Image-based Lighting

T2

Computational Photography

Derek Hoiem, University of Illinois

Many slides from Debevec, some from Efros

Next two classes

Today

- Details on final projects
- Go over some exam questions
- Start on ray tracing, environment maps, and relighting 3D objects

Thursday

- Finish relighting
- Start on hardware side of computational photography: plenoptic camera, coded aperture

Final Projects

- To do (11/24 or sooner): Send me an e-mail with
  1. a one-paragraph summary of your project idea
  2. when you'd like to meet with me

     - either this Thursday afternoon except 2:30-3:30, this Friday, or the week after break

- Ideas
  - Implement one or more related papers: texture synthesis, image analogies, single-view 3D reconstruction, inserting 3D models, hole-filling, etc., etc.
  - Extend one of the projects, bringing in ideas from a couple related papers
  - Do something that seems fun/interesting to you or that builds on interests/research in other areas

- What is the scope?
  - 3 credit version: it's sufficient to get something working that has been done before
  - 4 credit version: try something new, or try experimenting with variations on an idea, integrate some ideas into your own research, or provide a thorough experimentation, perhaps comparing two methods

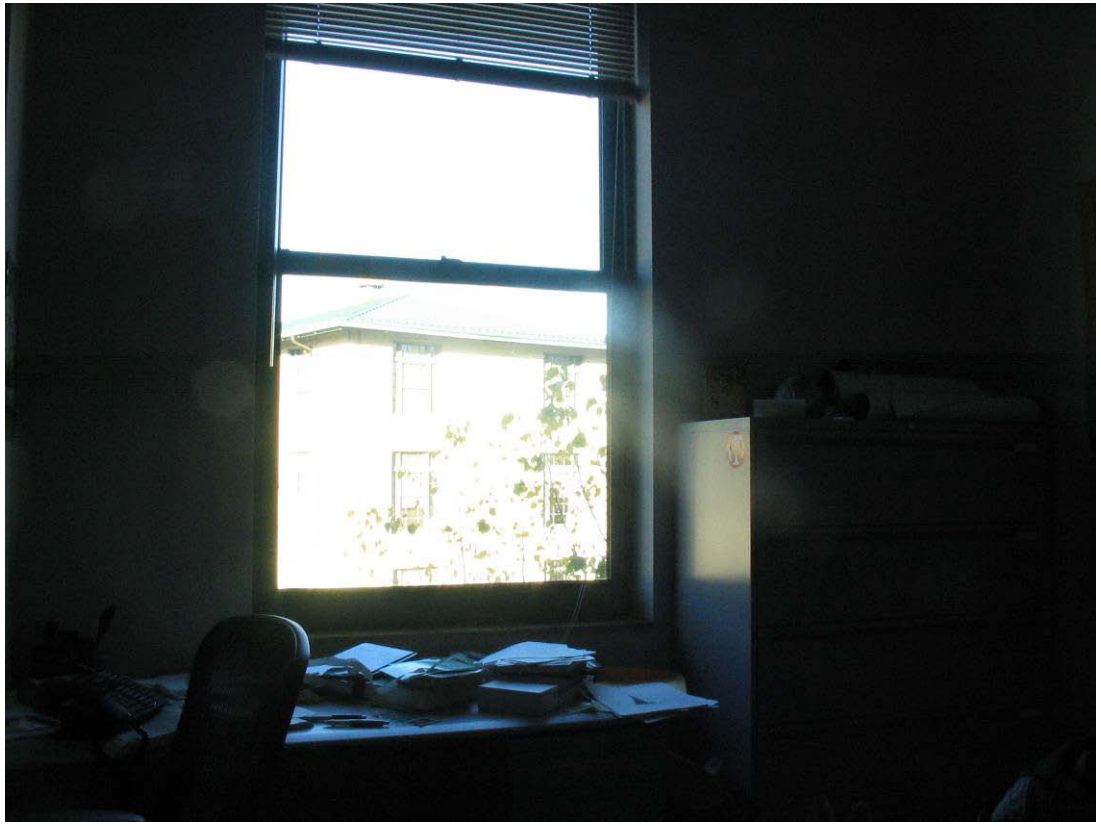
Final Projects

- Project page write-up due on Dec 13 (11:59pm)
  - Similar to other projects, but with some more detail on how to do it
  - Can be in html or pdf
  - Store at url below or include a link from there
    http://<username>.projects.cs.illinois.edu/cs498dwh/final/

- Class presentations on Dec 14 (1:30-4:30pm)
  - ~7 minutes per presentation

- Project Grade
  - 80%: implementation, results
  - 20%: presentation

How to render an object inserted into an image?



What’s wrong with the teapot?

How to render an object inserted into an image?

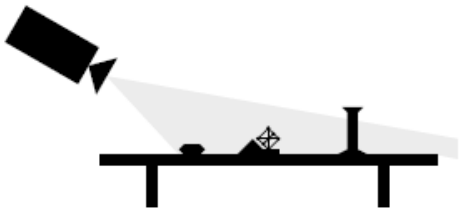
Traditional graphics way

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

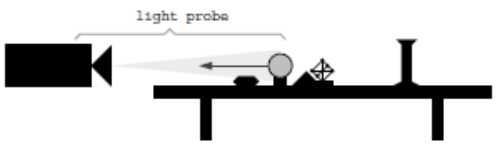
How to render an object inserted into an image?

Image-based lighting

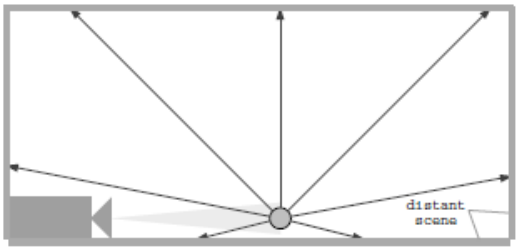
- Capture incoming light with a "light probe"
- Model local scene
- Ray trace, but replace distant scene with info from light probe



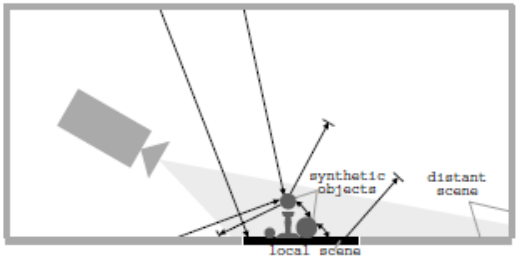
(a) Acquiring the background photograph



(b) Using the light probe



(c) Constructing the light-based model

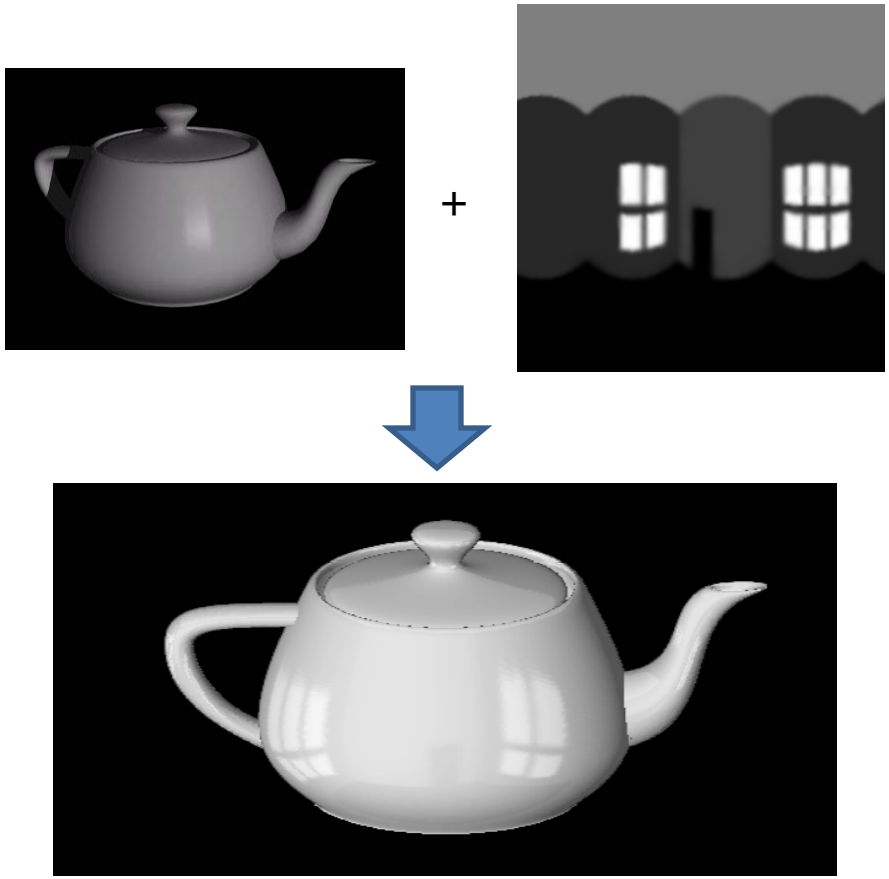


(d) Computing the global illumination solution

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

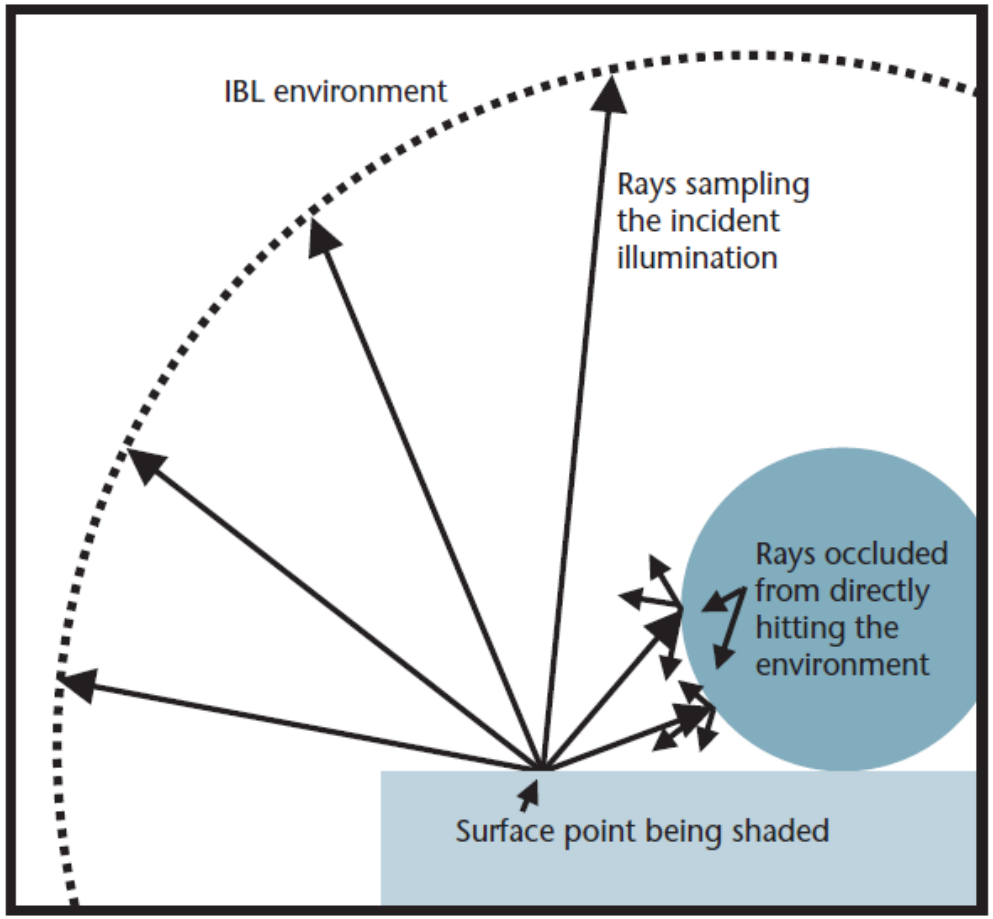
- Light probes: a way of capturing environment maps in real scenes

