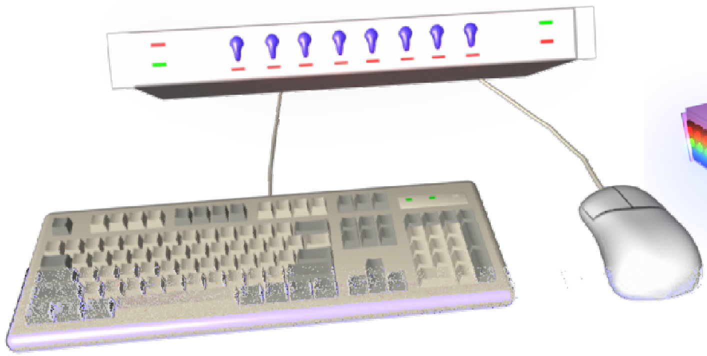


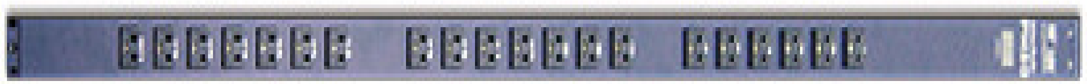

- Power and Cabling
  - Video
  - Network

- Controlled Environment
  - Light (Filters, Black wall)
  - Soundproofing, Vibrations


Control and Automation solutions

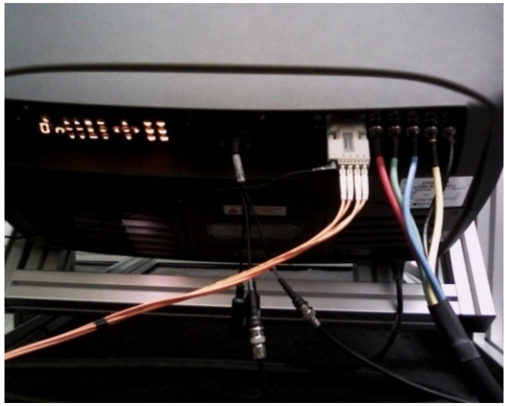
- Multi-Use Rooms
  – Light, Media Manager
  (ex: Creston, Lutron)
- Remote Power Control
- KVM Switch

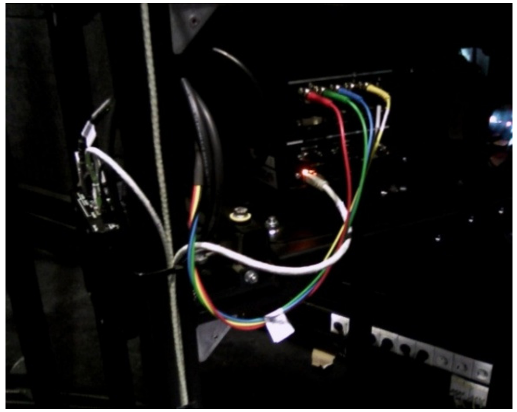






Video Transmission and Control

- Cable Length Pb.
  - AutoPatch
  - EyeViz



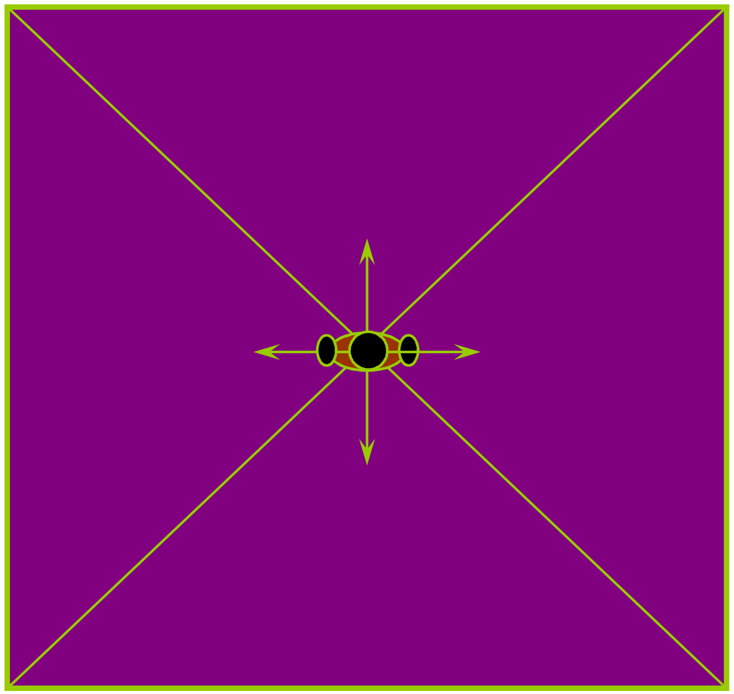


- Video Matrix
  - Extron
  - Miranda

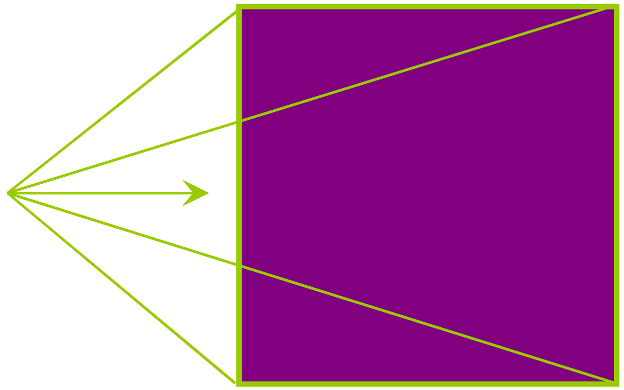
Section II: I/O (Tracking & Audio)

Tracking a user pose (position and orientation) in an immersive projection environment is the only way to correct any projection distortion and simplify the interaction in the virtual environment. However tracking solutions are not easy to implement and even traditional tracking hardware needs complex calibration. We are going to overview common techniques, but we are going to focus in infrared (optical) tracking since it is getting very popular in VR installations. We will also present some new ideas for tracking. Audio is also covered, since it is typically not very well planned in multi-projection environments and its integration in already started facilities, is not straightforward.

Why User Tracking



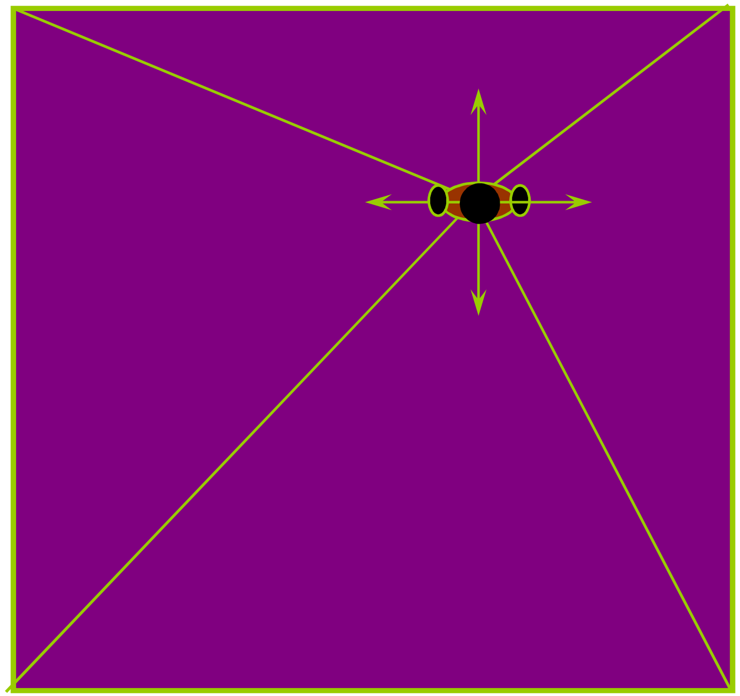
Top view



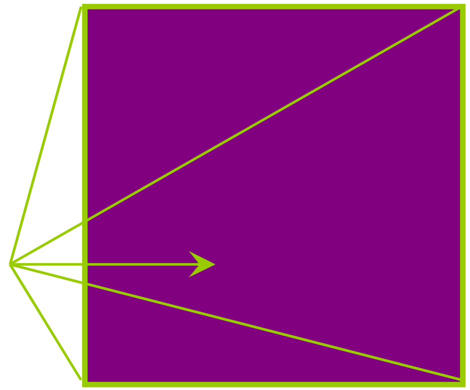
Frustum

Why User Tracking

Dynamic adjustment of viewpoints and view frustums



Top view



Frustum

User Tracking

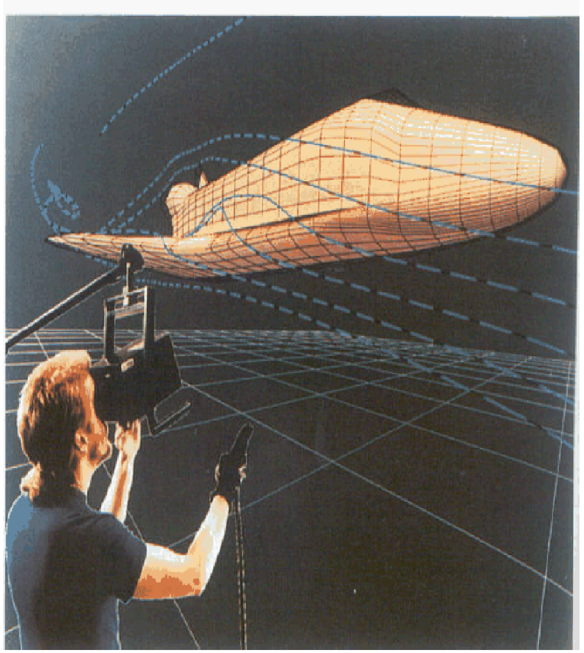
Technologies:

- Mechanical
- Inertial
- Optical
- Electromagnetic
- Acoustic

User Tracking

Mechanical Tracking Devices:

- Track Position and Orientation (6DOF)
- Mechanical arm paradigm
- Lag of less than 5msec, 300 Hz
- Very accurate



Problems:

- <u>Motion constrained by the mechanical arm</u>

Example: Boom by Fake Space Labs

User Tracking

Inertial Tracking Devices:

- Orientation (3DOF) – conservation of the angular momentum
- Measures orientation changes using gyroscopes
- Fast and accurate, and only limited by cabling

Problems:

- Drift between actual and reported values is accumulated over time (can reach 10º per minute)

Example: InertiaCube by Intersense

User Tracking

Optical Tracking Devices:

- Track Position and Orientation (6DOF)
- Outside-in (fixed receivers and mobile emitters)
- Inside-out (mobile receivers and fixed emitters)
- Lag of 20-80msec, 2 mm and 0.1º precision

Problems:

- <u>Line of sight, ambient light and infrared radiation problem</u>

Example: ARTrack by A.R.T

User Tracking

Electromagnetic Tracking Devices:

- Track Position and Orientation (6DOF)
- Measures the strenght of the generated magnetic fields (3 perpendicular wire coils)
- Lag of 5msec

Problems:

- <u>Interference in the presence of other magnetic fields (metal objects, office furniture, CRTs)</u>

Example: Fastrak by Polhemus

User Tracking

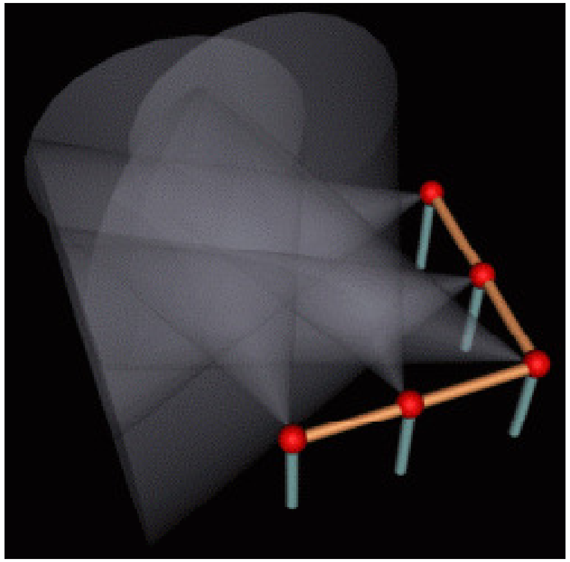
Acoustic Tracking Devices:

- Track Position and Orientation (6DOF)
- Measures the time-of-flight or the phase coherence of ultrasonic waves
- Lag of 5msec

Problems:

- <u>Phase coherence systems are subject to error accumulation</u>
- <u>Time-of-flight systems suffer from low update rate, and body occlusions</u>

Example: Arena by ADETTI



User Tracking

Wanted system:

- Without motion constraints
- No drift
- Without error accumulation
- Robust to interference
- Real-time update rate (> 30 Hz)

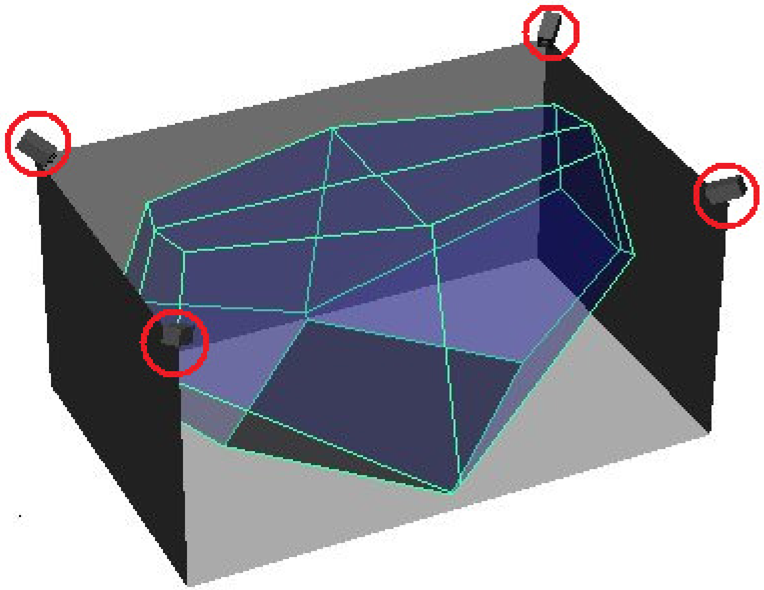
Chosen: Infrared Tracking System

- **Problems**: Line of sight and infrared radiation problem
- **Minimization**: 4 cameras setup and controlled environment

User Tracking

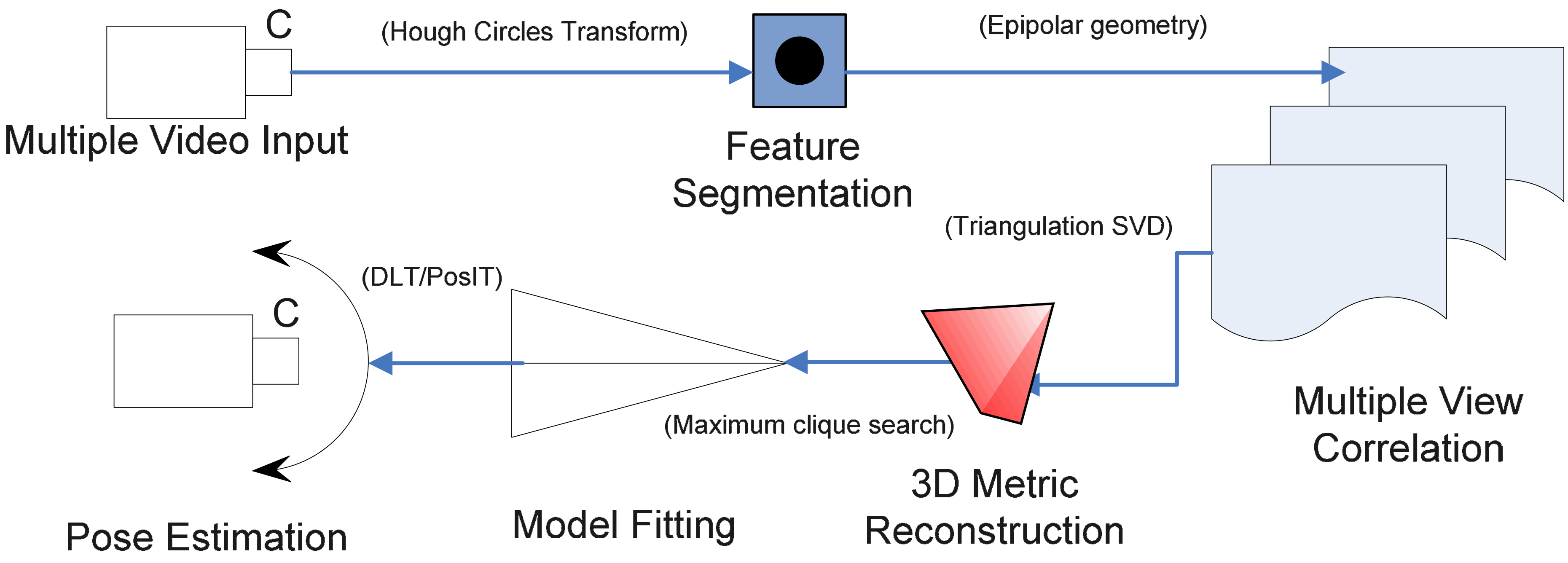
Hardware Setup:

- 4 AVT Firewire Pike Cameras (640x480, 205 fps)
- 4 LED ring array emitters
- 1 Shutter Controller
- Several retroreflective markers



User Tracking

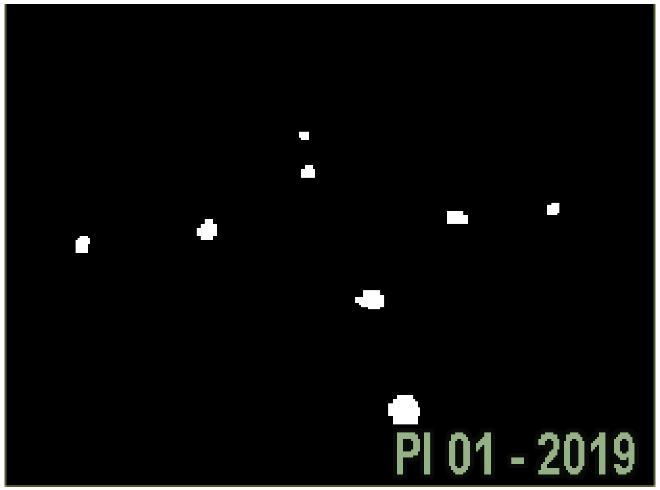
Infrared Tracking System Algorithm Overview:



Infrared Tracking System Algorithm

1. Feature Segmentation

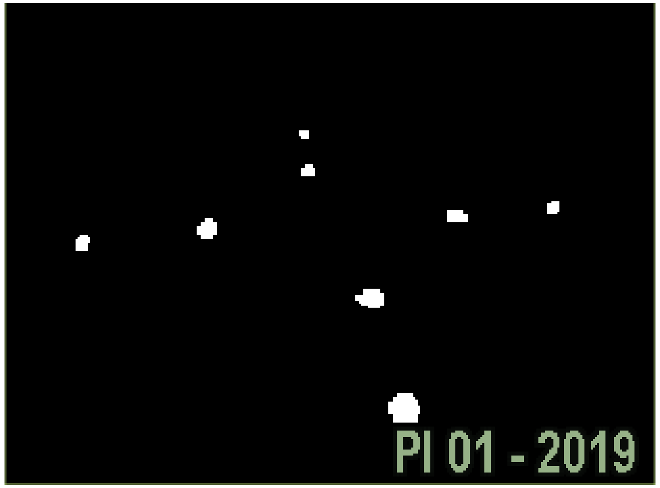
threshold

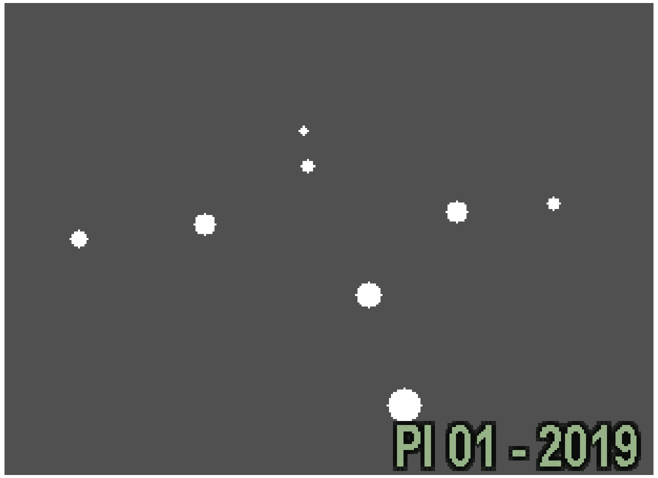


Infrared Tracking System Algorithm

2. Feature Identification

Hough Transform

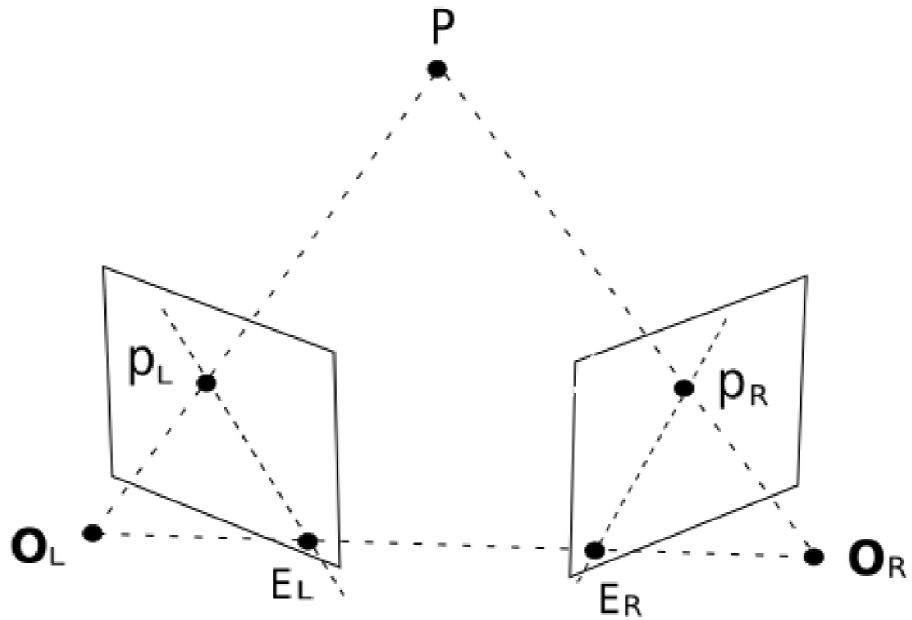




Infrared Tracking System Algorithm

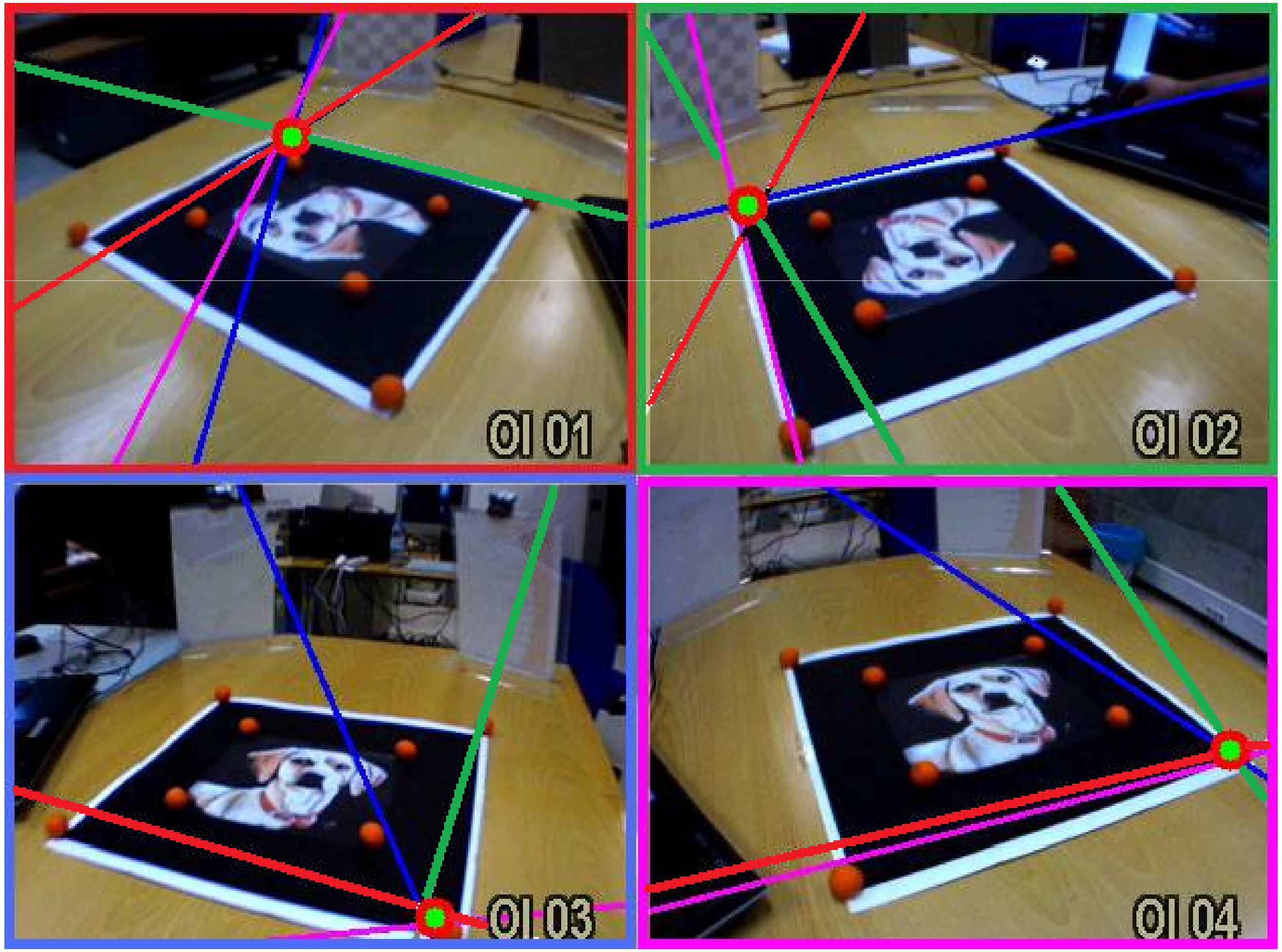
3. Multiple View Correlation via Epipolar Geometry (I)

- Epipolar geometry theory describes that a 3D point can be extracted through triangulation, from the projections on two different planes



Infrared Tracking System Algorithm

3. Multiple View Correlation via Epipolar Geometry (II)



Infrared Tracking System Algorithm

4. 3D Metric Reconstruction via Singular Value Decomposition Triangulation (I)

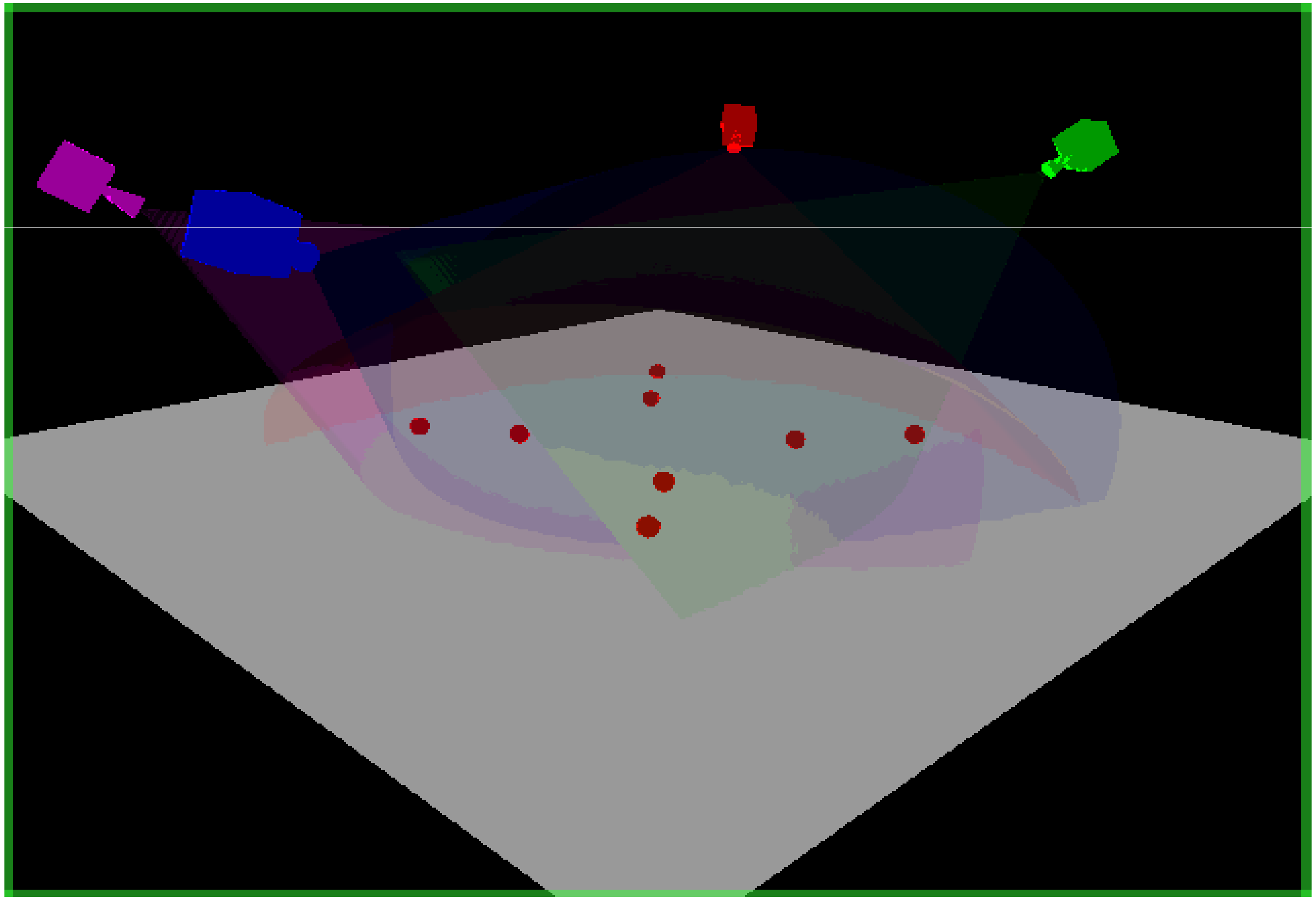
- Using each camera's intrinsic (K) and extrinsic parameters (M), stack into matrix A the existing information for each view i (2D point location – $x(i), y(i)$)
- Solve the A matrix by SVD, retaining the last row of the V matrix

$$M_{ext} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad K_{\text{int}} = \begin{bmatrix} f_x & 0 & c_x & 0 \\ 0 & f_y & c_y & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad P_{mat} = K_{\text{int}} \times M_{ext}$$

$$A = \begin{bmatrix} P(i)_{31} \times x(i) - P(i)_{11} & P(i)_{32} \times x(i) - P(i)_{12} & P(i)_{33} \times x(i) - P(i)_{13} & P(i)_{34} \times x(i) - P(i)_{14} \\ P(i)_{31} \times y(i) - P(i)_{21} & P(i)_{32} \times y(i) - P(i)_{22} & P(i)_{33} \times y(i) - P(i)_{23} & P(i)_{34} \times y(i) - P(i)_{24} \\ P(i+1)_{31} \times x(i+1) - P(i+1)_{11} & P(i+1)_{32} \times x(i+1) - P(i+1)_{12} & P(i+1)_{33} \times x(i+1) - P(i+1)_{13} & P(i+1)_{34} \times x(i+1) - P(i+1)_{14} \\ P(i+1)_{31} \times y(i+1) - P(i+1)_{21} & P(i+1)_{32} \times y(i+1) - P(i+1)_{22} & P(i+1)_{33} \times y(i+1) - P(i+1)_{23} & P(i+1)_{34} \times y(i+1) - P(i+1)_{24} \\ & \cdots & & \end{bmatrix}$$

Infrared Tracking System Algorithm

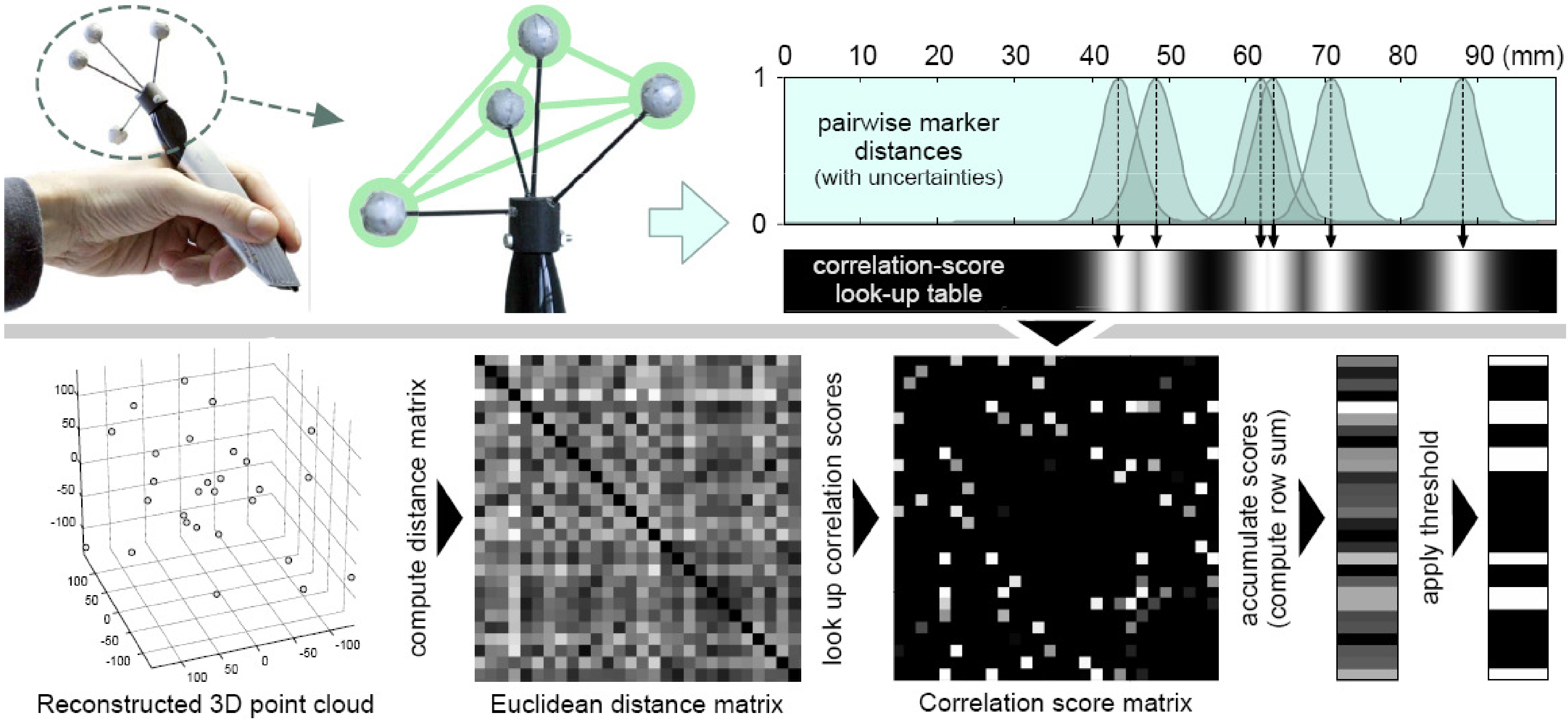
4. 3D Metric Reconstruction via Singular Value Decomposition Triangulation (II)



Infrared Tracking System Algorithm

5. Candidate Evaluation (Pintaric & Kaufmann)

- For each artifact construct a lookup table with pairwise marker distances
- At each frame create an Euclidean distance matrix and a correlation score matrix



Thomas Pintaric, Hannes Kaufmann, “Affordable Infrared-Optical Pose-Tracking for Virtual and Augmented Reality”, in Proceedings of “Trends and Issues in Tracking for Virtual Environments” Workshop, IEEE VR 2007, Charlotte, NC, USA, March 2007

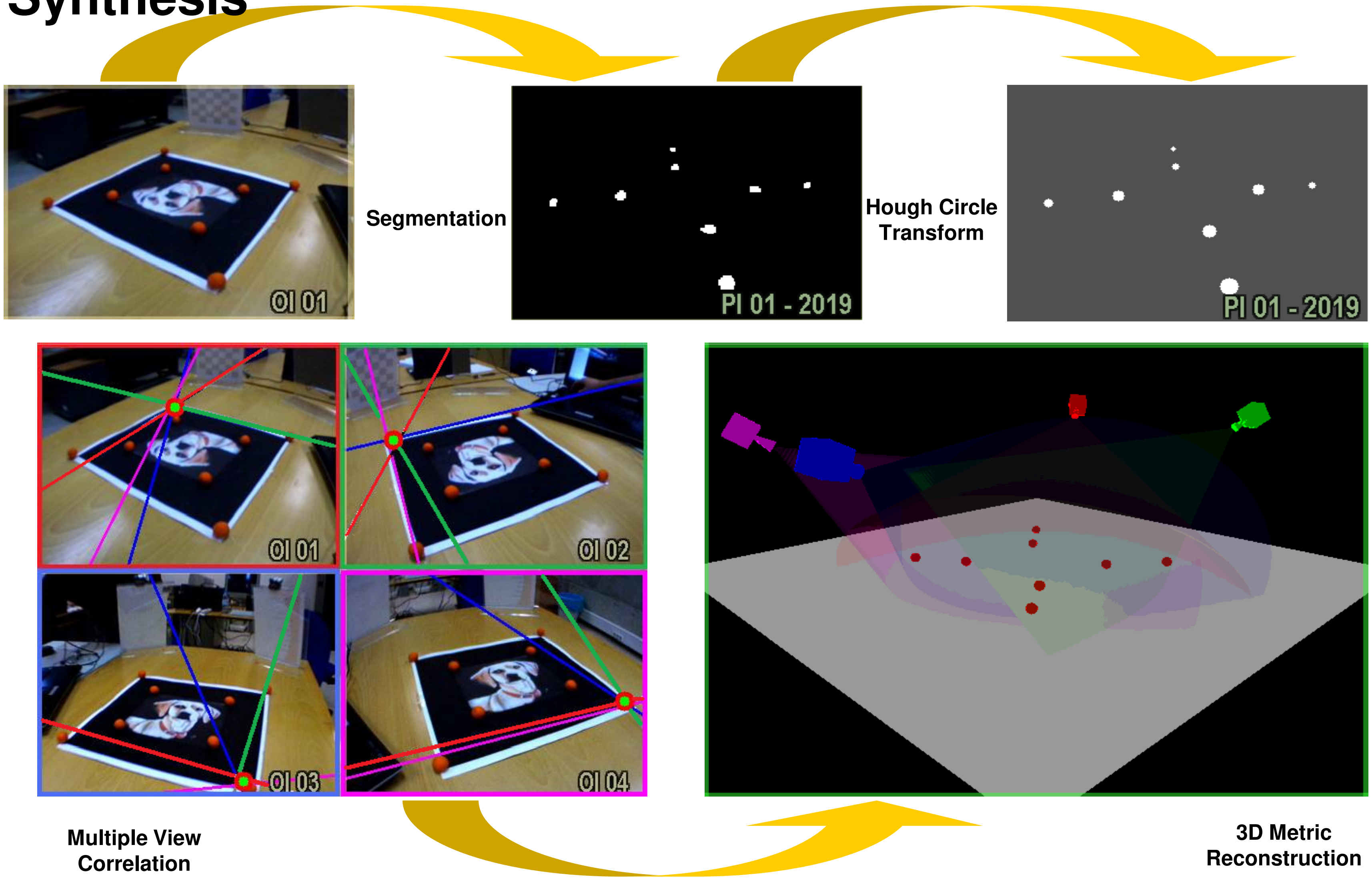
Infrared Tracking System Algorithm

7. Pose Retrieval

- When more than 3 are reconstructed and matched use DLT (Direct Linear Transformation) algorithm
- When only 3 features are reconstructed and matched, use PosIT (Pose from Orthography and Scaling in Iterations) algorithm
- If less then 3 features are reconstructed and matched, the tracking fails!

