Advanced Computer Graphics

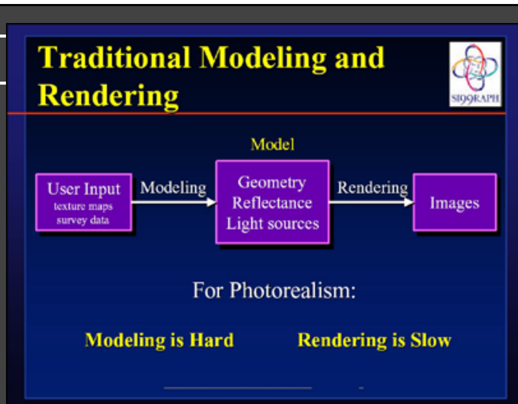
CSE 163 [Spring 2018], Lecture 17

Ravi Ramamoorthi

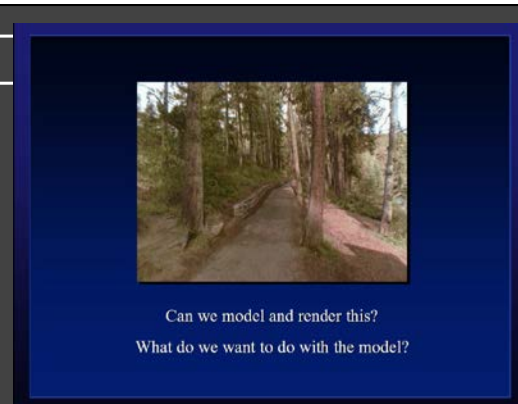
http://www.cs.ucsd.edu/~ravir

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

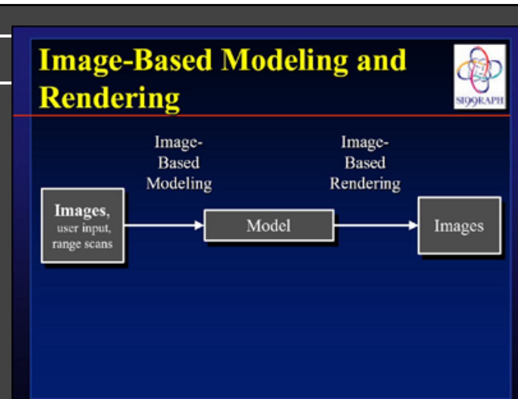


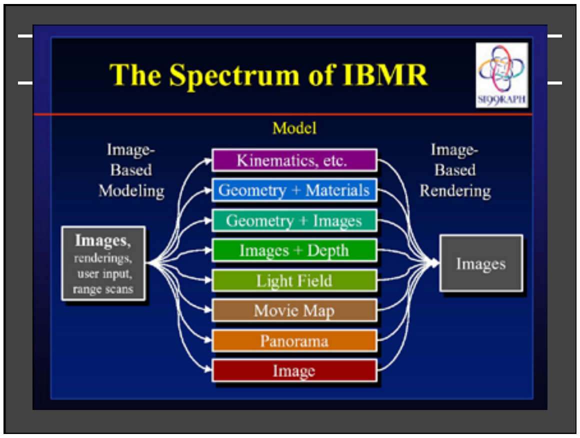
Next few slides courtesy Paul Debevec; SIGGRAPH 99 course notes



To Do

- Assignment 3 milestone due Jun 1
  - Upload on TritonEd
  - If unusual, send to both instructor and TA
  - 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
- Please fill out CAPE evaluations now
- HW 2 videos





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

Image-Based Models: What do they allow?

Model	Movement	Geometry	Lighting
Geometry + Materials	Continuous	Global	Dynamic
Geometry + Images	Continuous	Global	Fixed
Images + Depth	Continuous	Local	Fixed
Light Field	Continuous	None	Fixed
Movie Map	Discrete	None	Fixed
Panorama	Rotation	None	Fixed
Image	None	None	Fixed

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 rgbz	range image
2.5D rgbαz	layered depth images
4D rgb	light field / Lumigraph
4D rgbz	array of range images
4.5D rgbαz	layered light fields

© 1997 Marc Levoy

Game #2: replace the quantity represented

4D rgb — light field / Lumigraph
$\{u, v, s, t\}$

5D rgb — plenoptic function
$\{x, y, z\} \times \{\theta, \varphi\}$

6D ρ — free-space BRDF field
$\{u, v, s, t\} \times \{\theta_i, \varphi_i\}$

7D ρ — BRDF volume
$\{x, y, z\} \times \{\theta_i, \varphi_i, \theta_r, \varphi_r\}$

© 1997 Marc Levoy

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

Warping slides courtesy Leonard McMillan, SIGGRAPH 99 course notes

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

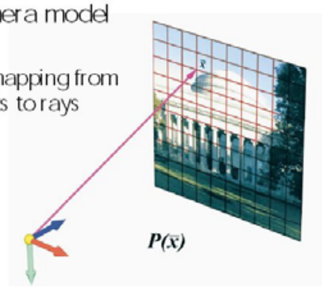
...reconstructing a plenoptic function from a set of samples taken from it.

