Designing multi-projector VR systems: from bits to bolts
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Main Topics
- Introduction
- Display Technologies
- Display Hardware Infrastructure
- Image Generation
- Tracking
- Multimodal Interaction
- Audio in Immersive Environments
- Software for Immersive Environments
- Case studies

Introduction
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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
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

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Visualization Systems

ePaper - Flexible, full-color OLED (Sony)

Projection Technologies

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

Brightness “Luminance”

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

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible Light</td>
<td>light that excite the retina</td>
<td>nm</td>
</tr>
<tr>
<td>Luminous Flux</td>
<td>light energy / unit of time</td>
<td>lumen</td>
</tr>
<tr>
<td>Luminous Intensity</td>
<td>luminous flux from a point</td>
<td>cd</td>
</tr>
<tr>
<td>Luminance</td>
<td>luminous intensity per projected area</td>
<td>cd/m² (nit)</td>
</tr>
<tr>
<td>Illuminance</td>
<td>luminous flux incident on a surface/area</td>
<td>Lux (fc)</td>
</tr>
<tr>
<td>Radiance</td>
<td>amount of light from area in a solid angle</td>
<td>W/sr*m²</td>
</tr>
<tr>
<td>Brightness</td>
<td>subjective perception light intensity</td>
<td></td>
</tr>
</tbody>
</table>

**Hot to work with these units?**

Lumen is the SI unit of luminous flux. Formula: \( 1 \text{ lm} = 1 \text{ cd} \times \text{sr} \)

Conversions:

\[ 1 \text{ candela/meter}^2 = (1 \text{ lm} / \text{area}) \times \text{gain} / \pi \]

\[ \text{Lux} = 1 \text{ lumen/meter}^2 \]

\[ \text{Foot-lambert} = (1 / \pi) \text{ candela} / \text{foot}^2 \]

siemens (SMPTE) recommends 16fL (55 candela / meter²)

* (Le Système International d'Unités)

**How to measure?**

Several ways:

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

ANSI (American National Standards Institutes):

- 25 degree Celsius;
- Wait 15 minutes;
- Dividing image into 9 equal rectangles;
- Values are divided by the screen size (m²);

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**

\[ L = \frac{K \times N^2}{t \times S} \]

**Displays Brightness**

<table>
<thead>
<tr>
<th>Display</th>
<th>Brightness (cd/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRT monitor</td>
<td>50 - 150</td>
</tr>
<tr>
<td>LCD monitor</td>
<td>250 - 450</td>
</tr>
<tr>
<td>Plasma monitor</td>
<td>1000 - 1500</td>
</tr>
<tr>
<td>DLP TV</td>
<td>450 - 700</td>
</tr>
<tr>
<td>LED TV</td>
<td>450 - 650</td>
</tr>
</tbody>
</table>

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/m²)

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

Ranges (lumens) large screen

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

Depends on some factors:

- Ambient light
- Screen size
- Stereoscopy
- Subject

Contrast

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

\[ \text{Contrast} = \frac{(\text{max intensity} - \text{min intensity})}{\text{min intensity}} \]

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

<table>
<thead>
<tr>
<th>Standard</th>
<th>Resolution (pixel dimensions)</th>
<th>Aspect Ratio</th>
<th>Pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>VGA</td>
<td>640x480</td>
<td>4:3</td>
<td>307,200</td>
</tr>
<tr>
<td>SVGA</td>
<td>800x600</td>
<td>4:3</td>
<td>480,000</td>
</tr>
<tr>
<td>XGA</td>
<td>1024x768</td>
<td>4:3</td>
<td>776,432</td>
</tr>
<tr>
<td>SXGA</td>
<td>1280x1024</td>
<td>4:3</td>
<td>1,916,720</td>
</tr>
<tr>
<td>SXGA+</td>
<td>1400x1050</td>
<td>4:3</td>
<td>1,976,800</td>
</tr>
<tr>
<td>Full HD</td>
<td>1920x1080</td>
<td>16:9</td>
<td>2,073,600</td>
</tr>
<tr>
<td>WUXGA</td>
<td>1920x1200</td>
<td>16:10</td>
<td>2,304,000</td>
</tr>
<tr>
<td>WQXGA</td>
<td>2560x1600</td>
<td>16:10</td>
<td>4,096,000</td>
</tr>
<tr>
<td>4K</td>
<td>4096x2160</td>
<td>1.896:1</td>
<td>8,747,980</td>
</tr>
<tr>
<td>8K</td>
<td>8192x4096</td>
<td>2:1</td>
<td>33,354,432</td>
</tr>
</tbody>
</table>

