Designing immersive VR systems: from bits to bolts

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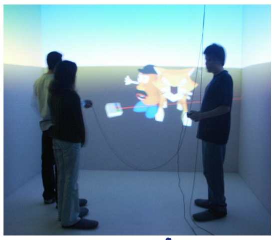
Background

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

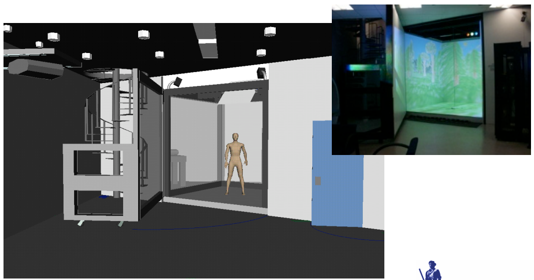
Used to improve the feeling of immersion.



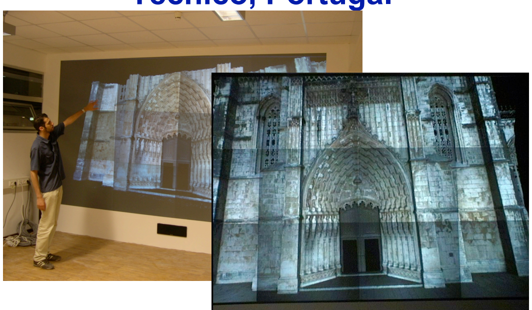
Applications

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

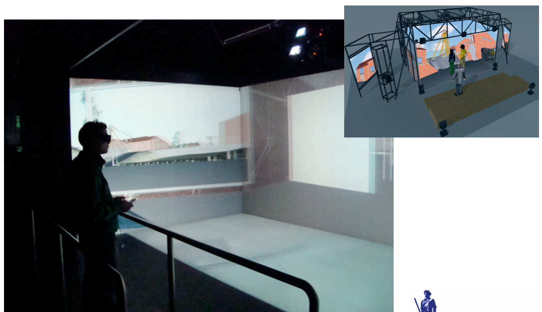
Caverna Digital at University of São Paulo, Brazil



LEMeWall at Instituto Superior Técnico, Portugal

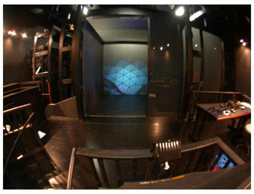


Lousal at Fundação Frederic Velge, Grândola, Portugal

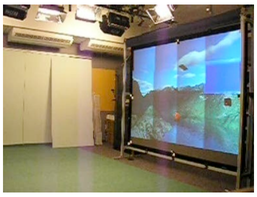


Partners

Integrated System Laboratory
Beckman Institute - USA

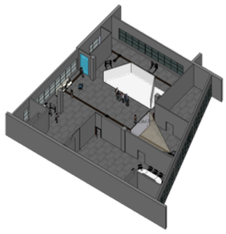


Grimage / INRIA
Grenoble - France

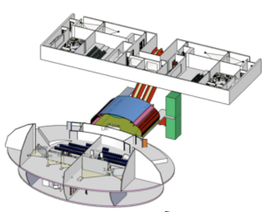


Coming Projects

VRSpace – PUC-Rio



NVC – CENPES Petrobras



Agenda

- Display Technologies
- Display Hardware Infrastructure
- Software for Immersive Environments
- Tracking
- Multimodal Interaction and Audio

Display Technologies

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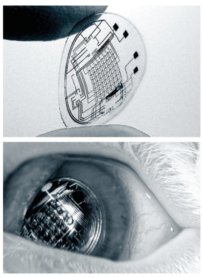
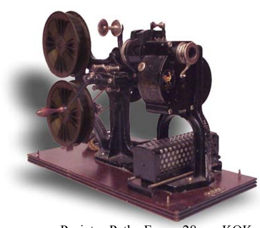
Visualization Systems



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?

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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	-

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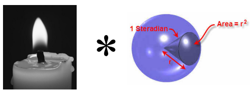
Hot to work with these units?

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)

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How to measure?

Several ways:

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

ANSI (American National Standards Institutes) lumens is to most common way:

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

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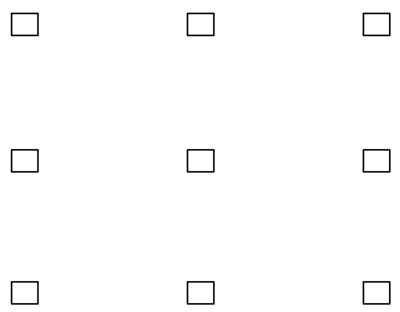

How to Choose the Brightness ?

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.

Depends on some factors:

- Ambient light
- Screen size
- Stereoscopy
- Subject

Ranges (cd/m²)

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

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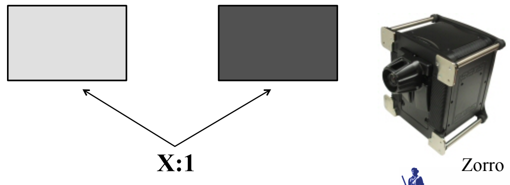
Contrast

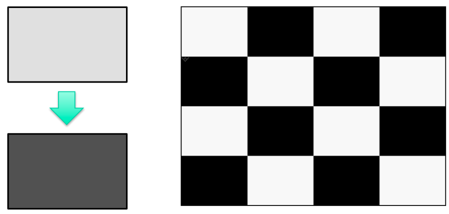
Expressed as a ratio between the brightest and darkest areas of the image.

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



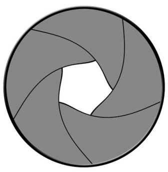
Contrast

On/Off contrast X ANSI contrast



Dynamic Iris

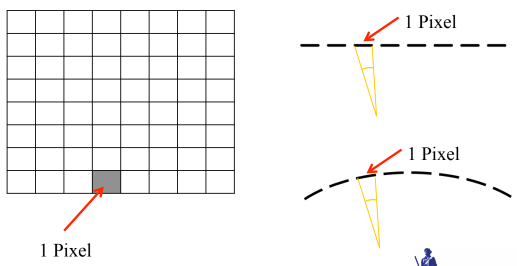
A dynamic iris is a device built into some projectors that sits between the lamp and the lens. The projector evaluates the overall brightness of the image being projected at the moment, and then opens or closes the iris to allow more or less light through.



Resolution

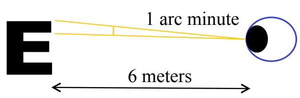
Standard	Resolution (*pixel dimensions*)	Aspect Ratio	Pixels
VGA	640x480	4:3	307,200
SVGA	800x600	4:3	480,000
XGA	1024x768	4:3	786,432
SXGA	1280x1024	5:4	1,310,720
SXGA+	1400x1050	4:3	1,470,000
Full-HD	1920x1080	16:9	2,073,600
WUXGA	1920×1200	16:10	2,304,000
WQXGA	2560×1600	16:10	4,096,000
4K	4096×2160	256:135 (1.896:1)	8,847,360
8K	8192x4096	2:1	33,554,432

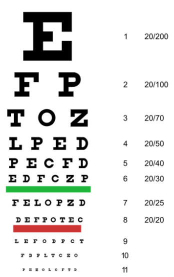
Pixel Size



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.