Infrared Tracking System Algorithm

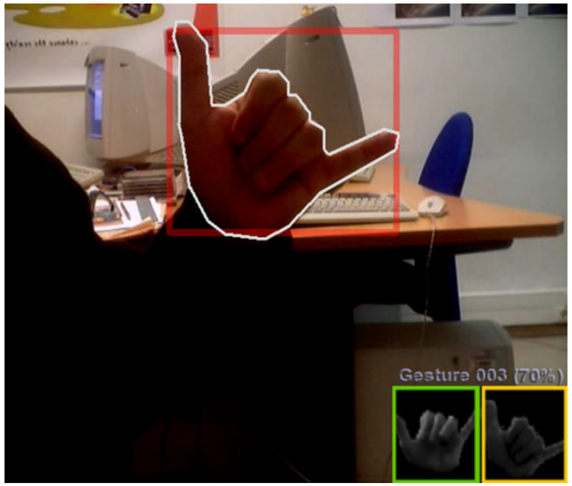
Synthesis



Multimodal Interfaces

Multimodal Interfaces

- Speech
- Tangible Interface:Wiimote & Nunchuk
- Gestures



Multimodal Interfaces

Speech:

- Command & control
- Can be used to start, pause and stop the simulation, control the navigation in VR, and choose gadgets
- Supports Portuguese Language (pt-pt and pt-br), developed by Microsoft Language Development Center, as well English, Spanish, Japanese, etc
- Commands are interpreted using XML format

Multimodal Interfaces

Wiimote:

- 11 buttons
- IR Sensor (at front)
- Rumble (vibration)
- Speaker (4200Hz)
- 3 DOF + 3 Accelerations

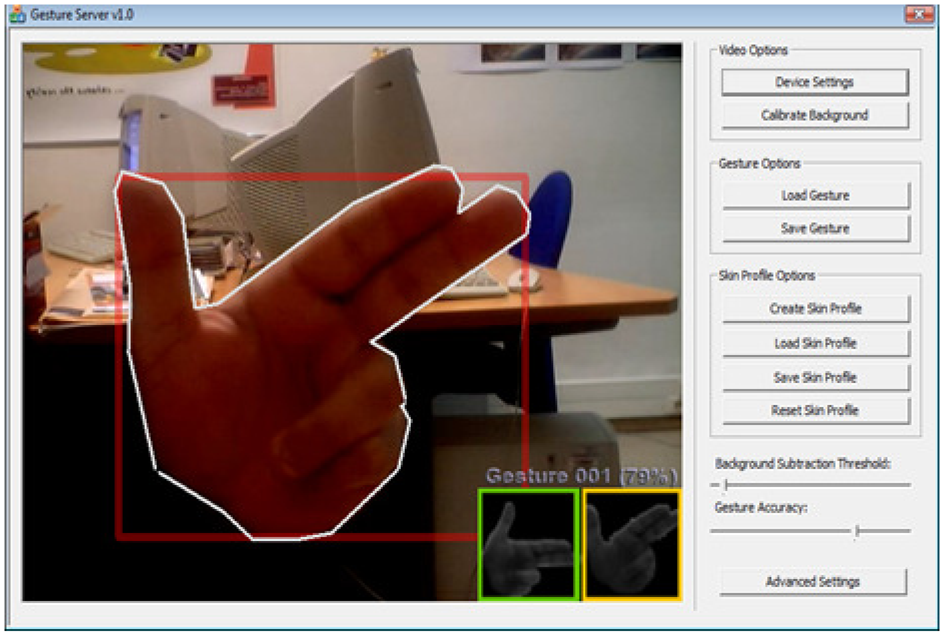
Nunchuk:

- 2 buttons
- Analog Stick
- 3 DOF + 3 Accelerations

Multimodal Interfaces

Gestures:

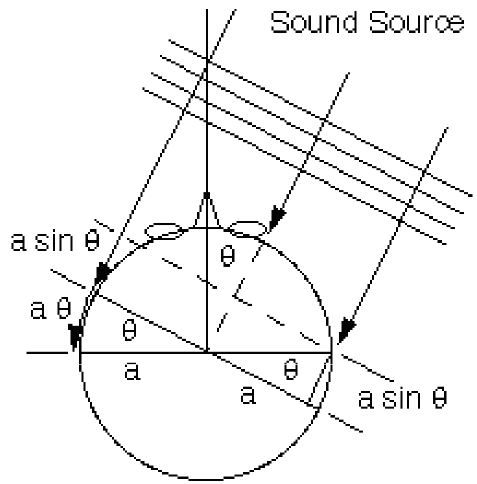
- Can be used to perform simple actions
- Invariant to rotation and scaling
- Based on a networked Gesture Server (client-server)



Audio

Sound Localization Perception:

- Lord Rayleigh's *Duplex Theory*:
  - Inter-aural Time Difference (ITD).
  - Inter-aural Level Distance (ILD).
- Pinna Filtering (Batteau): due to the ear's morphology, a sound arrives to it with different distortions, depending on its position
- Other Clues:
  - Movement of the head
  - Visual confirmation and disambiguation
  - Early echo response and reverberation



Audio

Sound Auralization:

- Auralization is the concern of creating the sensation of spatial sound.
- Adrian Willaert XVIth century's Antiphons.
- *"Basic Principles of Stereophonic Sound"* (William Snow): sound auralization can only be achieved with at least 2 speakers (depending on dimensions of the hall).
- Two major approaches: binaural and fixed set of speakers
- Implementation of such systems must take special care with hall reflections and occlusions

Audio

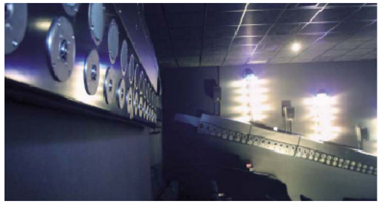
Binaural Techniques:

- Headphones and tracking system.
- 6 Degrees-of-Freedom (DOF) of positioning.
- Low cost.
- Pinna Filtering:
  - Requires previous filtering of sounds to simulate the effects of the pinna.
  - Head Related Transfer Functions (HRTF) represent a transfer function of a filter with the same impulse response than the pinna.
  - Each person has his own HRTF.
- Inapt for collaborative environments.

Audio

Fixed Set of Speakers Techniques:

- More comfortable and, usually, of better quality
- Harder to implement due to reflections and occlusions, and more expensive
- Vector-Based Amplitude Panning (VBAP) Techniques:
  - They use vector algebra for assigning to each speaker a different amplitude for a sound
  - Some posterior corrections were made to this model (Speaker-Placement Correction Amplitude Panning and Multiple Direction Amplitude Panning)
- Wave Field Synthesis:
  - Huygens Principle states that any point of a front of a wave can be represented by secondary wave sources.
  - Large (and expensive) array of speakers.



Audio

Commodity 3D Sound:

- Multichannel technologies:
  - Planar configurations: 7.1 surround sound.
  - Multi-planar configurations: 10.2 (2 planes), 22.2 (3 planes).
- Audio libraries:
  - Allow the 3D positioning of sound sources and the listener.
  - Handle the sound sent to speakers, accordingly to their topology.
  - Free libraries: DirectSound3D and OpenAL (Open Source).
  - Commercial libraries: FMOD Ex Sound System

Audio

Audio Libraries:

- Free libraries (DirectSound3D and OpenAL):
  - Low-level libraries that allow simple operations, such as the positioning of sound sources and listener
  - In virtual environments with many sound sources, the programmer needs to manage the limited PCM buffers of the sound cards
  - Open Source nature of OpenAL makes it the preferred choice for custom sound kernels
- FMOD Ex Sound System:
  - Gaming sound library with geometry processing, for sound reverberation and occlusion effects
  - Spatial organization, sound prioritization and sound mixing for managing hardware resources
  - Internal DSP functionality for sound pre-processing
  - In Windows, it uses DirectSound3D for its final output

Audio

Audio Implementation:

- FMOD Ex Sound System
- Engine for audio simulation and sound source updates
- Sound source as a scene graph node, in order to ease its use in the application
- Map node, for reverberation and occlusion effects
- At each simulation step, the application transverse the scene graph:
  - Each sound source node update its (world) position for that step
  - The engine receives a step command with a listener position, and advances the simulation of the audio library
  - The engine sends new audio state to all nodes for data consistency

Section III: Clusters

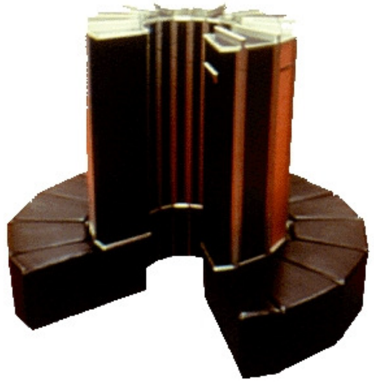
We briefly start with an evolution from the expensive main-frames to cheaper cluster, showing several configurations with the standard commodity hardware. The issues related to clusters like frame-locking, gen-lock and data-lock. We are going to explaining step by step how to configure and set-up a cluster, and several open source solutions to install and run in clusters. Since a cluster can use even specialized and commodity components we are going to present some possibilities and advantages of each one.

Computers architectures

- Mainframes
- Mini-computers
  - Supermini
- Supercomputers

IBM zSeries

HP3000



Cray 1

Supercomputers

- Vector x Scalar Processing
- Shared x Distributed Memory
- Symmetric x Asymmetric Architecture

Vector x Scalar

- Vector Processors:
  - One instruction in several data
    Examples: Cray, NEC

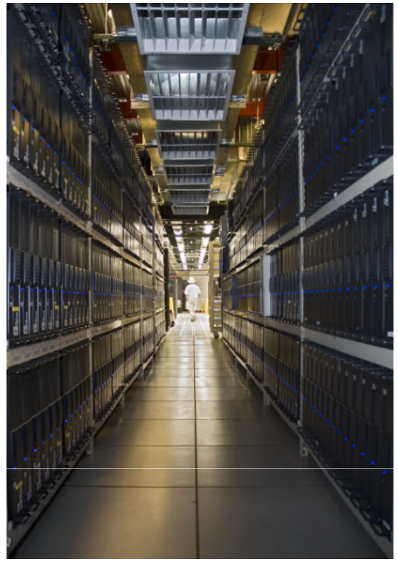
NEC SX-9

- Scalar Processors:
  - Several processors in several data
    Examples: SGI, SUN

SGI Onyx 3000

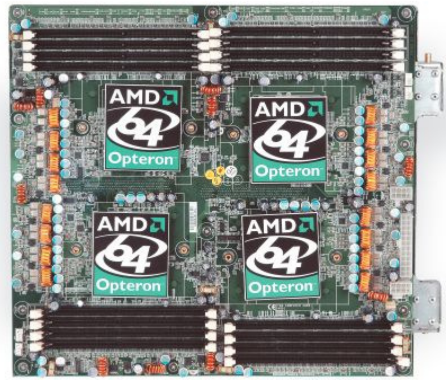
Memory Access

- Distributed Memory
  - Each processor is independent, has its own operational system and memory
  - Examples: basically *Clusters*



Cluster

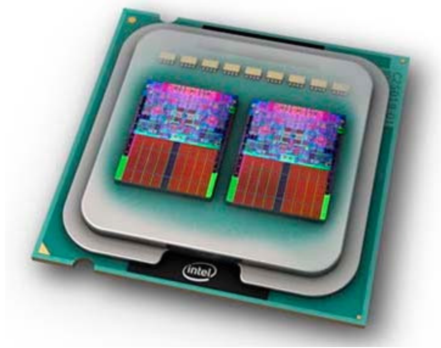
- Shared Memory (SMP)
  - All processors work over the same operational system, all the memory is accessible by any processor
  - Examples: SGI, multicore



8-way Opteron

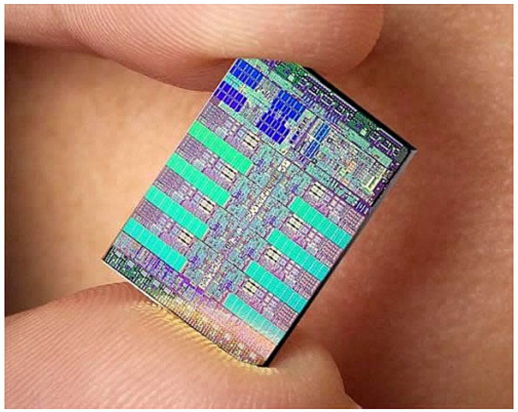
Symmetric x Asymmetric

- Symmetric Multiprocessing
  - Every processor is capable to run the operating system



Intel Core 2 Quad

- Asymmetric Multiprocessing
  - Dedicated processors for different tasks



Cell

Parallelism Taxonomy

- *Single instruction, single data stream* (SISD)
- *Multiple instruction, single data stream* (MISD)
- *Single instruction, multiple data streams* (SIMD)
- *Multiple instruction, multiple data streams* (MIMD)

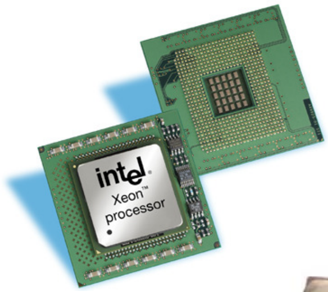
- *Single Program, multiple data streams* (SPMD)

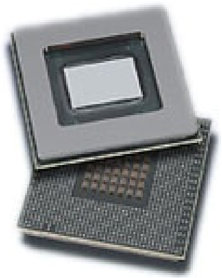
PC Clusters

- Low cost, because they are mainly built of commodity components produced for a mass market;
- Modularity that enables to built a cluster adapted to the user's need regarding components, size or performance;
- Compliance with standards, that favors software and hardware interoperability;
- Upgradeability, since the commodity marked produce new and more powerful devices often;
- Availability of a large range of open source software solutions that enables to customize, if required, a given software layer.

Numerical Processing

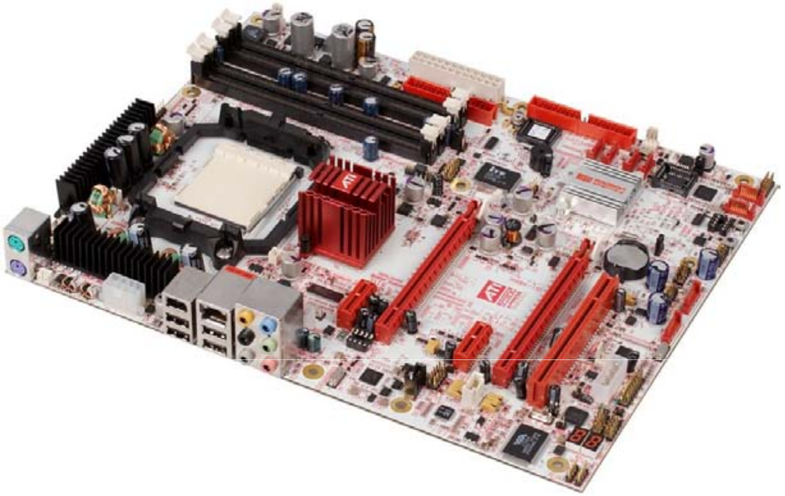
- Intel
- AMD
- PowerPC/Cell
  - Apple-IBM-Motorola
  - IBM-Toshiba-Sony
- MIPS






Chipsets

- ATI Crossfire Xpress and AMD 7-Series
  - Processor:
    AMD64 and Intel
  - *Slots* for graphics:
    up to 3 x16 PCIE slots
    PCI Express 2.0 support



- Nvidia nForce
  - Processor:
    AMD64 and Intel
  - *Slots* for graphics:
    up to 3 x16 PCIE slots
    PCI Express 2.0 support

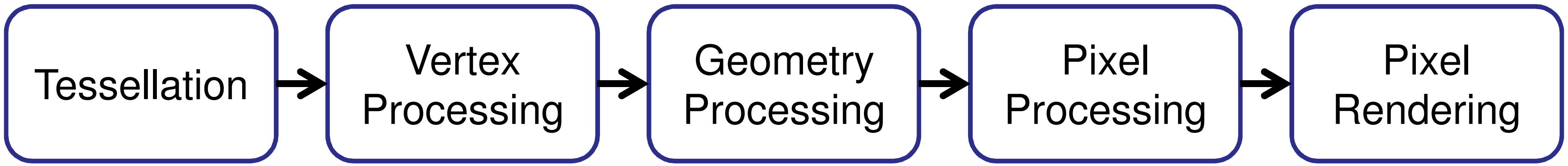
Network connection Communication Latency

Network	Latency
InfiniPath (InfiniBand)	1.31 microseconds
Cray RapidArray	1.63 microseconds
Quadrics	4.89 microseconds
NUMAlink	5.79 microseconds
Myrinet	19.00 microseconds
Gigabit Ethernet	42.23 microseconds
Fast Ethernet	603.15 microseconds

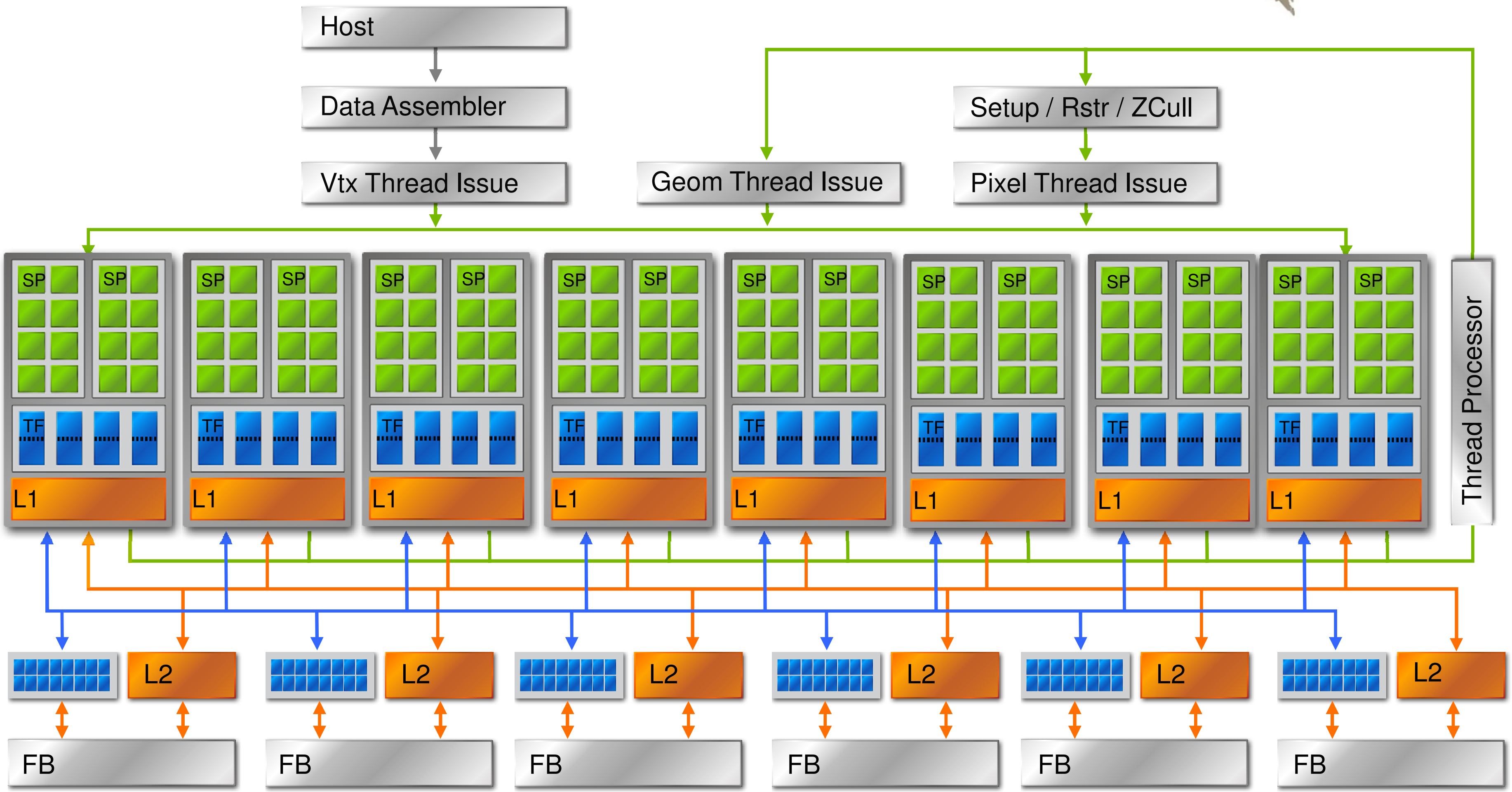
Source: HPC Challenge

Graphic Cards

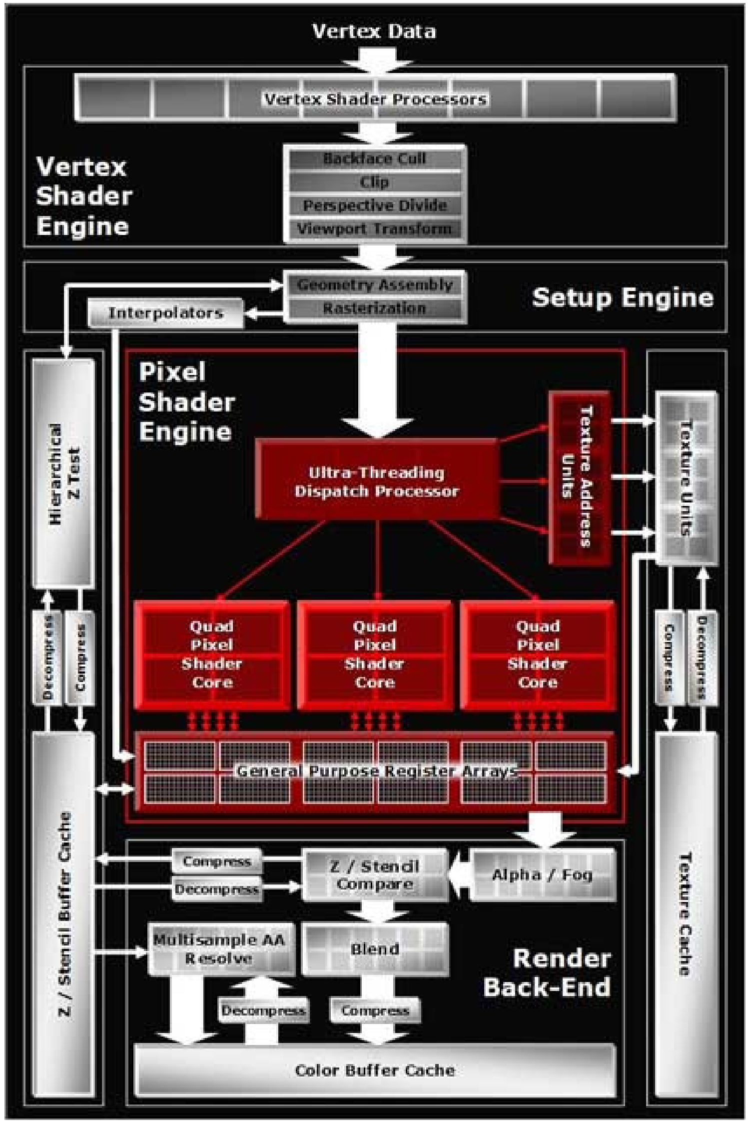
- Implements several graphical *pipelines:*
  - Nvidia (programmable)
  - ATI (programmable)
  - SGI (not programmable)



Nvidia pipeline model

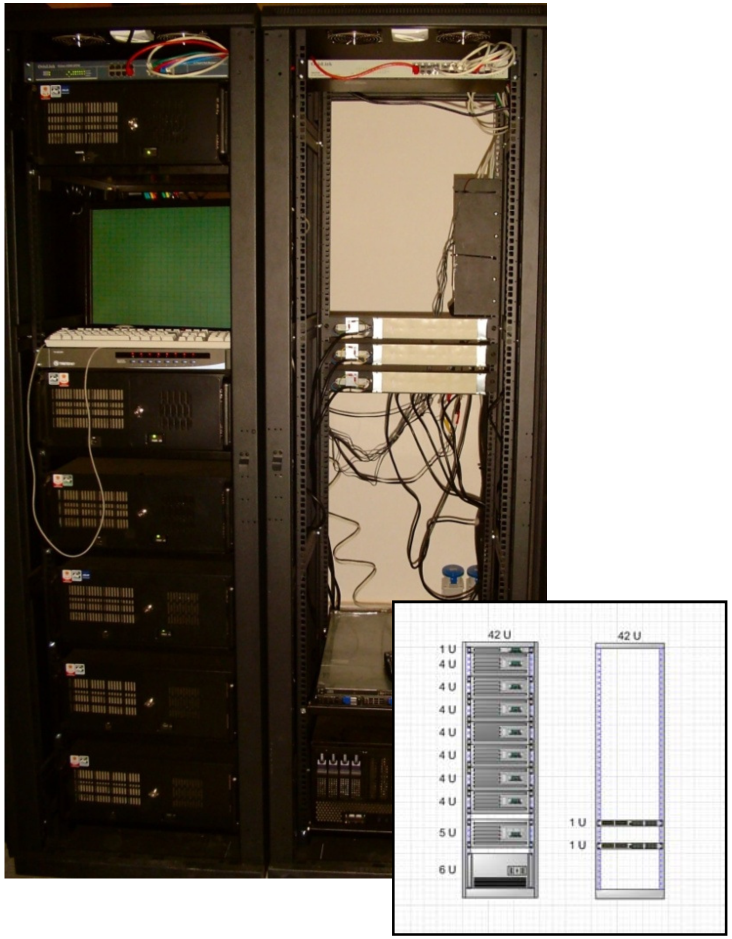


ATI / AMD


Vertex Data
Vertex Shader Processors
Vertex Shader Engine
Backface Cull
Clip
Perspective Divide
Viewport Transform
Geometry Assembly
Rasterization
Interpolators
Setup Engine
Hierarchical Z Test
Pixel Shader Engine
Ultra-Threading Dispatch Processor
Texture Address Units
Texture Units
Decompress
Compress
Quad Pixel Shader Core
Quad Pixel Shader Core
Quad Pixel Shader Core
Compress
Decompress
General Purpose Register Arrays
Z / Stencil Buffer Cache
Compress
Decompress
Z / Stencil Compare
Alpha / Fog
Multisample AA Resolve
Blend
Render Back-End
Decompress
Compress
Color Buffer Cache
Texture Cache

Organization

Rack



Shelf

Graphic Cards Parallelism

- Voodoo(1996)
  - Each board draws half of the entire screen.
- Split Frame Rendering (SFR)
- Alternative Frame Rendering (AFR)
- Anti-aliasing
- ATI supports Supertiling

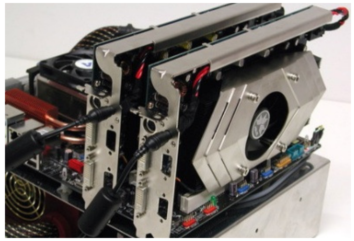
Quantum 3D

Nvidia SLI

ATI CrossFire

High Density Multi GPU

- 2 x NVidia 7800 GT (ASUS)
  - 2 x PCI-Express x32



- 3-way SLI NVIDIA

- NVIDIA Quadro Plex
  - 4 GPUs per Box

- 4-way Crossfire

Graphical Parallelism

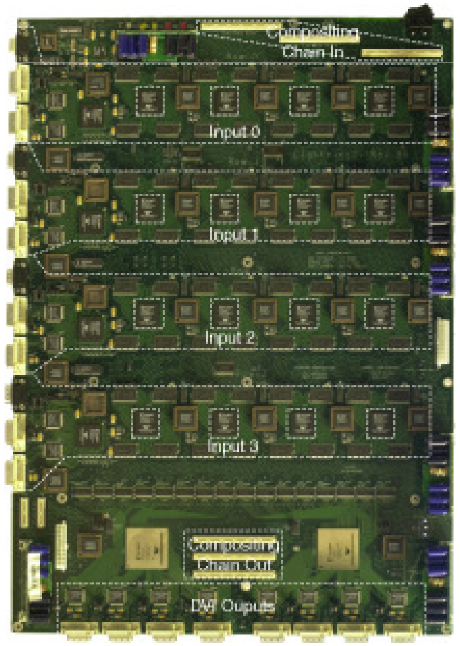
- Graphical parallelism can be achieved by:
  - More modern graphic cards (more *pixel shaders* and *fragment shaders)*
  - Combining graphic cards (SLI ou Crossfire)
  - *Clusters*
  - *Compositing Hardware*

Techniques

- Sample division
- Time division
- Image division
  - Static partitioning
  - Interleaved
  - Dynamic partitioning
- Eye division
- Scene division
- Volume division
- Operational Decomposition

Lightning2 & Sepia

- Two systems for *Sort-last*, they have a dedicated hardware for video compositing from several processing nodes.



