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


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SNOW CRYSTALS
MATHEMATICS
MAN AND SPACE
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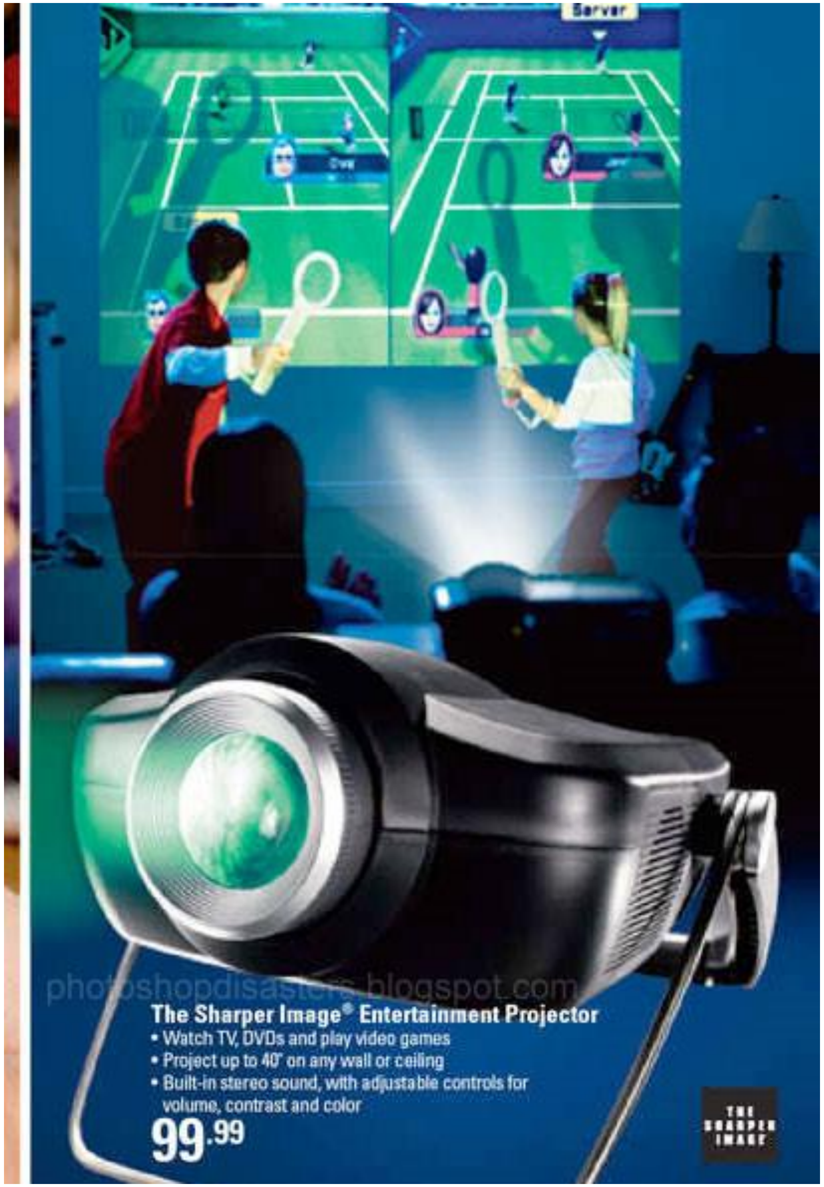
STACK-ON

What is wrong with this picture?



Recap from Lecture 2

Pinhole camera model

Perspective projections

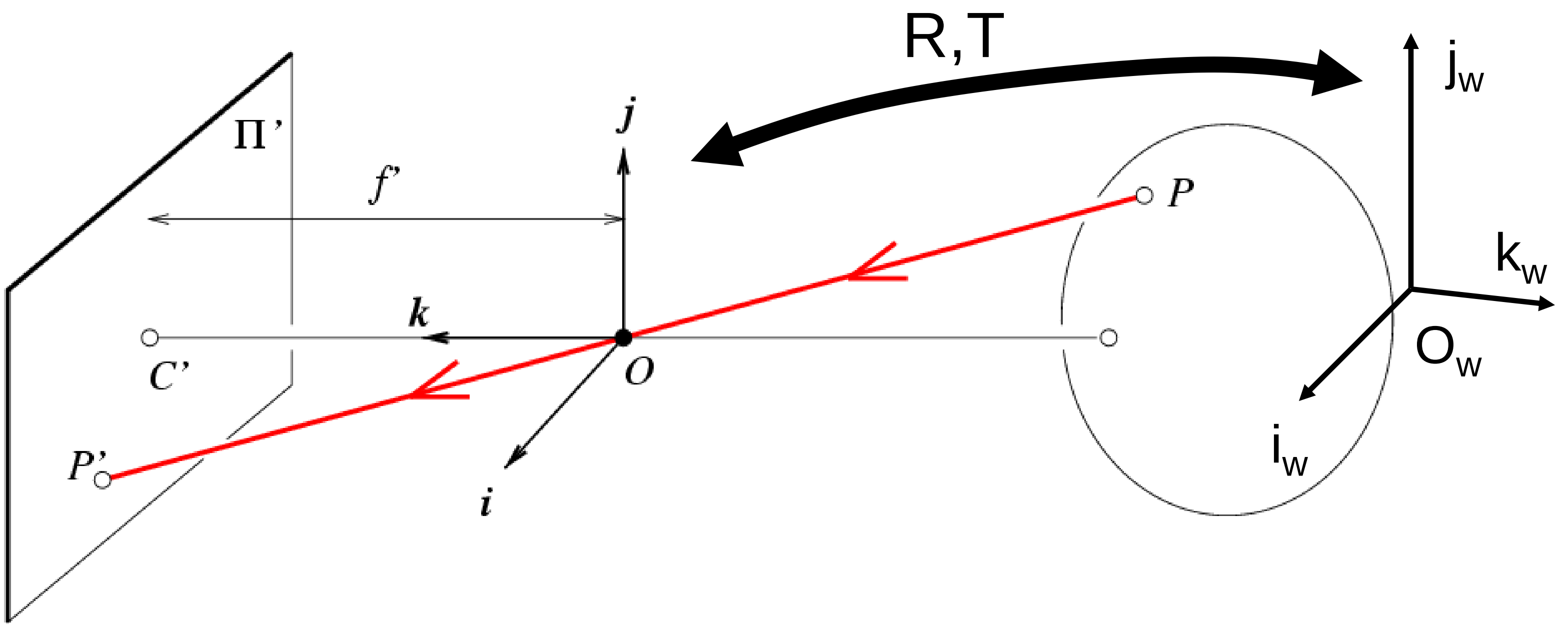
Focal length and field of view

Remember to use your textbook:

Chapter 2 of Szeliski

Slide Credit: Saverese

Recap - Projection matrix



$$\mathbf{x} = \mathbf{K}\begin{bmatrix}\mathbf{R} & \mathbf{t}\end{bmatrix}\mathbf{X}$$

x: Image Coordinates: (u,v,1)
K: Intrinsic Matrix (3x3)
R: Rotation (3x3)
t: Translation (3x1)
X: World Coordinates: (X,Y,Z,1)

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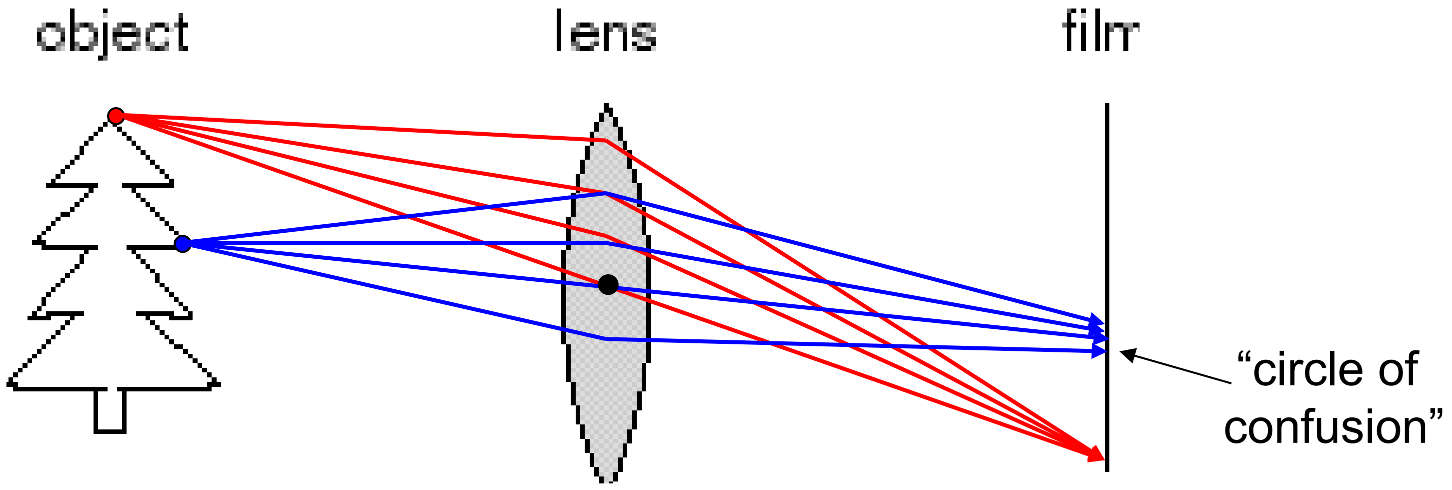
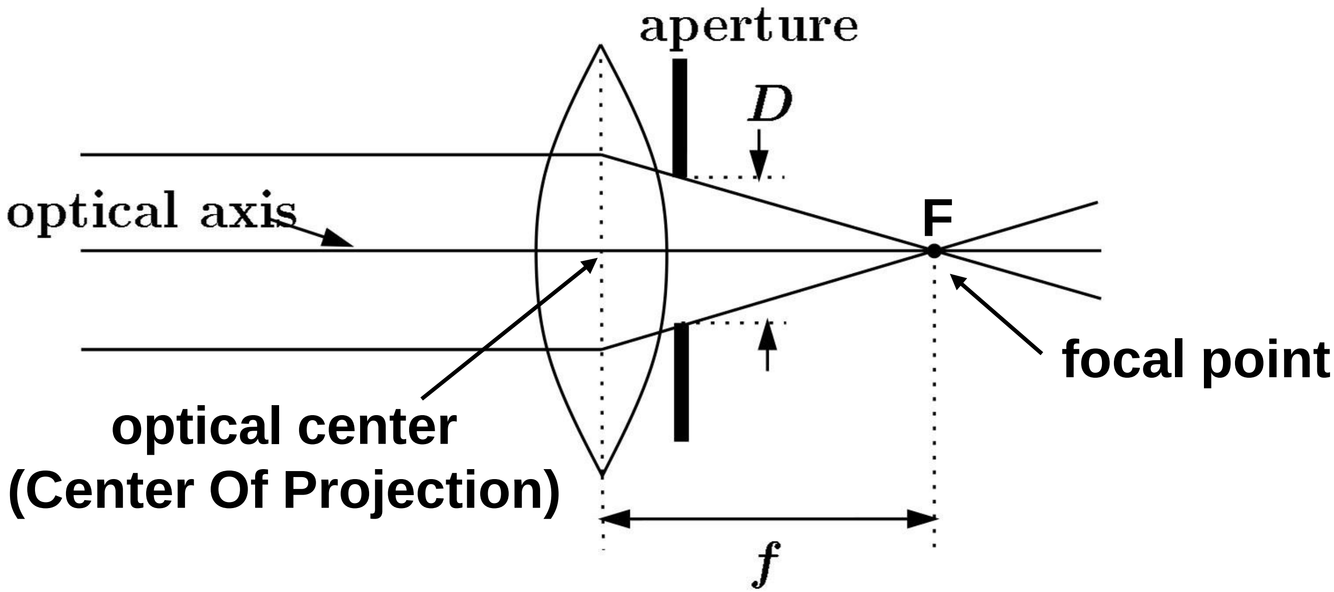
Adding a lens



A lens focuses light onto the film

- There is a specific distance at which objects are “in focus”
  - other points project to a “circle of confusion” in the image
- Changing the shape of the lens changes this distance

