

# Image-based Lighting



T2

Computational Photography  
Derek Hoiem, University of Illinois

# Reminder of upcoming deadlines

- Oct 24: Project 3 due
- Oct 31: Project proposal due
- Nov 7: Project 4 due

Derek is away Oct 24-26

- No office hours Oct 24
- View recording for Oct 25 lecture (linked on website)

# Next two classes

## Today

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

## Next class

- More HDR, light probes, etc.

# Image-based Lighting Project



# 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

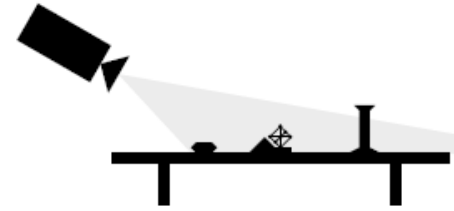
- Manually model BRDFs of all room surfaces
- Manually model radiance of lights
- Do ray tracing to relight object, shadows, etc.



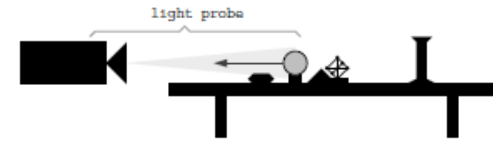
# How to render an object inserted into an image?

## Image-based lighting

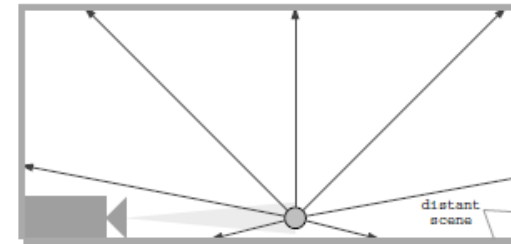
- Capture incoming light with a “light probe”
- Model local scene
- Ray trace, but replace distant scene with info from light probe



