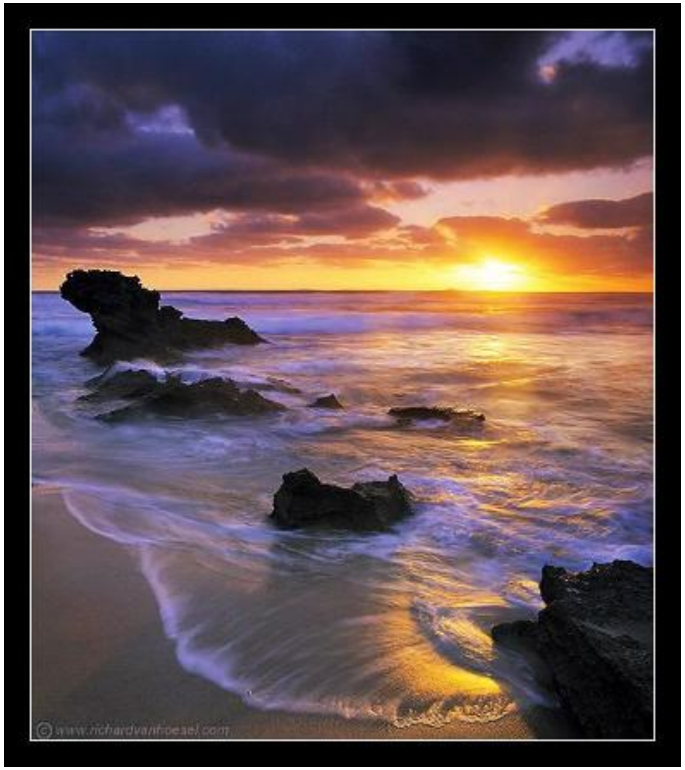
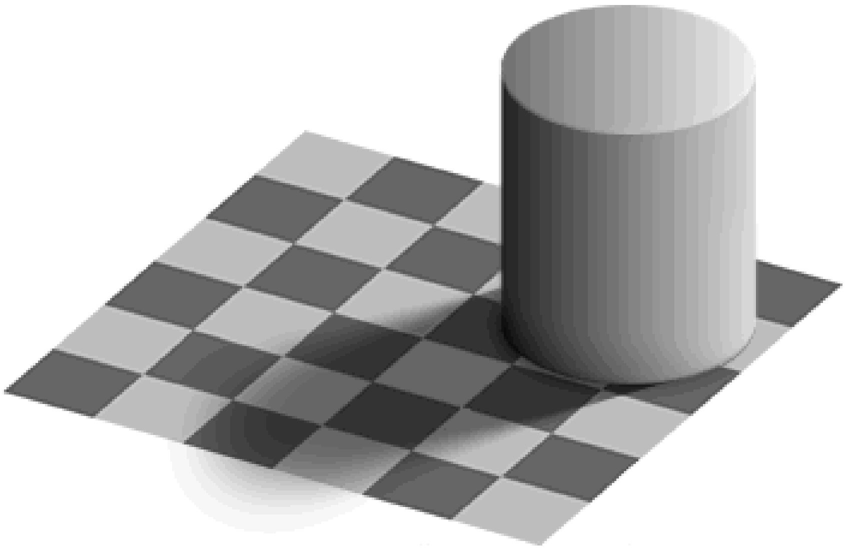
CS4670: Computer Vision

