COSC579: Radiometry

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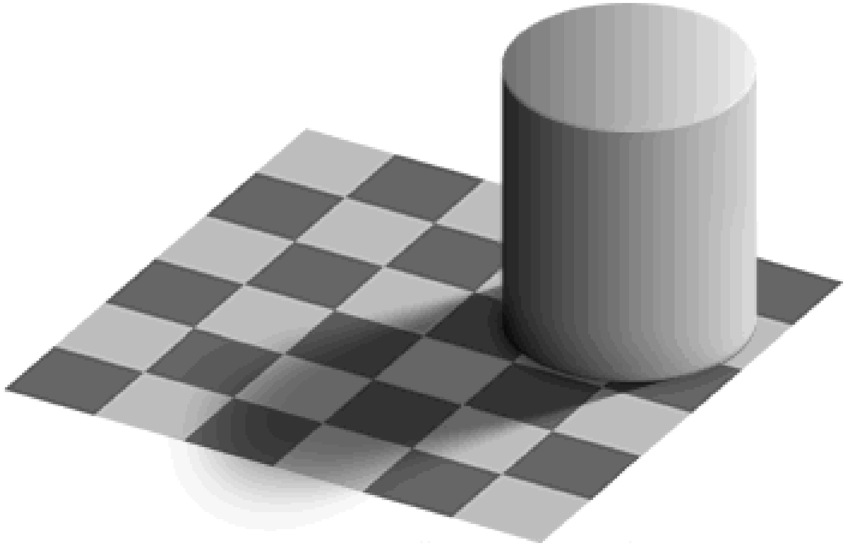
Light



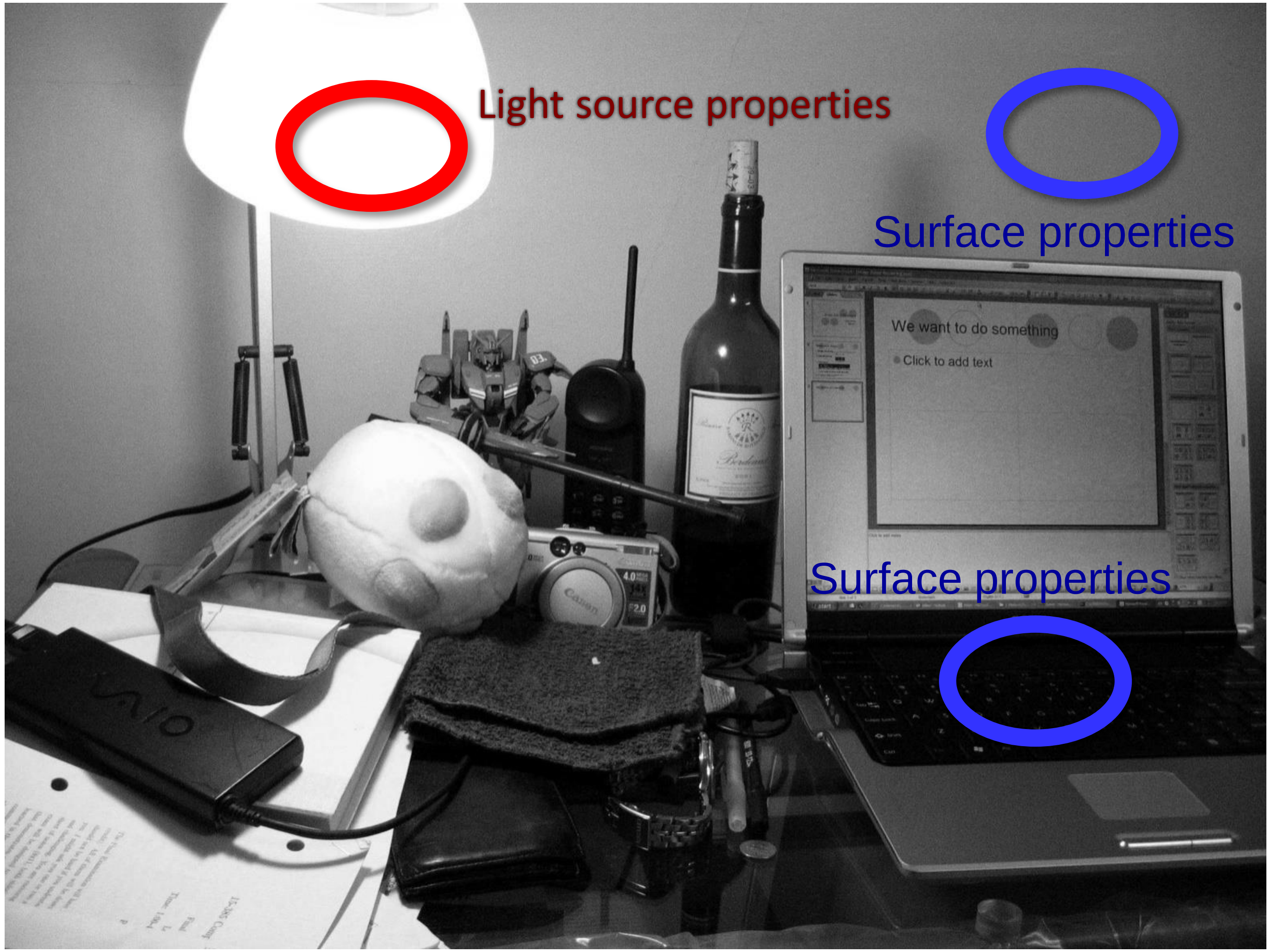
- Readings
  - Szeliski, 2.2, 2.3.2

Properties of light

- Today
  - What is light?
  - How do we measure it?
  - How does light propagate?
  - How does light interact with matter?

