Designing multi-projector VR systems: from bits to bolts

Luciano Pereira Soares, TecGraf - PUC-Rio / CENPES - Petrobras
Joaquim A. Pires Jorge, INESC-ID, DEI Instituto Superior Técnico
Miguel Salles Dias, ADETTI / ISCTE, MLDC Microsoft
Bruno Araujo, INESC-ID, DEI Instituto Superior Técnico
Alberto Raposo, TecGraf - PUC-Rio

ISCTE Instituto Superior de Ciências do Trabalho e da Empresa · Tecgraf PUC-RIO · inesc id lisboa

Main Topics

- Introduction
- Display Technologies
- Display Hardware Infrastructure
- Image Generation
- Tracking
- Multimodal Interaction
- Audio in Immersive Environments
- Software for Immersive Environments
- Case studies

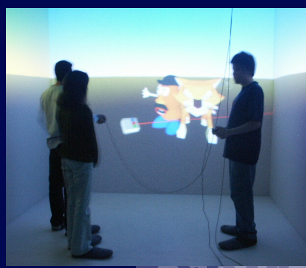
Introduction

Luciano P. Soares
Tecgraf - *Computer Graphics Technology Group*
Pontifical Catholic University of Rio
lpsoares@tecgraf.puc-rio.br
http://www.tecgraf.puc-rio.br/~lpsoares/

Background

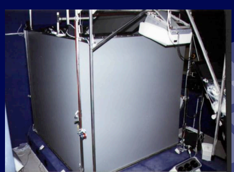
- Immersive Environments
  – Stereoscopy
  – Tracking
  – Computers
  – Screens
  – Projectors…

Used to improve the feeling of immersion.

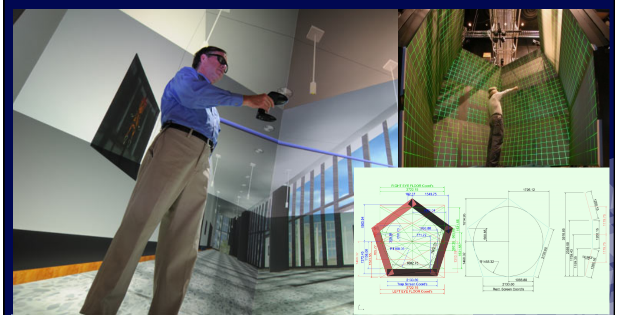


Cave Automatic Virtual Environment

- **First cubic multi-projection**
  – University of Illinois (1992)
  – Cluster of SGI Personal IRIS
  – Shared Memory



StarCAVE



calit2

Fish Tank

Many users enjoy because they are used to this solution and the perceived resolution, brightness, crispness are different from the current immersive solutions available.

Applications

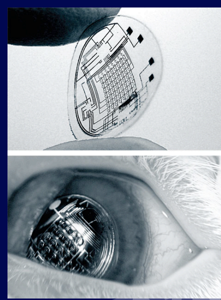
- Education
- Medicine
- Engineering
- Military
- Entertainment
- Etc…

Display Technologies

Luciano P. Soares
Tecgraf - *Computer Graphics Technology Group*
Pontifical Catholic University of Rio
lpsoares@tecgraf.puc-rio.br
http://www.tecgraf.puc-rio.br/~lpsoares/

Visualization Systems

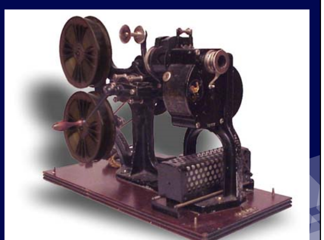
ePaper - Flexible, full-color OLED (Sony)



University of Washington

Projection Technologies

- Several Solutions
- Several Parameters
  - Brightness
  - Contrast
  - Resolution
  - Refresh Rate
  - Color
  - Lens
  - Connections
  - Management



Projetor Pathe Freres 28mm KOK

Brightness "Luminance"

- What are the terms?
- Which are the units?
- How to measure?
- How to choose?

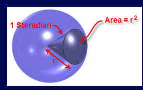
Light Terms

Term	Definition	Unit
Visible Light	light that excite the retina	nm
Luminous Flux	light energy / unit of time	lumen
Luminous Intensity	luminous flux from a point	cd
Luminance	luminous intensity per projected area	cd/m^2(nit)
Illuminance	luminous flux incident on a surface/area	Lux (fc)
Radiance	amount of light from area in a solid angle	$w/sr{*}m^2$
Brightness	subjective perception light intensity	-

Hot to work with these units?

Lumen is the SI* unit of luminous flux.

Formula : 1 lm = 1 cd x sr

 * 

Conversions:

1 candela / meter^2 = (lm / area) * gain / π

Lux = 1 lumen / meter^2

Foot-lambert = (1 / π) candela / foot^2

cinema (SMPTE) recommends 16fL (55 candela / meter^2)

* (Le Système International d'Unités)

How to measure?

Several ways:

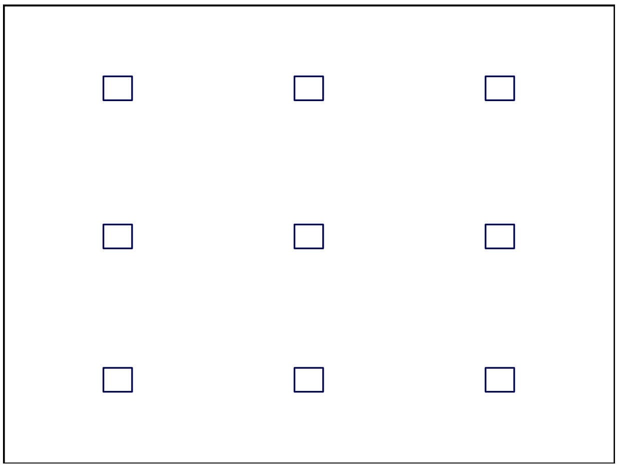
- Peak lumens (beam current limiter)
- ANSI Lumens (created in 1993)

PR-550 LiteMate Procan

ANSI (American National Standards Institutes) :

- 25 degree Celsius;
- Wait 15 minutes;
- Dividing image into 9 equal rectangles;
- Values are divided by the screen size (m^2);

Projector brightness is not homogeneous, for instance CRTs can have only 30% of brightness in the corners compared to the center of projection. Modern projectors usually have more than 90% the same brightness.



Measuring Luminance

$$L = \frac{K * N^2}{t * S}$$

Olympus X915

		N (aperute)	t (exposure time)	S (ISO speed)	K (constant)	calculate value	theorical value (specification)
macbook	Olympus	5	0,004	400	14	**218,75**	250

Displays Brightness

Display	Brightness (cd/m^2)
CRT monitor	50 - 150
LCD monitor	250 - 450
Plasma monitor	1000 - 1500
DLP TV	450 - 700
LED TV	450 - 550

FPDM—the Flat Panel Display Measurements Standard offered by the Video Electronics Standards Association

Illumination Balance

- Adapt to high illumination is fast: seconds;
- Adapt to dark is slow: minutes;
- Constant changes leads to eye fatigue;

- *Solution: keep the illumination balanced*

How to Choose the Brightness ?

Ranges (lumens) small screen

< 1.000: cheap, home use;
1.000 to 2.000: cheap, office;
2.000 to 3.000: expensive, office;
> 3.000: expensive, auditoriums.

Ranges (cd/m^2)

< 50: dark rooms;
50 to 100: dim rooms;
100 to 200: regular rooms;
> 200: outside.

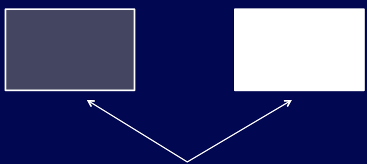
Depends on some factors:

- Ambient light
- Screen size
- Stereoscopy
- Subject

Contrast

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

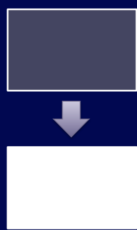
Contrast = (max intensity – min intensity) / min intensity

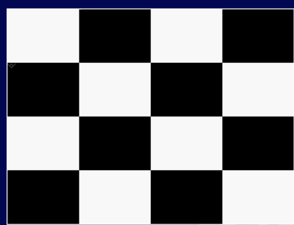


X:1

Contrast

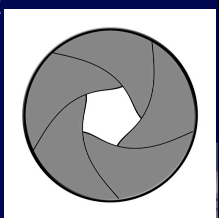
On/Off contrast X ANSI contrast





Dynamic Iris

A dynamic iris is a device built into some projectors that sits between the lamp and the lens. 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.

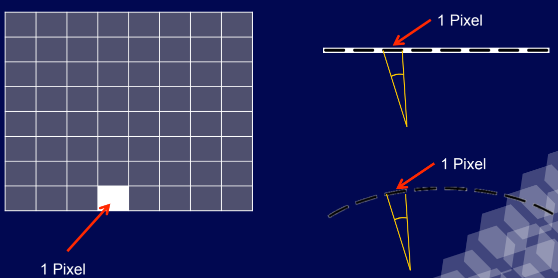


Resolution

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
Full-HD	1920x1080	16:9	2,073,600
WUXGA	1920×1200	16:10	2,304,000
WQXGA	2560×1600	16:10	4,096,000
4K	4096×2160	256:135 (1.896:1)	8,847,360
8K	8192x4096	2:1	33,554,432

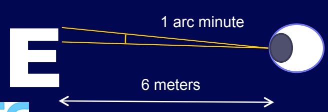
Not using the display's native resolution can degrade the quality of the final image.

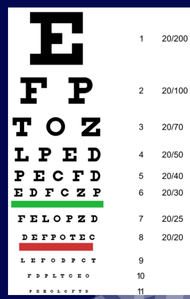
Pixel Size



Visual Acuity

- 6/6 vision(meters)
  – 20/20 (feets)
- Distance that a person see 1 arc minute





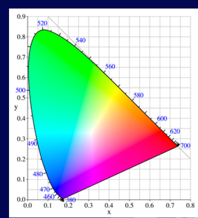
Snellen chart

Scan Rate / Display Frequency

- Frequency:
  – Bandwidth (MHz);
  – Horizontal frequency range (KHz);
  – Vertical frequency range (Hz).
- Some projectors compress or change the source frequency;
- Vertical Blanking Interval (VBI) – VBLANK;
  – Reduced Blanking Interval.
- People usually see 15Hz blinking for dark images and 50Hz in a bright environment;
- Increasing refresh rates, reduce eye strain;
- People are more sensitive to flicker at the edges of the field of view.

Colors

- 24 bits colors (8 bits per channel)
  – 256 gray scale, 256 for each color, etc;
  – total of 16.7 million colors.
- 30 bits colors (10 bits per channel)
  – ~1 billion colors
  – 1024 gray scale and each pure color
- 36 bits colors (12 bits per channel)
  – 69 billion colors
- 48 bits colors (16 bits per channel)
  – 2800 trillion colors



CIE color space chromaticity diagram

Color Temperature

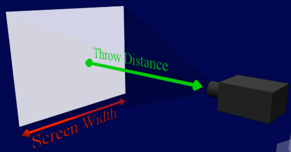
- The temperature is stated in Kelvin (K);
- Temperature of an ideal black-body radiator;
- Higher color temperatures (5,000 K or more) are cool colors - bluish;
- Lower color temperatures (3,000 K or less) are warm colors – reddish.
- The human eye seems to be more receptive to the primary color wavelengths that are used by LED and laser displays to other conventional displays.

