Image-based Lighting

T2

Computational Photography

Derek Hoiem, University of Illinois

Many slides from Debevec, some from Efros

Next week

- Derek away for ICCV (Venice)
  - Zhizhong and Aditya will teach and hold office hours, etc.

- Joe is away this week and next

Next two classes

Today

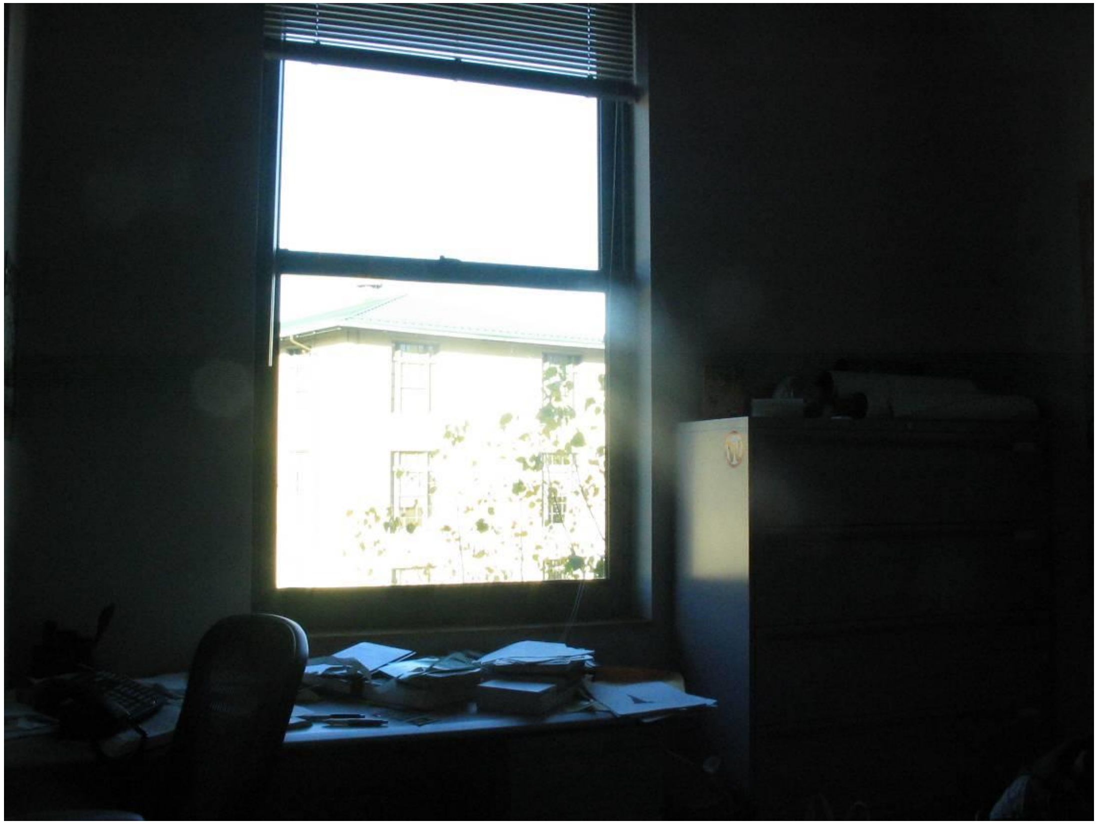
- Start on ray tracing, environment maps, and relighting 3D objects (project 4 topics)

Thursday

- More HDR, light probes, etc.

Project 4

How to render an object inserted into an image?



What’s wrong with the teapot?

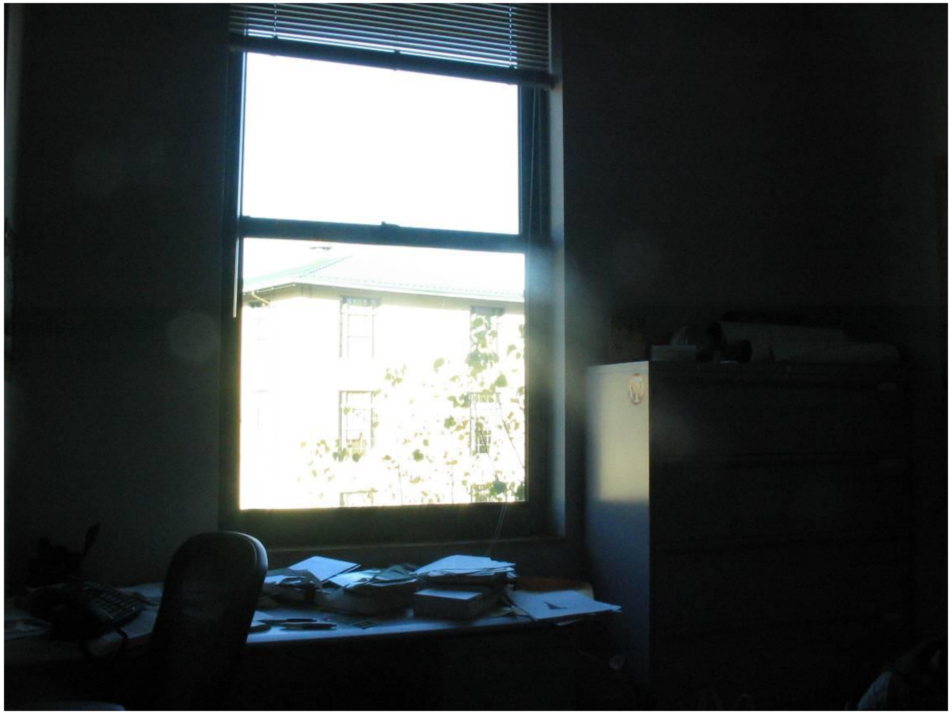
Relighting is important!

- http://smashinghub.com/8-of-the-most-epic-government-photoshop-fails-ever.htm
- http://petapixel.com/2013/10/13/another-north-korean-photoshop-fail/

How to render an object inserted into an image?

Traditional graphics way

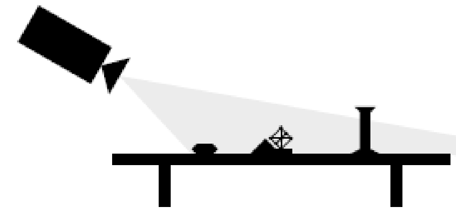
- Manually model BRDFs of all room surfaces
- Manually model radiance of lights
- Do ray tracing to relight object, shadows, etc.



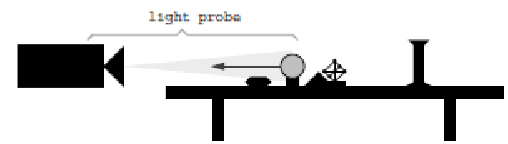
How to render an object inserted into an image?

Image-based lighting

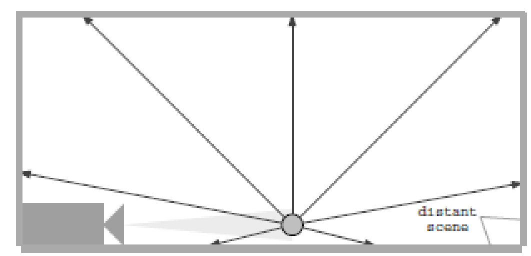
- Capture incoming light with a "light probe"
- Model local scene
- Ray trace, but replace distant scene with info from light probe



