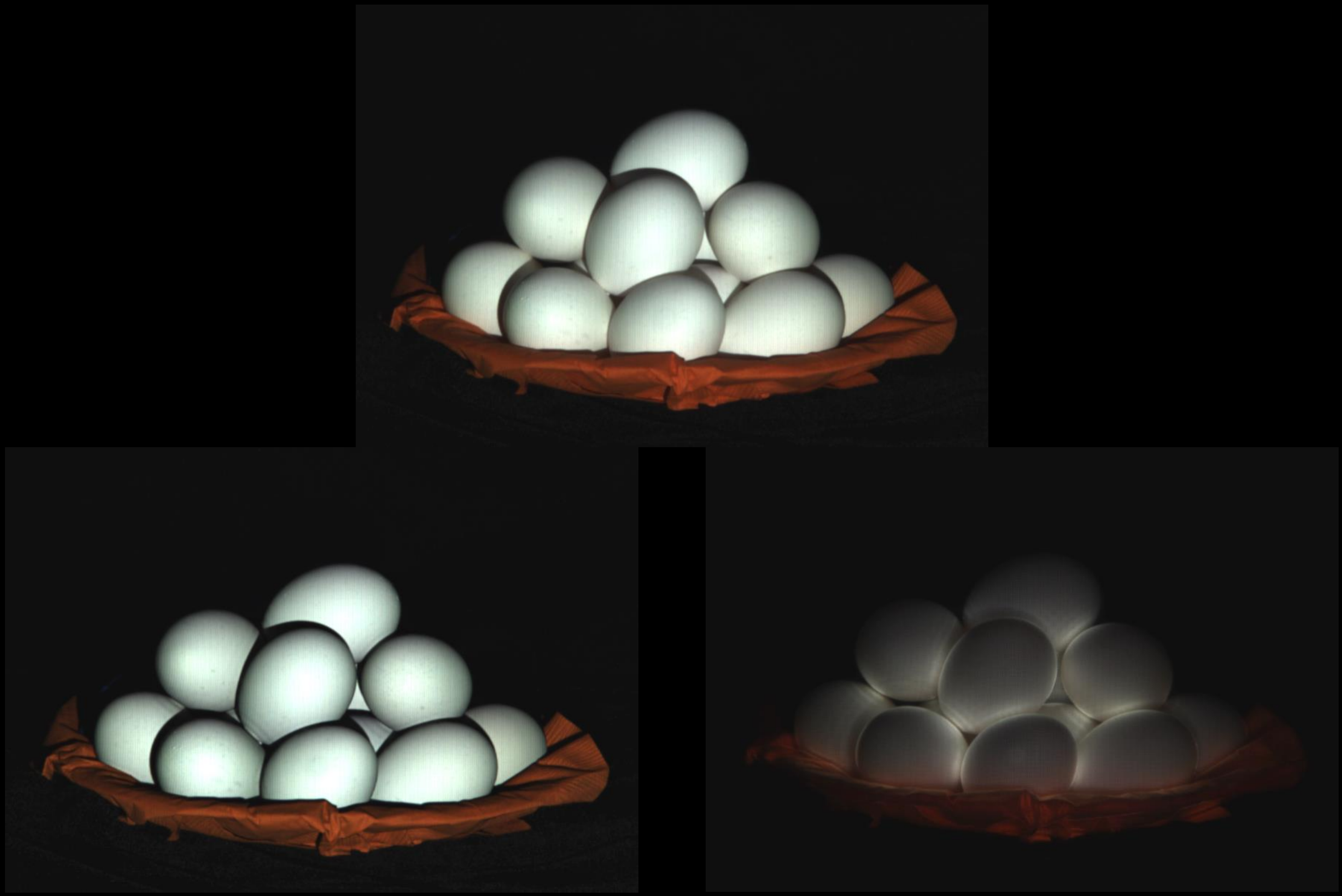
Computational light transport



15-463, 15-663, 15-862
Computational Photography
Fall 2018, Lecture 19

http://graphics.cs.cmu.edu/courses/15-463

Course announcements

- Homework 5 has been posted.
  - Due on Friday November 9th.
- Friday's office hours will be held by Alankar.
- Great talk this Thursday: Eric Fossum, inventor of the CMOS sensor, will talk about quantum (i.e., photon-counting) CMOS sensors.

Overview of today’s lecture

- Direct and global illumination.
- Direct-global separation using high-frequency illumination.
- Light transport probing.
- Direct-global separation using diagonal probing (coaxial case).
- Direct-global separation using epipolar probing (non-coaxial case).
- Energy-efficient epipolar imaging.

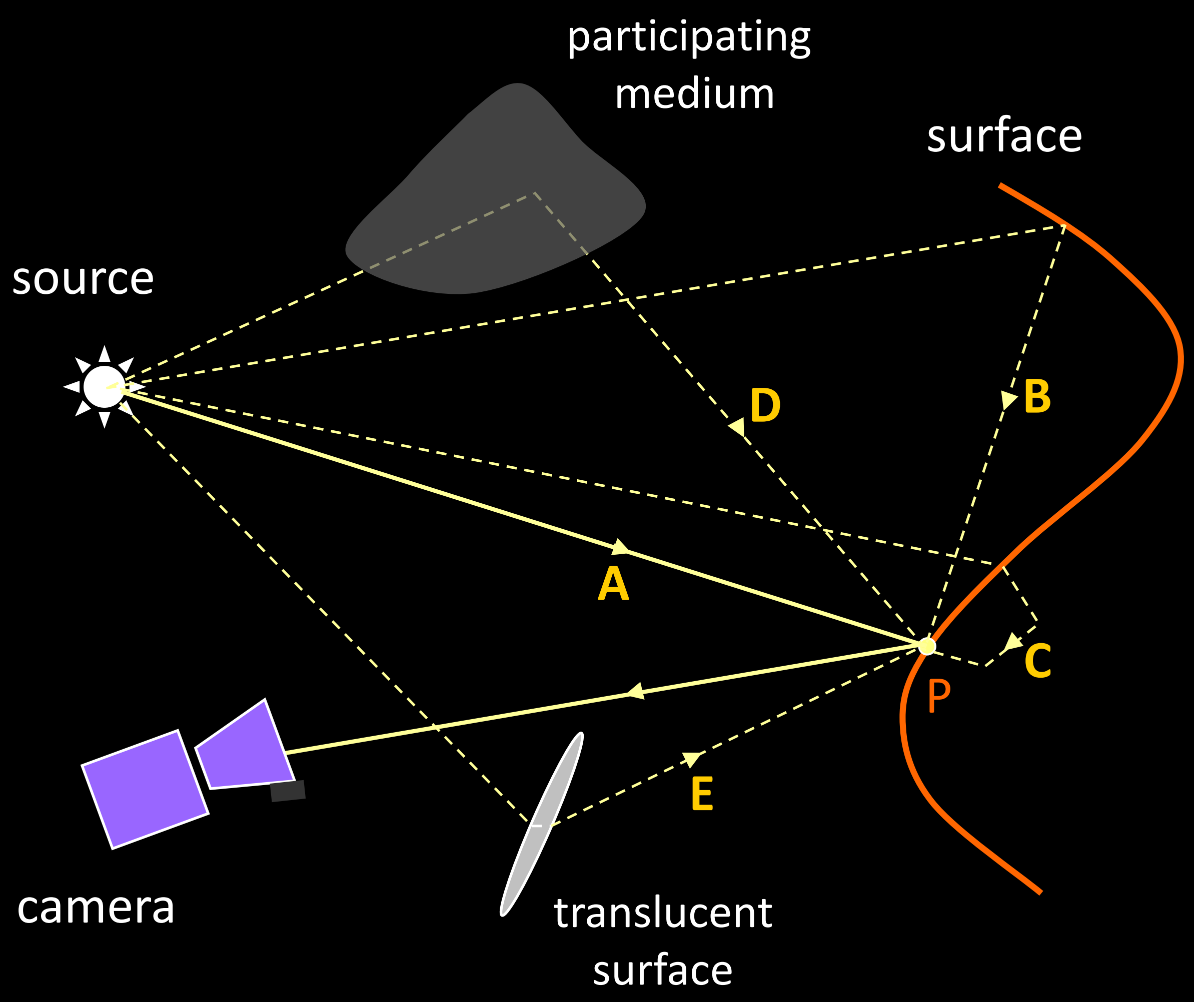
Slide credits

These slides were directly adapted from:

- Shree Nayar (Columbia).
- Matthew O'Toole (CMU).
- Supreeth Achar (Google, formerly CMU).

Direct and global illumination

Direct and Global Illumination



A : Direct

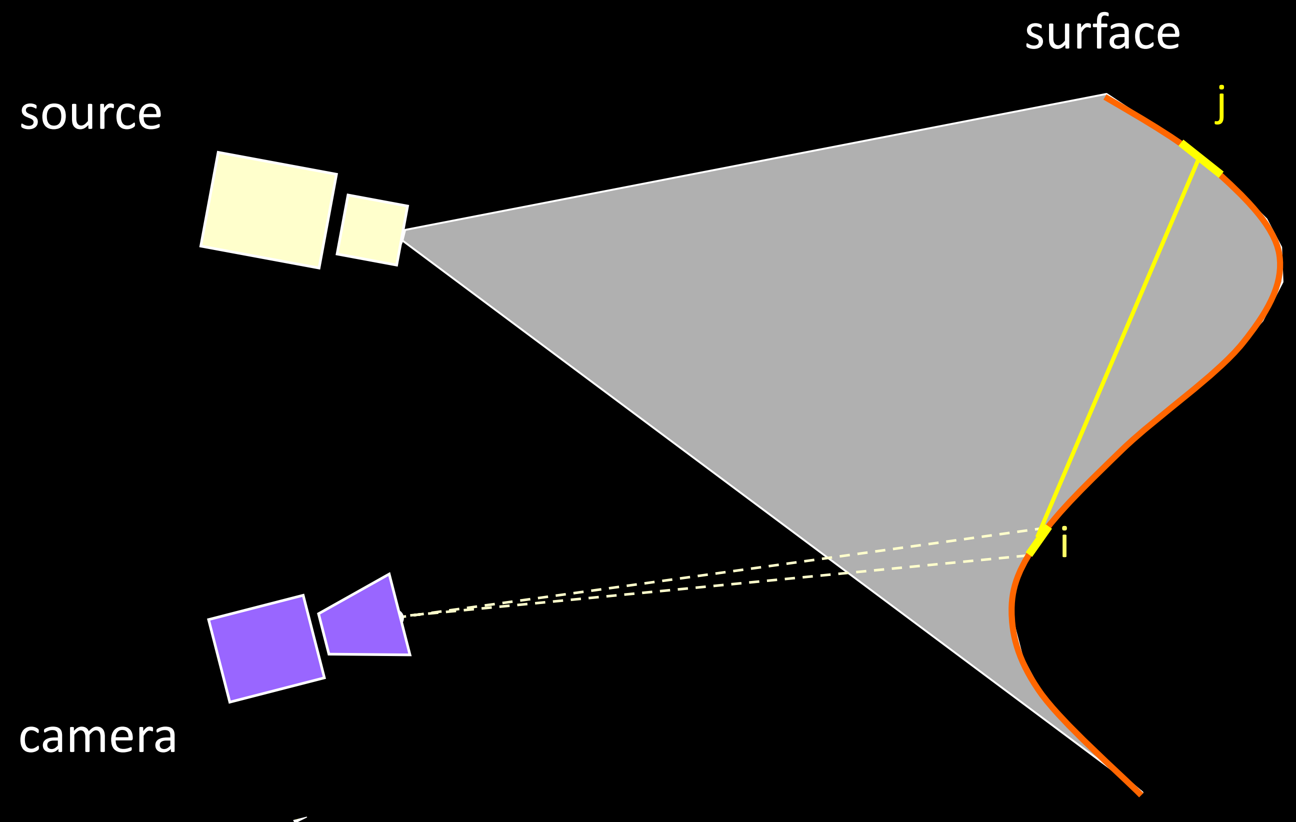
B : Interrelection

C : Subsurface

D : Volumetric

E : Diffusion

Direct and Global Components: Interreflections



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

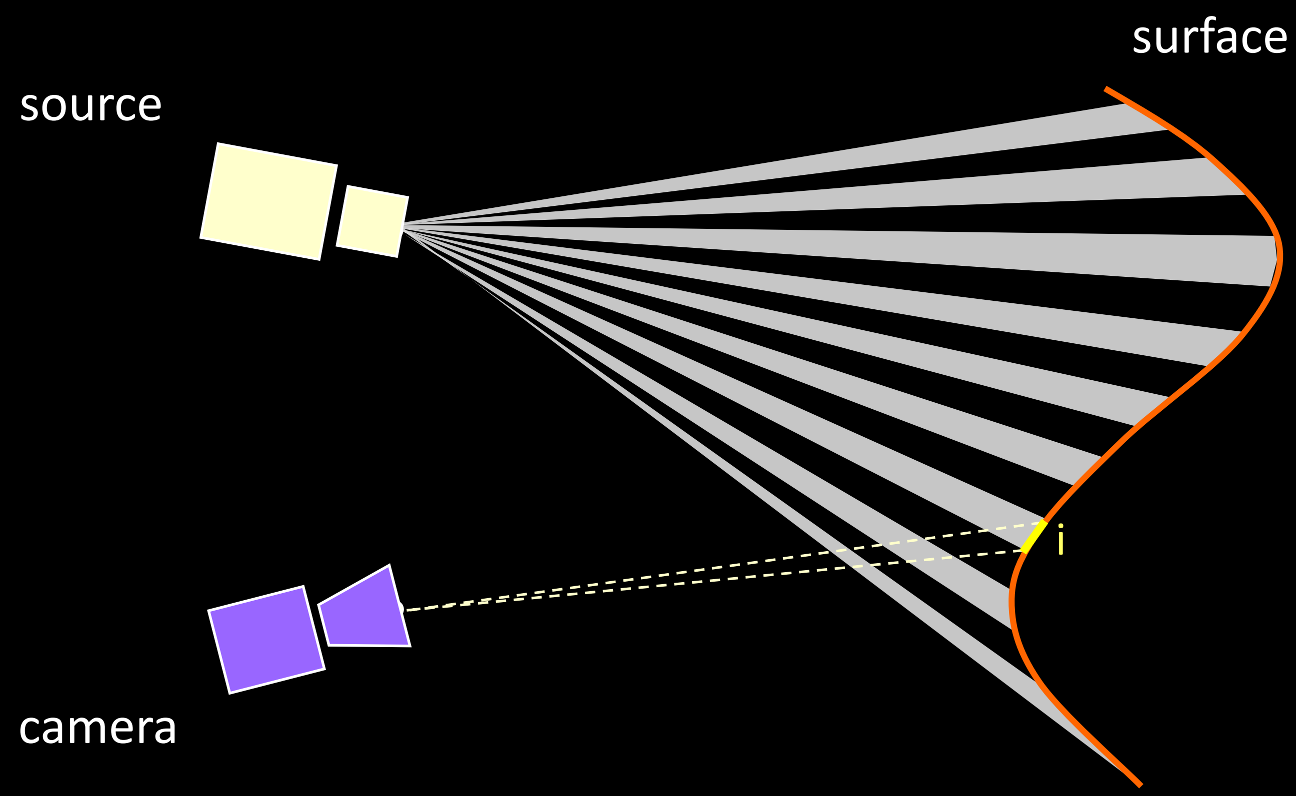
radiance direct global

$$L_g[c,i] = \sum_P A[i,j]\, L[i,j]$$

BRDF and geometry

Direct-global separation using high-frequency illumination

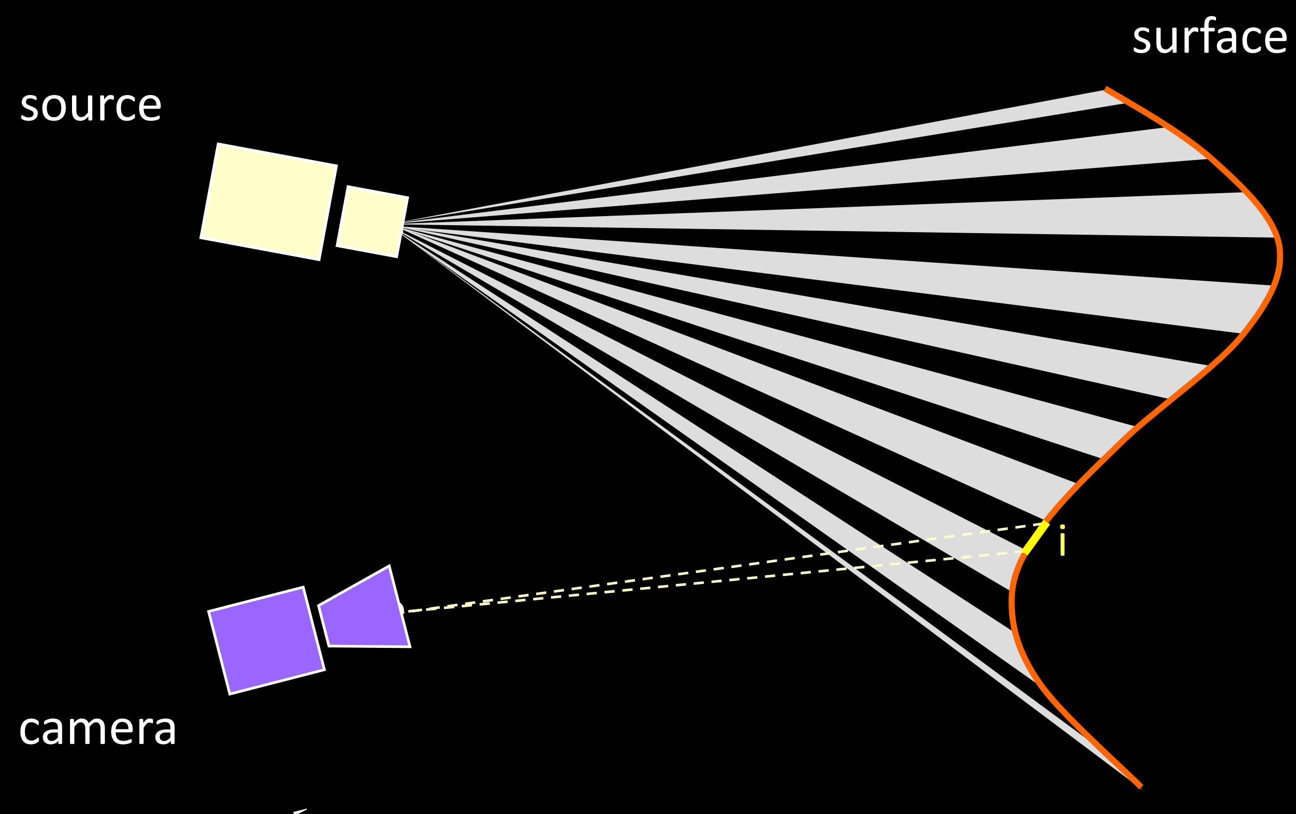
High Frequency Illumination Pattern



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

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

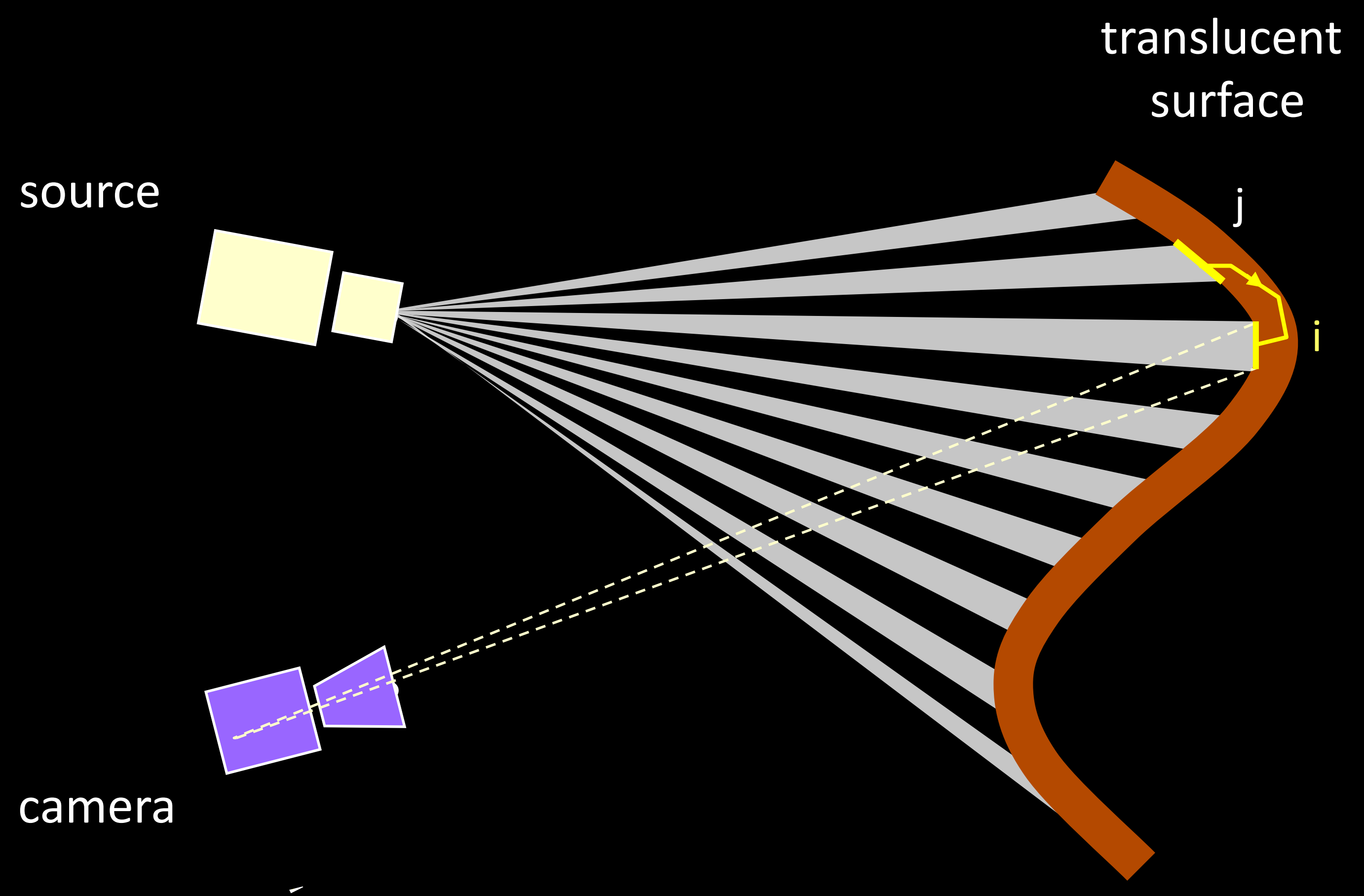
Separation from Two Images

$$\alpha = \frac{1}{2}: \quad \boxed{L_d = L_{\max} - L_{\min} \;,\; L_g = 2L_{\min}}$$

