Image-based Lighting (Part 2)

T2

Computational Photography

Derek Hoiem, University of Illinois

Many slides from Debevec, some from Efros, Kevin Karsch

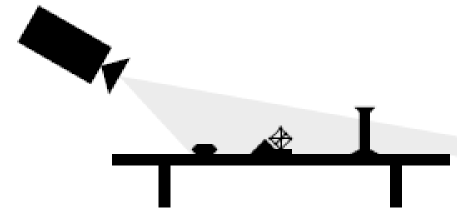
Today

- Brief review of last class
- Show how to get an HDR image from several LDR images, and how to display HDR
- Show how to insert fake objects into real scenes using environment maps

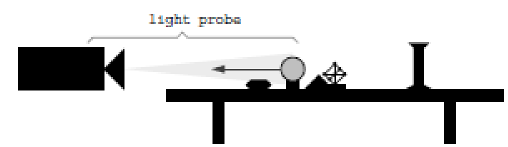
How to render an object inserted into an image?

Image-based lighting

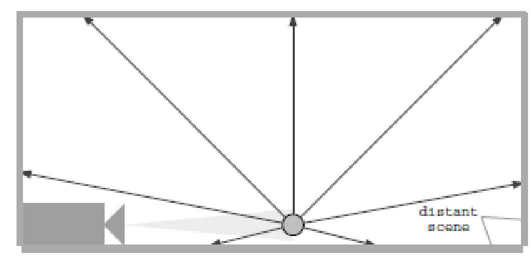
- Capture incoming light with a "light probe"
- Model local scene
- Ray trace, but replace distant scene with info from light probe



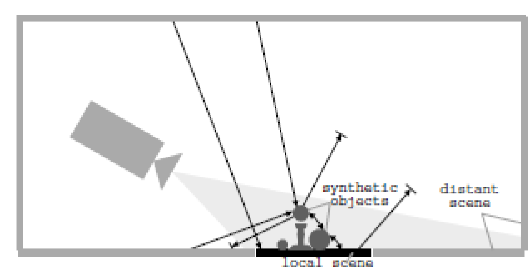
(a) Acquiring the background photograph



(b) Using the light probe



(c) Constructing the light-based model

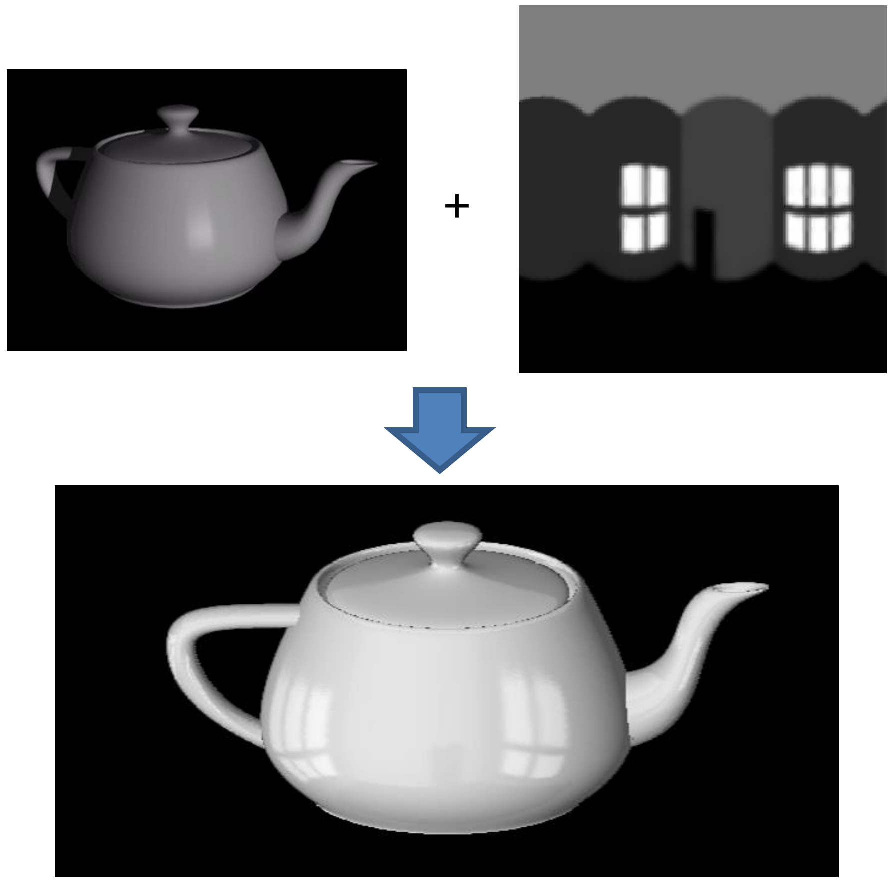


(d) Computing the global illumination solution

Debevec SIGGRAPH 1998

Key ideas for Image-based Lighting

- Environment maps: tell what light is entering at each angle within some shell

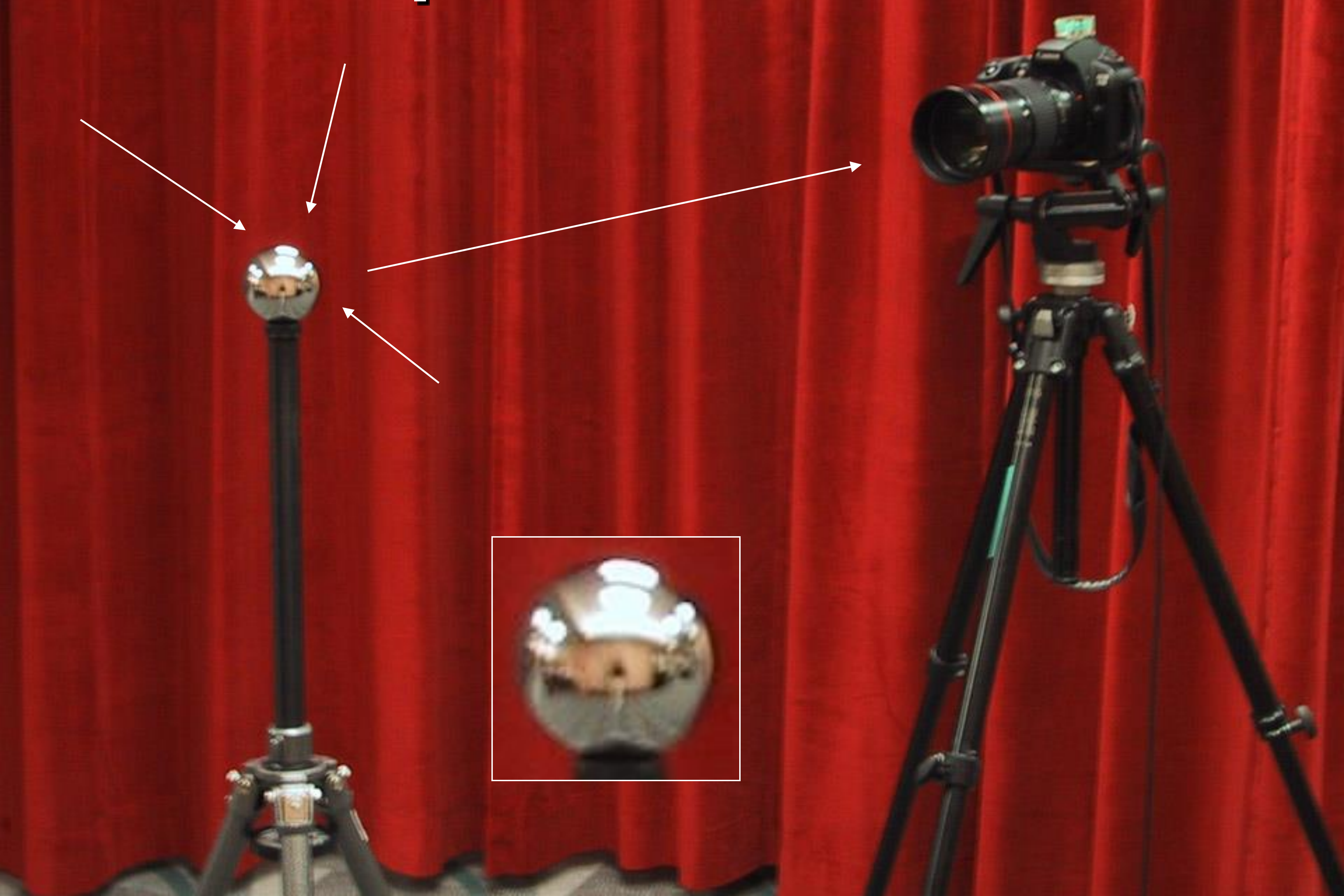


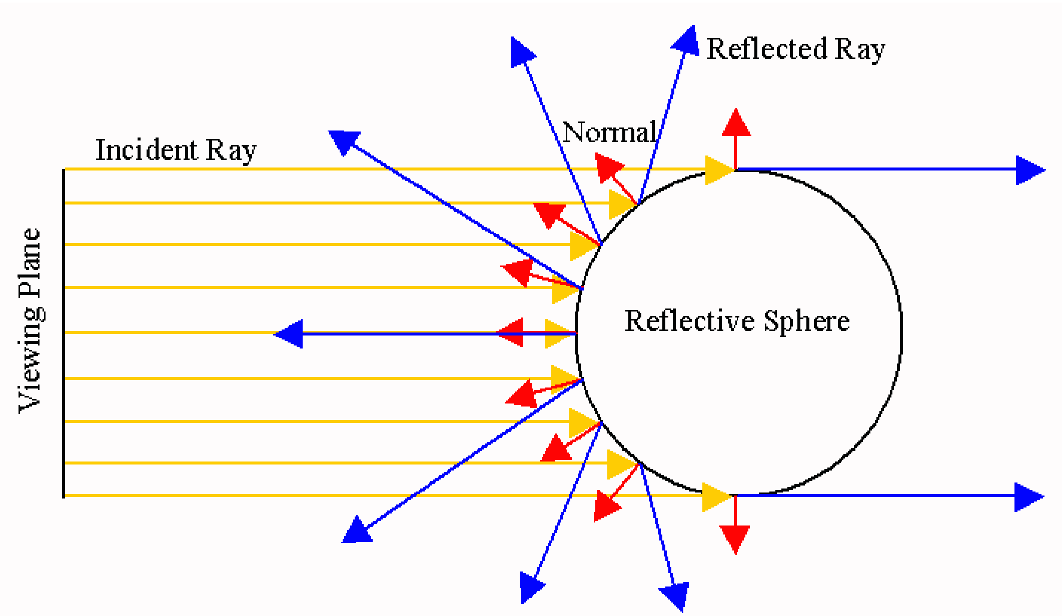
Spherical Map Example

Key ideas for Image-based Lighting

- Light probes: a way of capturing environment maps in real scenes

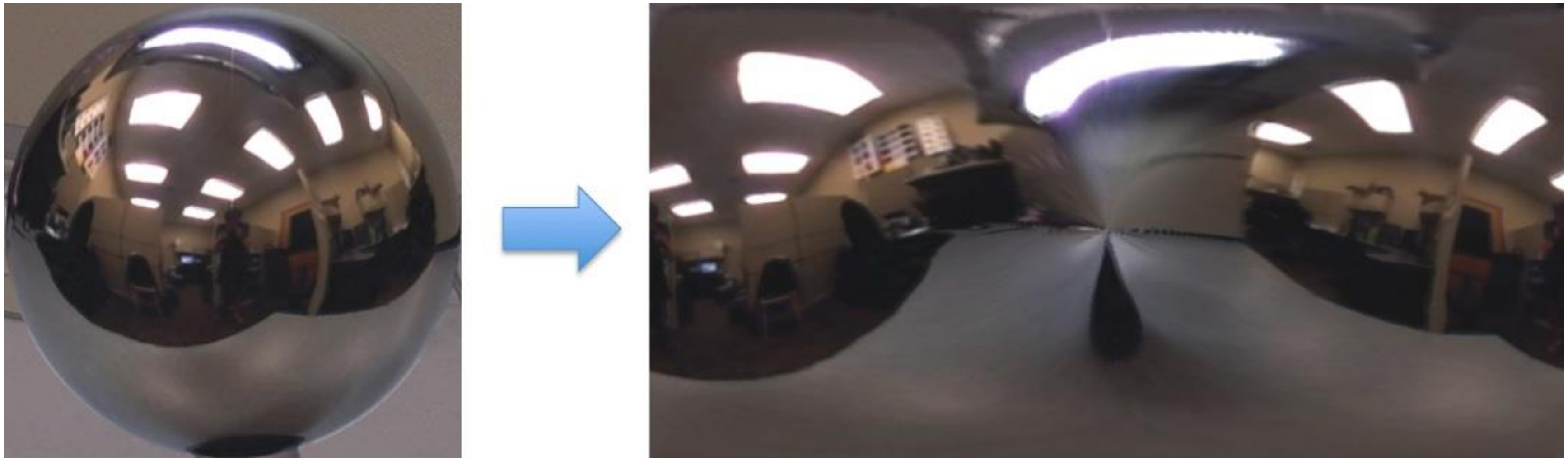
Mirrored Sphere





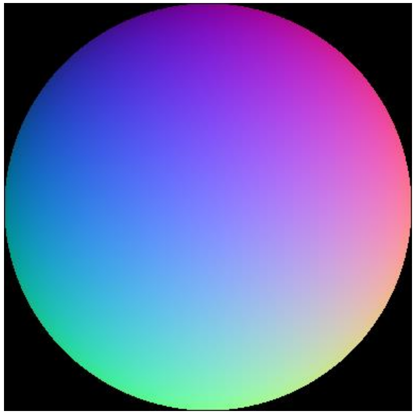
1) Compute normal of sphere from pixel position
2) Compute reflected ray direction from sphere normal
3) Convert to spherical coordinates (theta, phi)
4) Create equirectangular image

