Light Transport

CS535
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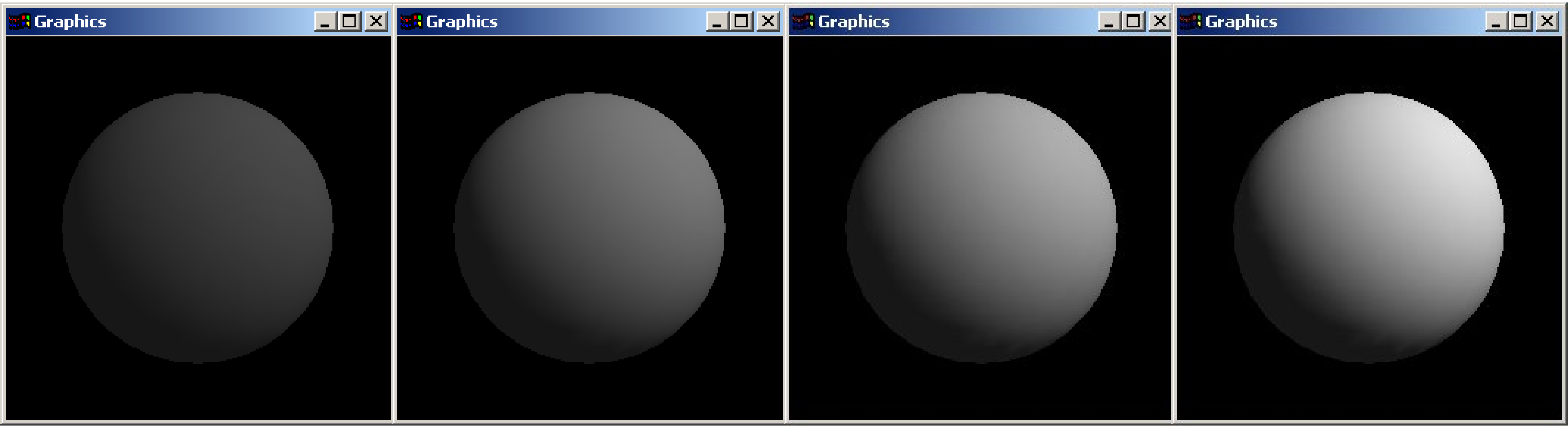
Topics

- Local and Global Illumination Models
- Helmholtz Reciprocity
- Dual Photography/Light Transport in Real-World

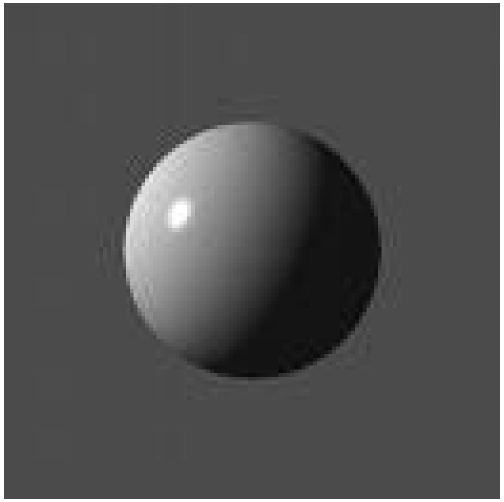
Diffuse Lighting

- A.k.a. Lambertian illumination
- A fraction of light is radiated in every direction
- Intensity varies with cosine of the angle with normal



Specular Lighting

- Shiny surfaces reflect predominantly in a particular direction, creating *highlights*
- Where the highlights appear depends on the viewer's position



Global Illumination

- Ray tracing

Conclusion

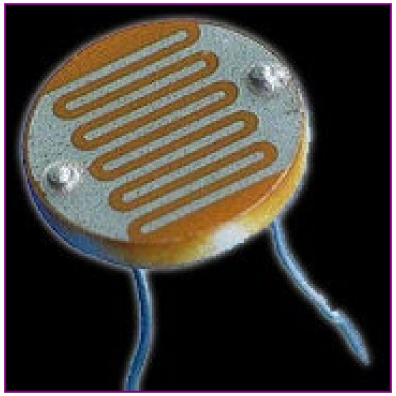
- Modeling illumination is hard
- “Undoing” physically-observed illumination in order to discover the underlying geometry is even harder

- Insight: let’s sample it and “re-apply” it!