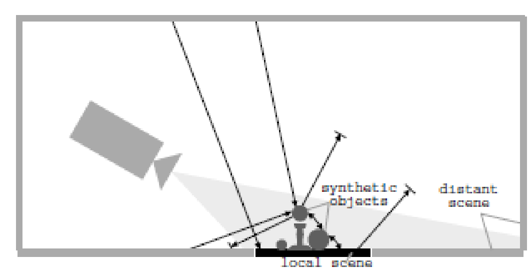
(a) Acquiring the background photograph



(b) Using the light probe



(c) Constructing the light-based model

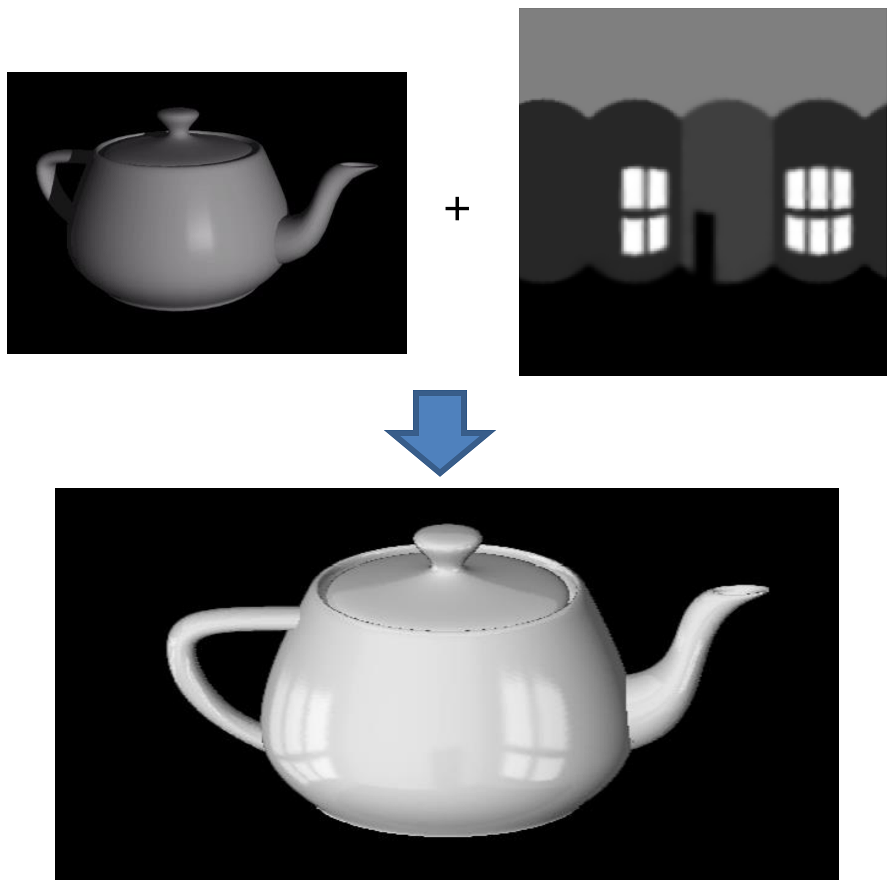


(d) Computing the global illumination solution

Debevec SIGGRAPH 1998

Key ideas for Image-based Lighting

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



Key ideas for Image-based Lighting

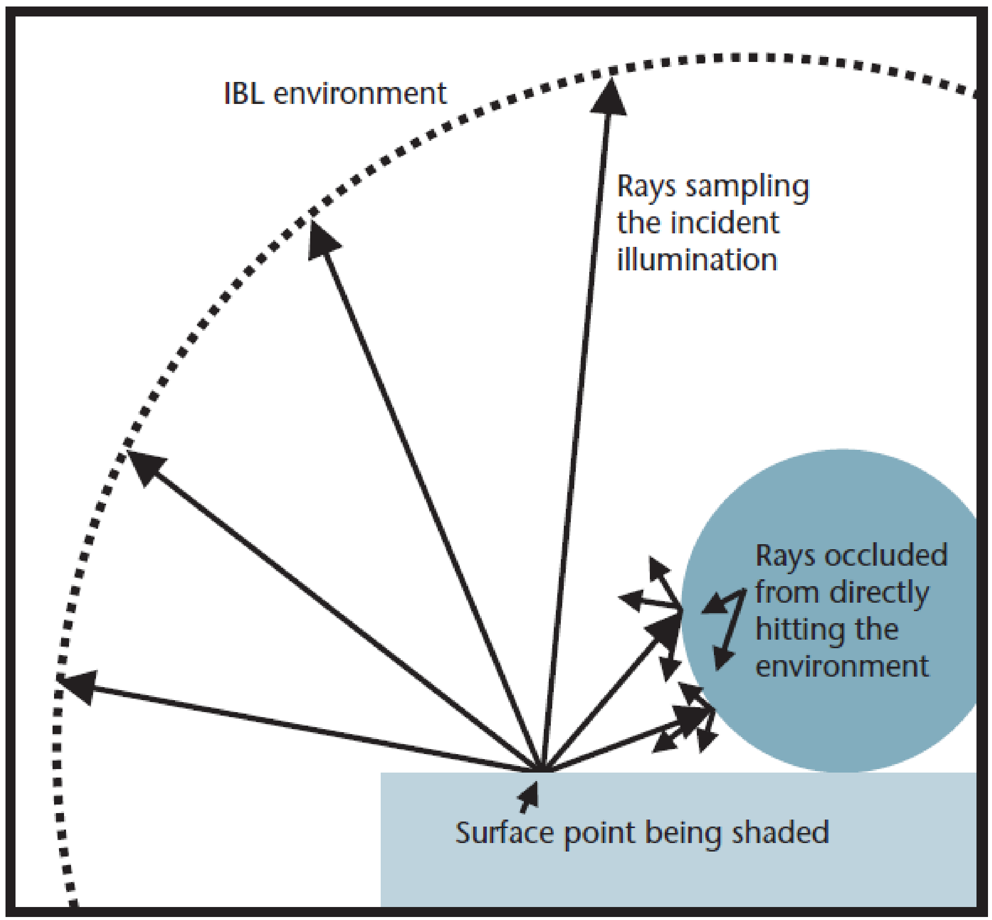
- Light probes: a way of capturing environment maps in real scenes

Key ideas for Image-based Lighting

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

Key ideas for Image-based Lighting

- Relighting: environment map acts as light source, substituting for distant scene

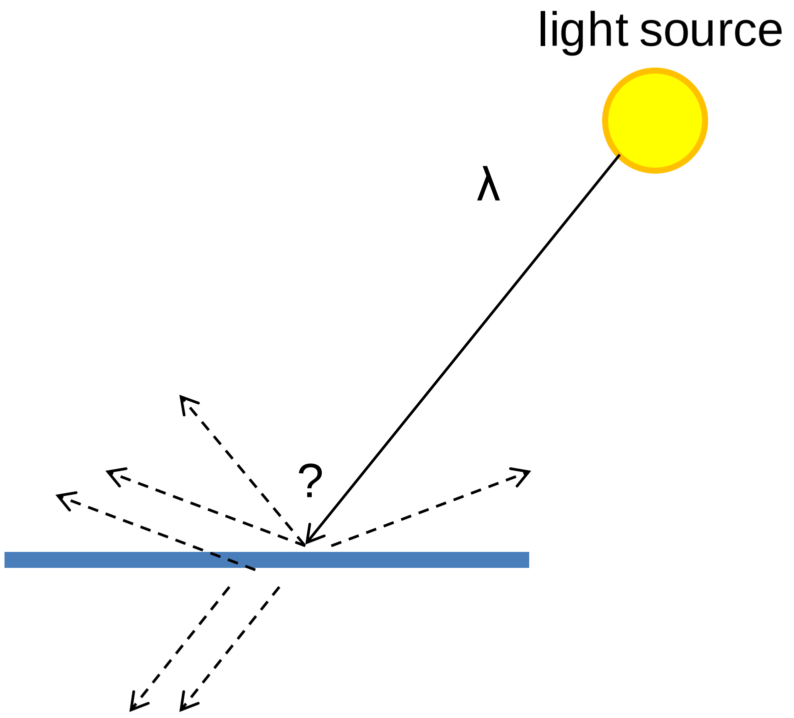


Today

- Ray tracing
- Capturing environment maps

A photon's life choices

- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



A photon's life choices

- **Absorption**
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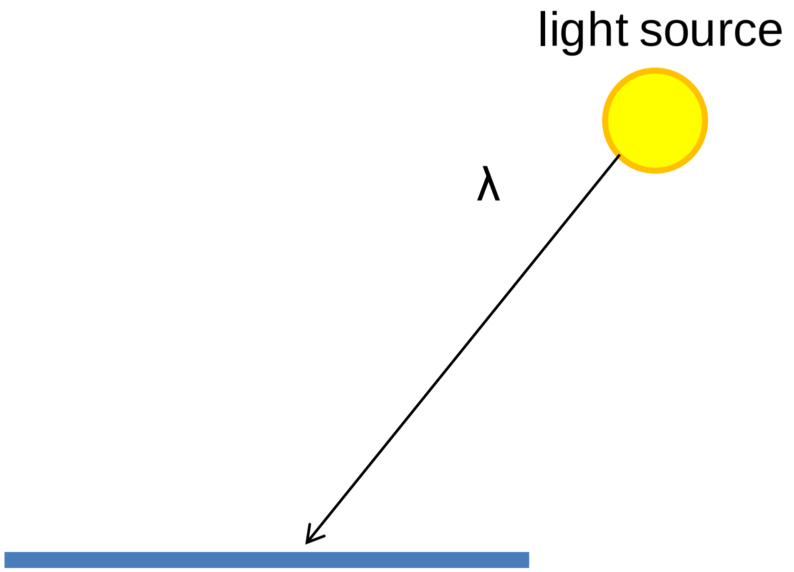
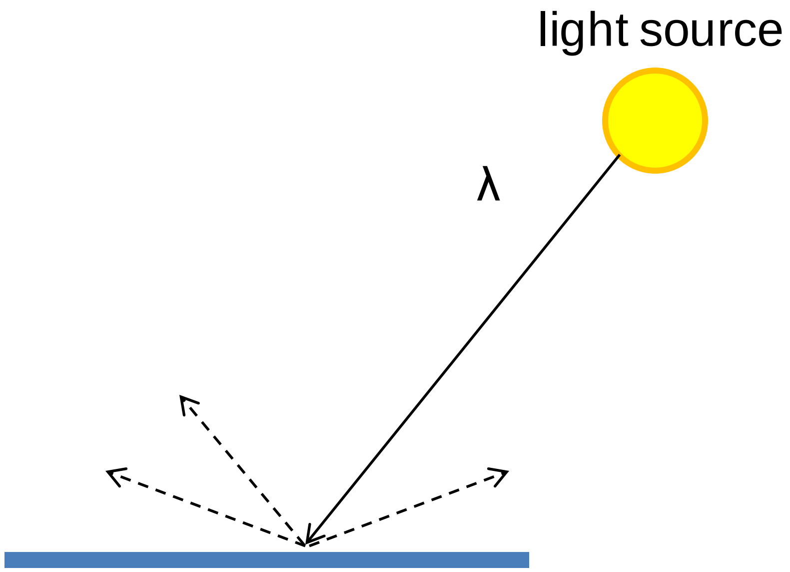
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



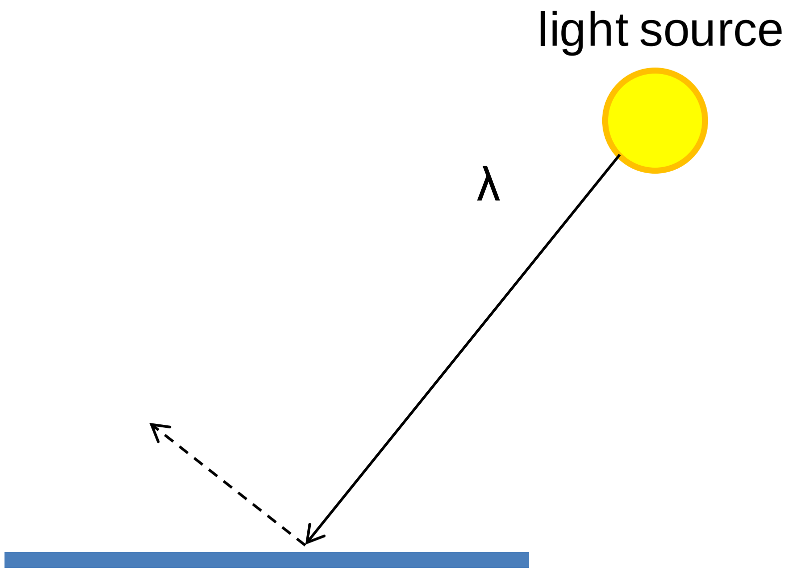
A photon's life choices

- Absorption
- **Diffuse Reflection**
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



A photon's life choices

- Absorption
- Diffusion
- **Specular Reflection**
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