Not using the display’s native resolution can degrade the quality of the final image.
**Pixel Size**

- **1 Pixel**

**Visual Acuity**

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

**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:**
- 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

**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.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>D50</td>
<td>5003</td>
</tr>
<tr>
<td>D55</td>
<td>5503</td>
</tr>
<tr>
<td>D65</td>
<td>6504</td>
</tr>
<tr>
<td>D75</td>
<td>7504</td>
</tr>
</tbody>
</table>
**Lens**
- Short throw, Fish Eye x Tele(zooming)
- Motorized x Fixed
  - Lens Shift
  - Zoom Lens
- Focal length
- Throw ratio
  
  \[ \text{Throw Distance} = \text{Screen Width} \times \text{Lens Throw Ratio} \]

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 below 1400 K.

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

**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.
Connections

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

Degradation

<table>
<thead>
<tr>
<th>New projector</th>
<th>Old projector</th>
</tr>
</thead>
<tbody>
<tr>
<td>![New Projector Image]</td>
<td>![Old Projector Image]</td>
</tr>
</tbody>
</table>

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.

LCD (Liquid Crystal Displays)

- Based on liquid crystal technologies
- Advantages: low cost, several options in the market
- Disadvantages: low refresh rates, screen door effect
DLP (Digital Lighting Processing)
- Based on Digital Micromirror Devices - DMD
- Advantages: supports high lumens lamps, some models supports active stereo,
- Disadvantages: some screen door effect

LCOS (Liquid Crystal On Silicon)
- Based on reflexive liquid crystal;
- Advantages: high resolution, small screen door effect, high contrast;
- Disadvantages: only few models.

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

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.

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 (MgCO3);
- 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 reduce 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

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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 (Workbenches)
- Cilindric, Conics, Torus
- Spherics
- Domes

Plane - Display Wall

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

CAVEs

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

Cylindrical

- Large Audience
- Projection Overlap
- Requires Blending

Spherical

- Large Field of View
- Deformation Correction
Alternative Solutions
- Hang-glider
- Thorus
- WorkBench

Multi-Projector Structure
- Screen Frames
- Projector Mount and Arrays
- Possible Materials
  - Wood
  - Aluminum
  - Plastic Pipes
- 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 of 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

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
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Computers architectures
- Mainframes
- Mini-computers
  - Supermini
- Supercomputers

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

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

Symmetric x Asymmetric

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

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

Numerical Processing

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

- ATI Crossfire
- Nvidia nForce

Network connection
Communication Latency

<table>
<thead>
<tr>
<th>Network</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>InfiniPath (InfiniBand)</td>
<td>1.31 ms</td>
</tr>
<tr>
<td>Cray RapidArray</td>
<td>1.63 ms</td>
</tr>
<tr>
<td>Quadrics</td>
<td>4.89 ms</td>
</tr>
<tr>
<td>NUMAlink</td>
<td>5.79 ms</td>
</tr>
<tr>
<td>Myrinet</td>
<td>19.00 ms</td>
</tr>
<tr>
<td>Gigabit Ethernet</td>
<td>42.23 ms</td>
</tr>
<tr>
<td>Fast Ethernet</td>
<td>603.15 ms</td>
</tr>
</tbody>
</table>

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)
### ATI / AMD

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

### Graphic Cards Parallelism

- **Nvidia SLI**
- **ATI CrossFire**
- **Quantum 3D**

### 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.

### 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

Tracking

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Overview

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

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 strength 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 10º per minute) without compensation of drift. With compensation, < 1º 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