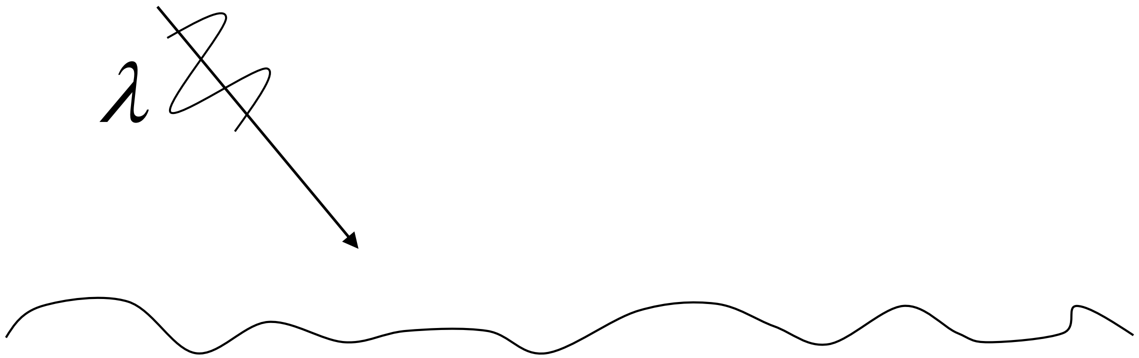
Radiometry

- What determines the brightness of an image pixel?



Reflectance Models

Reflection: An Electromagnetic Phenomenon



Two approaches to derive Reflectance Models:

- Physical Optics (Wave Optics)
- Geometrical Optics (Ray Optics)

Geometrical models are approximations to physical models

But they are easier to use!

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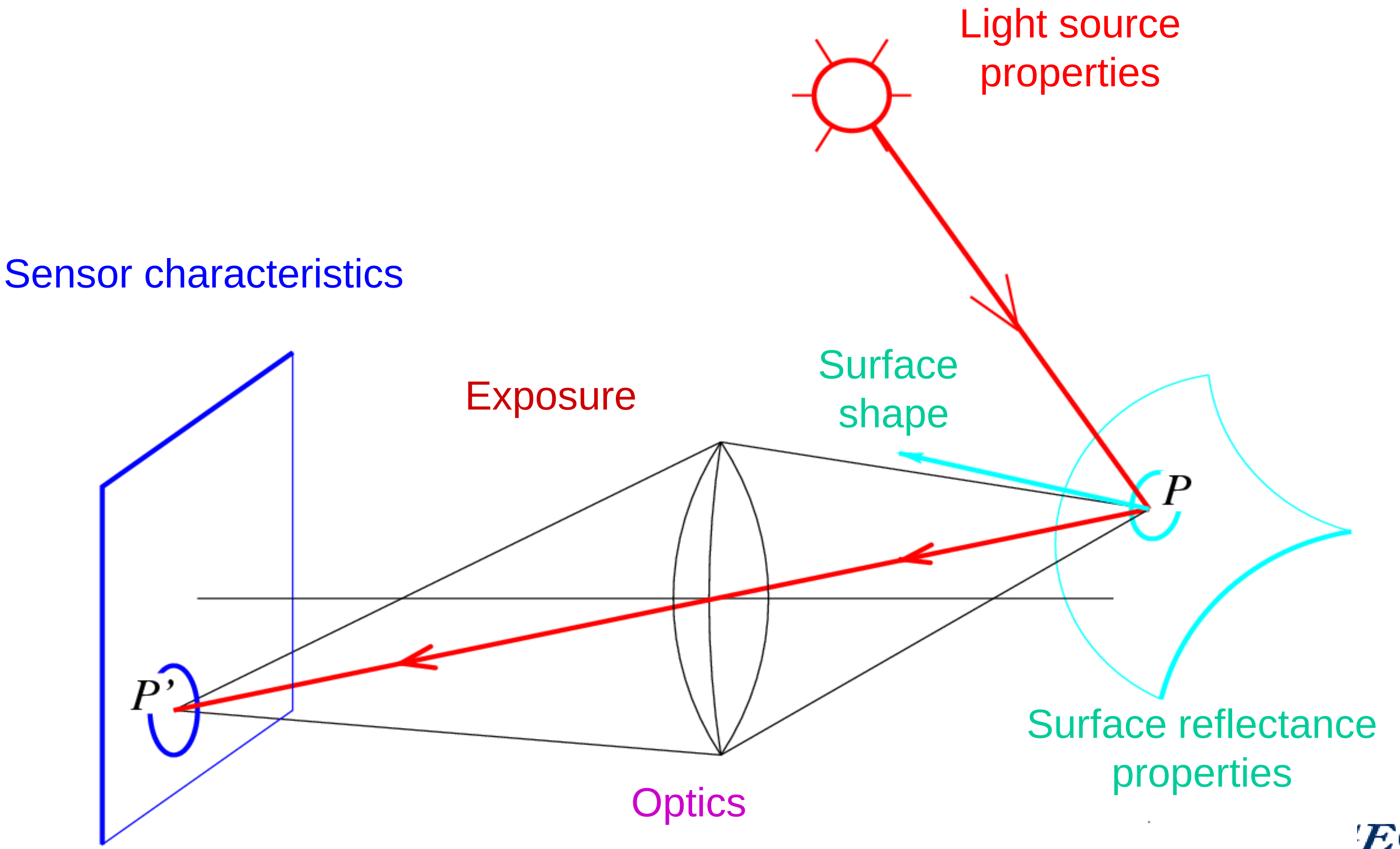
Radiometry

- What determines the brightness of an image pixel?



Slide by L. Fei-Fei

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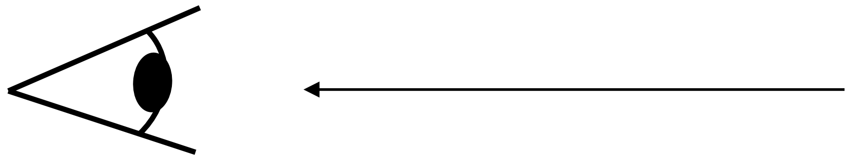
What is light?