A photon's life choices

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- **Transparency**
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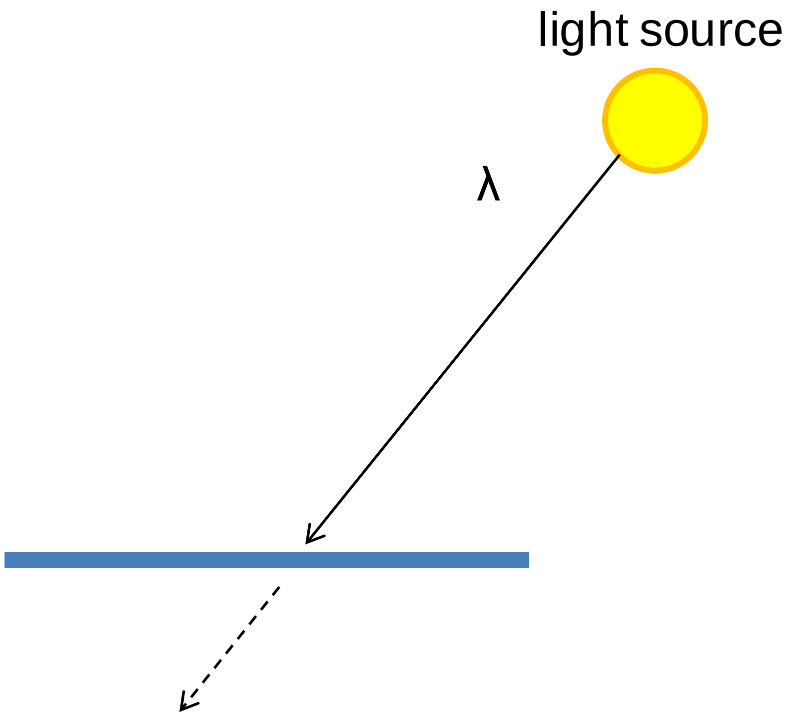

A photon’s life choices

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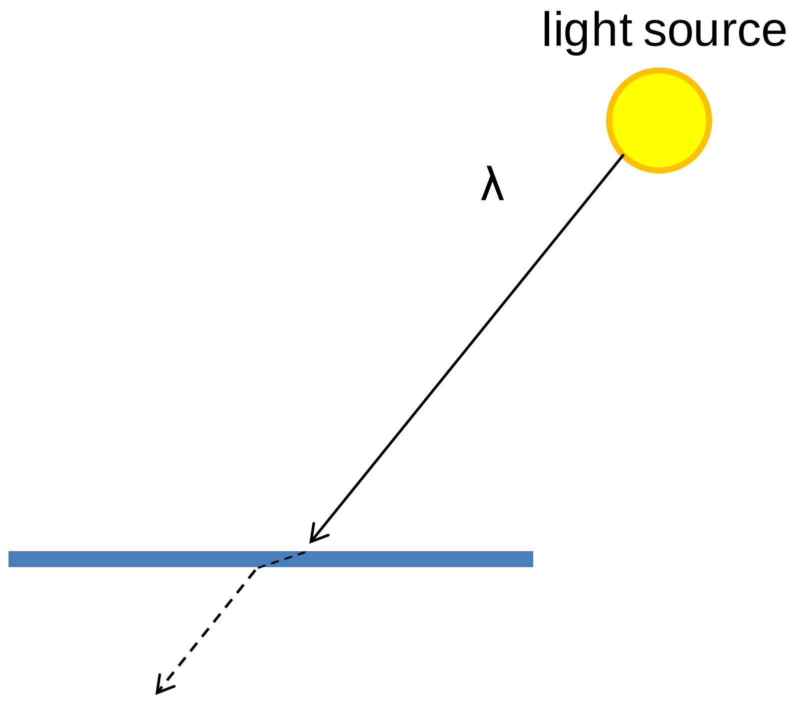

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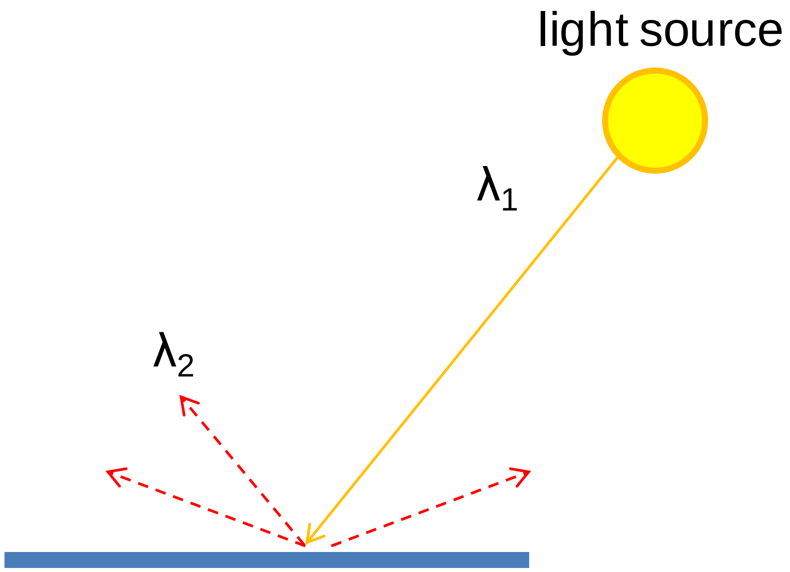

A photon's life choices

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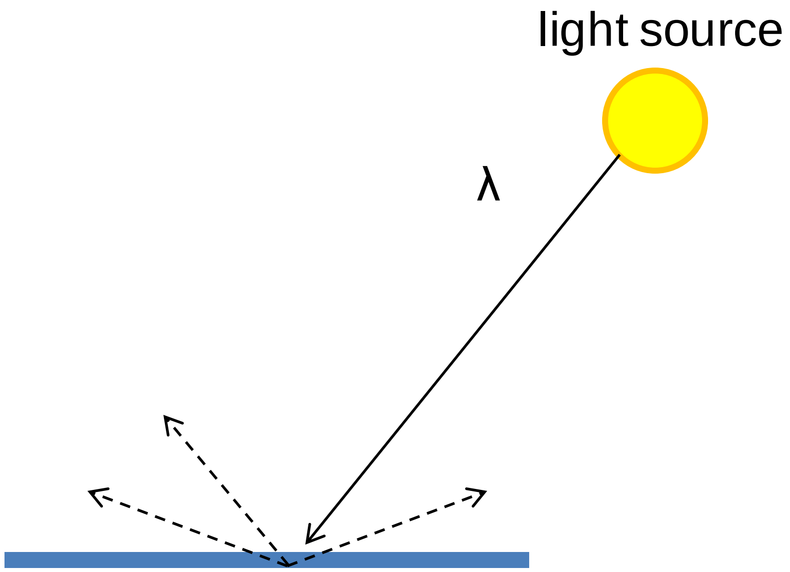
- Fluorescence
- **Subsurface scattering**
- Phosphorescence
- Interreflection



A photon's life choices

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- **Phosphorescence**
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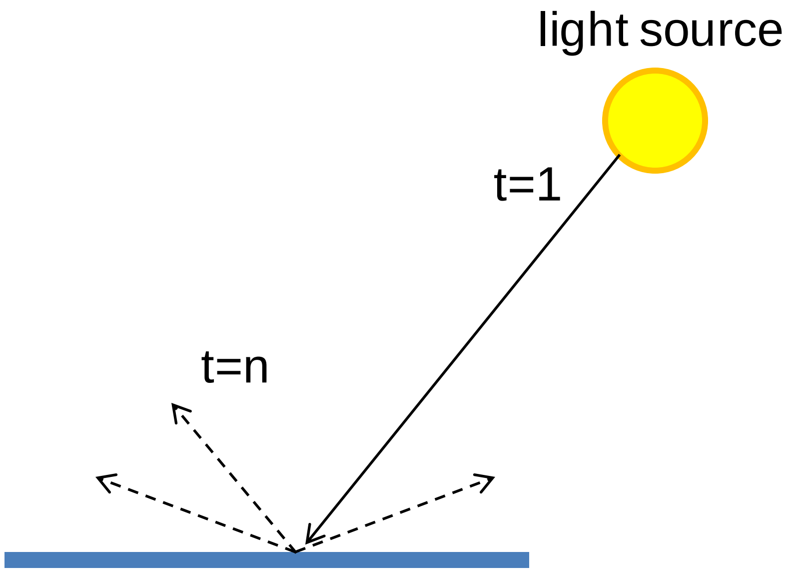
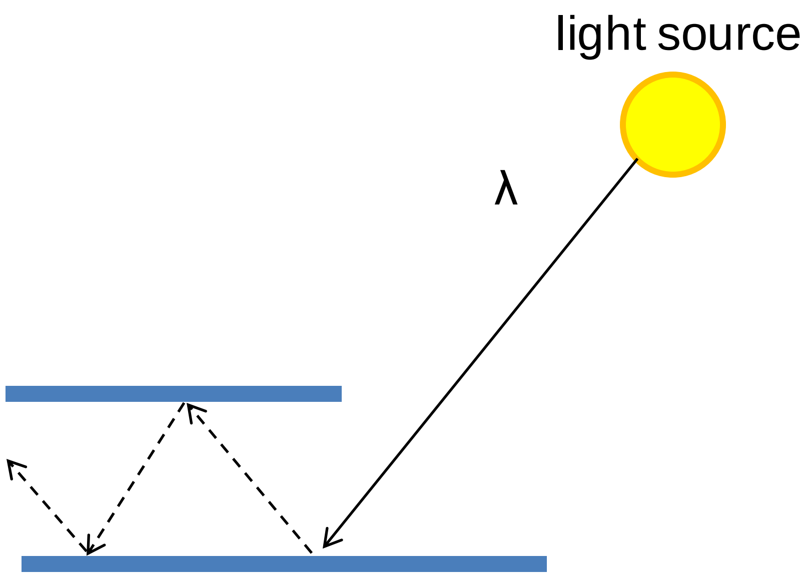


A photon's life choices

- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- **Interreflection**



(Specular Interreflection)

Where are the light sources are in this room?

