CS 428: Fall 2009

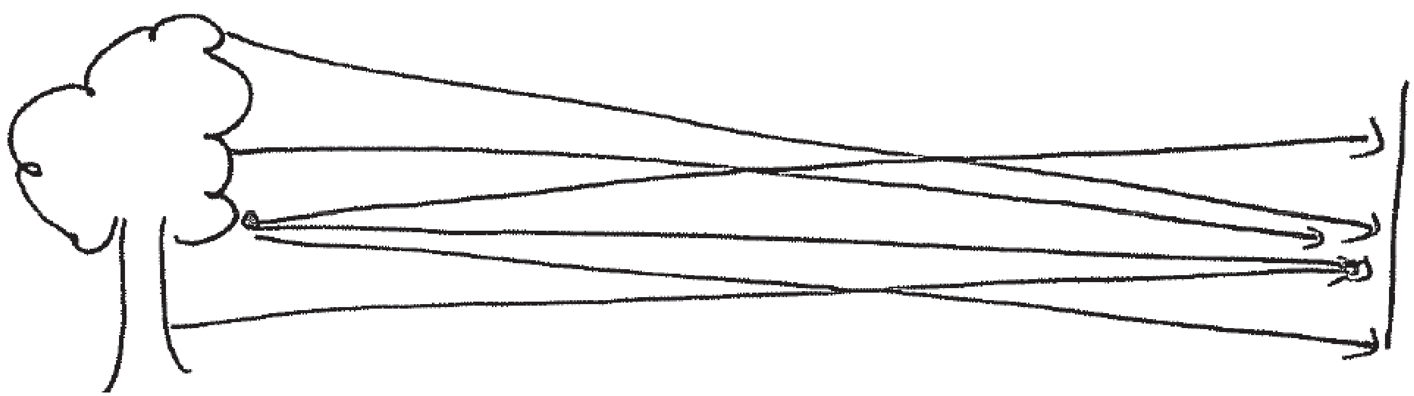
Introduction to Computer Graphics

Image formation
Color and perception

Image formation

Image formation

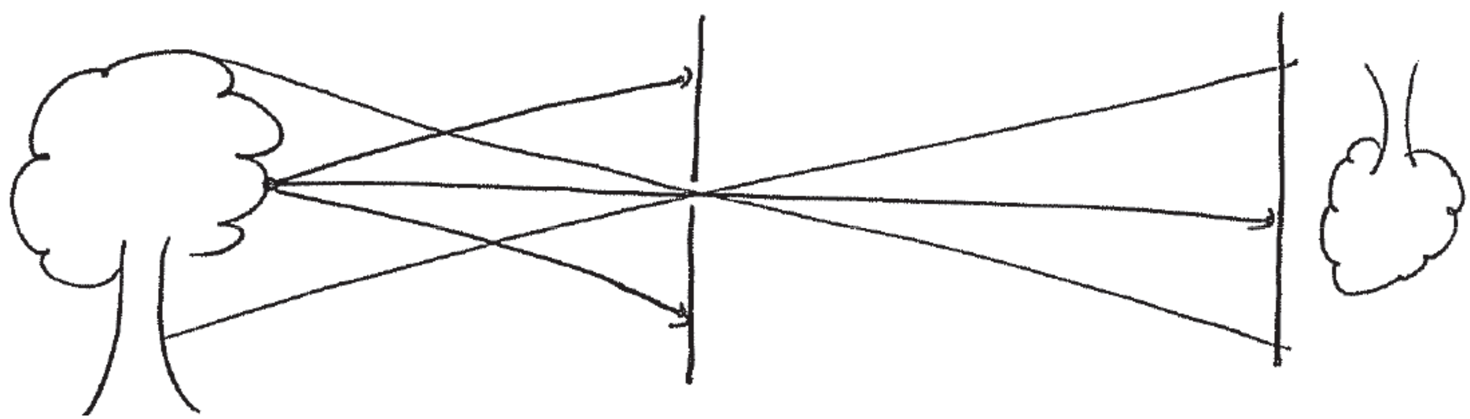
- Need a **model** of this process



- Resulting image is at best a blur (more likely, it's white)

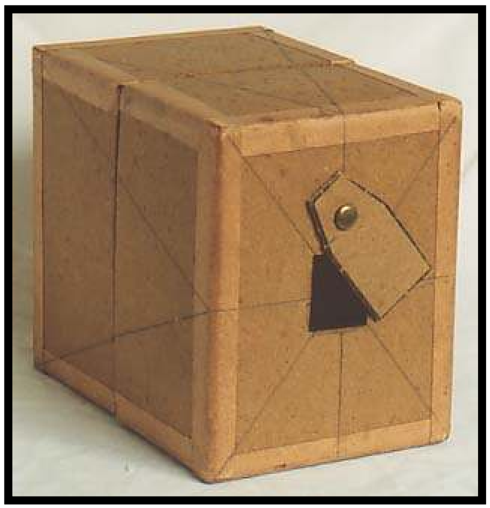
Restricting the light

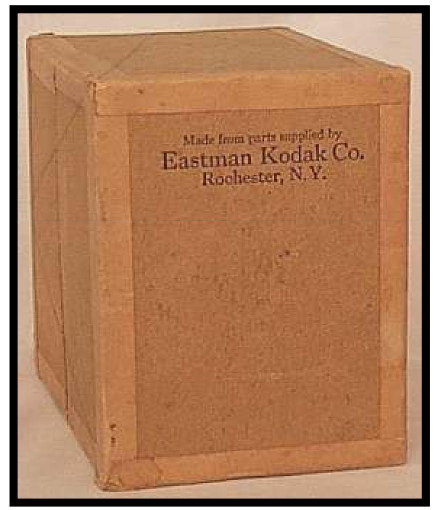
- Use a **barrier** to select rays, block the rest



- This is a **pinhole** camera
  - One light ray for each loc. on film is let through
  - Resulting image is **inverted**

Pinhole cameras





Kodak, 1930s

Pinhole cameras

www.zzz.cz

Pinhole cameras

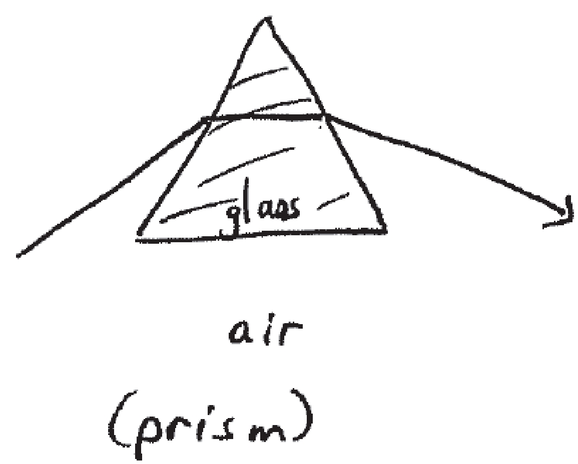
www.pinholeday.org

Pinhole cameras

Advantages	**Disadvantages**
Easy to model and simulate	Requires a lot of light (bright light or long exposure)
Everything is in focus	Everything is in focus

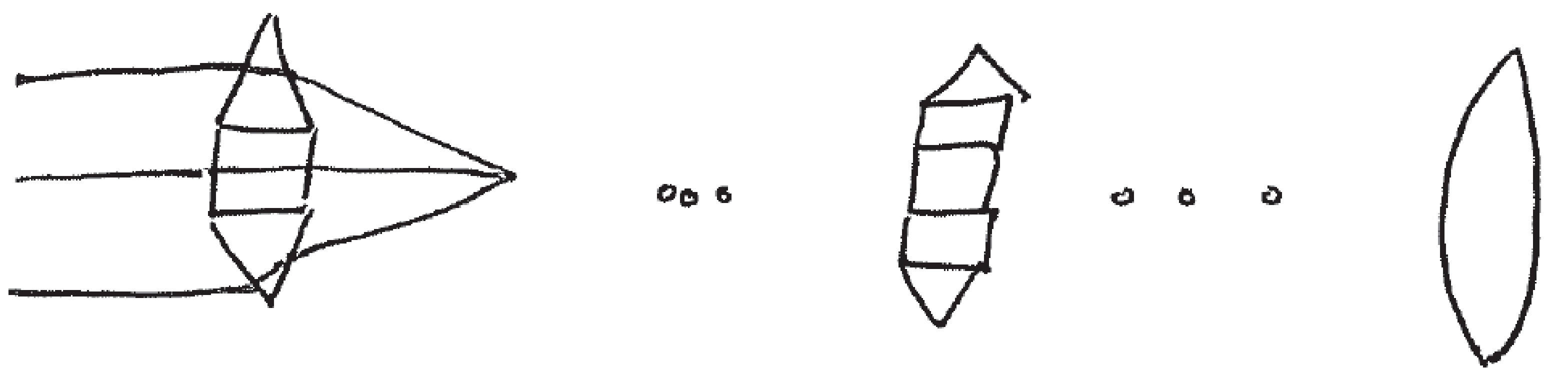
Collecting the light

- Collect a bunch of rays and concentrate them in one place on the sensor
- Light paths are bent using **refraction**
  - Light passing into optically denser material bends towards surface normal



Stacking prisms

- We can use different arrangements of prisms to have particular light rays pass through a single point