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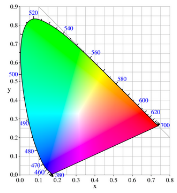
Colors

- 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

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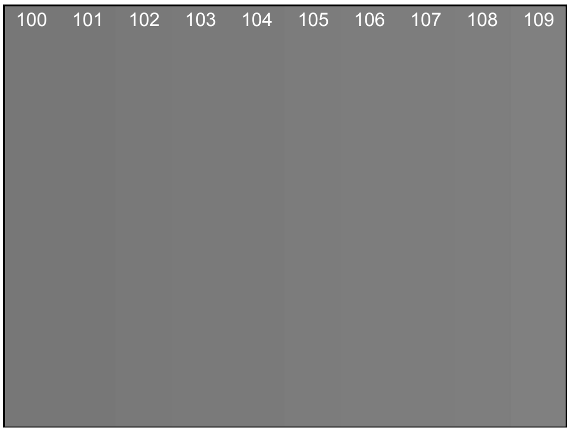
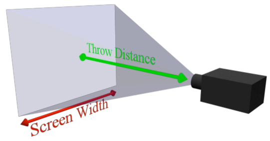


Lens

- 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

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Lamps Characteristics

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

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Lamps

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

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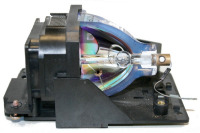
UHP

- 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

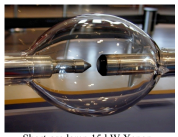

Philips UHP lamp

Xenon Lamp


automotive HID headlights 1991 BMW 7-series.

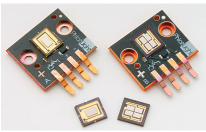
- Xenon short-arc lamp
  - Noble gas (atomic number 54);
  - Expensive;
  - Short life time.


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

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)

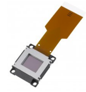
- Based on 3 independent tubes (Red, Green, Blue);
- Advantages: calibration flexibility, high refresh rate (> 120MHz), high resolution, anti-aliasing;
- Disadvantages: low brightness, noise signals, complex color convergence.



Marquee 9500

LCD (Liquid Crystal Displays)

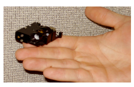
- Based on liquid crystal technologies
- Advantages: low cost, several options in the market
- Disadvantages: low refresh rates, screen door effect


Sony BrightEra LCD Panel


Christie LX66

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


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

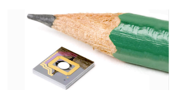


Evans and Sutherland

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.

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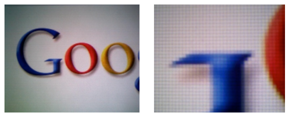
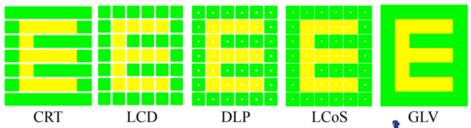
Fill-rate / Fill-factor / Aperture ratio

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





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Screens

- Flexible
- Semi-rigid
- Rigid
- Painted

Substrate
- Glass
- Acrylic

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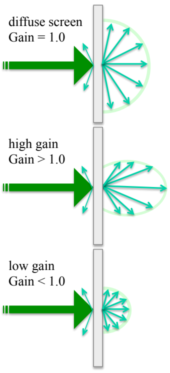

Screen gain

- 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.

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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.

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Display Hardware Infrastructure

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Overview

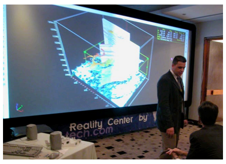
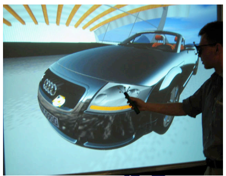
- Projection Geometries (Planar, Cubic, Domes)
- Multi-projection (Arrays and Mounts)
- Field Of View, Inter-reflection
- Hardware Color and Geometry Calibration
- Hardware Warping and Edge-Blending
- Site preparation, Video Transmission
- Control and Automation solutions

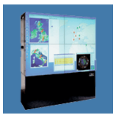
Projection and Screen Geometries

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

Plane - Display Wall

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

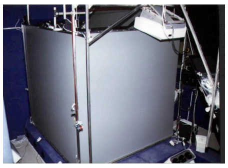





CAVEs

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






Cylindrical

- Large Audience
- Projection Overlap
- Requires Blending

Spherical

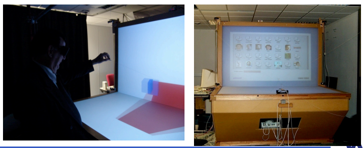
- Large Field of View
- Deformation Correction

Alternative Solutions

Hang-glider

Thorus

WorkBench

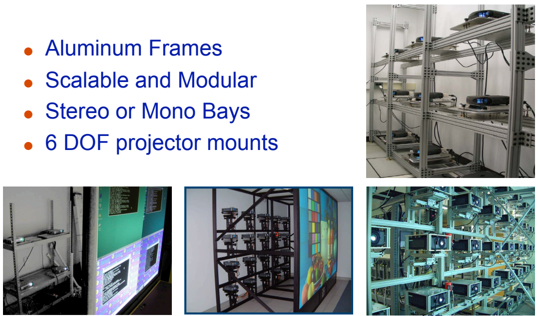


Multi-Projector Structure

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

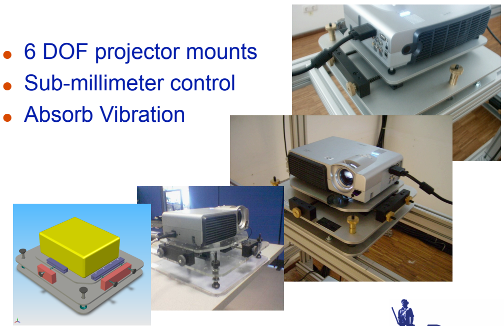
Projector Arrays

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



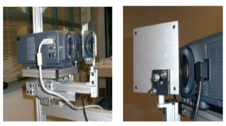
Projector Mounts

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

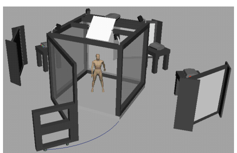


Planar Mirrors

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



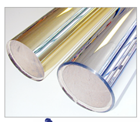
- Front Surface Mirrors/First Surface Mirror
  - **for Polarized Light**
  - Frontal reflection
- Reflection over 99.99%
- **Plastic Substrates**



Mirrors Substrate

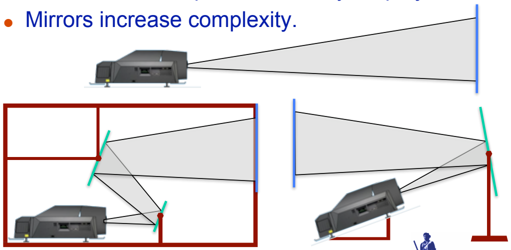
- Glass
  - Ease of fabrication
  - Rigidity
  - Scratch-resistant
  - Reflective material silver or aluminum
  - Heavy

- Polyester film
  - Polyethylene Terephthalate (PET)
  - Usually known as Mylar
  - Thickness from 12um (0,0005")
  - Light
- Acrylic and Plastic Mirror



Mirrors

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

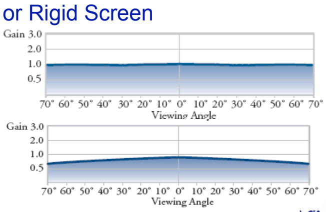


Projection Issue: Homogeneous Brightness and Hot Spots

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

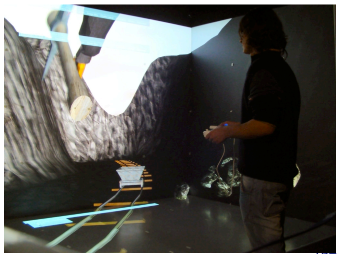
Projection Issue: Viewing Angle

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



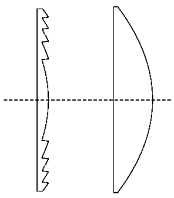
Projection Issue: Inter-reflection

- Cave: Light from other screens



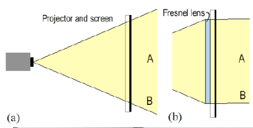
Redirecting Light: Fresnel Lens

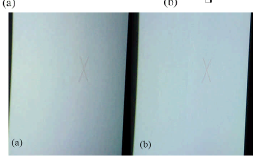
- To guarantee constant angle between viewing direction and protected light rays



