More computational light transport
Course announcements

• Sign-up for final project checkpoint meeting.
  - Moved to Monday-Tuesday,
  - Email me if you cannot make it then.

• Any questions about homework 5?
Overview of today’s lecture

- Direct and global illumination.
- Direct-global separation using high-frequency illumination.
- Direct-global separation using epipolar probing.
- Energy-efficient epipolar imaging.
These slides were directly adapted from:

- Shree Nayar (Columbia).
- Matthew O’Toole (Stanford).
Direct and global illumination
Direct and Global Illumination

A : Direct
B : Interreflection
C : Subsurface
D : Volumetric
E : Diffusion
Direct and Global Components: Interreflections

\[ L[c, i] = L_d[c, i] + L_g[c, i] \]

Radiance = Direct + Global

\[ L_g[c, i] = \sum_{P} A[i, j] L[i, j] \]

BRDF and geometry
Direct-global separation using high-frequency illumination
High Frequency Illumination Pattern

\[ L^+ [c, i] = L_a [c, i] + \alpha L_g [c, i] \]

fraction of activated source elements
High Frequency Illumination Pattern

\[ L^+[c,i] = L_d[c,i] + \alpha L_g[c,i] \]

\[ L^-[c,i] = (1 - \alpha) L_g[c,i] \]

fraction of activated source elements
Separation from Two Images

\[ \alpha = \frac{1}{2} \]

\[ L_d = L_{\text{max}} - L_{\text{min}} \quad \text{and} \quad L_g = 2L_{\text{min}} \]
Other Global Effects: Subsurface Scattering

source

camera

translucent surface

i

j
Other Global Effects: Volumetric Scattering
Diffuse Interreflections

Specular Interreflections

Volumetric Scattering

Subsurface Scattering

Diffusion
V-Grooves: Diffuse Interreflections

Psychophysics:
Gilchrist 79, Bloj et al. 04
Real World Examples:

Can You Guess the Images?
Eggs: Diffuse Interreflections

Direct

Global
Wooden Blocks: Specular Interreflections

Direct

Global
Novel Images
Photometric Stereo: The Pseudo Shape

Actual Shape
($\rho = 0.95$)

Pseudo Shape

Nayar et al., 1991
Photometric Stereo using Direct Images

Source 1  Source 2  Source 3

Bowl

Global

Direct

Shape
Variants of Separation Method

- Coded Structured Light
- Shifted Sinusoids
- Shadow of Line Occluder
- Shadow of Mesh Occluders
Building Corner

\[ L_d = L_{\text{max}} - L_{\text{min}} \, , \, L_g = L_{\text{min}} \]

3D from Shadows: Bouguet and Perona 99
Shower Curtain: Diffuser

\[ L_d = L_{\text{max}} - \beta L_{\text{min}} \quad , \quad L_g = \beta L_{\text{min}} \]
Shower Curtain: Diffuser

Direct

Global
Kitchen Sink: Volumetric Scattering

Volumetric Scattering:
Chandrasekar 50, Ishimaru 78
Peppers: Subsurface Scattering

Direct

Global
Tea Rose Leaf

Leaf Anatomy: Purves et al. 03
Translucent Rubber Balls
Hand

Skin: Hanrahan and Krueger 93, Uchida 96, Haro 01, Jensen et al. 01, Igarashi et al. 05, Weyrich et al. 05
Separation from a Single Image
Pebbles: 3D Texture

Direct

Global
Pink Carnation

Spectral Bleeding: Funt et al. 91
Mirror Ball: Failure Case

Direct

Global
Direct-global separation using epipolar probing
basic light paths

indirect light (scattered)

camera

projector
basic light paths

Indirect light (specular)

Camera

Mirror

Projector
basic light paths

camera

mirror

projector
epipolar constraint & light transport

direct paths satisfy epipolar constraints
epipolar constraint & light transport

indirect paths almost never satisfy constraints

camera
epipolar line

mirror

epipolar line
projector
indirect paths almost never satisfy constraints
blocking epipolar paths with patterns & masks
blocking epipolar paths with patterns & masks

camera

mask pattern

projection pattern

projector

mirror
blocking epipolar paths with patterns & masks

complementary random epipolar patterns
blocking epipolar paths with patterns & masks

complementary random epipolar patterns
blocking epipolar paths with patterns & masks

complementary random epipolar patterns
blocking epipolar paths with patterns & masks

complementary random epipolar patterns
blocking epipolar paths with patterns & masks

1. open electronic shutter
2. for $i = 1$ to $N$
   use random epipolar mask & project complementary pattern
3. close electronic shutter
top-left: conventional  
top-right: indirect-only  
bottom-right: epipolar-only
top-left: conventional
top-right: indirect-only
bottom-right: epipolar-only
top-left: conventional
top-right: indirect–only
bottom-right: epipolar–only
top-left: conventional
top-right: indirect-only
bottom-right: epipolar-only
top-left: conventional
top-right: indirect-only
bottom-right: epipolar-only
top-left: conventional
top-right: indirect-only
bottom-right: epipolar-only
top-left: conventional
top-right: indirect-only
bottom-right: epipolar-only
top-left: conventional
top-right: indirect-only
bottom-right: epipolar-only
top-left: conventional
top-right: indirect-only
bottom-right: epipolar-only
Energy-efficient epipolar imaging
Energy-efficient transport parsing

Epipolar Plane

Laser Projector

Beam

Camera & Mask
Energy-efficient transport parsing
all paths

planar (mostly direct)

non-planar (always indirect)

a great deal of indirect transport occurs in many common LOS scenes
all paths

planar (mostly direct)

non-planar (always indirect)
References

Basic reading:
  the paper on separation of direct and global illumination using high-frequency illumination.
• O’Toole et al., “Primal-dual coding to probe light transport,” SIGGRAPH 2012.
• O’Toole et al., “3d shape and indirect appearance by structured light transport,” CVPR 2014.
  these two papers introduce the concepts of light transport probing and epipolar probing, as well as explain how to use primal-dual coding to achieve them.
• O’Toole et al., “Homogeneous codes for energy-efficient illumination and imaging,” SIGGRAPH 2015.
  this paper shows how to efficiently implement epipolar imaging with a simple projector and camera.

Additional reading:
  this early paper shows a way to exactly decompose light transport by number of bounces, under certain assumptions for the imaged scene.
  these two papers have additional analysis about the relationship between direct and global illumination and illumination frequency.