- As the number of prisms increases, we have a **lens**

Image formation with a lens

- Shape of the lens controls how light is bent

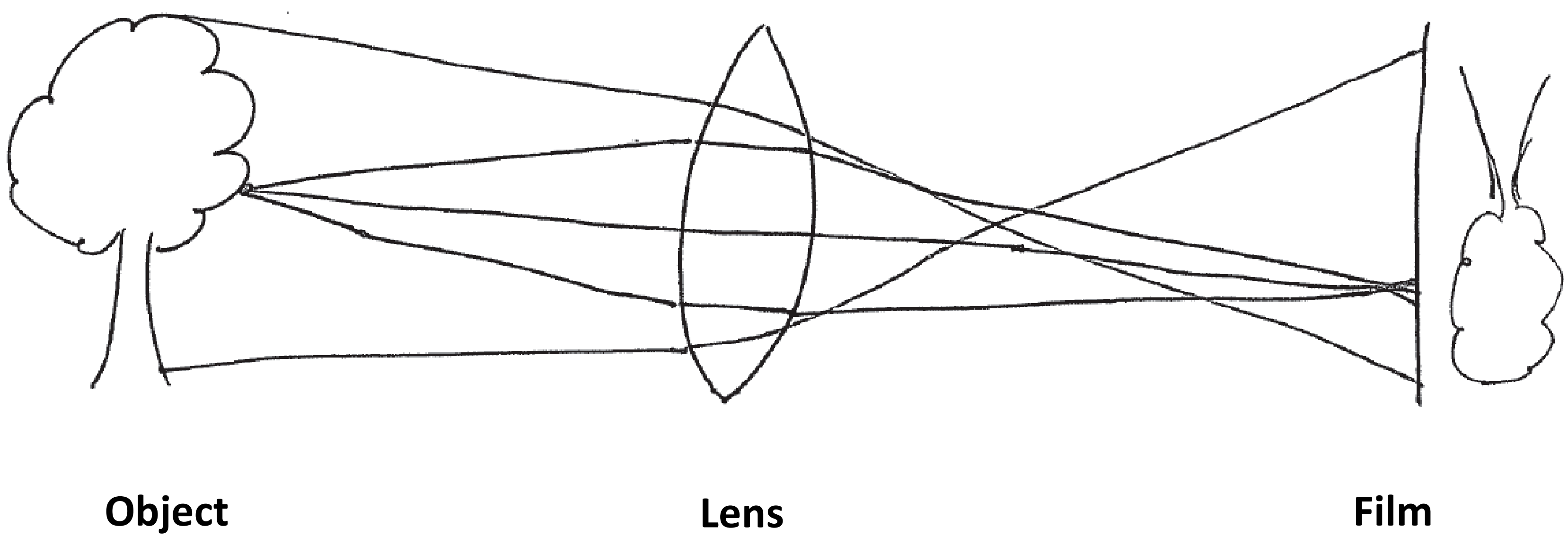
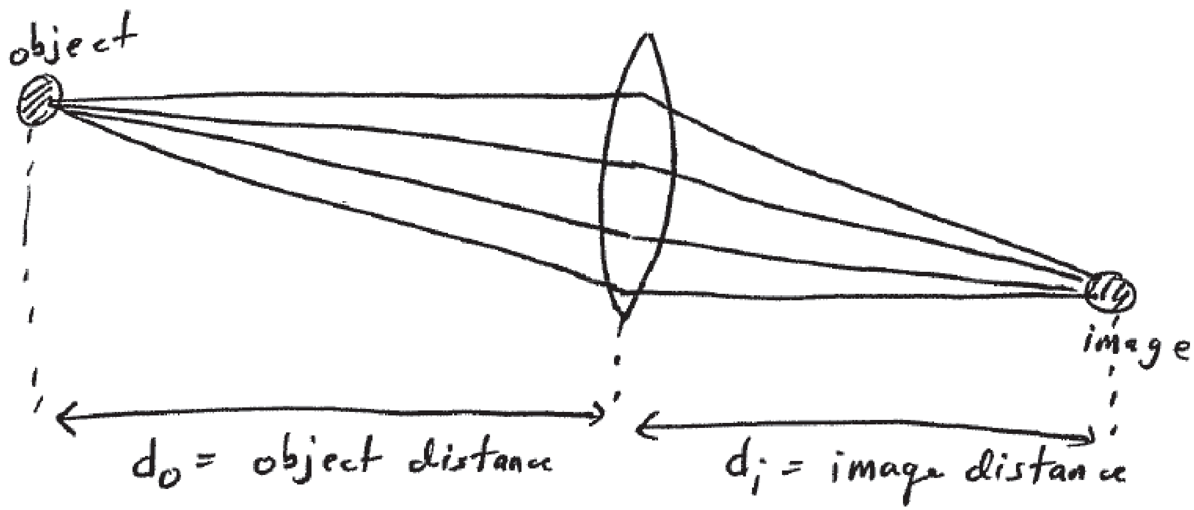
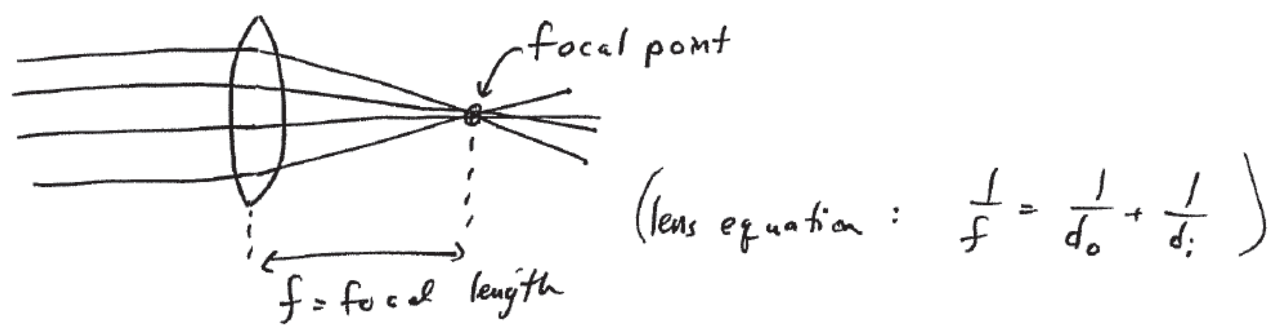


Image formation with a lens

- Specific distance at which objects are in focus



- The **focal point** is where incoming parallel rays meet



Depth of field

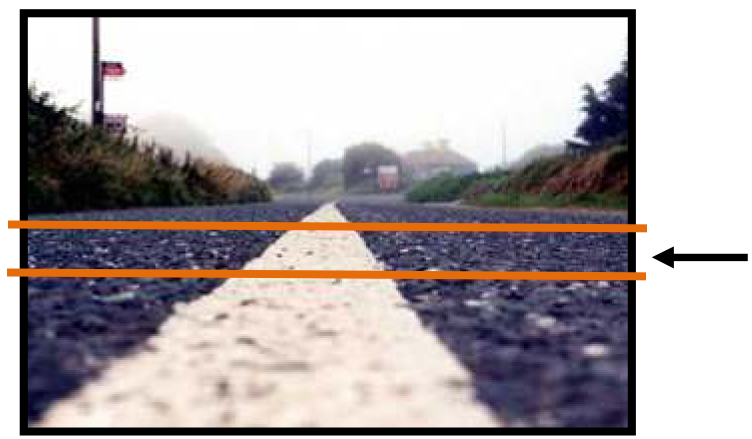
- Range of distance in “good” focus

low

high

Depth of field

separating subject from background

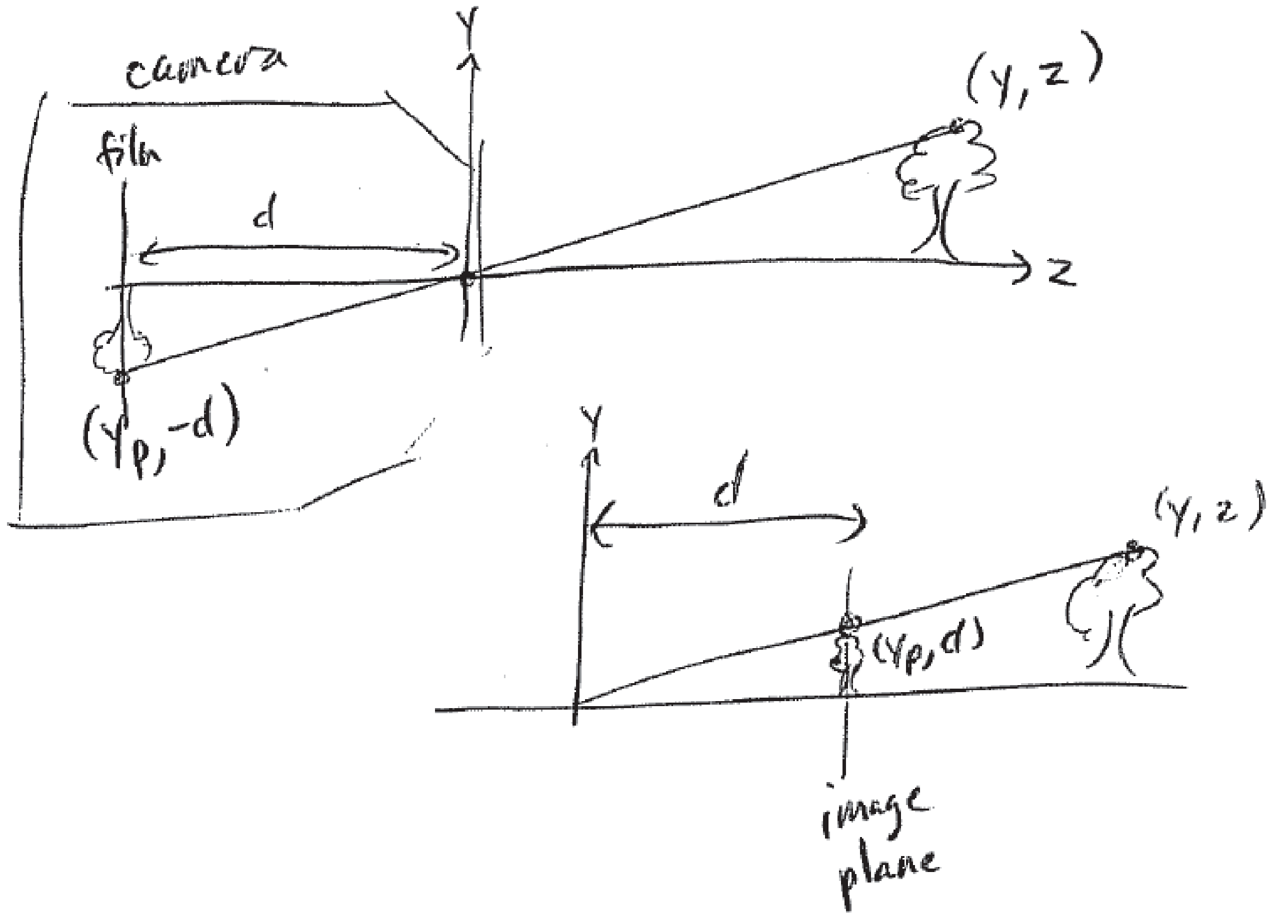


in sharp focus

Tilt shift photography

Model of image formation

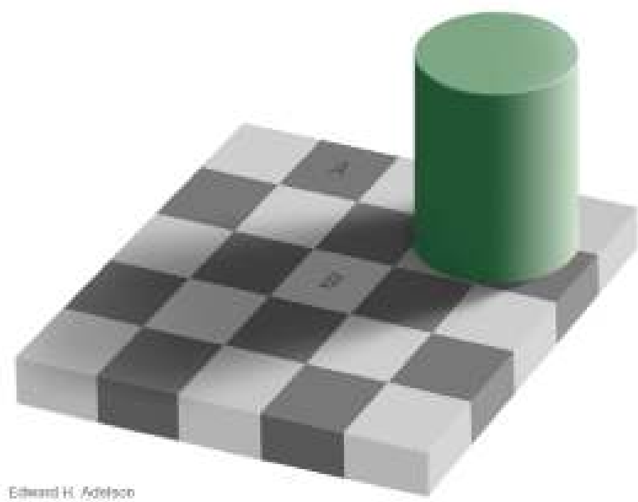
- Synthetic camera model **typical in CG**