How to use Fresnel Lens

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

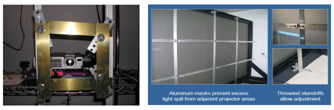
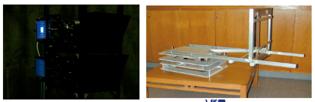




Stone, "Color and Brightness Appearance Issues in Tiled Displays",2001

Edge-blending

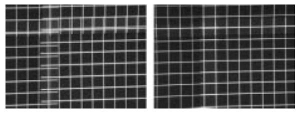
- Seamless edge blending
- Light Leak
- Small Overlap
- Almost aligned
- Solutions:
  - Physical
  - Software Mask
  - Hardware Projector

VR2010

Geometry Calibration and Warping

- Inter Projector Calibration
- Remove Seams
- Falloff Correction

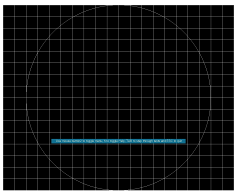
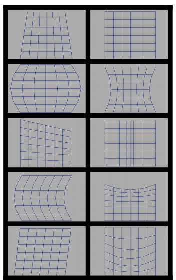


- Popular Technique:
  - Camera based Projector Registering
  - 2D Warping Map (Mesh)
  - Intensity Correction (Alpha-> Seams area)

VR2010

Geometric Calibration

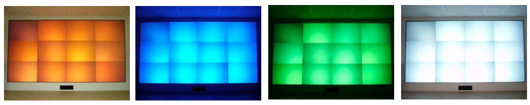
- Projector Registering
- Pattern Lines or Circle Dots
- Lens Distortion

VR2010

Color Calibration

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



VR2010

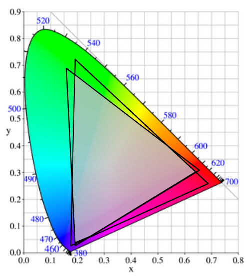
How to achieve the calibration color

- Eye
- Spectroradiometer
- Digital Camera or Webcam

VR2010

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



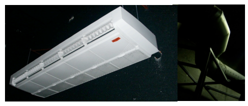
VR2010

Color Calibration

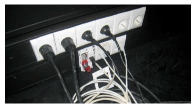
- Test card / Test pattern
- Vectorscope
- SMPTE Color Bars 16x9
- Usefull for Calibration evaluation


Site preparation

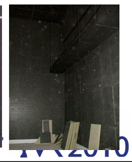
- Cooling System
  - Stable Temperature
  - Particle Clean



- Power and Cabling
  - Video
  - Network



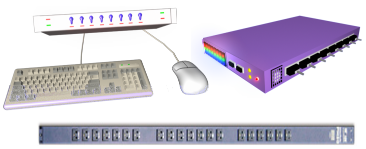
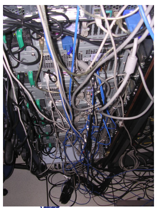
- Controlled Environment
  - Light (Filters, Black wall)
  - Soundproofing, Vibrations

Control and Automation solutions

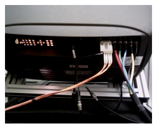
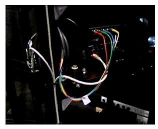
- Multi-Use Rooms
  - Light, Media Manager (ex: Creston, Lutron)
- Remote Power Control
- KVM Switch



Video Transmission and Control

- Cable Length Pb.
  - AutoPatch (VGA)
  - EyeViz (DVI)

- Video Matrix
  - Extron
  - Miranda


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

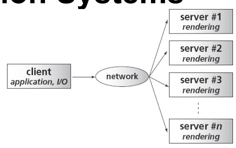
- Graphical parallelism can be achieved by:
  - Modern graphic cards (more *shaders)*
  - Combining graphic cards (SLI ou Crossfire)
  - *Clusters*
  - *Compositing Hardware*

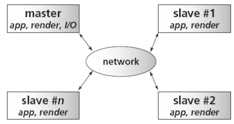
Techniques

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

Graphics Data Distribution in Multi-Projection Systems

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

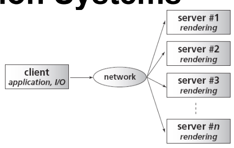


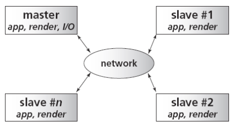


-All nodes run the simulation.
-Master node distributes global input state (inputs, timestamps).
-Application runs on all nodes using the same inputs => same outputs.

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

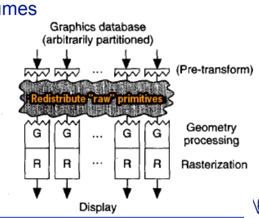
It's a sorting problem:

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

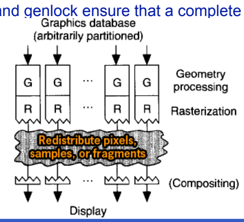
Sort-First

- 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



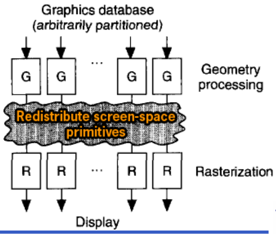
Sort-Last

- 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



Sort-Middle

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



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

- Options:
  - Syzygy
  - Avango
  - OpenSceneGraph
  - OpenSG
  - VRJuggler
  - Diverse
  - FlowVR
  - Covise
  - OpenMask
  - InVrs
  - Open5

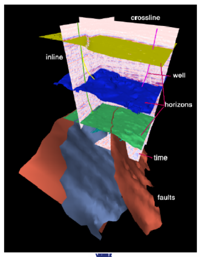
Syzygy

- 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

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

Avango

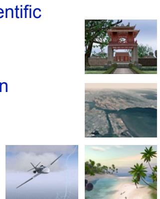
- Based in a shared scene graph
- Supports different projection geometries
- Supports data replication
- Originally based in OpenGL Performer



http://www.avango.org/

OpenSceneGraph

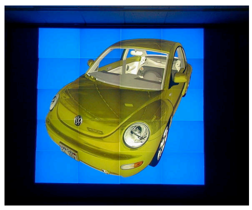
- Influenced by Performer
- Own Scene Graph
- Highly optimized for large model simulation, terrain visualization, games, virtual reality, scientific visualization
- Supports a large set of 3D file formats
- Incipient support for cluster visualization
- C++, Python, Java
- Multi-platform



http://www.openscenegraph.org/

OpenSG

- Own Scene Graph
- Client-Server distribution
- Sort-first and sort-last
- C++
- Multi-platform



http://opensg.vrsource.org/

VRJuggler

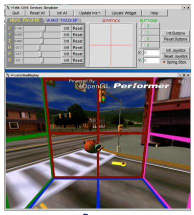
- Middleware for VR application development
- Supports different projection geometries
- Master-Slave architecture and distribution
- Scene Graph: OpenSG or OpenSceneGraph
- 3D Audio
- Input distribution and synchronization with Net Juggler and Cluster Juggler
- C++, Python, Java
- Multi-platform