Standard	Temperature
D50	5003
D55	5503
D65	6504
D75	7504

100 101 102 103 104 105 106 107 108 109

Lens

- Short throw, Fish Eye x Tele(photo) zoom
- Motorized x Fixed
  - Lens Shift
  - Zoom Lens
- Focal length
- Throw ratio



Throw Distance = Screen Width X Lens Throw Ratio

Example:

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

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

Lamps Characteristics

- Well suited spectrum;
- Life cycle;
- Lumen maintenance;
- Cooling solutions.
- Noisy
- Dual-mode

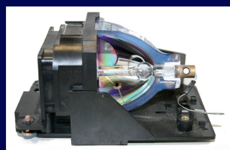
Lamps


- Incandescent
- Arc-lamps / Gas discharge
  - UHP - Ultra-High Performance
  - Xenon arc lamps
- LED - light-emitting diode
- Laser



UHP

- The Hg pressure inside the lamp has to be higher than 200 bar 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 < *1400 K*


IWASAKI HSCR165Y5H

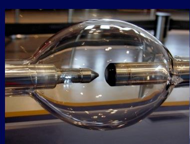

Philips UHP lamp

Xenon Lamp


automotive HID headlights 1991 BMW 7-series.

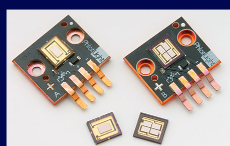
- Xenon short-arc lamp
  - Noble gas (atomic number 54);
  - Expensive;
  - Short life time.


Christie 3.0kW Xenon Lamp


Short-arc lamp 15 kW Xenon

LED light

- Long life, little maintenance;
- Do not lose brightness as they age;
- Improvements in color reproduction;
- Small luminous flux;
- Avoids color wheel;
- Not yet very efficient.


Phlatlight - PHotonic LATtice (Samsung)

Connections

- VGA
- DVI (single-link x dual-link)
- HDMI
- Display Port (mini display port)
- SDI
- wireless

Degradation

New projector

Old projector

Other Points to Evaluate

- Aspect Ratio
- Color and Geometric Alignment
- Weight
- Audio (Speakers)
- Auto focus
- Price

Common Projection Technologies


CRT Cathode Ray Tubes


LCD Liquid Crystal Displays

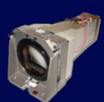

DLP Digital Lighting Processing


LCoS Liquid Crystal On Silicon


Laser Diffraction and Raster

CRT (Cathode Ray Tubes)

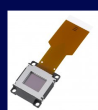
- Based on 3 independent tubes (Red, Green, Blue);
- Advantages: calibration flexibility, high refresh rate (> 120MHz), high resolution, anti-aliasing;
- Disadvantages: low brightness, noise signals, complex color convergence.



Marquee 9500

LCD (Liquid Crystal Displays)

- Based on liquid crystal technologies
- Advantages: low cost, several options in the market
- Disadvantages: low refresh rates, screen door effect



Sony BrightEra LCD Panel

Christie LX66

D
LP (Digital Lighting Processing)

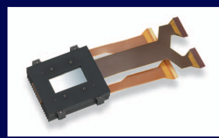
- Based on Digital Micromirror Devices - DMD
- Advantages: supports high lumens lamps, some models supports active stereo,
- Disadvantages: some screen door effect

Texas Instruments, Inc.

Christie Mirage S+14K

LCOS (Liquid Crystal On Silicon)

- Based on reflexive liquid crystal;
- Advantages: high resolution, small screen door effect, high contrast;
- Disadvantages: only few models.



Silicon X-tal Reflective Display

Barco's LX-5

GLV (Grating Light Valve)

- Based on diffraction in 1D light scanning and laser as light source
- Advantages: ultra high resolution, support to active stereo, no screen door effect
- Disadvantages: speckle, not very bright, line pattern

Evans and Sutherland

Laser 2D Scanning Projector

- Based on a 2D light scanning of a laser light source;
- Advantages: vivid colours, can be very small;
- Disadvantages: speckle, not very bright.

Laser Display Technology

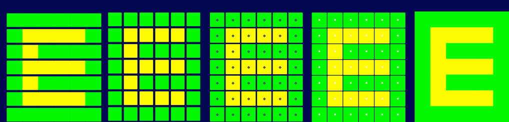
Microvision (MVIS) Blog

Color sample

- Low exposure (due to color wheel cycle);
- Rainbow effect can appear around bright on-screen objects.

Fill-rate / Fill-factor / Aperture ratio

- The space between the pixels has no image, creating a grid-like structure.
- LCD ~83%
- DLP ~88%
- LCoS ~93%
- GLV ~100%



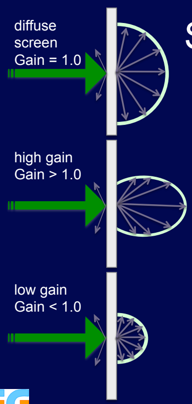
Screens

- Flexible
- Semi-rigid
- Rigid
- Painted

Substrate

- Glass
- Acrylic

Screen gain



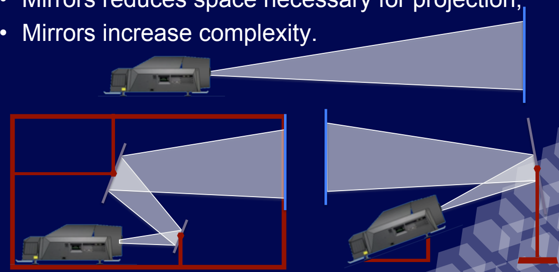
- The gain is defined by the ratio of the light intensity in the perpendicular direction of the screen compared to the reflection of a standard diffuse screen (MgC03);
- This standard screen has a gain of 1.0;
- The name of this measurement is Peak Gain at Zero Degrees Viewing Axis.

Half-gain Angle and Viewing Angle

- The viewing angle that the luminance is half of the luminance in the frontal angle is known as half-gain angle;
- This angle can be measured at horizontal and vertical positions, but this is not common;
- The viewing angle of a screen is defined when the contrast gets smaller than 10:1 in a dark room.

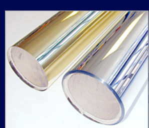
Mirrors

- Used to fold projection image paths
- Mirrors reduces space necessary for projection;
- Mirrors increase complexity.



Mirrors Substrate

- Glass
  - Ease of fabrication
  - Rigidity
  - Scratch-resistant
  - Reflective material silver or aluminum
  - Heavy
- Polyester film
  - Polyethylene Terephthalate (PET)
  - Usually known as Mylar
  - Thickness from 12um (0,0005")
  - Light
- Acrylic and Plastic Mirror



Display Hardware Infrastructure

Bruno R. de Araújo
Instituto Superior Técnico
Universidade Técnica de Lisboa
brar@vimmi.inesc-id.pt
http://immi.inesc-id.pt/~brar/

Overview

- Projection Geometries (Planar, Cubic, Domes)
- Multi-projection (Arrays and Mounts)
- Field Of View, Inter-reflection
- Hardware Color and Geometry Calibration
- Hardware Warping and Edge-Blending
- Site preparation, Video Transmission
- Control and Automation solutions

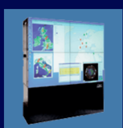
Projection and Screen Geometries

- Planes (PowerWall, InfinityWall, Panorama,etc)
- CAVEs
- Irregular (Workbenchs)
- Cilindric, Conics, Torus
- Sphercis
- Domes

Plane - Display Wall

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

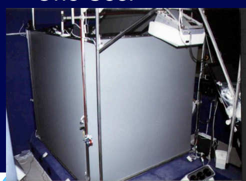





CAVEs

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





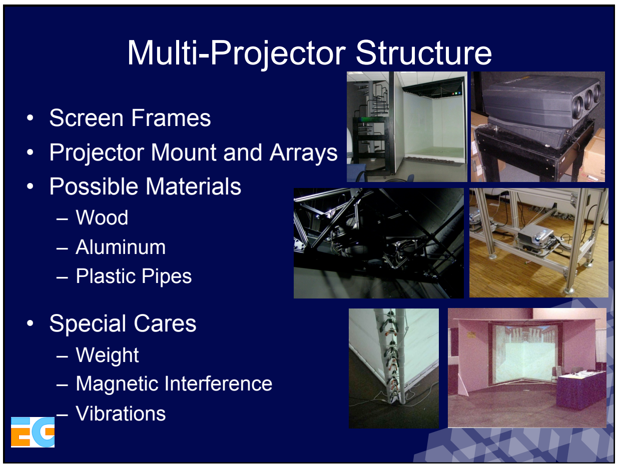

Cylindrical

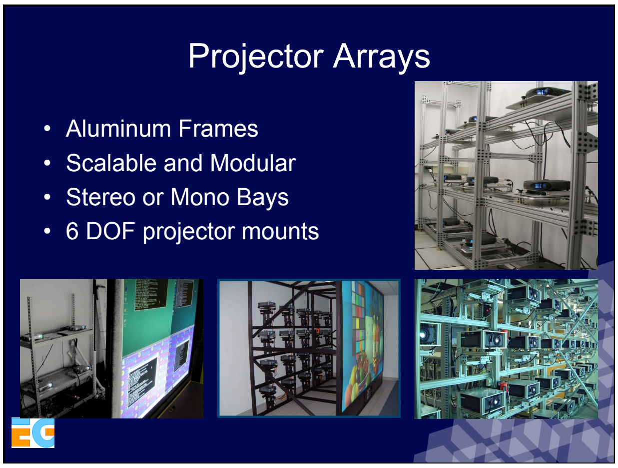
- Large Audience
- Projection Overlap
- Requires Blending

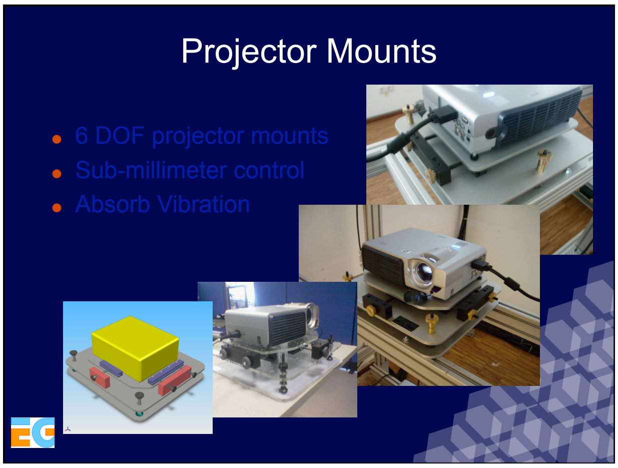
Spherical

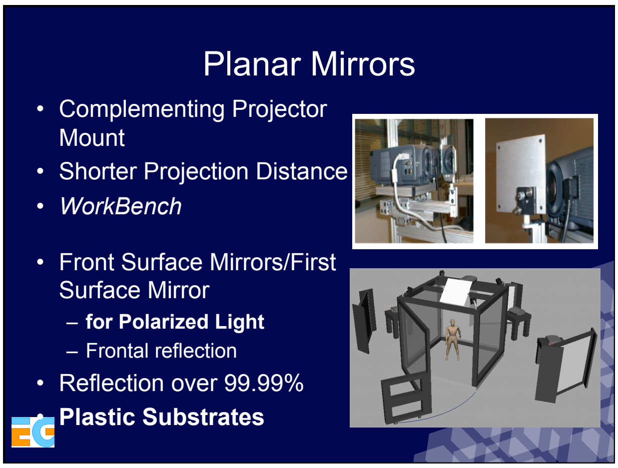
- Large Field of View
- Deformation Correction

