Computer Science 631
Lecture 6: Color

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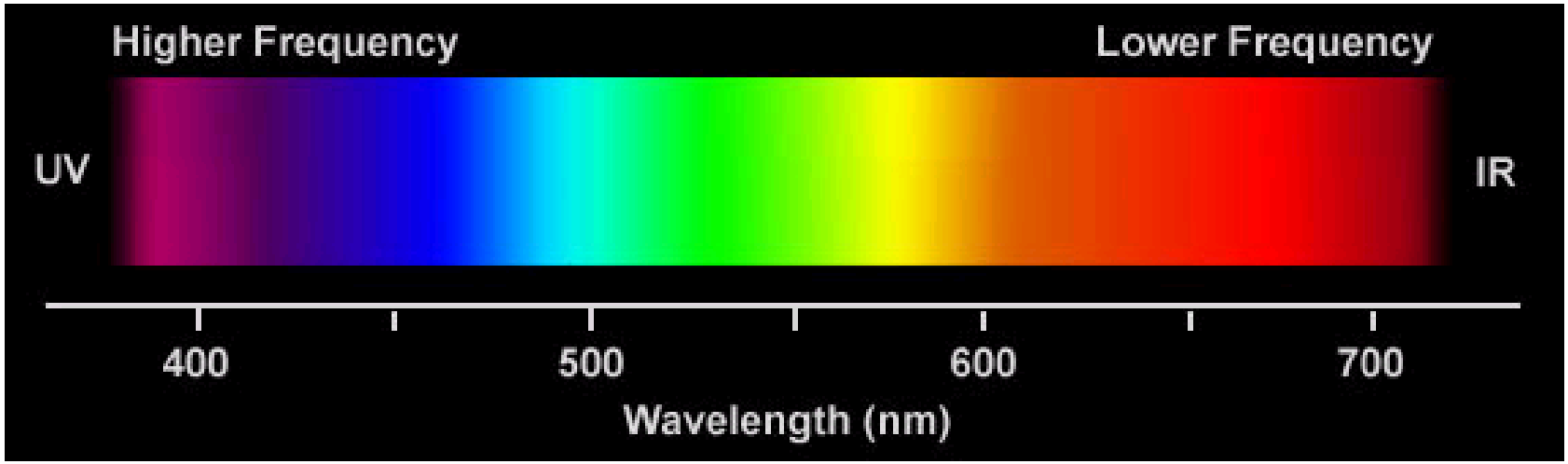
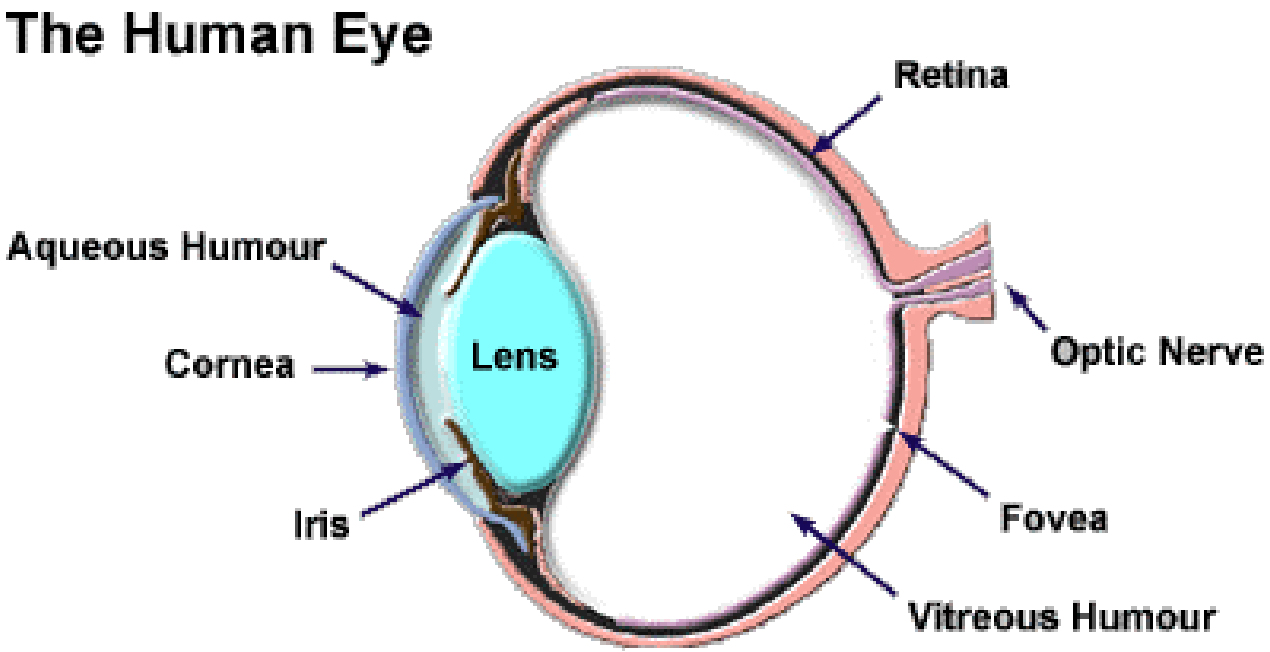
Outline

- The visible spectrum and human color perception
- Color cameras
- How color is encoded in images

