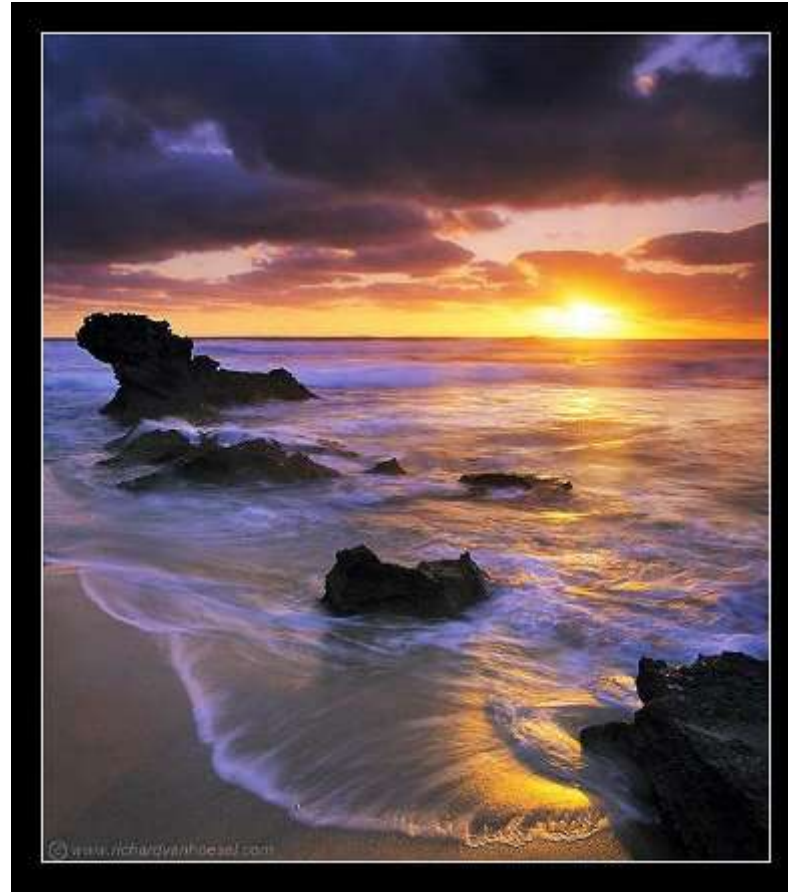
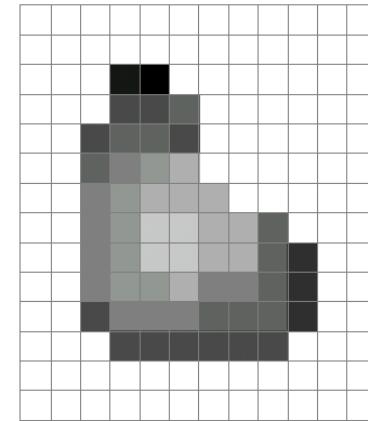
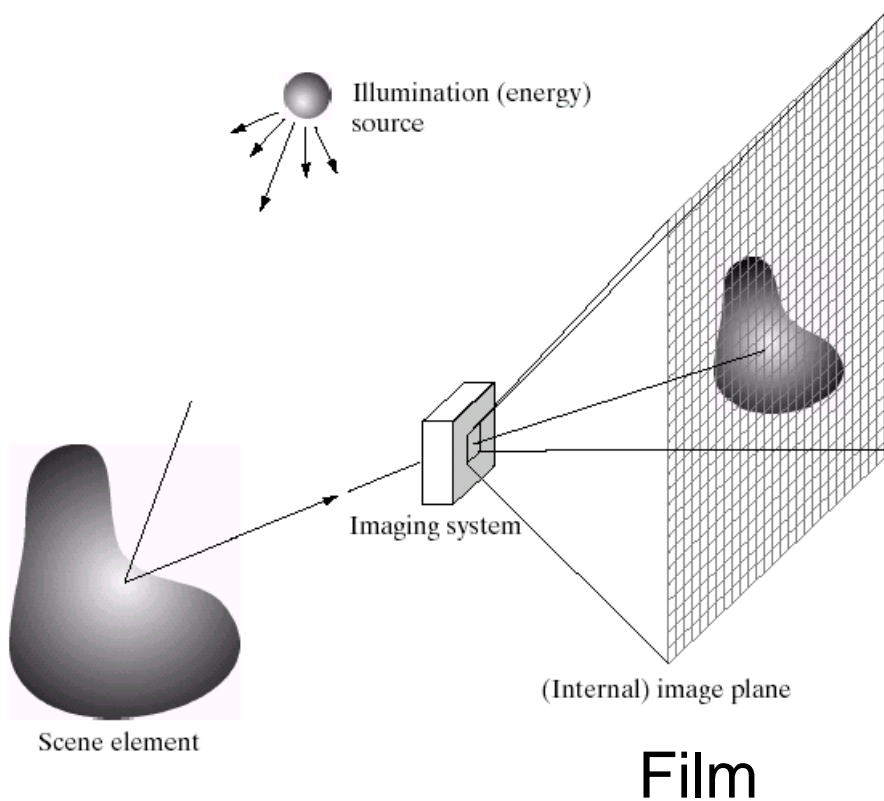


Capturing Light... in man and machine

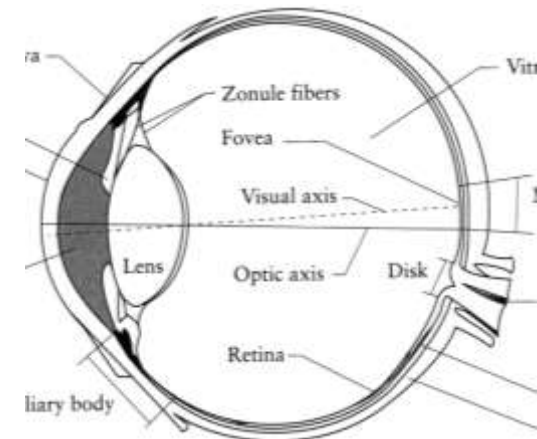


15-463: Computational Photography
Alexei Efros, CMU, Spring 2010

Image Formation



Digital Camera



The Eye

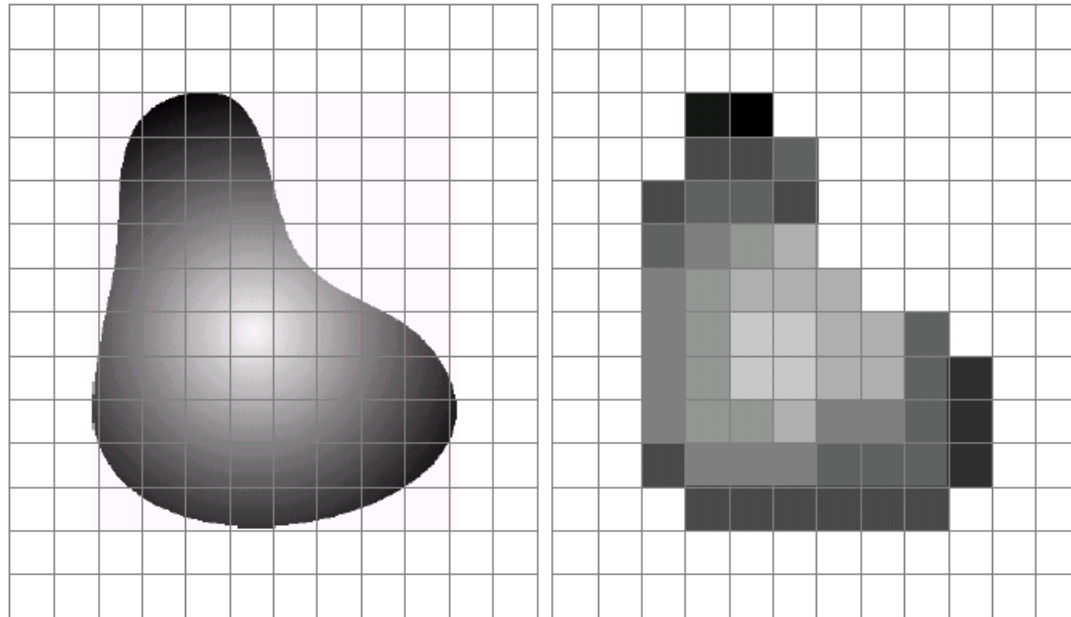
Digital camera



A digital camera replaces film with a sensor array

- Each cell in the array is light-sensitive diode that converts photons to electrons
- Two common types
 - Charge Coupled Device (CCD)
 - CMOS
- <http://electronics.howstuffworks.com/digital-camera.htm>