direct

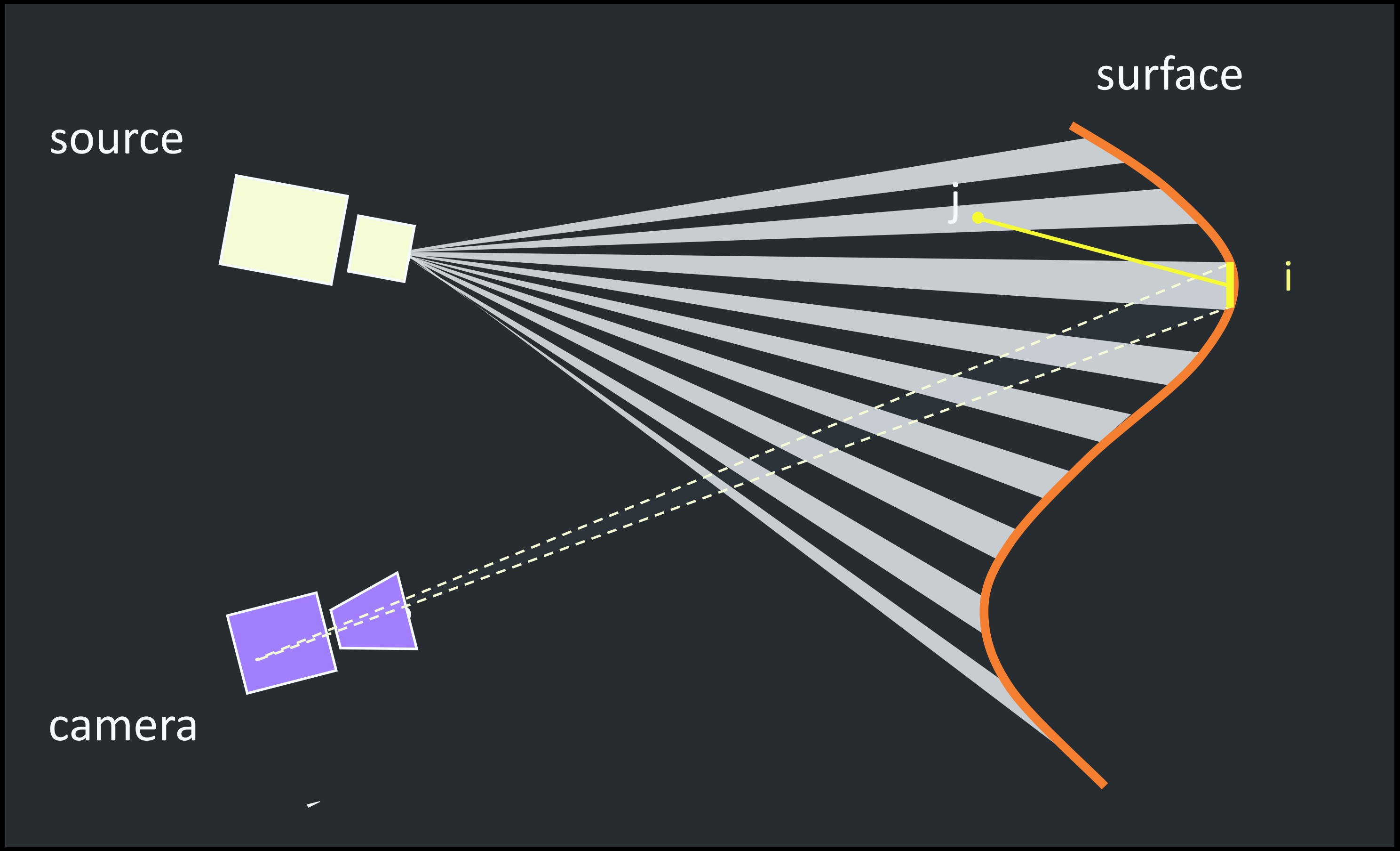
global

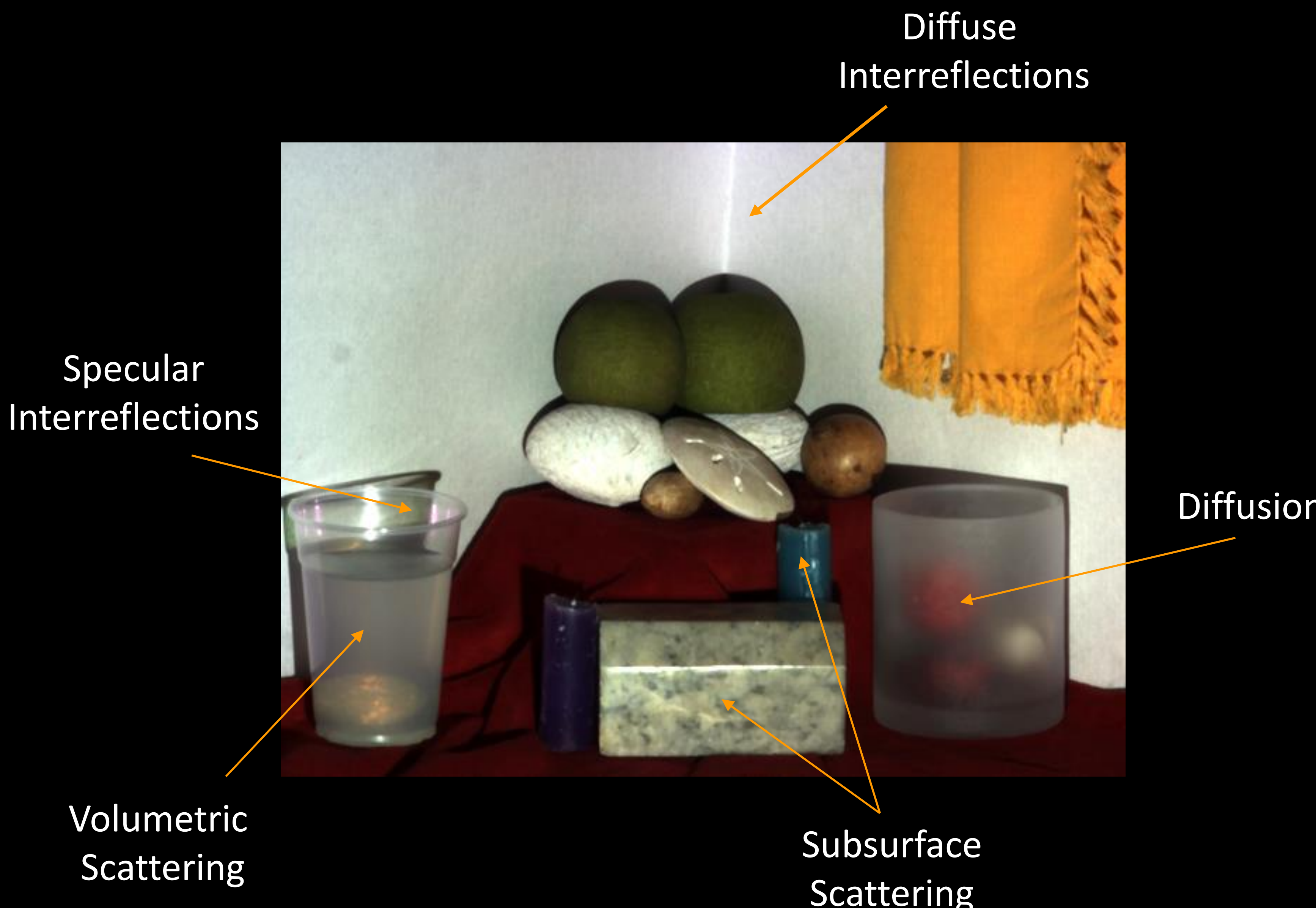
Other Global Effects: Subsurface Scattering



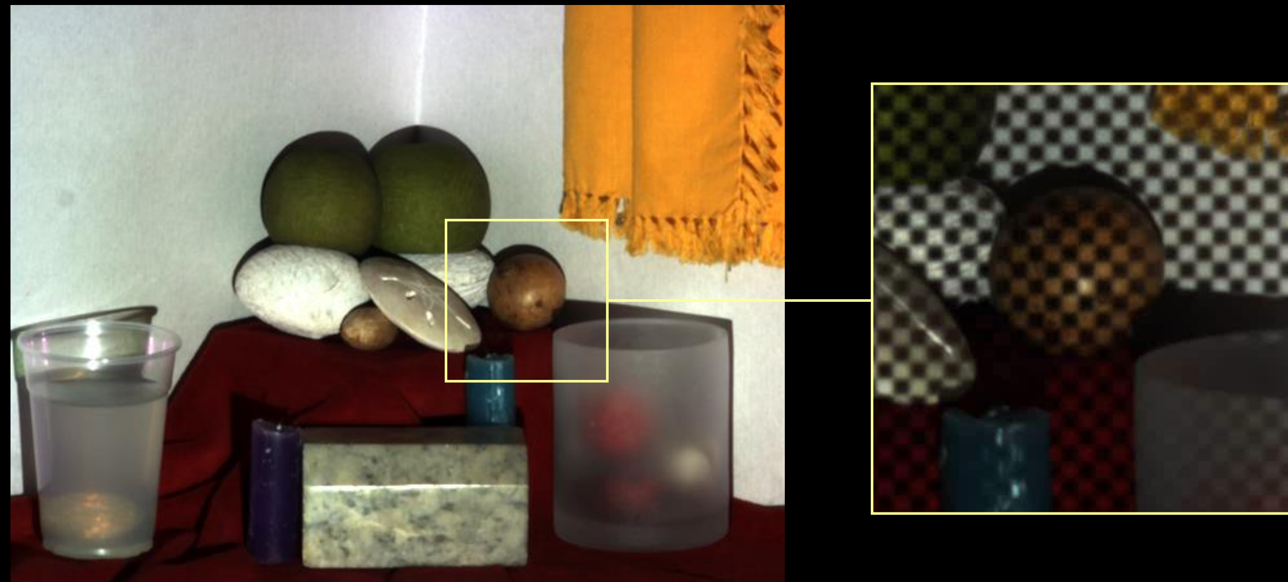
Other Global Effects: Volumetric Scattering

participating medium




Diffuse Interreflections
Specular Interreflections
Diffusion
Volumetric Scattering
Subsurface Scattering

Scene

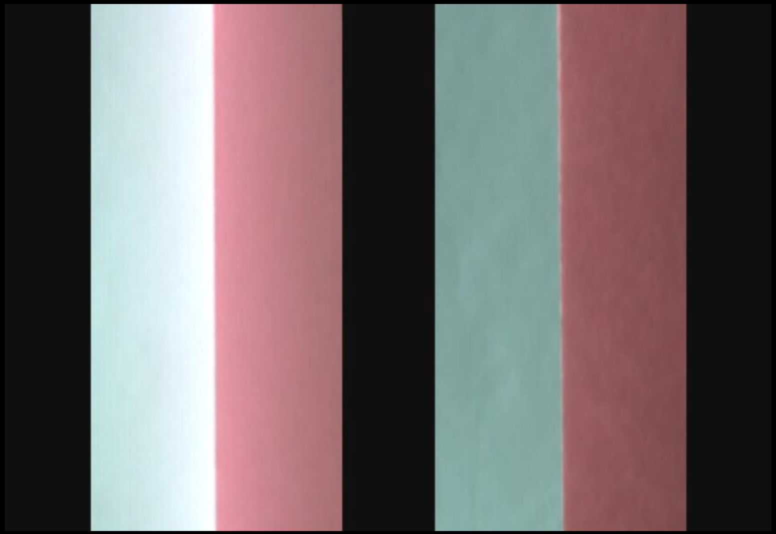


Direct

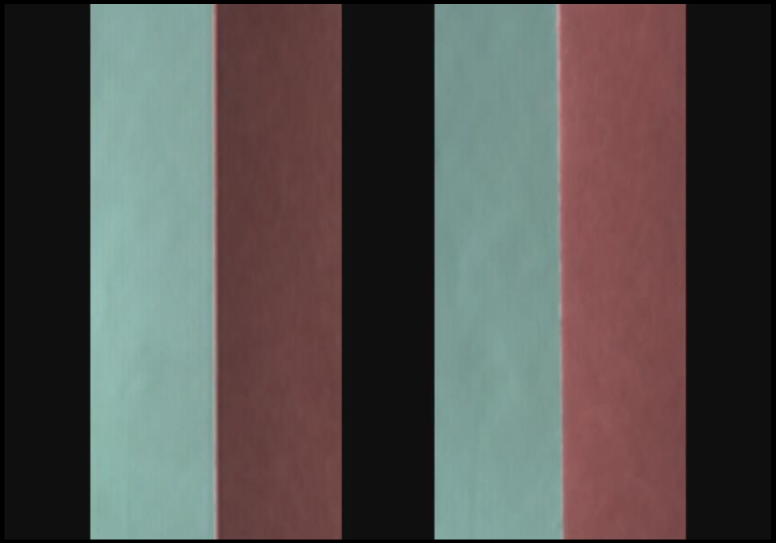
Global

V-Grooves: Diffuse Interreflections

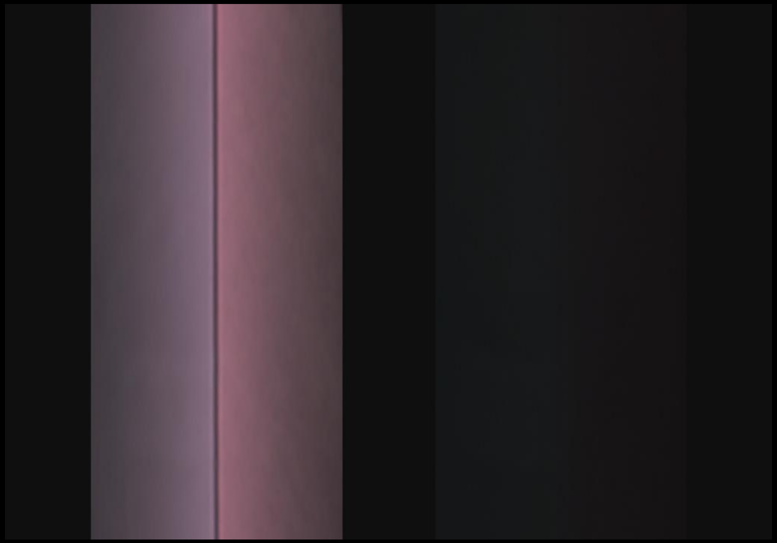
concave convex



Psychophysics:
Gilchrist 79, Bloj et al. 04



Direct



Global

Real World Examples:

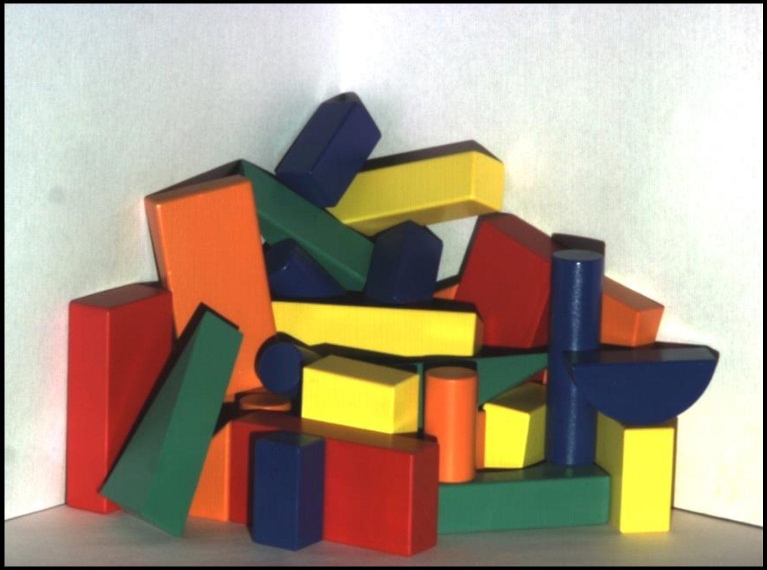
Can You Guess the Images?