http://www.vrjuggler.org

VR2010

Diverse

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

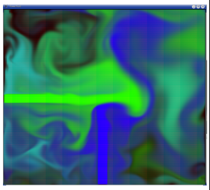


http://diverse.sourceforge.net/

VR2010

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

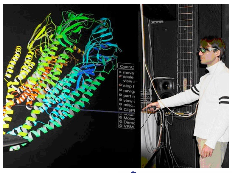


http://flowvr.sourceforge.net/

VR2010

Covise

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

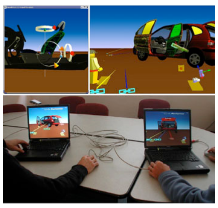


http://www.hlrs.de/organization/vis/covise/

VR2010

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

VR2010

InVrs

- Design of highly interactive and responsive NVEs
- Cross platform
- Uses OpenSG for rendering
- Tutorial at IEEE VR 2010 (yesterday)

www.invrs.org/

VR2010

Open5

- Framework for Interactive Virtual Environments
- Separate Visualization from Interaction Metaphors
- Abstract Visualization Setup and Input Devices
- Relies on both OpenSG and OpenTracker

http://open5.sourceforge.net/

VR2010

Basho

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

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

VR2010

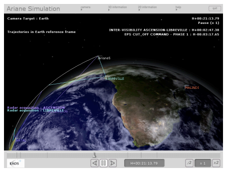
Commercial Tools

- 3DVia Virtools
- EON
- CAVELib
- DeltaGen
- IC:IDO
- Instant Reality

VR2010

3DVia Virtools

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



http://www.virtools.com/

VR2010

EON

- Several products (modeler, visualizer, etc)
- Initially developed for desktopVR and now integrated into immersive setups

http://www.eonreality.com/

VR2010

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

VR2010

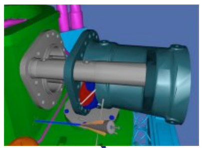
DeltaGen

- 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

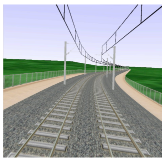
- Intuitive Interface coupling with CAD tools (Catia, Unigraphics, Autocad, Pro/ENGINEER, Solid Designer, Intergraph e Nemetschek)
- Optimizations for Massive models



http://www.icido.de

Instant Reality

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



http://www.instantreality.org/

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)

http://www.multigenparadigm.com/

Tracking

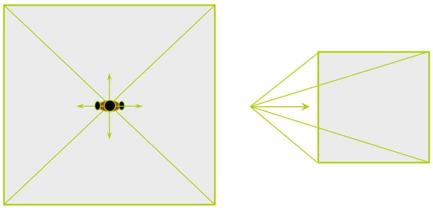
Miguel Dias
MLDC - Microsoft Language Development Center
Miguel.Dias@microsoft.com
http://www.adetti.iscte.pt/

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
- Interaction Techniques (Refresh Rate, Latency, Jitter)
- Tracking Technologies (Mechanical, Inertial, electro-magnetic, Ultra-sonic and Camera)
- Tracking Algorithms
- Camera Tracking in Details
- Alternative Devices for Tracking

Why User Tracking

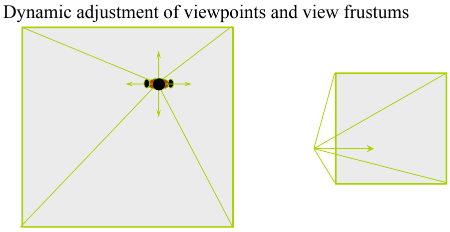


Top view

Frustum

Why User Tracking

Dynamic adjustment of viewpoints and view frustums



Top view

Frustum

User Tracking

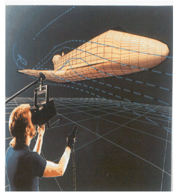
Technologies:

- Mechanical
- Inertial
- Electromagnetic
- Acoustic
- Optical
  - example

User Tracking

Mechanical Tracking Devices:

- Track Position + Orientation (6DOF)
- Mechanical arm paradigm
- Lag < 5msec @ 300 Hz
- Very accurate



Problems:

- Motion constrained by mechanical arm

Example: Boom by Fake Space Labs

User Tracking

Inertial Tracking Devices:

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

Problems:

- Drift between actual and reported values accumulates over time (~10° / min)

Example: InertiaCube by Intersense

User Tracking

Electromagnetic Tracking Devices:

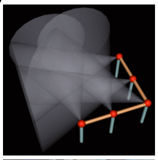
- Track Position and Orientation (6DOF)
- Measures strength generated magnetic field (3 perpendicular wire coils)
- 5msec Lag

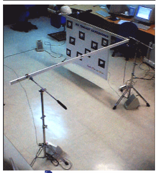
Problems:

- Interference w/ other magnetic fields (metal objects, office furniture, CRTs)

Example: Fastrak by Polhemus

User Tracking





Acoustic Tracking Devices:
- Track Position and Orientation (6DOF)
- Measures time-of-flight or phase coherence of ultrasonic waves
- 5ms Lag

Problems:
- Phase coherence systems subject to error accumulation
- Time-of-flight systems -> low update rate
- body occlusions

Example: Arena by ADETTI

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 20-80msec,
Precision: 2 mm and 0.1°

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

Example: ARTrack by A.R.T

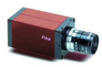
User Tracking

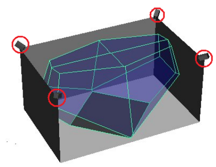
Wanted :
- No motion constraints, No drift
- No error accumulation
- Robust to interference
- Real-time update rate (> 30 Hz)

Chosen: Infrared Tracking System
- **Problems**: Line of sight and infrared radiation problem
- **Minimization**: 4 camera setup + controlled environment

User Tracking

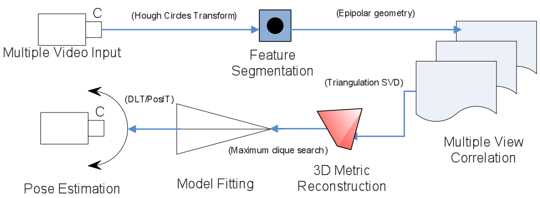
Hardware Setup:
- 4 AVT Firewire Pike Cameras (640x480, 205 fps)
- 4 LED ring array emitters
- 1 Shutter Controller
- N retroreflective markers





User Tracking

Infrared Tracking System Traditional Algorithm:



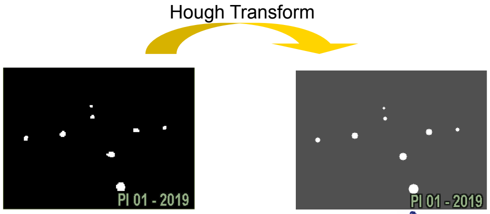
I/R Tracking System Algorithm

1. Feature Segmentation

threshold

I/R Tracking System Algorithm

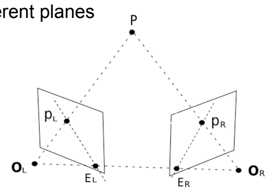
2. Feature Identification



I/R Tracking System Algorithm

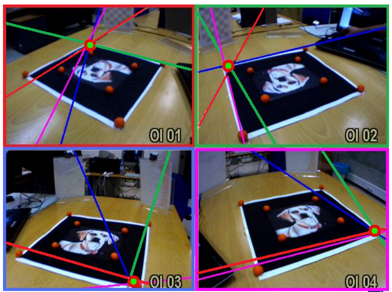
3. Multiple View Correlation via Epipolar Geometry (I)