Noah Snavely

Lecture 30: Light, color, and reflectance



Light

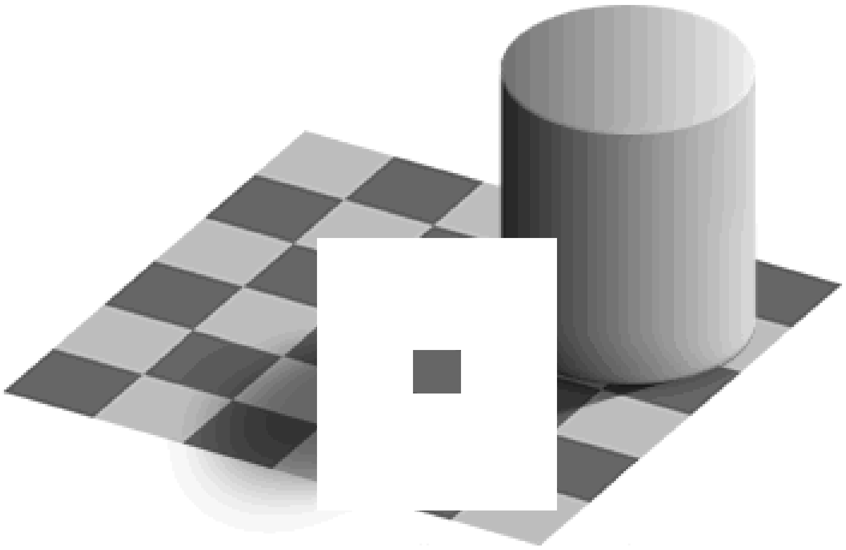


by Ted Adelson

Readings

- Szeliski, 2.2, 2.3.2

Light



by Ted Adelson

Readings

- Szeliski, 2.2, 2.3.2

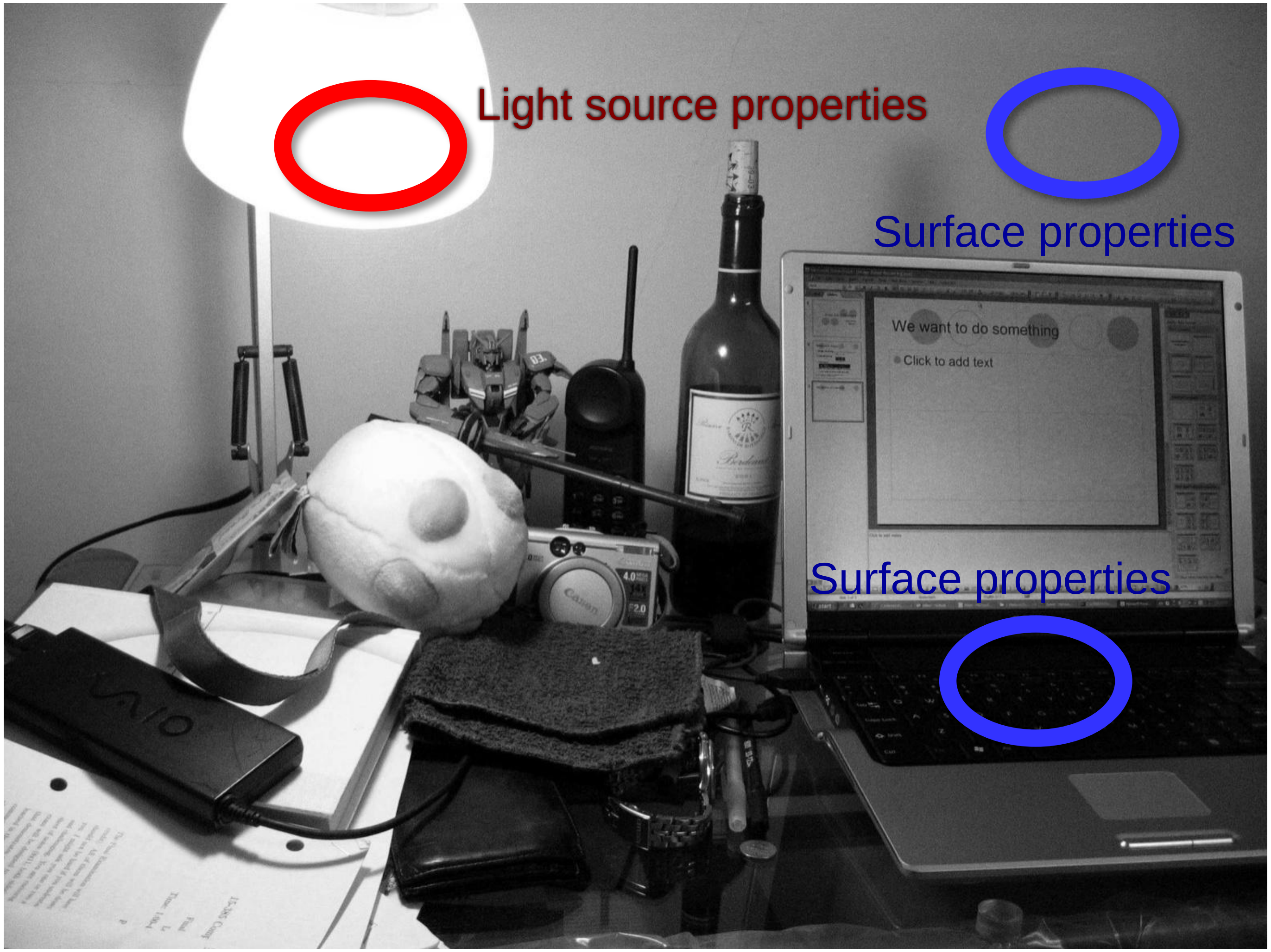
Properties of light

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 a pixel?

