ECE 4973: Lecture 3
Color and representation

Samuel Cheng

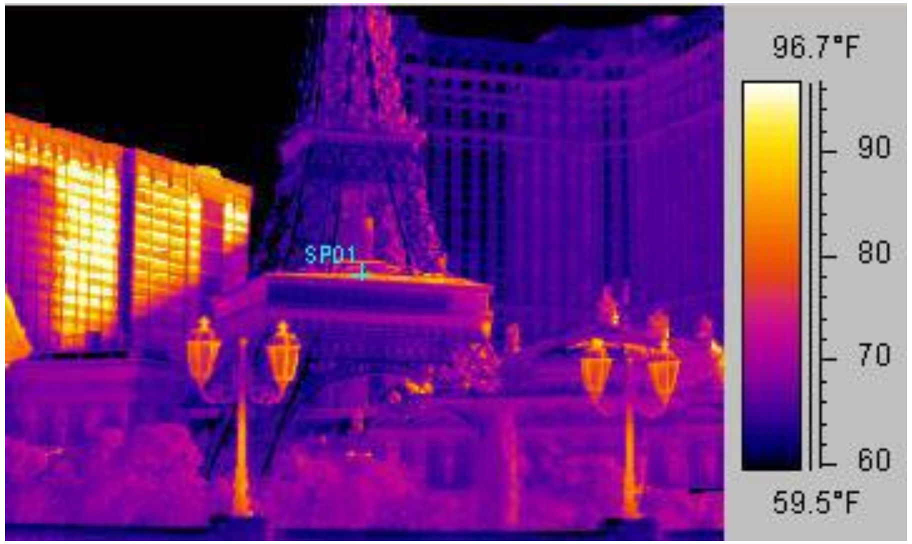
Slide credits: James Thompkin, Juan Carlos Niebles and Ranjay Krishna

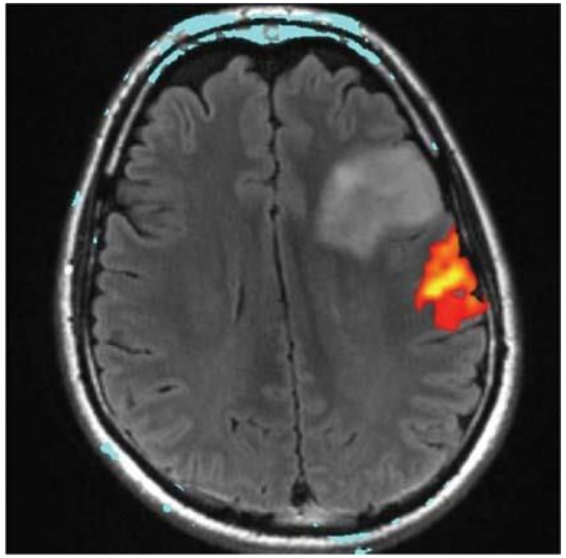

WÓDKA
Cuisinart
VISIONS of JAPAN
SNOW CRYSTALS
DOVER
MYSTERIES OF MIND SPACE & TIME
FOTOGRAFIE UND DAS UNSICHTBARE
DER KLEINE STOWASSER
MATHEMATICS
MAN AND SPACE
DRUGS
STACK-ON


Cuisinart
WÓDKA
SNOW CRYSTALS
MATHEMATICS
MAN AND SPACE
DRUGS
STACK-ON

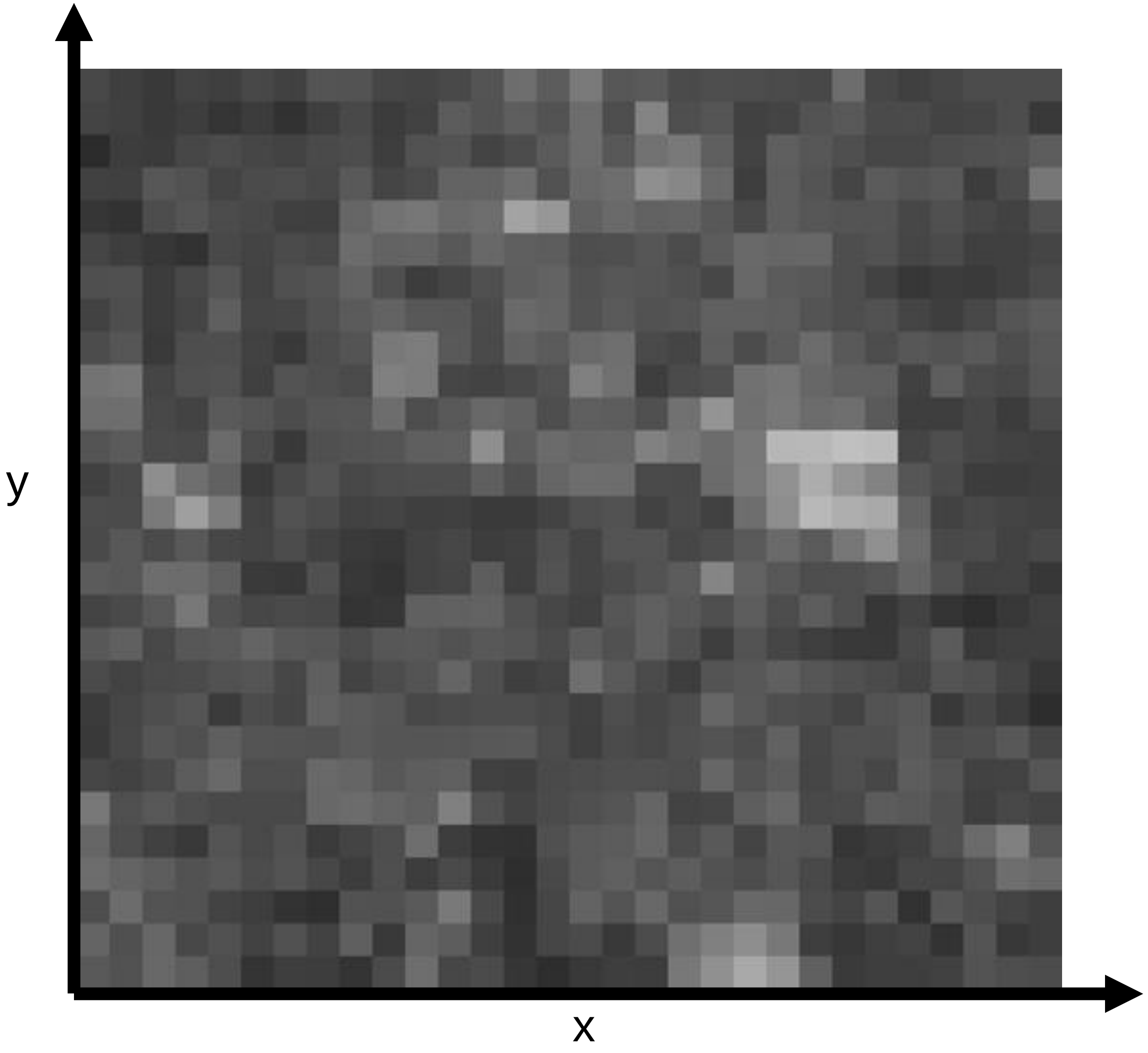
WHAT IS AN IMAGE?

Example 2D Images



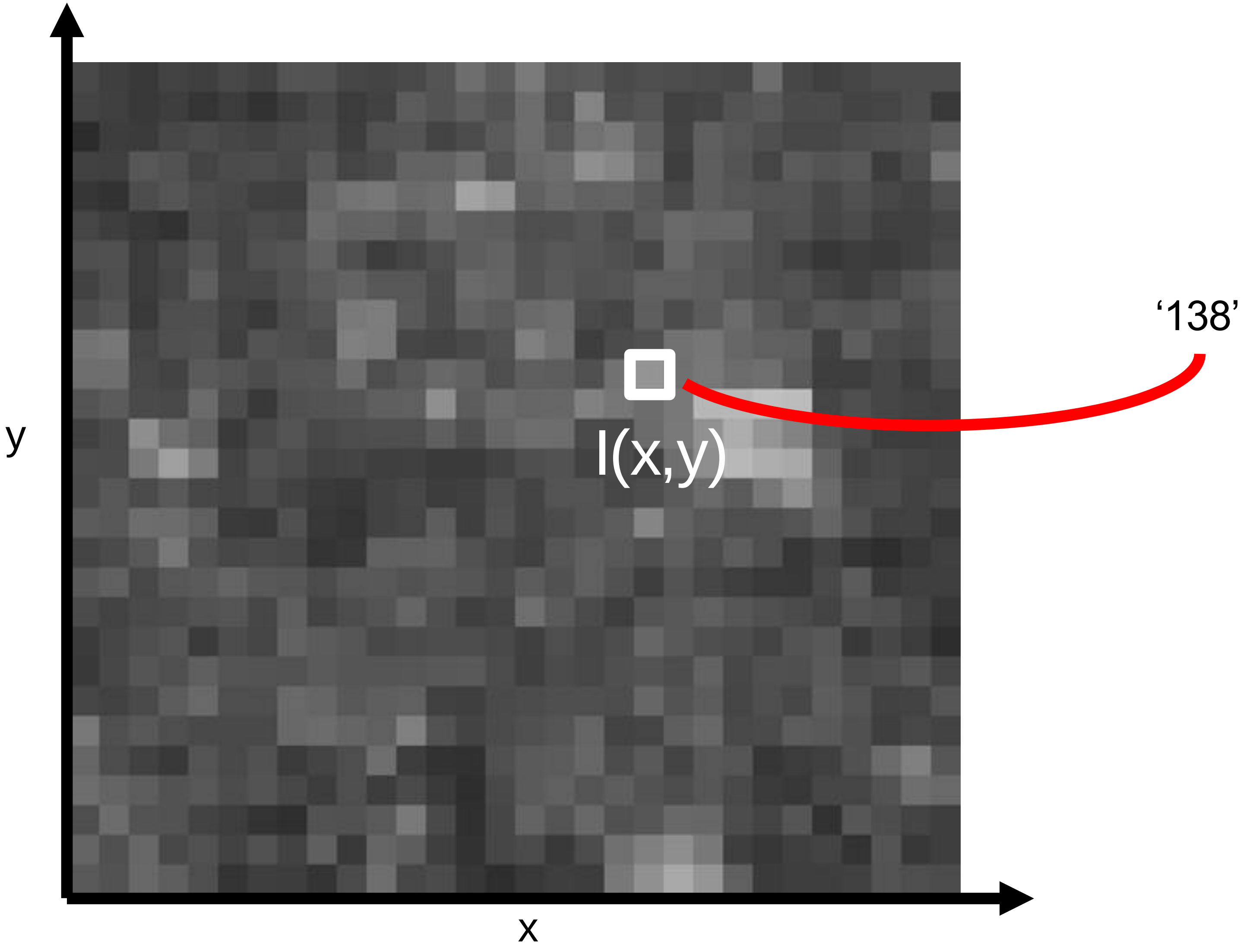


What is each part of a greyscale image?

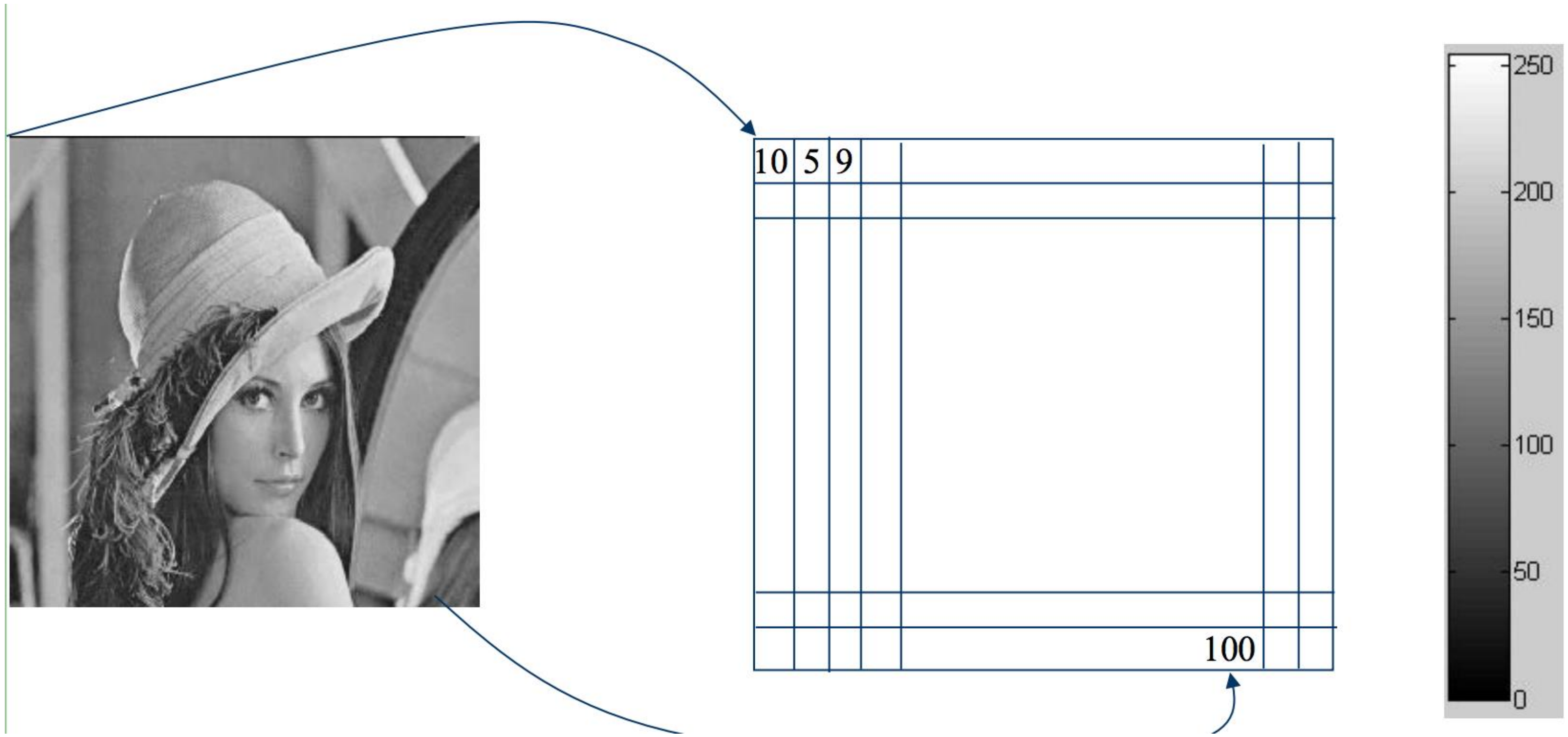


What is each part of a greyscale image?

