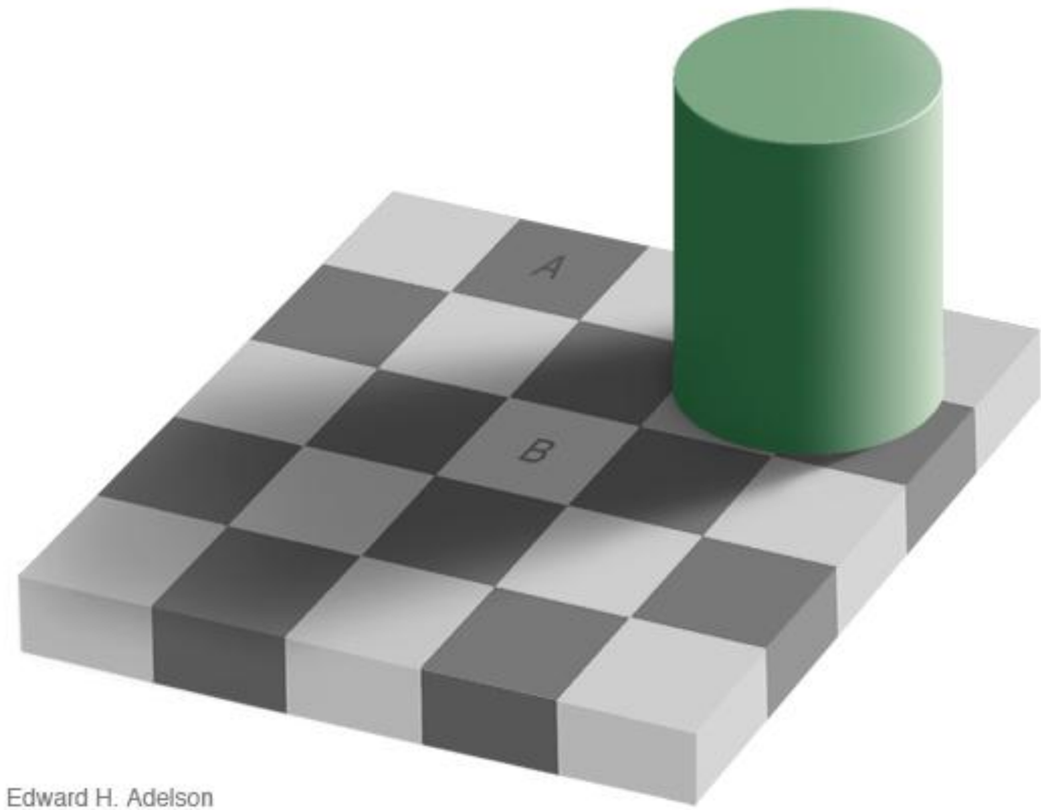
Announcements

- Office hours today 2:30-3:30
- Graded midterms will be returned at the end of the class