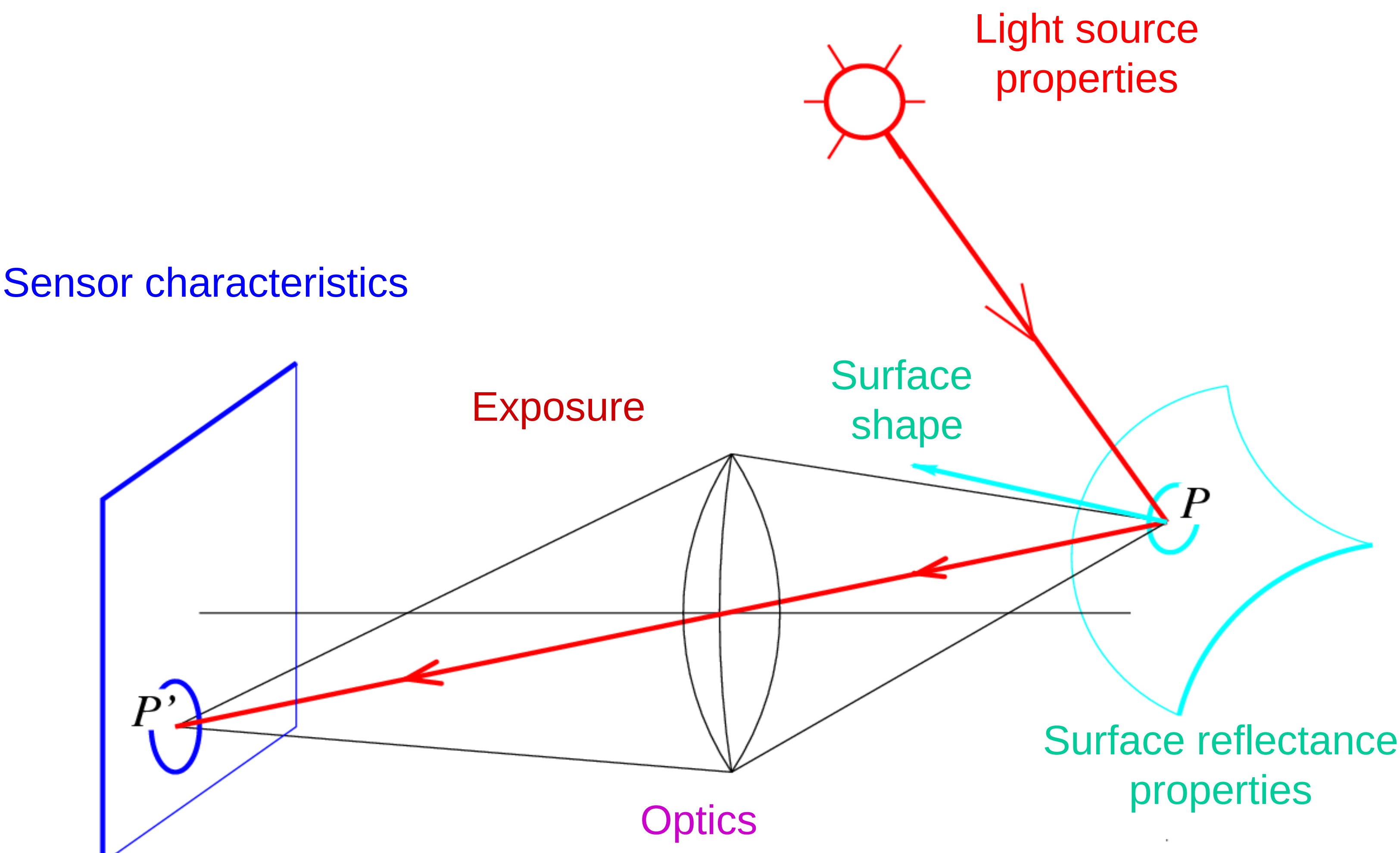


Radiometry

What determines the brightness of a pixel?

Radiometry

What determines the brightness of an image pixel?

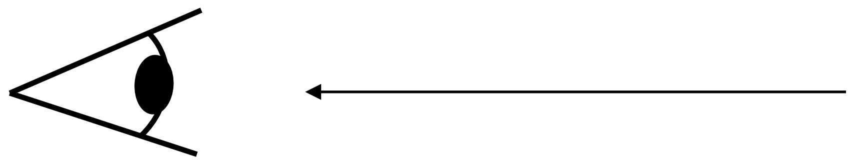


Slide by L. Fei-Fei

What is light?

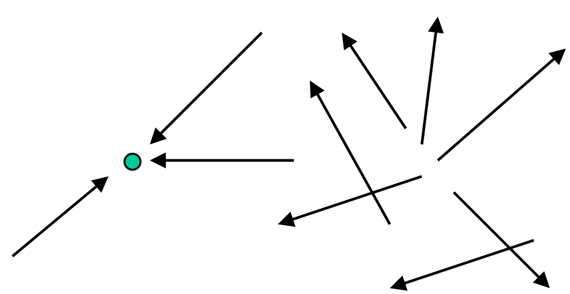
Electromagnetic radiation (EMR) moving along rays in space

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



Light field

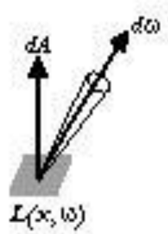
- We can describe all of the light in the scene by specifying the radiation (or **"radiance"** along all light rays) arriving at every point in space and from every direction



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

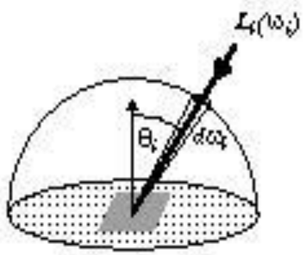
Radiometry

Radiometry **is the science of light energy measurement**



Radiance

The energy carried by a ray
energy/(area solidangle)