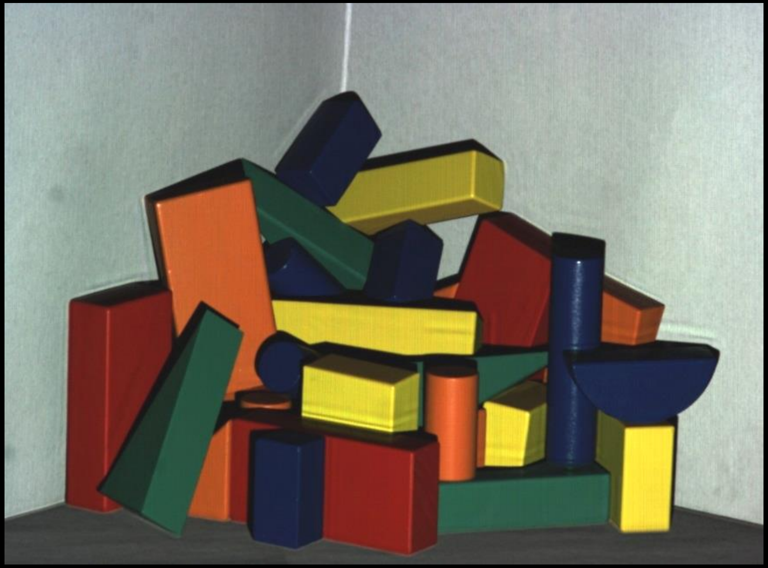
Eggs: Diffuse Interreflections

Direct

Global

Wooden Blocks: Specular Interreflections

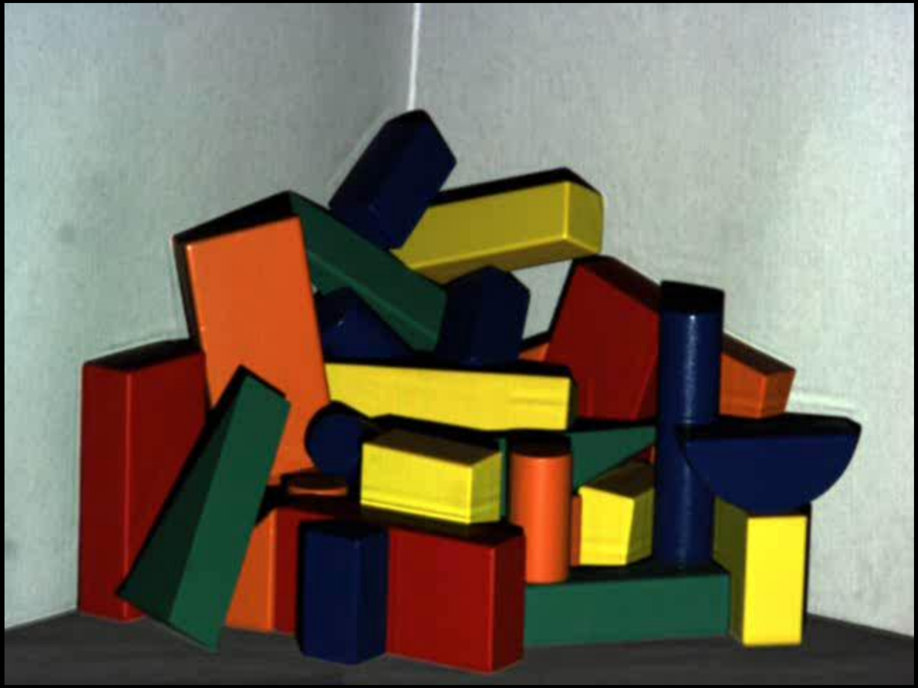




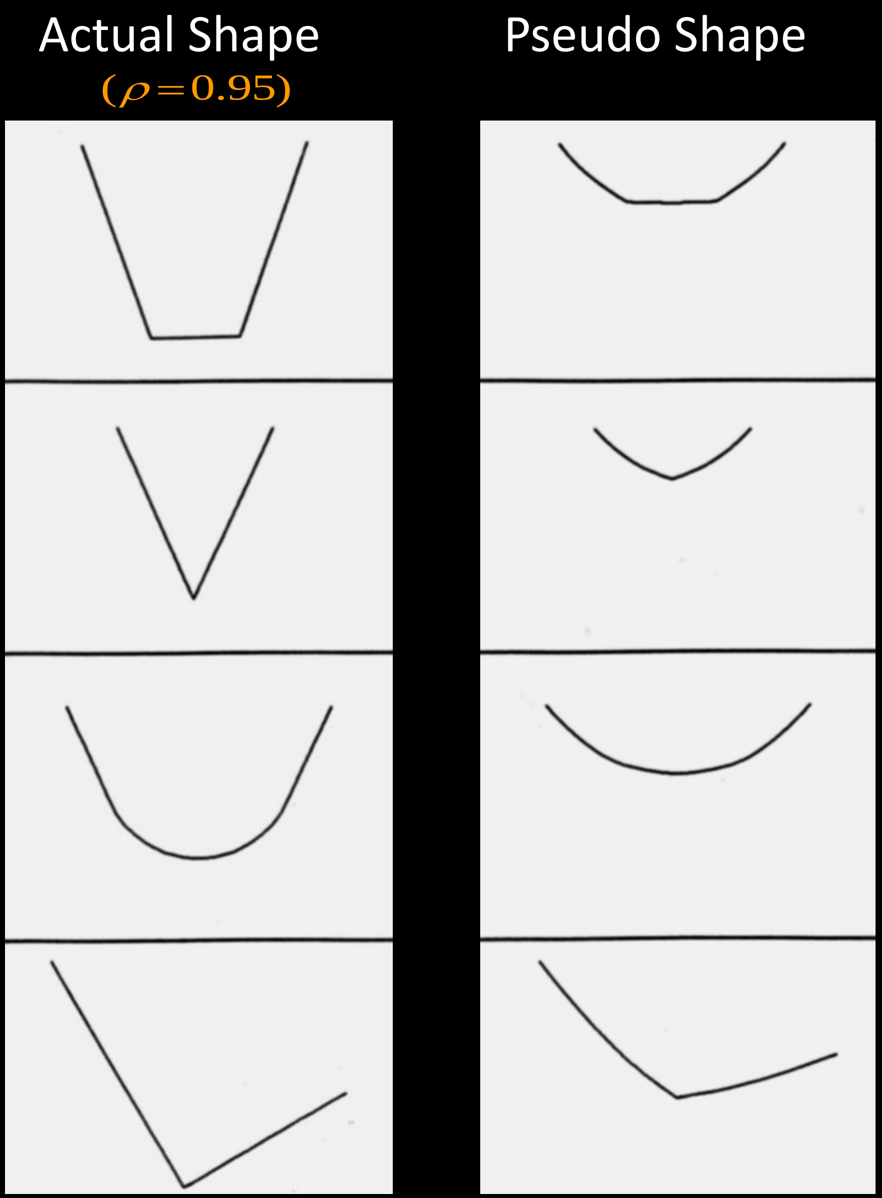
Direct

Global

Novel Images

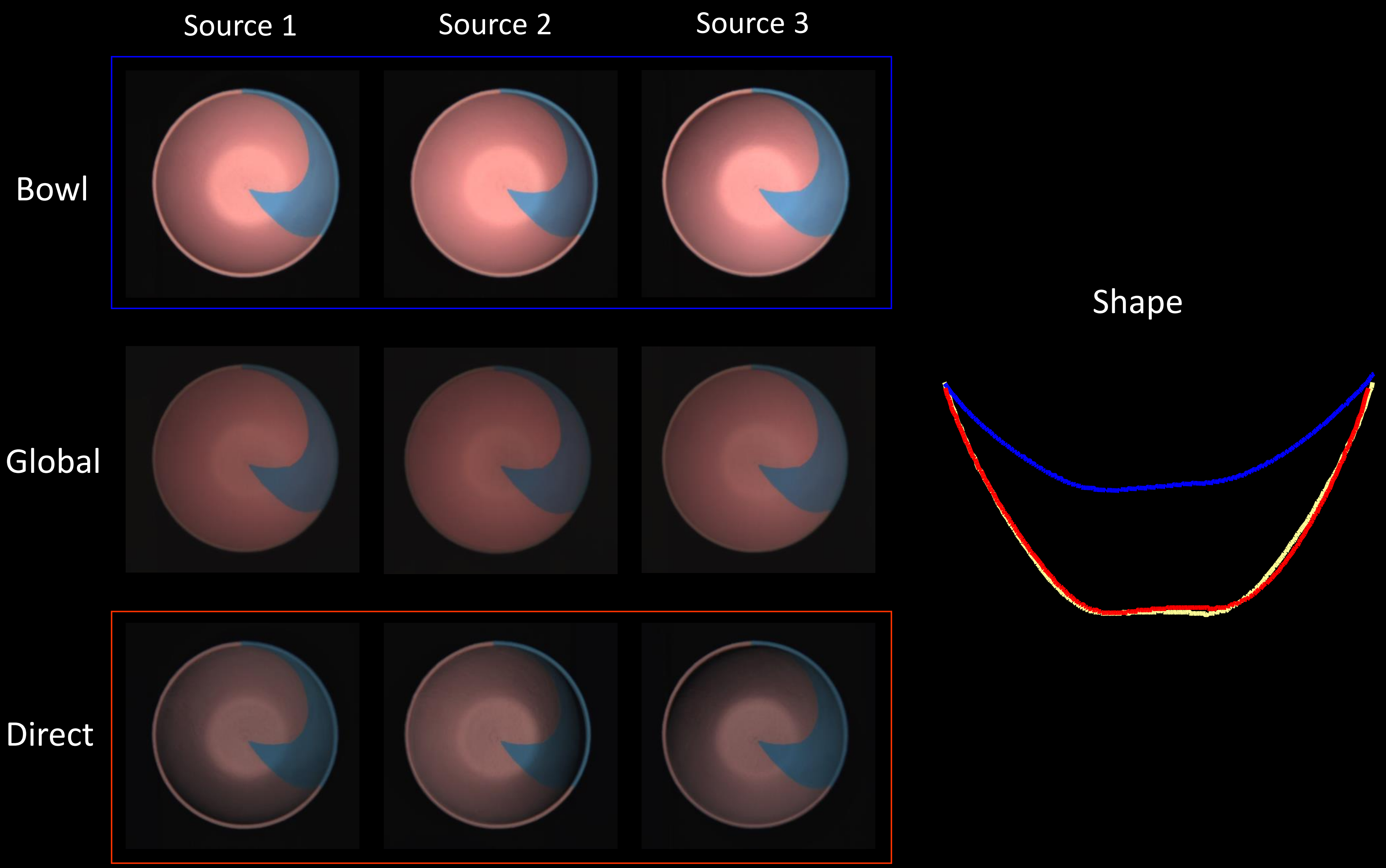


Photometric Stereo: The Pseudo Shape



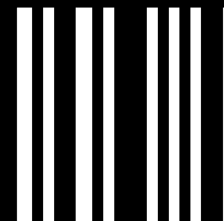
Nayar et al., 1991

Photometric Stereo using Direct Images



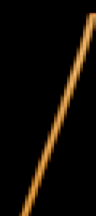
Variants of Separation Method

- Coded Structured Light

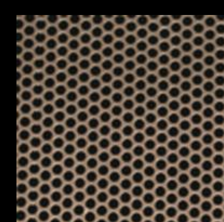


- Shifted Sinusoids

- Shadow of Line Occluder



- Shadow of Mesh Occluders



Building Corner

Stick

Shadow

3D from Shadows:
Bouguet and Perona 99

$$L_d = L_{\max} - L_{\min} \,, \quad L_g = L_{\min}$$

direct

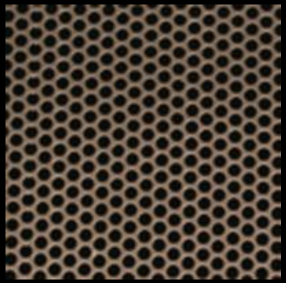
global

Building Corner

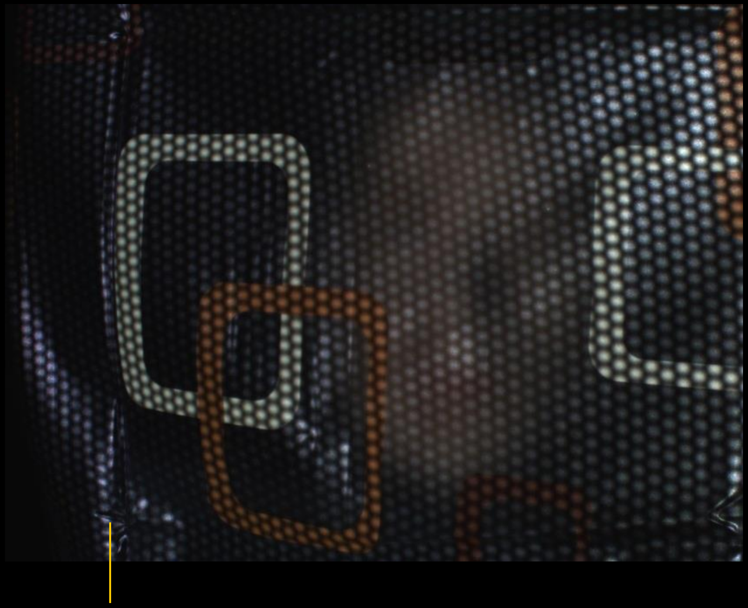
Direct

Global

Shower Curtain: Diffuser



Mesh



$$L_d = L_{max} - \beta L_{min}, \quad L_g = \beta L_{min}$$

direct

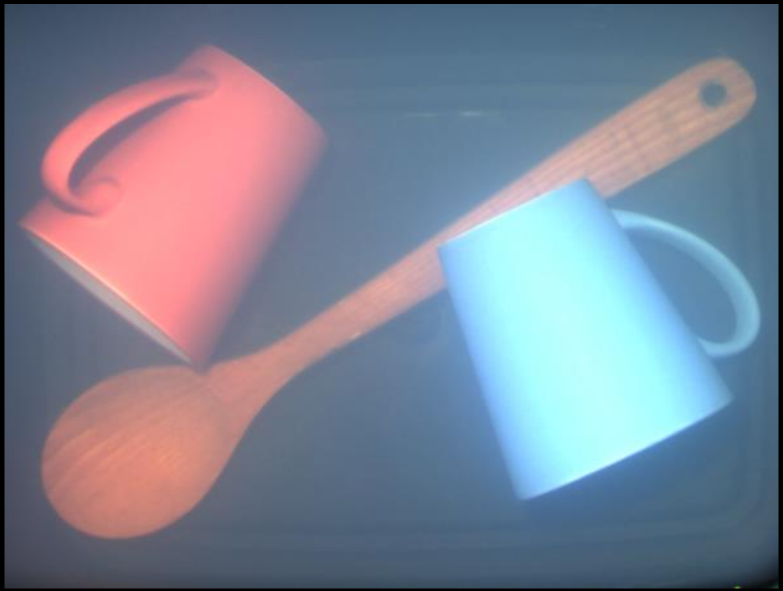
global

Shower Curtain: Diffuser

Direct

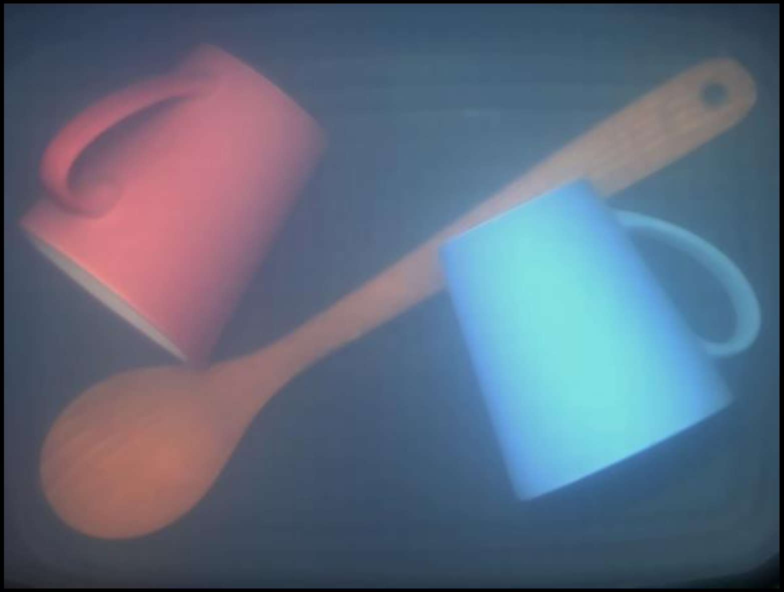
Global

Kitchen Sink: Volumetric Scattering



Volumetric Scattering:
Chandrasekar 50, Ishimaru 78

Direct

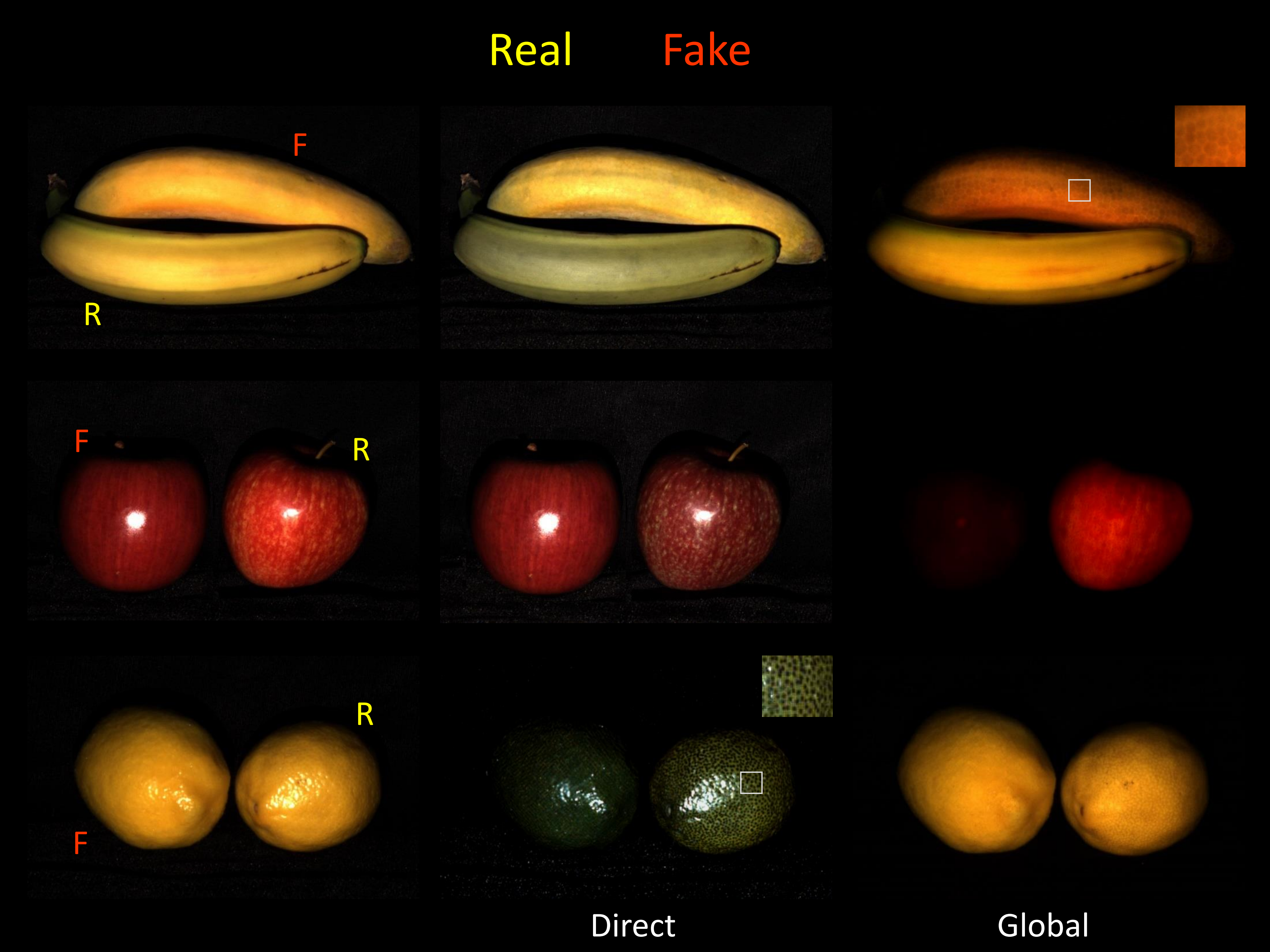


Global

Peppers: Subsurface Scattering

Direct

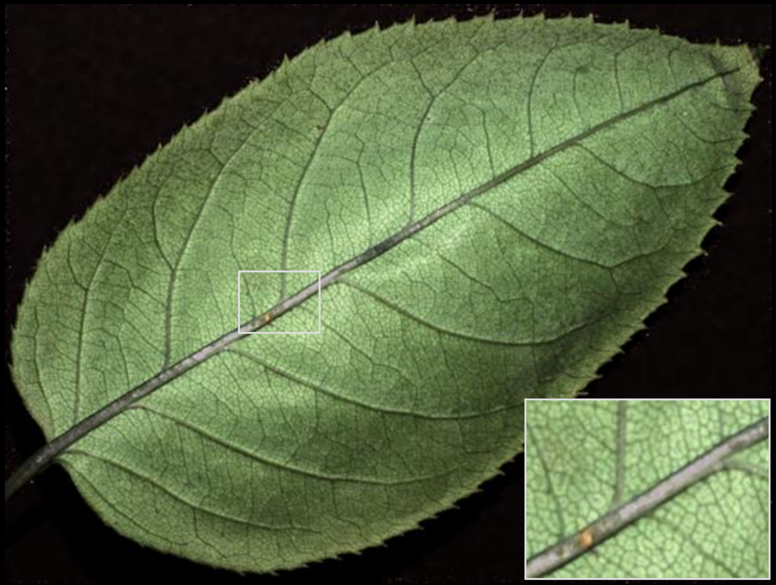
Global



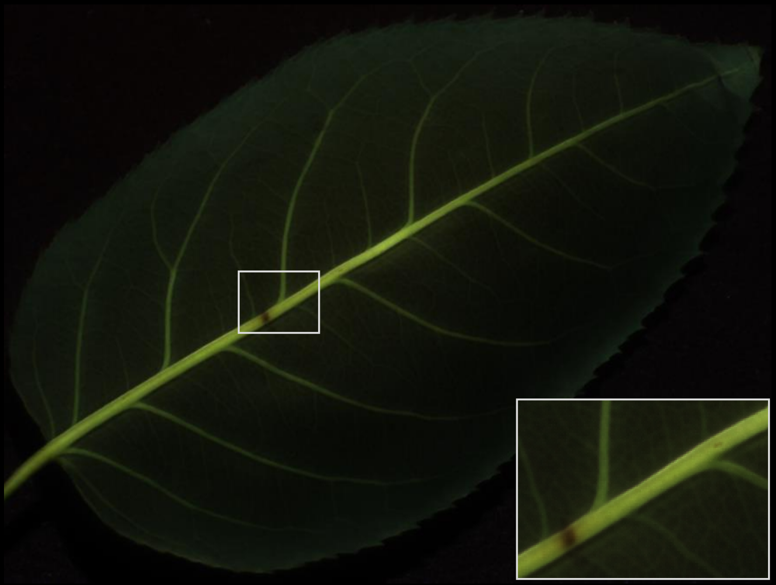
Real
Fake
F
R
F
R
R
F
Direct
Global

Tea Rose Leaf

Leaf Anatomy: Purves et al. 03

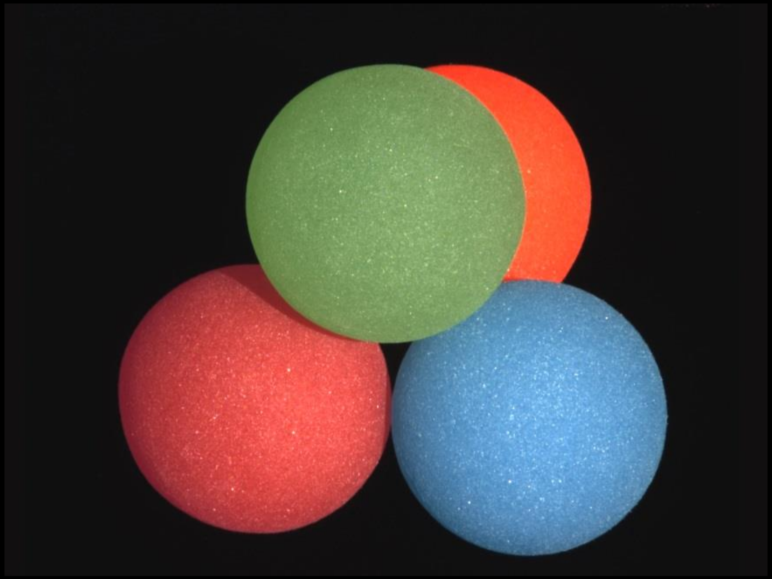


Direct

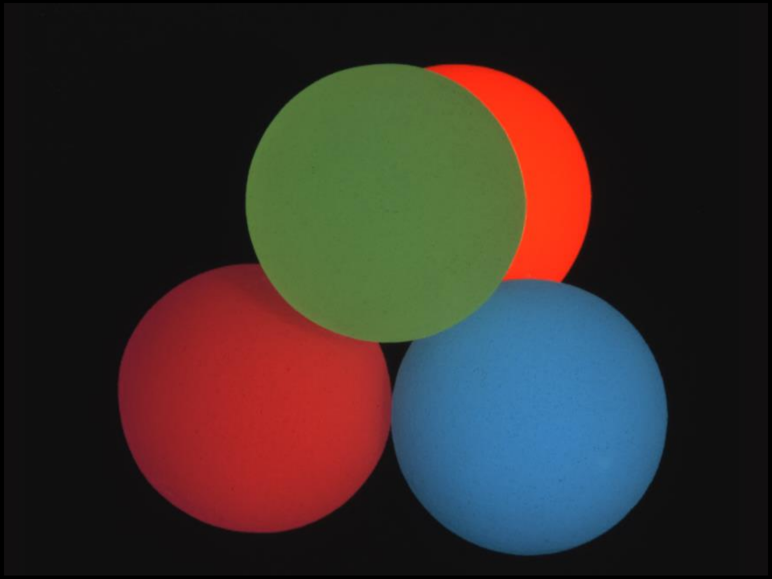


Global

Translucent Rubber Balls

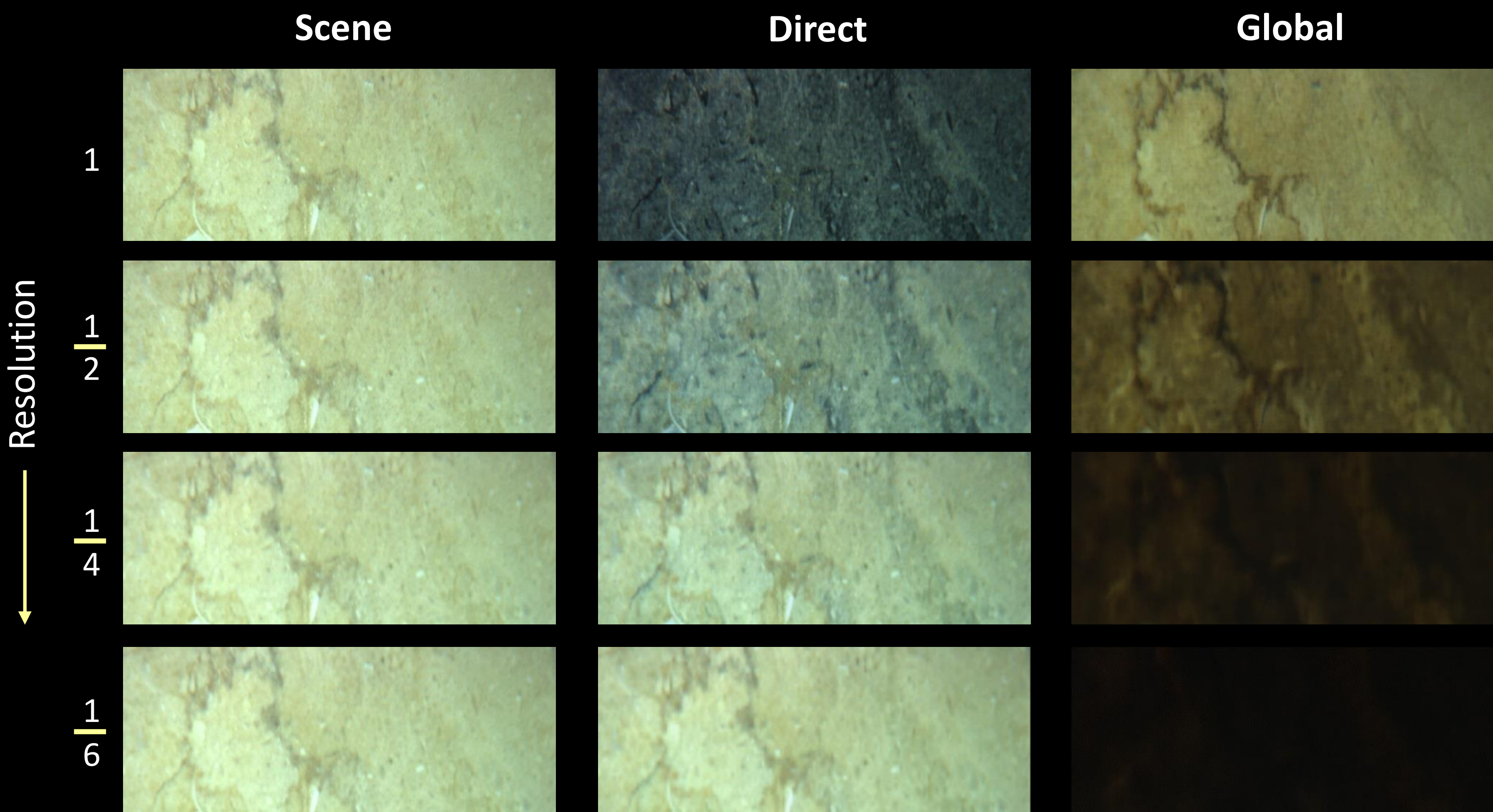


Direct



Global

Marble: When BSSRDF becomes BRDF

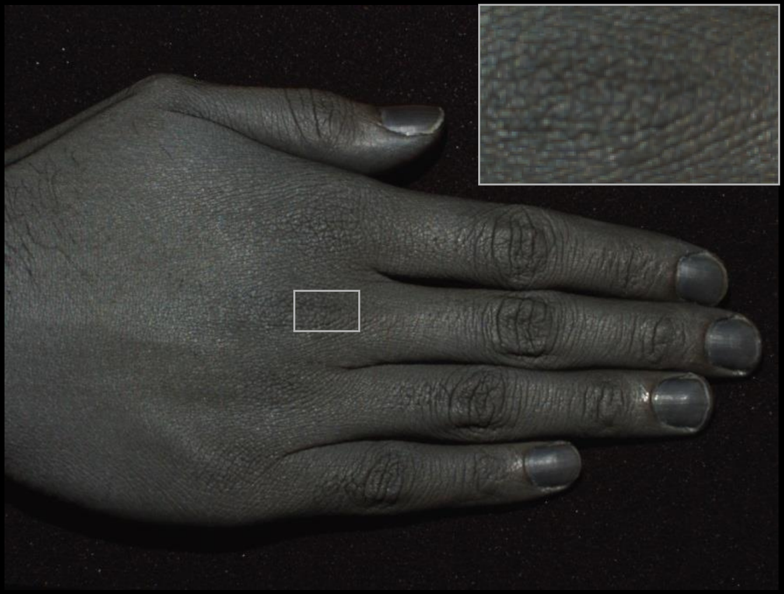


Subsurface Measurements:

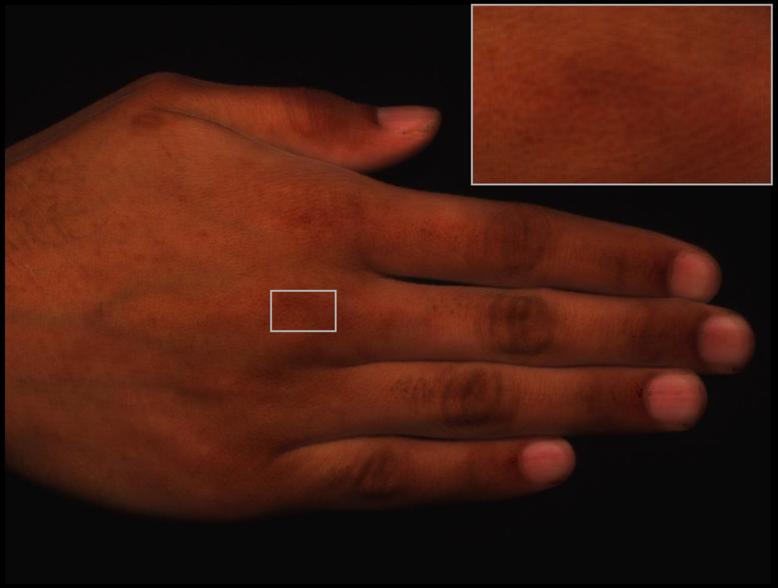
Jensen et al. 01, Goesele et al. 04

Hand

Skin: Hanrahan and Krueger 93, Uchida 96, Haro 01, Jensen et al. 01, Igarashi et al. 05, Weyrich et al. 05



Direct



Global

Hands

Afric. Amer. Female | Chinese Male | Spanish Male

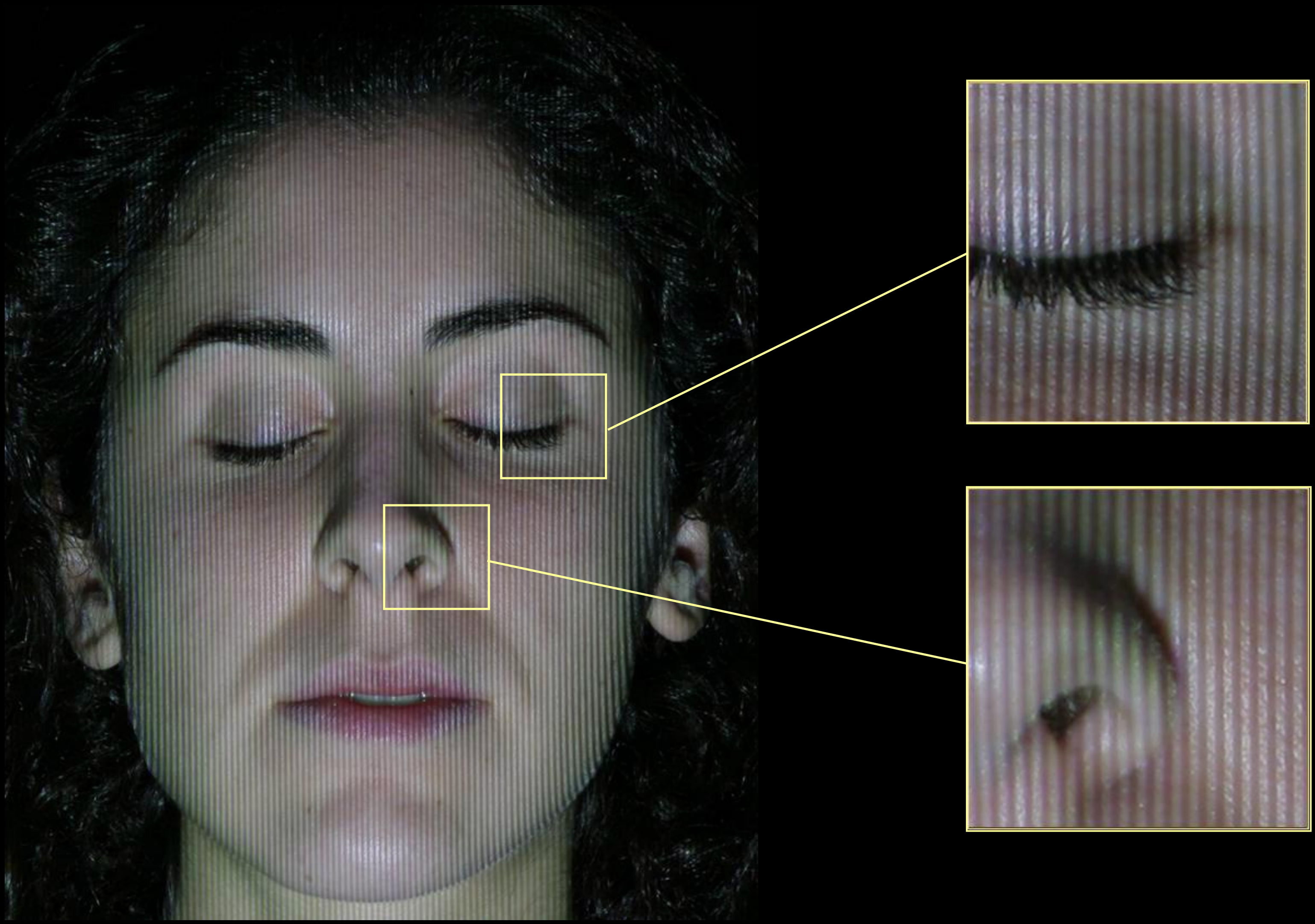
Afric. Amer. Female | Chinese Male | Spanish Male

Direct

Afric. Amer. Female | Chinese Male | Spanish Male

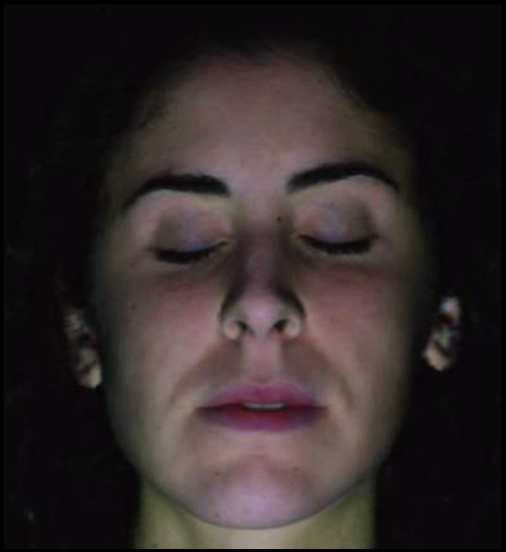
Global

Separation from a Single Image



Face

Direct



Global

Sum

Blonde Hair

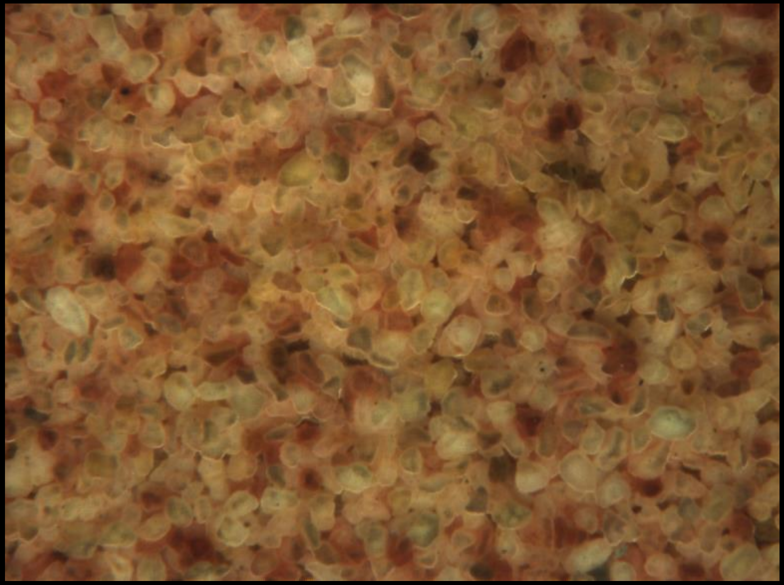
Hair Scattering: Stamm et al. 77, Bustard and Smith 91, Lu et al. 00 Marschner et al. 03