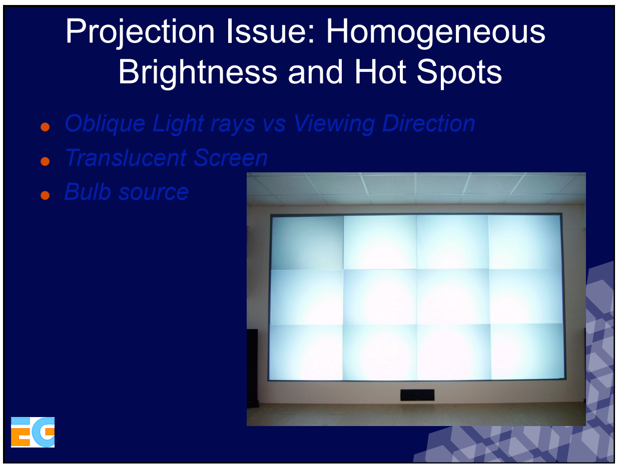

Alternative Solutions
Hang-glider
Thorus
WorkBench


Multi-Projector Structure
• Screen Frames
• Projector Mount and Arrays
• Possible Materials
– Wood
– Aluminum
– Plastic Pipes
• Special Cares
– Weight
– Magnetic Interference
– Vibrations


Projector Arrays
• Aluminum Frames
• Scalable and Modular
• Stereo or Mono Bays
• 6 DOF projector mounts

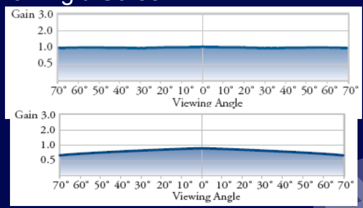

Projector Mounts
• 6 DOF projector mounts
• Sub-millimeter control
• Absorb Vibration


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

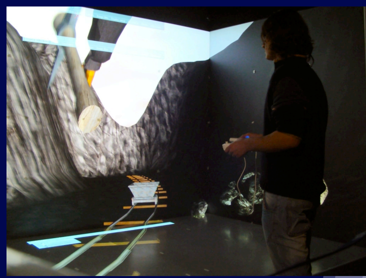
Projection Issue: Viewing Angle

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



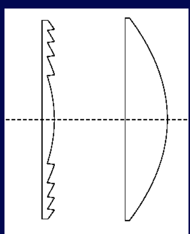
Projection Issue: Inter-reflection

- Cave: Light from other screens



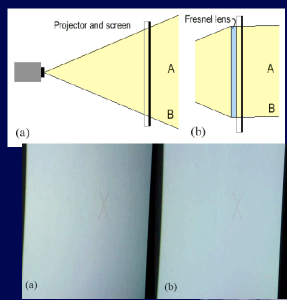
Redirecting Light: Fresnel Lens

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



How to use Fresnel Lens

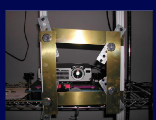
- Correct Projector rays
- Lens Size = Tile Size
- Minimum Space between tile > 0

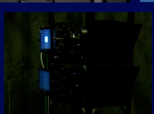


Stone, "Color and Brightness Appearance Issues in Tiled Displays",2001

Edge-blending

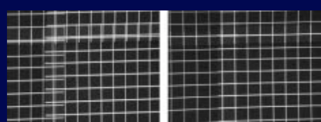
- Seamless edge blending
- Light Leak
- Small Overlap
- Almost aligned
- Solutions:
  - Physical
  - Software Mask
  - Hardware Projector





Geometry Calibration and Warping

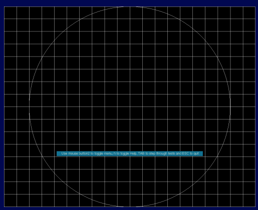
- Inter Projector Calibration
- Remove Seams
- Falloff Correction

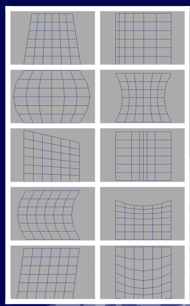


- Popular Technique:
  - Camera based Projector Registering
  - 2D Warping Map (Mesh)
  - Intensity Correction (Alpha-> Seams area)

Geometric Calibration

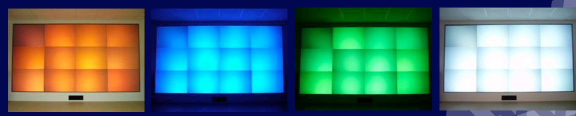
- Projector Registering
- Pattern Lines or Circle Dots
- Lens Distortion





Color Calibration

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

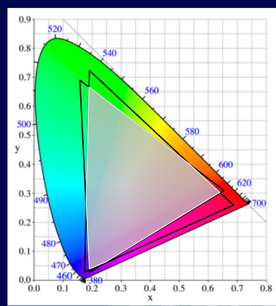


How to achieve the calibration color

- 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

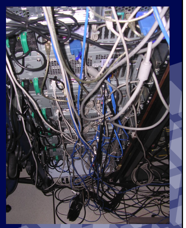
- Test card / Test pattern
- Vectorscope
- SMPTE Color Bars 16x9
- Usefull for Calibration evaluation

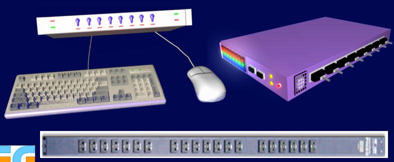
Site preparation

- 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 (VGA)
  - EyeViz (DVI)

- Video Matrix
  - Extron
  - Miranda

Image Generation

Luciano P. Soares
Tecgraf - *Computer Graphics Technology Group*
Pontifical Catholic University of Rio
lpsoares@tecgraf.puc-rio.br
http://www.tecgraf.puc-rio.br/~lpsoares/

Computers architectures

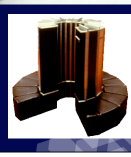
- Mainframes

IBM zSeries

- Mini-computers
  - Supermini

HP3000

- Supercomputers



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

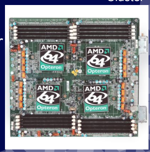
- Scalar Processors:
  - Several processors in several data
    Examples: SGI, SUN

SGI Onyx 3000

Memory Access

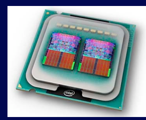
- Distributed Memory
  - Each processing unit is indep
    endent, has its own operating system and memory
  - Examples: basically *Clusters*
- Shared Memory (SMP)
  - All processors work over the same operational syst
    em, all the memory is accessible by any processor
  - Examples: SGI, multicore

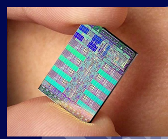

Cluster


8-way Opteron

Symmetric x Asymmetric

- Symmetric Multiprocessing
  - Every processor is capable to run the operating system
- Asymmetric Multiprocessing
  - Dedicated processors for different tasks


Intel Core 2 Quad


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)

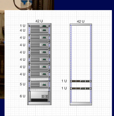
- *Single Program, multiple data streams* (SPMD)

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.

Organization

Rack



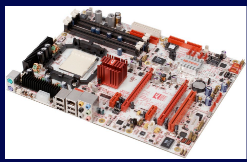
Shelf

Numerical Processing

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

Chipsets

- ATI Crossfire



- Nvidia nForce

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

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

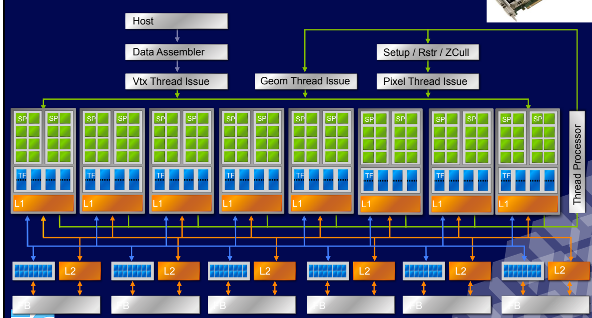
- Sample division
- Time division
- Image division
  - Static partitioning
  - Interleaved
  - Dynamic partitioning
- Eye division
- Scene division
- Volume division
- Operational Decomposition

Graphic Cards

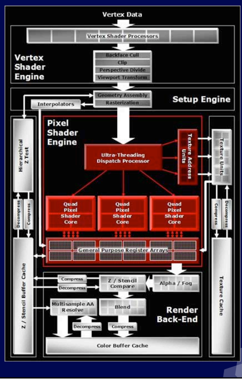
- Implements several graphical *pipelines:*
  - Nvidia (programmable)
  - ATI (programmable)
  - SGI "IR" (not programmable)

Tessellation → Vertex Processing → Geometry Processing → Pixel Processing → Pixel Rendering

Nvidia pipeline model



ATI / AMD

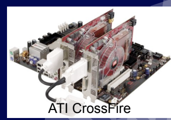


Graphic Cards Parallelism

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


Quantum 3D


Nvidia SLI


ATI CrossFire

High Density Multi GPU

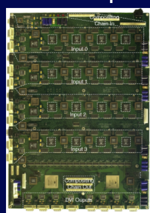
- SLI NVIDIA

- NVIDIA Quadro Plex

- Crossfire

Lightning2 & Sepia

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


Lightning2

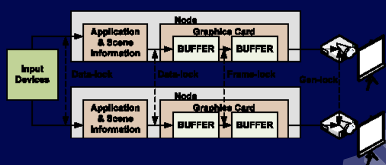

Sephia-2

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

Cluster 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

Tracking

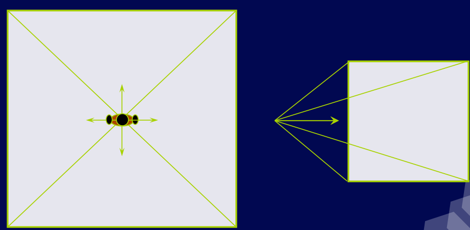
Miguel Dias
MLDC - Microsoft Language Development Center
Miguel.Dias@microsoft.com
http://www.adetti.pt/

Joaquim A. Jorge
Instituto Superior Técnico
Universidade Técnica de Lisboa
jaj@vimmi.inesc-id.pt
http://web.ist.utl.pt/jorgej/

Overview

- *Why User Tracking*
- *Tracking systems characteristics*
- *Tracking Technologies (Mechanical, Electromagnetic, Acoustic, Inertial, GPS, Optical)*
- *Infrared Tracking System in Detail*

Why User Tracking

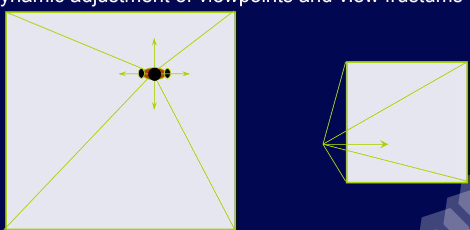


Top view

Frustum

Why User Tracking

Dynamic adjustment of viewpoints and view frustums

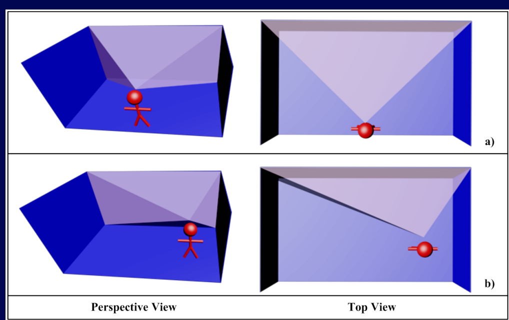


Top view

Frustum

Why User Tracking

Dynamic adjustment of viewpoints and view frustums



User Tracking

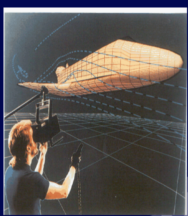
Technologies:
- Mechanical
- Electromagnetic
- Acoustic
- Inertial
- GPS
- Optical
  - example

Tracking systems characteristics

Update rate
Latency/Lag/Delay
Precision
Accuracy
Resolution
Interference/Distortion
Absolute/Relative
Range/Working volume
Size/Weight
Robustness to environmental factors
Degrees of freedom (DOFs)
Safety
Wired/Wireless

User Tracking

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



Problems:
- Motion constrained by the mechanical arm

Example: Boom by Fake Space Labs

User Tracking

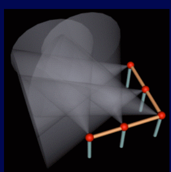
Electromagnetic Tracking Devices:
- Track Position and Orientation (6DOF)
- Measures the strenght of the generated magnetic fields (3 perpendicular wire coils)
- Lag of 5msec

Problems:
- Interference in the presence of other magnetic fields (metal objects, office furniture, CRTs)

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

Example: Arena by ADETTI

User Tracking

Inertial Tracking Devices:
- Orientation (3DOF) – conservation of the angular momentum
  - Measures angular acceleration, velocity orientation changes using gyroscopes
- Position (3DOF)
  - Measures acceleration, velocity and position changes using accelerometers
- Fast and accurate, and only limited by cabling

Problems:
- Drift between actual and reported values is accumulated over time (can reach 10° per minute) without compensation of drift. With compensation < 1° during 5 days.