The visible spectrum



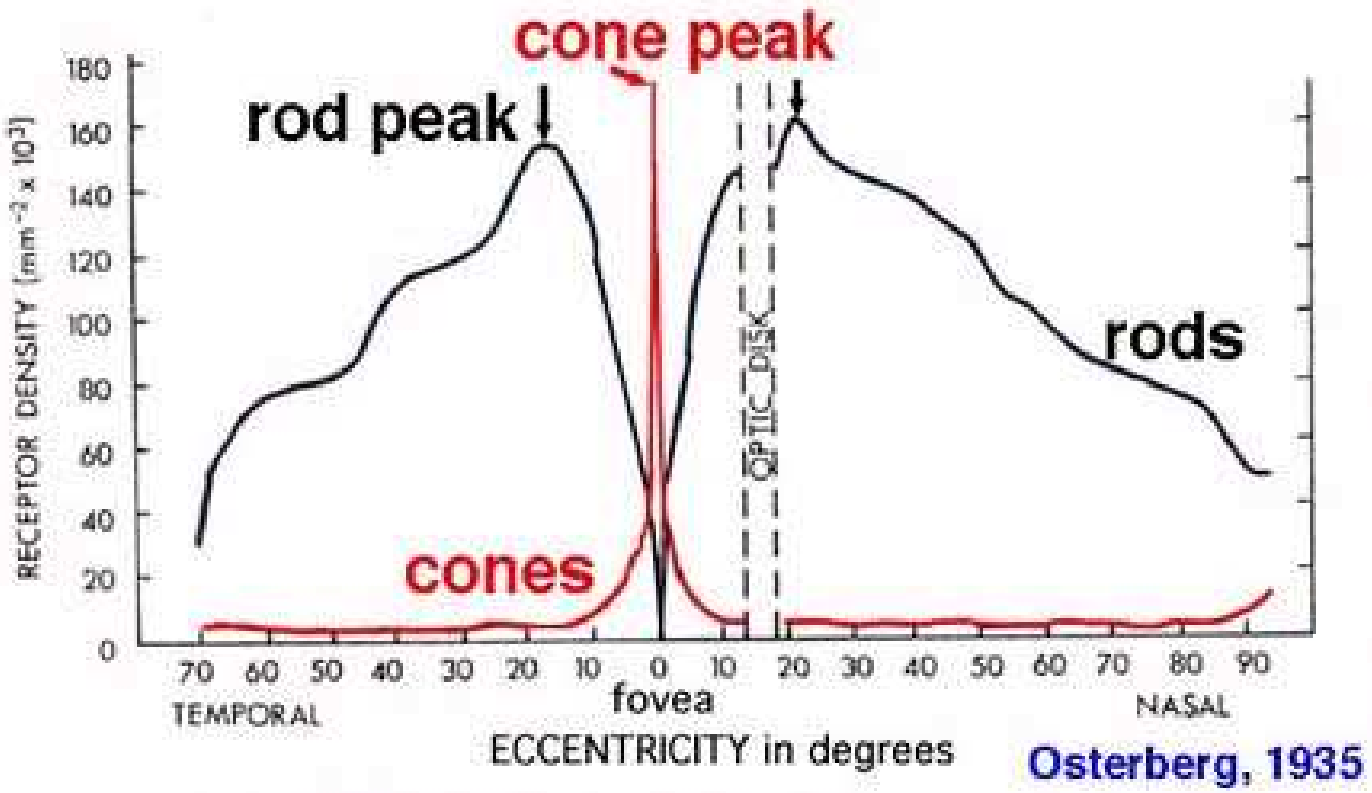
Evolution’s camera



Human color perception

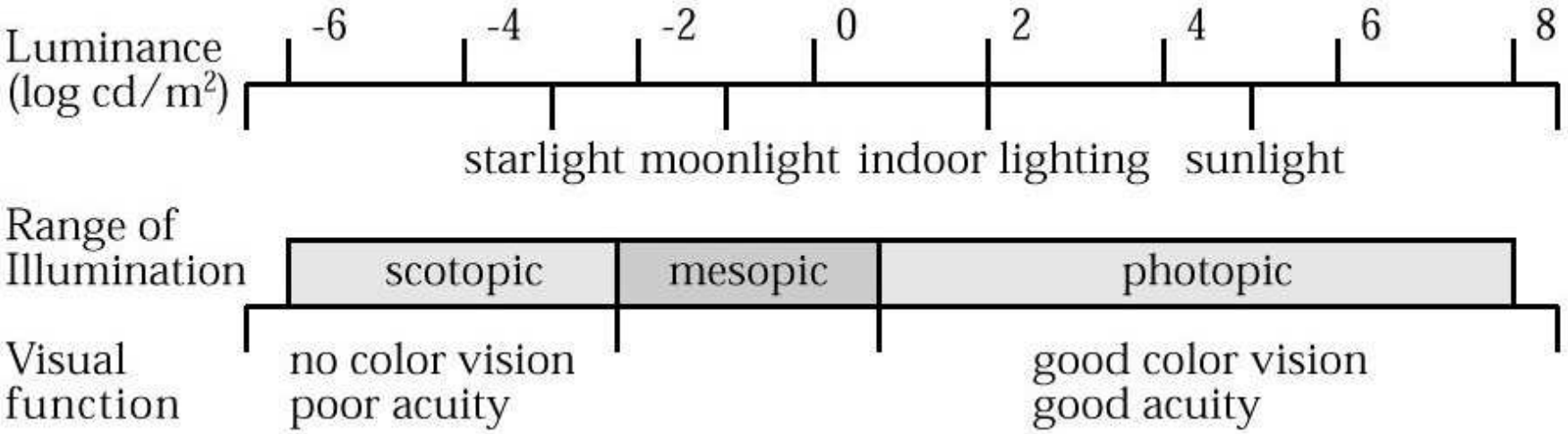
- There are two kinds of cells in the retina
  - Rods and cones
    - What kind of cells are they?
- Most retinal cells are in the *fovea* (center)
- Rods sense luminance (black and white)
  - Concentrated in the fovea, but not exclusively
- Cones sense color

Spatial distribution (cross-section)