Focal length, aperture, depth of field



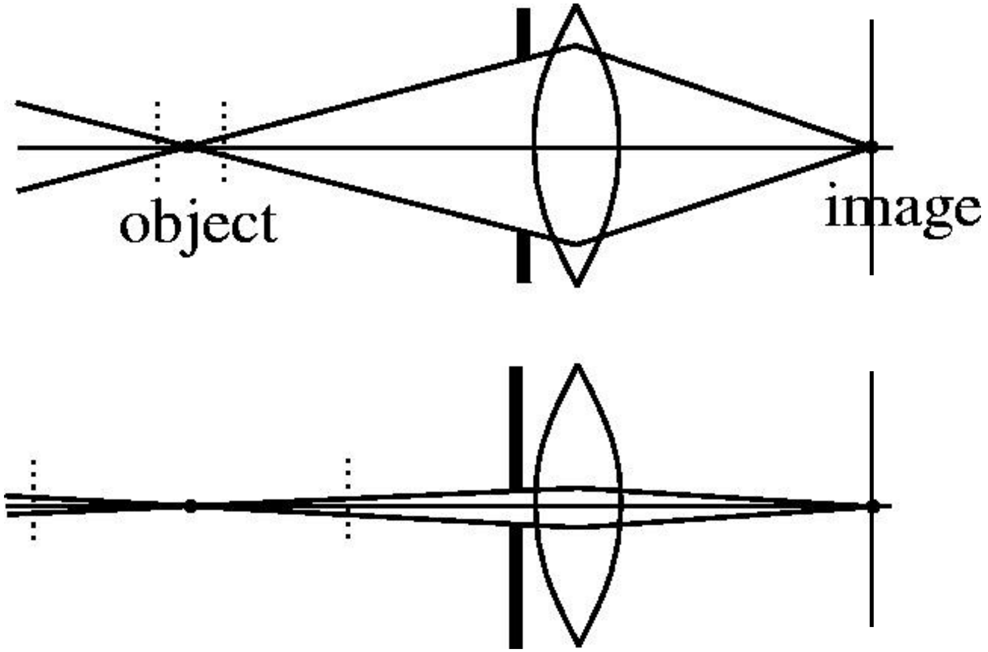
A lens focuses parallel rays onto a single focal point

- focal point at a distance *f* beyond the plane of the lens
- Aperture of diameter D restricts the range of rays

Slide source: Seitz

Slide source: Seitz

Depth of field



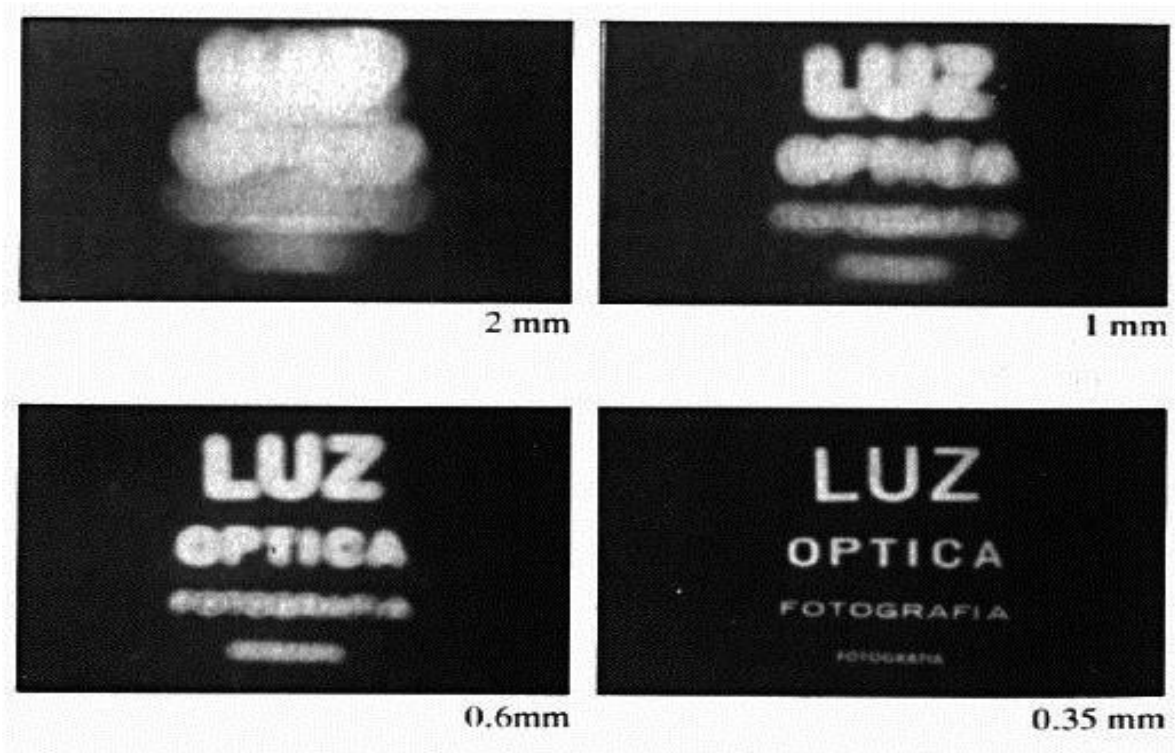
f / 5.6

f / 32

Changing the aperture size or focal length affects depth of field

Flower images from Wikipedia http://en.wikipedia.org/wiki/Depth_of_field

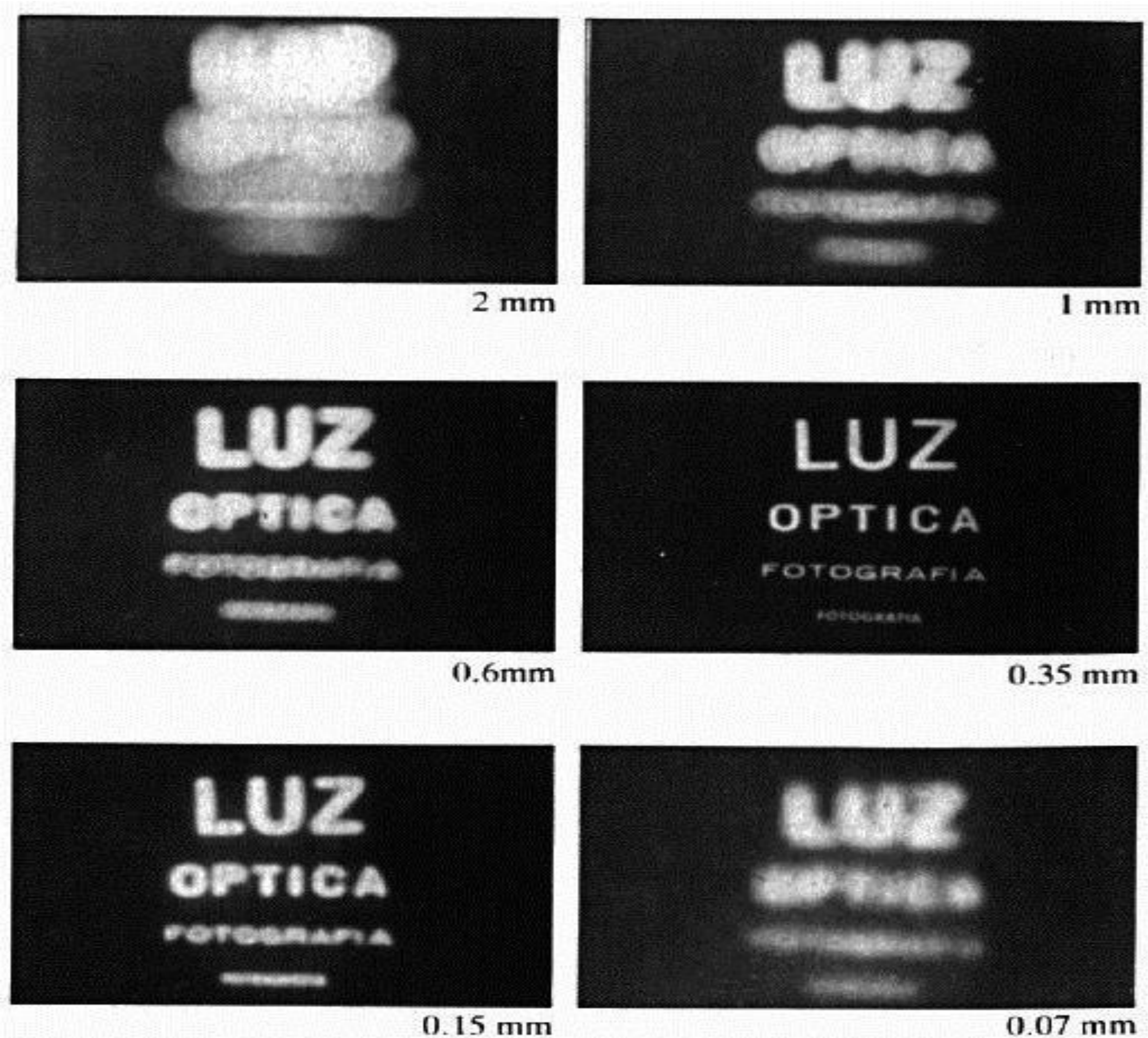
Shrinking the aperture



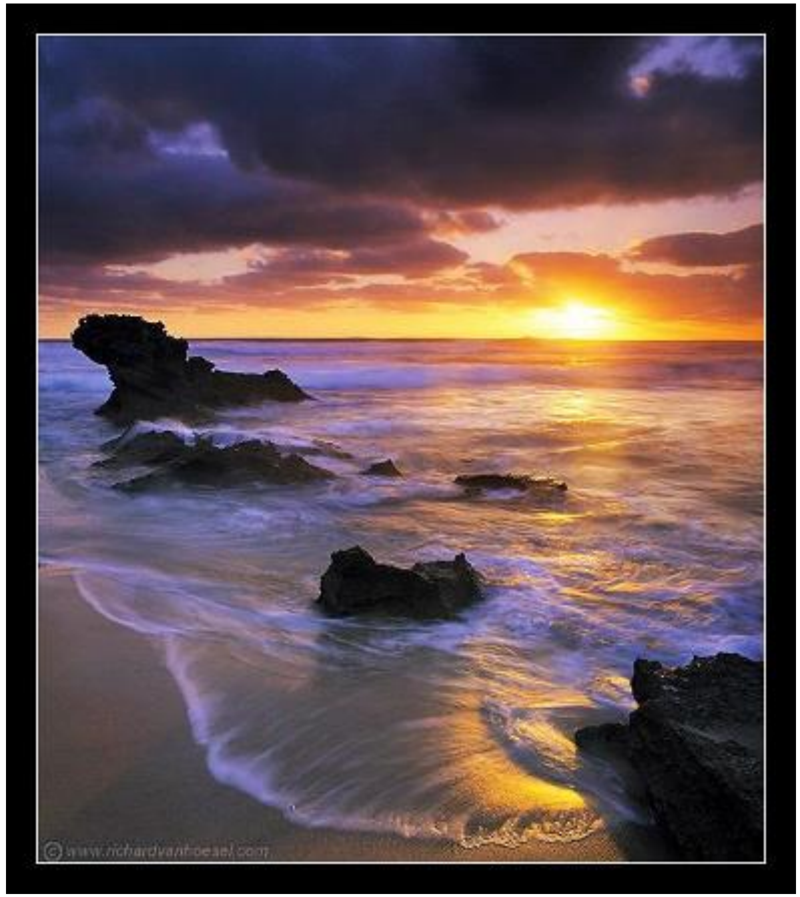
Why not make the aperture as small as possible?