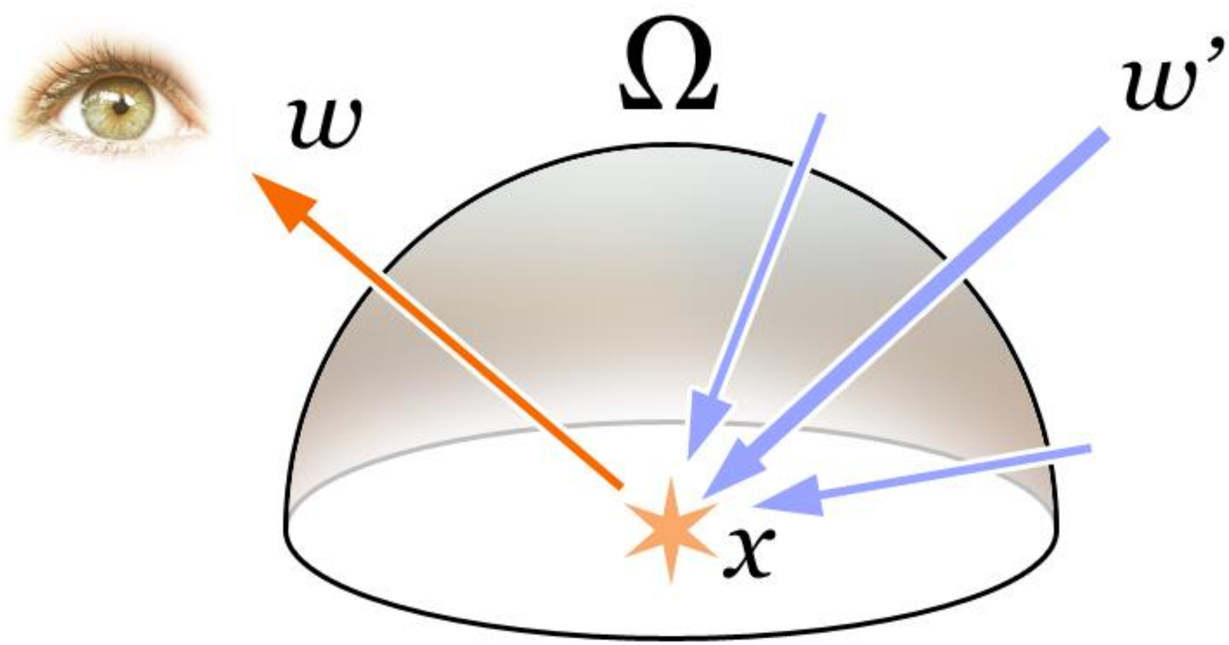
http://www.flickr.com/photos/chrisdonbavand/493707413/sizes/z/in/photostream/

Rendering Equation

Outgoing light
Generated light
Total reflected light

$$L_o(\mathbf{x},\omega,\lambda,t) = L_e(\mathbf{x},\omega,\lambda,t) + \int_\Omega f_r(\mathbf{x},\omega',\omega,\lambda,t)\,L_i(\mathbf{x},\omega',\lambda,t)\,(-\omega'\cdot\mathbf{n})\,d\omega'$$

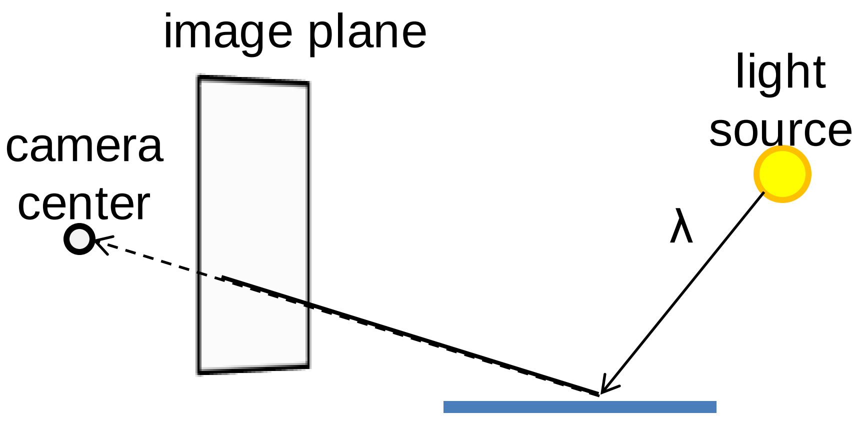
BRDF
Incoming Light
Incident angle

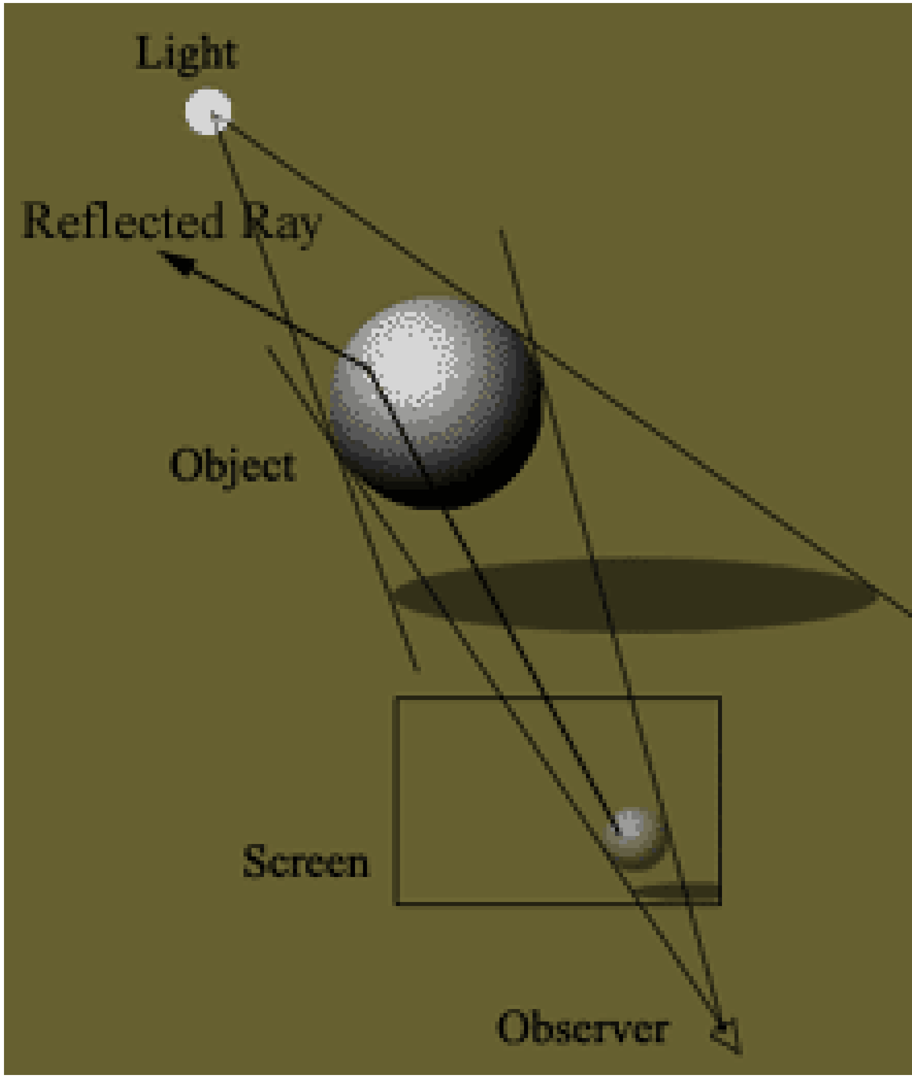


Rendering a scene with ray tracing

http://en.wikipedia.org/wiki/File:Glasses_800_edit.png

Ray tracing: basics





Ray casting

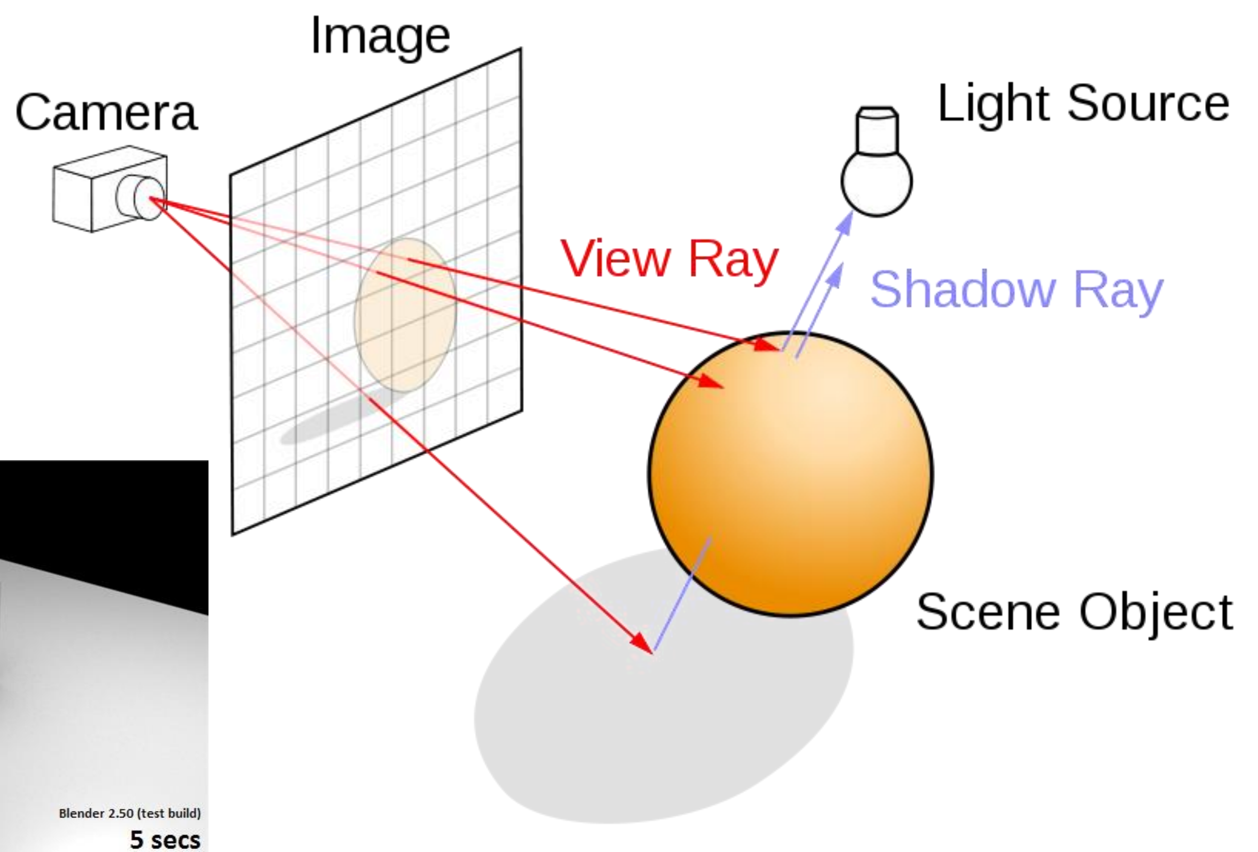
- Store colors of surfaces, cast out rays, see what colors each ray hits

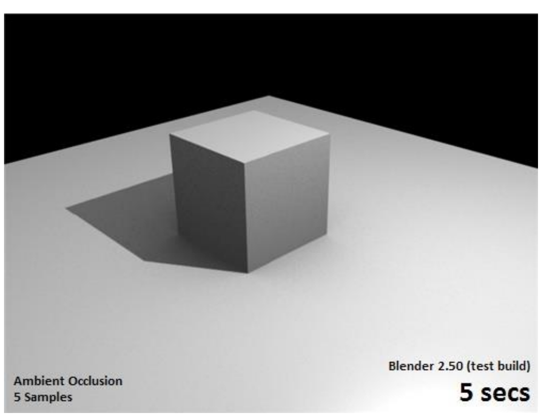
Wolfenstein 3D (1992)

Ray tracing: fast approximation

Upon hitting a surface

- Cast reflection/refraction ray to determine reflected or refracted surface
- Cast shadow ray: go towards light and see if an object is in the way