Sensor Array



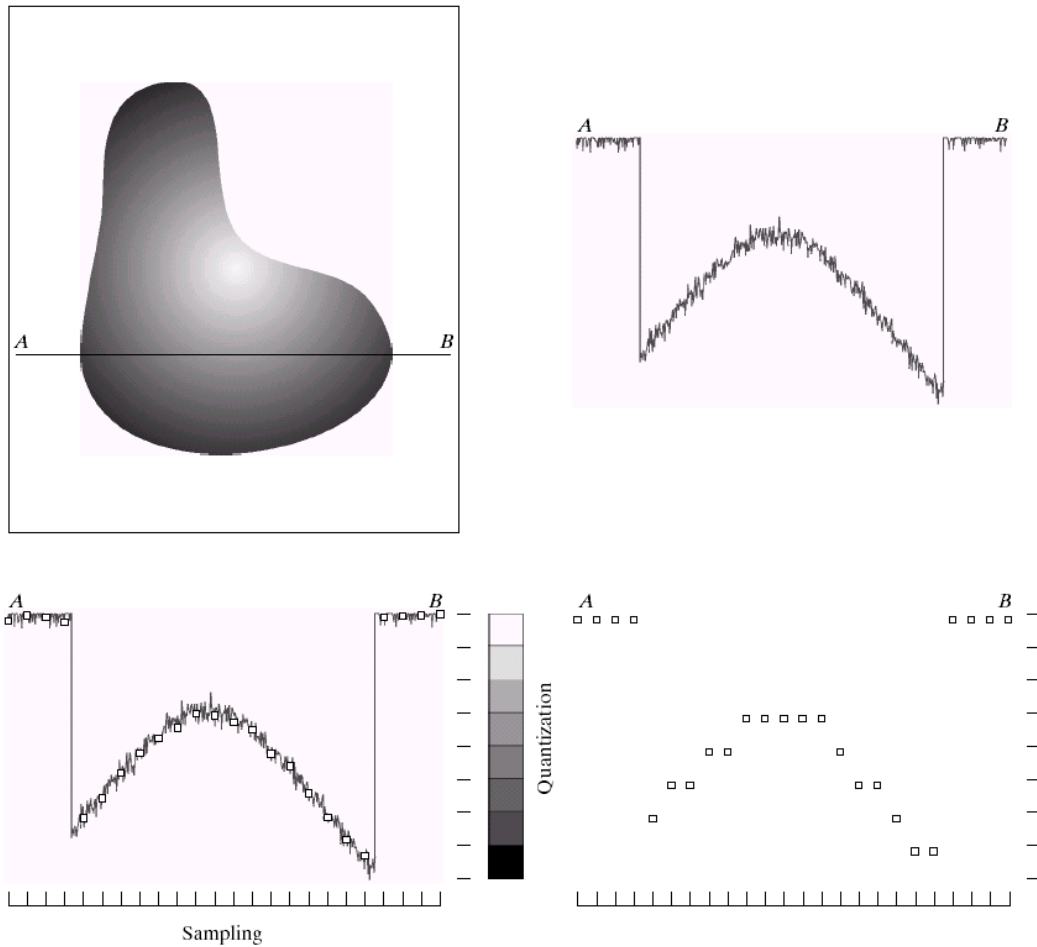
a b

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.