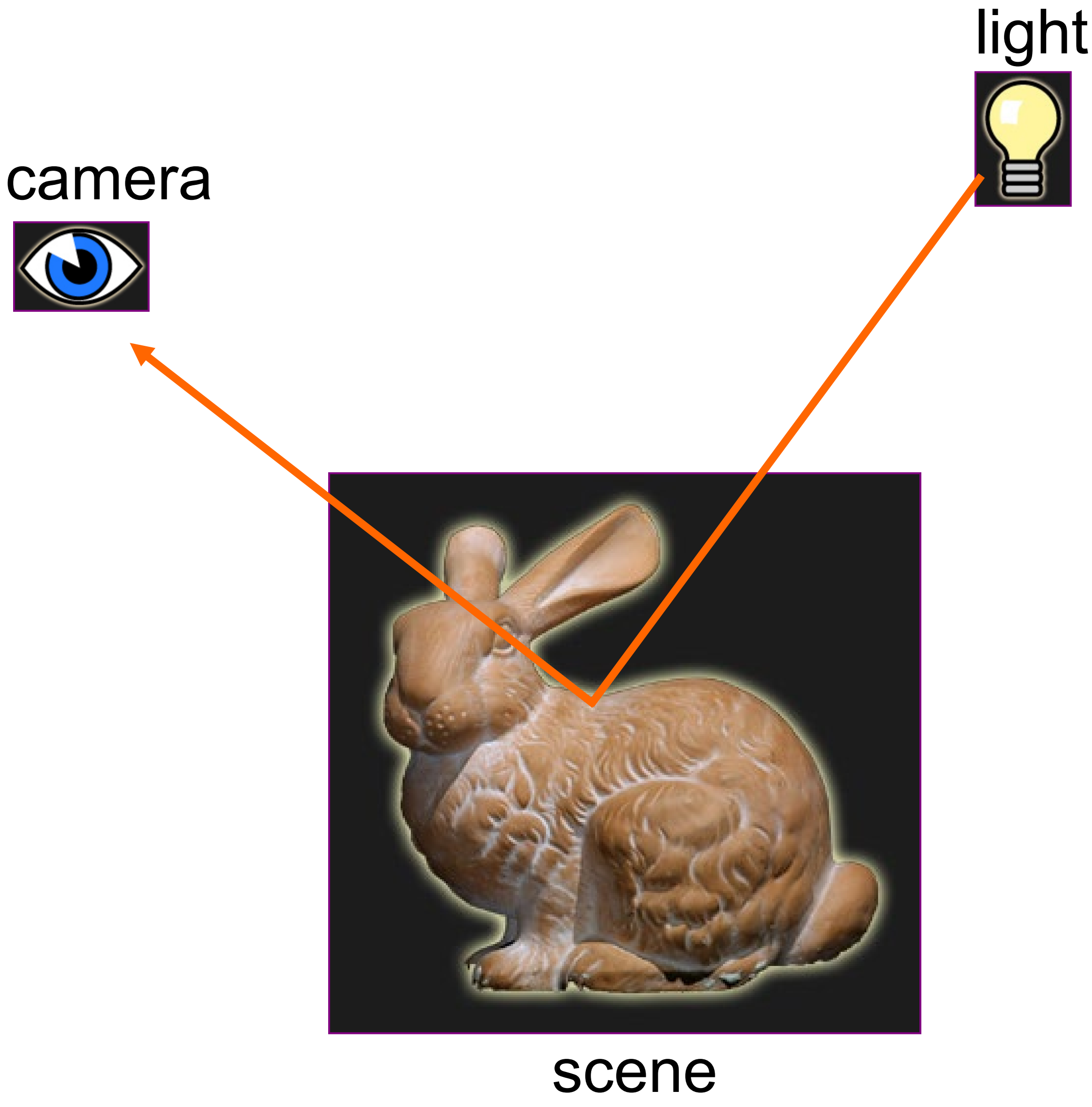
Dual Photography

Sen et al., SIGGRAPH 2005

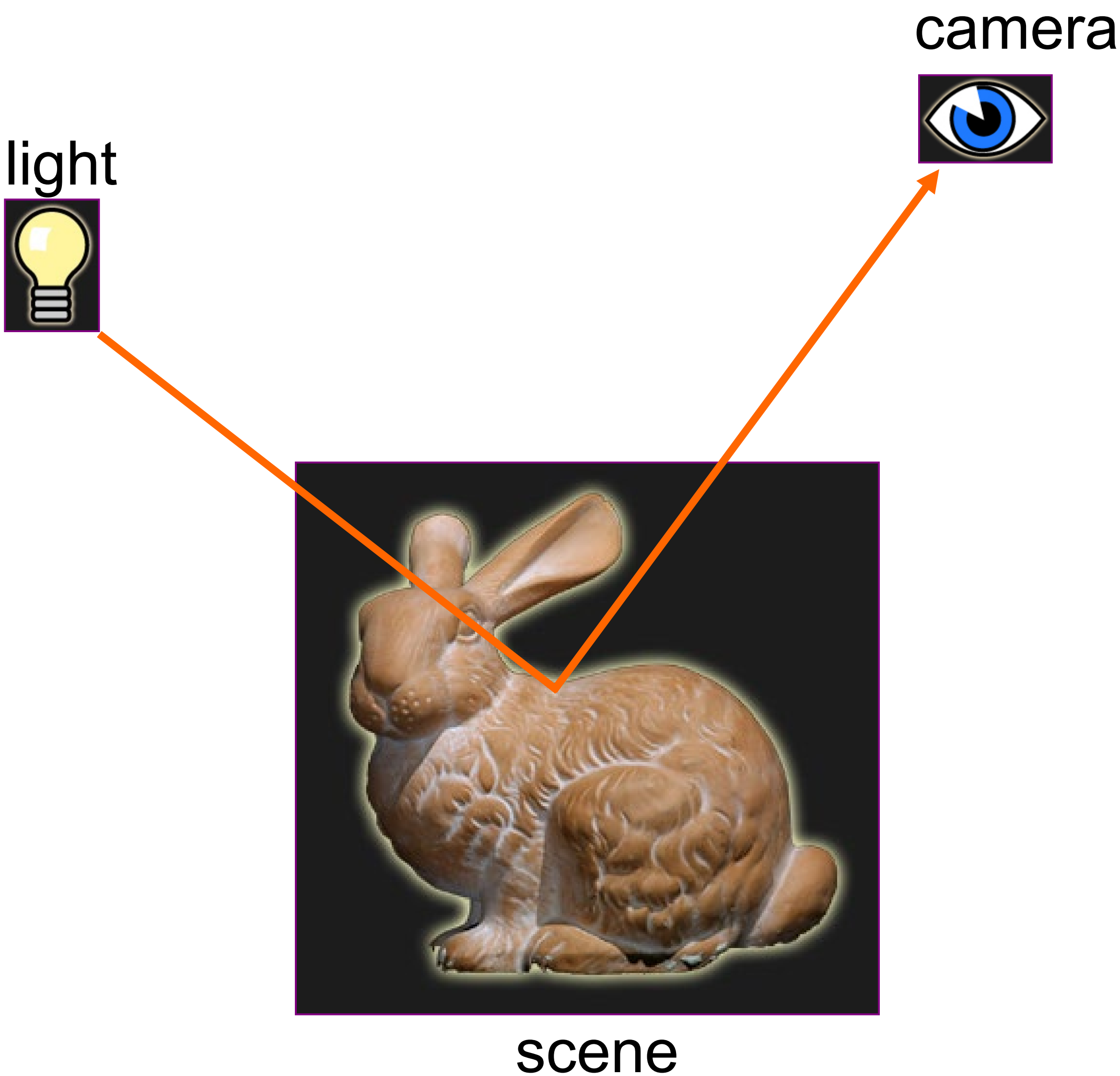
(slides courtesy of M. Levoy)