Irradiance

The energy per unit area falling on a surface

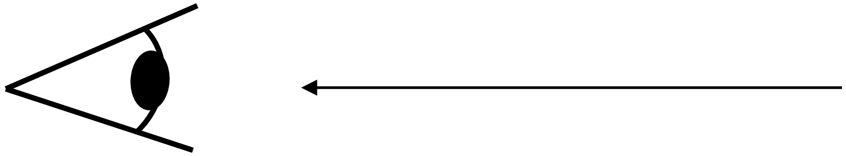
Radiosity

The energy per unit area leaving a surface

Color perception

Electromagnetic radiation (EMR) moving along rays in space

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

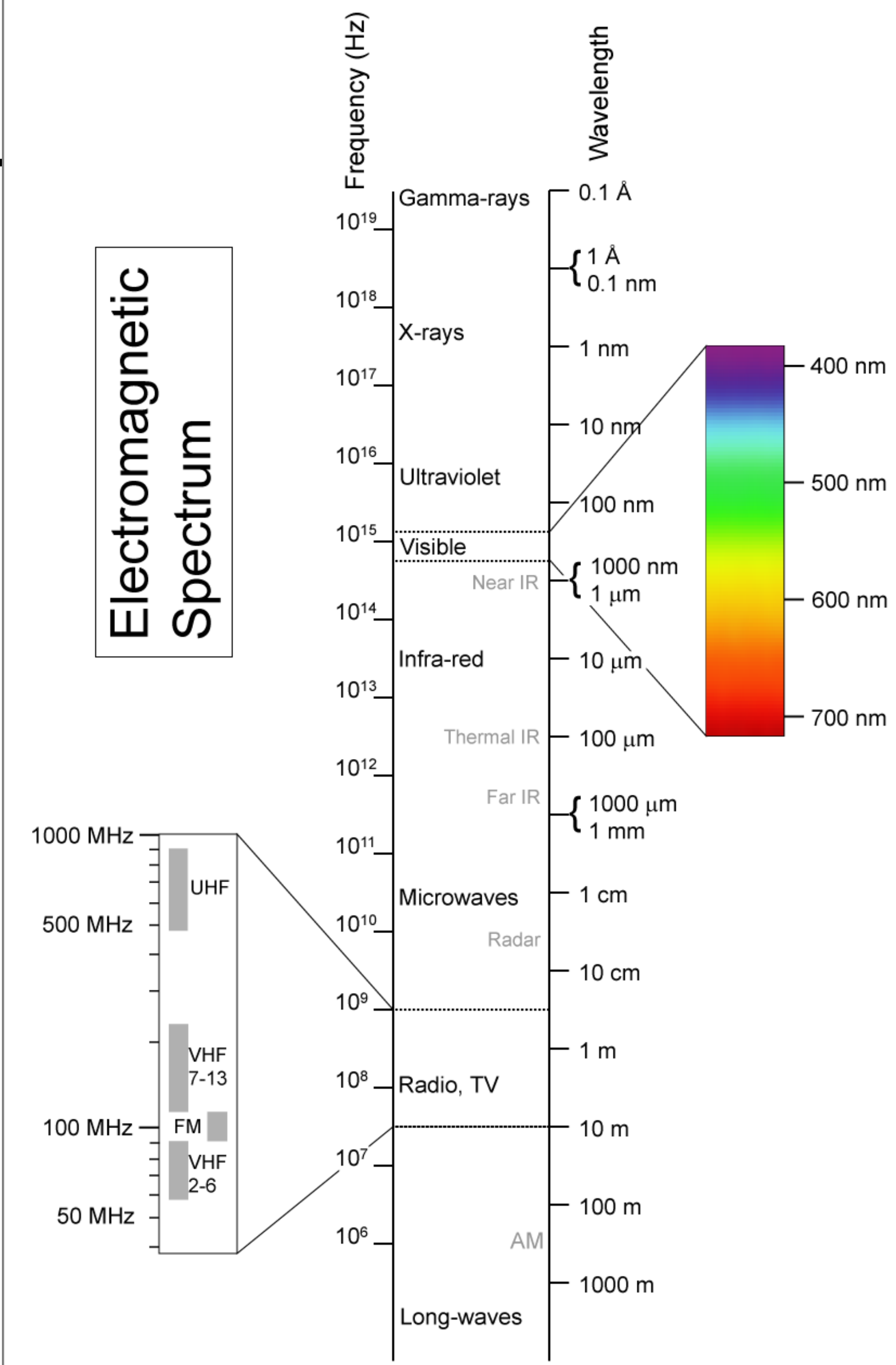


Perceiving light

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

Visible light

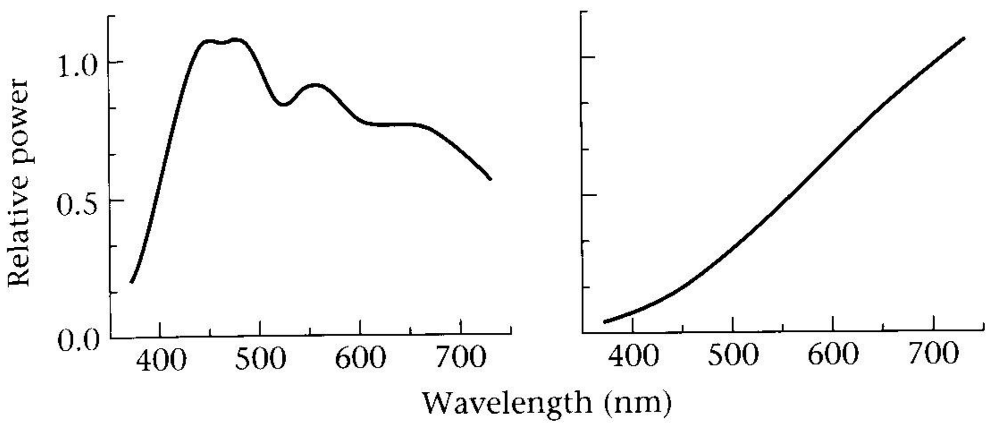
We “see” electromagnetic radiation in a range of wavelengths