- Pixel -> picture element

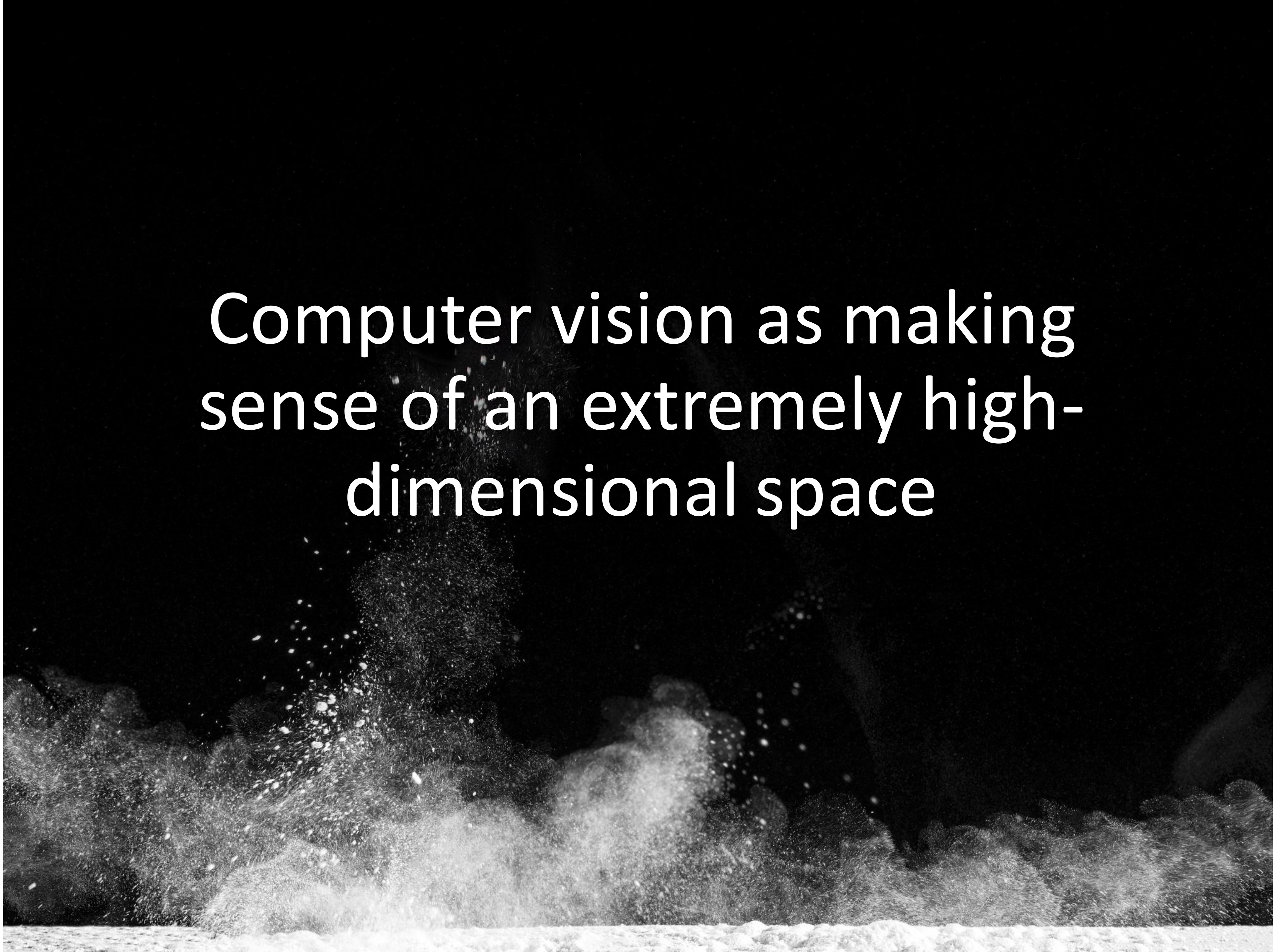


Another example: Lena

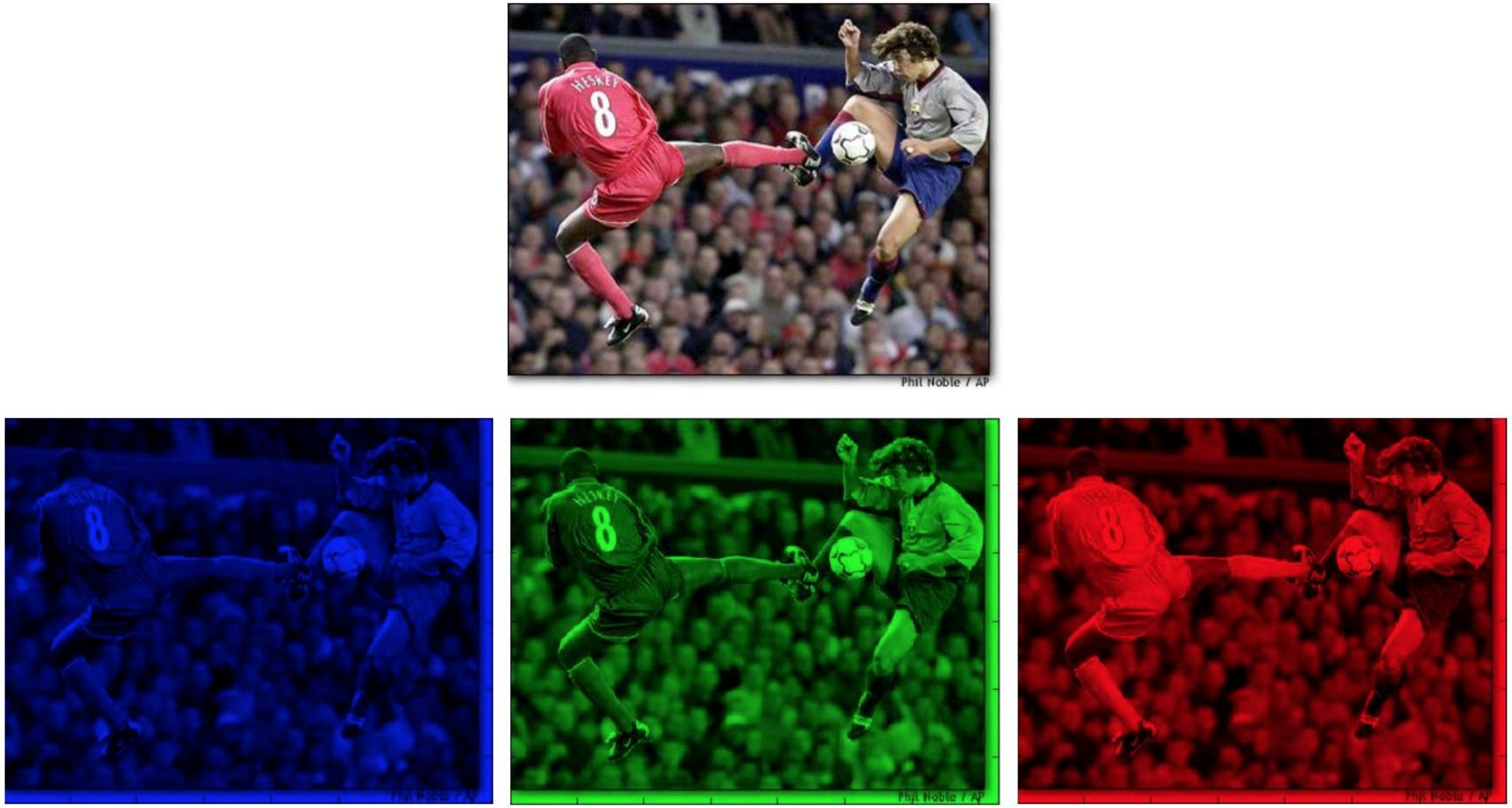


Slide credit: Ulas Bagci

Computer vision as making sense of an extremely high-dimensional space



Color image representation



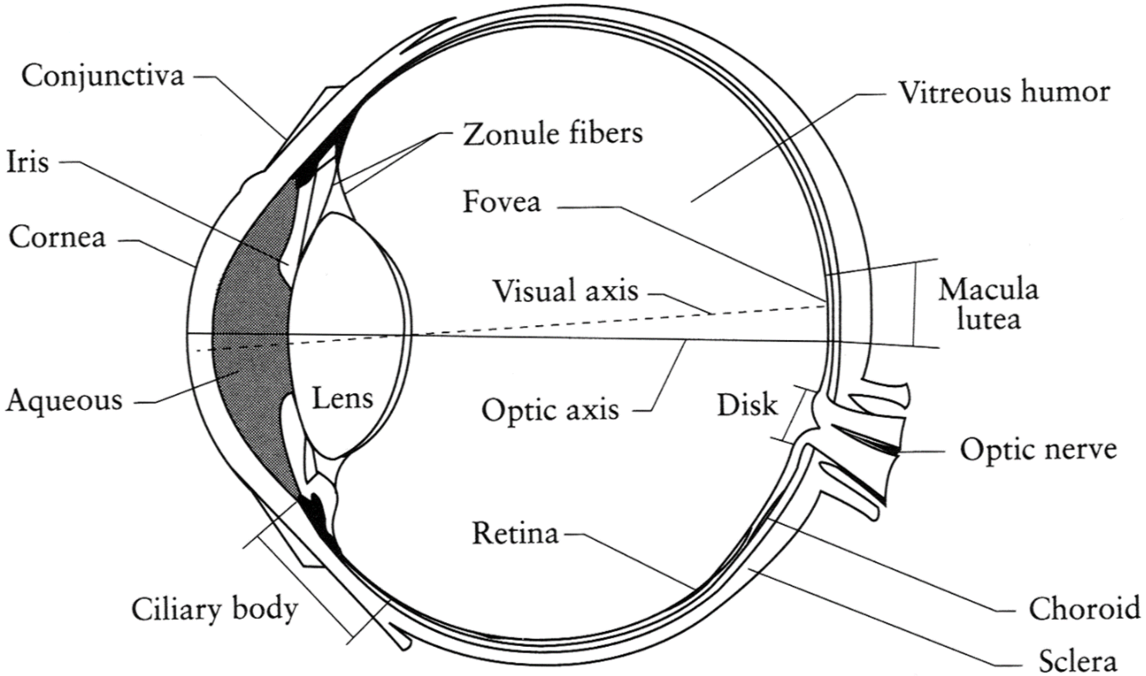
Why red, green, and blue?

Slide credit: Ulas Bagci

Color in human vision

ANATOMY

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 sensor?
    - photoreceptor cells (rods and cones) in the **retina**

Slide by Steve Seitz

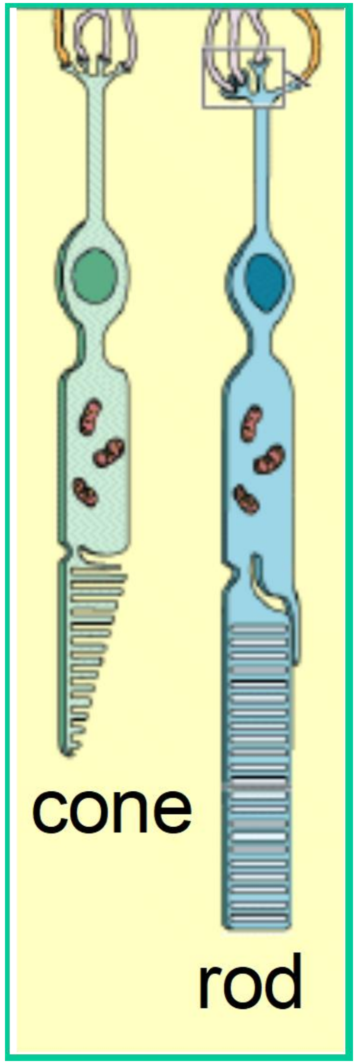
Two types of light-sensitive receptors

Cones

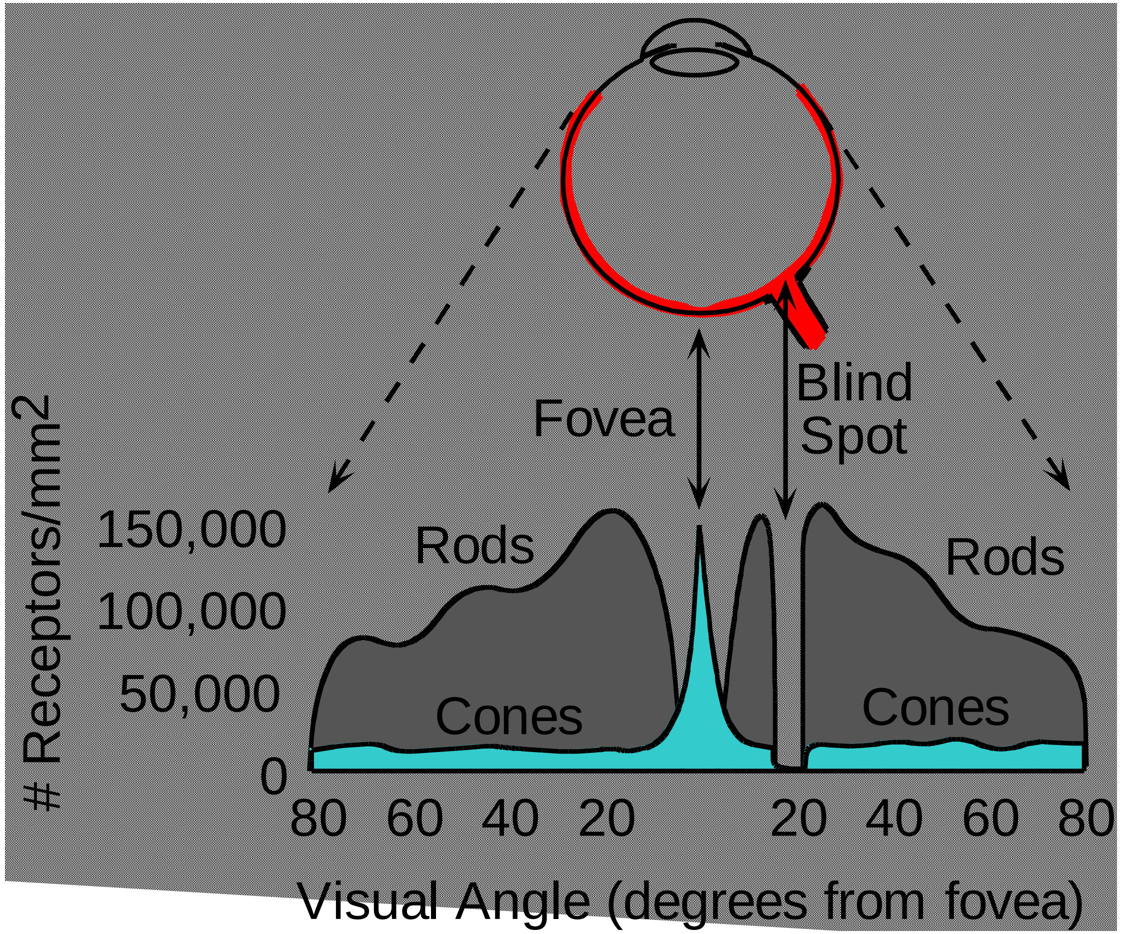
cone-shaped
less sensitive
operate in high light
color vision

