


Advanced Computer Graphics (Fall 2009)

CS 294, Rendering Lecture 8:
Image-Based Rendering and Light Fields

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<http://inst.eecs.berkeley.edu/~cs294-13/fa09>

Traditional Modeling and Rendering



```

    graph LR
      subgraph Model
        direction TB
        M1[Geometry]
        M2[Reflectance]
        M3[Light sources]
      end
      UI[User Input  
texture maps  
survey data] -- Modeling --> Model
      Model -- Rendering --> I[Images]
  
```

For Photorealism:


Modeling is Hard Rendering is Slow

Next few slides courtesy Paul Debevec; SIGGRAPH 99 course notes



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


Image-Based Modeling and Rendering



```

    graph LR
      I1[Images,  
user input,  
range scans] -- Image-Based Modeling --> M[Model]
      M -- Image-Based Rendering --> I2[Images]
  
```

The Spectrum of IBMR




```

    graph LR
      subgraph Model
        direction TB
        M1[Kinematics, etc.]
        M2[Geometry + Materials]
        M3[Geometry + Images]
        M4[Images + Depth]
        M5[Light Field]
        M6[Movie Map]
        M7[Panorama]
        M8[Image]
      end
      I1[Images,  
renderings,  
user input,  
range scans] -- Image-Based Modeling --> Model
      Model -- Image-Based Rendering --> I2[Images]
  
```

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

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 rgb α z	layered depth images
4D rgb	light field / Lumigraph
4D rgbz	array of range images
4.5D rgb α z	layered light fields

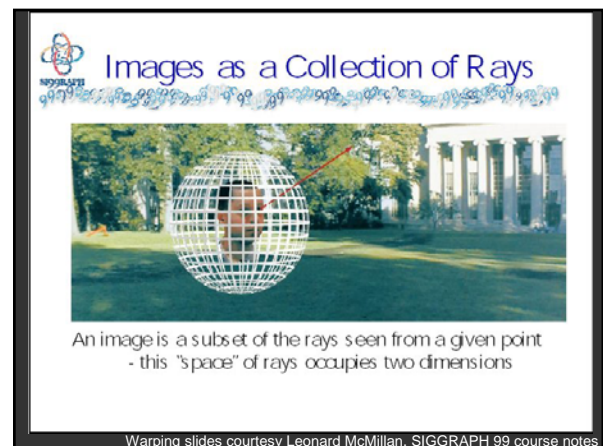
© 1997 Marc Levoy

Game #2: replace the quantity represented

4D rgb	light field / Lumigraph
$\{u, v, s, t\}$	
5D rgb	plenoptic function
$\{x, y, z\} \times \{\theta, \phi\}$	
6D ρ	free-space BRDF field
$\{u, v, s, t\} \times \{\theta, \phi\}$	
7D ρ	BRDF volume
$\{x, y, z\} \times \{\theta_1, \phi_1, \theta_2, \phi_2\}$	


© 1997 Marc Levoy

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



The Plenoptic Function

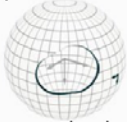
✓ The set of rays seen from all points ...



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

Image-based rendering is about

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

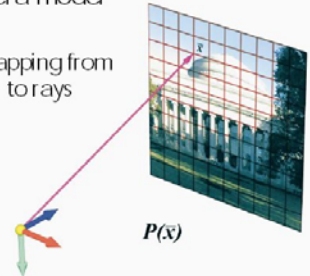


✓ Ignoring time, and selecting a discrete set of wavelengths gives a 5-D plenoptic function

Where to Begin?

✓ Pinhole camera model

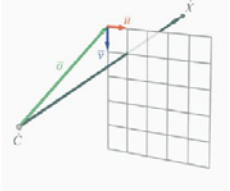
- Defines a mapping from image points to rays in space



$P(\vec{x})$

Mapping from Rays to Points

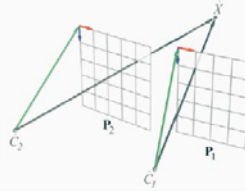
✓ Simple Derivation



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

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

Correspondence



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

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

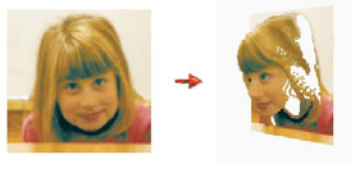
$$t_2 \vec{x}_2 = P_2^{-1} (\dot{C}_1 - \dot{C}_2) + t_1 P_2^{-1} P_1 \vec{x}_1$$

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

$$\vec{x}_2 \triangleq \frac{1}{t_1} P_2^{-1} (\dot{C}_1 - \dot{C}_2) + \frac{P_2^{-1} P_1 \vec{x}_1}{H_{21}}$$

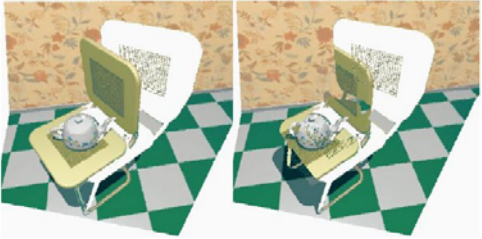
Warping in Action

✓ A 3D Warp



Visibility

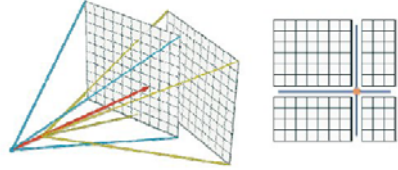
- ✓ The warping equation determines where points go...