CMOS sensor

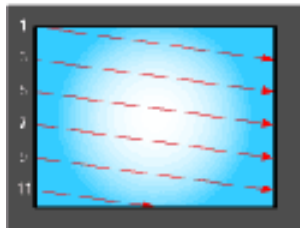
Sampling and Quantization



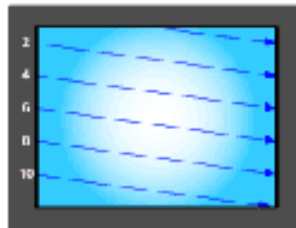
a b
c d

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

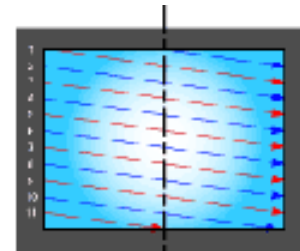
Interlace vs. progressive scan



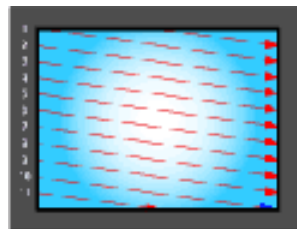
1st field: Odd field



2nd field: Even field



One complete frame
using interlaced scanning



One complete frame
using progressive scanning

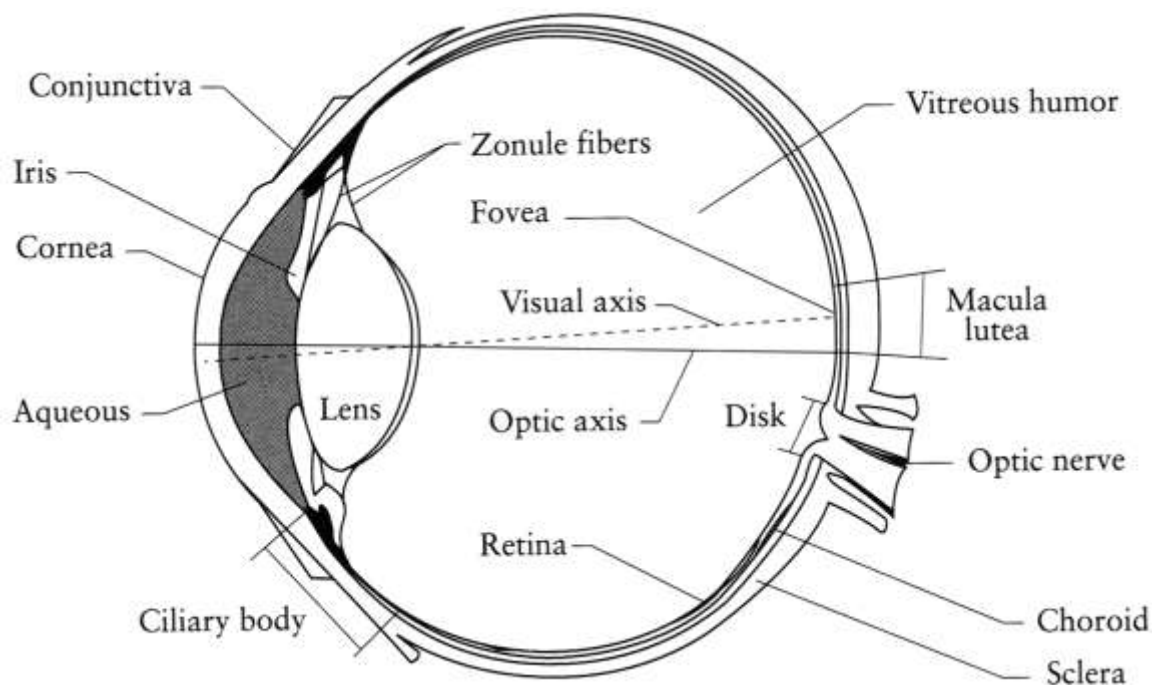
Progressive scan



Interlace



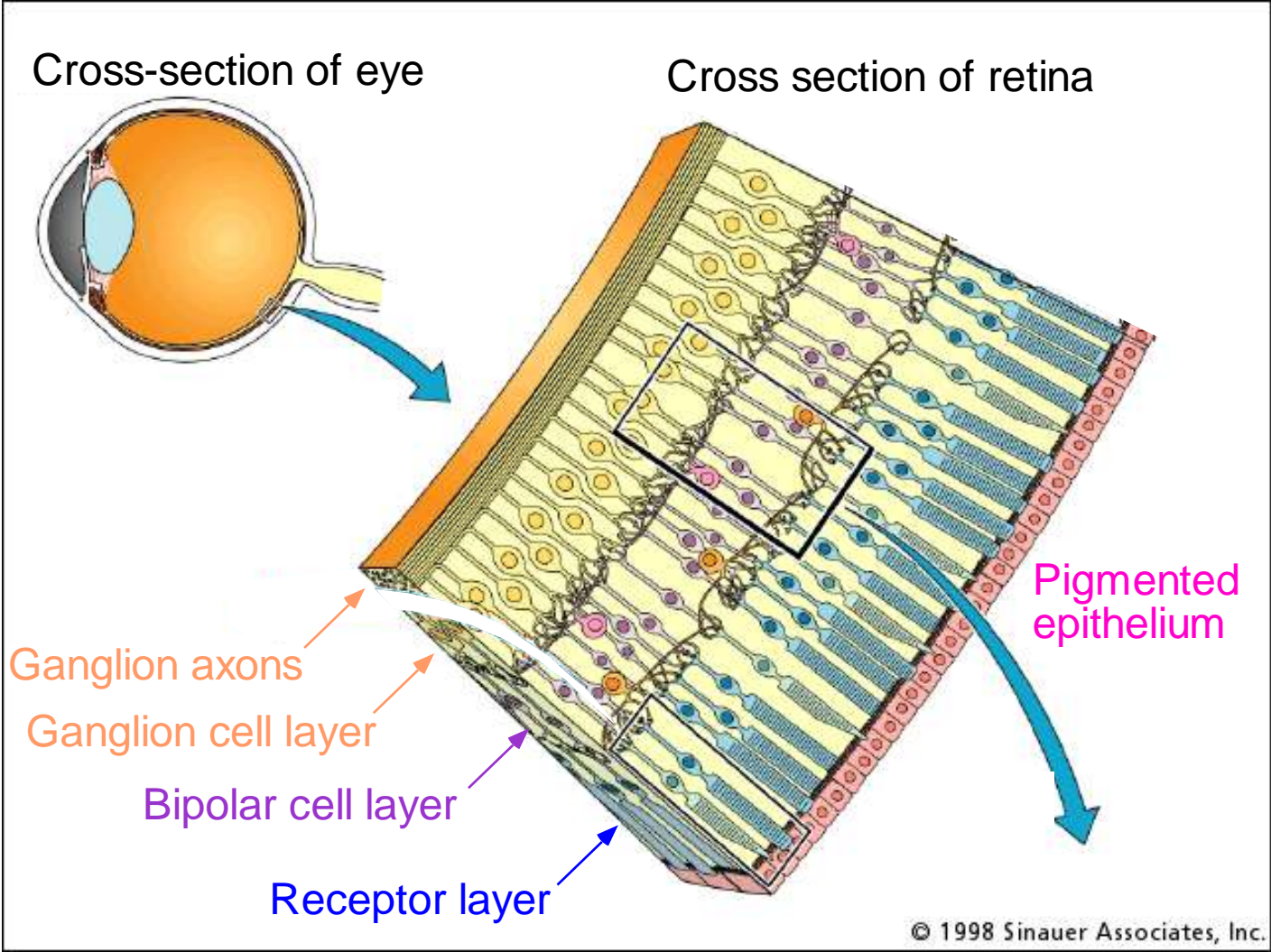
The Eye



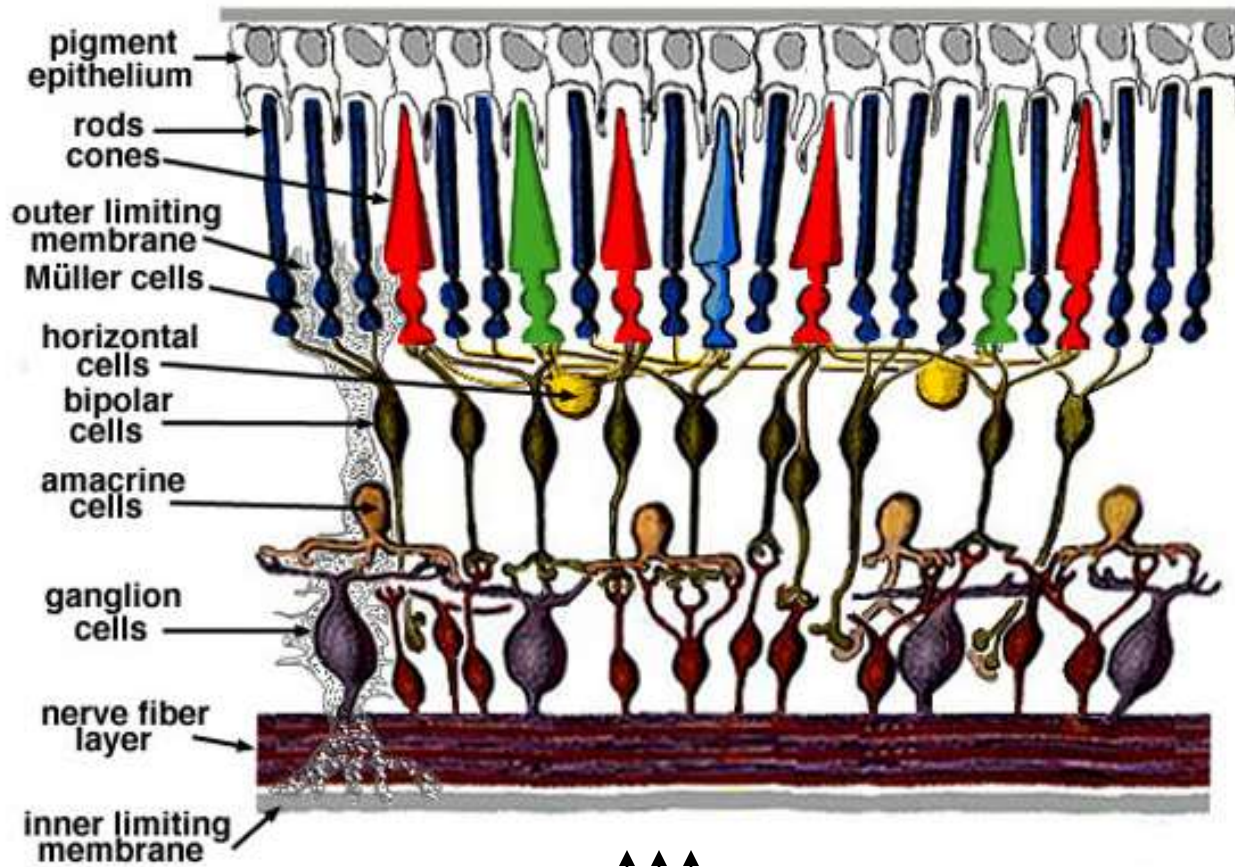
The human eye is a camera!

- **Iris** - colored annulus with radial muscles
- **Pupil** - the hole (aperture) whose size is controlled by the iris
- What's the "film"?
 - photoreceptor cells (rods and cones) in the **retina**

The Retina



Retina up-close



Light

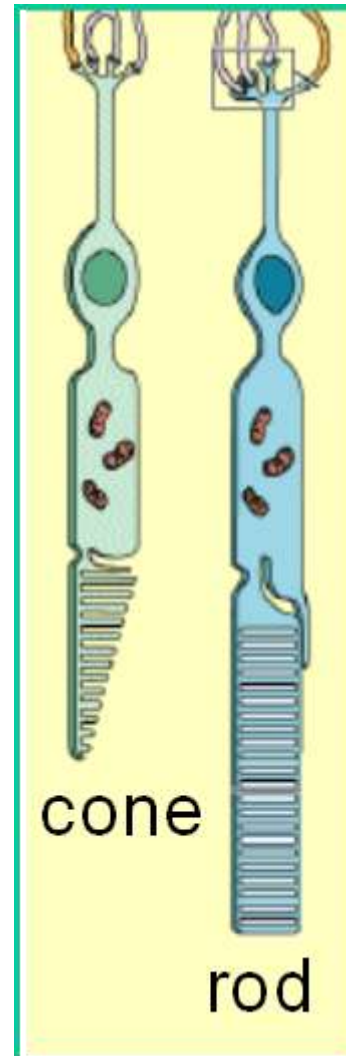
Two types of light-sensitive receptors

Cones

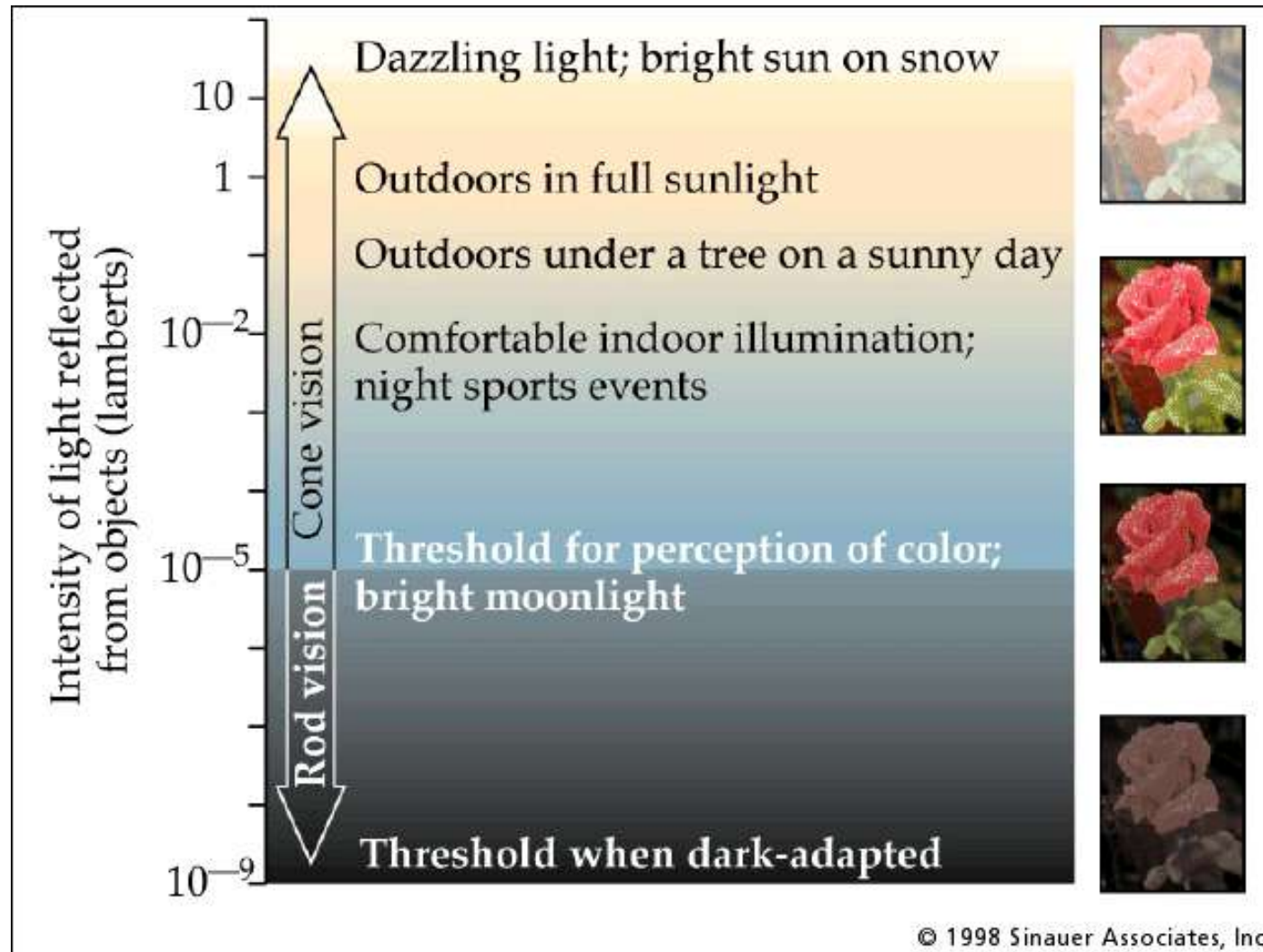
cone-shaped
less sensitive
operate in high light
color vision