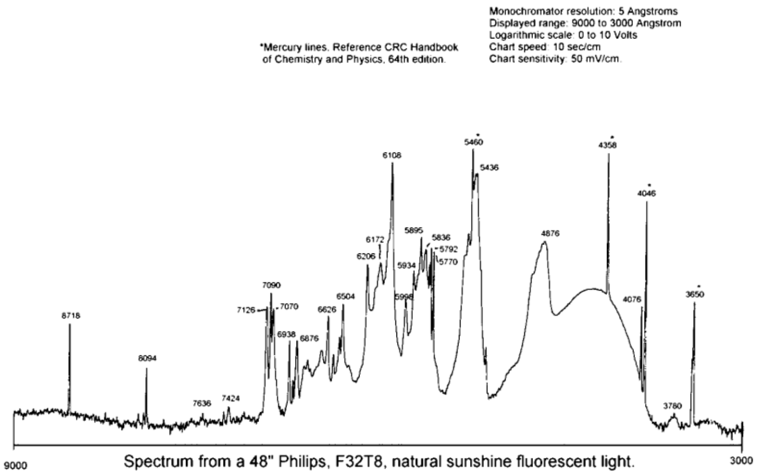
Light spectrum

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

- How much power (or energy) at each wavelength



daylight tungsten bulb

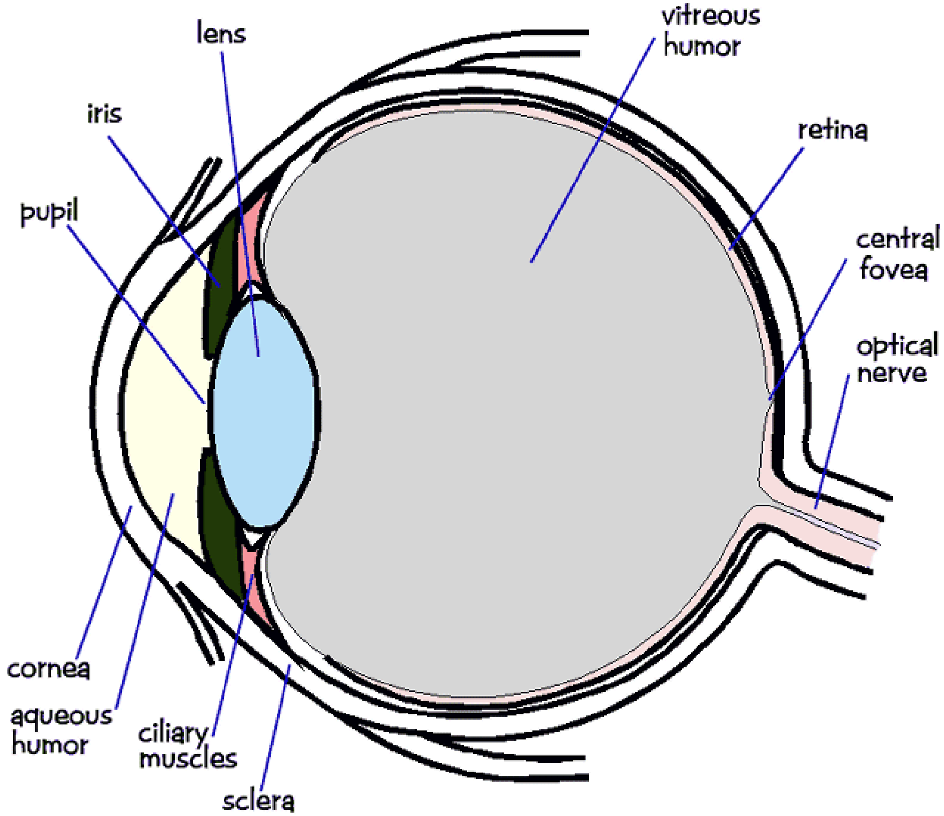


fluorescent bulb

Our visual system converts a light spectrum into “color”

- This is a rather complex transformation

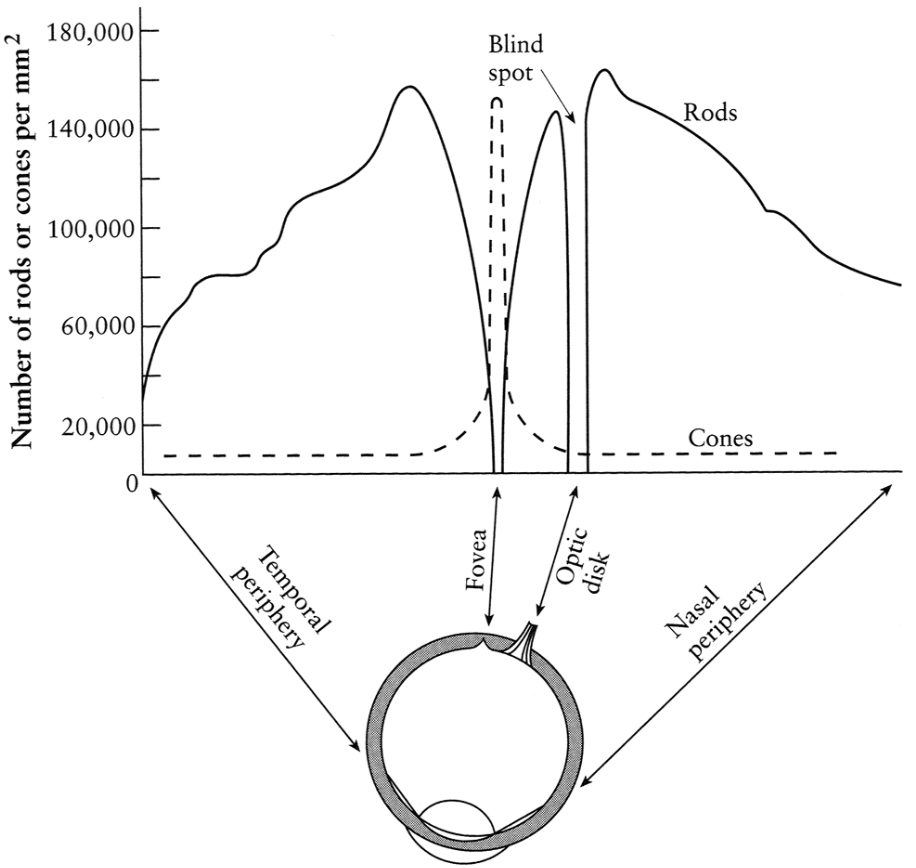
The human visual system



Color perception

- Light hits the retina, which contains photosensitive cells
  - rods and cones
- These cells convert the spectrum into a few discrete values