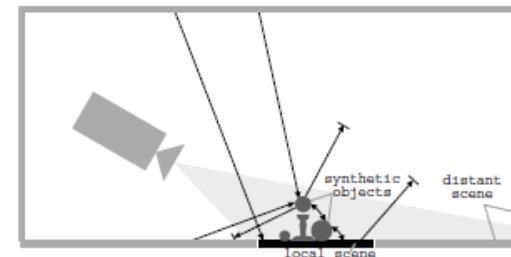
(a) Acquiring the background photograph



(b) Using the light probe



(c) Constructing the light-based model

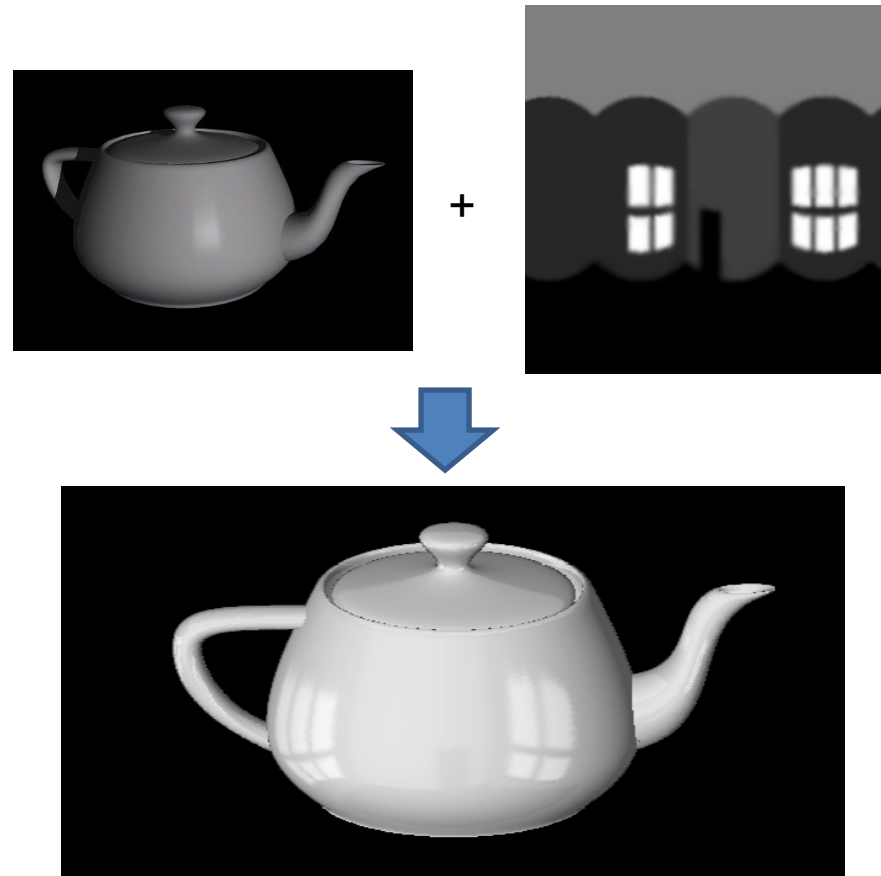


(d) Computing the global illumination solution



# 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



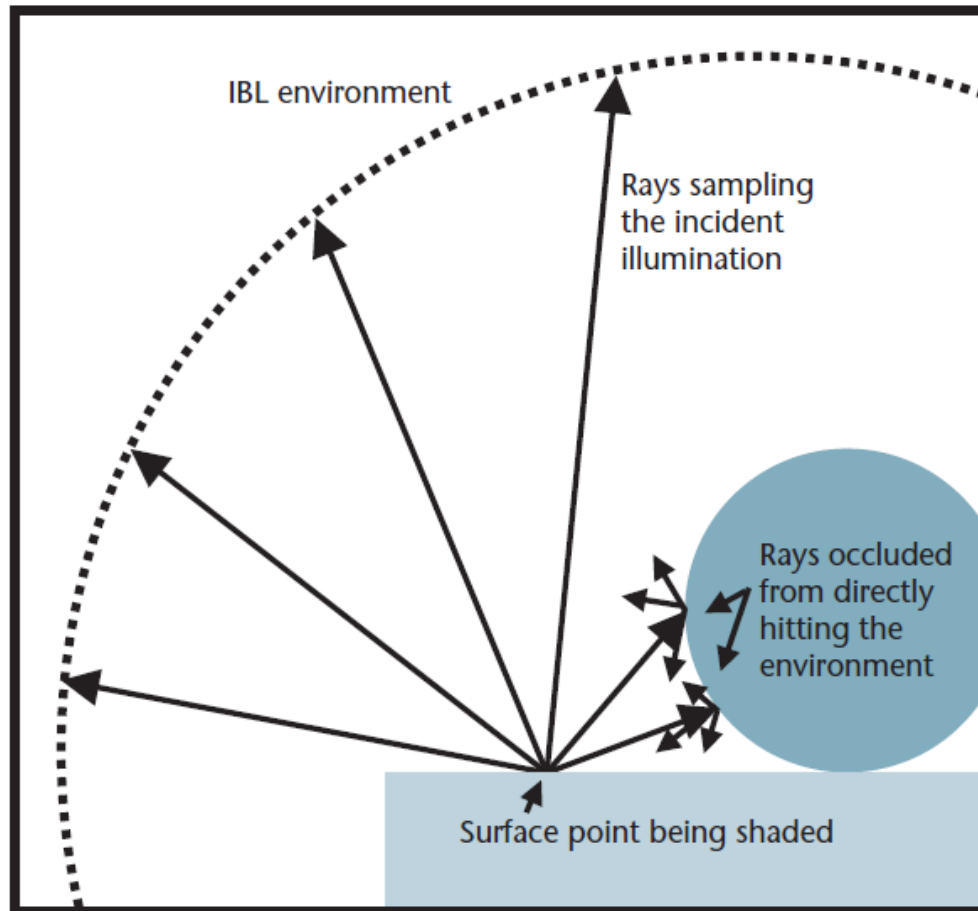
# Key ideas for Image-based Lighting

- 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

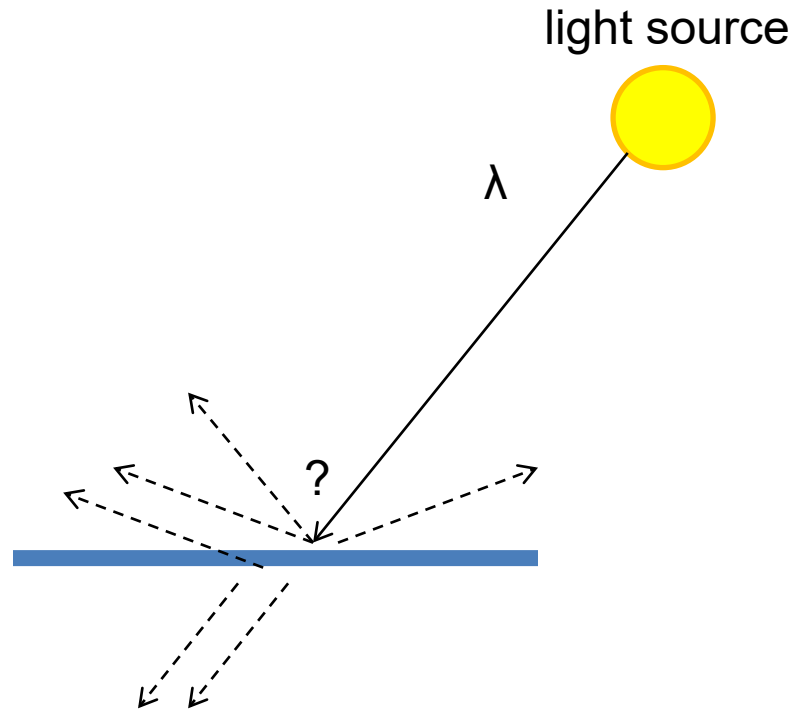


# Today

- Ray tracing
- Capturing environment maps

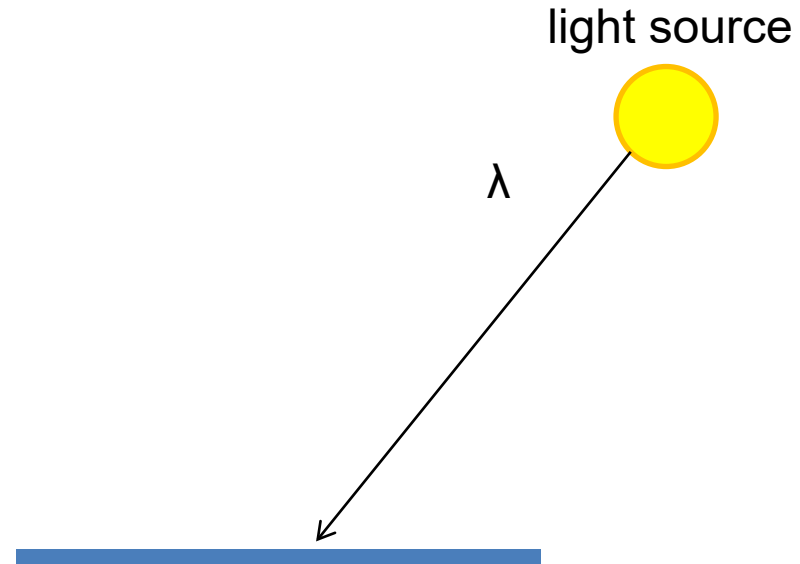
# A photon's life choices

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



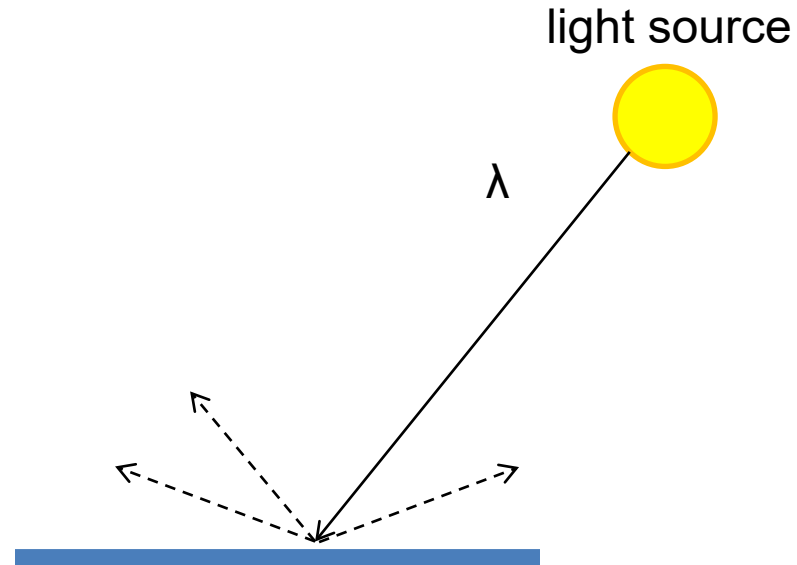
# A photon's life choices

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



# A photon's life choices

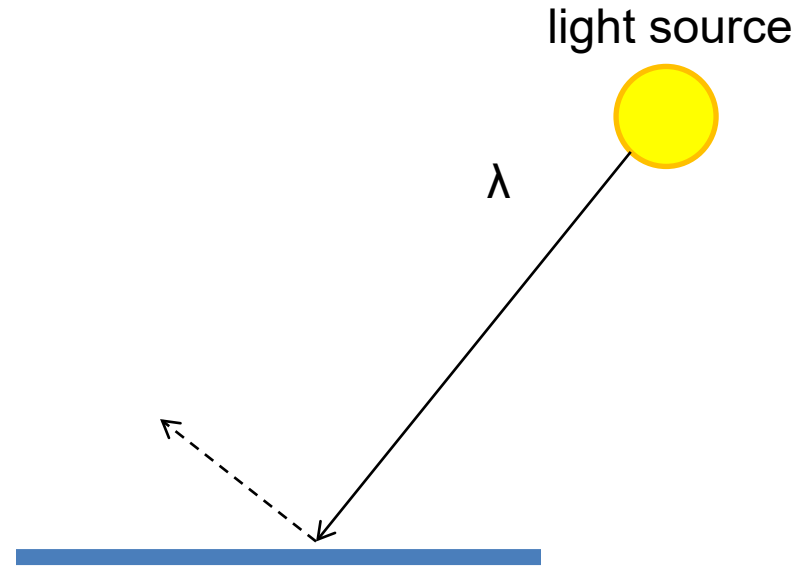
- Absorption
- **Diffuse Reflection**
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection





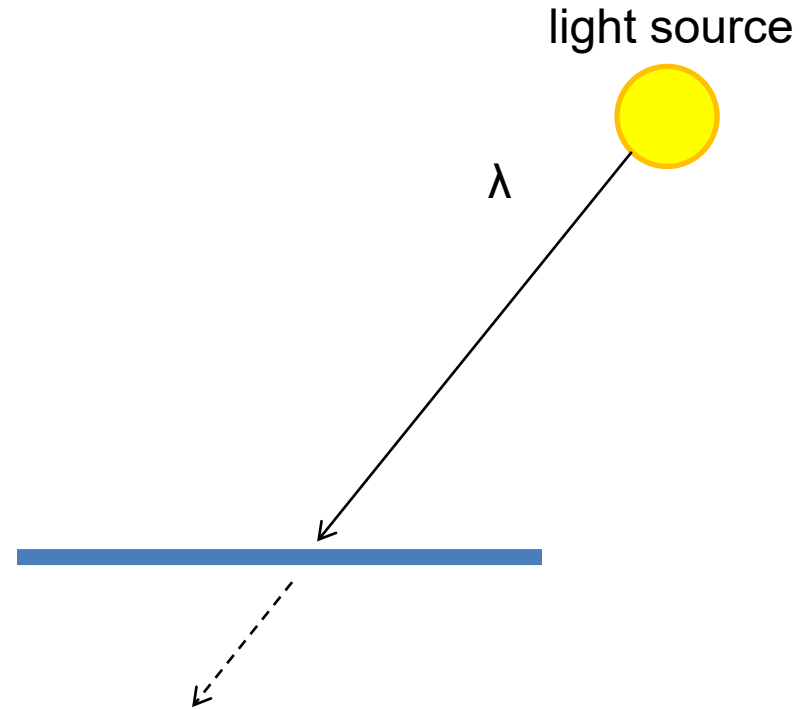
# A photon's life choices

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



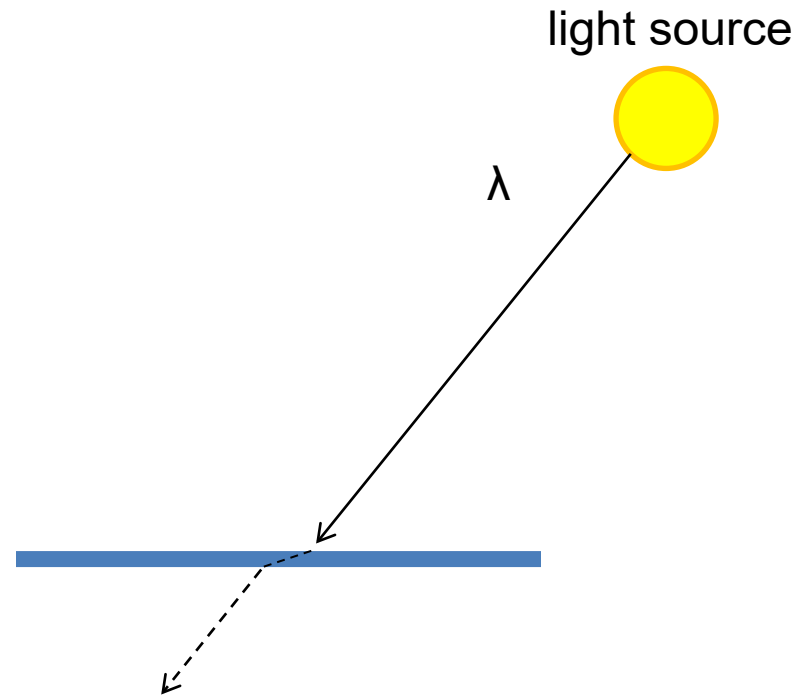
# A photon's life choices

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



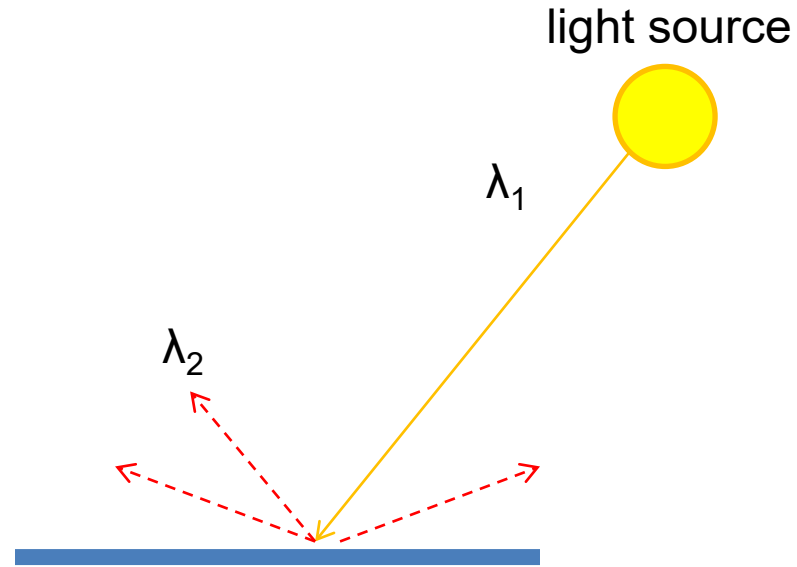
# A photon's life choices

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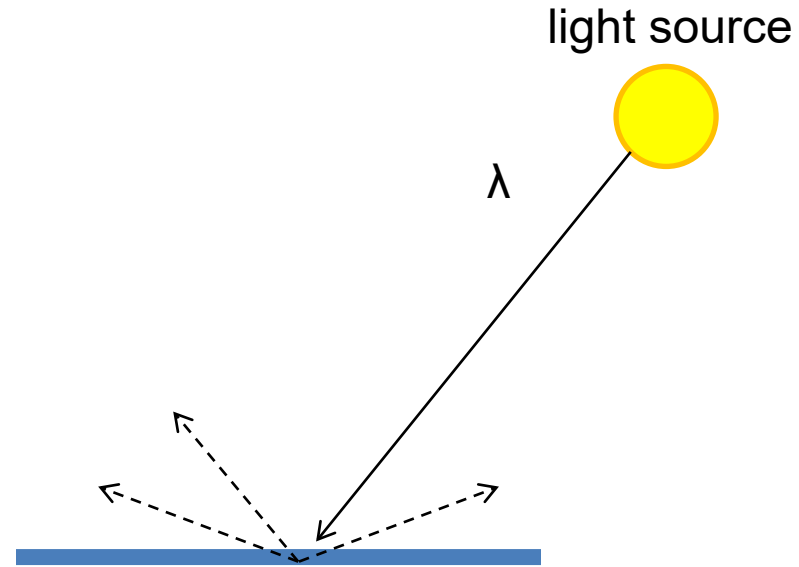
# A photon's life choices