Direct

Global

Pebbles: 3D Texture

Direct



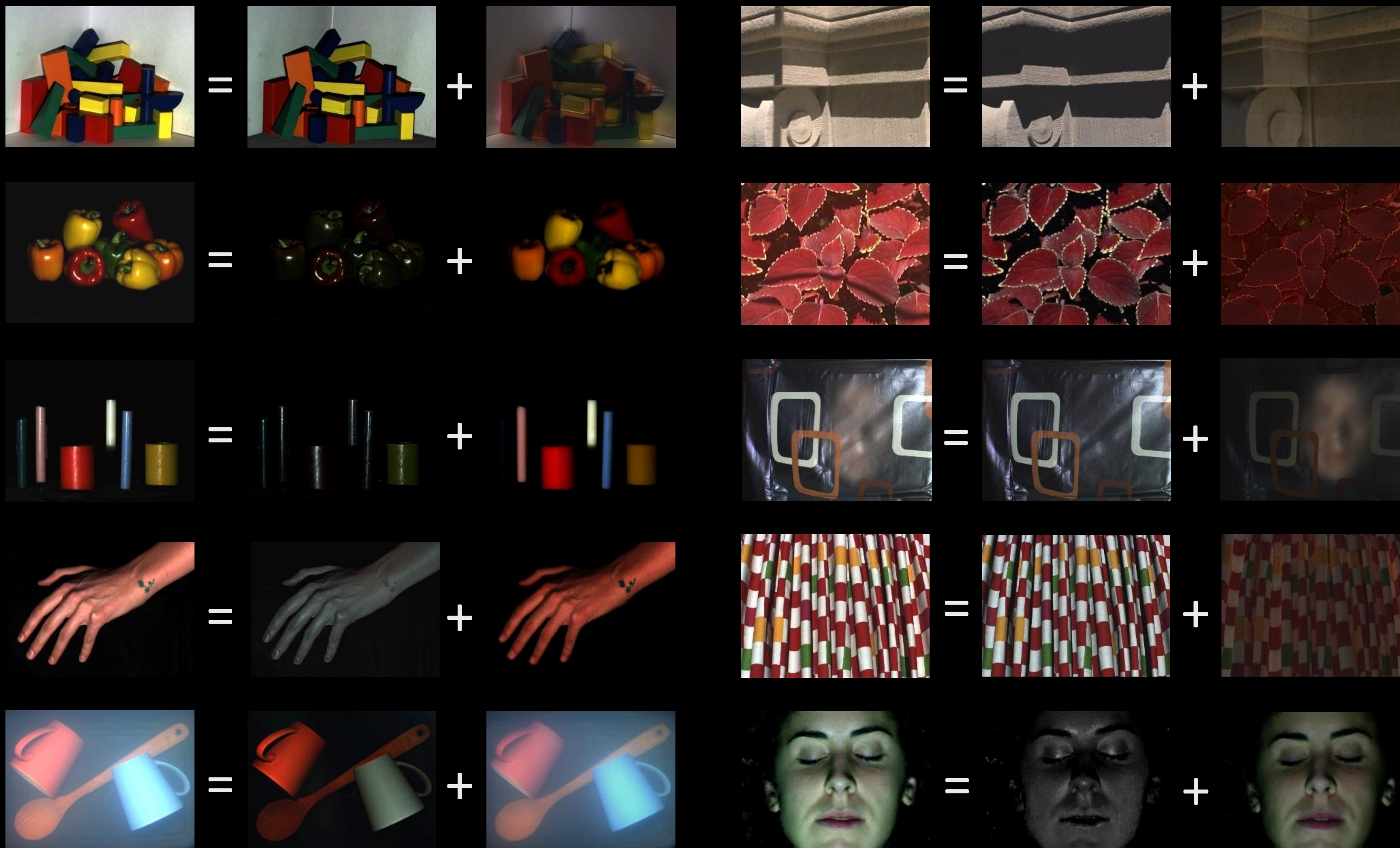
Global

Pink Carnation

Spectral Bleeding: Funt et al. 91

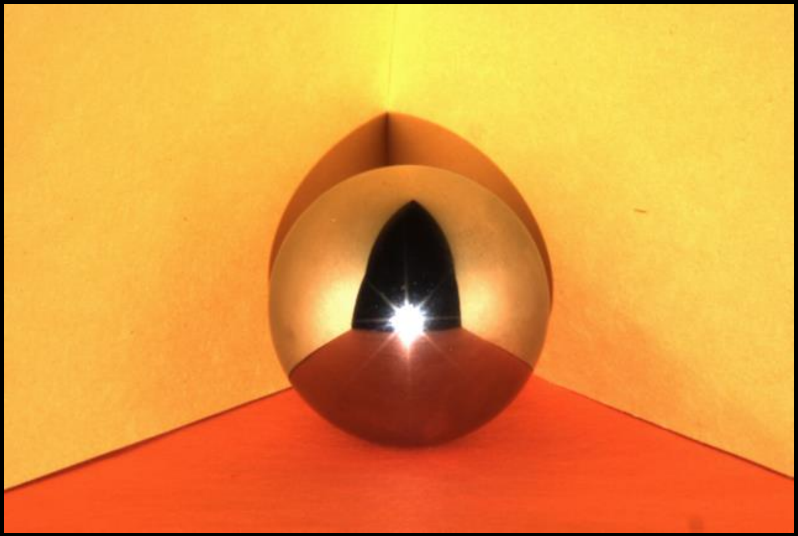
Direct

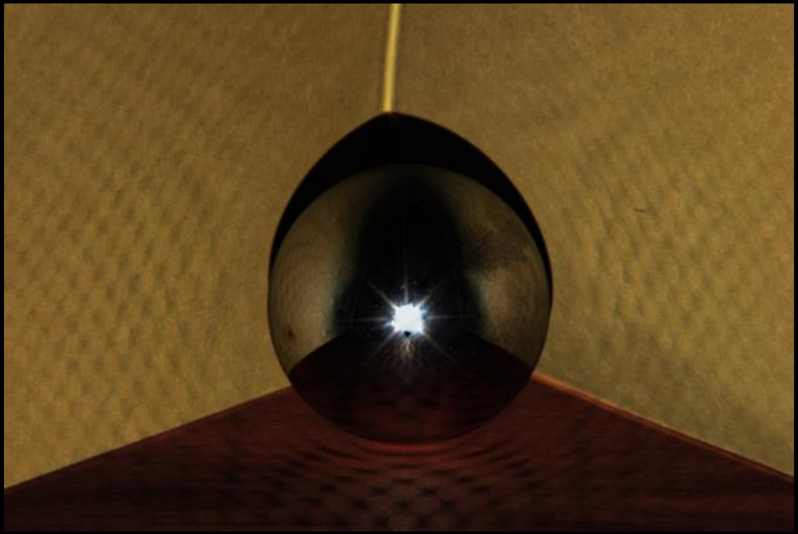
Global



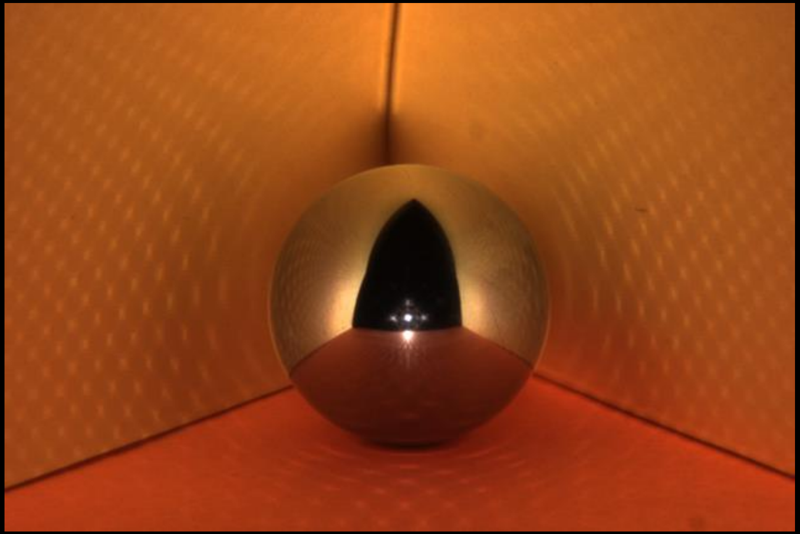
www.cs.columbia.edu/CAVE

Mirror Ball: Failure Case





Direct

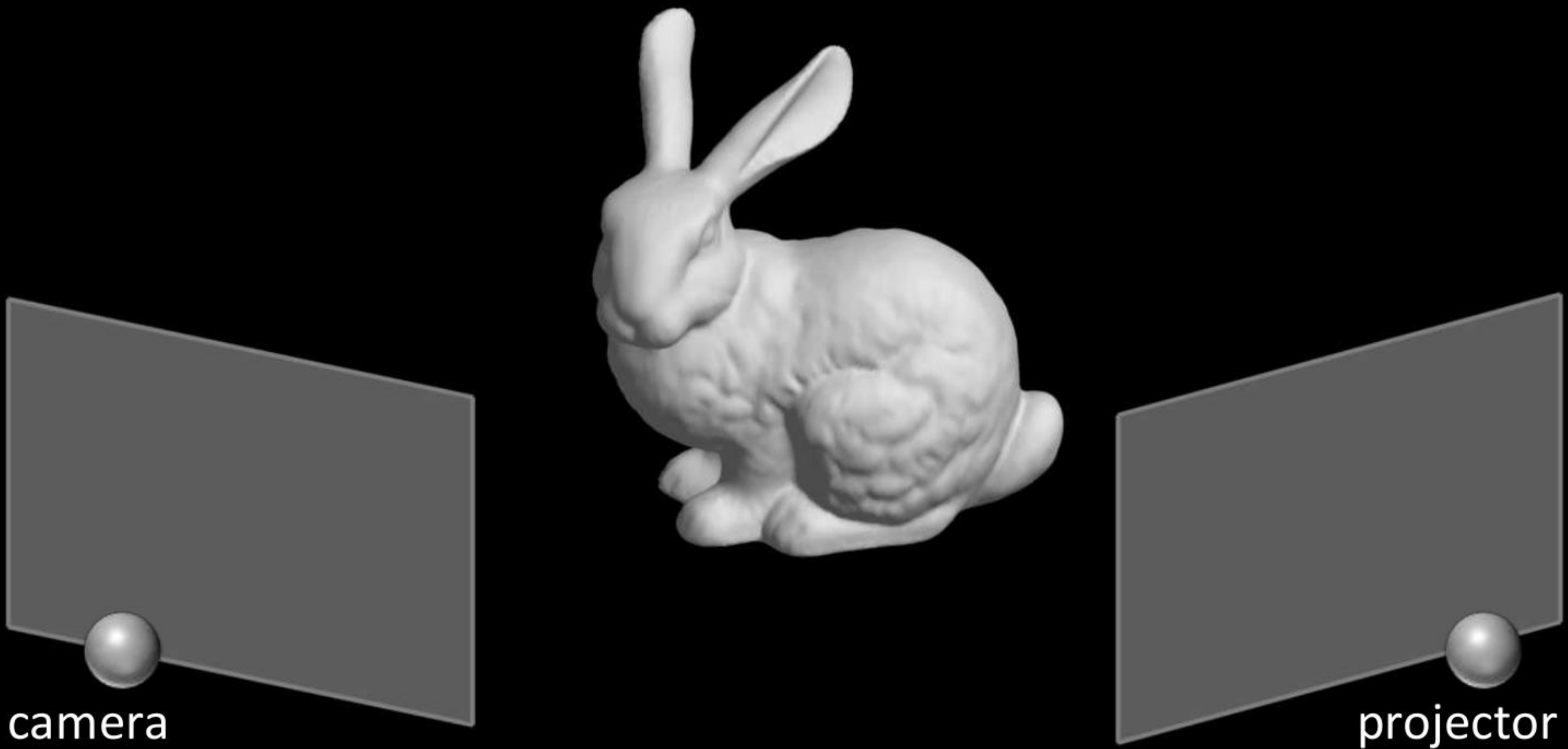


Global

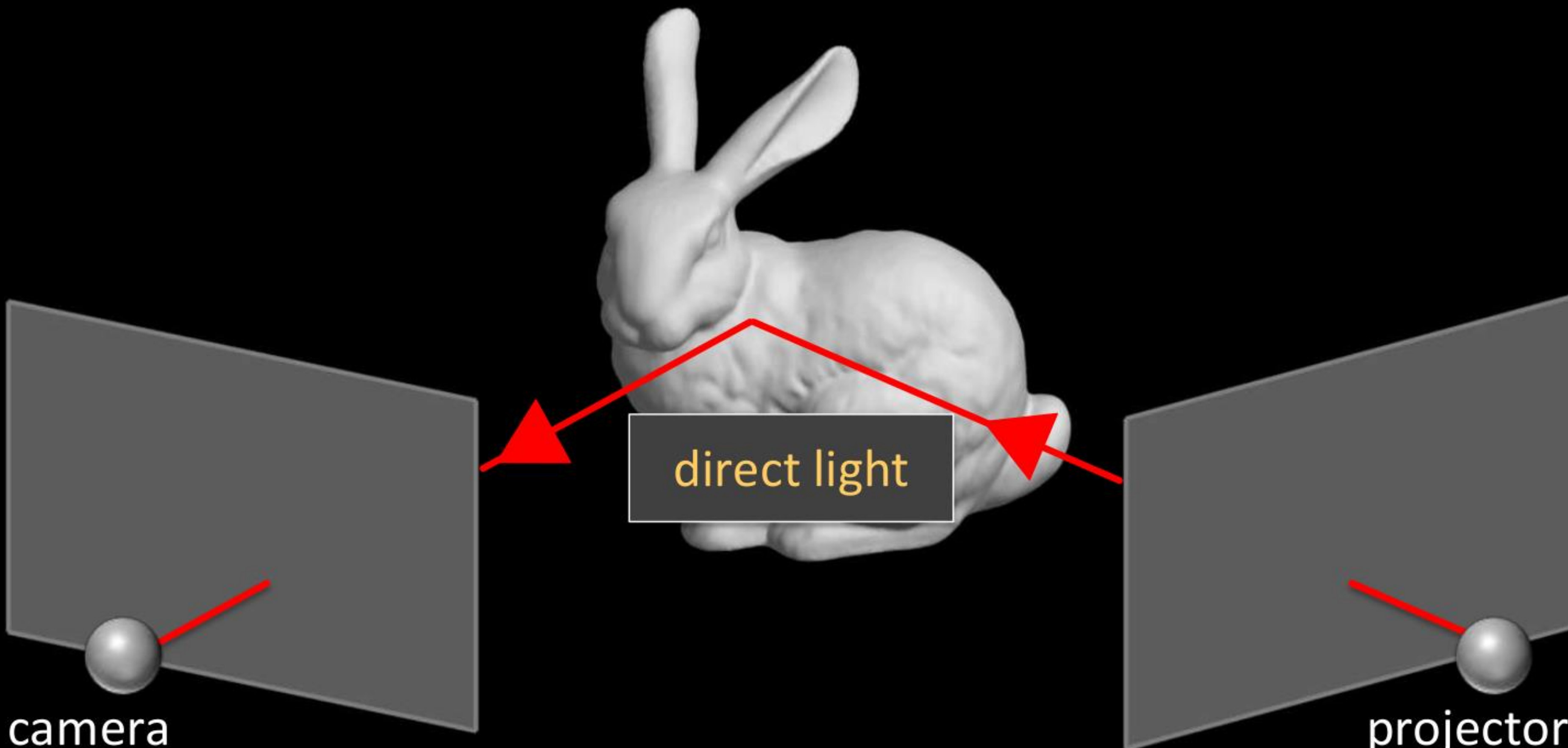
Light transport probing (see part 2)

Direct-global separation using epipolar probing (non-coaxial case)