Key ideas for Image-based Lighting

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

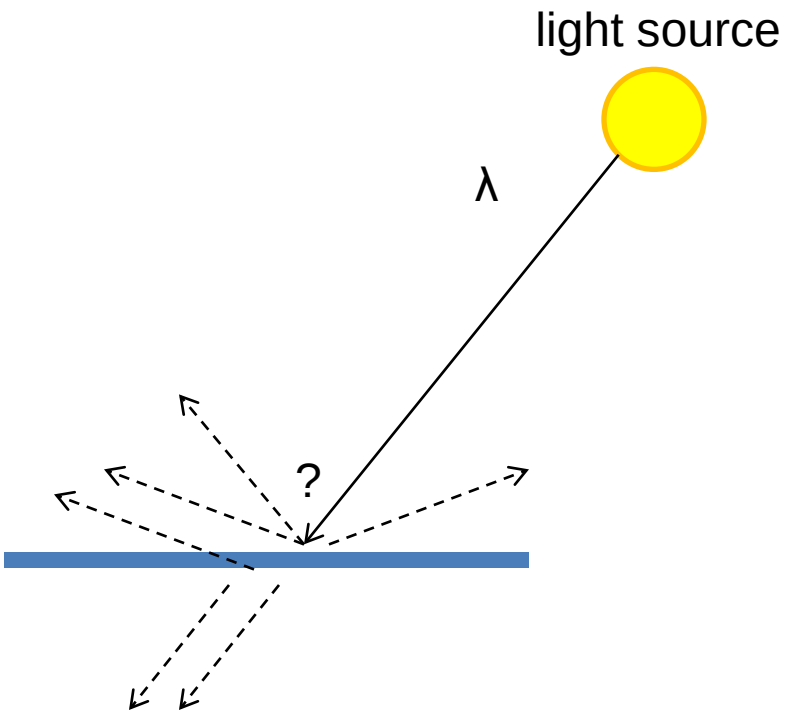
Key ideas for Image-based Lighting

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



A photon's life choices

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



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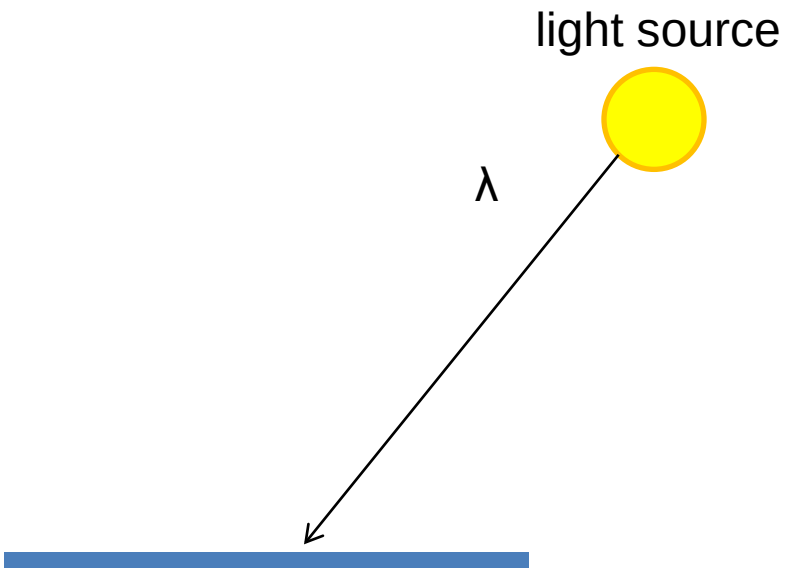

A photon's life choices

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- **Diffuse Reflection**
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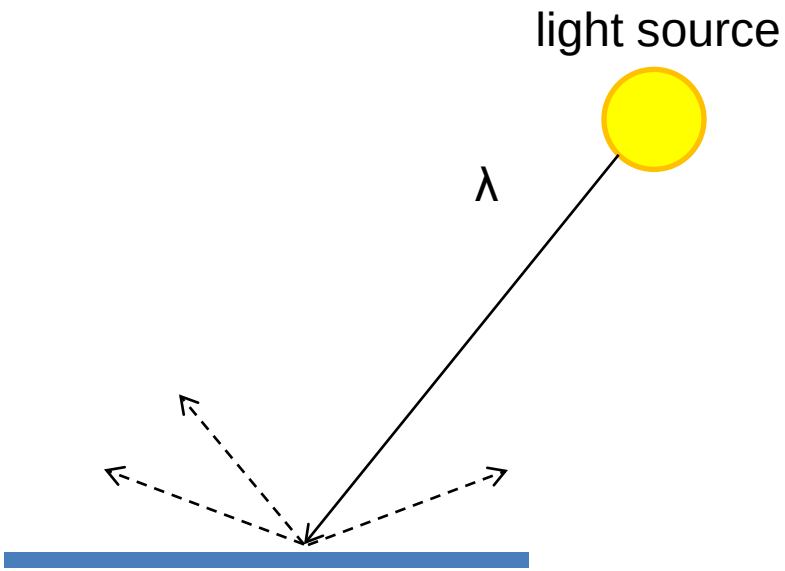

A photon's life choices

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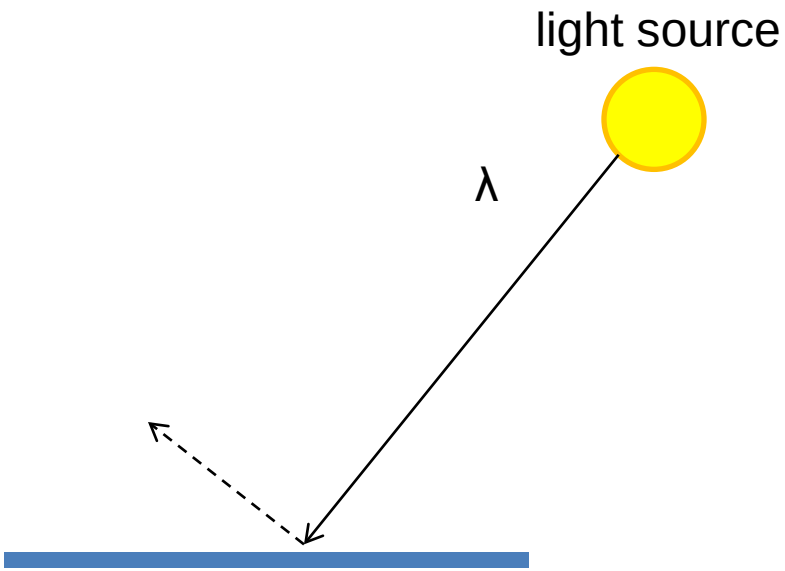
- Diffusion
- **Specular Reflection**
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



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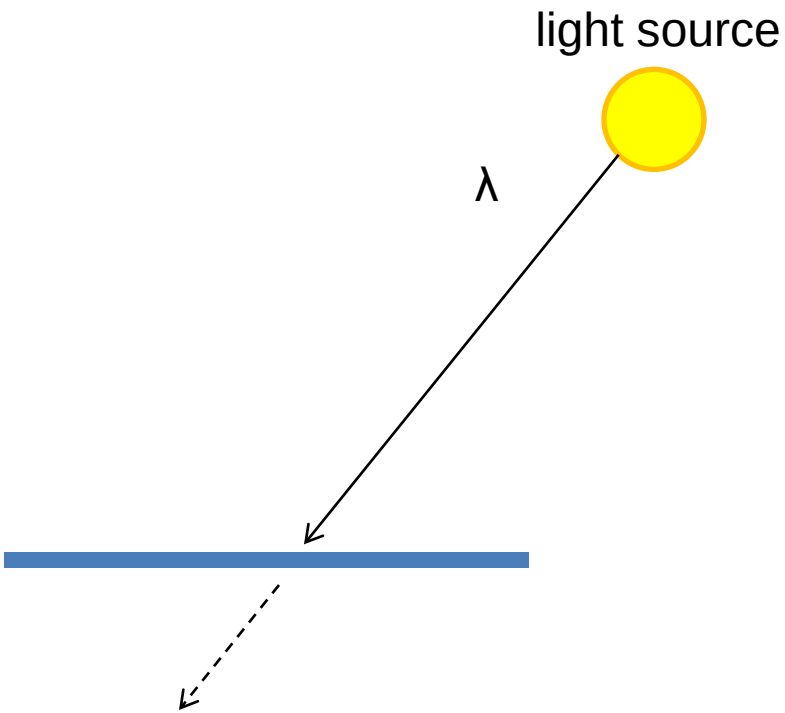

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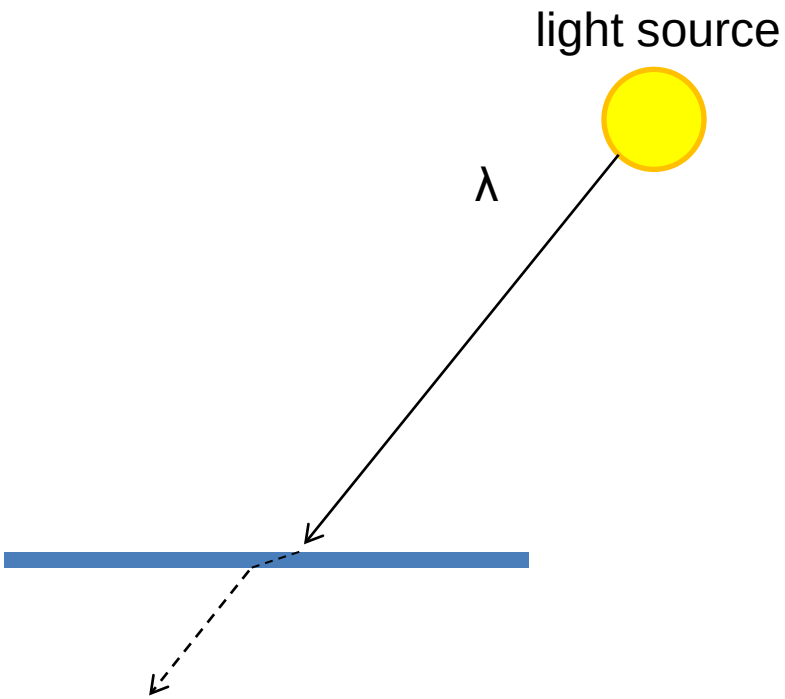