Mirror ball -> equirectangular

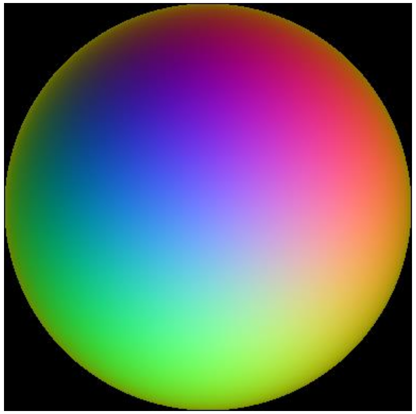


Mirror ball -> equirectangular

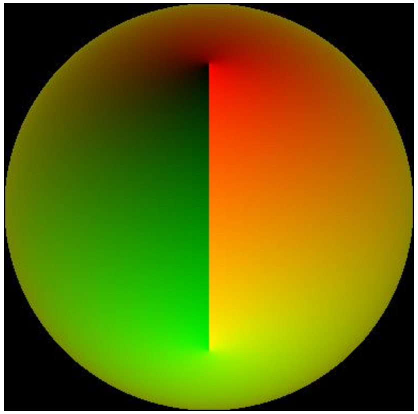
Mirror ball



Normals



Reflection vectors



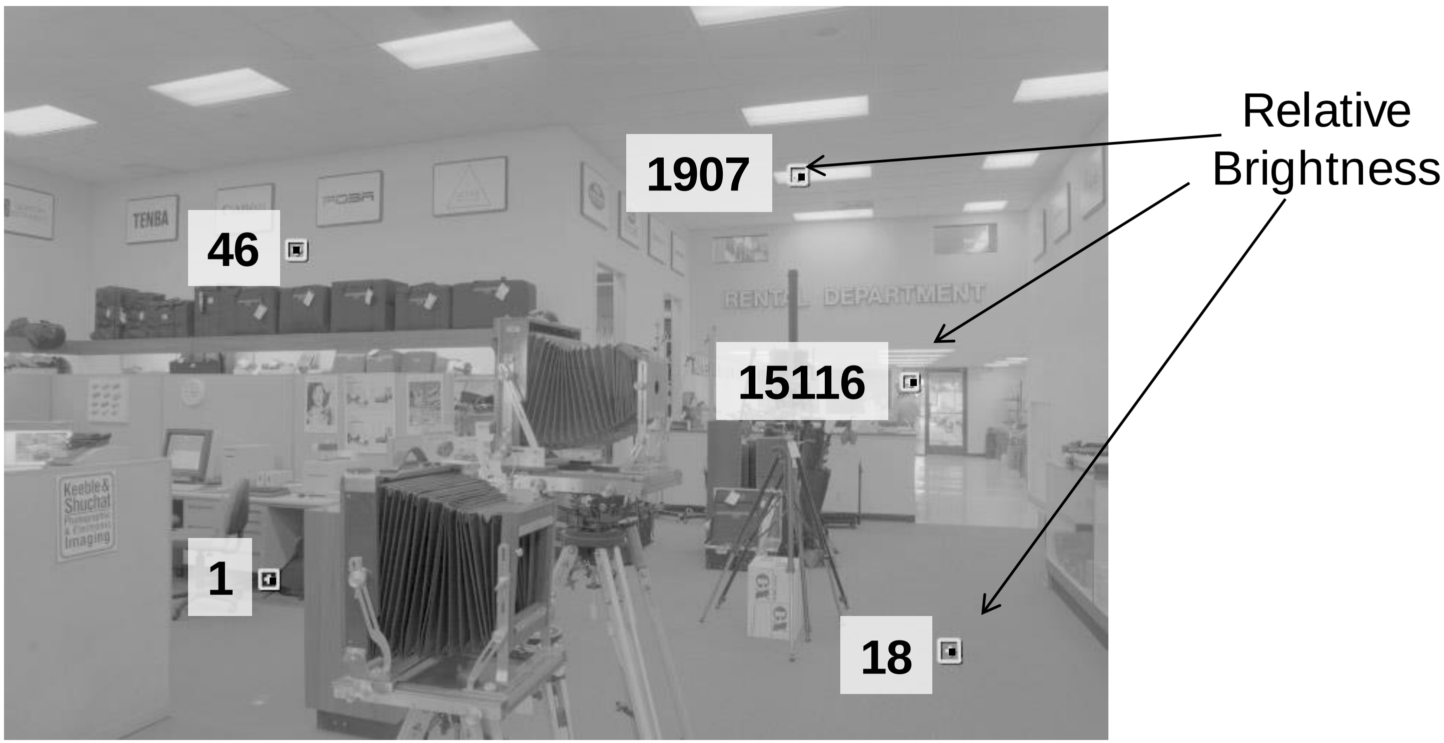
Phi/theta of reflection vecs

Equirectangular

Phi/theta equirectangular domain

One small snag

- How do we deal with light sources? Sun, lights, etc?
  - They are much, much brighter than the rest of the environment

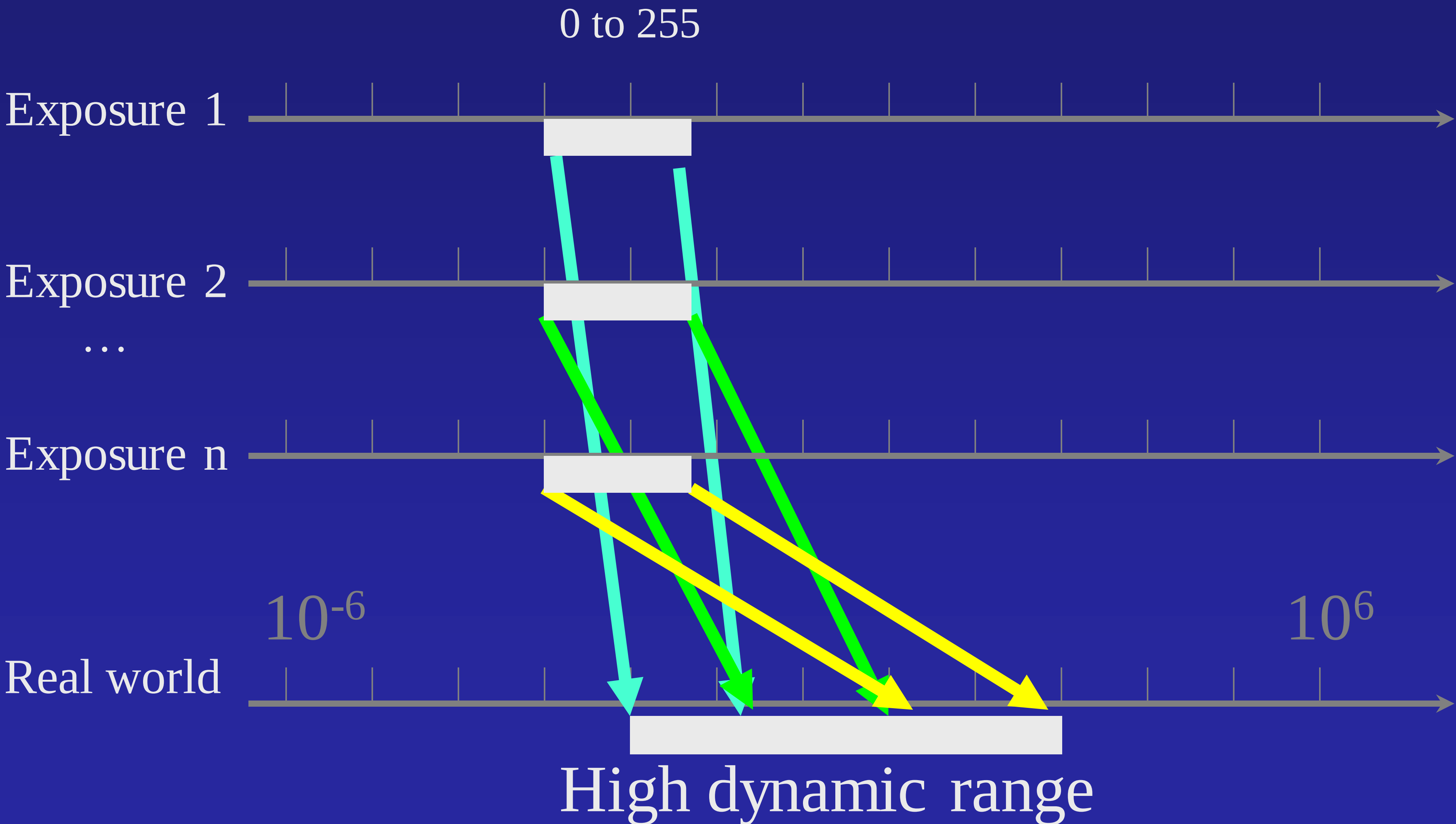


- Use High Dynamic Range photography!

Key ideas for Image-based Lighting

- Capturing HDR images: needed so that light probes capture full range of radiance

LDR->HDR by merging exposures



Ways to vary exposure

- Shutter Speed (*)
- F/stop (aperture, iris)


- Neutral Density (ND) Filters

Recovering High Dynamic Range Radiance Maps from Photographs

Paul Debevec
Jitendra Malik

Computer Science Division
University of California at Berkeley

August 1997

The Approach

- Get pixel values Z_{ij} for image with shutter time Δt_j (i^{th} pixel location, j^{th} image)
- Exposure is irradiance integrated over time:

$$E_{ij} = R_i \cdot \Delta t_j$$

- Pixel values are non-linearly mapped E_{ij}'s:

$$Z_{ij} = f(E_{ij}) = f(R_i \cdot \Delta t_j)$$

- Rewrite to form a (not so obvious) linear system:

$$\ln f^{-1}(Z_{ij}) = \ln(R_i) + \ln(\Delta t_j)$$

$$g(Z_{ij}) = \ln(R_i) + \ln(\Delta t_j)$$

The objective

Solve for radiance R and mapping g for each of 256 pixel values to minimize:

$$\sum_{i=1}^{N}\sum_{j=1}^{P} w(Z_{ij})\left[\ln R_i + \ln \Delta t_j - g(Z_{ij})\right]^2 + \lambda \sum_{z=Z_{min}}^{Z_{max}} w(z) g''(z)^2$$

give pixels near 0 or 255 less weight

known shutter time for image j

exposure should smoothly increase as pixel intensity increases

irradiance at particular pixel site is the same for each image

exposure, as a function of pixel value

Matlab Code

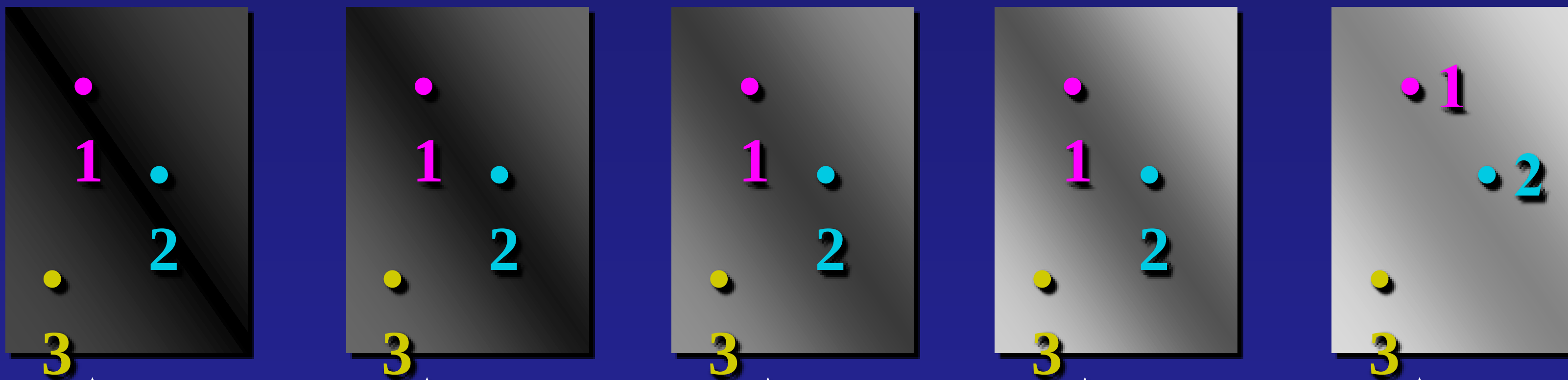
```
%
% gsolve.m - Solve for imaging system response function
%
% Given a set of pixel values observed for several pixels in several
% images with different exposure times, this function returns the
% imaging system's response function g as well as the log film irradiance
% values for the observed pixels.
%
% Assumes:
%
%  Zmin = 0
%  Zmax = 255
%
% Arguments:
%
%  Z(i,j) is the pixel values of pixel location number i in image j
%  B(j)   is the log delta t, or log shutter speed, for image j
%  l      is lamdba, the constant that determines the amount of smoothness
%  w(z)   is the weighting function value for pixel value z
%
% Returns:
%
%  g(z)   is the log exposure corresponding to pixel value z
%  lE(i)  is the log film irradiance at pixel location i
%

function [g,lE]=gsolve(Z,B,l,w)

n = 256;

A = zeros(size(Z,1)*size(Z,2)+n+1,n+size(Z,1));
b = zeros(size(A,1),1);

%% Include the data-fitting equations

k = 1;
for i=1:size(Z,1)
  for j=1:size(Z,2)
    wij = w(Z(i,j)+1);
    A(k,Z(i,j)+1) = wij;  A(k,n+i) = -wij;       b(k,1) = wij * B(i,j);
    k=k+1;
  end
end

%% Fix the curve by setting its middle value to 0

A(k,129) = 1;
k=k+1;

%% Include the smoothness equations

for i=1:n-2
  A(k,i)=l*w(i+1);        A(k,i+1)=-2*l*w(i+1);  A(k,i+2)=l*w(i+1);
  k=k+1;
end

%% Solve the system using SVD

x = A\b;

g = x(1:n);
lE = x(n+1:size(x,1));
```

Matlab Code

```
function [g,lE]=gsolve(Z,B,l,w)

n = 256;
A = zeros(size(Z,1)*size(Z,2)+n+1,n+size(Z,1));
b = zeros(size(A,1),1);

k = 1;                      %% Include the data-fitting equations
for i=1:size(Z,1)
  for j=1:size(Z,2)
    wij = w(Z(i,j)+1);
    A(k,Z(i,j)+1) = wij; A(k,n+i) = -wij; b(k,1) = wij * B(j);
    k=k+1;
  end
end

A(k,129) = 1;               %% Fix the curve by setting its middle value to 0
k=k+1;

for i=1:n-2                 %% Include the smoothness equations
  A(k,i)=l*w(i+1); A(k,i+1)=-2*l*w(i+1); A(k,i+2)=l*w(i+1);
  k=k+1;
end

x = A\b;                    %% Solve the system using pseudoinverse

g = x(1:n);
lE = x(n+1:size(x,1));
```