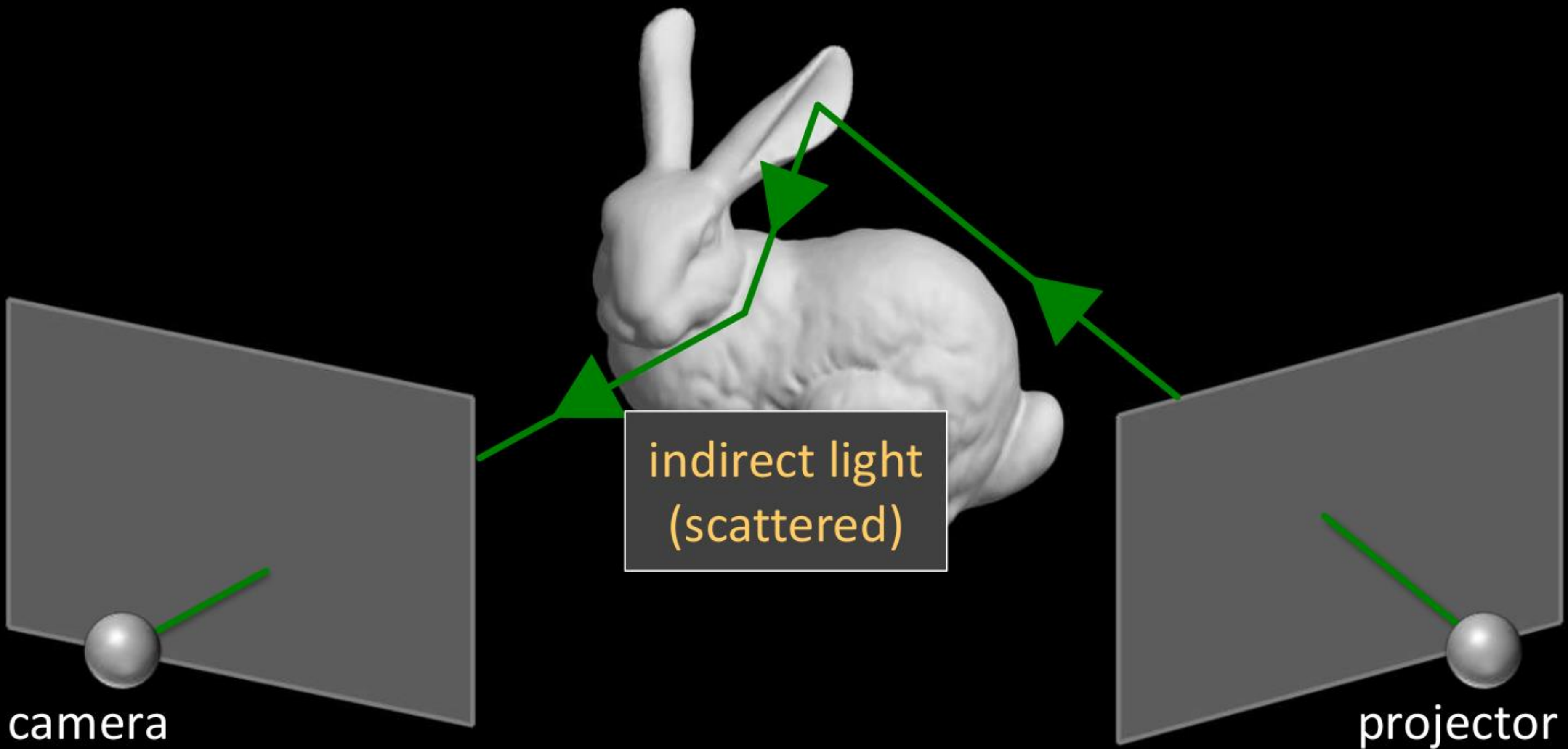
basic light paths



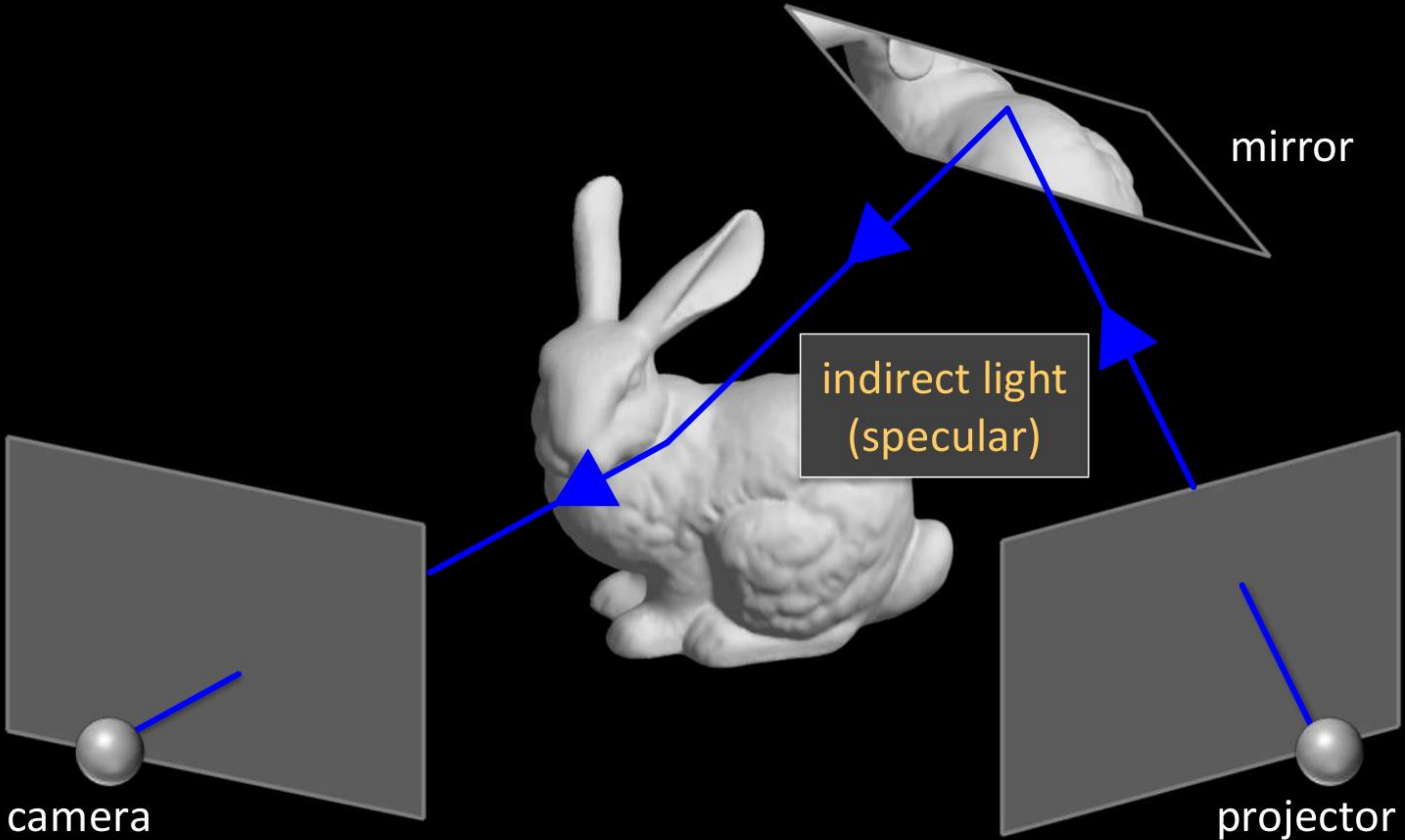
basic light paths



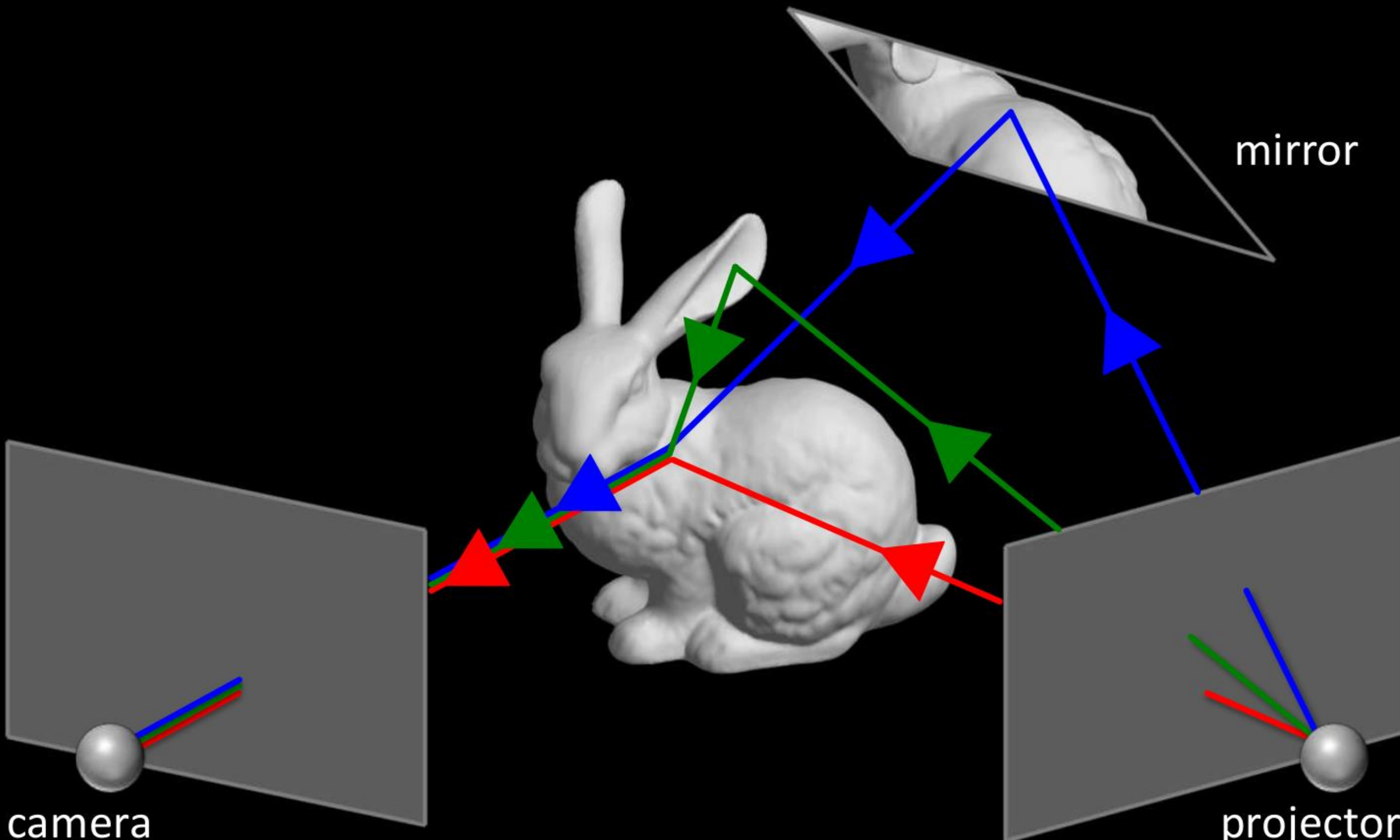
basic light paths



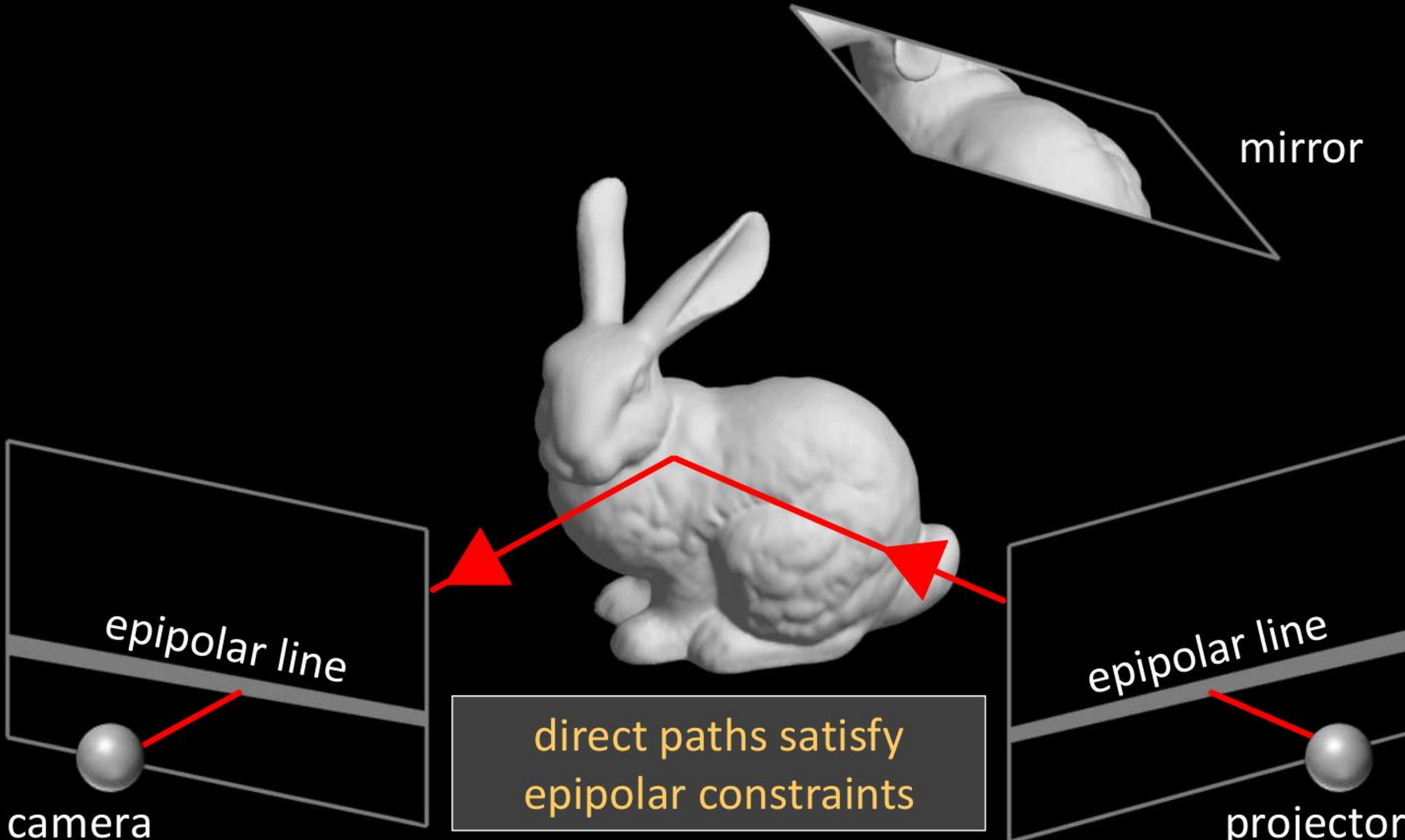
basic light paths



basic light paths

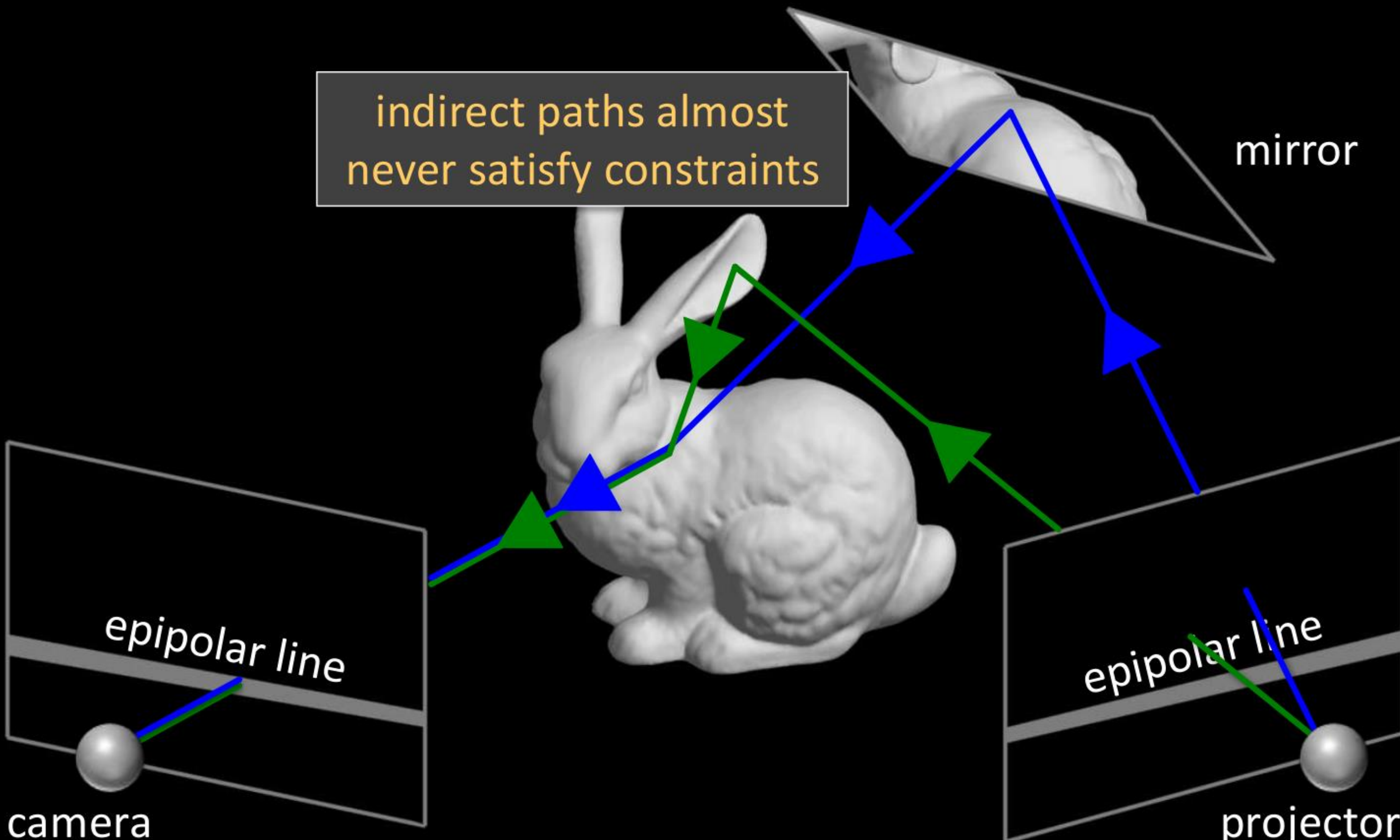


epipolar constraint & light transport

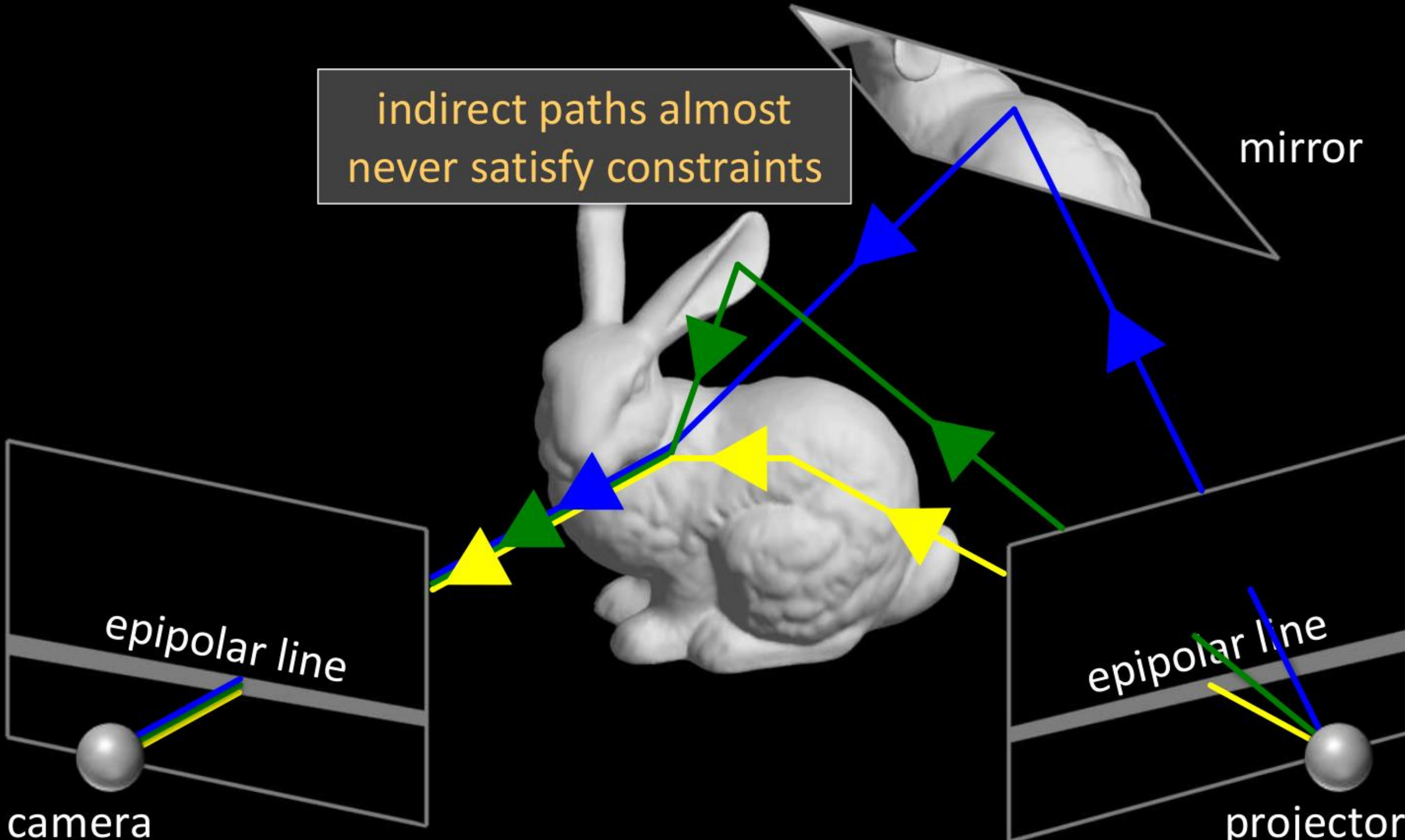


direct paths satisfy
epipolar constraints