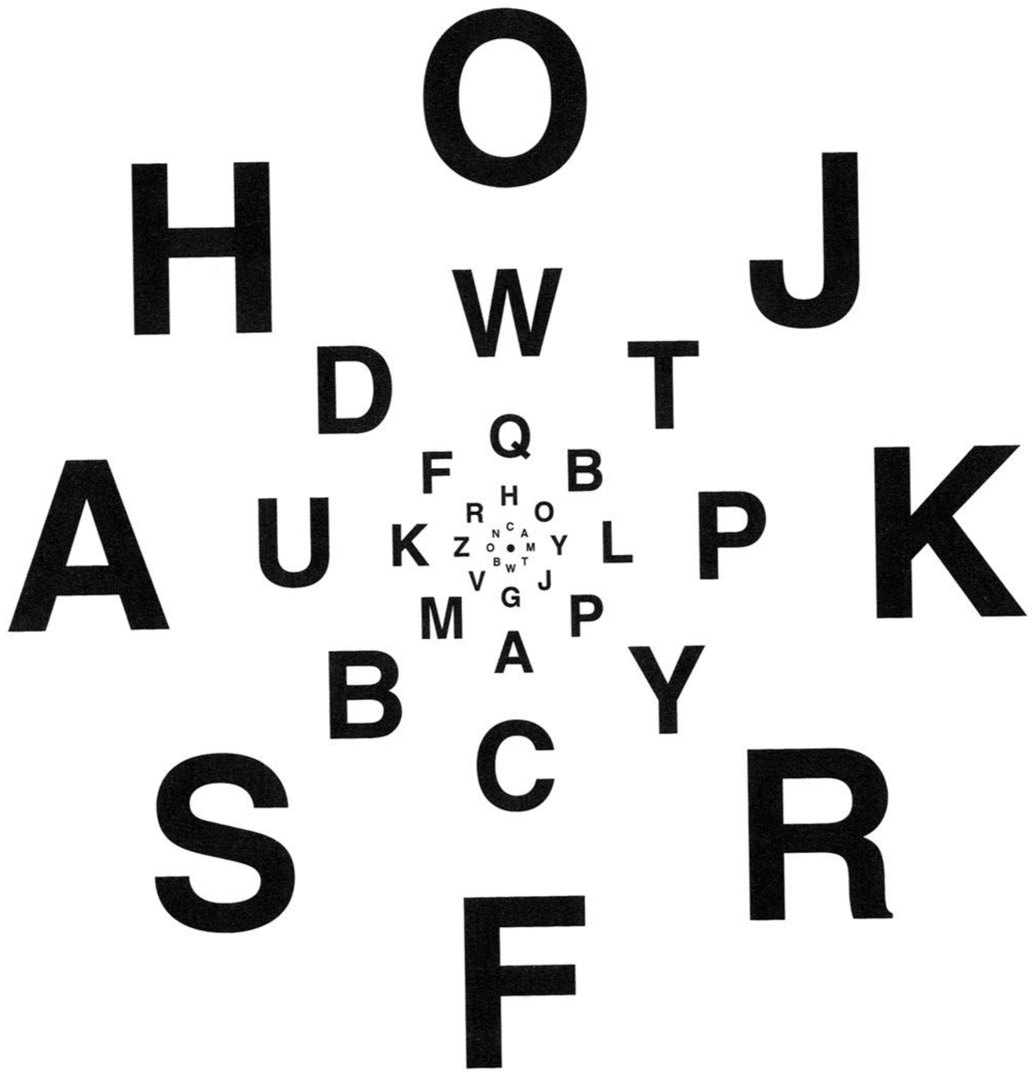
Density of rods and cones



Rods and cones are *non-uniformly* distributed on the retina

- Rods responsible for intensity, cones responsible for color
- **Fovea** - Small region (1 or 2°) at the center of the visual field containing the highest density of cones (and no rods).
- Less visual acuity in the periphery—many rods wired to the same neuron

Demonstrations of visual acuity



With one eye shut, at the right distance, all of these letters should appear equally legible (Glassner, 1.7).

Demonstrations of visual acuity

With left eye shut, look at the cross on the left. At the right distance, the circle on the right should disappear (Glassner, 1.8).

Brightness contrast and constancy

The apparent brightness depends on the surrounding region

- **brightness contrast**: a constant colored region seems lighter or darker depending on the surrounding intensity:

  - http://www.sandlotscience.com/Contrast/Checker_Board_2.htm

- **brightness constancy**: a surface looks the same under widely varying lighting conditions.

Light response is nonlinear

Our visual system has a large *dynamic range*

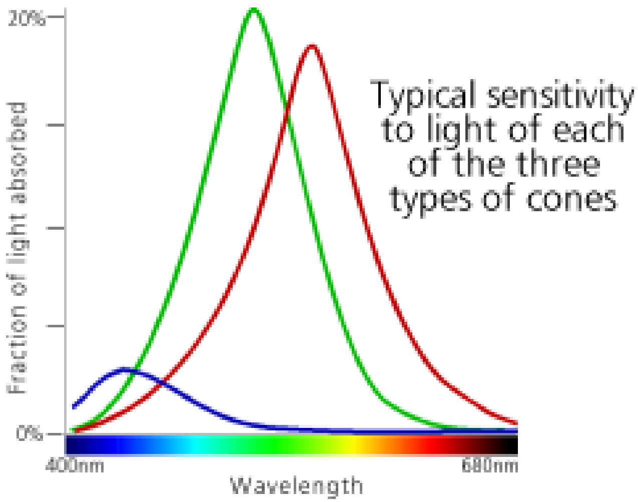
- We can resolve both light and dark things at the same time
- One mechanism for achieving this is that we sense light intensity on a *logarithmic scale*
  - an exponential intensity ramp will be seen as a linear ramp
- Another mechanism is *adaptation*
  - rods and cones adapt to be more sensitive in low light, less sensitive in bright light.

Visual dynamic range

Background	Luminance (candelas per square meter)
Horizon sky	
Moonless overcast night	0.00003
Moonless clear night	0.0003
Moonlit overcast night	0.003
Moonlit clear night	0.03
Deep twilight	0.3
Twilight	3
Very dark day	30
Overcast day	300
Clear day	3,000
Day with sunlit clouds	30,000
Daylight fog	
Dull	300–1,000
Typical	1,000–3,000
Bright	3,000–16,000
Ground	
Overcast day	30–100
Sunny day	300
Snow in full sunlight	16,000

FIGURE 1.13
Luminance of everyday backgrounds. *Source:* Data from Rea, ed., *Lighting Handbook 1984 Reference and Application*, fig. 3-44, p. 3-24.