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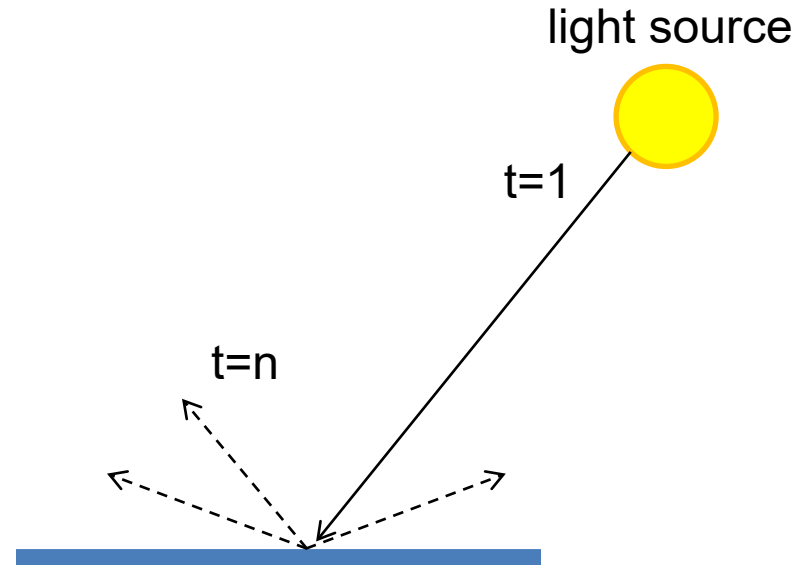
# A photon's life choices

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



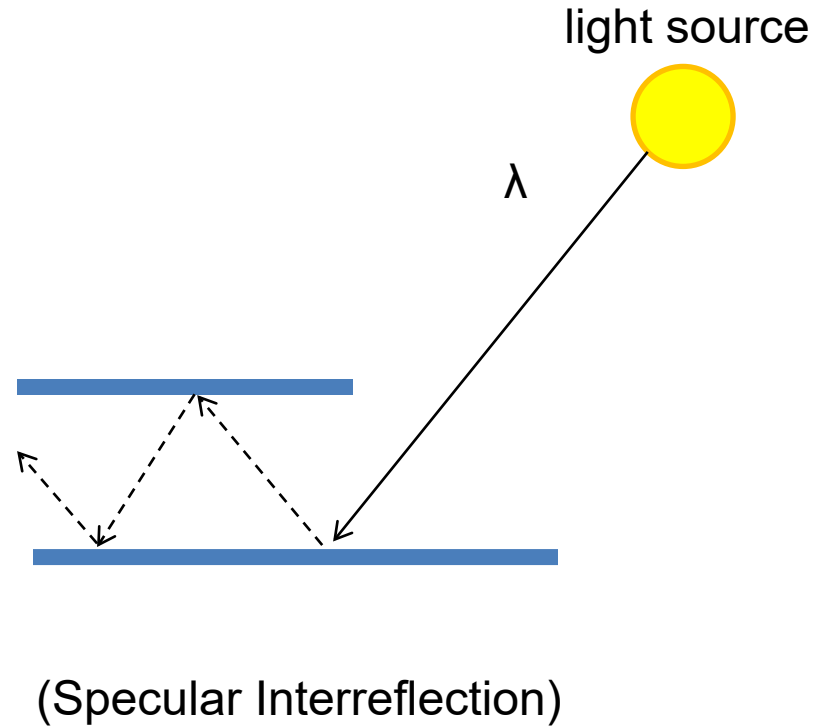
# A photon's life choices

- Absorption
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# A photon's life choices

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



Where are the light sources in this room?



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

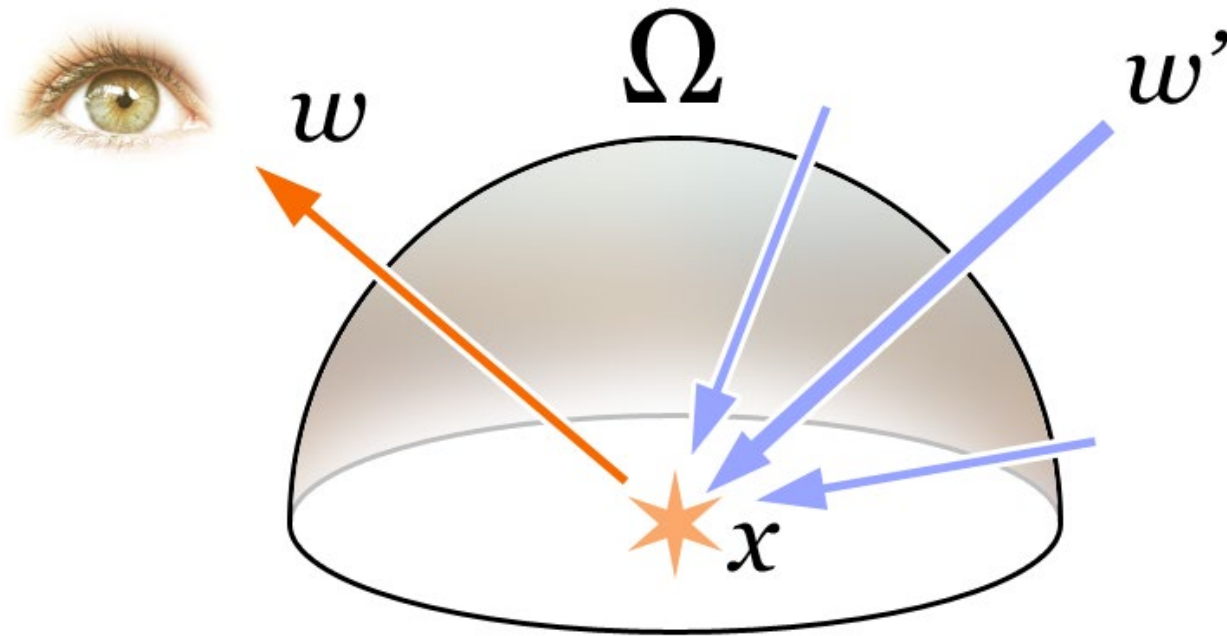


# Rendering Equation

Outgoing light      Generated light      Total reflected light

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

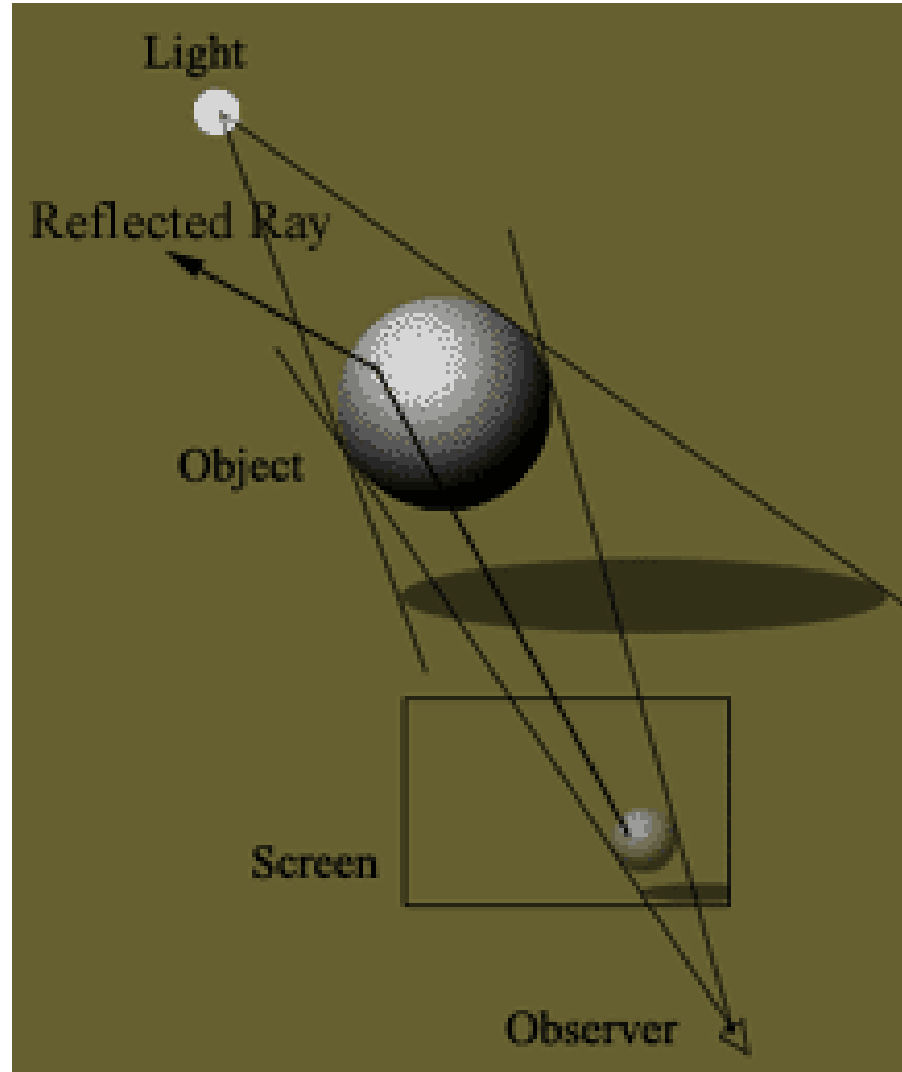
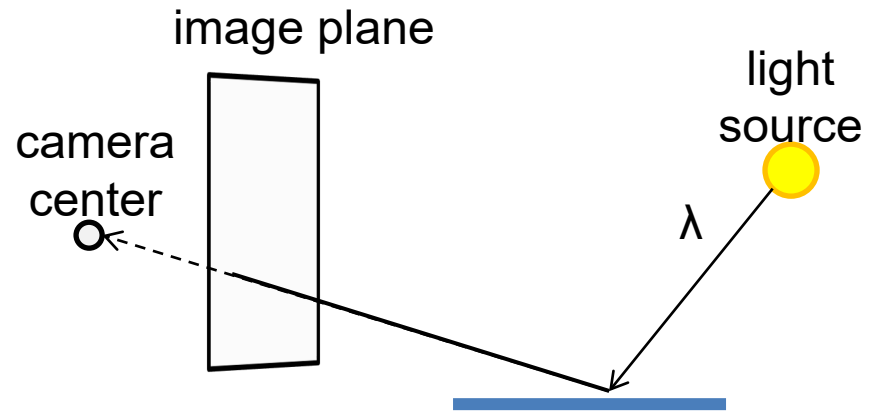
BRDF      Incoming Light      Incident angle