Rods

rod-shaped
highly sensitive
operate at night
gray-scale vision

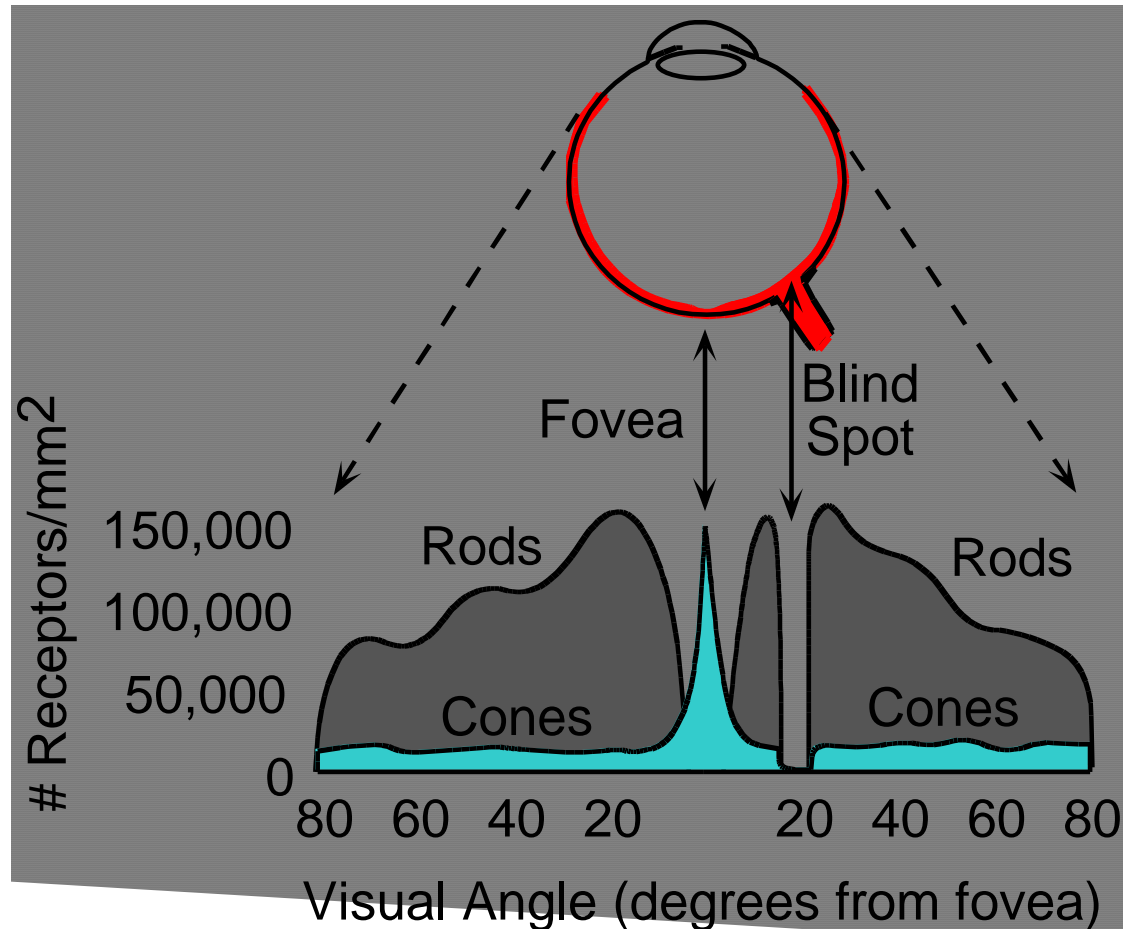


Rod / Cone sensitivity



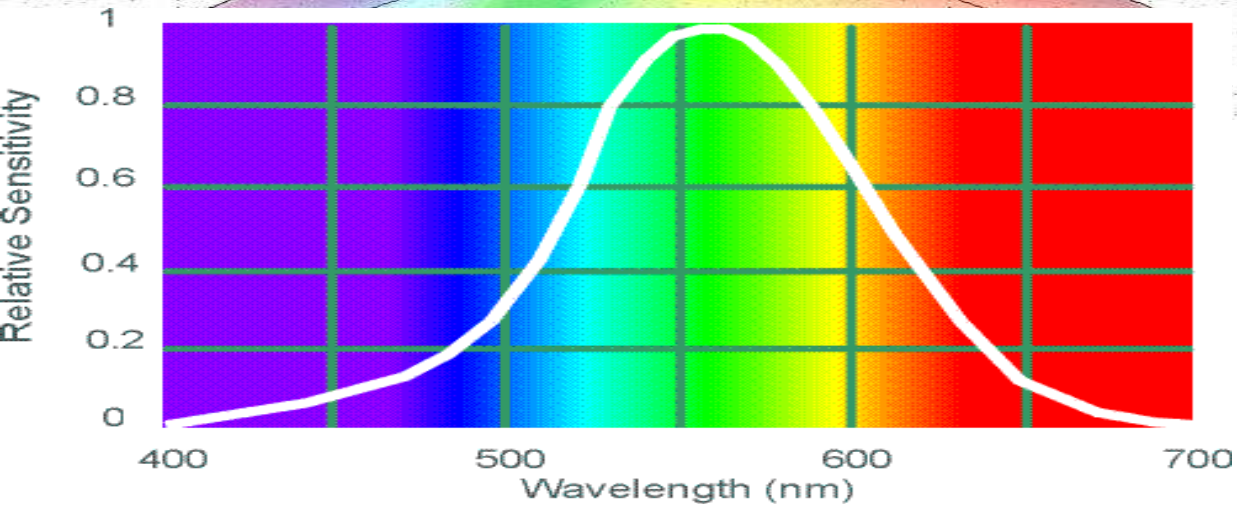
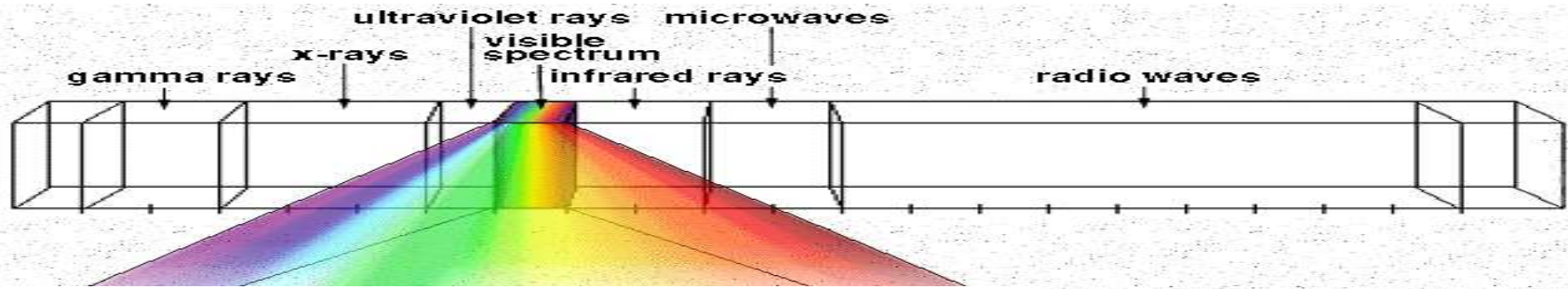
The famous sock-matching problem...

Distribution of Rods and Cones



Night Sky: why are there more stars off-center?

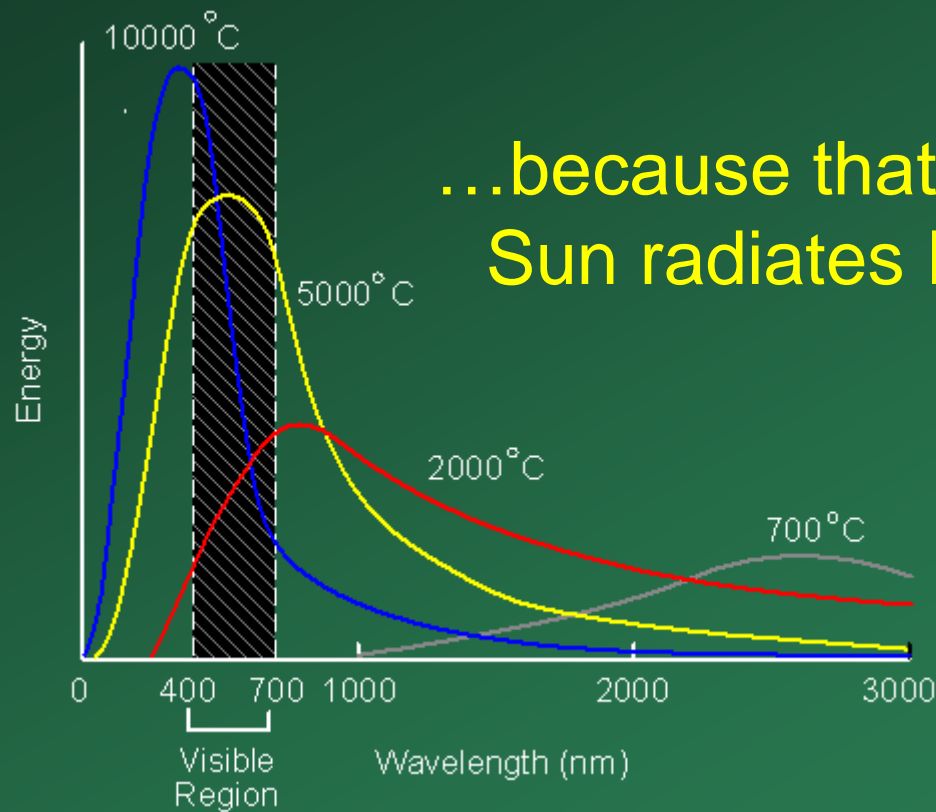
Electromagnetic Spectrum



Human Luminance Sensitivity Function

Visible Light

Why do we see light of these wavelengths?