Color perception

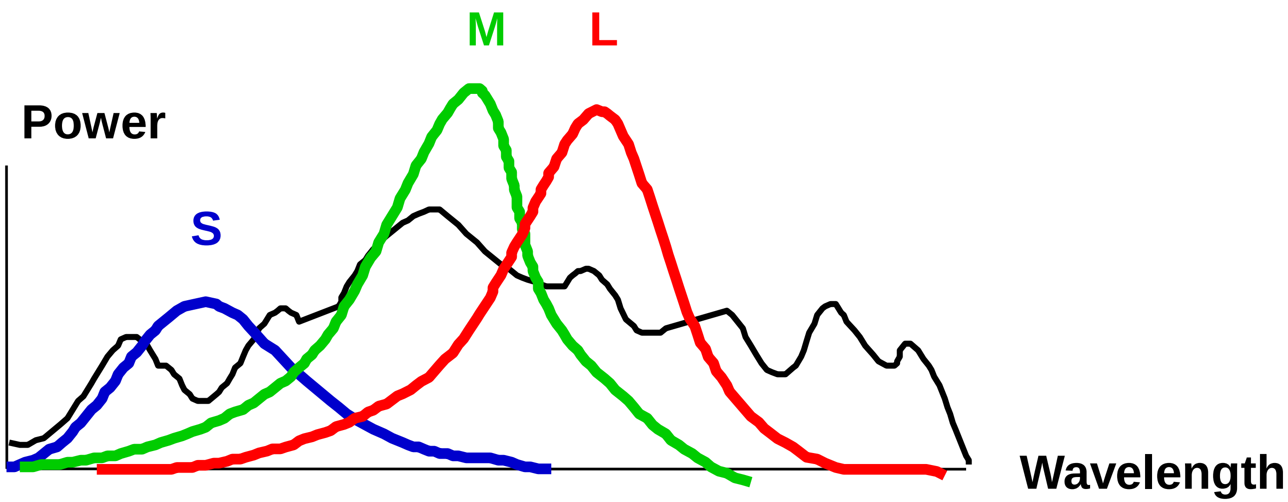


L response curve

Three types of cones

- Each is sensitive in a different region of the spectrum
  - but regions overlap
  - Short (S) corresponds to blue
  - Medium (M) corresponds to green
  - Long (L) corresponds to red
- Different sensitivities: we are more sensitive to green than red
  - varies from person to person (and with age)
- Colorblindness—deficiency in at least one type of cone

Color perception



Rods and cones act as filters on the spectrum

- To get the output of a filter, multiply its response curve by the spectrum, integrate over all wavelengths
  - Each cone yields one number
- Q: How can we represent an entire spectrum with 3 numbers?
- A: We can't! Most of the information is lost.
  - As a result, two different spectra may appear indistinguishable
    - » such spectra are known as **metamers**
    - » http://www.cs.brown.edu/exploratories/freeSoftware/repository/edu/brown/cs/exploratories/applets/spectrum/metamers_guide.html

Perception summary

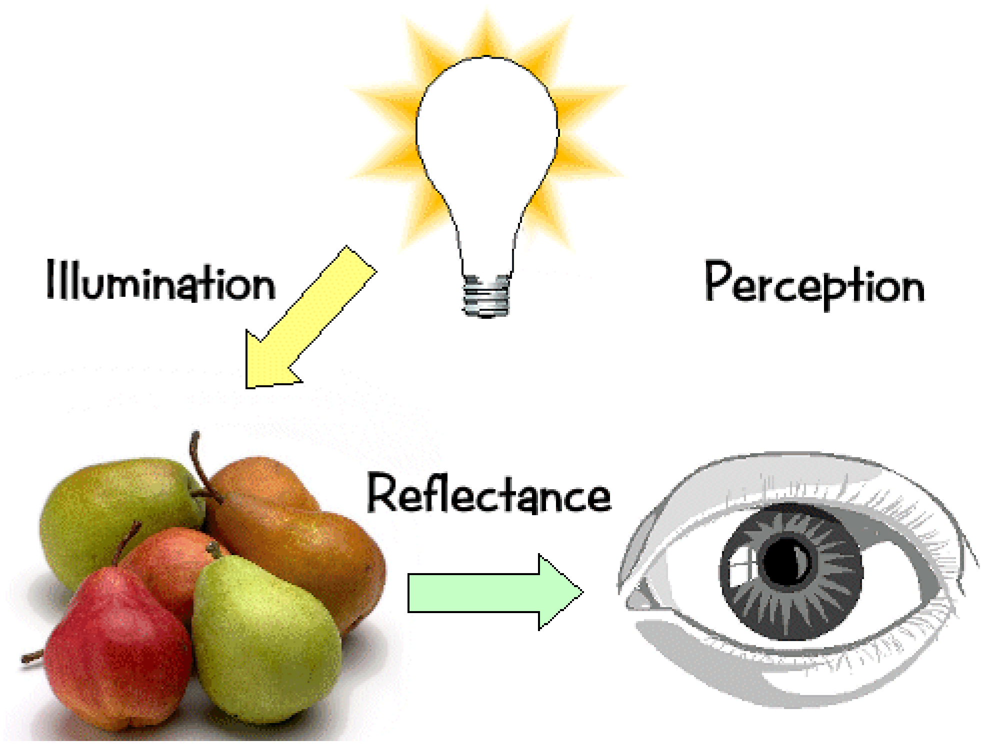
The mapping from radiance to perceived color is quite complex!

