Computer Graphics II: Rendering
CSE 168 [Spr 20], Lecture 17: Image-Based Rendering
Ravi Ramamoorthi
http://viscomp.ucsd.edu/classes/cse168/sp20

To Do
- Project proposals due tomorrow (May 27)
- Final Projects due Jun 9
- PLEASE FILL OUT CAPE EVALUATIONS!!
- KEEP WORKING HARD

Motivation for Lecture
- Image-Based Rendering major new idea in graphics in past 25 years
- Many of the rendering methods, especially precomputed techniques borrow from it
- And many methods use measured data
- Also, images are an important source for rendering
- Sampled data rapidly becoming popular
- Core IBR problem of view synthesis/light fields renewed popularity (VR other applications)

Traditional Modeling and Rendering
-Modeling
-Geometry
-Reflectance
-Light sources
-Rendering
-Images

For Photorealism:
Modeling is Hard
Rendering is Slow

Image-Based Modeling and Rendering
-Image-Based Modeling
-Image-Based Rendering
-Images

Can we model and render this?
What do we want to do with the model??

Next few slides courtesy Paul Debevec; SIGGRAPH 99 course notes
### IBR: Pros and Cons

**Advantages**
- Easy to capture images: photorealistic by definition
- Simple, universal representation
- Often bypass geometry estimation?
- Independent of scene complexity?

**Disadvantages**
- WYSIWYG but also WYSIAYG
- Explosion of data as flexibility increased
- Often discards intrinsic structure of model?

Today, IBR-type methods also often used in synthetic rendering (e.g. real-time rendering PRT)
- General concept of data-driven graphics, appearance
- Also, data-driven geometry, animation, simulation
- Spawned light field cameras for image capture

### IBR: A brief history

- Texture maps, bump maps, environment maps [70s]
- Poggio MIT 90s: Faces, image-based analysis/synthesis
- Mid-Late 90s
  - Chen and Williams 93, View Interpolation [images+depth]
  - Chen 95 Quicktime VR [images from many viewpoints]
  - McMillan and Bishop 95 Plenoptic Modeling [images with disparity]
  - Gortler et al, Levoy and Hanrahan 96 Light Fields [4D]
  - Shade et al. 98 Layered Depth Images [2.5D]
  - Debevec et al. 00 Reflectance Field [4D]
  - Inverse rendering (Marschner,Sato,Yu,Boivin,...)
- Today: IBR hasn't replaced conventional rendering, but has brought sampled and data-driven representations to graphics

### Game #1: increase the dimensionality

<table>
<thead>
<tr>
<th>2D rgb</th>
<th>2D rgbz</th>
<th>2.5D rgb/oz</th>
<th>4D rgb</th>
<th>4D rgbz</th>
<th>4.5D rgb/oz</th>
</tr>
</thead>
<tbody>
<tr>
<td>texture</td>
<td>range image</td>
<td>layered depth images</td>
<td>light field / Lumigraph</td>
<td>array of range images</td>
<td>layered light fields</td>
</tr>
</tbody>
</table>

### Game #2: replace the quantity represented

<table>
<thead>
<tr>
<th>4D rgb</th>
<th>5D rgb</th>
<th>6D p</th>
<th>7D p</th>
</tr>
</thead>
<tbody>
<tr>
<td>light field / Lumigraph</td>
<td>plenoptic function</td>
<td>free-space BRDF field</td>
<td>BRDF volume</td>
</tr>
</tbody>
</table>

\{(u, v, s, t)\} \times \{\theta, \phi\} \quad \{(s, y, z)\} \times \{\theta, \phi, \theta, \phi\}
Outline

- Overview of IBR
- Basic approaches
  - Image Warping  
    - (2D + depth. Requires correspondence/disparity)
  - Light Fields [4D]
  - Survey of some early work

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The Plenoptic Function

- The set of rays seen from all points...

\[ p = P(\theta, \phi, x, y, z, \lambda, t) \]

Image-based rendering is about

- reconstructing a plenoptic function from a set of samples taken from it.

- Ignoring time, and selecting a discrete set of wavelengths gives a 5-D plenoptic function

Where to Begin?