Rods

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



Distribution of Rods and Cones

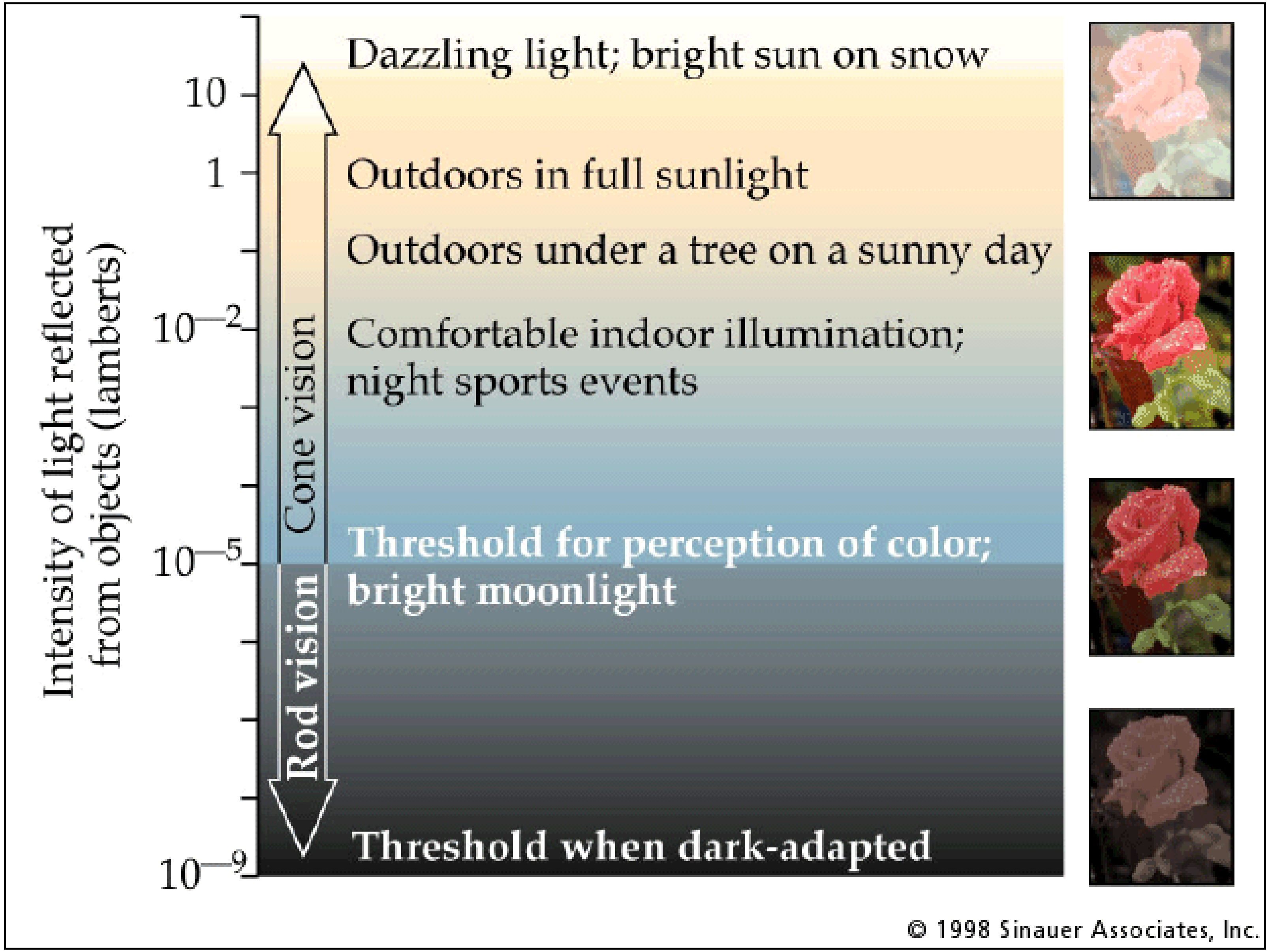


Night Sky: why are there more stars off-center?

Averted vision: http://en.wikipedia.org/wiki/Averted_vision

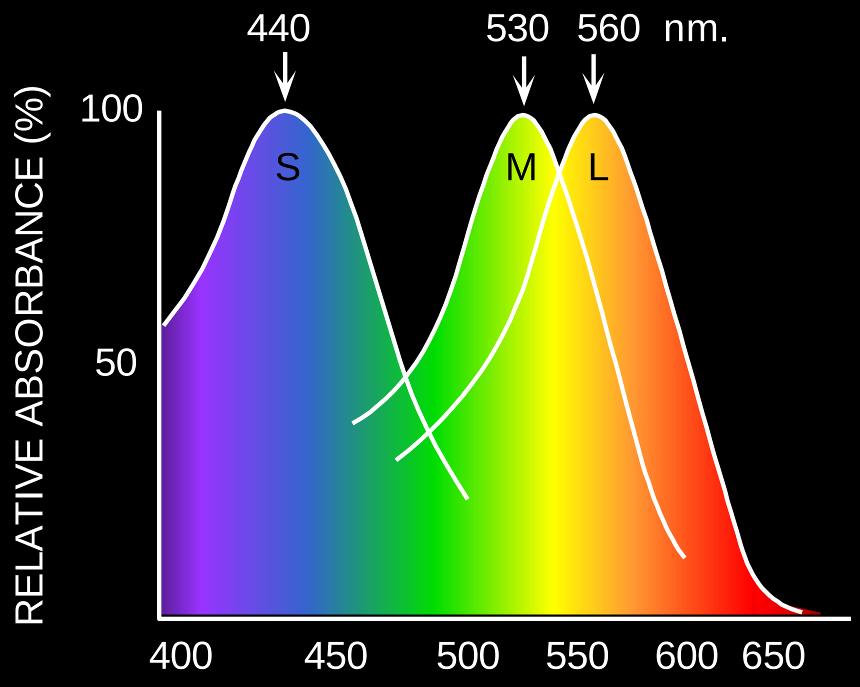
James Hays

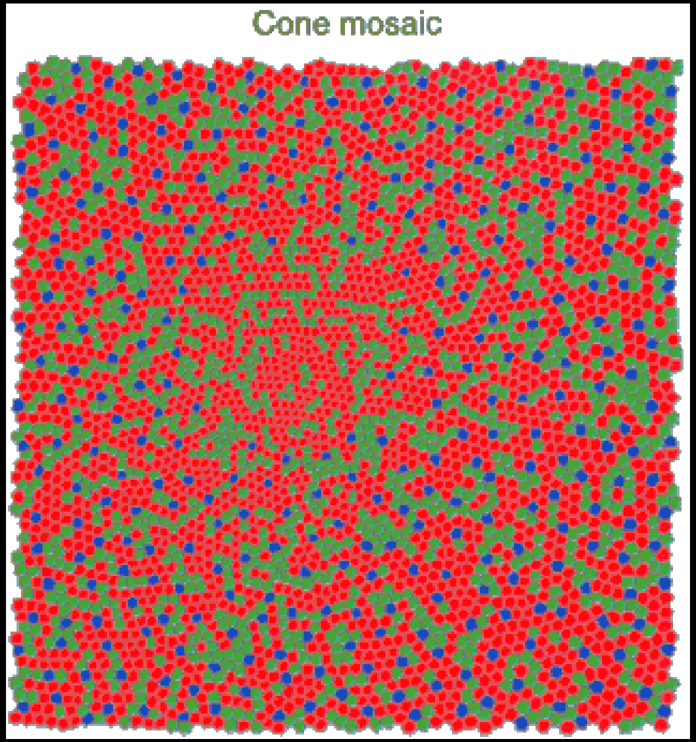
Rod / Cone sensitivity

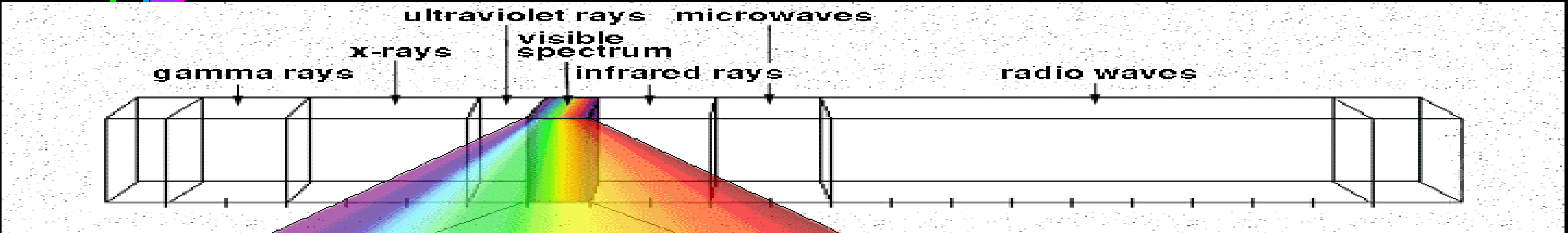


Physiology of Color Vision

Three kinds of cones:

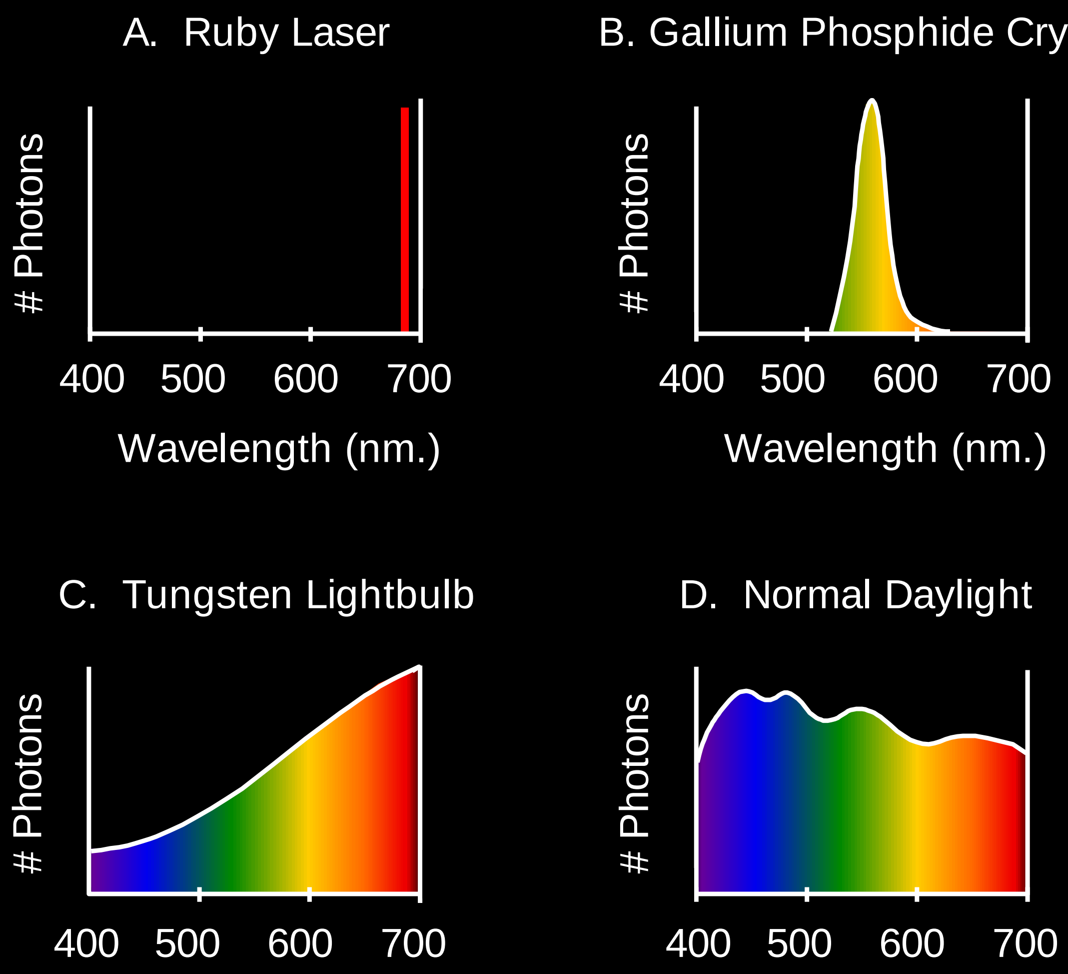




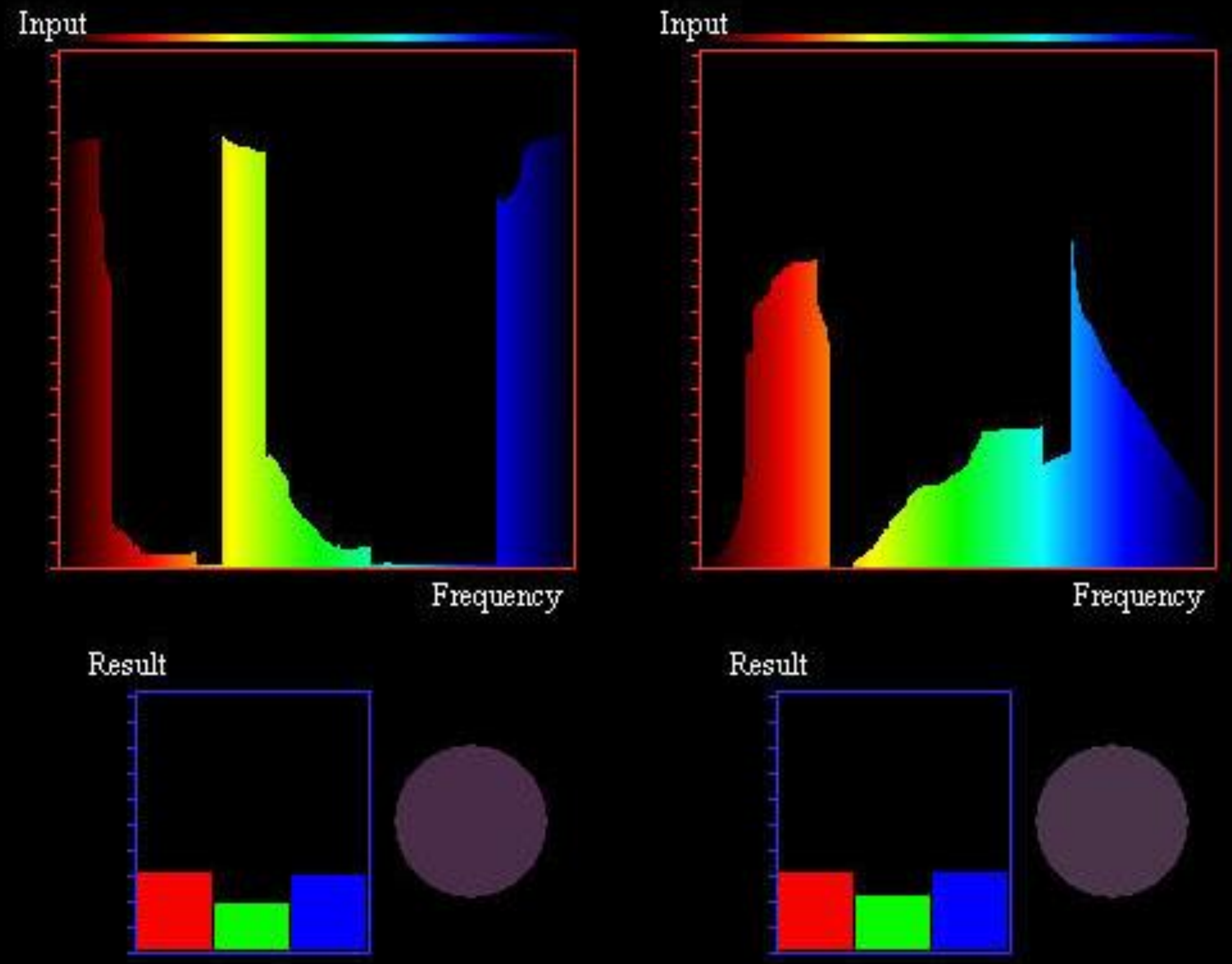


The Physics of Light

Some examples of the spectra of light sources

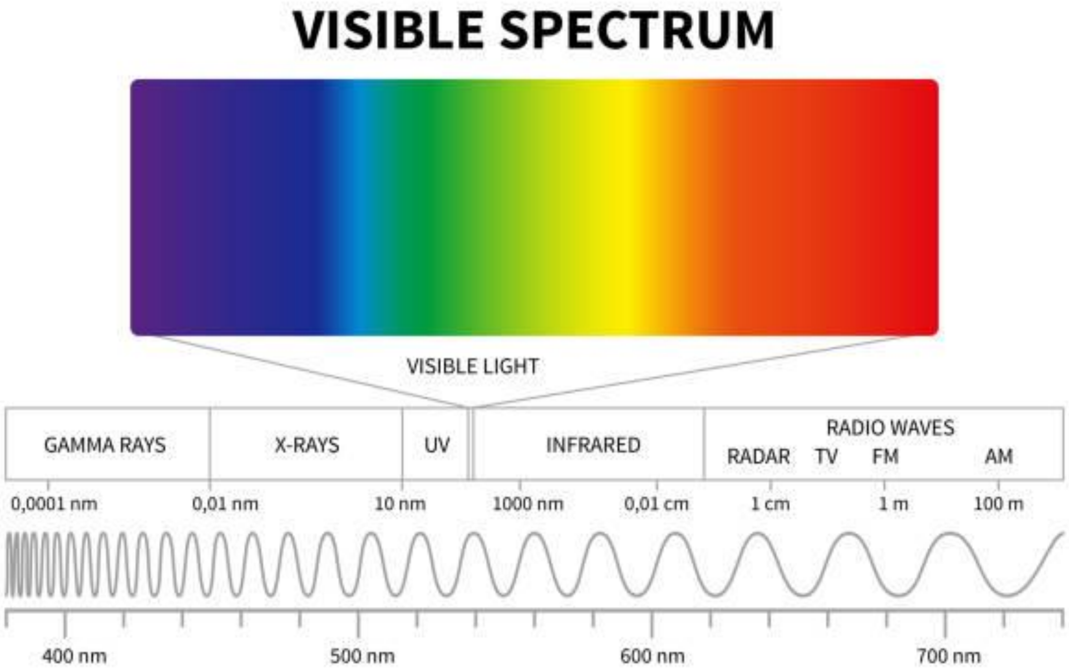


Metamers



by Jeff Beall, Adam Doppelt and John F. Hughes

What color will you see?



- What is red + green?
  - Yellow
- What is blue + green?
  - Cyan
- How about blue + red?

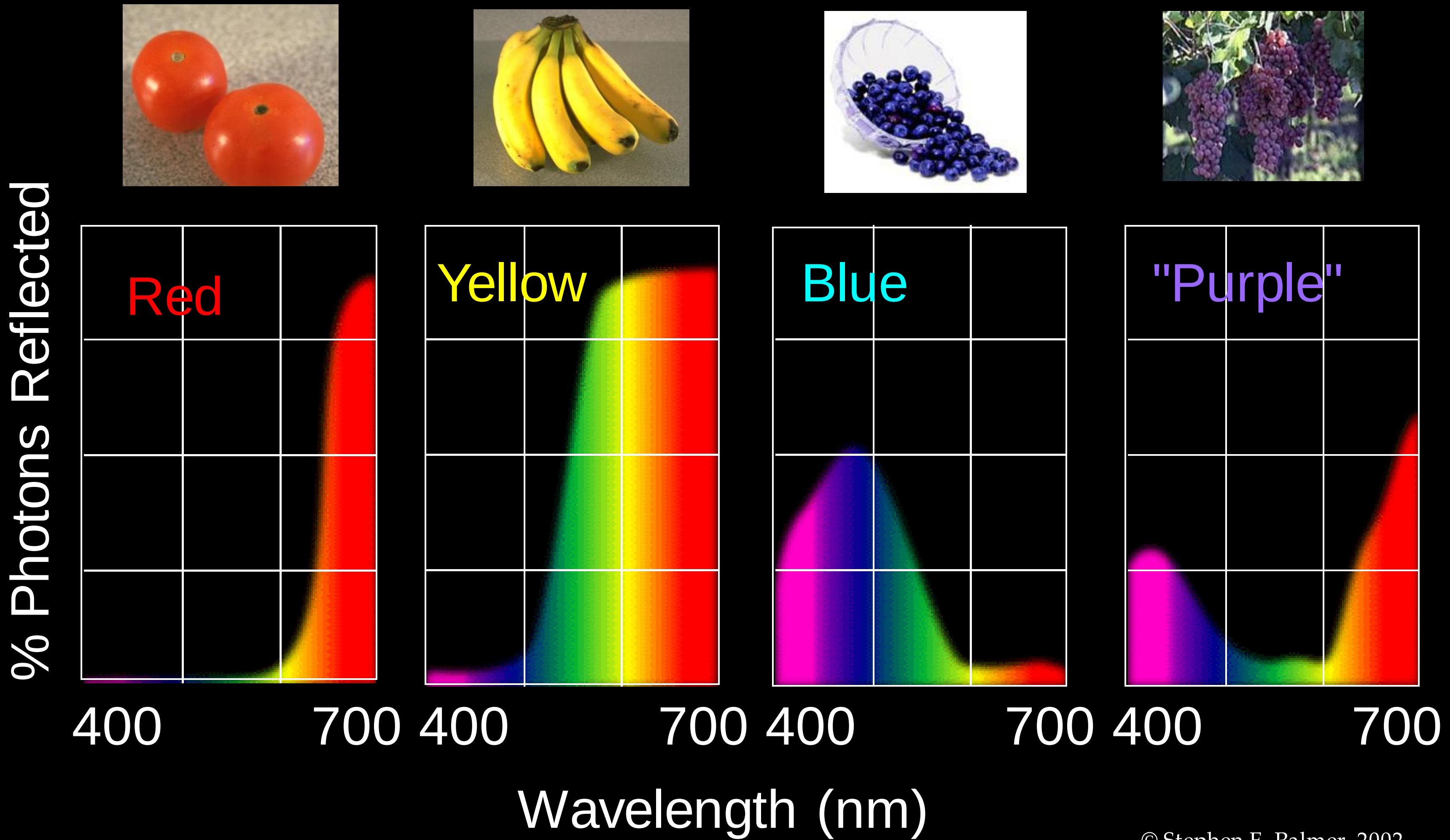
Magenta is a ``fake" color

- You won't see Magenta in a rainbow

- Color Mixing: The Mystery of Magenta

The Physics of Light

Some examples of the reflectance spectra of surfaces



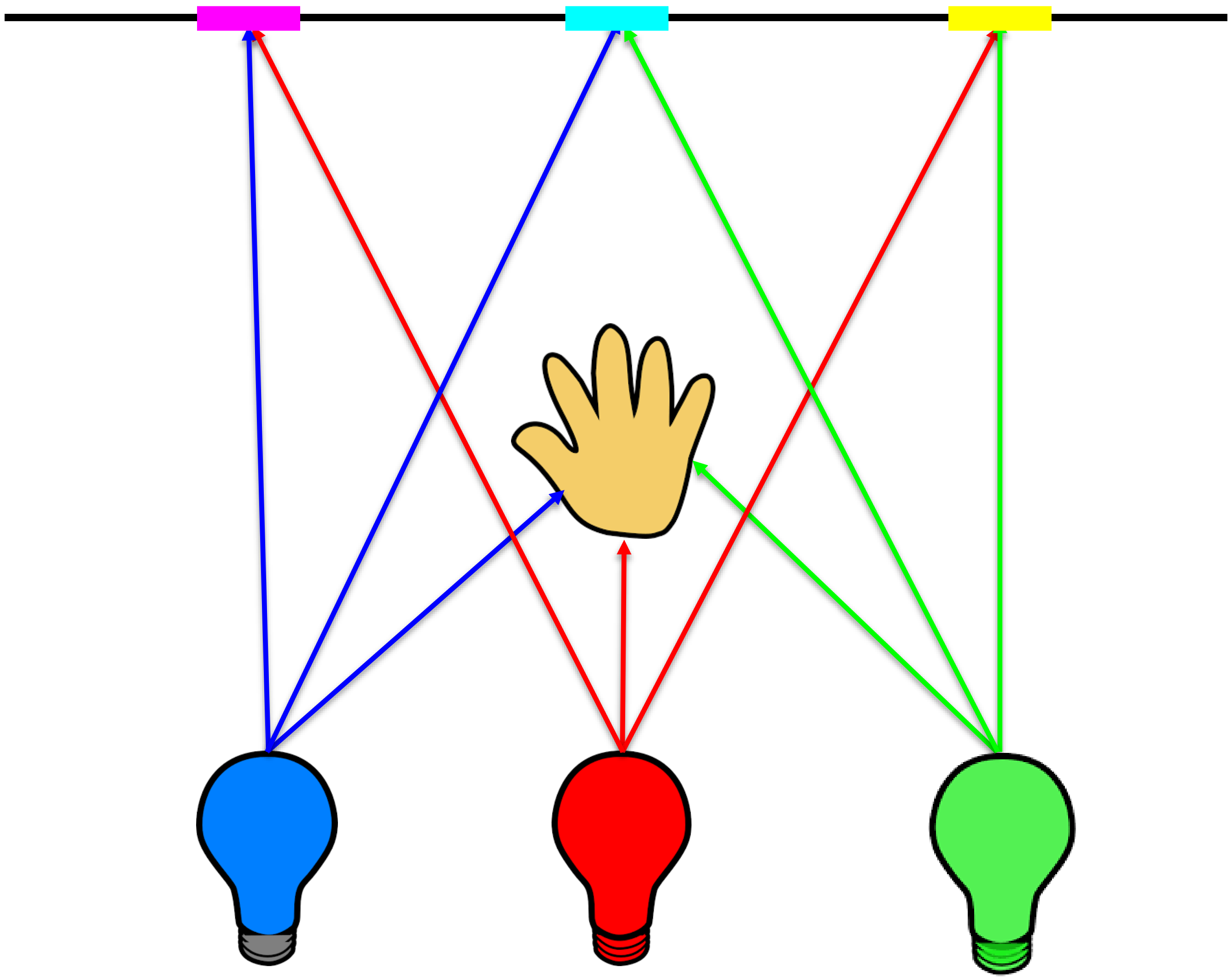
Colorful shadow

- Have you seen such thing before?
- Can you reconstruct something similar?
- Hint: 3 color light sources. Can you guess how the light sources oriented?

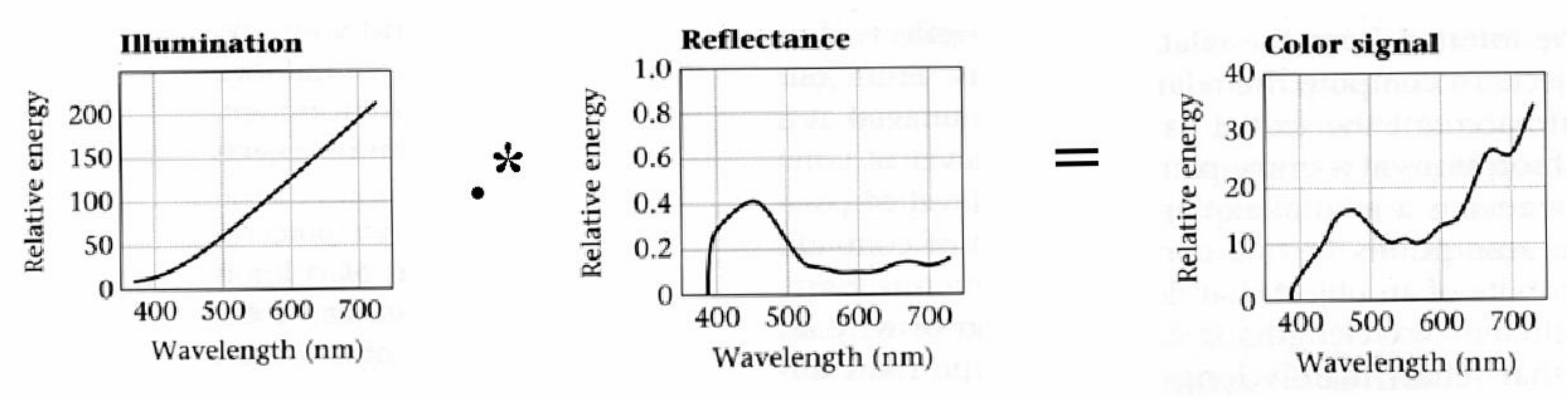
Colorful shadows

Can you guess the order of the light (from left to right)?