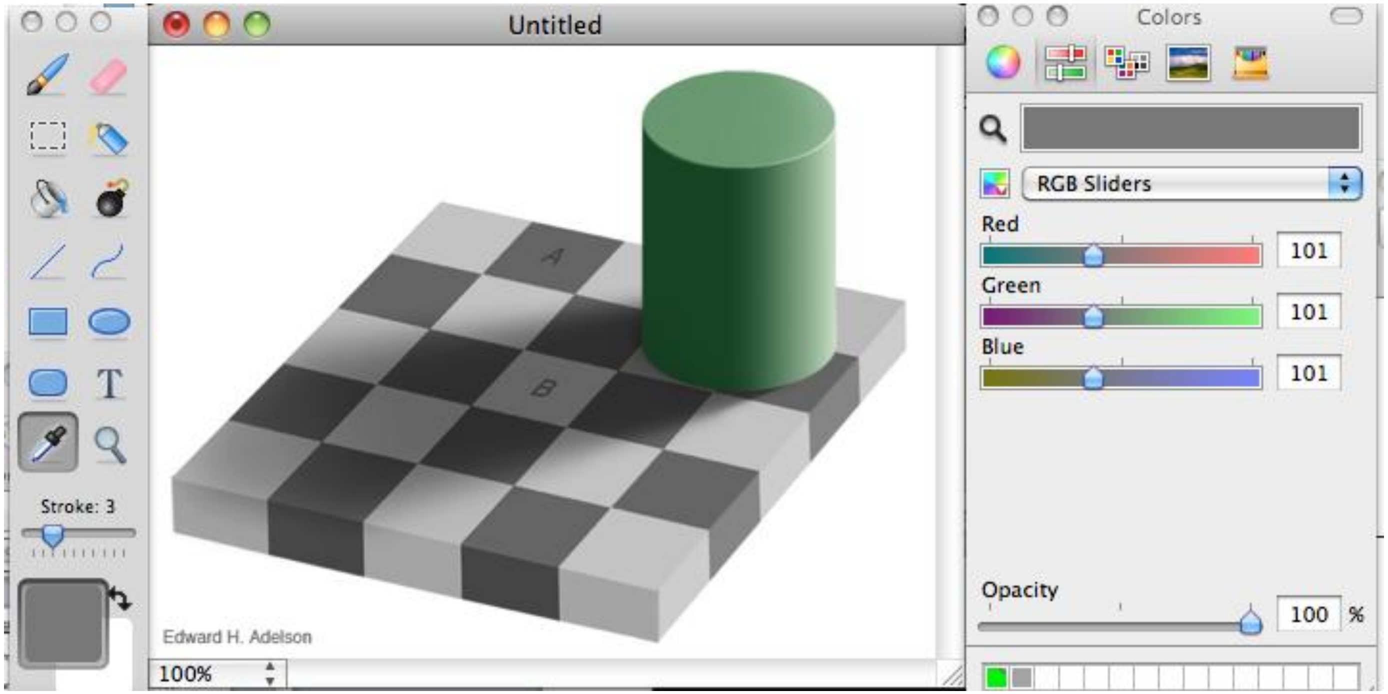
Lighting and Reflectance

Lighting and Reflectance



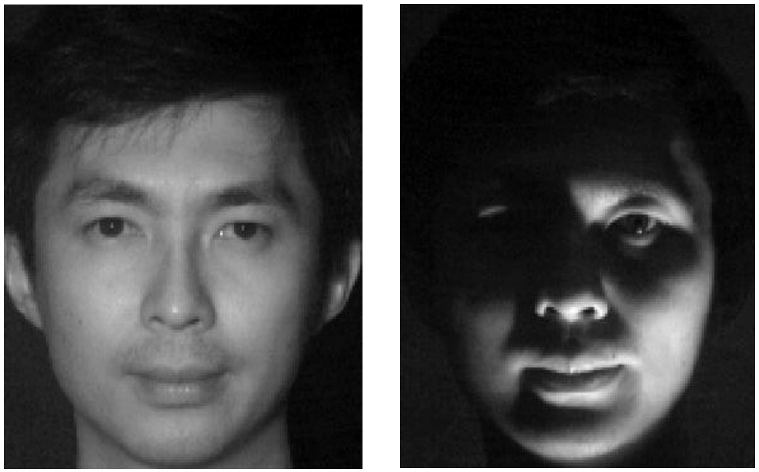
The squares marked A and B are the same shade of gray

Lighting



Lets go to paintbrush

Lighting



Lighting can have a big effect on how an object looks.

Modeling the effect of lighting can be used for:

Recognition – particularly face recognition

Shape reconstruction

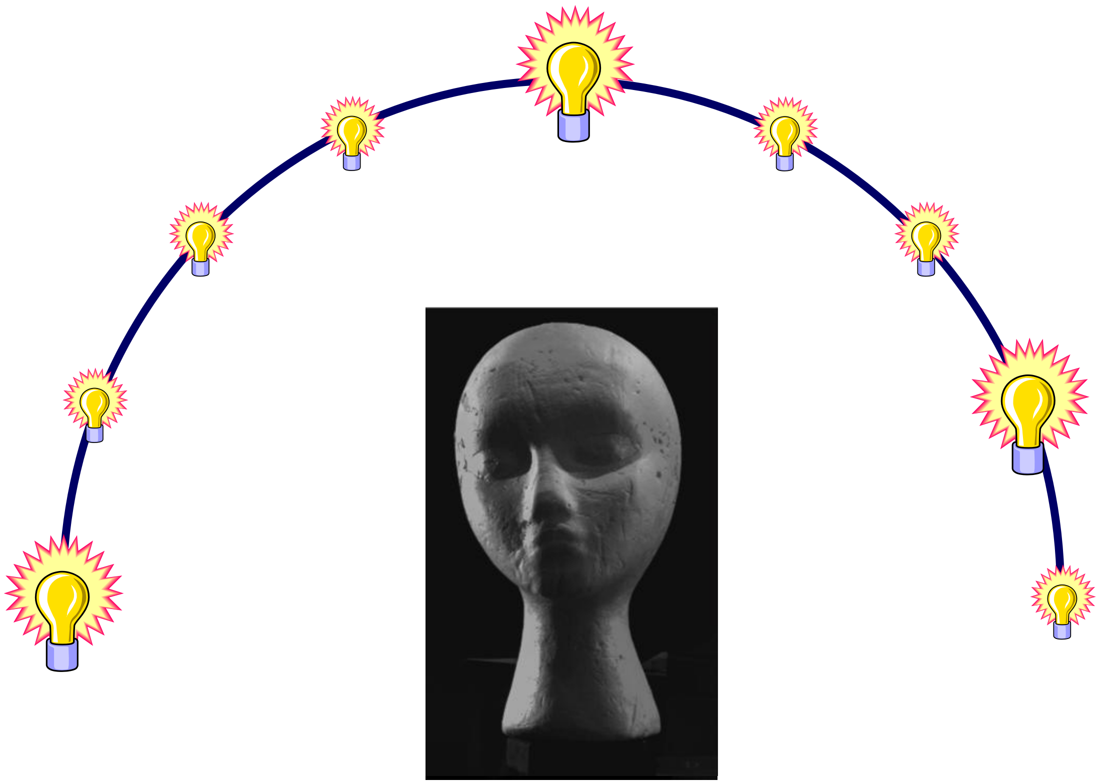
Motion estimation

Re-rendering / Re-lighting

…

Lighting is Complex

- Lighting can come from any direction and at any strength
- Infinite degree of freedom