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



I/R Tracking System Algorithm

3. Multiple View Correlation via Epipolar Geometry (II)



I/R Tracking System Algorithm

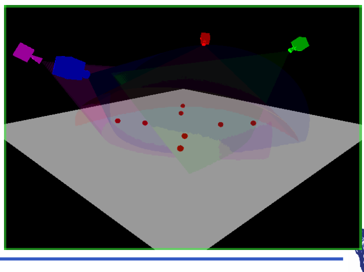
4. 3D Metric Reconstruction via Singular Value Decomposition Triangulation (I)

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

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

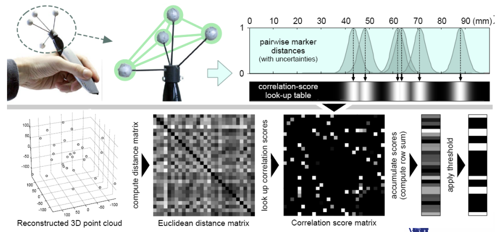
I/R Tracking System Algorithm

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



I/R Tracking System Algorithm

5. Candidate Evaluation (Pintaric & Kaufmann)

- For each artifact construct lookup table: pairwise marker distances
- 

ion

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

I/R Tracking System Algorithm

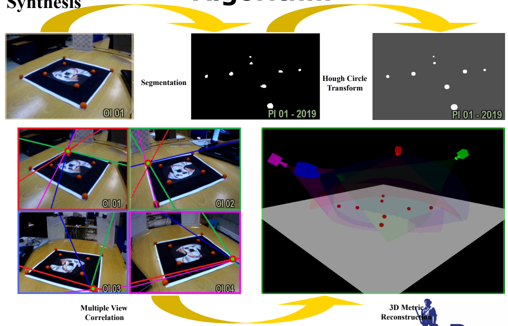
7. Pose Retrieval

> 3 features reconstructed & matched use DLT

= 3 features reconstructed &matched, use PosIT

< 3 features reconstructed &matched, tracking fails!

Infrared Tracking System Algorithm



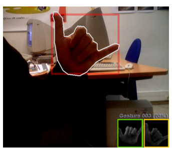
The future

- Use Structured Light to capture body posture
- Pervasive Cameras (Retinas)
- Some Commercial systems
- Background patterns
- Light Conditions

Multimodal Interfaces

Multimodal Interfaces

- Speech
- Tangible Interface:Wiimote & Nunchuk
- Gestures



Multimodal Interfaces

Speech:

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

Multimodal Interfaces

Wiimote:

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

Nunchuk:

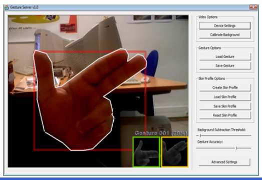
- 2 buttons
- Analog Stick
- 3 DOF + 3 Accelerations

VR2010

Multimodal Interfaces

Gestures:

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

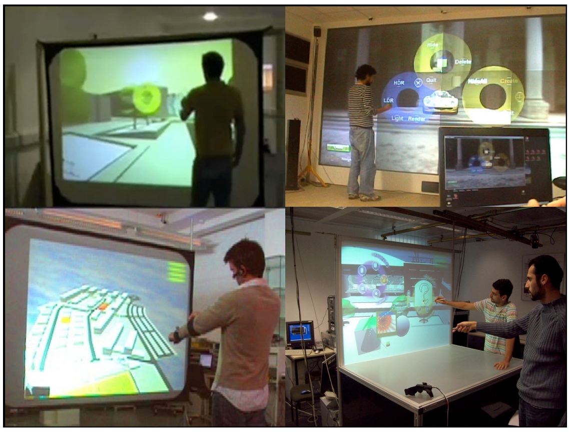


VR2010

Interactions

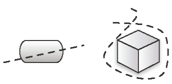
- Interaction Metaphors
  - Stroke based interaction (laser/PowerWall 3DPen Mouse/Pen)
  - Tracking/Body Gesture based interaction
  - Voice based interaction
- Input Devices
  - Laser
  - Mobile Computing (PDA)
- New User Interface (Advanced GUI)
- Multi-user and Multimodal Framework

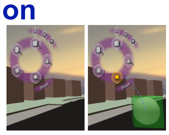
VR2010

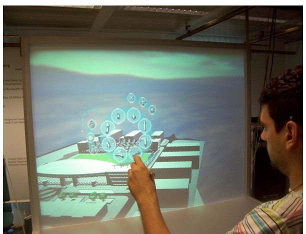


Stroke based Interaction

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



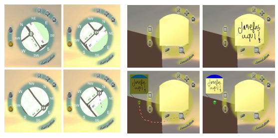


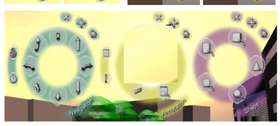


VR2010

GUI for Large Scale display

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

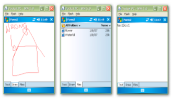
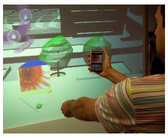




VR2010

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

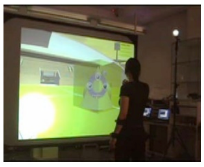




Speech Interaction

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

Used in conjunction with
- Laser
- Menus
- Body Tracking

Microsoft Speech SDK




Speech Synthesis

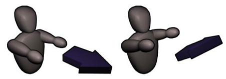
Good commercial systems
Prosody
Emphasis
Comparatively small footprint
e.g.
Microsoft
Loquendo

Tracking Based Interaction

Two arm tracking
- Gestures
- Pointing
- Composition with vc

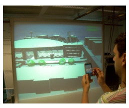
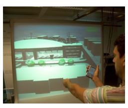
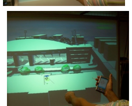
Functionality
- Navigation
- Dragging objects
- Scaling
- Rotation






Multimodal Interaction

Combinations
- PDA + Pointing
- Spech + Menus
- Speech + Pointing
- Tracking + Speech

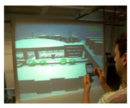
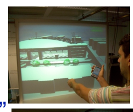
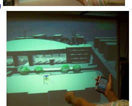




Multimodal Interaction Examples

Delete object : “**Delete This**”

Open navigation menu + select option with: “**Turn left**”

Enter scale mode: “**Begin Scale**” + use Body Tracking to scale object

Multimodal interaction

Knowledge Base Built on Open5

Actuators
- preconditions represent sequences of interaction

Preconditions
- Token, Context, Objects

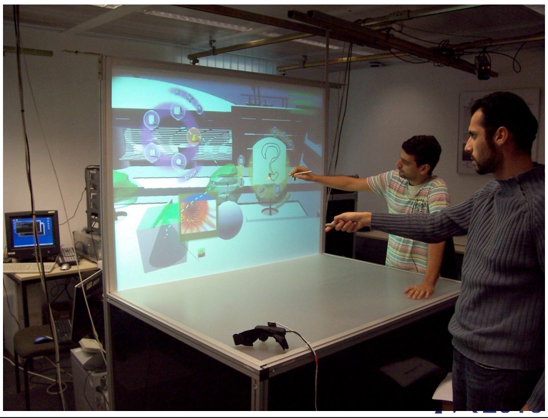
Inference system
- Actions fire when preconditions matched
- Ambiguities solved using More Recent Token policy

VR 2010

Multi-User Support

- Can use several modalities
- Several devices supported
- Use knowledge definition for support
- Temporal / Spatial Adjacencies

VR 2010

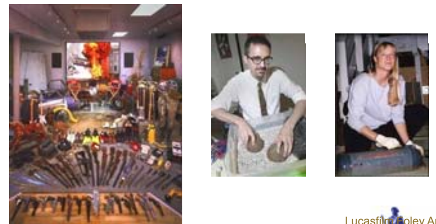


Interactive Auditory Display

Ming C. Lin
Department of Computer Science
University of North Carolina
lin@cs.unc.edu
http://gamma.cs.unc.edu/Sound

How can it be done?