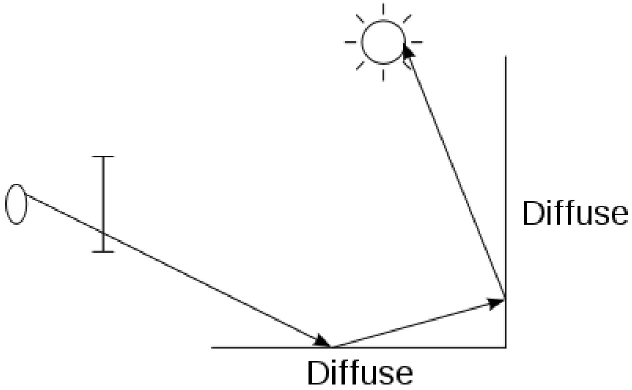




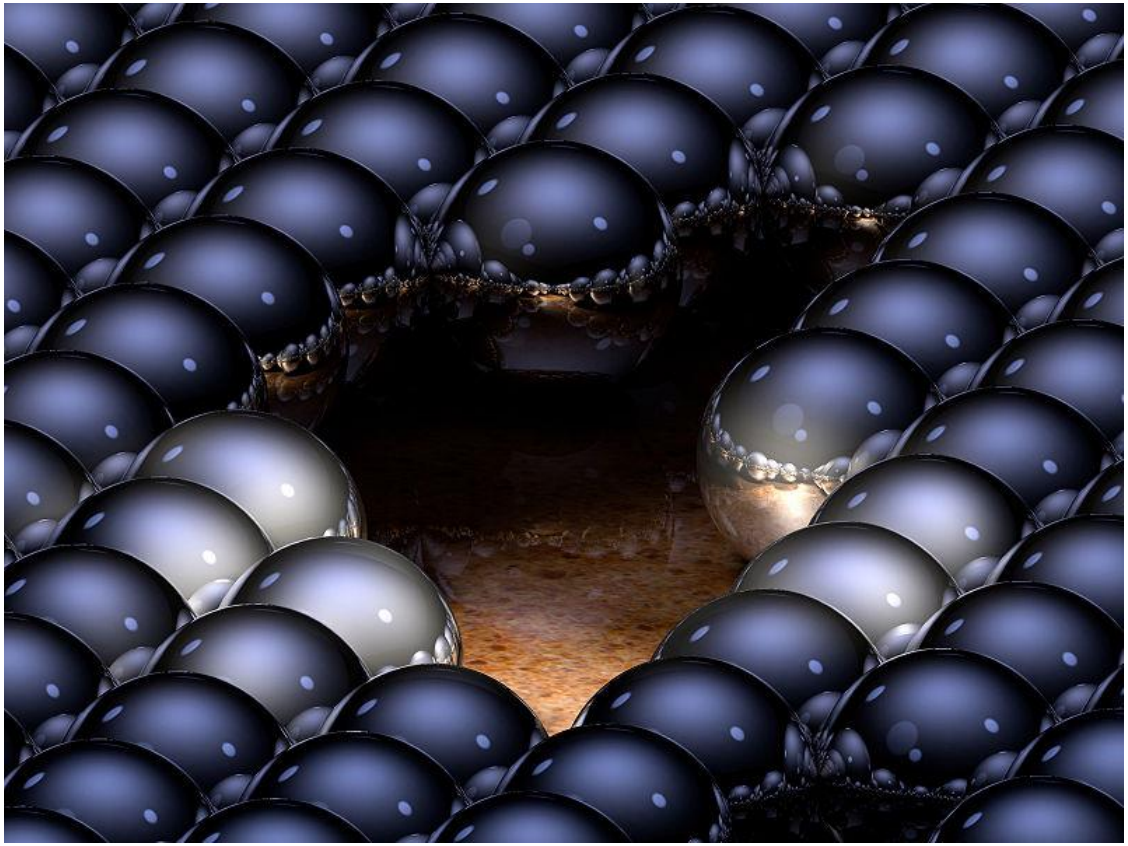
http://en.wikipedia.org/wiki/File:Ray_trace_diagram.svg

Ray tracing: interreflections

- Reflect light N times before heading to light source



N=2



N=16

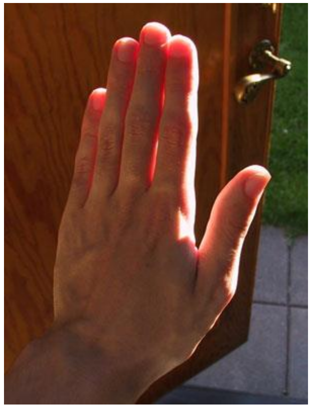
http://en.wikipedia.org/wiki/Ray_tracing_(graphics)#mediaviewer/File:Ray-traced_steel_balls.jpg

Ray tracing

- Conceptually simple but hard to do fast

- Full solution requires tracing millions of rays for many inter-reflections

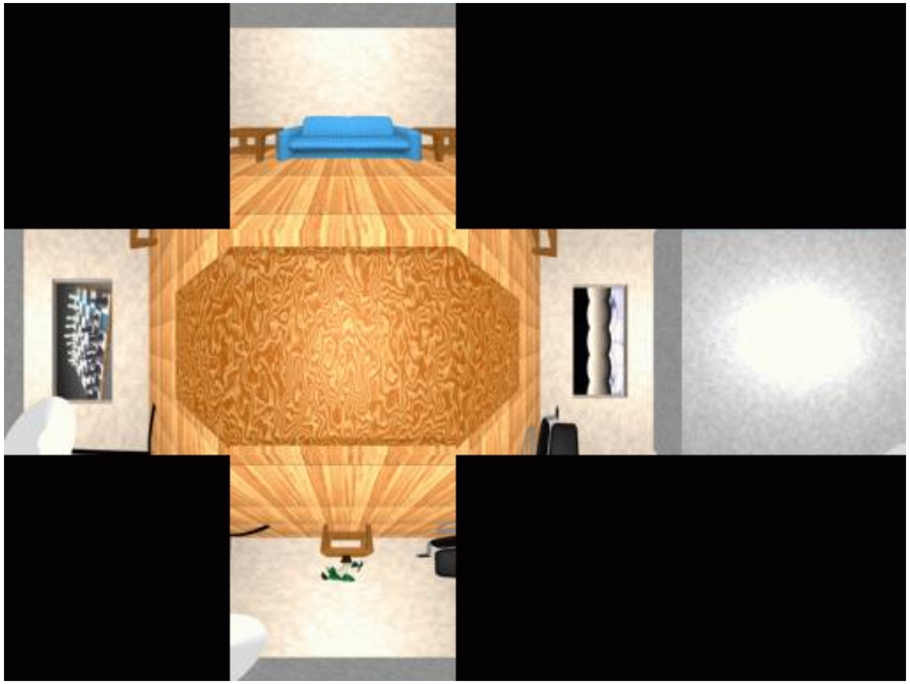
- Design choices
  - Ray paths: Light to camera vs. camera to light?
  - How many samples per pixel (avoid aliasing)?
  - How to sample diffuse reflections?
  - How many inter-reflections to allow?
  - Deal with subsurface scattering, etc?



Environment Maps

- The environment map may take various forms:
  - Cubic mapping
  - Spherical mapping
  - other
- Describes the shape of the surface on which the map "resides"
- Determines how the map is generated and how it is indexed

Cubic Map Example



Cubic Mapping

- The map resides on the surfaces of a cube around the object
  - Typically, align the faces of the cube with the coordinate axes
- To generate the map:
  - For each face of the cube, render the world from the center of the object with the cube face as the image plane
    - Rendering can be arbitrarily complex (it's off-line)
- To use the map:
  - Index the R ray into the correct cube face
  - Compute texture coordinates

Spherical Map Example

Sphere mapping

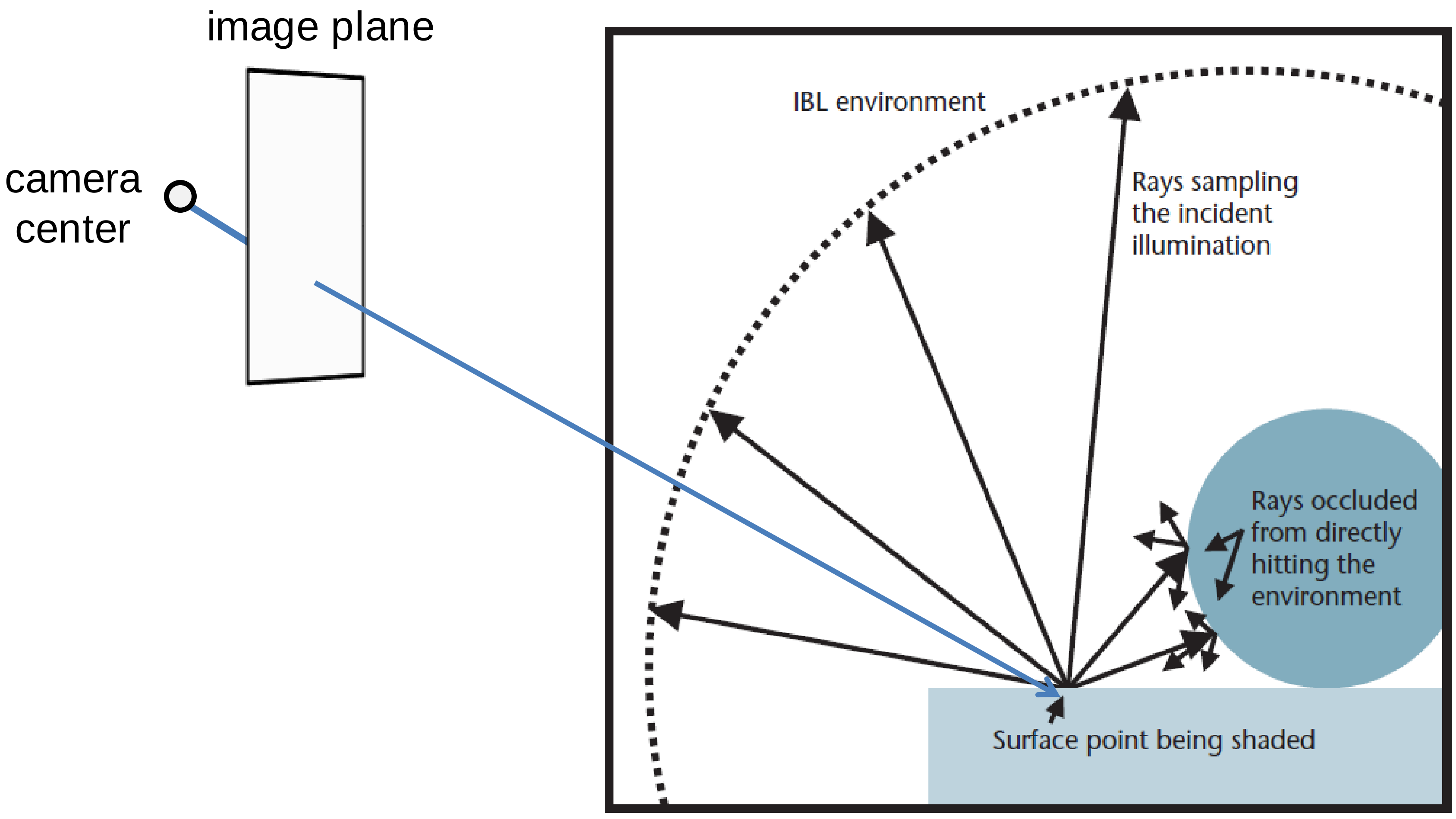
- Map lives on a sphere
- To generate the map:
  - Render a spherical panorama from the designed center point
- Rendering with environment map:
  - Use the orientation of the R ray to index directly into the sphere

What approximations are made?