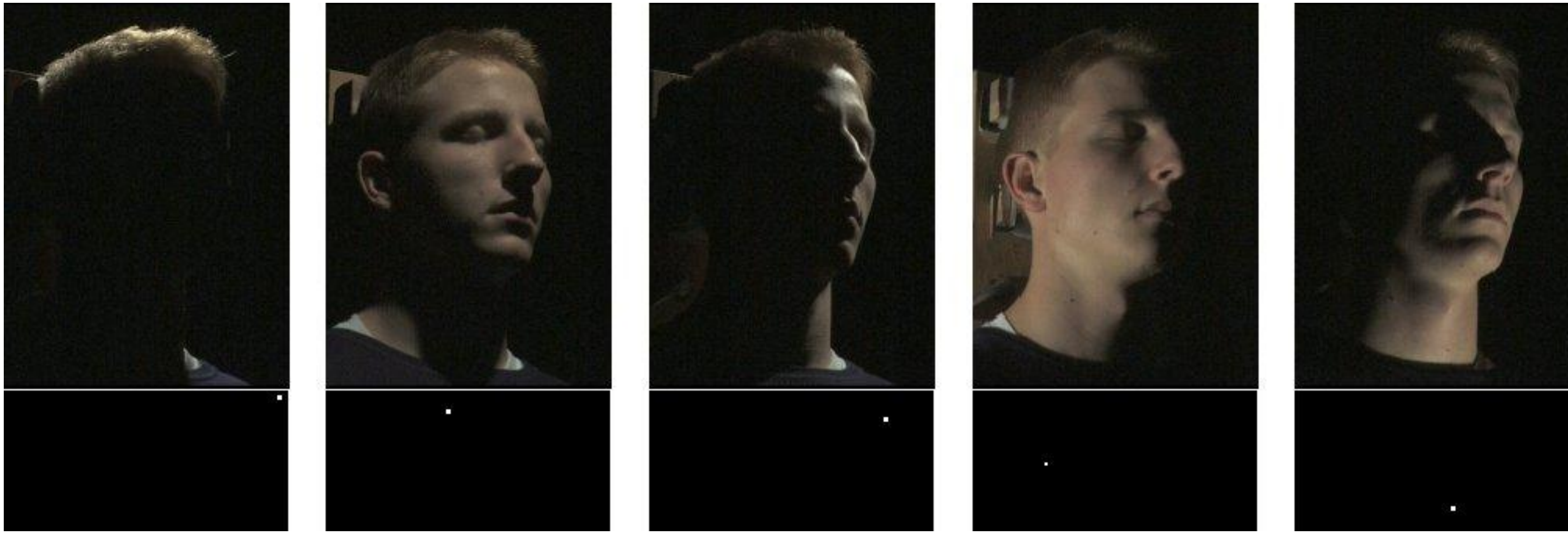


Capture lighting variation

Illuminate subject from many incident directions

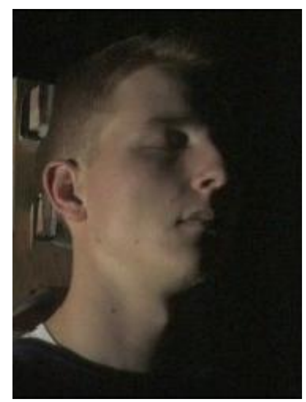
From Ravi Ramamoorthi

Example images:



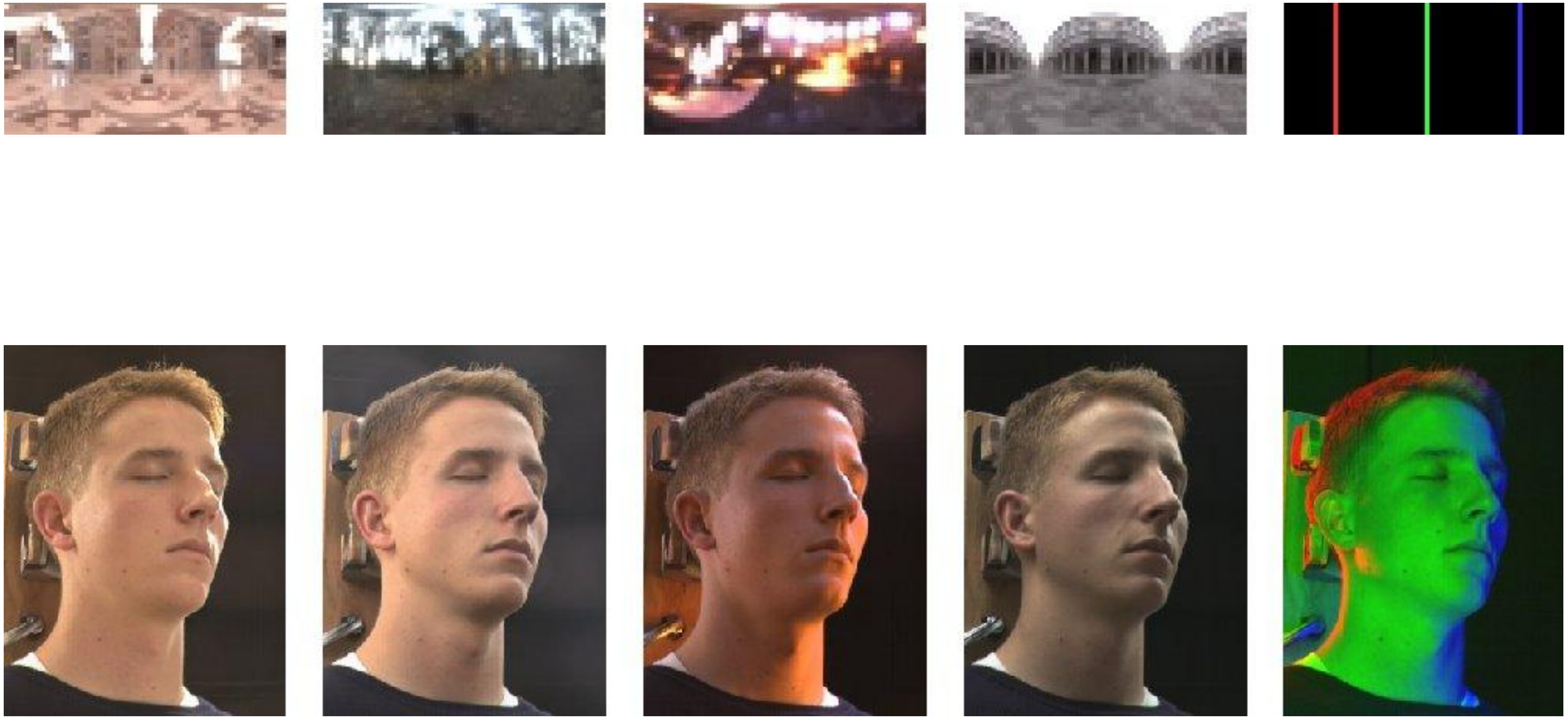
= .2

+ .3



+ ...