$$\frac{y}{y_p} = \frac{z}{+d}$$

$$y_p = +d\,\frac{y}{z}$$

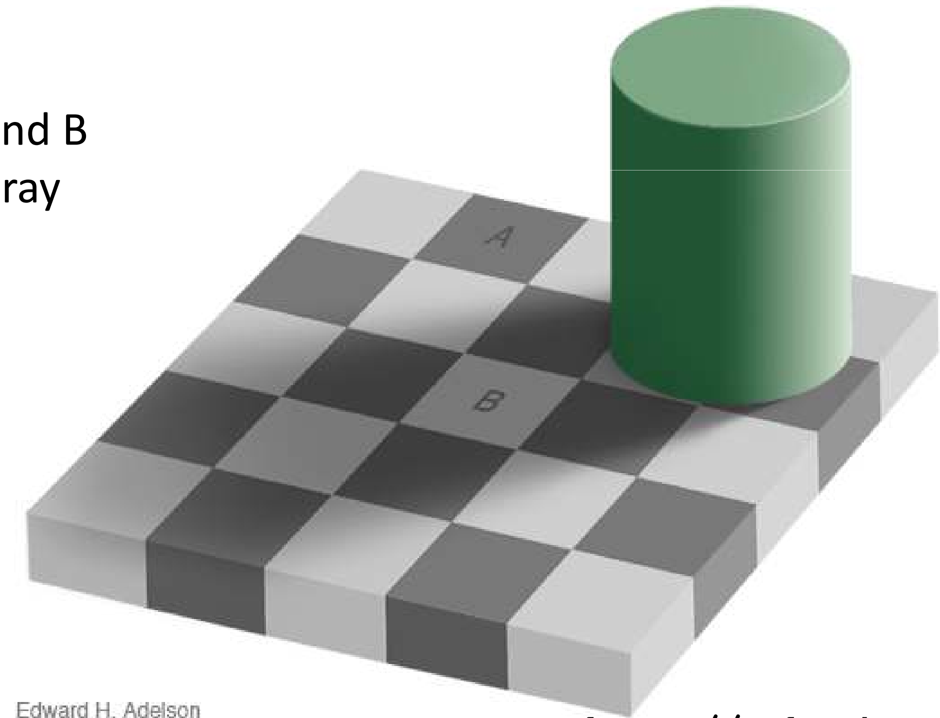
Human visual perception



Human visual perception

- You do not **see the image**, but rather **understand the scene** presented to you!

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



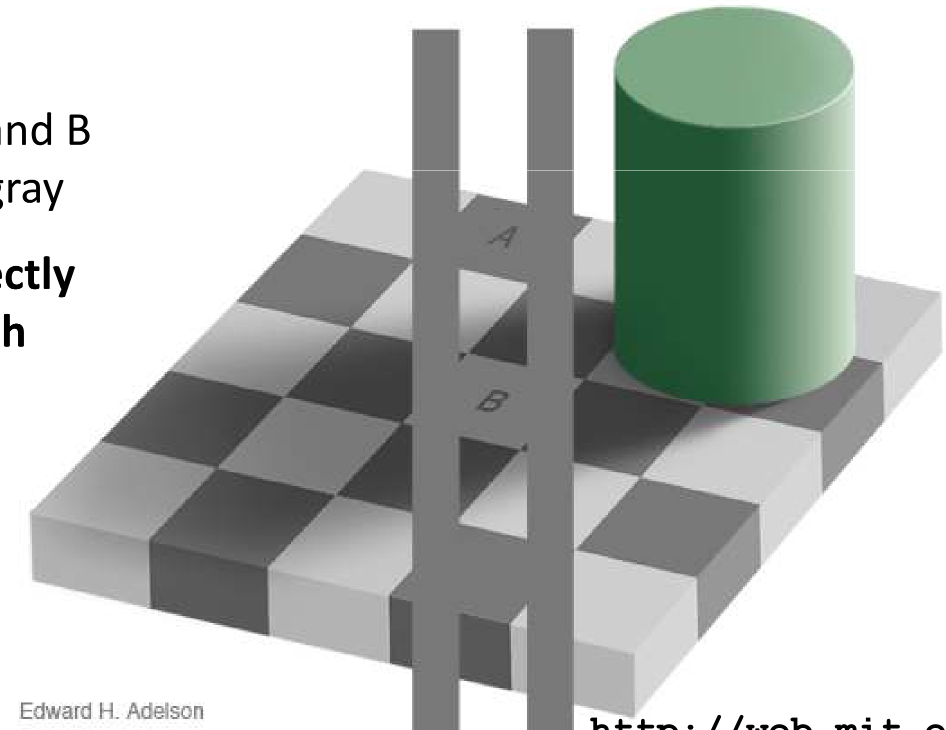
http://web.mit.edu/persci/people/adelson/checkershadow_illusion.html

Human visual perception

- You do not **see the image**, but rather **understand the scene** presented to you!

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

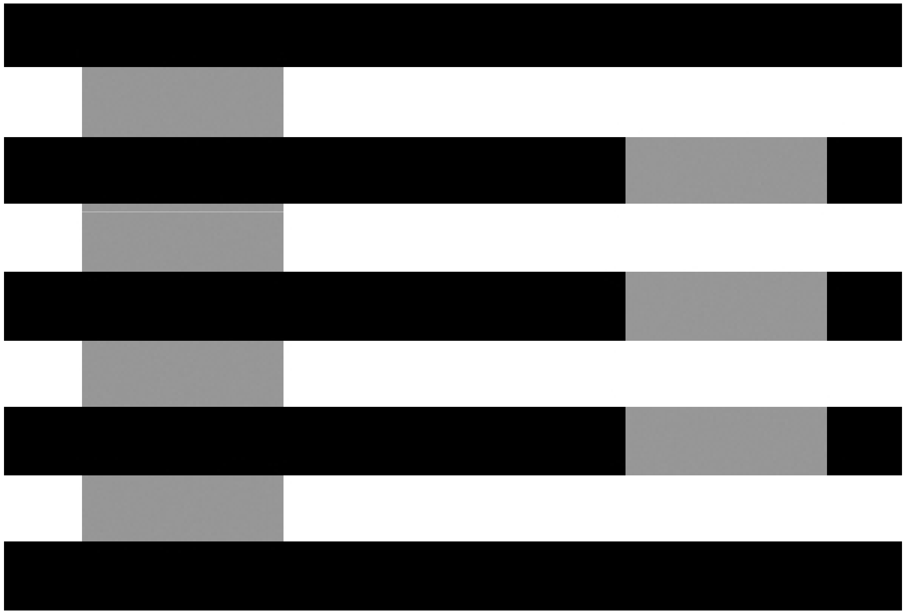
It is not possible to directly measure intensities with your eyes in normal circumstances