- The map should contain a view of the world with the point of interest on the object as the Center of Projection
  - We can't store a separate map for each point, so one map is used with the COP at the center of the object
  - Introduces distortions in the reflection, but we usually don't notice
  - Distortions are minimized for a small object in a large room

- The object will not reflect itself (based on the environment map)

Rendering with environment maps and local models



Storing spherical environment maps

Angular mapped

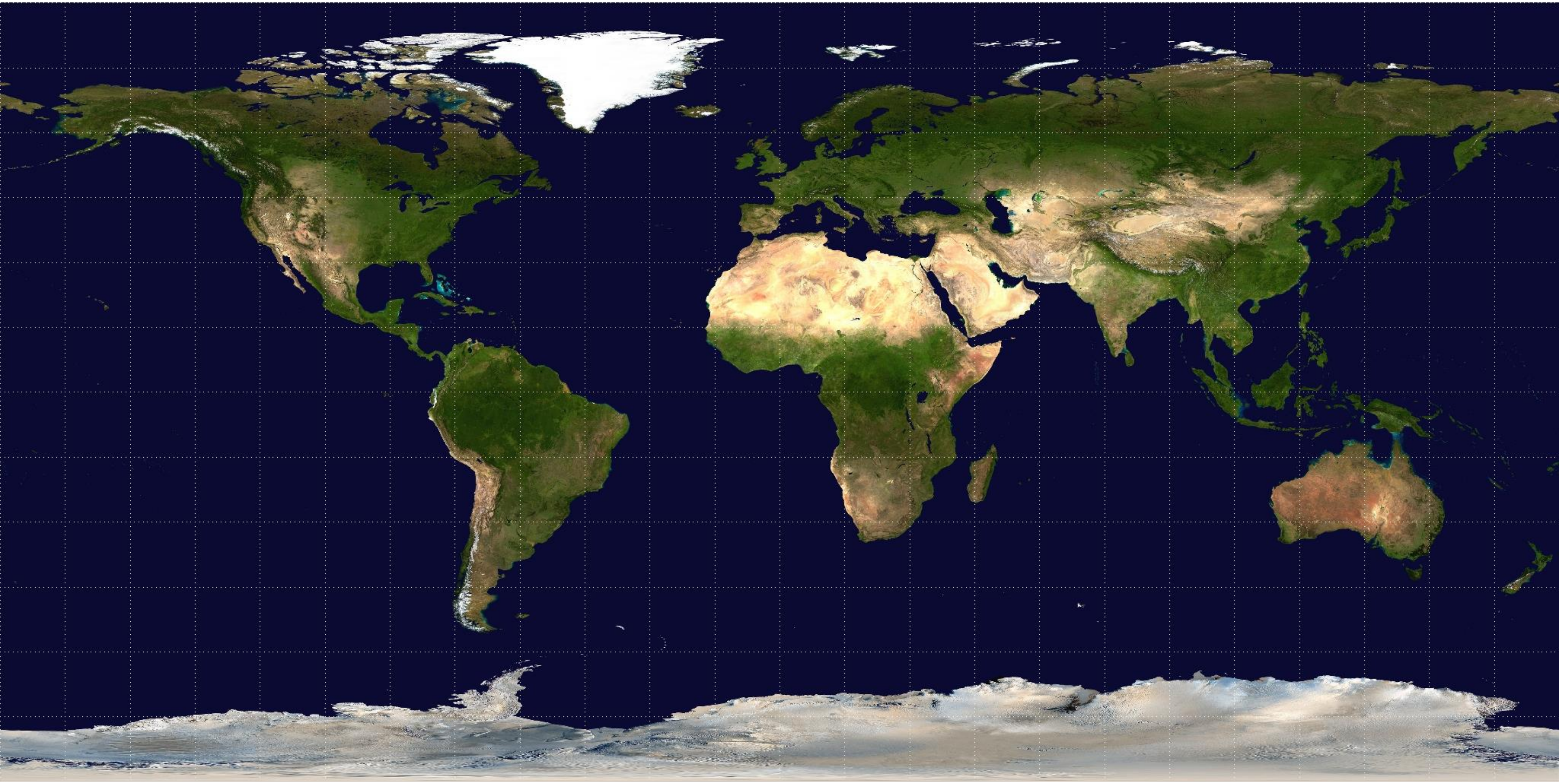
Spherical
Equirectangular
LatLong
Latitude/Longitude

Vertical Cross
Cubic (vcross)

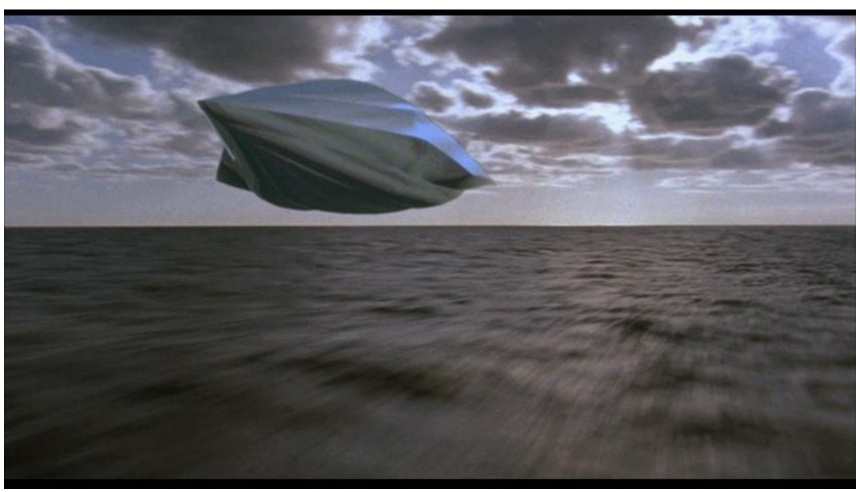
SkyDome Spherical

Equirectangular (latitude-longitude) projection

Equirectangular (latitude-longitude) projection



How to capture light in real scenes?



From *Flight of the Navigator*

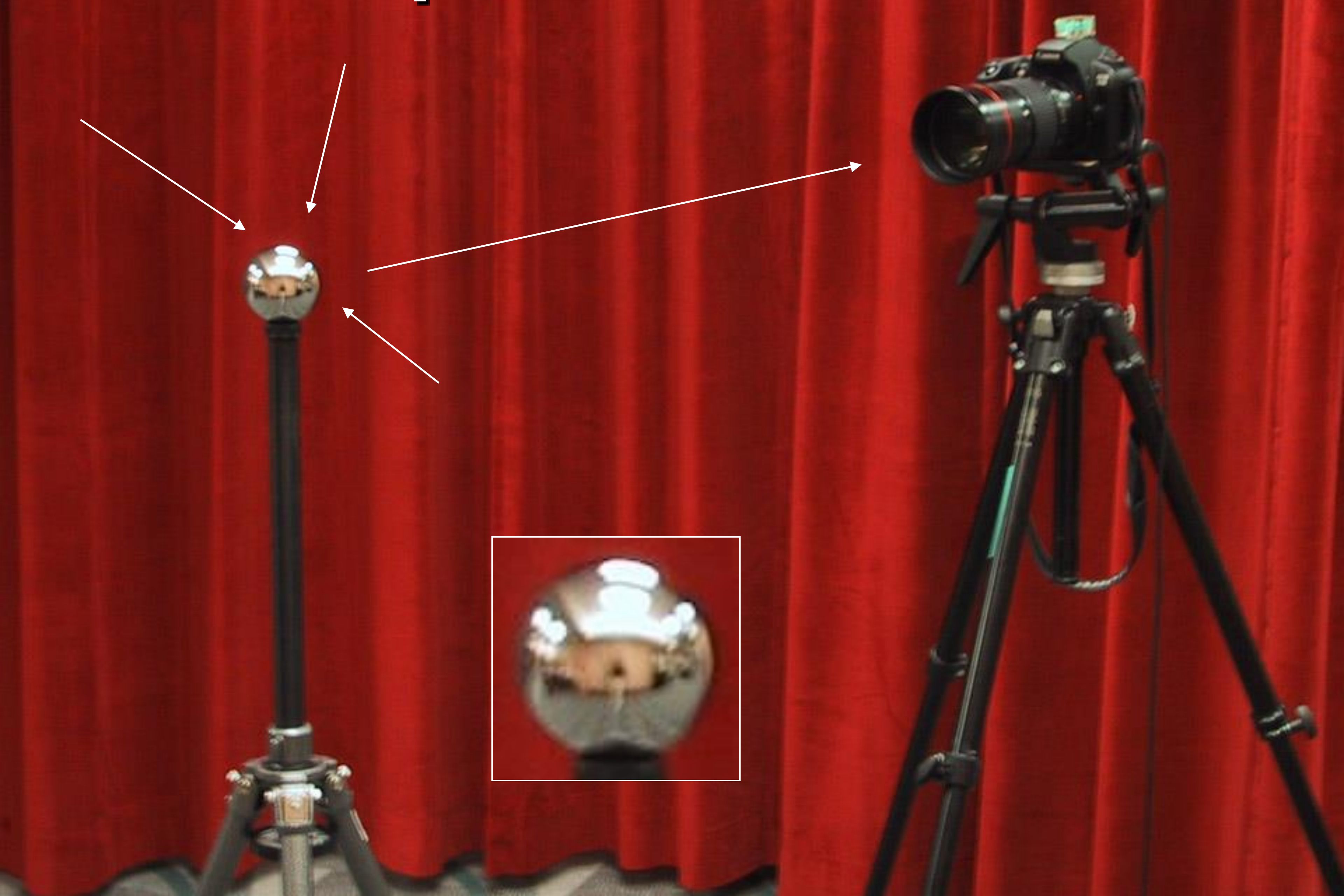
How to capture light in real scenes?

