Modeling Light

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15-463: Computational Photography
Alexei Efros, CMU, Fall 2005
What is light?

Electromagnetic radiation (EMR) moving along rays in space

- $R(\lambda)$ is EMR, measured in units of power (watts)
  - $\lambda$ is wavelength

Useful things:

- Light travels in straight lines
- In vacuum, radiance emitted = radiance arriving
  - i.e. there is no transmission loss
What do we see?

3D world

2D image

Point of observation

Figures © Stephen E. Palmer, 2002
What do we see?

3D world

2D image

Painted backdrop
On Simulating the Visual Experience

Just feed the eyes the right data
  • No one will know the difference!

Philosophy:
  • Ancient question: “Does the world really exist?”

Science fiction:
  • Many, many, many books on the subject
  • Latest take: *The Matrix*

Physics:
  • *Slowglass* might be possible?

Computer Science:
  • Virtual Reality

To simulate we need to know:
  What does a person see?
The Plenoptic Function

Q: What is the set of all things that we can ever see?
A: The Plenoptic Function (Adelson & Bergen)

Let’s start with a stationary person and try to parameterize everything that he can see…
Grayscale snapshot

\[ P(\theta, \phi) \]

is intensity of light

- Seen from a single viewpoint
- At a single time
- Averaged over the wavelengths of the visible spectrum

(can also do \( P(x,y) \), but spherical coordinate are nicer)
Color snapshot

\[ P(\theta, \phi, \lambda) \]

is intensity of light

- Seen from a single view point
- At a single time
- As a function of wavelength
A movie

\[ P(\theta,\phi,\lambda,t) \]

is intensity of light

- Seen from a single view point
- Over time
- As a function of wavelength
Holographic movie

\[ P(\theta, \phi, \lambda, t, V_X, V_Y, V_Z) \]

is intensity of light

- Seen from ANY viewpoint
- Over time
- As a function of wavelength
The Plenoptic Function

\[
P(\theta, \phi, \lambda, t, V_x, V_y, V_z)
\]

- Can reconstruct every possible view, at every moment, from every position, at every wavelength
- Contains every photograph, every movie, everything that anyone has ever seen! It completely captures our visual reality! Not bad for a function…
Sampling Plenoptic Function (top view)

Just lookup -- Quicktime VR
Let’s not worry about time and color:

\[ P(\theta, \phi, V_x, V_y, V_z) \]

- 3D position
- 2D direction
How can we use this?

Lighting

Surface

No Change in Radiance

Camera
Ray Reuse

Infinite line

- Assume light is constant (vacuum)

4D

- 2D direction
- 2D position
- non-dispersive medium
Only need plenoptic surface

Figure 1: The surface of a cube holds all the radiance information due to the enclosed object.
Synthesizing novel views
Lumigraph / Lightfield

Outside convex space

4D

Empty

Stuff

Slide by Rick Szeliski and Michael Cohen
Lumigraph - Organization

2D position

2D direction
Lumigraph - Organization

2D position
2D position

2 plane parameterization
Lumigraph - Organization

2D position

2D position

2 plane parameterization

Slide by Rick Szeliski and Michael Cohen
Lumigraph - Organization

Hold $s,t$ constant
Let $u,v$ vary
An image
Lumigraph / Lightfield
Lumigraph - Capture

Idea 1

- Move camera carefully over $s,t$ plane
- Gantry
  - see Lightfield paper
Lumigraph - Capture

Idea 2

- Move camera anywhere
- Rebinning
  - see Lumigraph paper
For each output pixel

- determine $s, t, u, v$

- either
  - use closest discrete RGB
  - interpolate near values
Lumigraph - Rendering

Nearest
- closest s
- closest u
- draw it

Blend 16 nearest
- quadrilinear interpolation

Slide by Rick Szeliski and Michael Cohen
Stanford multi-camera array

- 640 × 480 pixels × 30 fps × 128 cameras
- synchronized timing
- continuous streaming
- flexible arrangement
Light field photography using a handheld plenoptic camera

Ren Ng, Marc Levoy, Mathieu Brédif, Gene Duval, Mark Horowitz and Pat Hanrahan
Conventional versus light field camera
Conventional versus light field camera

Subject

Main lens

Photosensor

$uv$-plane

$st$-plane

Main lens
Prototype camera

Contax medium format camera

Kodak 16-megapixel sensor

Adaptive Optics microlens array

125μ square-sided microlenses

\[
4000 \times 4000 \text{ pixels} \div 292 \times 292 \text{ lenses} = 14 \times 14 \text{ pixels per lens}
\]
Digitally stopping-down

- stopping down = summing only the central portion of each microlens
Digital refocusing

- refocusing = summing windows extracted from several microlenses
Example of digital refocusing
Digitally moving the observer

- moving the observer = moving the window we extract from the microlenses
Example of moving the observer
Moving backward and forward
3D Lumigraph

One row of s,t plane

• i.e., hold t constant
3D Lumigraph

One row of s, t plane

- i.e., hold t constant
- thus s, u, v
- a “row of images”
$P(x,t)$  

by David Dewey
What is an image?

All rays through a point

- Panorama?
Image

Image plane

2D position
Spherical Panorama

All light rays through a point form a panorama
Totally captured in a 2D array -- $P(\theta, \phi)$
Where is the geometry???
Other ways to sample Plenoptic Function

Moving in time:

• Spatio-temporal volume: $P(\theta, \phi, t)$
• Useful to study temporal changes
• Long an interest of artists:

Claude Monet, Haystacks studies
Space-time images

Other ways to slice the plenoptic function…
The “Theatre Workshop” Metaphor

(Adelson & Pentland, 1996)

Painter
Lighting Designer
Sheet-metal worker

desired image
Painter (images)
Lighting Designer (environment maps)

Show Naimark SF MOMA video
http://www.debevec.org/Naimark/naimark-displacements.mov
Sheet-metal Worker (geometry)

Let surface normals do all the work!
... working together

Want to minimize cost

Each one does what’s easiest for him

- Geometry – big things
- Images – detail
- Lighting – illumination effects