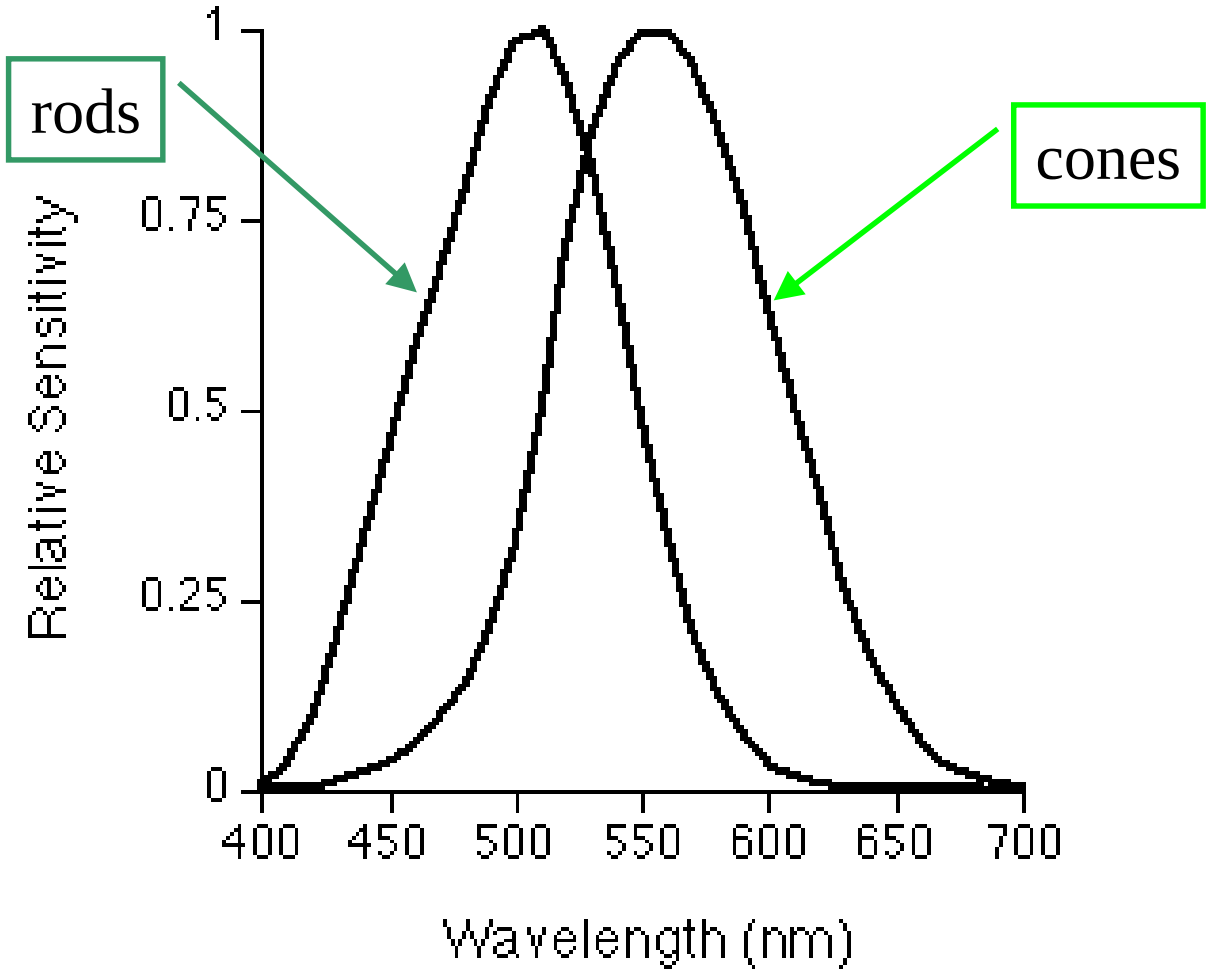


Rods versus cones

- Rods are more tolerant in terms of handling low light conditions
  - You don't see color when it's night
- Cones give you better spatial acuity

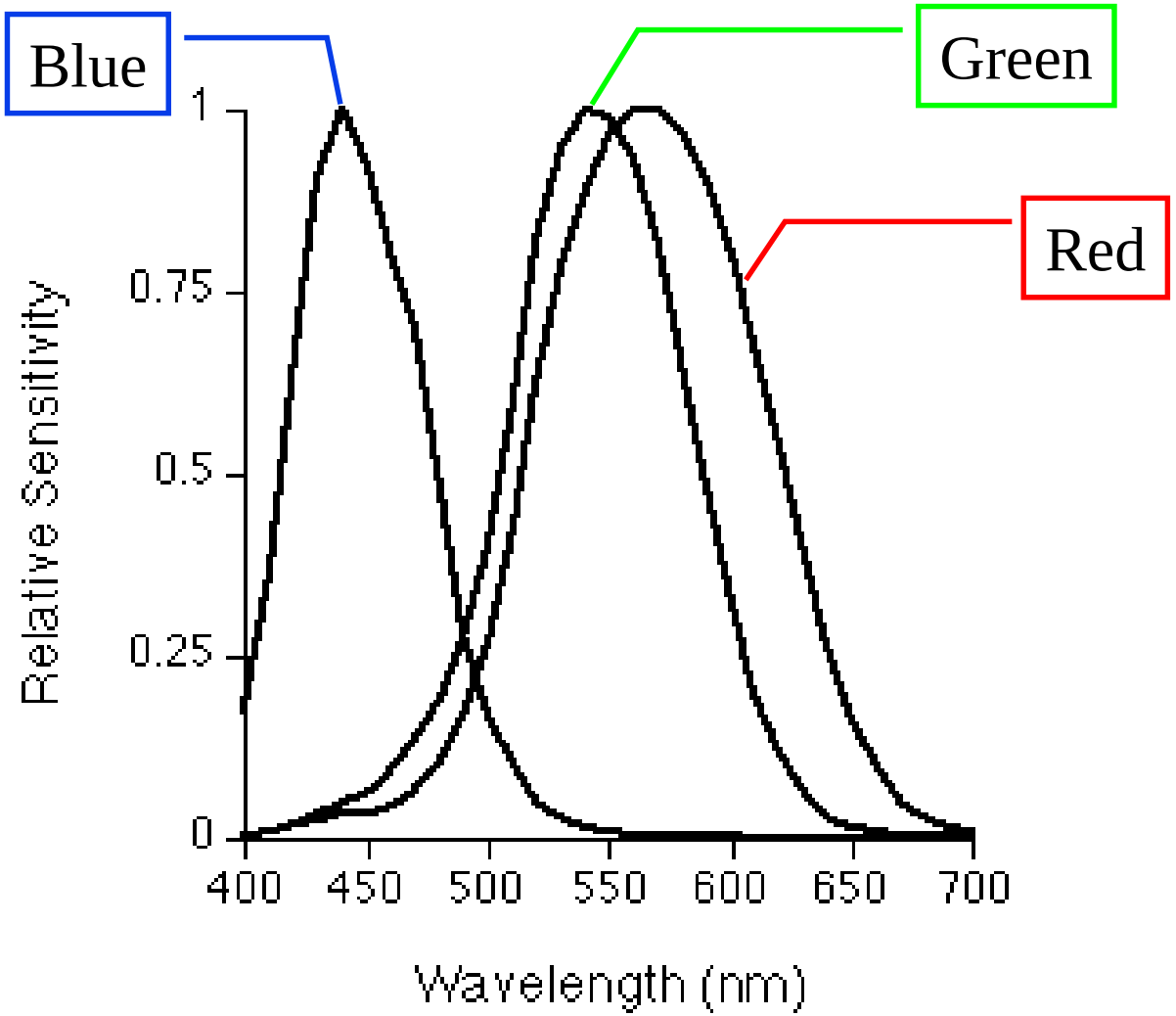


Different overall light sensitivity



Results in the *Purkinje* shift: What appears brightest changes as the sun sets!