Illustration

Image series



Δt = 1/64 sec | Δt = 1/16 sec | Δt = 1/4 sec | Δt = 1 sec | Δt = 4 sec

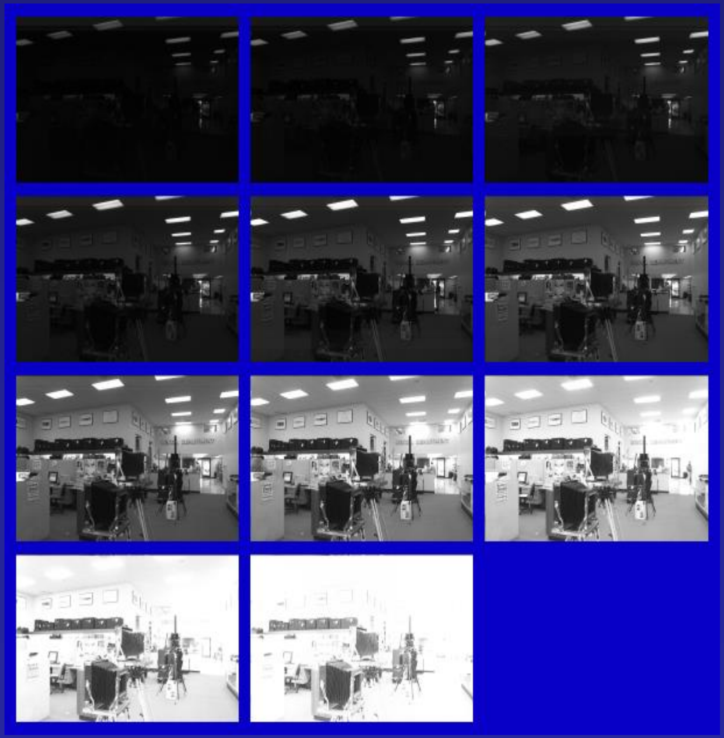
$$\text{Pixel Value } Z = f(\text{Exposure})$$

$$\text{Exposure} = \text{Radiance} * \Delta t$$

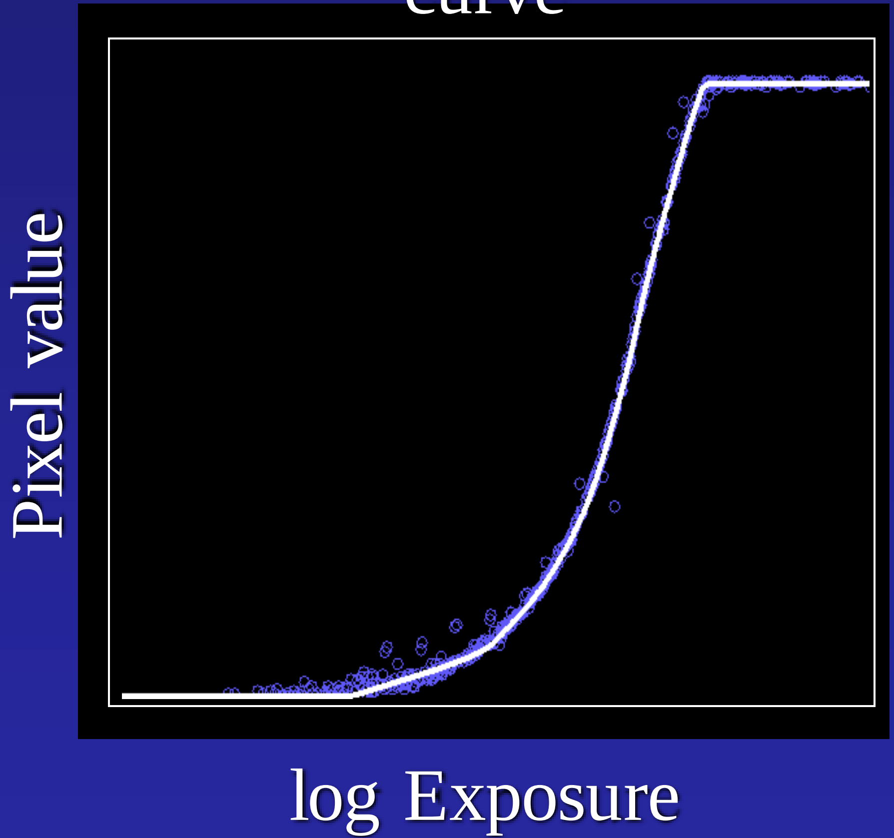
$$\log \text{Exposure} = \log \text{Radiance} + \log \Delta t$$

Results: Digital Camera

Kodak DCS460
1/30 to 30 sec



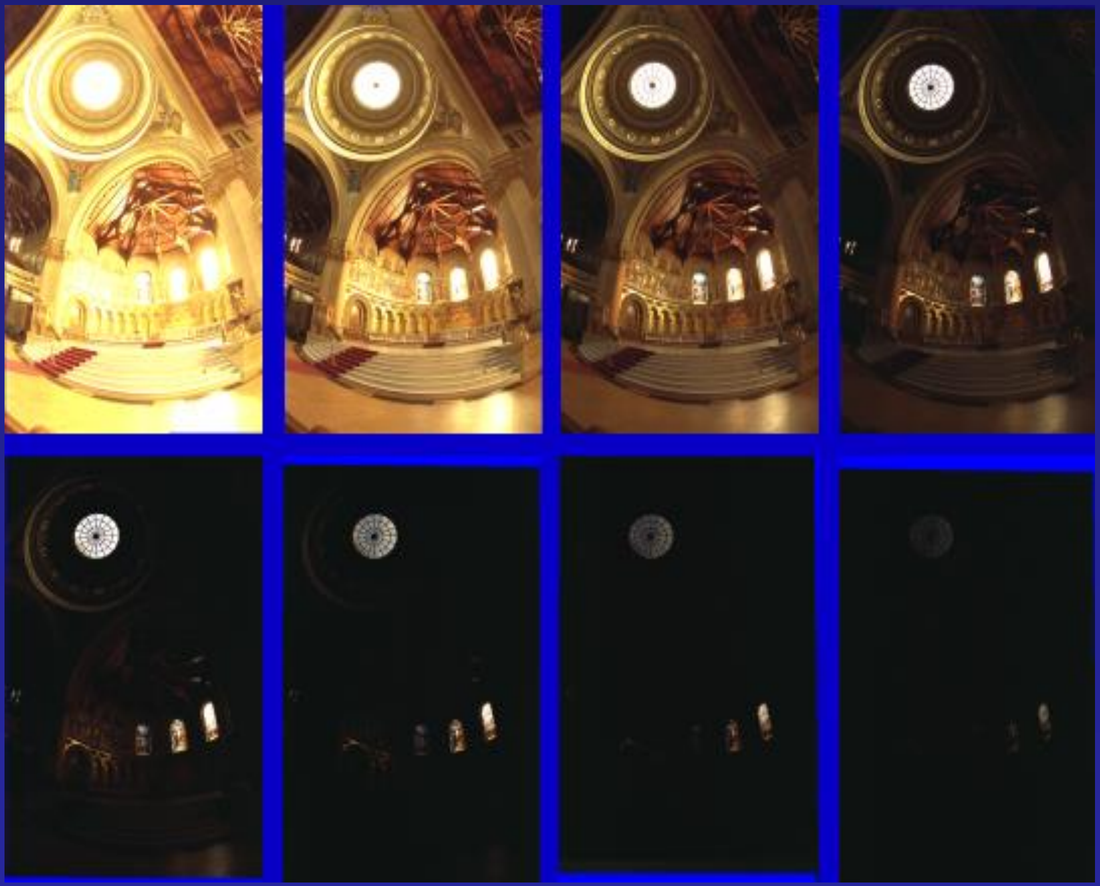
Recovered response curve



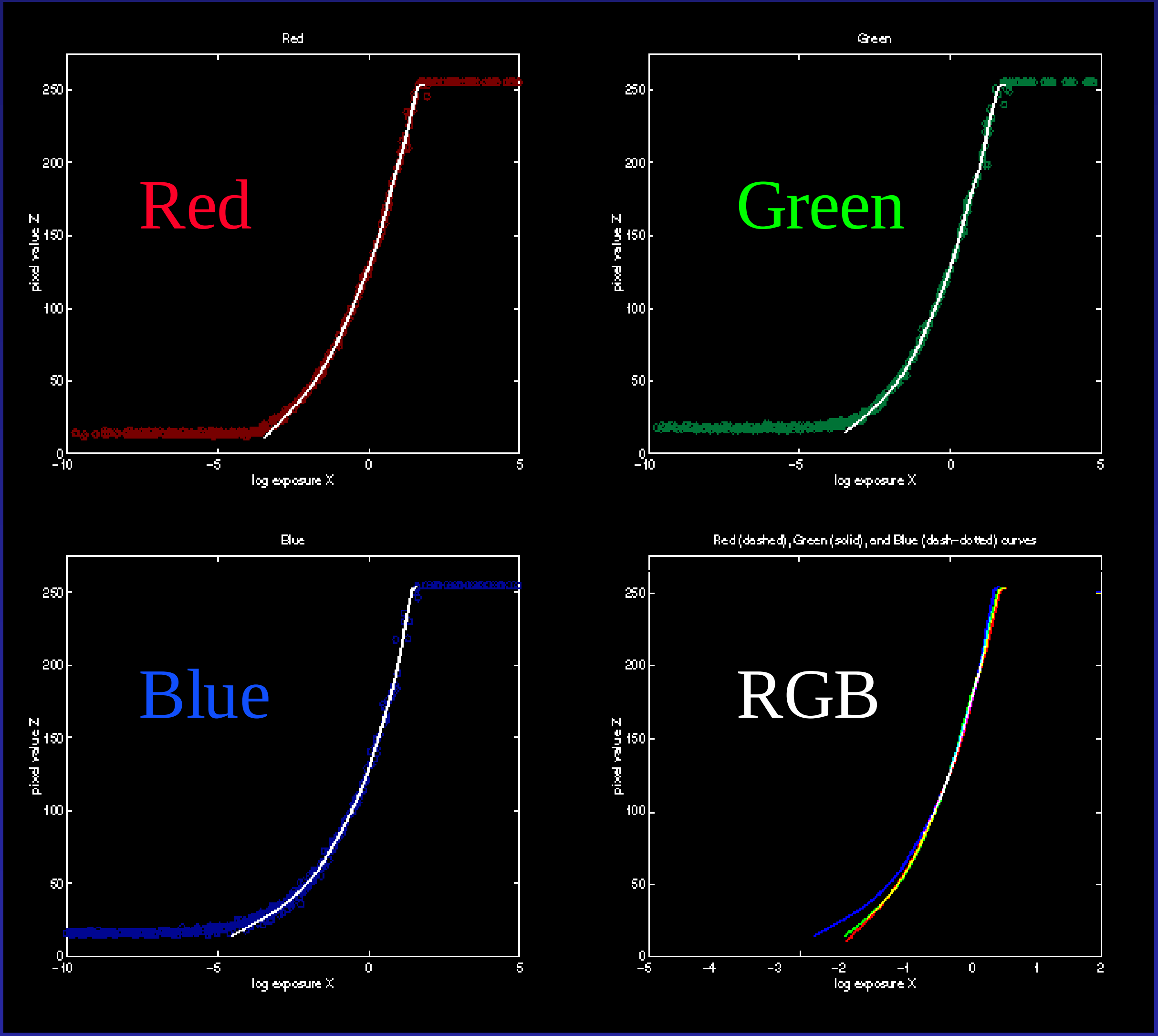
Reconstructed radiance map

Results: Color Film

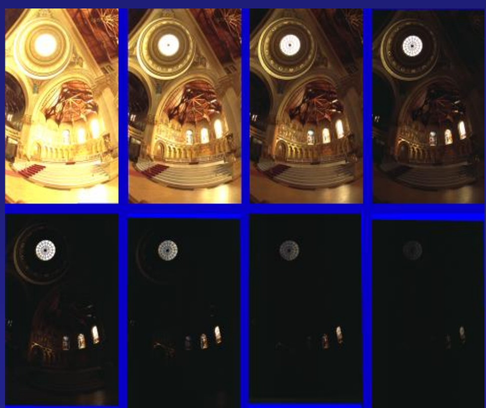
- Kodak Gold ASA 100, PhotoCD

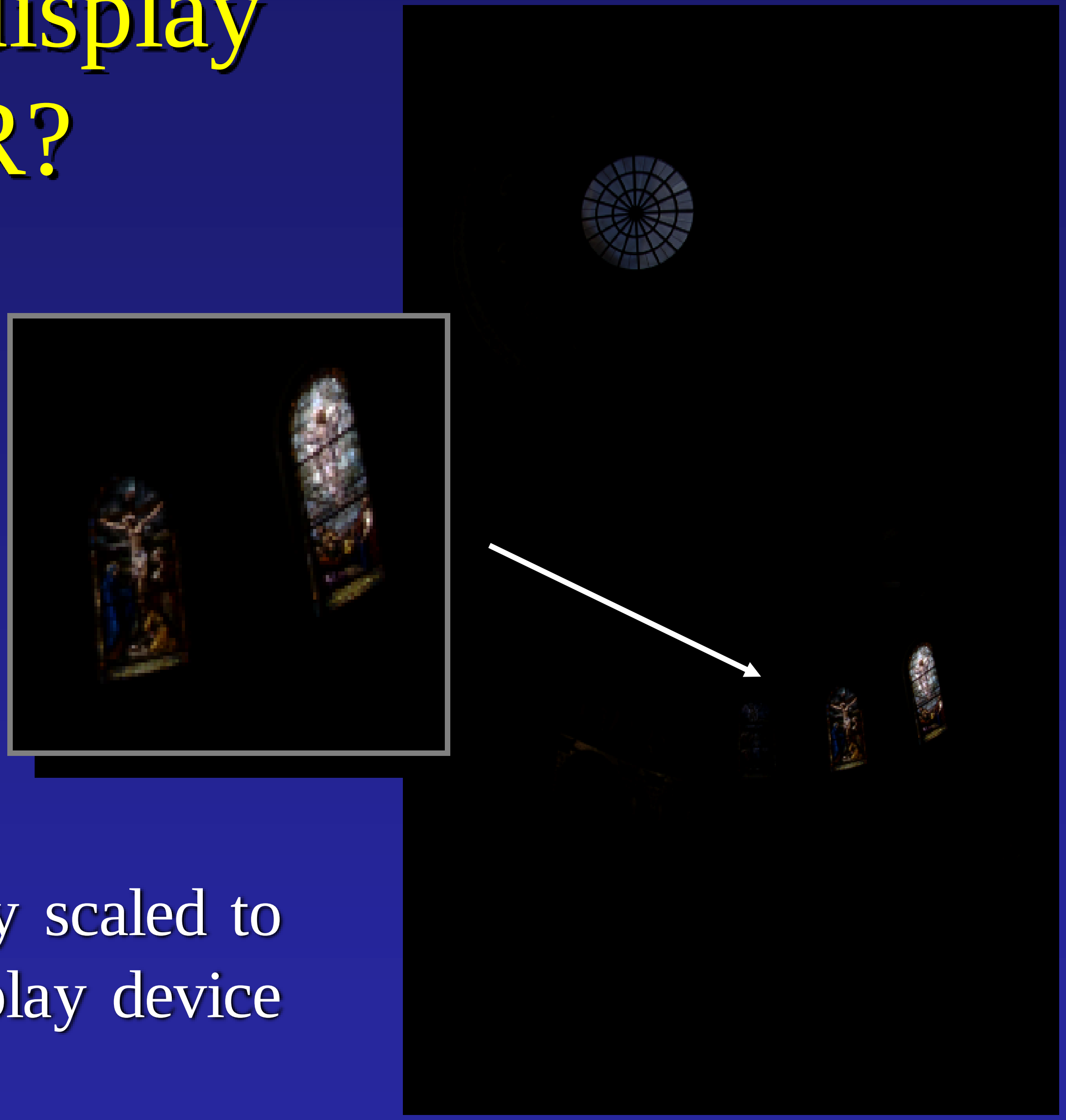


Recovered Response Curves



How to display HDR?