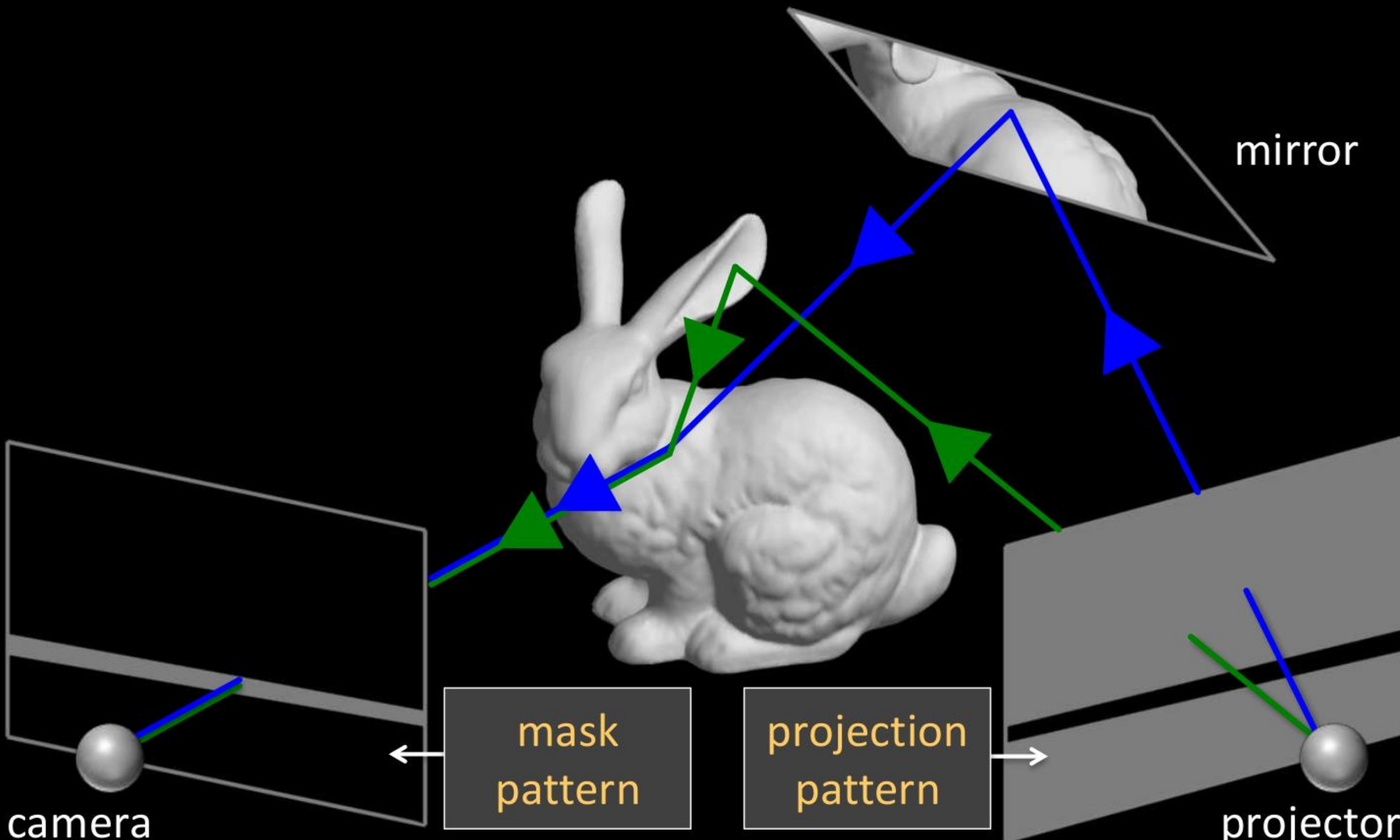
epipolar constraint & light transport



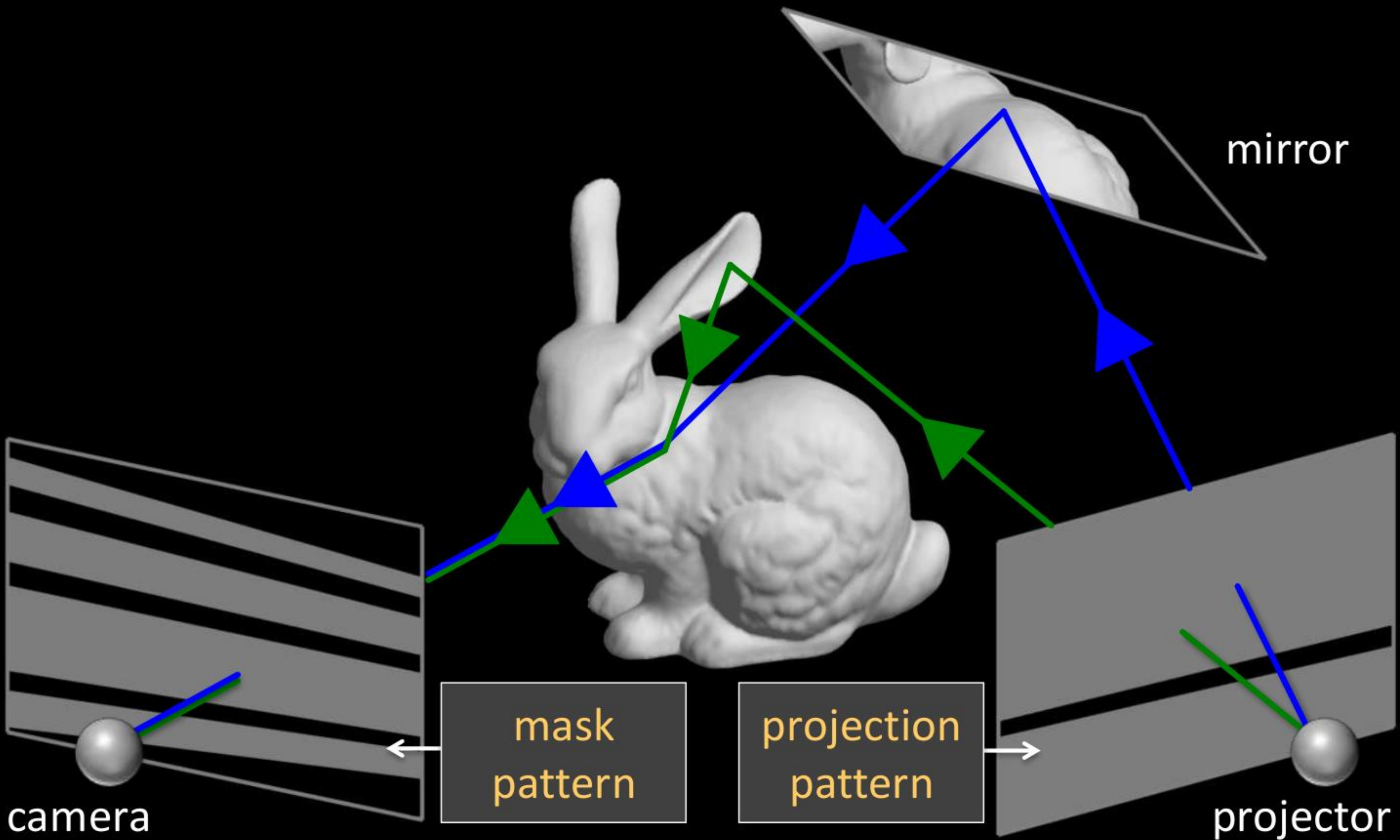
epipolar constraint & light transport



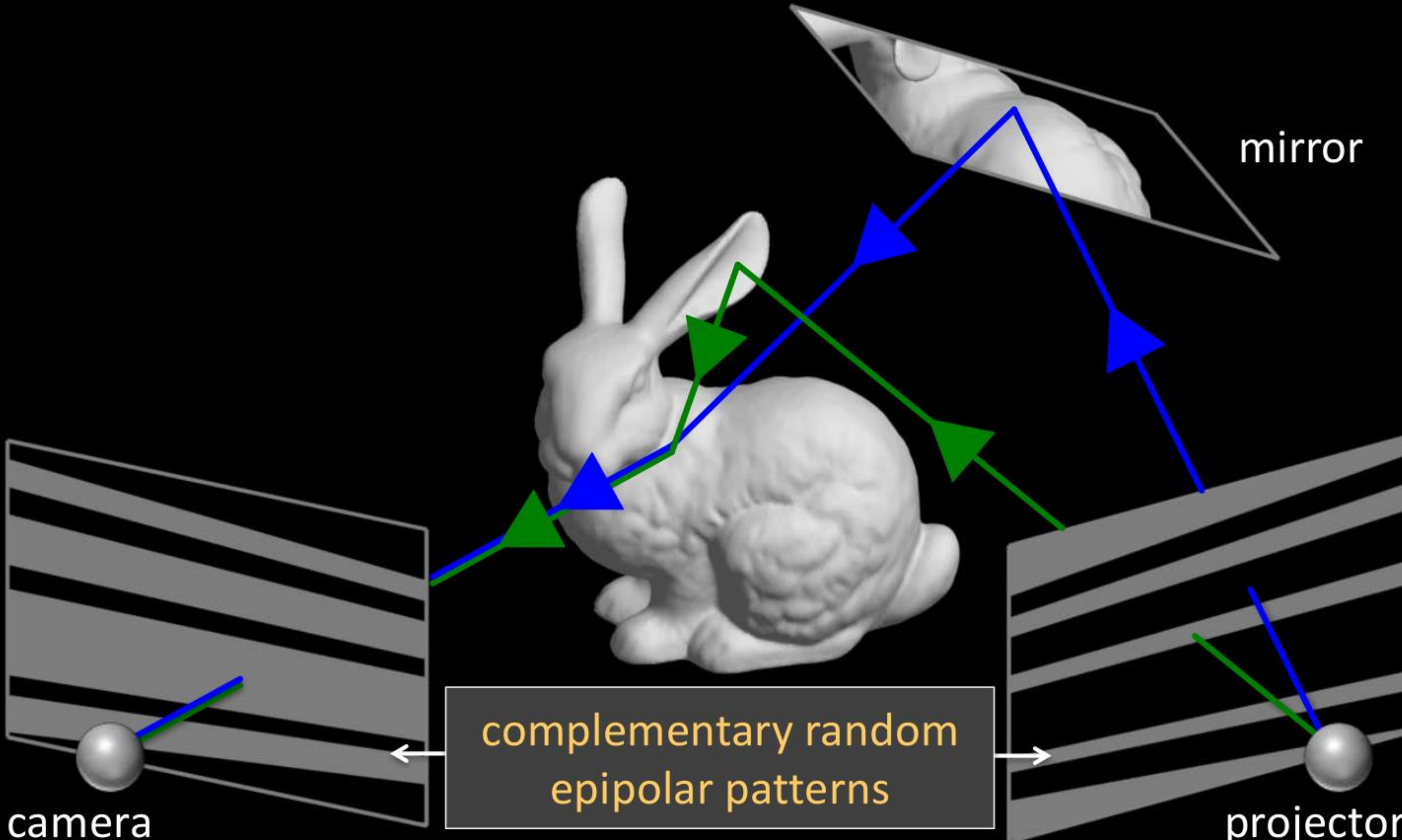
blocking epipolar paths with patterns & masks



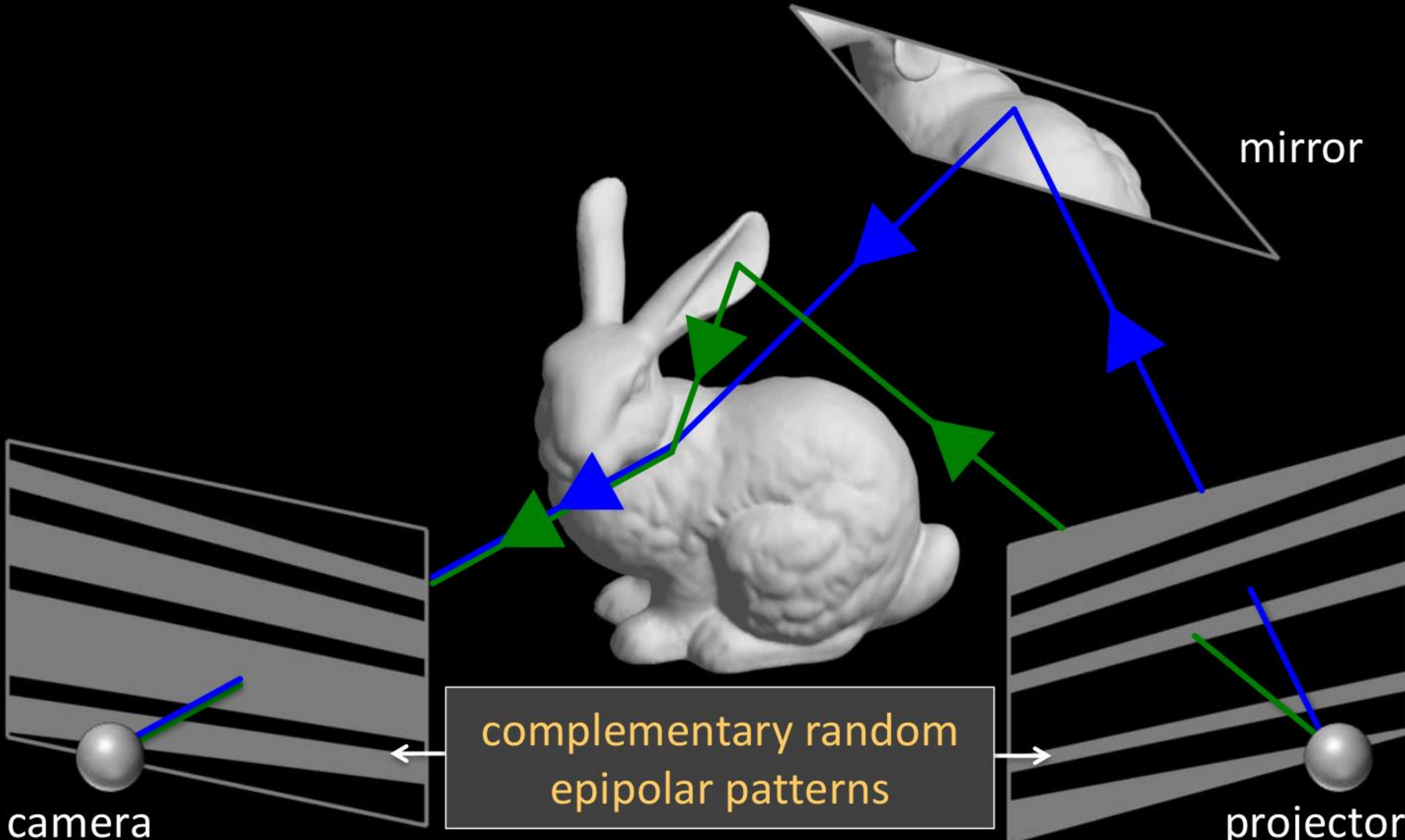
blocking epipolar paths with patterns & masks



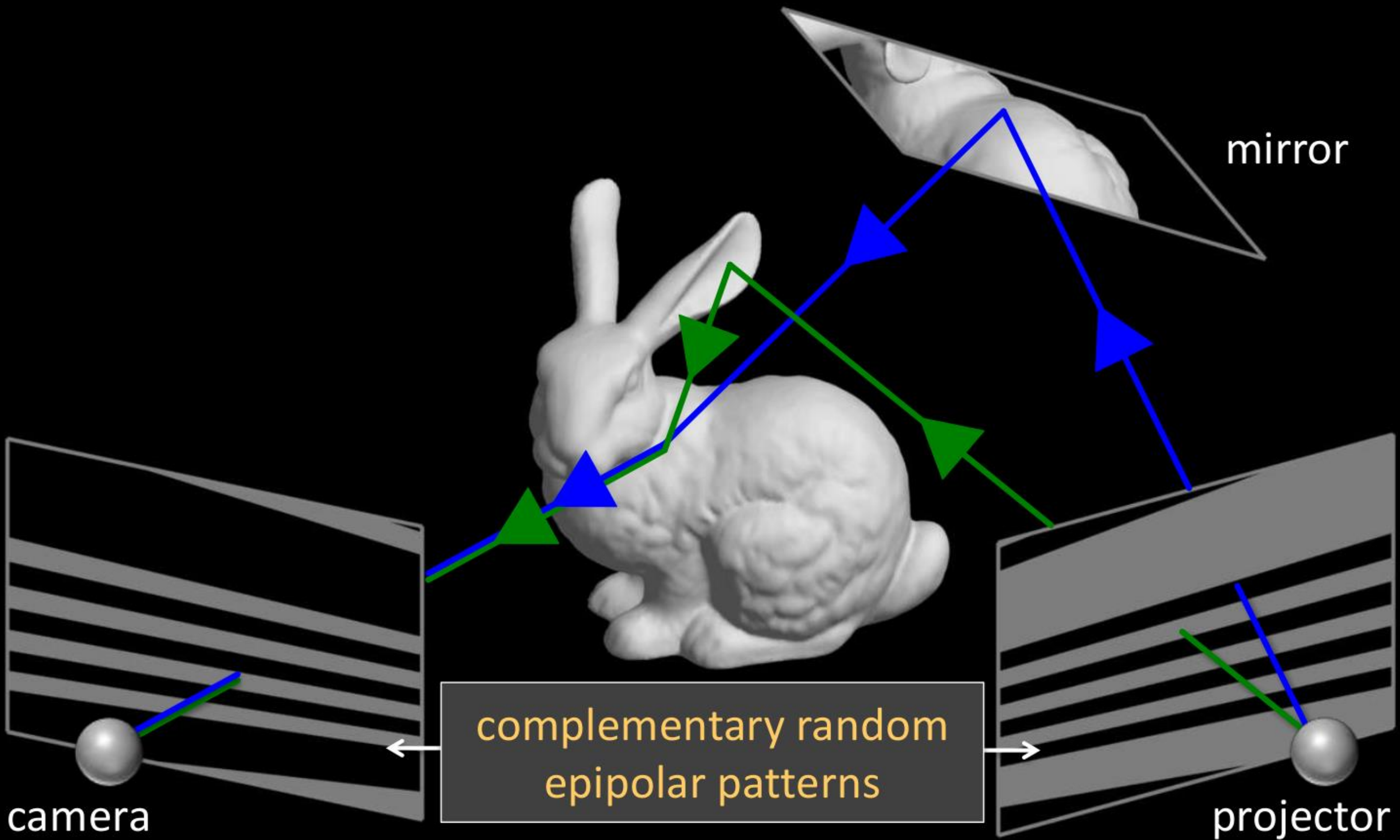
blocking epipolar paths with patterns & masks