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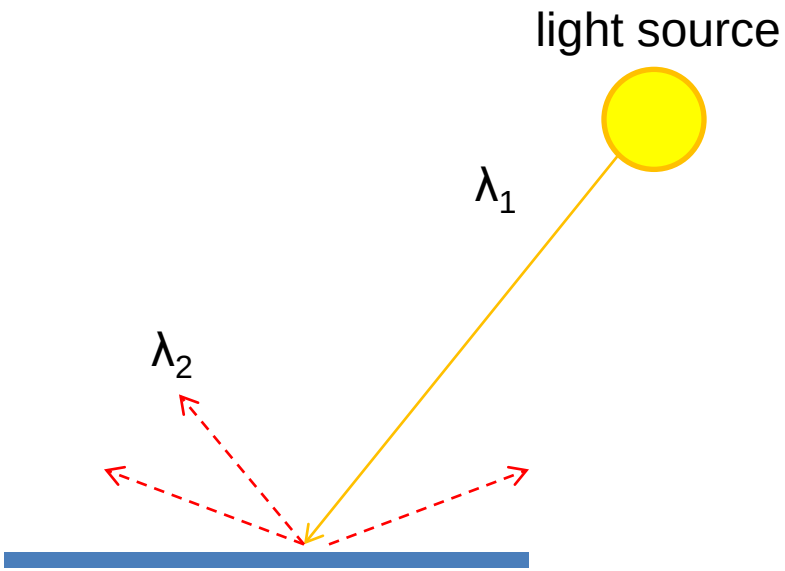

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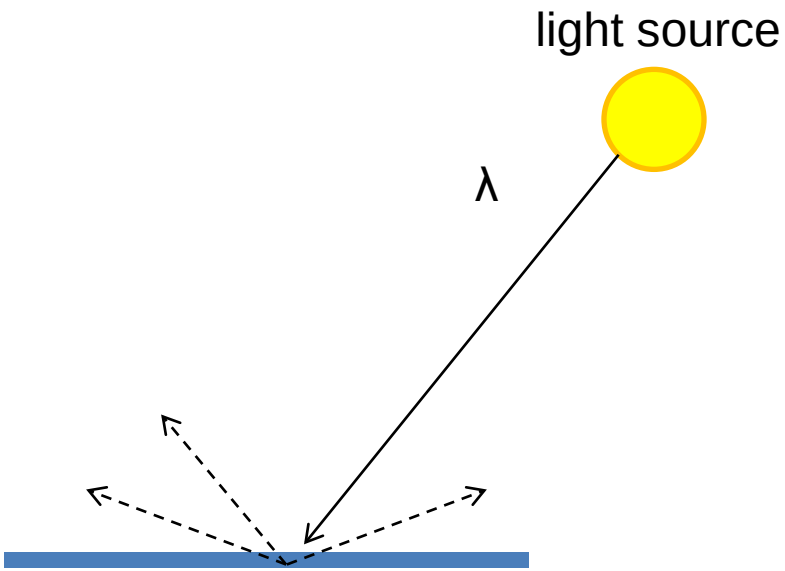

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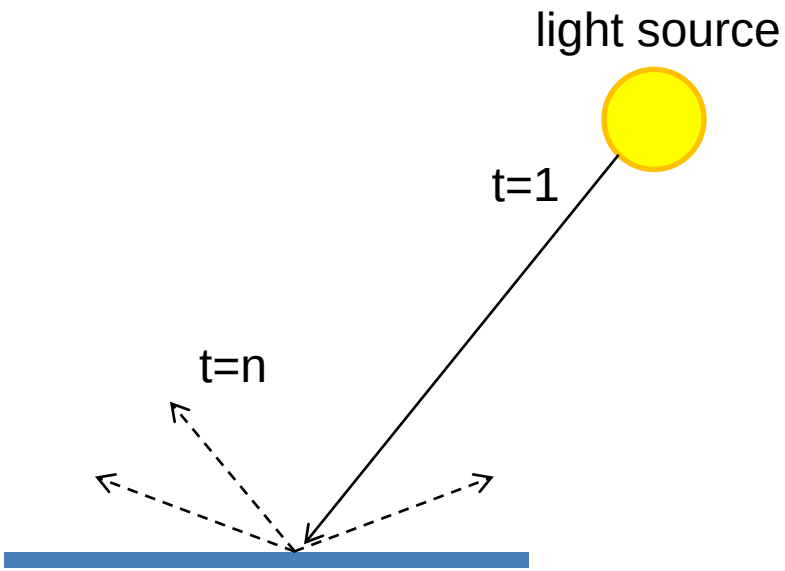

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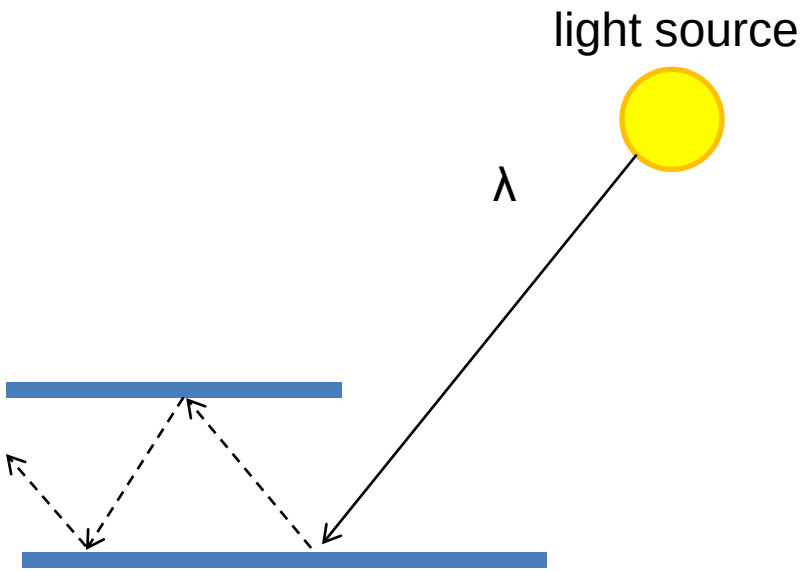


(Specular Interreflection)

Where are the light sources are in this room?

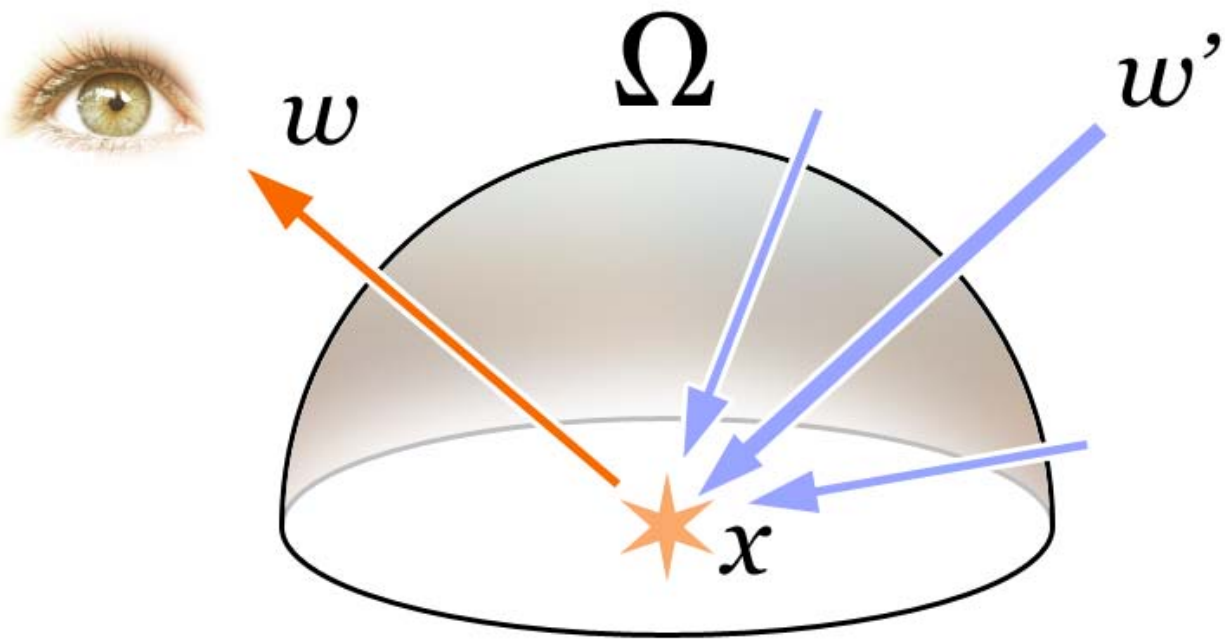
http://www.flickr.com/photos/chrisdonbavand/493707413/sizes/z/in/photostream/

