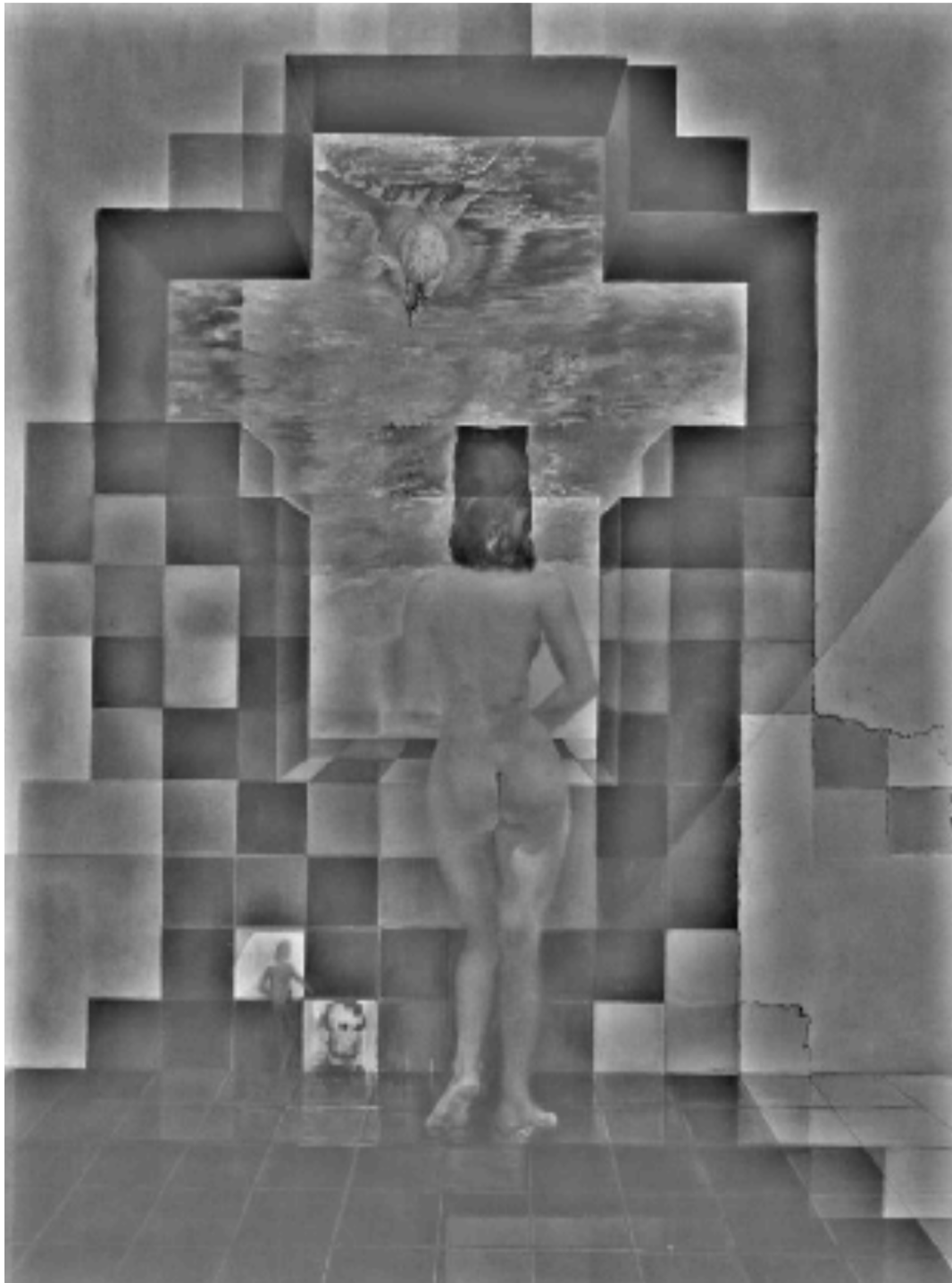
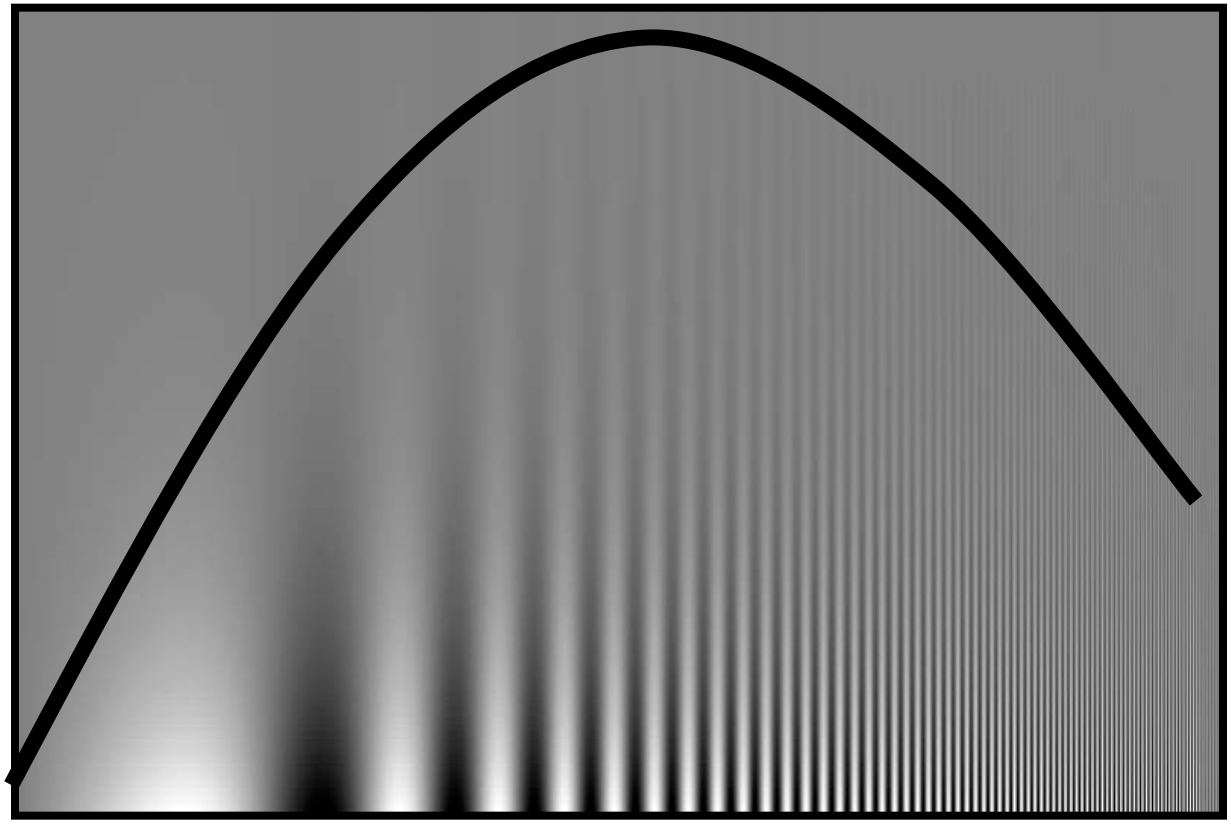
Frequencies and Color

Alexei Efros, CS280, Spring 2018

Salvador Dali
"Gala Contemplating the Mediterranean Sea, which at 30 meters becomes the portrait of Abraham Lincoln", 1976

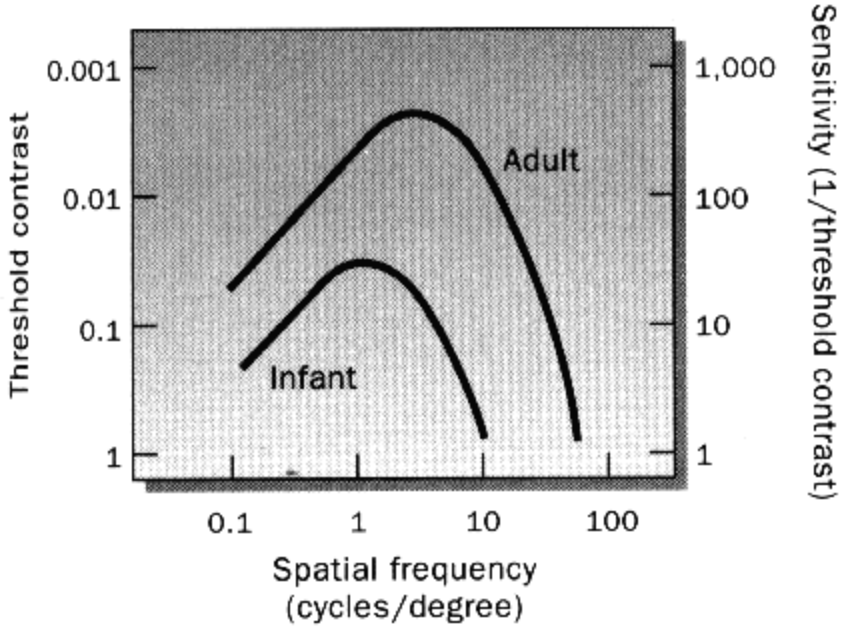


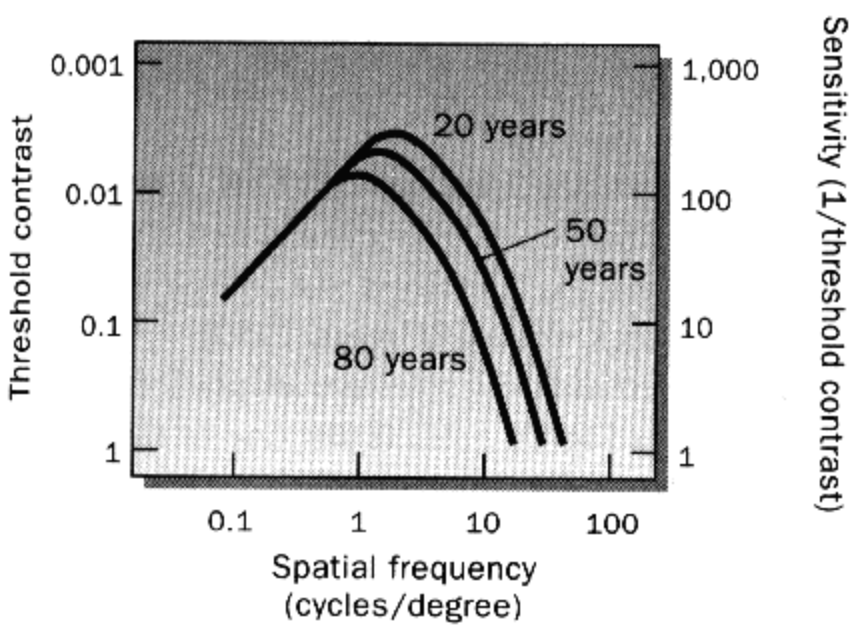
Spatial Frequencies and Perception



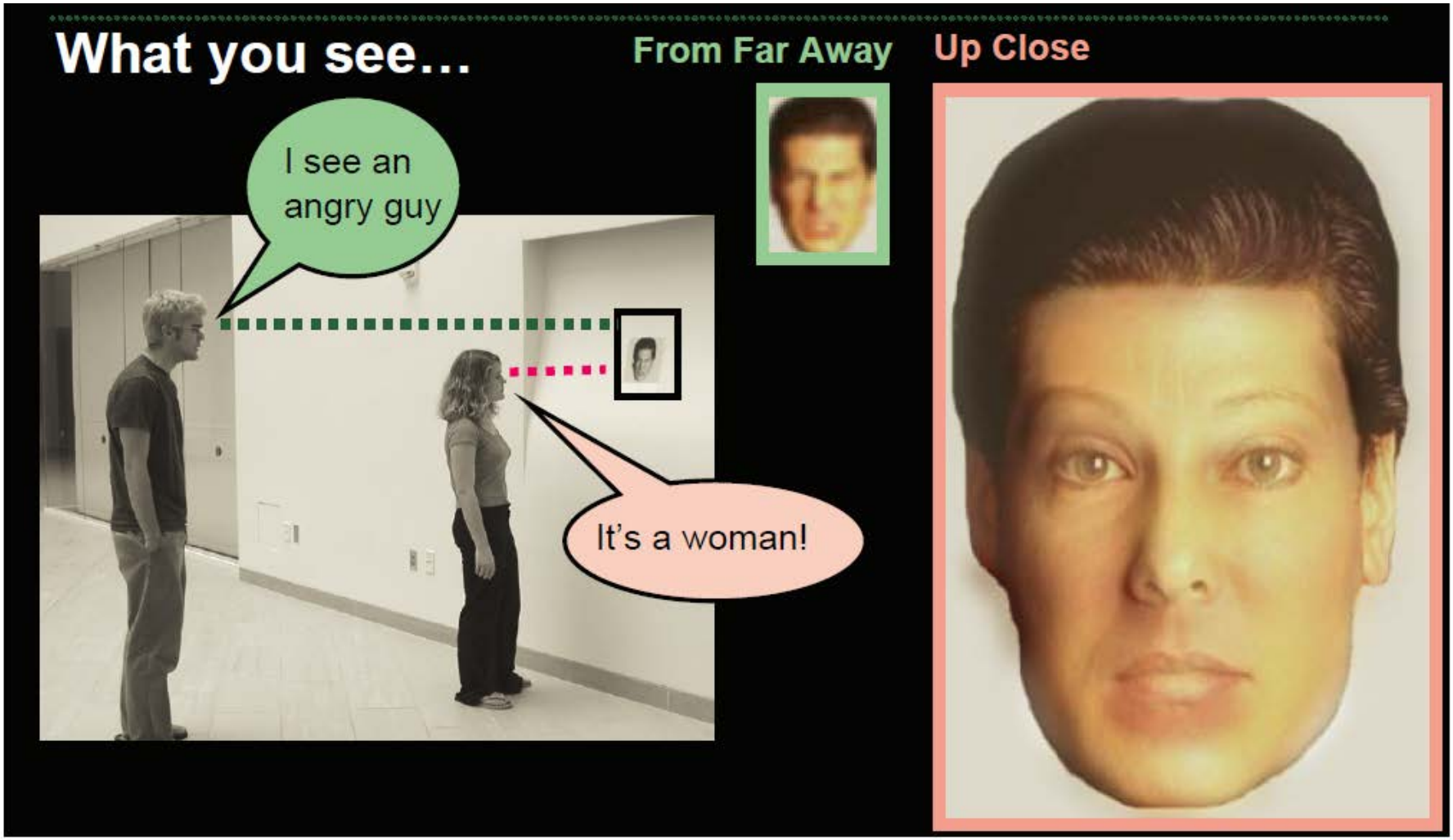
Campbell-Robson contrast sensitivity curve