From Ravi Ramamoorthi



From Ravi Ramamoorthi

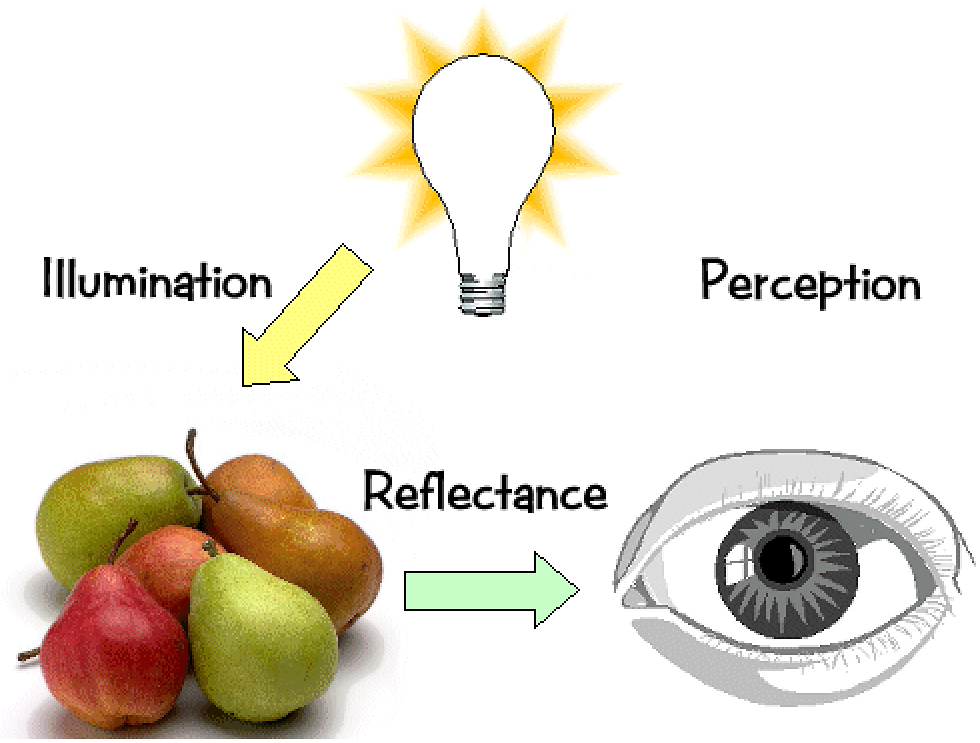
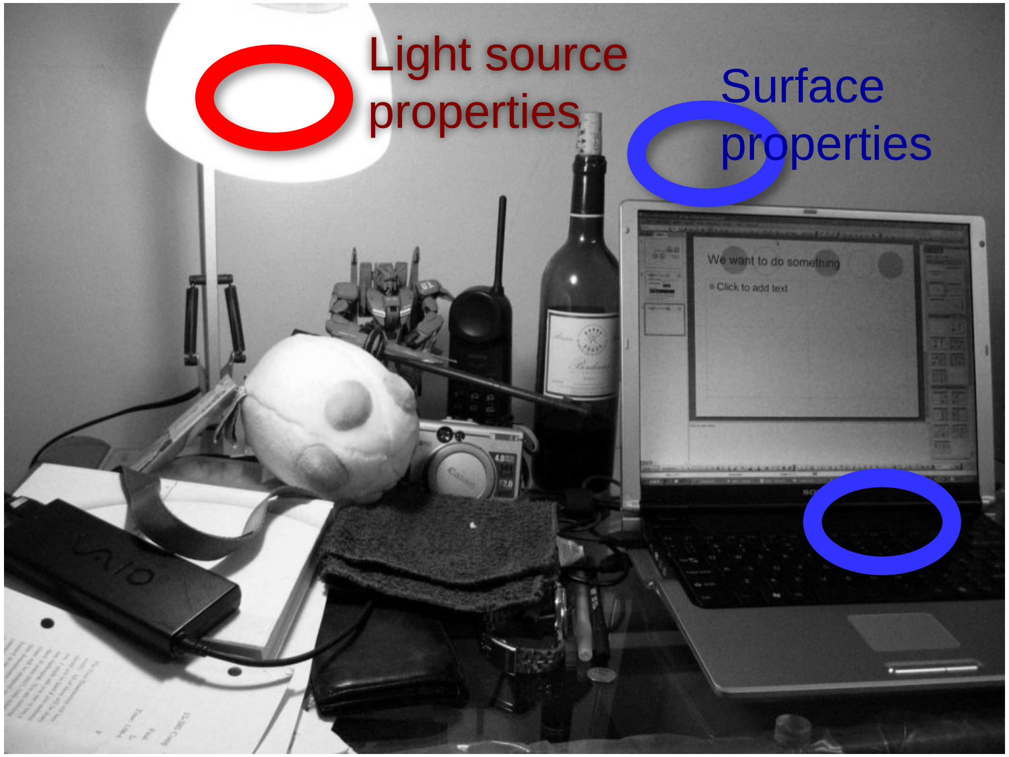

Illumination
Perception
Reflectance

Image brightness

What determines the brightness of an image pixel?

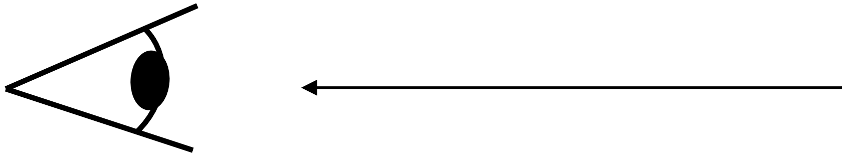


- lighting
- Surface BRDF (local reflectance)
- Shadowing
- Inter-reflections (global reflectance)

What is light?

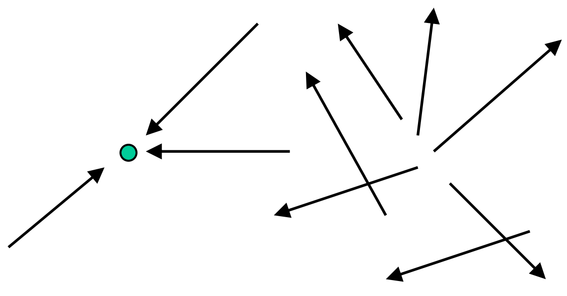
Electromagnetic radiation (EMR) moving along rays in space

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



Light field

- We can describe all of the light in the scene by specifying the radiation (or **"radiance"** along all light rays) arriving at every point in space and from every direction

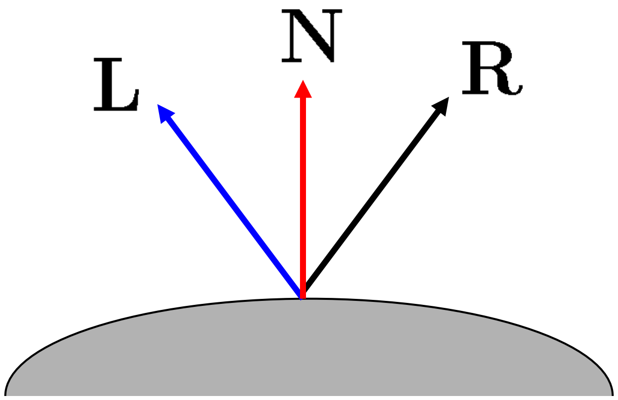


$$R(X, Y, Z, \theta, \phi, \lambda, t)$$

The light field

$$R(X, Y, Z, \theta, \phi, \lambda, t)$$

- Known as the **plenoptic function**
- If you know *R*, you can predict how the scene would appear from any viewpoint.
- Common to think of lighting at infinity (a function on the sphere, a 2D space)
- Usually drop λ and time parameters



