Course #25

Computer Graphics for Large-Scale Immersive Theaters

Spherical Image Generation and Projection

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Overview

- Immersive Display Metrics
- Spherical Theater Metrics
- Spherical Image Representation: Skinning a Sphere
- Spherical Projection Formats
- Edge Blending and Spherical Mapping Techniques
- Video Projector Technologies
- Image Generation: Feeding the Dome
Immersive Display Image Metrics

• Field of View

• Brightness

• Resolution

• Contrast
Field of View

= Total horizontal and vertical image angle in spherical coordinates with respect to viewer’s eyepoint -or- spherical screen origin
Image Brightness (Luminance)

- **Video Projector Brightness** » Lumens
  - Available projector range: 250 - 12,000 Lumens
  - ANSI Standard for Lumens - Full Frame Brightness

- **Theater Brightness** » Foot Lamberts
  - SMPTE standard for film is 12 fL
  - IMAX® Dome format around 3-4 fL
  - Hayden Planetarium around 0.2 fL

1 Foot Lambert = 1 Lumen over 1 Sq. Ft. 
for Lambertian Screen with 100% Reflectivity
Image Brightness

• Brightness Comparisons
  • 0.0001 fL - Night Sky
  • 1 fL - White paper one foot from candle
  • 12 fL - White paper in good reading light
  • 1000 fL - Average earth on clear day

• High Brightness = High Color Saturation

• Planetaria are Special Case
  • Dark-adapted eyes
  • Starfield simulation integrated with video projection
  • Requires “true black” video - limited to CRT projectors which have very low brightness
Image Resolution

• Acuity of Eye = 1 arcminute/line pair
  • Line pair refers to minimally resolvable alternating black/white lines (10% criteria)
  • 1 arcminute = 1/60 degrees = 0.017°
  • Acuity drops dramatically outside of fovia

• Ideally it takes 2 pixels to represent a resolvable line pair
  • Thus, # of Resolvable line pairs < # pixels/2

• In Dome Theater, Resolution is Typically Measured W.R.T. Dome Center
Image Resolution

Number of Pixels Required to Project Eye-Limited Resolution over Hemisphere:

\[
\text{Number of Pixels} = \frac{(0.5) (4\pi \text{ steradians}) (57.3^\circ/\text{steradian})^2 (60 \text{ arc min/deg})^2}{(0.5 \text{ arc min/pixel})^2}
\]

\[= 300 \text{ Million Pixels}!!!\]
Image Contrast

• Contrast Ratio = Full White/Full Black

• Typical Video Projector Contrast
  • CRT Projectors over 1,000,000:1
  • “Light Valve” projectors typically less than 2000:1

• Cross-Dome Scatter Degrades Contrast
  • Image reflects back onto dome screen
  • Contrast ratio for fulldome checkerboard <10:1
  • Reduced dome reflectivity improves contrast ratio
  • Typical screen reflectivity 0.28 - 0.55
Theater Design Metrics

• Dome Tilt
  • Level dome requires reclined seating
  • Tilted dome + stadium seating brings dome screen into viewer’s field of view
  • Common dome tilts $10^\circ - 30^\circ$
Theater Design Metrics

• Seating Configurations
  • Unidirectional seating provides single point of focus
  • Concentric seating popular in older planetarium designs and special applications (more seats)
Theater Design Goal:

When the lights go out...

The theater disappears!

Minimize all “reality intrusions”
Skinning the Sphere

- **Dome Master Format**
  - Single large frame representing up to entire sphere
  - Master format for archiving, distribution, etc.
  - Independent of particular projection geometry
  - Defined only by resolution and field-of-view

- **Spherical Projection Format (Sub Frames)**
  - Multi-pipe format that matches projection geometry
  - Sub frames individually warped and blended
Spherical Mastering Format

Equidistant Cylindrical

Longitude

Latitude

+90°  +0°  -90°

-180°  0°  +180°
Equidistant Cylindrical Master

Entire Edge Maps to Single Pixel at Pole
Spherical Mastering Format

Polar Fisheye (Equidistant Polar)
Polar Fisheye Mastering

Entire Outside Edge Maps to Single Pixel at South Pole

Polar Image Fills 78.5% of Square Frame

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Polar versus Cylindrical Mastering

File Size = $4N^2$

File Size = $2N^2$
Skinning a Sphere with Platonic Solids
Skinning a Sphere - Cubic Mapping

File Size $> 1.5N^2$

Advantage - Efficient File Format
Disadvantage - Scene is Broken Up, Discontinuous
Spherical Projection Formats

Single Projector (Fisheye)

Arrayed/Mosaicked Projectors (Edge-Blended)
Fisheye Projection

- Simple Configuration
- Limited Hemispheric Resolution (1536x1536 pixels)
- Requires Obtrusive Projector Inside Theater Space
Fisheye Projection Applications

- Dome Production Monitors
- Educational Digital Planetariums, Art Exhibits
- Systems by Spitz, Minolta, E&S, Elumens

Elumens VisionStation™  Spitz SciDome™
Fisheye Projection Applications

- Large-Format Fisheye Systems
  - Approaching cinematic quality with QXGA resolution
  - Higher resolutions on the way…

Spitz’s ElectricSky® II
Edge-Blended Projection

Polar Source is Split Into Sub-Frames and Edge-Blended
Many Projection Configurations

Five Projectors
Six Projectors
Seven Projectors
Edge-Blending Pros and Cons

- Greater Brightness & Res. with Multiple Projectors
- Master Image Must BeParsed, Warped, Blended
- Multiple Projectors to Align, Color Balance
- Multiple Video Channels or Image Generator Pipes
- Obviously More Complex and Costly… But
- Near-Cinematic Quality Hemispheric Image!
Edge Blending and Spherical Mapping Techniques

