### Advanced Computer Graphics

CSE 190 [Spring 2015], Lecture 14
Ravi Ramamoorthi
http://www.cs.ucsd.edu/~ravir

#### To Do

- Assignment 3 milestone due May 29
  - 1-2 page PDF or website
  - What you have done so far (at least one image)
  - 1-2 para proposal of what you hope to accomplish
  - We may say ok or schedule time to meet, discuss
  - Talk to us if any difficulty finding project
    - Assignment gives some well specified, loose, other options; you can do something else too

### Motivation for Lecture

- Image-Based Rendering major new idea in graphics in past 20 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

### Traditional Modeling and Rendering

![Diagram](Next few slides courtesy Paul Debevec; SIGGRAPH 99 course notes)

For Photorealism:

- **Modeling** is Hard
- **Rendering** is Slow

### Image-Based Modeling and Rendering

Can we model and render this?
What do we want to do with the model?
IBR: Pros and Cons

Advantages
- Easy to capture images: photorealistic by definition
- Simple, universal representation
- Often bypasses 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 w 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

- 2D rgb: texture
- 2D rgby: range image
- 2.5D rgbytcz: layered depth images
- 4D rgb: light field/Lumigraph
- 4D rgby: array of range images
- 4.5D rgbytcz: layered light fields

Game #2: replace the quantity represented

- 4D rgb: light field/Lumigraph
  \{(u,v,s,t)\}
- 5D rgb: plenoptic function
  \{(x,y,z) \times (\theta, \phi)\}
- 6D \rho: free-space BRDF field
  \{(u,v,s,t) \times (\theta, \phi)\}
- 7D \rho: BRDF volume
  \{(x,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

Images as a Collection of Rays

An image is a subset of the rays seen from a given point. This “space” of rays occupies two dimensions.

The Plenoptic Function

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

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

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

\[ \hat{x} = \hat{C} + t \hat{P} \hat{S} \]
**Correspondence**

\[ \hat{C}_1 + t_1 P_1 \hat{x}_1 = \hat{C}_2 + t_2 P_2 \hat{x}_2, \]

\[ t_1 P_1 \hat{x}_1 = \hat{C}_1 - \hat{C}_2 + t_2 P_2 \hat{x}_2, \]

\[ t_1 P_2 = P_2^{-1} (\hat{C}_1 - \hat{C}_2) + t_2 P_1^{-1} \hat{x}_2, \]

\[ \hat{x}_2 = \frac{1}{t_2} P_2^{-1} (\hat{C}_1 - \hat{C}_2) + P_1^{-1} \hat{x}_1. \]

**Warping in Action**

- A 3D Warp

**Demo: Lytro Perspective Shift**

- See demos at [pictures.lytro.com](http://pictures.lytro.com)
- Notice image is everywhere in focus
- Only small motions, interpolate in aperture

**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 a 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
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Light Field Rendering

Marc Levoy    Pat Hanrahan

Computer Science Department
Stanford University

Generating New Views

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

Light Fields

Gershun’s and Moon’s idea of a light field:

\[ \text{Radiance as a function of a ray or line}: I(\mathbf{x}, y, z, \theta, \phi) \]

- 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

Light Field as a 2D Array of Image

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

Dual Interpretation of Light Field

Compression Example

Original  
Compressed 120:1
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Layered Depth Images [Shade 98]

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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

Outline

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

Example Images

Conclusion (my views)

- IBR initially spurred great excitement: revolutionize pipeline
- But, IBR in pure form not really practical
  - WYSIAYG
  - 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
  - Factorized representations, Fourier analysis
- Light Fields fundamental in many ways, including imaging