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

Where to Begin?

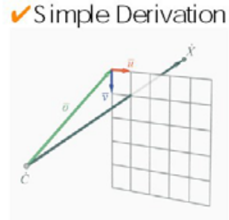
✔ Pinhole camera model

- Defines a mapping from image points to rays in space



Mapping from Rays to Points

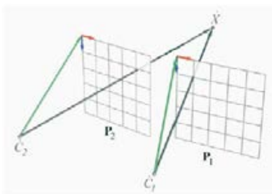
✔ Simple Derivation



$$P = \begin{bmatrix} u_x & v_x & o_x \\ u_y & v_y & o_y \\ u_z & v_z & o_z \end{bmatrix}$$

$$\dot{X} = \dot{C} + t\,P\,\vec{x}$$

Correspondence



$$\dot{C}_2 + t_2 P_2 \vec{x}_2 = \dot{C}_1 + t_1 P_1 \vec{x}_1$$

$$t_2 P_2 \vec{x}_2 = \dot{C}_1 - \dot{C}_2 + t_1 P_1 \vec{x}_1$$

$$t_2 \vec{x}_2 = P_2^{-1}\left(\dot{C}_1 - \dot{C}_2\right) + t_1 P_2^{-1} P_1 \vec{x}_1$$

$$\tfrac{t_2}{t_1} \vec{x}_2 = \tfrac{1}{t_1} P_2^{-1}\left(\dot{C}_1 - \dot{C}_2\right) + P_2^{-1} P_1 \vec{x}_1$$

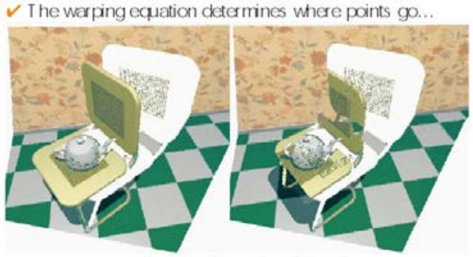
$$\vec{x}_2 \doteq \underbrace{\tfrac{1}{t_1}}_{\delta} \underbrace{P_2^{-1}\left(\dot{C}_1 - \dot{C}_2\right)}_{\vec{e}_{21}} + \underbrace{P_2^{-1} P_1}_{H_{21}} \vec{x}_1$$

Warping in Action

- A 3D Warp

Visibility

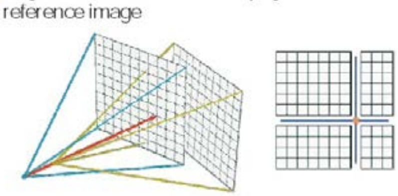
- The warping equation determines where points go…



… but that is not sufficient

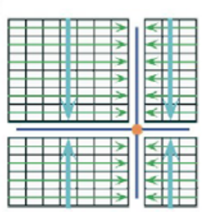
Partition Reference Image

- Project the *desired* center-of-projection onto the reference image



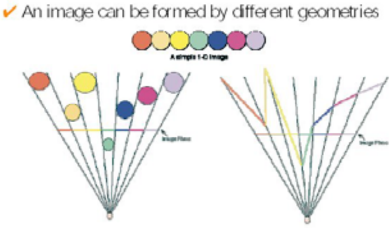
Enumeration

- 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



Outline

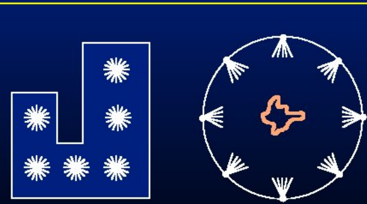
- Overview of IBR
- Basic approaches
  - Image Warping
    - [2D + depth. Requires correspondence/disparity]
  - *Light Fields [4D]*
  - Survey of some early work

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

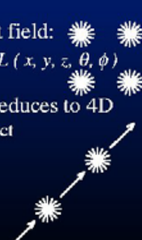
- Interpolating between range images (Chen and Willams, 1993)
- Correspondences and epipolar analysis (McMillan and Bishop, 1995)

-> Requires depths or correspondences:
<u>must be extracted from acquired imagery</u>
<u>relatively expensive and error-prone morph</u>