Electromagnetic radiation (EMR) moving along rays in space

- Radiance L(λ) is EMR, measured in units of power (watts)
  - λ is wavelength

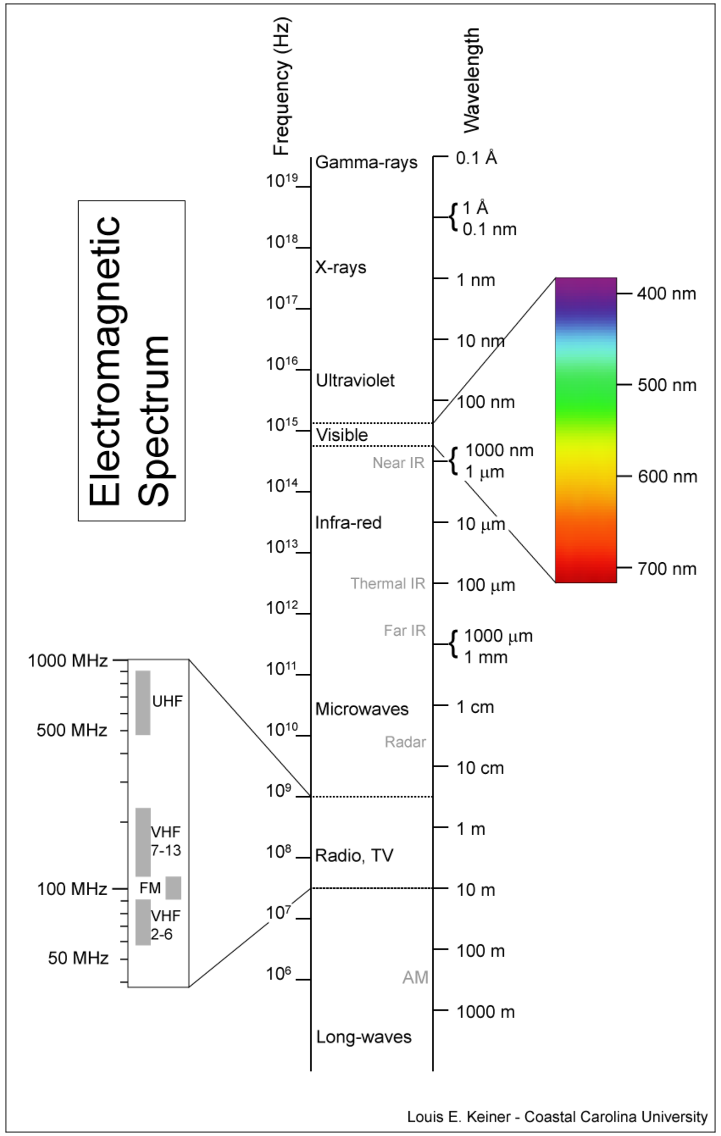


Perceiving light

- How do we convert radiation into “color”?
- What part of the spectrum do we see?

Visible light

- We "see" electromagnetic radiation in a range of wavelengths



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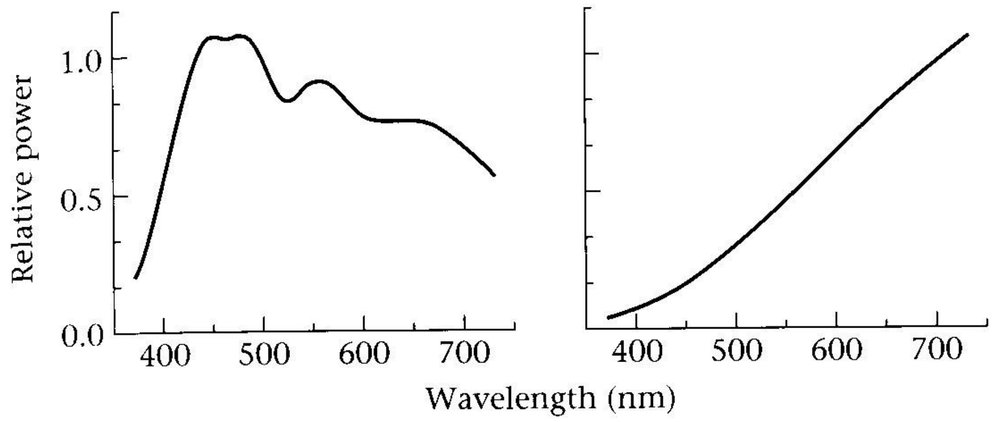
Light spectrum

- The appearance of light depends on its power **spectrum**
  - How much power (or energy) at each wavelength



daylight　　　　tungsten bulb

Our visual system converts a light spectrum into “color”

- This is a rather complex transformation

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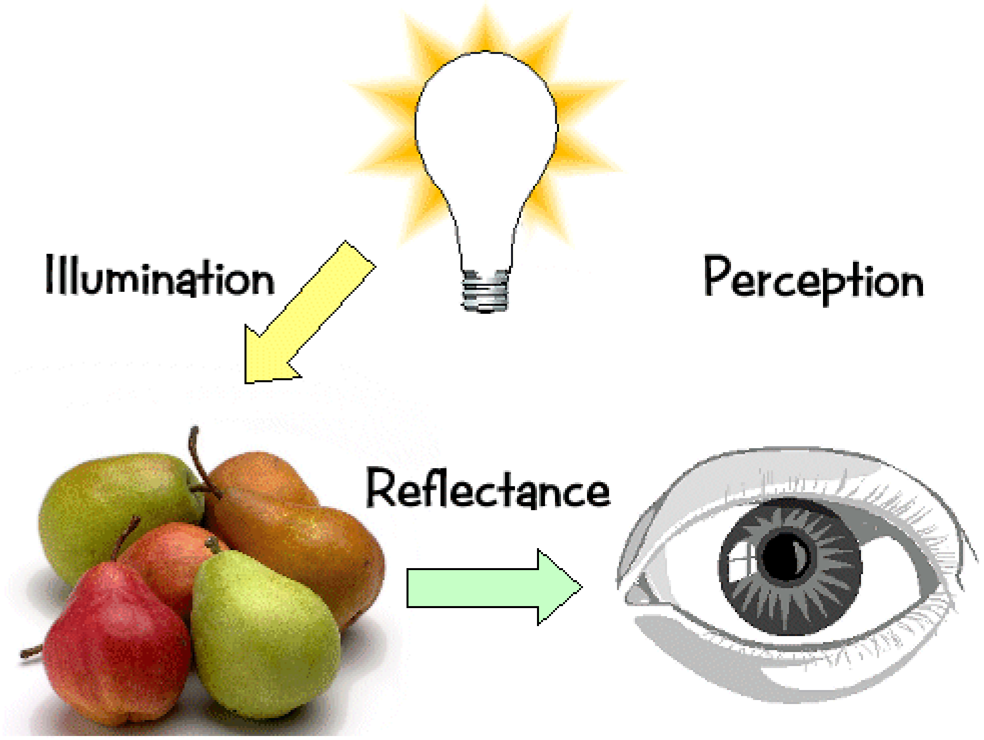
Light transport