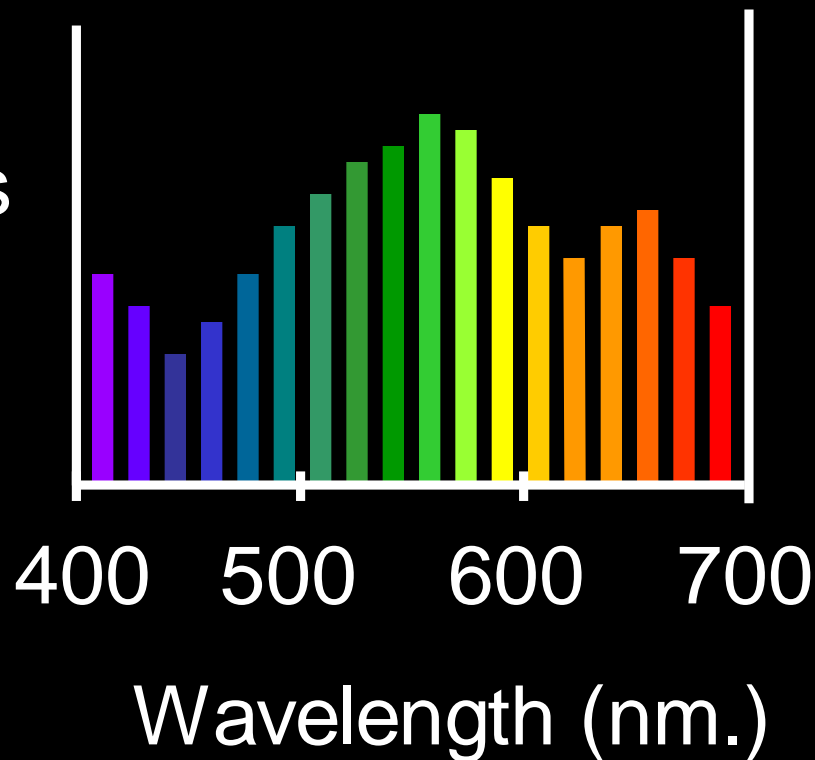


...because that's where the Sun radiates EM energy

The Physics of Light

Any patch of light can be completely described physically by its spectrum: the number of photons (per time unit) at each wavelength 400 - 700 nm.

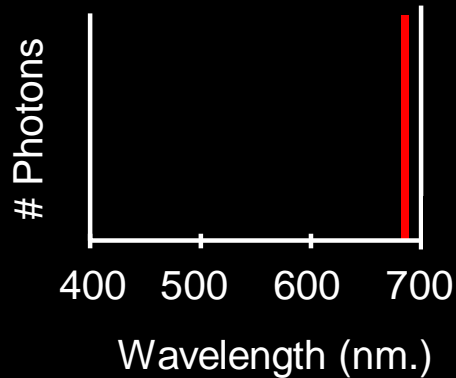
Photons
(per ms.)



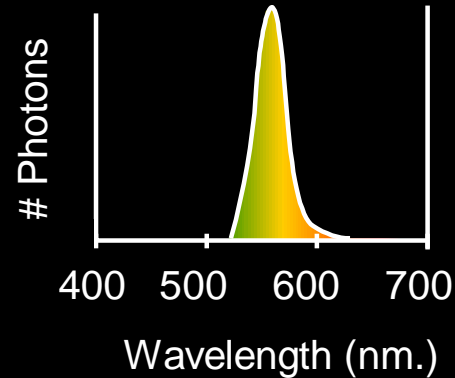
The Physics of Light

Some examples of the spectra of light sources

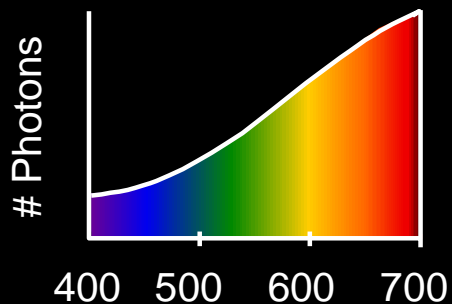
A. Ruby Laser



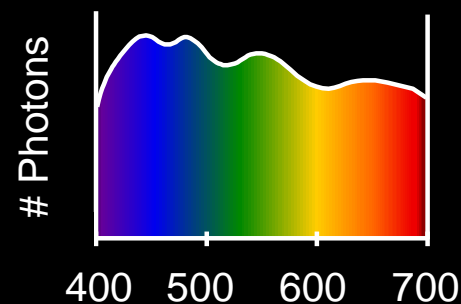
B. Gallium Phosphide Crystal



C. Tungsten Lightbulb



D. Normal Daylight

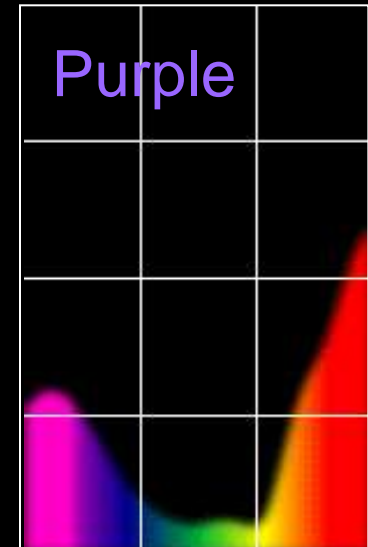
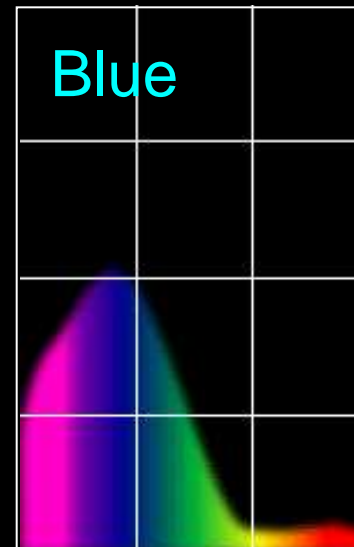
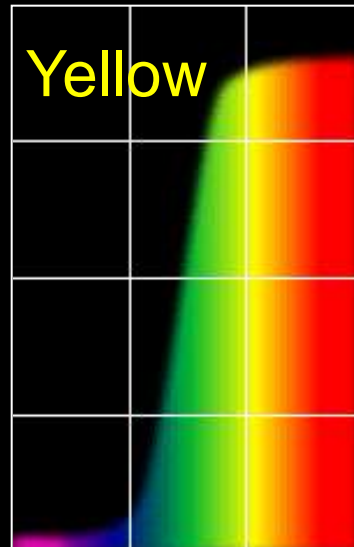
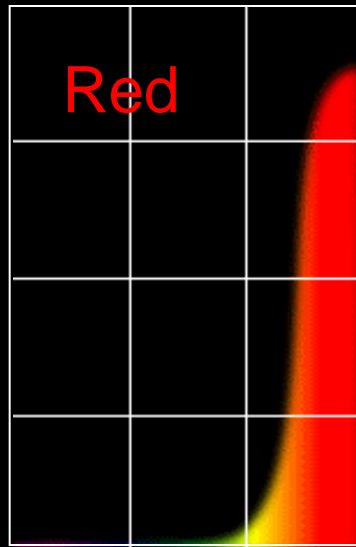


The Physics of Light

Some examples of the reflectance spectra of surfaces



% Photons Reflected



400

700

400

700

400

700

400

700

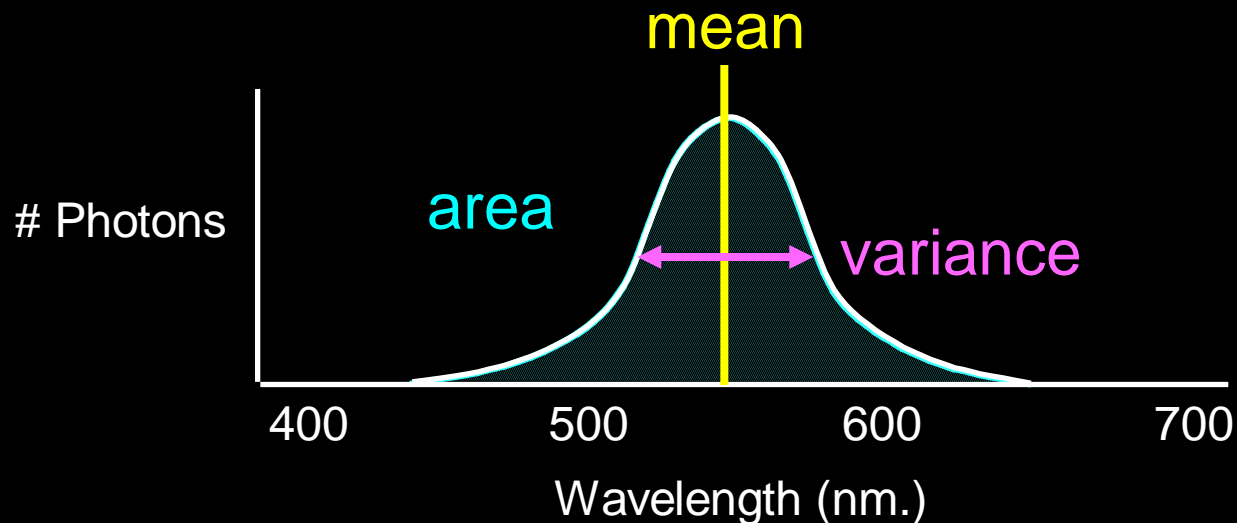
Wavelength (nm)

The Psychophysical Correspondence

There is no simple functional description for the perceived color of all lights under all viewing conditions, but