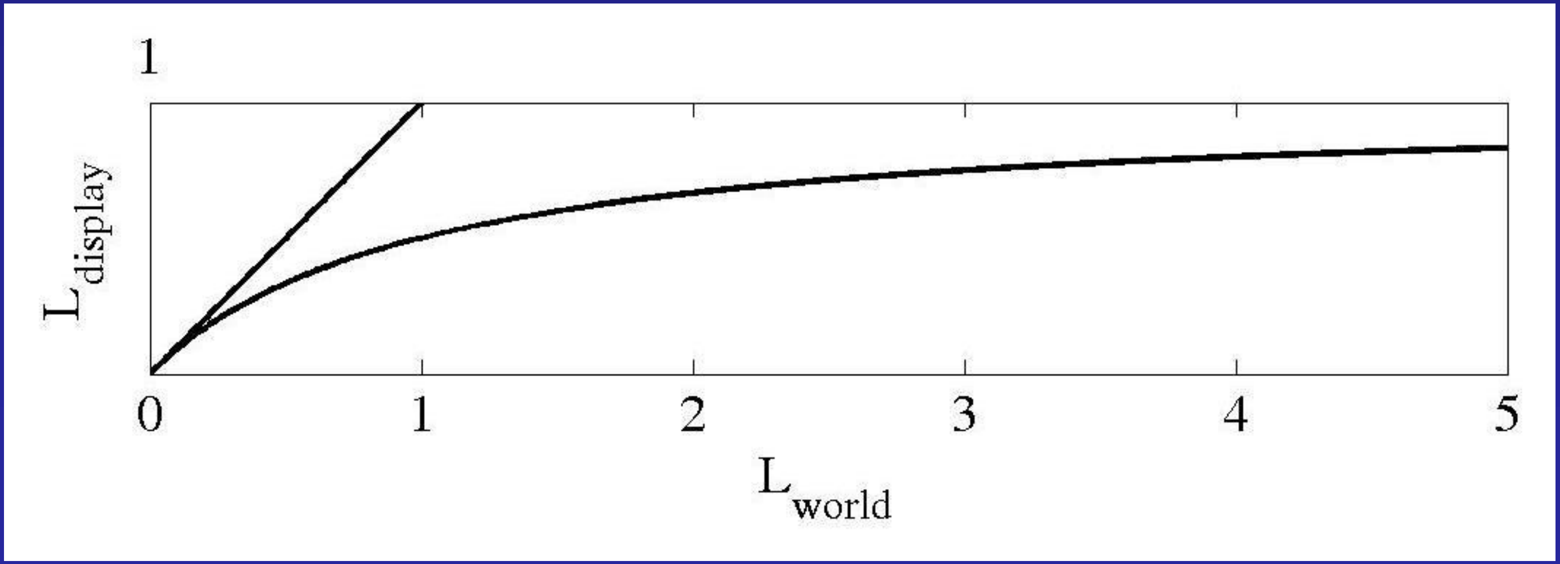




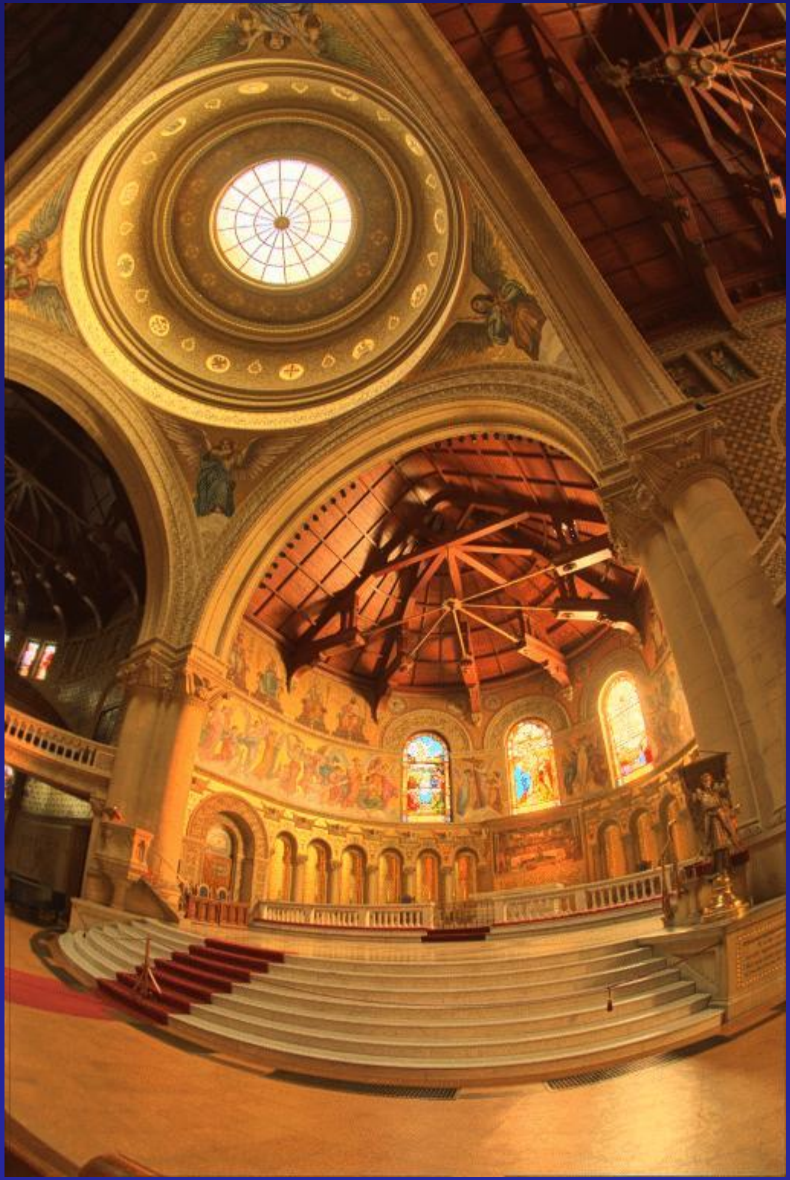
Linearly scaled to display device

Global Operator (Reinhart et al)

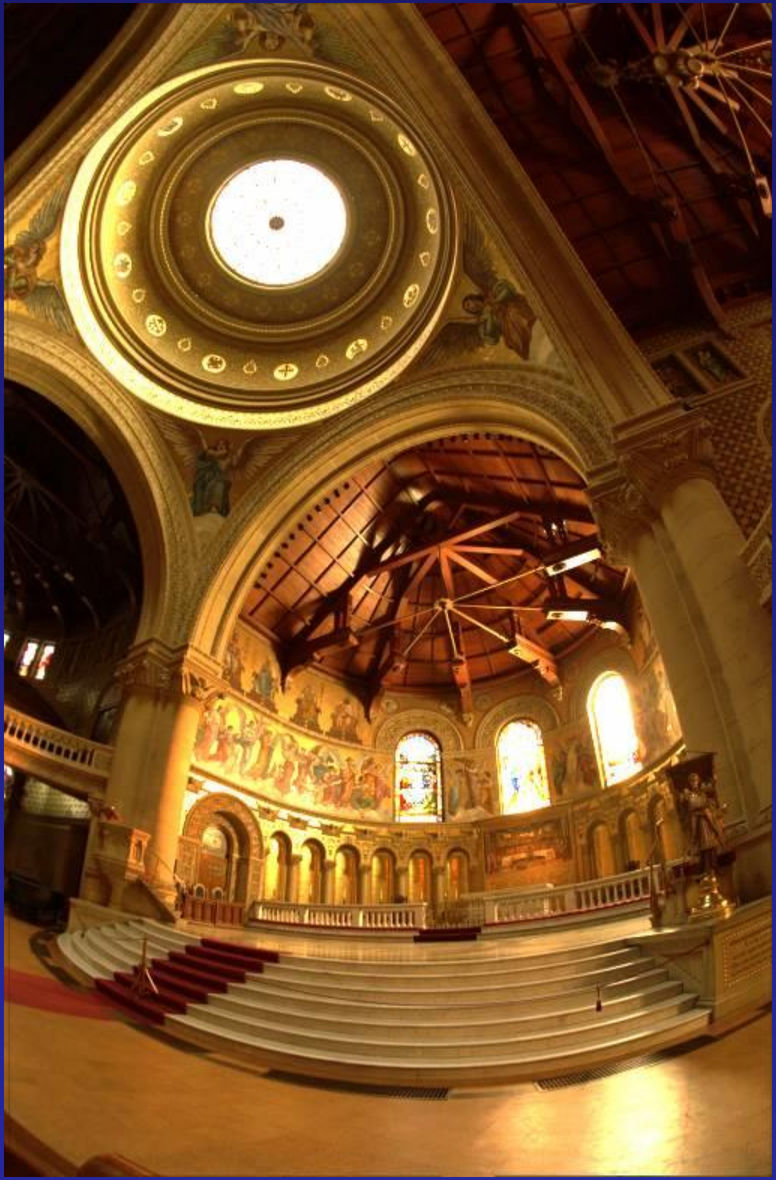
$$L_{display} = \frac{L_{world}}{1 + L_{world}}$$