- Foley artists manually make and record the sound from the real-world interaction

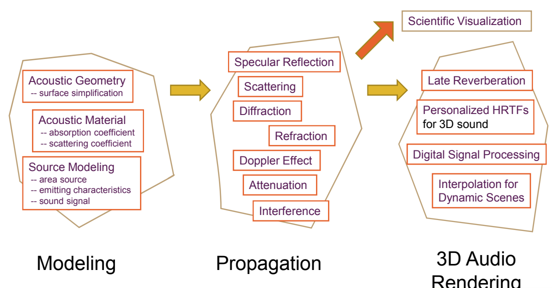


Lucasfilm Foley Artist

How about Computer Simulation?

- Physical simulation drives visual simulation
  - Sound rendering can also be ***automatically*** generated via 3D physical interaction

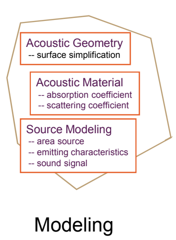
Sound Rendering: An Overview



Modeling

Acoustic vs. Graphics

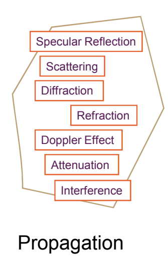
- Low geometric detail vs. High geometric detail



Propagation

Acoustic vs. Graphics

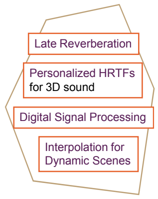
- 343 m/s vs. 300,000,000 m/s
- 20 to 20K Hz vs. RGB
- 17m to 17cm vs. 700 to 400 nm



3D Audio Rendering

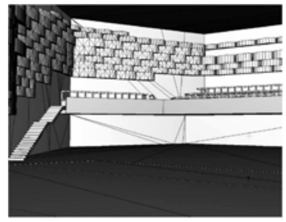
Acoustic vs. Graphics

- Compute intensive DSP vs. addition of colors
- 44.1 KHz vs. 30 Hz
- Psychoacoustics vs. Visual psychophysics

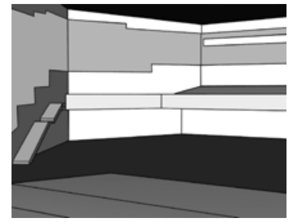


3D Audio Rendering

Modeling Acoustic Geometry [Vorländer,2007]

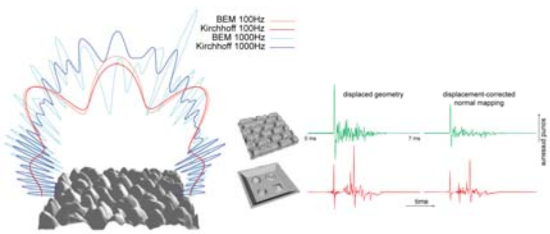


Visual Geometry



Acoustic Geometry

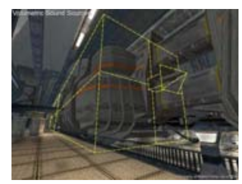
Modeling Sound Material



[Embrechts,2001] [Christensen,2005] [Tsingos,2007]

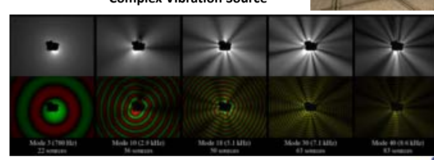
Modeling Sound Source

Volumetric Sound Source



Directional Sound Source

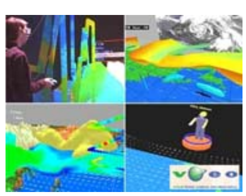
Complex Vibration Source



Applications

- Advanced Interfaces
- Multi-sensory Visualization

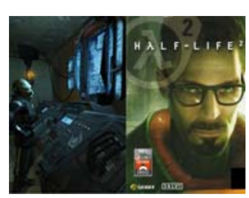
Minority Report (2002)



Multi-variate Data Visualization

Applications

- Games
- VR Training



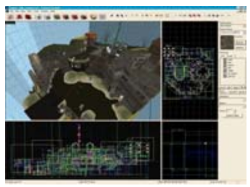
Game (Half-Life 2)

Medical Personnel Training

Applications

- Acoustic Prototyping

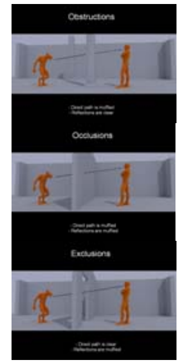
Symphony Hall, Boston



Level Editor, Half Life

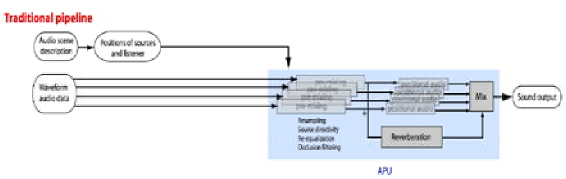
Sound Propagation in Games

- Strict time budget for audio simulations
- Games are dynamic
  - Moving sound sources
  - Moving listeners
  - Moving scene geometry
- Trade-off speed with the accuracy of the simulation
- Static environment effects (assigned to regions in the scene)



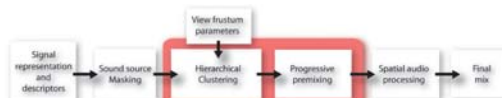
3D Audio Rendering

- Main Components
  - 3D Audio and HRTF
  - Artifact free rendering for dynamic scenes
  - Handling many sound sources

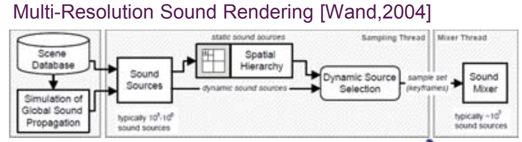


3D Audio Rendering

- Perceptual Audio Rendering [Moeck,2007]

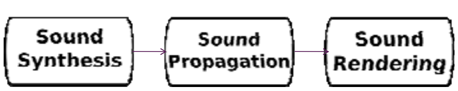


- Multi-Resolution Sound Rendering [Wand,2004]



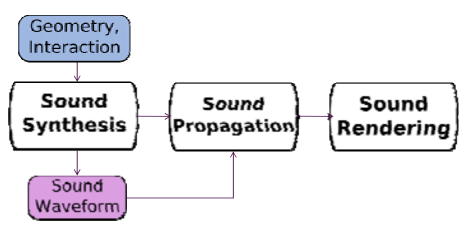
Overview of Sound Simulation

- The complete pipeline for sound simulation
  - Sound Synthesis
  - Sound Propagation
  - Sound Rendering