Colorful shadows

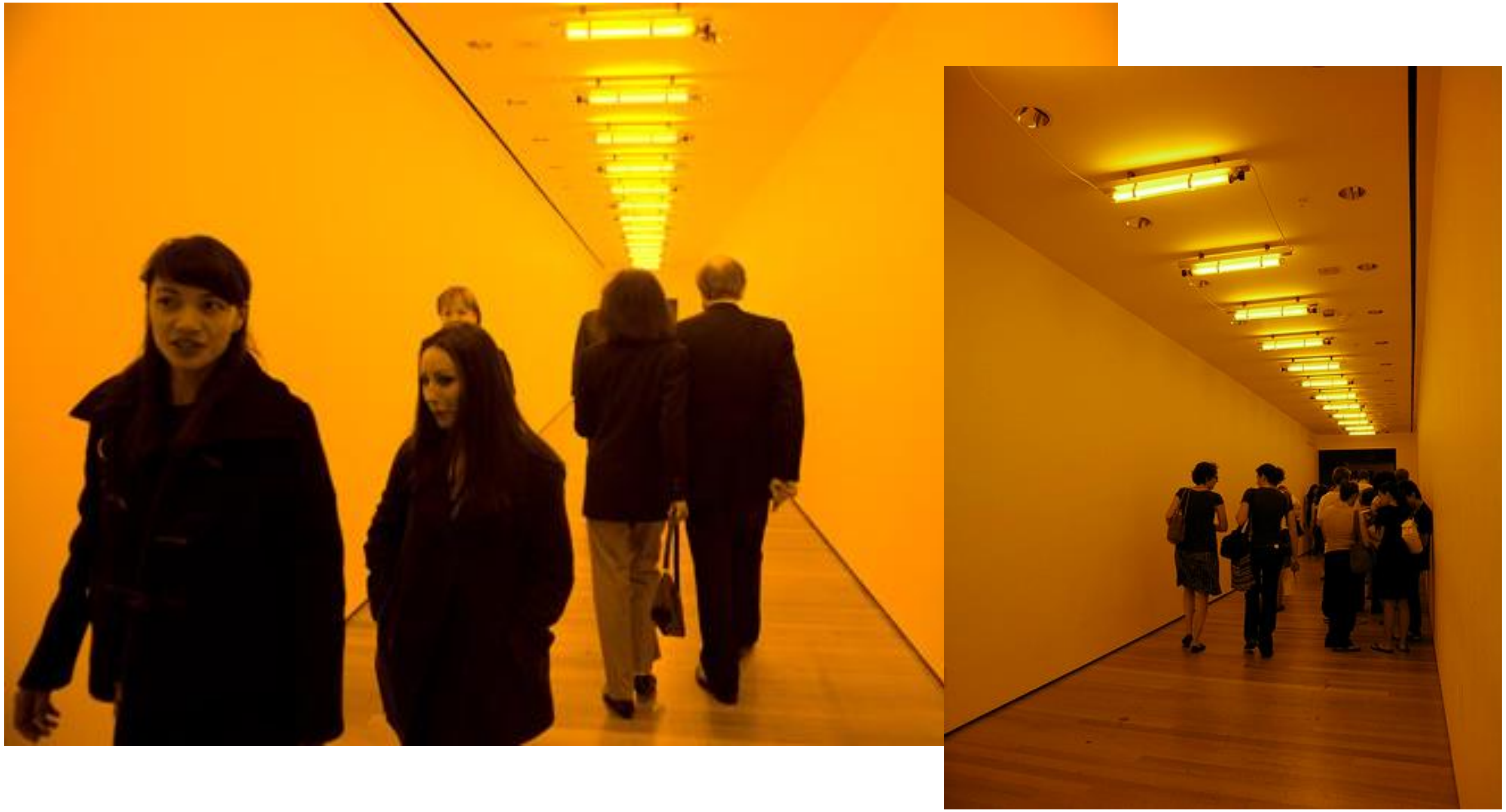


Interaction of light and surfaces



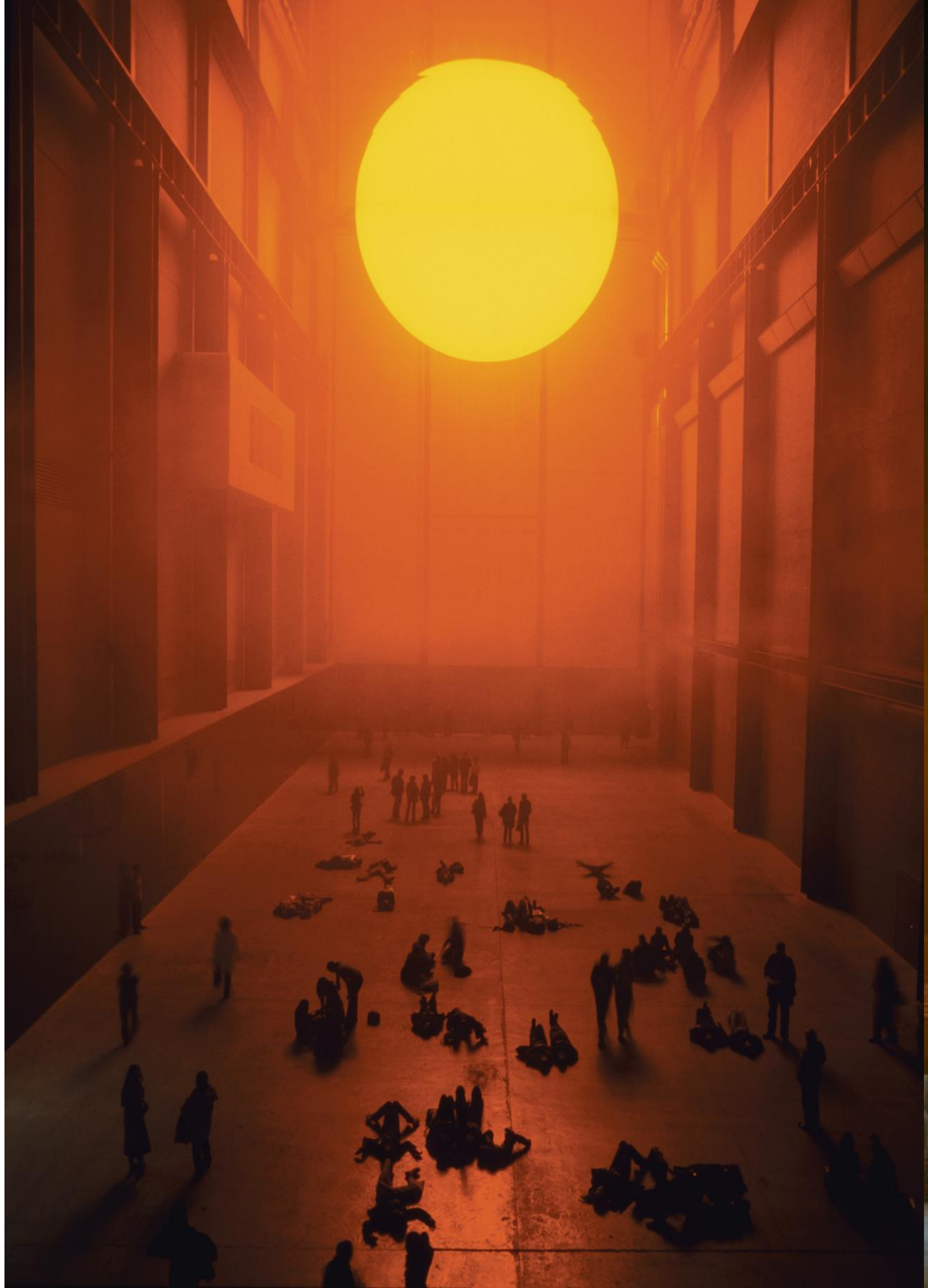
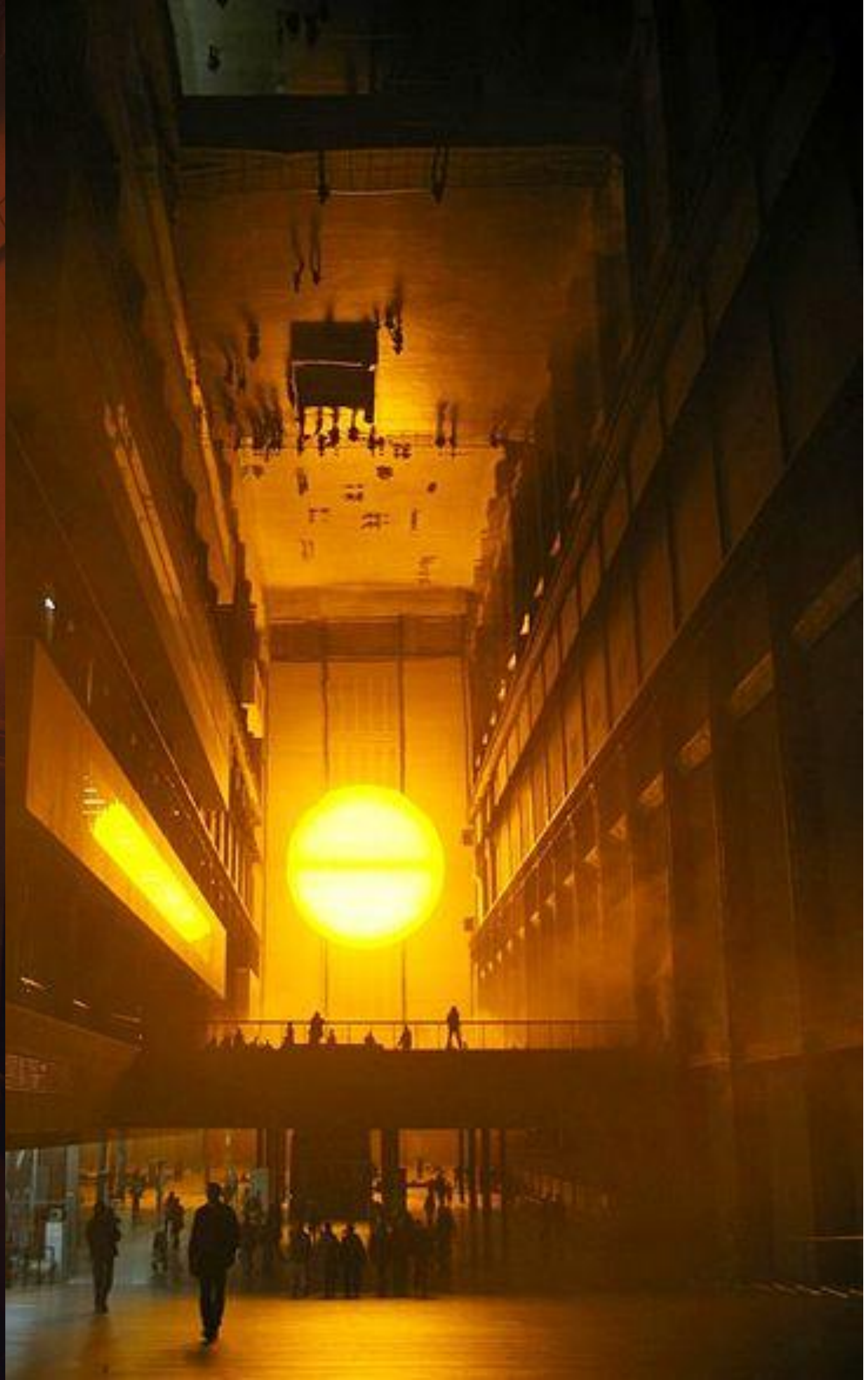
From Foundation of Vision by Brian Wandell, Sinauer Associates, 1995

Under monochromatic light



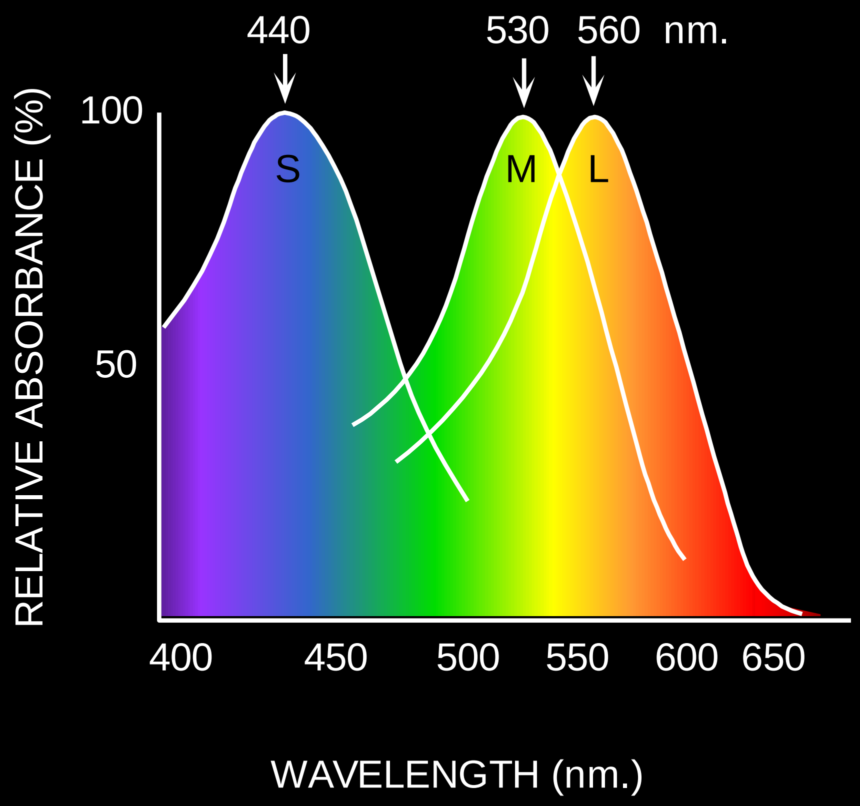
[Olafur Eliasson, *Room for one color*]