Rendering Equation

Outgoing light Generated light Total reflected light

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

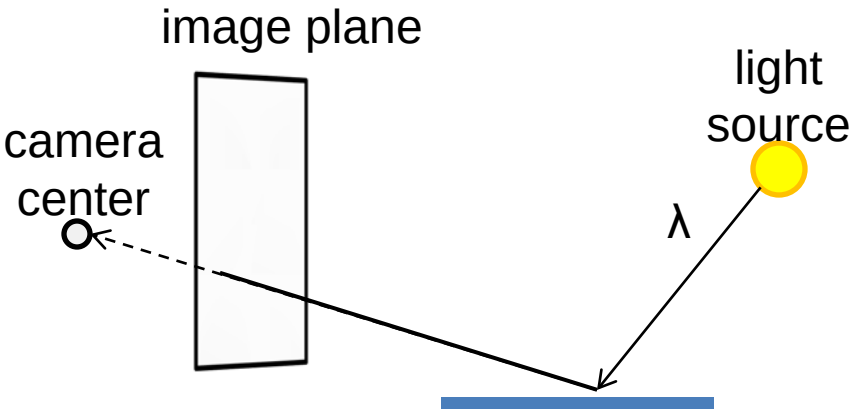
BRDF Incoming Light Incident angle



Rendering a scene with ray tracing

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

Ray tracing: basics



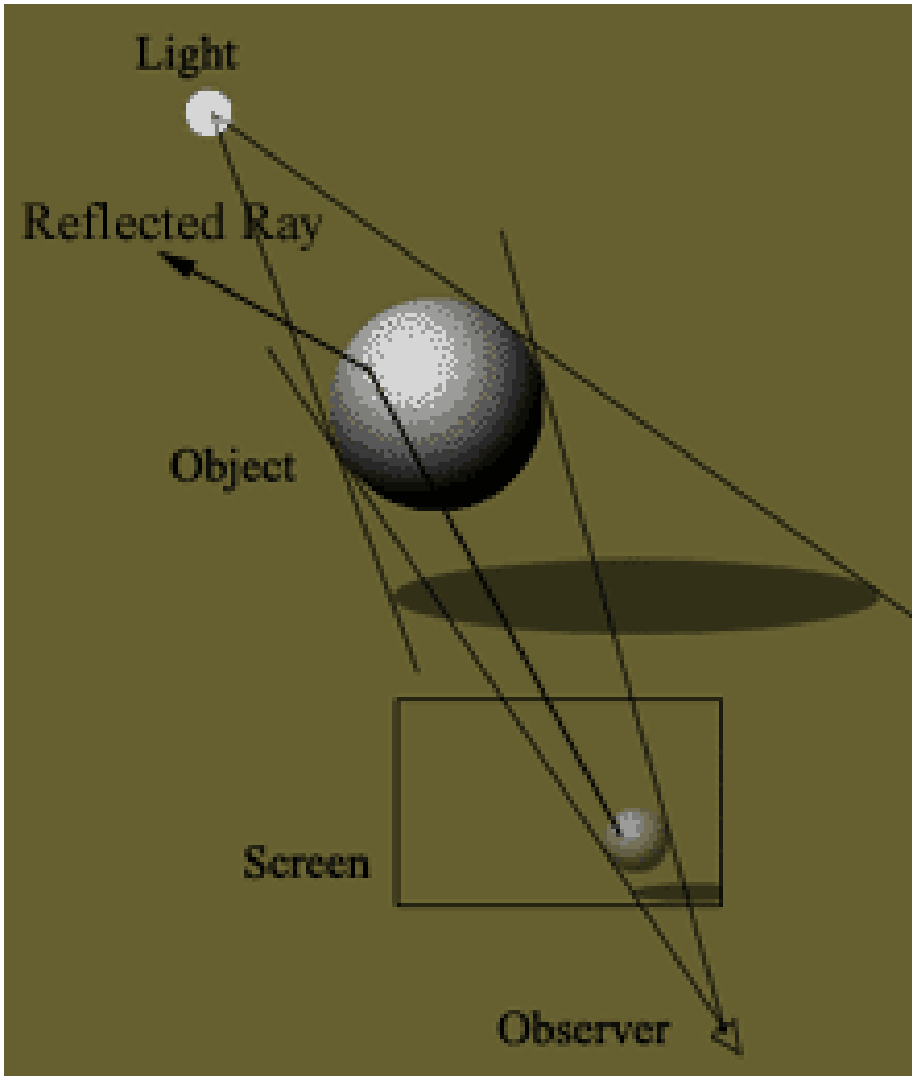


Illustration from http://www.groovyvis.com/other/raytracing/basic.html

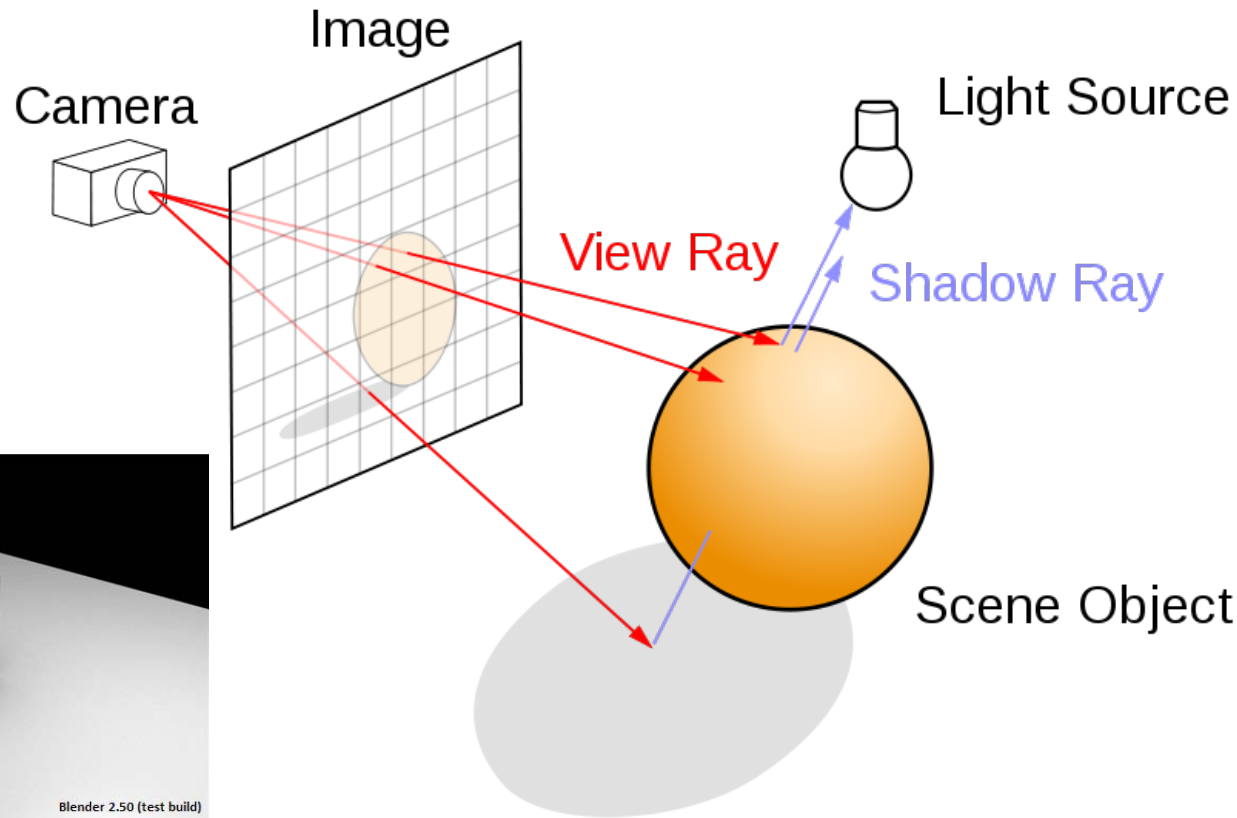
Ray casting

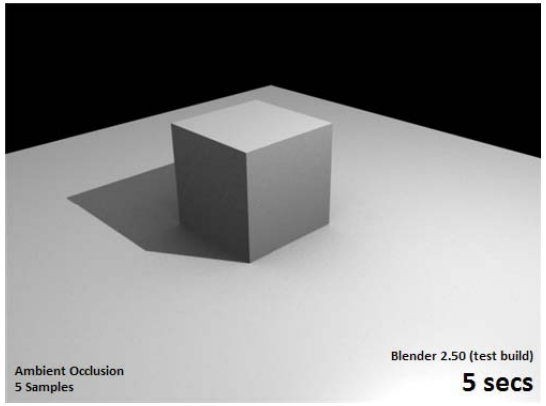
- Store colors of surfaces and see what you hit

Wolfenstein 3D (1992)

Ray tracing: fast approximation

- Cast diffuse ray: go towards light and see if an object is in the way
- Cast reflection ray: see what reflected object is

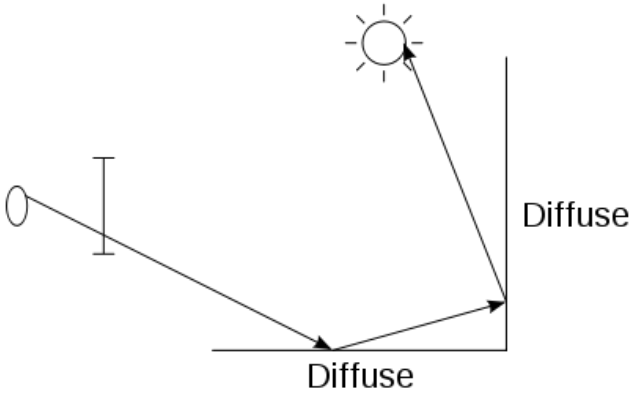




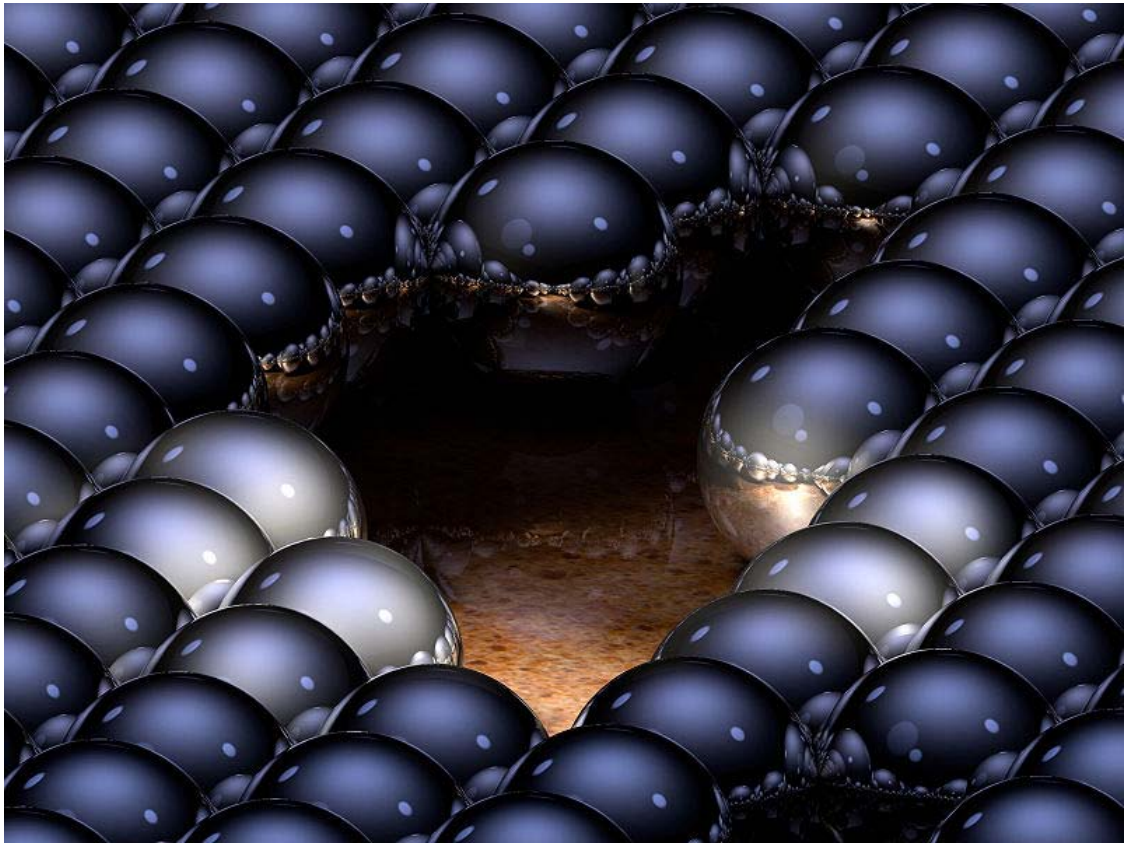
http://en.wikipedia.org/wiki/File:Ray_trace_diagram.svg