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Light sources

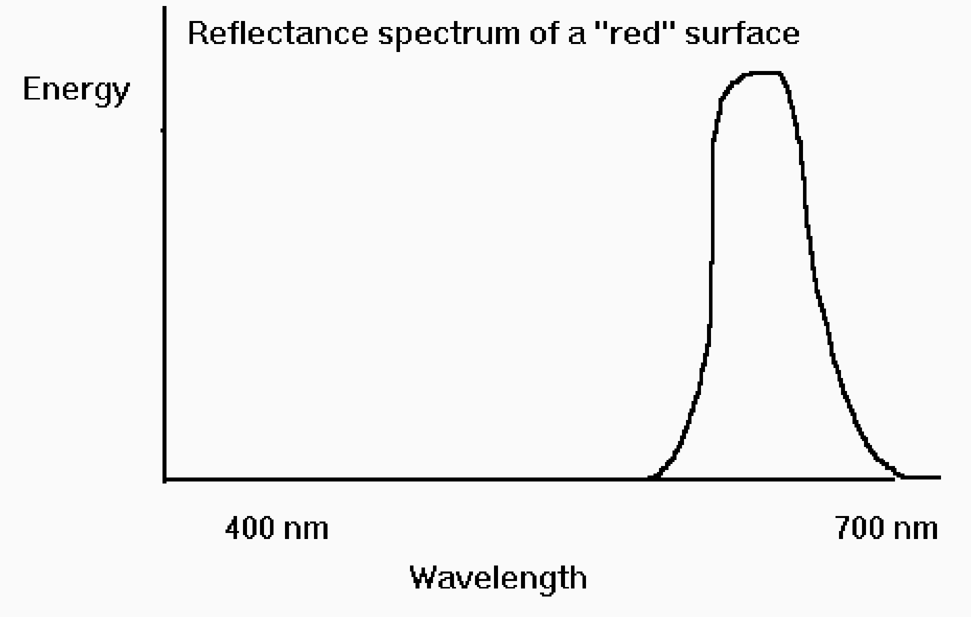
- Basic types
  - point source
  - directional source
    - a point source that is infinitely far away
  - area source
    - a union of point sources
- More generally
  - a light field can describe *any* distribution of light sources
- What happens when light hits an object?

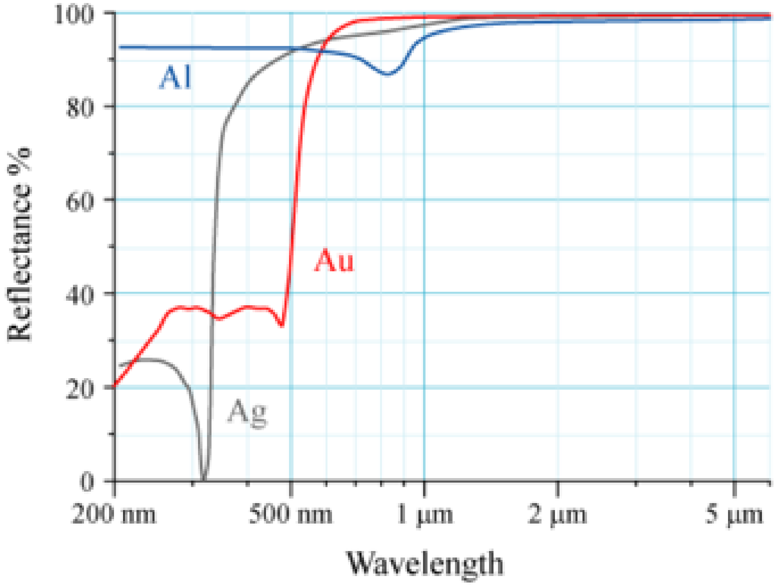
What happens when a light ray hits an object?

- Some of the light gets absorbed
  - converted to other forms of energy (e.g., heat)
- Some gets transmitted through the object
  - possibly bent, through “refraction”
  - a transmitted ray could possible bounce back
- Some gets reflected
  - as we saw before, it could be reflected in multiple directions (possibly all directions) at once
- Let’s consider the case of reflection in detail

*Reflectance spectrum (**albedo**)*

- To a first approximation, surfaces absorb some wavelengths of light and reflect others





- These spectra are multiplied by the spectra of the incoming light, then by the spectra of the sensors