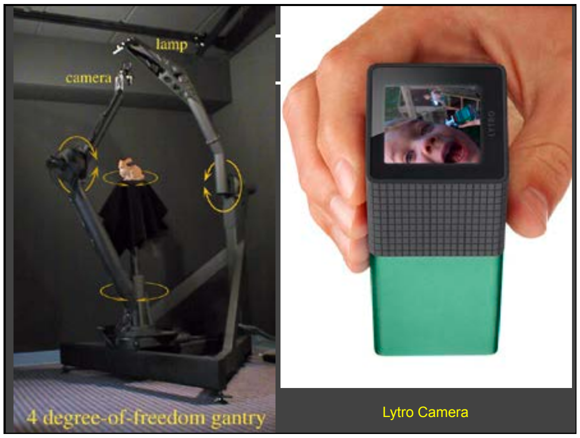
Light Fields

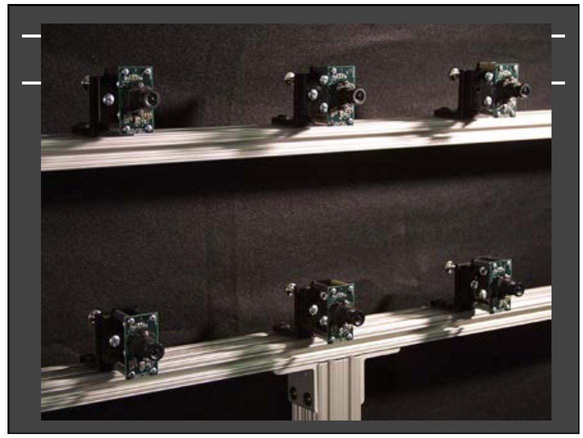
Gershun's and Moon's idea of a light field:
Radiance as a function of a ray or line: $L(x, y, z, \theta, \phi)$

- 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



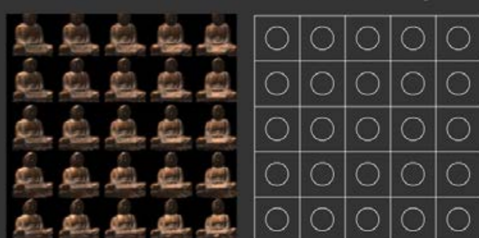
4D Light Field





Light Field as a 2D Array of Image

Camera Array



$$L(r) = L(u, v, s, t)$$

Dual Interpretation of Light Field

Plenoptic Light Field Field radiance	Surface Light Field Surface radiance

UV Array of ST Images | ST Array of UV Images

Compression Example

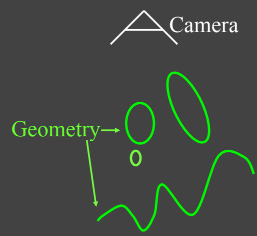
Original

Compressed 120:1

Outline

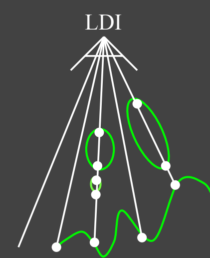
- Overview of IBR
- Basic approaches
  - Image Warping
    - [2D + depth. Requires correspondence/disparity]
  - Light Fields [4D]
  - *Survey of some early work*

Layered Depth Images [Shade 98]

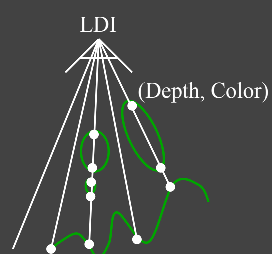


Slide from Agrawala, Ramamoorthi, Heirich, Moll, SIGGRAPH 2000

Layered Depth Images [Shade 98]

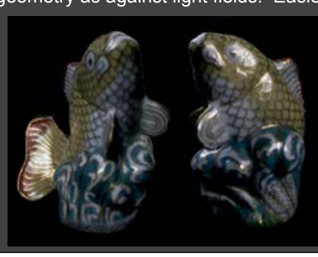


Layered Depth Images [Shade 98]



Surface Light Fields

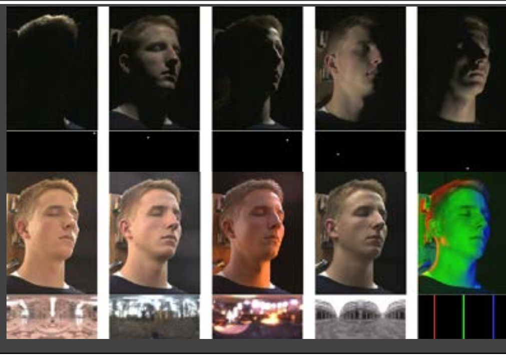
- Miller 98, Nishino 99, Wood 00
- Reflected light field (lumisphere) on surface
- Explicit geometry as against light fields. Easier compress



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
  - 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
  - Factored representations, Fourier analysis
- Light Fields fundamental in many ways, including imaging