- Less light gets through
- Diffraction effects

Shrinking the aperture



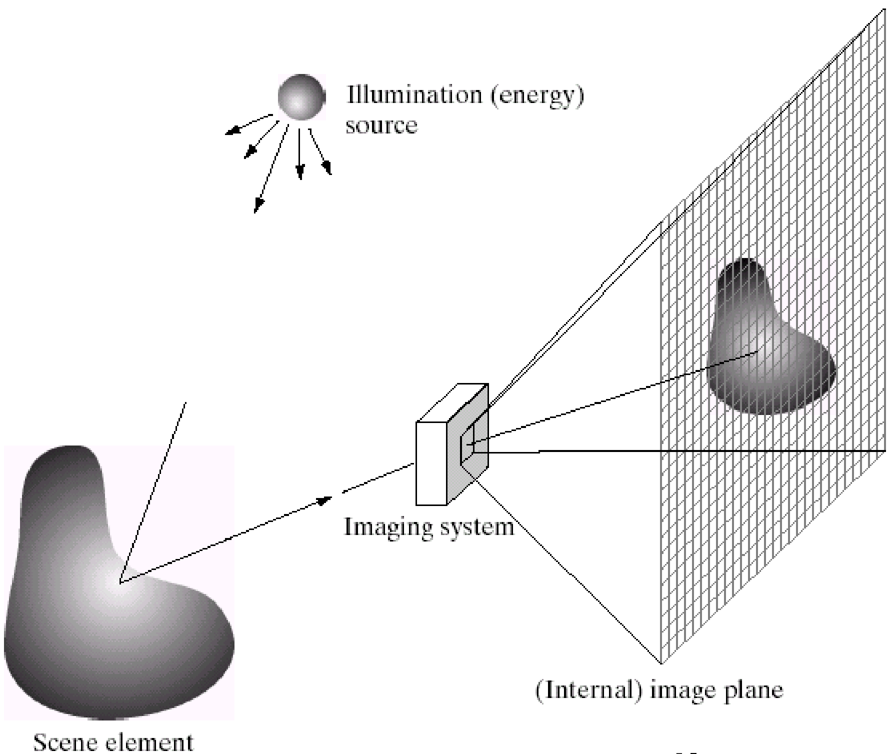
Capturing Light… in man and machine



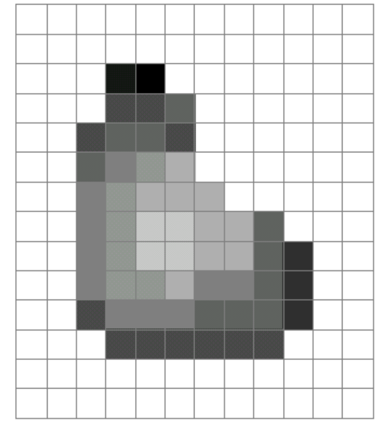
Many slides by
Alexei A. Efros

CS 143: Computer Vision
James Hays, Brown, Fall 2013

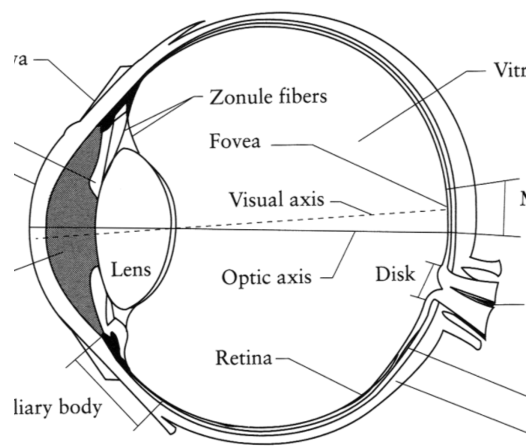
Image Formation



Film



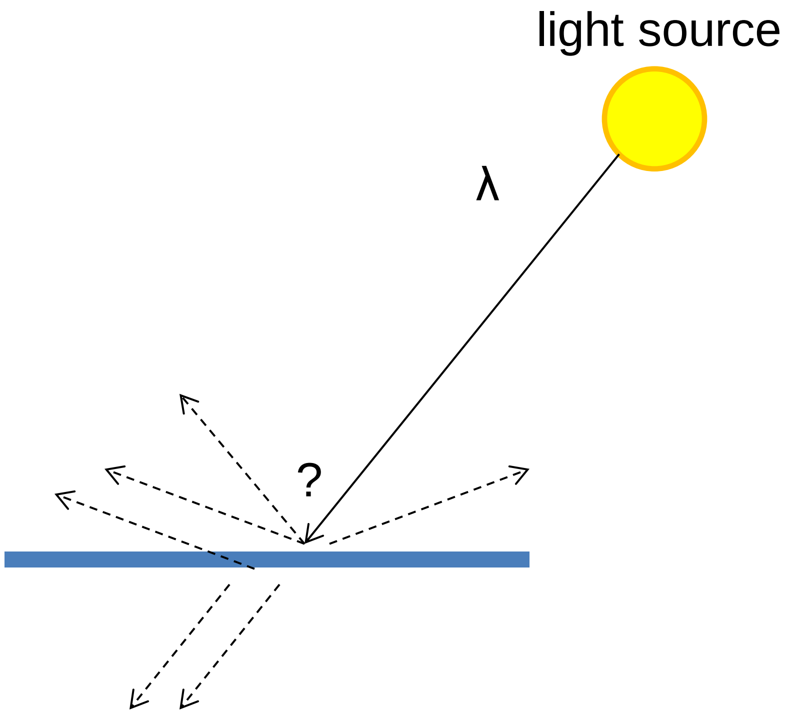
Digital Camera



The Eye

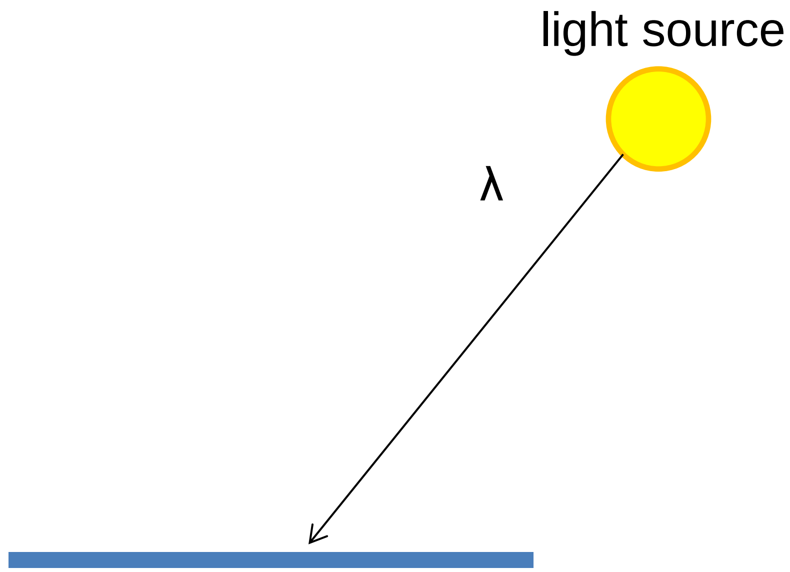
A photon's life choices

- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



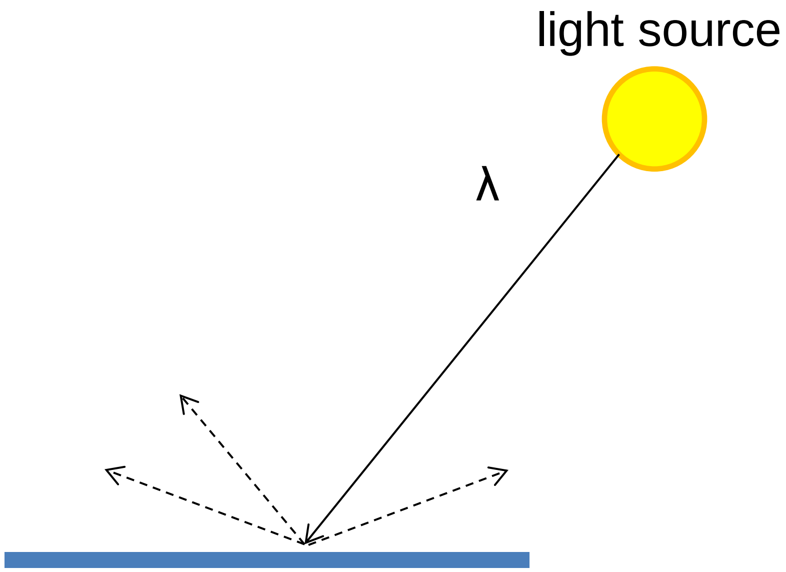
A photon's life choices

- **Absorption**
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



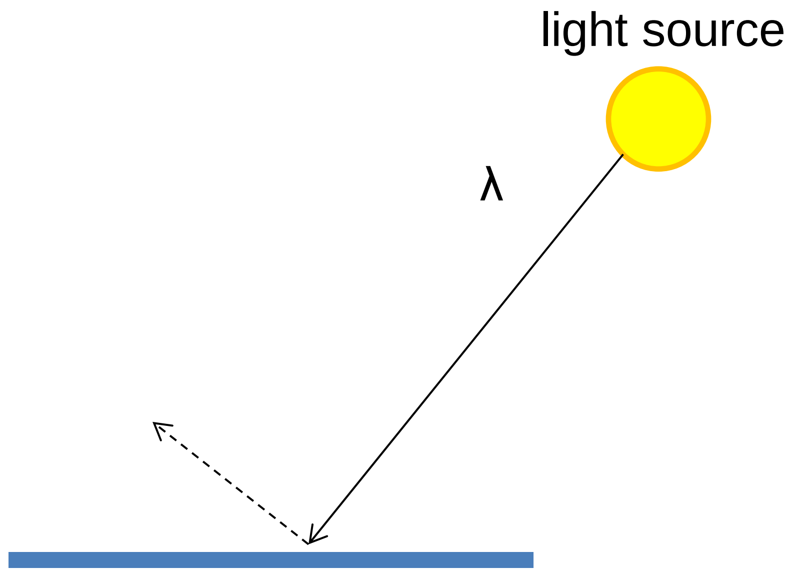
A photon's life choices

- Absorption
- **Diffuse Reflection**
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



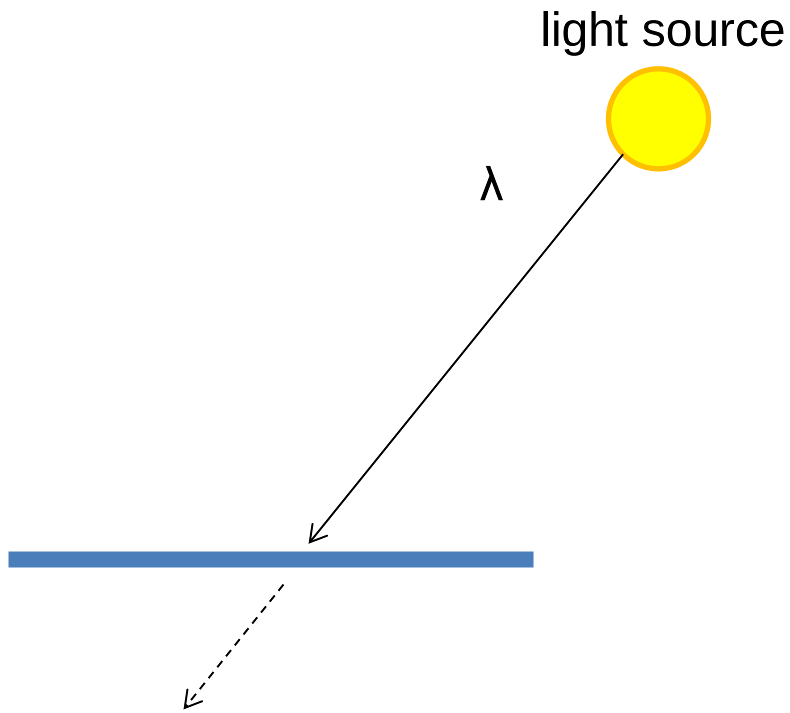
A photon's life choices

- Absorption
- Diffusion
- **Specular Reflection**
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



A photon's life choices

- Absorption
- Diffusion
- Reflection
- **Transparency**
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



A photon's life choices

- Absorption
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- Transparency
- **Refraction**
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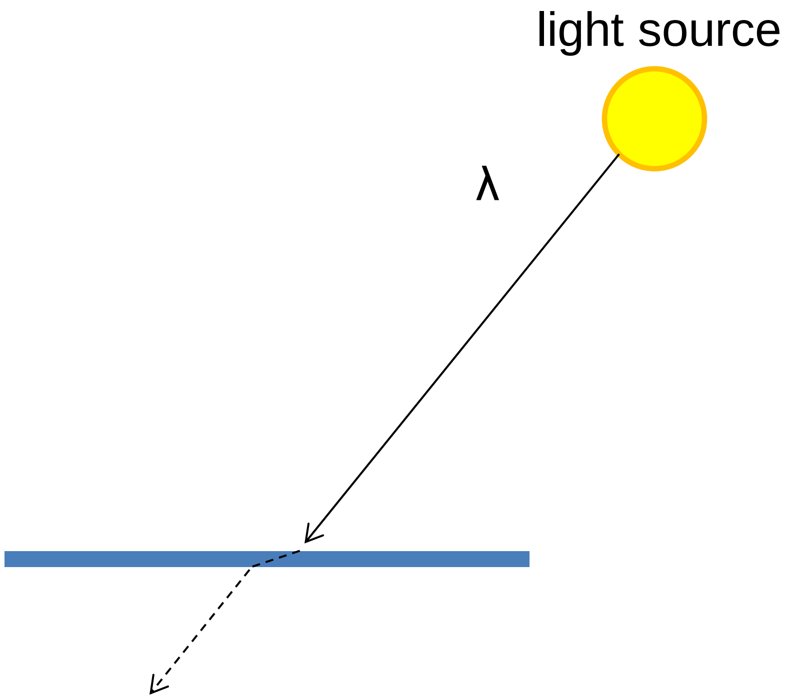