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Material Properties

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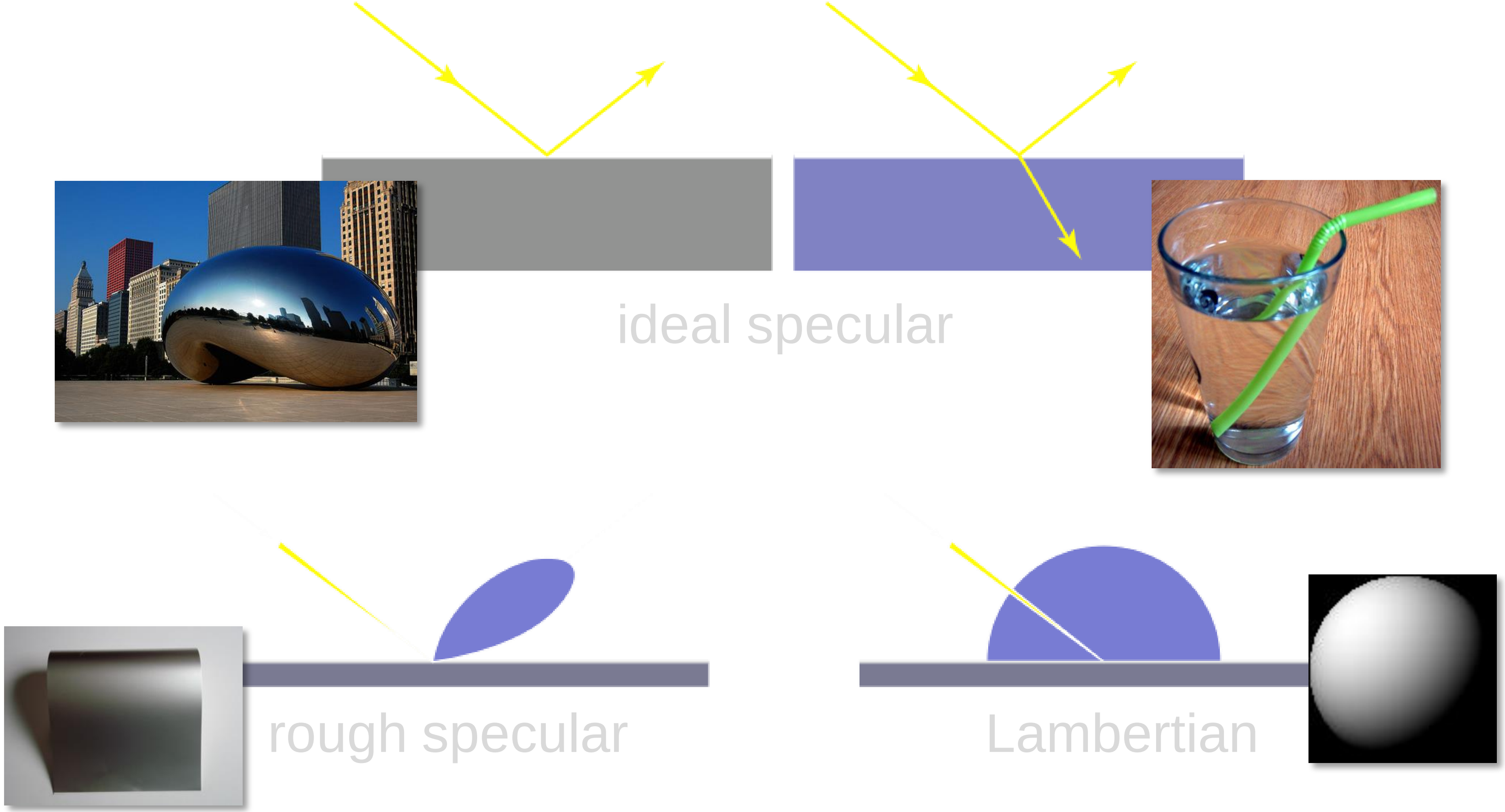
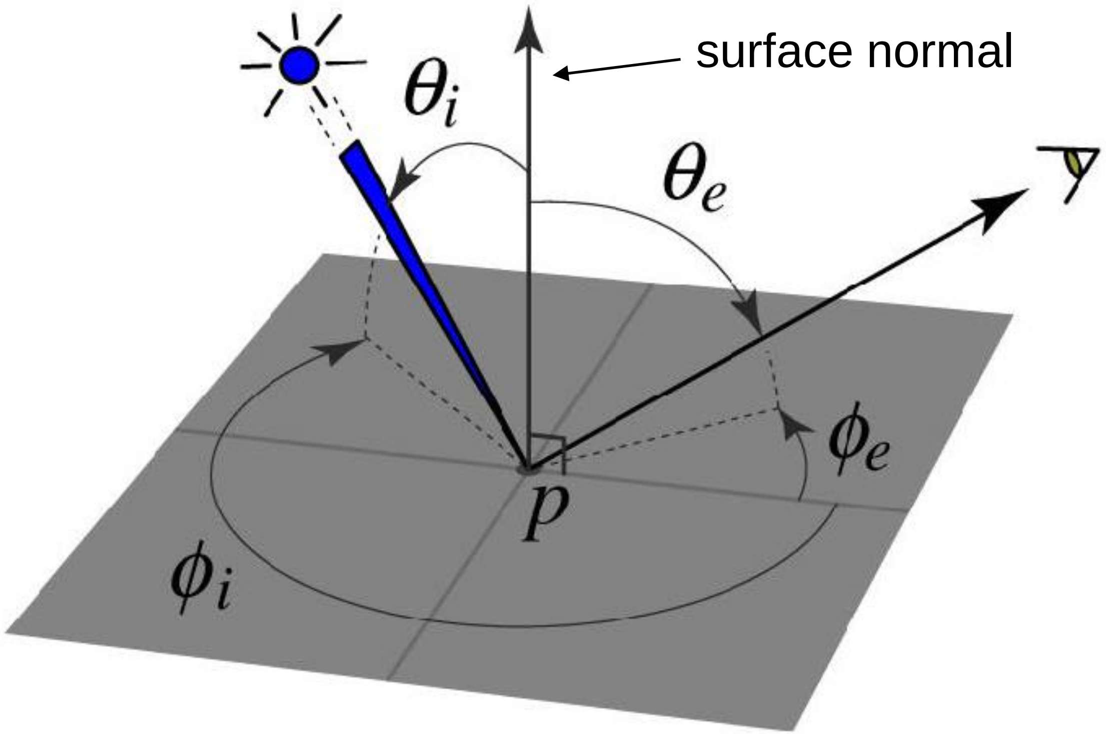
Classic reflection behavior



The BRDF

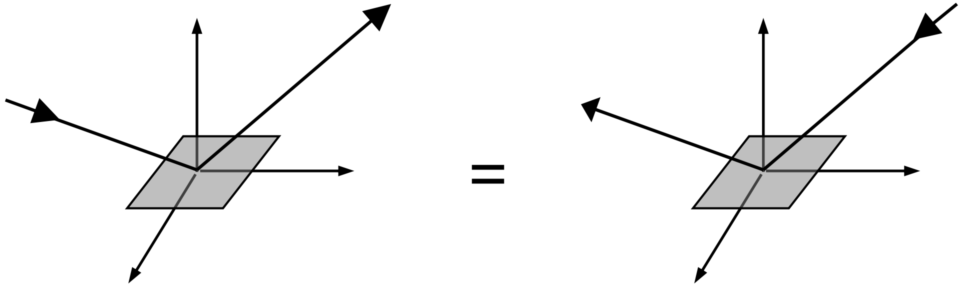
- The Bidirectional Reflection Distribution Function
  - Given an incoming ray (θ_i, ϕ_i) and outgoing ray (θ_e, ϕ_e) what proportion of the incoming light is reflected along outgoing ray?