http://web.mit.edu/persci/people/adelson/checkershadow_illusion.html

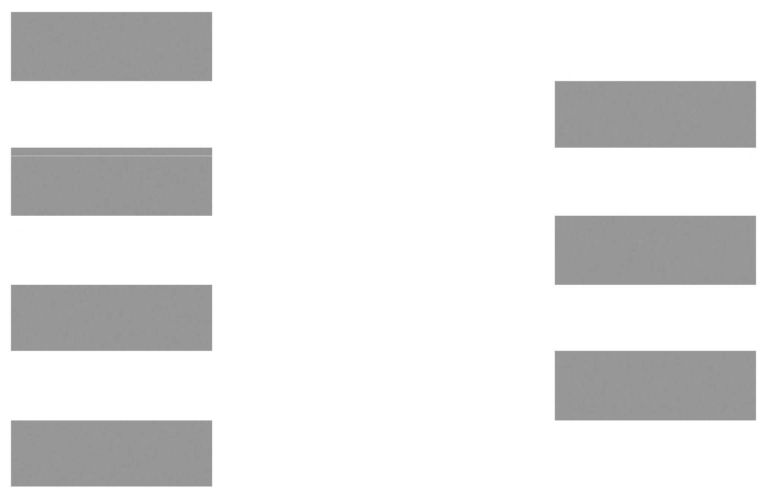
Intensity perception

- White's illusion

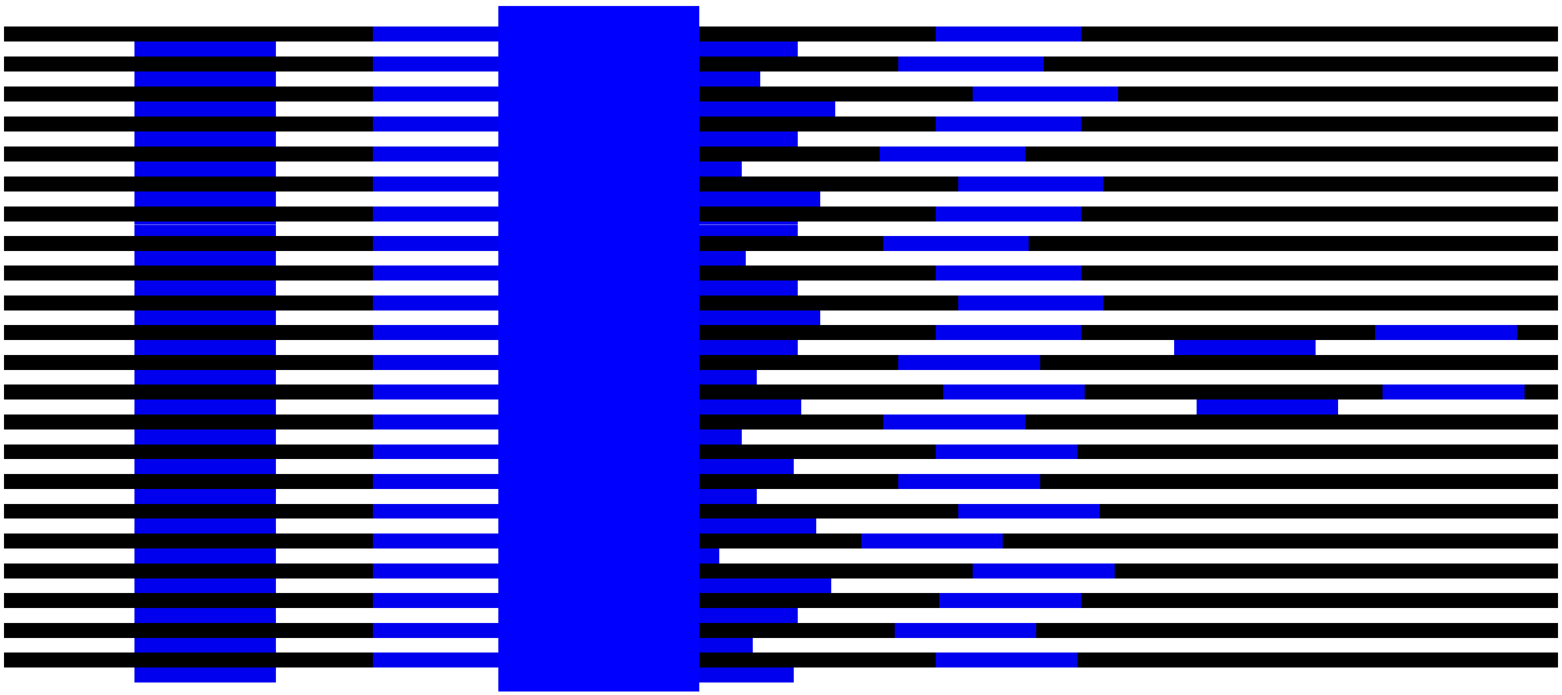


Intensity perception

- White's illusion



Brightness depends on context



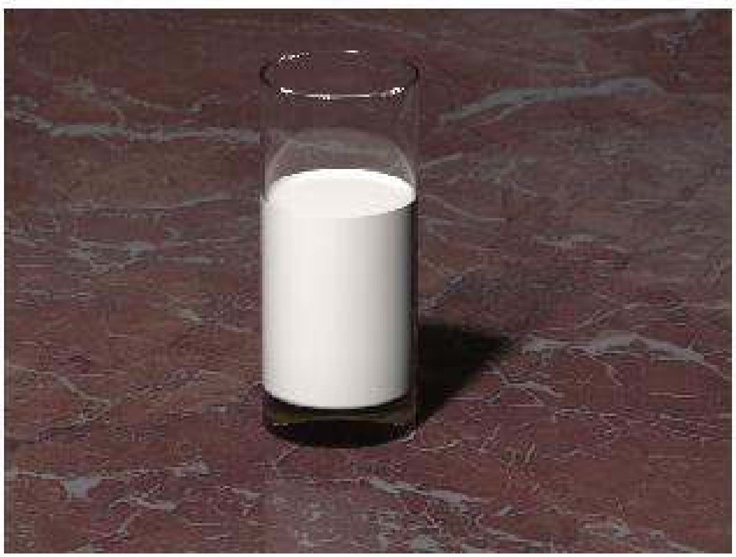
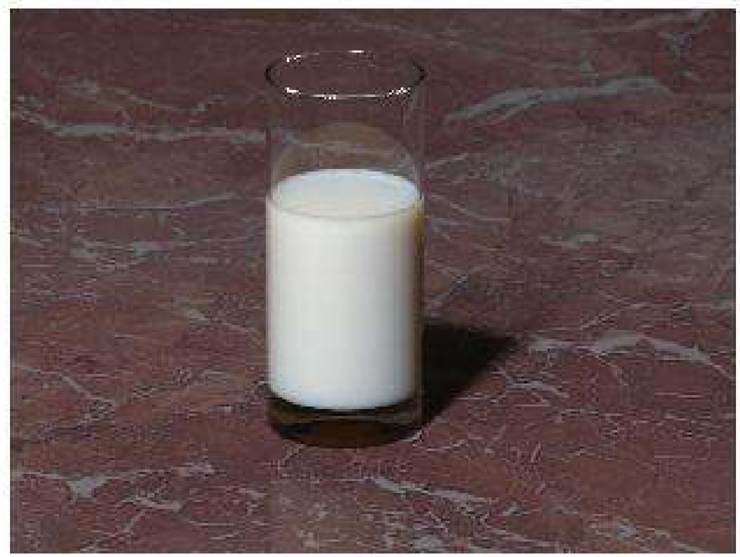
Human visual perception

- Why do you need to be familiar with this?
- **Photorealism**
  Need to convince people that CG images are real

Human visual perception

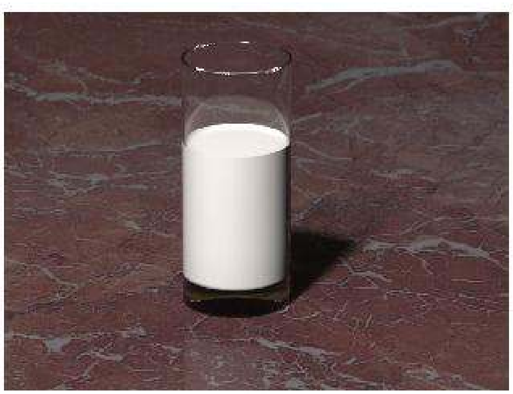
- Why do you need to be familiar with this?
- **Photorealism**

  Need to know what aspects of the world are can be noticed, so the right model is used (translucency)

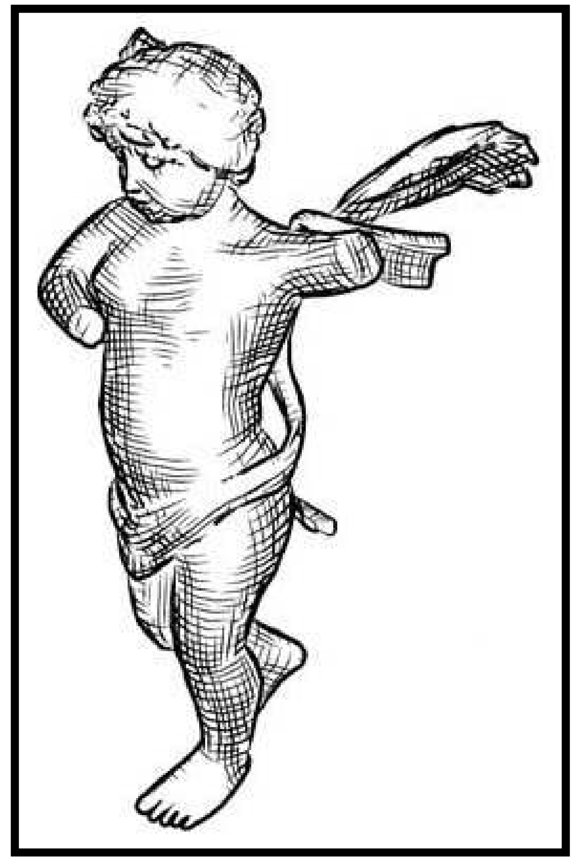
Human visual perception

- Why do you need to be familiar with this?
- **Photorealism**
  Don’t compute what people don’t notice or can’t distinguish!



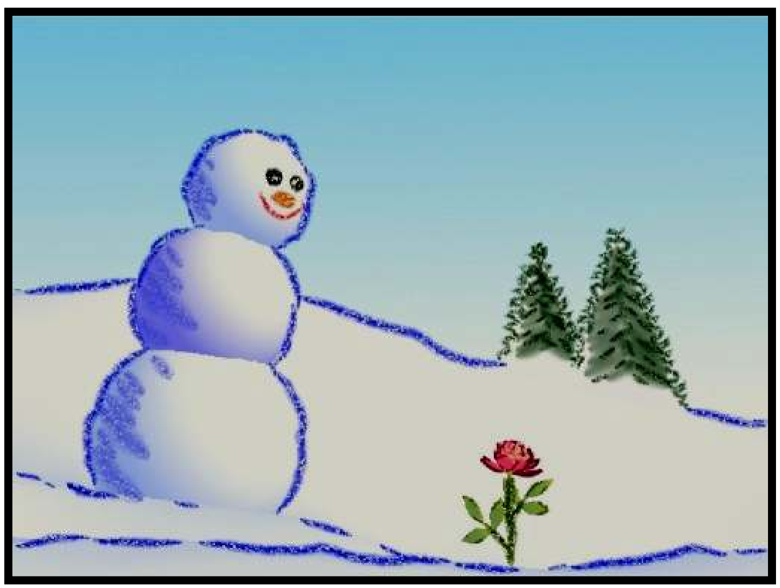
Human visual perception

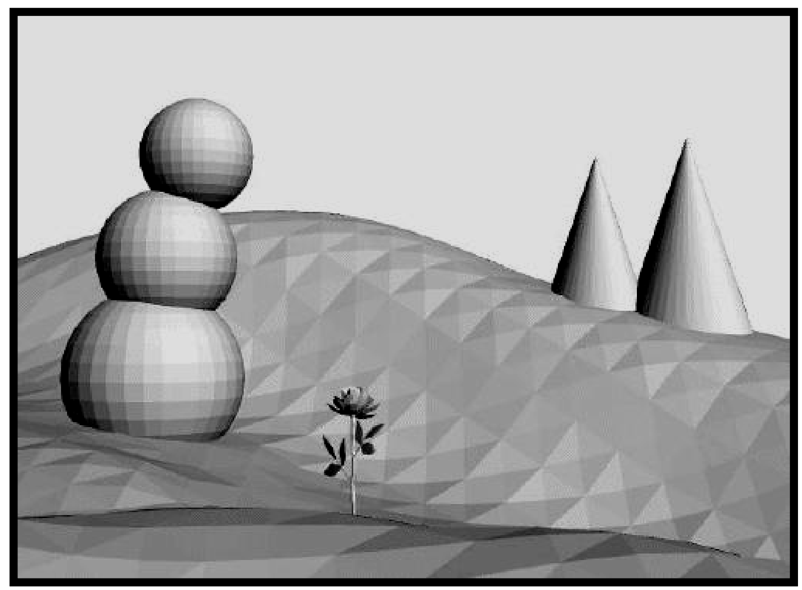
- Why do you need to be familiar with this?
- **Non-photorealism**
  Need to understand what artists are doing precisely
  → Depend on HVP!