- We throw away most of the data
- We apply a logarithm
- Brightness affected by pupil size
- Brightness contrast and constancy effects

The same is true for cameras

- But we have tools to correct for these effects
  - Coming soon: Computational Photography lecture

Light transport



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

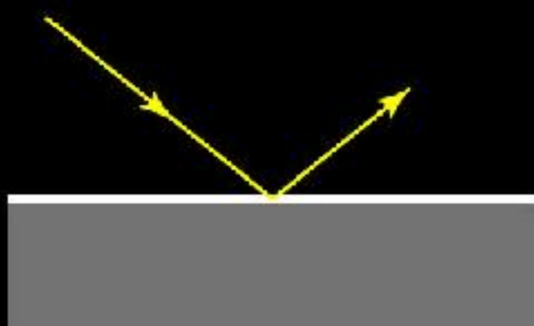
What happens when light hits an object?

from Steve Marschner

Materials

conductor

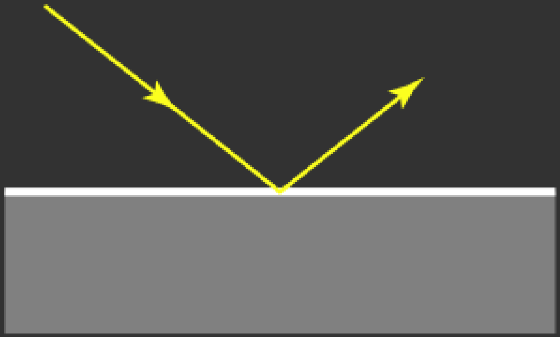
conductor plus microgeometry

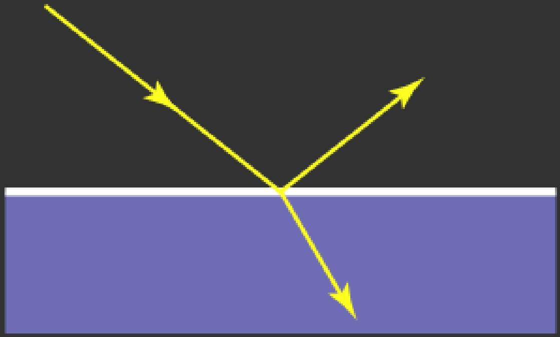


Specular reflection/ transmission

conductor

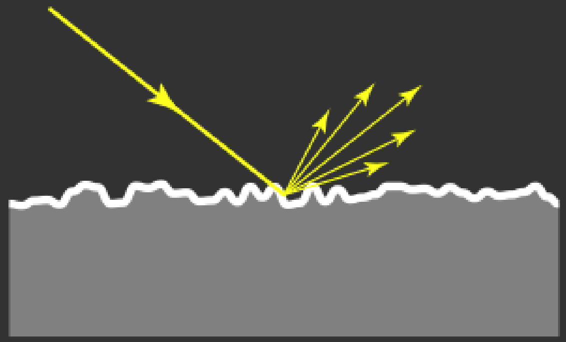
insulator

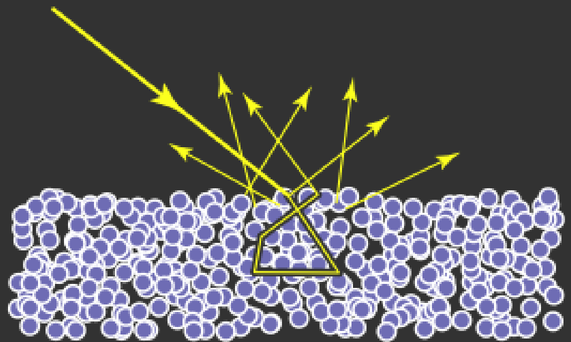




from Steve Marschner

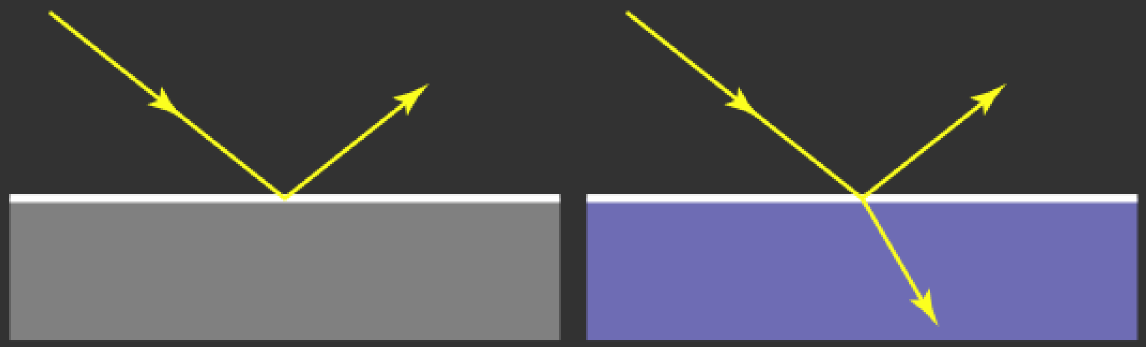
Non-smooth-surfaced materials



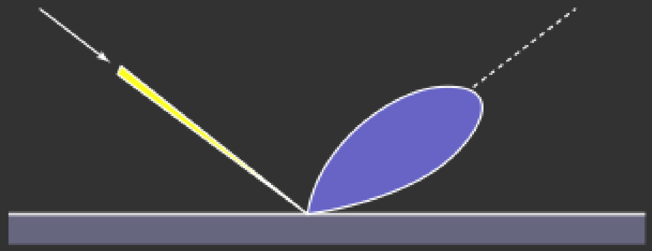


from Steve Marschner

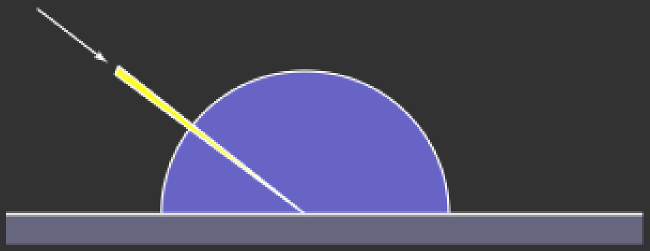
Classic reflection behavior



ideal specular (Fresnel)



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