Answer given by the BRDF: $\rho(\theta_i, \phi_i, \theta_e, \phi_e)$

Constraints on the BRDF

- Energy conservation
  - Quantity of outgoing light ≤ quantity of incident light
    - integral of BRDF ≤ 1
- Helmholtz reciprocity
  - reversing the path of light produces the same reflectance



BRDF's can be incredibly complicated…

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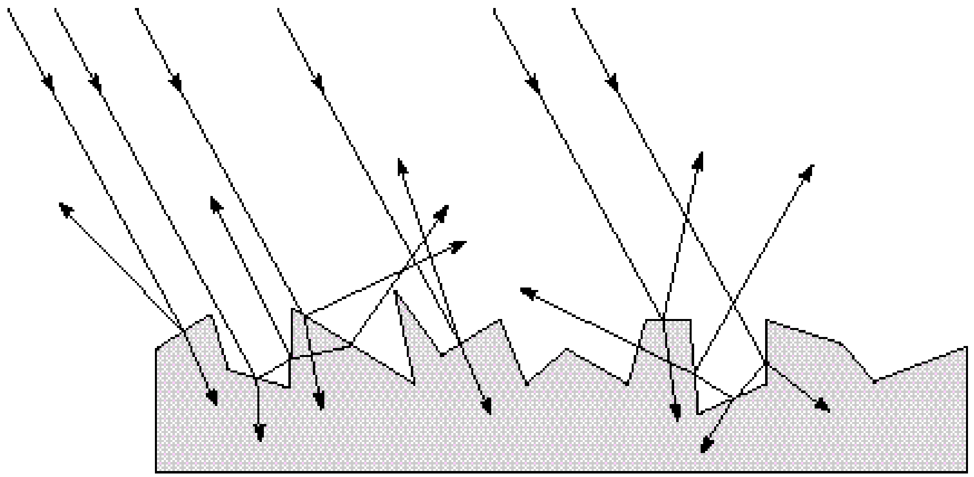
Diffuse reflection

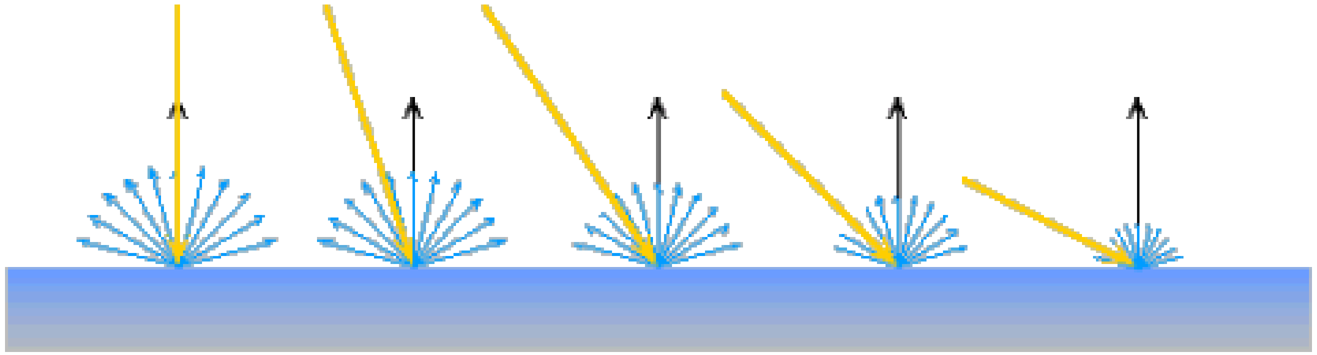


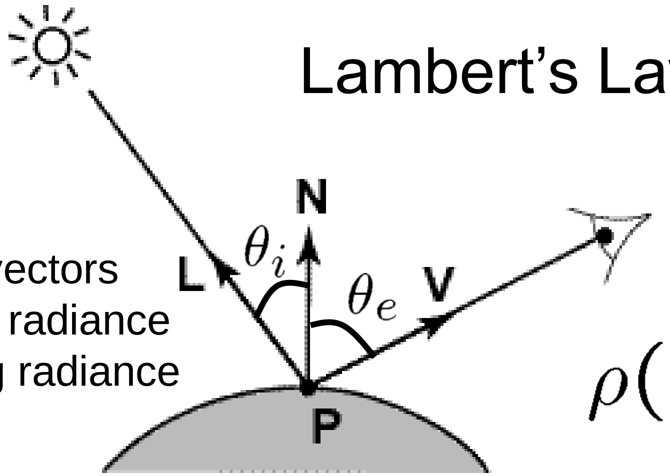
- Diffuse reflection
  - Dull, matte surfaces like chalk or latex paint
  - Microfacets scatter incoming light randomly
  - Effect is that light is reflected equally in all directions

Diffuse reflection

Diffuse reflection governed by **Lambert's law**

- Viewed brightness does not depend on viewing direction
- Brightness *does* depend on direction of illumination
- This is the model most often used in computer vision





L, **N**, **V** unit vectors
I_e = outgoing radiance
I_i = incoming radiance

Lambert's Law: $I_e = k_d \mathbf{N} \cdot \mathbf{L} I_i$

k_d is called **albedo**

BRDF for **Lambertian surface**

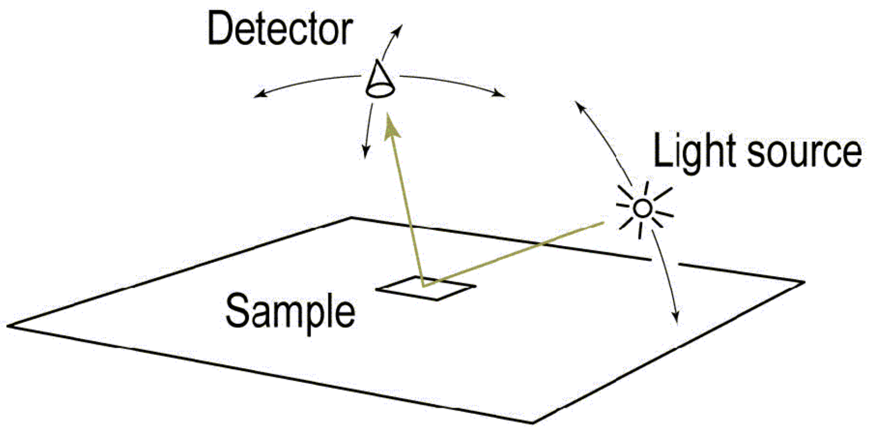
$$\rho(\theta_i, \phi_i, \theta_e, \phi_e) = k_d cos\theta_i$$