Example: InertiaCube by Intersense

User tracking

GPS Tracking Devices:
- GPS ~ 13m,22m
- DGPS – EGONOS (EUROPE) ~2m,3m
- DGPS-OMNISTAR (global) ~2,5cm-10cm (less expensive), or <10 cm (more expensive)

Problems:
- Needs line of sight with more than 2 satellites
- Pseudolites for in-door

Example: Trimble GPS Pathfinder Pro XRS

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 0.1° precision

Problems:
- Line of sight, ambient light and ambient infrared radiation problem

Example: ARTrack by A.R.T

Tracking technologies revised

Acoustic - ultra-sound
Phase coherence
Time of flight

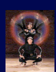

Intersense's IS-600 Mark2

Inertial
Accelerometers
Gyroscopes


Intersense's Inertia Cube

Magnetic
3 orthogonal magnetic fields


Ascension's Flock of Birds and PcBIRD


Polheumes' StarTrak

GPS ~ 13m,22m

DGPS – EGONOS (EUROPE) ~2m,3m

DGPS-OMNISTAR ~2,5cm-10cm, <10 cm


Trimble GPS Pathfinder Pro XRS

Mechanical


EXOS dexterous hand

Optical
Laser
Infrared


Ascension's LaserBIRD


ART

Vision-based
Kato: ARToolkit
ADETTI: TTS, X3M, ARTIC,FIRST

Hybrid

User Tracking

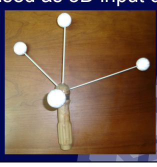
Wanted system:
- Without motion constraints
- No drift
- Without error accumulation
- Robust to interference
- Real-time update rate (> 30 Hz)

Chosen: Infrared Tracking System

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

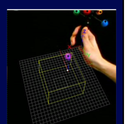
Infrared Tracking System

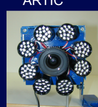
Precise tracking system that:
1) Follows an artefact attached to the user's stereo glasses, tracking its position (3 DOF), and enabling the underlying distribuited 3D graphics system to ajust the image of displays in real- time
2) Tracks several artefacts used as 3D input devices

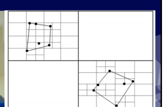


Related Work

Commercial Solutions Vicon / ART	- High performance and realibity - Prohibitive costs
ARTIC [Dias05] ADETTI	- Coulour Evaluation - Image ROI analysis - Update Rate: 50Hz - Precision: 2.93 mm / 2.58 °
Ptrack [Santos06]	- Divide and conquer quad-tree - Update Rate: 60 Hz - Precision: 4.60 mm / 1.98 ° - Accuracy: 6.50 mm / 2.48 °
ioTracker [Pintaric07]	- Stereo Reconstruction; - Model Fitting - Update Rate: 60 Hz - Precision: 0.05 mm / 0.20 ° - Accuracy: 5.30 mm RMS


ARTIC



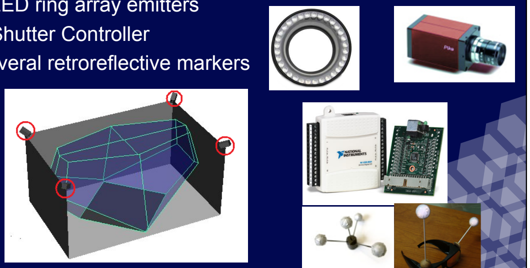

PTrack


ioTracker

Infrared Tracking System

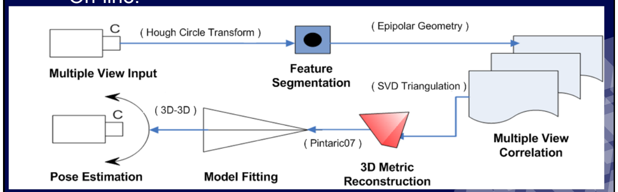
Hardware Setup:

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

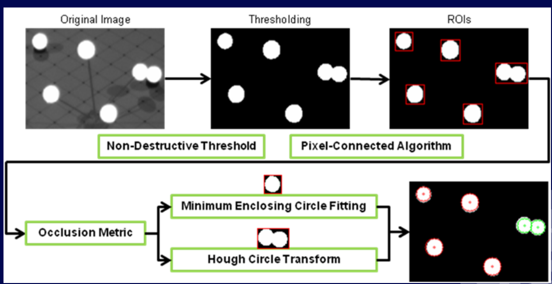


Tracking Algorithm

- Off-line steps:
  1. Camera Calibration: based on [Zhang99], using the DLT [Abdel-AzizKarara71] algorithm, available in OpenCV Library
  2. Artefact Calibration
- On-line:



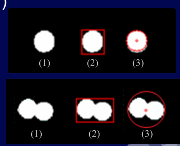
Feature Segmentation Workflow



Feature Segmentation

- **Occlusion Metric**
  - Based on five rules to label a bounding box as "occluded" or "normal" and decide which algorithm use (MEFC or HCT)

Rule	Decision Value
Bounding box white pixels percentage	≤ 65%
Bounding box width and height sizes difference	≥ 1.5 pixels
MECF and bounding box radius difference	≥ 0.9 pixels
MECF and bounding box area difference	≥ 60 pixels2
MECF circle exceeding bounding box limits	≥ 2.5 pixels

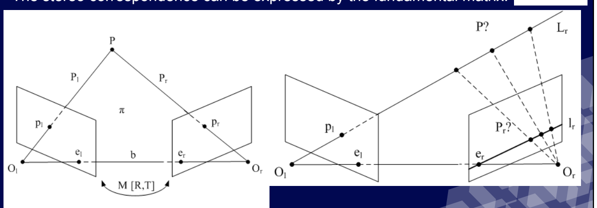


  - 97% of labelling robustness in Occlusion Metric
  - 10.06 ms saved per frame

124

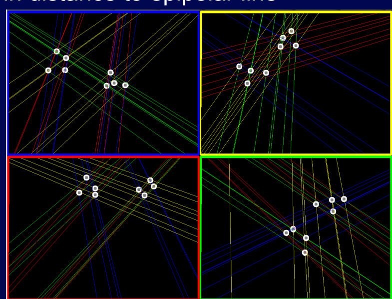
Multiple View Correlation

- **Epipolar Geometry**
- The position of a 3D point, *P*, can be extracted through two imaged points into two different views, if the geometric relation between the stereo pair (orientation and position, *M* [R, *T*]) is known.
- The stereo correspondence can be expressed by the fundamental matrix: $l_r = F\, p_l$



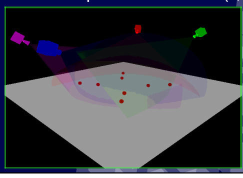
Multiple View Correlation

- Based in distance to epipolar line

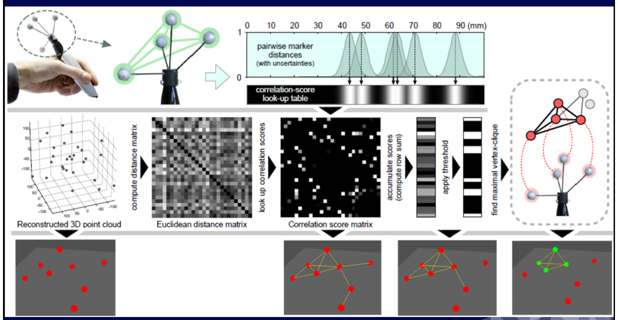


3D Reconstruction Metric

1) Direct Triangulation
   - Faster, can lead to numerical instability affecting the system robustness
2) Singular Value Decomposition [Golub93]
   - Using each camera's intrinsic (*K*) and extrinsic parameters (*M*), stack into matrix *A* the information for each view *i* (2D point location – *x(i), y(i)*)
   - Solve the *A* matrix by SVD, where $A = V \Lambda U$. Retaining the last row of the *V* matrix, the 3D reconstruction point coordinates (*x, y, z*) are the singular values of Λ

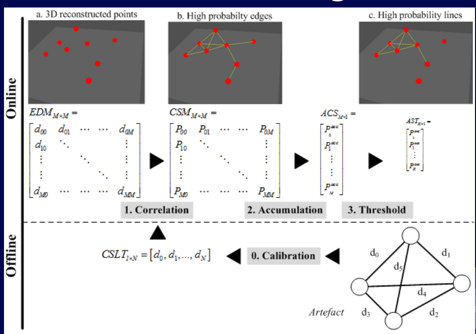


Model Fitting



Adapted from Pintaric, T., Kaufmann, H., Affordable Infrared-Optical Pose-Tracking for Virtual and Augmented Reality, 2007

Model Fitting



Adapted from Pintaric, T., Kaufmann, H., Affordable Infrared-Optical Pose-Tracking for Virtual and Augmented Reality, 2007

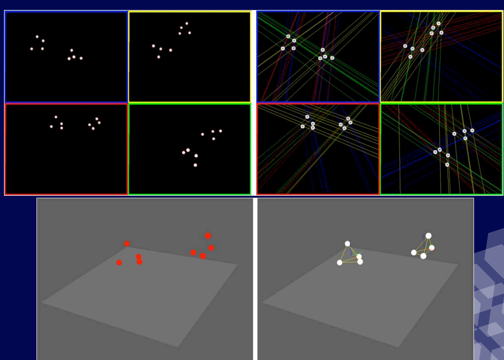
Pose Estimation

- [Haralick89]
  - Infer a rotation matrix, R and a translation vector, T that transforms the runtime 3D points, denoted by $\{x_1, x_2, \ldots, x_N\}$ into the calibrated model points $\{y_1, y_2, \ldots, y_N\}$ expressed the following equation, where N is the number of points (3 non-collinear points are required to estimate a 6 DOF pose) :

$$\sum_{n=1}^{N} w_n \| y_n - R x_n + T \|^2$$

  - By minimizing this error function a solution the rotation matrix and translation vector can be determined through SVD [Golub93]

Tracking Algorithm Review



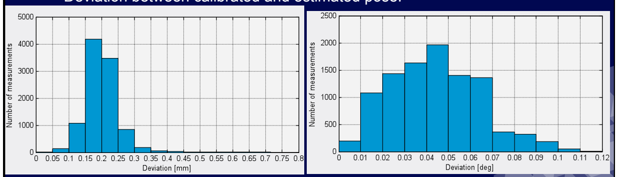
Tracking Results

- To assess the system performance and reliability we have assembled a preliminary setup in our Computer Graphics lab at ISCTE-IUL, of size 4 m x 4 m x 2m.
- Frame Rate and Latency
  - 10 minutes experiment
  - While moving 2 artefacts
  - Mean frame rate: 24.80 fps
  - Mean latency: 40.32 ms

17

Tracking Results

- Precision in artefact pose estimation
  - 10 000 samples
  - 4-markers artefact statically placed in working volume
  - Deviation between calibrated and estimated pose:



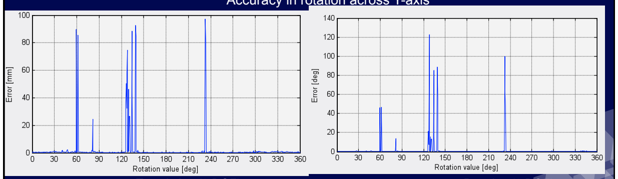
Translation (3 DOF) Rotation (3 DOF)

- **Mean precision: 0.08 mm / 0.04 º**

Tracking Results

- Accuracy in artefact pose estimation
  - Tests across all 6 DOF.