A photon's life choices

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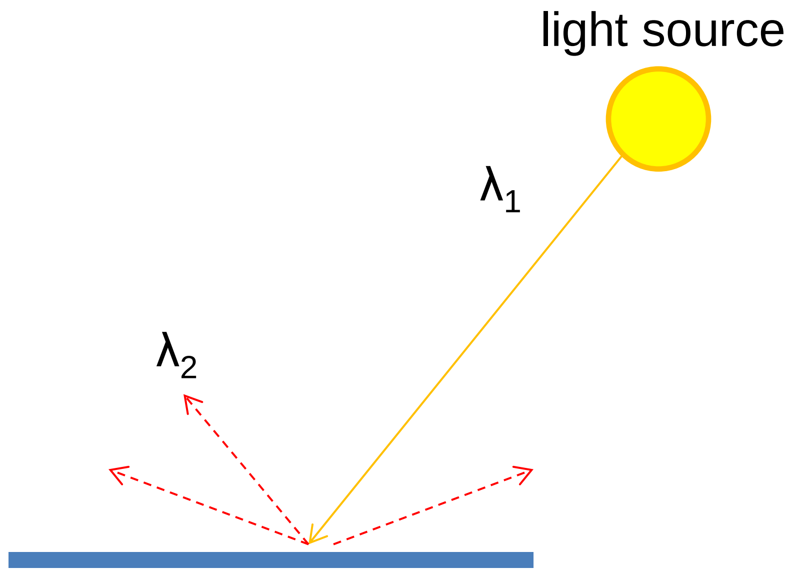

A photon's life choices

- Absorption
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- **Subsurface scattering**
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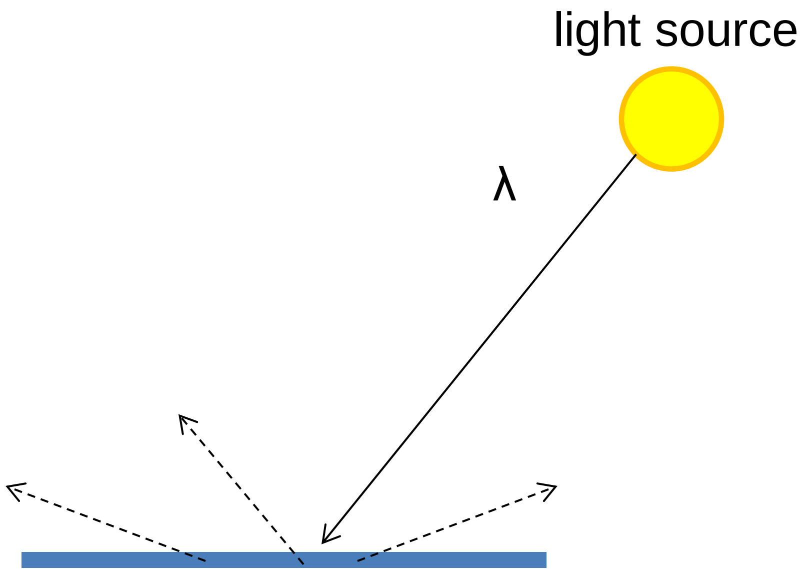

A photon's life choices

- Absorption
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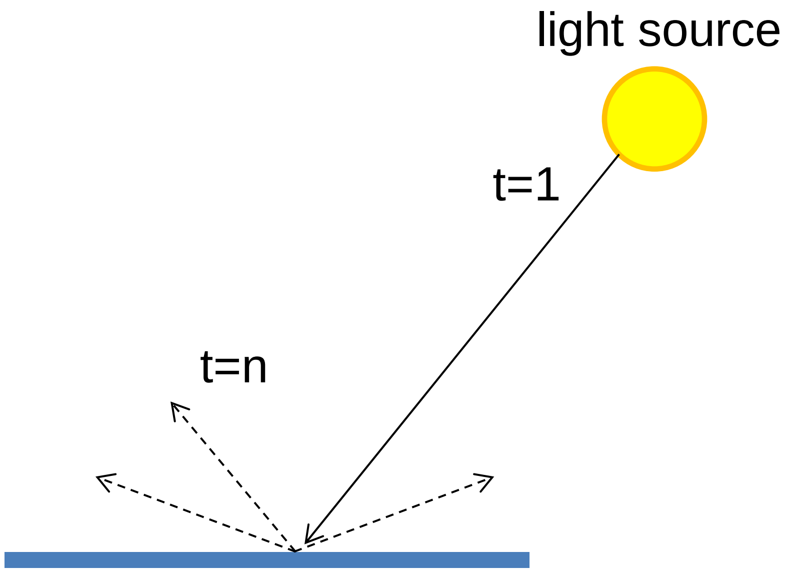
- Subsurface scattering
- **Phosphorescence**
- Interreflection



A photon’s life choices

- Absorption
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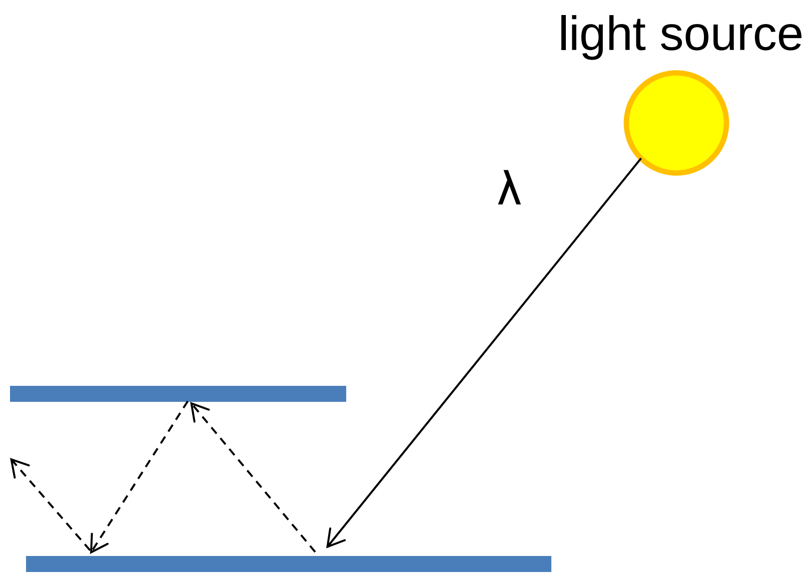
- Subsurface scattering
- Phosphorescence
- **Interreflection**



(Specular Interreflection)

Lambertian Reflectance

- In computer vision, surfaces are often assumed to be ideal diffuse reflectors with know dependence on viewing direction.

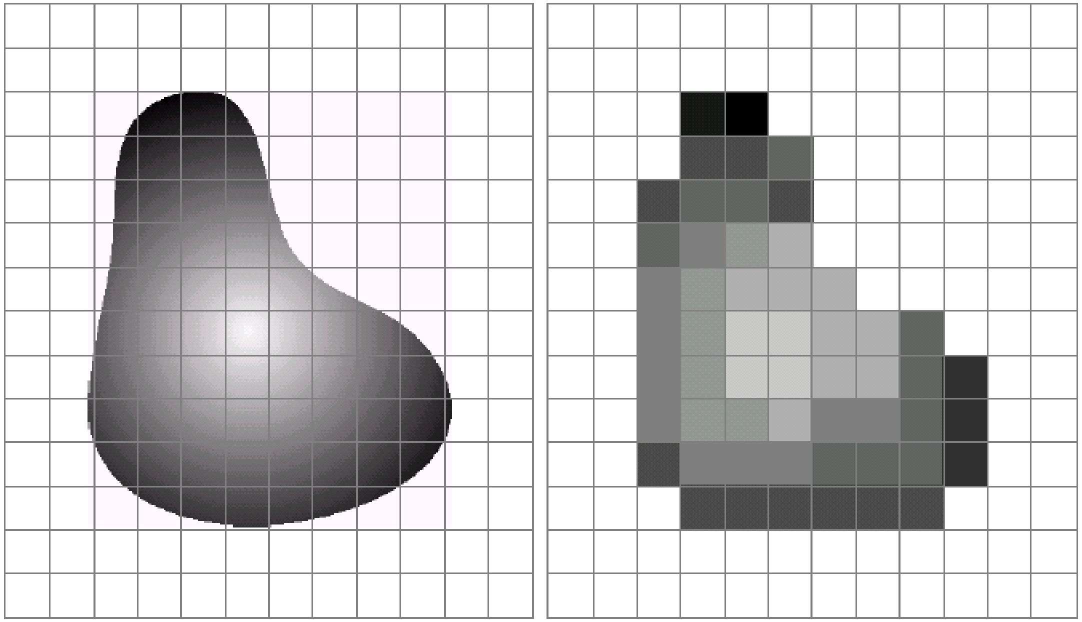
Digital camera

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

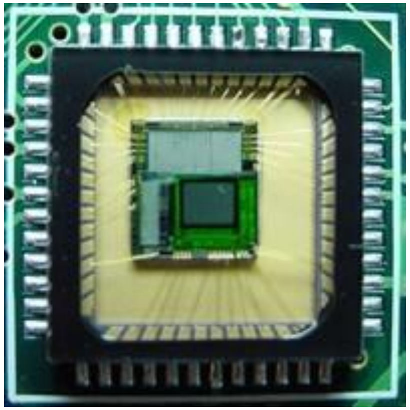
Slide by Steve Seitz

Sensor Array



a b

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



CMOS sensor

Sampling and Quantization

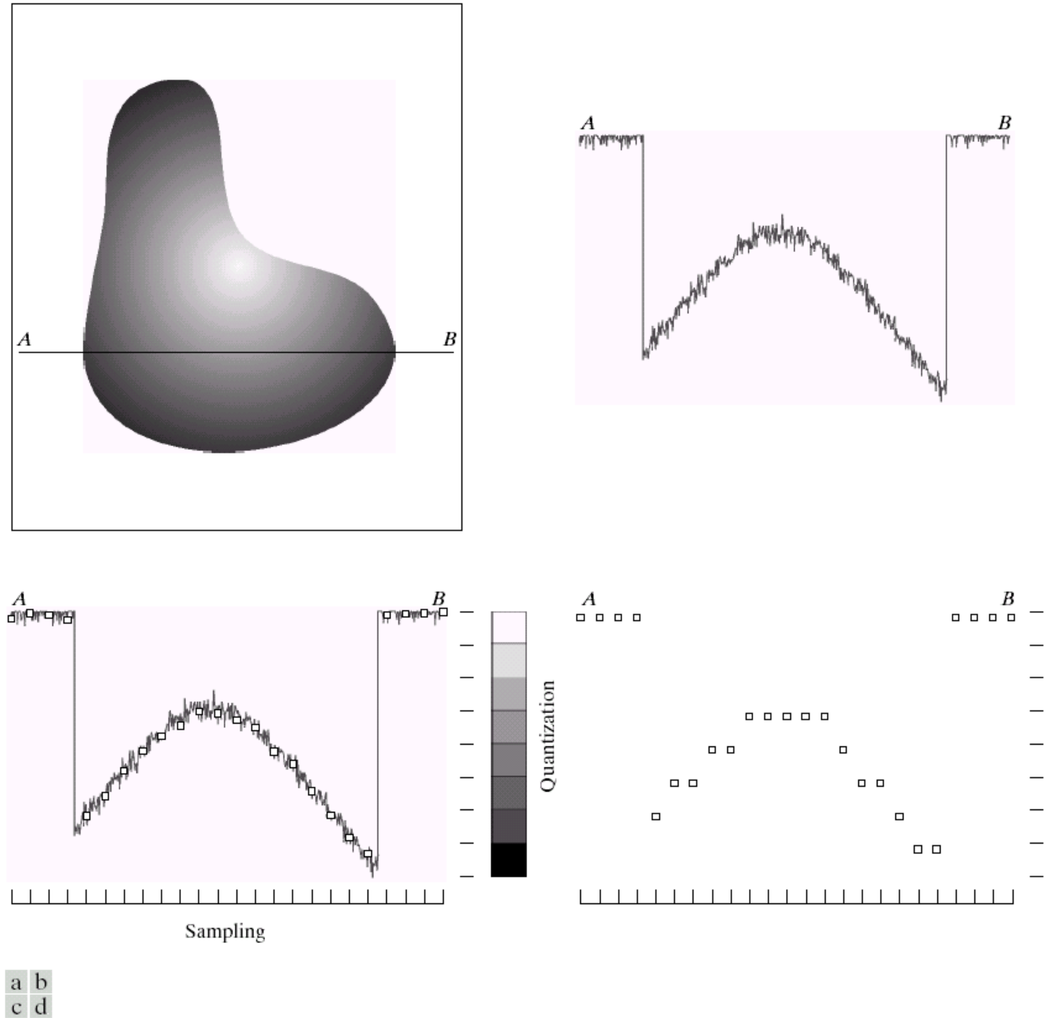
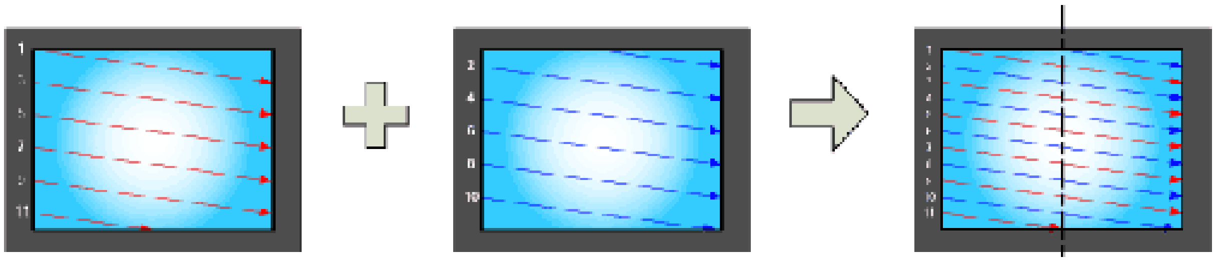