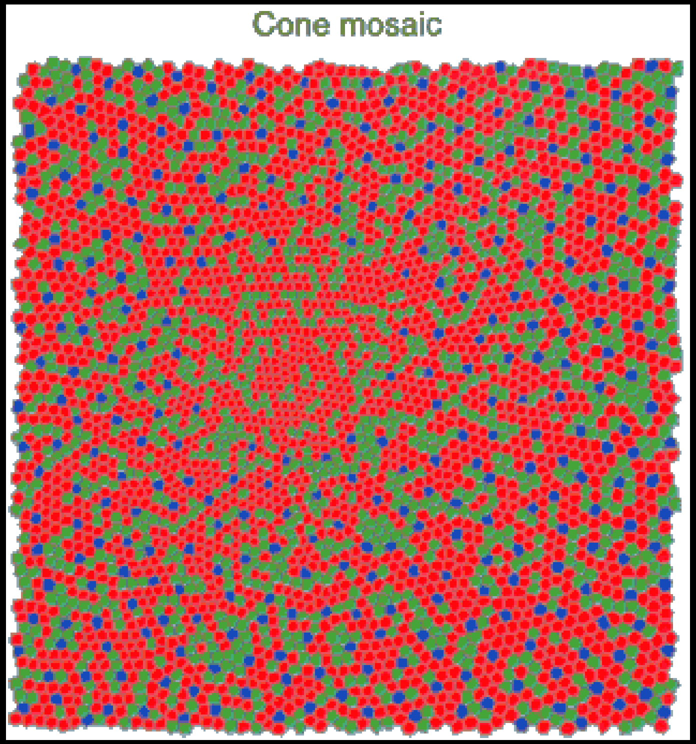
Slide by S. Lazebnik

Physiology of Color Vision

Three kinds of cones:





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

S are more different from the M and L

- S cones (peak at 420 nm, bluish-violet)
- M cones (peak at 534 nm, bluish-green)
- L cones (peak at 564 nm, yellowish-green)

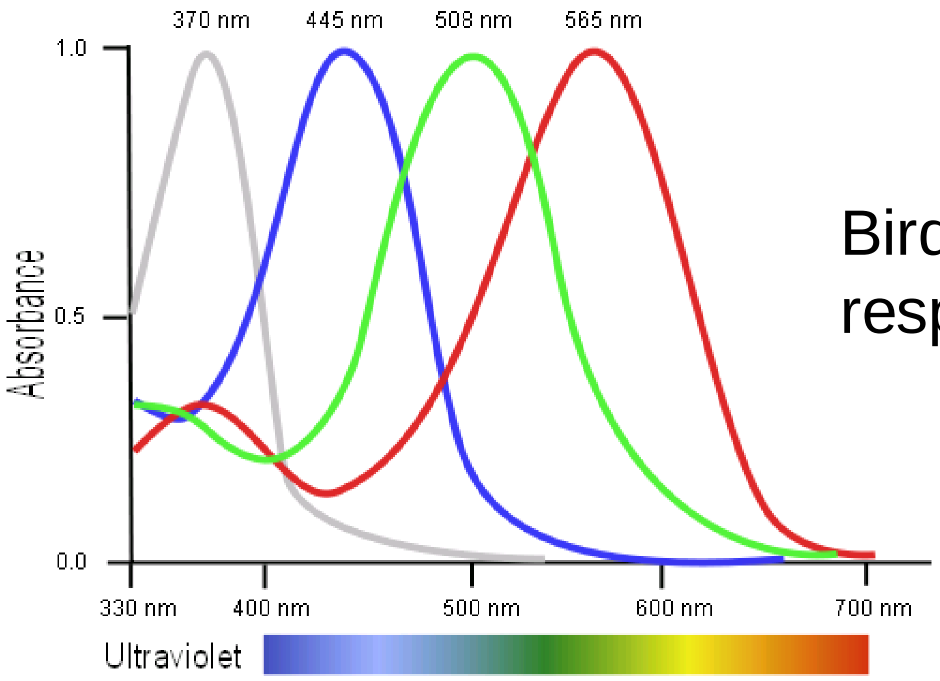
- S cones and rods are totally absent in the foveal area
- Note that both M and L are sensitive to green

S are more different from the M and L

The genes of the photoreceptors lie on different chromosomes

- rod lies on chromosome 8,
- S cone lies on chromosome 7
- Both L and M cones lie on the X chromosome

Tetrachromatism



Bird cone responses

- Most birds, and many other animals, have cones for ultraviolet light.
- Some humans seem to have four cones (12% of females).
- True tetrachromatism is *rare*; requires learning.

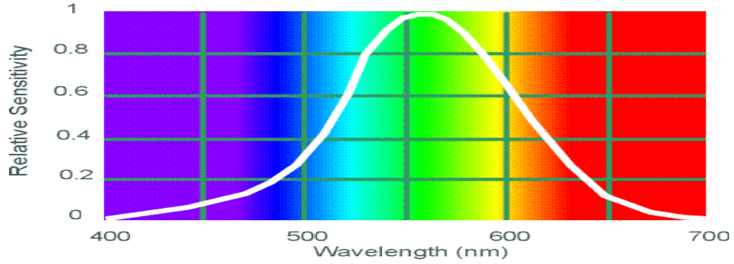
James Hays

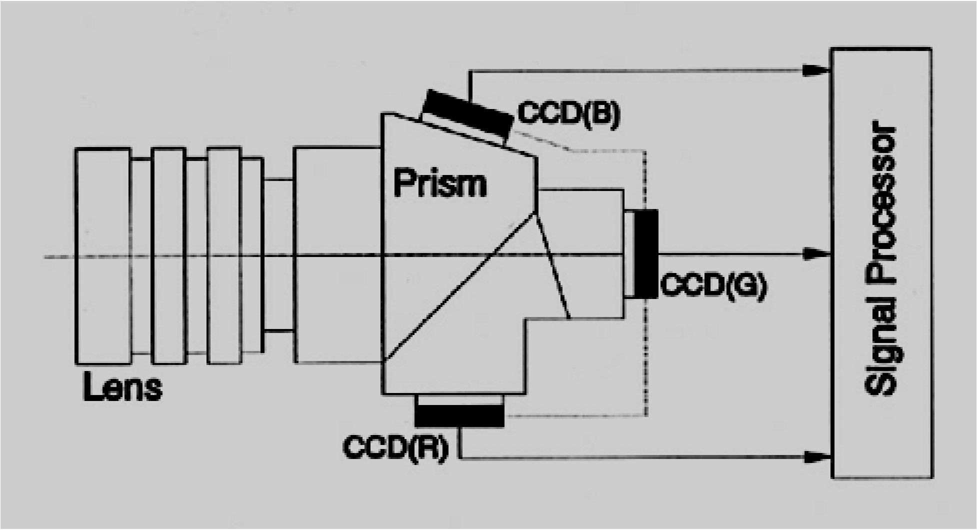
Bee vision

COLOR SENSING IN CAMERA

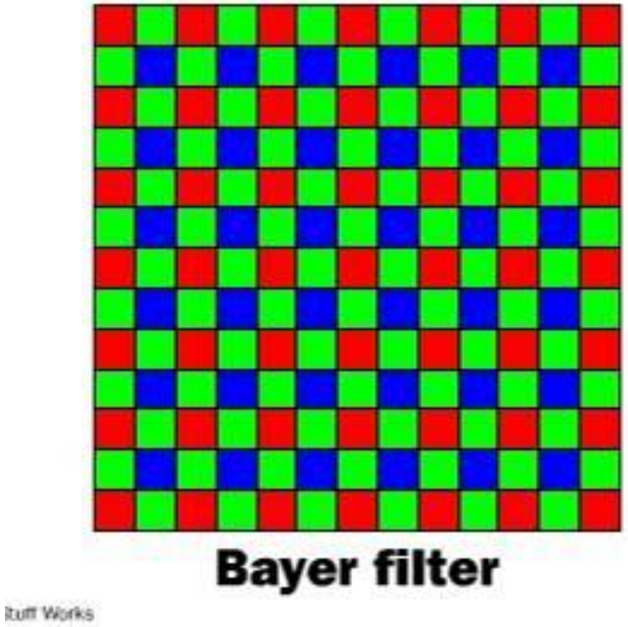
Color Sensing in Camera (RGB)

- 3-chip vs. 1-chip: quality vs. cost
- Why more green?





Why 3 colors?



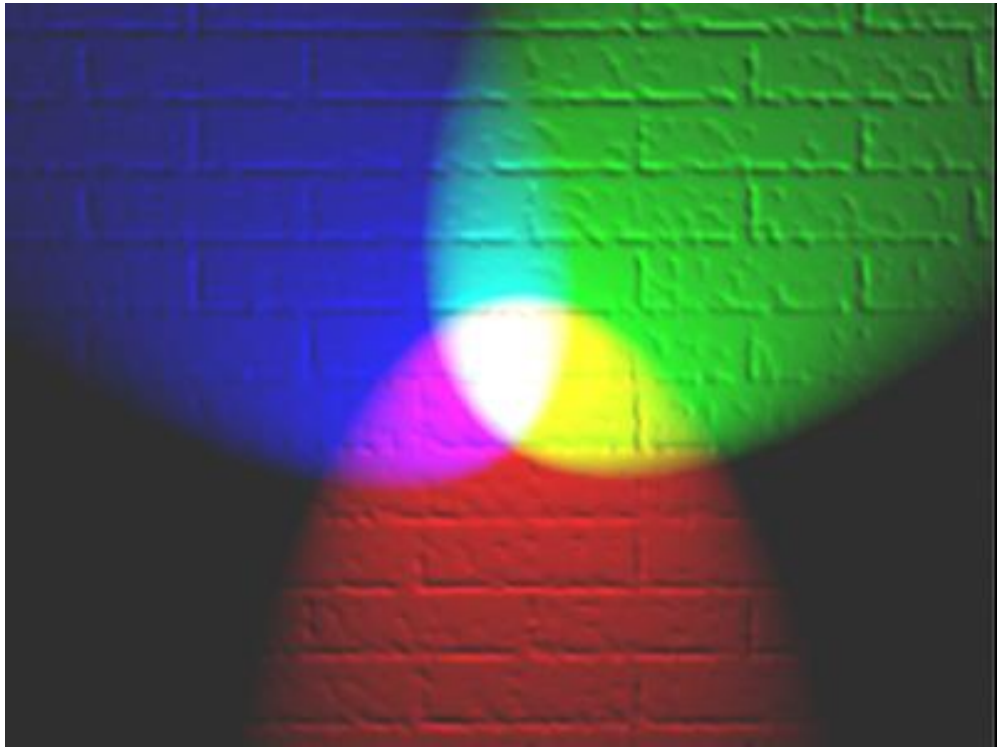
http://www.cooldictionary.com/words/Bayer-filter.wikipedia

Slide by Steve Seitz

COLOR SPACES

Color spaces

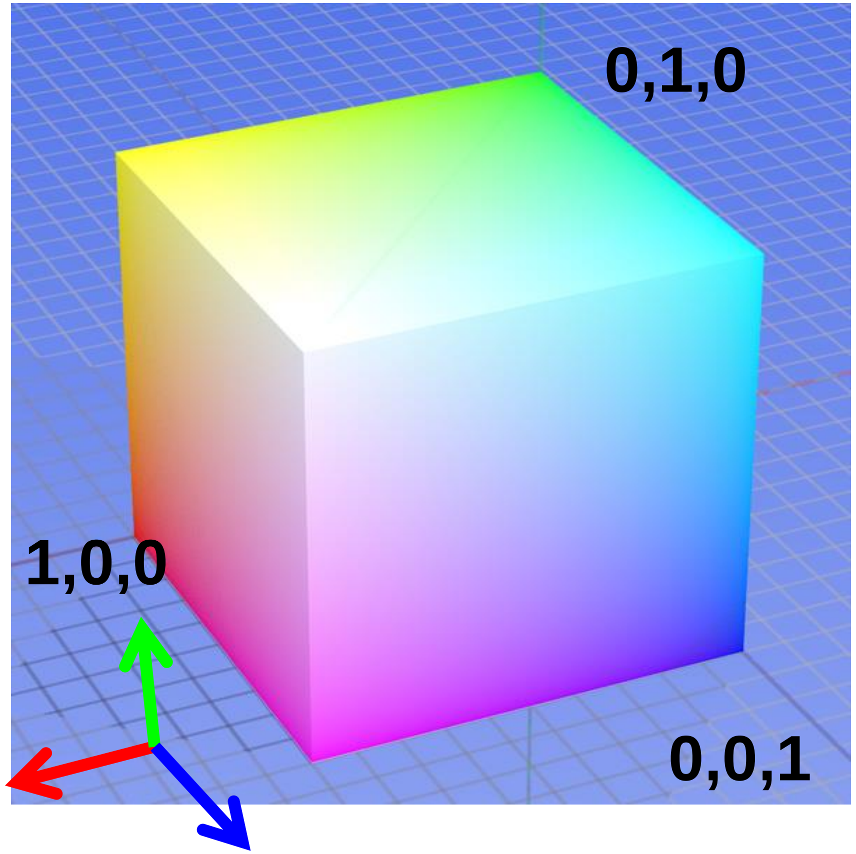
- How can we represent color?



http://en.wikipedia.org/wiki/File:RGB_illumination.jpg

Color spaces: RGB

Default color space



Any color = r*R + g*G + b*B
- Strongly correlated channels
- Non-perceptually uniform

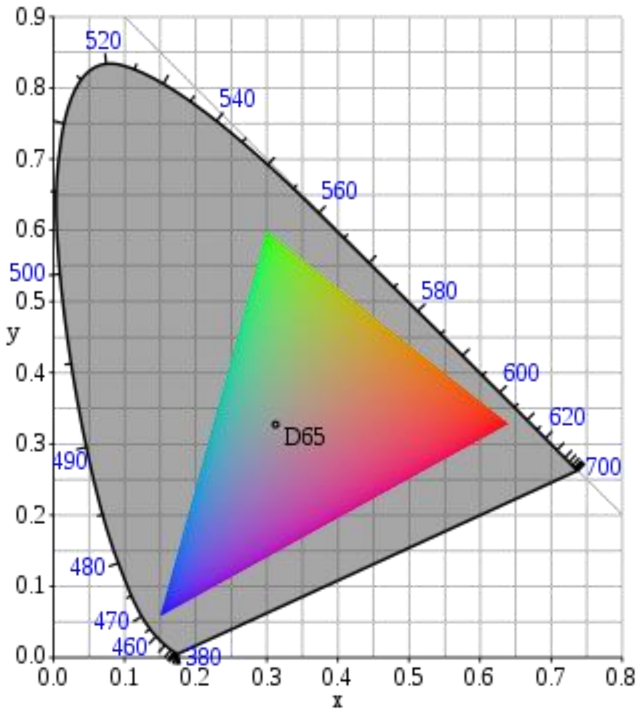
R = 1
(G=0,B=0)