Lightning2

Sephia-2

Display Managers

- Cyviz: active stereo to passive stereo and vice-versa

- OpenWARP: *Chroma Key,edge-blending, image-warp*

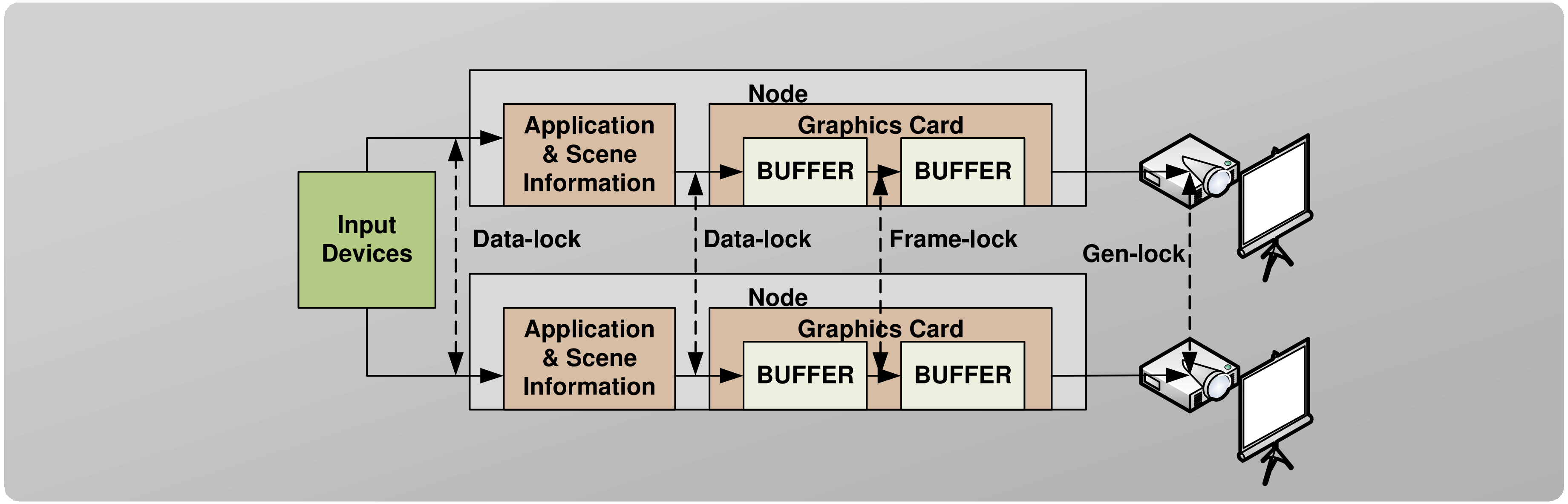
- ORAD DVG: several compositing resources, such as time or space

- XDS-1000: Embedded Windows XP interface, PIP, ultra-high bandwidth

- NetPix: All types of multiple display source, PIP

Synchronization

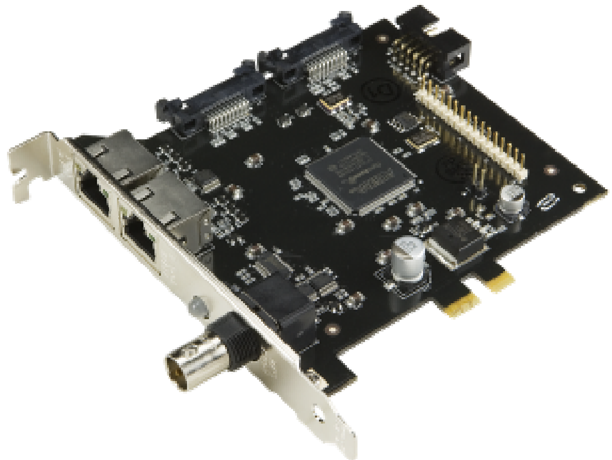
- gen-lock: projector level
- frame-lock (or swap-lock): graphics processor level
- data-lock: application level



Graphical Clusters

- Computers that compute graphics together
- Synchronization is mandatory

SoftGenLock



NVIDIA Quadro G-Sync Board

Physical Symulation

- Very fast physical processor.
- It works quite well in VR scenarios.
  - Collision Detection
  - Particles
- PhysX AGEIA

GPGPU on Clusters

- CUDA (Compute Unified Device Architecture Nvidia)
- CTM (Close To Metal ATI/AMD)

Product	Core/GPU	TFlop/ Device	MSRP/ Device	Max Power	Quantity Required	Power (KW)	TF Total	Cost Total
2S 1U Server	4	0,07	$6.000,00	500	2143	1071	150	$12.857.142,86
Cisco 48 port GigE Switch			$7.000,00		57			$399.000,00
					Total	**1071,4**	**150**	**$13.256.142,86**
					Racks	**57,00**		
x86-64 CPU with Tesla Acceleration								
Product	**Core/GPU**	**TFlop/ Device**	**MSRP/ Device**	**Max Power**	**Quantity Required**	**Power (KW)**	**TF Total**	**Cost Total**
2S 1U Server	4	0,07	$6.000,00	500	114	57	7,98	$684.000,00
Tesla S870	4	1,32	$9.995,00	550	114	62,7	150,48	$1.139.430,00
Cisco 48 port GigE Switch			$7.000,00		6			$42.000,00
					Total	**119,7**	**158,46**	**$ 1.865.430,00**
					Racks	**6,00**		

Cluster Distribution

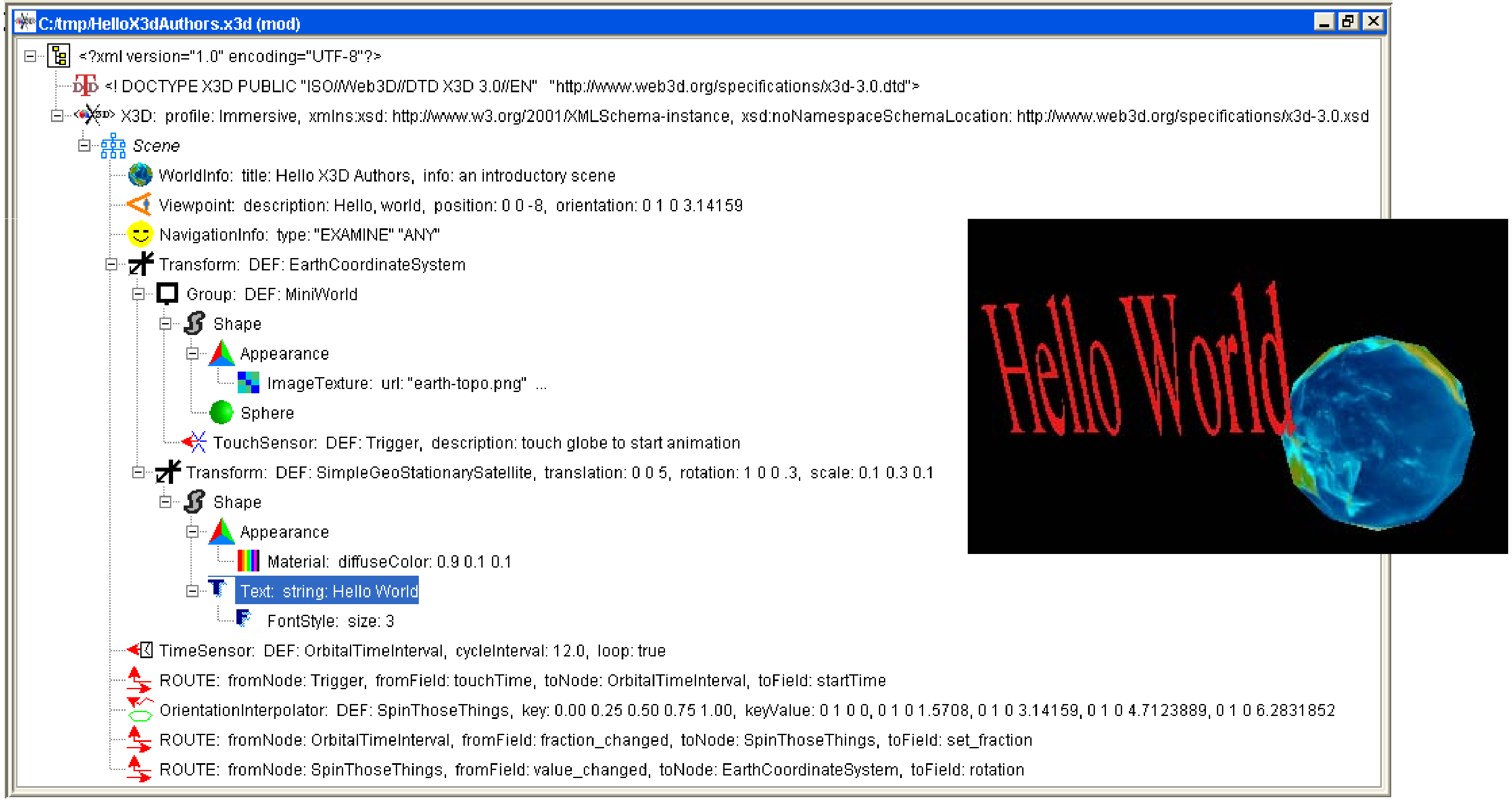
- Linux:
  - OSCAR « open cluster group » initiative (http://oscar.sourceforge.net)
  - NPACI kickstart based solution, (http://rocks.npaci.edu/index.php)
  - Score Myrinet based distribution (http://pdswww.rwcp.or.jp/dist/score/)
  - Ka scalable cloning tool (http://ka-tools.sourceforge.net)
  - Commercial solutions: Scyld (http://www.scyld.com/)
- Windows
  - Remote Installation Service (RIS), Norton Ghost, Ka

Installation

- Gather all information describing the cluster:
  - Names
  - IP addresses (private addresses)
  - Partition layout
- Standard Linux install on one node
- Install the cluster management software on the node

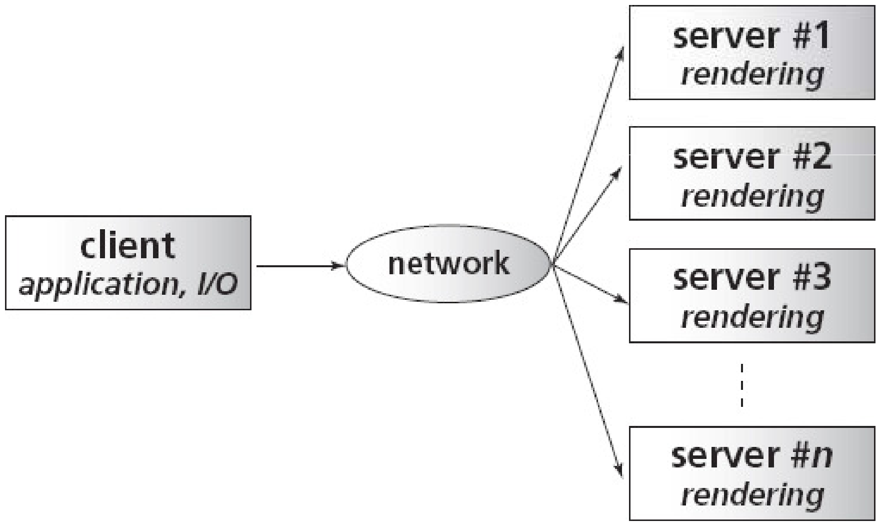
Graphics Data Organization

- Scene Graph X3D Example



Graphics Data Distribution in Multi-Projection Systems

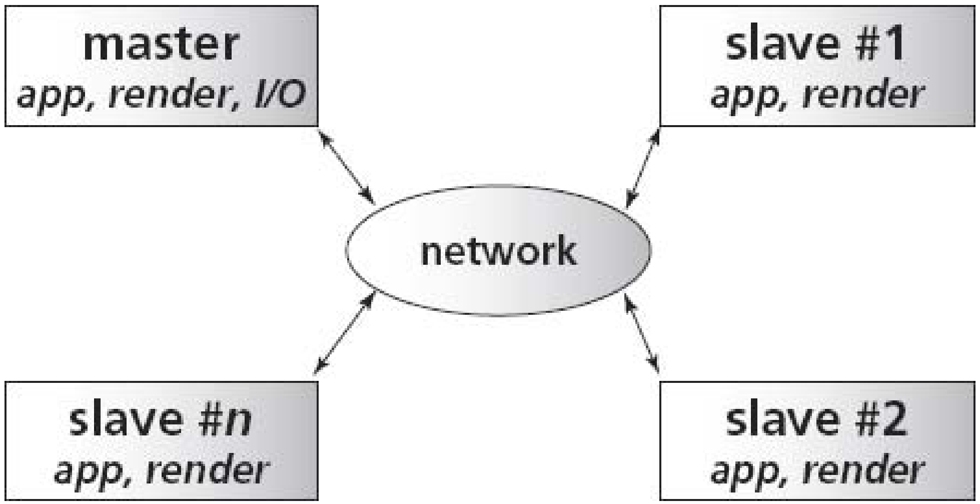
Client-Server (Centralized)



Source: *A Survey and Performance Analysis of Software Platforms for Interactive Cluster Based Multi-Screen Rendering* – Staadt, Walker, Nuber, Hamann

Graphics Data Distribution in Multi-Projection Systems

Master-Slave (Replicated)



Fonte: *A Survey and Performance Analysis of Software Platforms for Interactive Cluster Based Multi-Screen Rendering* – Staadt, Walker, Nuber, Hamann

Graphics Visualization in Multi-Projection Systems

It's a sorting problem:

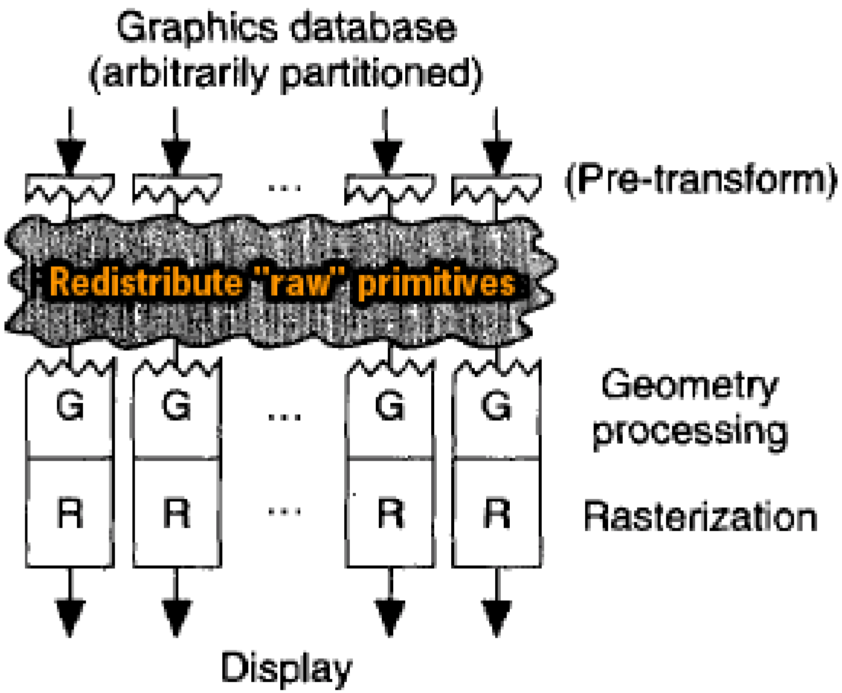
Sort-First
Sort-Middle
Sort-Last

Sources:

1. *Cinerealismo em Arquitecturas Paralelas de Uso Geral* - João Pereira
2. *A Sorting Classification of Parallel Rendering* - Molnar, Cox, Elisworth e Fuchs
3. *Sort-First Parallel Rendering with a Cluster of PCs* - Samanta, Funkhouser, Li e Singh

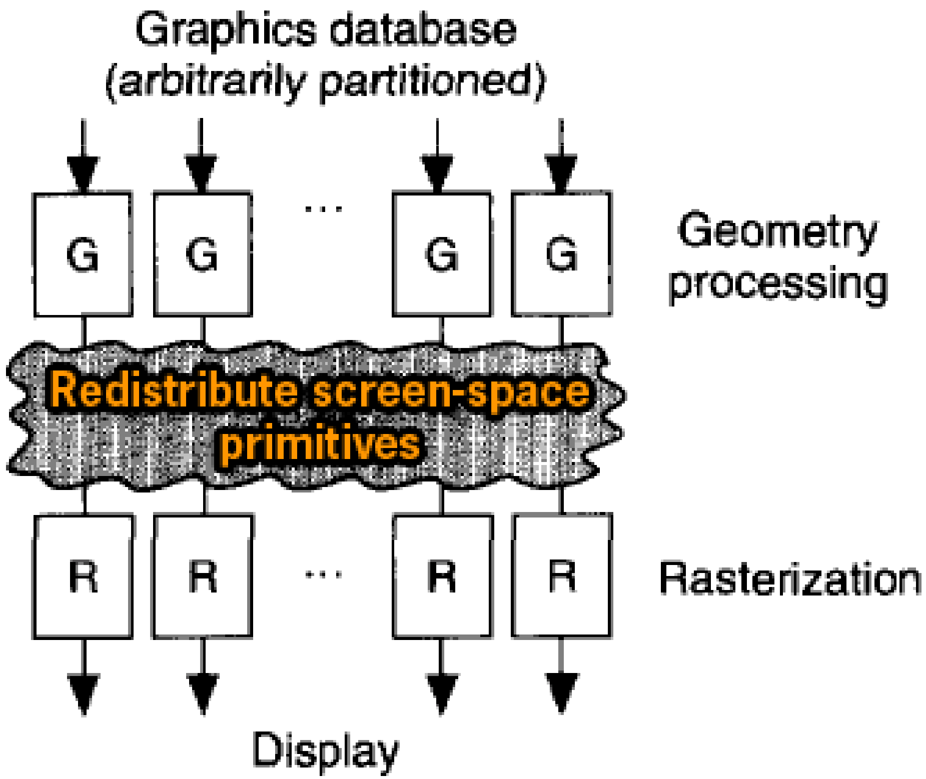
Sort-First

- The visualization area is divided in rectangles
- Graphics primitives are randomly distributed through cluster nodes, which find whose view volumes they intersect
- Graphics primitives are redistributed for the nodes dedicated to those view volumes



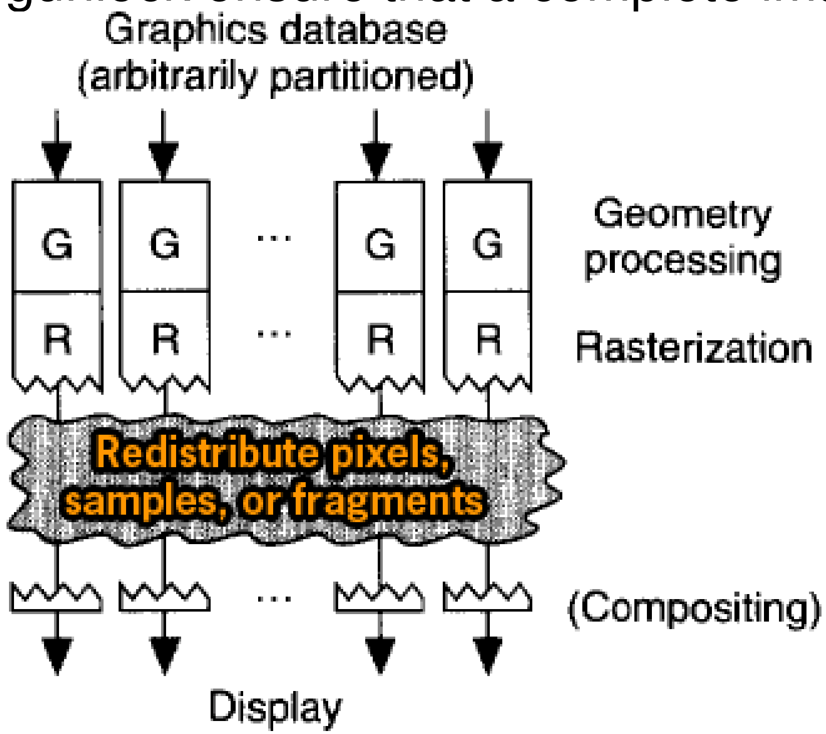
Sort-Middle

- Graphics primitives are randomly distributed through cluster nodes, that perform 3D pipeline transformation
- Projected geometry is redistributed for rasterization



Sort-Last

- Graphics primitives are randomly distributed through cluster nodes, that perform 3D pipeline transformation and rasterization
- Image fragments (R, G, B, A, Z) are sent to the dedicated nodes to update their frame buffers
- Frame lock and gunlock ensure that a complete image is composed

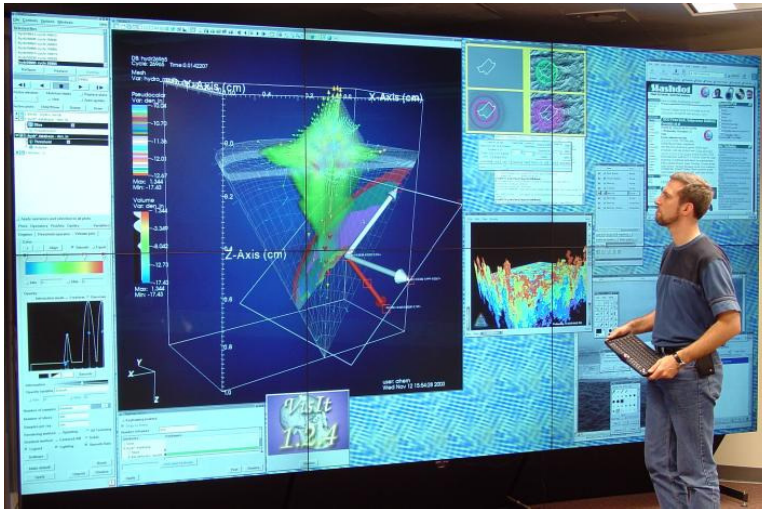


Available Open Source VR Software for Graphics Data Organization, Distribution and Visualization

- Options:
  - Chromium (WireGL)
  - Syzygy
  - OpenSG
  - Ogre3D
  - Inventor
  - Performer
  - OpenSceneGraph
  - VRJugler
  - Avango
  - Diverse
  - FlowVR
  - OpenGL Multipipe
  - OpenMask

Chromium (WireGL)

- University of Stanford
- Sort-first and sort-last for visualization
- Client-Server distribution
- Multi-platform
- C, C++
- Supports OpenGL only
- BSD license



Source

1. *A Survey and Performance Analysis of Software Platforms for Interactive Cluster Based Multi-Screen Rendering* – Staadt, Walker, Nuber, Hamann
2. *Plataformas de Suporte para Visualização Interactiva no Sistema Display Wall do Tagus* - Sérgio Cabrita, Dora Esteves

http://chromium.sourceforge.net/

Syzygy

- University of Illinois
- Scene Graph: Myriad
- Client-Server or Master-Slave distribution
- Audio and device support
- C++ or Phyton
- Multi-platform
- Illinois Open Source License

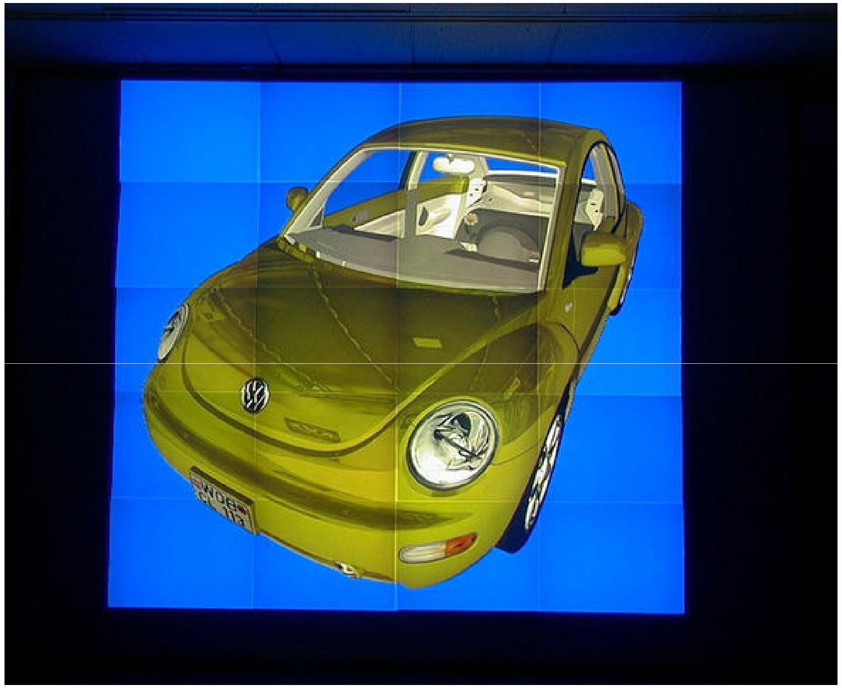
Source

1. *A Survey and Performance Analysis of Software Platforms for Interactive Cluster Based Multi-Screen Rendering* – Staadt, Walker, Nuber, Hamann
2. *Syzygy: Native PC Cluster VR* - Schaeffer, Goudeseune

http://www.isl.uiuc.edu/syzygy.htm

OpenSG

- German Institution (IGD)
- Own Scene Graph
- Client-Server distribution
- Sort-first and sort-last for cluster visualization
- C++
- Multi-platform
- LGPL License



http://opensg.vrsource.org/

1. *A Survey and Performance Analysis of Software Platforms for Interactive Cluster Based Multi-Screen Rendering* – Staadt, Walker, Nuber, Hamann
2. *A Multi-thread Safe Foundation for Scene Graphs and its Extension to Clusters* - Voß, Behr, Reiners e Roth

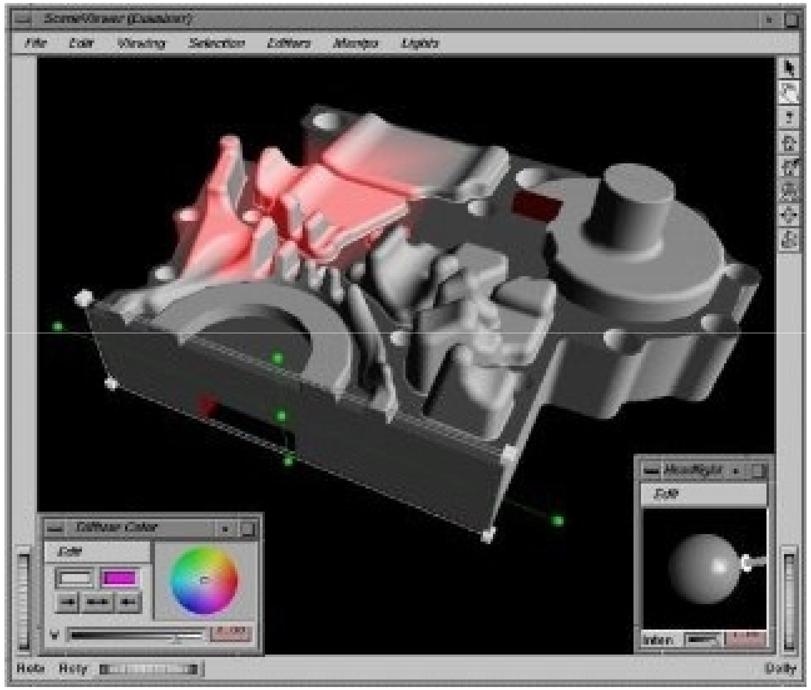
Ogre3D

- OGRE (Object-Oriented Graphics Rendering Engine)
- International Community
- Own Scene Graph
- Highly optimized for applications utilizing hardware-accelerated 3D graphics, such as gaming
- No support for cluster visualization
- C++
- Multi-platform
- LGPL License

http://www.ogre3d.org/

Open Inventor

- Open Inventor is a C++ object oriented retained mode 3D graphics API designed by SGI to provide a higher layer of programming for OpenGL
- Its in the origin of VRML 1.0 and VRML 2.0 (and ISO VRML 97)



http://www.tgs.com/

OpenGL Performer

- OpenGL Performer™ is a powerful and comprehensive programming interface for developers creating real-time visual simulation and other professional performance-oriented 3D graphics applications

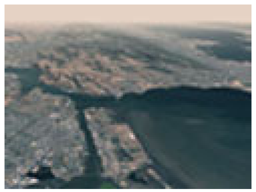
http://www.sgi.com/products/software/performer/

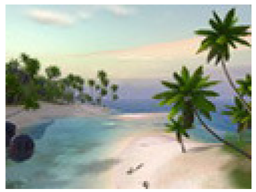
OpenSceneGraph

- Influenced by Performer
- International Community
- Own Scene Graph
- Highly optimized for large model simulation, terrain visualization, games, virtual reality, scientific visualization
- Supports a large set of 3D file formats
- Incipient support for cluster visualization
- C++, Python, Java
- Oriented to Master-Slave distribution
- Multi-platform
- LGPL License

http://www.openscenegraph.org/







A Survey and Performance Analysis of Software Platforms for Interactive Cluster Based Multi-Screen Rendering – Staadt, Walker, Nuber, Hamann

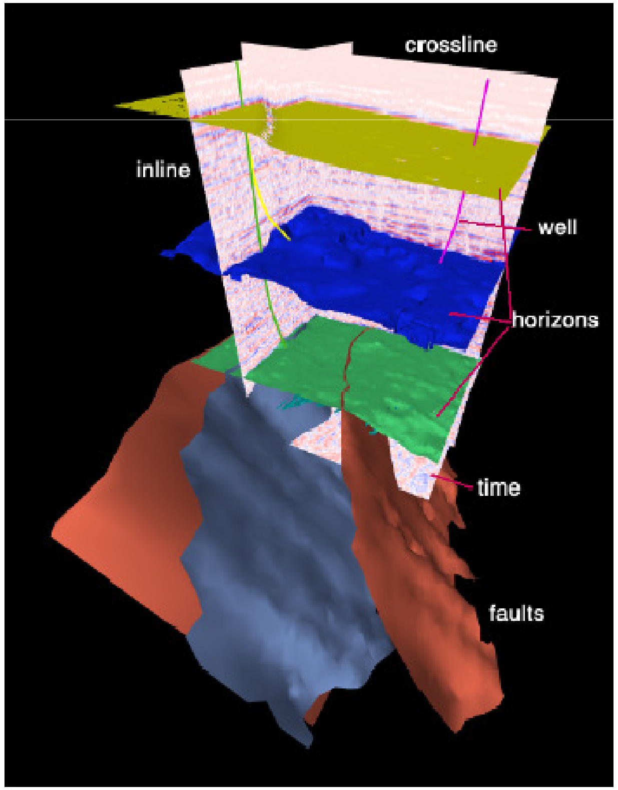
VRJuggler

- Middleware for VR application development
- Supports different projection geometries
- Master-Slave architecture and distribution
- Scene Graph: OpenSG or OpenSceneGraph
- 3D Audio
- Input distribution and synchronization (buggy behaviour) with Net Juggler and Cluster Juggler
- C++, Python, Java
- Multi-platform
- LGPL license

www.**vrjuggler**.org

Avango

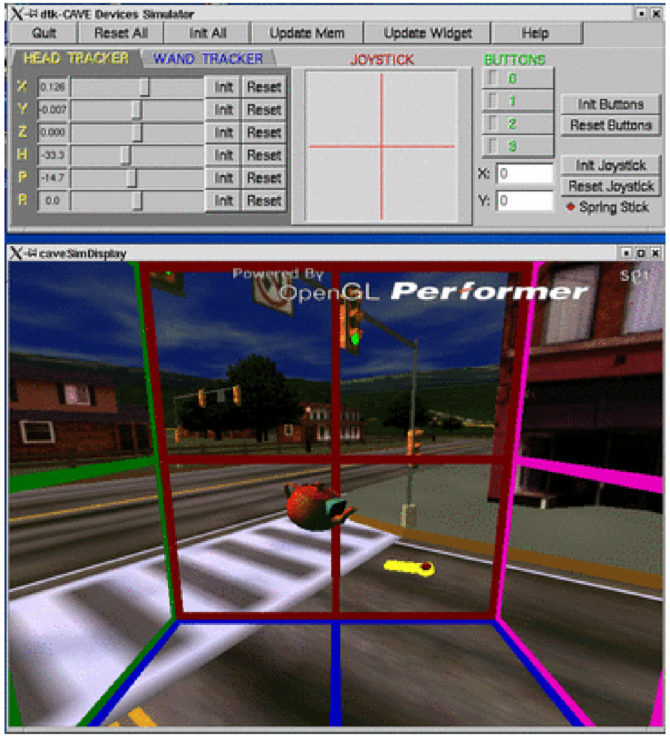
- Based in a shared scene graph
- Supports different projection geometries
- Supports distributed data flows
- Supports data replication
- Based in OpenGL Performer



http://www.avango.org/

Diverse

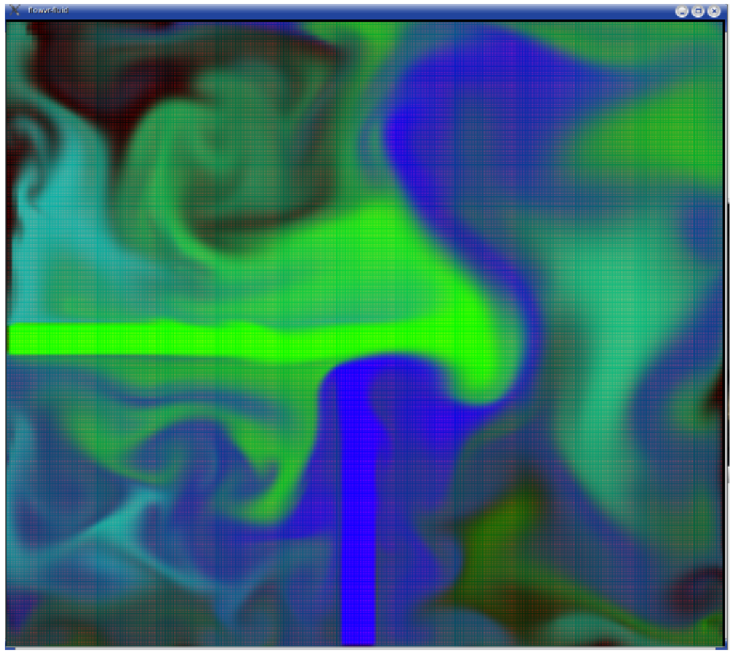
- Middleware for device independent VR application development
- Supports different projection geometries
- Supports data replication
- Based in OpenGL Performer



http://diverse-vr.org/

FlowVR

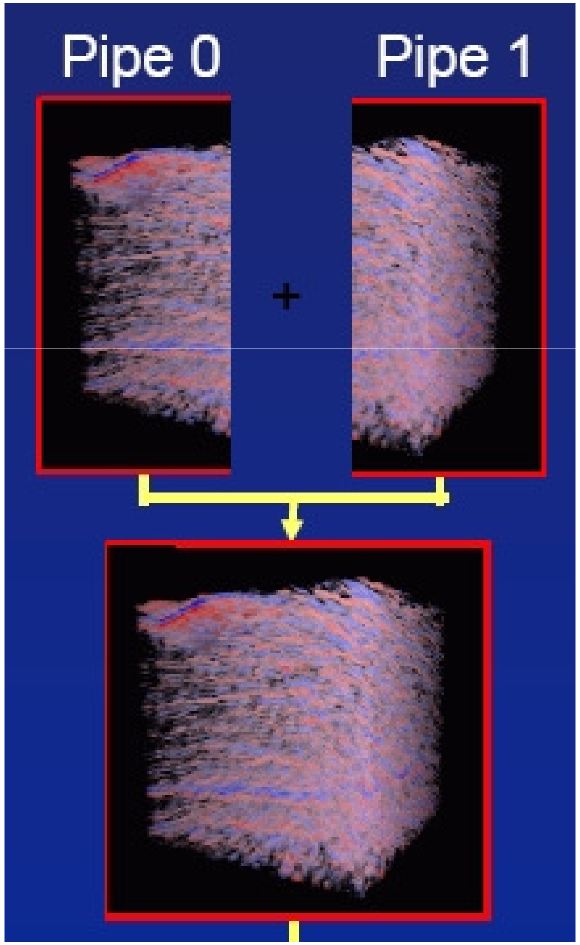
- Middleware for VR application development, based in data flows and modules which communicate
- *Daemons* handle the data transfer between modules
- Easy integration in high performance computing clusters
- Supports data replication



http://flowvr.sourceforge.net/

OpenGL Multipipe

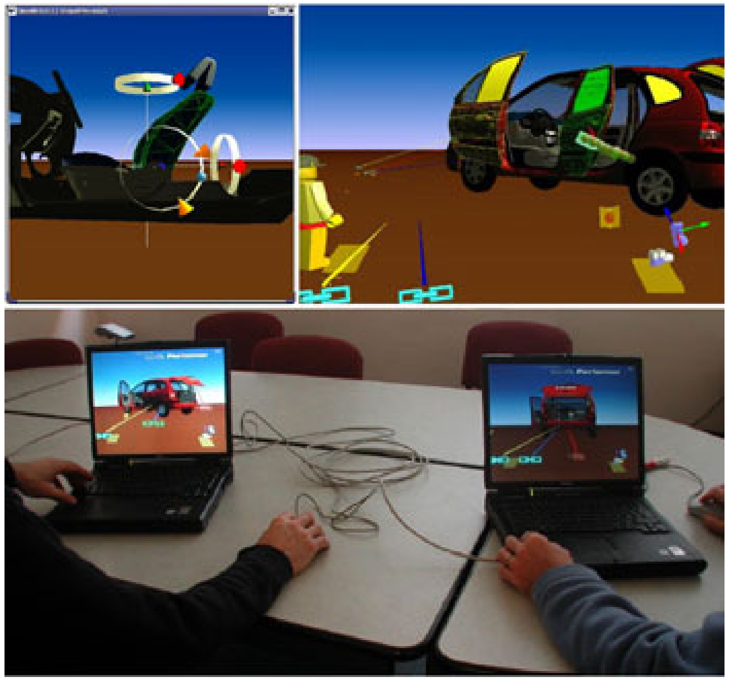
- OpenGL API with resources for the real-time compositing of images in multi-projection systems
- Client-server distribution
- Sort-first and Sort-last for cluster visualization
- Automatically detects the best way to parallelize the graphical resources
- Supports different operating systems



http://www.sgi.com/products/software/multipipe

OpenMask

- API for application development, which are distributed and multi-threaded
- Includes resources for simulation and animation
- Parallel rendering provided by an external system (OpenSG)