... but that is not sufficient

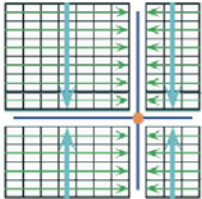
Partition Reference Image

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



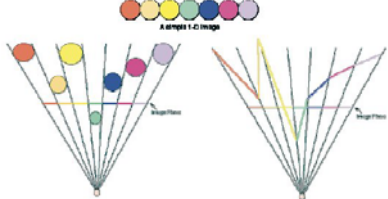
Enumeration

- ✓ 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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 - [2D + depth. Requires correspondence/disparity]
 - *Light Fields [4D]*
 - Survey of some recent work

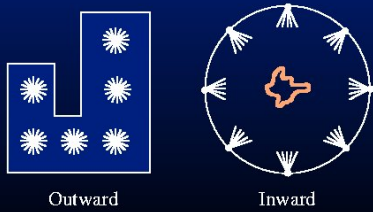
Light Field Rendering

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

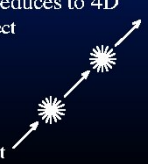
- Interpolating between range images (Chen and Williams, 1993)
- Correspondences and epipolar analysis (McMillan and Bishop, 1995)

-> Requires depths or correspondences:

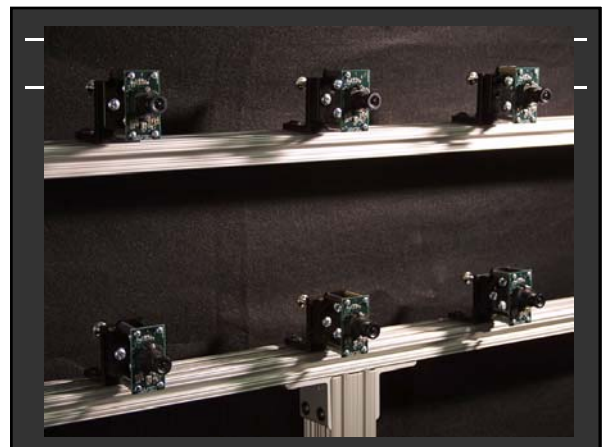
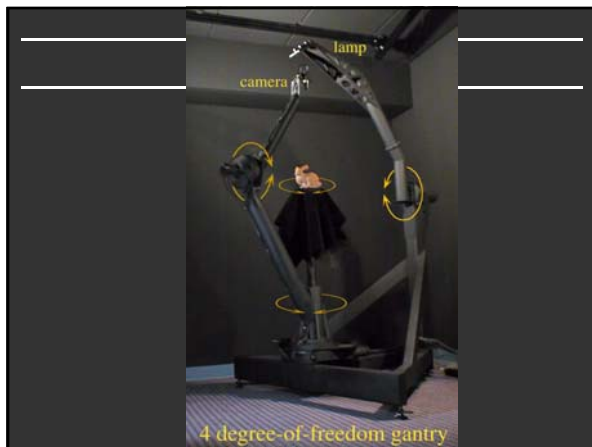
must be extracted from acquired imagery
relatively expensive and error-prone morph

Light Fields

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

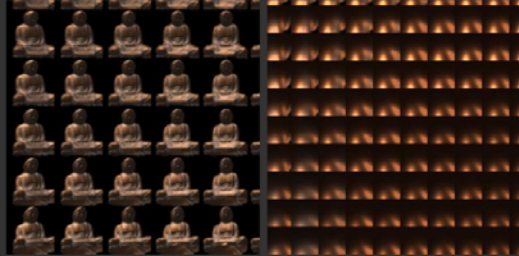


$$L(r) = L(u, v, s, t)$$

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



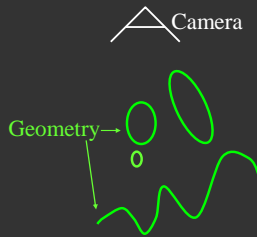
Original

Compressed 120:1

Outline

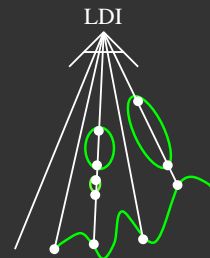
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 - *Survey of some recent work*

Layered Depth Images [Shade 98]

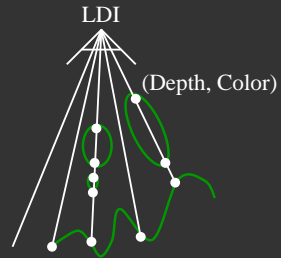


Slide from Agrawala, Ramamoorthi, Heirich, Moll, SIGGRAPH 2000

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

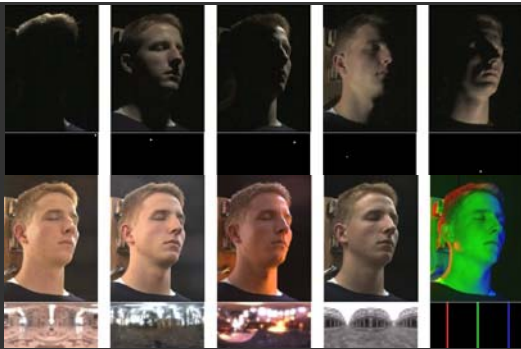


Acquiring Reflectance Field of Human Face [Debevec et al. SIGGRAPH 00]

Illuminate subject from many incident directions



Example Images



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 - 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