Human visual perception

- Why do you need to be familiar with this?
- **Non-photorealism**
  Detail in shape can be replaced by stylization

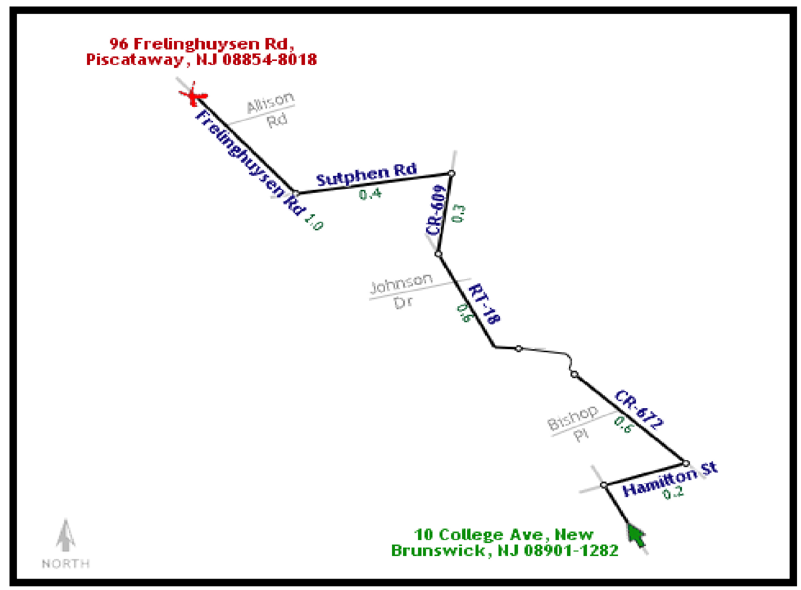




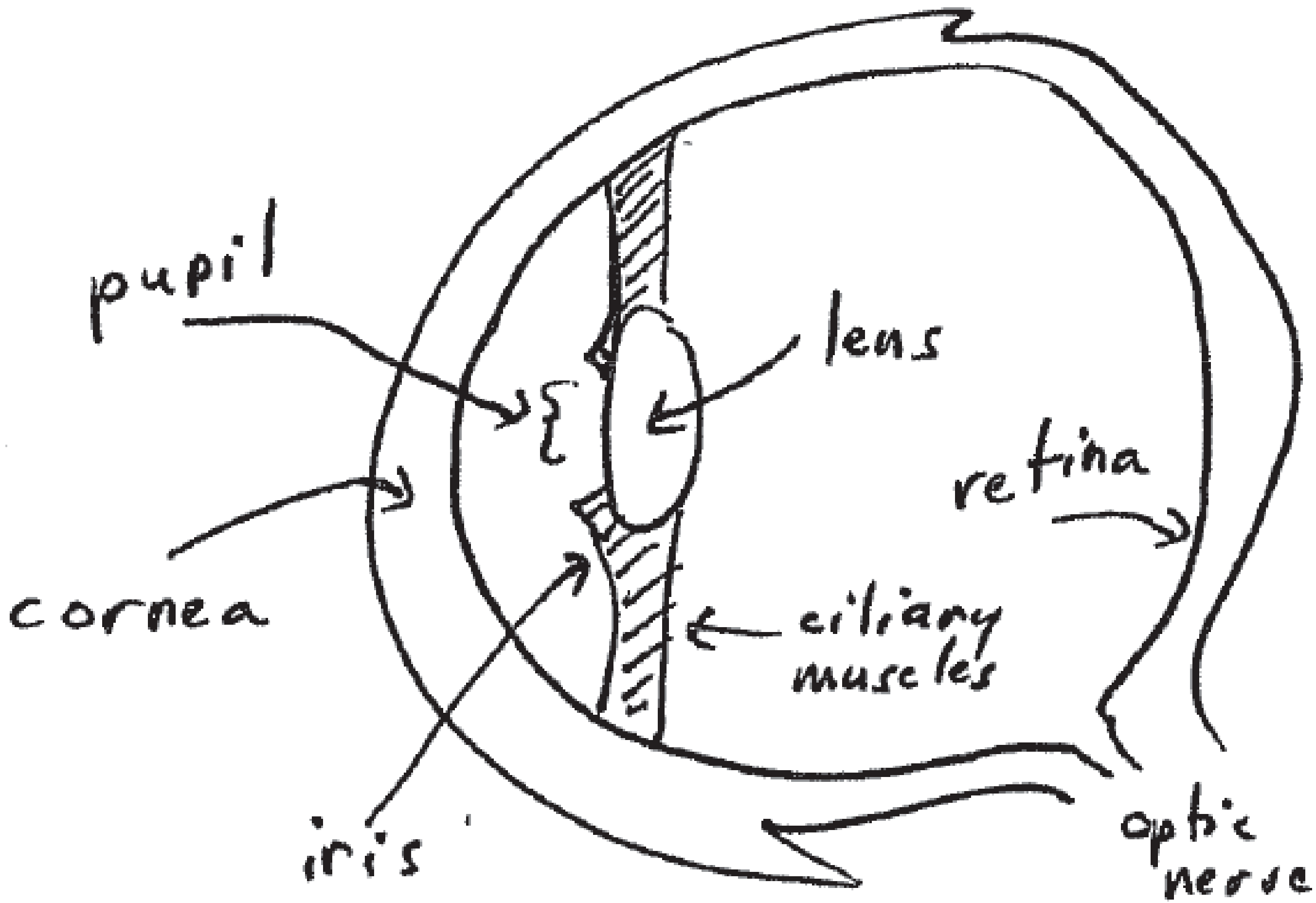
Human visual perception

- Why do you need to be familiar with this?
- **Visualization**

  Present information so people can see it and understand it easily

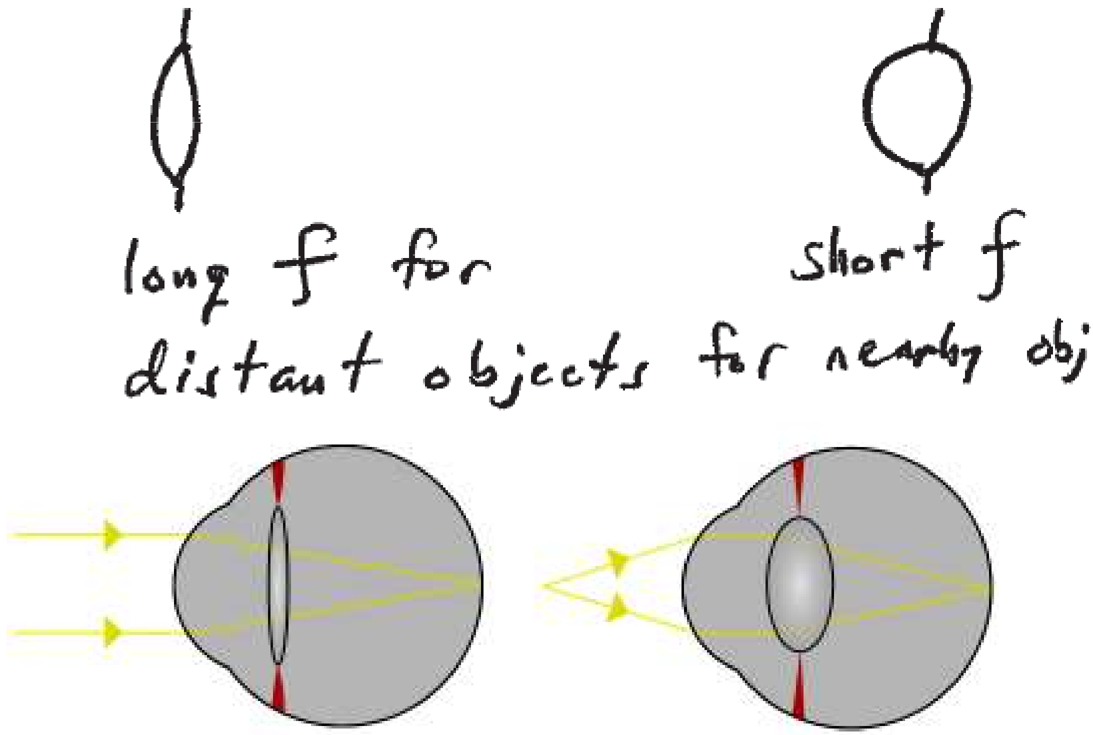


The human eye



Focusing

- Cornea for fixed (mitial) focusing
- Lens for main focus adjustment



Brightness adaptation

- Pupil size
- Retina
  - Layer of photosensitive cells
  - **Rods**: intensity perception (10x more sensitive)
    - Vision at low light levels (scotopic vision)
  - **Cones**: color perception
    - Active at higher light levels (photopic vision)
- 7 million cones (central area of retina)
- 75-150 million rods (periphery of retina)

Light intensity

- Perceived on a relative (logarithmic) scale

$$\frac{I_1}{I_0} \cong \frac{I_2}{I_1}$$

← **Same perceived difference**

0.2 → 0.3 **=** 0.4 → 0.6

0.1 difference   0.2 difference

Lightness contrast

Lightness contrast

- Depends on context
- Helps us maintain a consistent view of the world under changing lighting conditions
  - “Factor out” the lighting in the real world
  - Does this still work in CG? (… Yes, it does)

White

White

- Really?

- Gradually introduced some background gray over the past five slides…

Mach bands

- Impressions of brightness changes in regions near brightness discontinuities (C^0 or C^1)
- Or during rapid intensity change

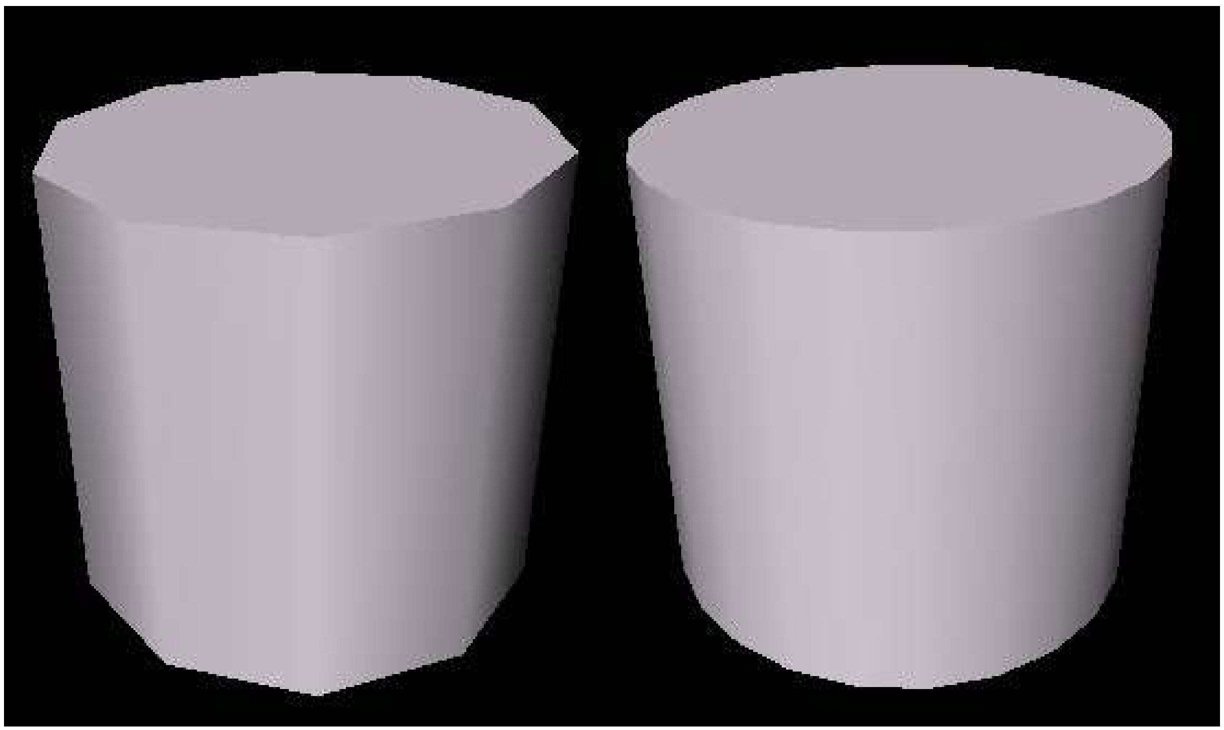
Mach bands

- Impressions of brightness changes in regions near brightness discontinuities (C^0 or C^1)
- Or during rapid intensity change