from Terminator 2

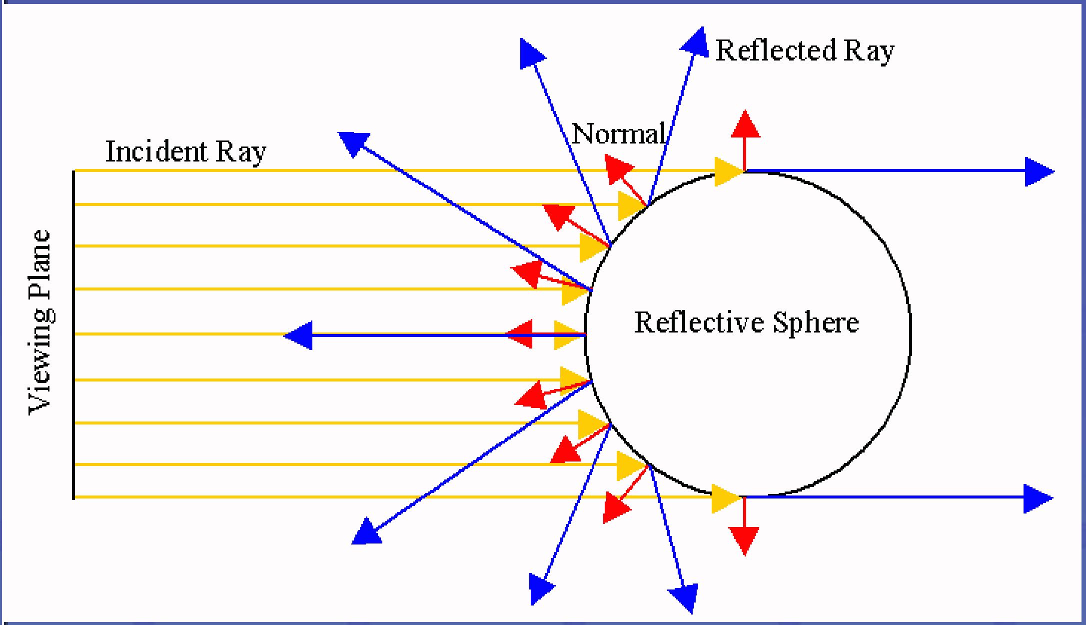
Real environment maps

- We can use photographs to capture environment maps
  - The first use of panoramic mosaics
  - Fisheye lens
  - Mirrored balls (**light probes**)

Mirrored Sphere



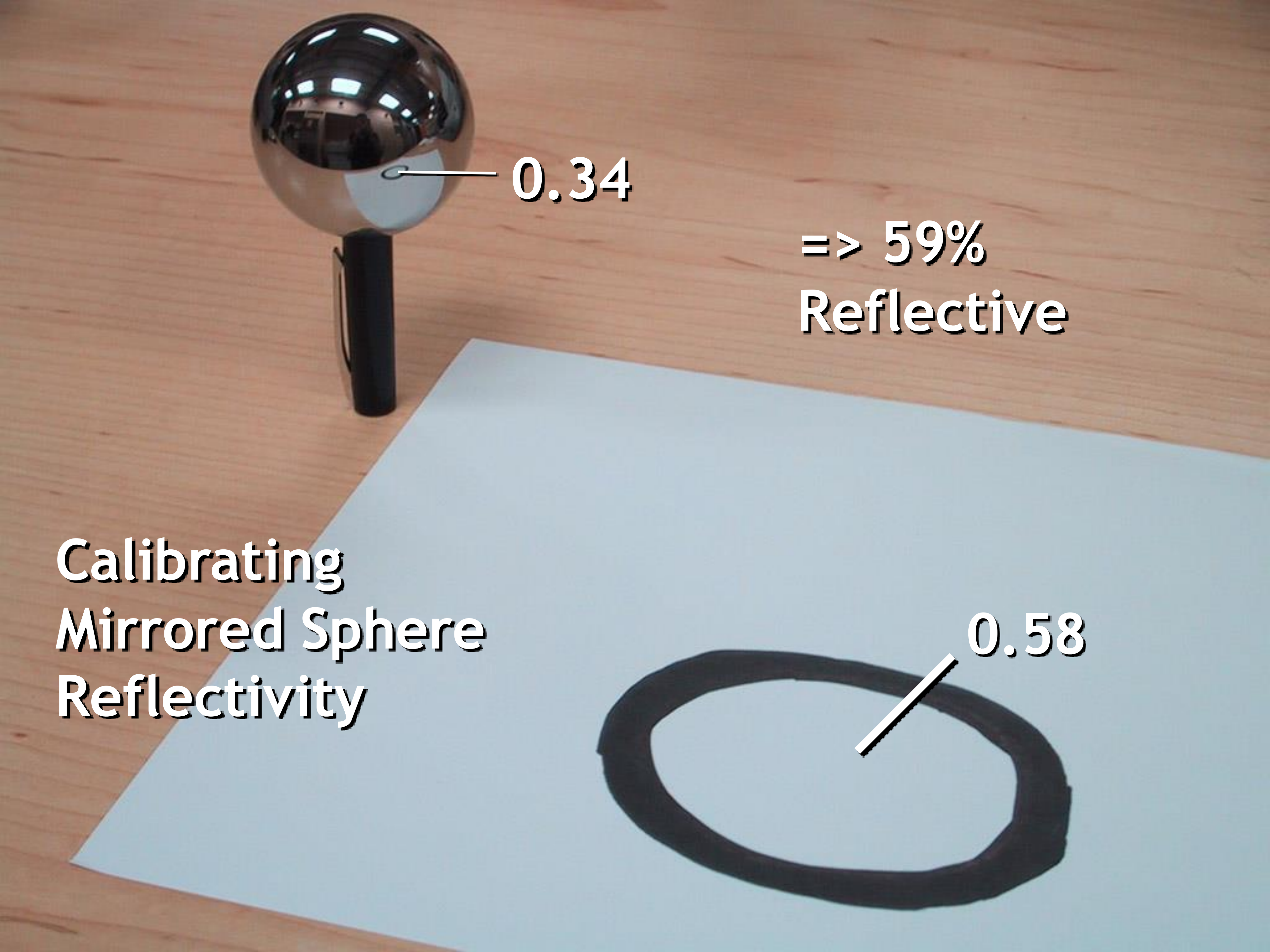

Canon
Canon
REMOTE SWITCH


Reflected Ray
Normal
Incident Ray
Viewing Plane
Reflective Sphere

Mirror balls for image-based lighting

Mirror balls for image-based lighting

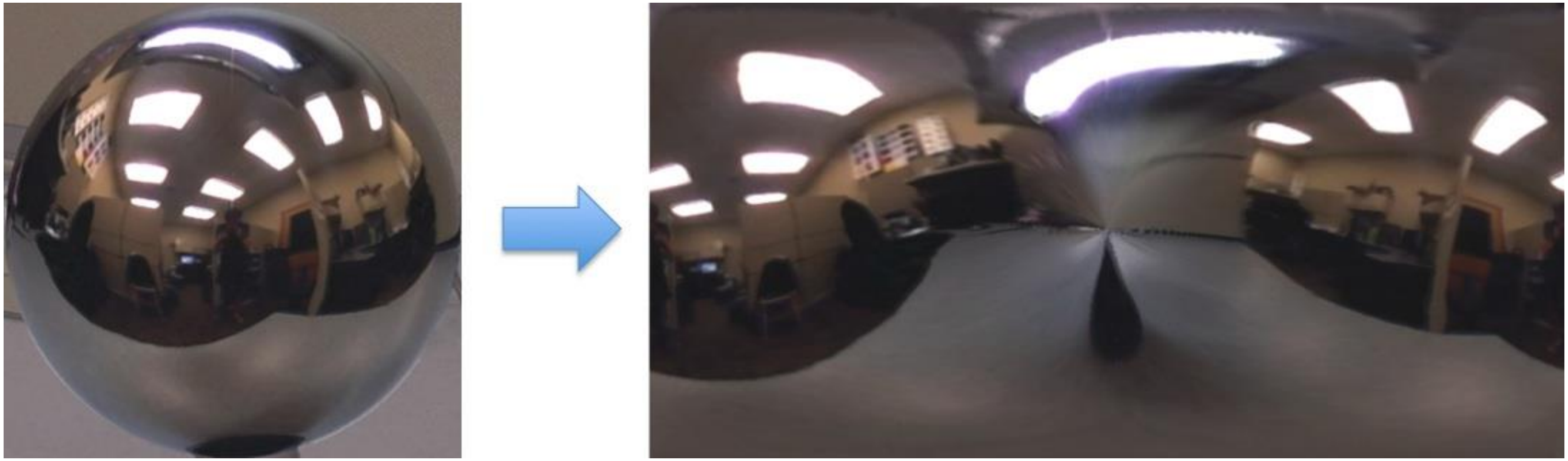
Mirror balls for image-based lighting


0.34
=> 59%
Reflective
Calibrating
Mirrored Sphere
Reflectivity
0.58

Spherical map domain transformations

- Many rendering programs only accept one format (mirror ball, equirectangular, cube map, etc)
  - E.g. Blender only accepts equirectangular maps
- How to convert mirror ball to equirectangular?