Depends on age





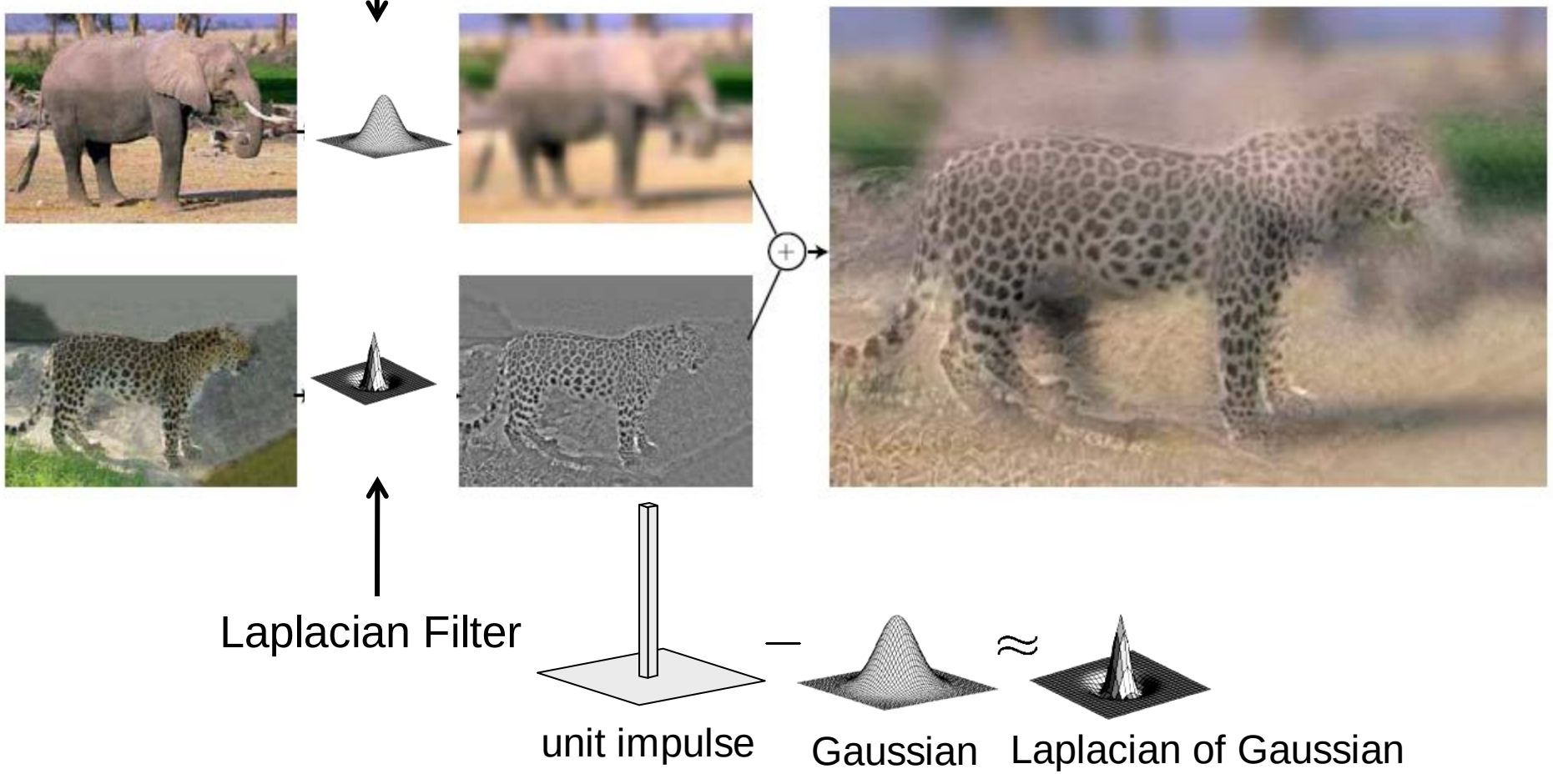
application: Hybrid Images



Aude Oliva & Antonio Torralba & Philippe G Schyns, SIGGRAPH 2006

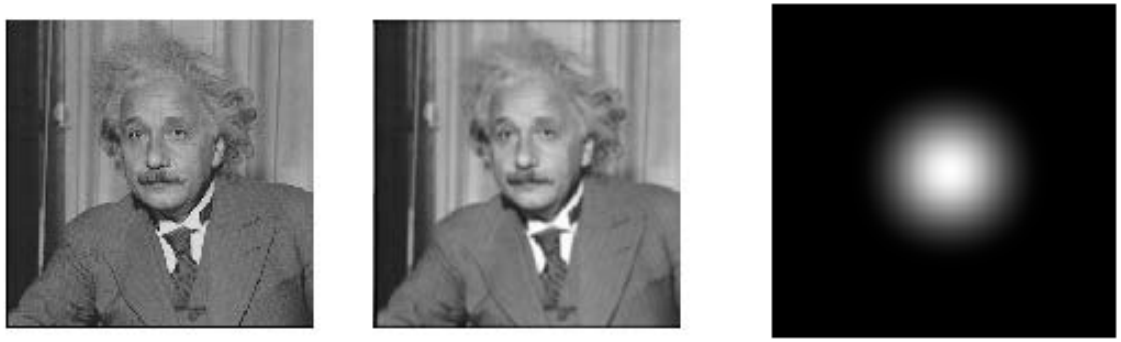
Application: Hybrid Images

A. Oliva, A. Torralba, P.G. Schyns, "Hybrid Images," SIGGRAPH 2006



Low-pass, Band-pass, High-pass filters

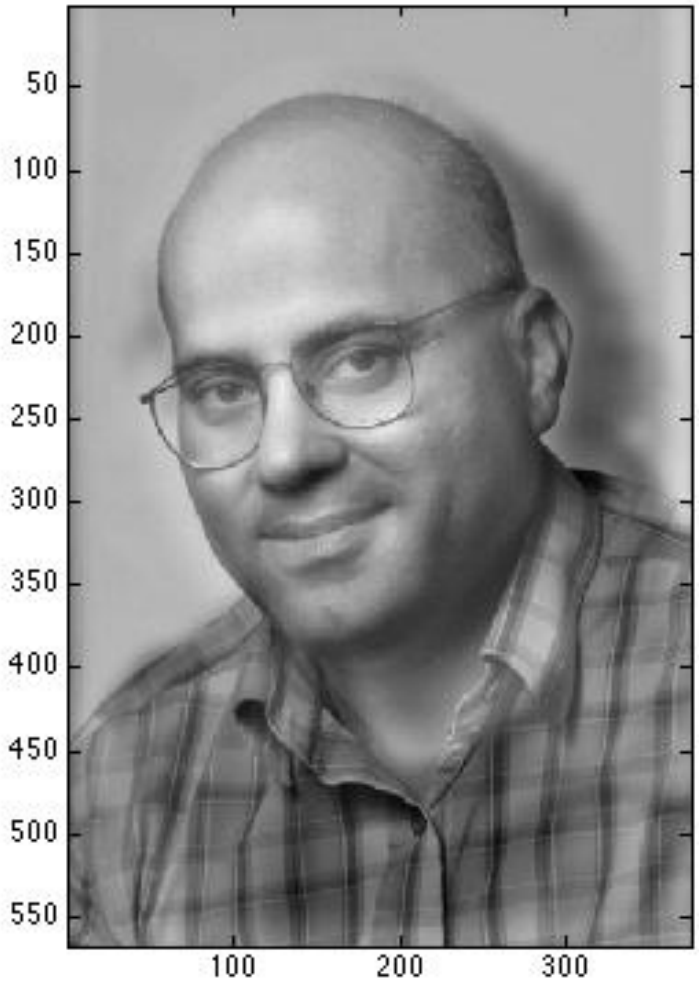
low-pass:



High-pass / band-pass:

CS194-26: Comp Photo homework

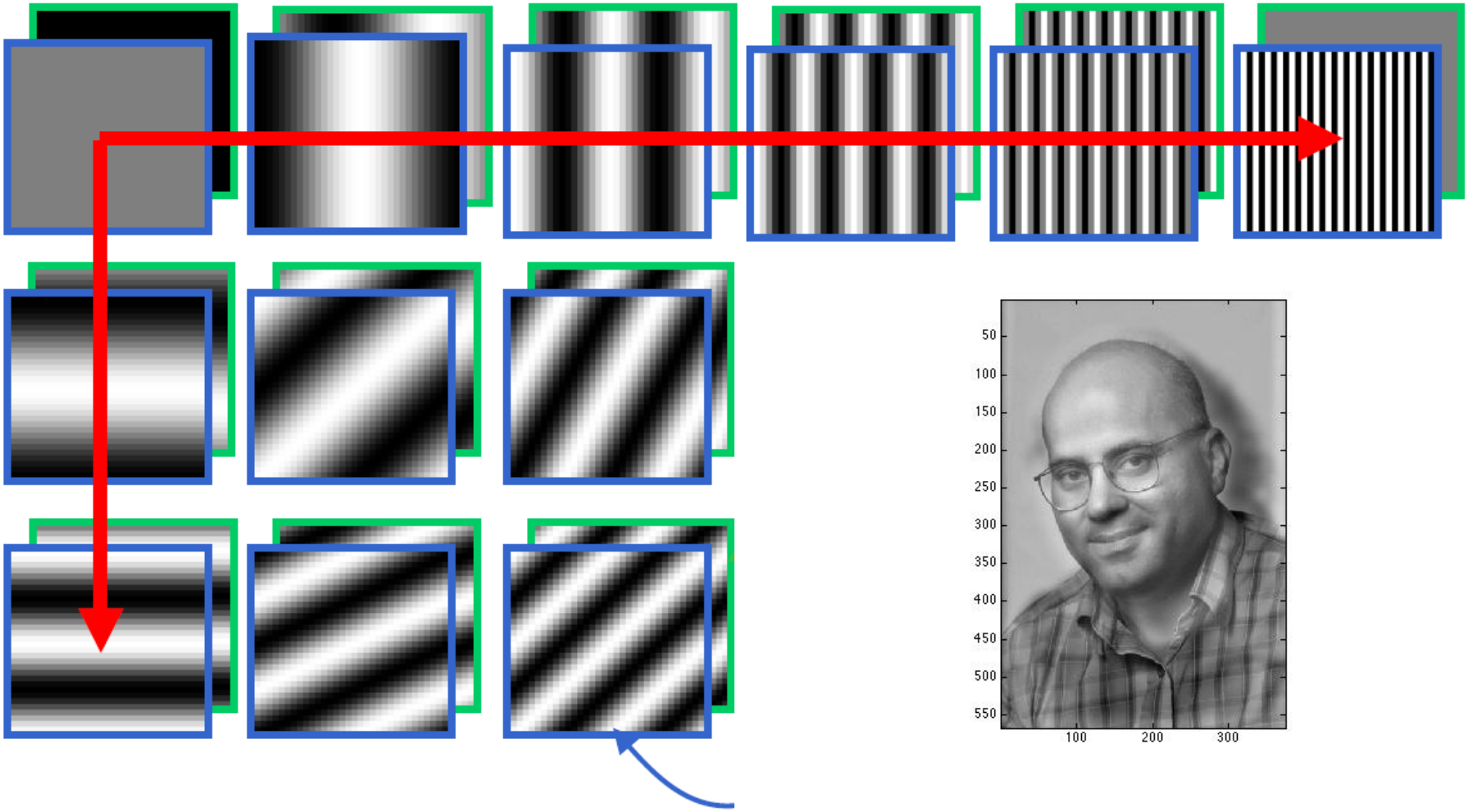
(by Riyaz Faizullabhoy)



Prof. Jitendros Papadimalik

Fourier transform: a nice set of basis

Teases away fast vs. slow changes in the image.

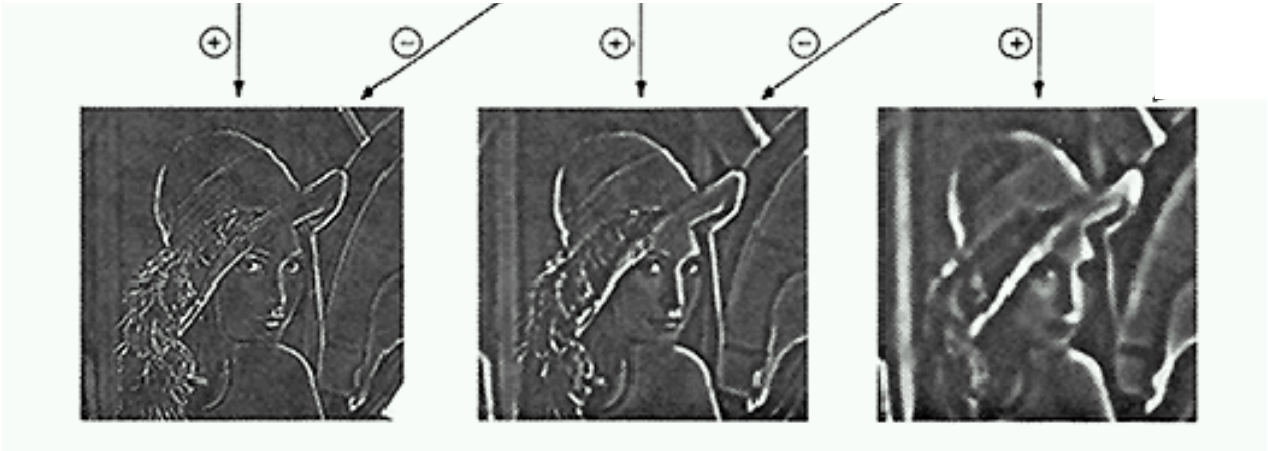


Band-pass filtering

Gaussian Pyramid (low-pass images)

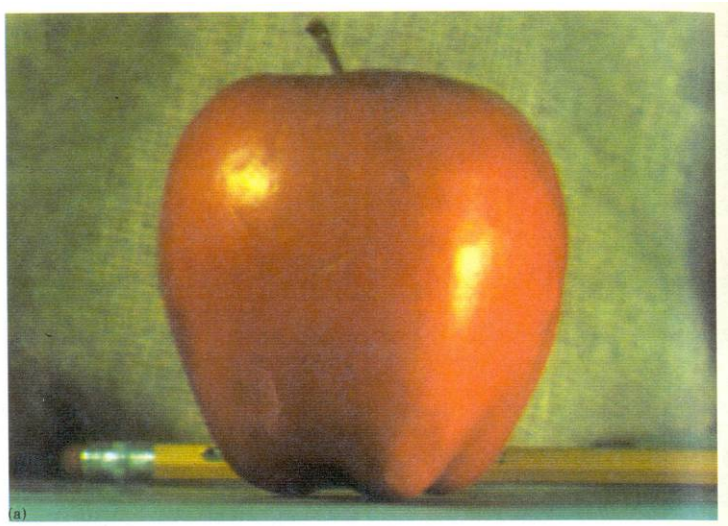
Laplacian Pyramid (Burt and Adelson, 83)

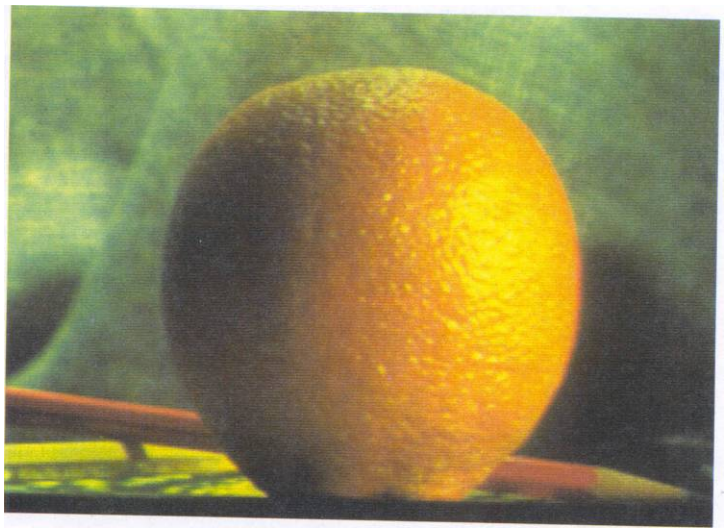
Original image

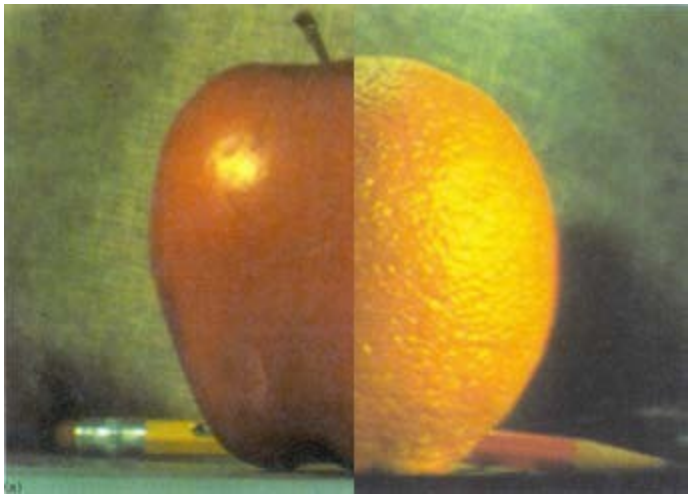


How can we reconstruct (collapse) this pyramid into the original image?