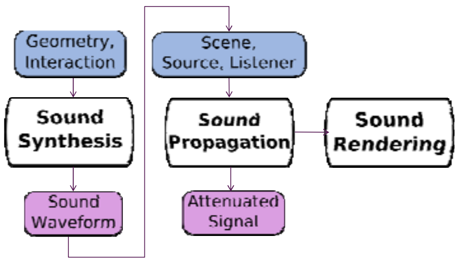
Overview of Sound Simulation

- Sound Synthesis



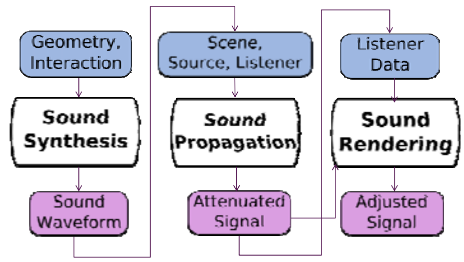
Overview of Sound Simulation

- Sound Propagation

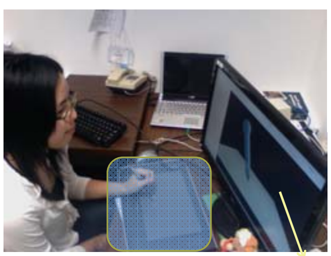


Overview of Sound Simulation

- Sound Rendering



Our System Set-up



Tablet Support
User Interface

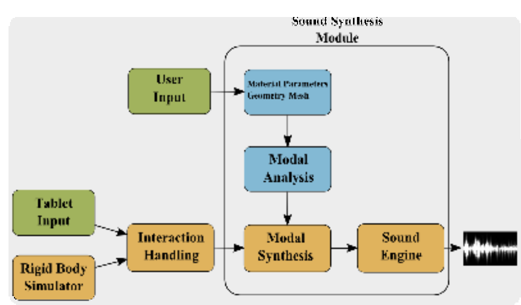
Main Results

- An interactive and flexible work flow for sound synthesis
  - User control over material parameters
  - Intuitive interaction and real-time auditory feedback for easy testing and prototyping
  - No event synchronization issue:
    users with little or no foley experience can start sound design and creation quickly
  - Easy integration with game engines

Main Results [Ren et al; VR 2010]

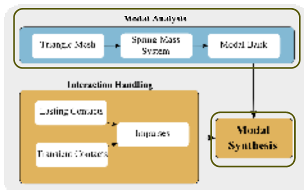
- A new frictional contact model for sound synthesis
  - Fast, allows real-time interaction
  - Simulates frictional interactions at different levels:
    - Macro shape
    - Meso bumpiness
    - Micro roughness
  - Better matches their virtually-simulated visual counterparts

System Overview



System Overview

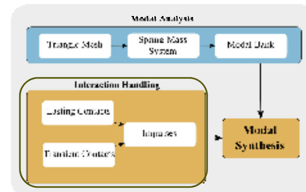
- Sound synthesis module
  - Modal Analysis: Raghuvanshi & Lin (I3D 2006)
  - Impulse response



VR2010

System Overview

- Interaction handling module
  - State detection: lasting and transient contacts
  - Converting interactions into impulses



VR2010

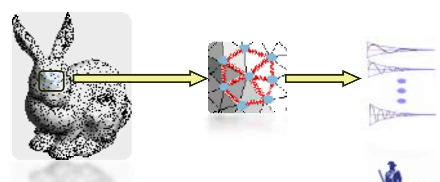
Modal Analysis

- Deformation modeling
  - Vibration of surface generates sound
  - Sound sampling rate: 44100 Hz
  - Impossible to calculate the displacement of the surface at sampling rate
  - Represent the vibration pattern by a bank of damped oscillators (modes)
- Standard technique for real-time sound synthesis

VR2010

Modal Analysis

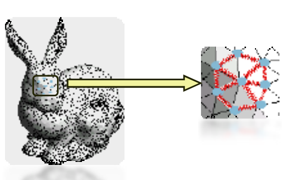
- Discretization
  - An input triangle mesh → a spring-mass system
  - A spring-mass system → a set of decoupled modes



VR2010

Modal Analysis

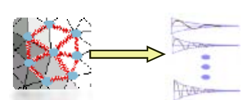
- The spring-mass system set-up
  - Each vertex is considered as a mass particle
  - Each edge is considered as a damped spring



VR2010

Modal Analysis

- Coupled spring-mass system to a set of decoupled modes



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Modal Analysis

- A discretized physics system
  - We use spring-mass system

$$\boxed{K}(d) + \boxed{C}(d, \dot{d}) + \boxed{M}(\ddot{d}) = f$$

Stiffness Damping Mass

- Small displacement, so consider it linear

$$\boxed{K}d + \boxed{C}\dot{d} + \boxed{M}\ddot{d} = f$$

Stiffness Damping Mass

Modal Analysis

- Solve the Ordinary Differential Equation (ODE)

$$Kd + C\dot{d} + M\ddot{d} = f$$

- Rayleigh damping

$$Kd + (\gamma M + \eta K)\dot{d} + M\ddot{d} = f$$

And diagonalizing $K = GDG^{-1}$

- Now, solve this ODE instead

$$DG^{-1}d + (\gamma G^{-1}M + \eta DG^{-1})\dot{d} + G^{-1}M\ddot{d} = G^{-1}f$$

Modal Analysis

- Solve the ODE

$$DG^{-1}d + (\gamma G^{-1}M + \eta DG^{-1})\dot{d} + G^{-1}M\ddot{d} = G^{-1}f$$

- Substitute $z = G^{-1}d$ (z are the modes)

Now, solve this ODE instead

$$Dz + (\gamma M + \eta D)\dot{z} + M\ddot{z} = G^{-1}f$$

Modal Analysis

- General solution

$$z_i = c_i e^{\omega_i^+ t} + \bar{c}_i e^{\omega_i^- t}$$

$$\omega_i^{\pm} = \frac{-(\gamma\lambda_i + \eta) \pm \sqrt{(\gamma\lambda_i + \eta)^2 - 4\lambda_i}}{2}$$

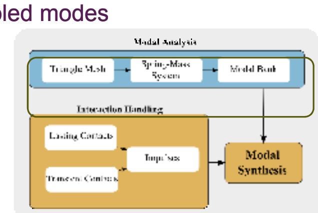
- External excitation defines the initial conditions

Modal Analysis

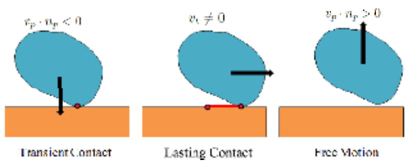
- Assumptions
  - In most graphics applications, only surface representations of geometries are given
  - A surface representation is used in modal Analysis
  - Synthesized sound appears to be “hallow”

Modal Analysis Summary

- An input triangle mesh →
  A spring-mass system →
  A set of decoupled modes



State Detection



State Detection

- Distinguishing between lasting and transient contacts
  - In contacts?

$$\begin{cases} v_p \cdot n_p < 0 & \text{in contact} \\ v_p \cdot n_p > 0 & \text{not in contact} \end{cases}$$

  - In lasting contacts?

$$\begin{cases} v_t \neq 0 & \text{lasting contact} \\ v_t = 0 & \text{not in lasting contact} \end{cases}$$

Interaction Handling

- Lasting contacts → a sequence of impulses
- Transient contacts → a single impulse

Impulse Response

- Dirac Delta function as impulse excitation
  - General solution

$$z_i = c_i e^{\omega_i^+ t} + \bar{c}_i e^{\omega_i^- t}$$

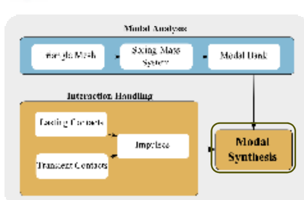
with initial condition given by the impulse, we have:

$$c_i' = c_i e^{\omega_i^+ t_0} + \frac{g_i}{m_i(\omega_i^+ - \omega_i^-)}$$

$$\bar{c}_i' = \bar{c}_i e^{\omega_i^- t_0} - \frac{g_i}{m_i(\omega_i^+ - \omega_i^-)}$$