Cones come in three flavors



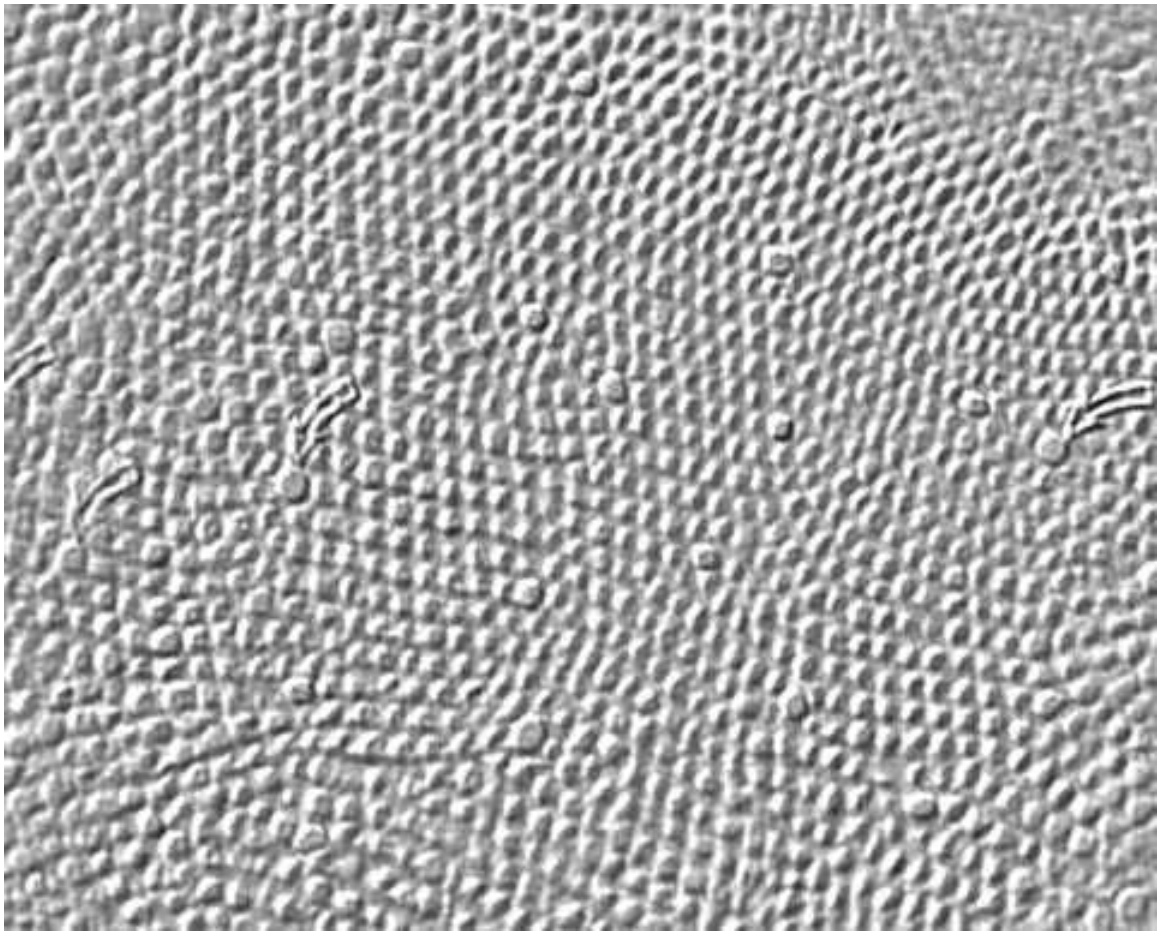
How we see color

- It all depends on how much the different cones are stimulated
- It is possible to have two different spectra that stimulate cones the same way
  - Called a *metamer*
- To a person, these colors look the same, but they are (in some sense) completely different

Some colors do not come from a single wavelength

- There will never be a purple laser
- Purple comes from blue (short wavelength) and red (long wavelength) light
  - More precisely, the sensation that we call purple comes from the blue and red cones being stimulated
    - And no others!

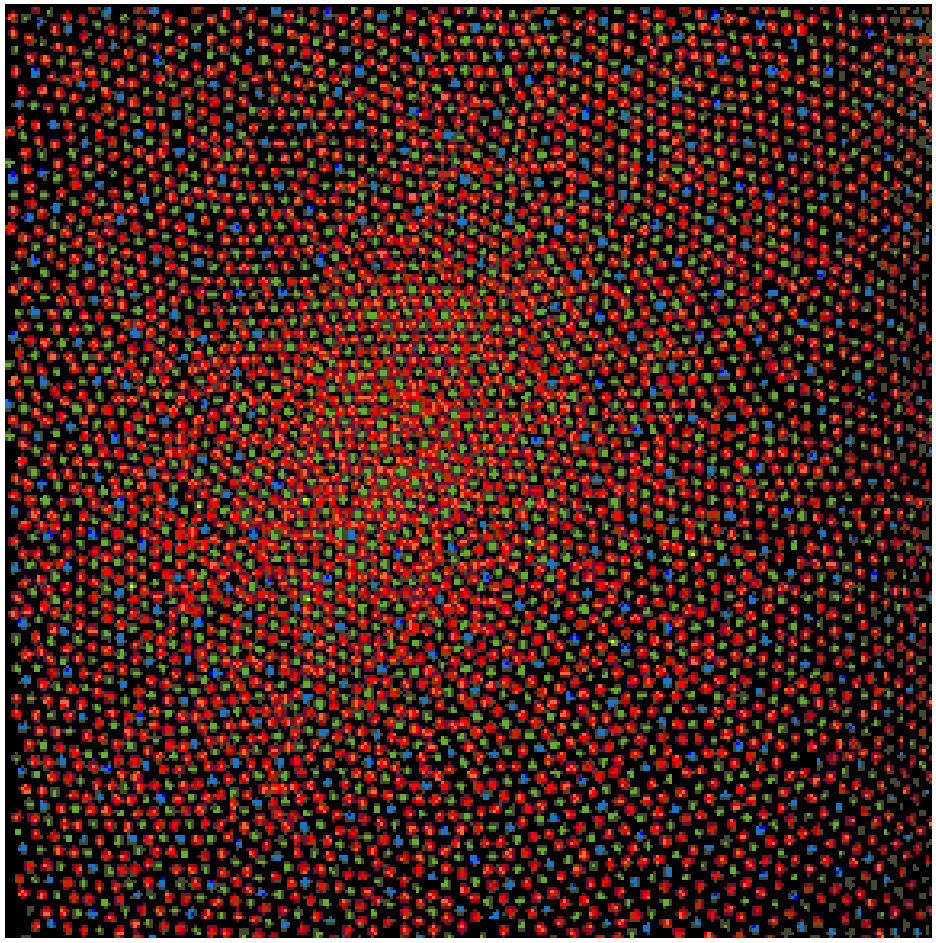
Blue cones are “odd”



Non-uniform distribution

- Blue cones are least dense in the fovea
  - 3-5%, versus about 8% elsewhere
- Red cones are about 33%, fairly evenly distributed
- Green are 64% in the fovea, about 55% elsewhere