# Rendering a scene with ray tracing



# Ray tracing: basics



# Ray casting

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

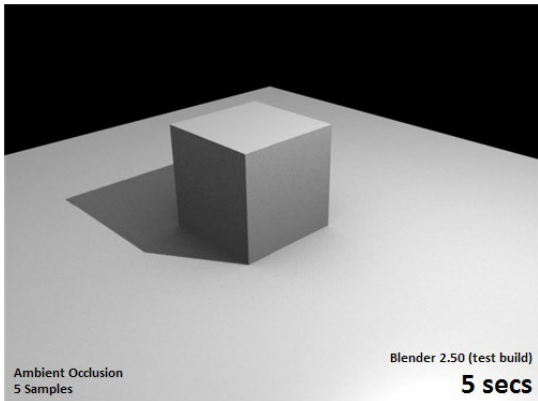
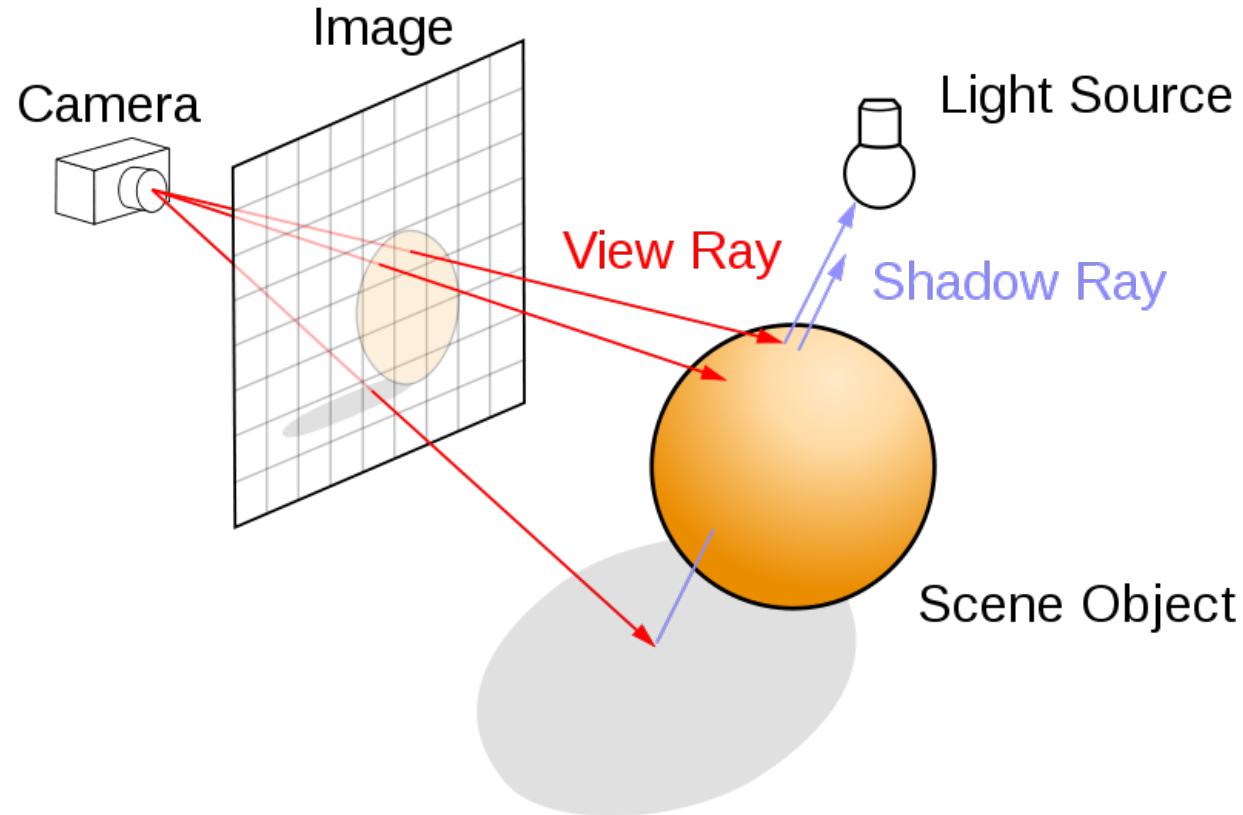


Wolfenstein 3D (1992)

# Ray tracing: fast approximation

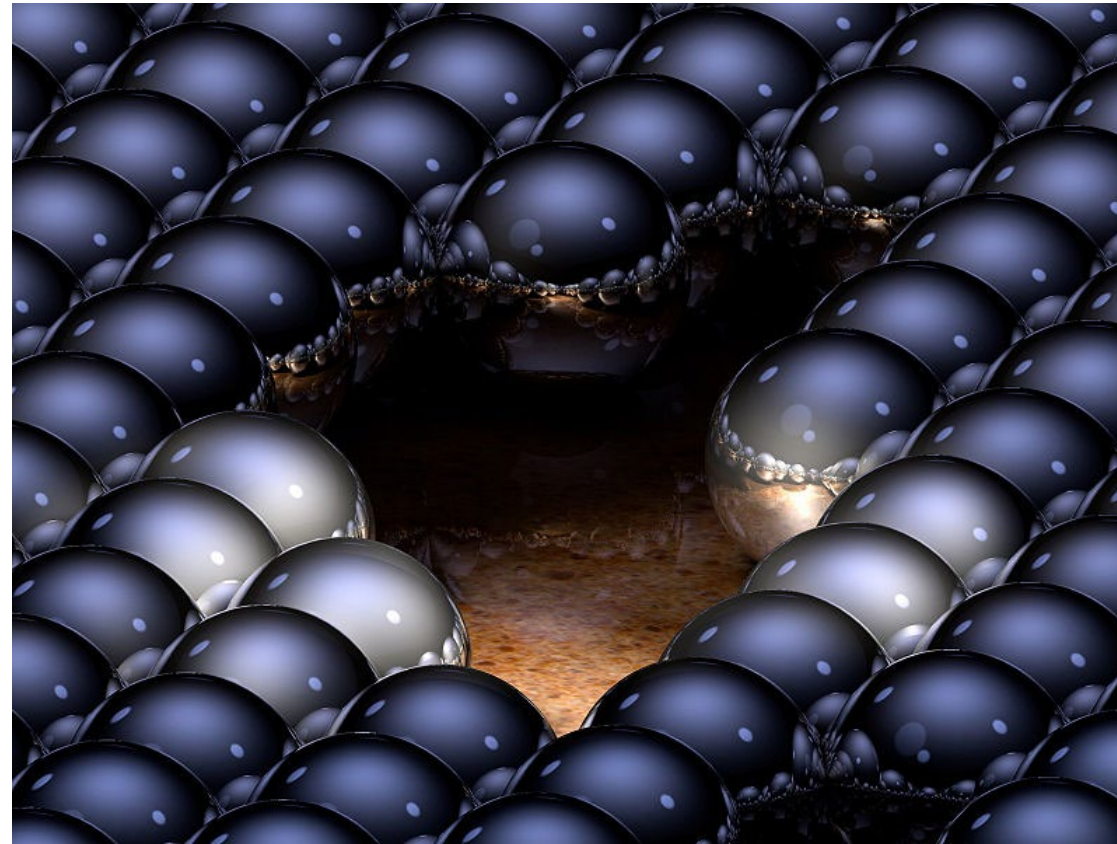
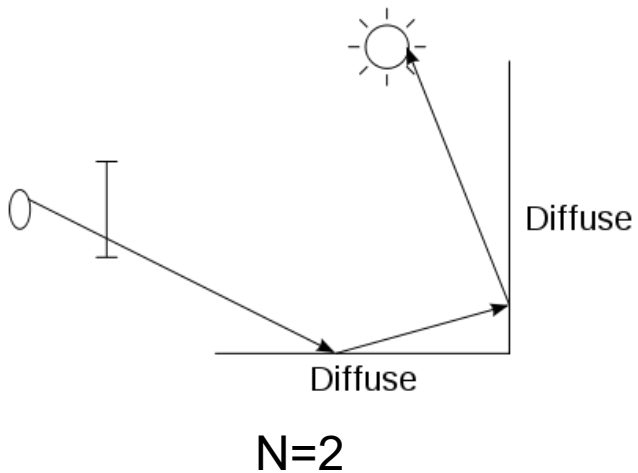
Upon hitting a surface

- Recursively (for N times), cast reflection/refraction ray(s) to determine reflected or refracted surface
- Cast shadow ray: go towards light and see if an object is in the way