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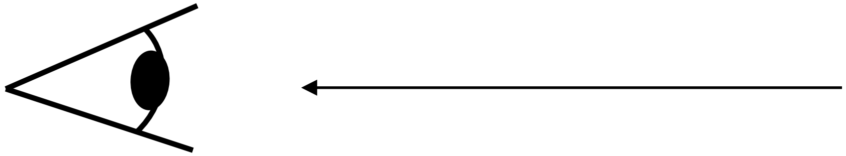
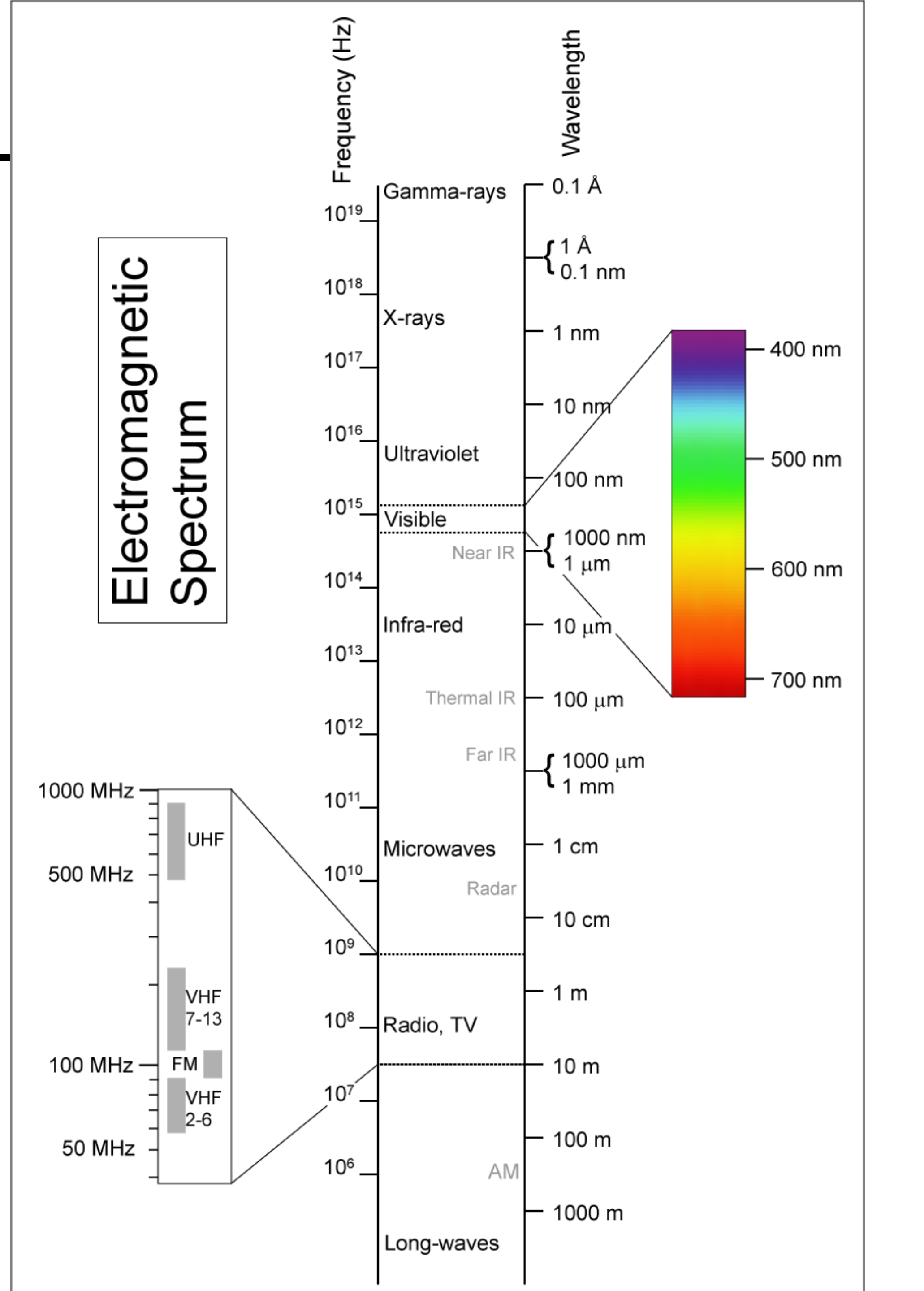


Perceiving light

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

Visible light

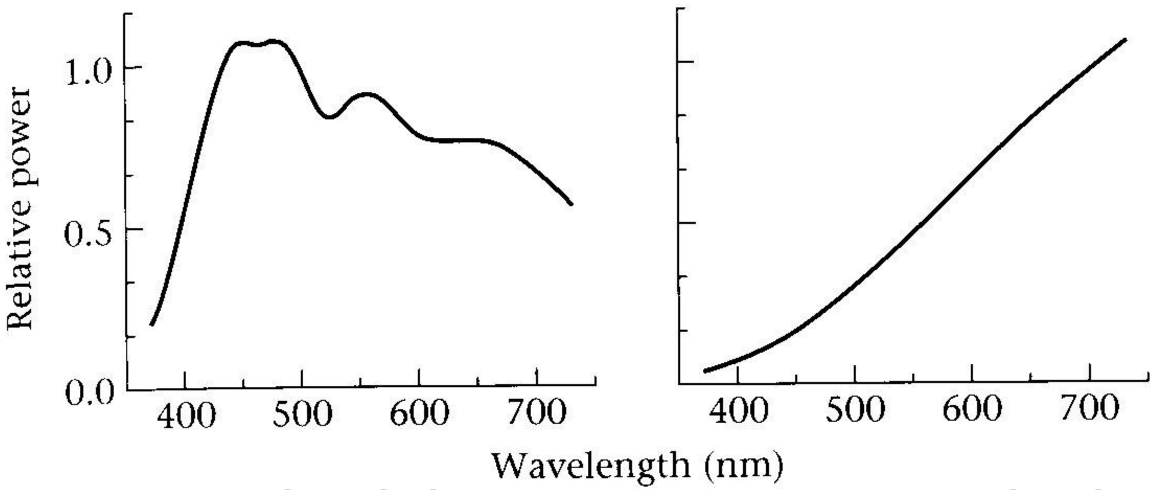
We "see" electromagnetic radiation in a range of wavelengths