Accuracy in rotation across Y-axis



Translation (3 DOF) Rotation (3 DOF)

- **Mean accuracy: 0.93 mm / 0.51 º**
- High maximum error due the Hough Circle Transform failure
- Although severe errors (>5.0 mm / 2.0 º) only represent 0.08% of experiment

Infrared Tracking System Conclusion

- A complete hardware and software architecture of an infrared-optical tracking system was presented showing some advances in current state-of-the-art
- Requirements fulfilled:

	Requirements	Results
Mean frame rate	25.0 fps	24.80 fps
Mean precision	0.10 mm / 0.10 º	0.08 mm / 0.04 º
Mean accuracy	1.0 mm / 0.50 º	0.93 mm / 0.51º

- Improvements should be addressed to solve Hough Circle Transform

20

Multimodal Interaction

Miguel Dias
MLDC - Microsoft Language Development Center
Miguel.Dias@microsoft.com
http://www.adetti.pt/

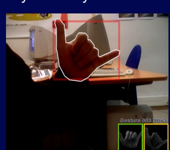
Joaquim A. Jorge,
Bruno Araújo
Instituto Superior Técnico
Universidade Técnica de Lisboa
jaj@vimmi.inesc-id.pt
http://web.ist.utl.pt/jorgej/

Human-Computer Interfaces for Virtual Reality

HCI for Virtual Reality

Styles of input devices:

- **Discrete input devices**: Any device which is producing button signals
- **Continuous input**: Gesture based devices like cyber gloves, joysticks, speech recognition, touch pads, etc.
- **Hybrid devices**: Combination of both discrete and continuous interaction into a single device. This is the mostly used style: Nintendo Wii



HCI for Virtual Reality

Text input:

- Standard keyboard
- Chord keyboard
- Contact glove keyboard
- Gesture glove keyboard
- Virtual keyboard operated with a pointer
- PDA based handwriting recognition

HCI for Virtual Reality

Graphical input:

- Joystick
- Trackball
- Gyration (3D) mouse
- 6 DOF

Multimodal:

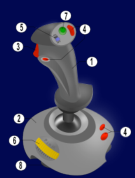
- Eye tracking
- Speech
- Bio-sensors
- Gesture

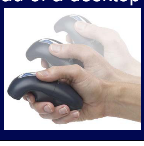
- Other:
  - Desktop wireless mouse, trackpad, touch screens
  - Game pad

HCI for Virtual Reality

Graphical input :

- Joystick
- Trackball: A trackball is a pointing device that is similar to a mouse turned upside down
- Gyration Mouse: A gyration mouse can be operated in the air instead of a desktop





HCI for Virtual Reality

Spaceball

Spacemouse

- 6DOF input
- They detect the slightest fingertip pressure applied to them and resolve the pressure into X, Y, and Z translations and rotations
- This provides interactive 6DOF control 3D graphical objects
- http://www.3dconnexion.com/index.php
- http://www.inition.co.uk/inition/products.php

HCI for Virtual Reality

Ascension Wanda

- 6DOF input
- Joystick
- http://www.ascension-tech.com/products/wanda.php

Hornet

- Hornet is a wired input device designed to house the sensors of electromagnetic tracking systems like, e.g. Polhemus.

HCI for Virtual Reality

Opti-Hornet

- Opti-Hornet is an additional wireless input device with characteristics comparable to Hornet. Attached wings with reflectors for optical tracking systems plus radio communication for the buttons supplement the functionality.

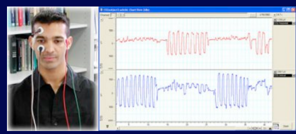
HCI for Virtual Reality

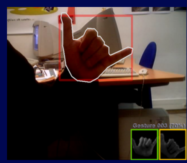
Nintendo Wiimote

- 11 buttons (Left, Right, Up, Down, Minus, Plus, One, Two, Home, A, B - Trigger)
- IR Camera Sensor (at front): detects 4 x 3D points, but only with 2DOF
- Rumble (vibration)
- Speaker (4200Hz)
- 5-6DOF:
  - Rotation: Pitch (local xx´), Roll (local zz´). NO Yaw (local yy´) without infrared activated
  - Translation: Unit acceleration (x, y, z) + Magnitude (Force)

Multimodal HCI for Virtual Reality

- Eye tracking
- Speech
- Gesture
- Bio-sensors





Multimodal HCI for Virtual Reality

Eye tracking

- Electro-oculography (EOG)
- Video-based

Multimodal HCI for Virtual Reality

Speech

- Command & control
- Can be used to start, pause and stop the simulation, control the navigation in VR, and choose gadgets
- Microsoft SDK supports several languages (Portuguese, English, Spanish, Japanese, etc.)
- Commands are interpreted using XML format

Speech Command & Control

Scenario

Enable Voice Dialing from stored contacts without prior training or enrollment

Background

Grammar
Lexicon
Frontend
Acoustic Model
Search

Contact List

Anoop Gupta
Bill Gates
Jeff Raikes
Steve Balmer

Call

Grammar

Anoop Gupta
Bill Gates
Jeff Raikes
Steve Balmer

Speech Command & Control

Scenario

Correct name pronunciation is crucial to this scenario

Background

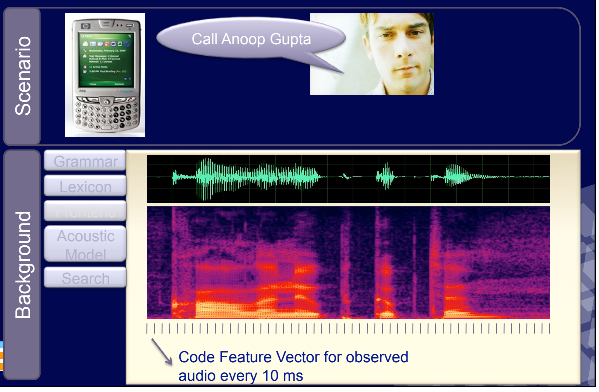
Grammar
Lexicon
Frontend
Acoustic Model
Search

Word	Phonetic Pronunciation
Anoop	ax n uw p
Gupta	g uw p t ax g ah p t ax
call	k aa l k ao l

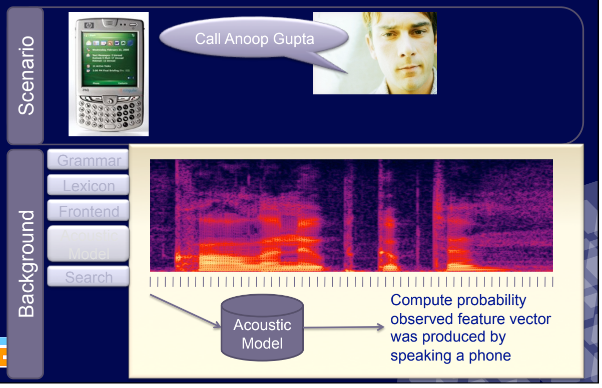
Lexicon Size: ~100,000 words

Letter-To-Phoneme conversion used if not in lexicon

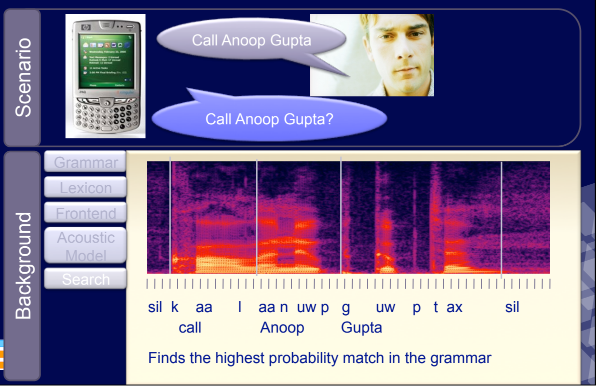
Speech Command & Control



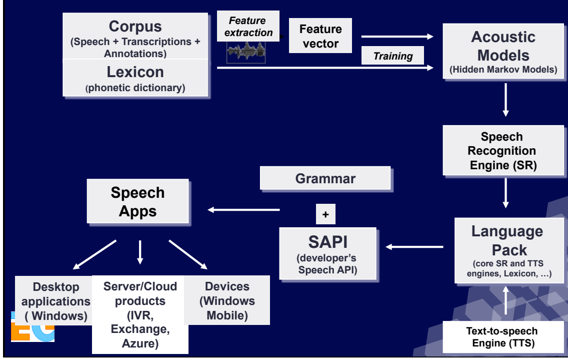
Speech Command & Control



Speech Command & Control



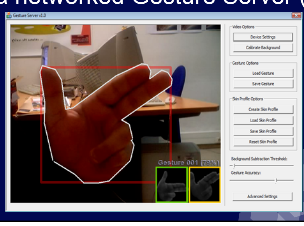
Run-time architecture with SR and TTS datapath



Multimodal HCI for Virtual Reality

Gesture

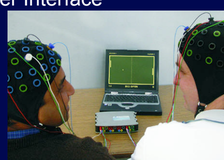
- Can be used to perform simple actions
- Invariant to rotation and scaling
- Based on a networked Gesture Server (client-server)



Multimodal HCI for Virtual Reality

Bio-sensors - EEG

- Electroencephalography (EEG) is a technique of exploration of the electrical activity of a brain based on measurements of electric potentials generated by neurons
- Used in BCI – Brain-Computer Interface



http://www.gtec.at/products/g.BCIsys/bci.htm

Multimodal interfaces

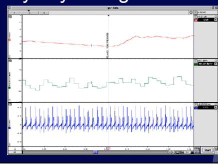
Bio-sensors - EMG

- Electromyography (EMG) is a medical technique for measuring muscle response to nervous stimulation.
- EMG is performed using an instrument called an electromyograph, which detects the electrical potentials generated by muscle cells when these cells contract

Multimodal interfaces

Bio-sensors - EDR

- Electrodermal response (EDR) is a method of measurement of the changes in the resistance of the skin usually resulted from varying emotional states. This technique measures the skin's conductance between two electrodes, which are small metal plates that apply a safe, imperceptibly tiny voltage across the skin