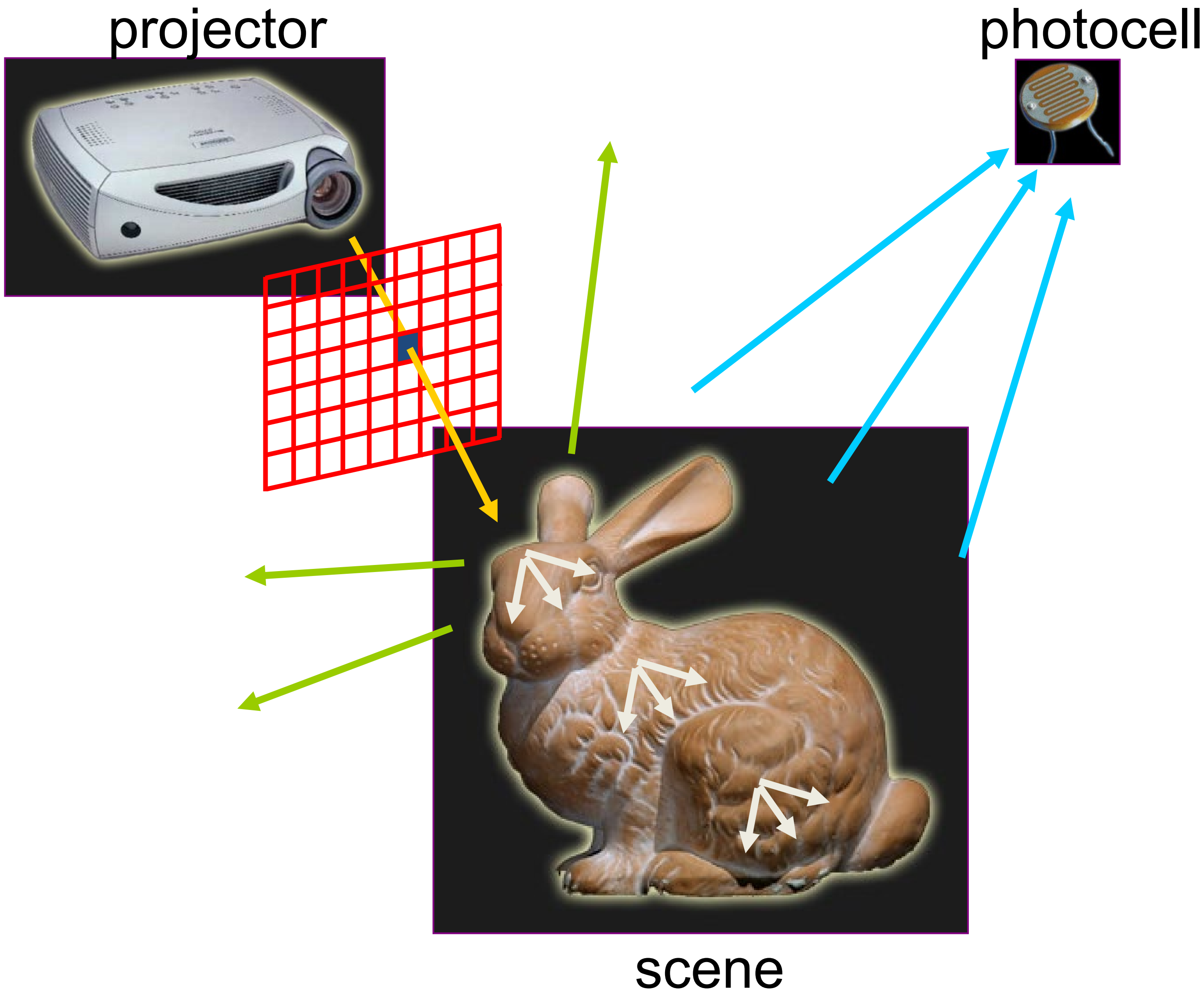
Helmholtz Reciprocity



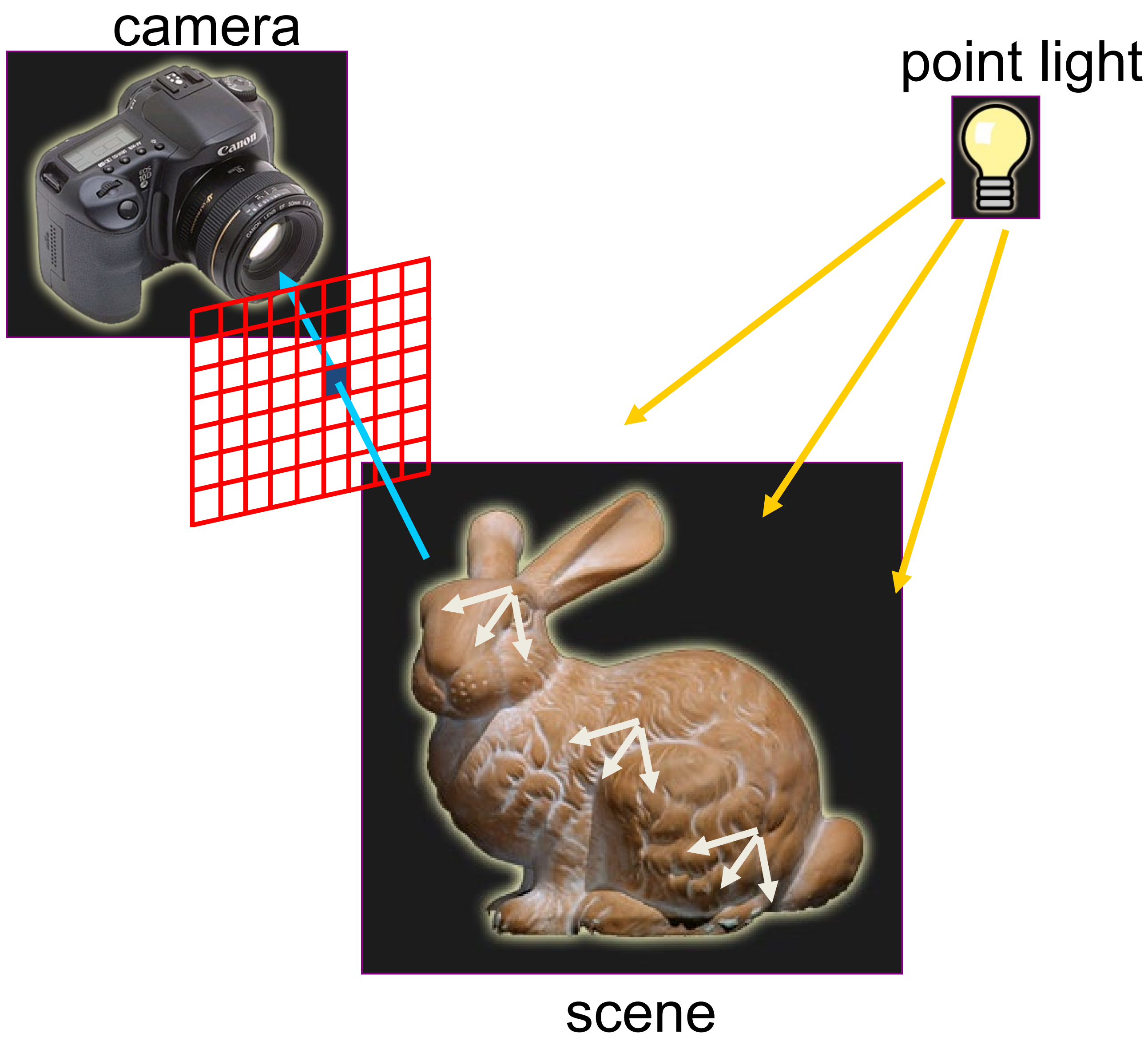
Helmholtz Reciprocity



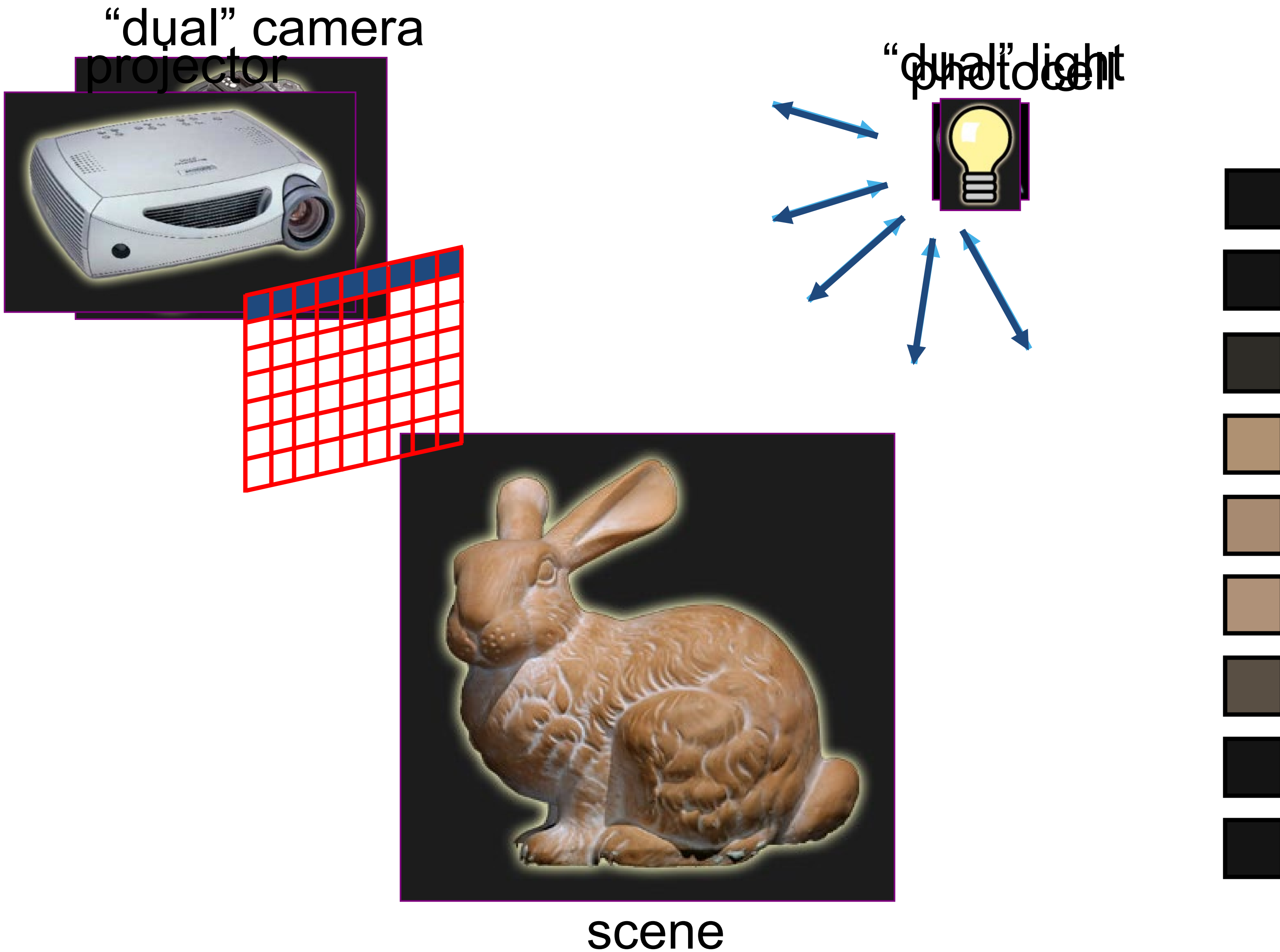
Measuring transport along a set of paths