Light spectrum

The appearance of light depends on its power **spectrum**

- How much power (or energy) at each wavelength

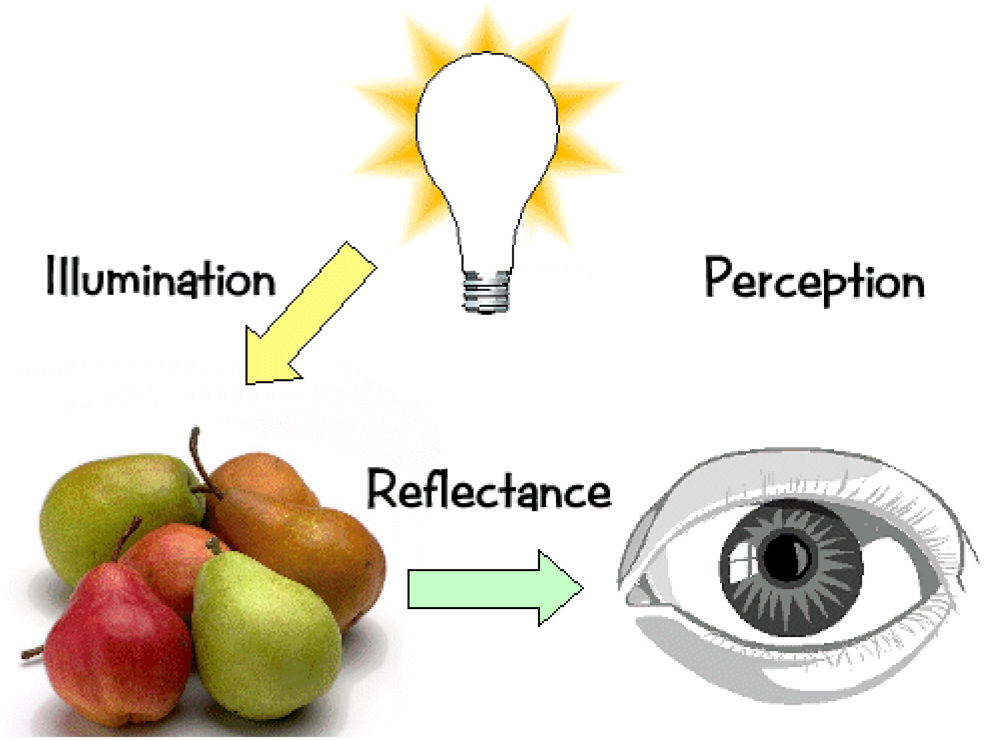


daylight tungsten bulb

Our visual system converts a light spectrum into “color”

- This is a rather complex transformation

Light transport



Light sources

Basic types

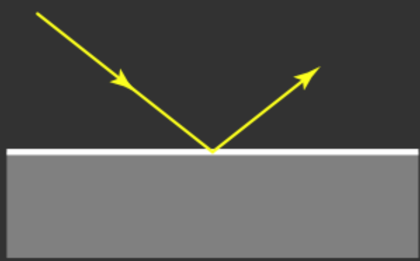
- point source
- Distant point source
- area source
  - a union of point sources

More generally

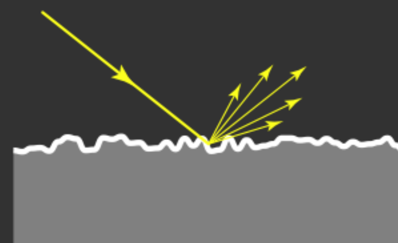
- a light field can describe *any* distribution of light sources

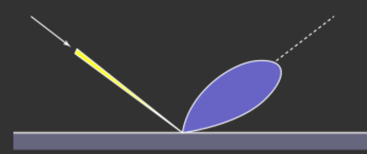
What happens when light hits an object?

Typical Reflections

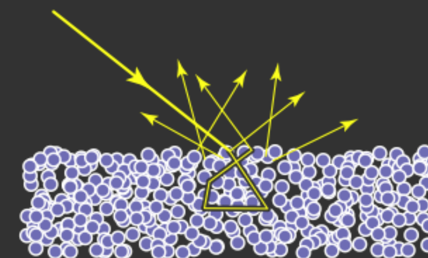


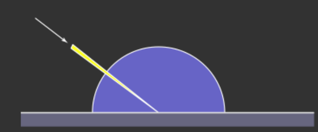
ideal specular





rough specular





Lambertian

from Steve Marschner

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

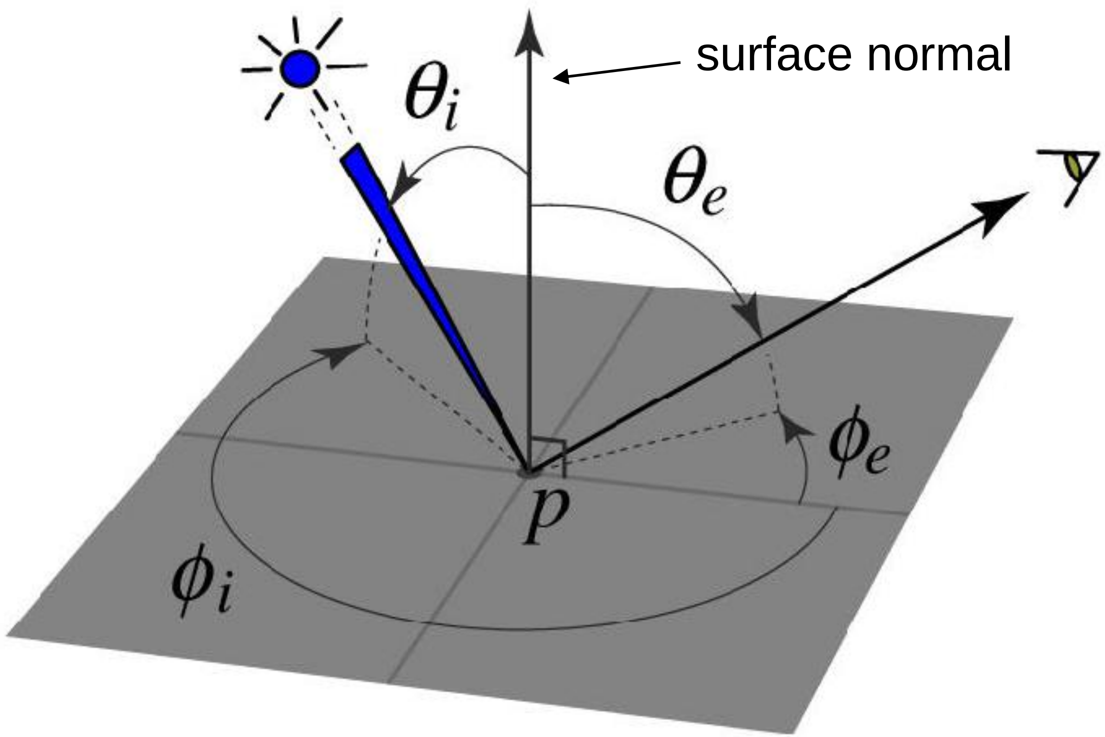
- as we saw before, it could be reflected in multiple directions (possibly all directions) at once