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

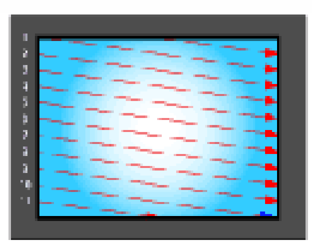
Interlace vs. progressive scan



1st field: Odd field

2nd field: Even field

One complete frame
using interlaced scanning



One complete frame
using progressive scanning

http://www.axis.com/products/video/camera/progressive_scan.htm

Slide by Steve Seitz

Progressive scan

http://www.axis.com/products/video/camera/progressive_scan.htm

Slide by Steve Seitz

Interlace

http://www.axis.com/products/video/camera/progressive_scan.htm

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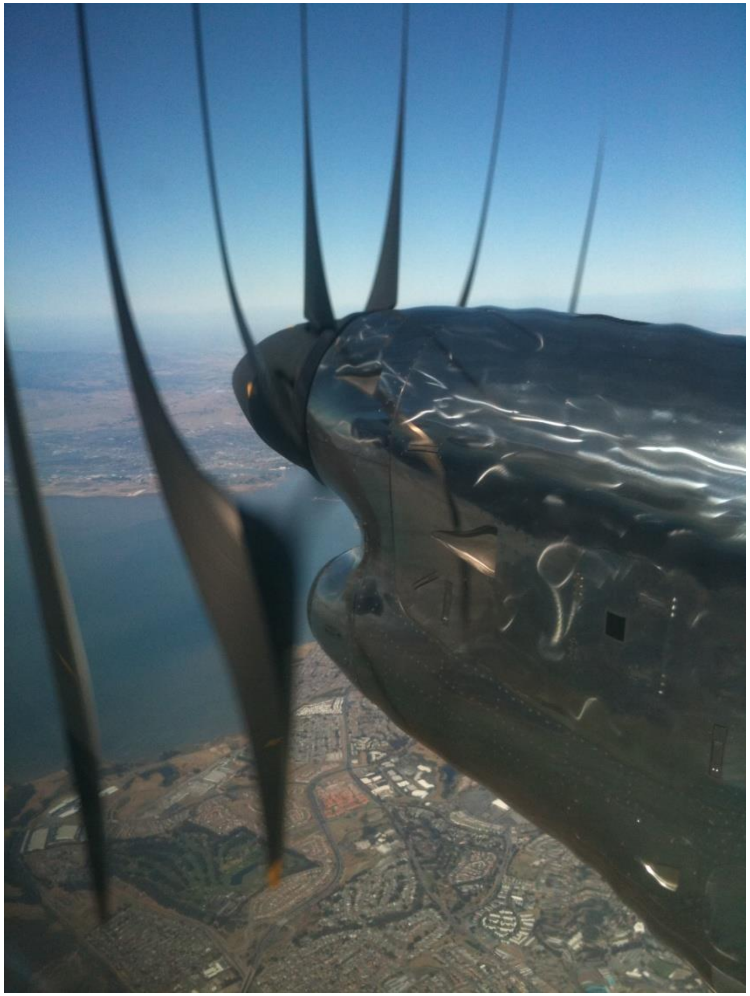
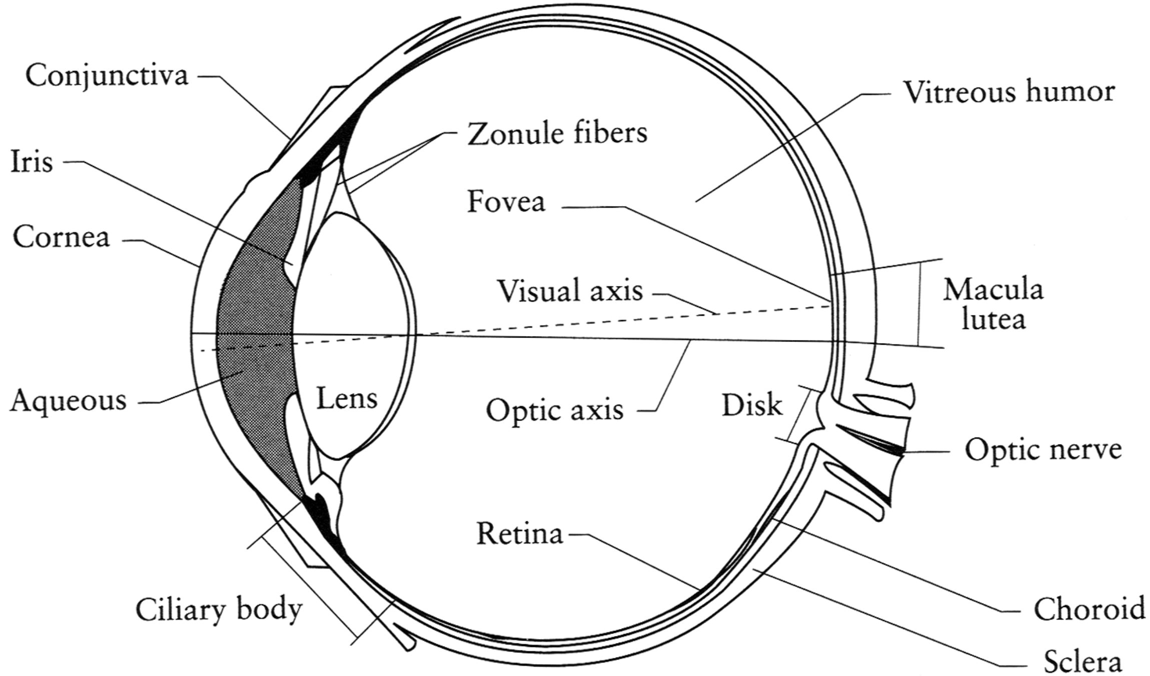
Rolling Shutter



The Eye

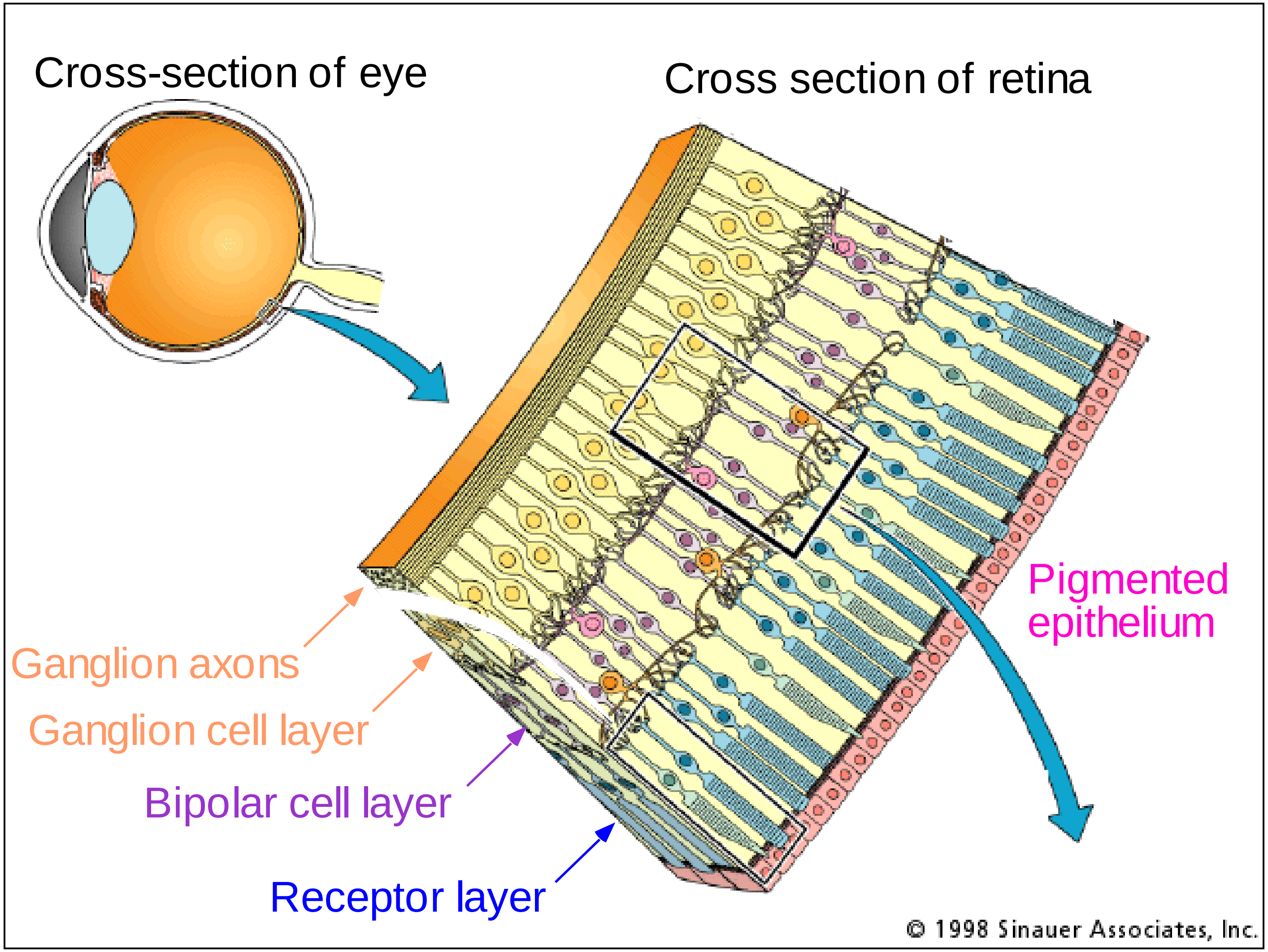


The human eye is a camera!

- **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**

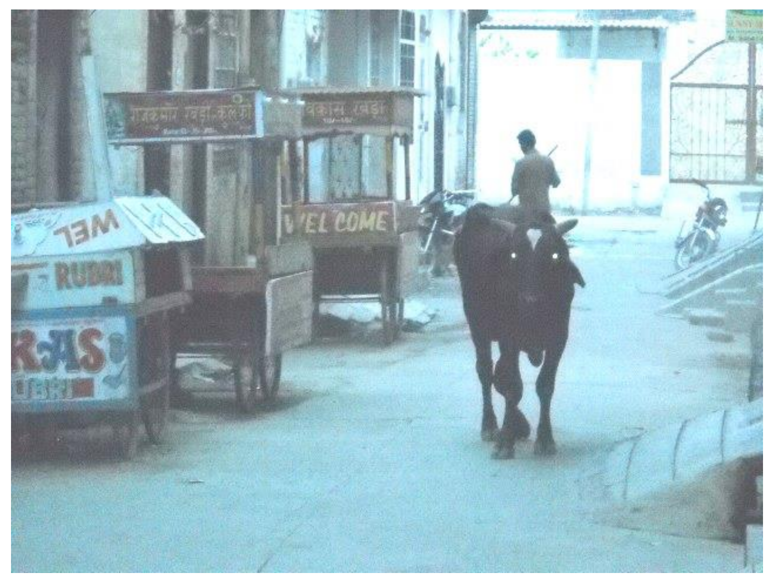
Slide by Steve Seitz

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.