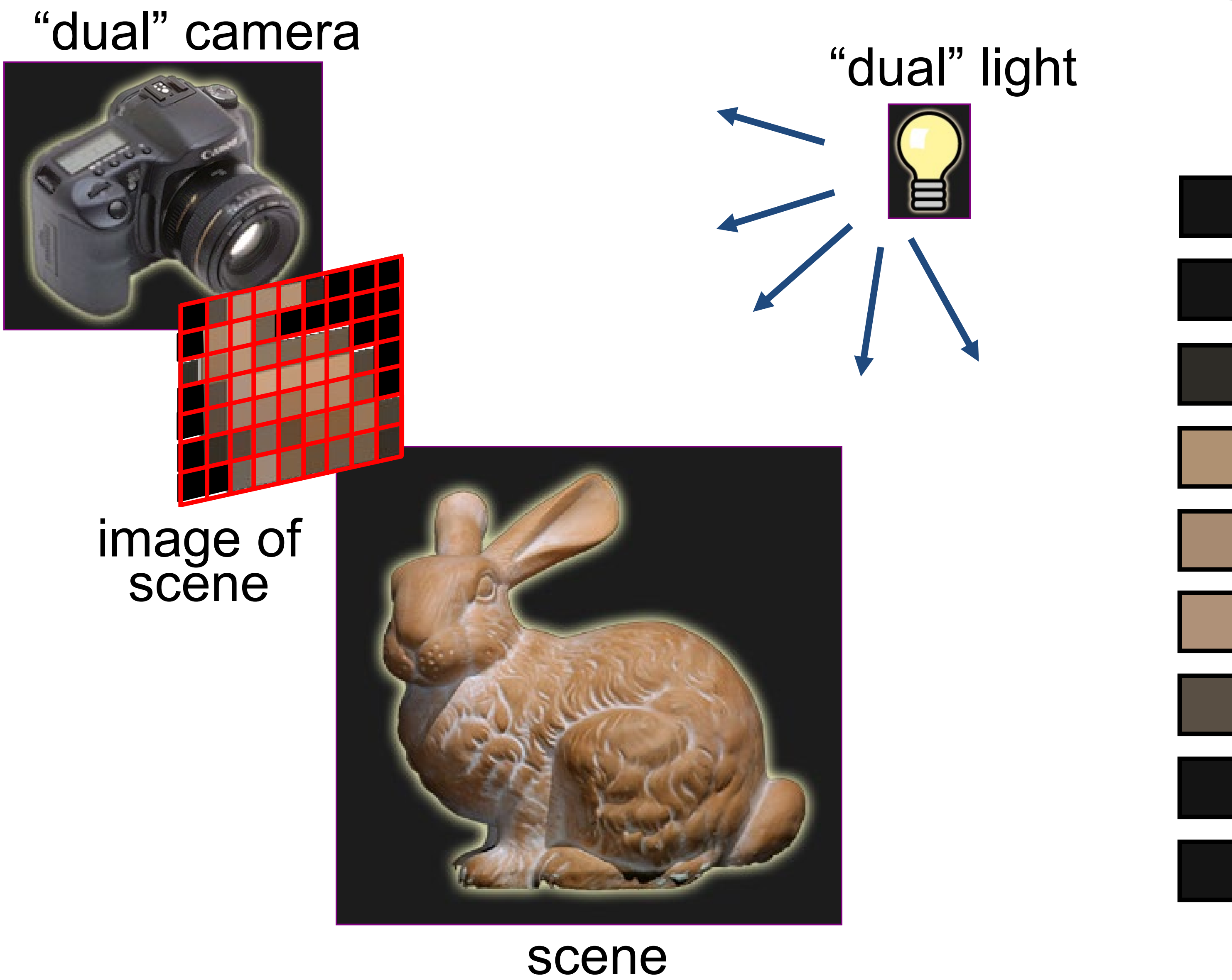
Reversing the paths



Forming a dual photograph



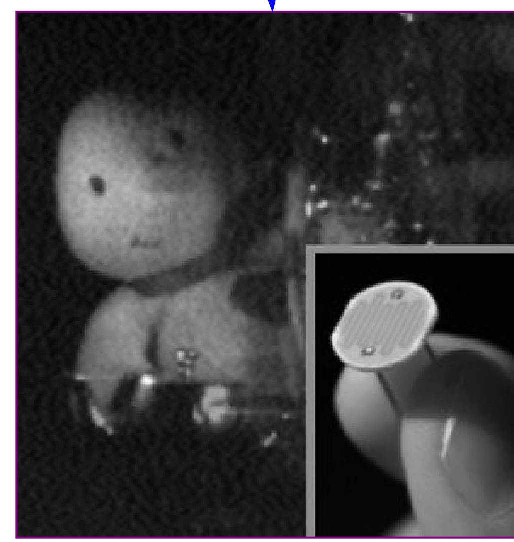
Forming a dual photograph



Physical demonstration

- light replaced with projector
- camera replaced with photocell
- projector scanned across the scene

conventional photograph,
with light coming from right

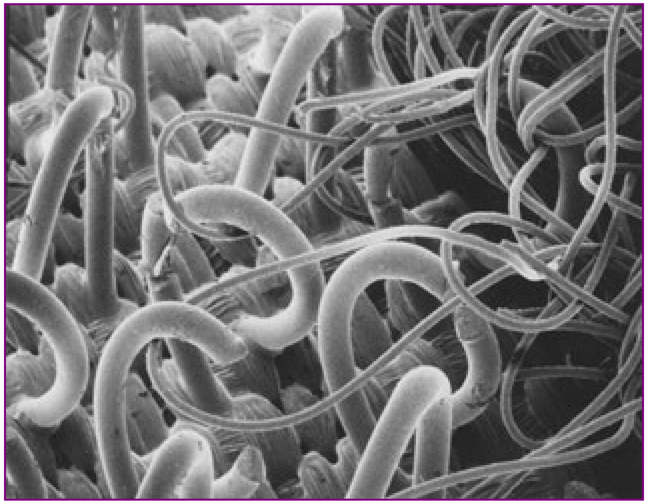


dual photograph,
as seen from projector's position
and as illuminated from photocell's position

Related imaging methods

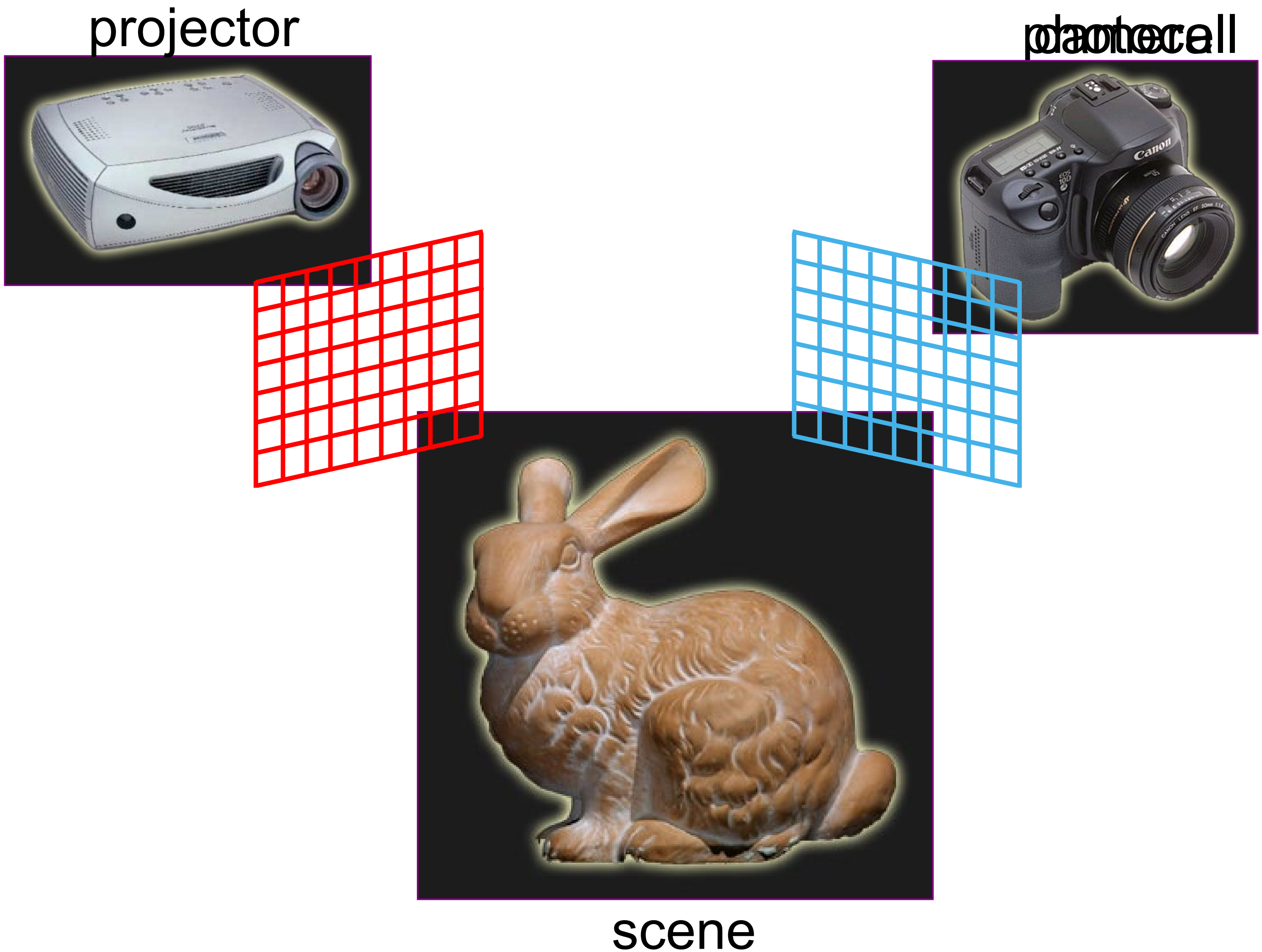
- time-of-flight scanner
  - if they return reflectance as well as range
  - but their light source and sensor are typically coaxial