Another way to see this



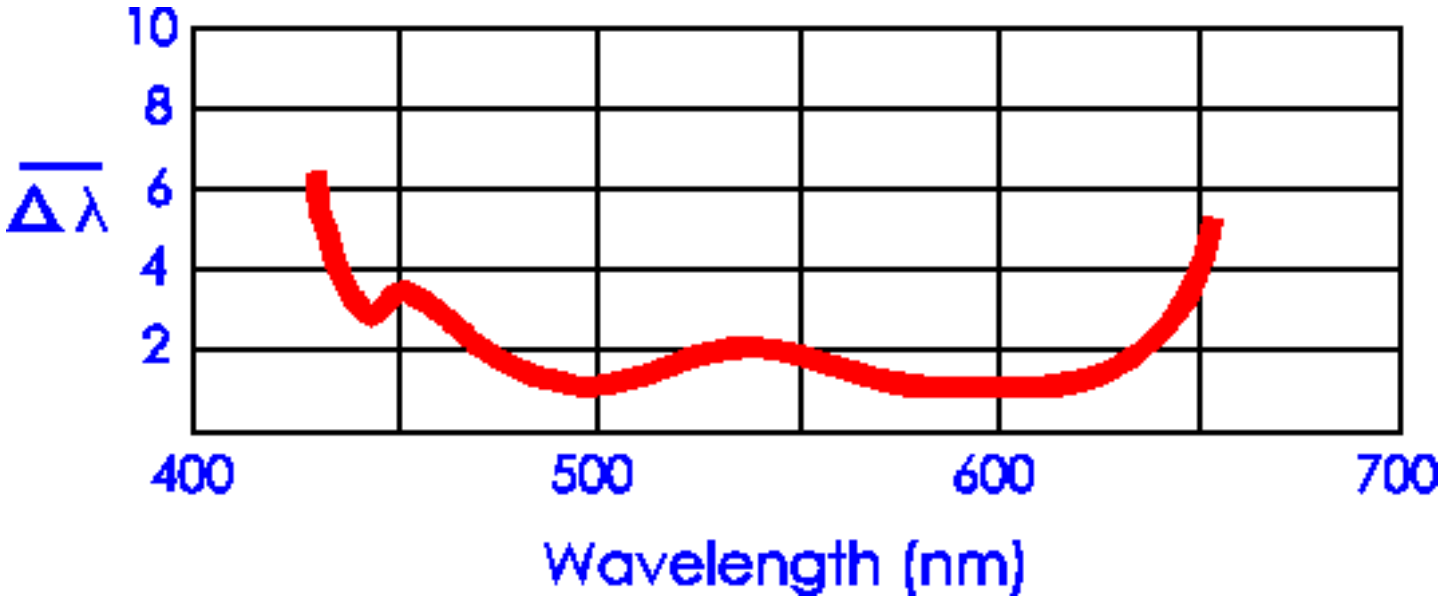
Color constancy

- As the spectrum of the illuminating light changes, so does the pattern of cone stimulus
  - Yet your red coat looks the same as you walk outside!
  - No one has a good (computational) understanding of this problem

How many colors can we see?

- Humans can discriminate about
  - 200 hues
  - 20 saturation values
  - 500 brightness steps
- The NBS lists 267 color names
- What about across languages?
  - Seem to be about 11 basic ones
    - white, black, red, green, yellow, blue, brown, purple, pink, orange, gray

Just noticeable difference



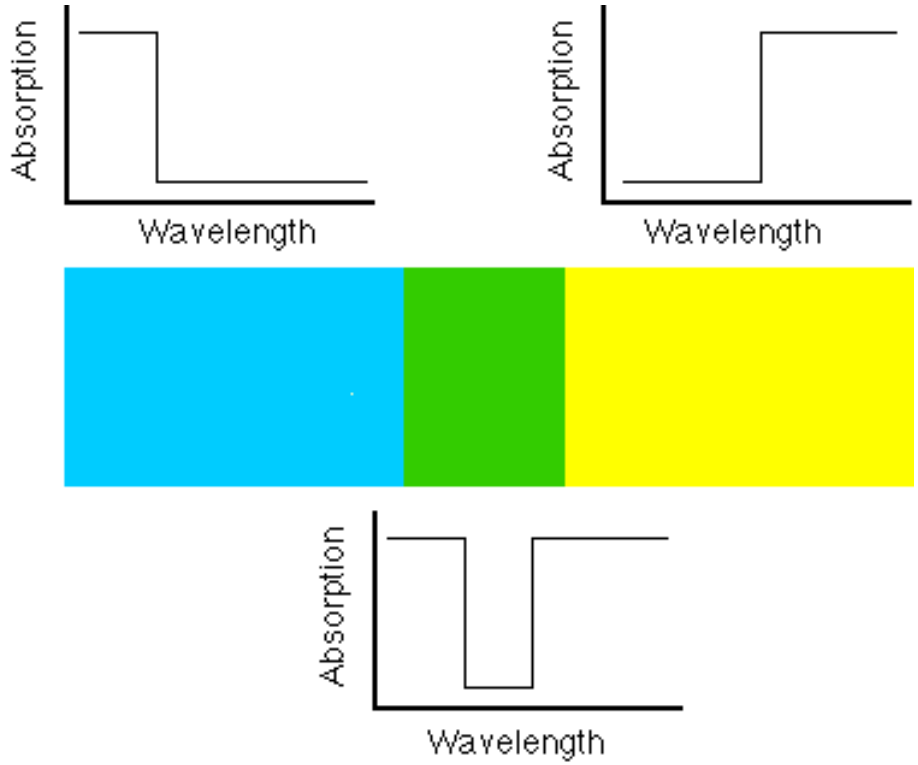
These results are for *adjacent* colors!