Mirror ball -> equirectangular



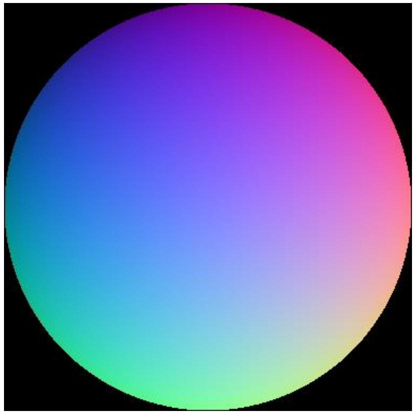
Mirror ball -> equirectangular

- Spherical coordinates
  - Convert the light directions incident to the ball into spherical coordinates (phi, theta)
  - Map from mirror ball phi, theta to equirectangular phi, theta

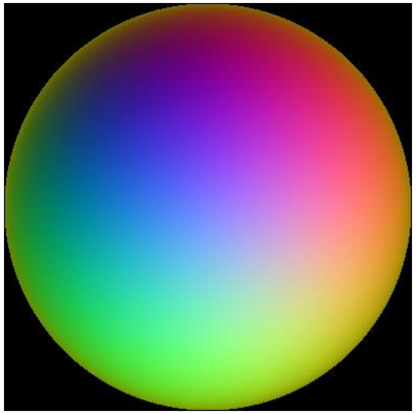
```
for i=1:d
    F = TriScatteredInterp(phi_ball, theta_ball, mirrorball(:,:,i));
    latlon(:,:,i) = F(phi_latlon, theta_latlon);
end
```

Mirror ball -> equirectangular

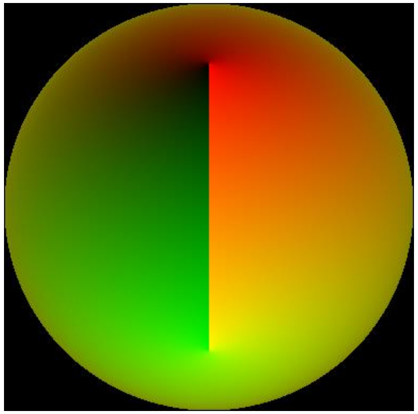
Mirror ball



Normals



Reflection vectors



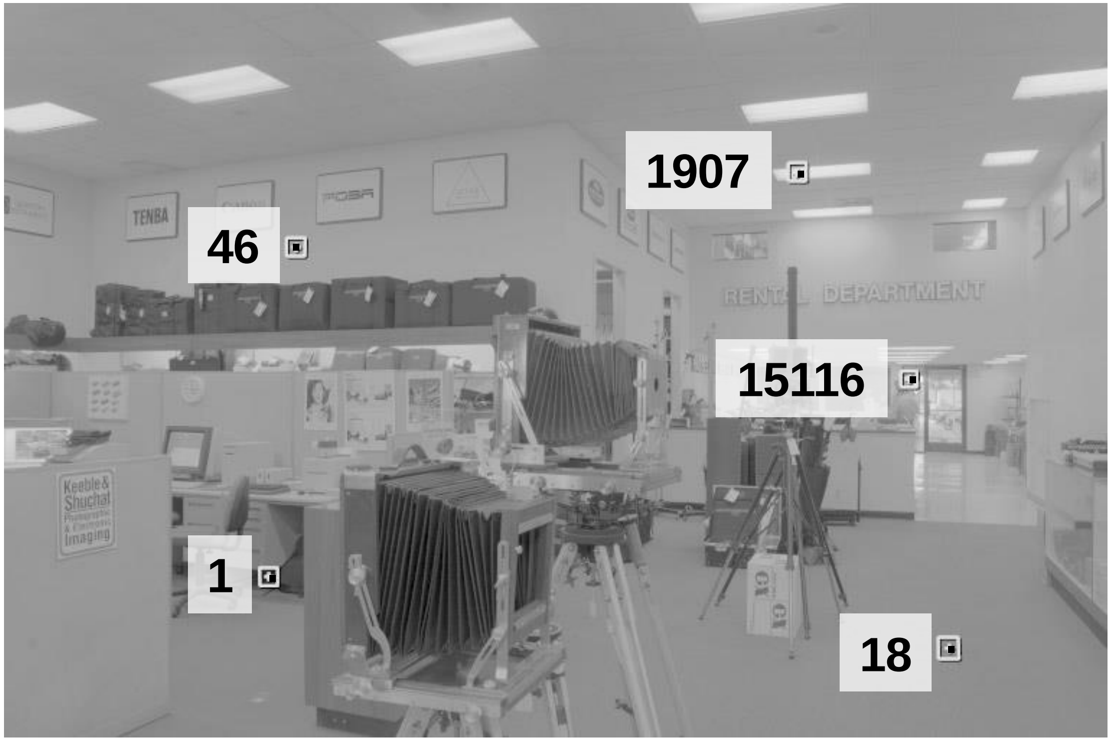
Phi/theta of reflection vecs

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



Problem: Dynamic Range

Problem: Dynamic Range

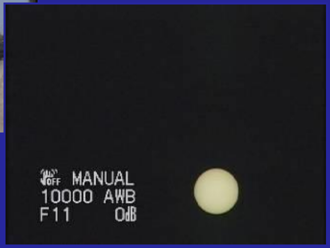
The real world is high dynamic range.

1

1500

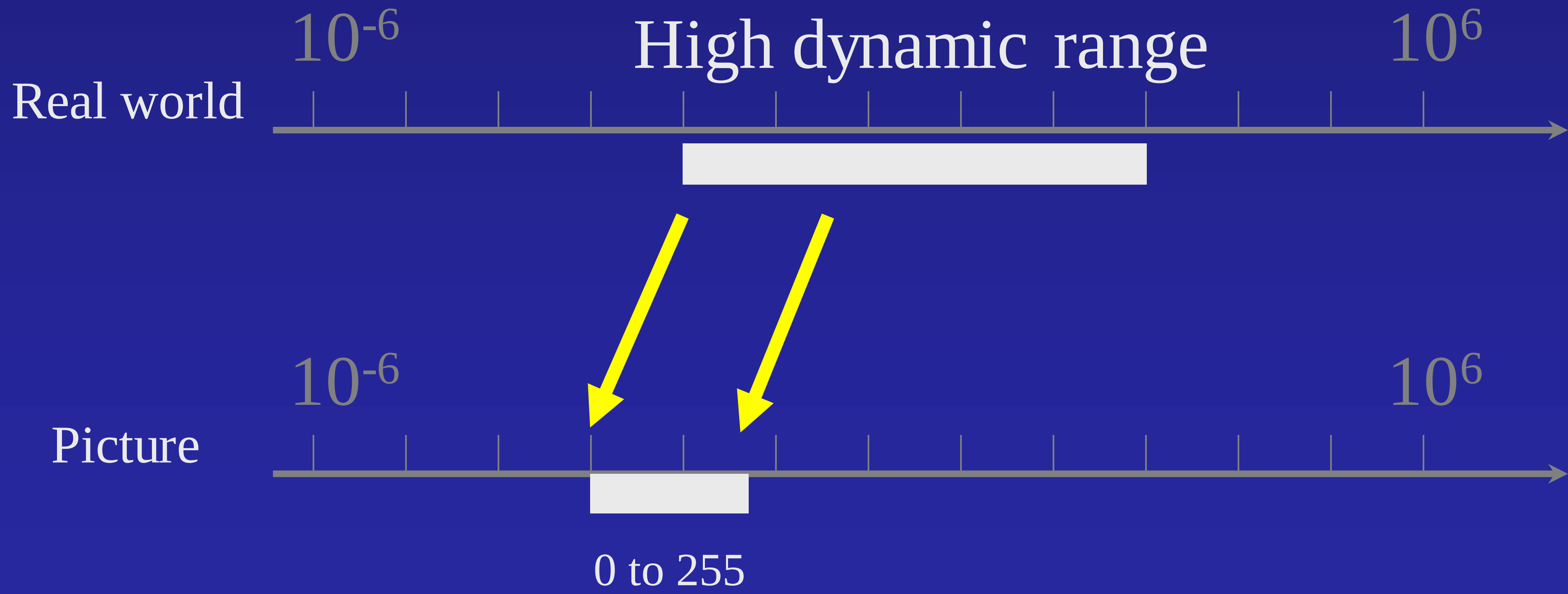
25,000

400,000

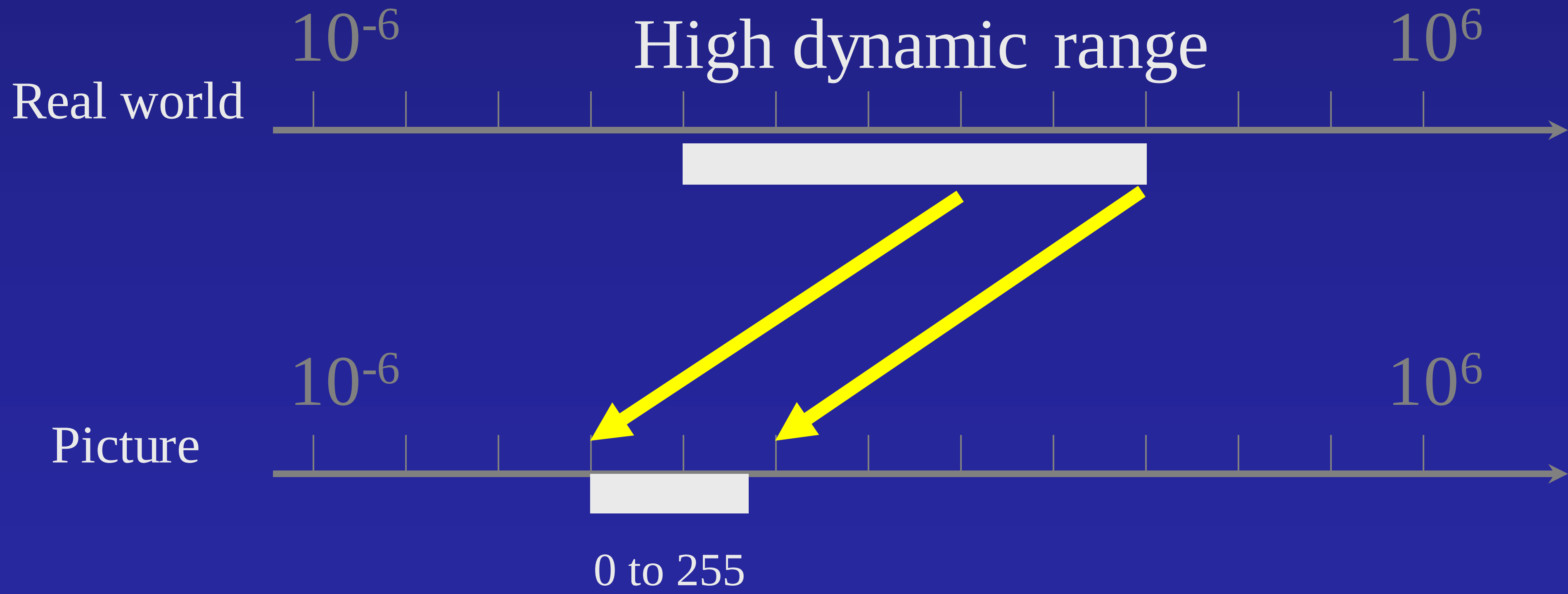


2,000,000,000

Long Exposure



Short Exposure



Varying Exposure

Camera is not a photometer!

- Limited dynamic range
  - ⇒ Perhaps use multiple exposures?
- Unknown, nonlinear response
  - ⇒ Not possible to convert pixel values to radiance
- Solution:
  - – Recover response curve from multiple exposures, then reconstruct the ***radiance map***

Next class

- How to capture HDR image using “bracketing”
- How to relight an object from an environment map