- scanning electron microscope

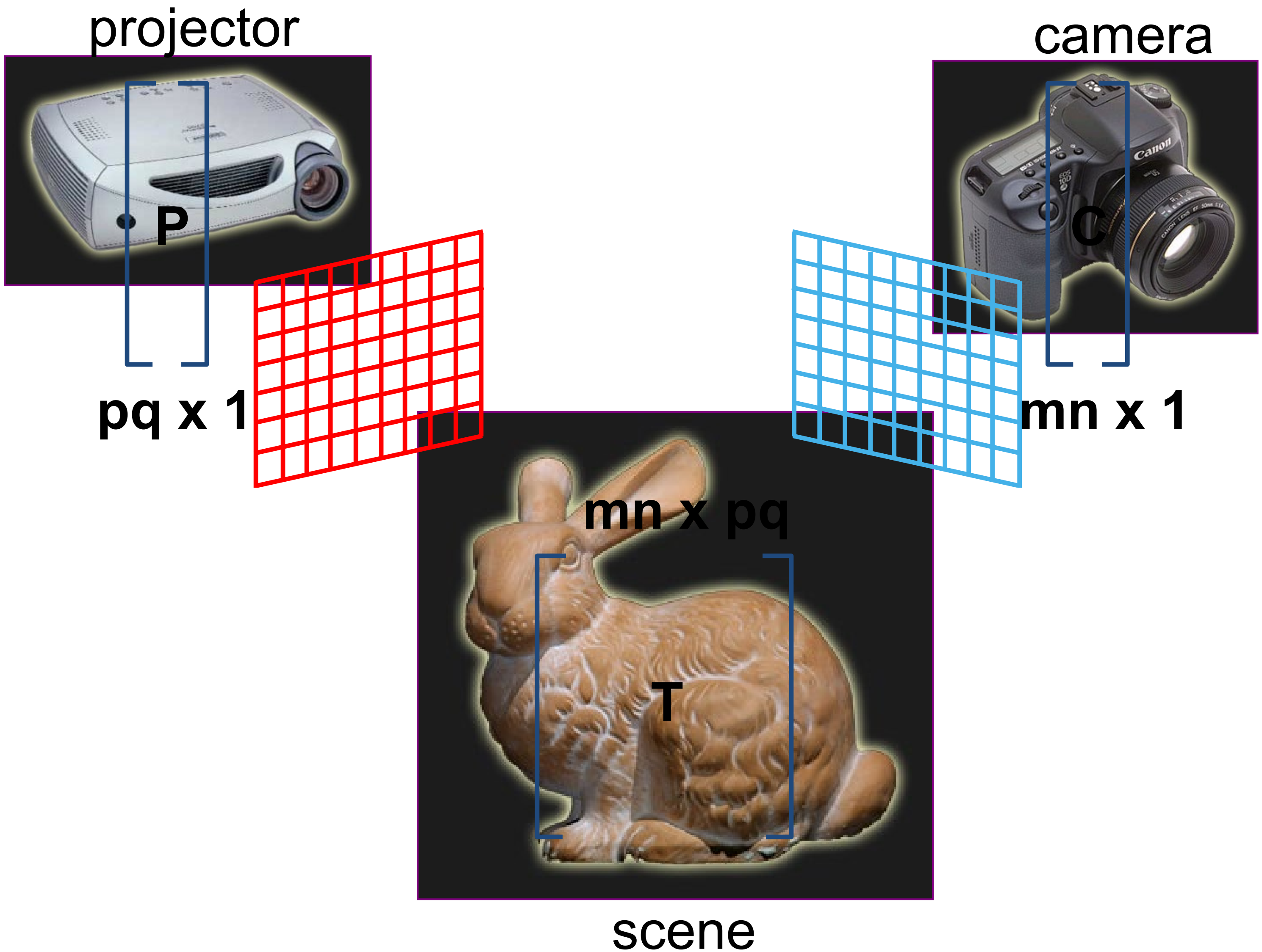


Velcro® at 35x magnification,
Museum of Science, Boston

The 4D transport matrix



The 4D transport matrix



The 4D transport matrix

$$\underbrace{\begin{bmatrix} C \end{bmatrix}}_{mn \times 1} = \overbrace{\begin{bmatrix} \quad T \quad \end{bmatrix}}^{mn \times pq} \underbrace{\begin{bmatrix} P \end{bmatrix}}_{pq \times 1}$$

The 4D transport matrix

mn x pq

$$\begin{bmatrix} C \end{bmatrix} = \begin{bmatrix} \quad T \quad \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

mn x 1   pq x 1

The 4D transport matrix

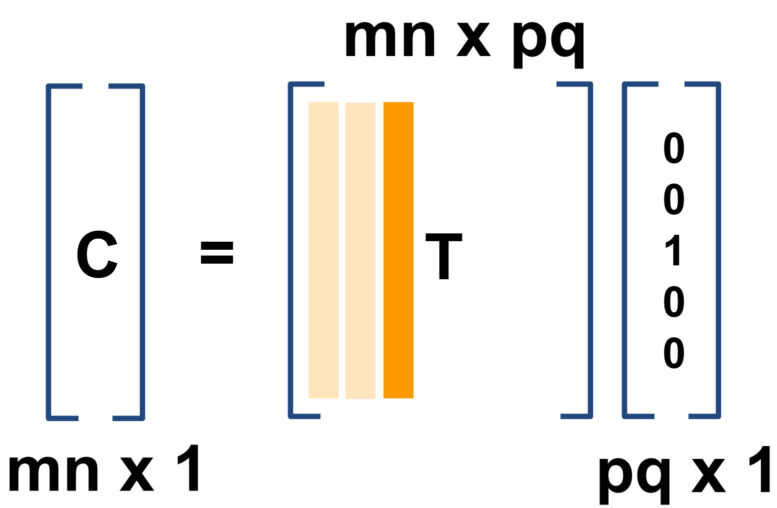
mn x pq

$$\begin{bmatrix} C \end{bmatrix} = \begin{bmatrix} T \end{bmatrix} \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

mn x 1

pq x 1

The 4D transport matrix



The 4D transport matrix

$$\underset{mn \times 1}{\begin{bmatrix} C \end{bmatrix}} = \overset{mn \times pq}{\begin{bmatrix} \quad T \quad \end{bmatrix}} \underset{pq \times 1}{\begin{bmatrix} P \end{bmatrix}}$$

