Image-Based Rendering

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Acknowledgments: Dan Aliaga, Thomas Funkhouser, Marc Levoy, Szymon Rusinkiewicz
Image-Based Rendering

- Generate new views of a scene directly from existing views
Image-Based Rendering

• Traditional vision / graphics rendering:

[Diagram showing the process of traditional vision and graphics rendering with nodes for World, Light sources, Reflectance, Geometry, and New Images.]

• Image-based rendering:

[Diagram showing the process of image-based rendering with nodes for World, Captured Images, and New Images.]
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

[Funkhouser]
Plenoptic Function Simplifications

- Simplification from 7D to $3 \times 5D$
  - Represent color as RGB: eliminate $\lambda$
  - Static scenes: eliminate $t$

- Other simplifications?
Image-Based Representations

7D  Ideal
6D  Consider only 3 frequencies (RGB)
5D  Consider only one time instant (static scene)
4D  Consider only viewpoints inside/outside scene
3D  Consider one dimension fewer directions/positions
2D  Consider viewpoints at finite set points or angles
IBR Representations

- Image pairs
- Sea of Images
- Lightfields / Lumigraphs
IBR Representations

- Image pairs
- Sea of Images
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View Interpolation

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

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

Morph with warp defined by pixel correspondences
Pixel Correspondences

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

Left

Right

Disparity
View Interpolation

- Problem: changes in visibility
  - Disocclusions
Disocclusions

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

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

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  - Multiple samples per pixel at different depths
Disocclusions

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

Reference Image

Warped Layered 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?
IBR Representations

- Image pairs
- Sea of Images
- Lightfields / Lumigraphs
Sea of Images

Large-scale Dense Capture

Interactive Walkthroughs

Data Management and Rendering Algorithms
Sea of Images Capture

- Use a hemispherical FOV camera driven on cart

Paraboloidal Catadioptric Camera
[Nayar97]
Sea of Images Capture

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

- Locate camera by tracking fiducials
Sea of Images Capture

- 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
Sea of Images Compression

- 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

floor plan

Novel viewpoint
Sea of Images Rendering

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

- **Bell Labs Museum**
  - 900 square ft
  - 9832 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
Sea of Images Results
Sea of Images Results
Sea of Images Results

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

- Multiresolution pre-filtering: far-to-near image sequence
Sea of Images Results

captured omnidirectional image

reconstructed omnidirectional image
IBR Representations

- Image pairs
- Sea of Images
- Lightfields / Lumigraphs
Lightfields

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

Outside looking in

Inside looking out
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 Two-Plane Parameterization

(a)

(b)
Multi-Slab Light Fields

[Levoy96]
Lightfield Capture

• Capture a 2D set of (2D) images

• Choices:
  – Camera motion: human vs. computer
  – Constraints on camera motion
  – Coverage and sampling uniformity
  – Aliasing
Lightfield Capture

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

[Gortler96]
Lightfield Capture

- 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
Lightfield Capture

- Acquire an entire light field at once
- Video rates
- Integrated MPEG2 compression for each camera

(Bennett Wilburn, Michal Smulski, Mark Horowitz)
Lightfield Capture

Lytro
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

[Gortler96]
Lightfield Rendering

• 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 \((u,v,s,t)\)
Lightfield Rendering

- Use rough depth information to improve rendering quality
Lightfield Rendering

- Use rough depth information to improve rendering quality
Lightfield Rendering

Without using geometry

Using approximate geometry

[Gortler96]
Lightfield Video

[Levoy96]
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.

Texture maps are an IBR representation!
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