- Pre-Rendered Blends and Mapping
  - Post-production processing of sub-frames
  - No special playback hardware
- Realtime Blends and Mapping
  - Allows realtime display of CGI, video sources, etc.
  - Dome becomes large virtual desktop!
  - Both electronic and optical blending techniques
Pre-Rendered Edge Blends and Spherical Mapping

- 2D image processing with DigiDome™ or PolyDome™
- Ad-hoc process using 3D renderer
- On-site “tweaking” possible prior to processing
- All immersive content must be post-processed
  - Live spherical images not possible
Realtime Edge Blends

• Real-Time Rendered Edge-Blends
  • Integral to some image generators incl. Digistar® 3, DigitalSky™
• Hardware (black-box) Edge-Blending Solutions
  • Panoram’s Panomaker™
  • SEOS’s DigiBlend™
  • Integral to Barco, Sony, 3D-Perception projectors
• Optical Edge-Blending
  • Gradient masks placed in projector beam path
Realtime Spherical Mapping

• Maps Planar Views to Spherical
  • Most rendering engines limited to planar
• Real-Time Rendered Mapping
  • Integral to some image generators
• Hardware (black-box) Mapping
  • SEOS’s Mercator™
• Video Projector Mapping
  • Barco, 3D-Perception projectors
  • CRT projectors
Spherical Mapping Process

**Six Projector Configuration**
Overlapped Projectors on Dome Periphery

**Six Camera Configuration**
Overlapped Cameras at Dome Center (must have common eyepoint)
Spherical Mapping Process

Camera FOV Must Fit Into Projector FOV
(well, mostly... anything outside of projector FOV is clipped)

Zenith camera and projector views shown mapped onto dome (under dome view)
Spherical Mapping Process

Spherical Environment Map (cameras within map)

Camera View of Map

2D warping function

Projector View of Map
Video Projector Technologies

• DLP - Digital Light Processor
• LCoS/D-ILA - Liquid Crystal on Silicon
• CRT - Cathode Ray Tube
• Laser Projection
• Grating Light Valve
DLP Projectors

- MEMS Mirrors on Silicon Substrate
- High Contrast >1200:1
- Good Resolution 1280x1024
- Very High Brightness >12,000 Lumens

Barco SLM-R8

Image Courtesy Texas Instruments
LCoS Projectors

- Liquid Crystal on Silicon Substrate
- Excellent Pixel Fill Factor - No “Screen Door” Effect
- High Contrast > 1200:1
- High Brightness > 7000 Lumens
- QXGA Resolution - 2048x1536 pixels

JVC DLA-QX1G
CRT Projectors

- Low brightness, high resolution, high contrast
- Analog technology
  - Flexible geometric alignment
  - Subject to drift
- Mature technology - still viable (VDC & Barco)
Laser Projectors

- Promises High Resolution, Very High Contrast
- New Semiconductor-Based Solid-State Lasers
- Several Competing Systems Emerging
- ZEISS Projector Optimized for Dome Projection

Images Courtesy Silicon Graphics, Inc.
Grating Light Valve

- Pixels are MEMS Diffraction Gratings
- Ultra High Resolution Possible – 8K x 8K!
- Ultra High Brightness Possible (low damage threshold)
- Projectors Not Yet on Market – 1-2 years

Image Courtesy Silicon Light Machines
Pre-Rendered Video/Graphics
- Graphics Playback Resolutions up to 2048x1536
- Pre-rendering provides superior image quality

Realtime Graphics
- Provides user interactivity
- Rendering speeds rapidly increasing

Live Video Feeds
- Immersive Cameras
- Videoconferencing
- Interactive performance

Image Generation: Feeding the Dome
Playback of Pre-Rendered Graphics

• VESA Graphics Formats Generally Employed
  • 1280x1024 up to 2048x1556 Pixel Resolutions
  • 30 fps Common, 60 fps for some systems
• Compressed and Uncompressed Players
• Software CODECs Rapidly Improving
• RAID and Mirrored Drives for Redundancy
Realtime Image Generation

- Dome Systems Pioneered in Training Simulators
- Immersive Visualization & VR Workspaces
  - CAVETM, Reality Center, etc. - group interactivity
- SGI and E&S Pioneering Dome Applications

Image Courtesy Spitz, Inc.
Realtime Image Generation

PC or Linux Clusters

Image Courtesy MetaVR
Realtime Image Generation

Mainframe Solutions Still Offer Highest Performance

Image Courtesy Silicon Graphics, Inc.
Realtime Interactivity

- Group Interactive
  - Computer facilitated group interaction
- Various Interface Devices
  - Pushbuttons (Spitz, E&S, Sky-Skan)
  - Joysticks (de pinxi)
  - Interactive wands/paddles (Cinematrix, de pinxi)
  - Laser pointers (Barco)

Images Courtesy de pinxi & Spitz, Inc.
Realtime Interactivity

• Operator Interactive
  • Operator is navigator – takes audience on journey
  • Realtime planetarium
  • Interactive lectures
• Personal Joysticks, Buttons, Control Panels

Images Courtesy Spitz, Inc.
Live Action on the Sphere...

Immersive Media’s Dodecahedral Camera

For more links:  www.cis.upenn.edu/~kostas/omni.html
Telepresence

CMU’s Nomad Robot Tested by NASA Ames in Atacama Desert… Live Audience Telepresence

http://www.cs.cmu.edu/afs/cs/project/lri-13/www/atacama-trek/
Live Performance: Coming Soon

Laser Light Shows, Step Aside...

The Ultimate Medium for Live VJ Performance...
Immersing the World...