Light Fields and Image Based Rendering

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What’s wrong with traditional photos
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Only 1 view!
What can we do about this?

Only 1 view!
What would be the simplest, most naïve, brute force approach?
CAPTURE ALL THE IMAGES!
We can’t capture all the images
Sample, Reconstruct, and Integrate

- Image formation is the integration of light rays
- Parameterize the space of light rays
- Sample and reconstruct in this space
- Integrate to form an image

Interpolation, Extrapolation
Sample, Reconstruct, and Integrate

• How to Sample?
• What is the right parameterization?
• How to Interpolate?
• How to form an image?
Recap: Ray Optics
Recap: Ray Optics

Light source

Scene
Recap: Ray Optics
Recap: Ray Optics
Recap: Ray Optics
Recap: Ray Optics
Recap: Ray Optics

Light source

Observer

Scene
Recap: Ray Optics
Recap: Ray Optics

• A pinhole image describes all the light passing through a point
• Each pixel integrates a small bundle of rays
Sampling, Interpolation, and Reconstruction
Sampling, Interpolation, and Reconstruction
Sampling, Interpolation, and Reconstruction

Samples
Sampling, Interpolation, and Reconstruction
Sample, Reconstruct, and Integrate

• How to Sample?
• What is the right parameterization?
• How to Interpolate?
• How to form an image?

Interpolation, Extrapolation
What is a good parameterization for light?

• Radiance:
  – $R(\text{position, angle})$
  – How many dimensions?
What is a good parameterization for light?

- Radiance: $R(\text{position, angle})$
  - Position = $(x,y,z)$
  - Angle = $(\theta, \phi)$
  - 5 dimensions
What is a good parameterization for light?

- The Light Field
  - Unobstructed, incoherent light rays
  - Each ray defined by intersection with 2 planes

Figure 1: The light slab representation.
What is a good parameterization for light?

- The Light Field
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Figure 1: The light slab representation.
The Light Field

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The Light Field
The Light Field

Epipolar Plane Image (EPI)

Line -> Point
The Light Field

Point -> Line
The Light Field

Point -> Line
The Light Field
The Light Field
The Light Field
The Light Field
The Light Field

b plane

a plane
The Light Field
The Light Field
The Light Field
The Light Field
The Light Field
The Light Field
The Light Field
The Light Field
The Light Field
Sample, Reconstruct, and Integrate

• How to Sample?
• What is the right parameterization?
• How to Interpolate?
• How to form an image?
The Light Field
The Light Field
The Light Field

Interpolate according to depth!
Projection Mapping

Captured Image

Requested Image
Projection Mapping
Projection Mapping
Projection Mapping
Projection Mapping
Projection Mapping
The Light Field
Sample, Reconstruct, and Integrate

• How to Sample?
• What is the right parameterization?
• How to Interpolate?
• How to form an image?
Light field cameras
Plenoptic/light field cameras

- [Lipmann 1908, Adelson and Wang, 1992, Ng et al. 06]

- Record 4D set of rays
  - using microlens array in front of sensor
PHOTOGRAPHIE. — *Épreuves réversibles. Photographies intégrales.*

Note de M. G. Lippmann.

1. La plus parfaite des épreuves photographiques actuelles ne montre que l'un des aspects de la réalité; elle se réduit à une image unique fixée dans un plan, comme le serait un dessin ou une peinture tracée à la main. La vue directe de la réalité offre, on le sait, infiniment plus de variété. On voit les objets dans l'espace, en vraie grandeur et en relief, et non dans un plan. De plus, leur aspect change avec les positions de l'observateur; les différents plans de la vue se déplacent alors les uns par rapport aux autres; la perspective se modifie; les parties cachées ne restent pas les mêmes; enfin, si le spectateur regarde le monde extérieur par une fenêtre, il est maître de voir les diverses parties d'un paysage venir s'encadrer successivement entre les bords de l'ouverture, si bien que dans ce cas ce sont des objets différents qui lui apparaissent successivement.