Ray tracing: interreflections

- Reflect light N times before heading to light source



N=2



N=16

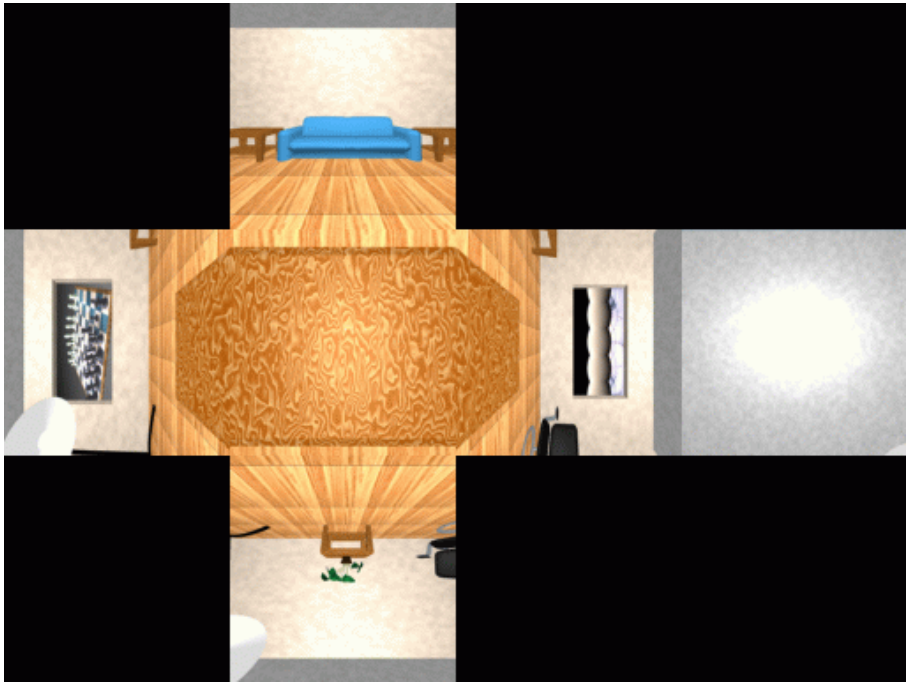
Ray tracing

- 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

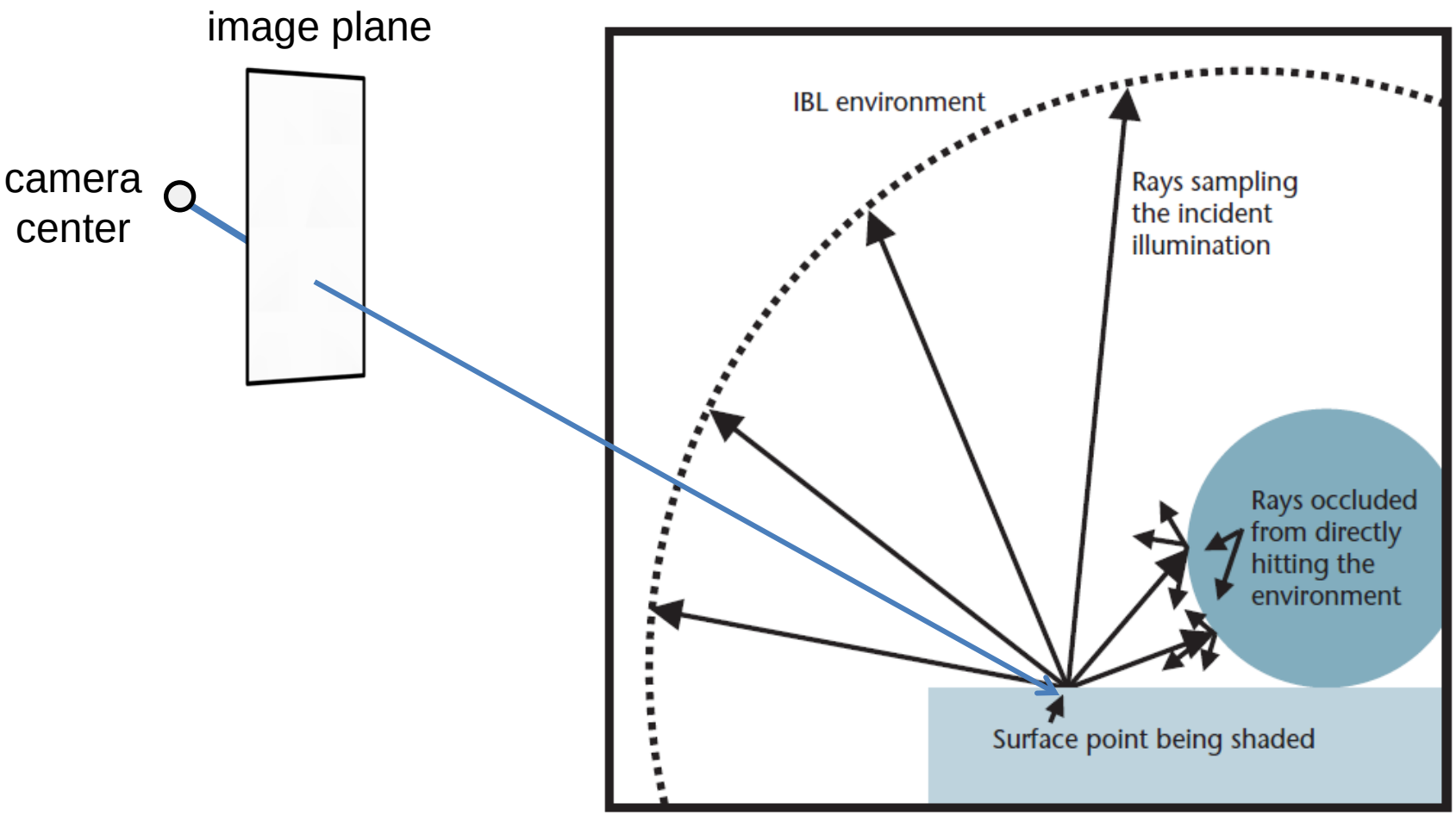
- The map resides on the surfaces of a cube around the object
  - Typically, align the faces of the cube with the coordinate axes
- To generate the map:
  - For each face of the cube, render the world from the center of the object with the cube face as the image plane
    - Rendering can be arbitrarily 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
- To use the map:
  - Use the orientation of the R ray to index directly into the sphere

Using the Environment Map

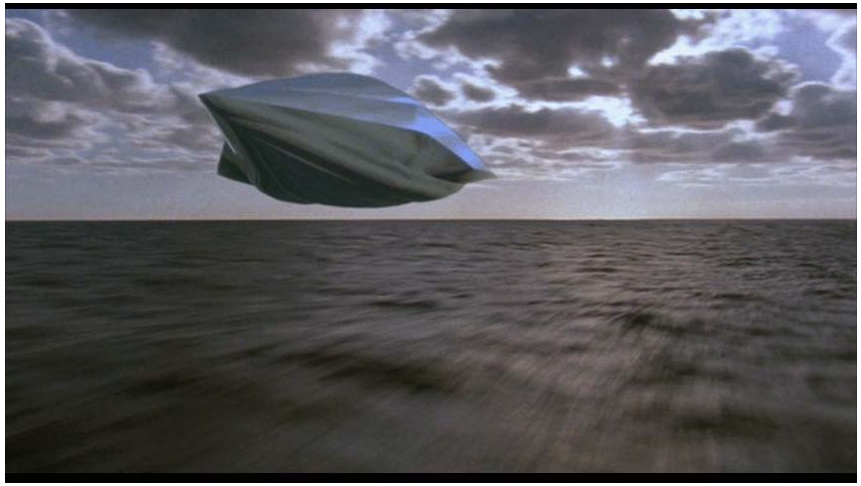


What approximations are made?

- 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!

What about real scenes?



From *Flight of the Navigator*

What about real scenes?