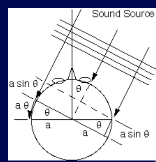
Audio

Bruno R. de Araújo
Instituto Superior Técnico
Universidade Técnica de Lisboa
brar@vimmi.inesc-id.pt
http://immi.inesc-id.pt/~brar/

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).
- 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 Example (Scene Graph):

- FMOD Ex Sound System
- Client/Server audio simulation
- Sound source as a scene graph node
- Map node, for reverberation and occlusion effects
- During the simulation step
  - Sound source pose are updated
  - The server uses the current listener position and step time to advance the simulation
  - The server sends new audio state to all clients for data consistency

Software for Immersive Environments

Alberto Raposo

Tecgraf - *Computer Graphics Technology Group*

abraposo@tecgraf.puc-rio.br

http://www.tecgraf.puc-rio.br/~abraposo

Graphical Parallelism

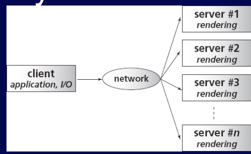
- Graphical parallelism can be achieved by:
  - Modern graphic cards (more *pixel shaders* and *fragment shaders)*
  - Combining graphic cards (SLI ou Crossfire)
  - *Clusters*
  - *Compositing Hardware*

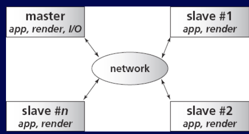
Techniques

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

Graphics Data Distribution in Multi-Projection Systems

Client-Server/Centralised
- One node for application and I/O
- Graphical information is sent to the rendering servers
- Optionally, an additional node for I/O



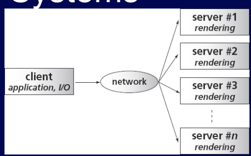


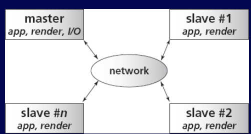
Master-Slave/Replicated
- All nodes run the simulation
- Master node distributes global input state (inputs, timestamps)
- Application runs on all nodes using the same inputs => same outputs.

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

-Cheaper (first buy & maintenance).
-More straightforward to install and configure.
-Higher (and assimetric) network load => performance bottleneck.





-More computational resources (parallel algorithms).
-Less network requirements.
-Higher cost.
-More complex installation and configuration.

Source: *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

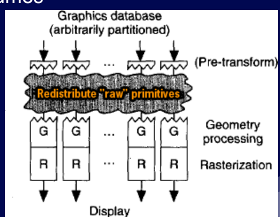
Specially for **for client-server distribution**
It's a sorting problem:

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, Ellsworth e Fuchs
3. *Sort-First Parallel Rendering with a Cluster of PCs* - Samanta, Funkhouser, Li e Singh

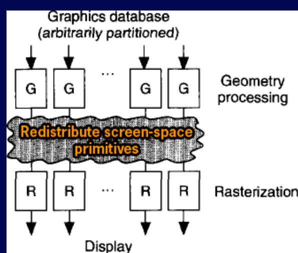
Sort-First

- 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



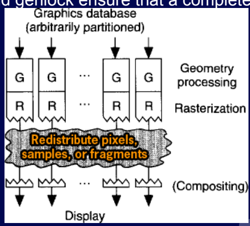
Sort-Middle

- 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 genlock ensure that a complete image is composed



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

- Options:
  - Syzygy
  - OpenSG
  - Performer
  - OpenSceneGraph
  - VRJugler
  - Avango
  - Diverse
  - FlowVR
  - OpenGL Multipipe
  - OpenMask

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

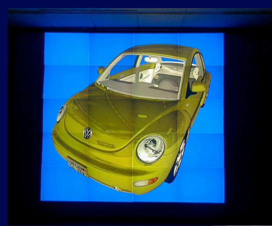
Source

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
- 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

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

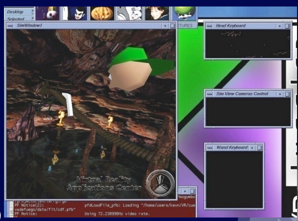
- Influenced by Performer
- International Community
- Own Scene Graph
- Highly optimized for large model simulation, terrain visualization, games, virtual reality, scientific visualization
- Supports a large set of 3D file formats
- Incipient support for cluster visualization
- C++, Python, Java
- Oriented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

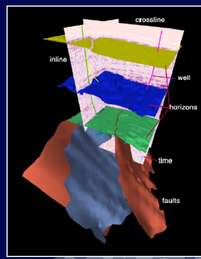
- Middleware for VR application development
- Supports different projection geometries
- Master-Slave architecture and distribution
- Scene Graph: OpenSG or OpenSceneGraph
- 3D Audio
- Input distribution and synchronization (buggy behaviour) with Net Juggler and Cluster Juggler
- C++, Python, Java
-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



www.**vrjuggler**.org

Avango

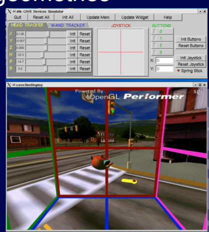
- Based in a shared scene graph
- Supports different projection geometries
- Supports data replication
- Based in OpenGL Performer



http://www.avango.org/

Diverse

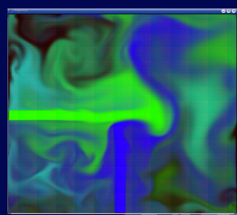
- Middleware for device independent VR application development
- Supports different projection geometries
- Supports data replication
- Based in OpenGL Performer



http://diverse-vr.org/

FlowVR

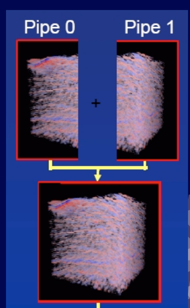
- Middleware for VR application development, based in data flows and modules which communicate
- *Daemons* handle the data transfer between modules
- Easy integration in high performance computing clusters
- Supports data replication



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)

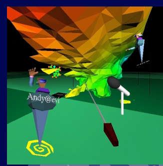
http://www.openmask.org

Commercial Tools

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

CaveLib

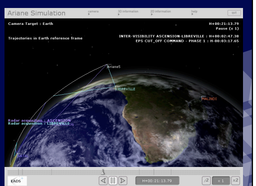
- Developed at EVL (Electronic Visualization Lab) for the first CAVE
- Originally for SGI computer clusters
- Several examples available
- Data replication



http://www.vrco.com/CAVELib

Virtools

- Very used by the industry and game developers;
- Has a powerful behaviors tools;
- Virtools 3D Life Player;
- Very easy to use.



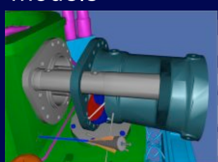
DeltaGen

- 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/

IC:IDO

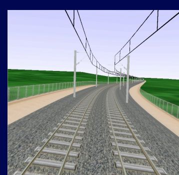
- Intuitive Interface coupling with CAD tools (Catia, Unigraphics, Autocad, Pro/ENGINEER, Solid Designer, Intergraph e Nemetschek)
- Optimizations for Massive models



http://www.icido.de

Avalon

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



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

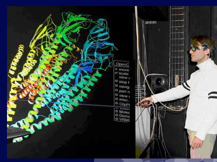
Basho

- 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)

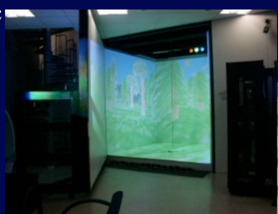
Cases

- Caverna Digital at University of São Paulo, Brazil
- Beckman Cube / ALICE at UIUC, USA
- Grimage at INRIA, France
- Tecgraf PUC-Rio, Brazil
- (CENPES and Others) at Petrobras, Brazil

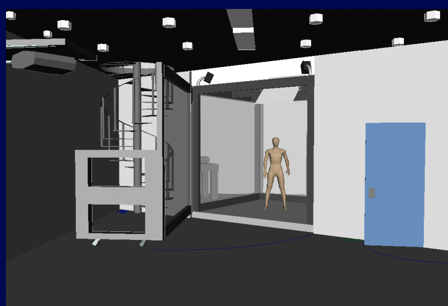
Luciano P. Soares
Tecgraf - *Computer Graphics Technology Group*
Pontifical Catholic University of Rio
lpsoares@tecgraf.puc-rio.br
http://www.tecgraf.puc-rio.br/~lpsoares/

Caverna Digital at University of São Paulo, Brazil

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



CAVERNA Digital Virtual Model

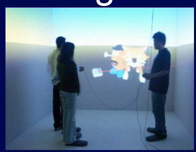


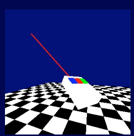
CAVERNA Digital Physical Project

Evolution

Tracking in Caverna Digital

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



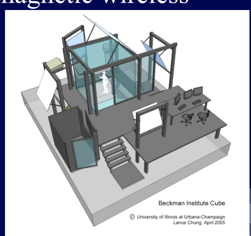


JINX

- 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

Beckman Cube / ALICE
Integrated Systems Laboratory/UIUC,USA

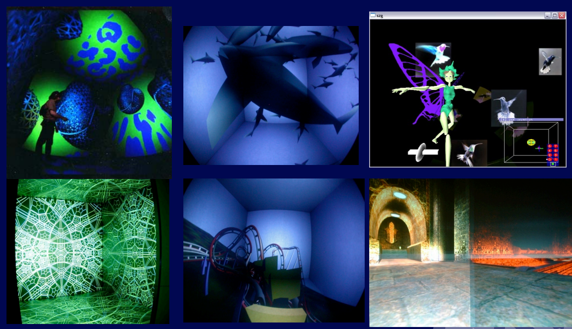
•6 sided CAVE
•Projectors: 6 CRTs (active stereo)
•Tracking: Eltromagnetic wireless
•Installed: 2001



Beckman Cube

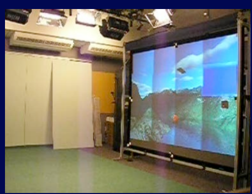
Beckman Cube

Syzygy



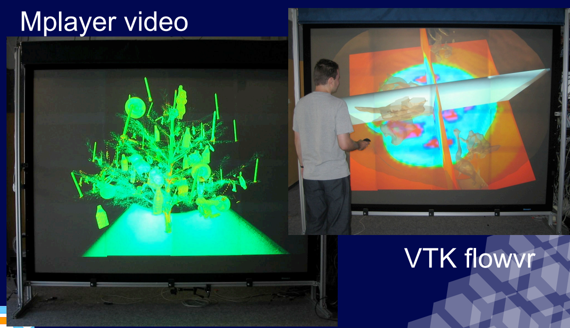
Grimage / INRIA
Grenoble - France

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



VTK/ FlowVR / FlowVR Render

Mplayer video

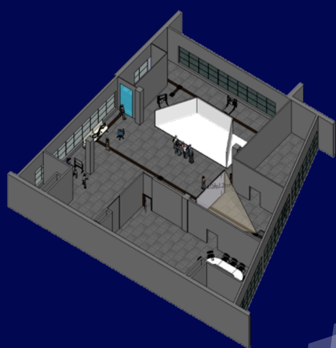


VTK flowvr

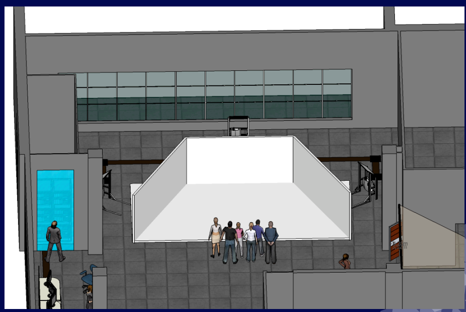
Tecgraf – PUC-Rio
Rio de Janeiro - Brazil