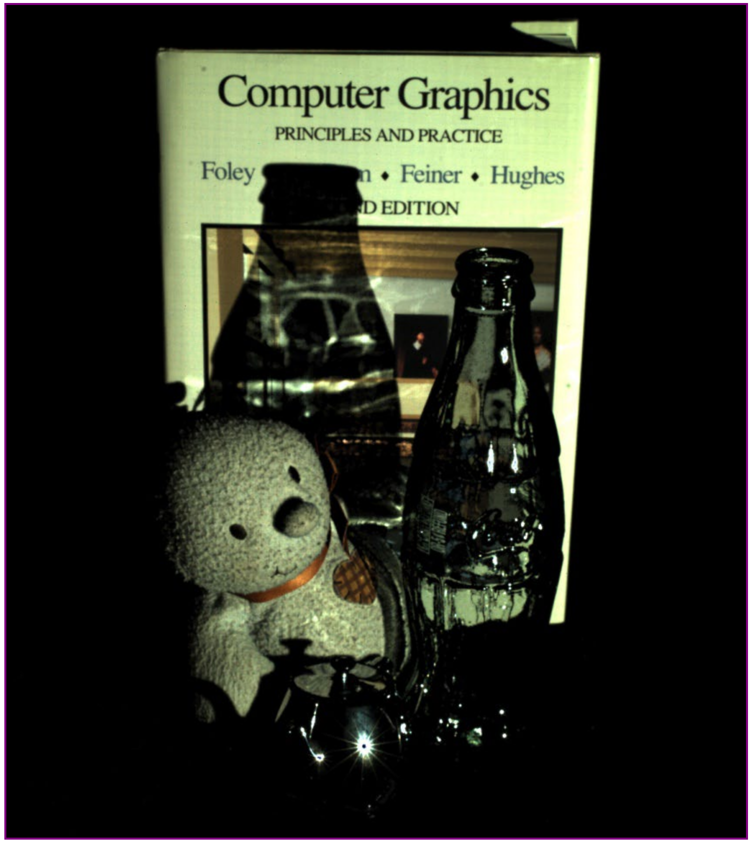
The 4D transport matrix

$$\underbrace{\begin{bmatrix} C \end{bmatrix}}_{mn \times 1} = \overbrace{\begin{bmatrix} \quad T \quad \end{bmatrix}}^{mn \times pq} \underbrace{\begin{bmatrix} P \end{bmatrix}}_{pq \times 1}$$

applying Helmholtz reciprocity...

$$\underbrace{\begin{bmatrix} C' \end{bmatrix}}_{pq \times 1} = \overbrace{\begin{bmatrix} \quad T^{T} \quad \end{bmatrix}}^{pq \times mn} \underbrace{\begin{bmatrix} P' \end{bmatrix}}_{mn \times 1}$$

Example



conventional photograph
with light coming from right

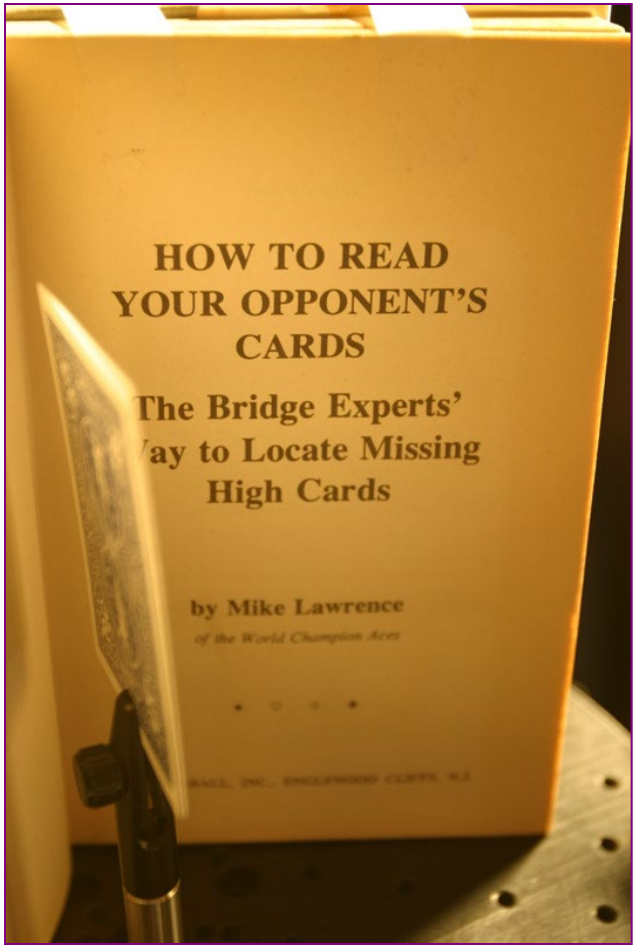
dual photograph
as seen from projector’s position

Properties of the transport matrix

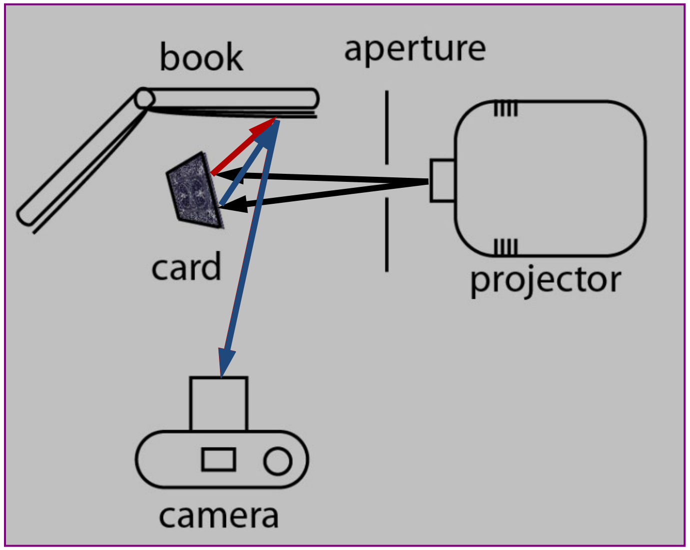
- little inter-reflection
  - → sparse matrix
- many inter-reflections
  - → dense matrix
- convex object
  - → diagonal matrix
- concave object
  - → full matrix

Can we create a dual photograph entirely from diffuse reflections?

Dual photography from diffuse reflections



the camera's view

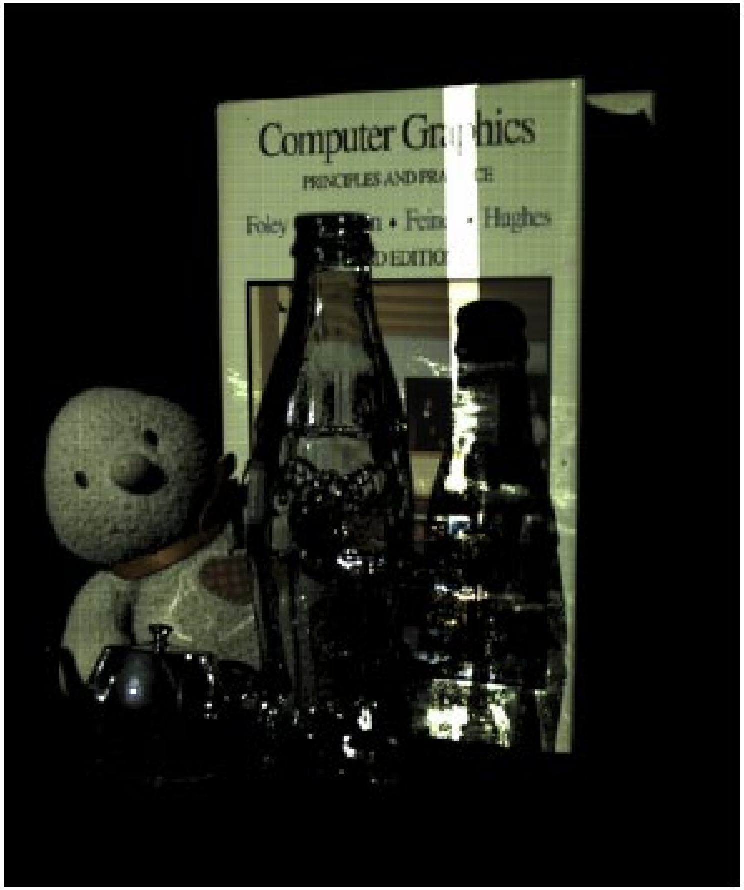


Relighting

Paul Debevec's
Light Stage 3

- subject captured under multiple lights
- one light at a time, so subject must hold still
- point lights are used, so can't relight with cast shadows