Peut-on demander à la Photographie de nous rendre toute cette variété

**Fig. 1.**
Plenoptic camera

• For depth extraction
• Adelson & Wang 92

http://www-bcs.mit.edu/people/jyawang/demos/plenoptic/plenoptic.html
Camera array

Camera arrays


Figure 2: Our camera tiles contain an Omnivision 8610 image sensor, passive electronics, and a lens mount. The ribbon cables carry video data, synchronization signals, control signals, and power between the tile and the processing board. To keep costs low, we use fixed-focus, fixed-aperture lenses.
Figure 12: Hybrid synthetic aperture photography for combining high depth of field and low motion blur. (a-c) Images captured of a scene simultaneously through three different apertures: a single camera with a long exposure time (a), a large synthetic aperture with short exposure time (b), and a large synthetic aperture with a long exposure time. Computing (a+b-c) yields image (d), which has aliasing artifacts because the synthetic apertures are sampled sparsely from slightly different locations. Masking pixels not in focus in the synthetic aperture images before computing the difference (a + b - c) removes the aliasing (e). For comparison, image (f) shows the image taken with an aperture that is narrow in both space and time. The entire scene is in focus and the fan motion is frozen, but the image is much noisier.
MIT version

- Jason Yang
Bullet time

• Time splice http://www.ruffy.com/frameset.htm
Robotic Camera

Image Leonard McMillan

Image Levoy et al.
Legos

- [link](http://lightfield.stanford.edu/aperture.swf?lightfield=data/self_portrait_lf/preview.zip&zoom=1)
Flatbed scanner camera

• By Jason Yang
Hand-Held Light Field Camera

Medium format digital camera

16 megapixel sensor

Camera in-use

Microlens array

Slide by Ren Ng.
New version: Lytro

- http://www.lytro.com/
- hexagonal microlens array
Your Next Assignment

• Given a bunch of \(u,v\) viewpoints, refocus into a focus stack
• Given a focal stack compute an all focus image
• We’ll work with the Stanford data sets and the LYTRO!
  – We will split you into groups of \(~4-5\), one camera per group
Digital Refocusing by Ray-Tracing

Let’s see where different aperture locations get reprojected.
Digital Refocusing by Ray-Tracing

Let's see where different aperture locations get reprojected.

Similar triangles:
- The rays from \( u_1 \) are shifted with respect to the rays from \( u_0 \) by the same amount.
- This amount is proportional to \( ||u_1u_0|| \).

![Diagram](image)
Algorithm

- For all aperture locations \( u, v \) in \([-1, 1]\)
  - translate image along \( y, x \) by \( ku, kv \)
  - add to final image
- Note: we ignore a scale factor (recall, field of view changes with refocusing)
Input light field

- Yes, the focal stack was synthetic!
Input light field
Input light field

Aperture images are square because it’s captured with a robotics rig.
Epipolar slices

- $y, v = \text{constant}$
Results
Results
Results
Results
Results
Results
More results
More results
Epipolar slice
More results
More results
More results
More results
More results
Le Thanks!
Focal stack & plenoptic camera

Light Field Photography with a Hand-Held Plenoptic Camera, Ren Ng, Marc Levoy, Mathieu Brédif, Gene Duval, Mark Horowitz, Pat Hanrahan

- See next time
- Capture light field

- Refocus to create focal stack

- Use photomontage to generate all-focus image
Focal stack & plenoptic camera

From Ng et al. [link]

Figure 15: Left: Extended depth of field computed from a stack of photographs focused at different depths. Right: A single sub-aperture image, which has equal depth of field but is noisier.
Photography = integration

Radiance: 
L(position, angle)

Position = (x,y,z)
Angle = (theta, phi)
Photography = integration

Radiance: 
\[ L(\text{position}, \text{angle}) \]

Position = (x, y, z)

Angle = (\theta, \phi)

5 dimensions!
Photography = integration

Radiance:
$L(\text{position, angle})$

Position = $(x,y,z)$
Angle = $(\text{theta, phi})$

5 dimensions!
Plenoptic/light field cameras

- Lipmann 1908
  - "Window to the world"

- Adelson and Wang, 1992
  - Depth computation

- Revisited by Ng et al. for refocusing
  - turned into Lytro
Caperture
Computer Graphics

Light source

Requested Image

Geometry