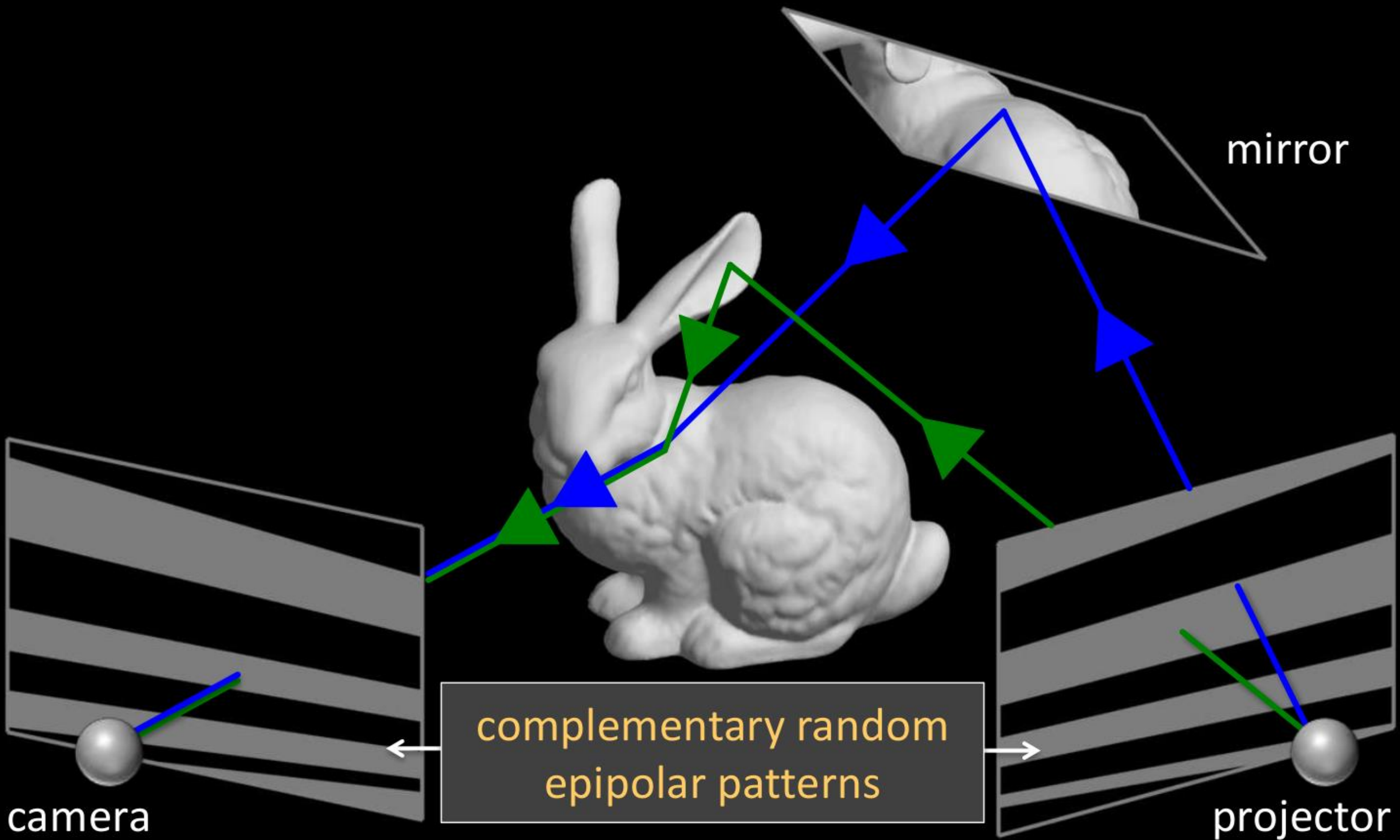
blocking epipolar paths with patterns & masks



blocking epipolar paths with patterns & masks

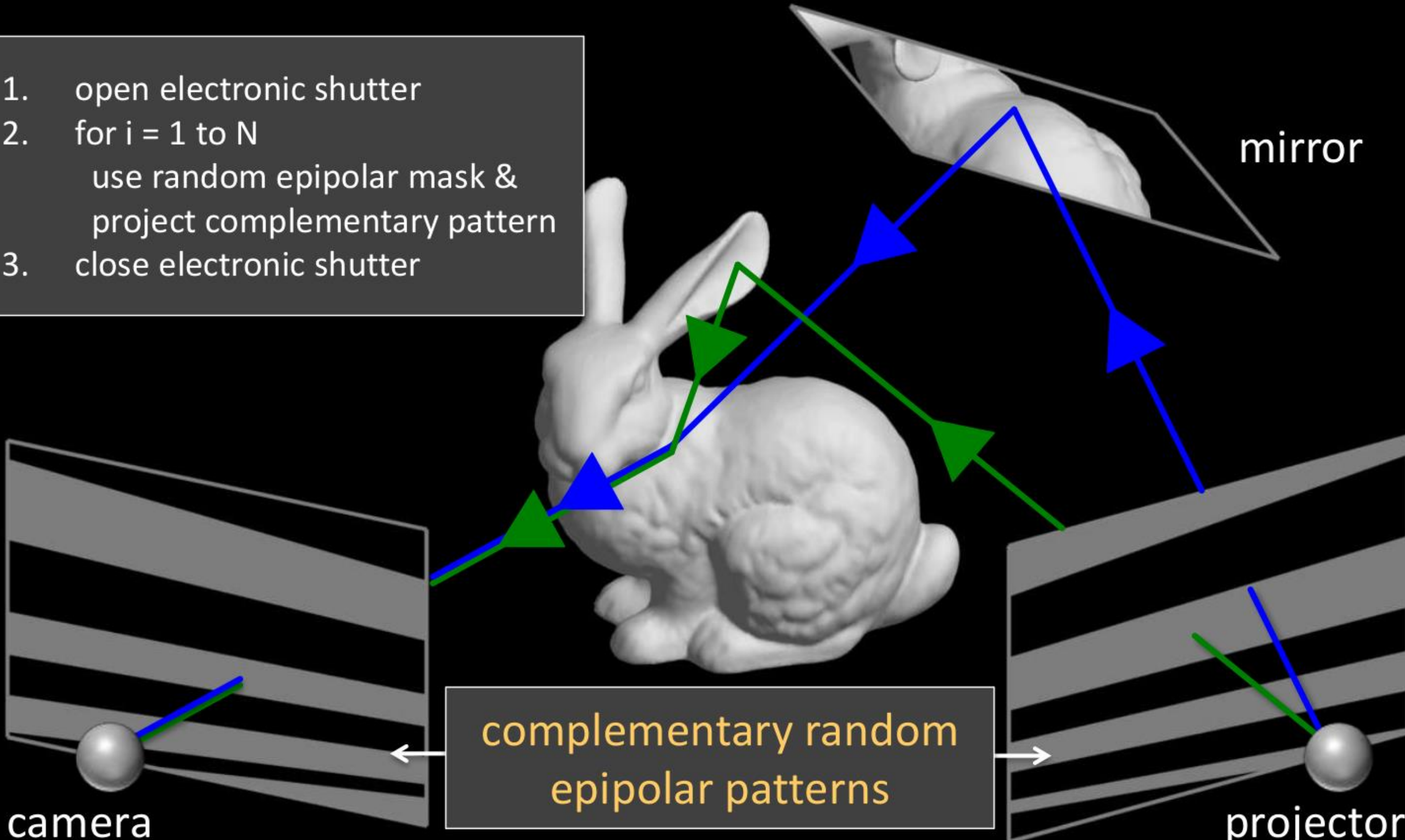


blocking epipolar paths with patterns & masks



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

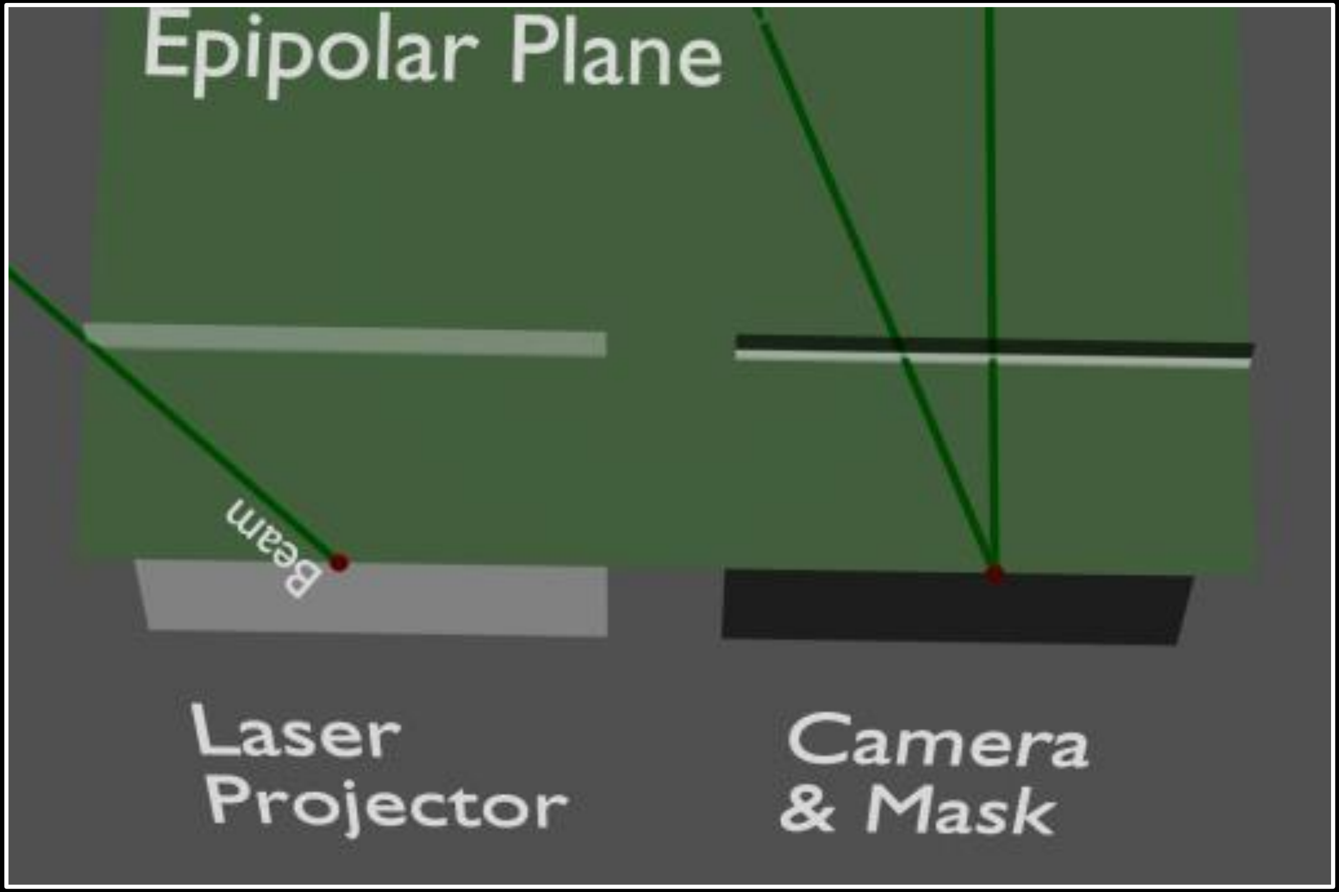
top–left: conventional
top–right: indirect–only
bottom–right: epipolar–only

top–left: conventional
top–right: indirect–only
bottom–right: epipolar–only

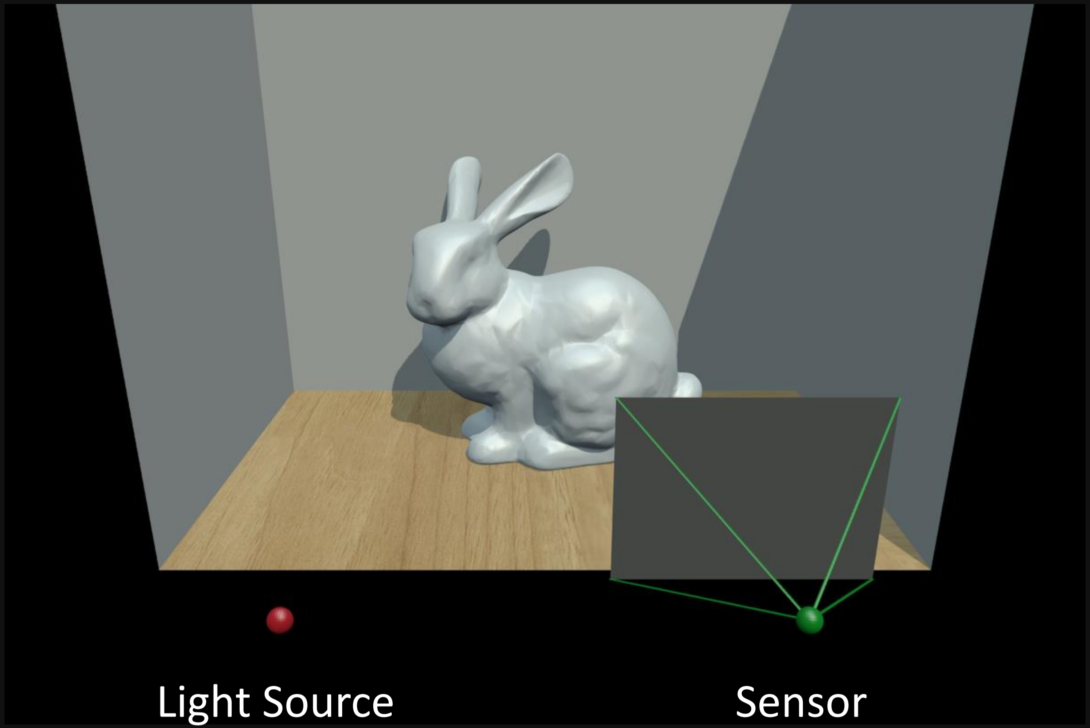
top–left: conventional
top–right: indirect–only
bottom–right: epipolar–only