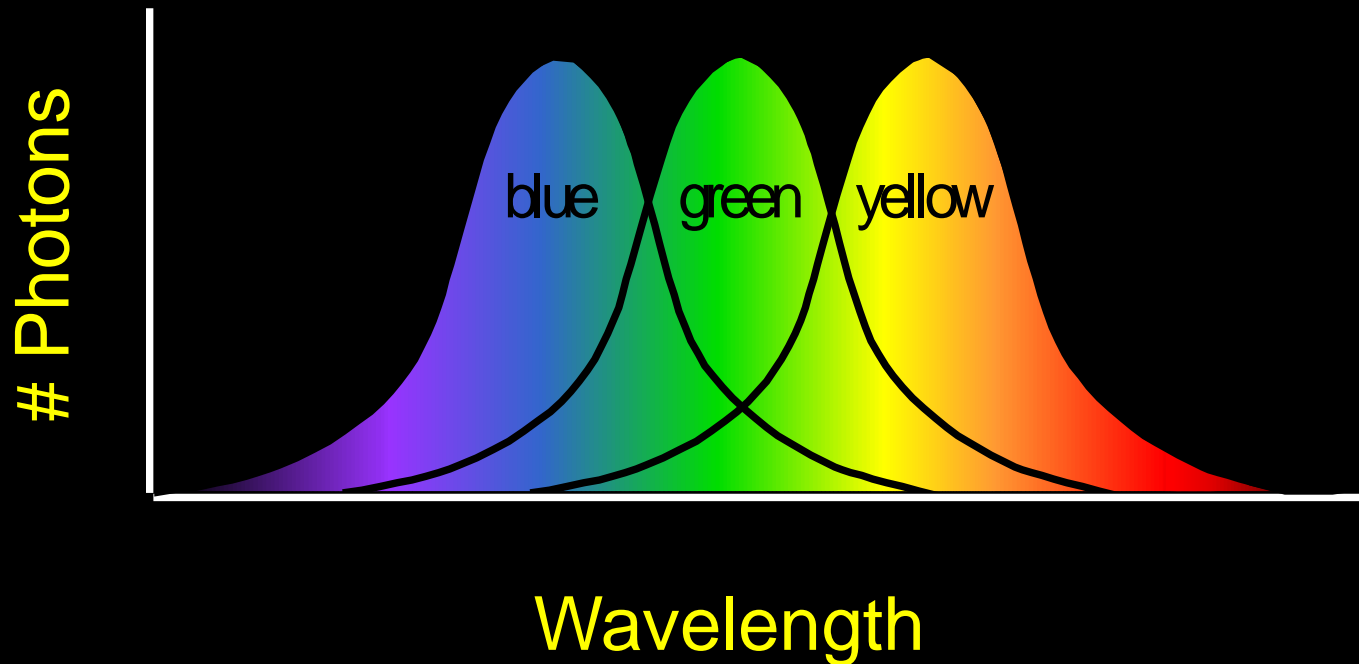
A helpful constraint:

Consider only physical spectra with normal distributions



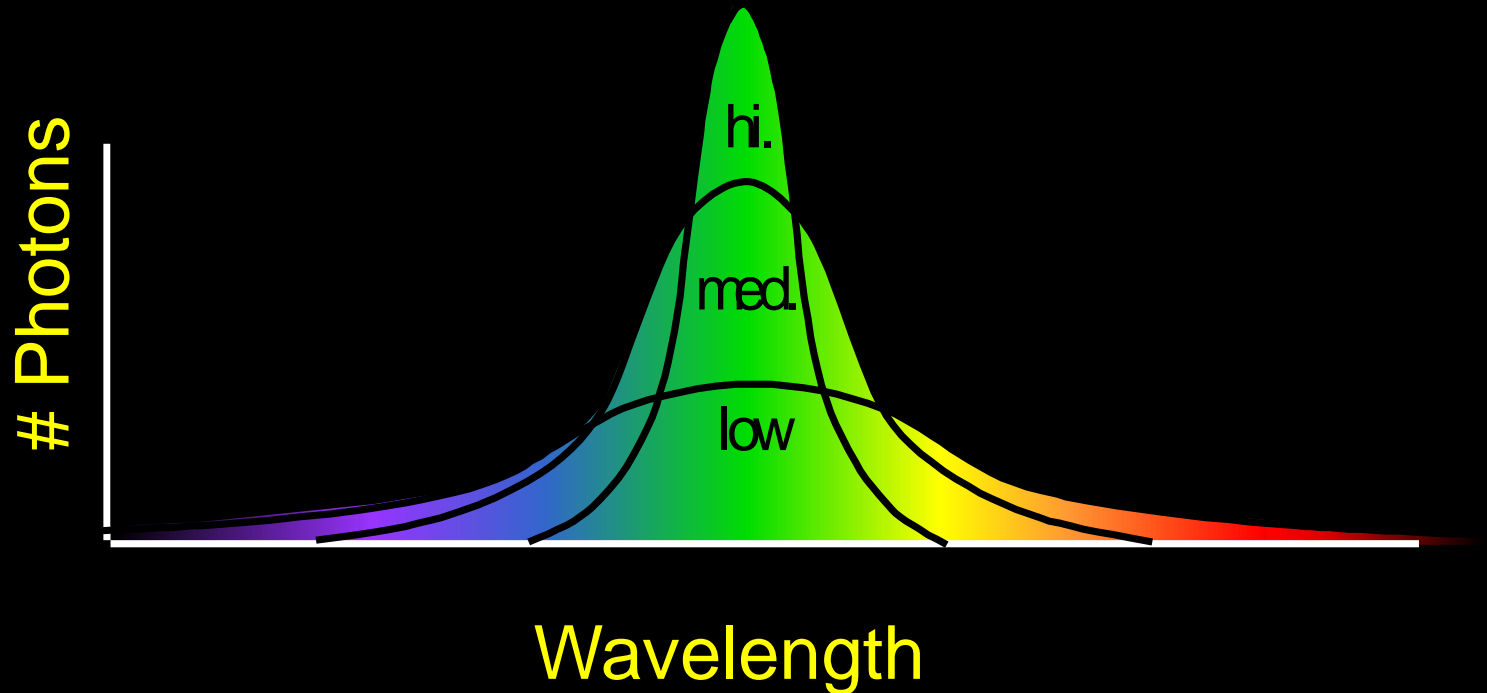
The Psychophysical Correspondence

Mean ↔ Hue



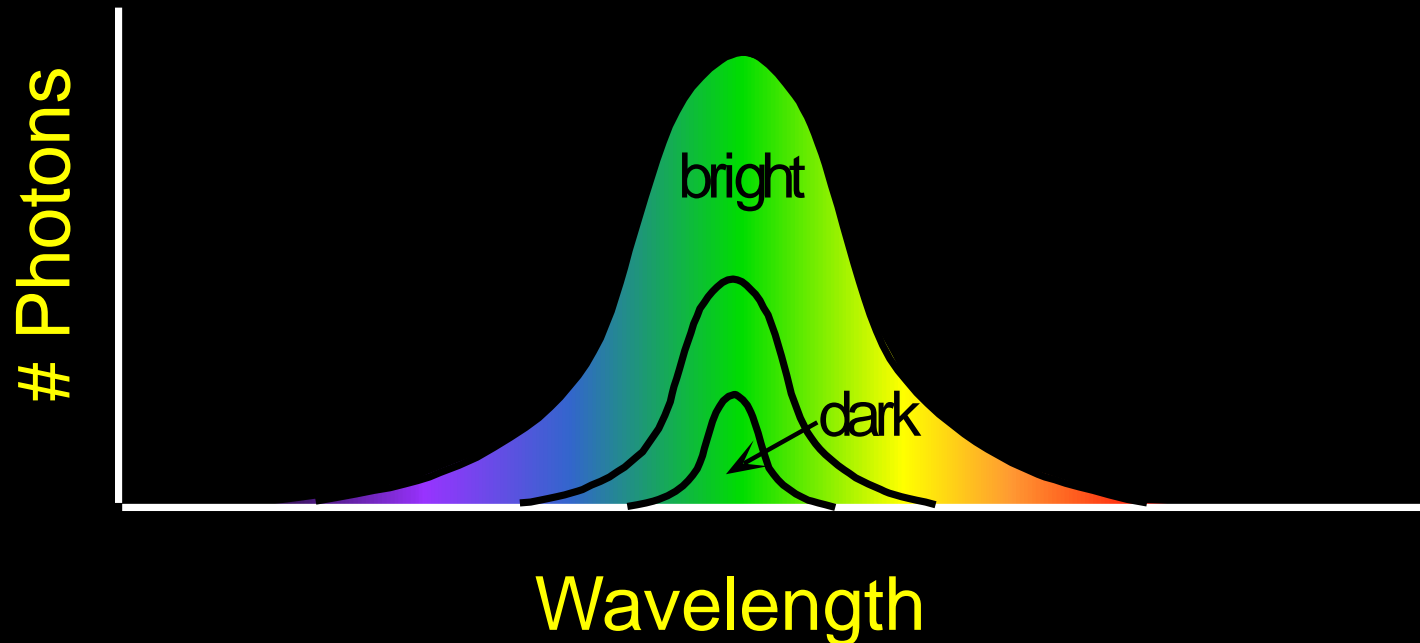
The Psychophysical Correspondence

Variance \longleftrightarrow Saturation



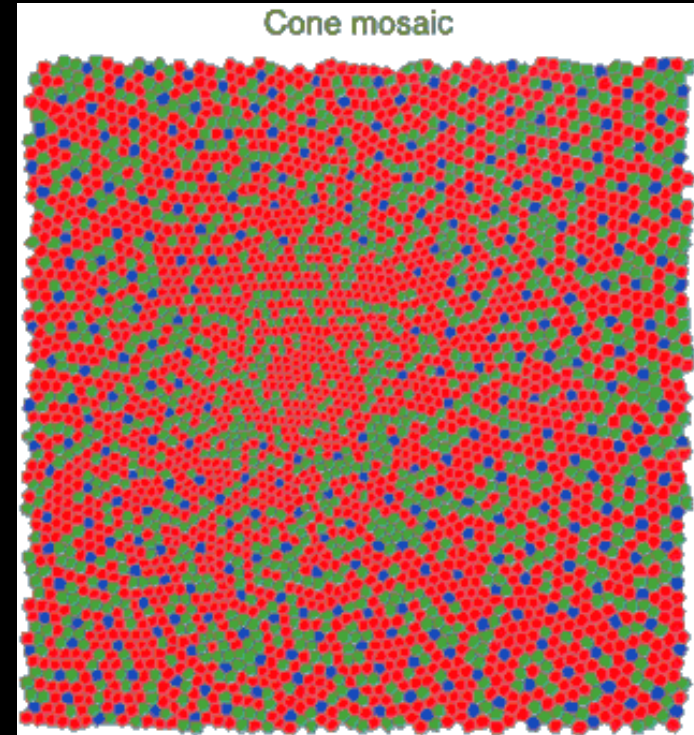
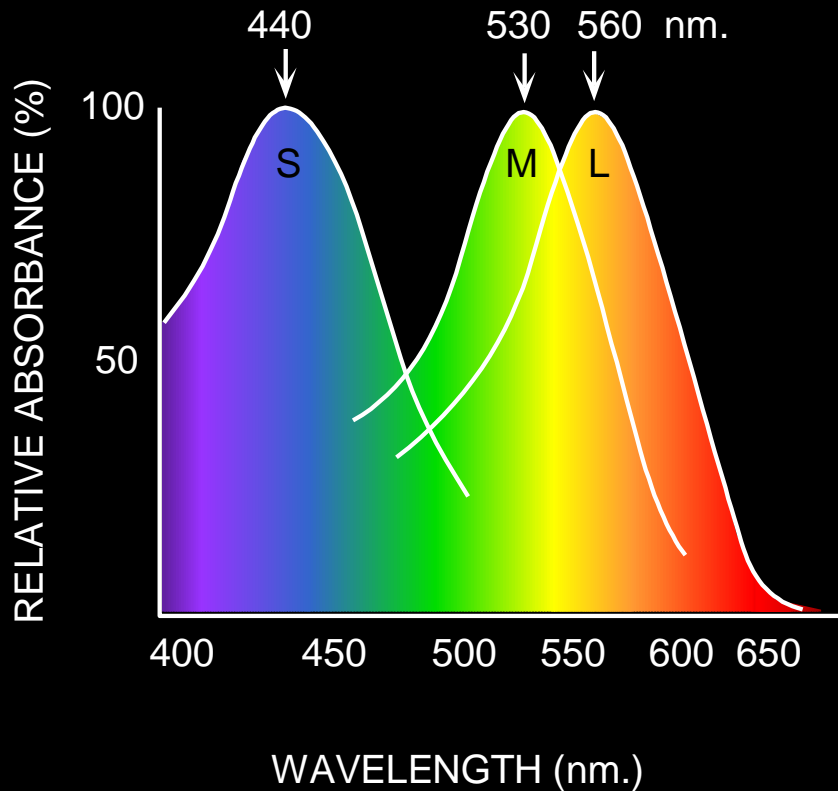
The Psychophysical Correspondence

Area \longleftrightarrow Brightness



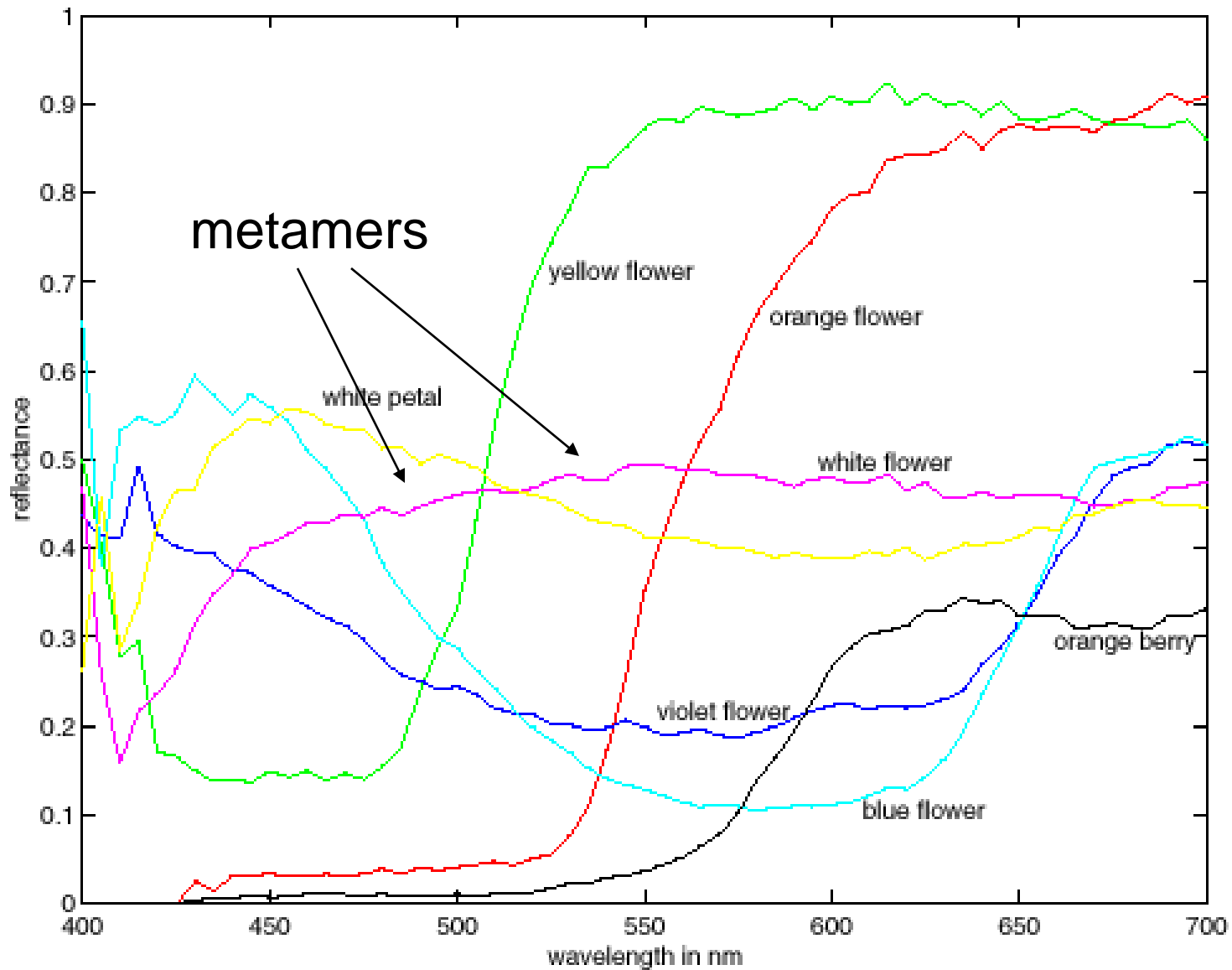
Physiology of Color Vision

Three kinds of cones:



- Why are M and L cones so close?
- Why are there 3?

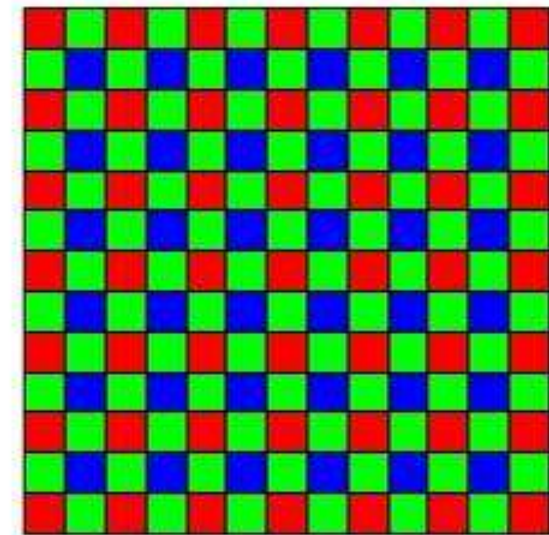
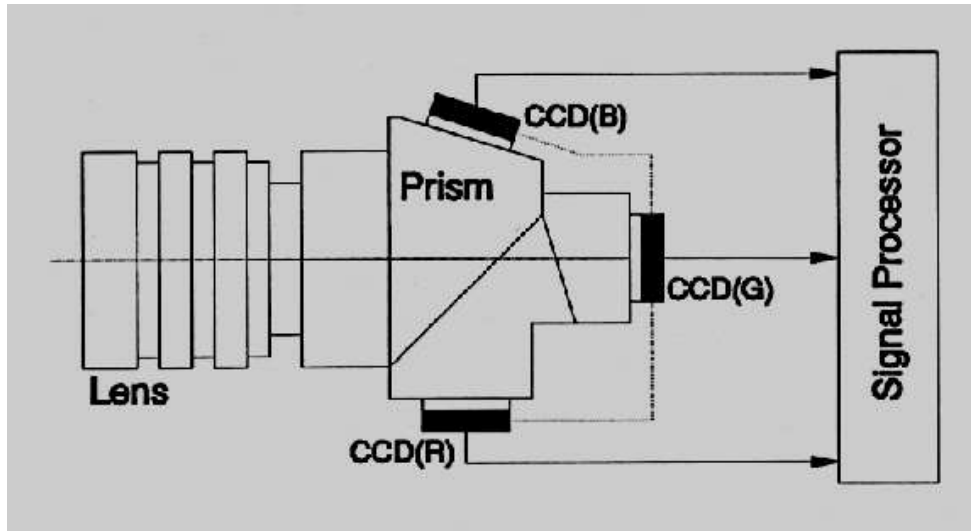
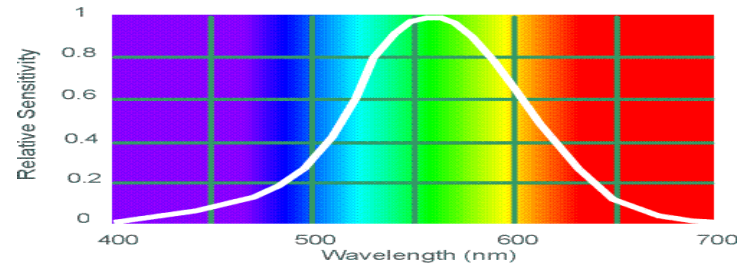
More Spectra



Color Sensing in Camera (RGB)

3-chip vs. 1-chip: quality vs. cost

Why more green?



