Image-Based Rendering

COS 526, Fall 2010

Acknowledgments: Dan, Marc, Szymon

Image-Based Rendering

• For many applications, re-rendering is goal
• Traditional vision / graphics pipelines:
  - World
  - Geometry
  - Reflections
  - Light sources
  - Graphics
  - New Images
• Image-based pipeline:
  - World
  - Captured Images
  - New Images

Image-Based Modeling and Rendering

• Generate new views of a scene directly from existing views
• "Pure" IBR (such as lightfields): no geometric model of scene
• Other IBR techniques try to obtain higher quality with less storage by building a model

Plenoptic Function

• \( L(x,y,z,\theta,\phi,t,\lambda) \)
• Captures all light flow in a scene
  - to/from any point \((x,y,z)\),
  - in any direction \((\theta,\phi)\),
  - at any time \((t)\),
  - at any frequency \((\lambda)\)
• Enough information to construct any image of the scene at any time

Plenoptic Function Simplifications

• Represent color as RGB: eliminate \(\lambda\)
• Static scenes: ignore dependence on \(t\)
• \(7D \rightarrow 3 \times 5D\)

Image-Based Representations

<table>
<thead>
<tr>
<th>7D</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>6D</td>
<td>Consider only 3 frequencies (RGB)</td>
</tr>
<tr>
<td>5D</td>
<td>Consider only one time instant (static scene)</td>
</tr>
<tr>
<td>4D</td>
<td>Consider only viewpoints inside/outside scene</td>
</tr>
<tr>
<td>3D</td>
<td>Consider one dimension fewer directions/positions</td>
</tr>
<tr>
<td>2D</td>
<td>Consider viewpoints at finite set points or angles</td>
</tr>
</tbody>
</table>
View Interpolation

- Create novel images by resampling photographs
  - Reference images sample 5D plenoptic function

Pixel Correspondences

- Vision (e.g. stereo): disparity
- Feature matching: sparse
- 3D model: possibly coarse

Disocclusions

- Partial solutions:
  - Use more photographs
  - Fill holes by interpolating nearby pixels

View Interpolation

- Method:
  - Warp nearby reference images to novel viewpoint
  - Blend warped images

Disocclusions

- Better solutions (when possible):
  - Multiple samples per pixel at different depths
Disocclusions

- Better solutions (when possible):
  - Multiple samples per pixel at different depths

Reference Image  Warped Depth Image

View Interpolation Challenges

- Capture
  - How do we obtain a dense set of calibrated images over a large area in a practical manner?
- Data Management
  - How do we store and access the large amount of data?
- Rendering
  - How do we create novel views from a dense sampling of images in real-time?

Sea of Images Capture

- Use a hemispherical FOV camera driven on cart

Sea of Images Capture

- Use a hemispherical FOV camera driven on cart
Sea of Images Capture

Locate camera by tracking fiducials

Result is a “sea of images” spaced a few inches apart

Sea of Images Compression

• Goal: provide access to images along arbitrary viewpoint paths in real-time

Approach: create a multiresolution spatial hierarchy of compressed original images and compressed difference images

Sea of Images Rendering

• Use captured images near the novel viewpoint to create new views

Interpolate three nearest views using detected feature correspondences
Sea of Images Results

- Bell Labs Museum
  - 900 square ft
  - 9032 images
  - 2.2 inch spacing
- Princeton Library
  - 120 square ft
  - 1947 images
  - 1.6 inches
- Personal Office
  - 30 square feet
  - 3475 images
  - 0.7 inches

Sea of Images Results

- Times
  - Setup: ~15 minutes
  - Capture: ~30-60 minutes
  - Preprocessing time: 4 to 17 hours
- Frame rate
  - 1024x1024 @ 20Hz, 512x512 @ 30Hz

Sea of Images Results

- Render complex light effects (specular highlights)
Sea of Images Results

- Multiresolution pre-filtering: far-to-near image sequence

*Image-Based Representations*

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7D</td>
<td>Ideal</td>
</tr>
<tr>
<td>6D</td>
<td>Consider only 3 frequencies (RGB)</td>
</tr>
<tr>
<td>5D</td>
<td>Consider only one time instant (static scene)</td>
</tr>
<tr>
<td><strong>4D</strong></td>
<td>Consider only viewpoints inside/outside scene</td>
</tr>
<tr>
<td>3D</td>
<td>Consider one dimension fewer directions/positions</td>
</tr>
<tr>
<td>2D</td>
<td>Consider viewpoints at finite set points or angles</td>
</tr>
</tbody>
</table>

*Lightfields*

- In unoccluded space, can reduce plenoptic function to 4D

*Using Lightfields*

- Obtain 2D slices of 4D data set
- Arbitrary views: take other 2D slices
- Challenges:
  - Parameterization
  - Capture
  - Compression
  - Rendering

*Lightfield Parameterization*

- Point / angle
- Two points on a sphere
- Points on two planes
- Original images and camera positions
Light Field Two-Plane Parameterization

- Two planes, evenly sampled: “light slab”
- In general, planes in arbitrary orientations
- In practice, one plane = camera locations
  - Minimizes resampling

Light Field Coverage

- Capture a 2D set of (2D) images
- Choices:
  - Camera motion: human vs. computer
  - Constraints on camera motion
  - Coverage and sampling uniformity
  - Aliasing

Multi-Slab Light Fields

- Levoy 06:
  - Computer-controlled camera rig
  - Move camera to grid of locations on a plane
**Lightfield Capture**
- Spherical motion of camera around an object
- Samples space of directions uniformly
- Second arm to move light source – measure reflectance

**Lumigraph Capture**
- Capture: move camera by hand
- Camera intrinsics assumed calibrated
- Camera pose recovered from markers

**Lightfield Compression**
- Compress individual images (JPEG, etc.)
- Adapt video compression to 2D arrays
- Decomposition into basis functions
- Vector quantization

**Lightfield Rendering**
- How to select rays?
- How to interpolate

For each desired ray:
- Compute intersection with \((u,v)\) and \((s,t)\) planes
- Take closest ray

Variants: interpolation
- Bilinear in \((u,v)\) only
- Bilinear in \((s,t)\) only
- Quadrilinear in \((u,v,s,t)\)
Lumigraph Rendering

- Use rough depth information to improve rendering quality

Lightfields

- Advantages:
  - Simpler computation vs. traditional CG
  - Cost independent of scene complexity
  - Cost independent of material properties and other optical effects
  - Avoid hard vision problems
- Disadvantages:
  - Static geometry
  - Fixed lighting
  - High storage cost

Other IBR Representations

- Texture maps
- VDTMs
- Surface lightfields
- Unstructured lightfields
- Concentric mosaics
- Panorama
- Etc.

IBR Summary

- Advantages:
  - Photorealistic - by definition
  - Do not have to create 3D detailed model
  - Do not have to do lighting simulation
  - Performance independent of scene
- Disadvantages:
  - Static scenes only
  - Real-world scenes only
  - Difficult for scenes with specularities, etc.
  - Limited range of viewpoints
  - Limited resolution