Synthetic example with USM

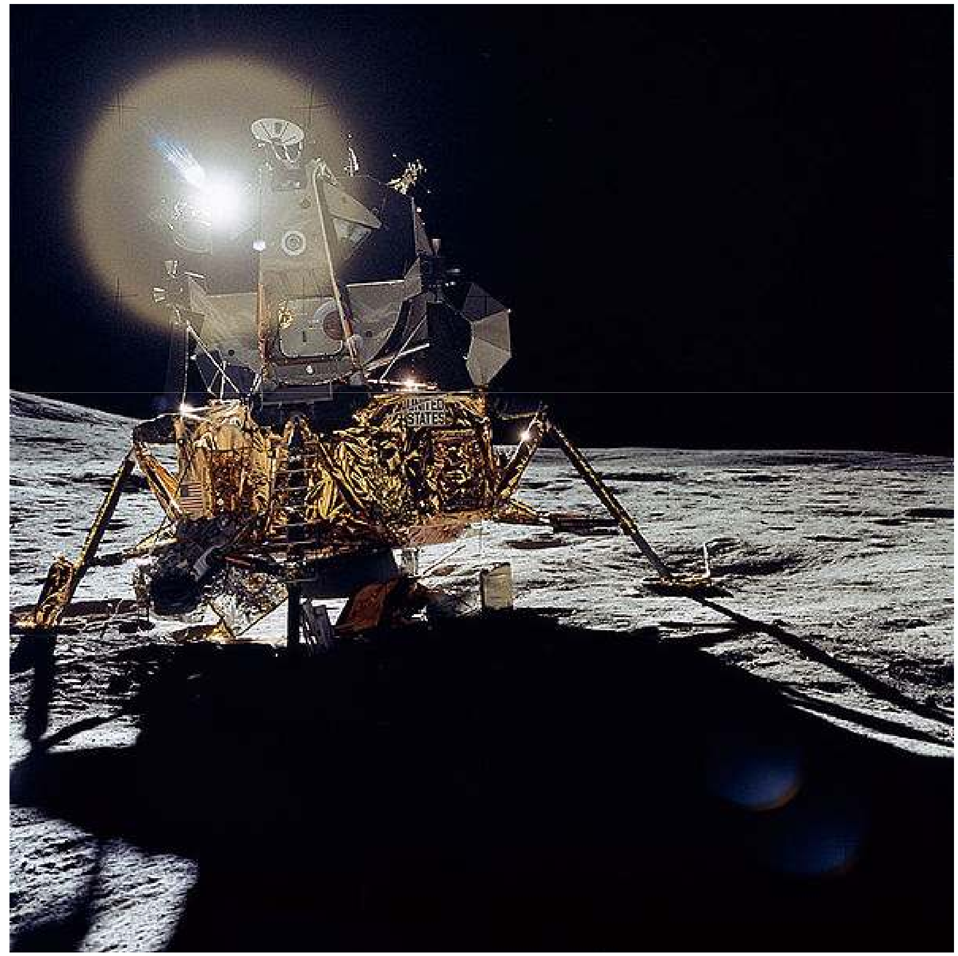
Mach bands

- Makes surface shading difficult
  - C^1 discontinuities are very noticeable



Lens flare

- Artifact of all lenses
  - Internal reflection and scattering
- A good cue for brightness, even when screens aren’t that bright

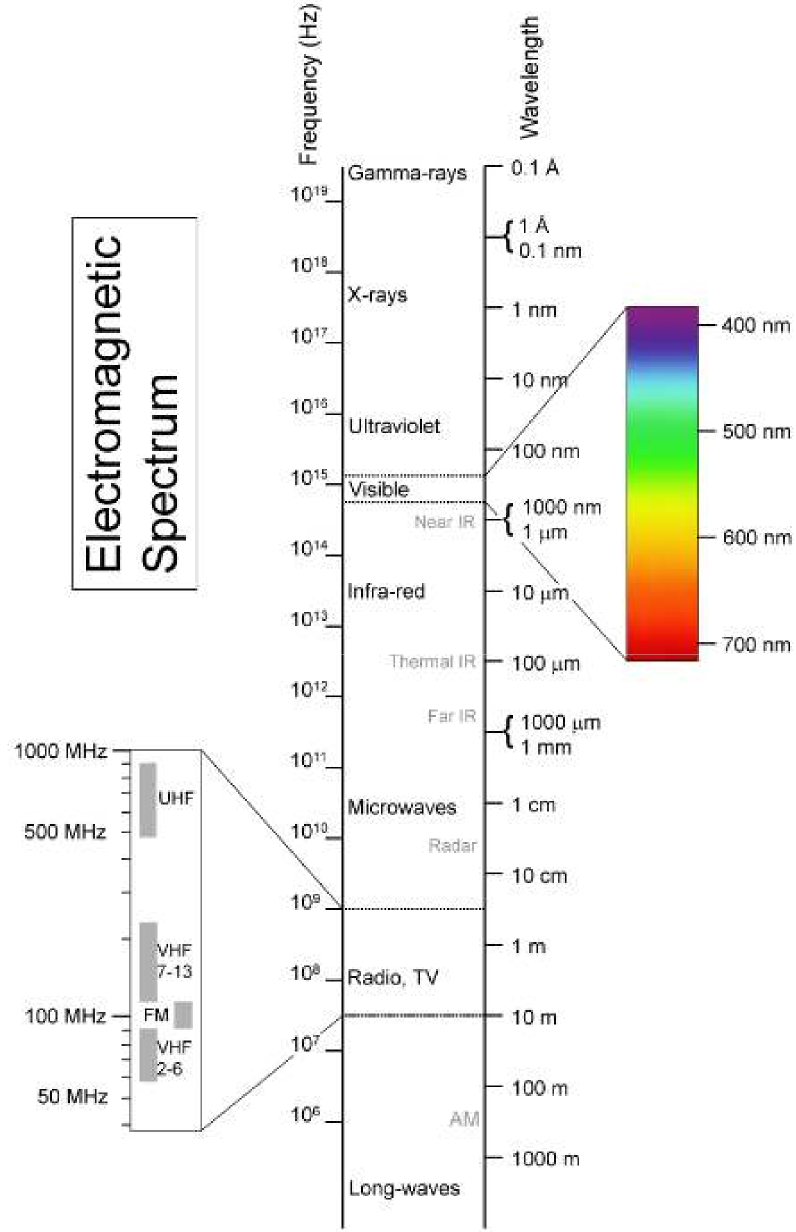


Tone mapping

- Taking a “picture of the sun”
  - Current limits of (commodity) display technology
- Tone mapping
  - Vary exposure length + combine (nonlinearly)

Color perception

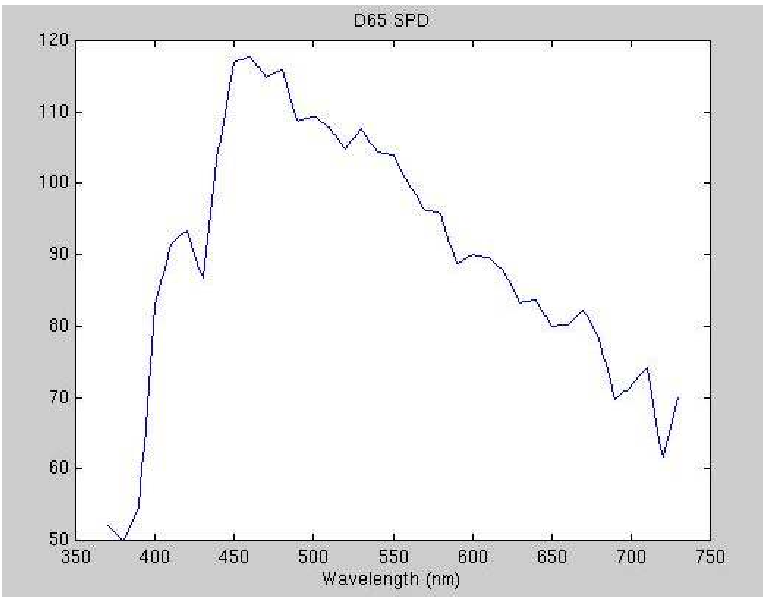
Color is not only about the physics of light..
It is a **sensation**

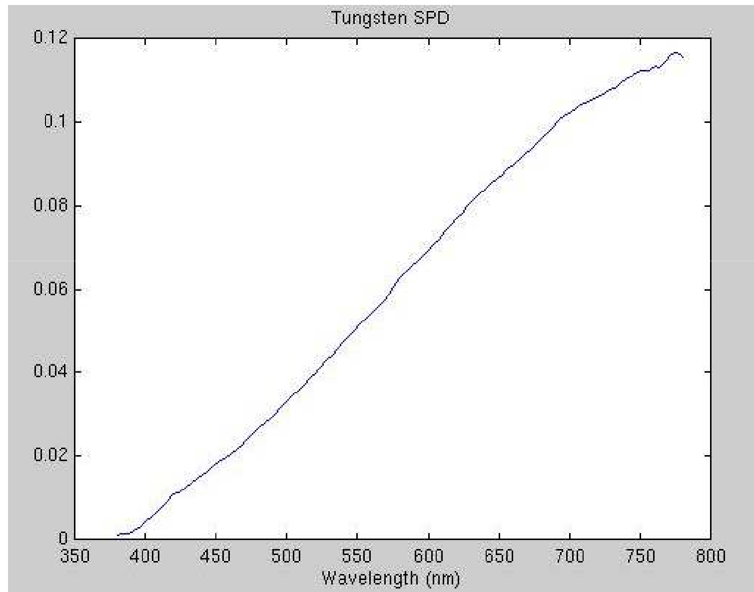


Louis E. Keiner - Coastal Carolina University

Emission spectrum

- Spectral power distribution (SPD)