Energy-efficient epipolar imaging

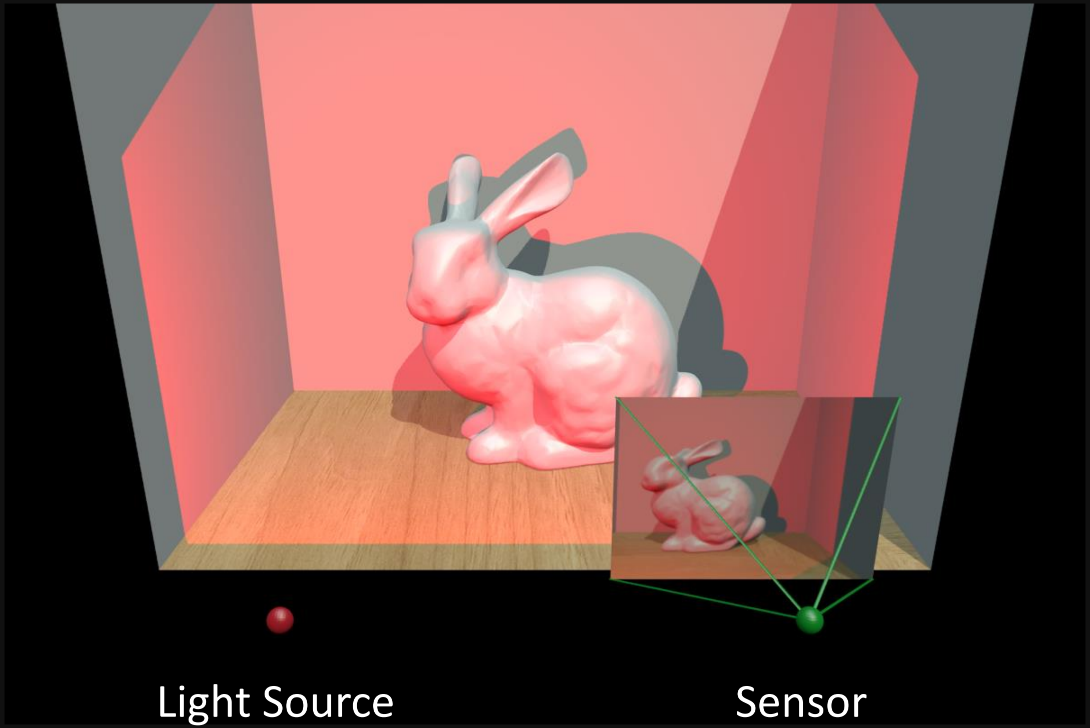
Energy-efficient transport parsing



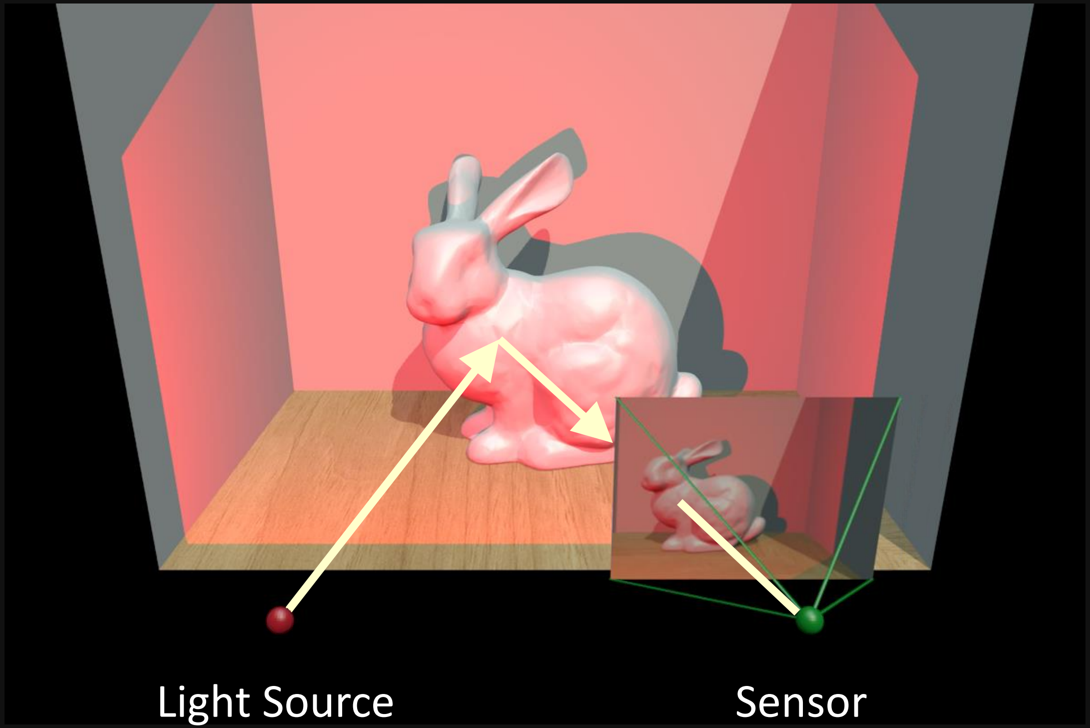
Regular Imaging



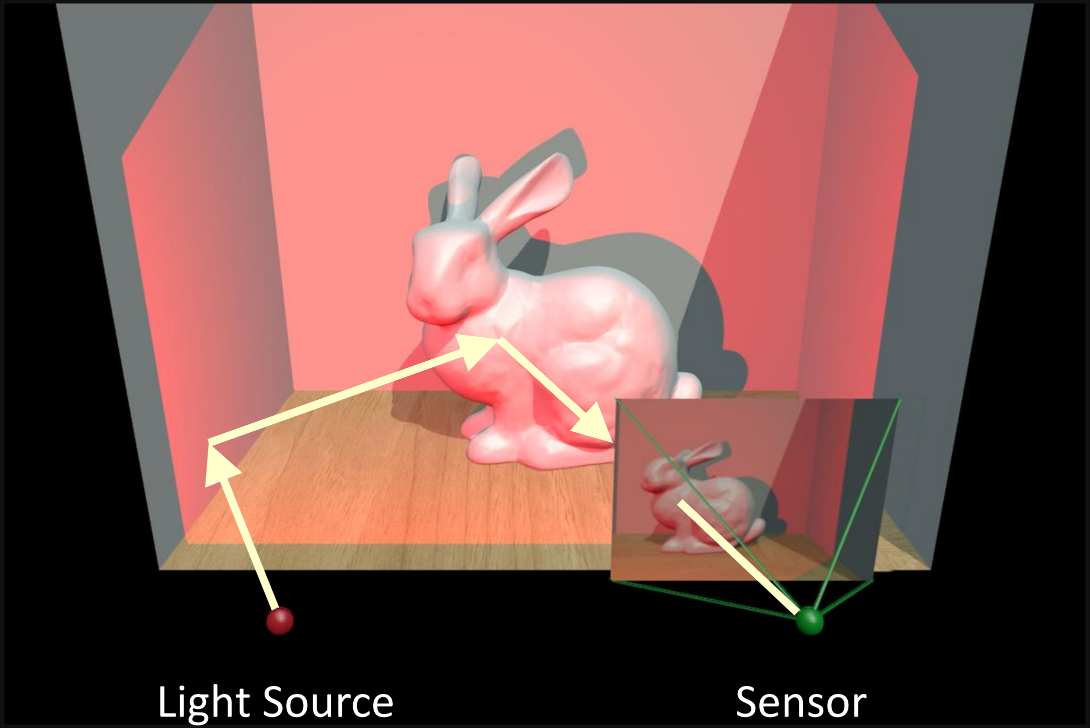
Regular Imaging



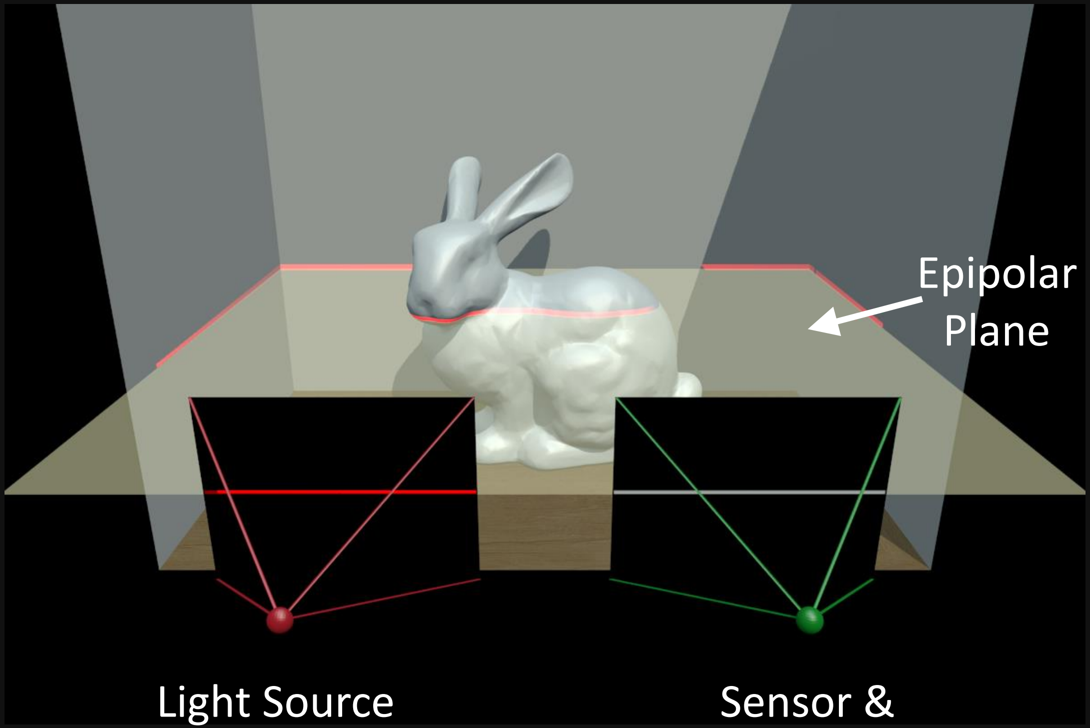
Regular Imaging



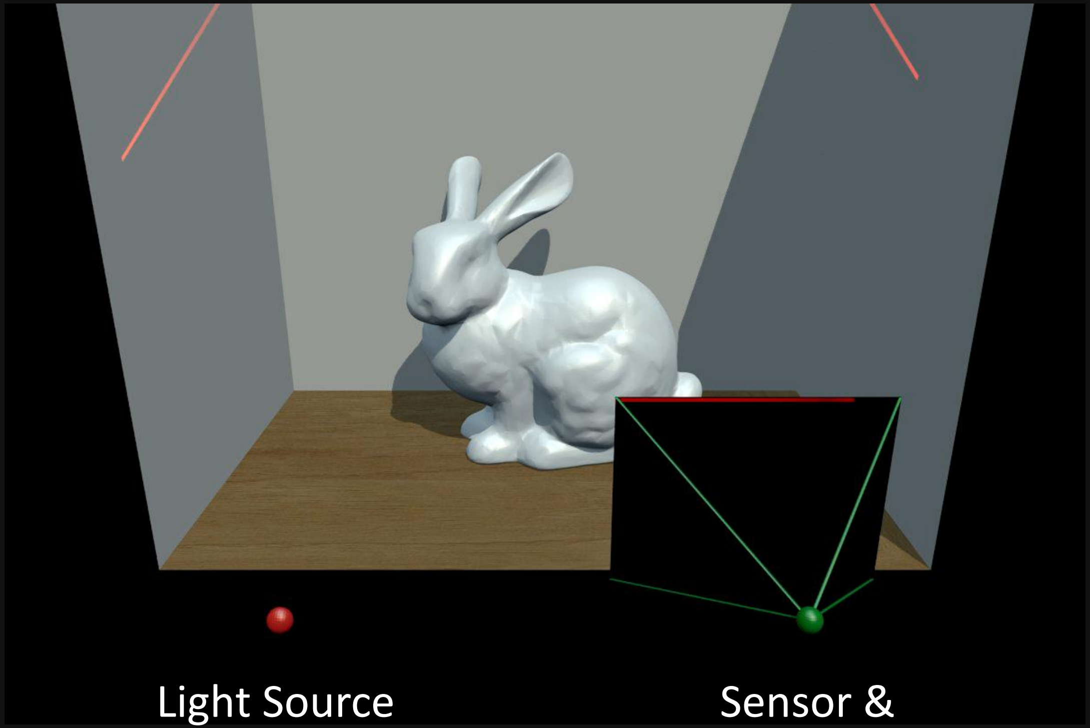
Regular Imaging



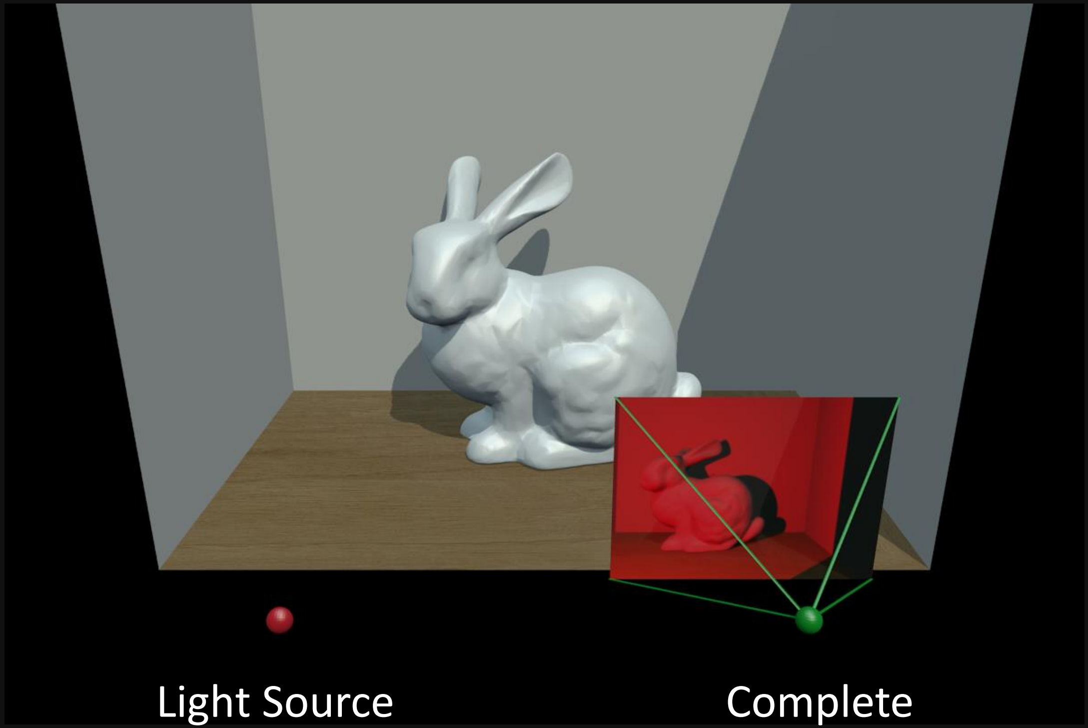
Epipolar Imaging



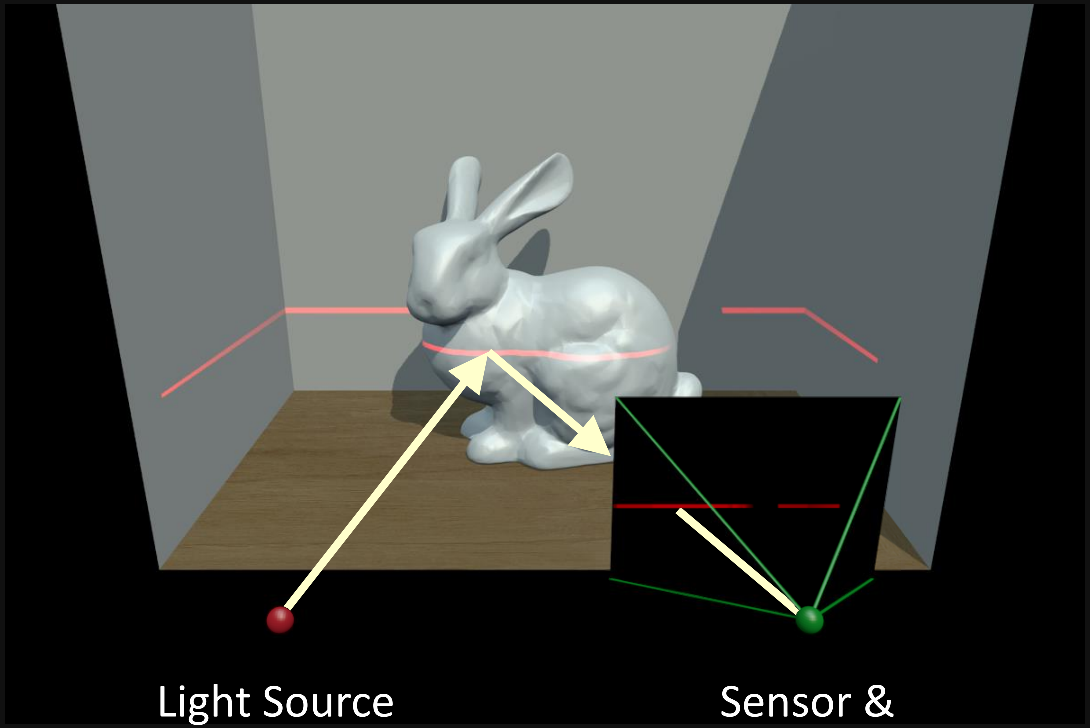
Epipolar Imaging



Epipolar Imaging



Epipolar Imaging



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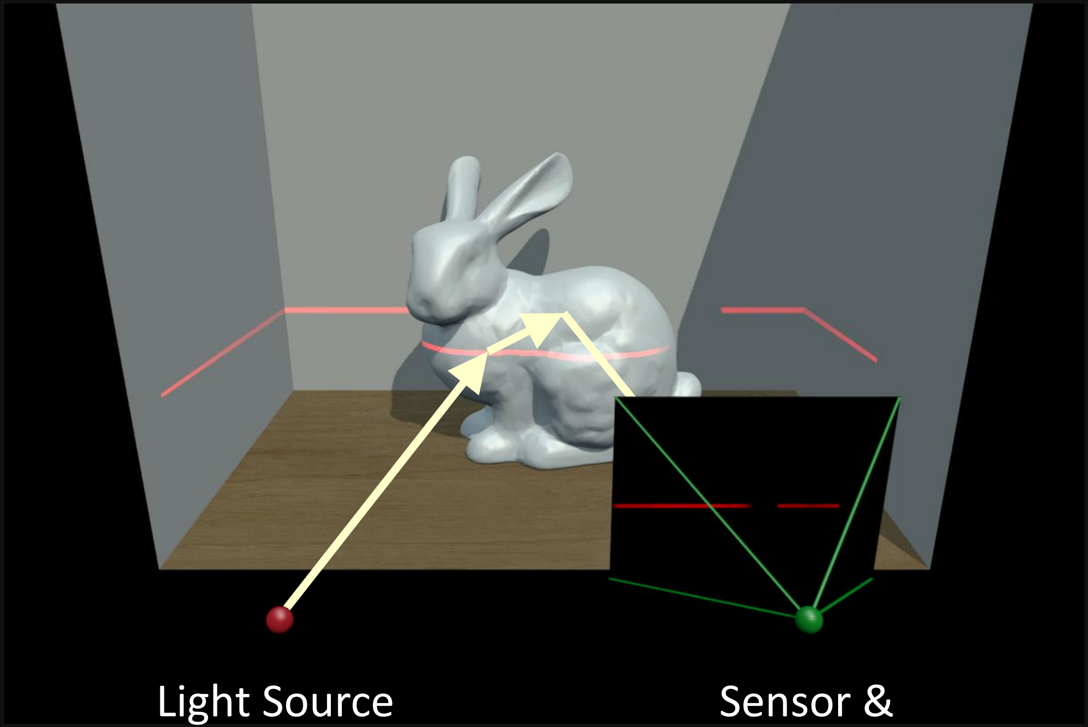
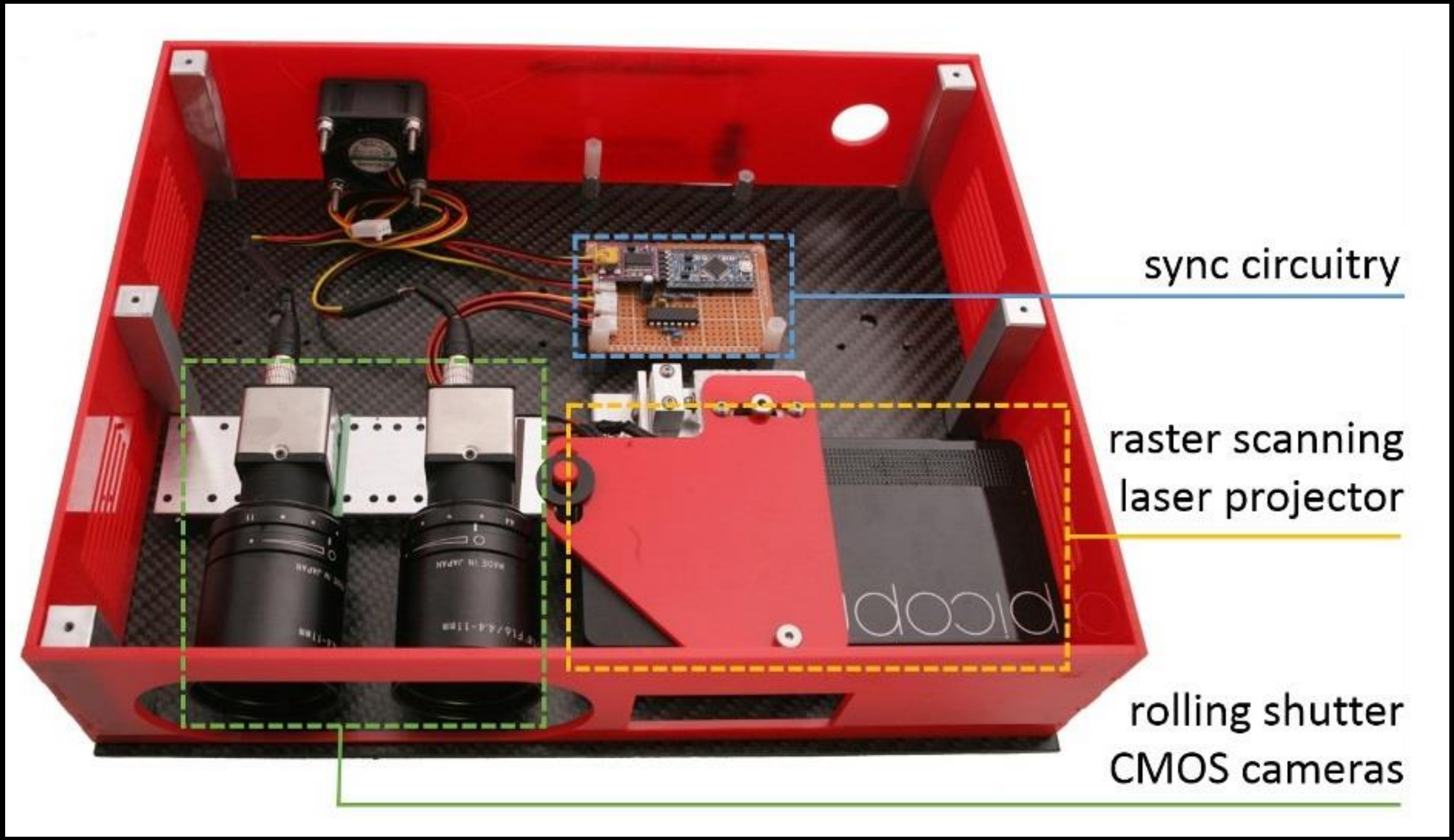


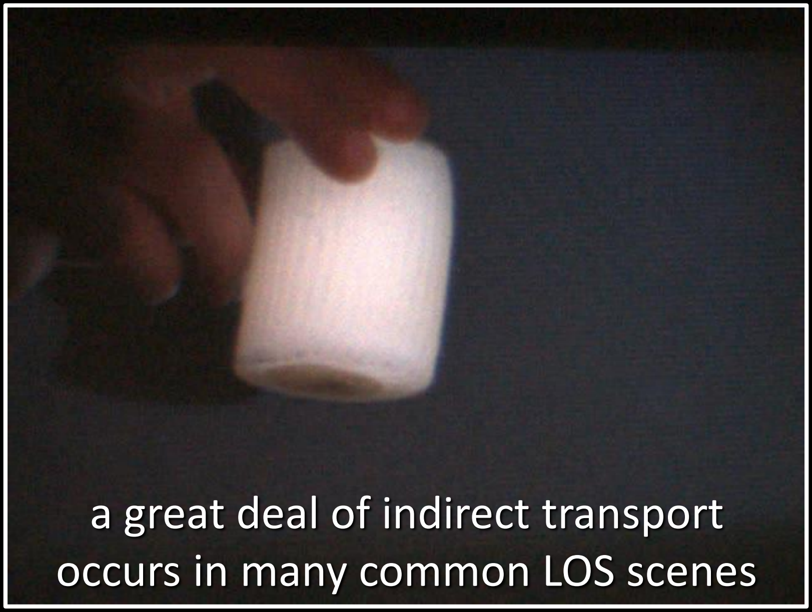
Energy-efficient transport parsing



all paths

planar (mostly direct)

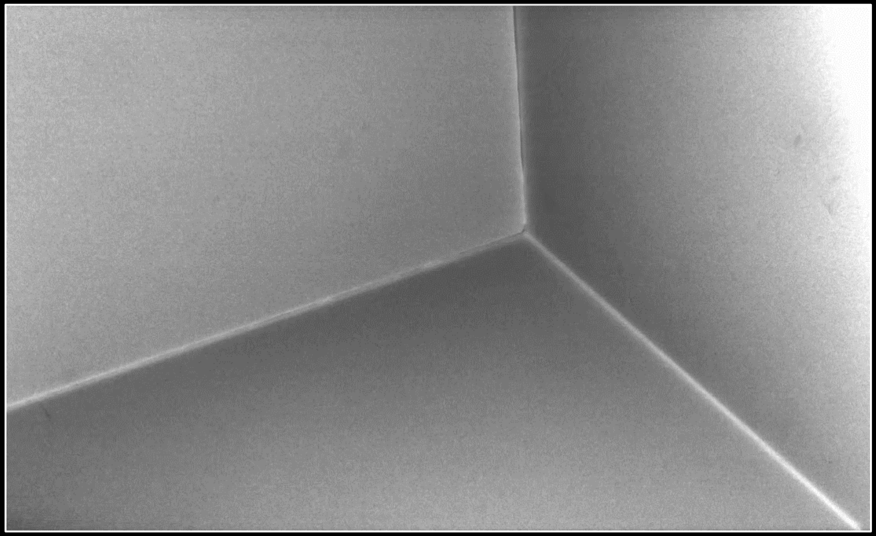
non-planar (always indirect)

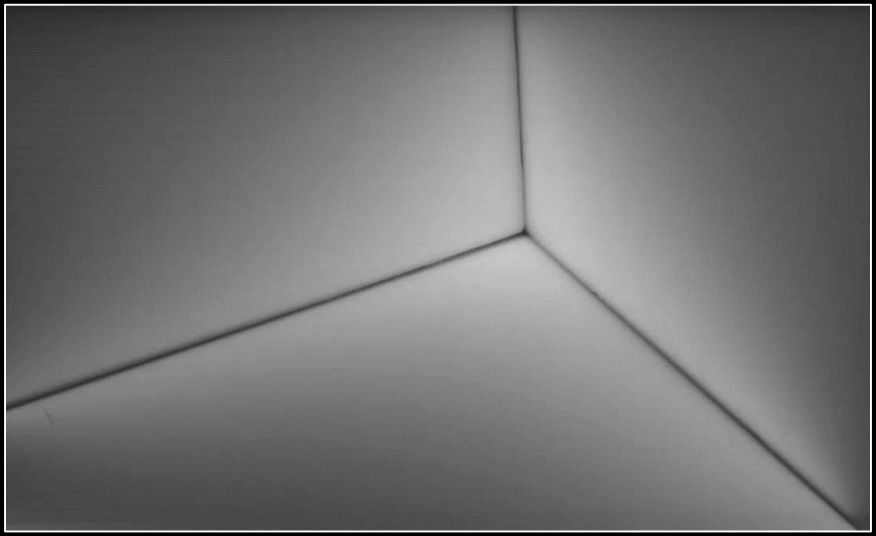


all paths

planar (mostly direct)

non-planar (always indirect)





References

Basic reading:

- Nayar et al., "Fast separation of direct and global components of a scene using high frequency illumination," SIGGRAPH 2004.

  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:

- Seitz et al., "A theory of inverse light transport," ICCV 2005.

  This early paper shows a way to *exactly* decompose light transport by number of bounces, under certain assumptions for the imaged scene.
- Chandraker et al., "On the duality of forward and inverse light transport," PAMI 2011.
- Reddy et al., "Frequency-space decomposition and acquisition of light transport under spatially varying illumination," ECCV 2012.

  These two papers have additional analysis about the relationship between direct and global illumination and illumination frequency.