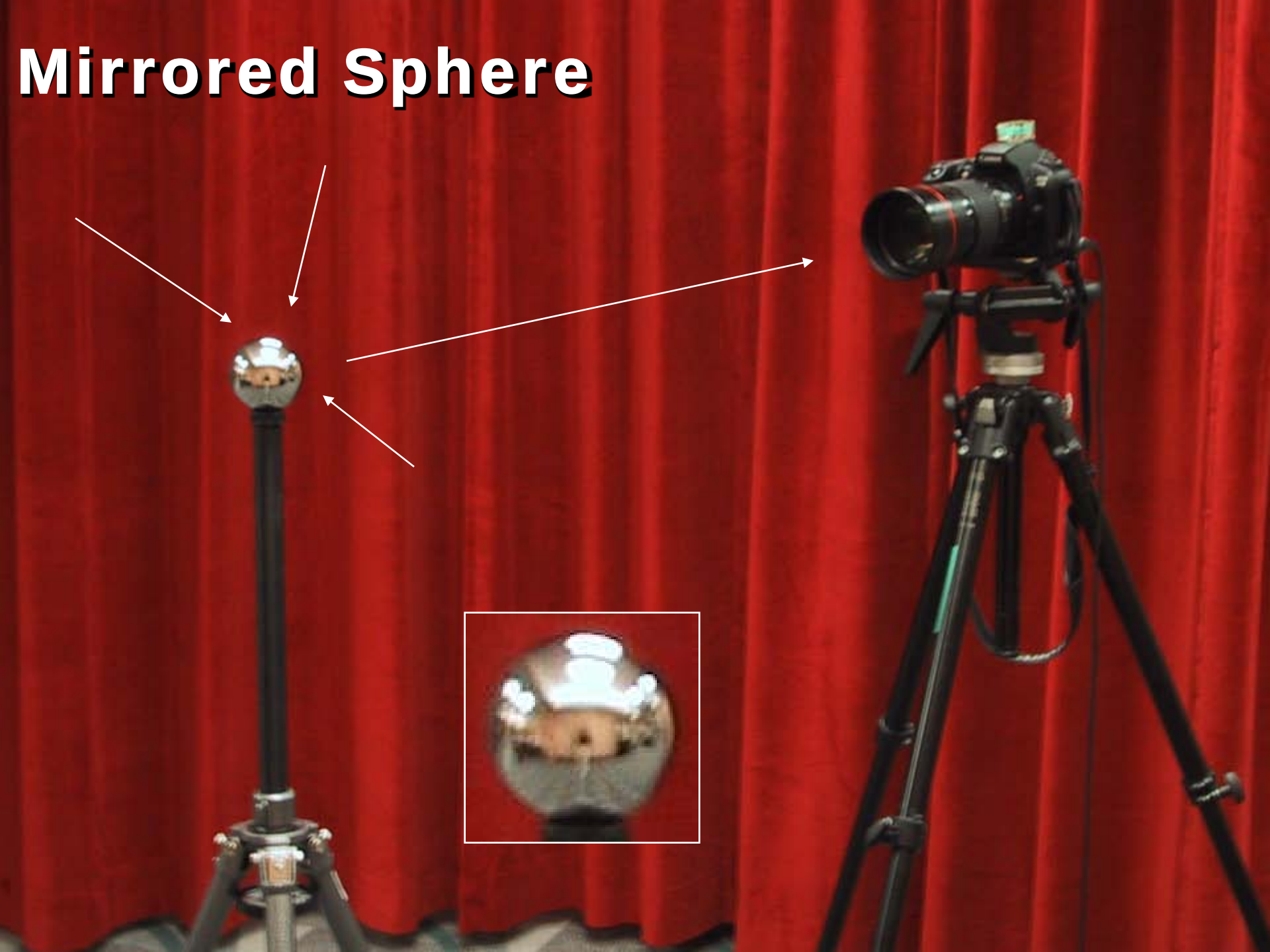
from Terminator 2

Real environment maps

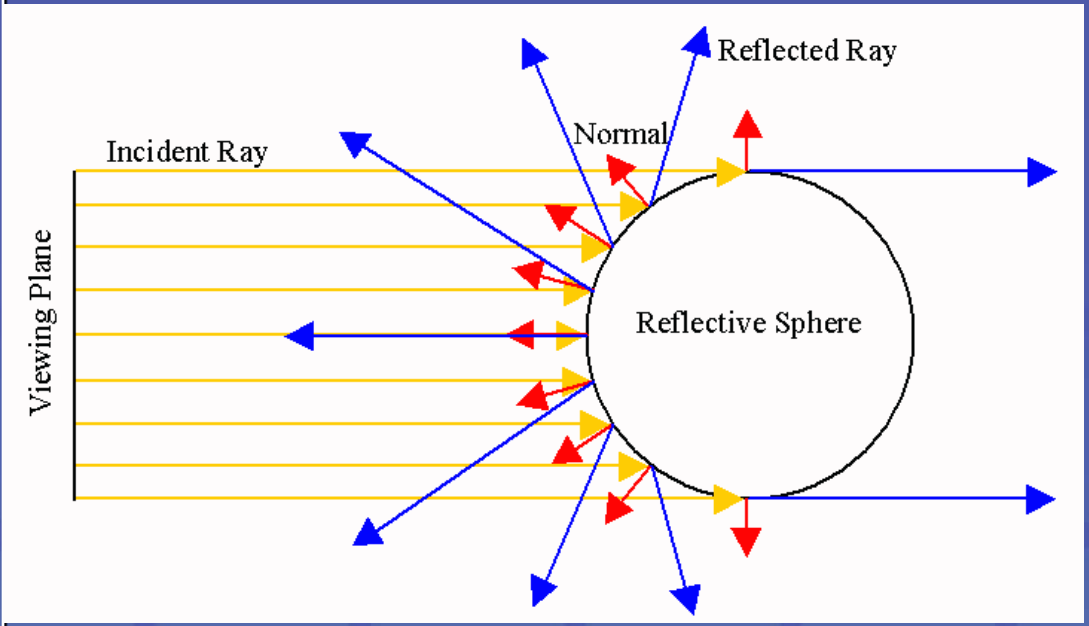
- We can use photographs to capture environment maps
  - The first use of panoramic mosaics

- Several ways to acquire environment maps:
  - Mirrored balls (**light probes**)
  - Stitching mosaics
  - Fisheye lens

Mirrored Sphere



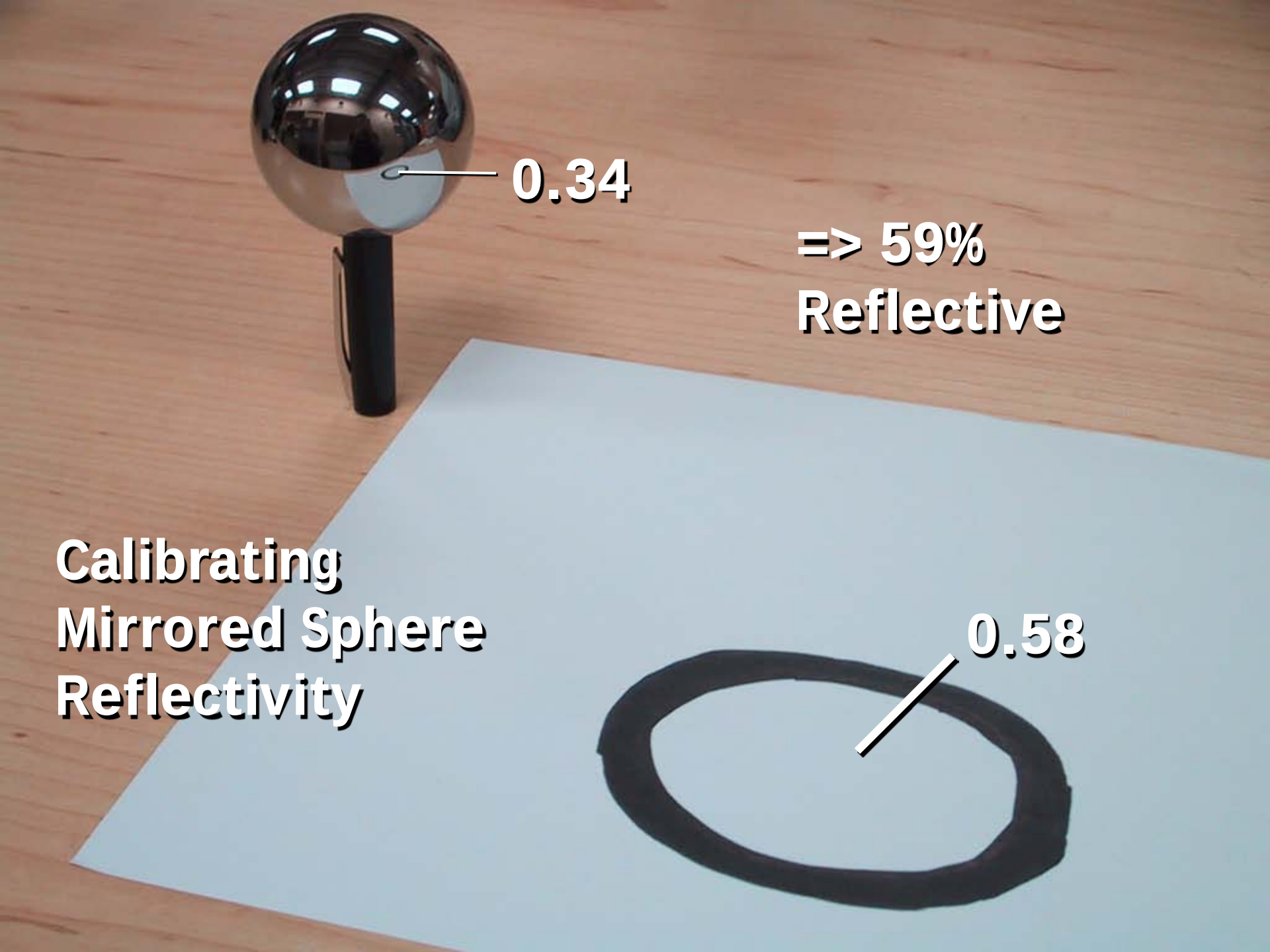

Canon
Canon


Reflected Ray
Normal
Incident Ray
Viewing Plane
Reflective Sphere

Sources of Mirrored Balls

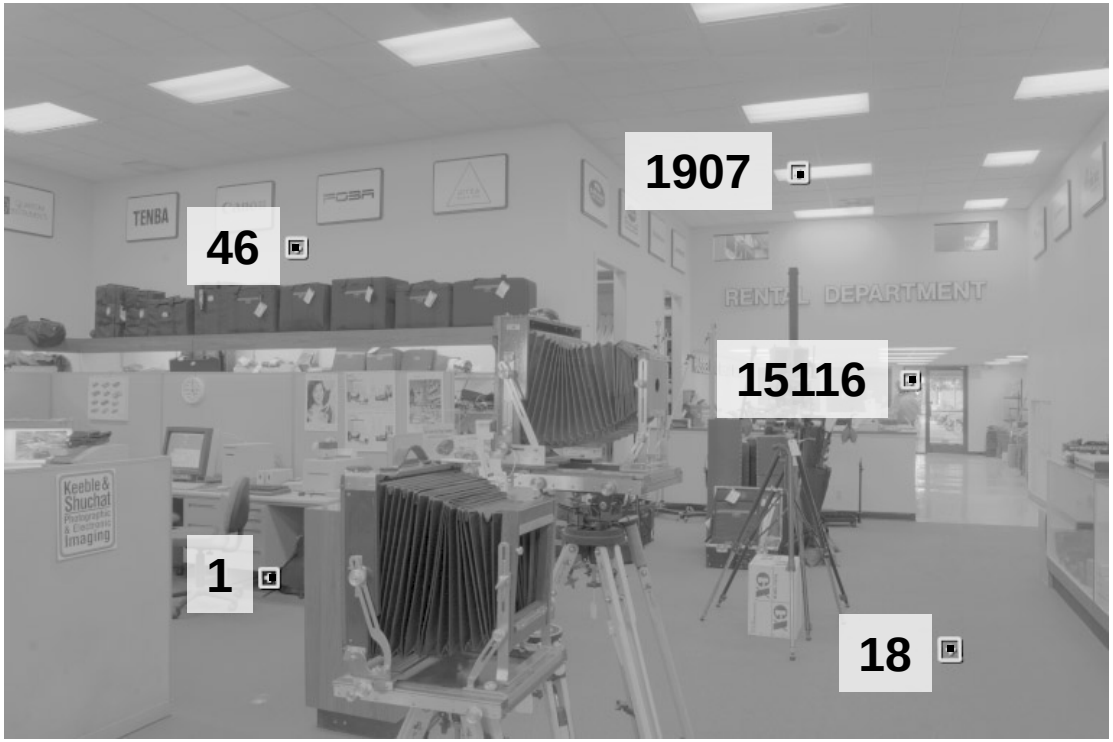
SIGGRAPH2004

- 2-inch chrome balls ~ $20 ea.
  - McMaster-Carr Supply Company www.mcmaster.com
- 6-12 inch large gazing balls
  - Baker's Lawn Ornaments www.bakerslawnorn.com
- Hollow Spheres, 2in – 4in
  - Dube Juggling Equipment www.dube.com
- FAQ on www.debevec.org/HDRShop/