Relighting

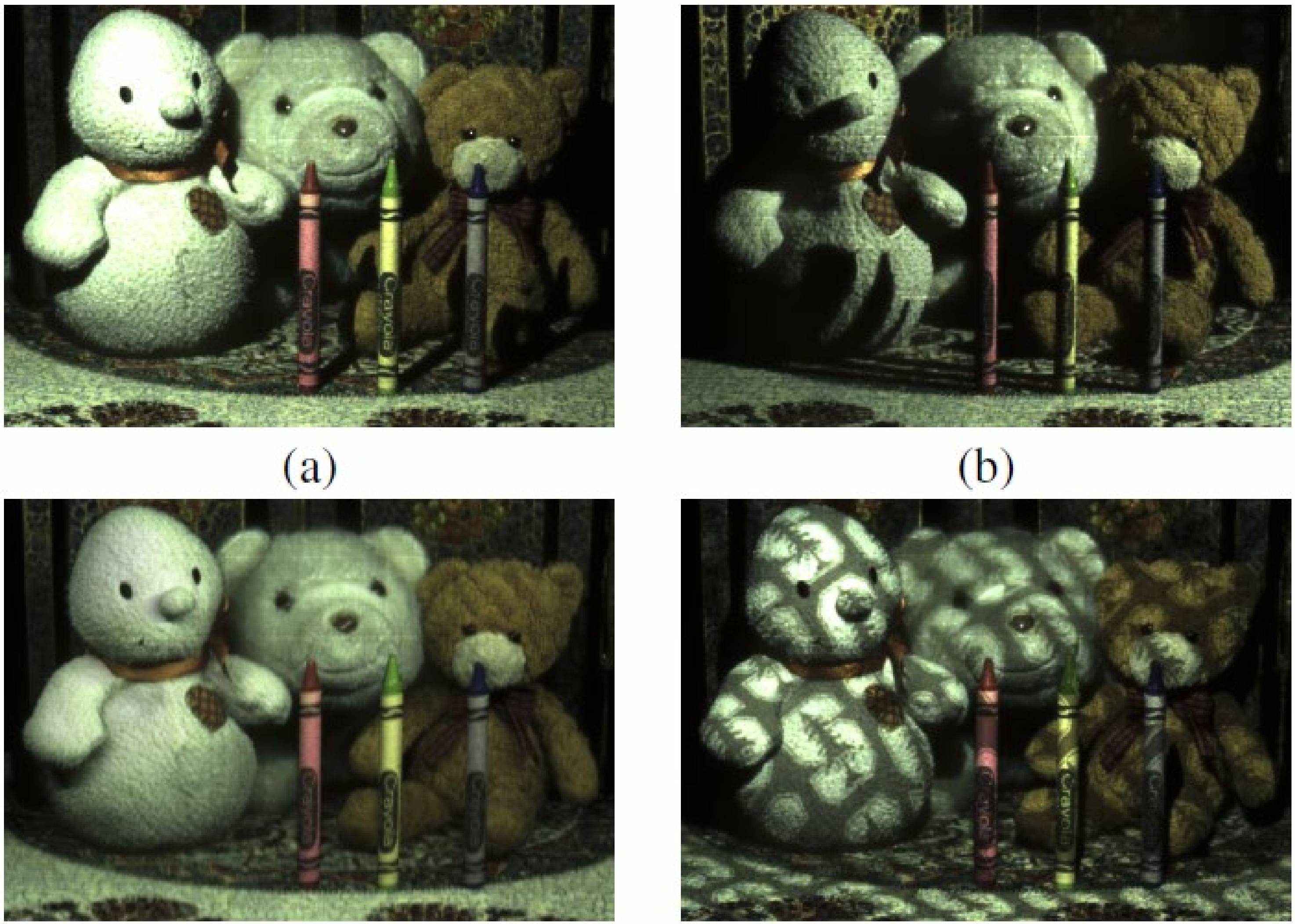


With Dual Photography…

Relighting

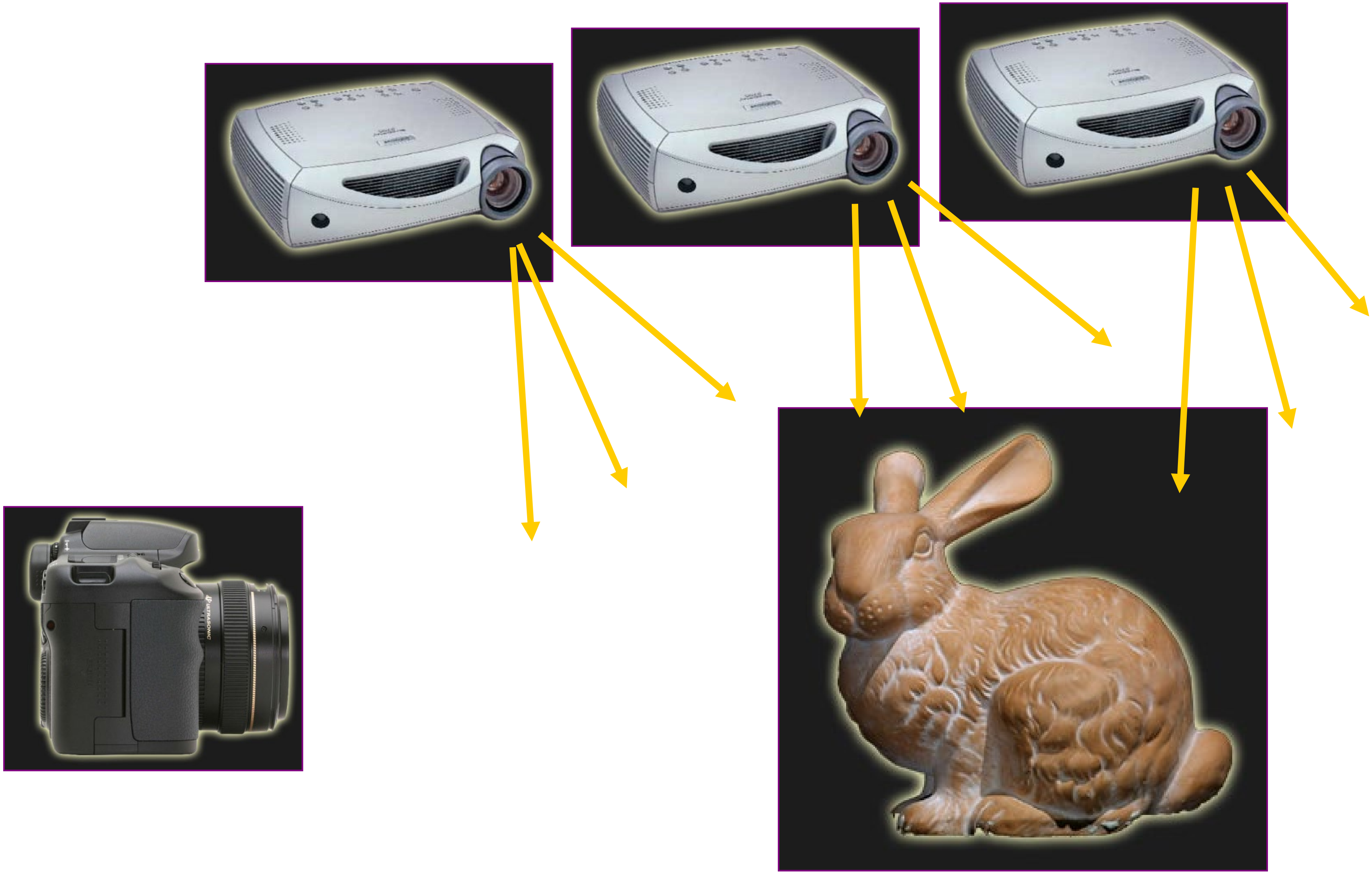
With Dual Photography…

Relighting

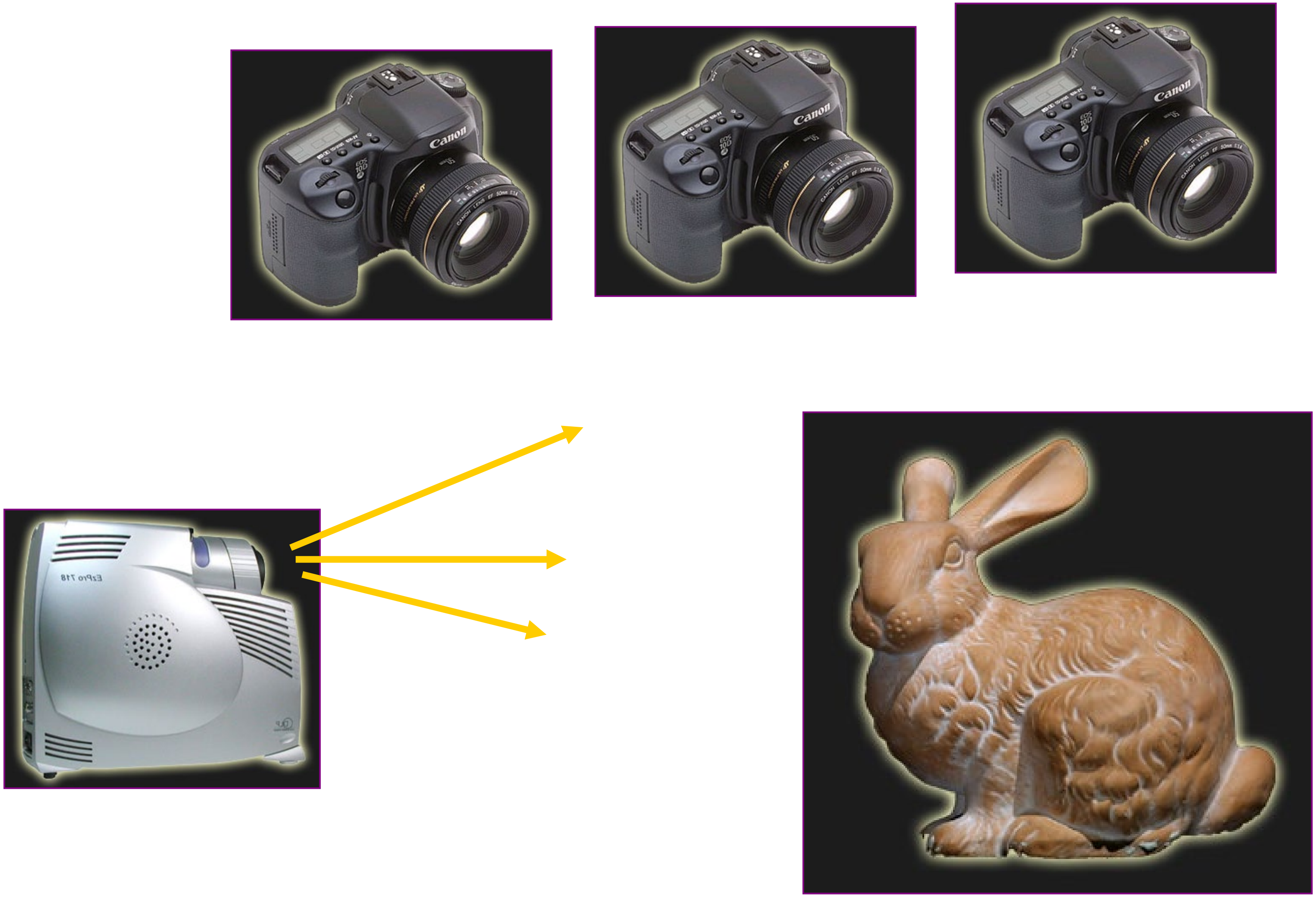


With Dual Photography…

The 6D transport matrix



The 6D transport matrix



The advantage of dual photography

- capture of a scene as illuminated by different lights cannot be parallelized

- capture of a scene as viewed by different cameras <u>can</u> be parallelized

Measuring the 6D transport matrix

projector

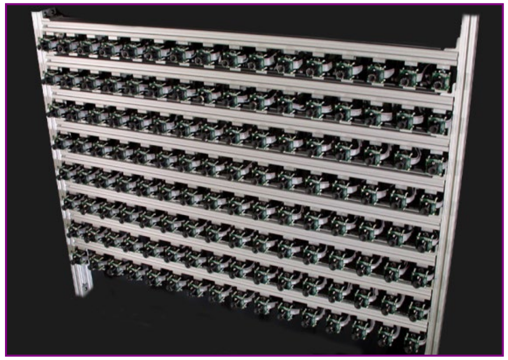
camera array

scene

Relighting with complex illumination

projector

camera array



scene