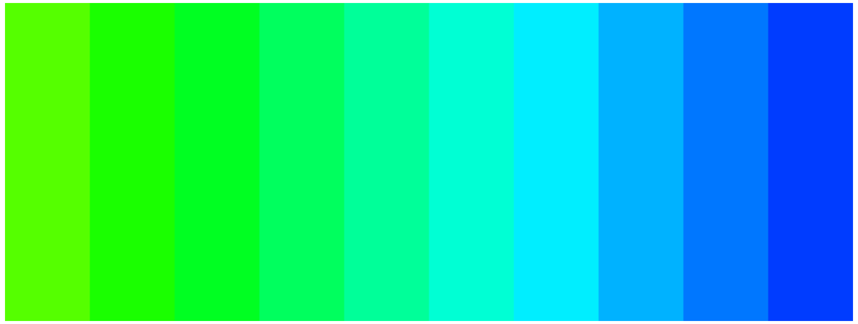
G = 1
(R=0,B=0)

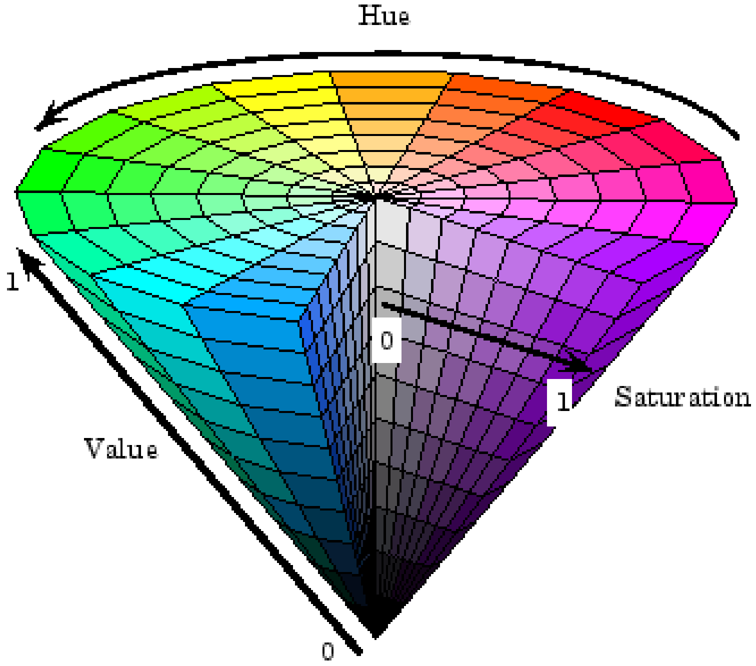
B = 1
(R=0,G=0)

Image from: http://en.wikipedia.org/wiki/File:RGB_color_solid_cube.png

RGB is not perceptually uniform







Color spaces: HSV

- More intuitive color space
- More perceptually uniform

If you had to choose, would you rather go without luminance or chrominance?

Most information in intensity

Only color shown – constant intensity

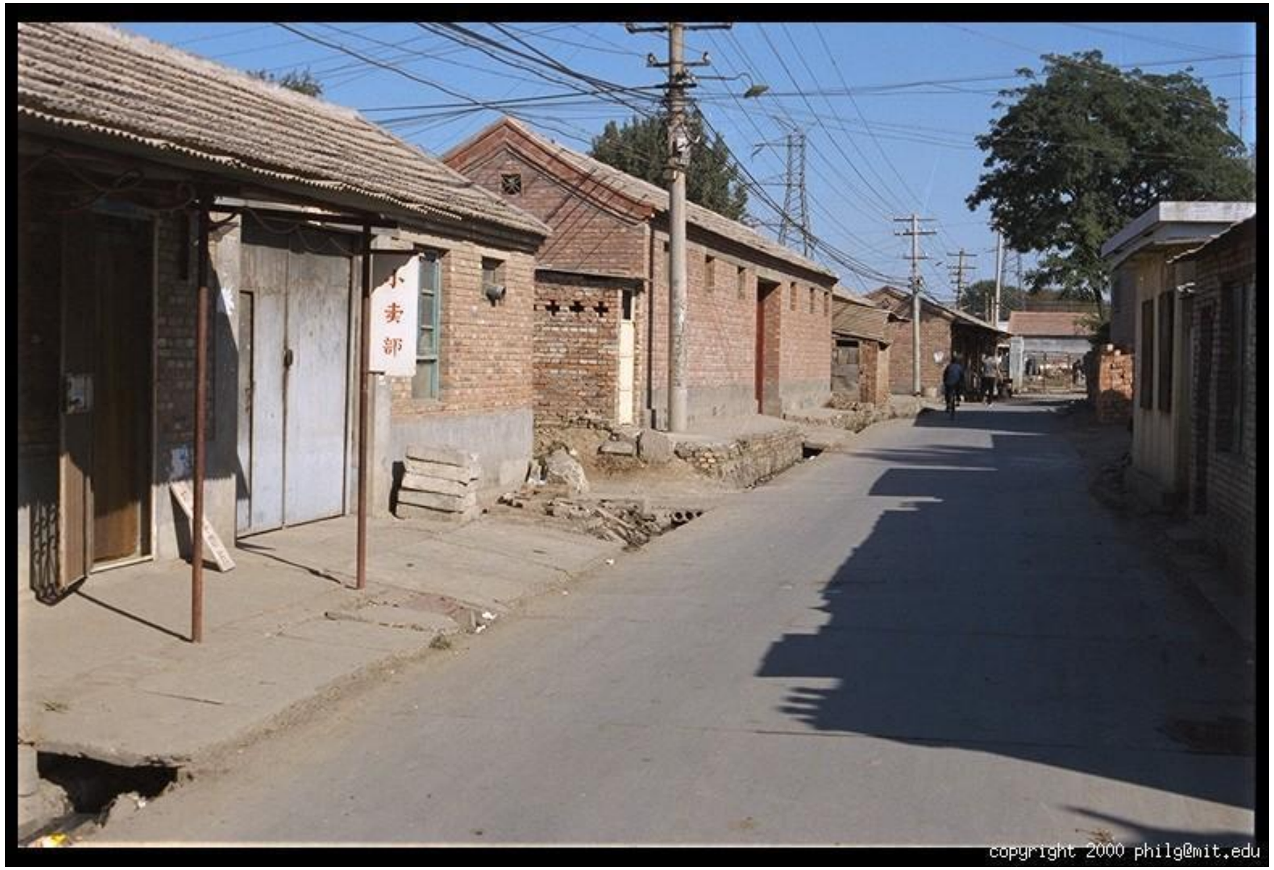
James Hays

Most information in intensity

Only intensity shown – constant color

James Hays

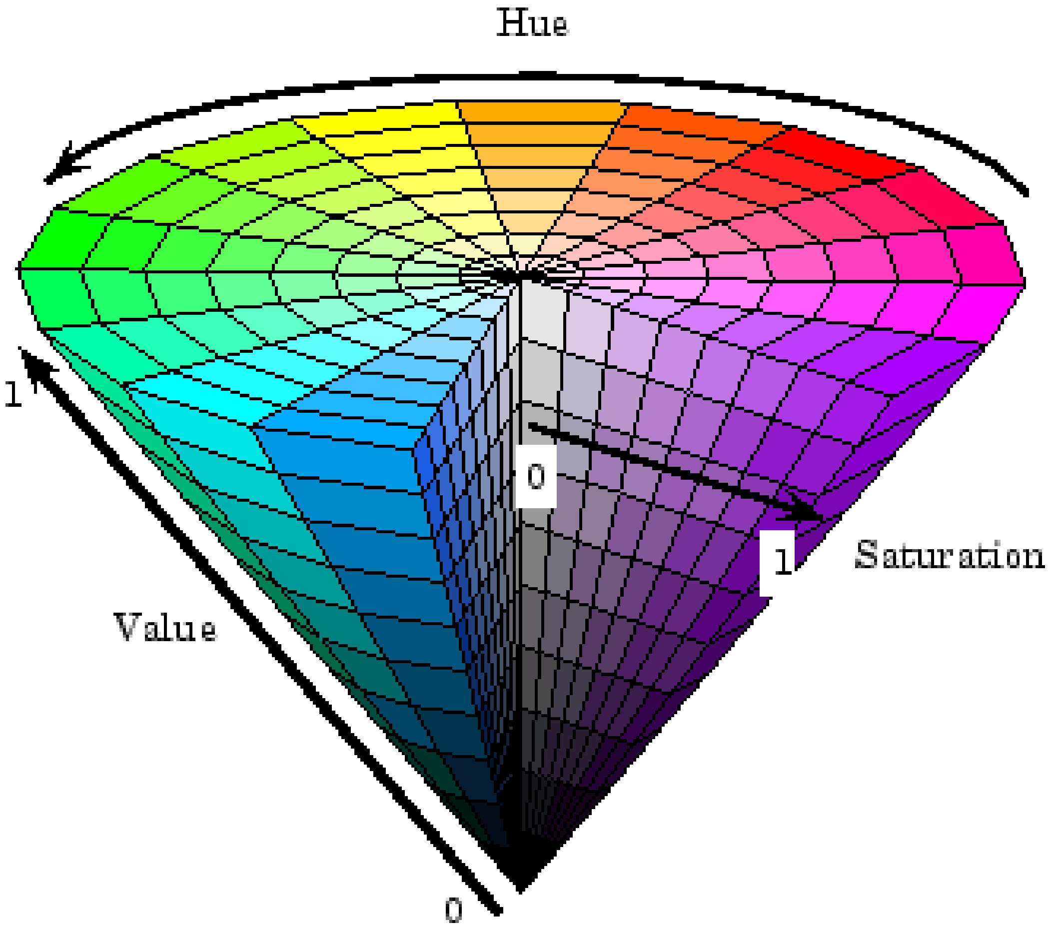
Most information in intensity

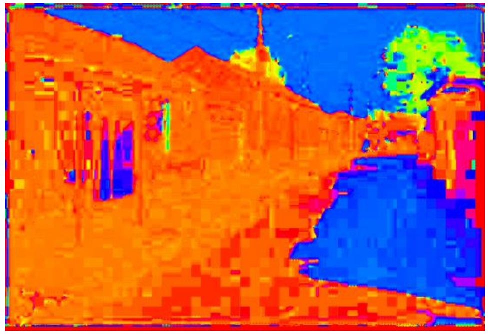


Original image

HSV

Intuitive color space





H
(S=1,V=1)

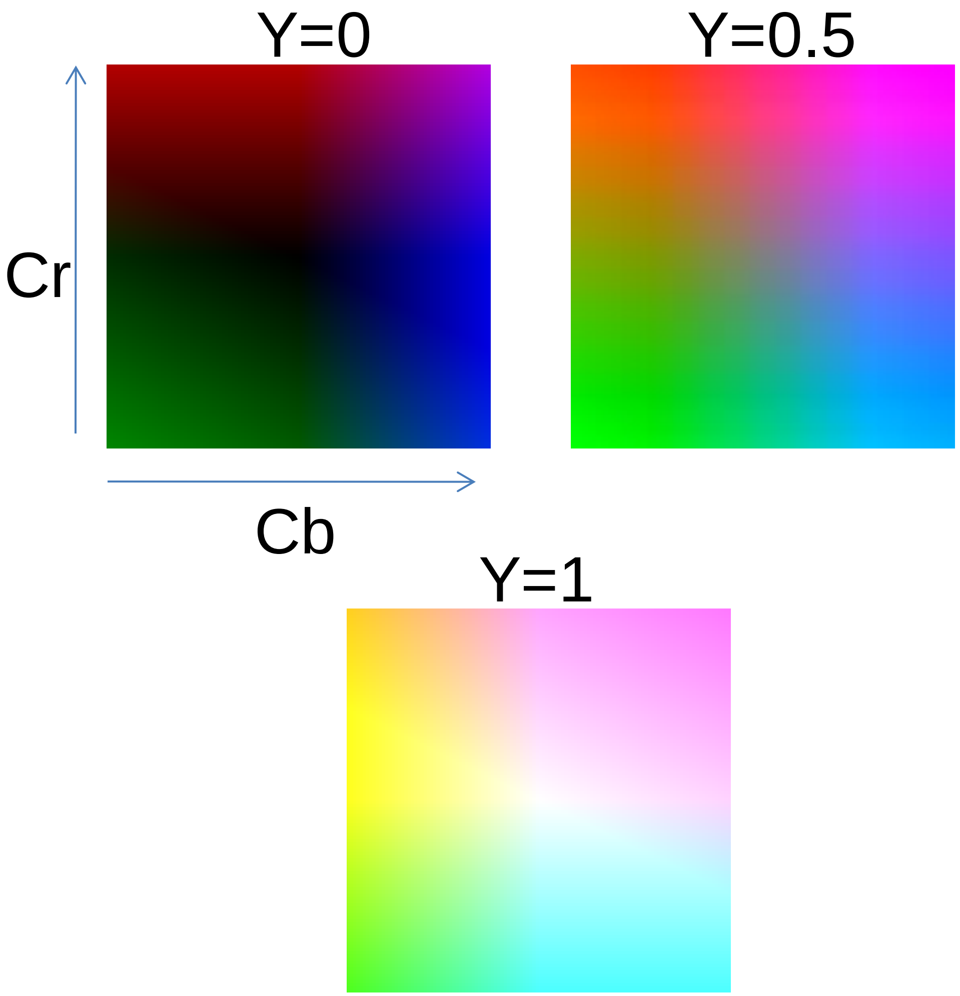
S
(H=1,V=1)

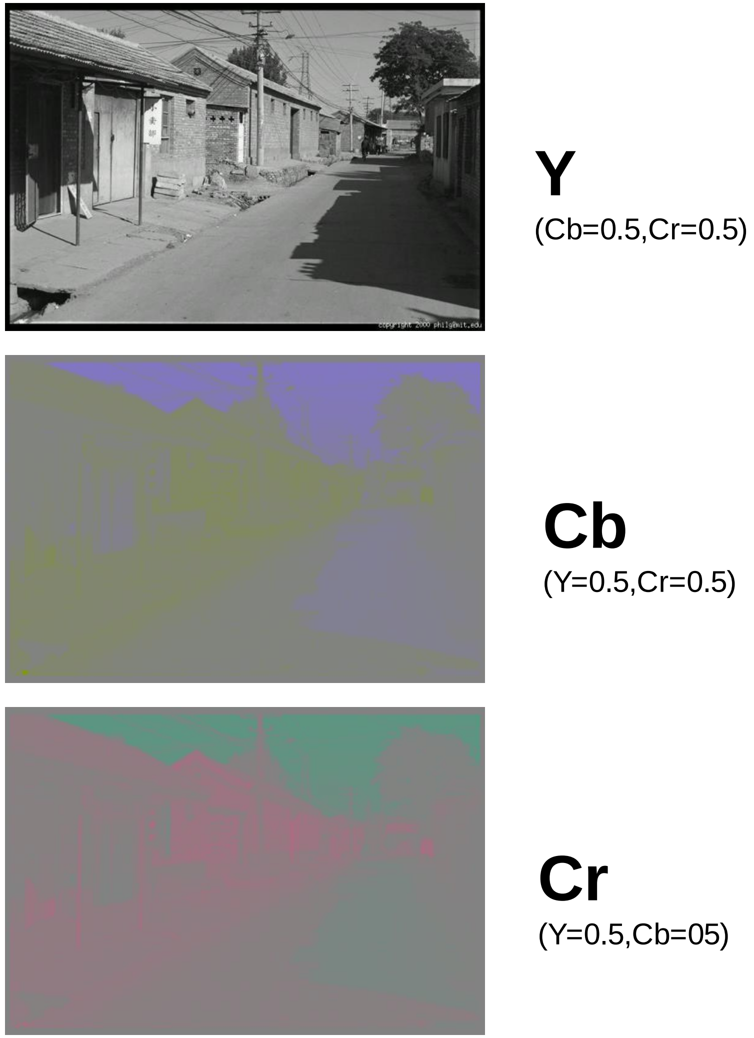
V
(H=1,S=0)