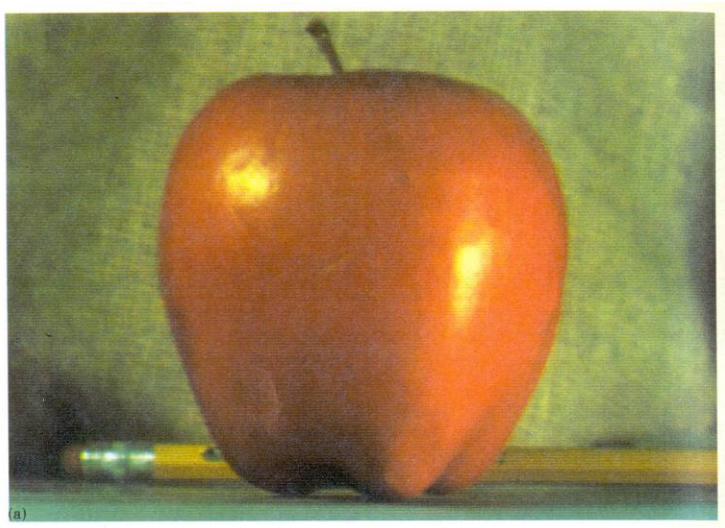
Cut and Paste Blending

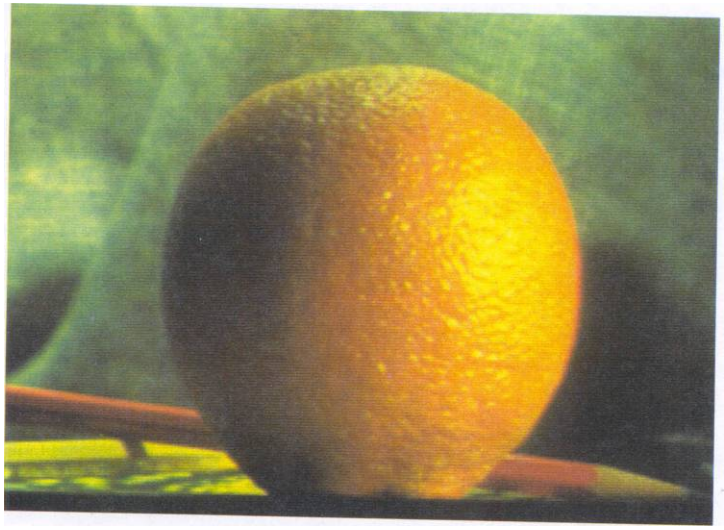


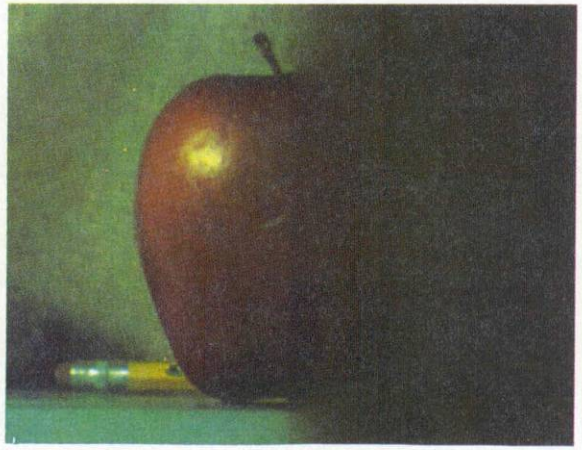




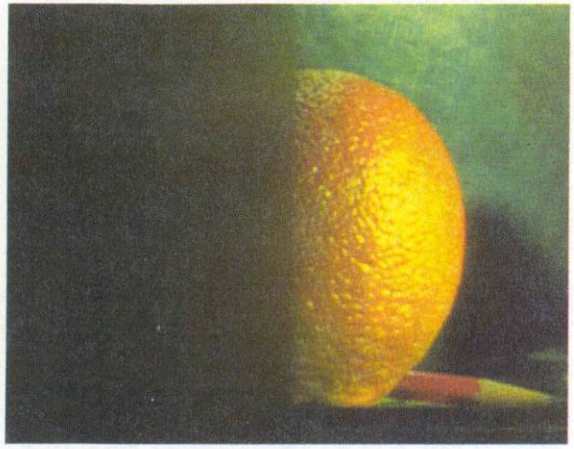
Pyramid Blending



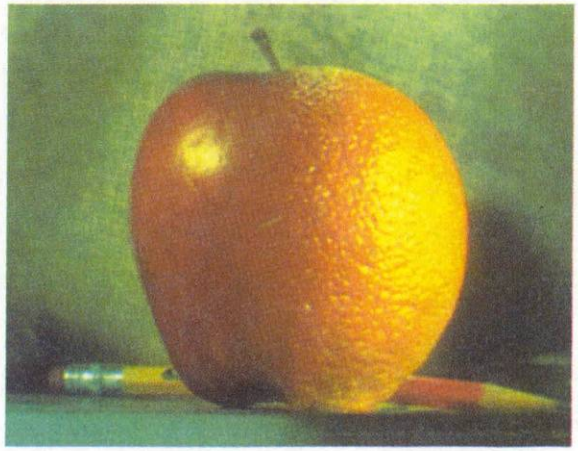




(d)

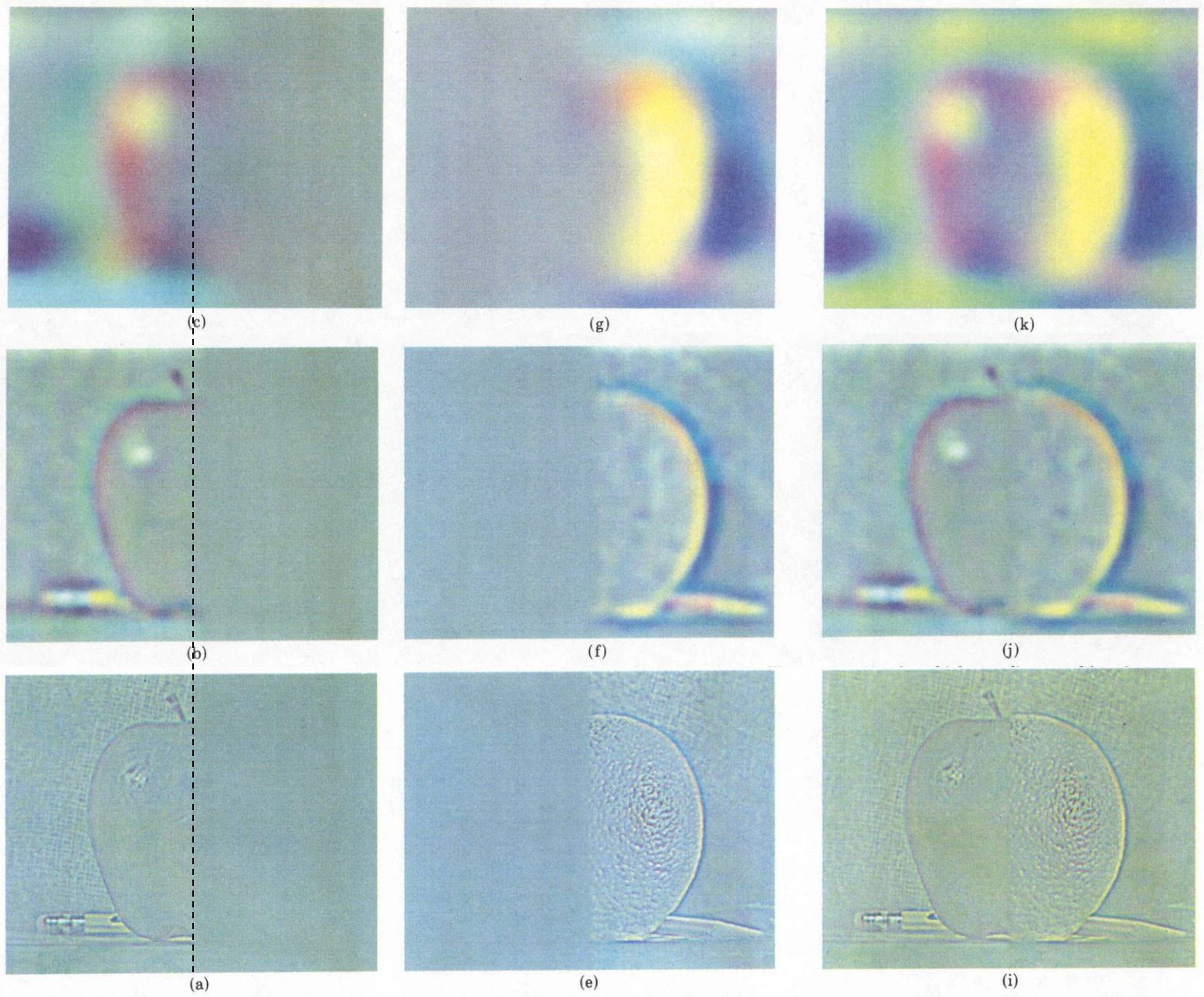


(h)

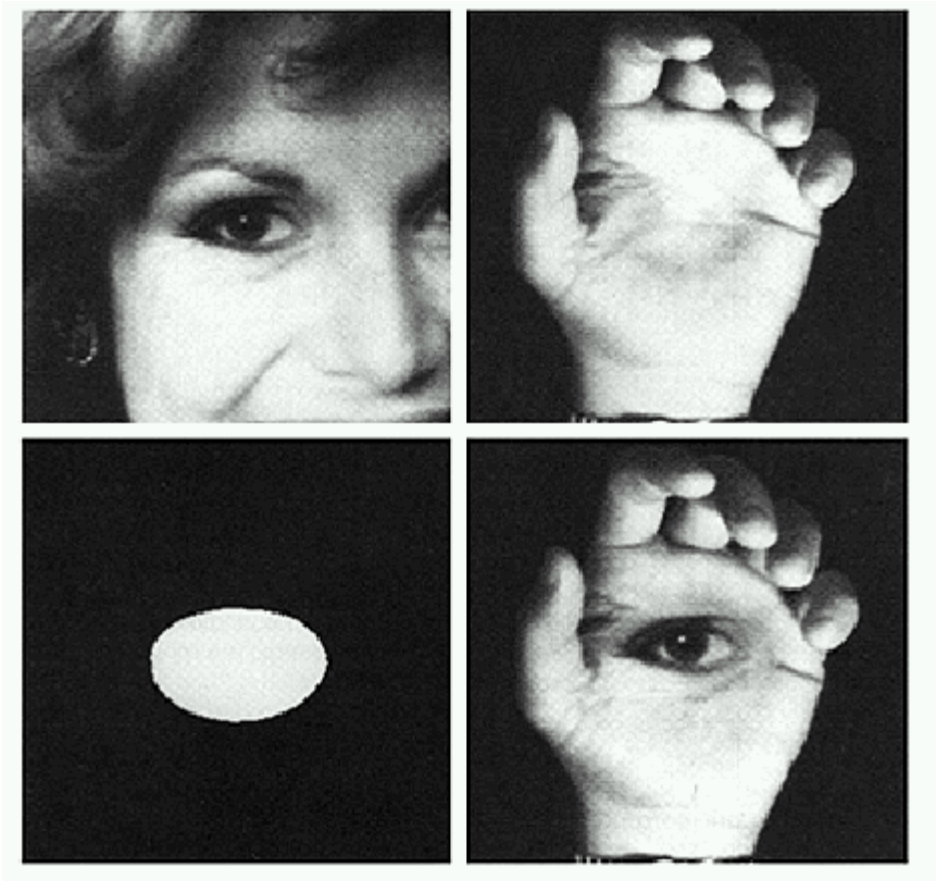


(l)

http://persci.mit.edu/pub_pdfs/spline83.pdf


laplacian level 4
laplacian level 2
laplacian level 0
(c)
(g)
(k)
(b)
(f)
(j)
(a)
(e)
(i)
left pyramid
right pyramid
blended pyramid