# Ray tracing: interreflections

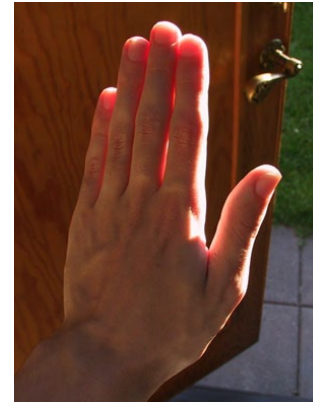
- Reflect light  $N$  times before heading to light source



$N=16$

# 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

- May take various forms, e.g.
  - Cubic map
  - Spherical map
- 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 from graphics:
  - 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



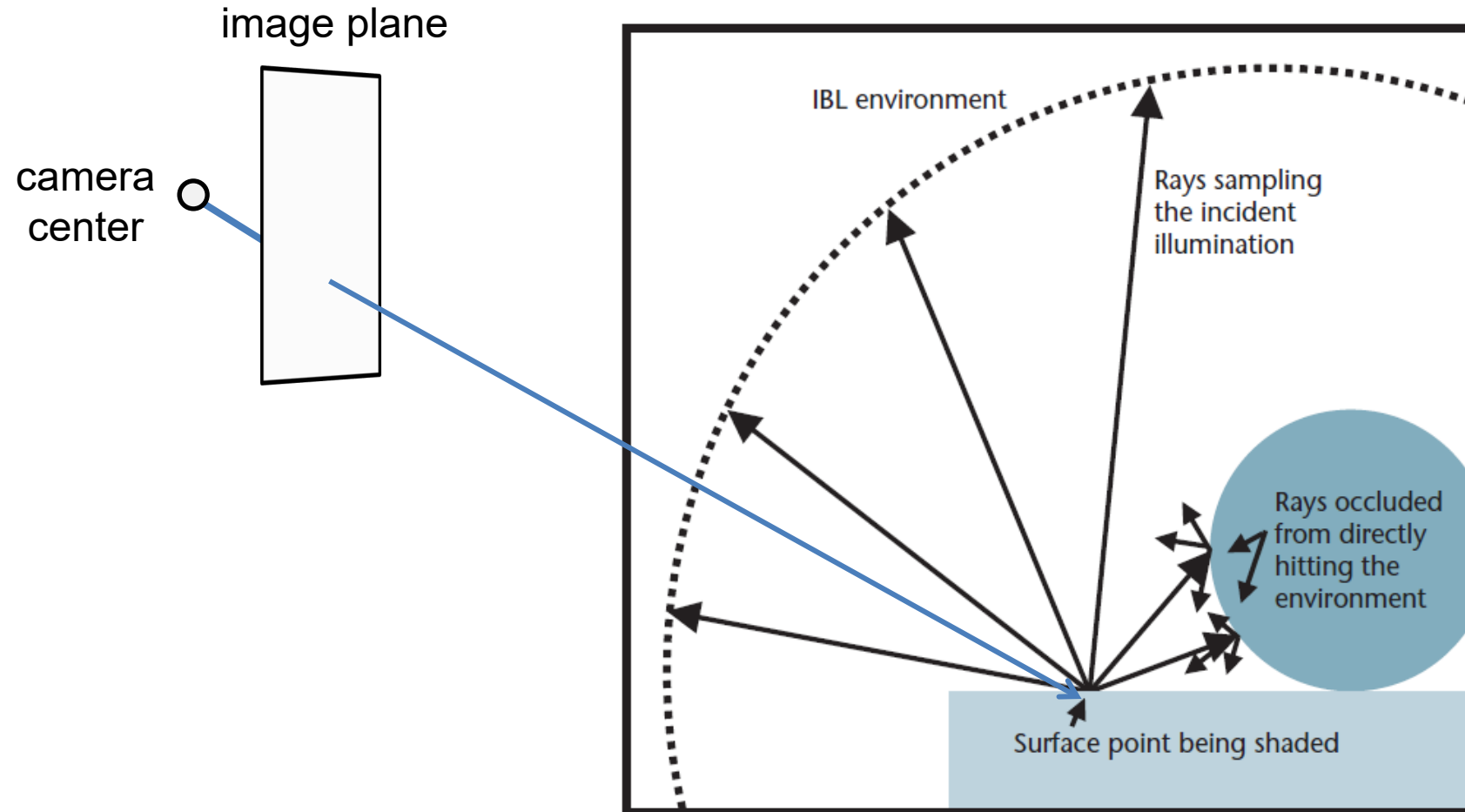
# Sphere mapping

- Map lives on a sphere
- To generate the map:
  - Render a spherical panorama from the designed center point
  - “Render” means obtain pixel intensities by casting rays from the camera center through the pixel positions
- 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 (CoP)
  - 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
- Interreflections among object and nearby surfaces are not captured by the environment map