Global Operator Results

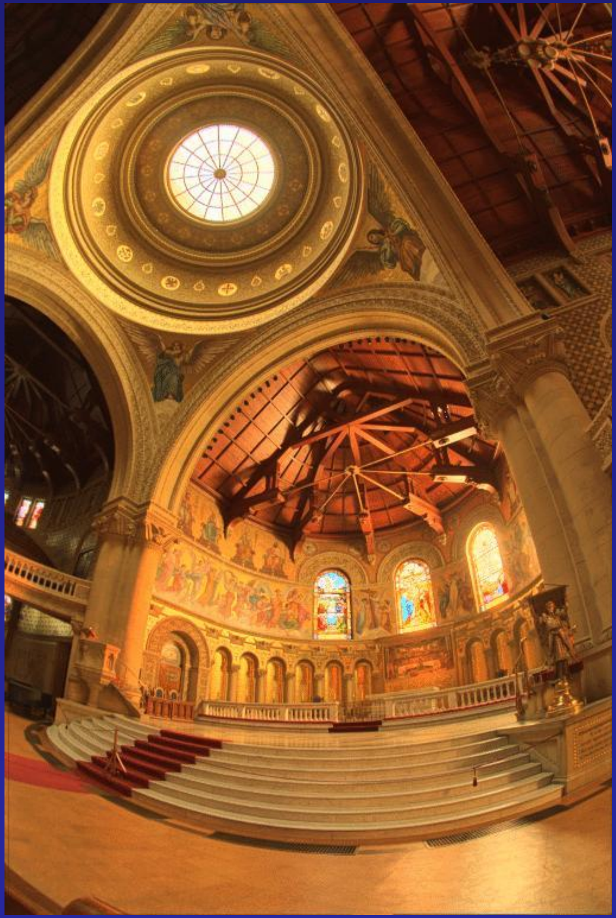


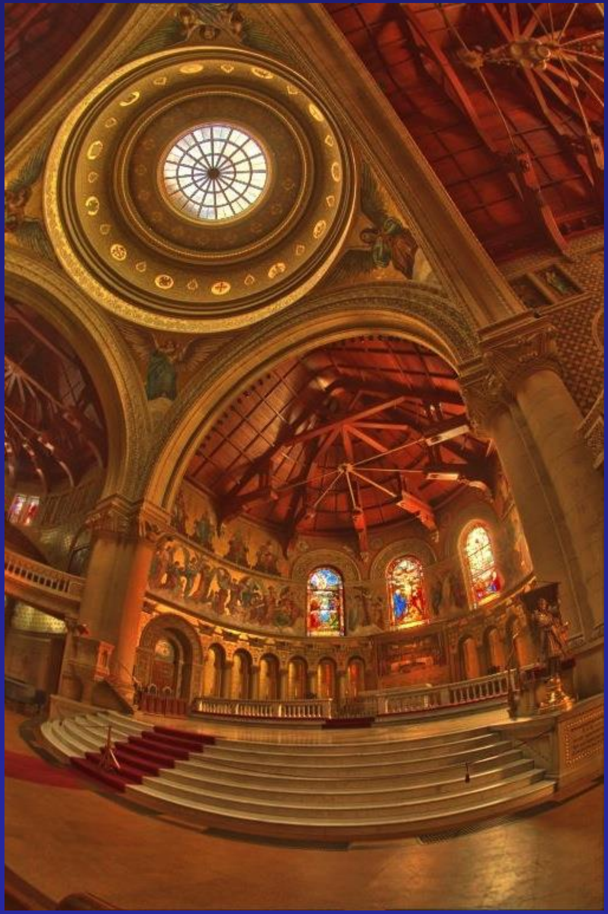
Reinhart Operator



Darkest 0.1% scaled to display device

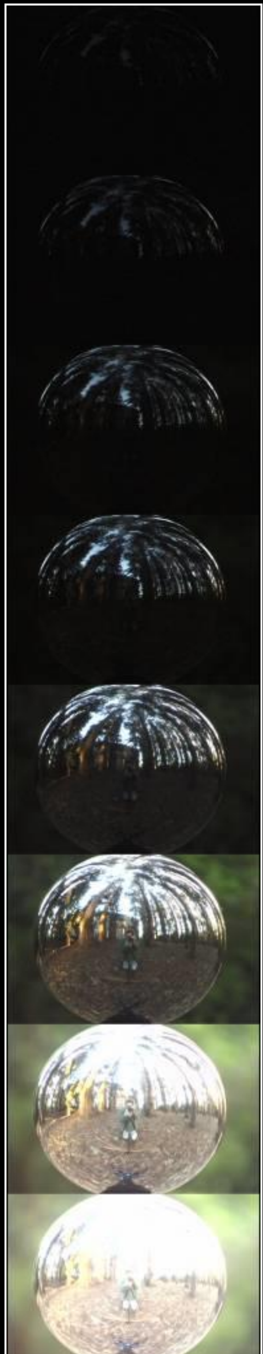
Local operator



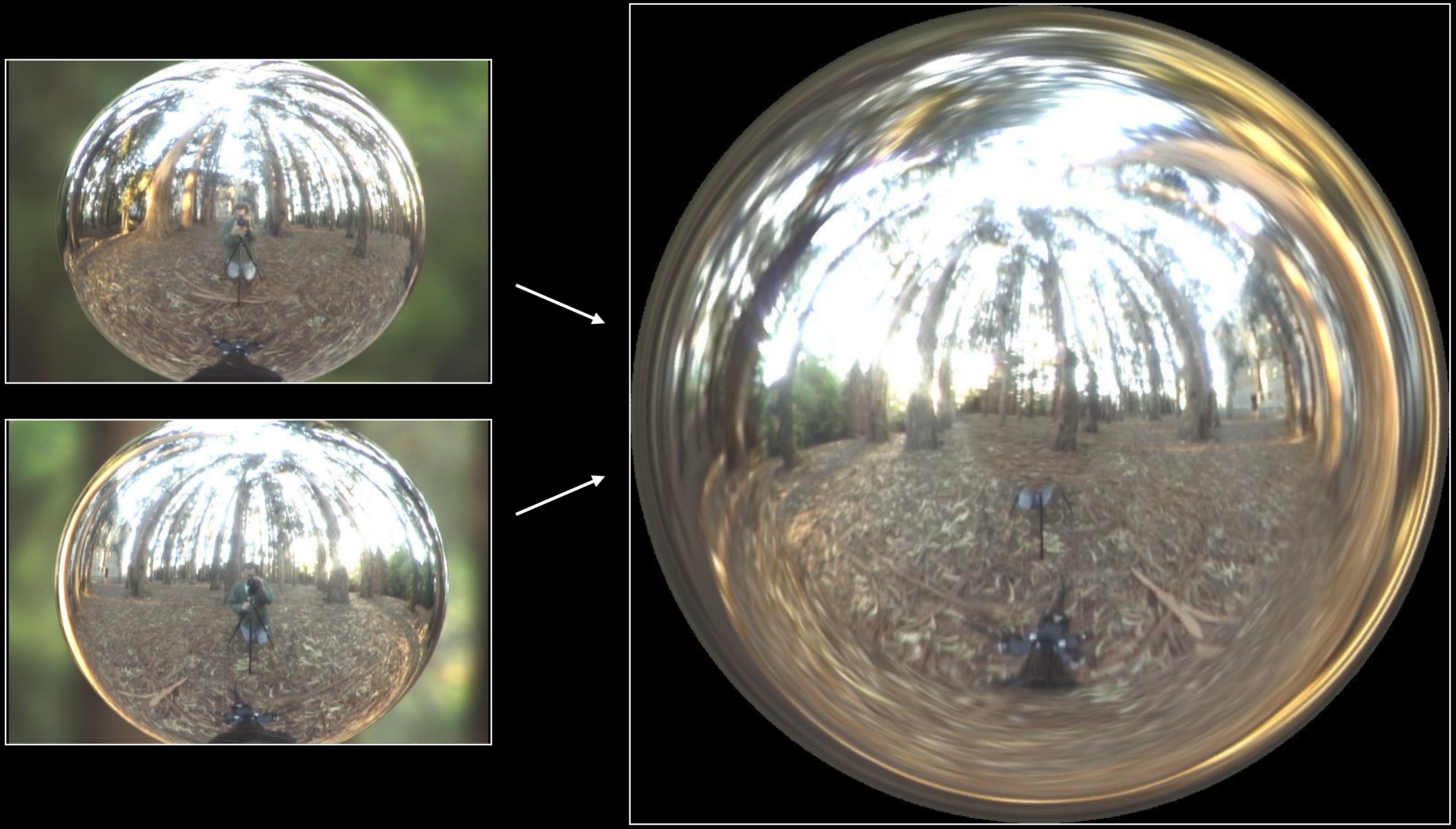


http://people.csail.mit.edu/fredo/PUBLI/Siggraph2002/DurandBilateral.pdf

Acquiring the Light Probe



Assembling the Light Probe

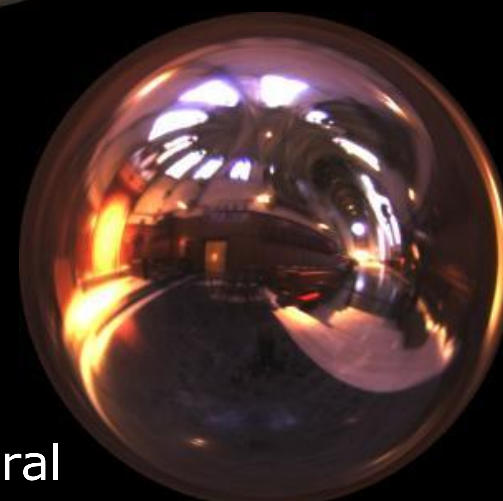


Real-World HDR Lighting Environments

Funston Beach

Eucalyptus Grove

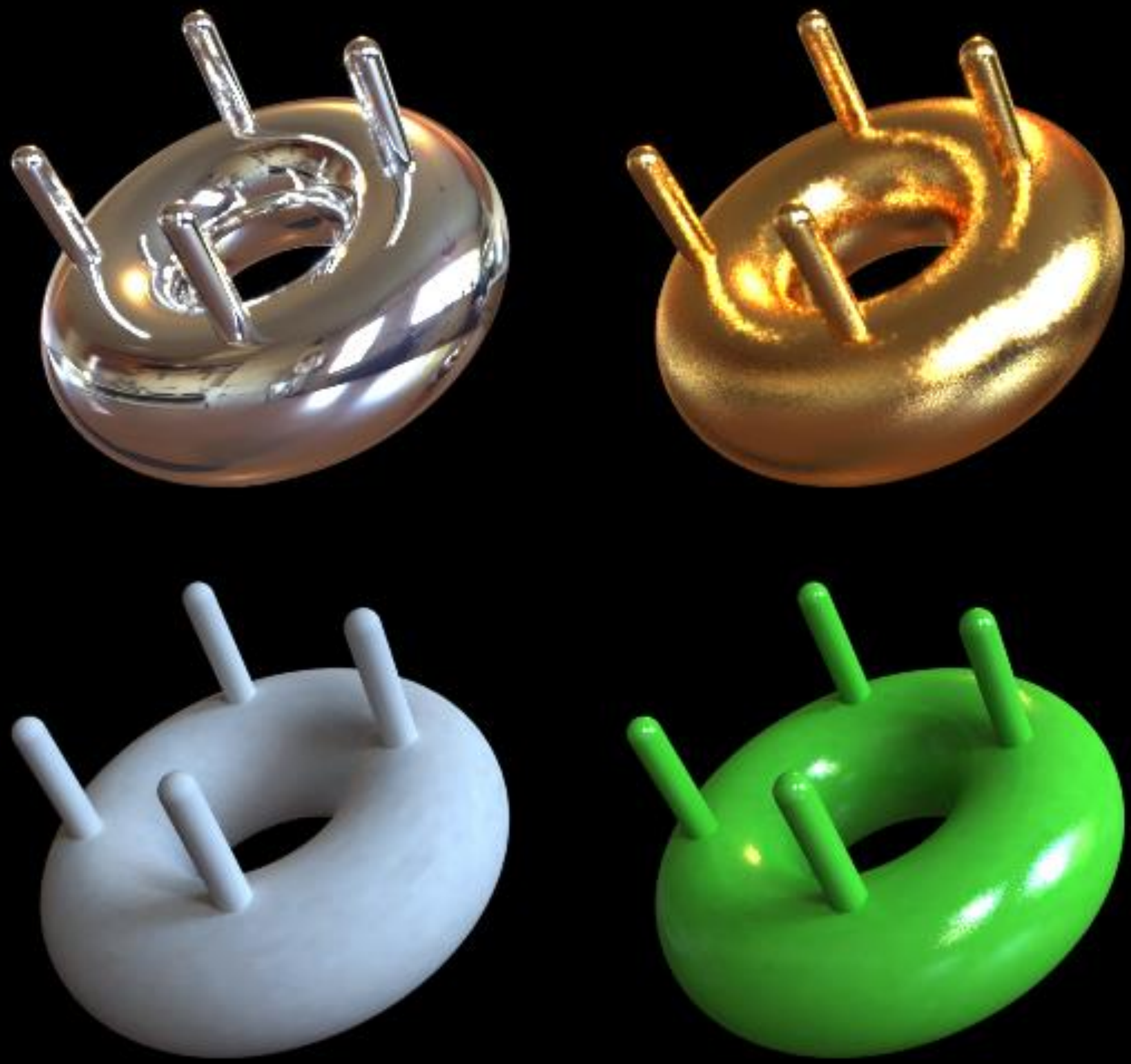
Uffizi Gallery



Grace Cathedral

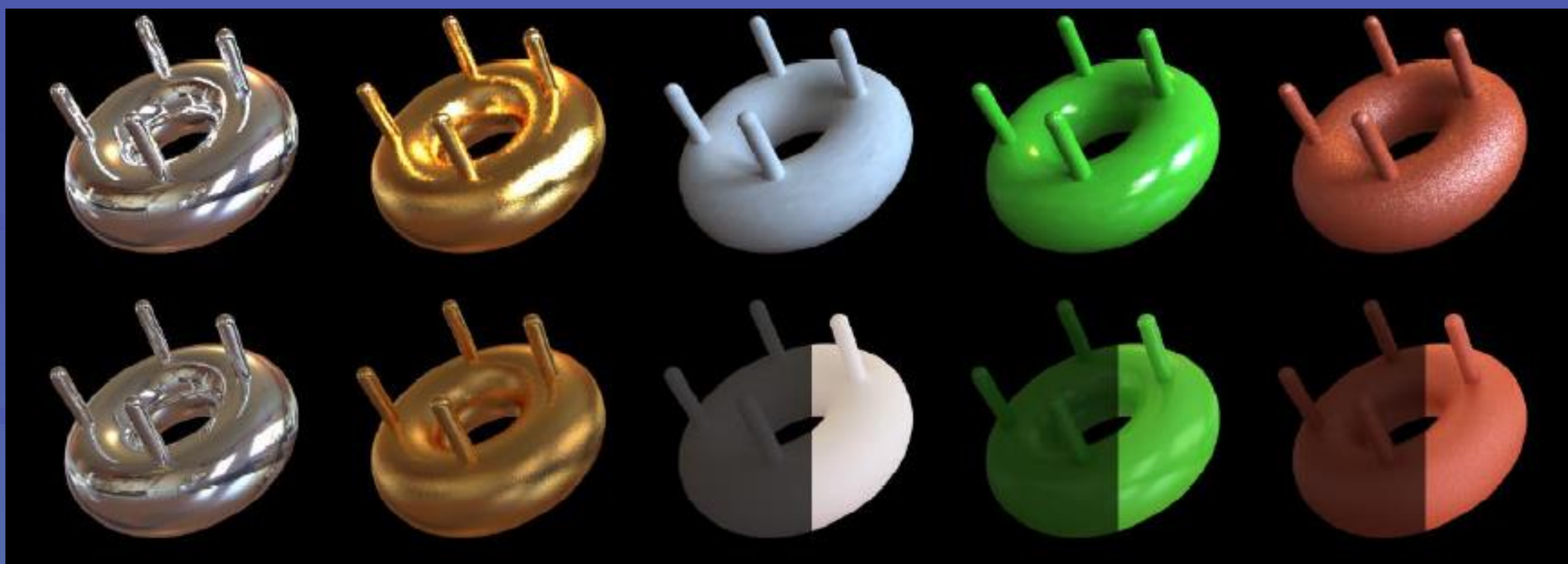
Lighting Environments from the Light Probe Image Gallery:
http://www.debevec.org/Probes/