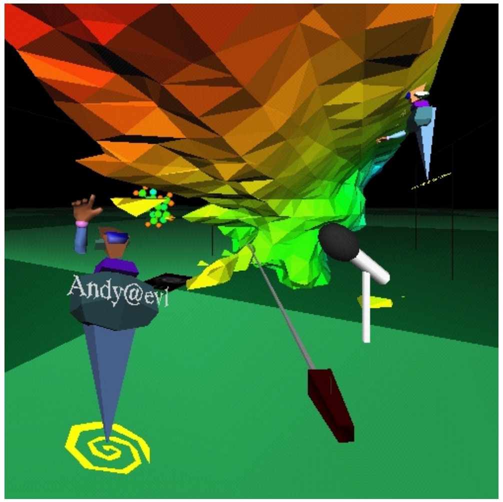
http://www.openmask.org

Comercial Tools

- CAVELib
- IC:IDO
- DeltaGen
- VGP
- Avalon
- Basho
- Covise

CaveLib

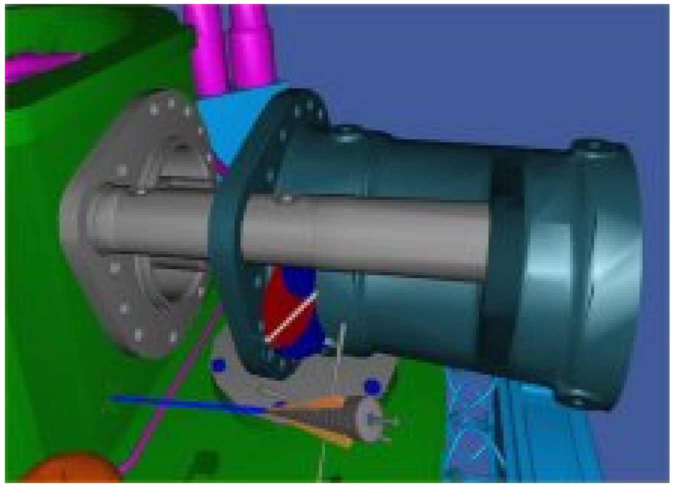
- Developed at EVL (Electronic Visualization Lab) for the first CAVE
- Originally for SGI computer clusters
- Several examples available
- Data replication



http://www.vrco.com/CAVELib

IC:IDO

- Intuitive Interface coupling with CAD tools (Catia, Unigraphics, Autocad, Pro/ENGINEER, Solid Designer, Intergraph e Nemetschek)
- Optimizations for Massive models



http://www.icido.de

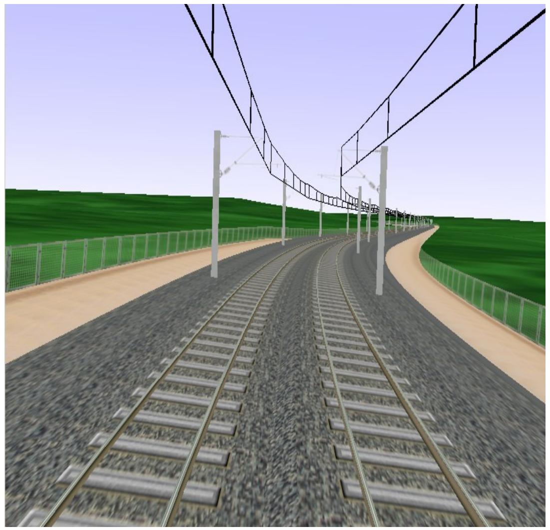
DeltaGen

- Intuitive Interface and interaction with CAD (WIRE, Catia, Parasolid, Pro/E, IGES, JT, STEP, VDA)
- Optimized for visual effects:
  - reflections
  - textures
- RTT Powerwall for clusters

http://www.realtime-technology.de/

Avalon

- API to develop application in X3D/VRML
- Extensions X3D/VRML
- OpenSG
- 3D Sound



http://www.zgdv.de/avalon/

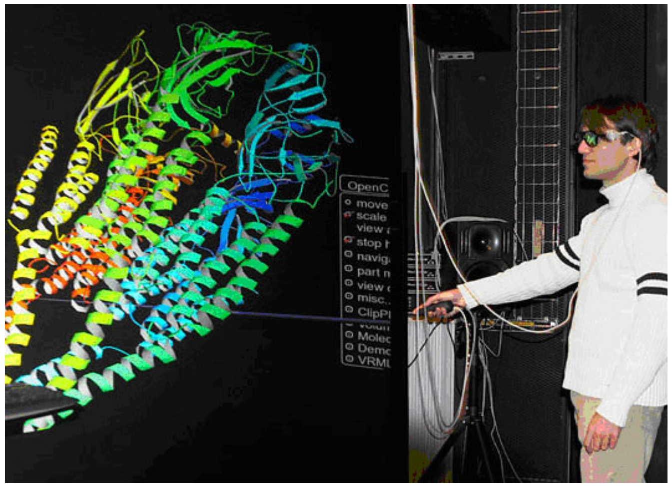
Basho

- Retained mode
- AVANGO e Performer
- Several rendering techniques
- Image Compositing in cascade
  (2 by 2 nodes)

http://cg.inf.fh-brs.de/basho.php

Covise

- Data-flow model distributed in cluster
- Colaborative solution
- Volume rendering
- Fast sphere rendering



http://www.hlrs.de/organization/vis/covise/

Multigen Paradigm

- Extends the Multigen Vega library, a visual simulation toolkit
- Master/slave
- Default configuration is to transmit input events. But this can be disabled to accept data from a simulation host.
- Uses TCP and UDP (via the ACE framework)

Real Time Rendering

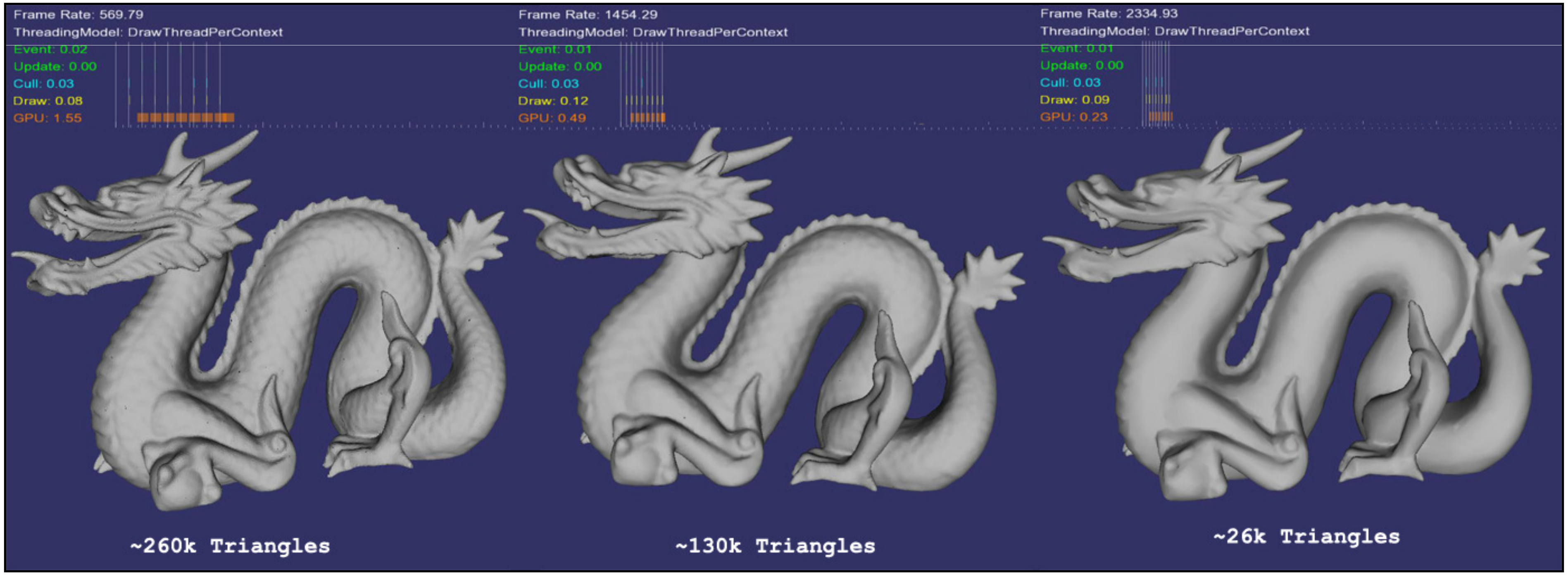
Real-Time Rendering

Problem: How to process a complex model allowing real-time image rendering?

- Visualization Acceleration:
  - Per object Level of Detail - LOD
  - Per object Octree spatial organization
  - Two alternatives:
    - BSP (Binary-Space-Partitioning) of entire scene
    - Octree (Space-Partitioning) of entire scene
  - View Frustum Culling
- Real Time Image Synthesis and Visual Special Effects (out of the scope of this tutorial)
  - Global and Local Lighting Models
  - Per pixel Phong Shading Model
  - Fragment and Vertex Shaders
  - Special Visual Effects: motion blur, bump mapping, shadows, etc

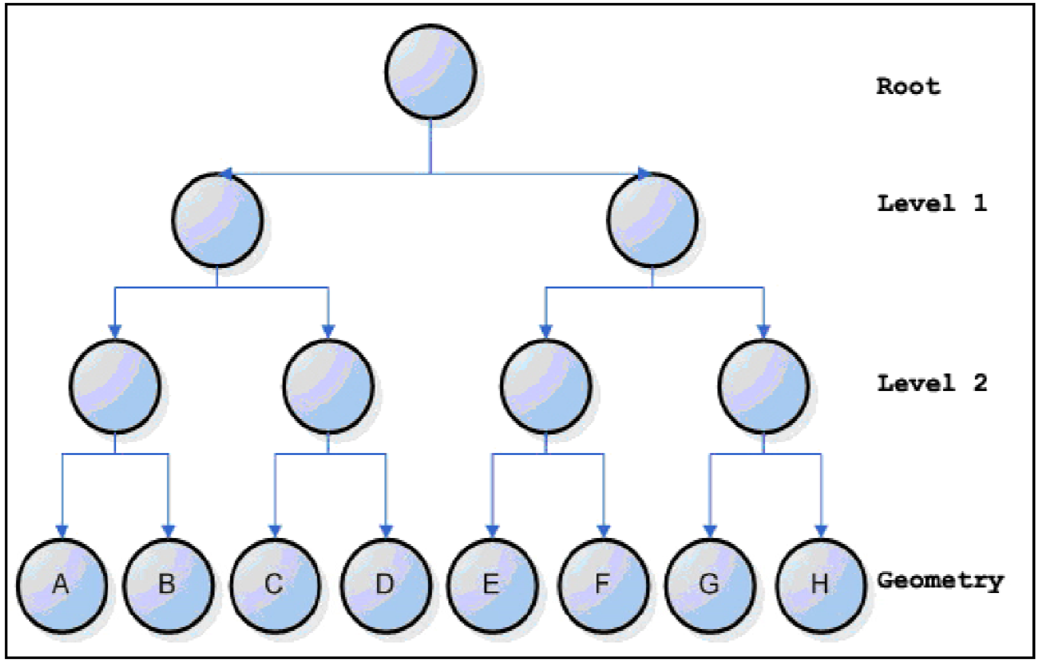
LOD - Level of Detail

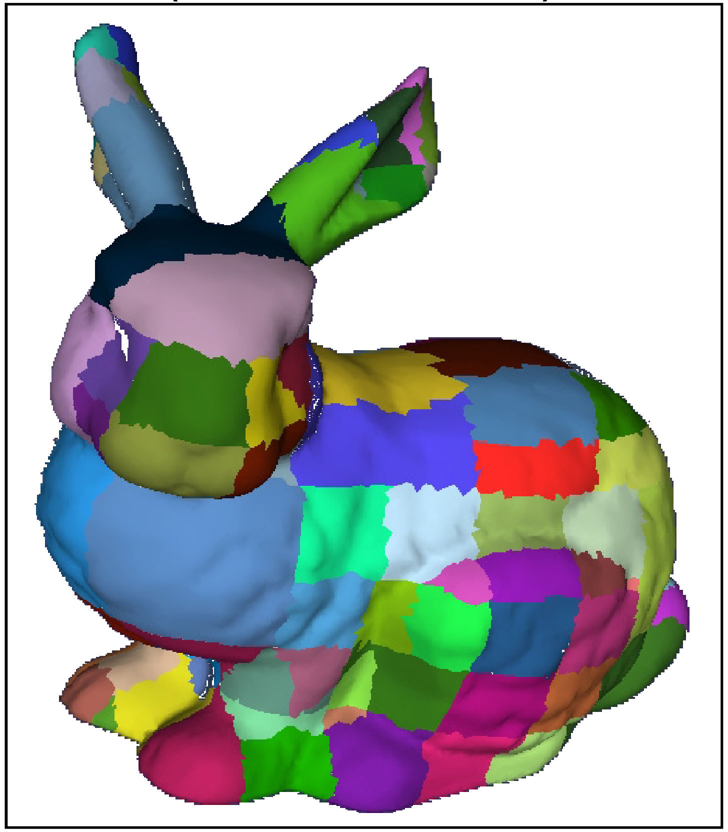
LOD: Uses simplified object replicas, which are chosen taking into account the camera's distance to the object



Octree & Culling

- An Octree partitions a 3D space by recursively subdividing it into eight octants
- Allows efficient removal of the geometry blocks which are outside of the visualization pyramid (view frustum) at culling stage

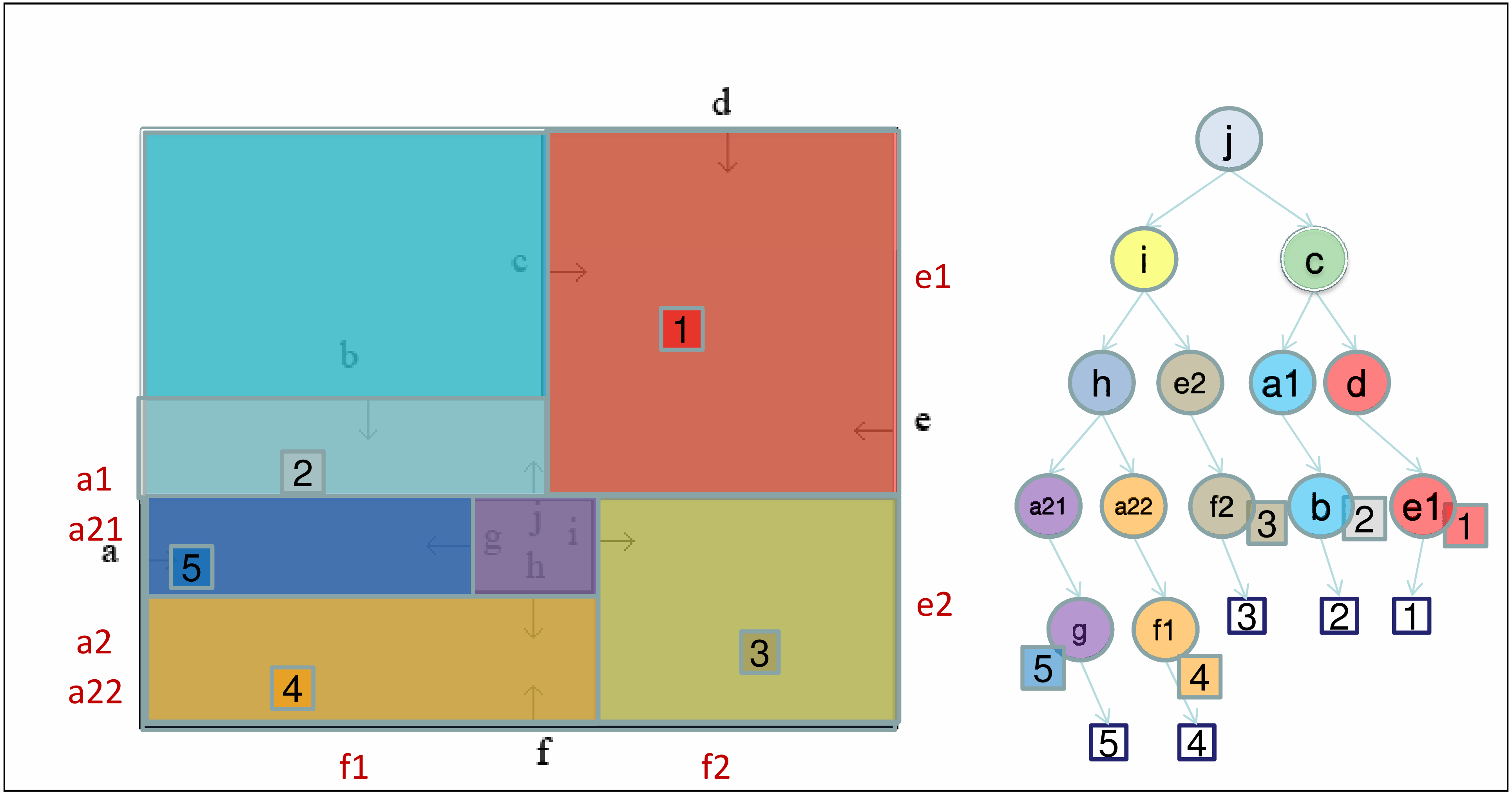




BSP (Binary-Space-Partitioning)

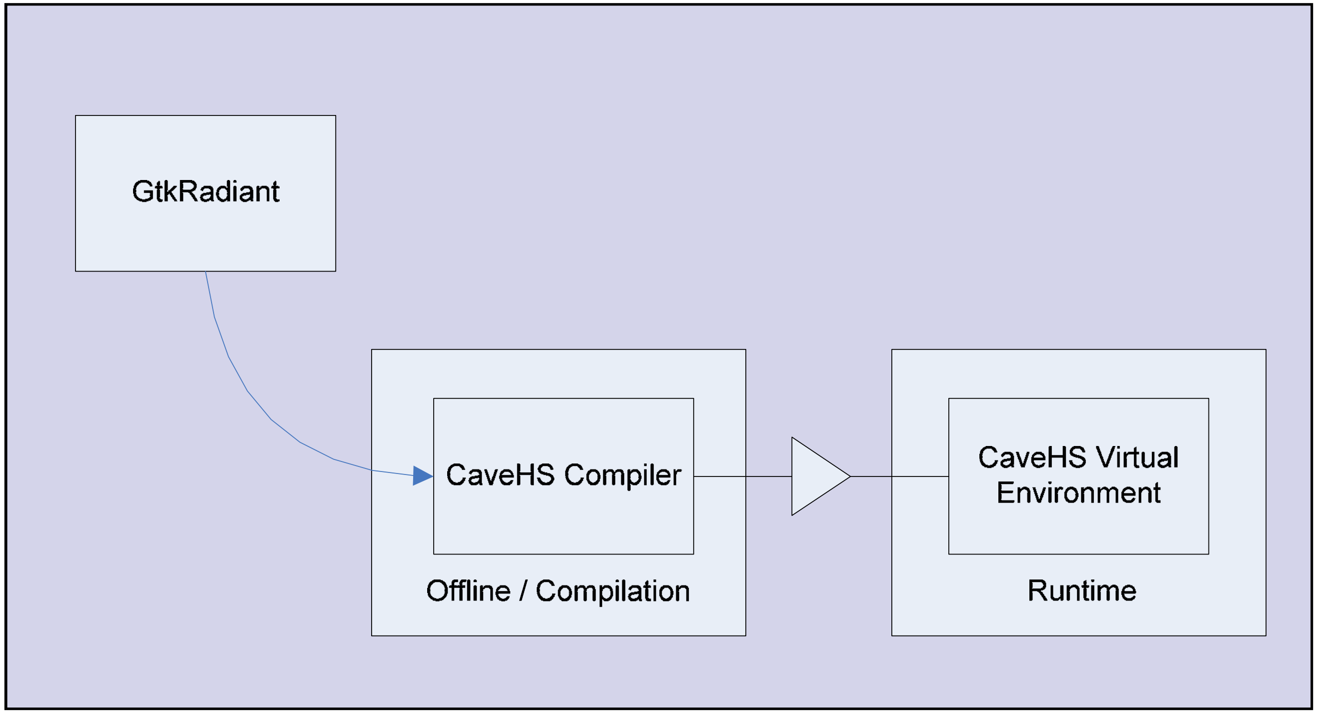
Organises space with the aid of planes

Very efficient for closed environments



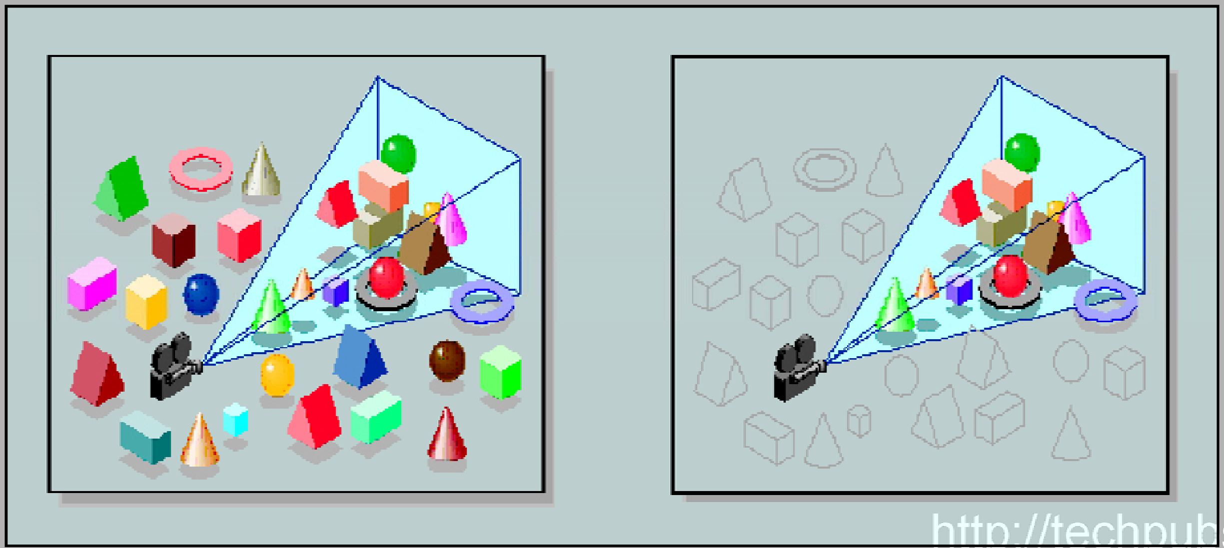
Scene Graph Organization and 3D Rendering

- **Goal**: create a data structure (BSP or Octree) for fast scene rendering
- This data structure must be generated from arbitrary complex geometry (millions of polygons)



View Frustum Culling

- Removes objects outside view volume
  - Two alternatives:
    - Entire-scene Octree traverse stage culls geometry blocks by the view volume, or
    - BSP traverse stage culls geometry blocks based on the split plane scheme
      - The resultant geometry set is then culled by the view volume
  - Complex models optimized with the LOD-Octree technique, allow culling of large geometry blocks within early frustum cull tests



http://techpubs.sgi.com/

Section IV: Cases

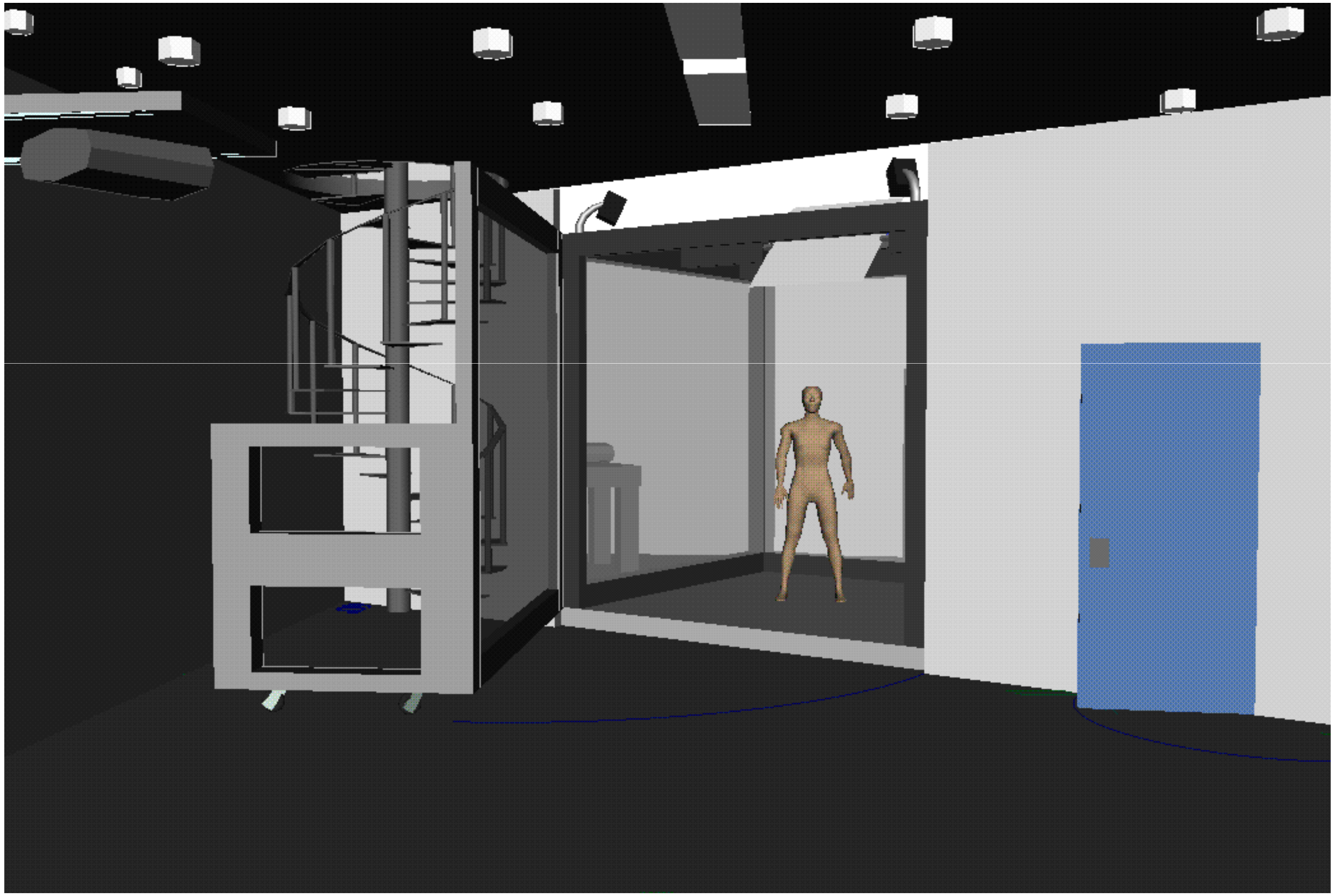
At the end, we are going to explore some environments implemented by the authors, explaining the decisions that were taken, the good and bad points, the obsolescence, and how users can interact.

- Caverna Digital at University of São Paulo, Brazil
- Beckman Cube / ALICE at UIUC, USA
- Grimage at INRIA, France
- (CENPES and Others) at Petrobras, Brazil
- Leme at Instituto Superior Técnico, Portugal
- Lousal at Instituto Superior de Ciências do Trabalho e da Empresa, Portugal

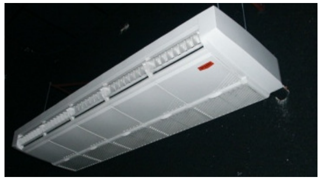
Caverna Digital at University of São Paulo, Brazil

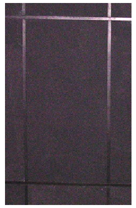
- 5 sided CAVE
- Projectors: 5 CRTs (active stereo)
- Tracking: Eltromagnetic
- Installed: 2001

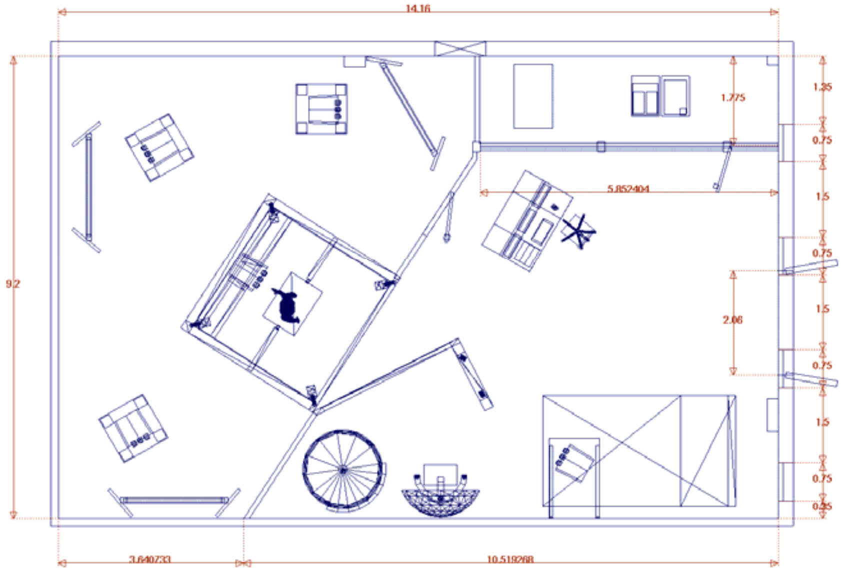
CAVERNA Digital
Virtual Model

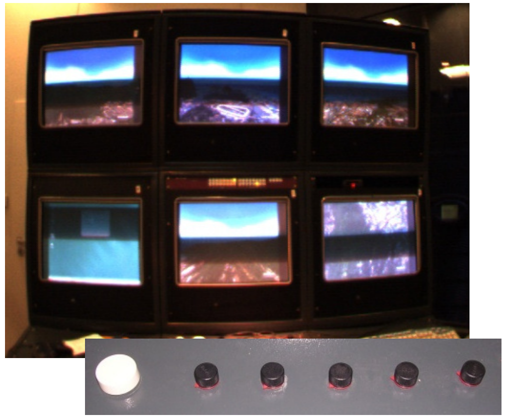


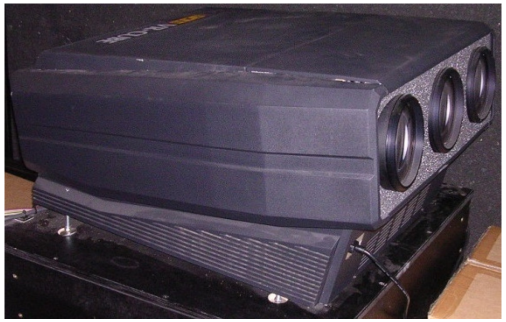
CAVERNA Digital Physical Project

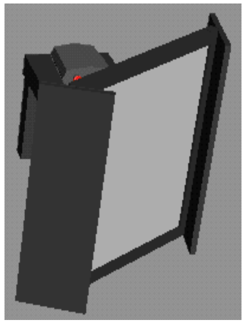












Aplicações

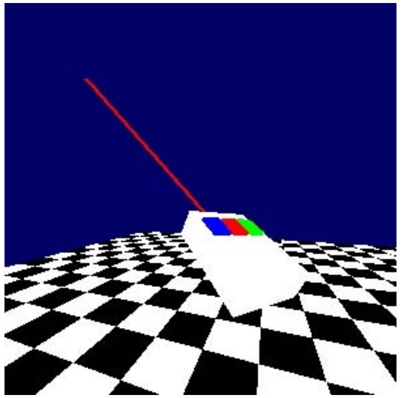
Evolution

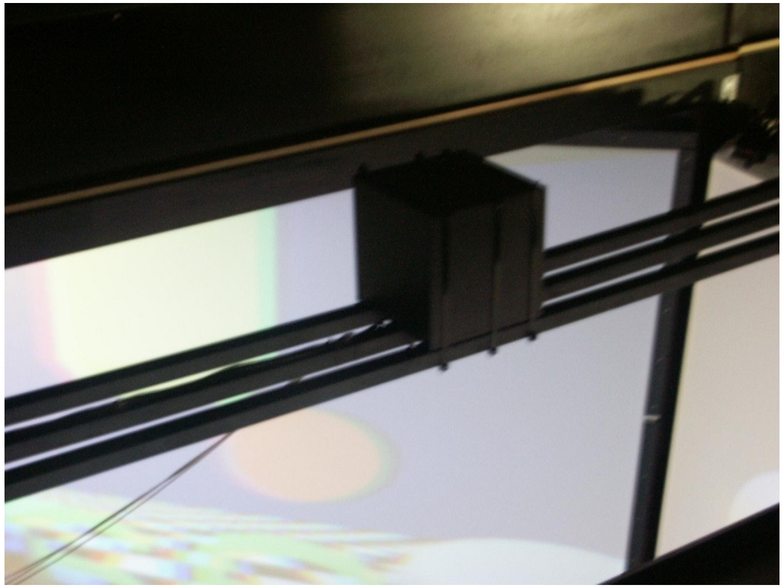
JINX

- X3D Browser
- Clusters
  - Commodity PC (Linux)
  - SGI (Irix)
- Based in MPI and Pthreads
  - Also supports Sockets
- Internaly uses XML
  - For configuration file
  - Transfer data from devices