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

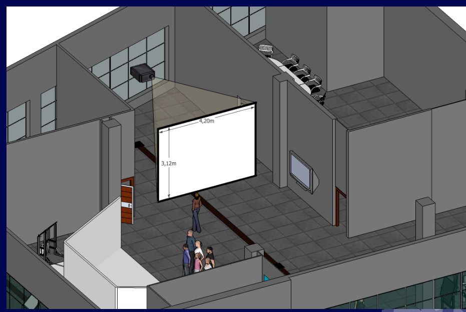
New System at PUC-Rio



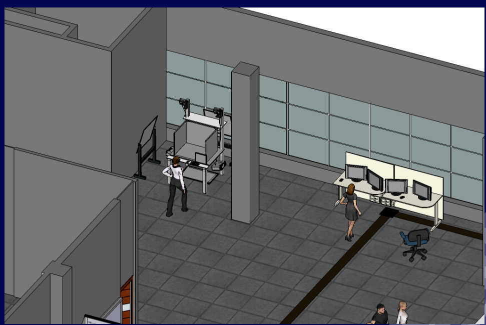
Immersive System



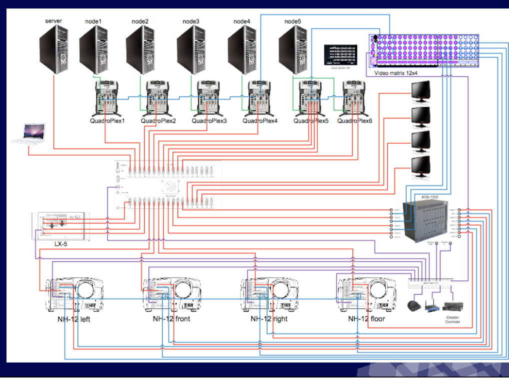
High-resolution



Hybrid-desk



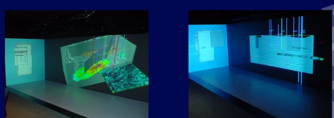
Connection Diagram



Petrobras

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

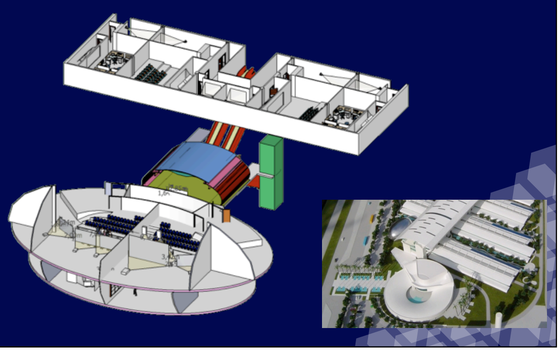
- EDISE (HollowSpace)



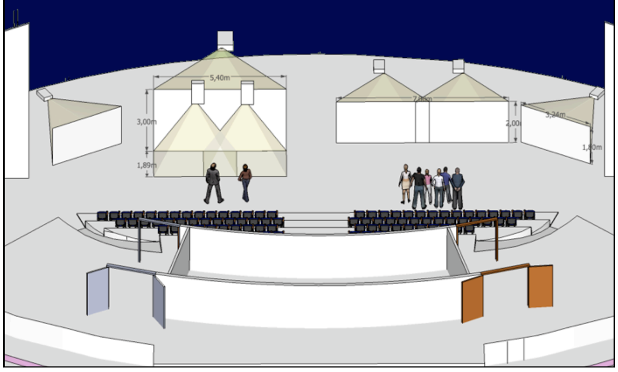
CENPES / MC

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

Future NVC Petrobras/CENPES



Main Systems



Cases

- Leme at Instituto Superior Técnico, Portugal

Bruno R. de Araújo
Instituto Superior Técnico
Universidade Técnica de Lisboa
brar@vimmi.inesc-id.pt
http://immi.inesc-id.pt/~brar/

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

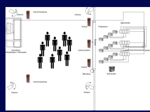
- **Cluster** 12 Workstation HP xw4100
  - Pentium 4 (800 FSB) 3.00GHz
  - 2 GB RAM (PC3200)
  - NVIDIA Quadro FX3000 (AGP 8x)
- **Cluster Server** Workstation HP xw8000
  - Pentium 4 Xeon 3.06 GHz
  - 4 GB RAM
  - NVIDIA Quadro FX3000 (AGP 8x)
- 12 **Projectors** HP VP6120
  - DLP
  - 2000 Lumens
  - 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

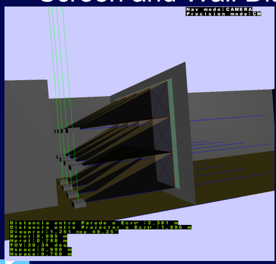
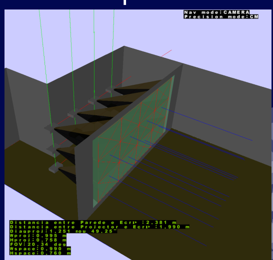
- 12 Off-the-shell XGA DLP projectors (<1700$ /unit)
- Cluster using Off-the-shell computer
- University Computer Laboratory





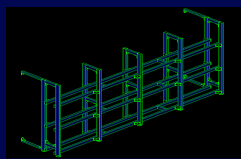
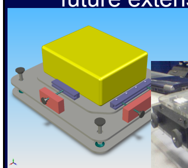

LEMeWall Simulator

- 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

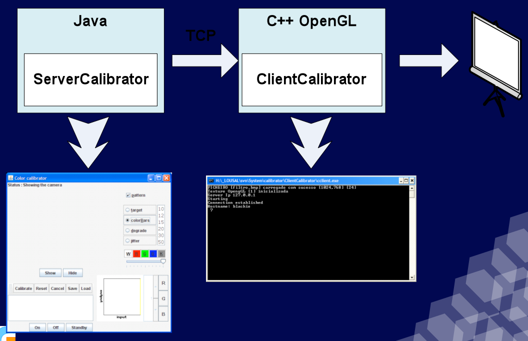
- Cooling System
- Light Control
- Geometric alignment



LEMeWall / IST

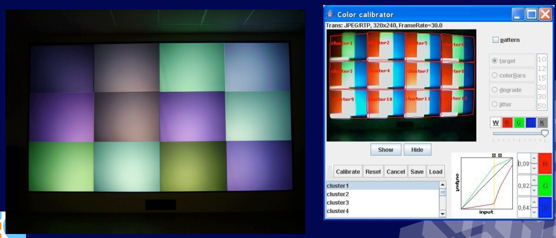



Projection Calibration and Control



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

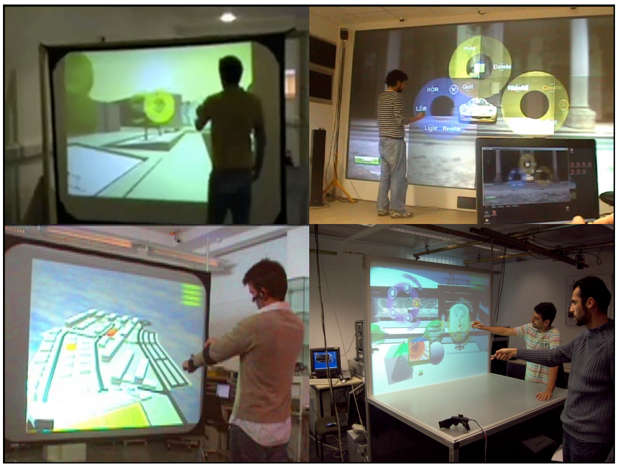
- Several VR system setup :
  - VR Juggler, OpenSG, Chromium, Jinx, Syzygy
- LEMeWall VR MiddleWare
  - OpenSG (Windows/Linux Applications)
  - Chromium (OpenGL Wrapper, Windows/ Linux)
- On Going: New VR Support Framework
  - OpenIVI: OpenSG+OpenTracker+OSGA+MM

Demos Running at the LEMeWall

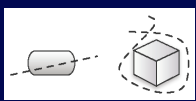
Demos Running at the LEMeWall

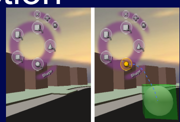
LemeWall Interactions

- 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

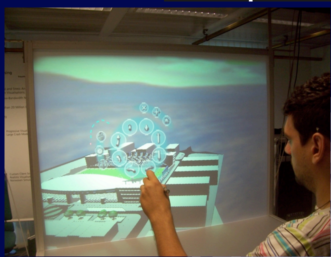


Stroke based Interaction



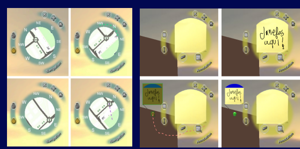


- Stroke
  - Line / Sketch
  - Path
  - Gesture
- Main metaphors
  - Crossing
  - Lasso selection
  - Pointing
  - Circular Menus



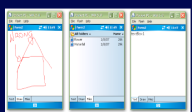
GUI for Large Scale display

- 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

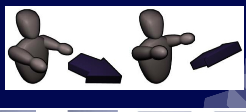
Used in conjunction with
- Laser
- Menus
- Body Tracking

Microsoft Speech SDK

Tracking Based Interaction

Two arm tracking
- Gestures
- Pointing
- Composition with voic

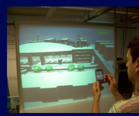
Functionality
- Navigation
- Dragging objects
- Scaling
- Rotation

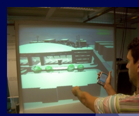


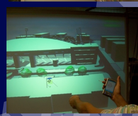
Multimodal Interaction

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

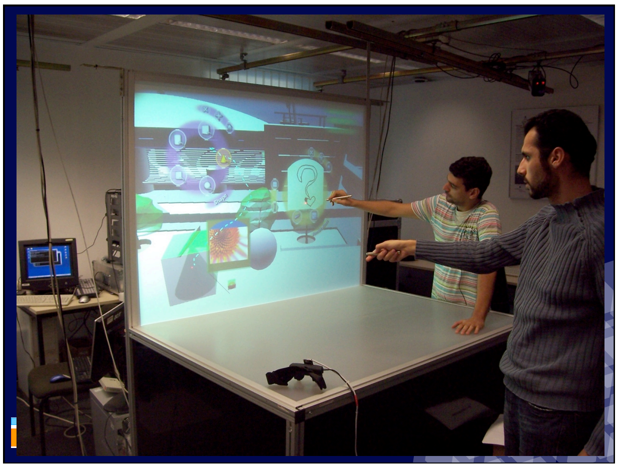
Multimodal interaction reacts to an Knowledge Base System:

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



Cases

- Lousal at Fundação Frederic Velge, Grândola, Portugal

Miguel Dias
MLDC - Microsoft Language Development Center
Miguel.Dias@microsoft.com
http://www.adetti.pt/

Joaquim A. Jorge,
Bruno Araújo
Instituto Superior Técnico
Universidade Técnica de Lisboa
jaj@vimmi.inesc-id.pt
http://web.ist.utl.pt/jorgej/

Lousal at Fundação Frederic Velge, Grândola, Portugal

- 4 sided CAVE Hollowspace (CaveH)
- 12 DLP Projectors with passive stereo INFITEC
- Optical Tracking
- Installed:
  - End of 2007

CAVE-H of Lousal: partners and suppliers

ISCTE Instituto Superior de Ciências do Trabalho e da Empresa

FUNDAÇÃO FREDERIC VELGE · FUNDAÇÃO DA FACULDADE DE CIÊNCIAS DA UNIVERSIDADE DE LISBOA · INSTITUTO SUPERIOR TÉCNICO · PUC RIO · GPCG · adetti · inesc id lisboa · BR PETROBRAS · Microsoft · NVIDIA · BARCO Visibly yours

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

Lousal Mine

Lousal Mine

Live Science Center at Lousal

The *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

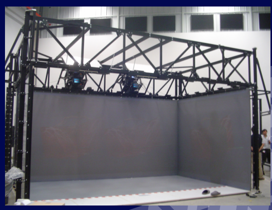
The Centers should be designed for a large-spectrum audience (e.g., age, education, social or geographic origin, etc.)