**Optical Tracking Devices:**
- Track Position and Orientation (6DOF)
- Outside-in (fixed receivers and mobile emitters)
- Inside-out (mobile receivers and fixed emitters)
- Lag of 20-80ms, 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
  - Time of flight
- Inertial
  - Accelerometers
  - Gyroscopes
- Magnetic
  - 3 orthogonal magnetic fields

**GPS – EGONOS (EUROPE) ~ 2m, 3m**

**DGPS-Omnistar**
- ~ 2.5cm - 10cm
- < 10 cm

**Intersense’s IS-600 Mark2**

**Intersense’s Inertia Cube**

**Ascension’s Flock of Birds and PCBIRD**

**Polheumes’ StarTrak**

**Mechanical**

- EXOS Industrier Hand

**Optical**

- Laser
- Infrared

**Vision-based**

- Key: ARTechs ADETT, X3M, ARTIC, FIRST

**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 distributed 3D graphics system to adjust 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 reliability
  - Prohibitive costs

**ARTIC**
- [Dias05]
- ADETT

**Ptrack**
- [Santos06]

**ioTracker**
- [Pintaric07]

**Chosen:** Infrared Tracking System

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

**Problems:** Line of sight and infrared radiation problem

**Minimization:** 4 cameras setup and controlled environment
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:
  2. Artefact Calibration
- On-line:

Feature Segmentation

Feature Segmentation Workflow

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 $F$.

<table>
<thead>
<tr>
<th>Rule</th>
<th>Occlusion Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bounding box white pixels percentage</td>
<td>≤ 65%</td>
</tr>
<tr>
<td>Bounding box width and height size difference</td>
<td>≥ 1.5 pixels</td>
</tr>
<tr>
<td>MEFC and bounding box ratio difference</td>
<td>≥ 1.5 pixels</td>
</tr>
<tr>
<td>MEFC and bounding box area difference</td>
<td>≥ 60 pixels²</td>
</tr>
<tr>
<td>MEFC circle exceeding bounding box limits</td>
<td>≥ 2.5 pixels</td>
</tr>
</tbody>
</table>

- 97% of labelling robustness in Occlusion Metric
- 10.06 ms saved per frame
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 \( \Lambda \)

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 \( \{x_1, x_2, ..., x_N\} \) into the calibrated model points \( \{y_1, y_2, ..., y_N\} \) expressed the following equation, where \( N \) is the number of points (3 non-collinear points are required to estimate a 6 DOF pose):
    \[
    \sum_{i=1}^{N} \left( \| x_i - R x_i + T \| \right)^2
    \]
  - By minimizing this error function a solution the rotation matrix and translation vector can be determined through SVD [Golub93]

Tracking Algorithm Review

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

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
Tracking Results

- Precision in artefact pose estimation
  - 10,000 samples
  - 4-markers artefact statically placed in working volume
  - Deviation between calibrated and estimated pose:
    - Mean precision: 0.08 mm / 0.04 °

Translation (3 DOF)
Rotation (3 DOF)

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:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirements</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean frame rate</td>
<td>25.0 fps</td>
<td>24.80 fps</td>
</tr>
<tr>
<td>Mean precision</td>
<td>0.10 mm / 0.10 °</td>
<td>0.08 mm / 0.04 °</td>
</tr>
<tr>
<td>Mean accuracy</td>
<td>1.0 mm / 0.50 °</td>
<td>0.93 mm / 0.51 °</td>
</tr>
</tbody>
</table>

- Improvements should be addressed to solve Hough Circle Transform

Tracking Results

- Accuracy in artefact pose estimation
  - Tests across all 6 DOF.
  - Mean accuracy: 0.93 mm / 0.51 °

Translation (3 DOF)
Rotation (3 DOF)

Multimodal Interaction

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 HCI for Virtual Reality

- 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

Human-Computer Interfaces for Virtual Reality
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

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

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

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 of 3D graphical objects

http://www.3dconnexion.com/index.php
http://www.inition.co.uk/inition/products.php

Ascension Wanda
- 6DOF input
- Joystick

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

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**
- Electro-oculography (EOG)
- Video-based

**Speech Command & Control**

Enable Voice Dialing from stored contacts without prior training or enrollment.