Tracking in Caverna Digital

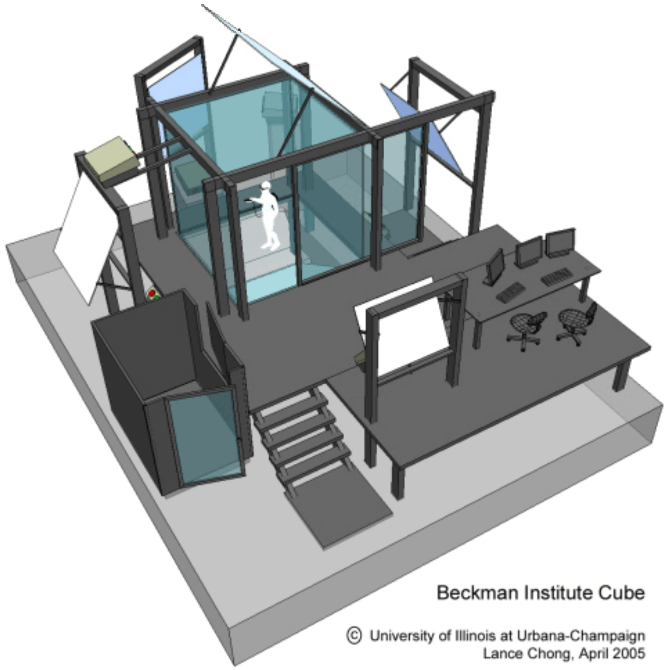
- Electro Magnetic
  - Emiter in the ceeling
  - Around 3m coverage
  - Device with butons



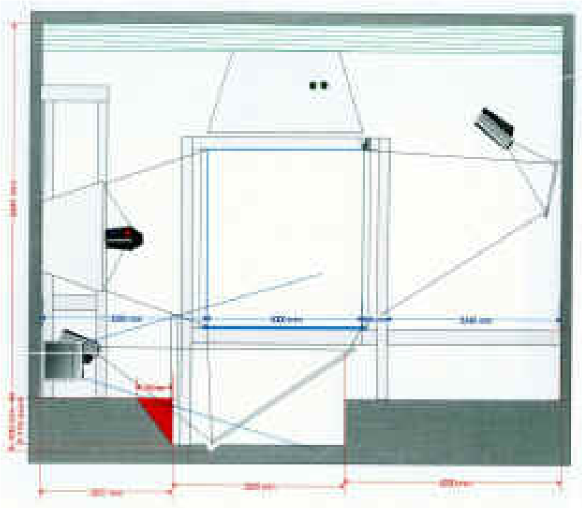


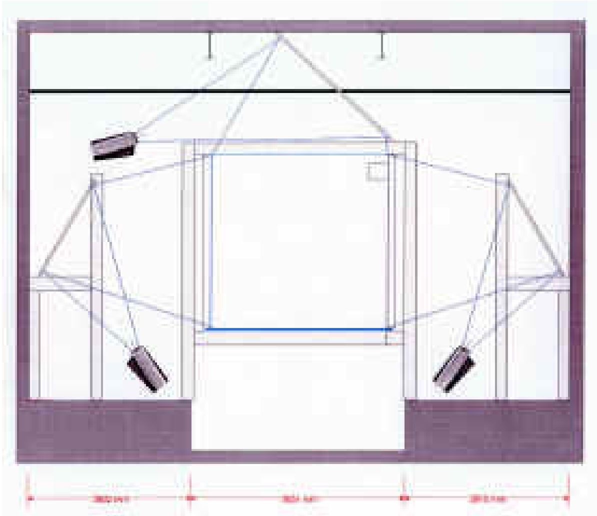
Beckman Cube / ALICE
Integrated Systems Laboratory/UIUC,USA

- 6 sided CAVE
- Projectors: 6 CRTs (active stereo)
- Tracking: Eltromagnetic wireless
- Installed: 2001



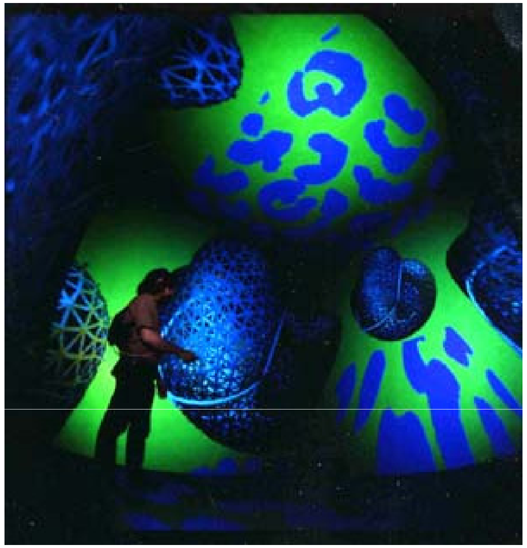
Beckman Cube

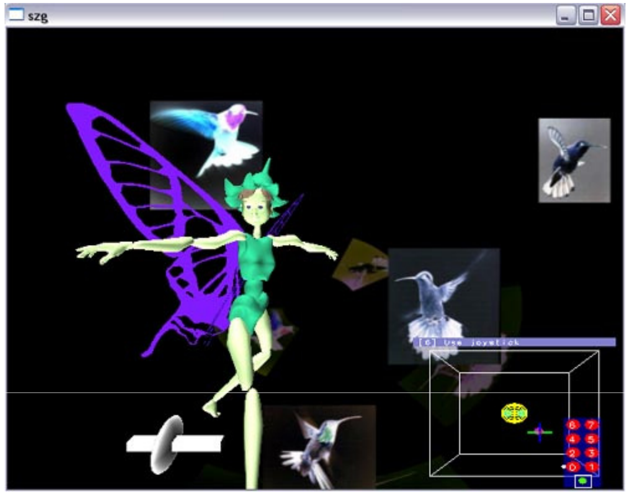


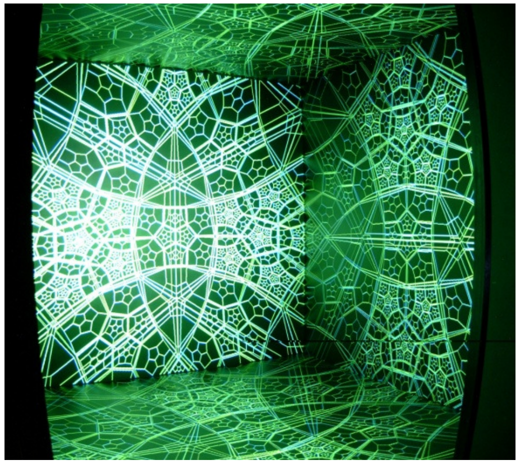


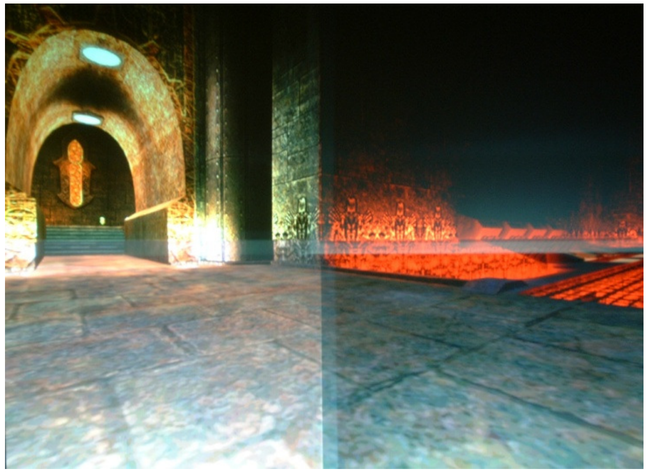
Beckman Cube

Syzygy



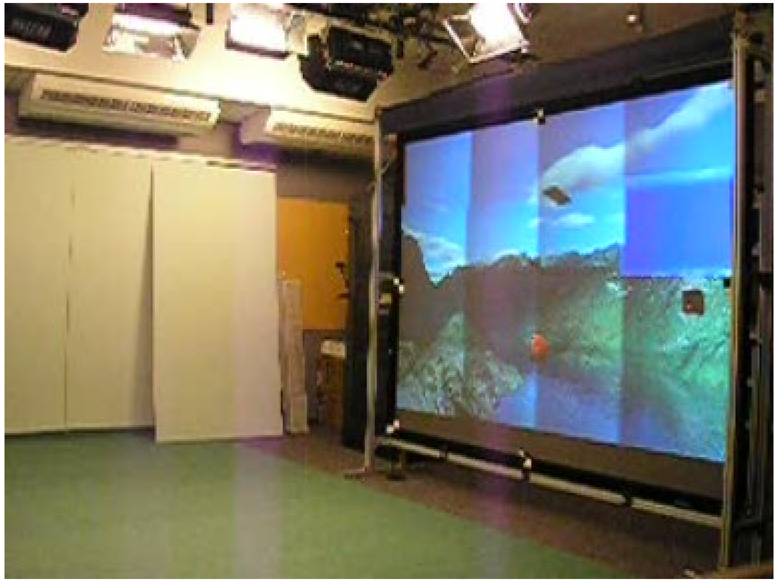






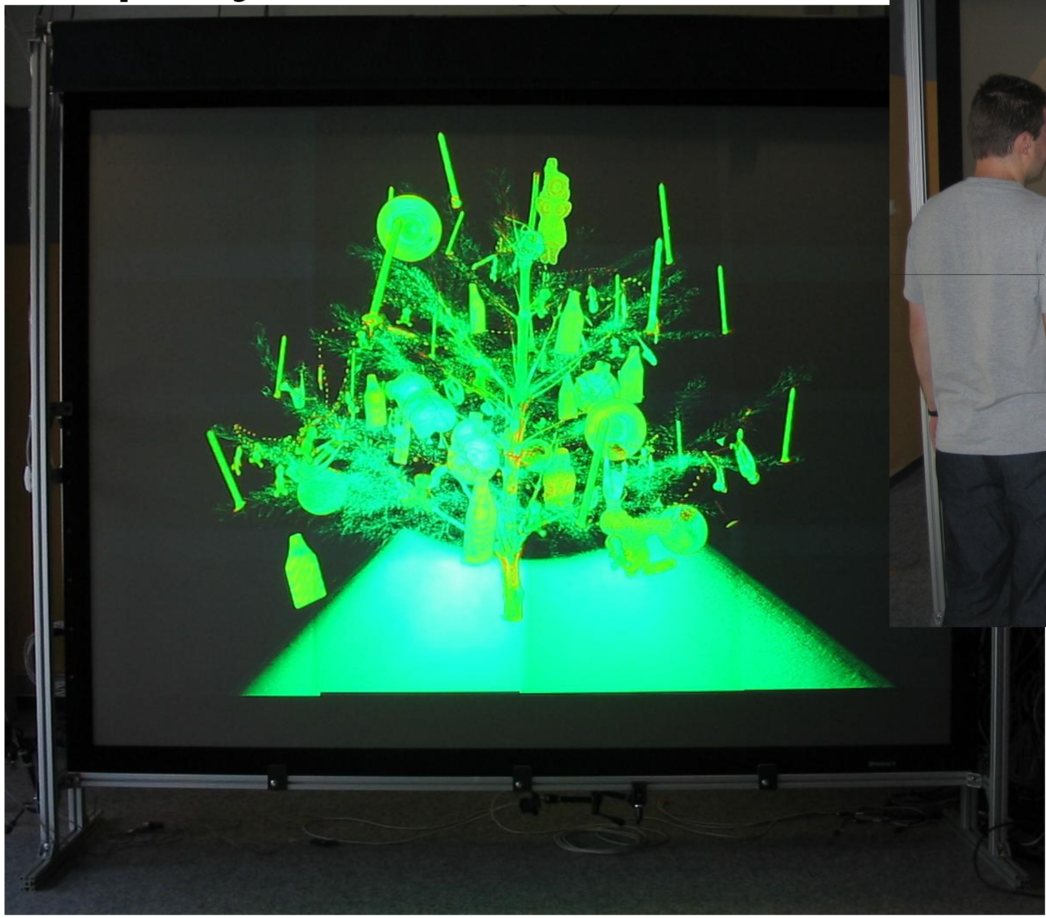
Grimage / INRIA
Grenoble - France

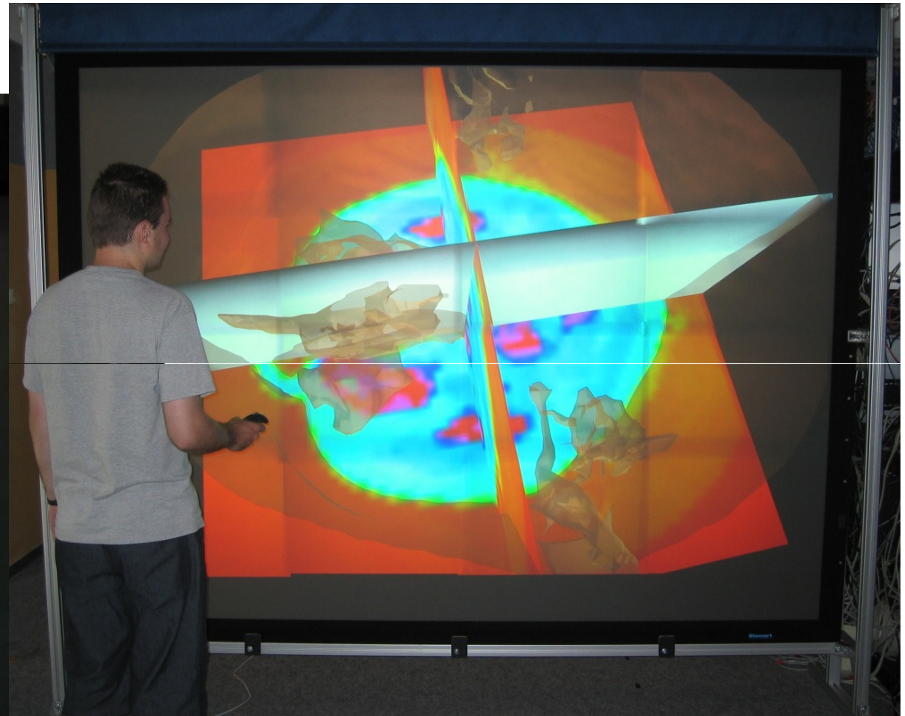
- Power Wall
- Projectors: 16 DLP (Possible Passive Stereo)
- Tracking: Color Cameras
- Installed: 2003



VTK/ FlowVR / FlowVR Render

Mplayer video





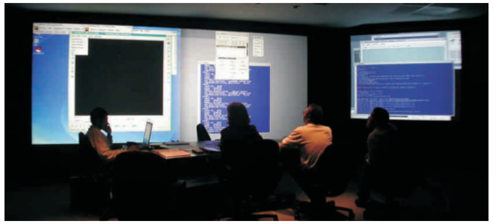
VTK flowvr

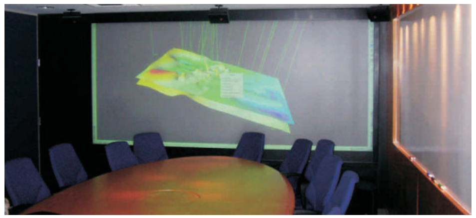
Tecgraf – PUC-Rio
Rio de Janeiro - Brazil

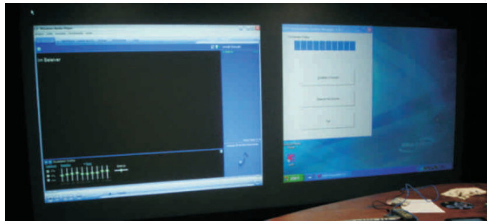
- Single Stereo Projection
- Projectors: 2 DLPs (passive linear stereo)
- Tracking: Camera tracking
- Installed: 2007

Petrobras

- UN-SEAL
- UN-BA
- REVAP
- ETEG
- ABAST
- ABAST
- 14 Andar
- UN-BC

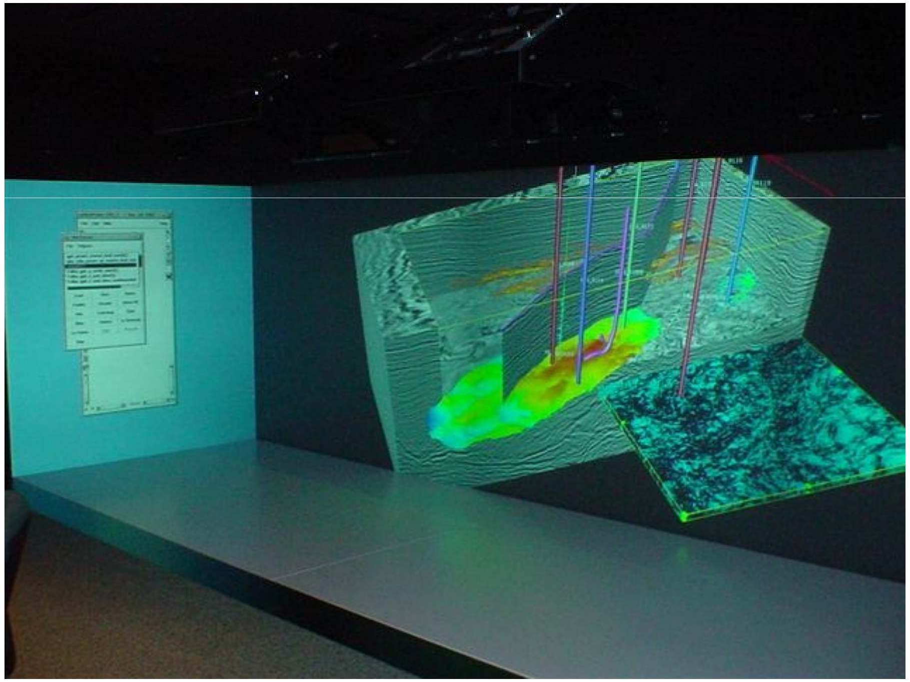


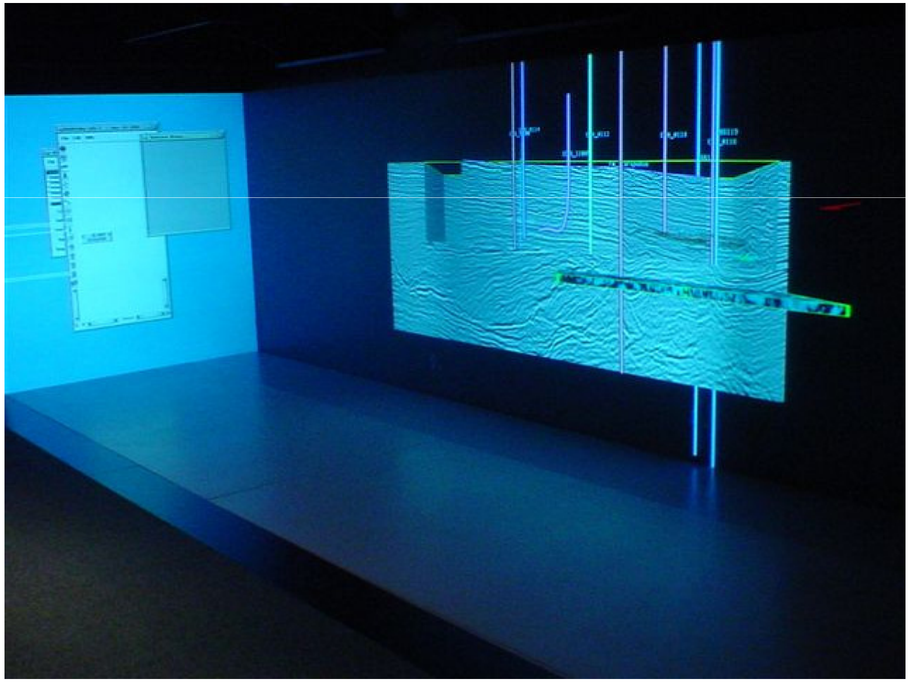




Petrobras cont.

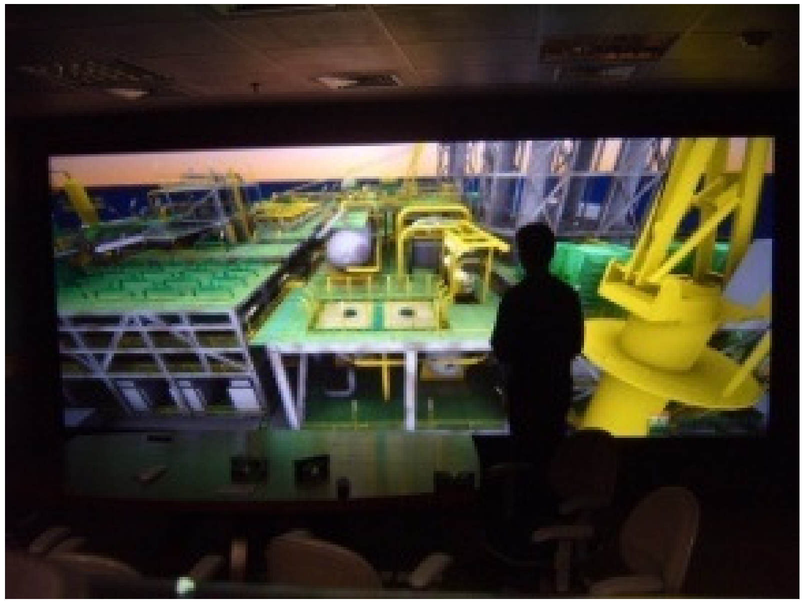
- EDISE (HollowSpace)



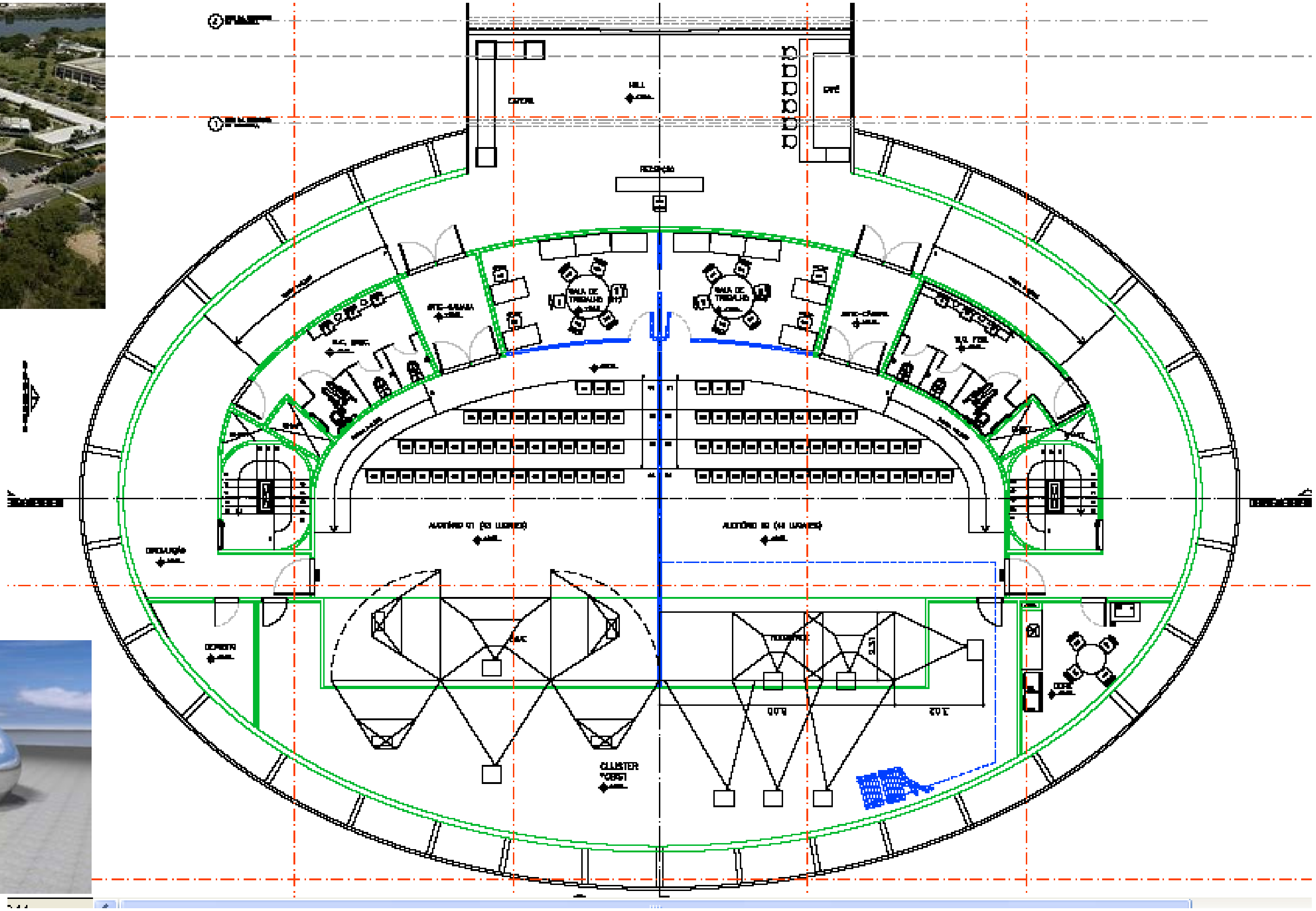


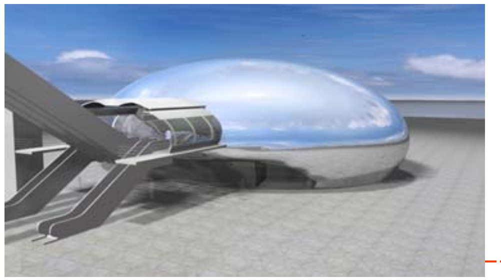
CENPES / MC

- PowerWall
- Projecotors: 2 DLPs (active stereo)
- Tracking: Optical
- Installed: 2006 (Original CRT installation 2001)



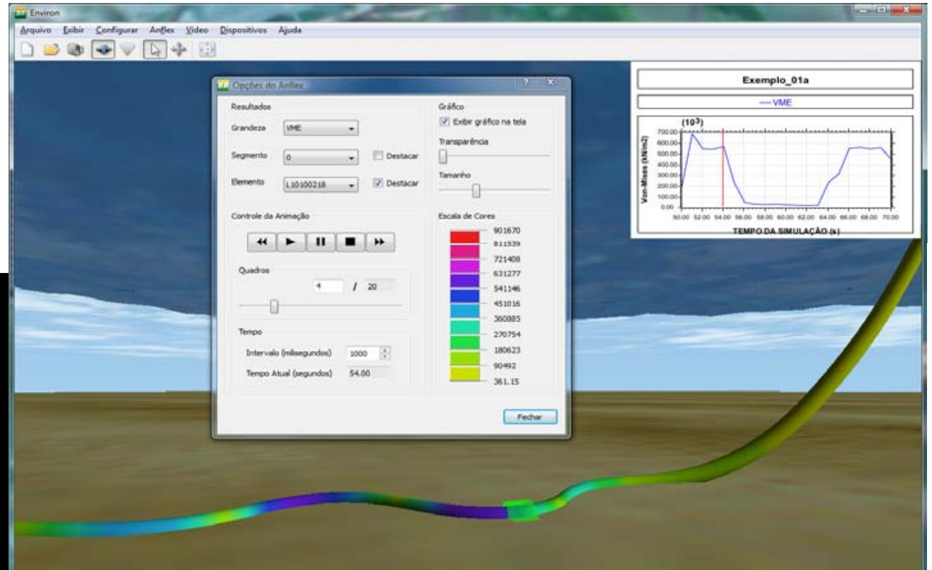
CENPES CRV (Future)

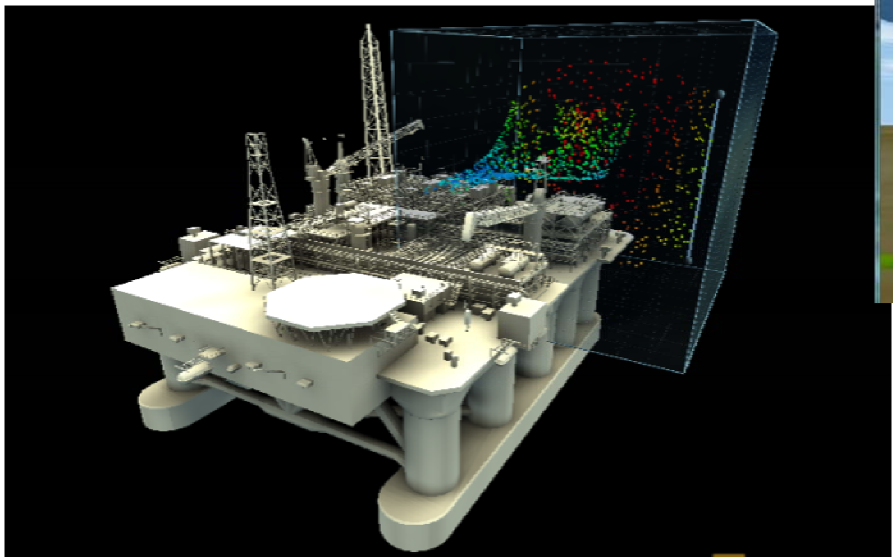




Environ

- Massive Models Visualization
- Simulations
- Effects





LEMeWall at Instituto Superior Técnico, Portugal

- PowerWall
- Projectors: 12 DLPs (mono)
- Tracking: Laser pointer + US Sensors + Optical
- Installed: 2005

LEMeWall

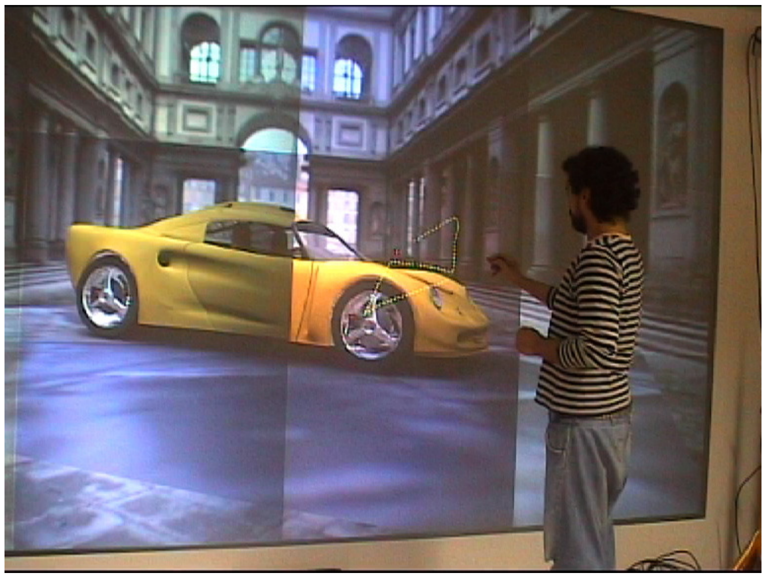
- *Instituto Superior Tecnico* , Technical University of Lisbon
- TagusPark Campus
- LEMe: Laboratory for Excellence in Mobile and Ubiquous Computing

- Retro-projection system using 12 DLP projectors
- Intelligent Environment enriched with a 5.1 Sound System, Microphones, US Sensor Network and Network Cameras for Optical Tracking

- PC Cluster of 13 Computers dedicated to graphics running Gentoo Linux Distribution
- Network of 6 Computers for interaction and applications

Display Characteristics

- Flexible Screen
- Screen Size: 4 m X 2,25 m
- 8,5 MPixeis (native) to 15 MPixeis (ext)
- Mono 4 by 3 configuration Array
- Graphic Cluster Boards Nvidia Quadro FX 3000 4:3

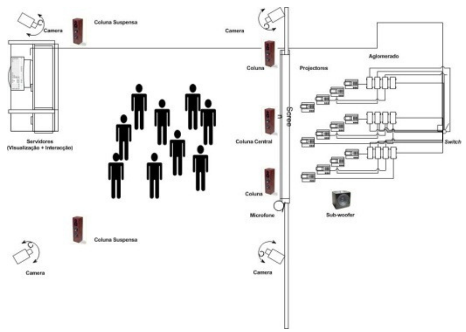


Hardware

- **Cluster** 12 Workstation HP xw4100
  - Pentium 4 (800 FSB) 3.00GHz
  - 2 GB RAM (PC3200)
  - NVIDIA Quadro FX3000 (AGP 8x)
- **Cluster Server** Workstation HP xw8000
  - Pentium 4 Xeon 3.06 GHz
  - 4 GB RAM
  - NVIDIA Quadro FX3000 (AGP 8x)
- 12 **Projectors** HP VP6120
  - DLP
  - 2000 Lumens
  - 1024x768 (Nat.)/ 1280x1024
- 5 **Cameras** Canon VC-C4
  - PAL
  - Pan/Tilt/Zoom remote control
- **Sound System** (AudioPhysic/ Denon)
  - 4 periph. channel + 1 central
  - 1 Sub-woofer
  - Tuner AV
- 2 **Microphones** AKG SE300B

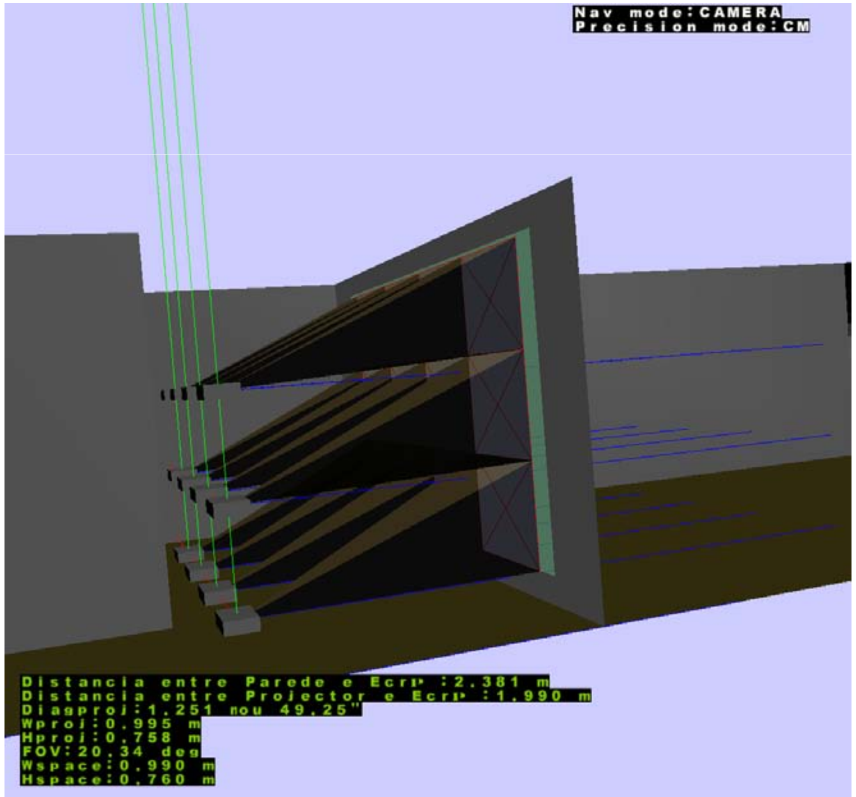
Starting Point

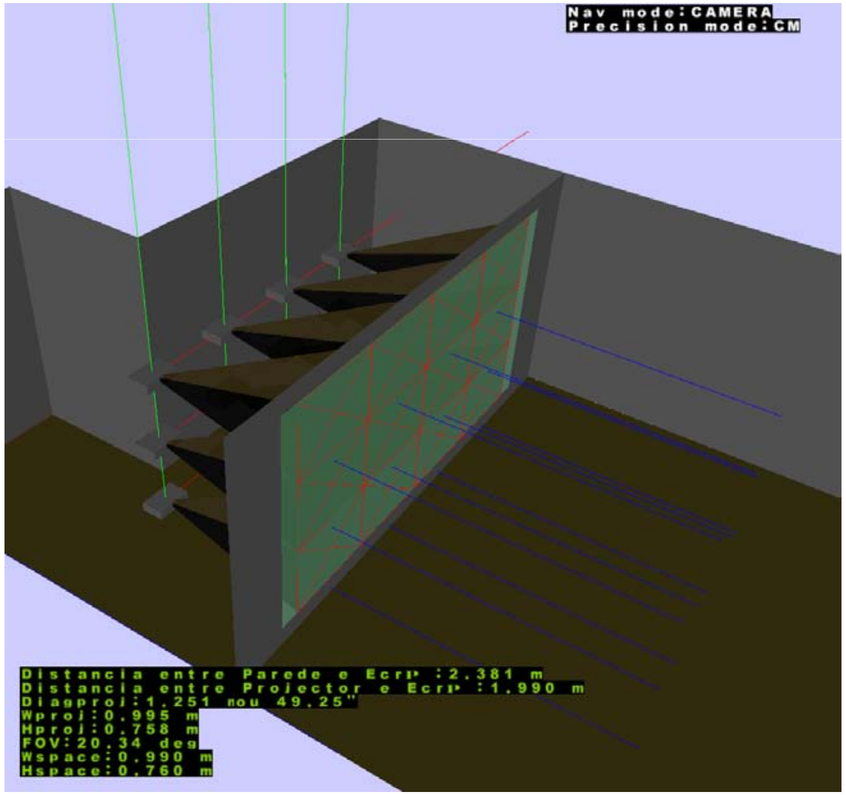
- 12 Off-the-shell XGA DLP projectors (<1700$ /unit)
- Cluster using Off-the-shell computer
- University Computer Laboratory