Live Science Center at Lousal

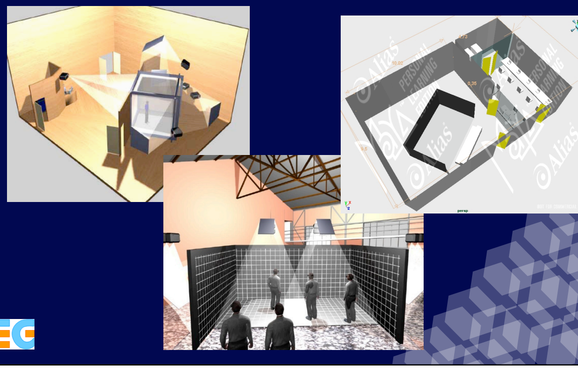
"Exploring Science, Exploiting Knowledge"

CaveH of Lousal in Detail

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

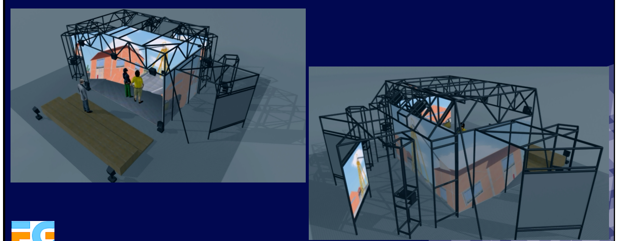


CaveH projection studies



Projection Studies

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

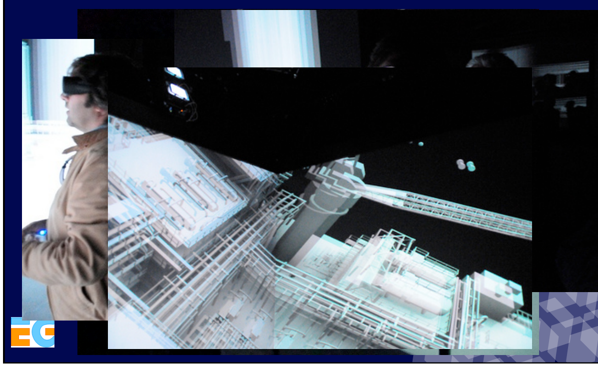


Main Objectives

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

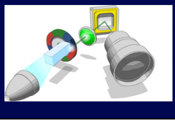
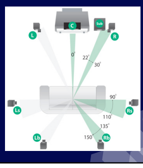
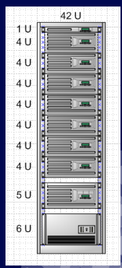
Preliminary Tests at Factory

CaveH in Operation



CaveH Main Points

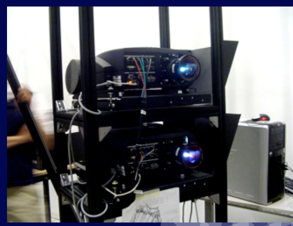
- High-end projection systems:8M pixel at 60 Hz
- State-of-the-art large semi-rigid screens
- Distributed 3D Audio “surround” 7:1
- Computer cluster and Gigabit ETHERNET
- High-performance computing server and 3D graphics: over 3M poly at 60 Hz
- In-house developed data synchronization middleware ensuring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

Projectors

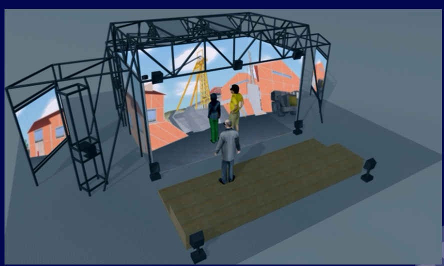
Technology = Single chip DLP
Resolution = SXGA+ (1400 x 1050 pixels)
Brightness = 4000 Lumens
Contrast =1:2000
Infitec stereo





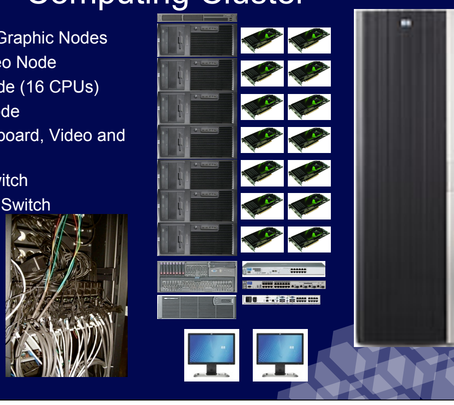
Surround Sound 7.1

- Spatially positioned
  - 7 High quality speakers and 1 subwoofer

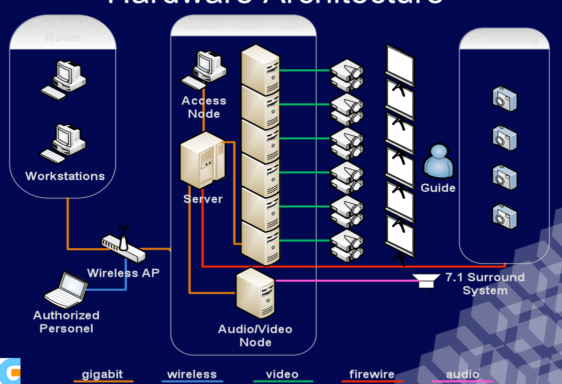


Computing Cluster

- 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



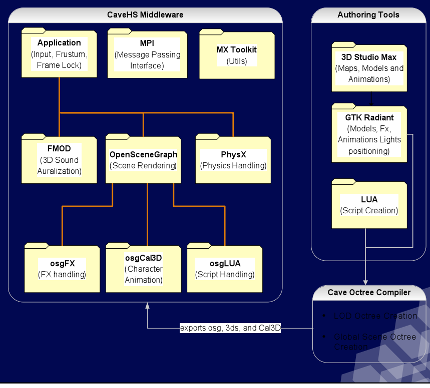
VR Middleware Approach for CaveH

- 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 client-server 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 Requirements

- 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 and 3D data consistency among computers
- Latency and bandwidth control (sustained 60 Hz)
- Content
  - 3D Modeling (supporting several 3D formats)
  - Character animation (*key-frame* and dynamic)
  - *scripting*
  - Immersive Virtual Environments authoring

CaveH Middleware



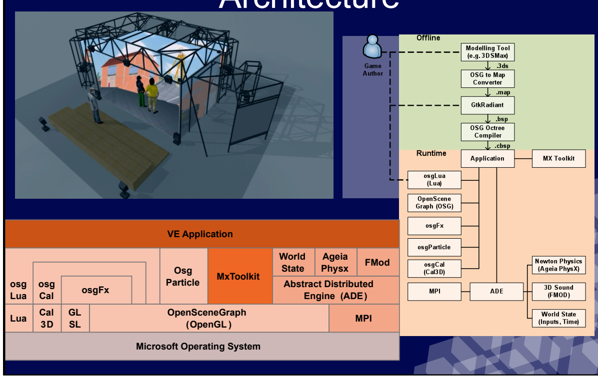
External Development Tools

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

Internal Development Tools

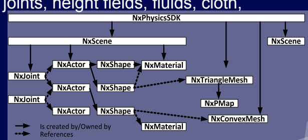
- MX-Toolkit
- Abstract Distributed Engine - ADE

Detailed CaveH Middleware Architecture



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

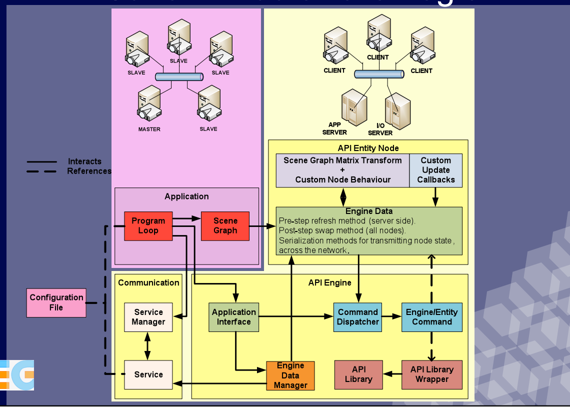


- Internal structure:
  - Scenes are independent worlds
  - Actors are the basic simulation entities. Each actor is defined as being static (for static scene elements), cinematic (for movable scene elements), or dynamic (subject of Newton physics simulation)
  - They can be physically linked through 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
- Cinematic 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
    - apply an impulse, using a derived force, to the contact point of the dynamic object

CaveH Middleware Logic

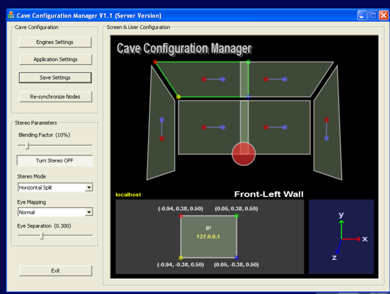


Newton Physics Engine

- Three entity nodes: static, cinematic and dynamic
- At each simulation step:
  - The cinematic nodes and the character poses are updated (scene graph update transversal).
  - The server applies the forces on dynamic entities, and calculates the entity and character collisions.
  - Next, it sends to client nodes the updated character and dynamic entities poses.
  - The clients propagate new state changes to the respective entity nodes.

Projection and CaveH Middleware Configuration

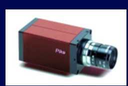
- User interface

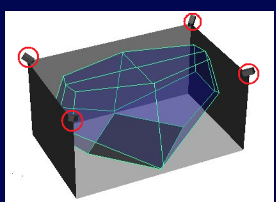


User Tracking for CaveH

Hardware Setup:

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

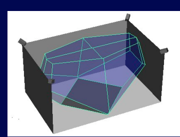




Lens Analysis

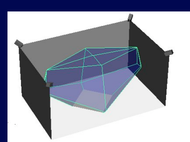
Lens: 3.5mm

- 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



Content Authoring

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

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

Autodesk → Radiant LEVEL DESIGN TOOLS

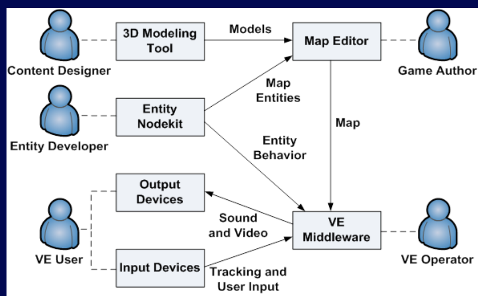
• 3D Studio Max for map modeling

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

Scripting Language

- Allows programming behaviors for certain objects/entities, in a completely independent environment
- The used scripting language is **LUA** (from PUC Brasil)
- Scripts are integrated with the application using the node kit **osgLua**

Content Authoring Flow



CaveH Content

Special Thanks

www.tecgraf.puc-rio.br/~lpsoares/courses/eurographics08.pdf