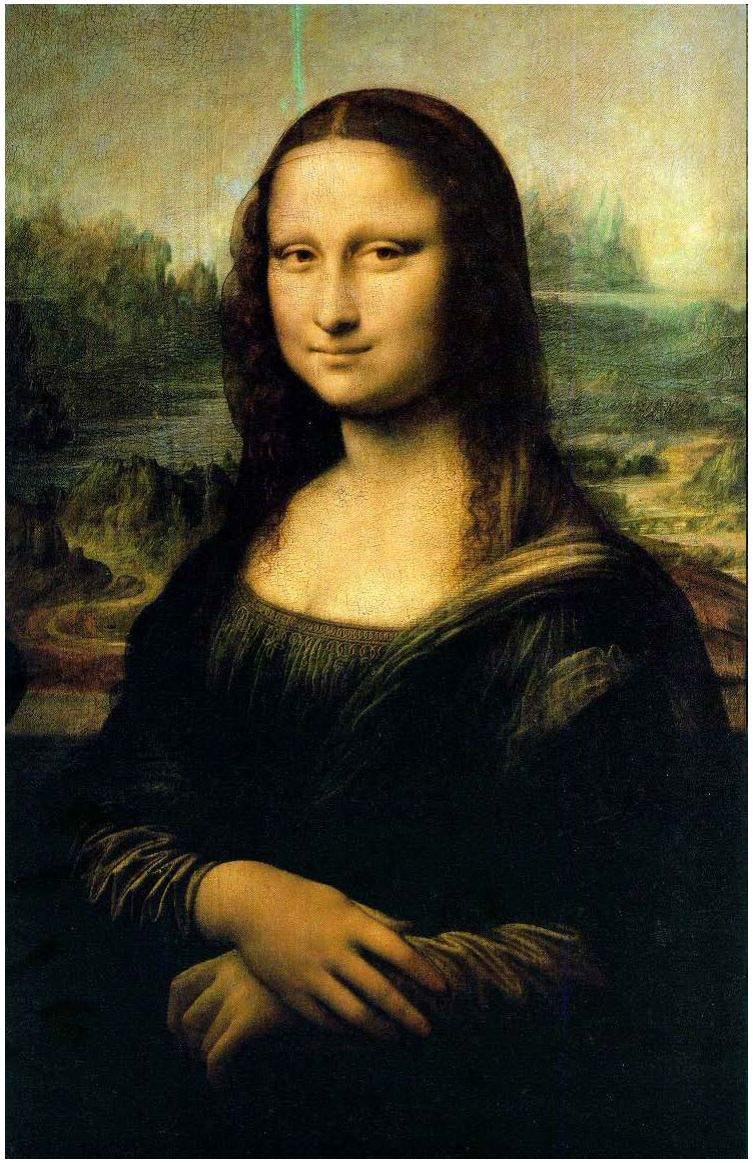
Blending Regions



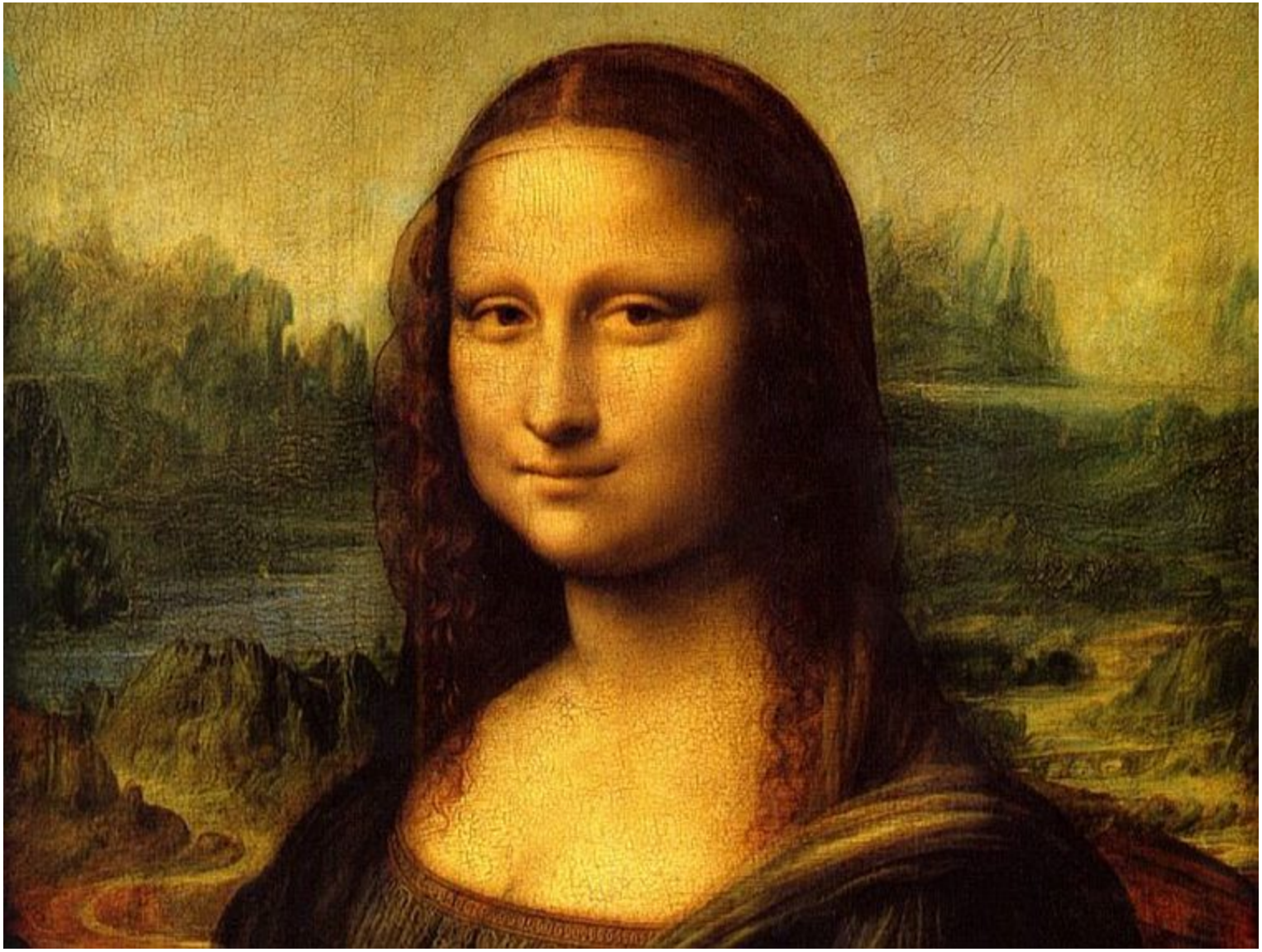
Results from previous class

© Chris Cameron

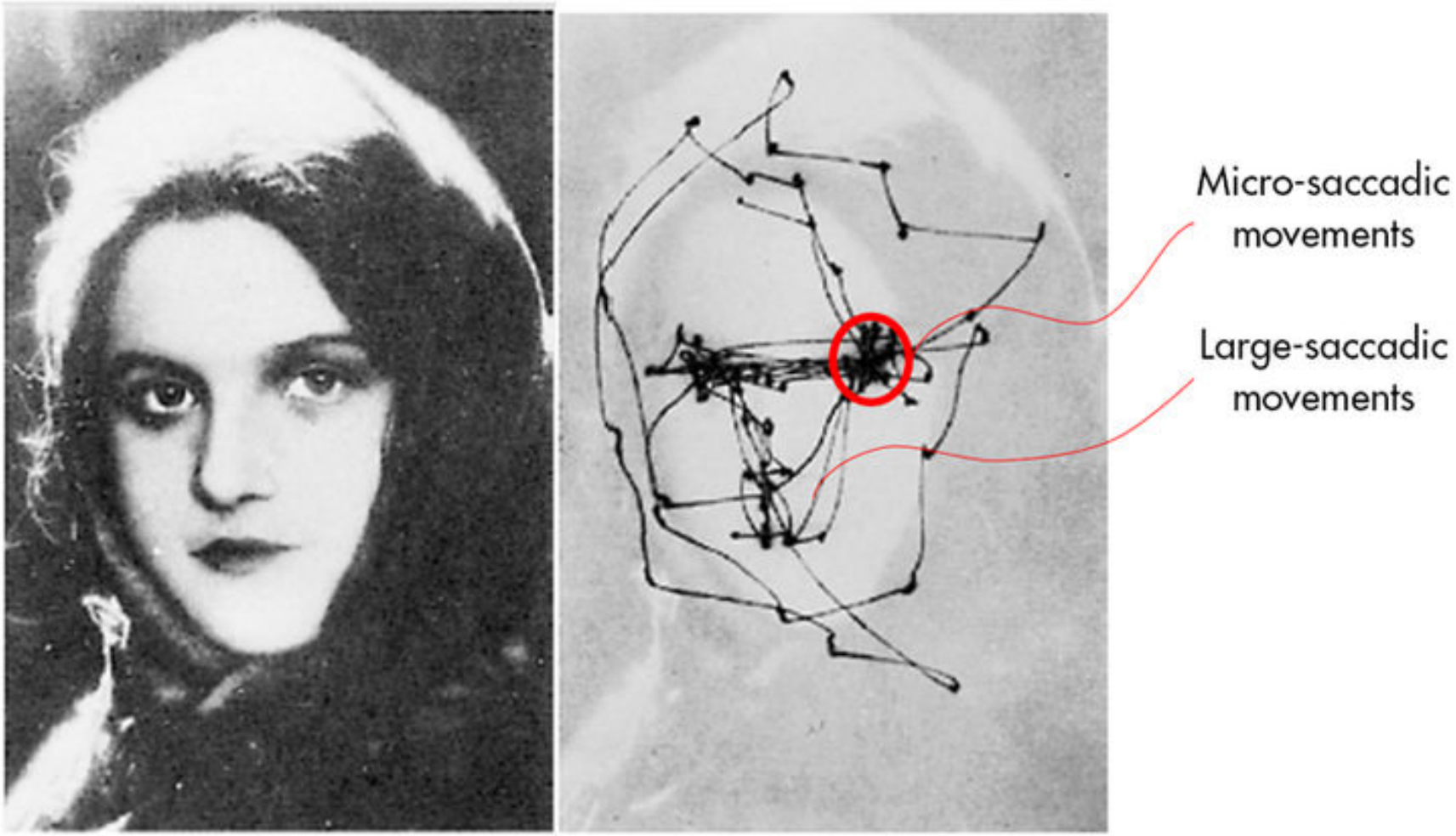
Da Vinci, the vision scientist



Da Vinci and Peripheral Vision

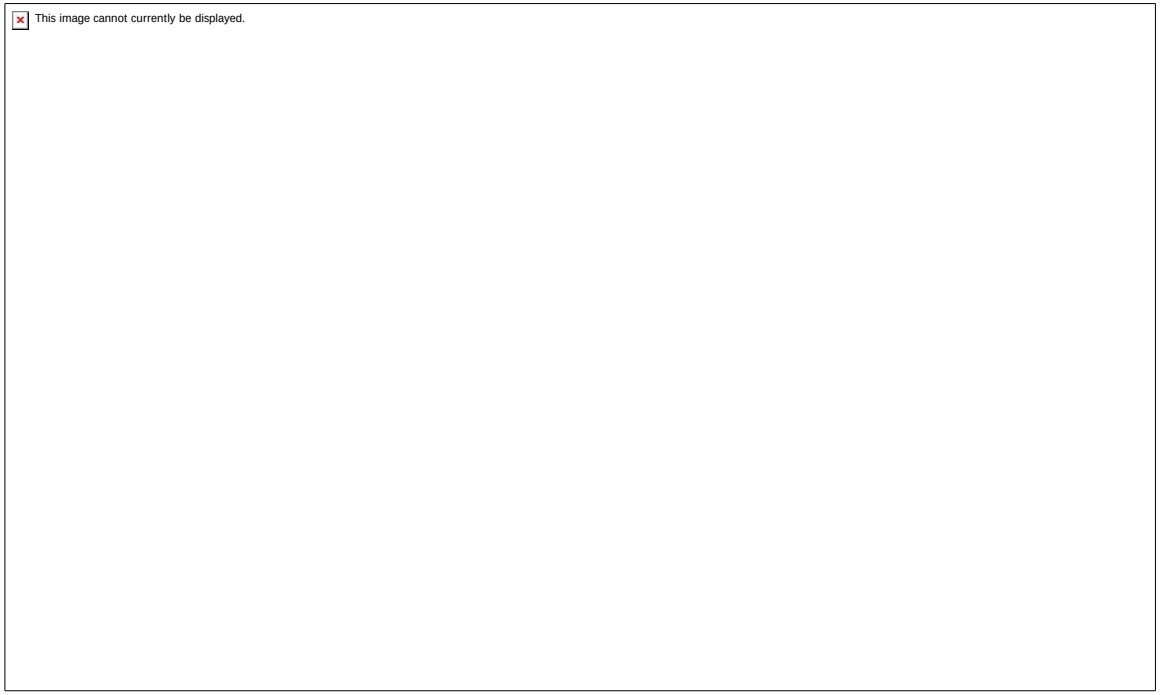


Saccadic eye movement



Saccadic eye movement

The Eye

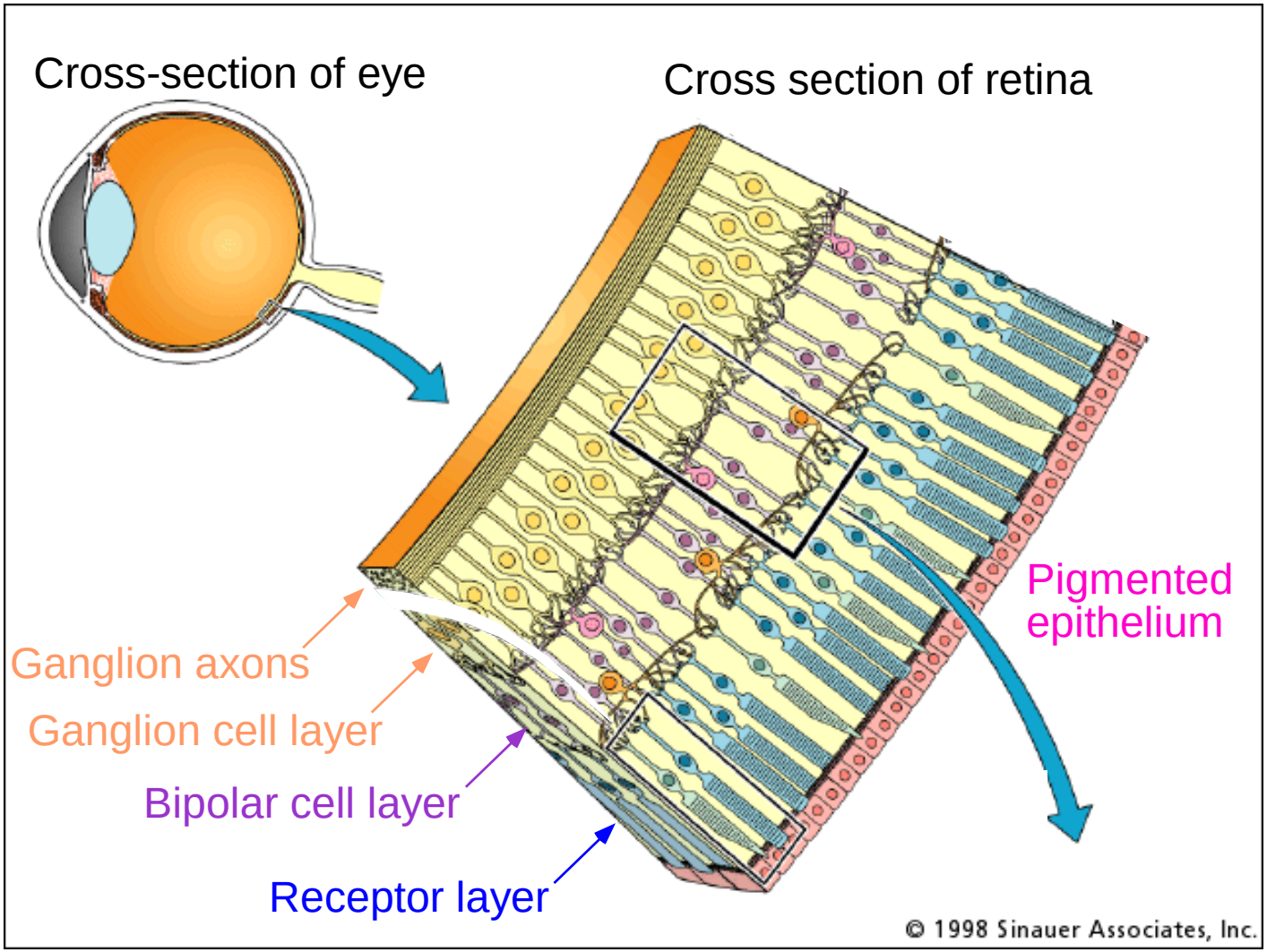


The human eye is a camera!

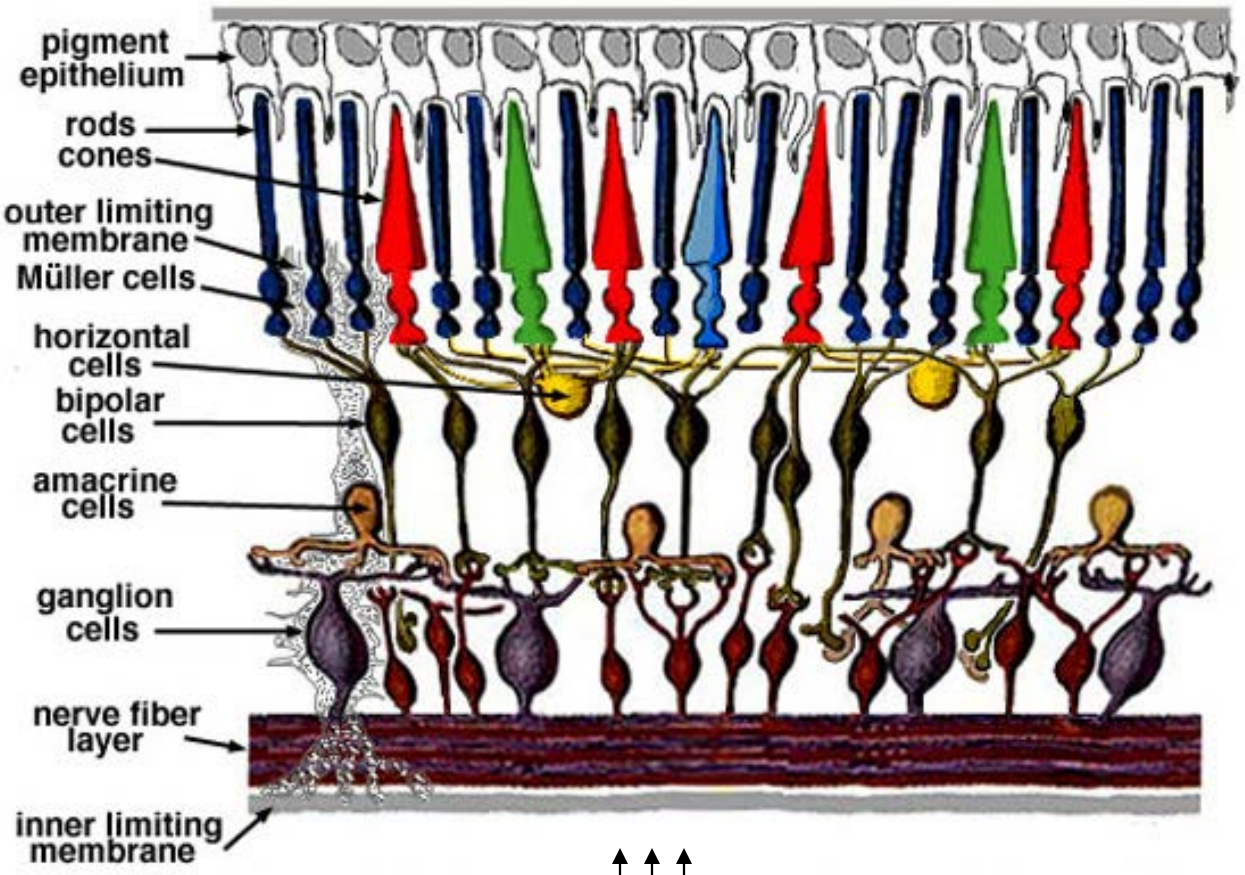
- **Iris -** colored annulus with radial muscles
- **Pupil -** the hole (aperture) whose size is controlled by the iris
- What's the "film"?
  - photoreceptor cells (rods and cones) in the **retina**

Slide by Steve Seitz

The Retina


Cross-section of eye
Cross section of retina
Pigmented epithelium
Ganglion axons
Ganglion cell layer
Bipolar cell layer
Receptor layer
© 1998 Sinauer Associates, Inc.