0.34
=> 59%
Reflective
Calibrating
Mirrored Sphere
Reflectivity
0.58

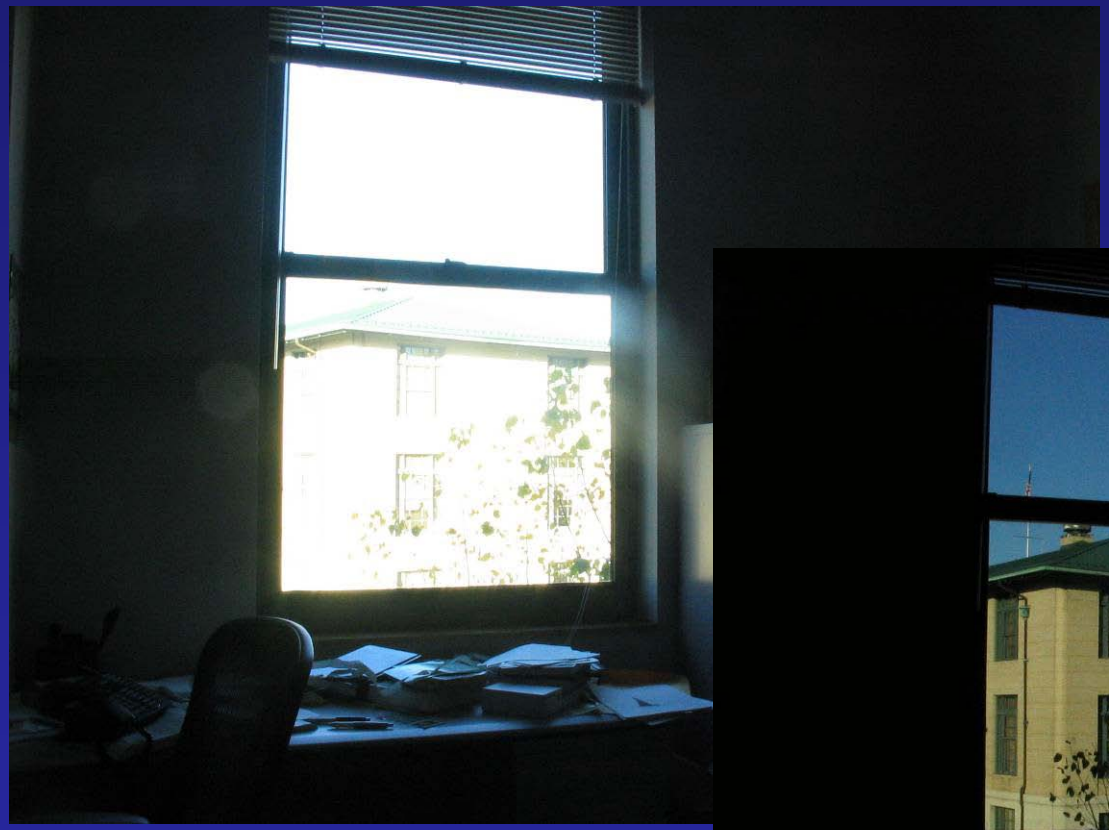
One small snag

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

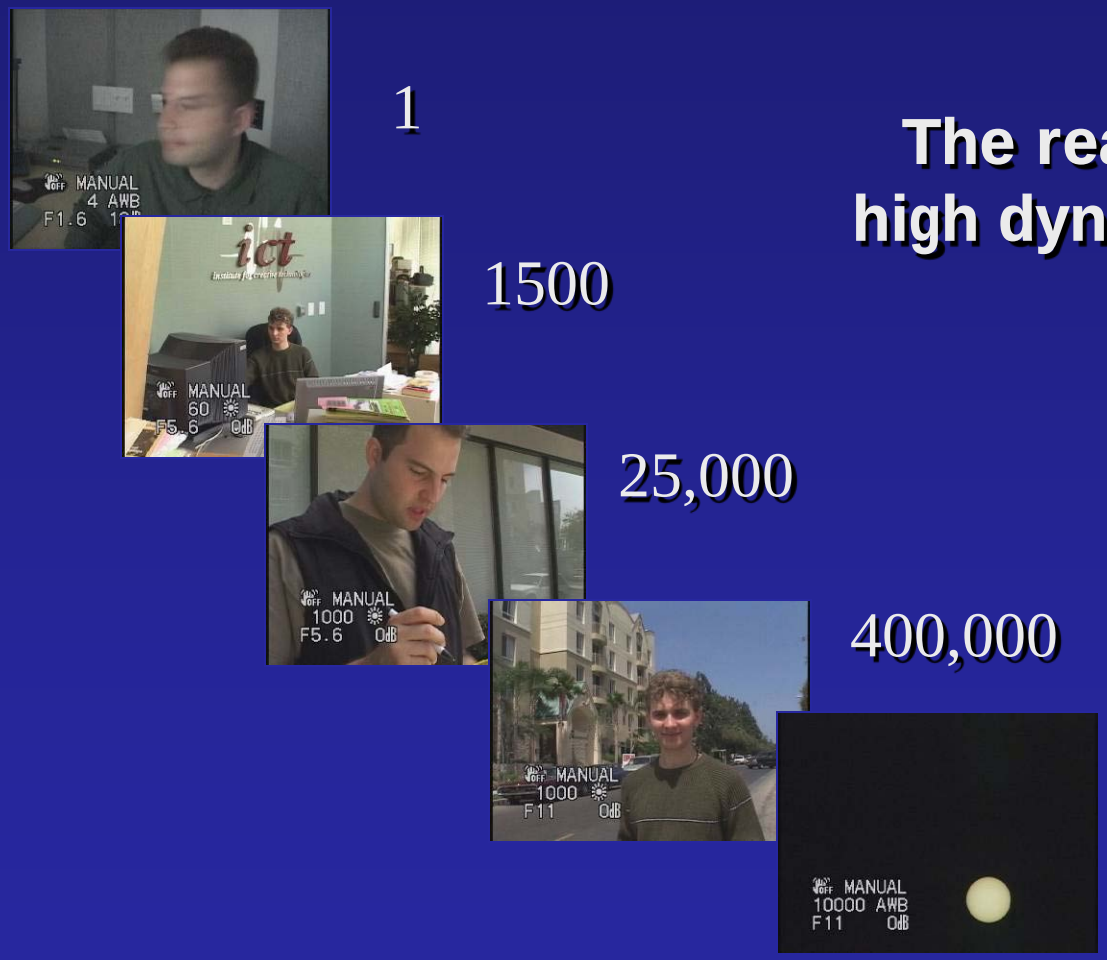


- Use High Dynamic Range photography!