Illumination Results

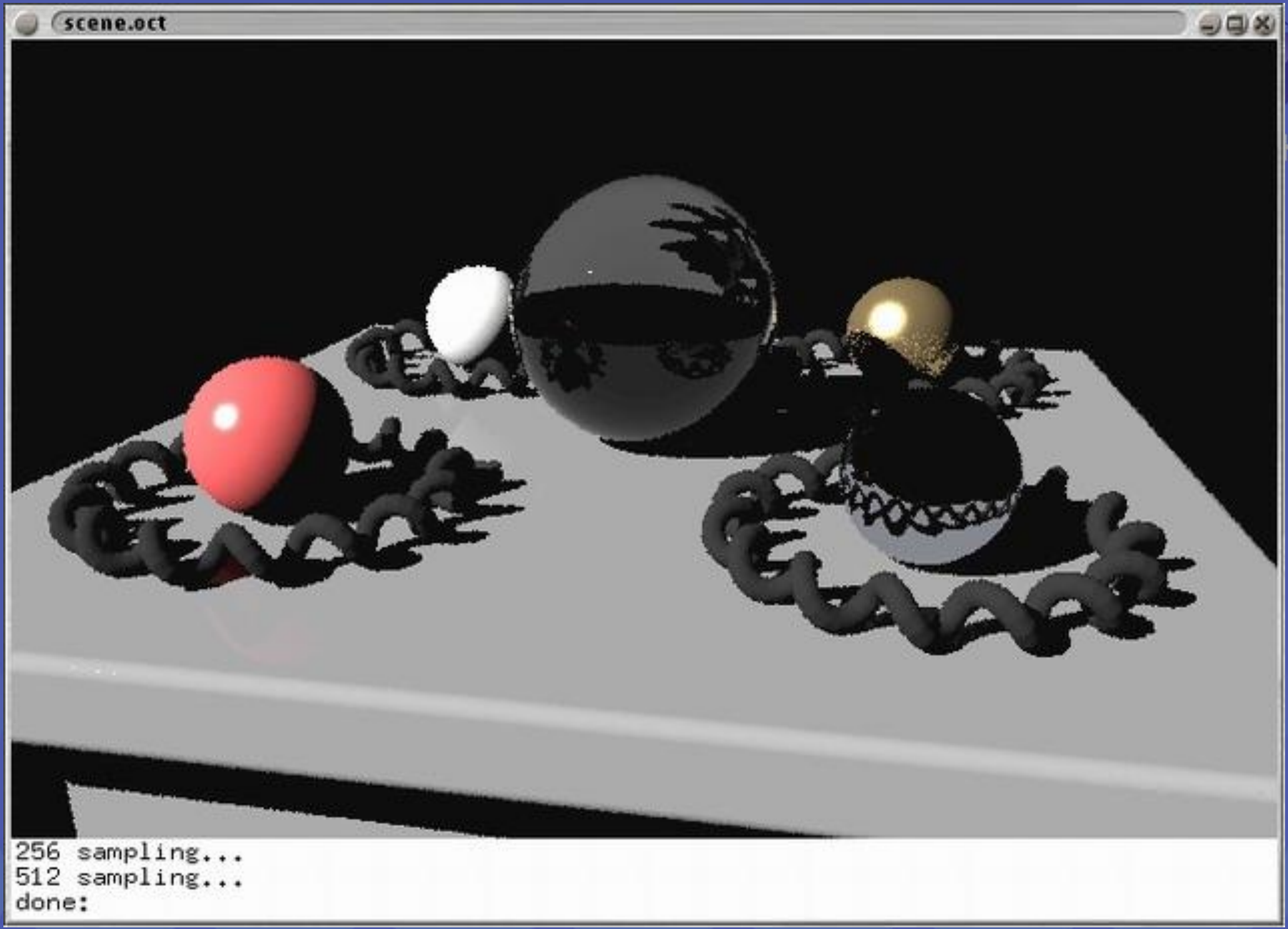


Comparison: Radiance map versus single image

HDR



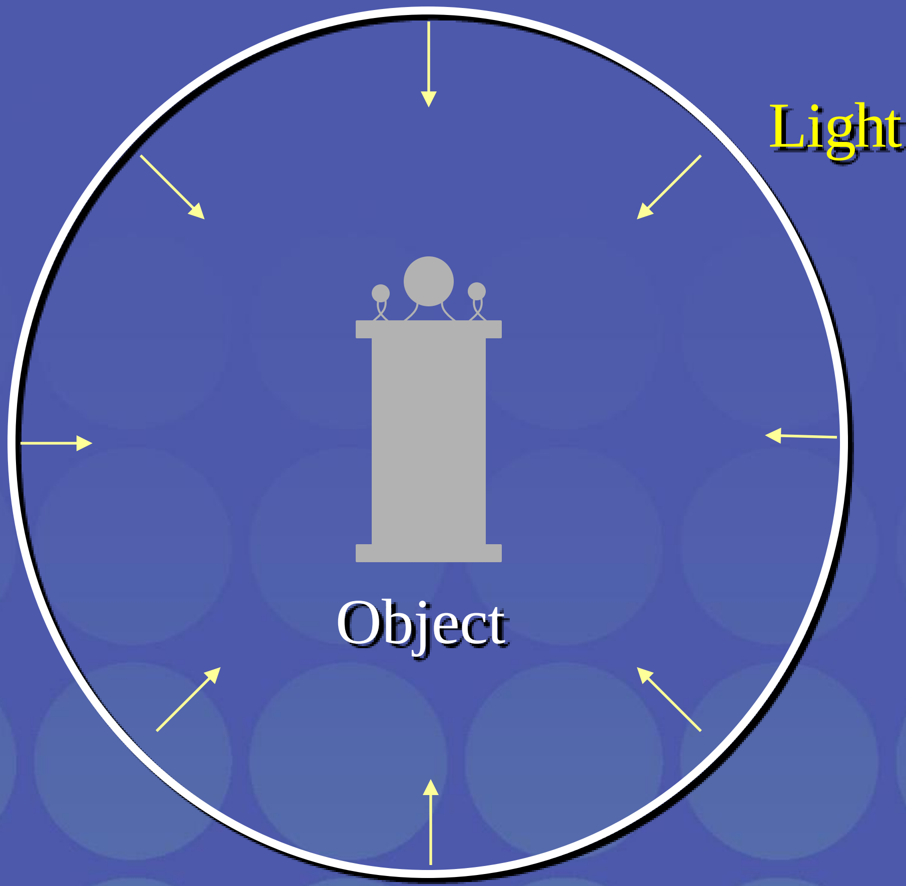
LDR



CG Objects Illuminated by a Traditional CG Light Source

Illuminating Objects using Measurements of Real Light

SIGGRAPH2004



Environment assigned "glow" material property in Greg Ward's RADIANCE system.

http://radsite.lbl.gov/radiance/

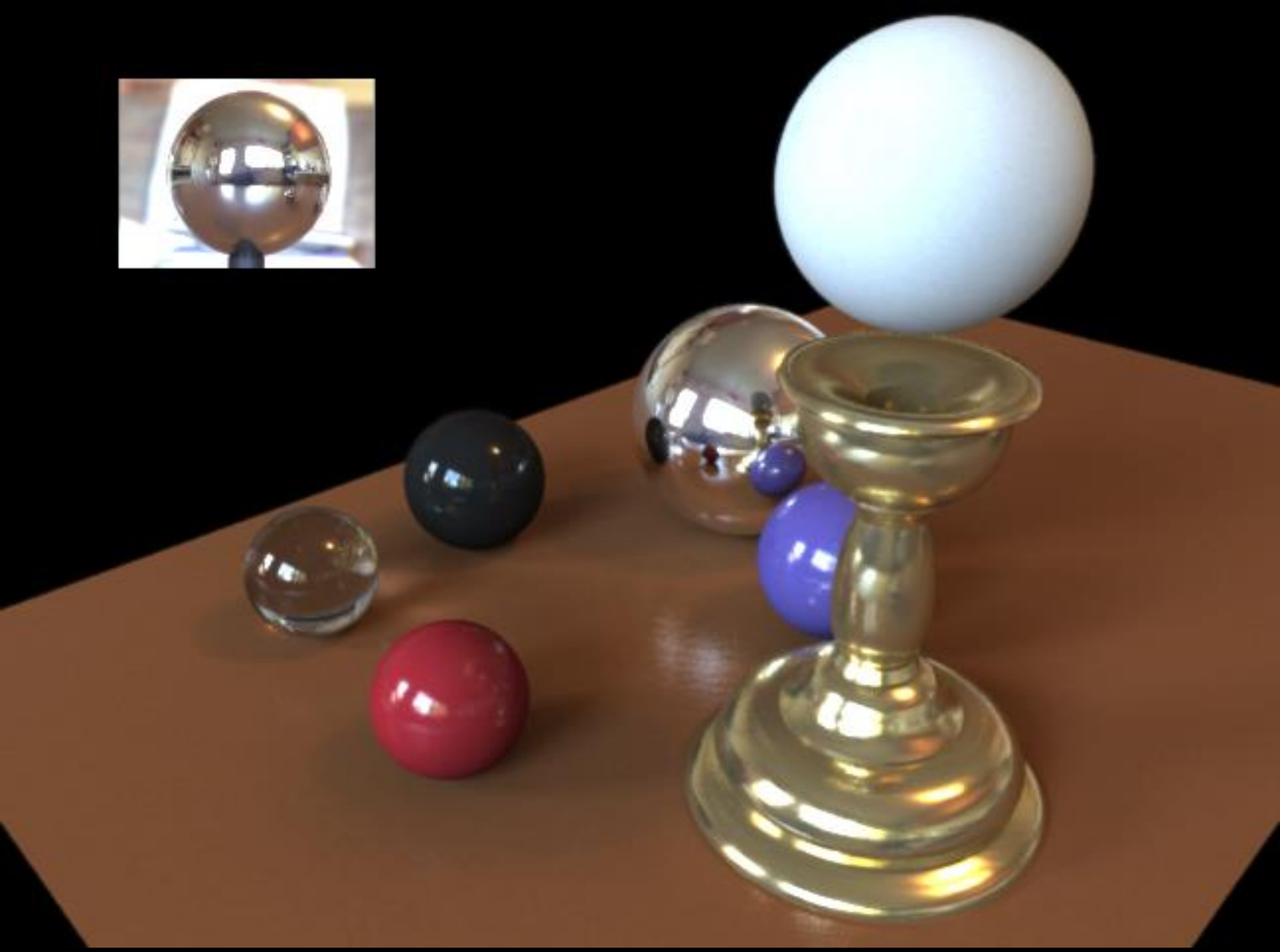
Paul Debevec. A Tutorial on Image-Based Lighting. IEEE Computer Graphics and Applications, Jan/Feb 2002.

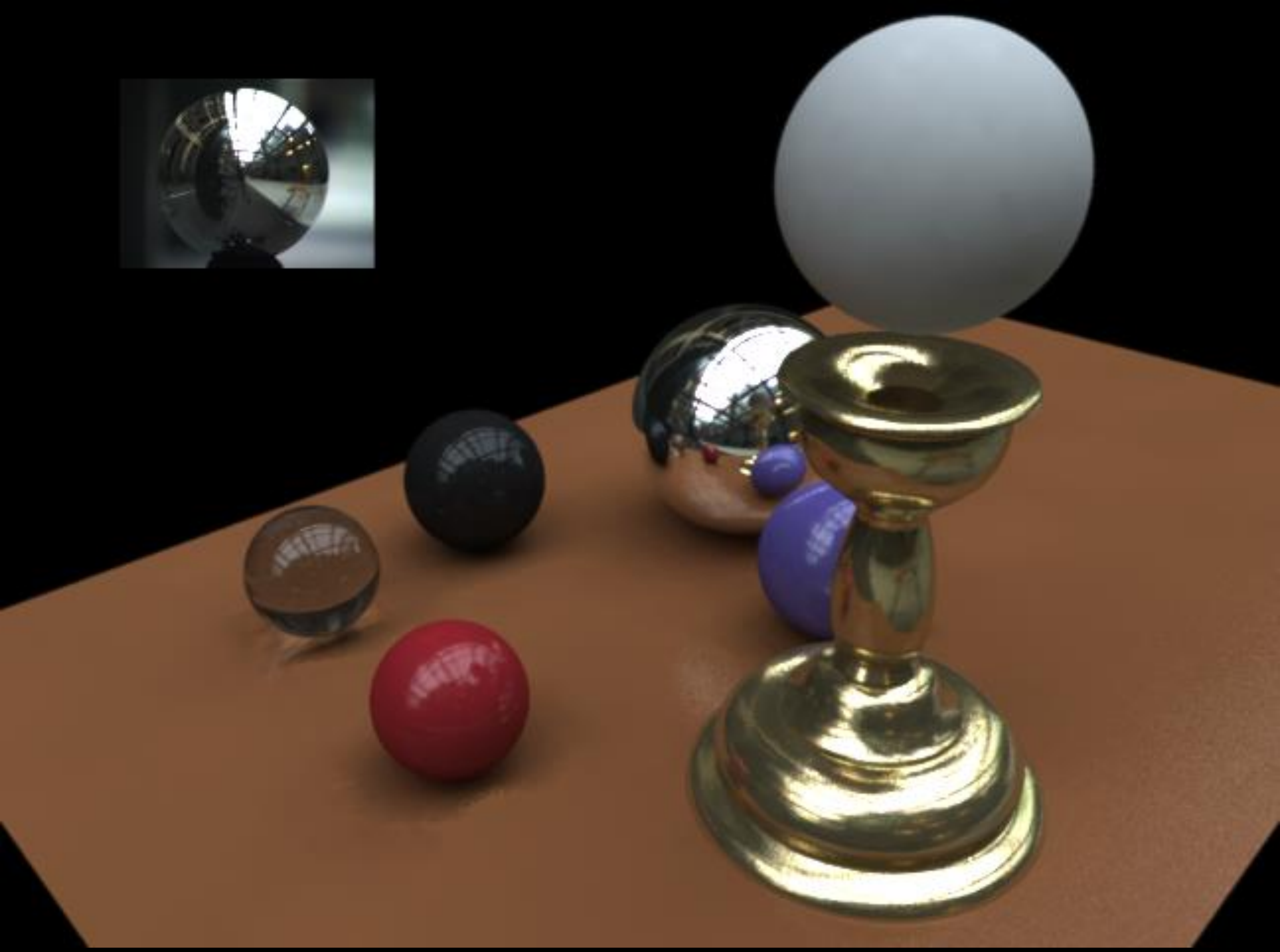
Rendering with Natural Light

SIGGRAPH 98 Electronic Theater

Movie

- http://www.youtube.com/watch?v=EHBgkeXH9lU





We can now illuminate
synthetic objects with **real light**.

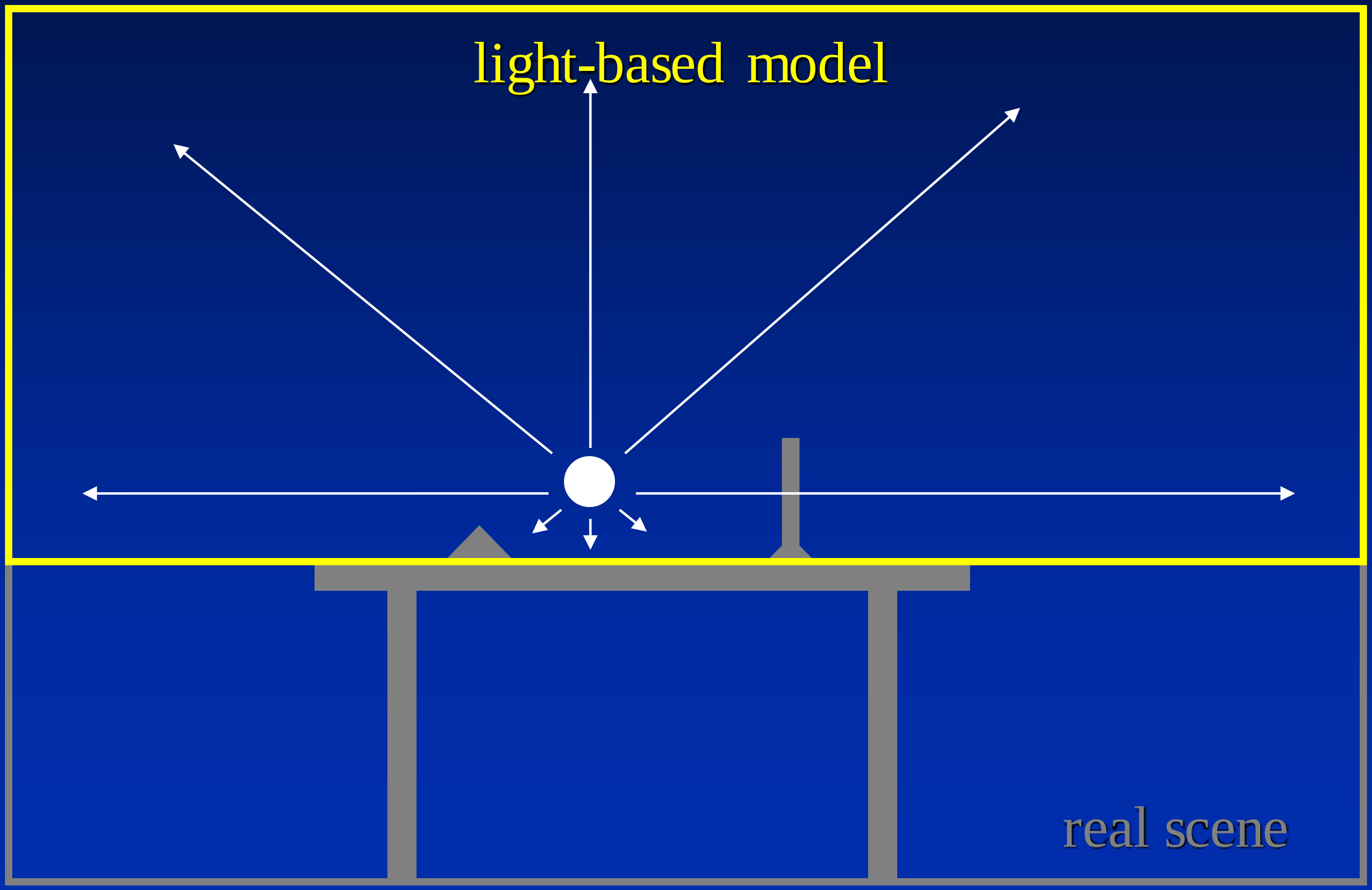
- Environment map
- Light probe
- HDR
- Ray tracing

How do we add synthetic objects to a **real scene**?