# Rendering with environment maps and local models



# Storing environment maps



**Angular mapped**



**Spherical  
Equirectangular  
LatLong  
Latitude/Longitude**



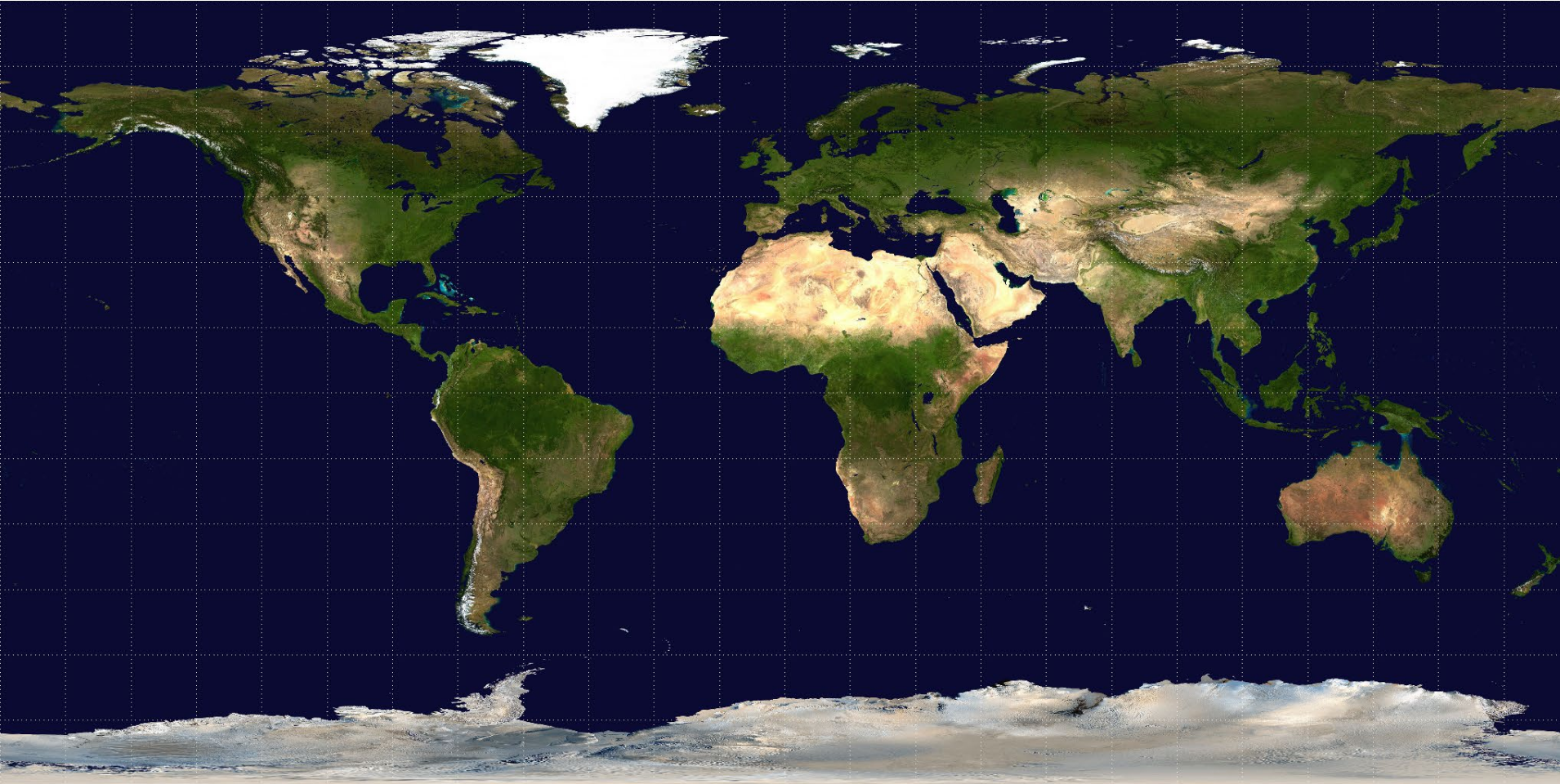
**Vertical Cross  
Cubic (vcross)**

# Equiarectangular (latitude-longitude) projection

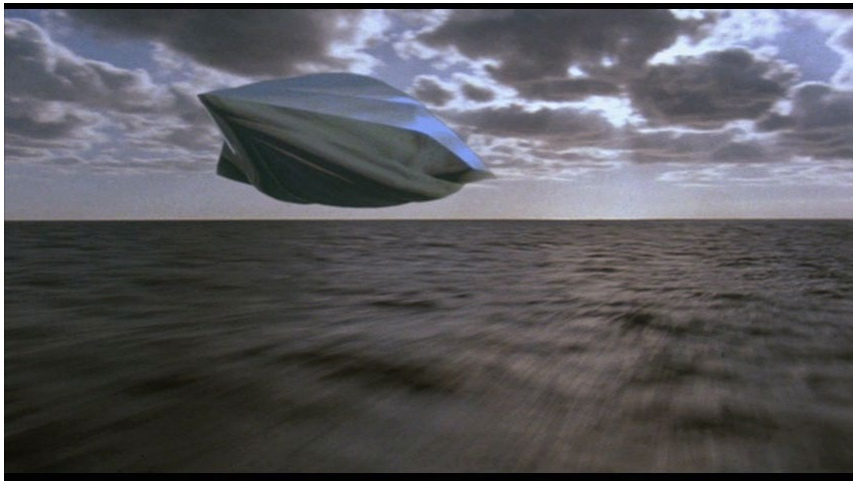




# Equiarectangular (latitude-longitude) projection



# How to capture light in real scenes?



From *Flight of the Navigator*

# How to capture light in real scenes?

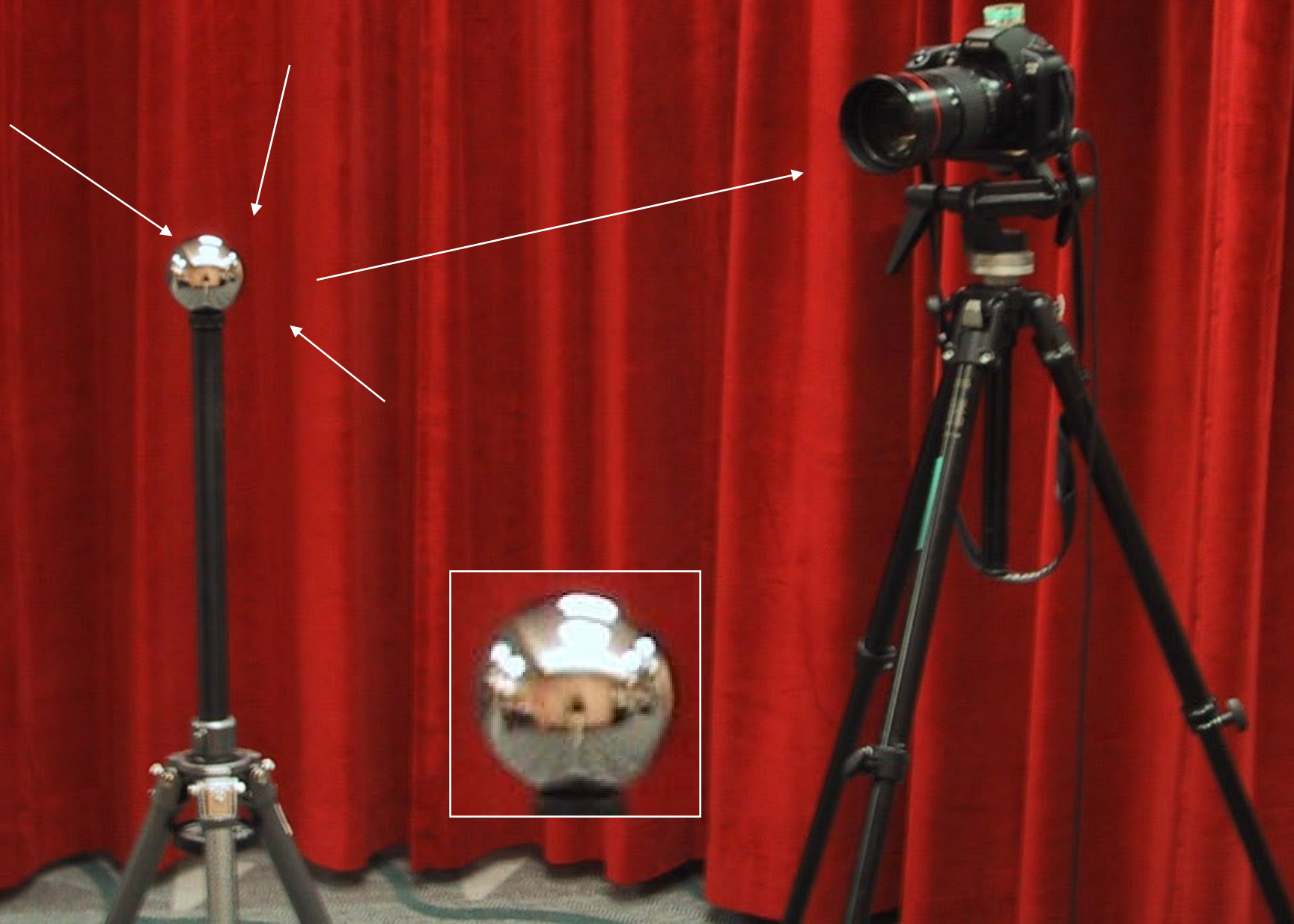


from Terminator 2

# Real environment maps

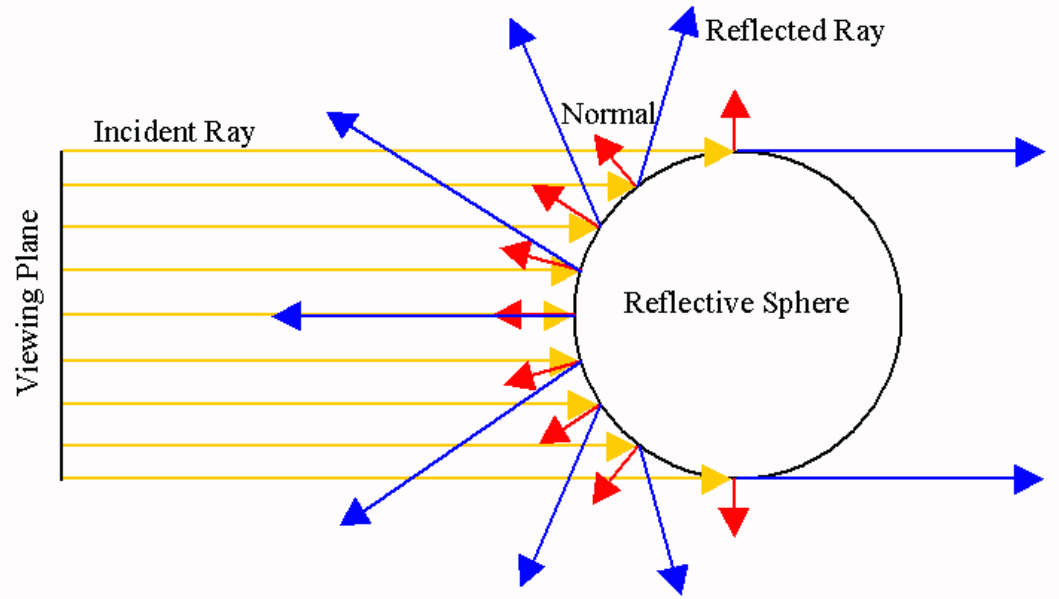
- We can use photographs to capture environment maps
  - The first use of panoramic mosaics
  - Fisheye lens
  - 360 camera
  - Mirrored balls (**light probes**)

# Mirrored Sphere





One picture of a mirrored ball received light coming into the ball from nearly all angles (including behind)