What humans don't have: tapetum lucidum



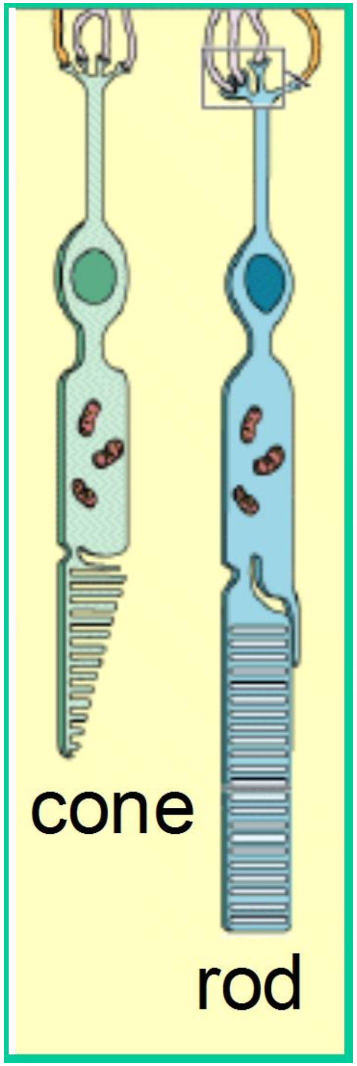
Two types of light-sensitive receptors

Cones

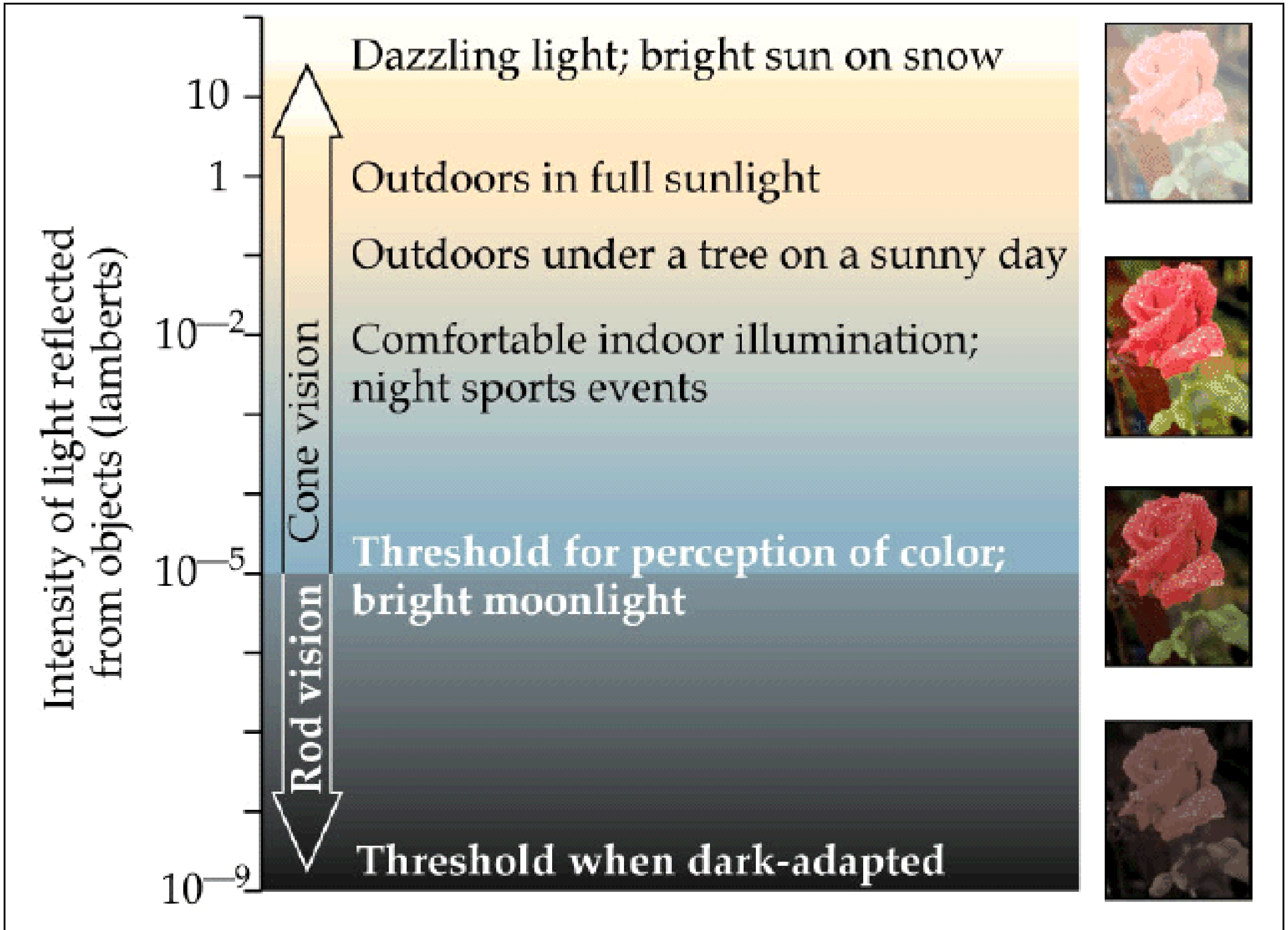
cone-shaped
less sensitive
operate in high light
color vision

Rods

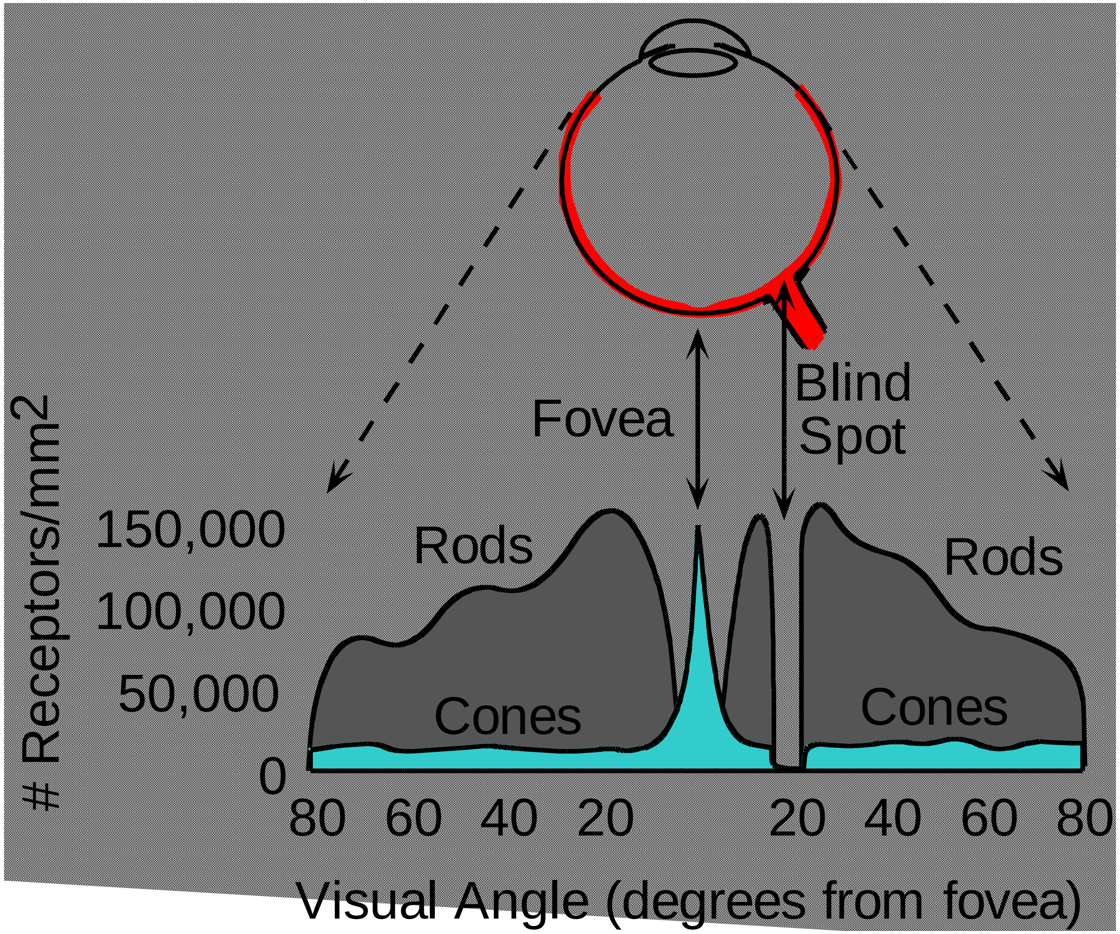
rod-shaped
highly sensitive
operate at night
gray-scale vision



Rod / Cone sensitivity



Distribution of Rods and Cones



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

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

Eye Movements

Saccades

Can be consciously controlled. Related to perceptual attention.

200ms to initiation, 20 to 200ms to carry out. Large amplitude.

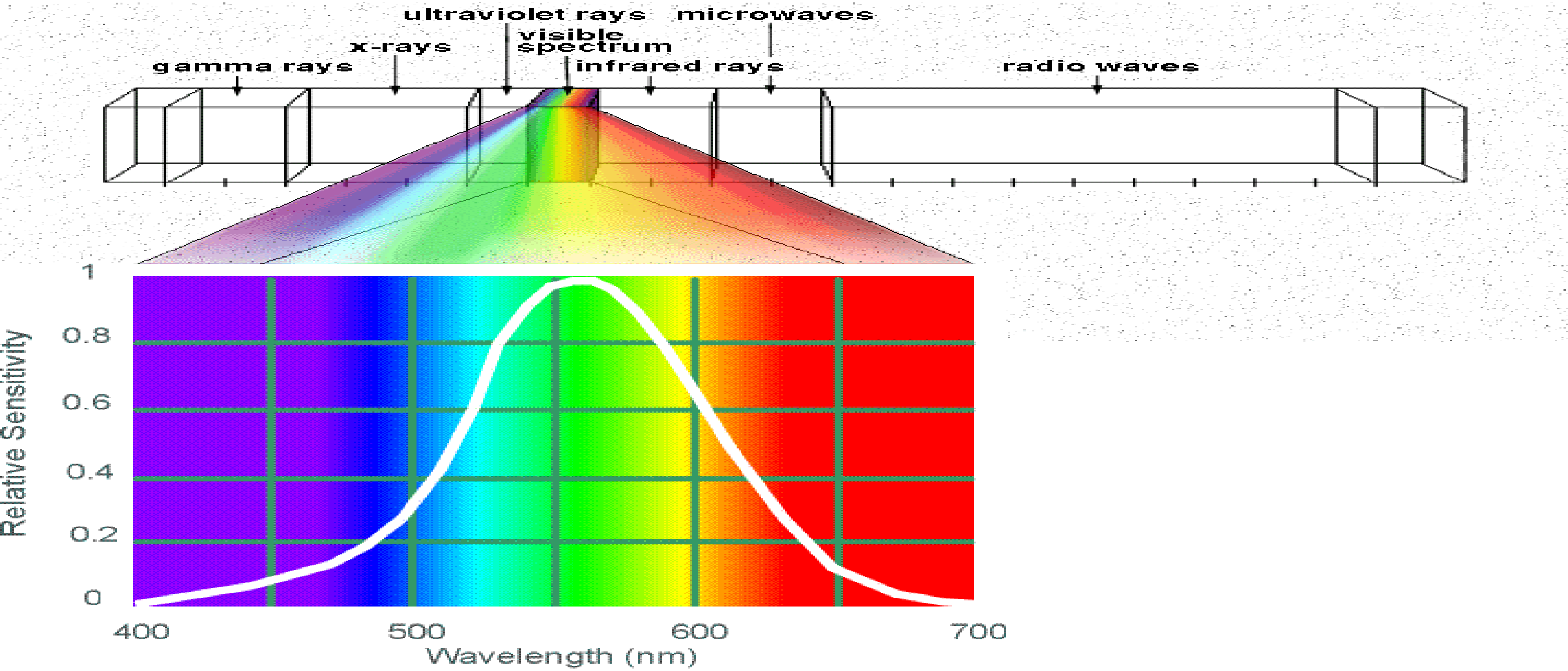
Microsaccades

Involuntary. Smaller amplitude. Especially evident during prolonged fixation. Function debated.

Ocular microtremor (OMT)

involuntary. high frequency (up to 80Hz), small amplitude.