Let’s consider the case of reflection in detail

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: $\rho(\theta_i, \phi_i, \theta_e, \phi_e)$

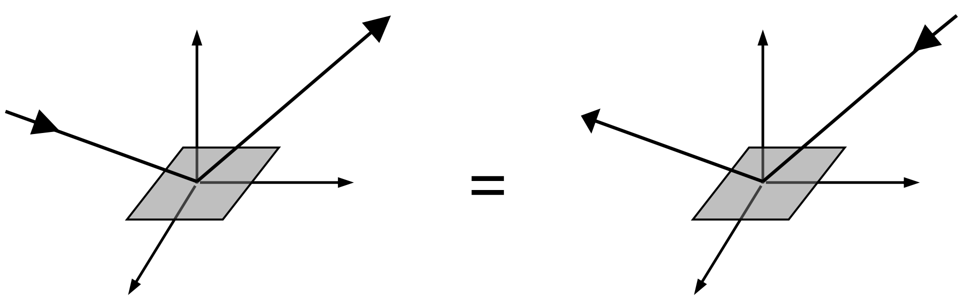
Constraints on the BRDF

Energy conservation

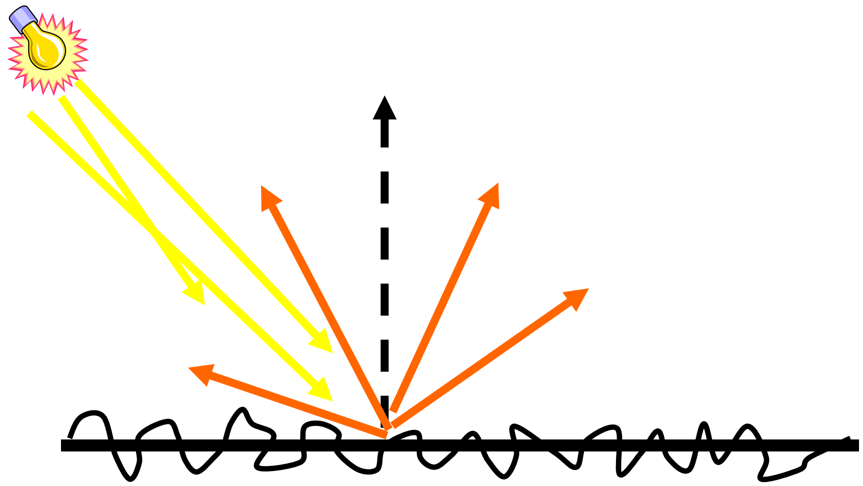
- Quantity of outgoing light ≤ quantity of incident light
  - integral of BRDF ≤ 1

Helmholtz reciprocity

- reversing the path of light produces the same reflectance



Diffuse (Lambertian) reflection



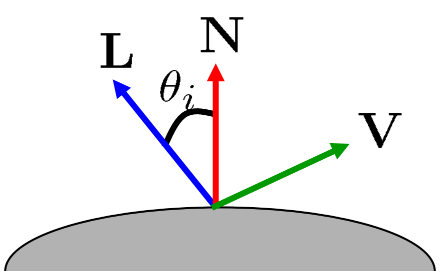
Diffuse reflection

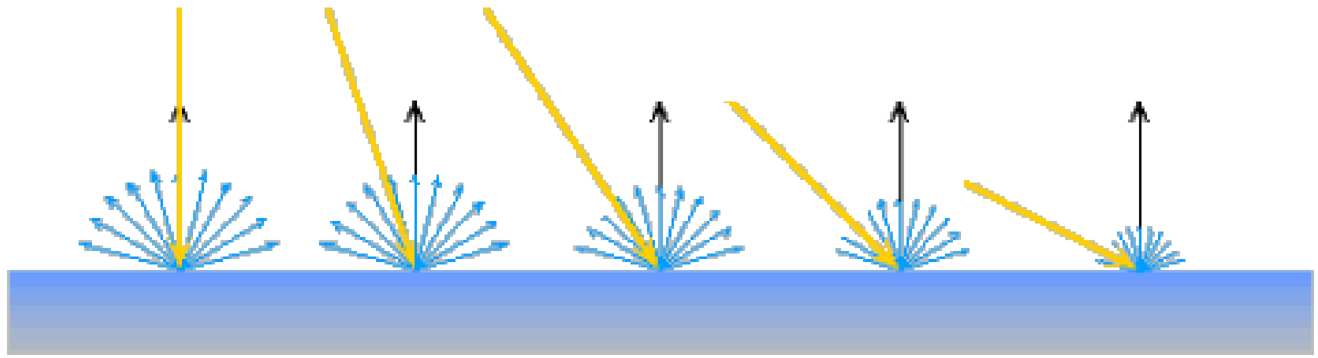
- Dull, matte surfaces like chalk or latex paint
- Microfacets scatter incoming light randomly
- Effect is that light is reflected equally in all directions

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: $I_e = k_d \mathbf{N} \cdot \mathbf{L} I_i$