$$\underset{pq \times 1}{\begin{bmatrix} C' \end{bmatrix}} = \overset{pq \times mn \times uv}{\begin{bmatrix} T^T \end{bmatrix}} \underset{mn \times uv \times 1}{\begin{bmatrix} P' \end{bmatrix}}$$

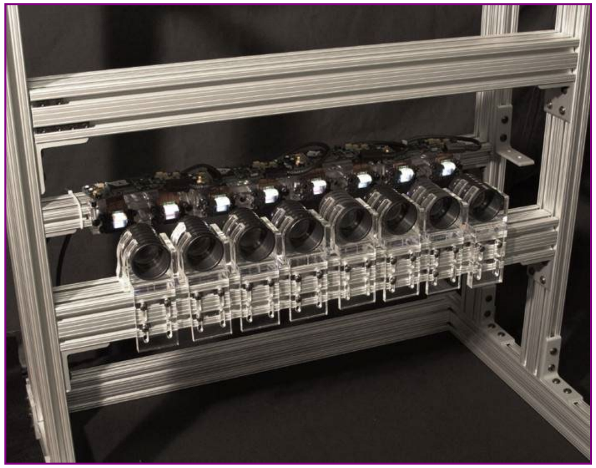
- step 1: measure 6D transport matrix T
- step 2: capture a 4D light field
- step 3: relight scene using captured light field

Running time

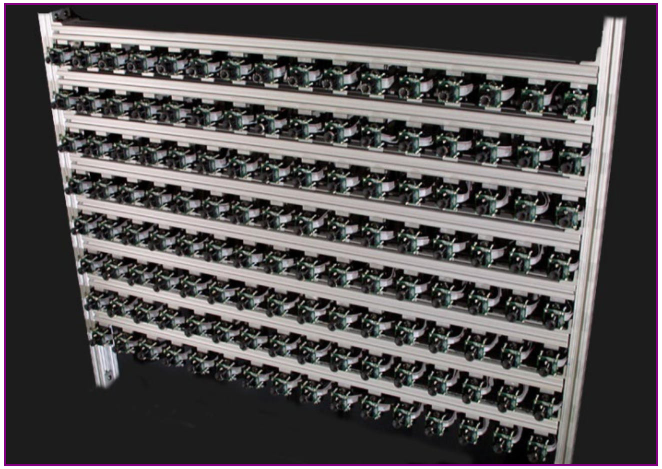
- the different rays within a projector can in fact be parallelized to some extent
- this parallelism can be discovered using a coarse-to-fine adaptive scan
- can measure a 6D transport matrix in 5 minutes

Can we measure an 8D transport matrix?

projector array



camera array



scene