With a several-second pause, answer is about 12

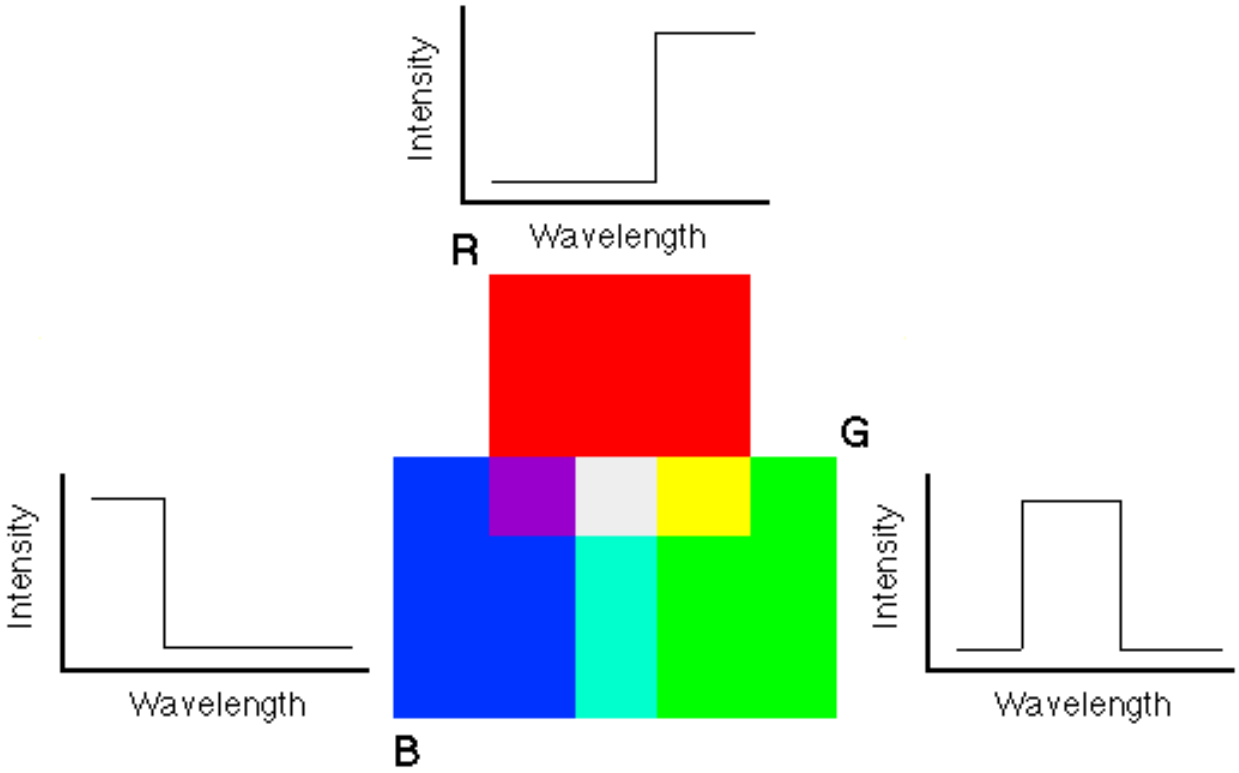
Additive versus subtractive colors

- Paint is colored because of the spectrum it *absorbs* (subtracts from the incident light)
  - Red paint absorbs non-red photons
  - Color filters are another example
- Lights have colors because of the spectrum they *emit*
  - Televisions and monitors work this way
- The two obey different rules!

Subtractive colors



Additive colors

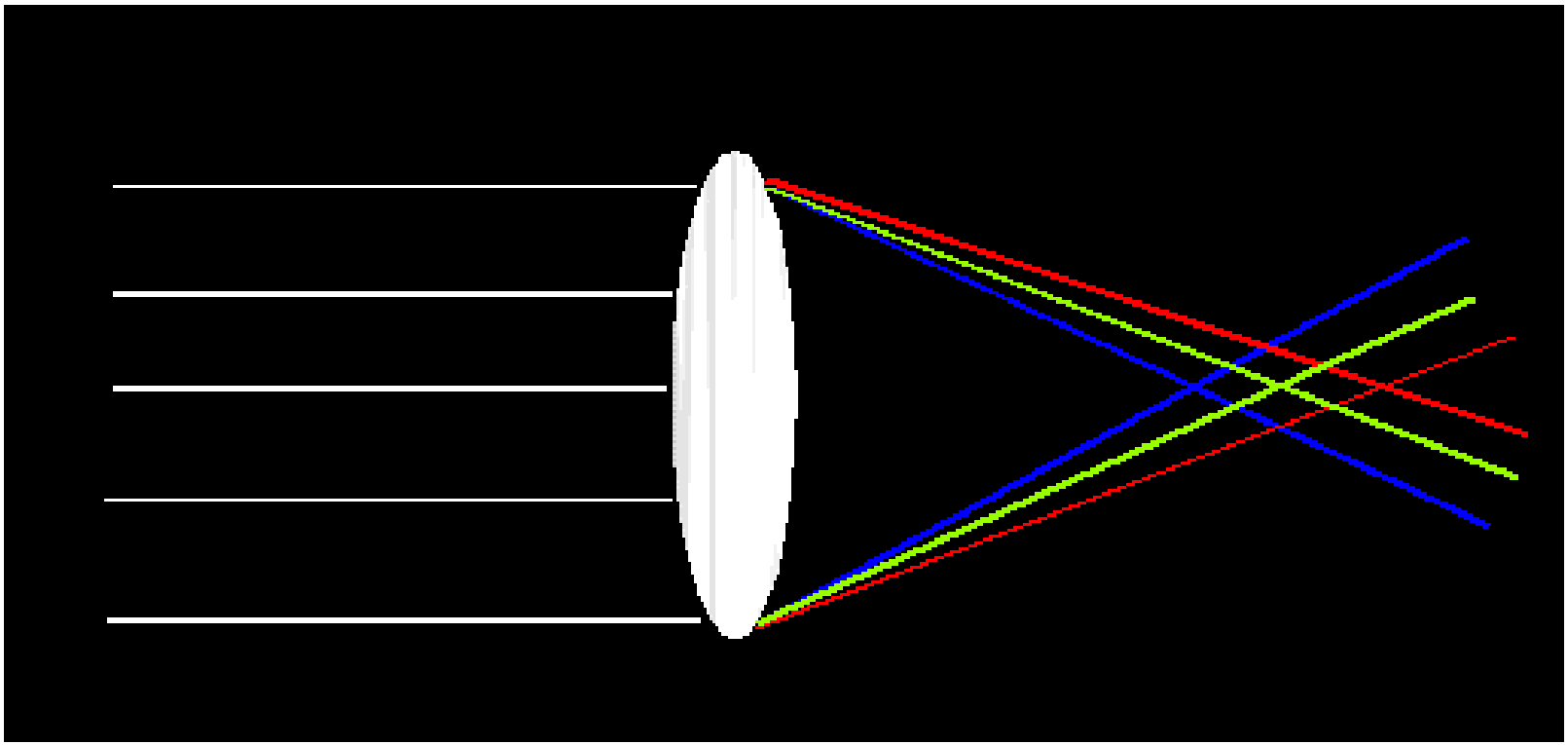


Yellow light plus blue light = what?

Cheap versus expensive cameras

- Cheap color (video) cameras have a single CCD
  - Mask in front of the imaging array
  - Reduces spatial resolution
- More expensive cameras have 3 different video cameras
  - Color output really is 3 different (independent) signals