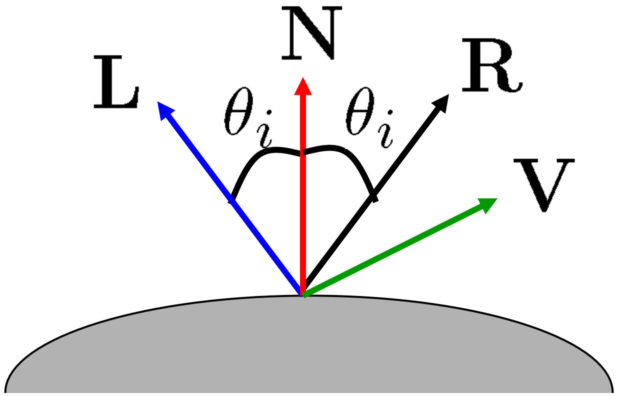
k_d is called **albedo**

BRDF for **Lambertian surface**

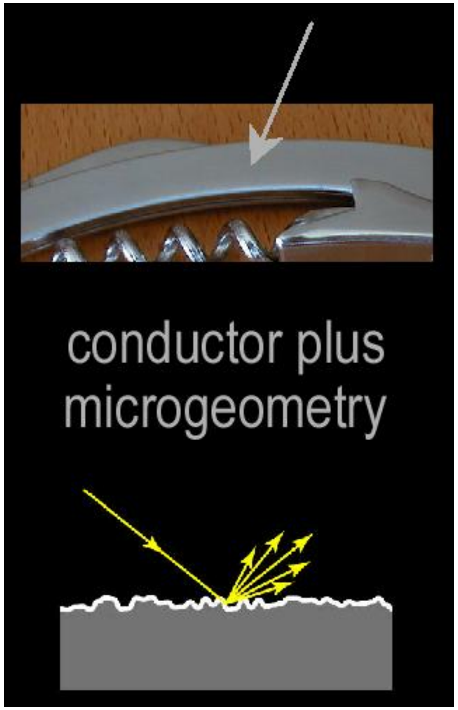
$$\rho(\theta_i, \phi_i, \theta_e, \phi_e) = k_d cos\theta_i$$

Specular reflection

For a perfect mirror, light is reflected about **N**



$$I_e = \begin{cases} I_i & \text{if } \mathbf{V} = \mathbf{R} \\ 0 & \text{otherwise} \end{cases}$$

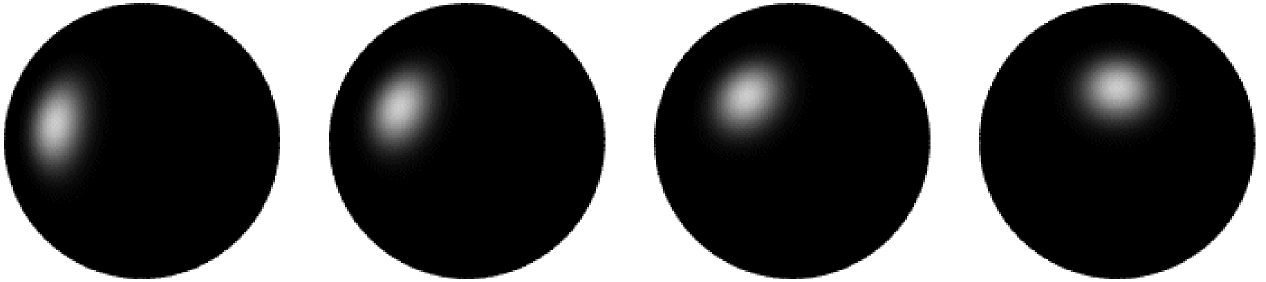


Near-perfect mirrors have a **highlight** around **R**

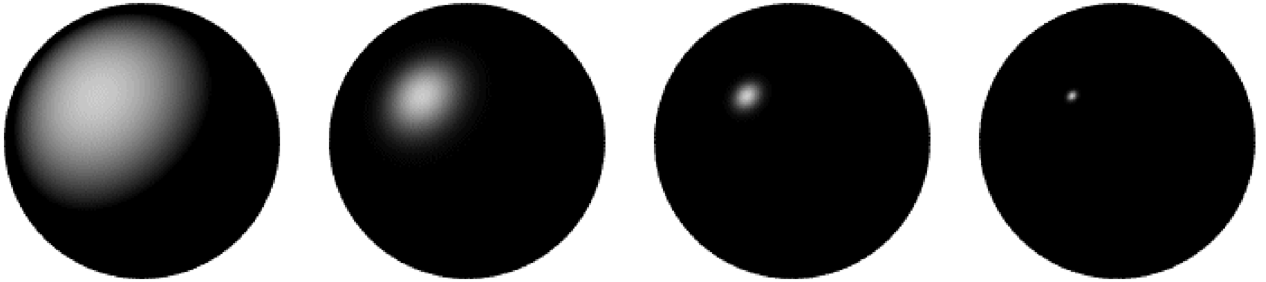
- common model:

$$I_e = k_s(\mathbf{V} \cdot \mathbf{R})^{n_s} I_i$$

Specular reflection



Moving the light source



Changing n_s

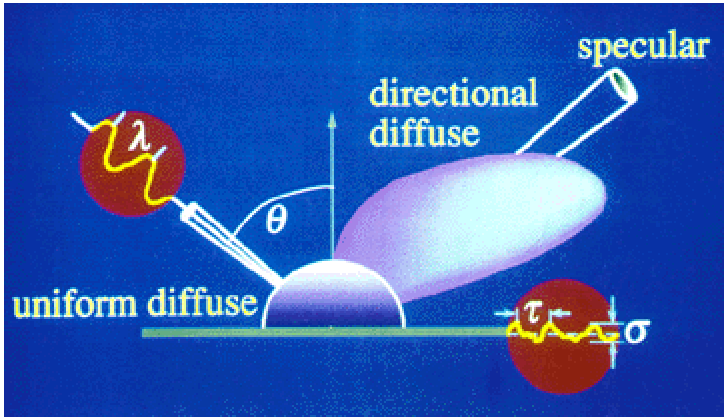
Phong illumination model

Phong approximation of surface reflectance

- Assume reflectance is modeled by three components
  - Diffuse term
  - Specular term
  - Ambient term (to compensate for inter-reflected light)

$$I_e = k_a I_a + I_i \left[k_d (\mathbf{N} \cdot \mathbf{L})_+ + k_s (\mathbf{V} \cdot \mathbf{R})_+^{n_s} \right]$$

L, **N**, **V** unit vectors
I_e = outgoing radiance
I_i = incoming radiance
I_a = ambient light
k_a = ambient light reflectance factor
$(x)_+ = \max(x, 0)$



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

- Next time Photometric Stereo
- Project 3 is due on Feb 26
- Don’t forget to take panorama kit from Stephen