- Pinhole camera model
  - Defines a mapping from image points to rays in space

Mapping from Rays to Points

- Simple Derivation

\[ P = \begin{bmatrix} u_1 & v_1 & \theta_1 \\ u_2 & v_2 & \theta_2 \end{bmatrix} \]

\[ \dot{X} = \hat{C} + t P \bar{P} \]
Correspondence

\[
\begin{align*}
\hat{C}_2 + s_1 R_1 \hat{x}_2 &= \hat{C}_1 + s_1 R_1 \hat{x}_1 \\
\hat{x}_2 - \hat{x}_1 &= s_2 (\hat{C}_2 - \hat{C}_1) \\
\hat{x}_2 &= R_2^{-1} ( \hat{C}_2 - \hat{C}_1 ) + s_2 R_2^{-1} \hat{x}_1 \\
\hat{x}_2 &= s_2 R_2^{-1} ( \hat{C}_2 - \hat{C}_1 ) + \frac{R_2^{-1} \hat{x}_1}{s_2}
\end{align*}
\]

Warping in Action

- A 3D Warp

Visibility

- The warping equation determines where points go...

... but that is not sufficient

Partition Reference Image

- Project the desired center of projection onto the reference image

Enumeration

- Drawing toward the projected point guarantees an occlusion-compatible ordering
- Ordering is consistent with a painter's algorithm
- Independent of the scene's contents
- Easily generalized to other viewing surfaces
- No auxiliary information required

Reconstruction

- Typical images are discrete, not continuous
- An image can be formed by different geometries
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Light Field Rendering

Marc Levoy  Pat Hanrahan

Computer Science Department
Stanford University

Apple’s QuickTime VR

Generating New Views

Problem: fixed vantage point/center
One Solution: view interpolation
  - Interpolating between range images
    (Chen and Williams, 1993)
  - Correspondences and epipolar analysis
    (McMillan and Bishop, 1995)
  - Requires depths or correspondences:
    must be extracted from acquired imagery
    relatively expensive and error-prone morph

Light Fields

Gerchun’s and Moon’s idea of a light field:
Radiance as a function of a ray or line: \( L(x, y, z, \theta, \phi) \)
- In “free space” (no occluders) 5D reduces to 4D
  - Exterior of the convex hull of an object
  - Interior of an environment
- Images are 2D slices
  - Insert acquired imagery
  - Extract image from a given viewpoint

4D Light Field
Outline

- Overview of IBR
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Light Field as a 2D Array of Images

\[ L(r) = L(u,v,s,t) \]

Compression Example

Original

Compressed 120:1

Dual Interpretation of Light Field

Plenoptic Light Field
Field radiance

ST Array of UV Images

Surface Light Field
Surface radiance

UV Array of ST Images
Layered Depth Images [Shade 98]

Camera

Geometry

Layered Depth Images [Shade 98]

LDI

(Depth, Color)

Layered Depth Images [Shade 98]

Layered Depth Images [Shade 98]

Surface Light Fields

- Miller 98, Nishino 99, Wood 00
- Reflected light field (lumisphere) on surface
- Explicit geometry as against light fields. Easier compress

Acquiring Reflectance Field of Human Face [Debevec et al., SIGGRAPH 00]

Illuminate subject from many incident directions
Example Images

Outline
- Overview of IBR
- Basic approaches
  - Image Warping
    - [2D + depth. Requires correspondence/disparity]
  - Light Fields [4D]
  - Survey of some recent work
    - Sampled data representations

Conclusion (my views)
- IBR initially spurred great excitement: revolutionize pipeline
- But, IBR in pure form not really practical
  - WYSIWYG
  - Explosion as increase dimensions (8D transfer function)
  - Good compression, flexibility needs at least implicit geometry/BRDF
- Real future is sampled representations, data-driven method
  - Acquire (synthetic or real) data
  - Good representations for interpolation, fast rendering
  - Much of visual appearance, graphics moving in this direction
- Understand from Signal-Processing Viewpoint
  - Sampling rates, reconstruction filters
  - Factored representations, Fourier analysis
- Light Fields fundamental in many ways, including imaging
  - Renewed interest in view synthesis (Mildenhall et al. SIGGRAPH 19)

Virtual Experiences of Real-World Scenes

Input Images

Output Light Field
Local Light Field Fusion