# Mirror balls for image-based lighting





# Mirror balls for image-based lighting



# Mirror balls for image-based lighting

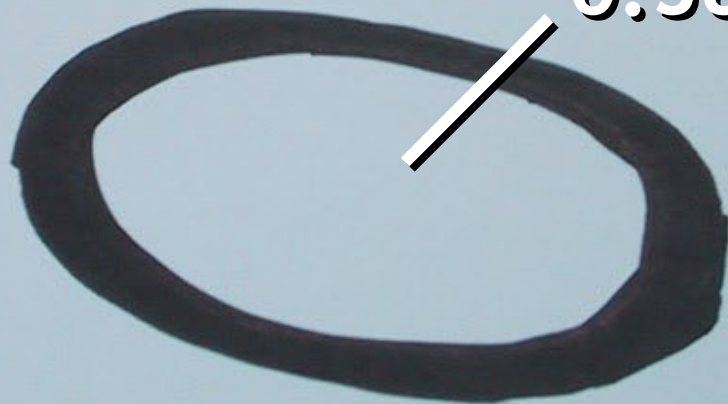




0.34

=> 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  $\phi$ ,  $\theta$

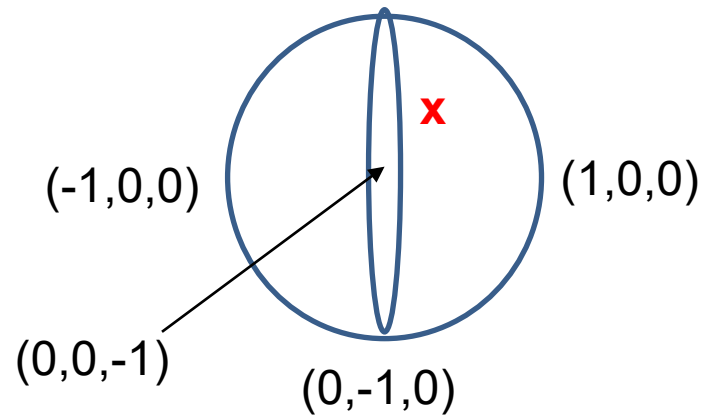
# Solving for normal vector



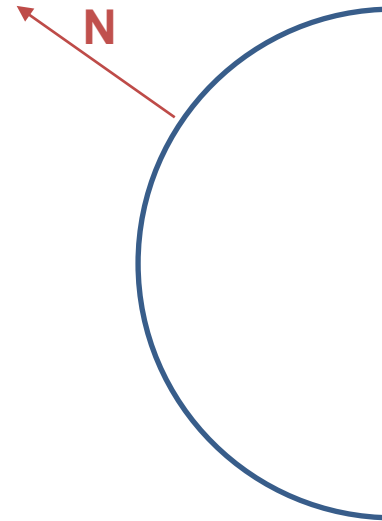
$(u, v) \rightarrow (N_x, N_y, N_z)?$

$$N_x = (u - \text{center}) / (\text{width}/2)$$

$$N_y = (v - \text{center}) / (\text{height}/2)$$



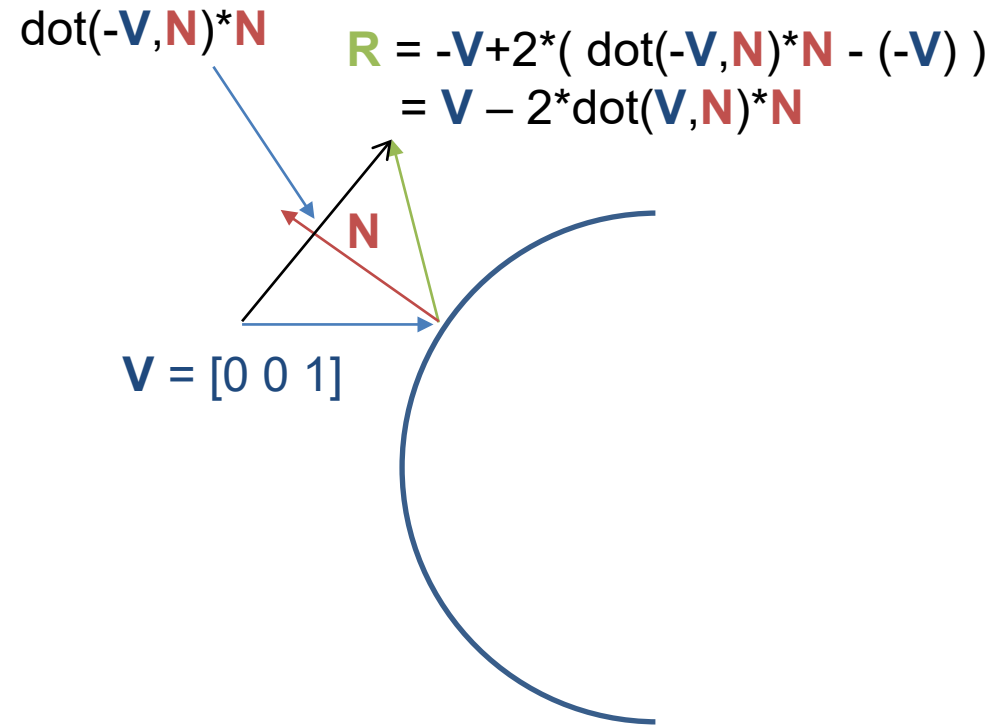
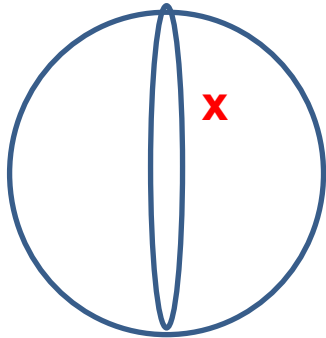
$$N_x^2 + N_y^2 + N_z^2 = 1$$



# Solving for reflection vector



$(u, v) \rightarrow (N_x, N_y, N_z)$





# Mirror ball -> equirectangular



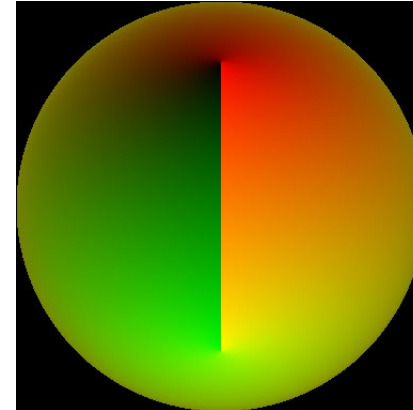
Mirror ball



Normals



Reflection  
vectors



Phi/theta of  
reflection vecs

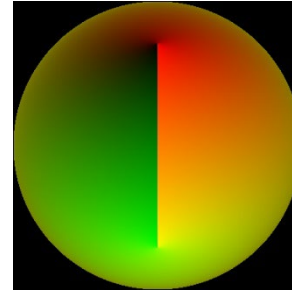
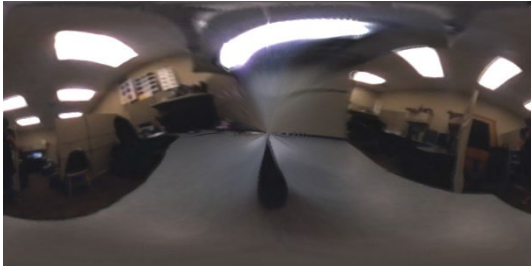


Equirectangular

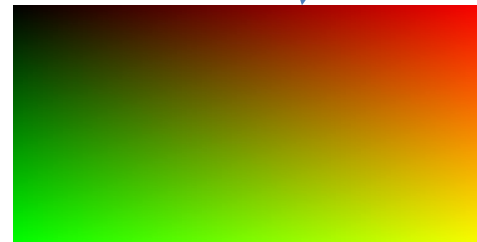


Phi/theta equirectangular  
domain

# Mirror ball -> equirectangular

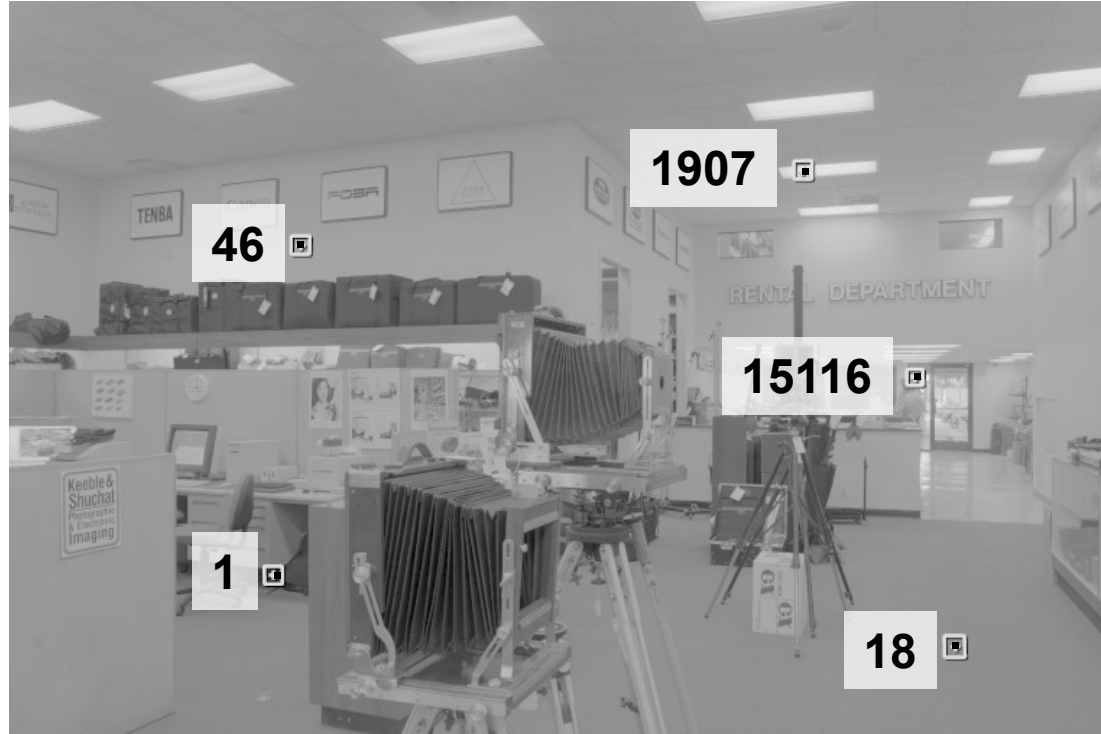


```
latlon(:, :, c) = griddata( (phi_ball, theta_ball),  
mirrorball(:, :, c),  
(phi_latlon, theta_latlon),  
method='linear',  
fill_value='0')
```