Different wavelengths, different focal lengths



Note: expensive (achromatic) lenses don’t do this

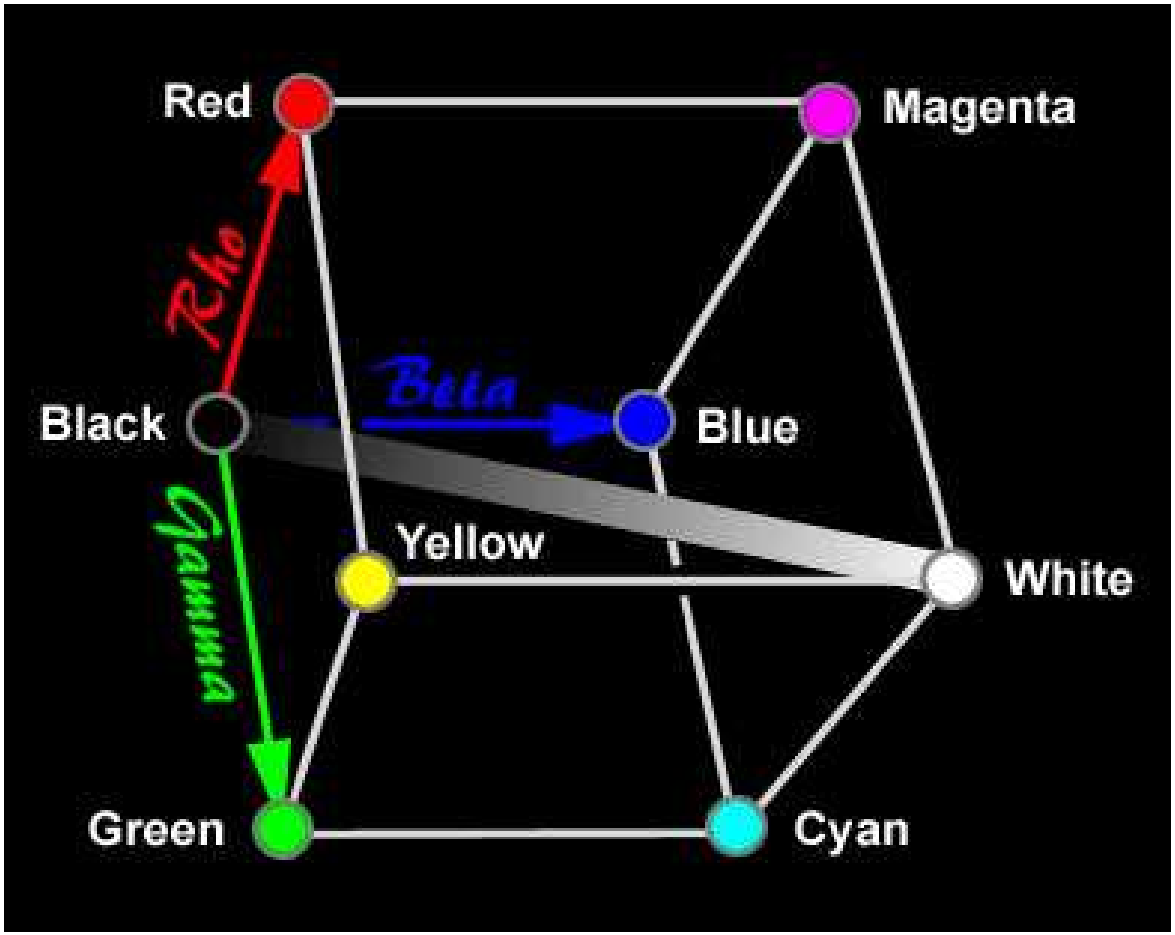
Consequences of different focal lengths

- On a single-CCD system, only one color is really in focus
  - Typically, it’s the green channel
- What about the human visual system?

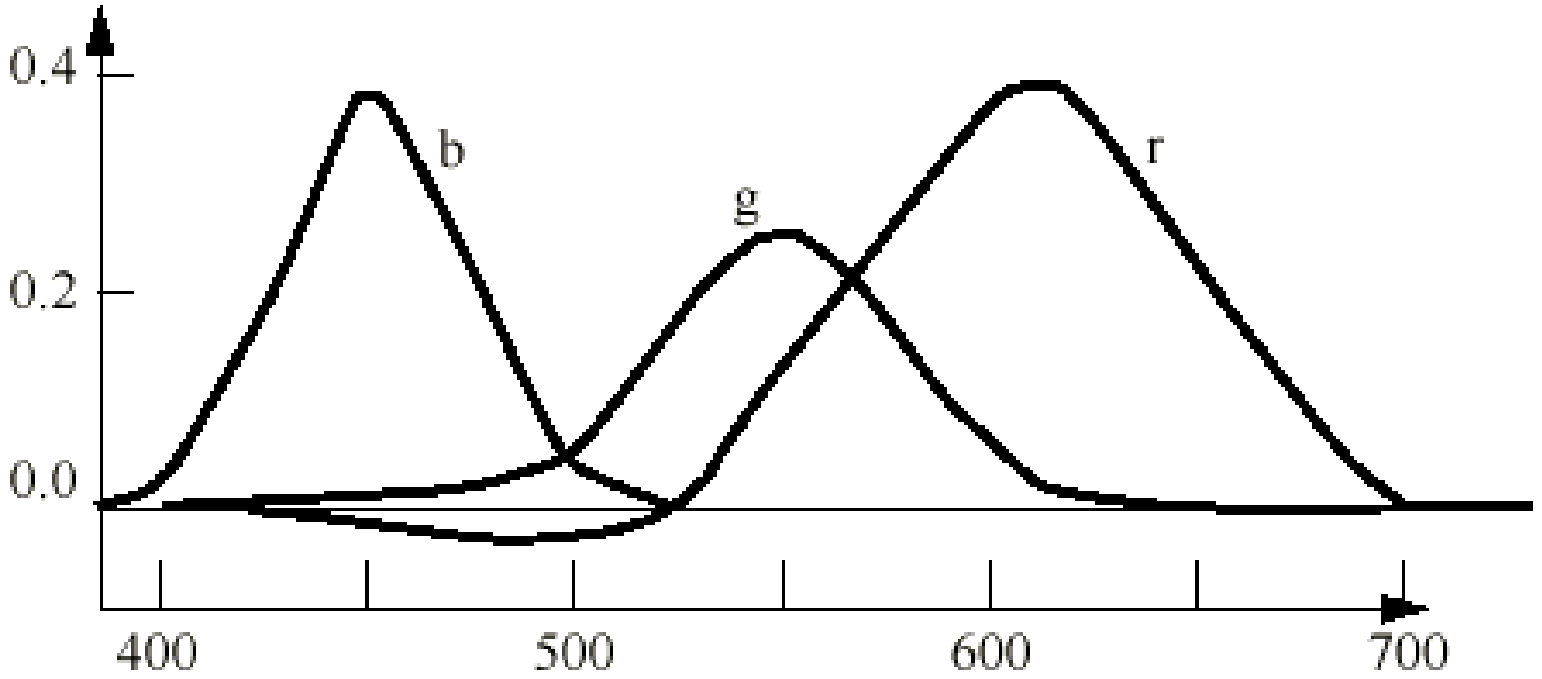
Colorspace

- The colorspace is obviously 3-dimensional
  - Different ways to represent this space
  - One goal: distance in color space corresponds to human notion of “similar” colors
    - Perceptually uniform colorspaces are hard!
- The obvious solution is to have one dimension per cone type
  - Additive, using red, green and blue

RGB color space



How to represent a pure color in RGB



There's a BIG problem here…

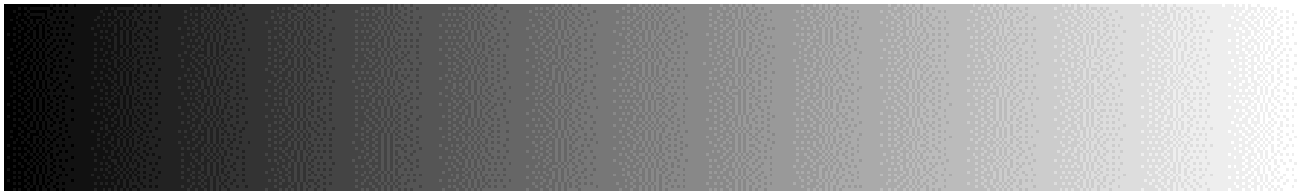
Another way to think about color

- RGB maps nicely onto the way monitors phosphors are designed
  - Cameras naturally provide something like RGB
  - 3 different wavelengths
- But there is a more natural way to think about color
  - Hue, saturation, brightness