<table>
<thead>
<tr>
<th>Contact List</th>
<th>Grammar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anoop Gupta</td>
<td>Call</td>
</tr>
<tr>
<td>Bill Gates</td>
<td></td>
</tr>
<tr>
<td>Jeff Rakes</td>
<td></td>
</tr>
<tr>
<td>Steve Balmer</td>
<td></td>
</tr>
</tbody>
</table>

**Contact List**
- Anoop Gupta
- Bill Gates
- Jeff Rakes
- Steve Balmer

**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

**Lexicon Size**: ~100,000 words

**Letter-To-Phoneme conversion used if not in lexicon**

**Correct name pronunciation is crucial to this scenario**
Speech Command & Control

Scenario
Background
Grammar
Lexicon
Frontend
Acoustic Model

Compute probability observed feature vector was produced by speaking a phone

Speech Command & Control

Corpus
Lexicon

Search

sil k aa l aa n uw p g uw p t ax sil

Finds the highest probability match in the grammar

Speech Command & Control

sil k aa l aa n uw p g uw p t ax sil

Finds the highest probability match in the grammar

Run-time architecture with SR and TTS datapath

Corpus
Lexicon

Speech Apps

Grammar

SAPI

Speech Recognition Engine (SR)

Language Pack

(Developers' Speech API)

Desktop applications

Server/Cloud products

(IVR, Exchange, Azure)

Devices

(Windows Mobile)

Acoustic Model

Acoustic Models

(Telephony and Speaker)

Speech Recognition Engine (SR)

Text-to-speech Engine (TTS)

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)

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.

Bio-sensors - EDR

- Electrophysiological 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

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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

Sound Auralization:
- Auralization is the concern of creating the sensation of spatial sound.
- Adrian Willaert Xth 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

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.
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.

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 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 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

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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 Visualization in Multi-Projection Systems

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
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/

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/
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

www.avango.org

Diverse

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

www.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)

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

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

IC:IDO

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

Avalon

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

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

Covise

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

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

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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

Tracking in Caverna Digital
- Electro Magnetic
  - Emitter in the ceiling
  - Around 3m coverage
  - Device with buttons

JINX
- X3D Browser
- Clusters
  - Commodity PC (Linux)
  - SGI (Irix)
- Based in MPI and Pthreads
  - Also supports Sockets
- Internally 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: Electromagnetic wireless
- Installed: 2001
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  

New System at PUC-Rio  

Tecgraf – PUC-Rio  
Rio de Janeiro - Brazil  
• Single Stereo Projection  
• Projectors: 2 DLPs (passive linear stereo)  
• Tracking: Camera tracking  
• Installed: 2007  

VTK flowvr
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
- Projectors: 2 DLPs (active stereo)
- Tracking: Optical
- Installed: 2006 (Original CRT installation 2001)
Cases

- Leme at Instituto Superior Técnico, Portugal

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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

Display Characteristics

- Flexible Screen
- Screen Size: 4 m X 2.25 m
- 8.5 MPixels (native) to 15 MPixels (ext)
- Mono 4 by 3 configuration Array
- Graphic Cluster Boards Nvidia Quadro FX 3000 4:3

LEMeWall

- Instituto Superior Técnico, 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

Future NVC Petrobras/CENPES

Main Systems
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

- Java
- TCP
- ServerCalibrator
- C++ OpenGL
- ClientCalibrator

Color calibration
- Non-Rigid Screen
- Color can shift among similar projectors
- Camera Based Gamma 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
LemeWall Interactions

- Interaction Metaphors
  - Stroke based interaction (laser/PowerWall 3D Pen 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
  - One-One relation with the content
- PDA
  - Allows us to share data
  - Sketch, Images, Text
- Other devices
  - Mouse, Pen 3D, 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 voice

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

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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

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

Live Science Center at Lousal
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
- Diffusion of Science and Technology

The Centers should be designed for a large-spectrum audience (e.g., age, education, social or geographic origin, etc.)
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 illumination
  - Cinematic and dynamic collision detection
  - Rigid 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

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 (rigid, scene elements), cinematic (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 mesh, and convex mesh
  - This shape 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

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.
Content Authoring

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

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

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

Special Thanks

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