Problem: Dynamic Range



Problem: Dynamic Range



1

1500

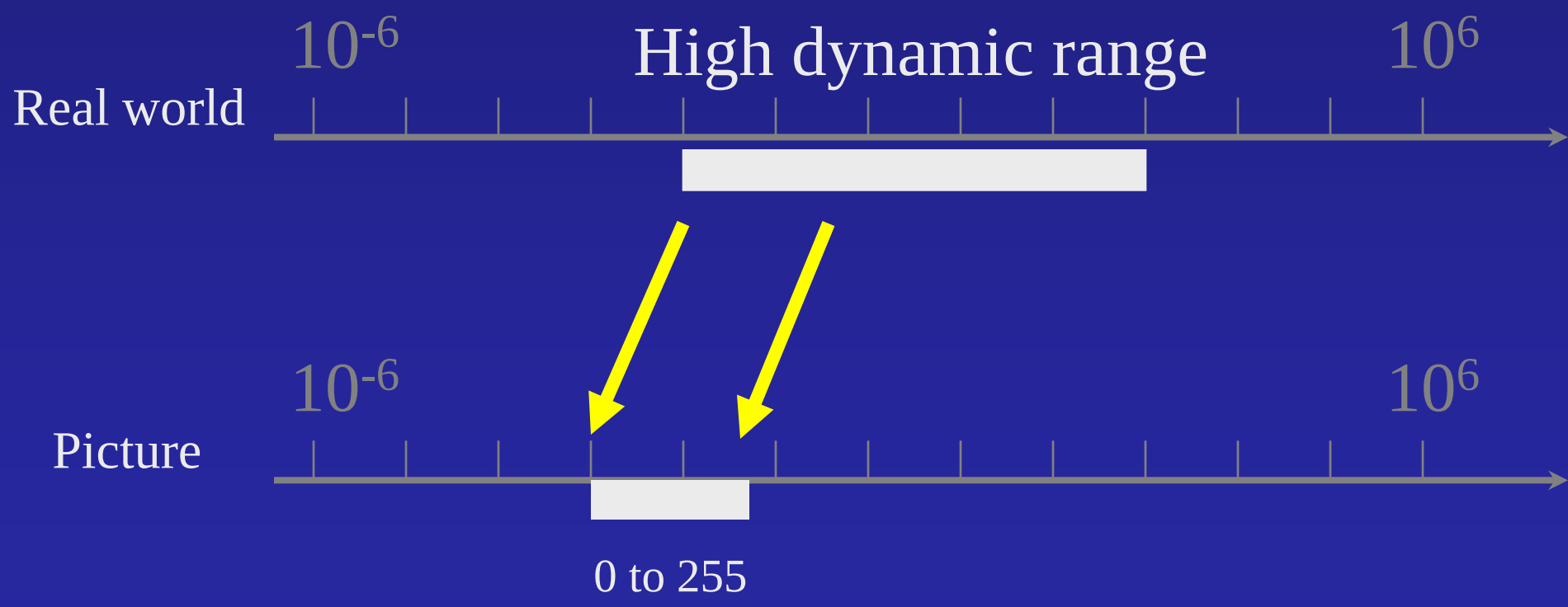
25,000

400,000

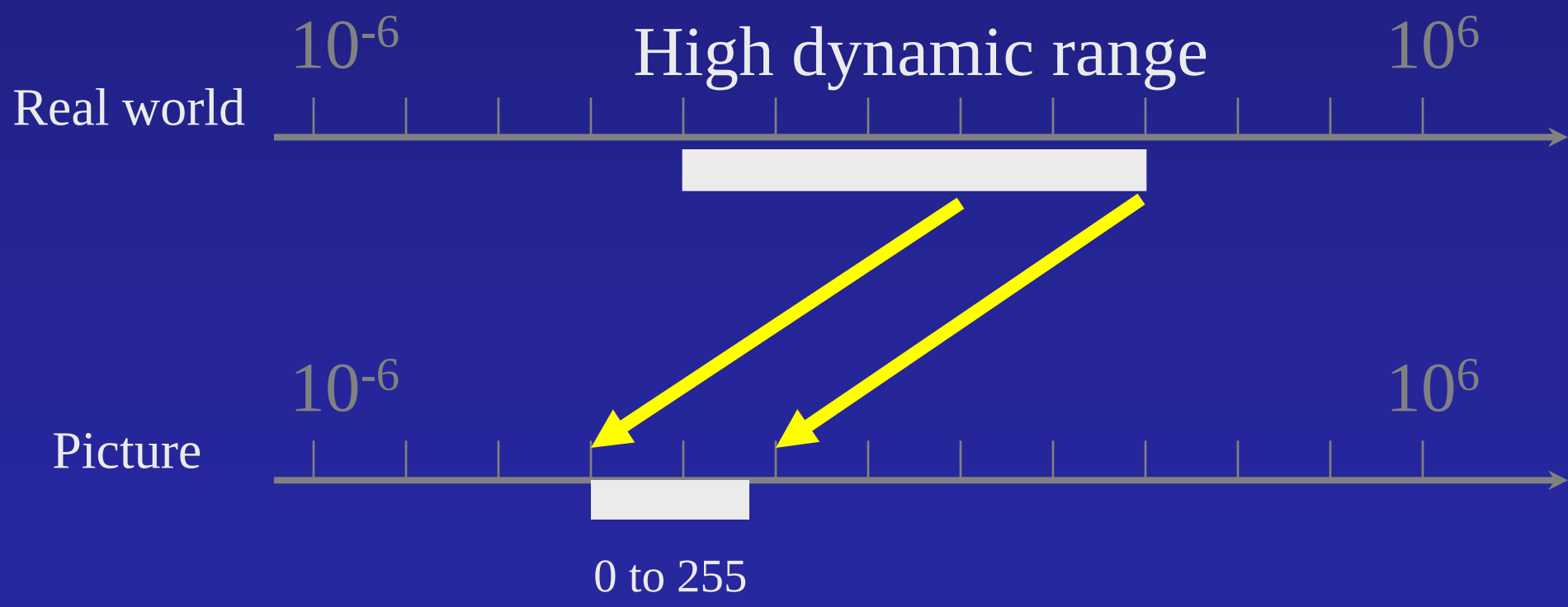
2,000,000,000

The real world is high dynamic range.

Long Exposure



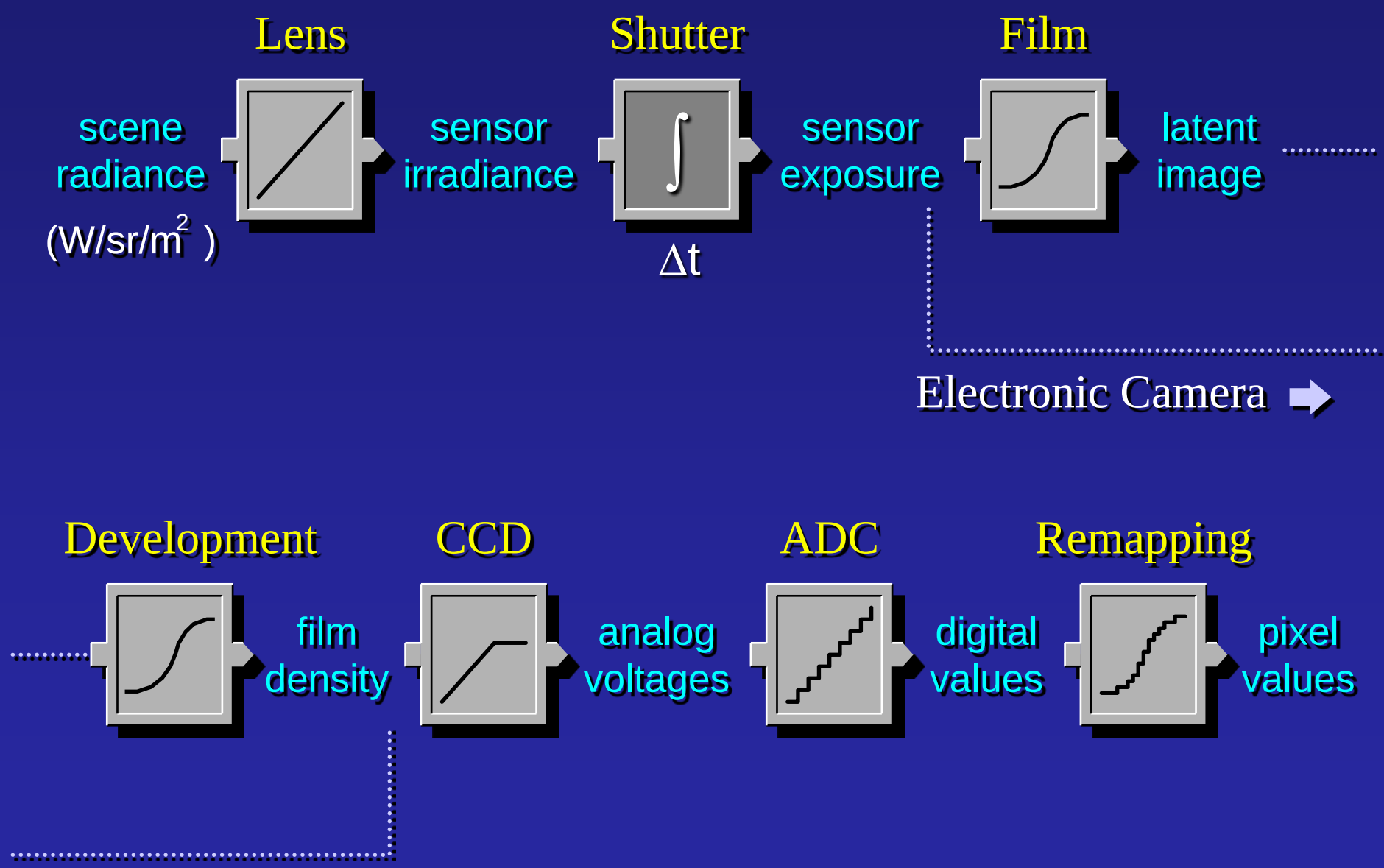
Short Exposure



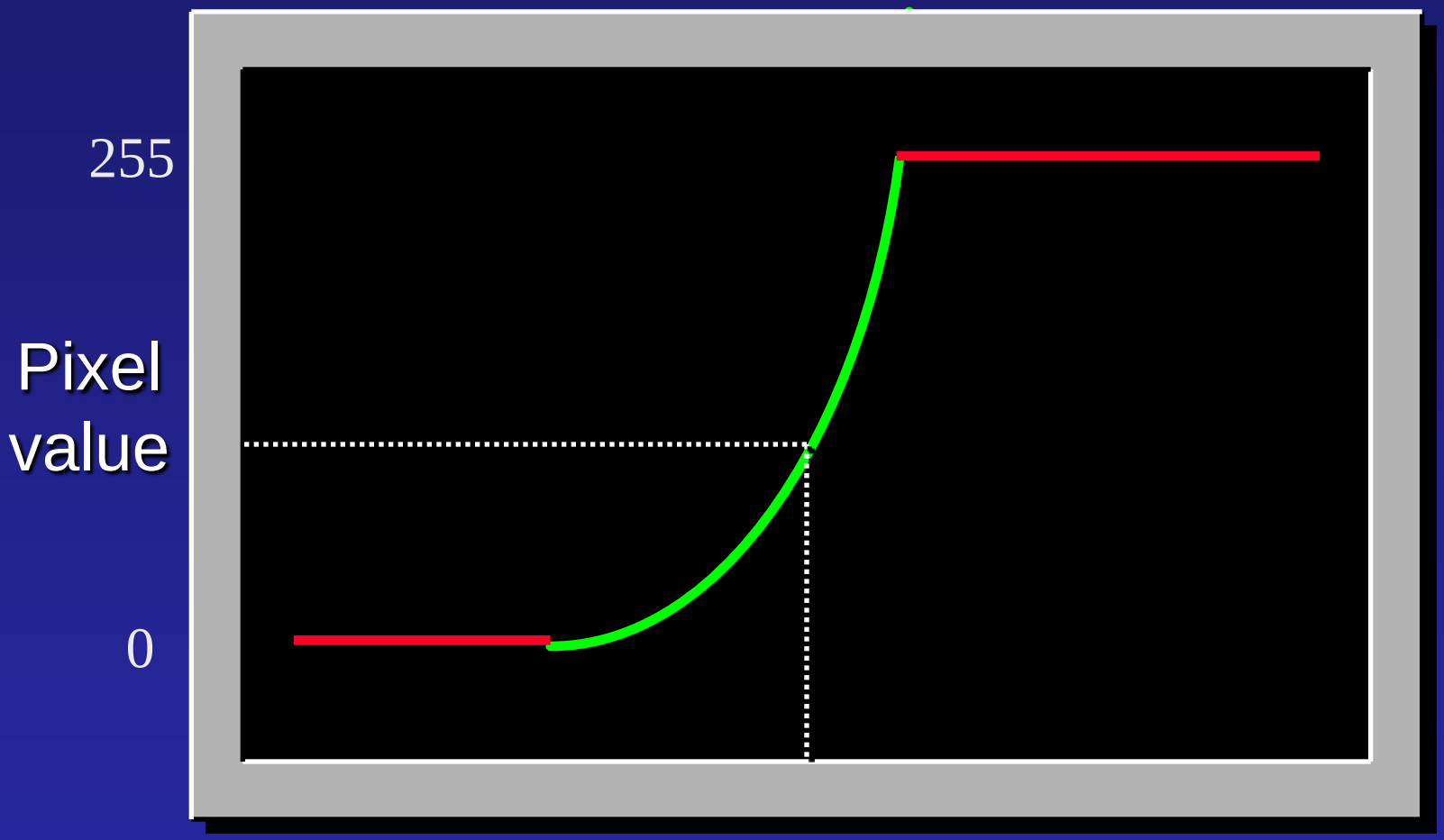
Camera Calibration

- Geometric
  - How pixel **coordinates** relate to **directions** in the world
- Photometric
  - How pixel **values** relate to **radiance** amounts in the world

The Image Acquisition Pipeline



Imaging system response function



log Exposure = log (Radiance * Δt)

(CCD photon count)

Varying Exposure

Camera is not a photometer!

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

To be continued…