LEMeWall Simulator

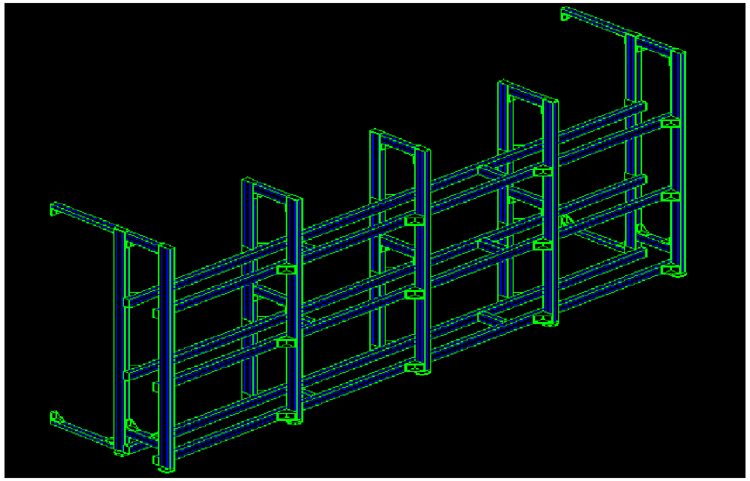
- Projector and Array
- Screen and Wall Distance Computation

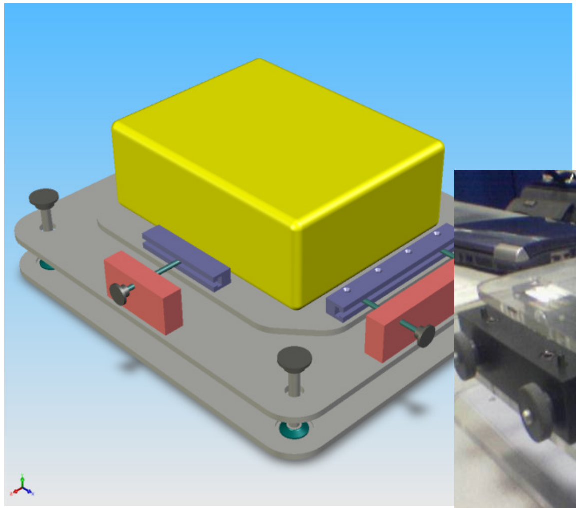


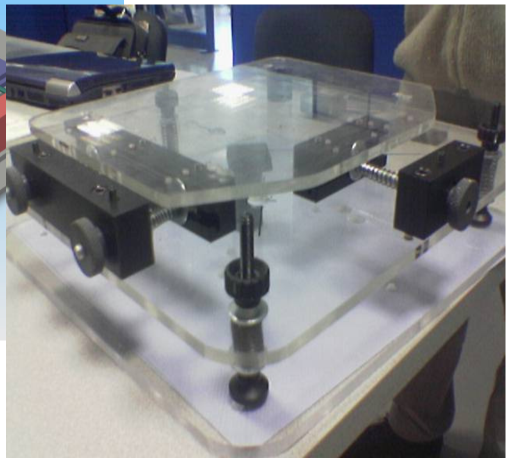


Projector Array and Mounts

- Aluminum Frame for 12 projector (4m x 2,25m x 0,5 m)
- Modular Array ready for future extension



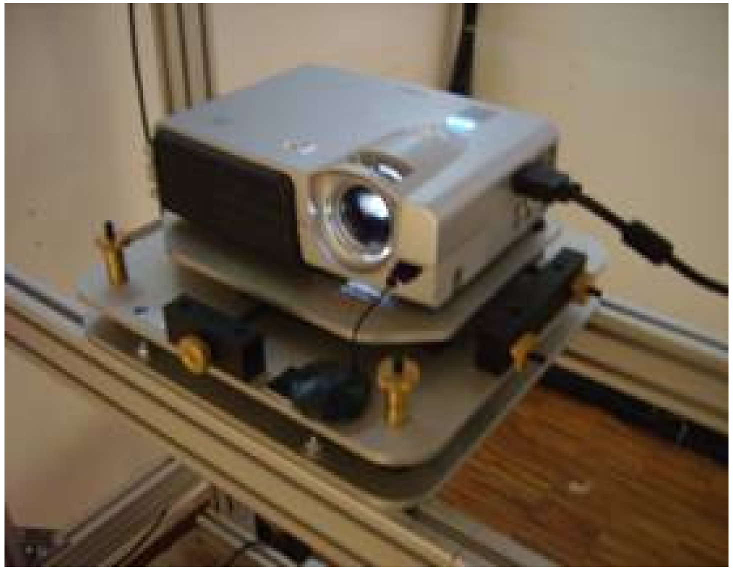


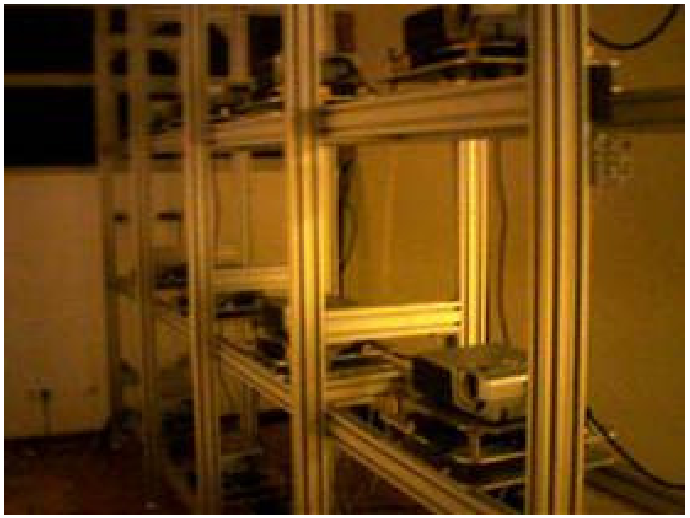


- 6DOF Aluminum Mount
- Sub-millimeter precision
- Two floor design (1T+1R

Infra-Struture Projection Setup

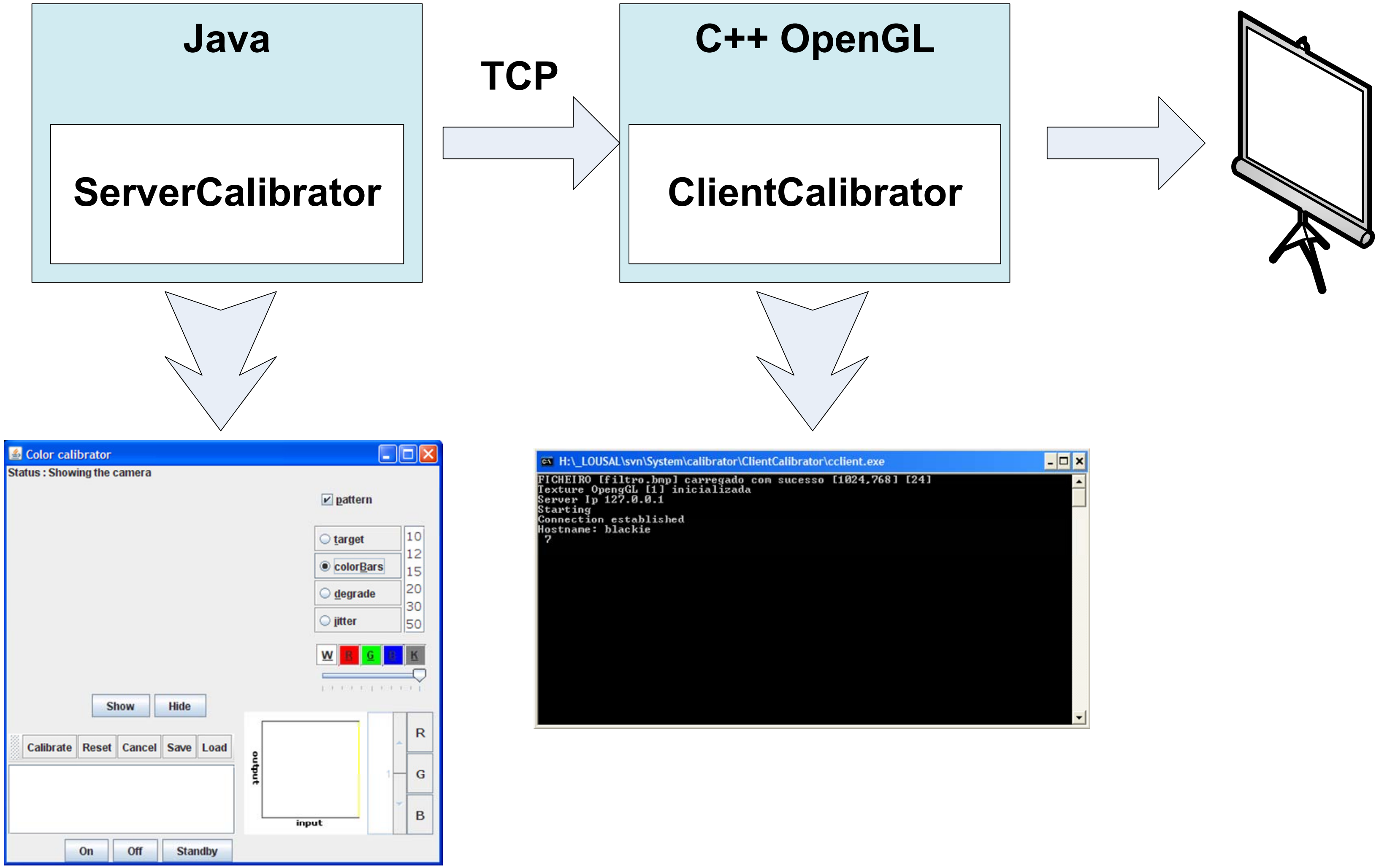
- Cooling System
- Light Control
- Geometric alignment





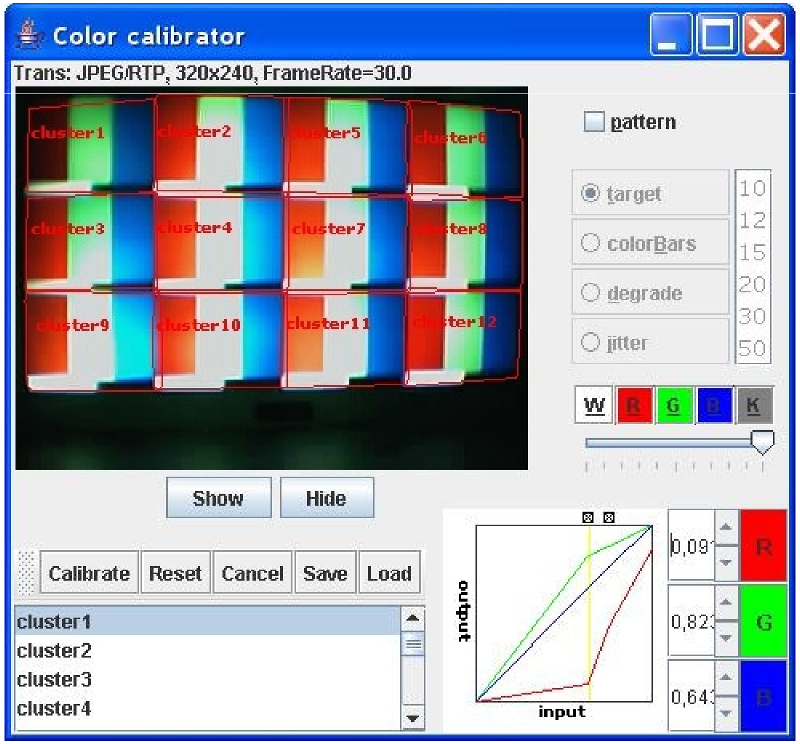
LEMeWall / IST

Projection Calibration and Control



Color calibration

- Non-Rigid Screen
- Color can shift among similar projectors
- Camera Based Gama Correction Software



Automation and Control

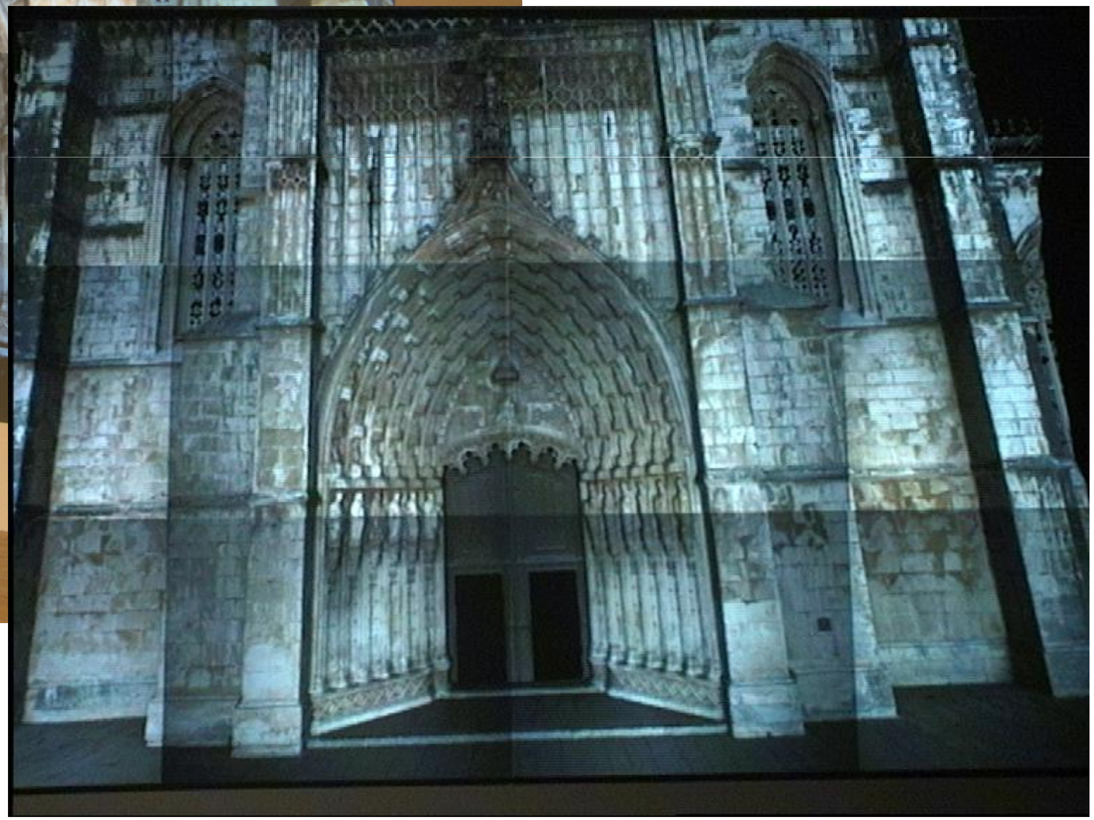
- Projectors connected to computers via VGA+Serial
- Linux Cluster Access (SSH, Rsync)
- Scripts for cluster control and Demo Launch

- Python based Tool (GUI GTK)
  - Avoid KVM HW to access computers
  - Script Launcher
  - Centralized Graphical Projector Control
  - Computer Cluster Monitoring (CPU,RAM,Network)

Application and Rendering Software

- Several VR system setup :
  - VR Juggler, OpenSG, Chromium, Jinx, Syzygy
- LEMeWall VR MiddleWare
  - OpenSG (Windows/Linux Applications)
  - Chromium (OpenGL Wrapper, Windows/Linux)
- On Going: New VR Support Framework
  - OpenIVI: OpenSG+OpenTracker+OSGA+MM

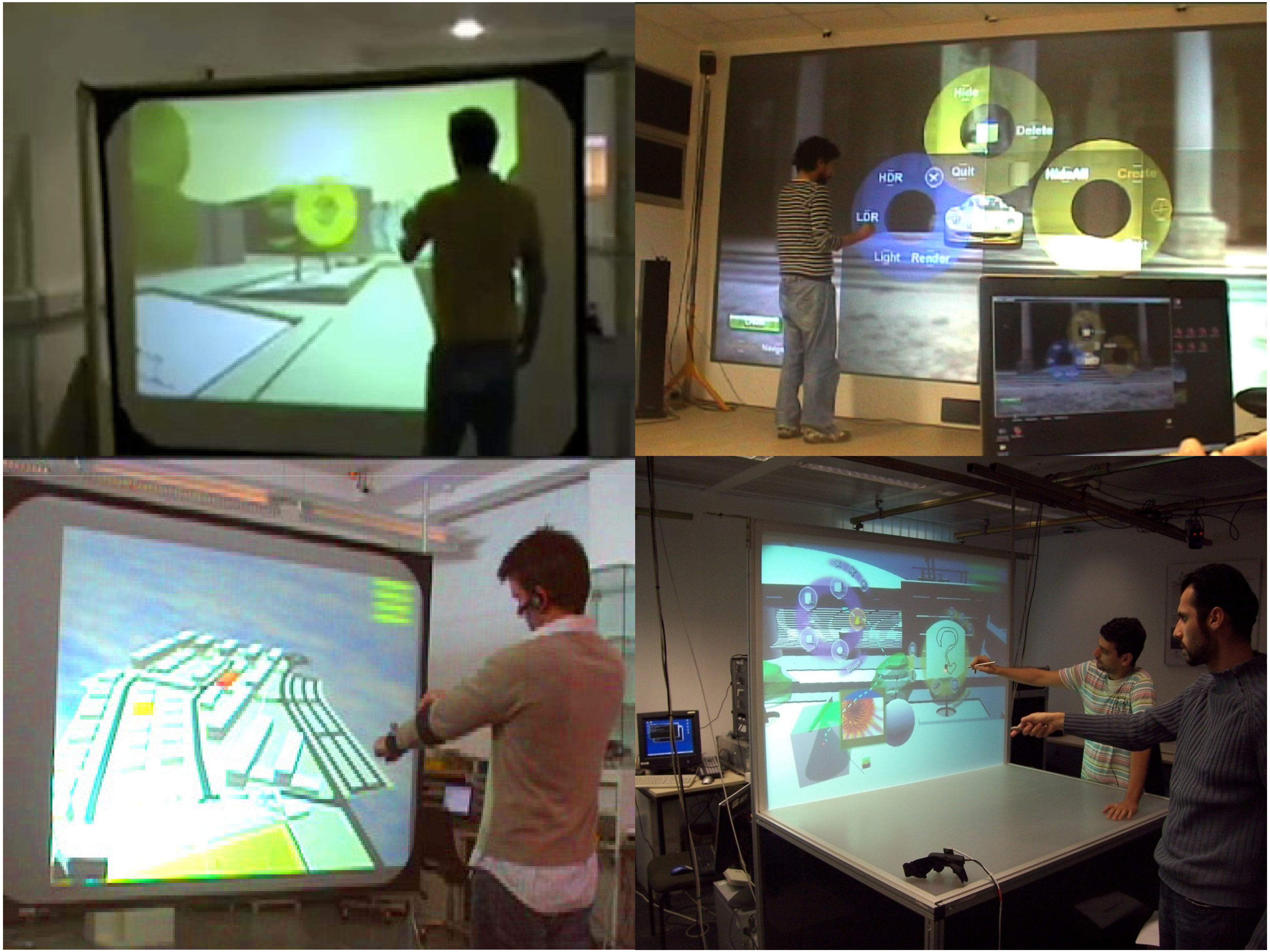
Demos Running at the LEMeWall



Demos Running at the LEMeWall

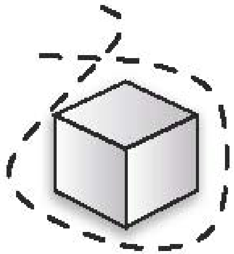
LemeWall Interactions

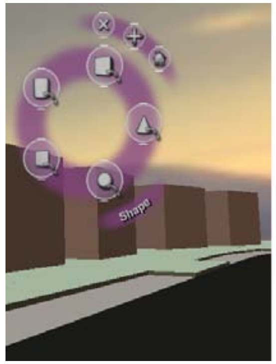
- Interaction Metaphors
  - Stroke based interaction (laser/PowerWall 3DPen Mouse/Pen)
  - Tracking/Body Gesture based interaction
  - Voice based interaction
- Input Devices
  - Laser
  - Mobile Computing (PDA)
- New User Interface (Advanced GUI)
- Multi-user and Multimodal Framework

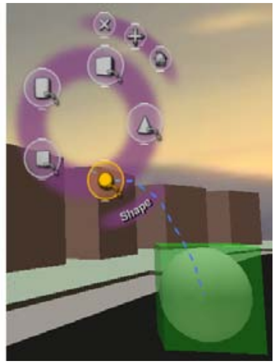

Hide
Delete
HDR
Quit
HideAll
LDR
Light
Render

Stroke based Interaction

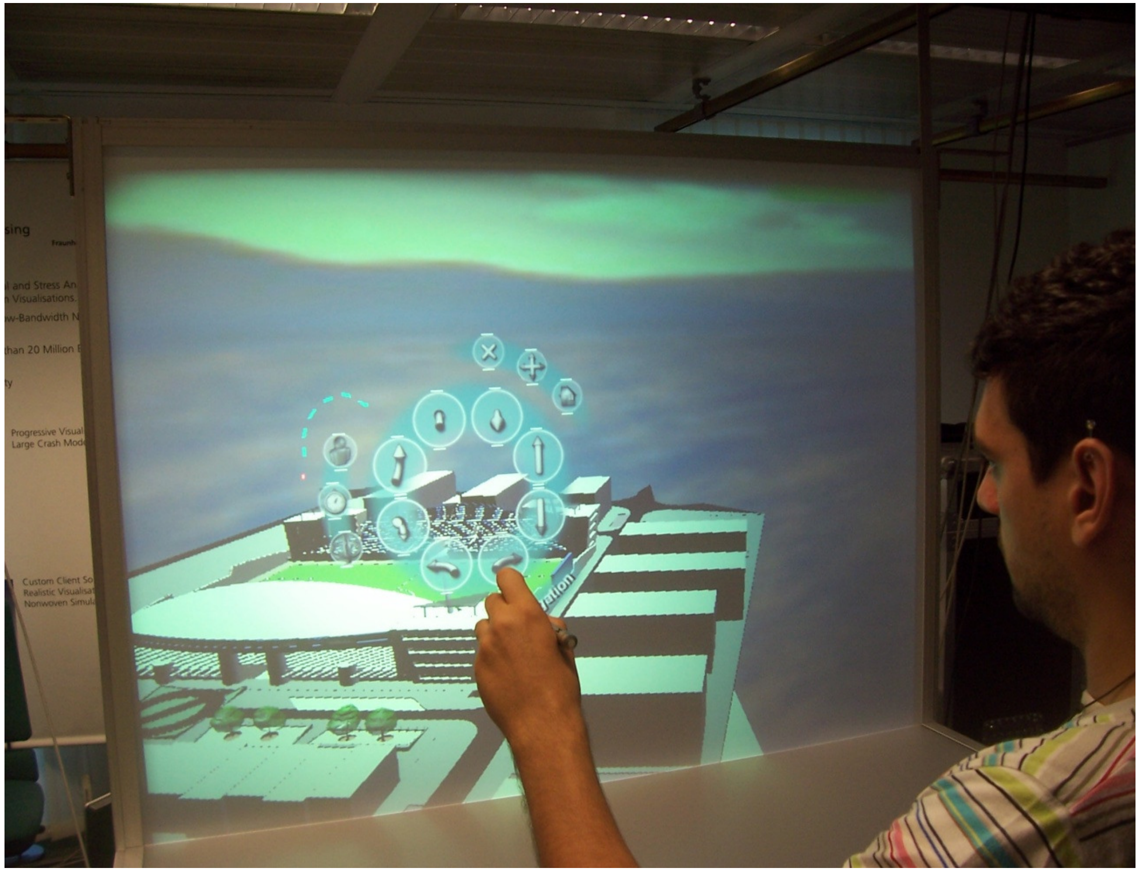
- Stroke
  - Line / Sketch
  - Path
  - Gesture





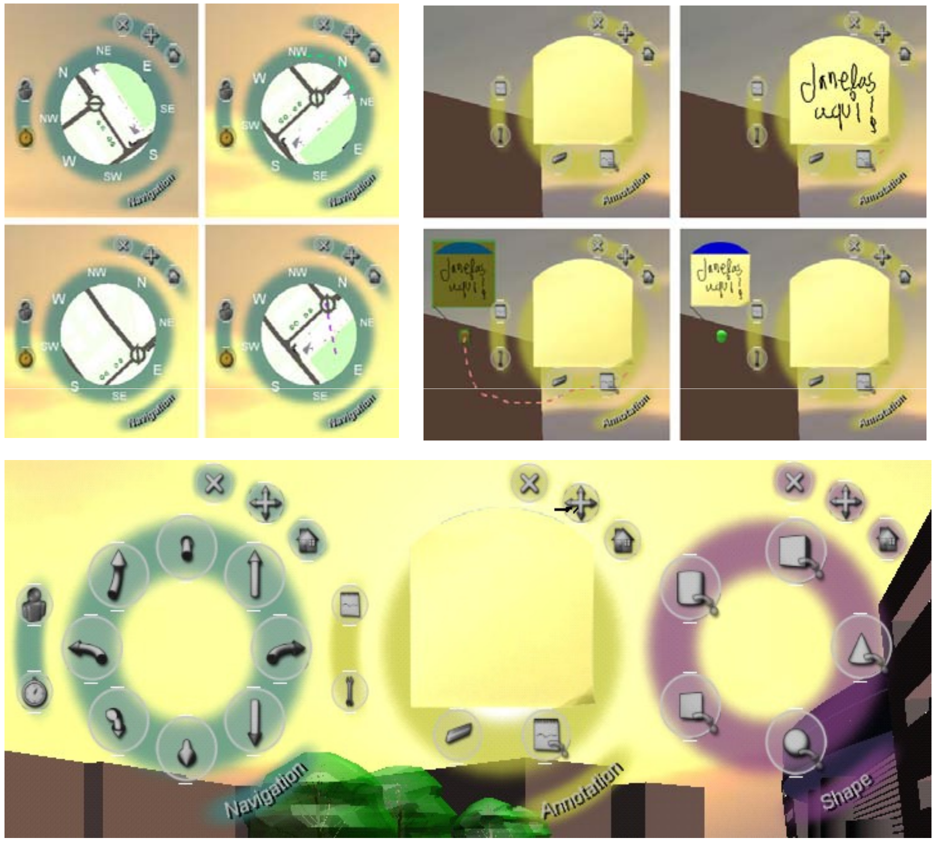


- Main metaphors
  - Crossing
  - Lasso selection
  - Pointing
  - Circular Menus



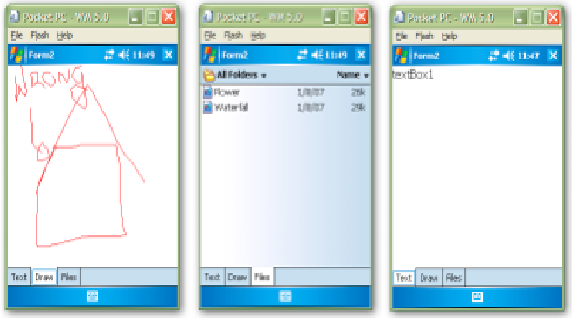
GUI for Large Scale display

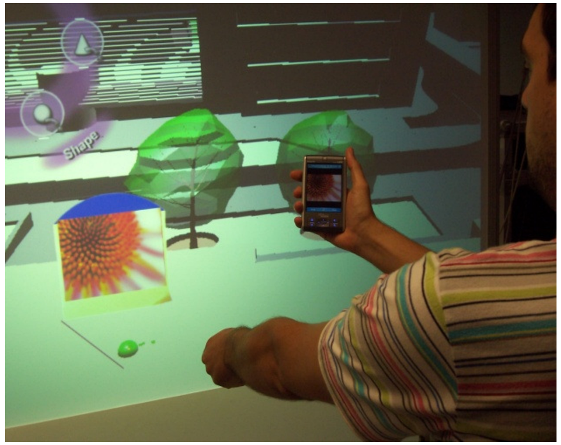
- Circular Menu
  - Only 2 Levels
  - Gate Activation by Crossing
  - Lasso bring up the context menu
  - Menus belong to an user
- Functionality using Menu
  - Annotations
  - Navigation
  - Shape Creation
  - Transformation
  - Rendering and Light Options

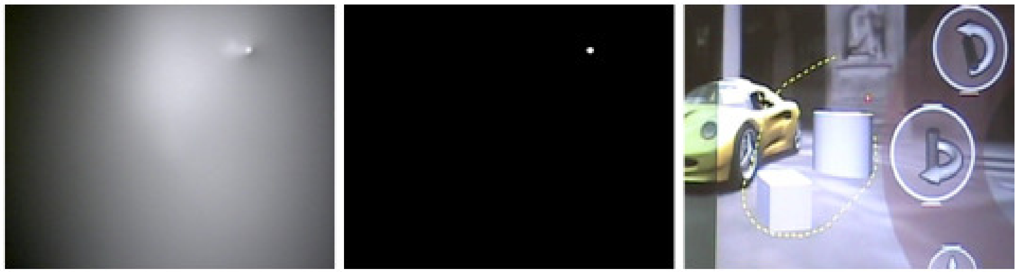


Supported Input Devices

- Laser Pointer
  - Enable Stroke Interaction
  - Supports multi-users
  - Large Area tracked
  - One-One relation with the content
- PDA
  - Allows us to share data
  - Sketch, Images, Text
- Other devices
  - Mouse, Pen3D, Tablet PC





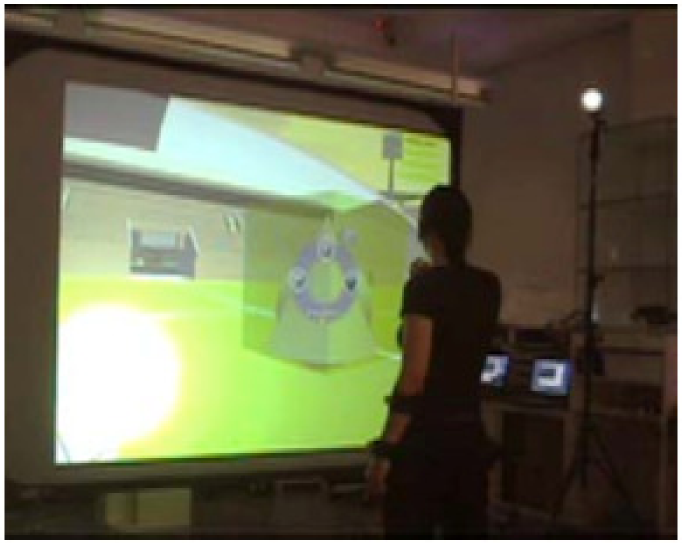


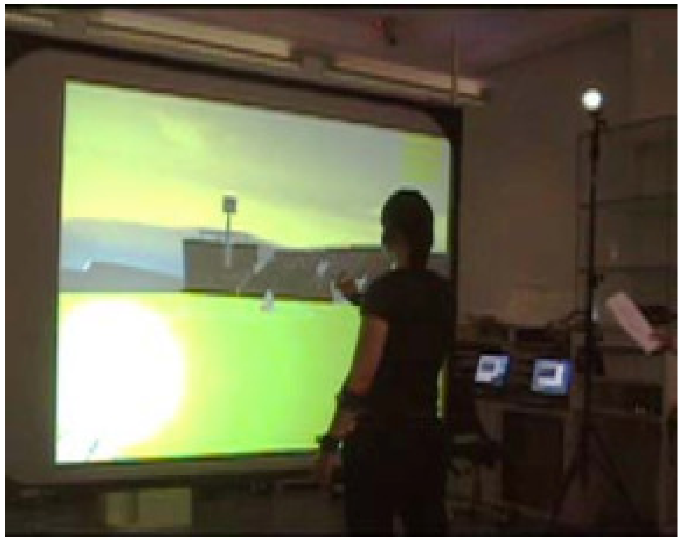
Speech based Interaction

Speech Recognized
- Global Functionality shortcuts
- Menu Interaction
- Objects
- Controlling Navigation

Used in conjunction with
- Laser
- Menus
- Body Tracking

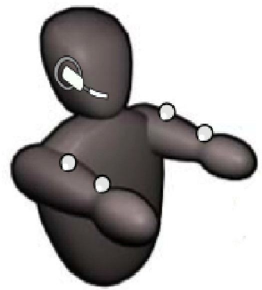
Microsoft Speech SDK



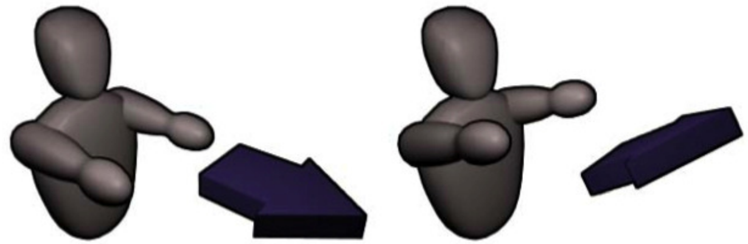


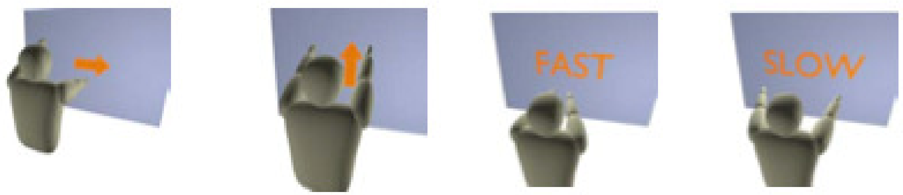
Tracking Based Interaction

Two arm tracking
- Gestures
- Pointing
- Composition with voic



Functionality
- Navigation
- Dragging objects
- Scaling
- Rotation





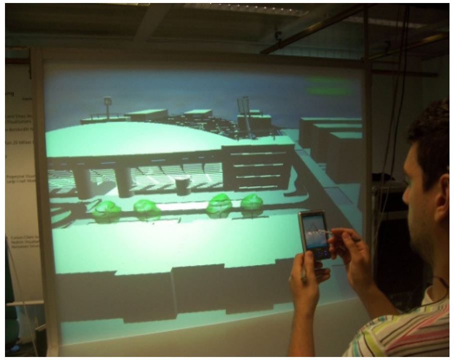
Multimodal Interaction

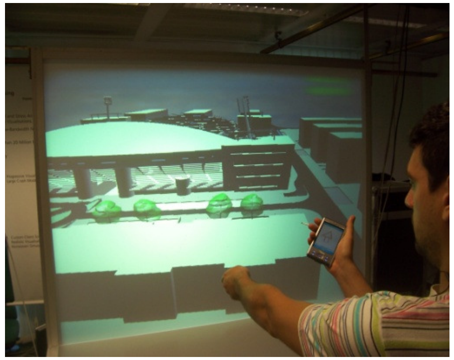
Further enhance the interaction

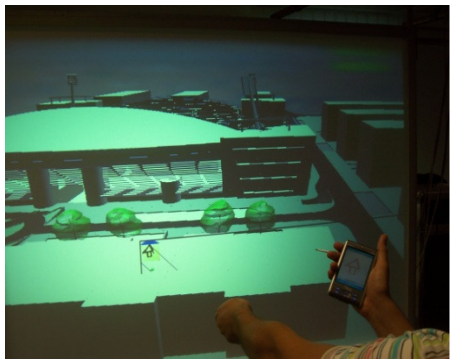
- PDA + Pointing
- Voice + Menu
- Voice + Pointing
- Tracking + Voice