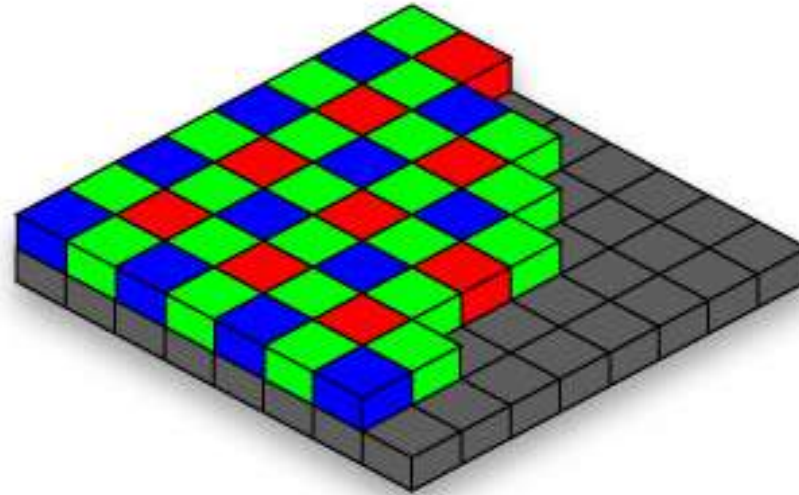
Bayer filter

Ituff Works

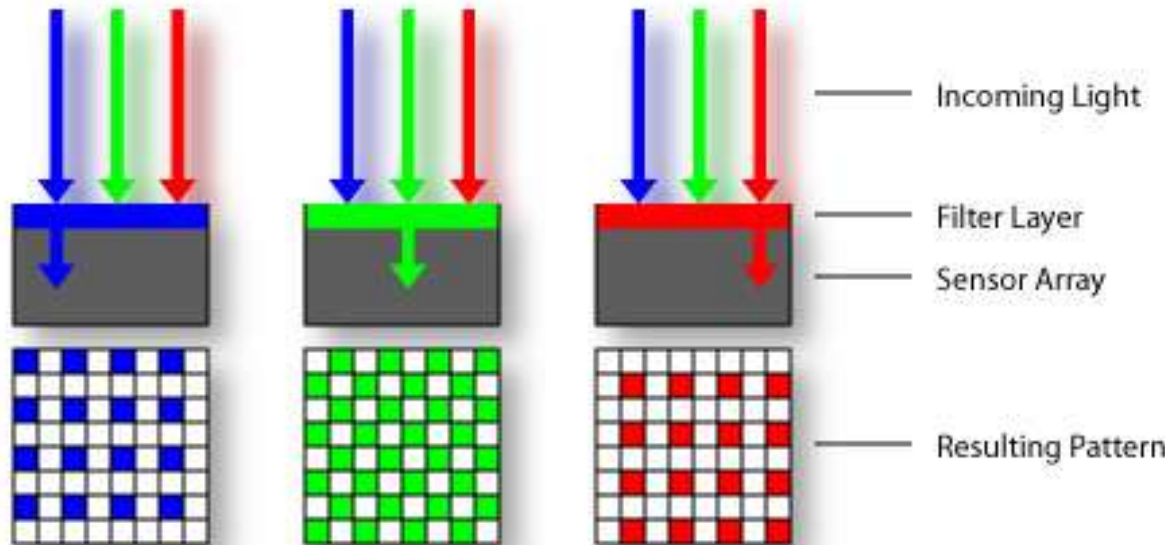
Why 3 colors?

<http://www.cooldictionary.com/words/Bayer-filter.wikipedia>

Practical Color Sensing: Bayer Grid



Estimate RGB
at 'G' cels from
neighboring
values



[http://www.cooldictionary.com/
words/Bayer-filter.wikipedia](http://www.cooldictionary.com/words/Bayer-filter.wikipedia)

RGB color space

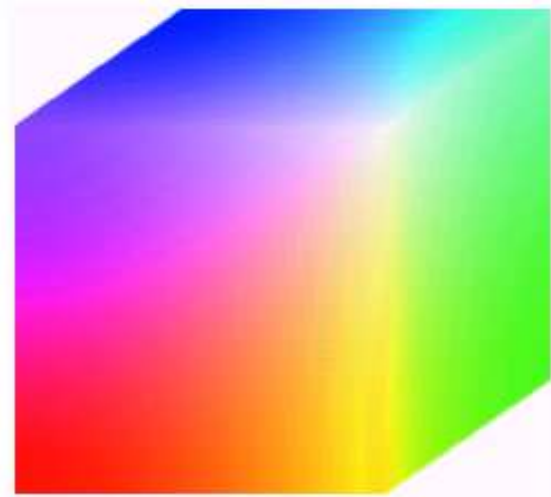
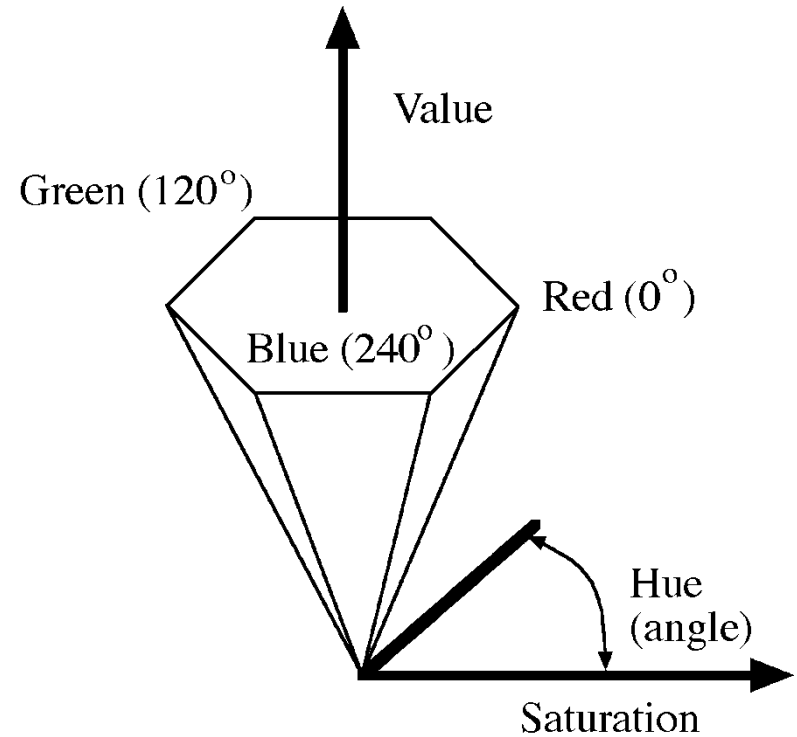
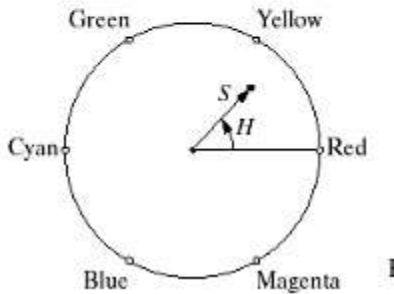
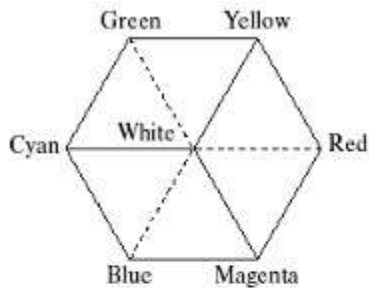


FIGURE 6.8 RGB 24-bit color cube.

RGB cube

- Easy for devices
- But not perceptual
- Where do the grays live?
- Where is hue and saturation?

HSV



Hue, Saturation, Value (Intensity)

- RGB cube on its vertex

Decouples the three components (a bit)

Use `rgb2hsv()` and `hsv2rgb()` in Matlab

Programming Project #1

- How to compare R,G,B channels?
- No right answer
 - Sum of Squared Differences (SSD):

$$ssd(u, v) = \sum_{(x,y) \in N} [I(u+x, v+y) - P(x,y)]^2$$

- Normalized Correlation (NCC):

$$ncc(u, v) = \frac{\sum_{(x,y) \in N} [I(u+x, v+y) - \bar{I}] [P(x,y) - \bar{P}]}{\sqrt{\sum_{(x,y) \in N} [I(u+x, v+y) - \bar{I}]^2 \sum_{(x,y) \in N} [P(x,y) - \bar{P}]^2}}$$