BRDF models

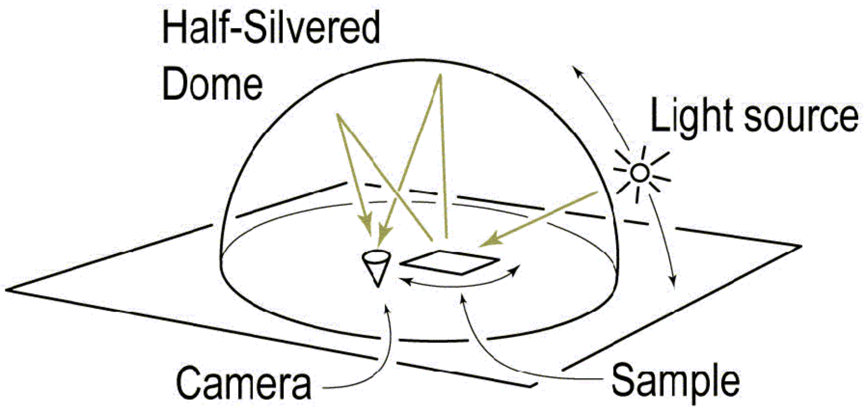
- Phenomenological
  - Phong [75]
  - Ward [92]
  - Lafortune et al. [97]
  - Ashikhmin et al. [00]
- Physical
  - Cook-Torrance [81]
  - Dichromatic [Shafer 85]
  - He et al. [91]

- Here we're listing only some well-known examples

Measuring the BRDF



traditional



design by Greg Ward

- Gonioreflectometer
  - Device for capturing the BRDF by moving a camera + light source
  - Need careful control of illumination, environment

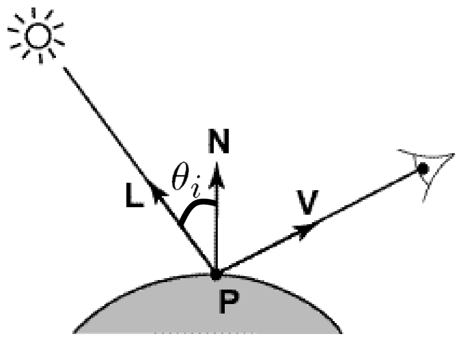
Why models for light?

- Why model these complex processes?

- Vision is all about extracting information about a scene from its 2-d representation

  - Shape from shading
  - Surface Properties
  - Texture Features
  - Information from reflections
  - Atmosphere

Shape from shading



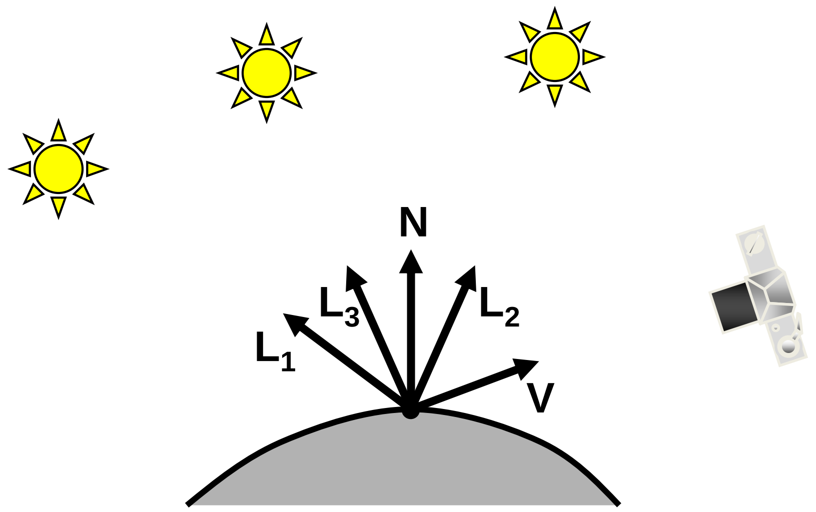
- Suppose $k_d = 1$

$$
\begin{aligned}
I &= k_d \mathbf{N} \cdot \mathbf{L} \\
&= \mathbf{N} \cdot \mathbf{L} \\
&= cos\ \theta_i
\end{aligned}
$$

You can directly measure angle between normal and light source

- Not quite enough information to compute surface shape
- But can be if you add some additional info, for example
  - assume a few of the normals are known (e.g., along silhouette)
  - constraints on neighboring normals—“integrability”
  - smoothness
- Hard to get it to work well in practice

Photometric stereo: for estimating surface normal (shape!)



$$I_1 = k_d \mathbf{N} \cdot \mathbf{L_1}$$
$$I_2 = k_d \mathbf{N} \cdot \mathbf{L_2}$$
$$I_3 = k_d \mathbf{N} \cdot \mathbf{L_3}$$

Can write this as a matrix equation:

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = k_d \begin{bmatrix} \mathbf{L_1}^T \\ \mathbf{L_2}^T \\ \mathbf{L_3}^T \end{bmatrix} \mathbf{N}$$

Light and Shadows

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Reflections

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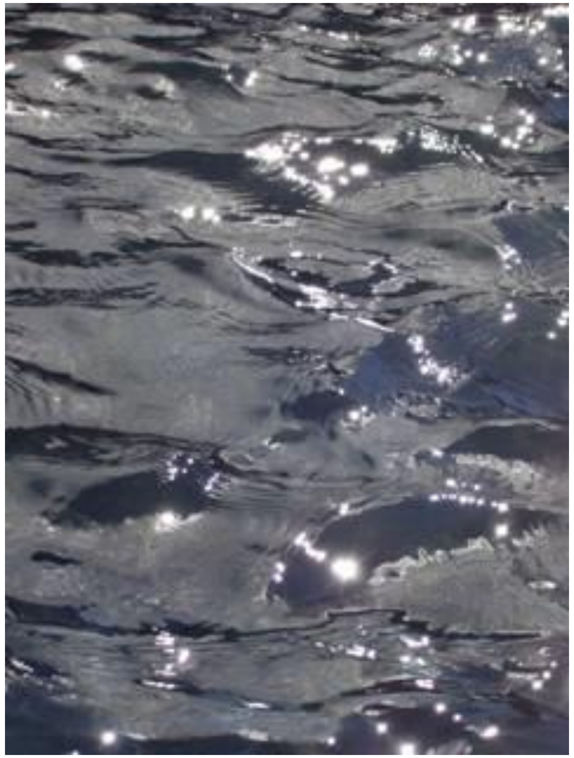