Examples

- Delete an object using : “Delete This”
- Open a navigation menu and select an option with: “Turn left”
- Enter scale mode with “Begin Scale” and use Body Tracking to scale the object







Multimodal and MultiUser

Multimodal interaction reacts to an Knowledge Base System:

Actuators

– Rules with preconditions that represent sequences of interaction

Preconditions

– Token, Context, Objects

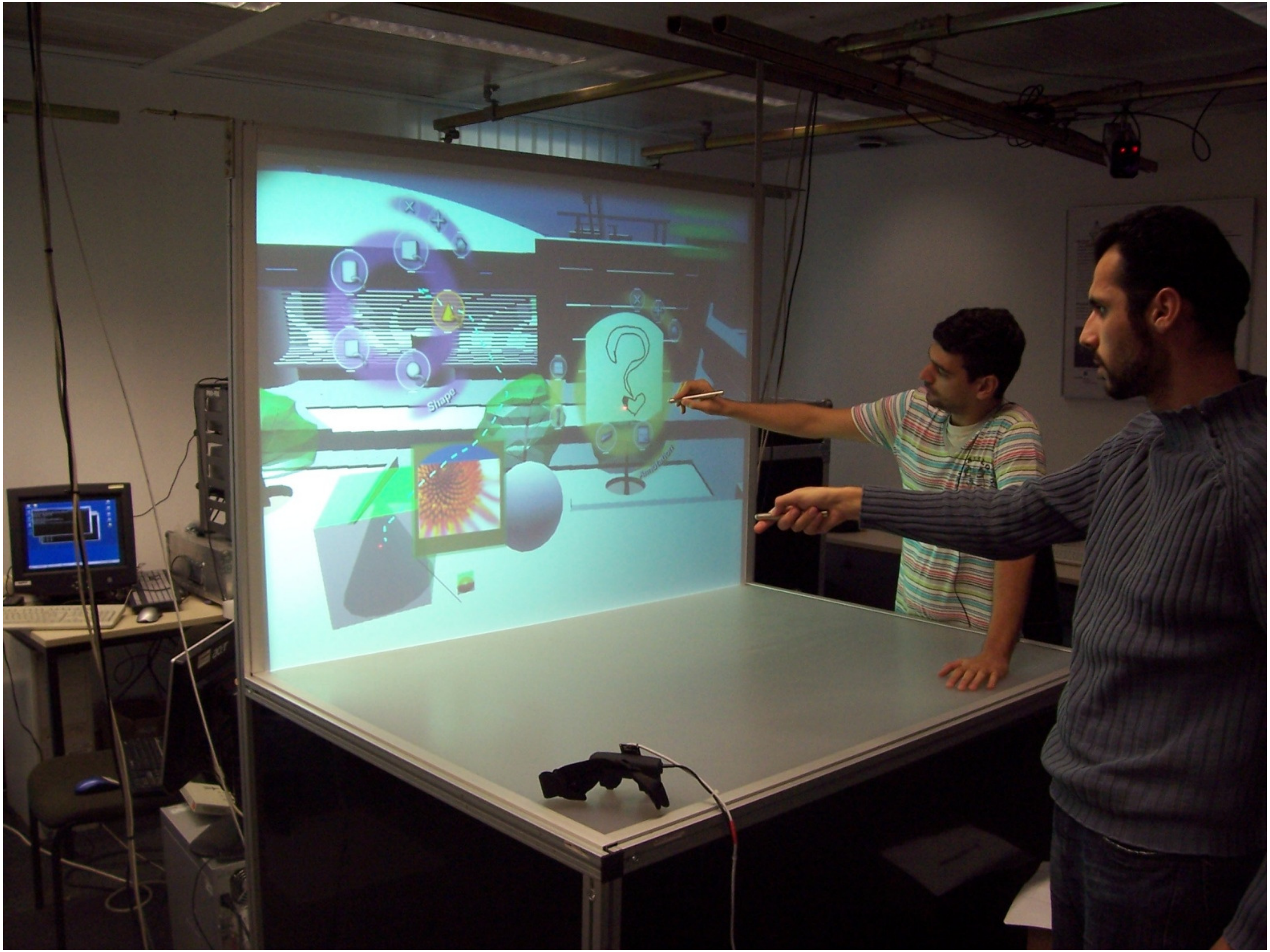
Inference system.

– When preconditions are satisfied, the correspondent actions are activated.

– Ambiguities are solved using a More Recent Token politic

Multi-User Support

- Can take advantage of several modalities
- Several devices supported
- Uses the knowledge definition for support


Shape

Lousal at Fundação Frederic Velge, Grândola, Portugal

- Cave Hollowspace
- 12 DLP Projectors with passive stereo INFITEC
- Optical Tracking
- Installed: 2007

Live Science Center at Lousal

- Center for the dissemination of Science for the population
- At Minas do Lousal – closed during the eighties
- Fundação Frederic Velge is the owner
- Project co-funded by MCTES and FEDER for the Centros de Ciência Viva Network
- Under Relousal

Live Science Center at Lousal

"Exploring Science,
Exploiting Knowledge"

Live Science Center at Lousal

Mine of Science – Live Science Center of Lousal will be part of the already existing Portuguese Network of Live Science Centers

The general objectives of this network have been defined by the National Agency for Scientific and Technological Culture:

Education for Science and Technology
Divulgation of Science and Technology

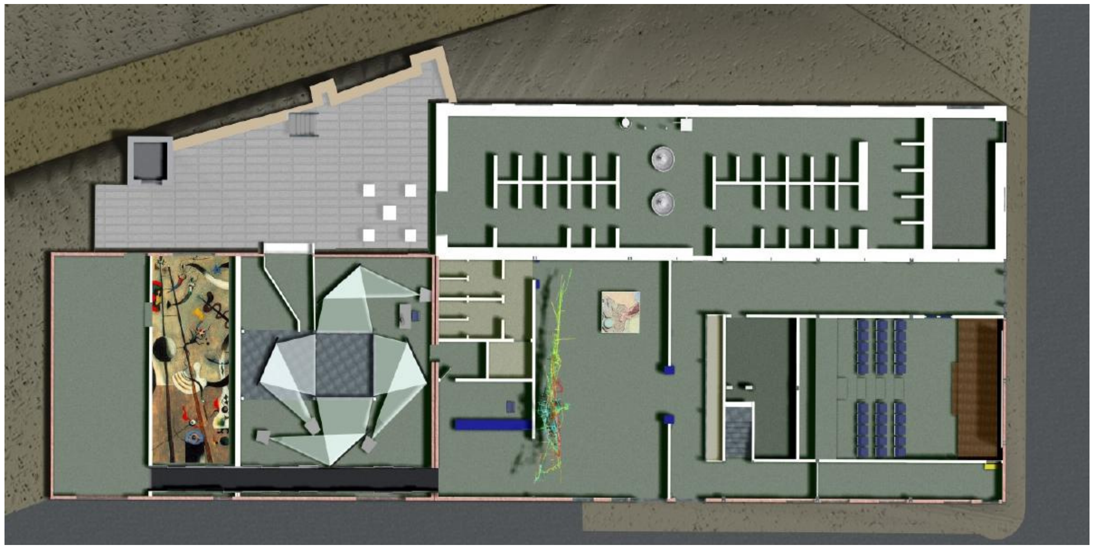
The Centers should be designed for a large-spectrum audience (e.g., age, education, social or geographic origin, etc.)


Lousal Mine

Lousal Mine

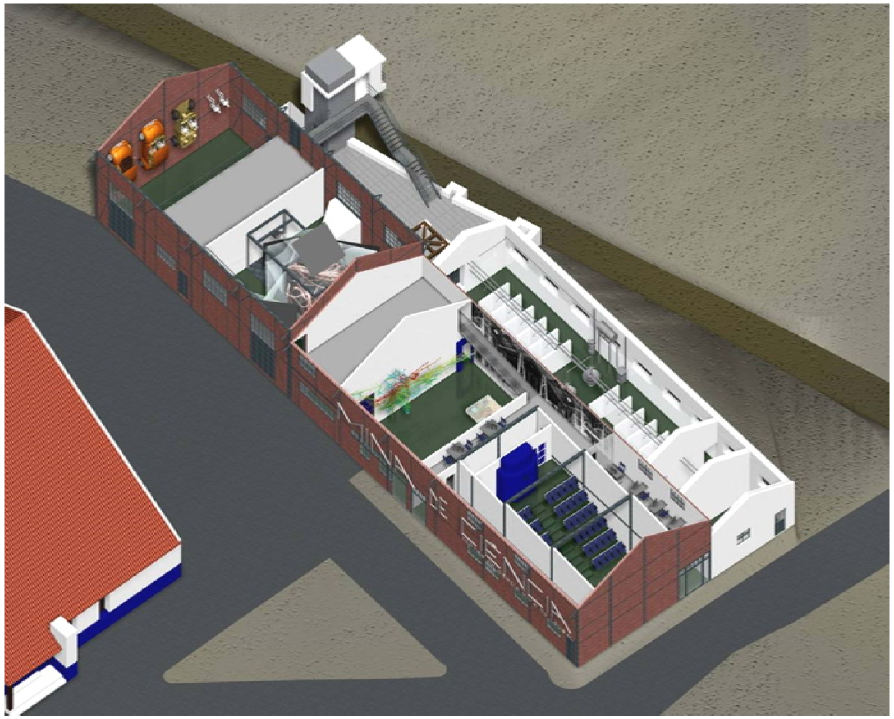
CAVE-HOLLOWSPACE of Lousal

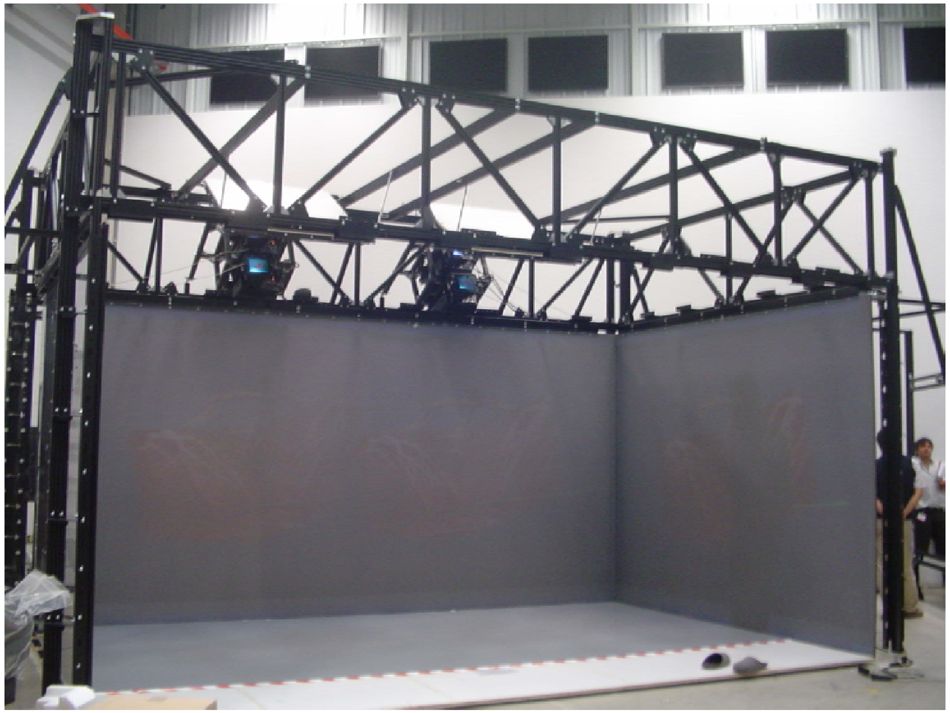
- First large scale immersive environment in Portugal
  - High resolution > 8 M Pixel
  - Wide field of view
  - Stereoscopy.



CaveH of Lousal

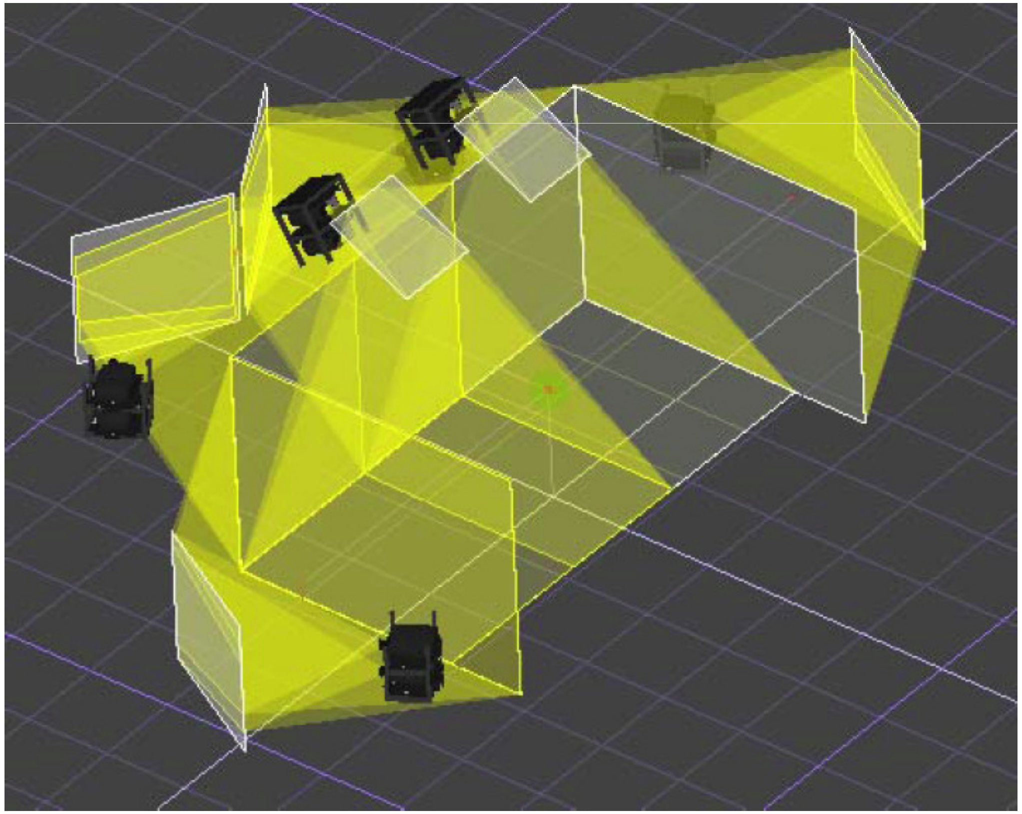
- First large scale immersive virtual environment in Portugal
  - 12 x single chip DLP™ projector with SXGA+ (1400x1050)
  - U topology, retro-projected: 5.6 m x 2.7 m x 3.4 m
  - High resolution: up to 8 295 000 pixel
  - Wide field of view: more than 180º
  - INFITEC Stereoscopy





Projection Studies

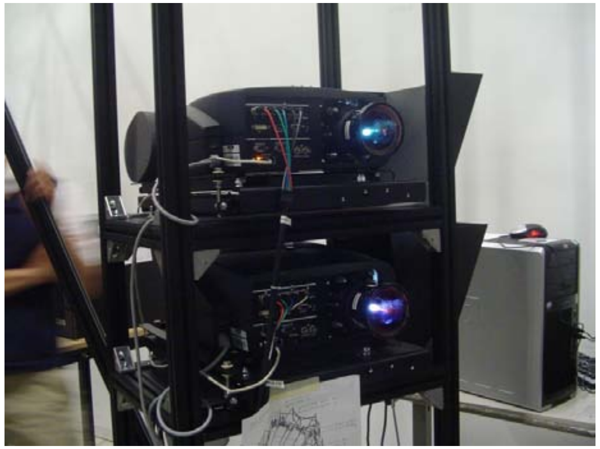
- Cave Hollowsapce - CaveH
- 4 Sided extended (Overlapping and 90º)

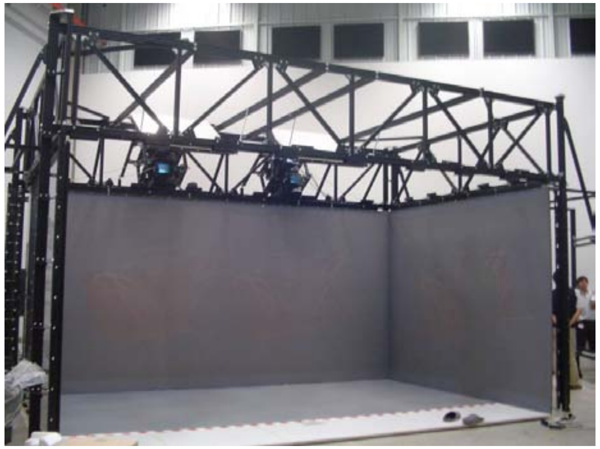


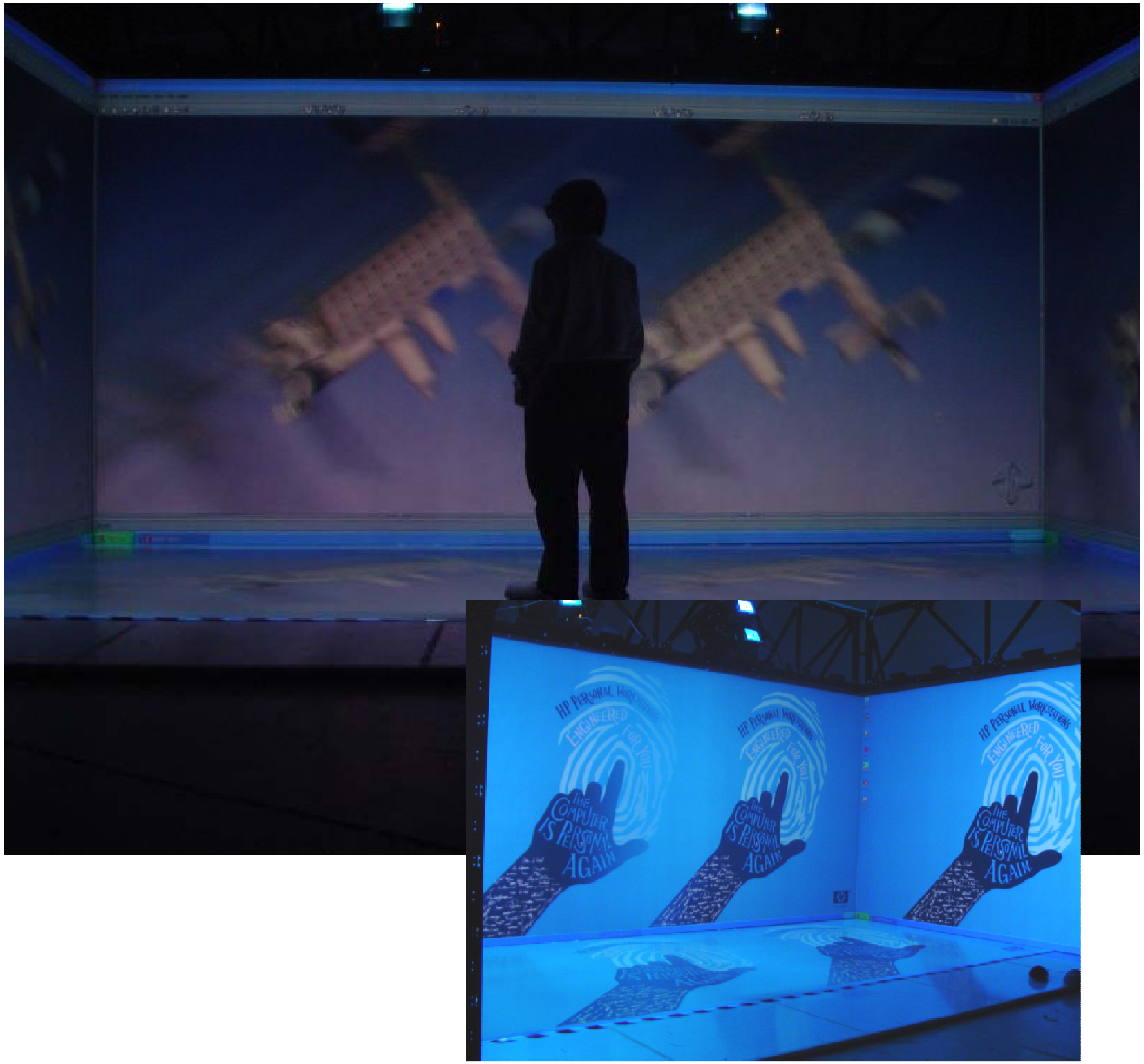
Main Objectives

- Simulate realistic mining procedures
- Information about geology and mining
- Entertainment with mining environments
- Academic research and education
- Service to the Portuguese industry

Preliminary tests at factory

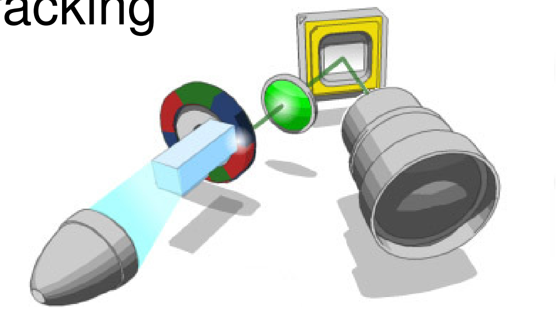


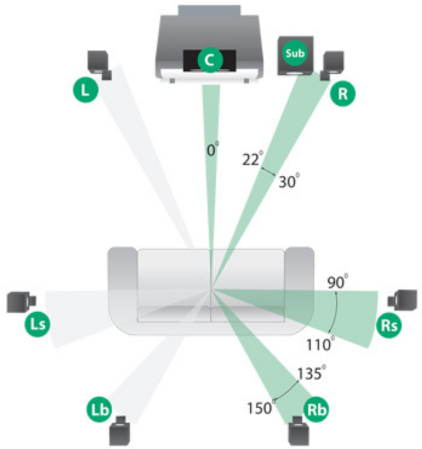


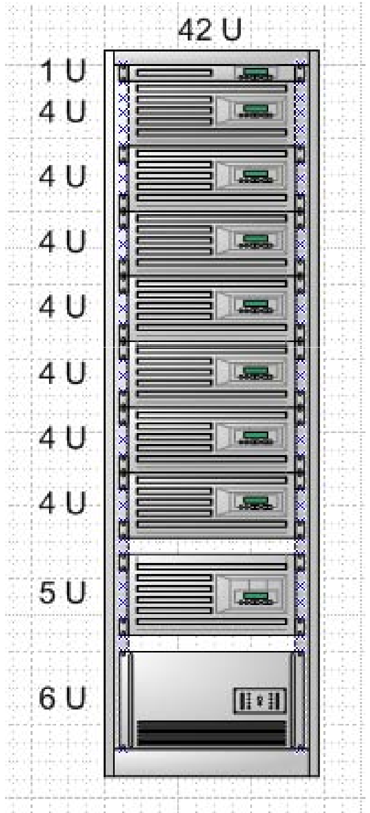


CaveH Main Points

- High-end projection systems:8M pixel at 60 Hz
- State-of-the-art large semi-rigid screens
- Distributed 3D Audio “surround” 7:1
- Computer cluster and Gigabit ETHERNET
- High-performance computing server and 3D graphics: over 3M poly at 60 Hz
- In-house developed data synchronization middleware ensuring data-lock and frame-lock in master-slave distribution
- In-house developed high-res optical tracking







Projectors

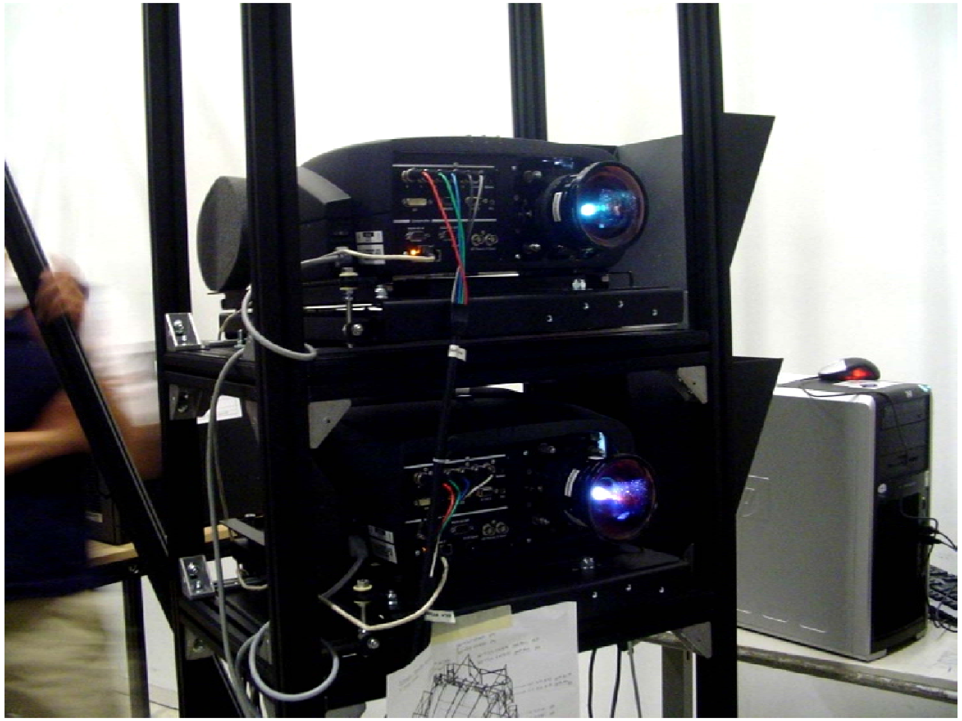
Technology = Single chip DLP

Resolution = SXGA+ (1400 x 1050 pixels)

Brightness = 4000 Lumens

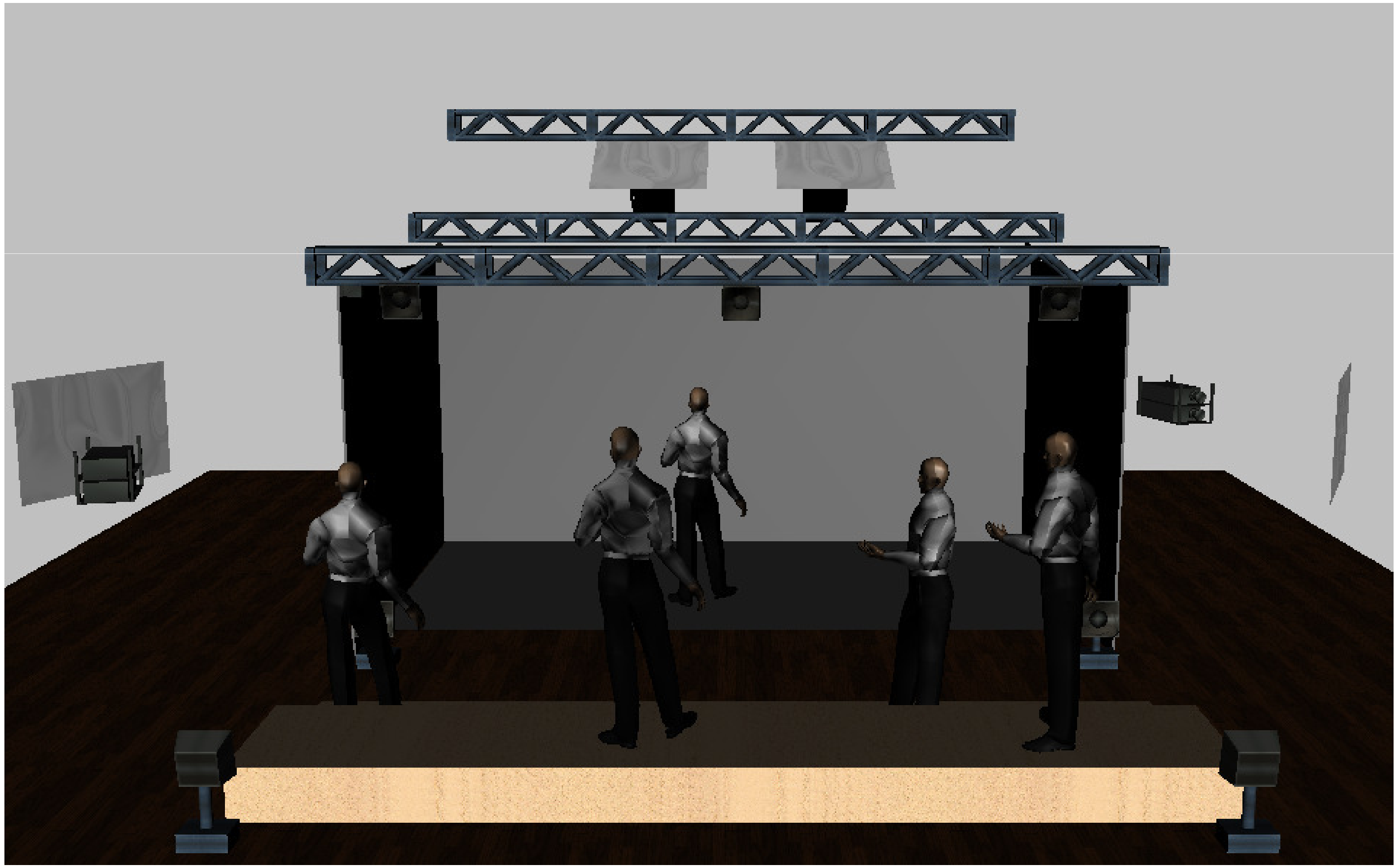
Contrast =1:2000

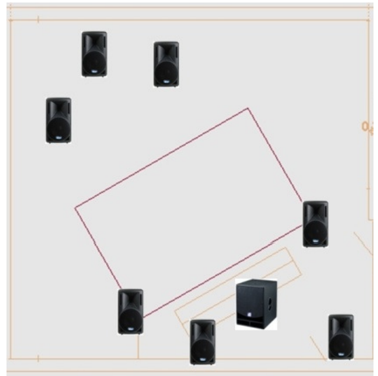
Infitec stereo



Surround Sound 7.1

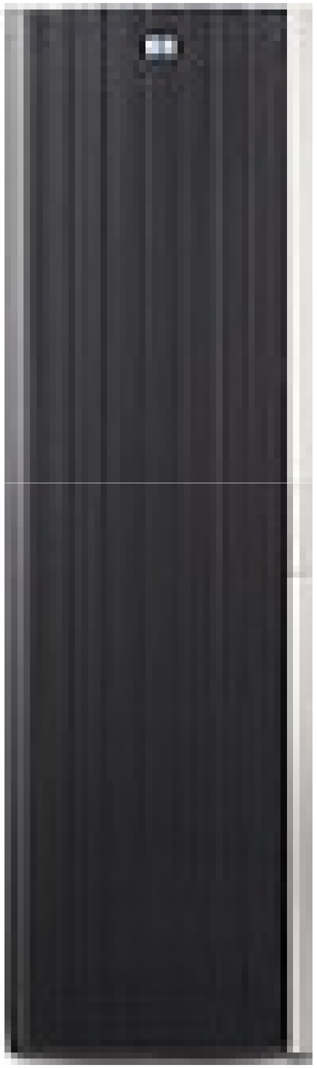
- Spatially positioned
  - 7 High quality speakers and 1 subwoofer



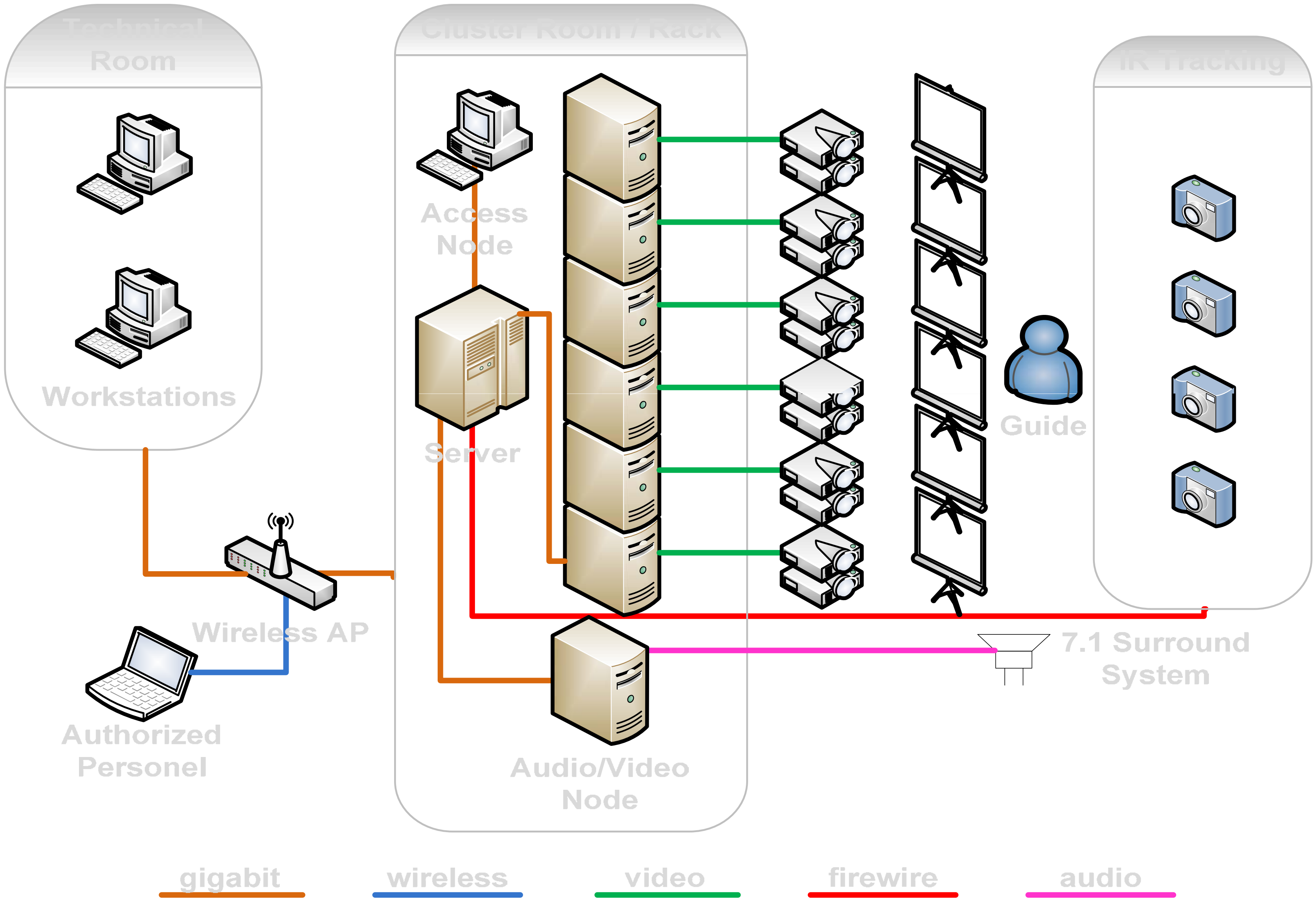


Computing Cluster

- 6 dual core Graphic Nodes
- 1 Audio/Video Node
- 1 Server Node (16 CPUs)
- 1 Access Node
- 1 KVM (Keyboard, Video and Mouse)
- 1 Cluster Switch
- 1 Projectors Switch
- 2 Displays