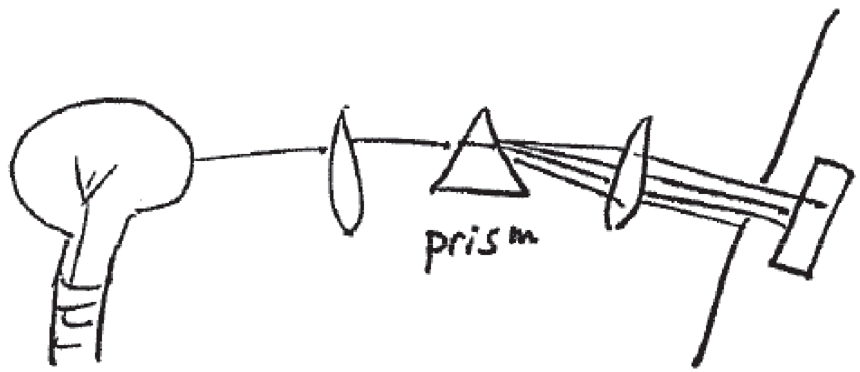


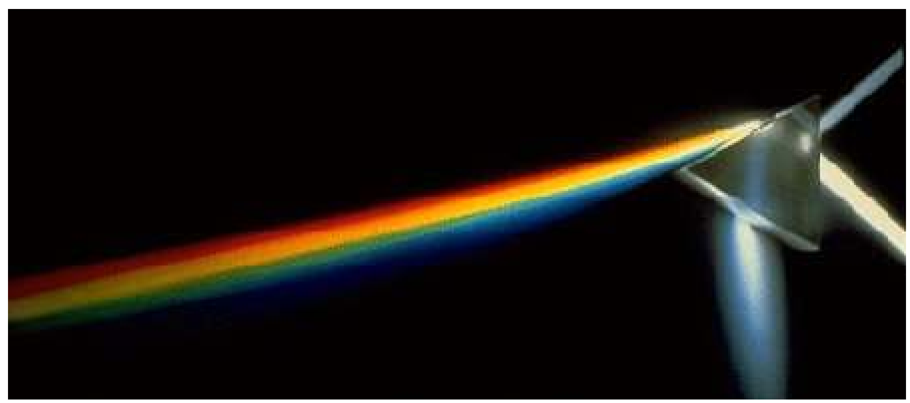


- This is not color!
  - Light is infinite dimensional (spectrum)

Emission spectrum

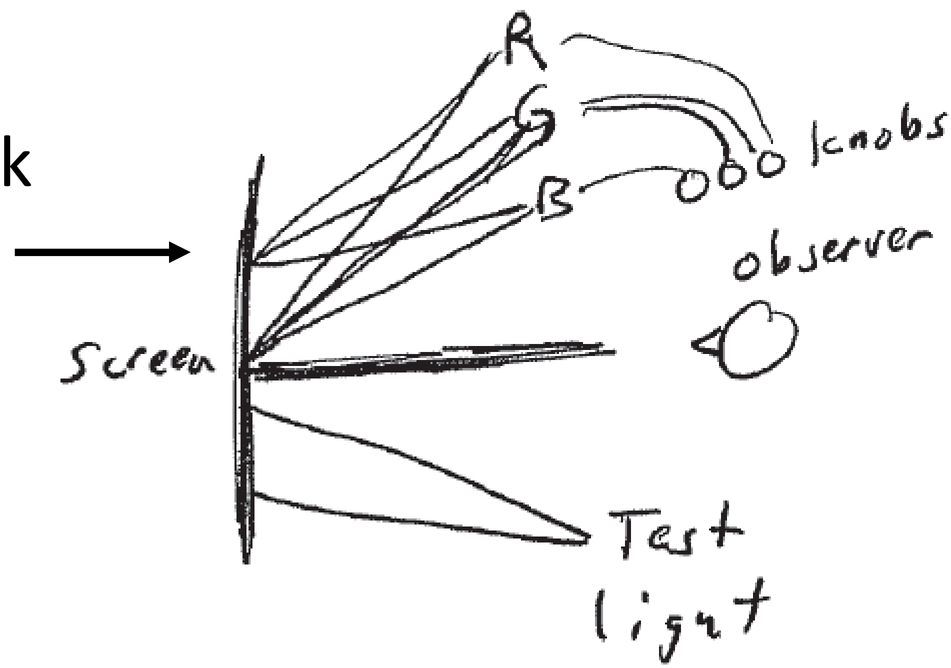
- Measured by spectroradiometer





Color matching

- Conjecture:
  - Every color can be uniquely expressed as mixing of a small number of **primaries**
- Experiment
  - Show colors and ask observer to match
  - 3 colors suffice
  - Yields color matching function for each **primary**



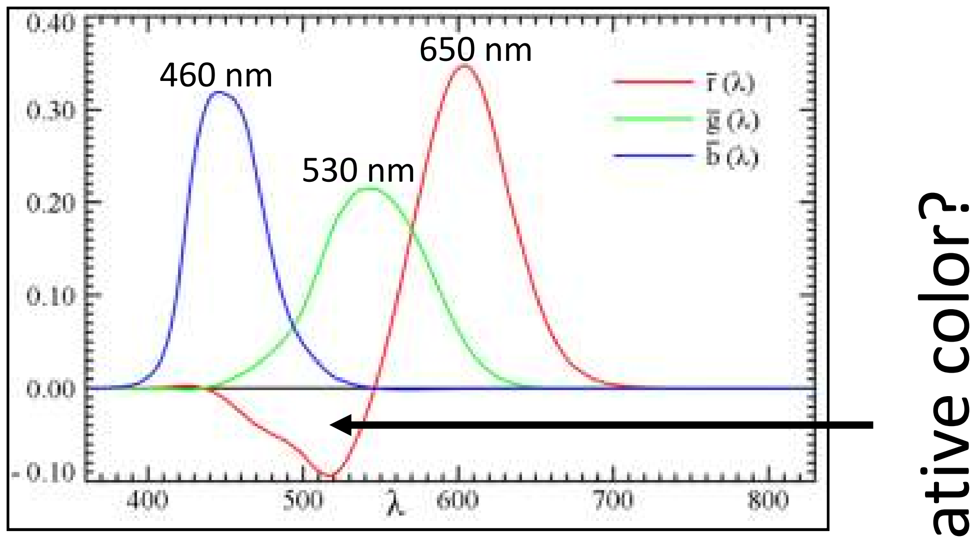
Color matching

- Given scaled color matching functions and a color with spectral power distribution $I(\lambda)$
  - Compute RGB (tristimulus) as

$$R = \int_0^\infty I(\lambda)\,\bar{r}(\lambda)\,d\lambda$$

$$G = \int_0^\infty I(\lambda)\,\bar{g}(\lambda)\,d\lambda$$

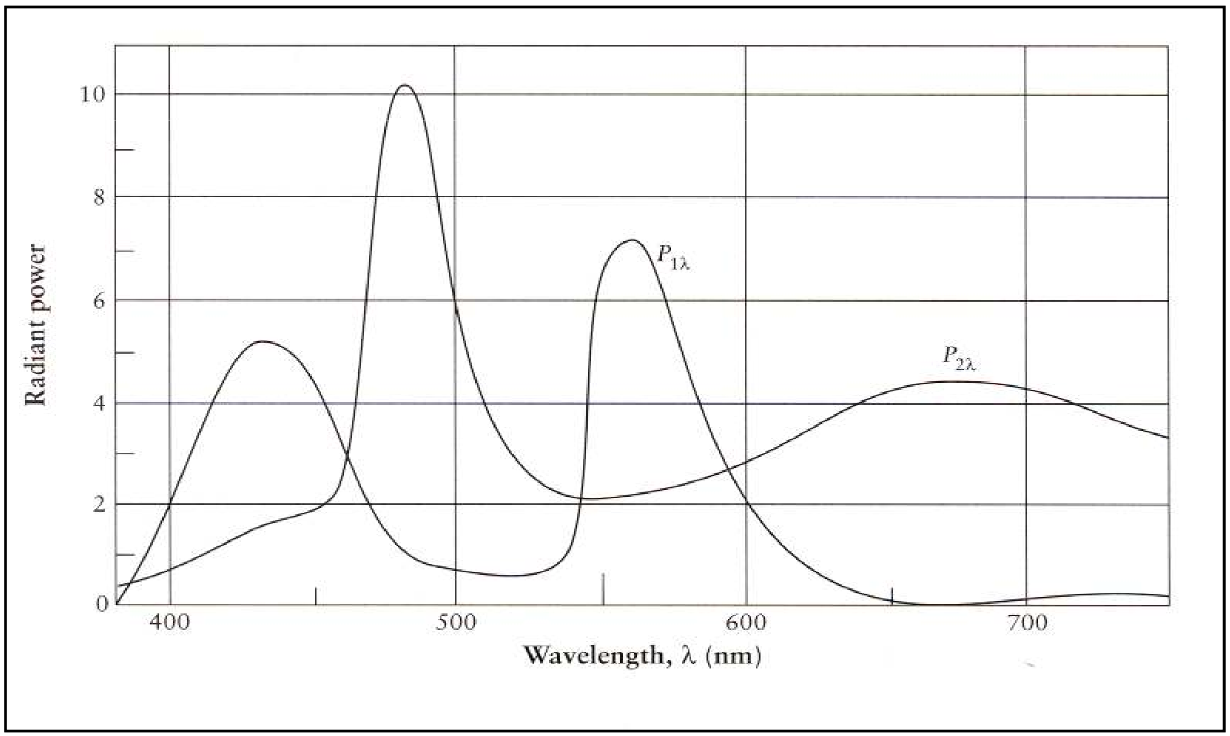
$$B = \int_0^\infty I(\lambda)\,\bar{b}(\lambda)\,d\lambda$$



- Inner product (projection) of infinite dimensional spectrum onto 3D color space

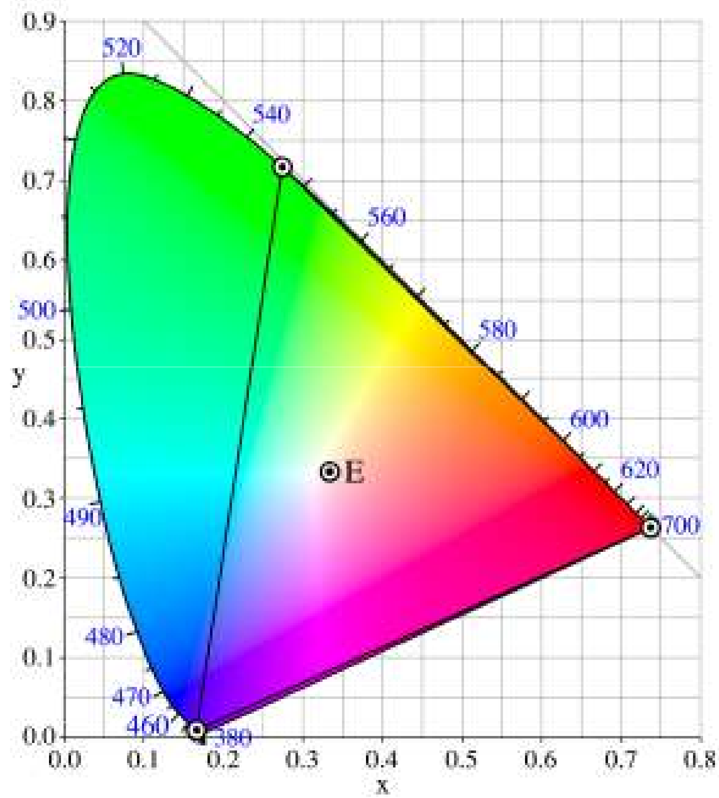
Perceptual equality of colors

- Different spectra create same color perception
- Known as **metamers**

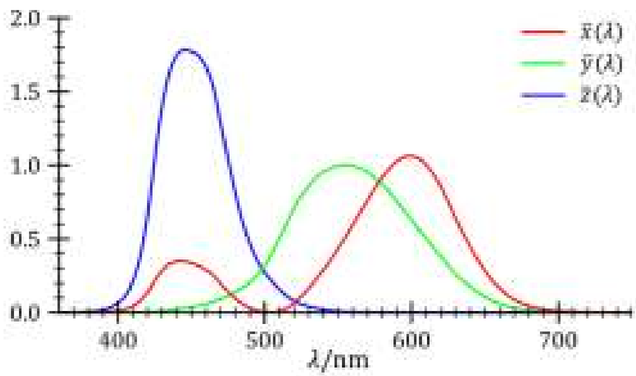


CIE color space
(Commission internationale de l'éclairage)

- Gamut of the CIE RGB primaries and location of primaries on the CIE 1931 *xy* chromaticity diagram



- CIE XYZ with all pos. values



See **`http://en.wikipedia.org/wiki/CIE_1931_color_space`**

Why three primaries?