Hue, saturation and brightness

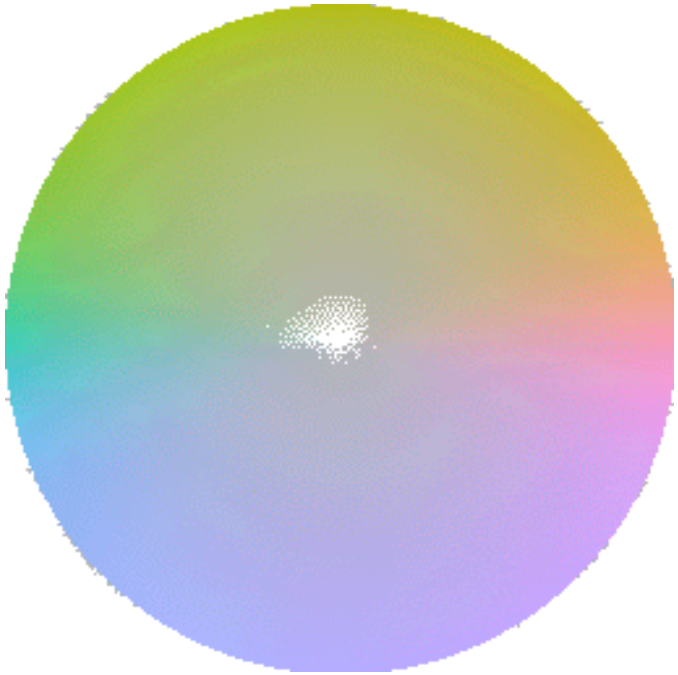
H
dominant wavelength

S
purity
% white



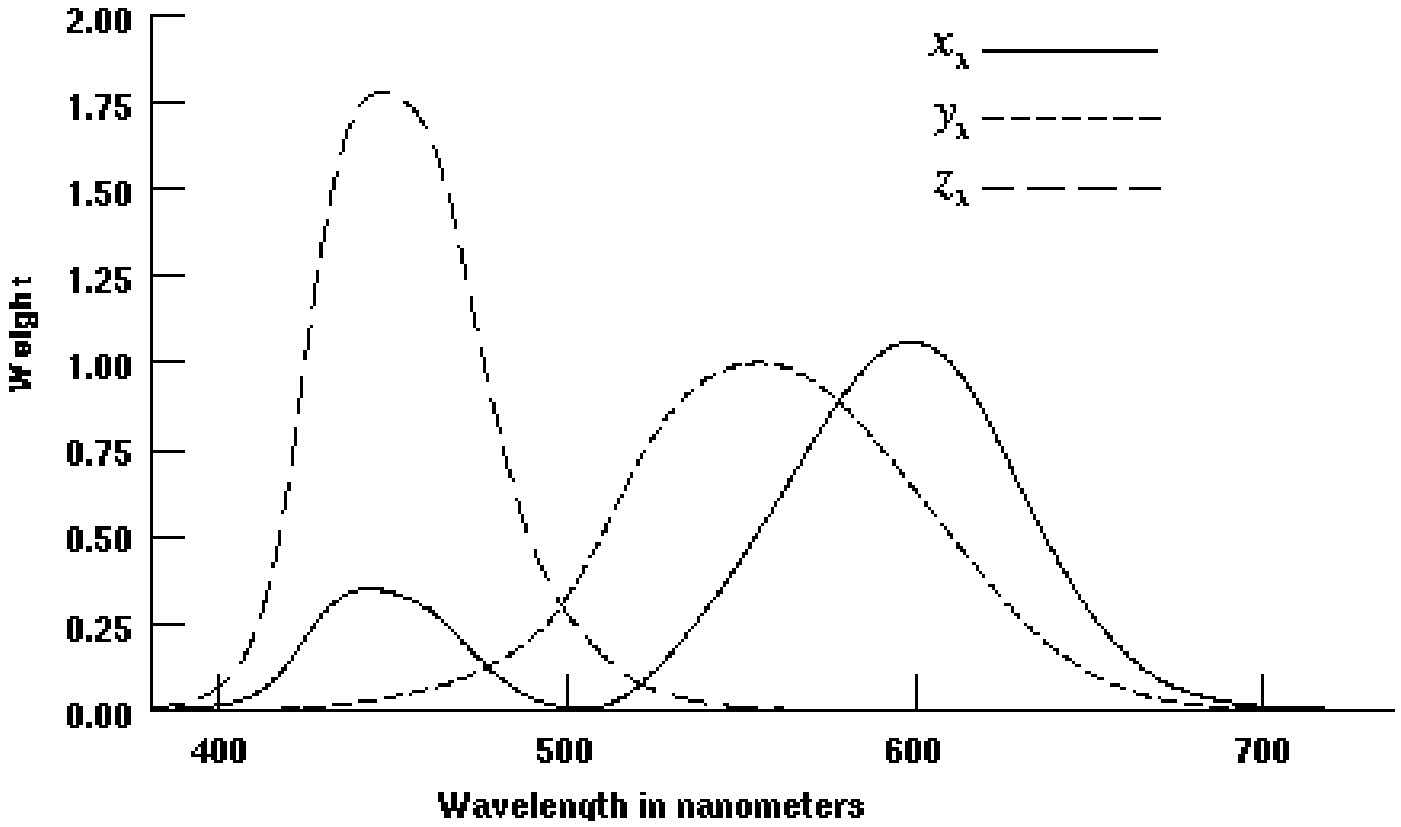
B
luminance

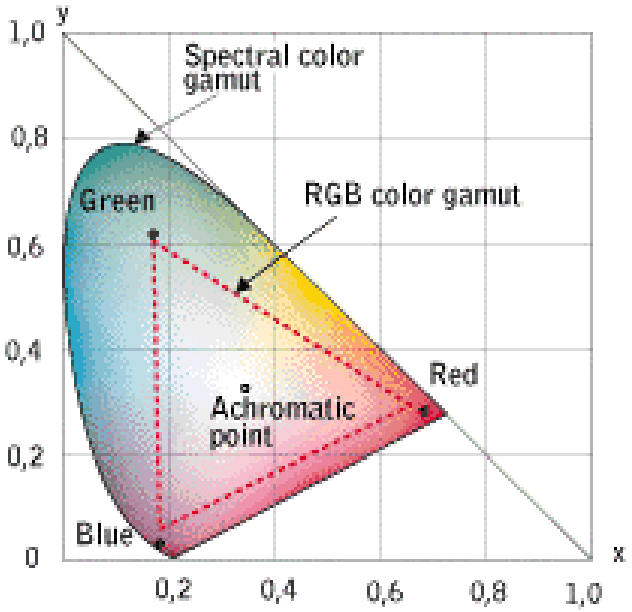
Color wheel (constant brightness)



In this view of color,
there is a color *cone*
(this is a cross-section)

CIE colorspace



CIE color chart

- X+Y+Z is more or less luminosity
  - Let’s look at the plane X+Y+Z = 1