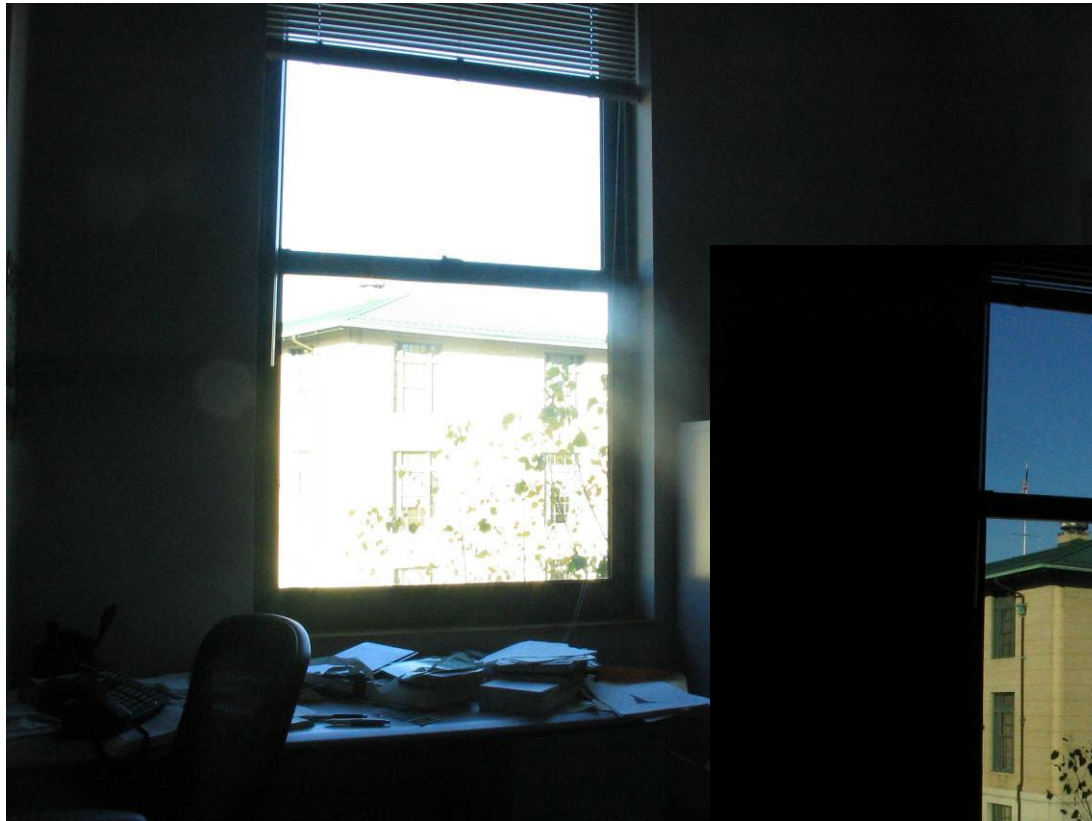


# One small snag

- 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



1

The real world is  
high dynamic range



1500



25,000

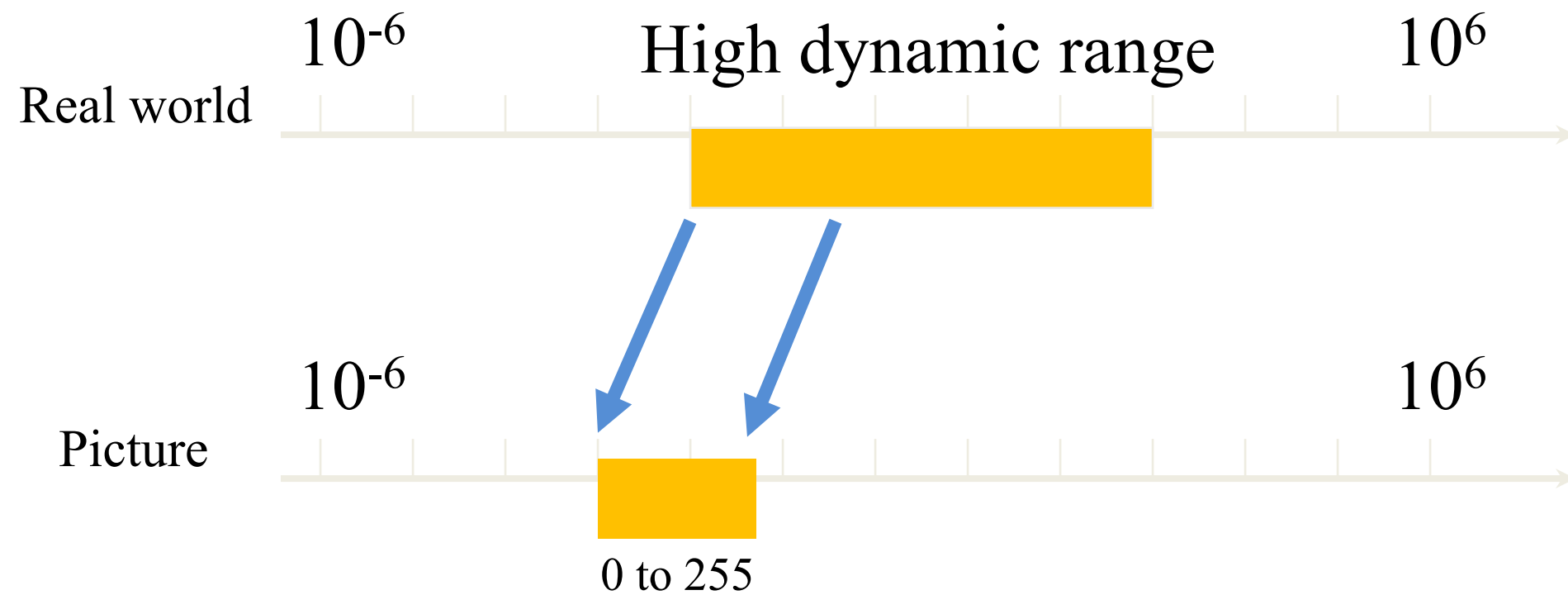


400,000

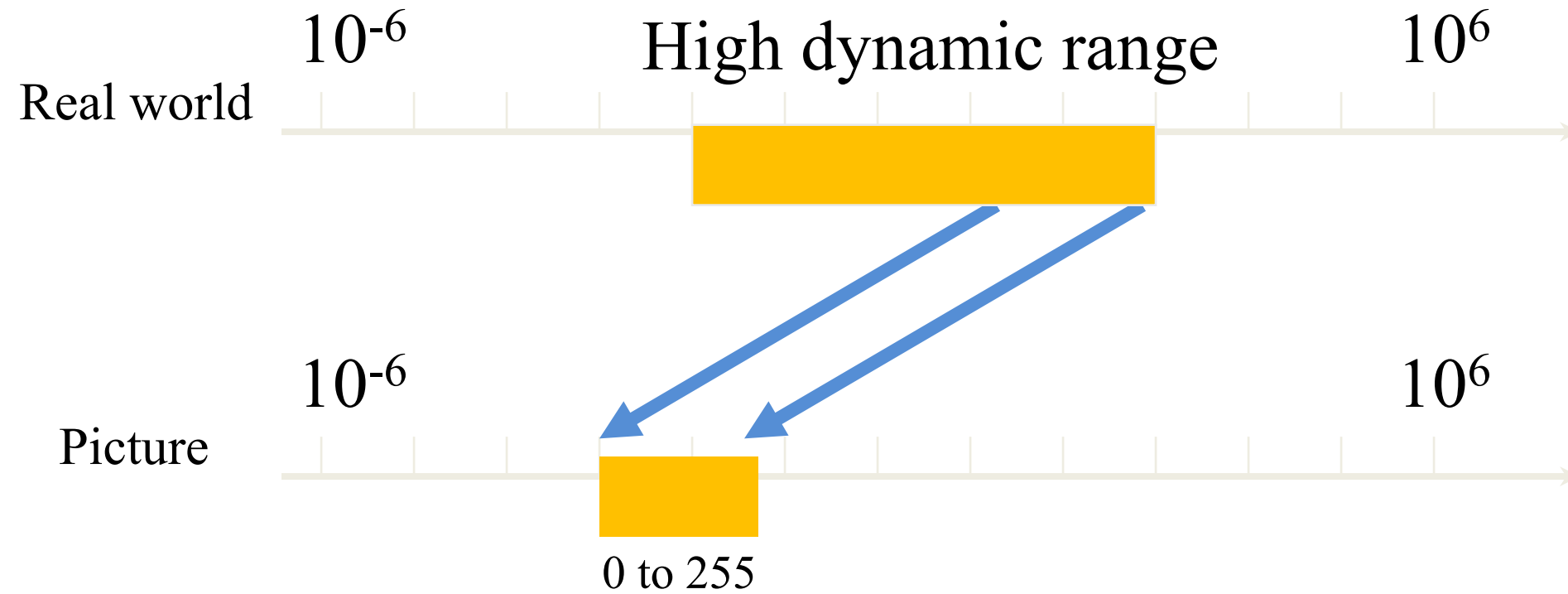


2,000,000,000

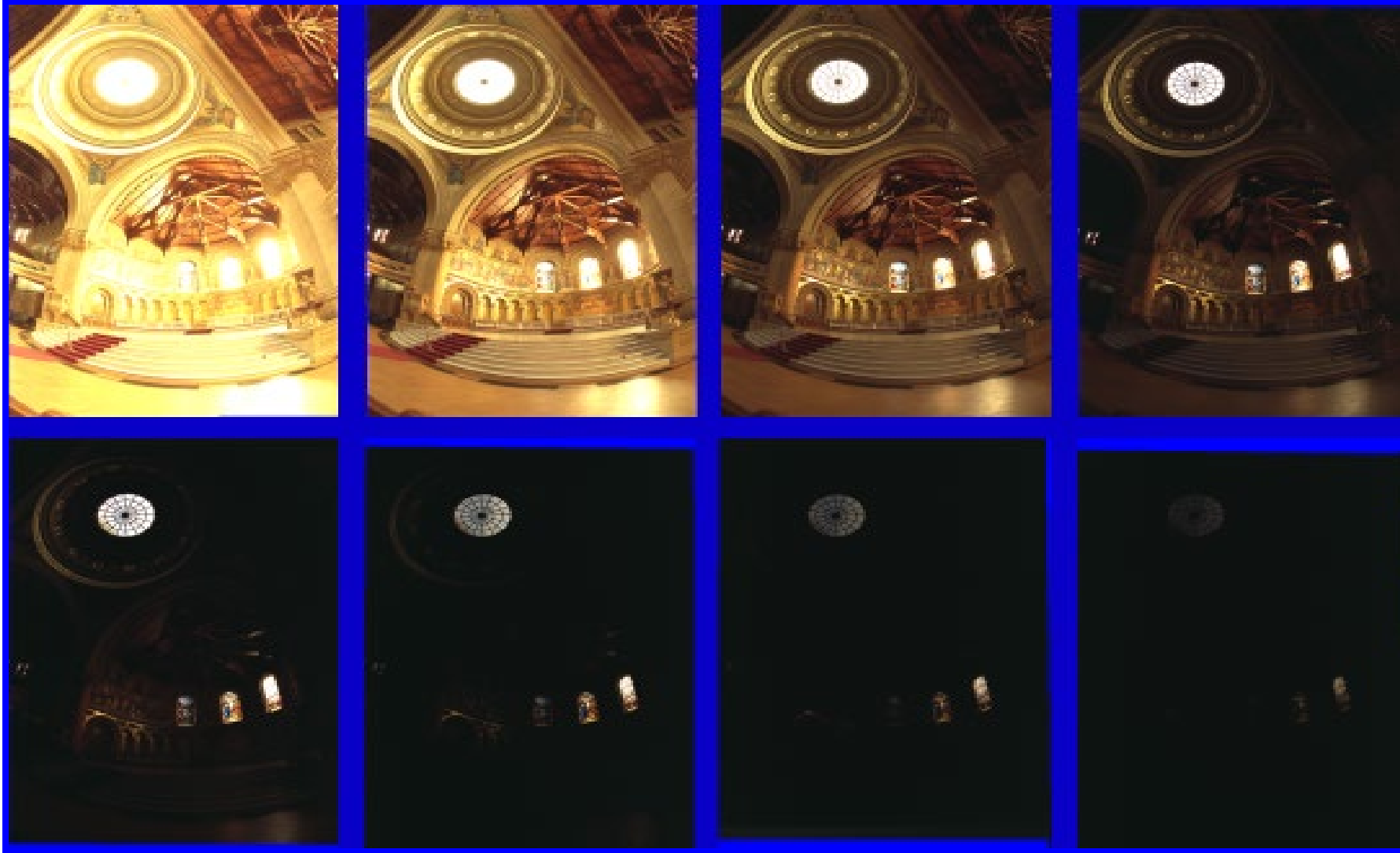
# Long Exposure



# Short Exposure



# Varying Exposure





# Camera is not a photometer

- Dynamic range is limited
  - Can use multiple exposures to capture fuller range
- Responds non-linearly to photon intensity
- Solution: Recover response curve from multiple exposures and reconstruct the *radiance map*

# Next class

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