Retina up-close



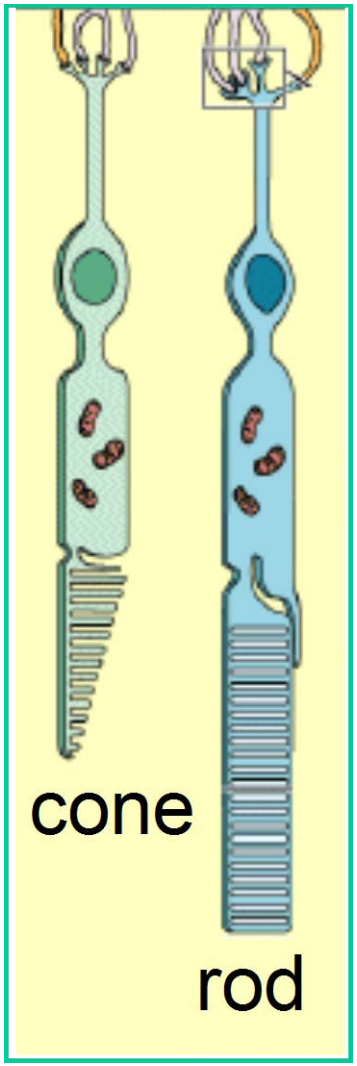
Two types of light-sensitive receptors

Cones

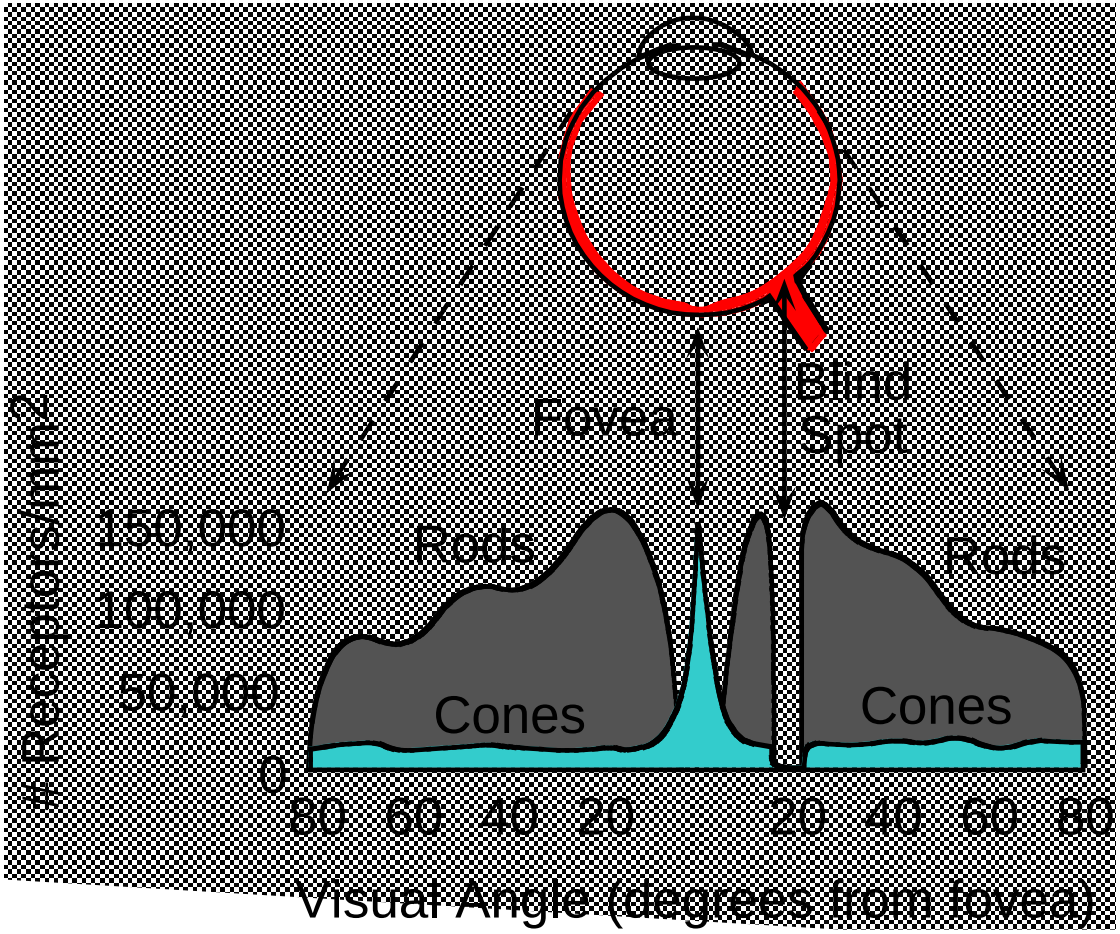
- cone-shaped
- less sensitive
- operate in high light
- color vision

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?


O
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K
B
W
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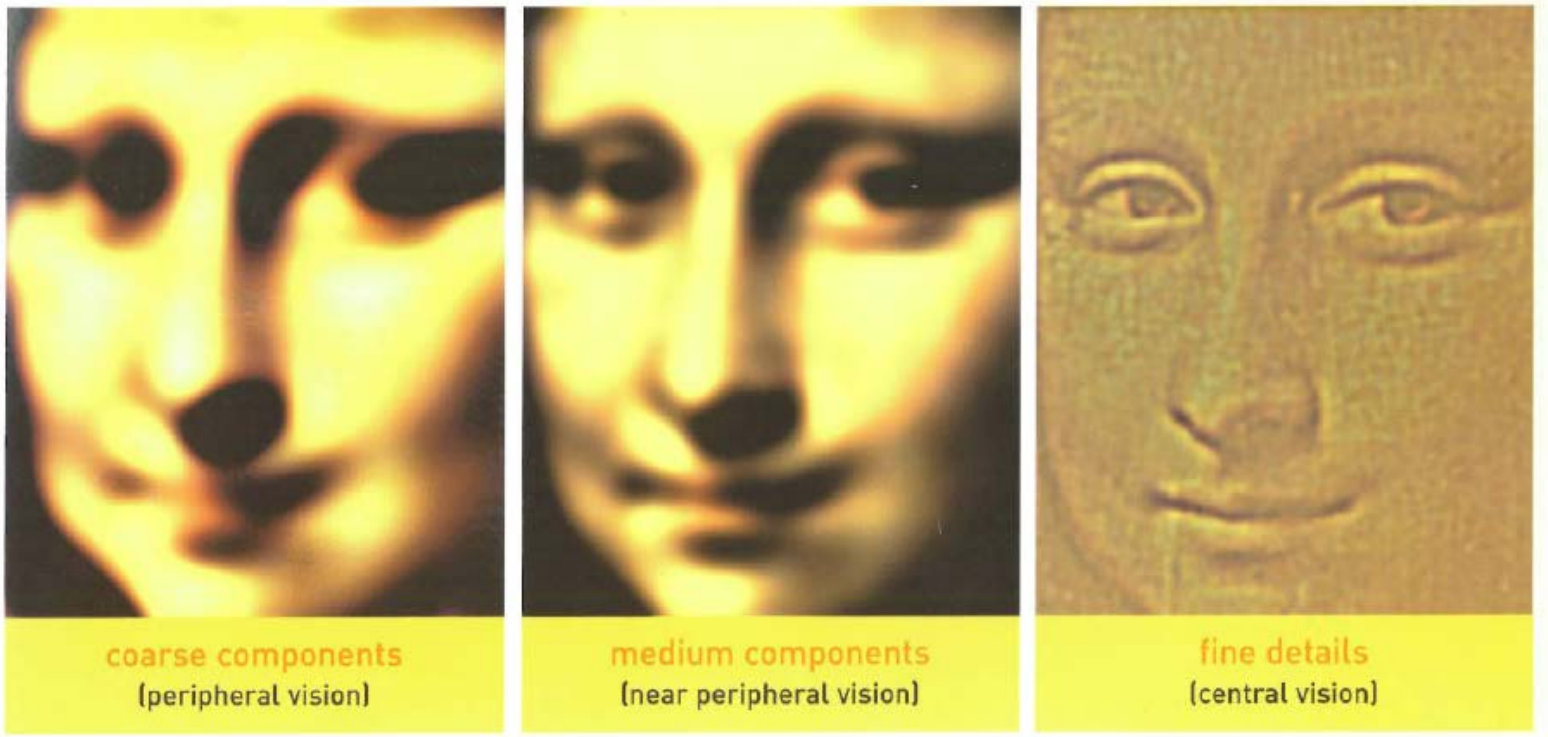
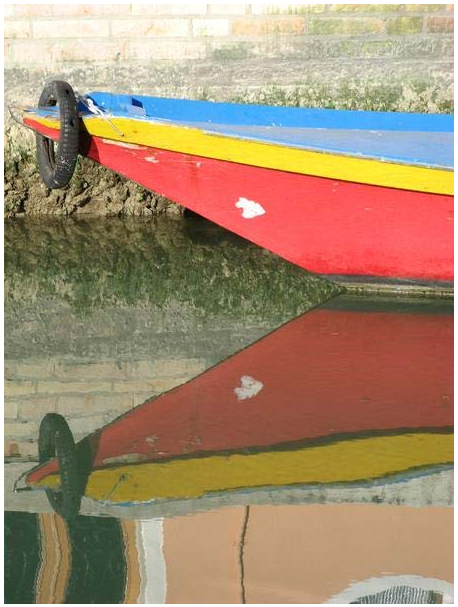