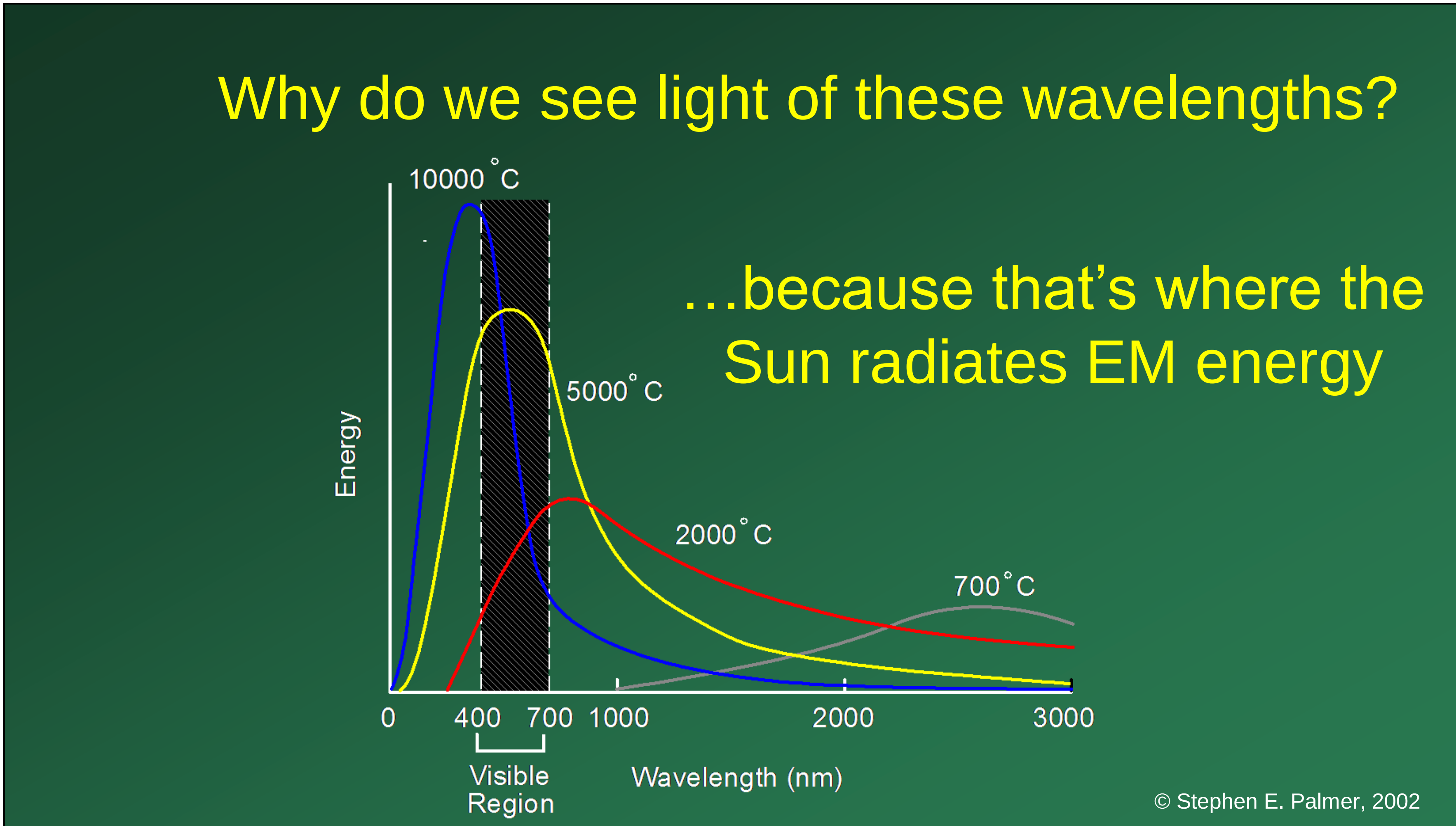
Electromagnetic Spectrum



Human Luminance Sensitivity Function

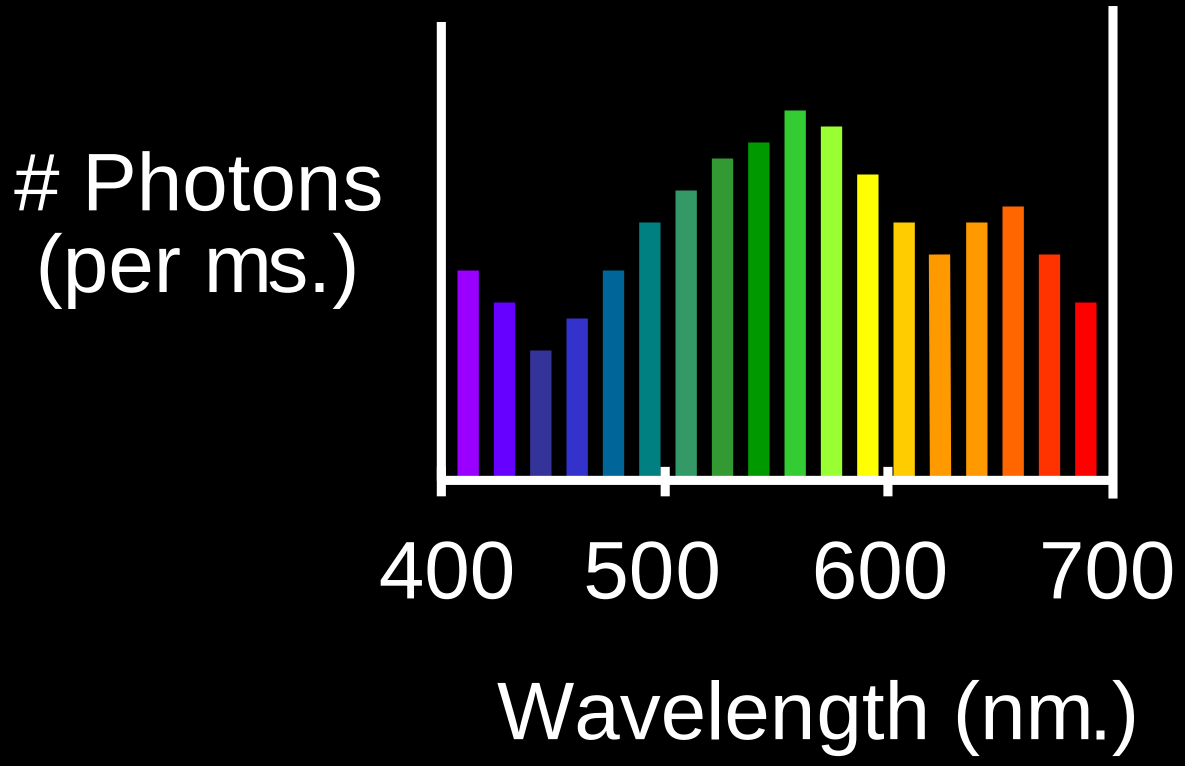
http://www.yorku.ca/eye/photopik.htm

Visible Light



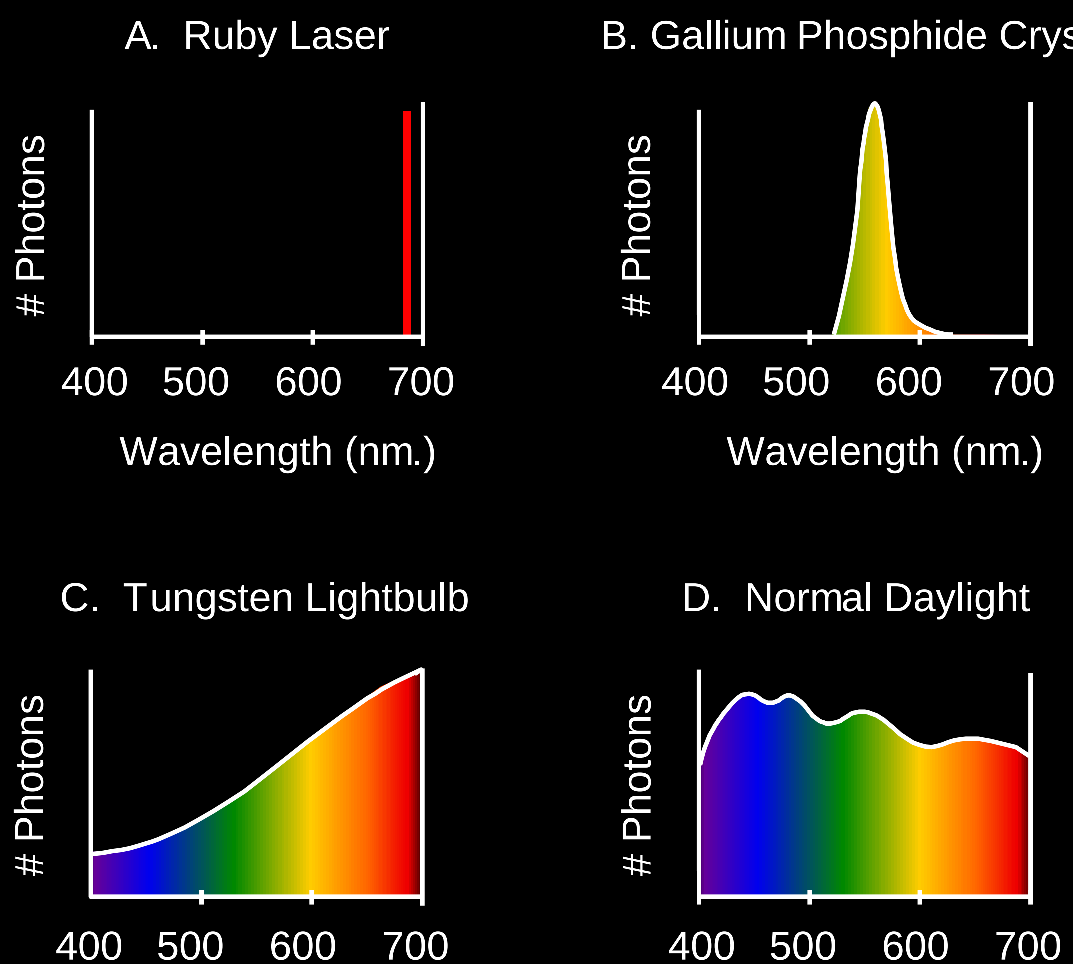
The Physics of Light

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.