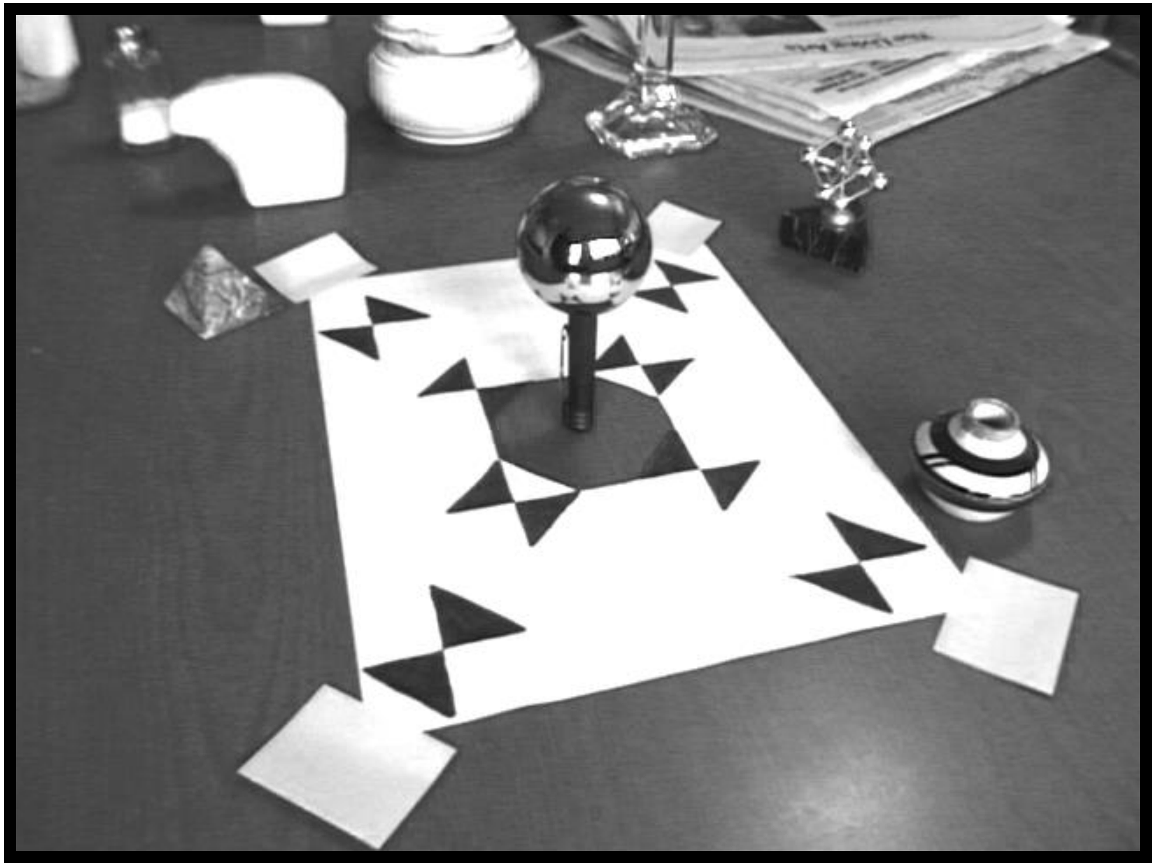
Real Scene Example

Goal: place synthetic objects on table

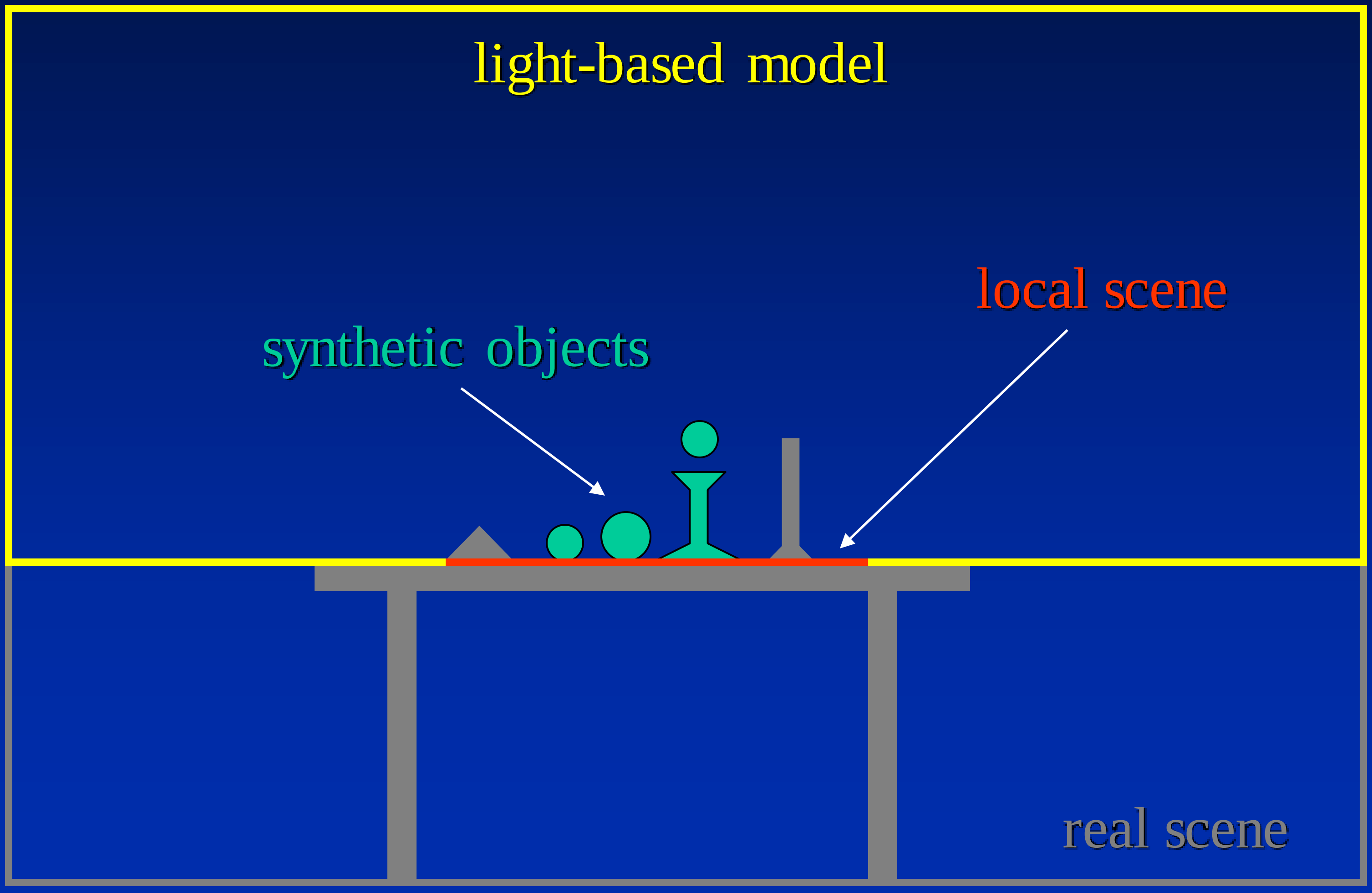
Modeling the Scene



Light Probe / Calibration Grid



Modeling the Scene



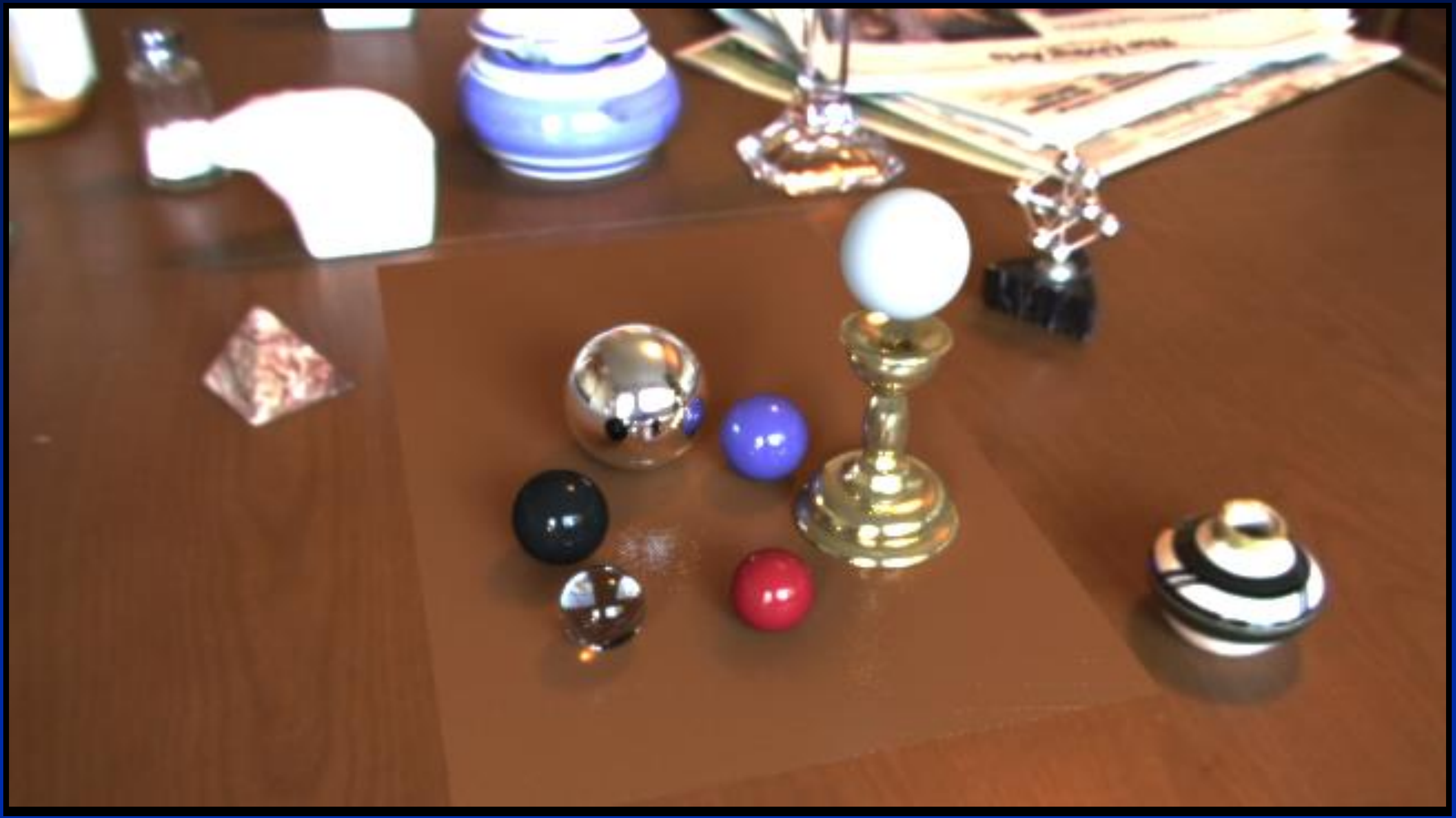
Rendering into the Scene

Background Image

Differential Rendering

Local scene w/o objects, illuminated by model

Rendering into the Scene



Objects and Local Scene matched to Scene

Differential Rendering
Difference in local scene

-

=

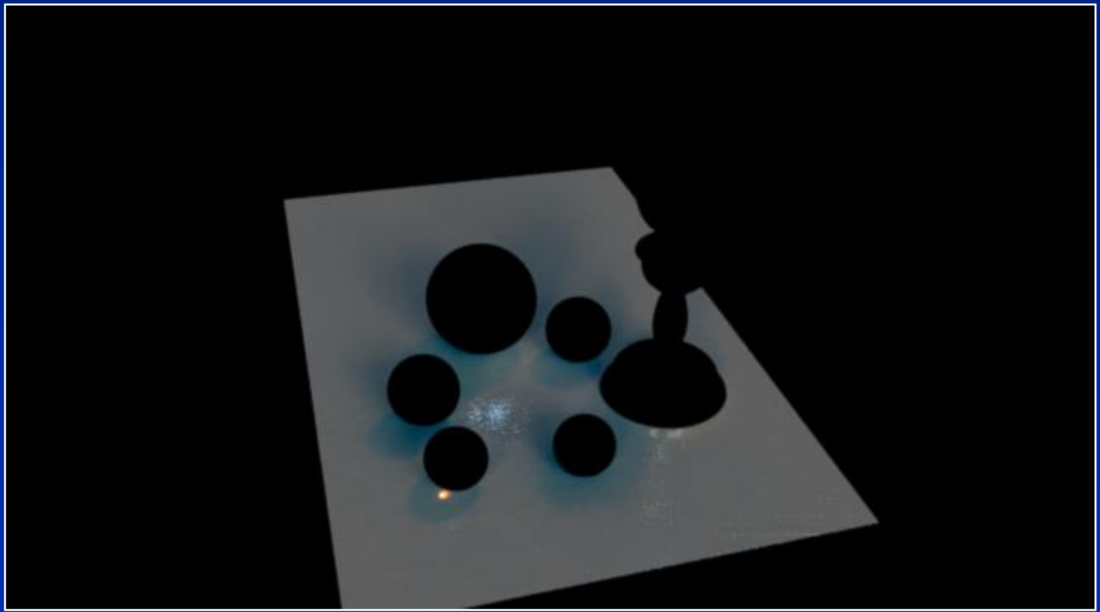


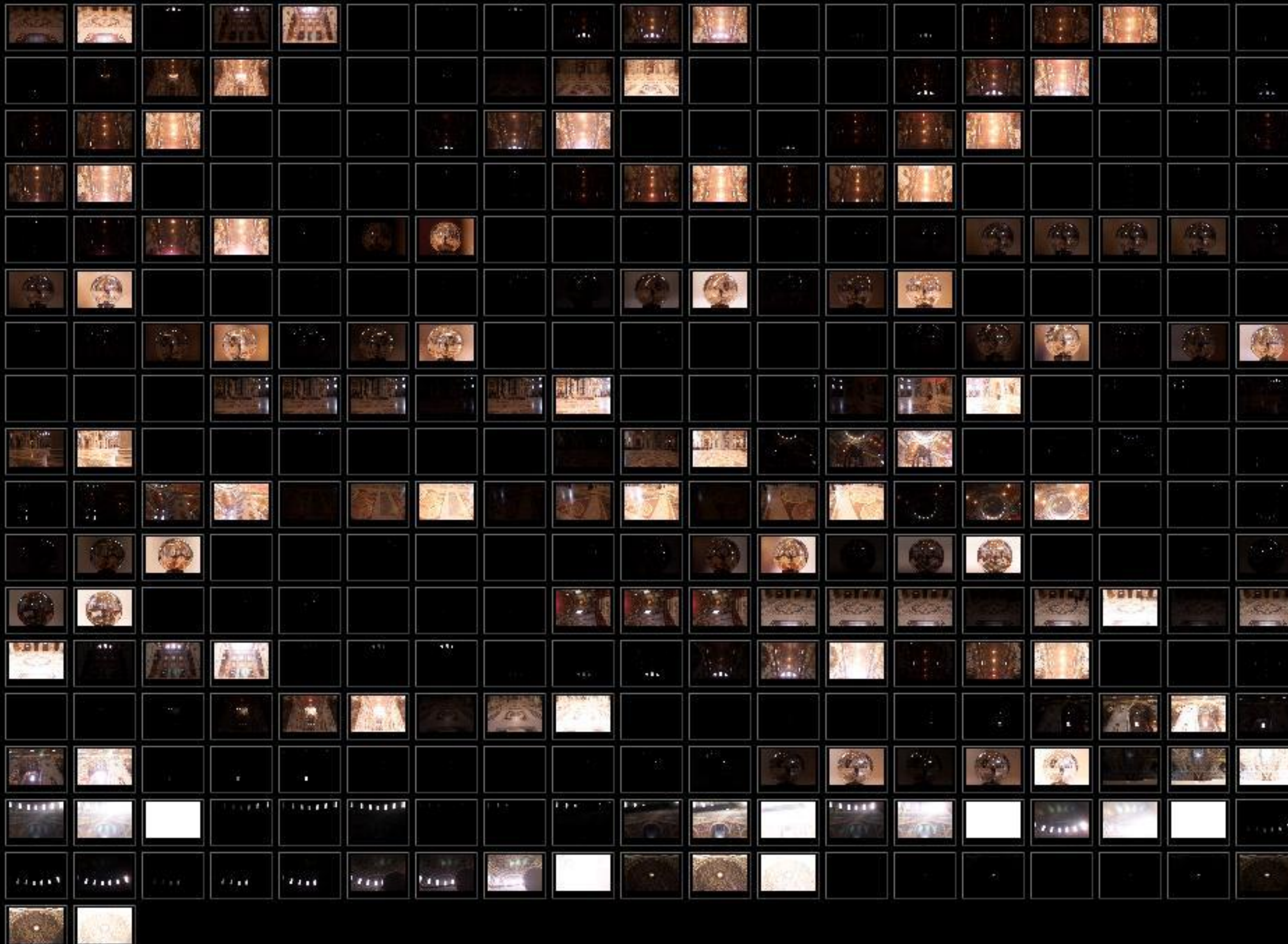
IMAGE-BASED LIGHTING IN ***FIAT LUX***

Paul Debevec, Tim Hawkins, Westley Sarokin, H. P. Duiker, Christine Cheng, Tal Garfinkel, Jenny Huang

SIGGRAPH 99 Electronic Theater

Fiat Lux

- http://ict.debevec.org/~debevec/FiatLux/movie/
- http://ict.debevec.org/~debevec/FiatLux/technology/

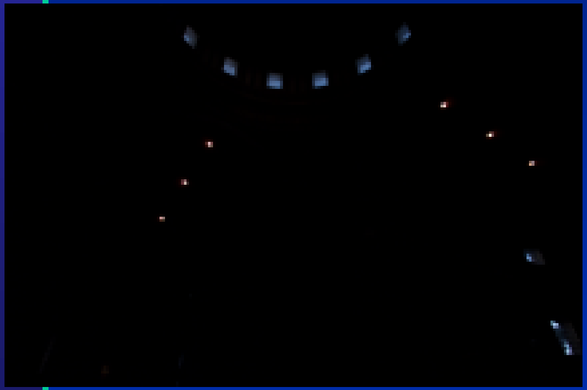


HDR Image Series