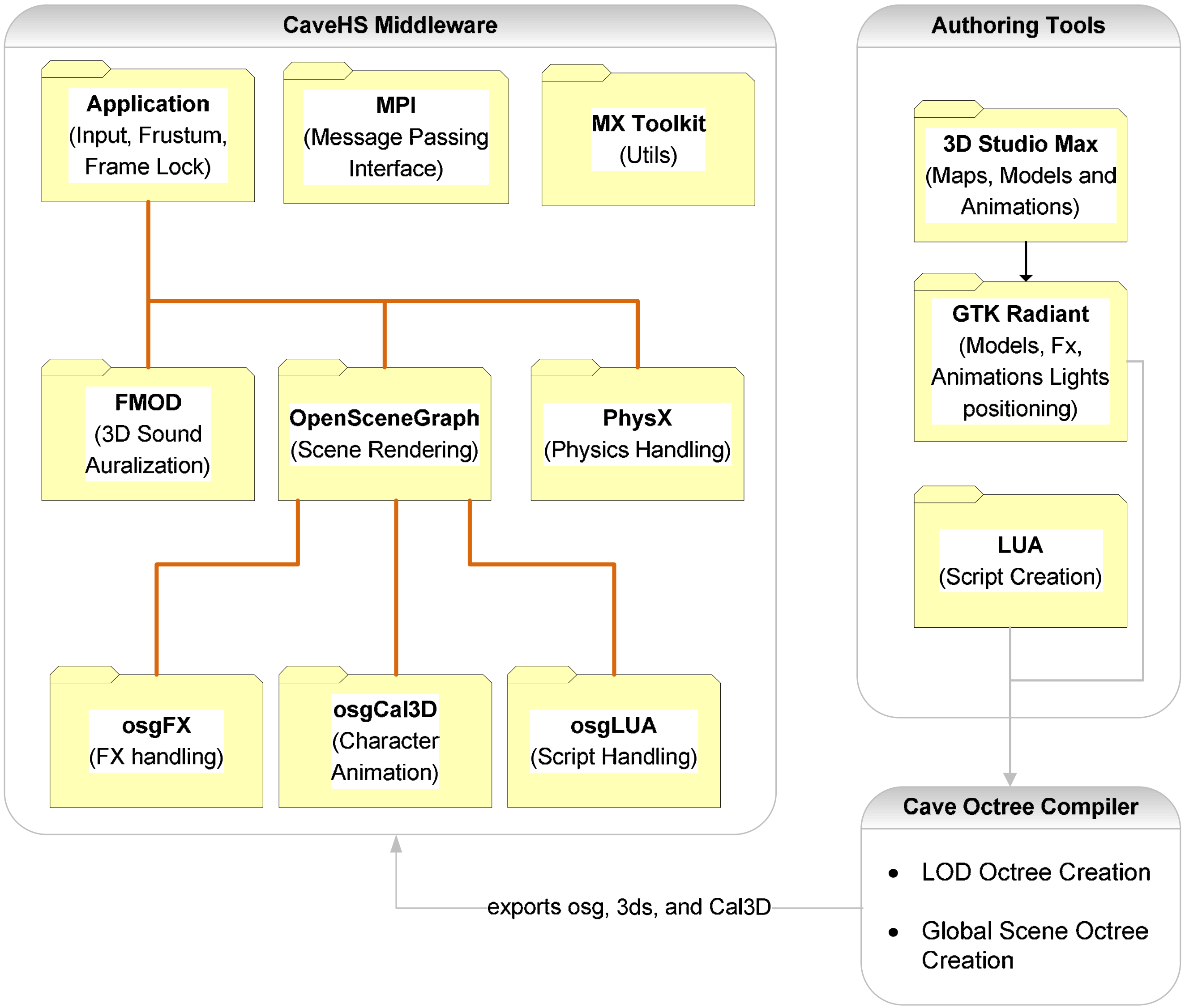
Hardware Architecture



VR Middleware Choice

- SceneGraph: OpenSceneGraph
- C++
- 3D Audio: FMOD music & soundeffects system (www.fmod.org)
- Our own graphics data distribution system supporting both Master-Slave and Client-Server: ADE – Abstract Distributed Engine
- No Visualization Distribution technique
  - ADE guarantees Data-lock over the replicated scenegraphs across all Cluster nodes
- Microsoft Windows platform
- Other external libraries to be presented later

CaveH Middleware



CaveH Middleware

- Produce high complex realistic real-time images;
  - GPU
  - Global and local ilumination
  - Cinematic and Dinamic Colision detection
  - Rigidy body dynamic simulation
- Spatialized 3D Audio
- Precise Synchronization among computers
- Latency and bandwidth control
- Content
  - 3D Modeling (supporint several 3D formats)
  - Character animation (*key-frame* and dynamic)
  - *scripting*
  - Immersive Environments Authoring

External development tools

- OpenSceneGraph (OSG)
- OpenGL
- Cal 3D
- Lua
- GL-SL
- Ageia PhysX
- FMOD Ex Sound Server
- MPI

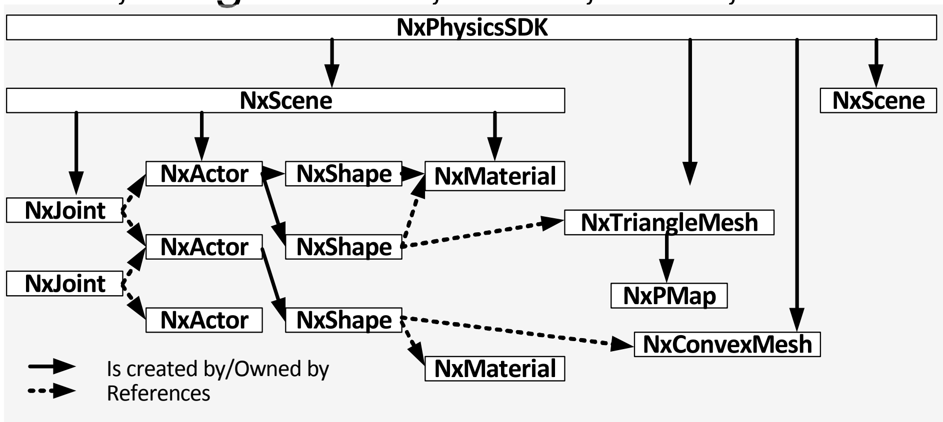
Internal development

- MX-Toolkit
- Abstract Distributed Engine - ADE

Newton Physics

- Selected a robust and mechanical precise physics engine: **Ageia PhysX** (free license)
- Supports rigid and soft bodies, joints, height fields, fluids, cloth, particle systems, vehicles,

  and character controller



- Internal structure:
  - Scenes are independent worlds
  - Actors are the basic simulation entities. Each actor is defined as being static (for static scene elements), cinematic (for movable scene elements), or dynamic (subject of Newton physics simulation)
  - They can be physically linked through joints (Ageia PhysX supports 9 predefined joints and an additional 6DOF-customizable joint)
  - They can have many shapes. The library offers many representations: box, sphere, capsule, plane, triangle meshes, and convex meshes
  - The shapes must have a material, which defines the shape's static and dynamic (isotropic and anisotropic) friction, and its restitution

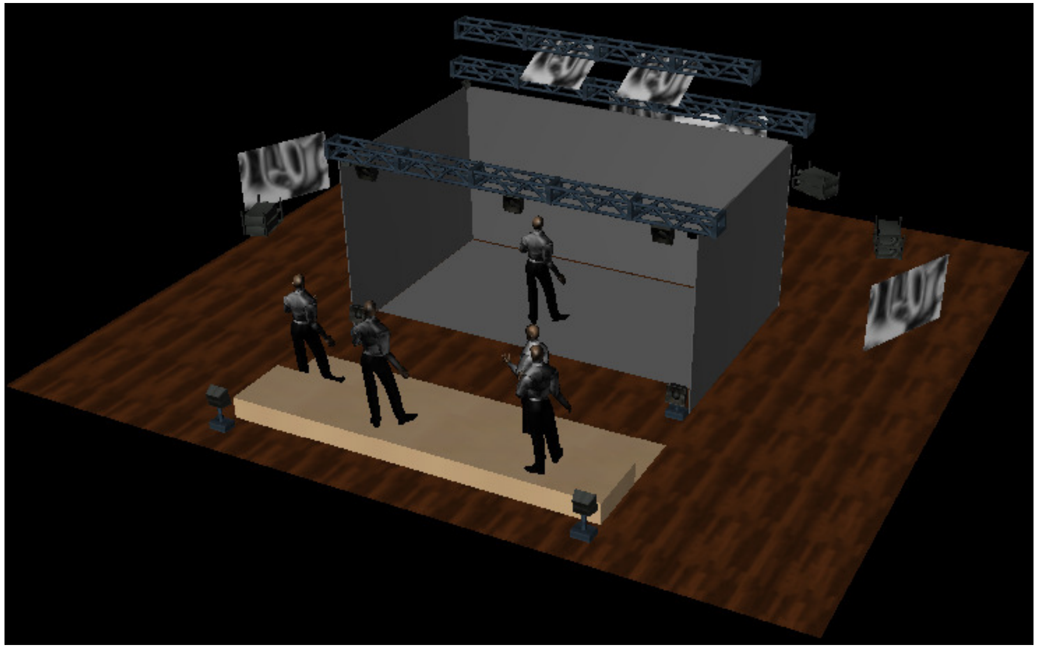
Collision Detection and Response

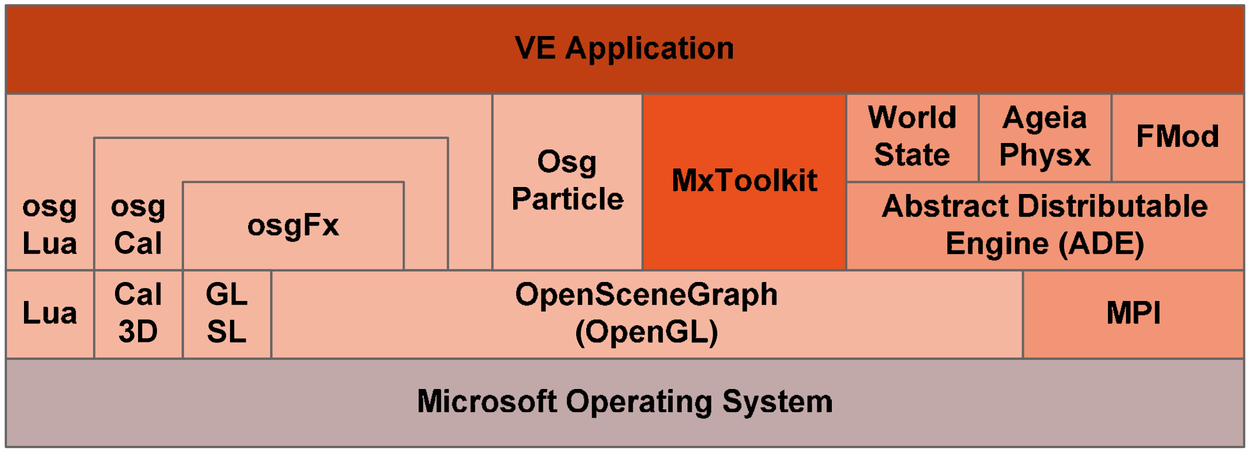
- The collision detection is performed by the PhysX API
- Kinematics' collision response:
  - Collide-And-Slide algorithm
- Dynamic collision response:
  - Dynamic Object –Dynamic Object: PhysX API solver
  - Avatar-Dynamic Object: Collide-And-Slide algorithm for the avatar and apply an impulse, using a derived force, to the contact point of the dynamic object

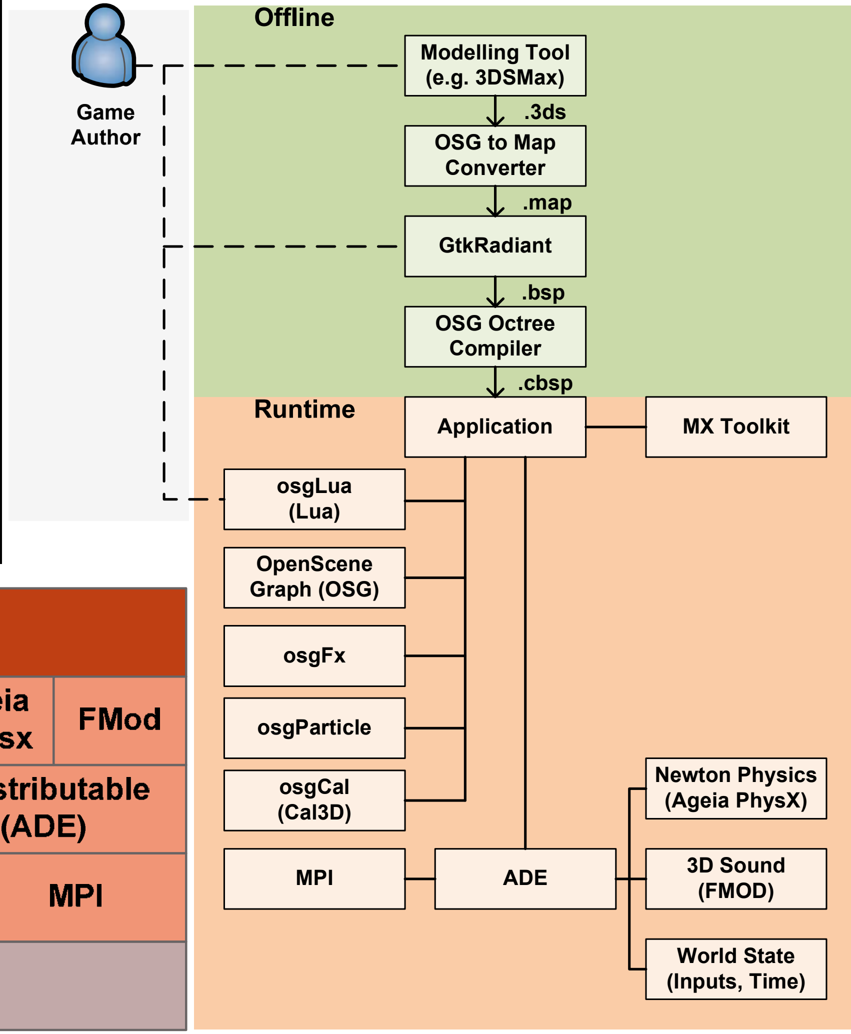
Newton Physics Engine

- Three entity nodes: static, cinematic, and dynamic
- At each simulation step, the application transverse the scene graph:
  - The cinematic nodes and the character update their (world) pose for that step
  - On step, the physics engine applies the forces on dynamic entities, and calculates the actor and character collisions.
  - Next, it sends to client nodes the updated character and dynamic entities poses
  - On all nodes of the cluster, the new dynamic and character state are propagated to the scene graph and application

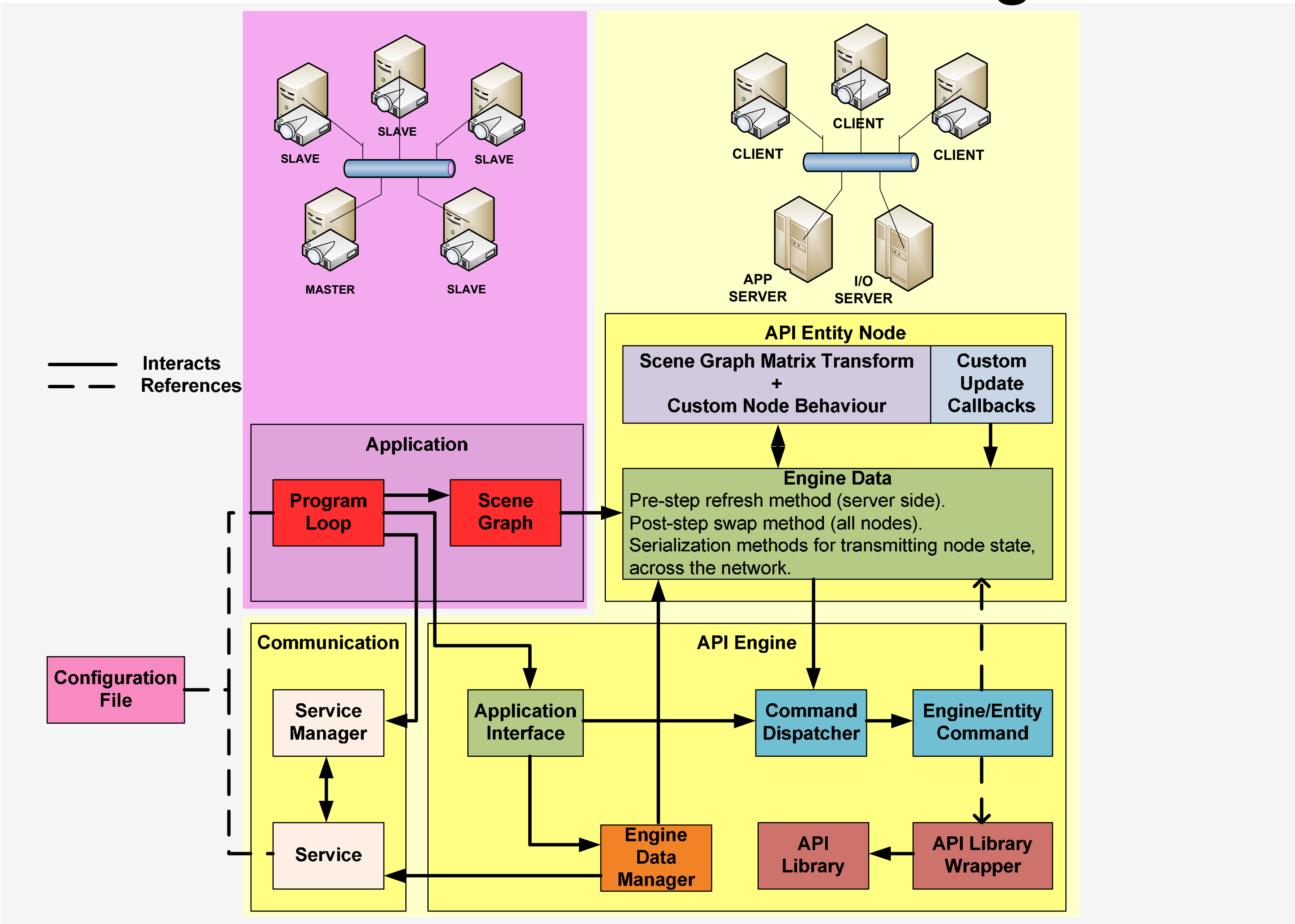
CaveH Middleware Architecture





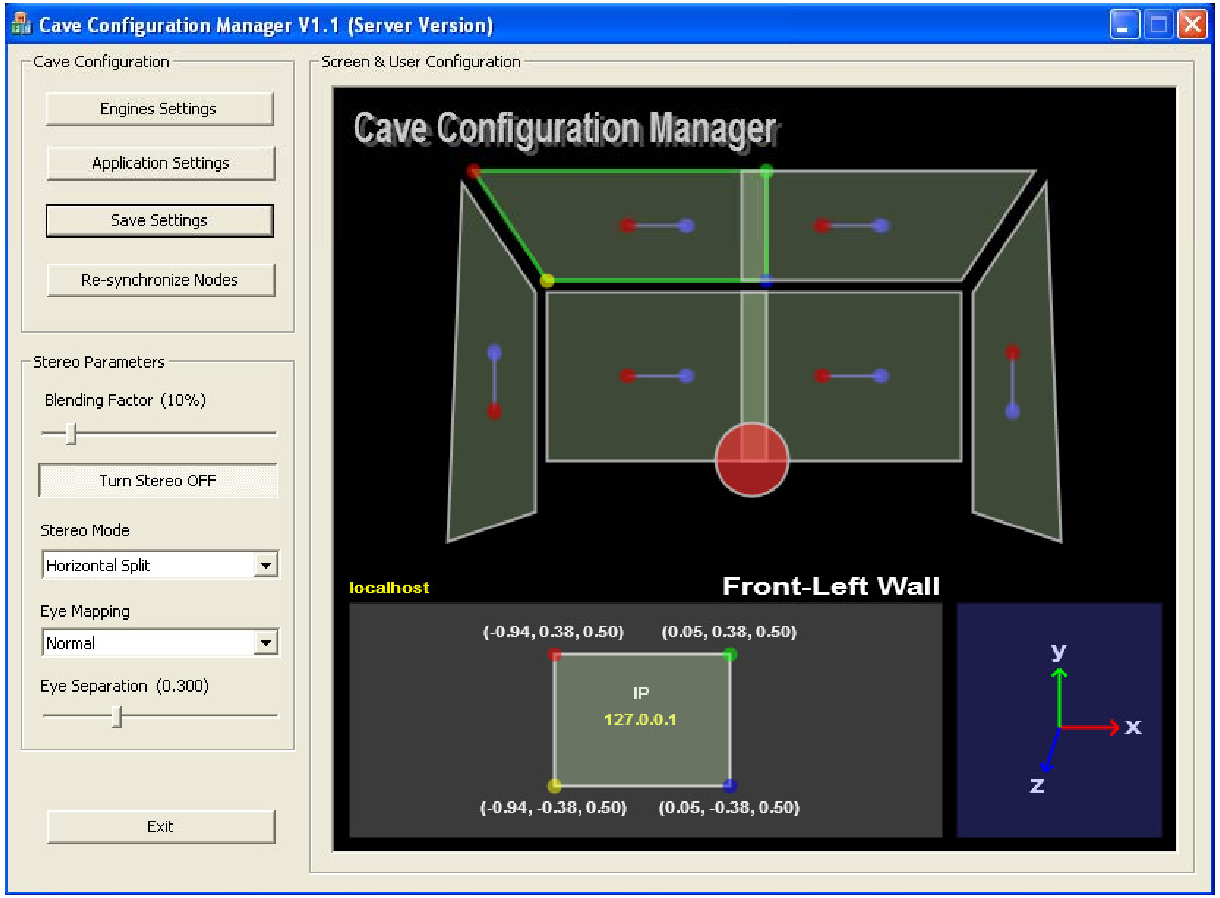


CaveH Middleware Logic



Projection and CaveH middleware Configuration

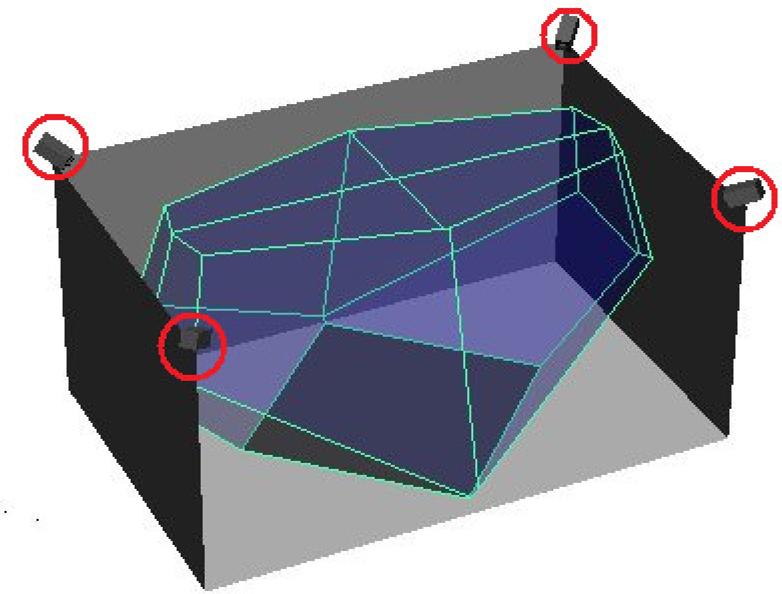
- User interface

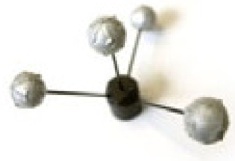


User Tracking for CaveH

Hardware Setup:

- 4 AVT Firewire Pike Cameras (640x480, 205 fps)
- 4 LED ring array emitters
- 1 Shutter Controller
- Several retro-reflective markers

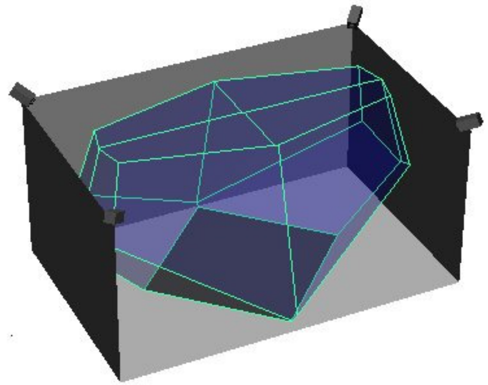




Lens Analises

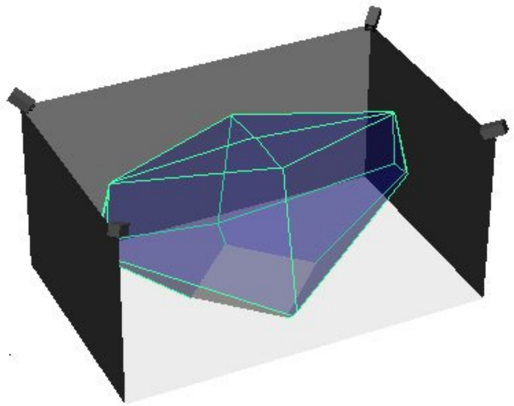
Lens: 3.5mm

- Field of View = 81,2º
- Resolution at the center = 3,52mm



Lens: 4.5mm

- Field of View = 67,4º
- Resolution at the center = 2,74mm



Scripting Language

- Allows programming behaviors for certain objects/entities, in a complete independent Cave environment

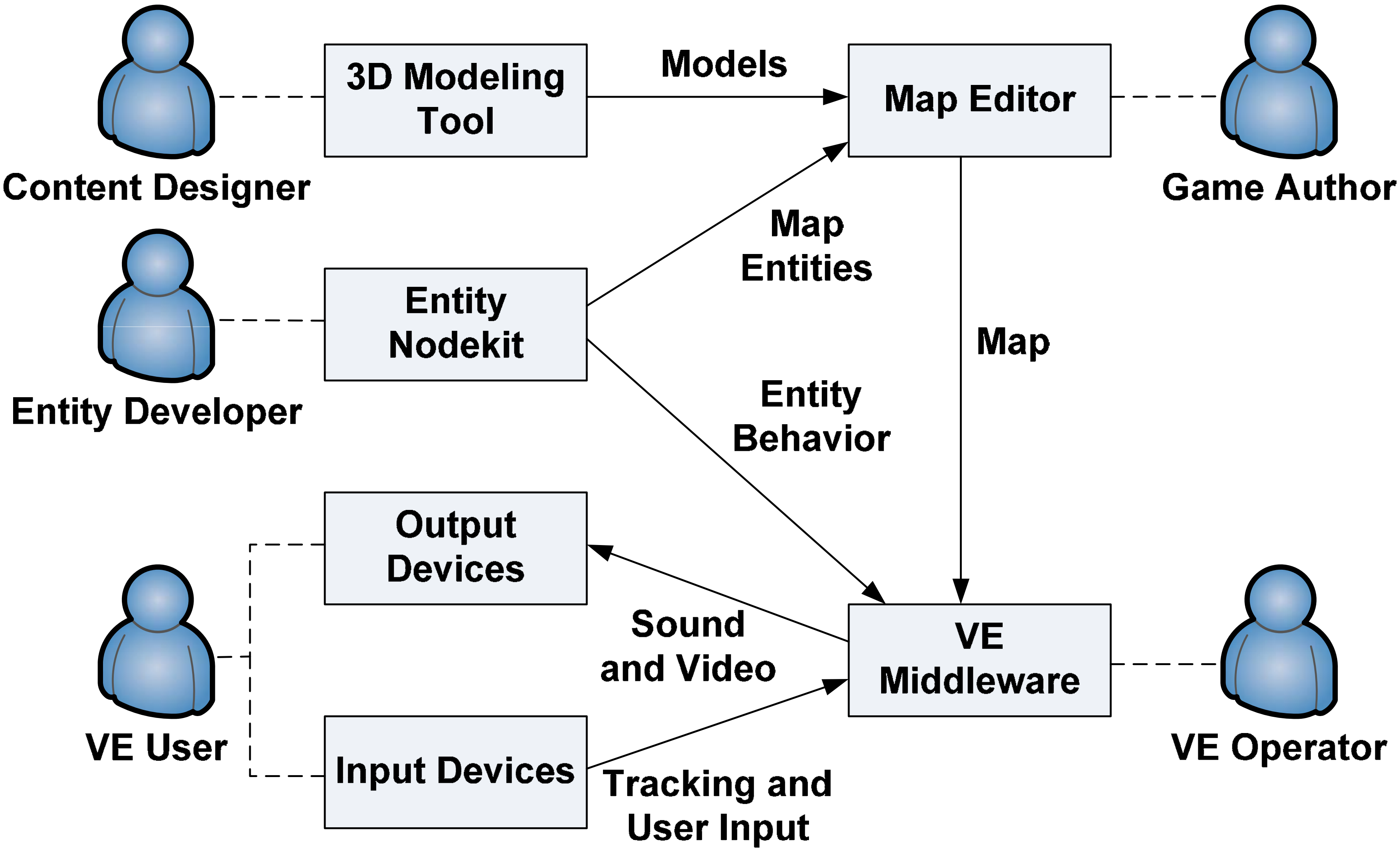
- The used scripting language is **LUA** (from PUC Brasil)

- Scripts are integrated with the application using the node kit **OsgLua**

Content Authoring

- 3D Modeling
  - 3D Studio, Maya, Blender
- Character Animation (Cinematic and Hierarchical)
- Scripting Languages
  - Lua
- 3D Scenario Development (Maps)
- 3D Audio

Content Authoring Flow



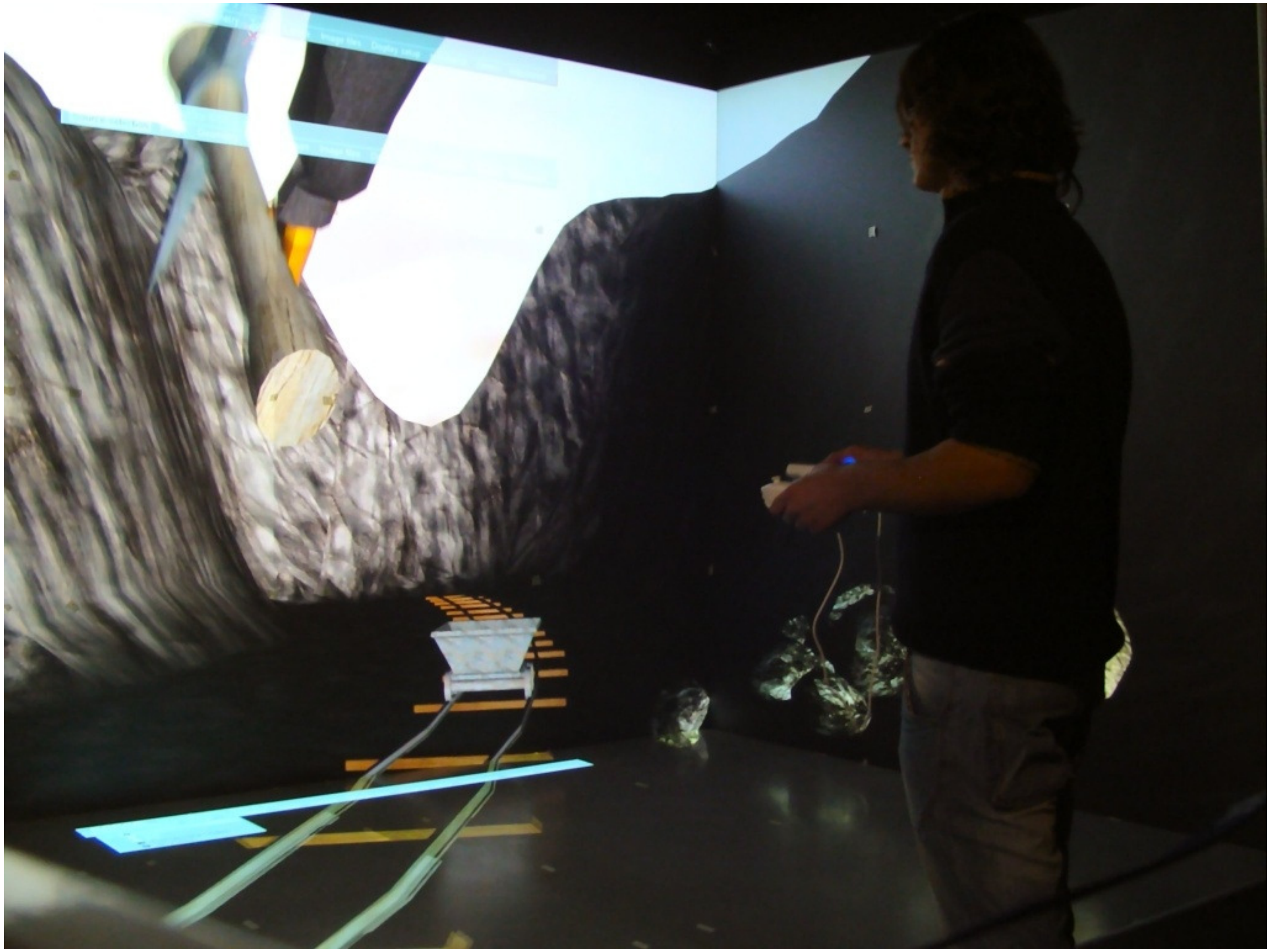
Content Authoring

- **3D Studio Max** for model and map (3D scenario) geometry creation as well as characters and animations
- **GtkRadiant** is used for content integration authoring

• 3D Studio Max for map modeling

• Used in game maps creation (i.e. Quake)
• Allows map entities to be edited in a single authoring environment

Virtual Mine Visit



Special Thanks

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