Impulse Response

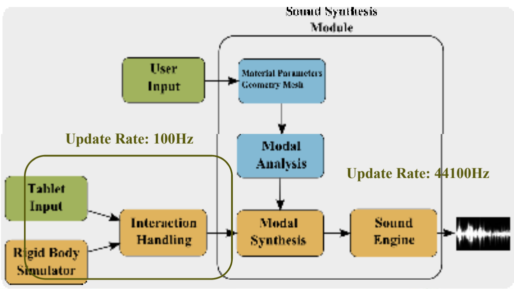
$$z_i = c_i e^{\omega_i^+ t} + c_i e^{\omega_i^- t}$$



Handling Lasting Contacts

- i.e. Frictional contacts
- How to add the sequence of impulses?
- The model has to be fast and simple, because…

Handling Lasting Contacts



Handling Lasting Contacts

- The interaction simulation has to be stepped at the audio sampling rate: 44100 Hz
- The update rate of a typical real-time physics simulator: on the order of 100’s Hz
- Not enough simulation is provided by the physics engine
- An customized interaction model for sound synthesis

Our Solution

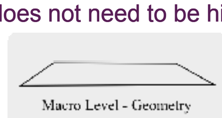
- Decompose the interaction into difference levels
- Different update rates at different levels
- Combined results offer a good approximation

Our Solution

- Three levels of simulation
  - Macro level: simulating the interactions on the overall surface shape
  - Meso level: simulating the interactions on the surface material bumpiness
  - Micro level: simulating the interactions on the surface material roughness

Three-level Simulation

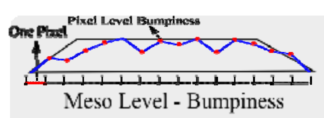
- Macro level: Geometry information
  - Update rate: 100’s Hz
- Update rate does not need to be high



  - The geometry information is from the input triangle mesh, and contacts are reported by collision detection in the physics engine.

Three-level Simulation

- Meso level: Bumpiness



  - Bump mapping is ubiquitous in real-time graphics rendering
  - Bump maps are visible to users but transparent to physics simulation

What Is Bump Mapping?

- Perturb vertex normals for shading
- No geometry details

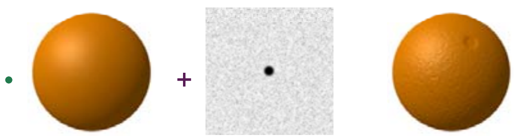


Image Courtesy to Wikipedia

Three-level Simulation

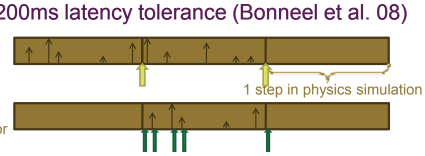
- Meso level simulation
  - Makes sure visual and auditory cues are consistent
  - Attends to surface bumpiness details
  - Update rate:
    - Event queue: 100's Hz
    - Event processor: 44100 Hz

Three-level Simulation

- Meso level simulation details (1)
  - Event queue is update at 100's Hz.
    - Linear velocity and position information from the physics simulator.
  - An event handler traverse back one time step to collect all "bumping" events in last time step

Three-level Simulation

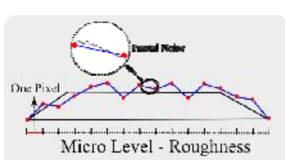
- Meso level simulation details (2)
  - Events from last time step are made up in this time at audio rate resolution. Latency: 10ms.
  - 200ms latency tolerance (Bonneel et al. 08)



Live demo of only meso-level simulation enabled and both macro and meso-level simulation enabled

Three-level Simulation

- Micro level simulation: Van den Doel et al. 01



  - Fractal noise is used to simulate the micro-level interaction

Live demo of only micro-level simulation enabled
And both micro, meso, and macro-level simulation enabled

Three-level Simulation

- Advantages:
  - Fast and simple. Makes real-time sound synthesis driven by complex interaction possible.
  - Captures the richness of sound varying at three levels of resolution
  - Visual and auditory feedbacks are consistent

System Implementation

- Tablet support
- Material manipulation
  – Users are allowed to change material parameters
  – Testing “new materials” right away
  – Material blending: linear interpolation
- Integration with physics & game engines
  – Physics engine: Open Dynamics Engine (ODE)
  – Graphics rendering engine: Open Source 3D Rendering Engine (OGRE)

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Video Demonstration

Video

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Sounding Liquids [Moss et al. 2009]

- Work in physics and engineering literature since 1917
  – Sound generated by resonating bubbles
- *Physically-based Models for Liquid Sounds* (van den Doel, 2005)
  – Spherical bubble model
  – No fluid simulator coupling
    - Hand tune bubble profile

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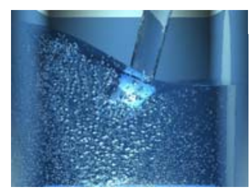
Background (Fluid)

- Grid-based methods
  – Accurate to grid resolution
    - Bubbles can be smaller
  – Slow
  – Can be two-phase



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Background (Fluid)

- Shallow Water Equations
  – Simulate water surface
    - No breaking waves
  – Real time
  – One phase
    - Explicit bubbles

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Overview

- Generate sound from existing fluid simulation
  – Model sound generated by bubbles
- Apply model to two types of fluid simulators
  - **Particle-Grid-based**
    – Extract bubbles
    – Process spherical and non-spherical bubbles
    – Generate sound
  - **Shallow Water Equations**
    – Processes surface
      - Curvature and velocity
    – Select bubble from distribution
    – Generate sound

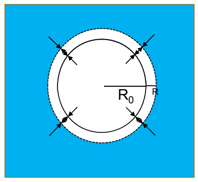
VR2010

Mathematical Formulations

- **Spherical Bubbles**

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{3\gamma p_0}{\rho R_0^2}}$$

$$\tau(t) = A\sin(2\pi f(t) t)e^{dt}$$

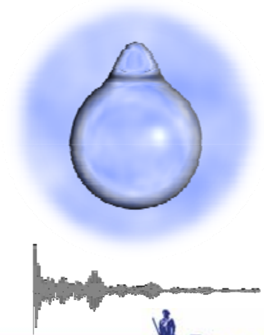


- **Non-spherical bubbles**
  - Decompose into a spherical harmonics

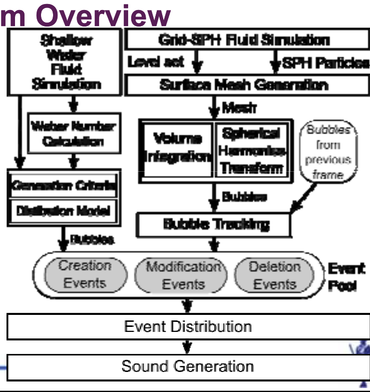
$$f_n^2 \approx \frac{1}{4\pi^2}(n-1)(n+1)(n+2)\frac{\sigma}{\rho R_0^3}$$

Without
Spherical Harmonics

With
Spherical Harmonics

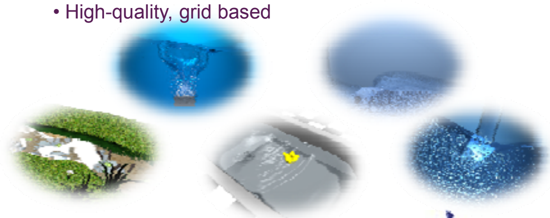


System Overview



Summary

- Simple, automatic sound synthesis
- Applied to two fluid simulators
  - Interactive, shallow water
  - High-quality, grid based



Video Demonstration

Video

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