Leonardo playing with peripheral vision

Livingstone, Vision and Art: The Biology of Seeing

Freq. Perception Depends on Color

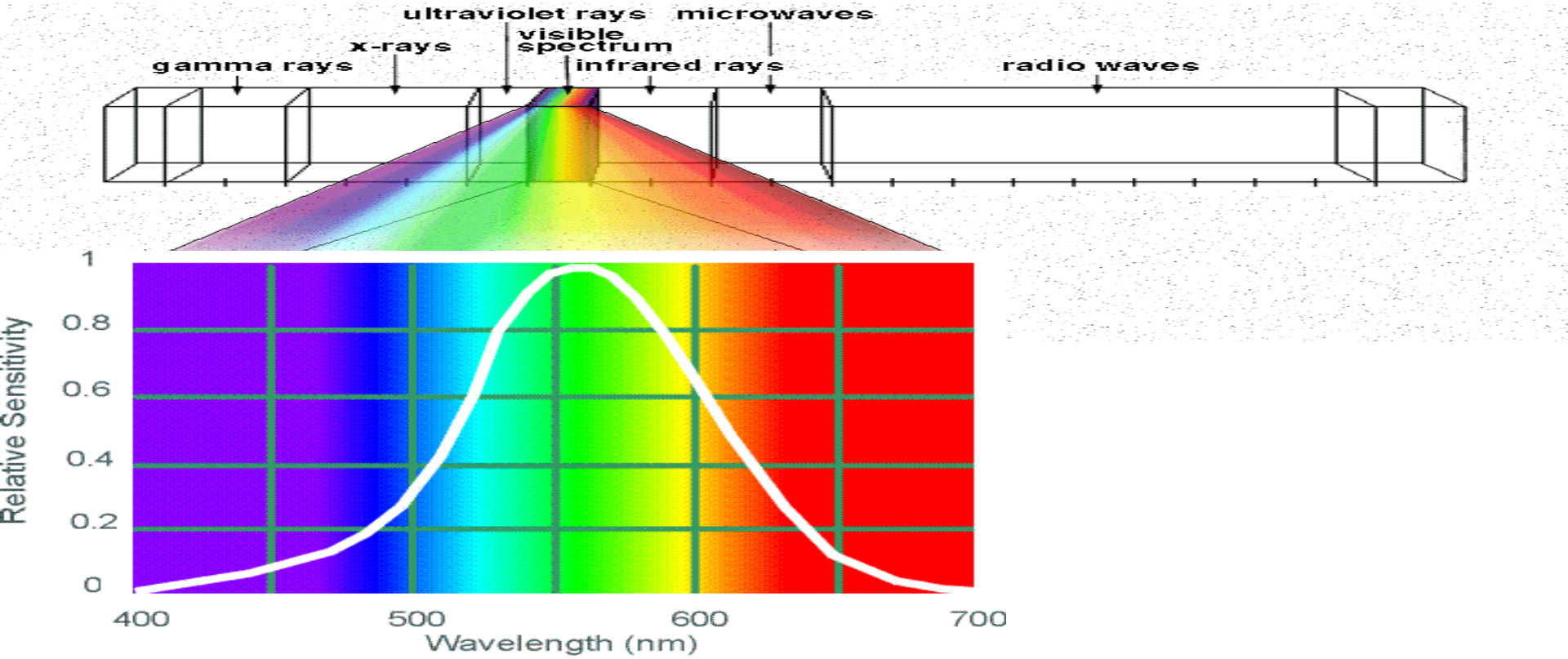


Blur R

Blur G

Blur B

Electromagnetic Spectrum

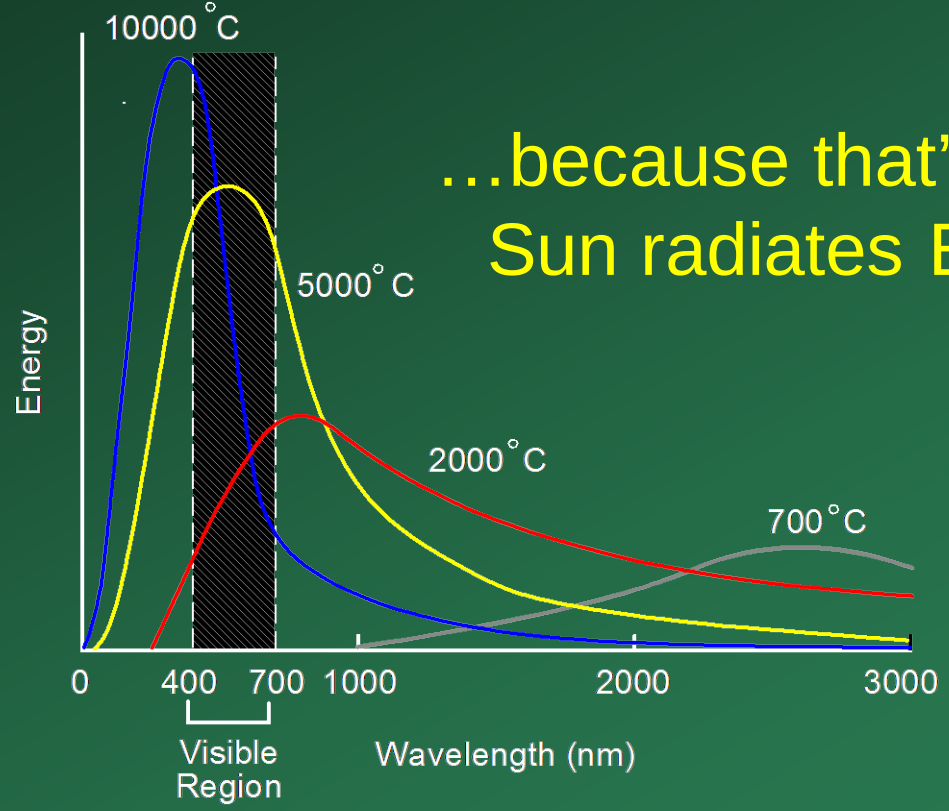


Human Luminance Sensitivity Function

http://www.yorku.ca/eye/photopik.htm

Visible Light

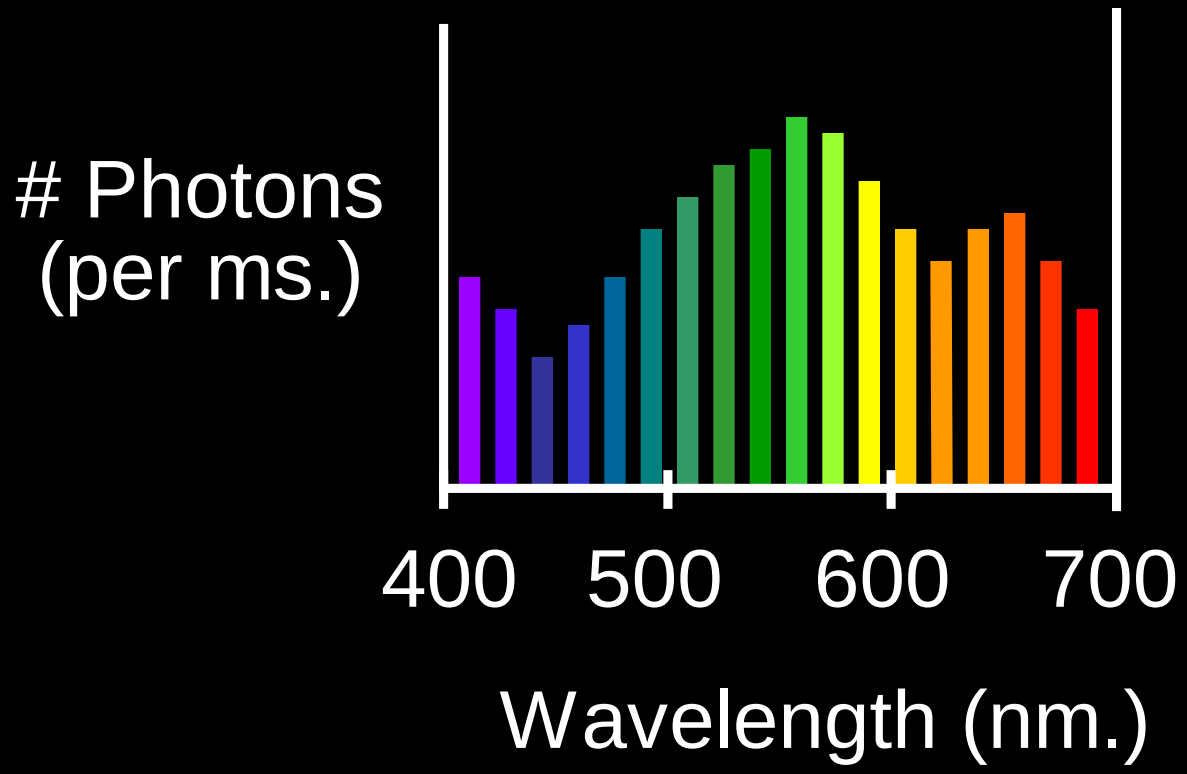
Why do we see light of these wavelengths?



…because that's where the Sun radiates EM energy

The Physics of Light

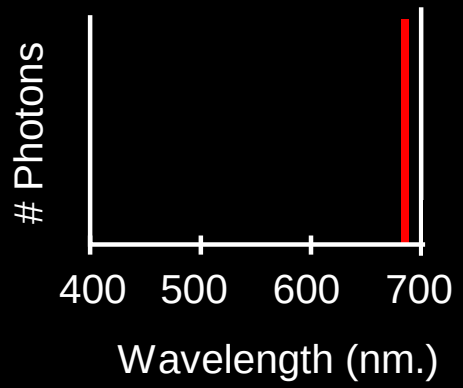
Any patch of light can be completely described physically by its spectrum: the number of photons (per time unit) at each wavelength 400 - 700 nm.



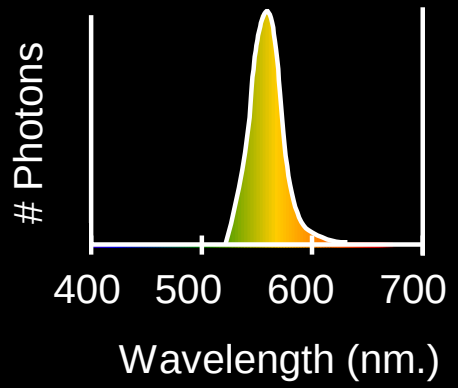
The Physics of Light

Some examples of the spectra of light sources

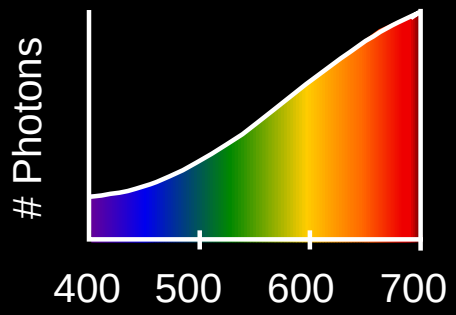
A. Ruby Laser



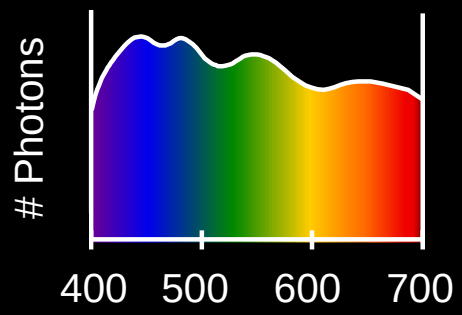
B. Gallium Phosphide Crystal



C. Tungsten Lightbulb



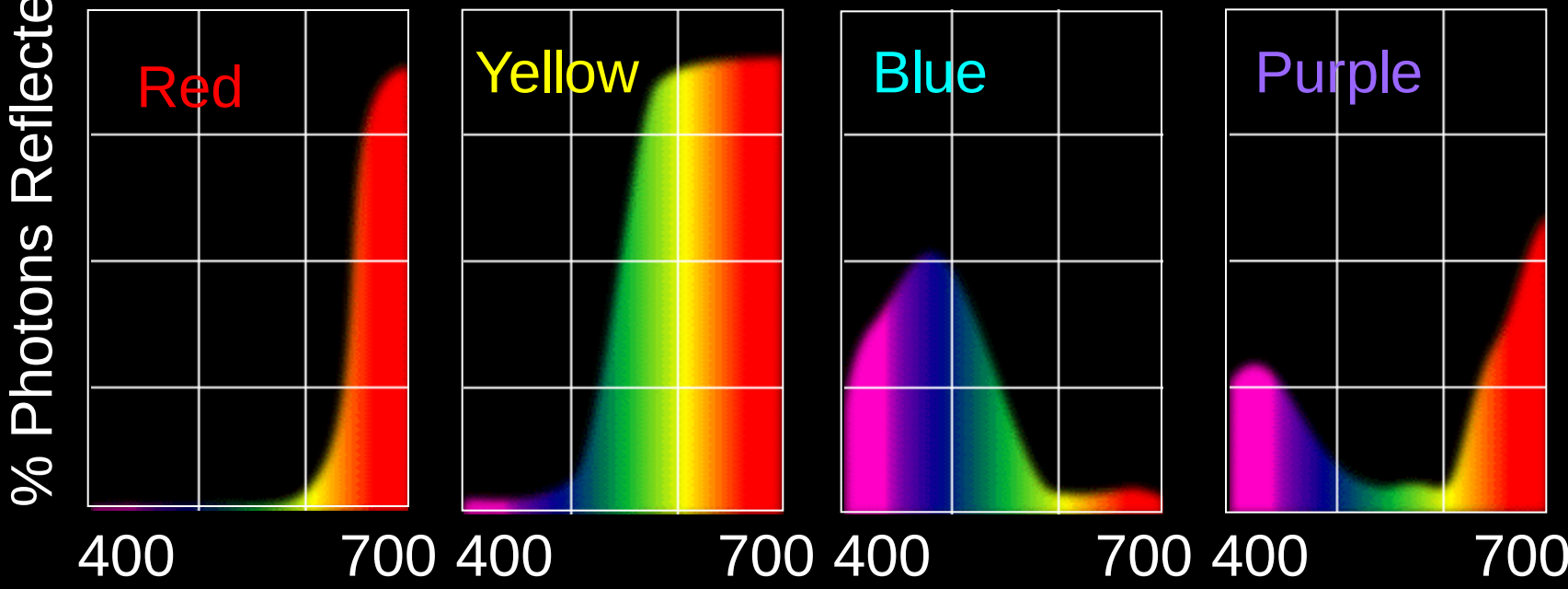
D. Normal Daylight



The Physics of Light

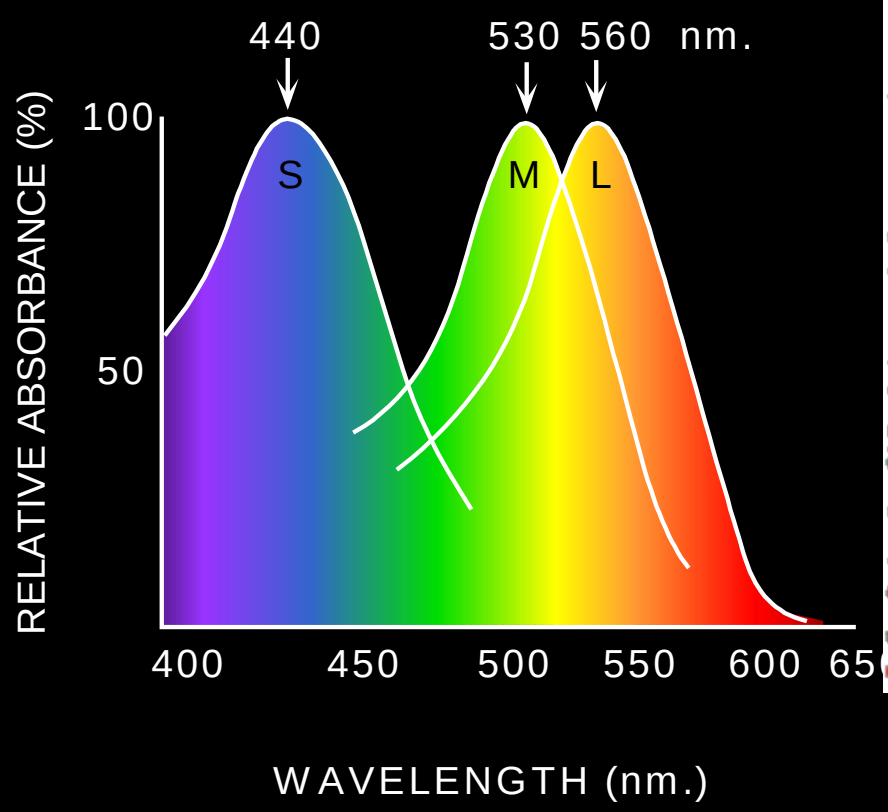
Some examples of the reflectance spectra of surfaces

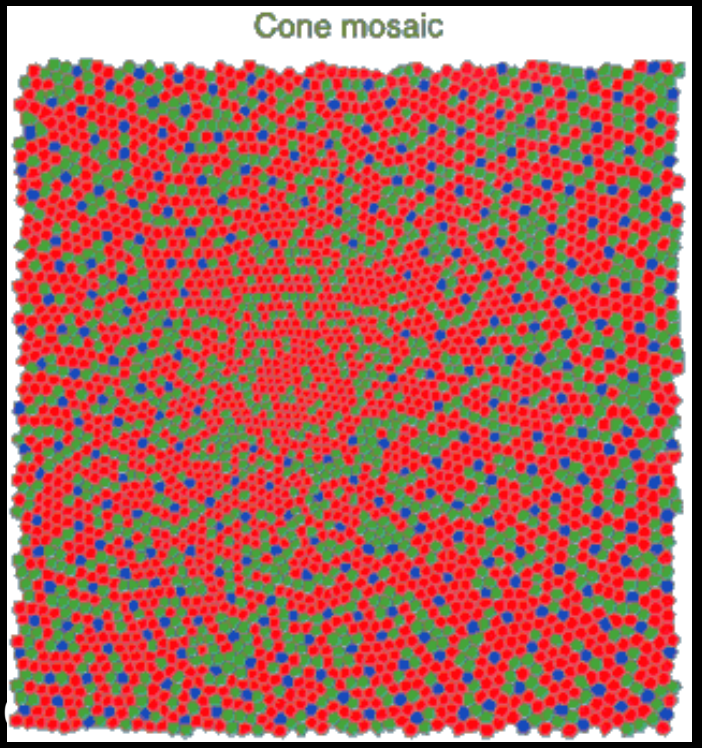


Physiology of Color Vision

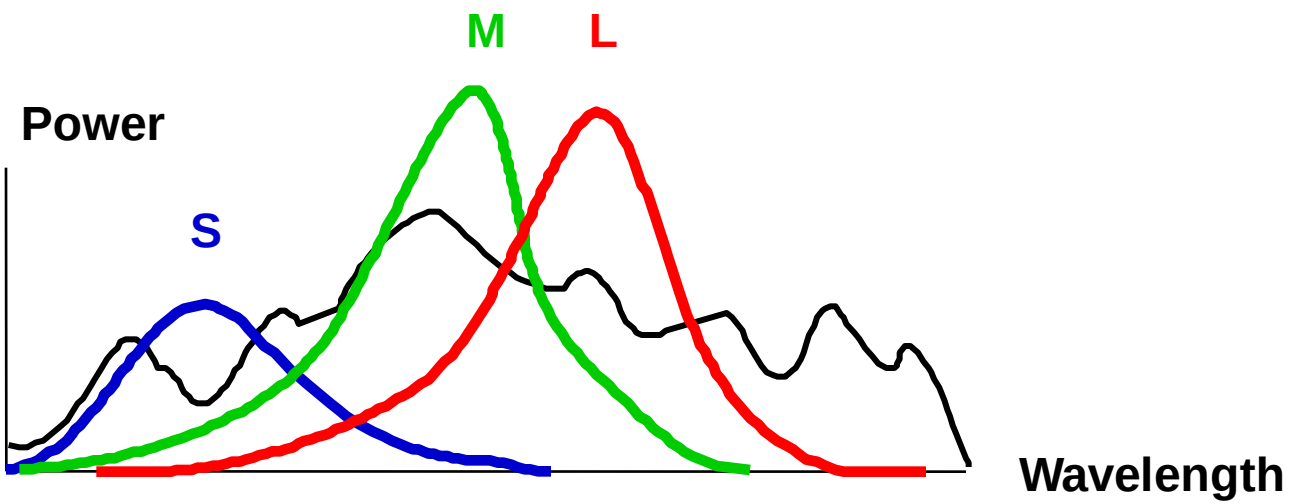
Three kinds of cones:





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

Trichromacy

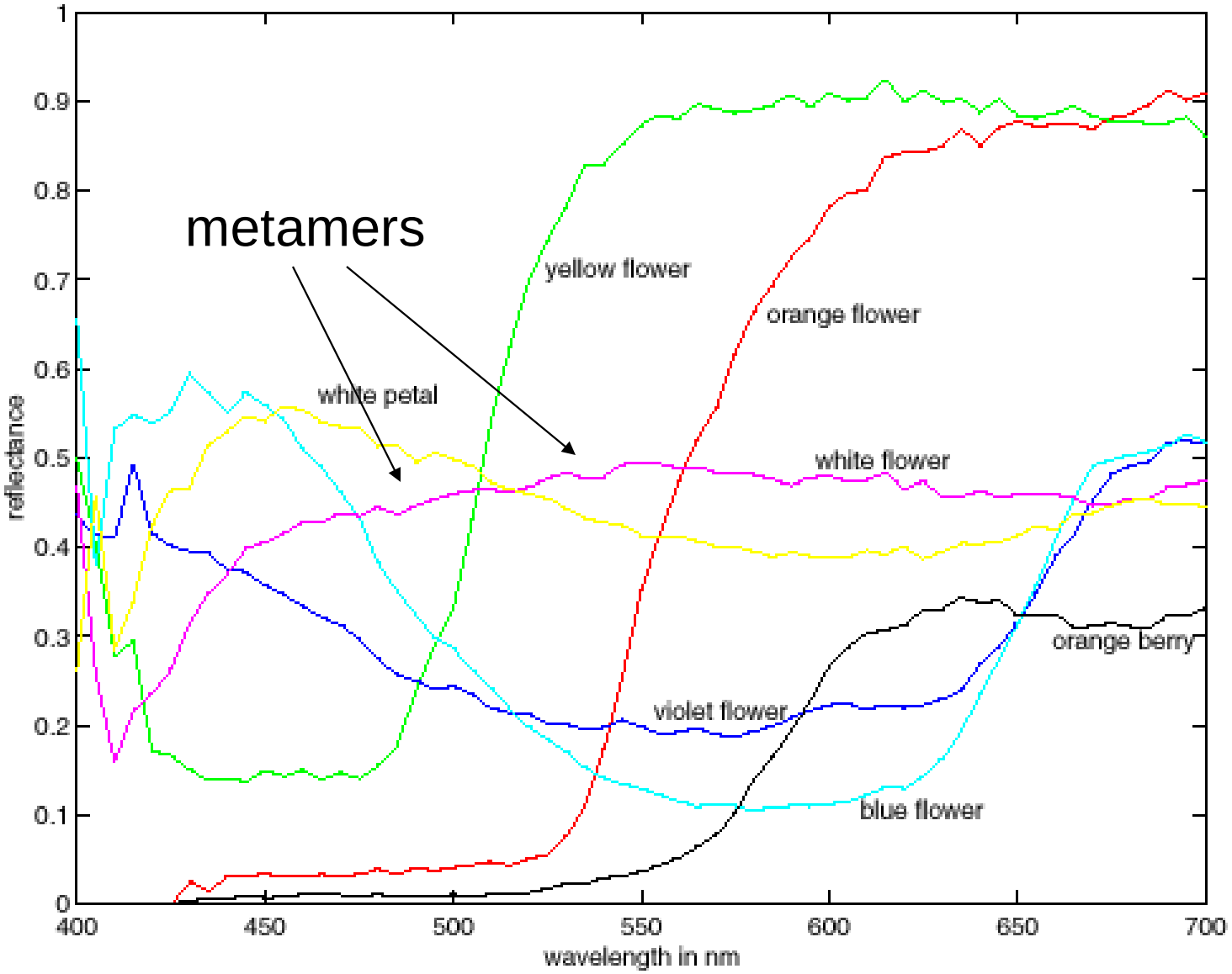


Rods and cones act as *filters* on the spectrum

- To get the output of a filter, multiply its response curve by the spectrum, integrate over all wavelengths
  - Each cone yields one number
- How can we represent an entire spectrum with 3 numbers?
- We can't! Most of the information is lost
  - As a result, two different spectra may appear indistinguishable
    - » such spectra are known as **metamers**

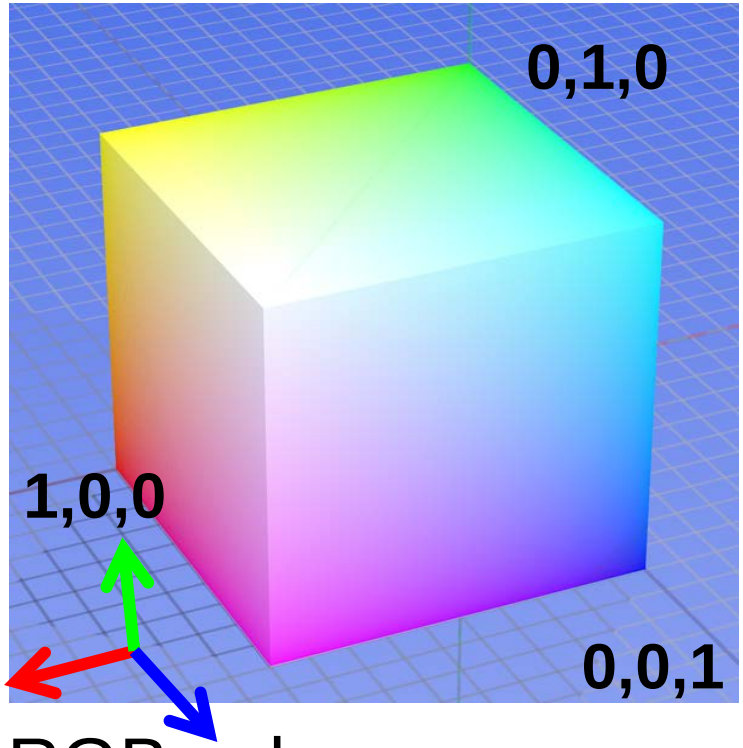
Slide by Steve Seitz

More Spectra



Color spaces: RGB

Default color space



RGB cube

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

R
(G=0,B=0)

G
(R=0,B=0)

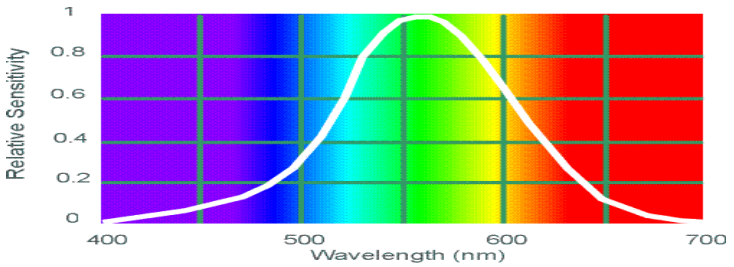
B
(R=0,G=0)

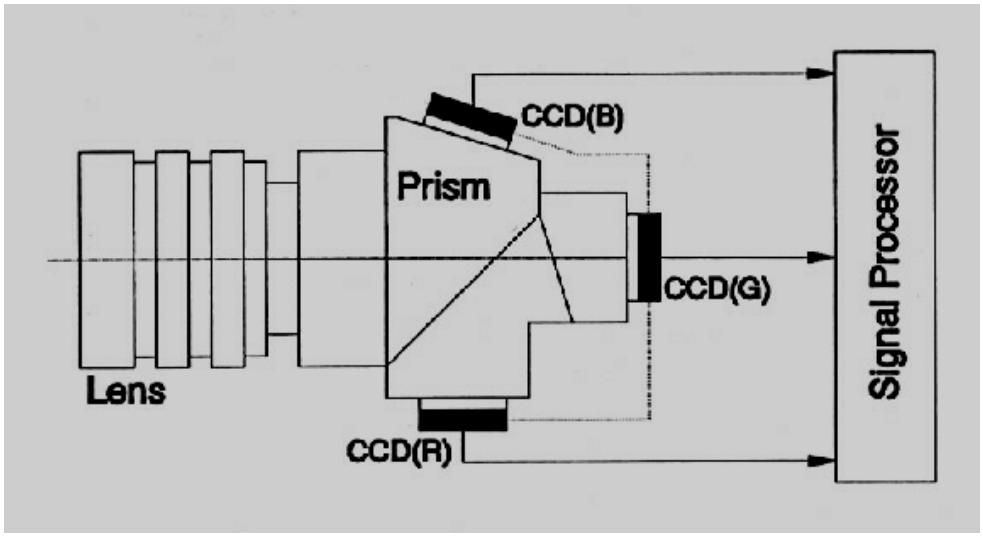
Image from: http://en.wikipedia.org/wiki/File:RGB_color_solid_cube.png

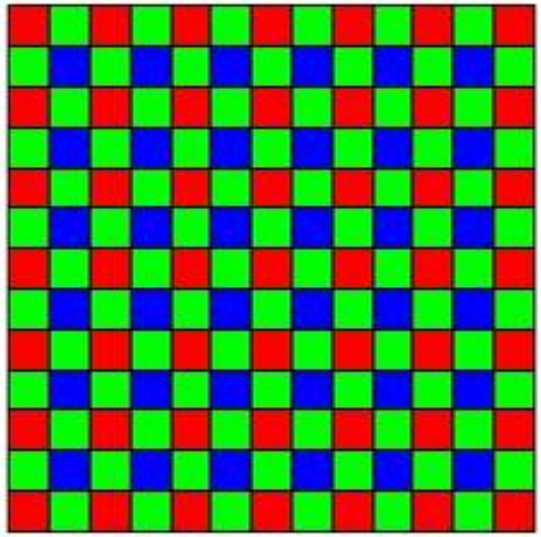
Color Sensing in Camera (RGB)

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

Why more green?







Bayer filter

Why 3 colors?

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

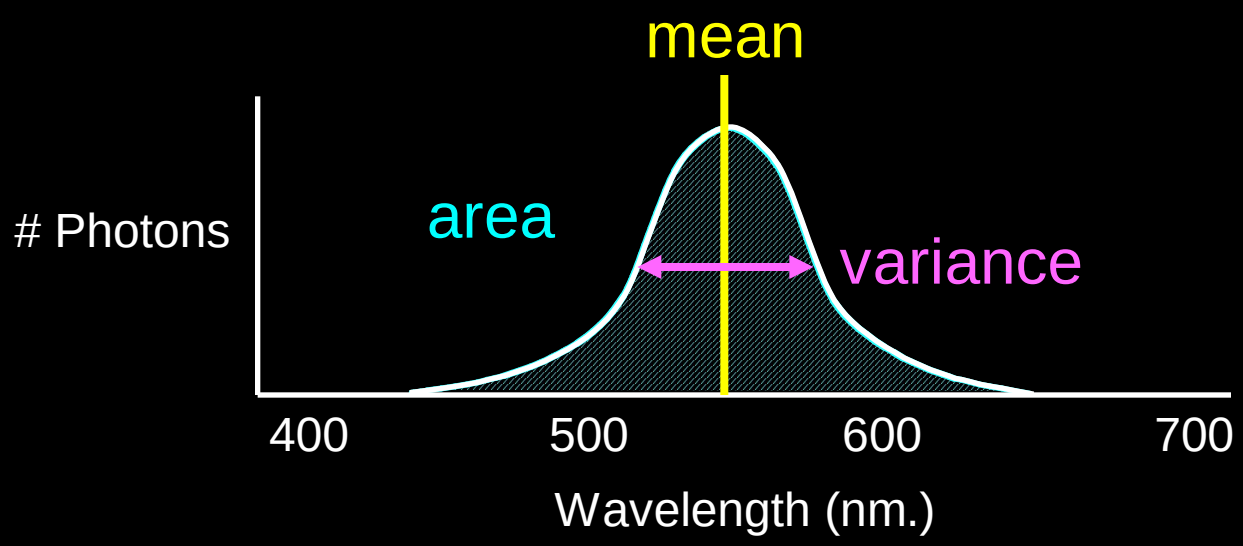
Slide by Steve Seitz

The Psychophysical Correspondence

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

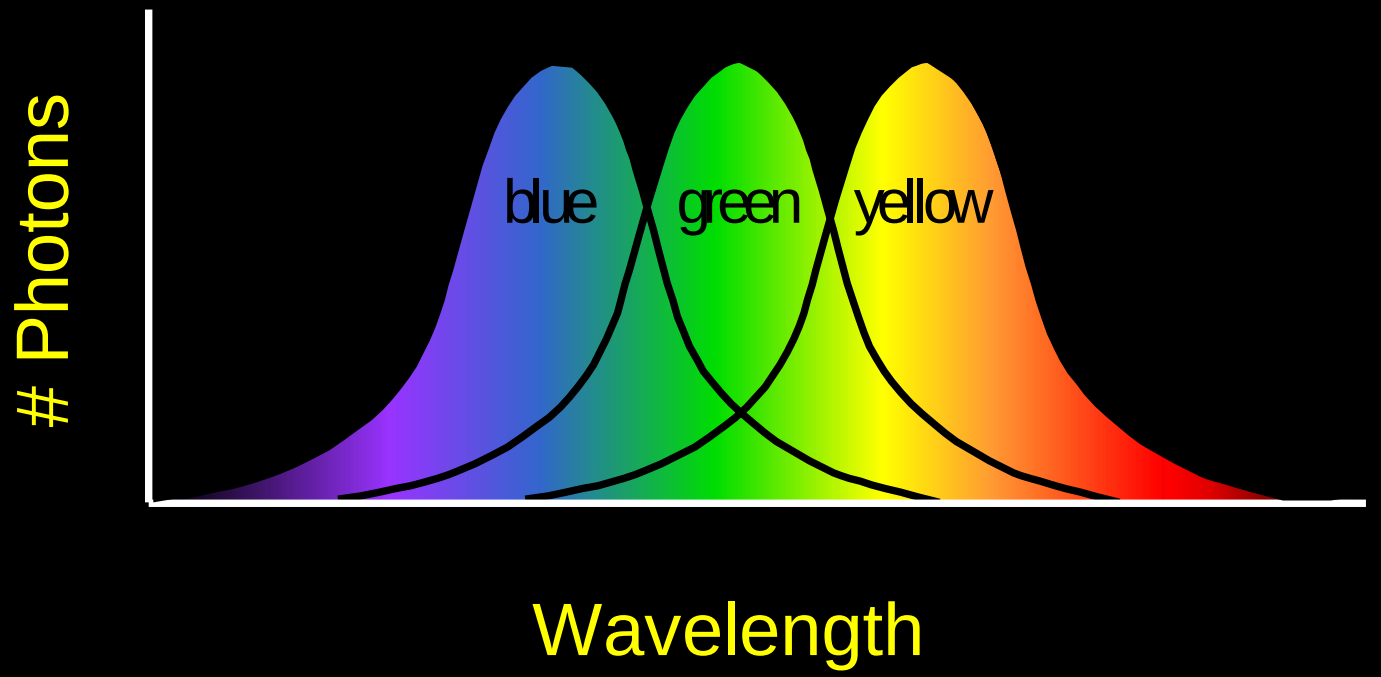
A helpful constraint:

Consider only physical spectra with normal distributions



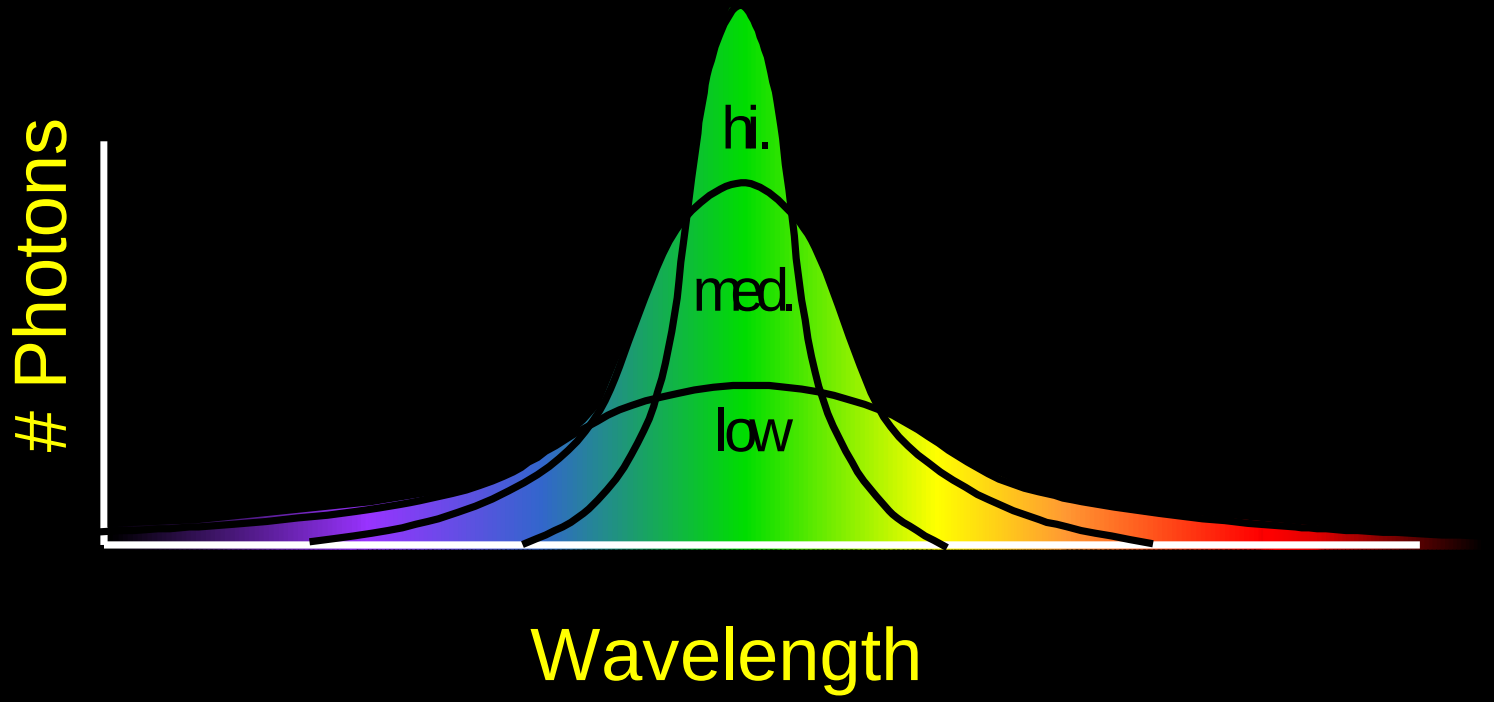
The Psychophysical Correspondence

Mean ⟷ Hue



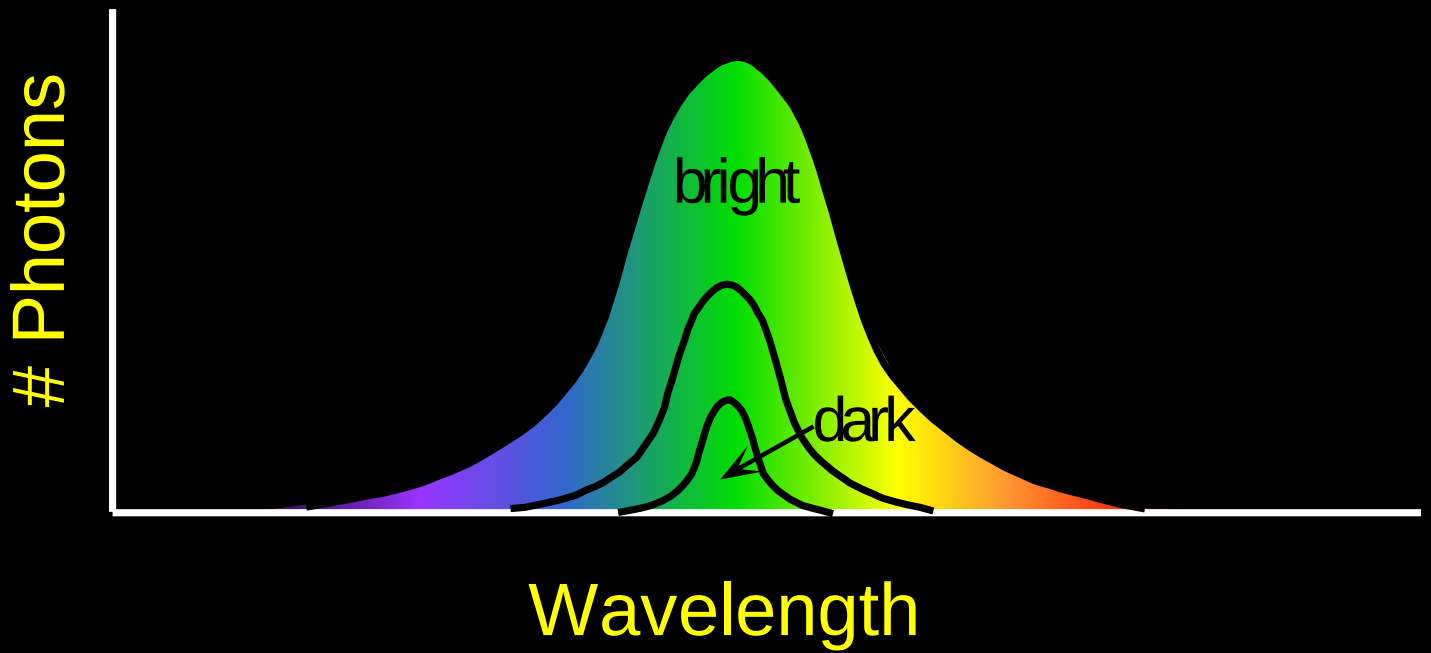
The Psychophysical Correspondence

Variance ⟷ Saturation

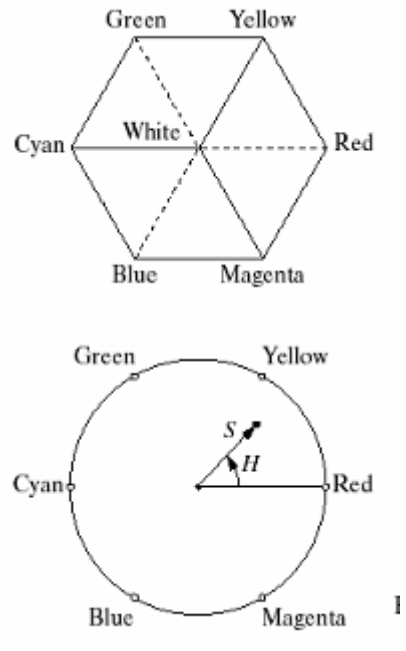


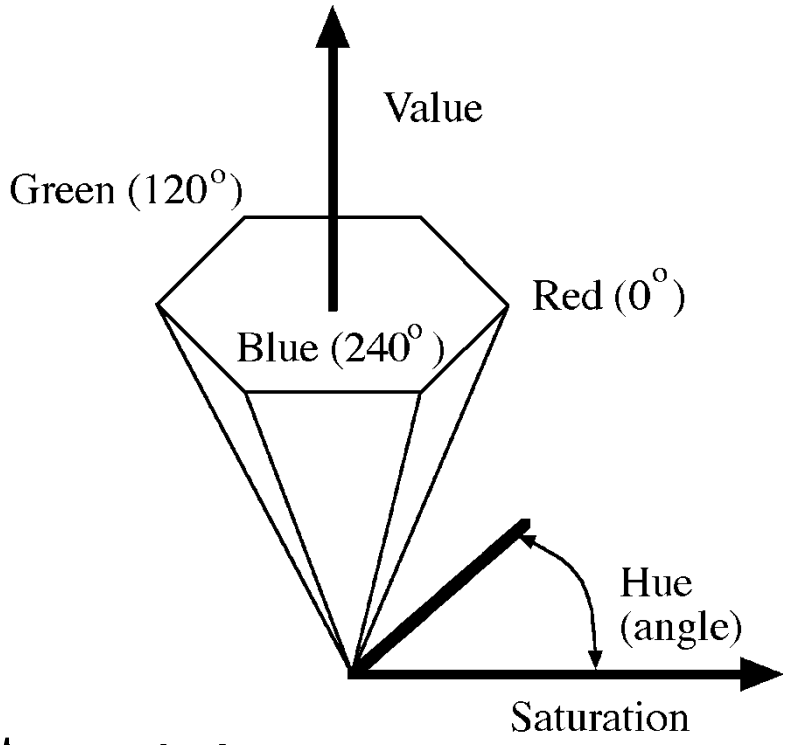
The Psychophysical Correspondence

Area ⟷ Brightness



HSV





Hue, Saturation, Value (Intensity)

- RGB cube on its vertex

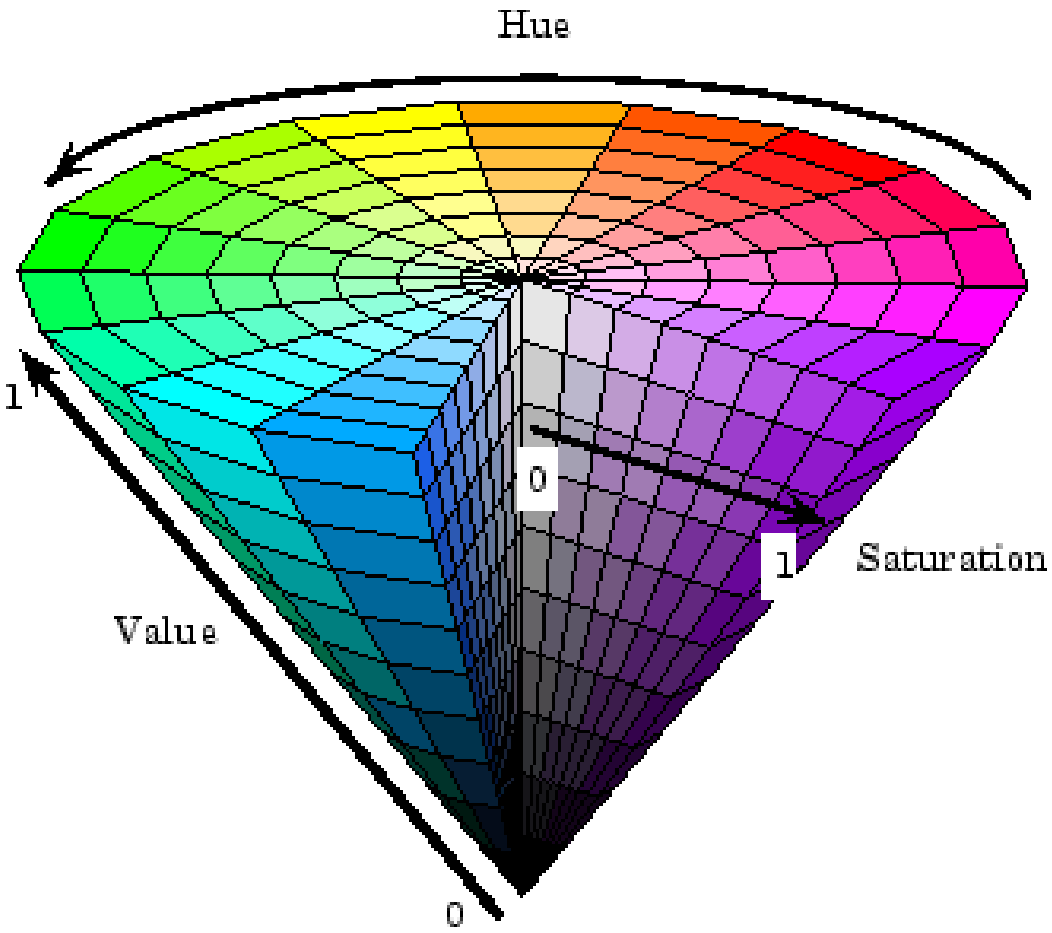
Decouples the three components (a bit)

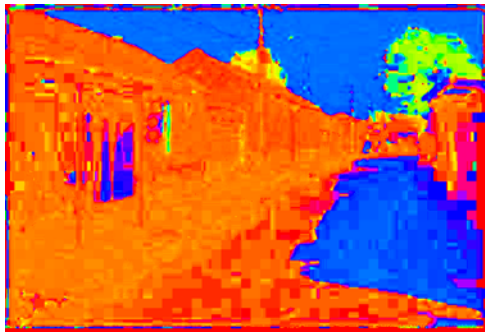
Use rgb2hsv() and hsv2rgb() in Matlab

Slide by Steve Seitz

Color spaces: HSV

Intuitive color space





H

(S=1,V=1)

S

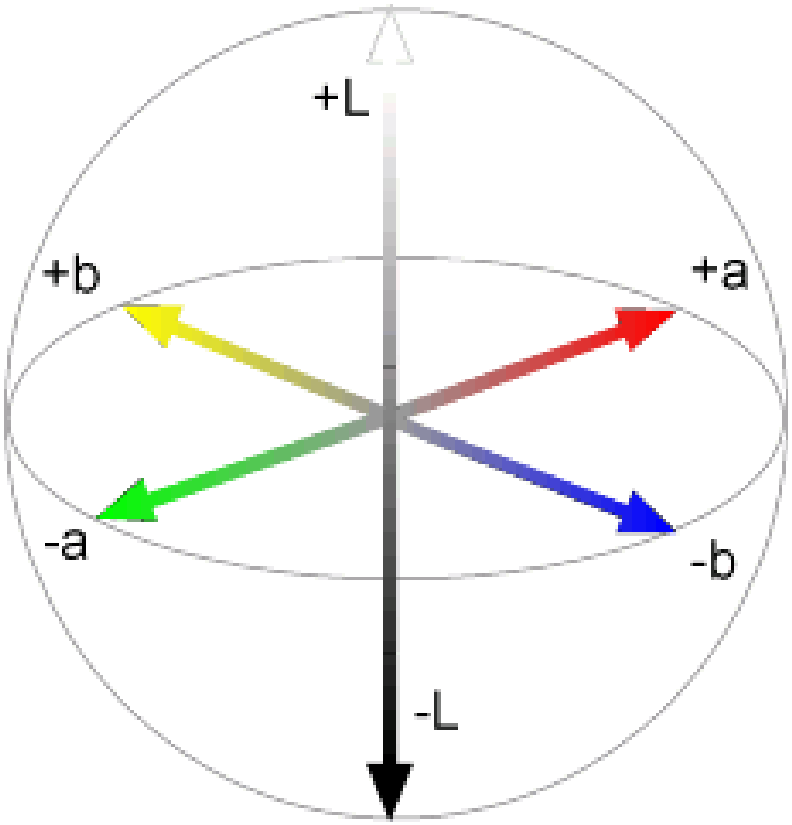
(H=1,V=1)

V

(H=1,S=0)

Color spaces: L*a*b*

"Perceptually uniform"* color space



L
(a=0,b=0)

a
(L=65,b=0)

b
(L=65,a=0)

Color Constancy

The "photometer metaphor" of color perception:
Color perception is determined by the spectrum of light on each retinal receptor (as measured by a photometer).

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Color Constancy

Do we have constancy over
all global color transformations?

60% blue filter

Complete inversion

Color Constancy

Color Constancy: the ability to perceive the invariant color of a surface despite ecological Variations in the conditions of observation.

Another of these hard inverse problems:

Physics of light emission and surface reflection underdetermine perception of surface color

Camera White Balancing

- Manual
  - Choose color-neutral object in the photos and normalize
- Automatic (AWB)
  - Grey World: force average color of scene to grey
  - White World: force brightest object to white

Different kinds of images

Radiance images, where a pixel value corresponds to the radiance from some point in the scene in the direction of the camera.

Other modalities

- X-rays, MRI…
- Light Microscopy, Electron Microscopy…
- …