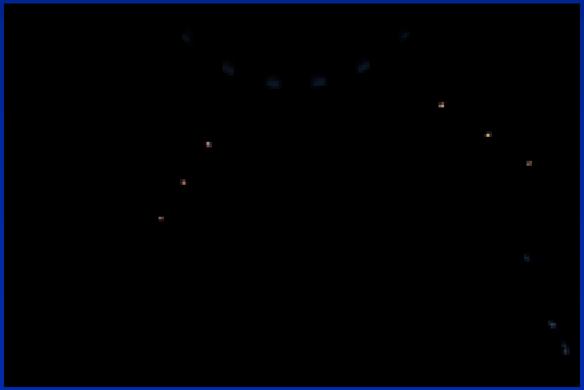
2 sec

1/4 sec

1/30 sec



1/250 sec



1/2000 sec

1/8000 sec

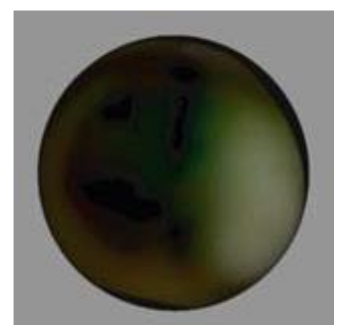
Assembled Panorama

Light Probe Images

Capturing a Spatially-Varying Lighting Environment

What if we don't have a light probe?

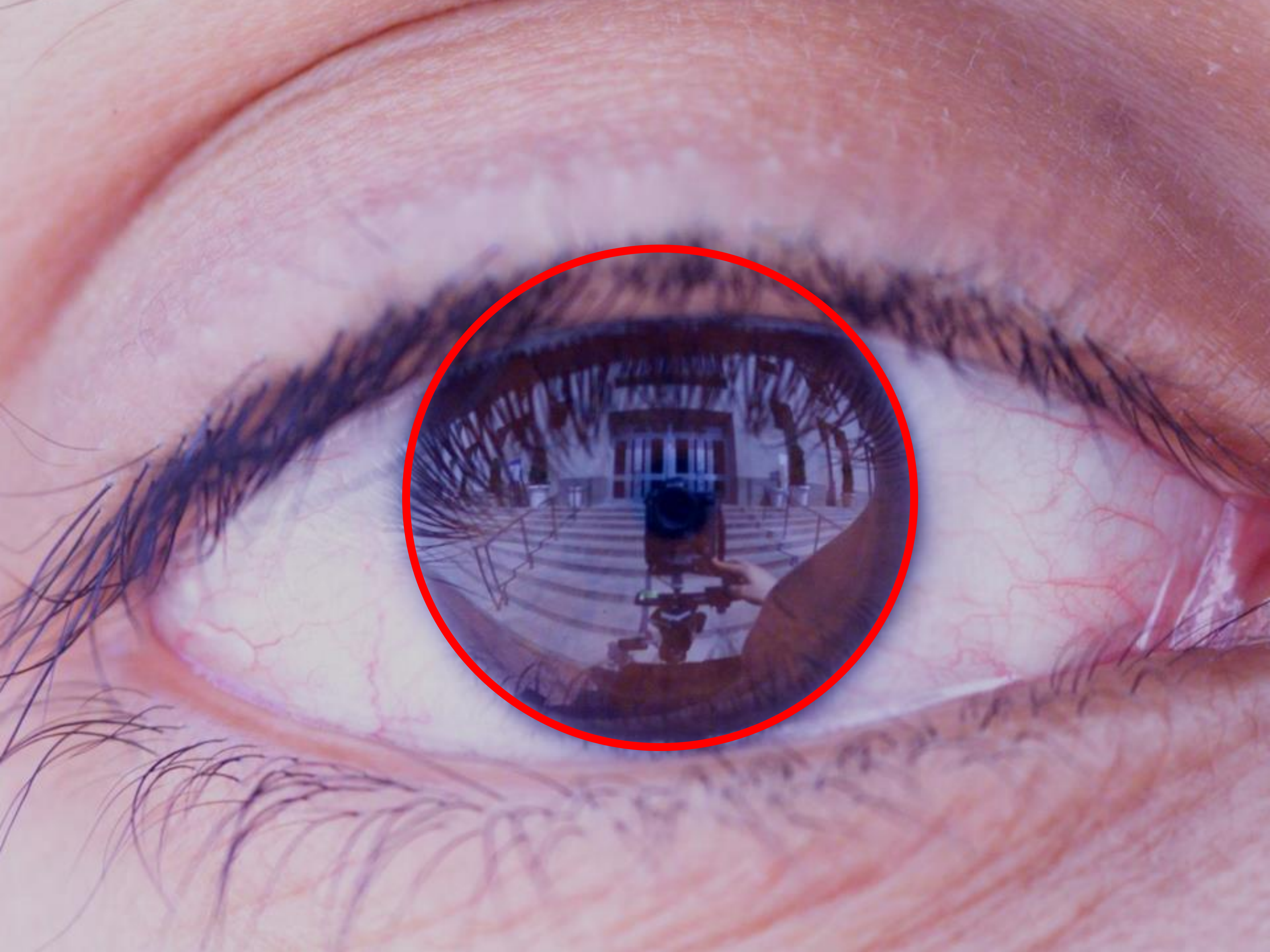
Zoom in on eye



Environment map

Insert Relit Face

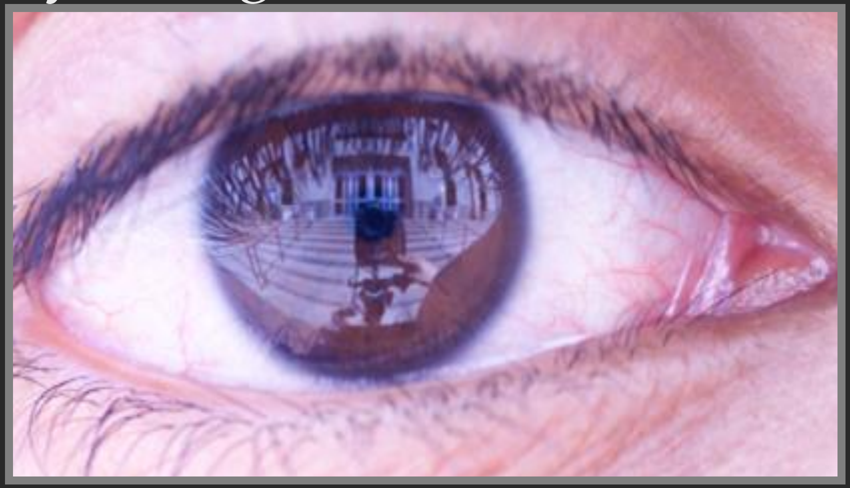
http://www1.cs.columbia.edu/CAVE/projects/world_eye/ -- Nishino Nayar 2004



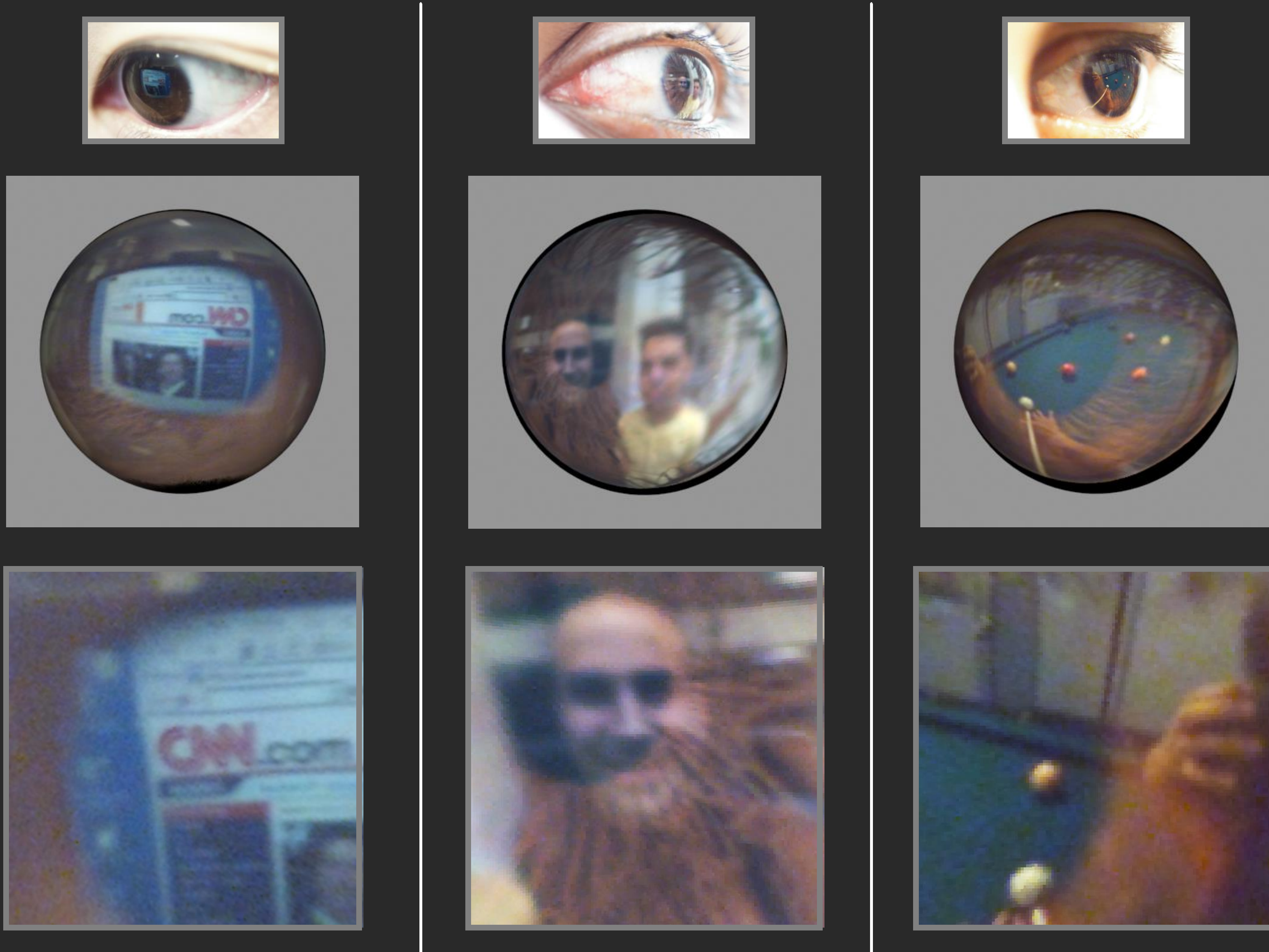
Environment Map from an Eye

Can Tell What You are Looking At

Eye Image:



Computed Retinal Image:


CNN.com

Video

Summary

- Real scenes have complex geometries and materials that are difficult to model

- We can use an environment map, captured with a light probe, as a replacement for distance lighting

- We can get an HDR image by combining bracketed shots
- We can relight objects at that position using the environment map