James Hays

YCbCr (YUV for analog)

Fast to compute, good for compression, used by TV





James Hays

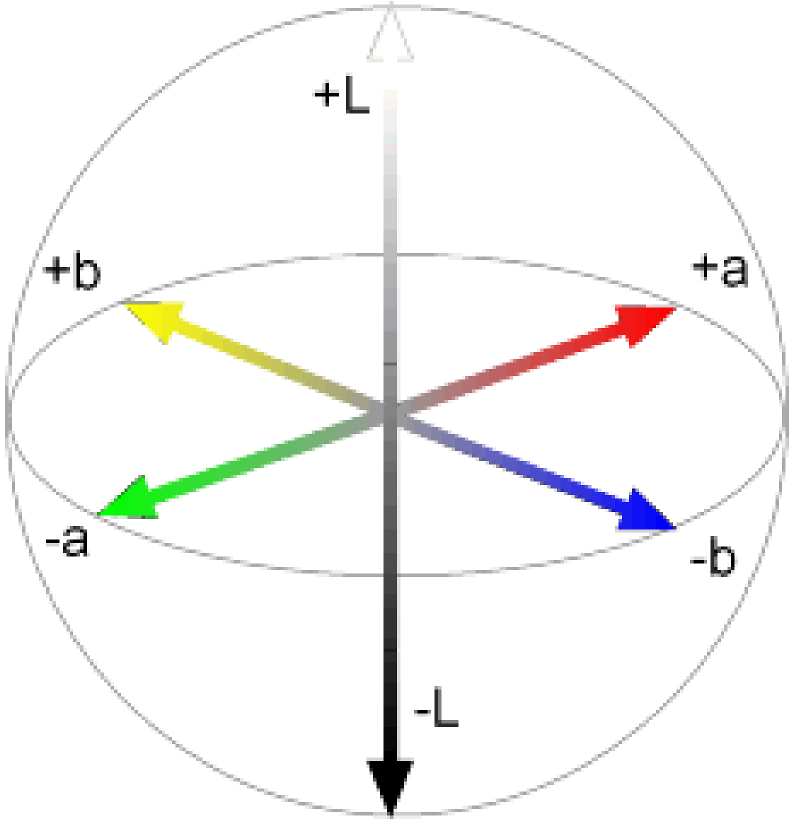
Most JPEG images & videos subsample chroma

PSP Comp 3
2x2 Chroma subsampling
285K

Original
1,261K lossless
968K PNG

Color spaces: L*a*b*

"Perceptually uniform"* color space

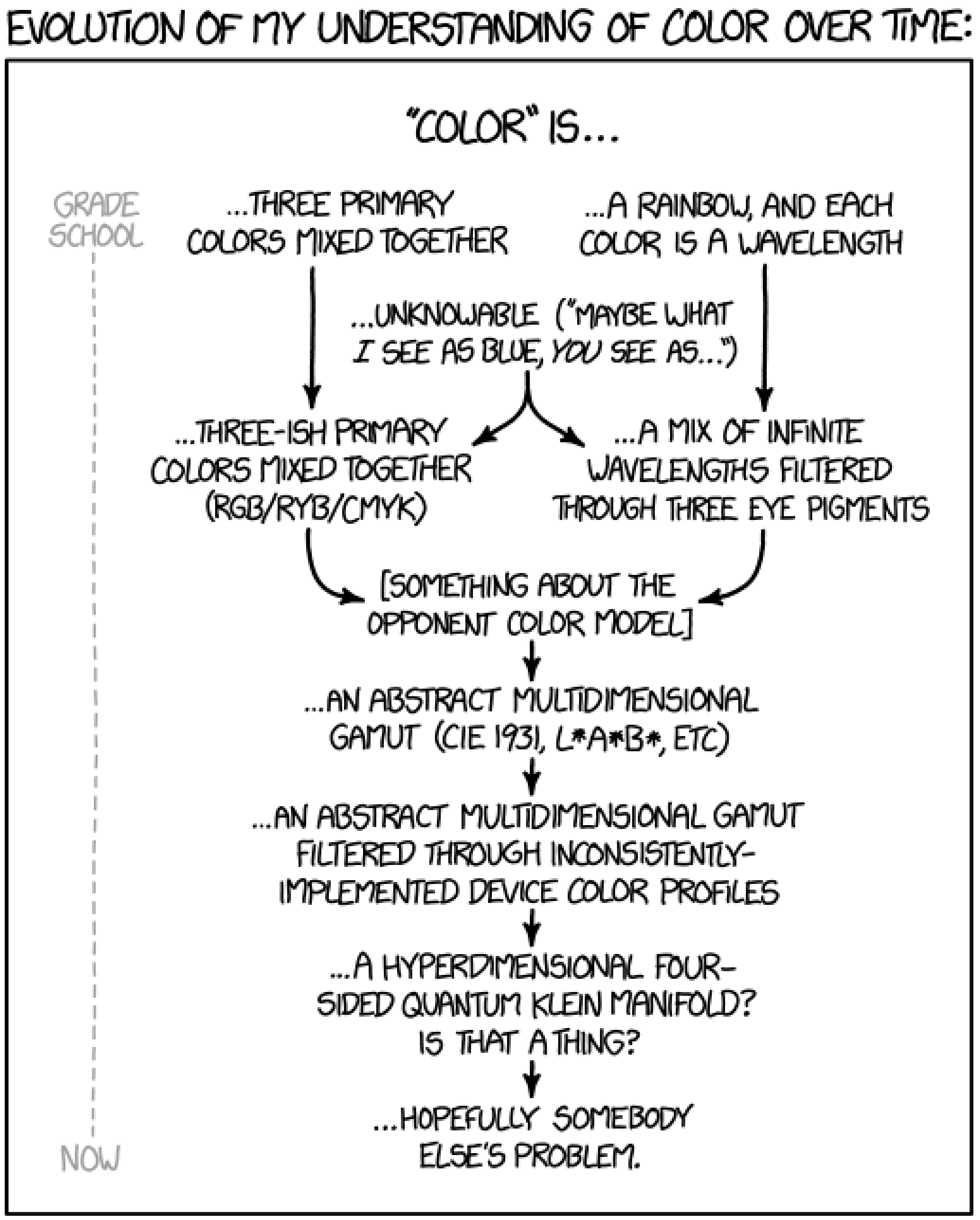


L
(a=0,b=0)

a
(L=65,b=0)

b
(L=65,a=0)

James Hays


EVOLUTION OF MY UNDERSTANDING OF COLOR OVER TIME:
"COLOR" IS...
GRADE SCHOOL
...THREE PRIMARY COLORS MIXED TOGETHER
...A RAINBOW, AND EACH COLOR IS A WAVELENGTH
...UNKNOWABLE ("MAYBE WHAT I SEE AS BLUE, YOU SEE AS...")
...THREE-ISH PRIMARY COLORS MIXED TOGETHER (RGB/RYB/CMYK)
...A MIX OF INFINITE WAVELENGTHS FILTERED THROUGH THREE EYE PIGMENTS
[SOMETHING ABOUT THE OPPONENT COLOR MODEL]
...AN ABSTRACT MULTIDIMENSIONAL GAMUT (CIE 1931, L*A*B*, ETC)
...AN ABSTRACT MULTIDIMENSIONAL GAMUT FILTERED THROUGH INCONSISTENTLY-IMPLEMENTED DEVICE COLOR PROFILES
...A HYPERDIMENSIONAL FOUR-SIDED QUANTUM KLEIN MANIFOLD? IS THAT A THING?
...HOPEFULLY SOMEBODY ELSE'S PROBLEM.
NOW

XKCD

White balance

- When looking at a picture on screen or print, we adapt to the illuminant of the room, not to that of the scene in the picture
- When the white balance is not correct, the picture will have an unnatural color "cast"

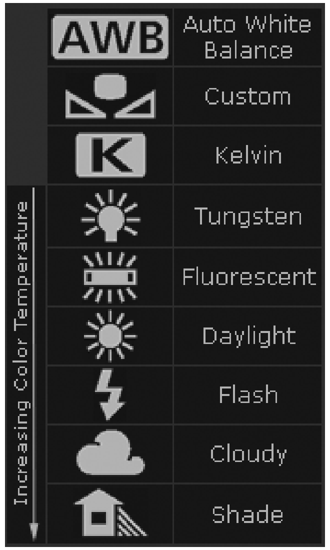
incorrect white balance

correct white balance

http://www.cambridgeincolour.com/tutorials/white-balance.htm

White balance

- Film cameras:
  - Different types of film or different filters for different illumination conditions
- Digital cameras:
  - Automatic white balance
  - White balance settings corresponding to several common illuminants
  - Custom white balance using a reference object



http://www.cambridgeincolour.com/tutorials/white-balance.htm

Slide: F. Durand

Image histograms

Histogram

Slide credit: Dr. Mubarak Shah

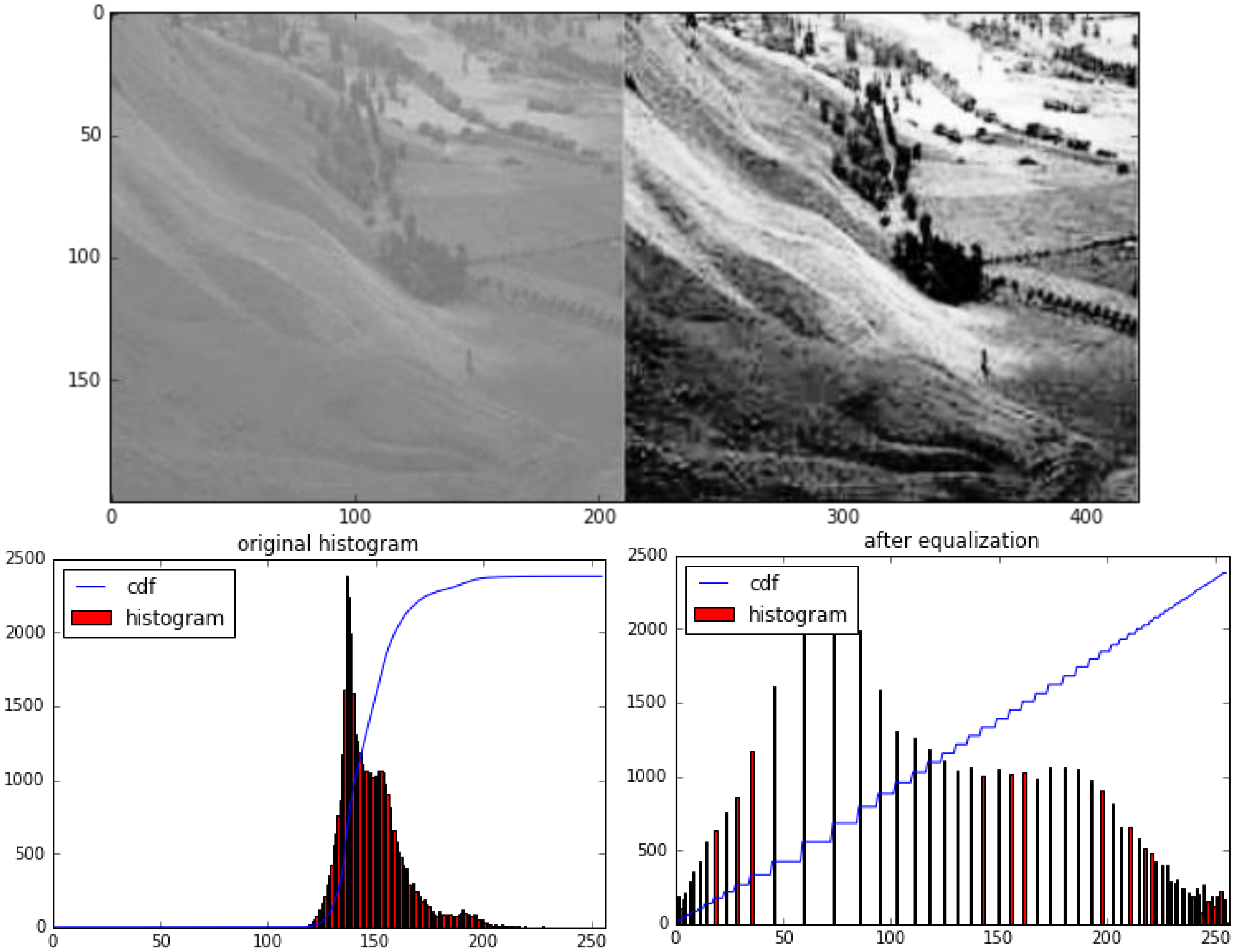
Histogram

- Histogram of an image provides the frequency of the brightness (intensity) value in the image.

```
function h=histogram(im)
    h=zeros(1,255);
    for row=1:size(im,1)
        for col=1:size(im,2)
            val = im(row,col)+1;
            h(val)=h(val)+1;
        end
    end
end
```

```
def histogram(im):
    h = np.zeros(255)
    for row in im.shape[0]:
        for col in im.shape[1]:
            val = im[row, col]
            h[val] += 1
```

A use case: histogram equalization



Summary

- Pixels (picture elements)
- Color ≈ light frequency, but is also a result of HVS
  - Different species (even individual) see the world differently!
  - Some colors are "fake". Pure "magenta" does not exist
  - Metamer: same color to us can be different spectrum
- Color spaces (RGB/HSV...)
- Color depth (8-bit typically per channel)
- Human Vision System can “measure” more green
  - More green sensors in camera (Bayer filter)
- White balancing/histogram/histogram equalization