- Three types of cones in the retina

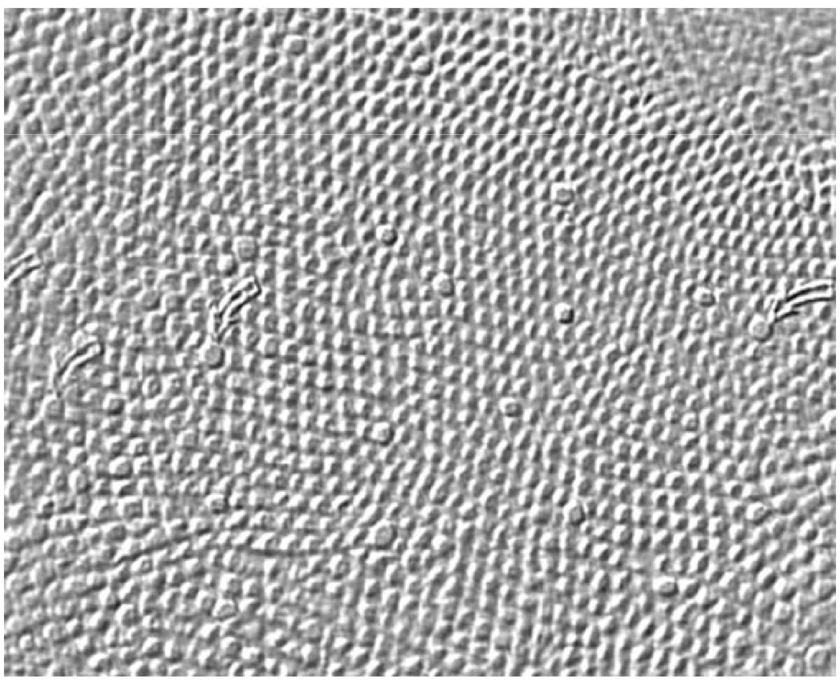
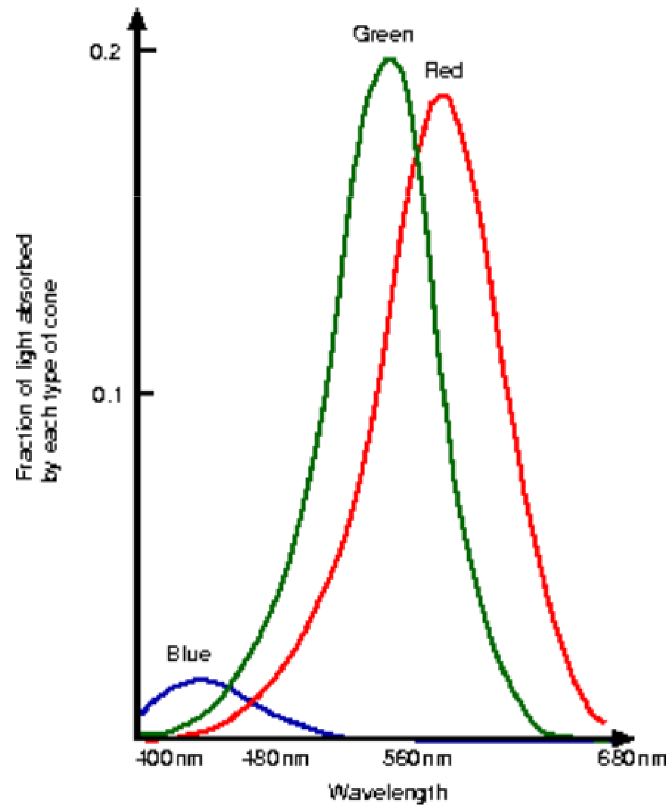


Fig. 13. Tangential section through the human fovea. Larger cones (arrows) are blue cones.

Figure 2: Spectral response curves for each cone type. The peaks for each curve are at 440nm (blue), 545nm (green) and 580nm (red).



Color mixing

- Grassmann’s first law
  Any color can be made by mixing three different primaries A, B, C

$$X = a\,A + b\,B + c\,C$$

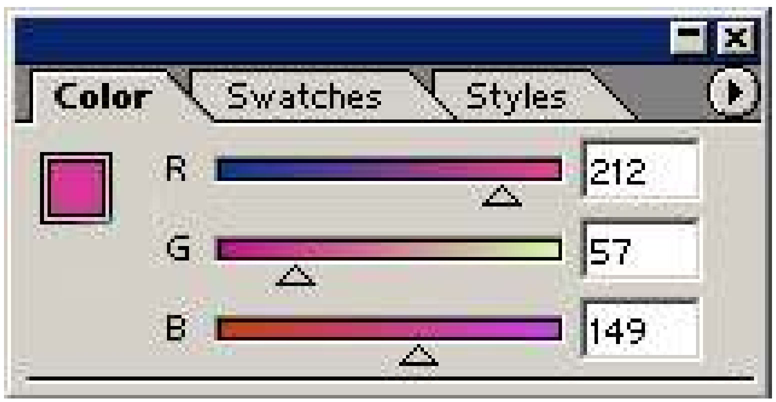
- Grassmann’s second law
  If $X = Y$ (perceptual equality of colors), then

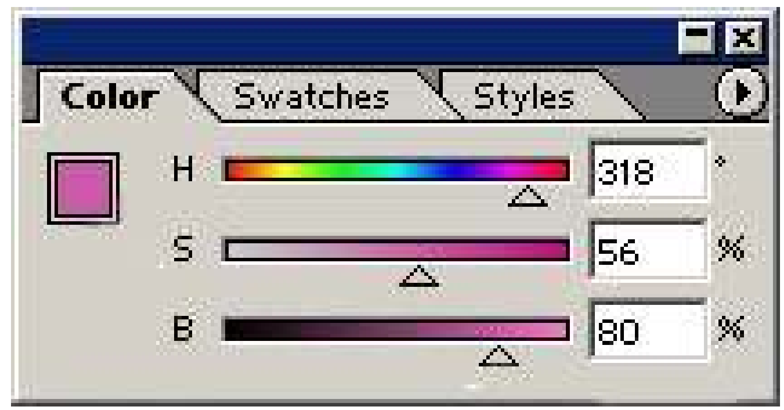
$$X + Z = Y + Z$$

- Color can be seen as a 3D **vector space**
  - Linearity!

Color pickers

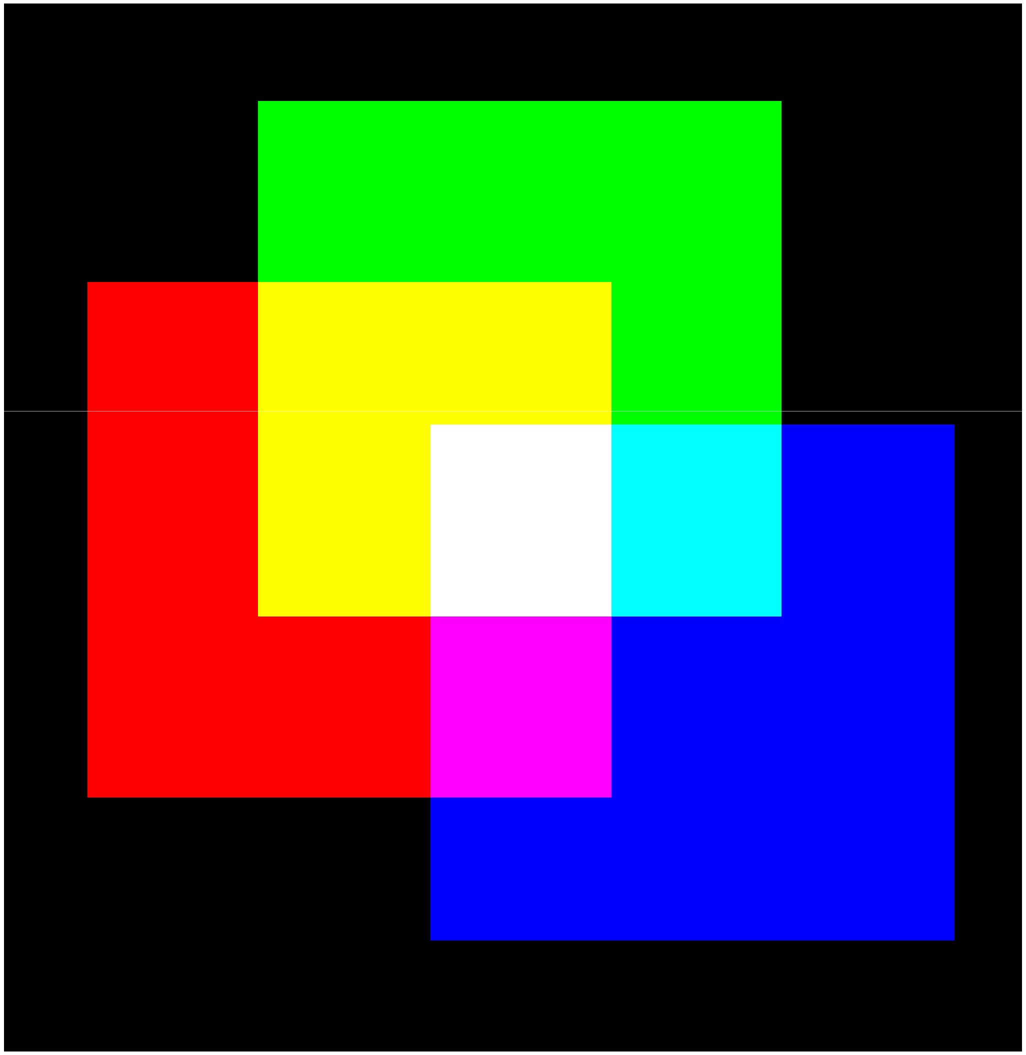
- Basis transformation (change of basis) between color (vector) spaces





RGB mixing
additive

Standard color model



CMY mixing
subtractive

Used in print media