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Refractions

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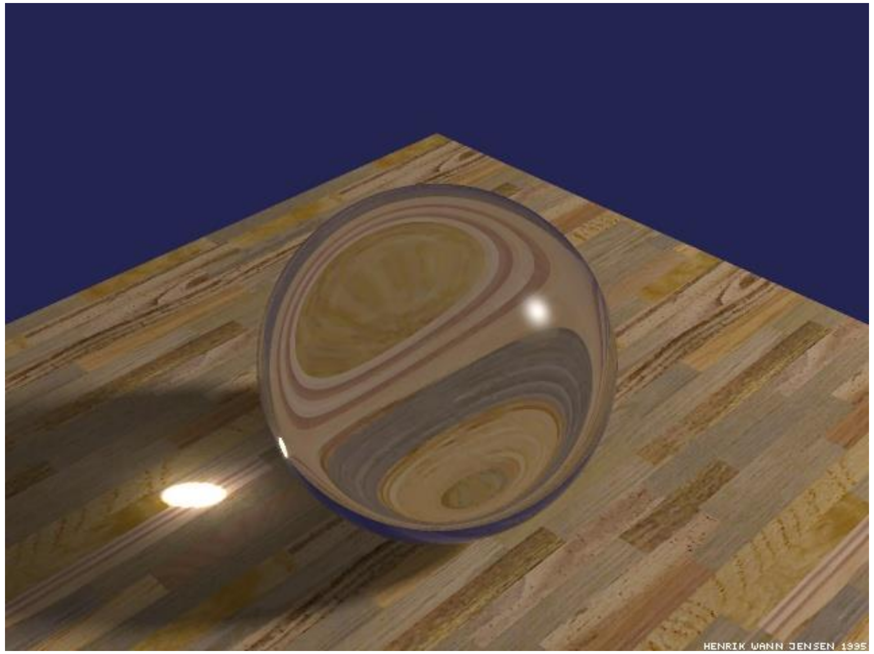

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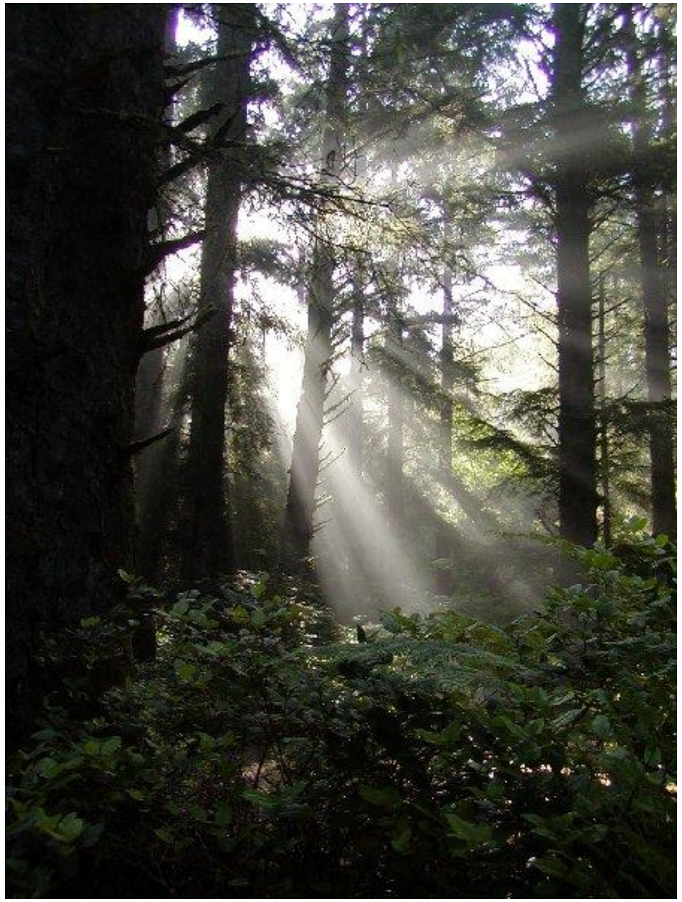
Interreflections


Mies Courtyard House with Curved Elements

Scattering



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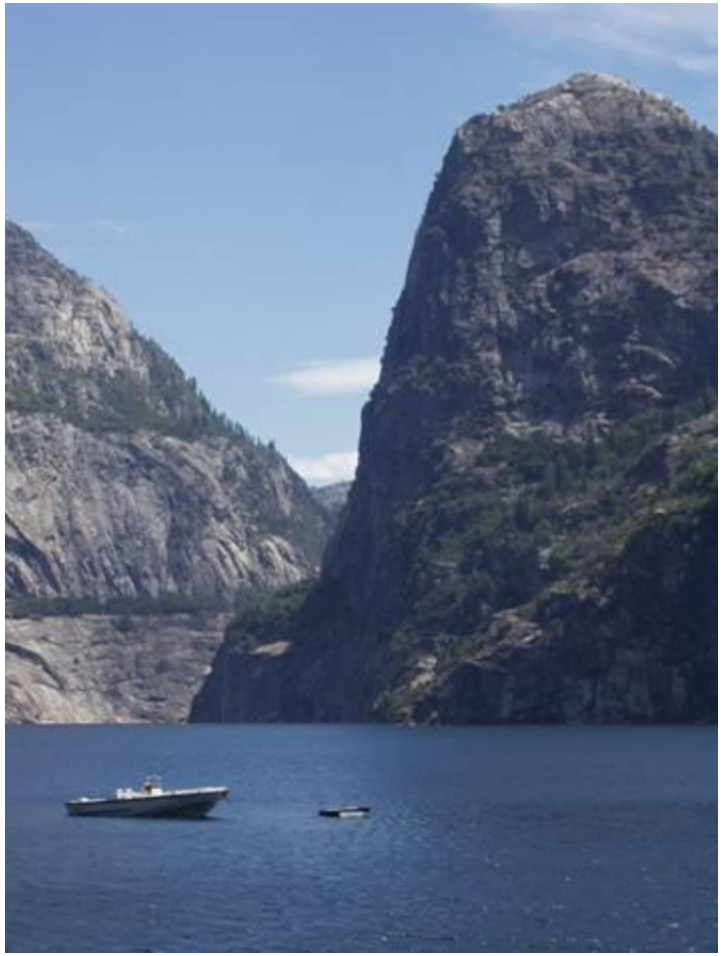

Haze

De-hazed

More Complex Appearances

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Appendix: Measuring Light

Jeremy Bolton, PhD

Assistant Teaching Professor

A special thanks to many contributors over the years: Szeliski, Snavely, Adelson

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