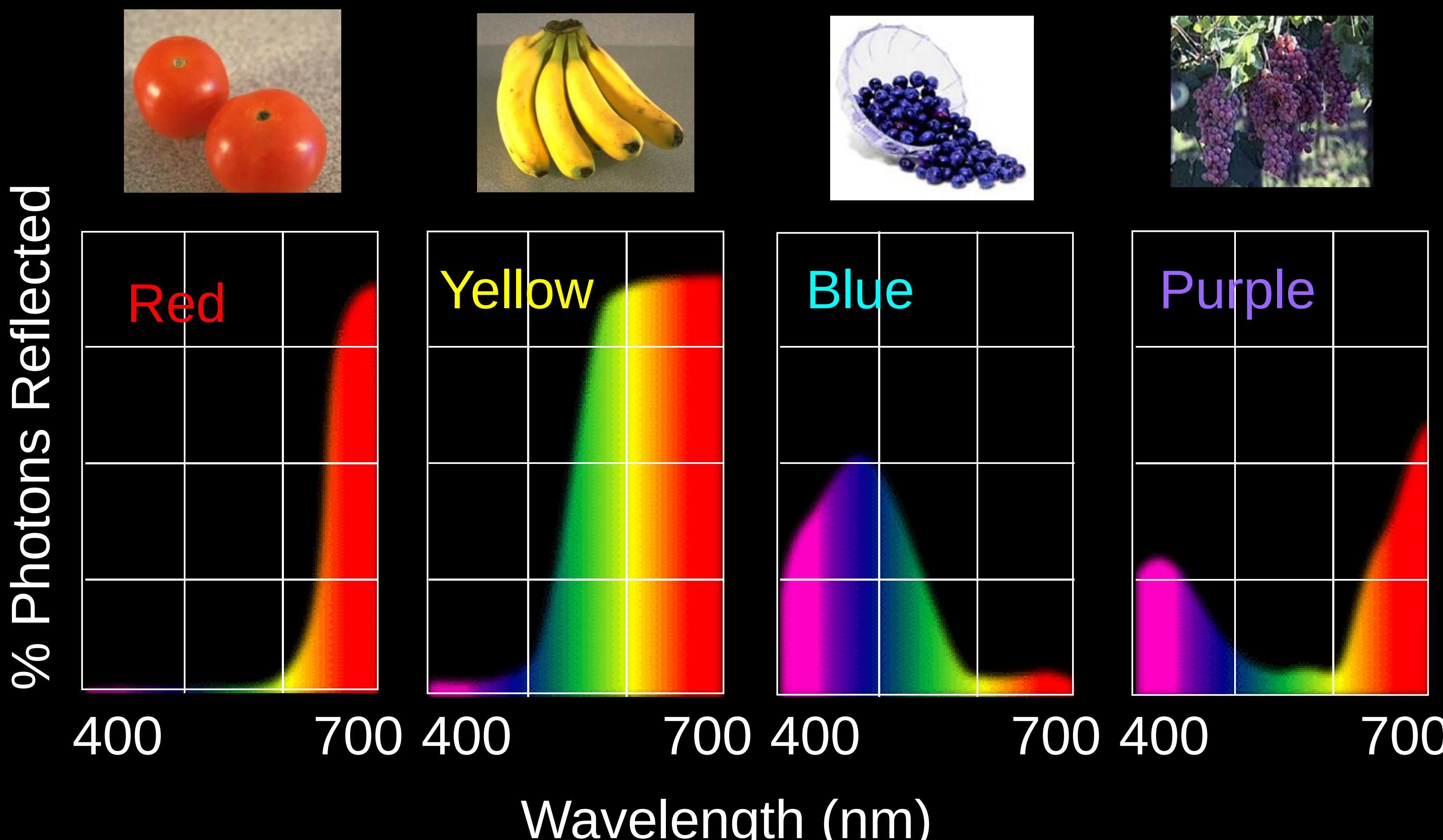
The Physics of Light

Some examples of the spectra of light sources



The Physics of Light

Some examples of the reflectance spectra of surfaces

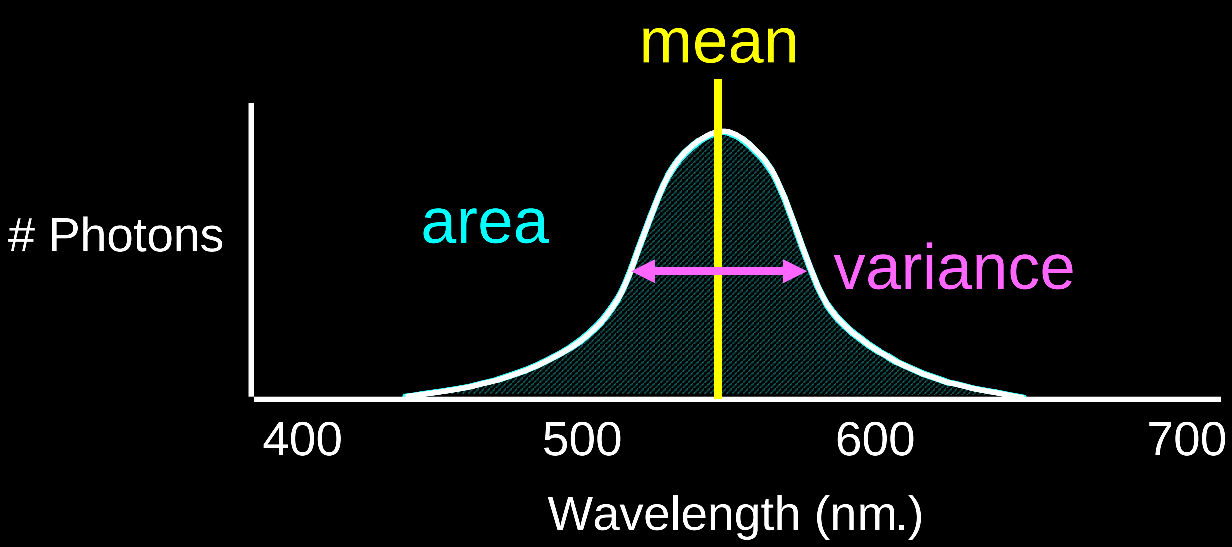


The Psychophysical Correspondence

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

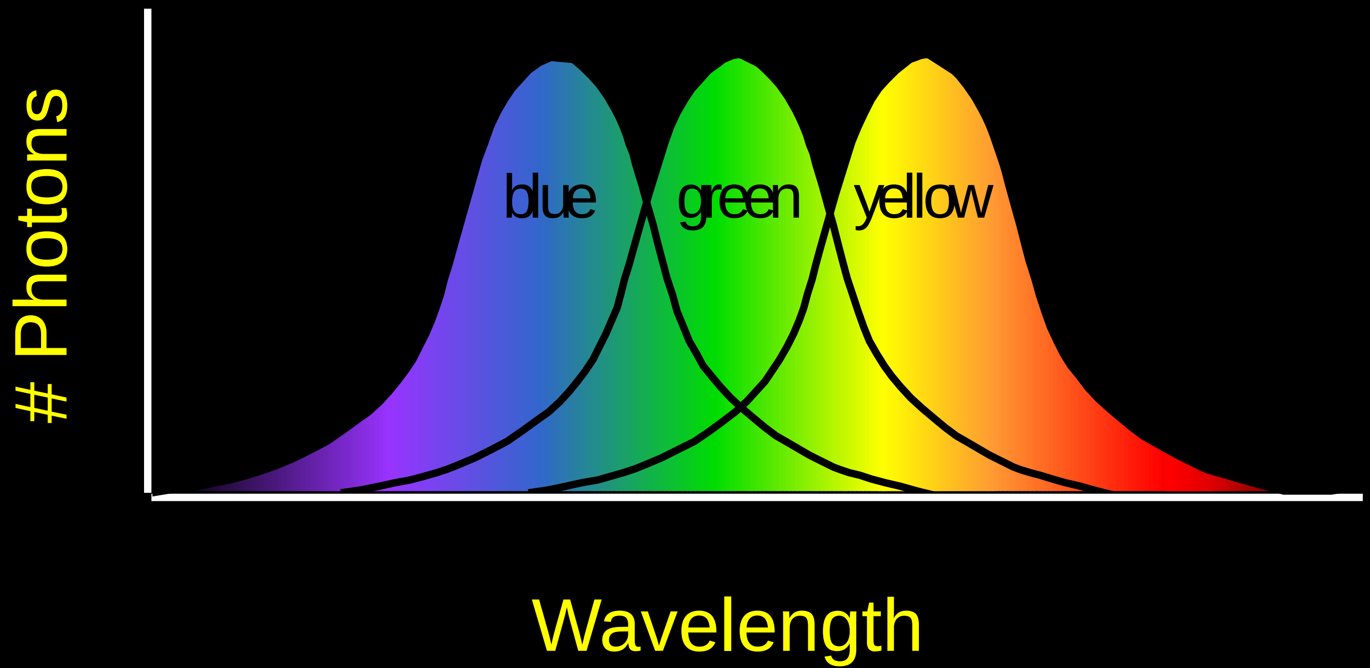
A helpful constraint:

Consider only physical spectra with normal distributions



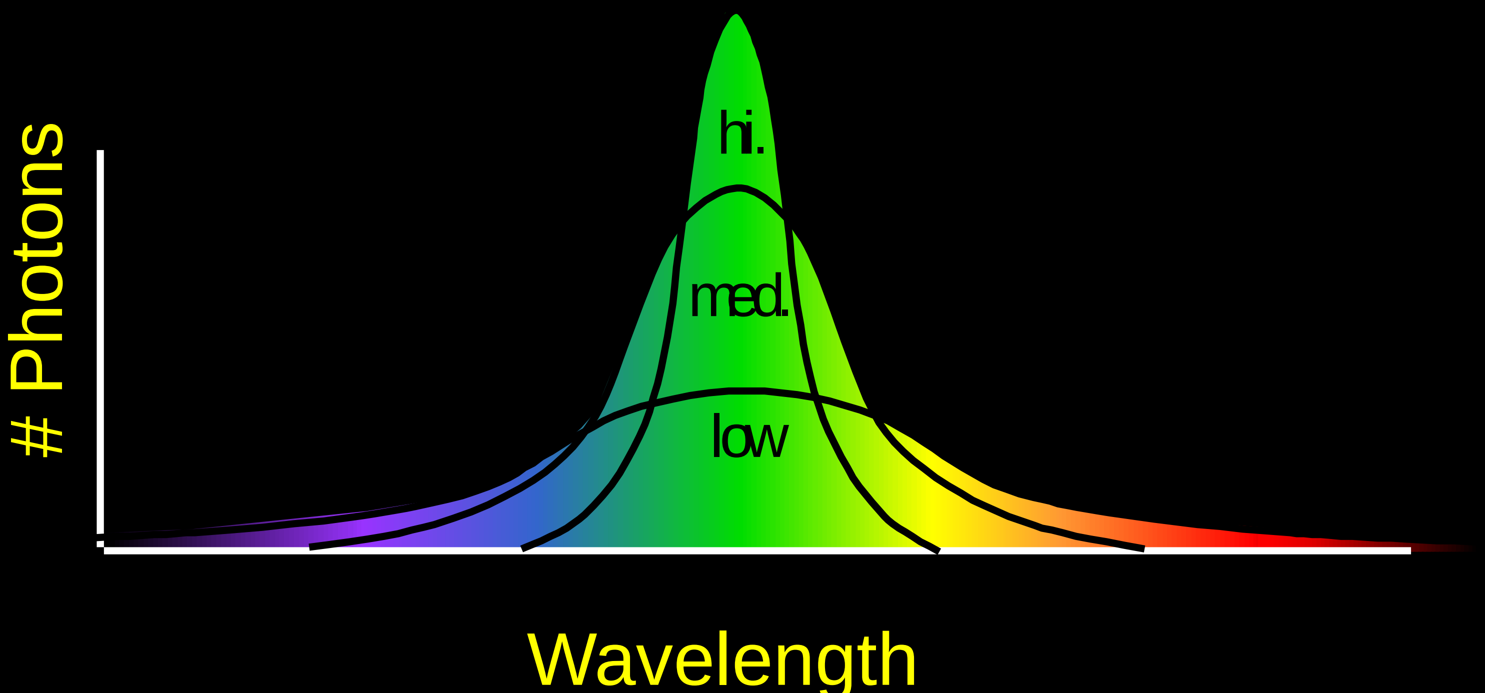
The Psychophysical Correspondence

Mean ⟷ Hue



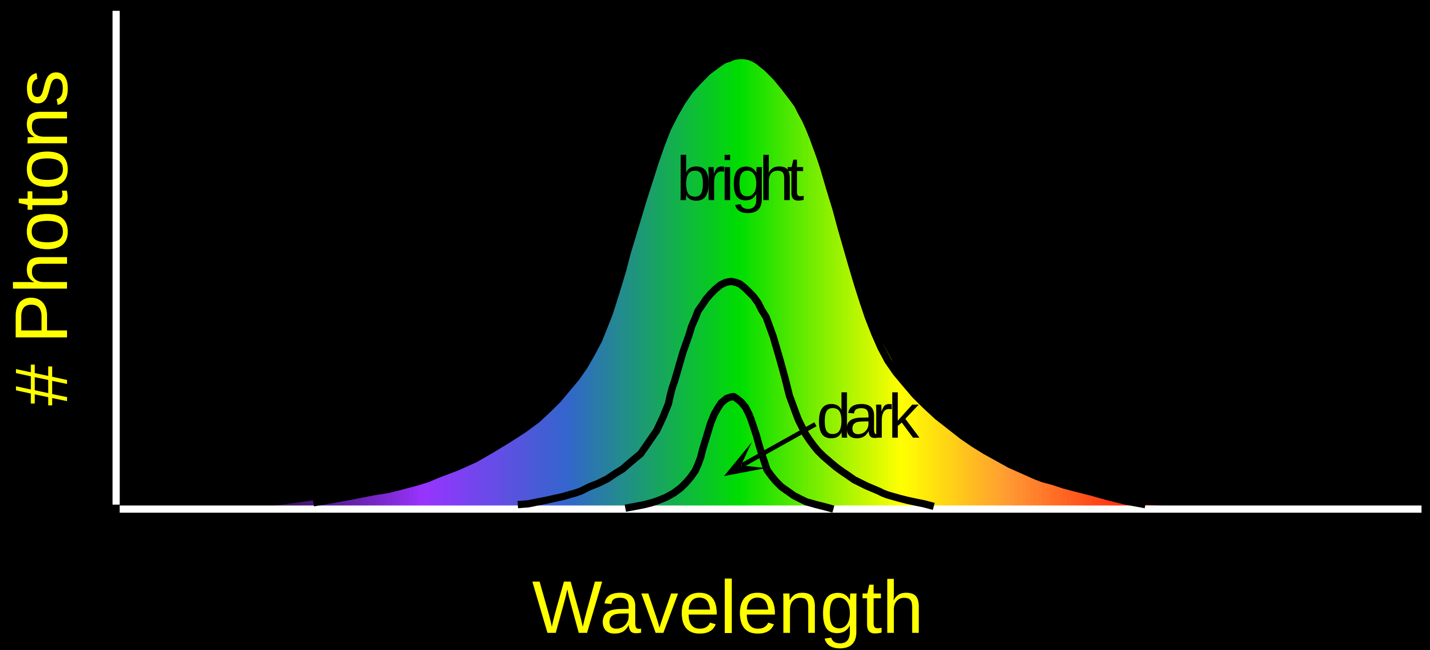
The Psychophysical Correspondence

Variance ⟷ Saturation



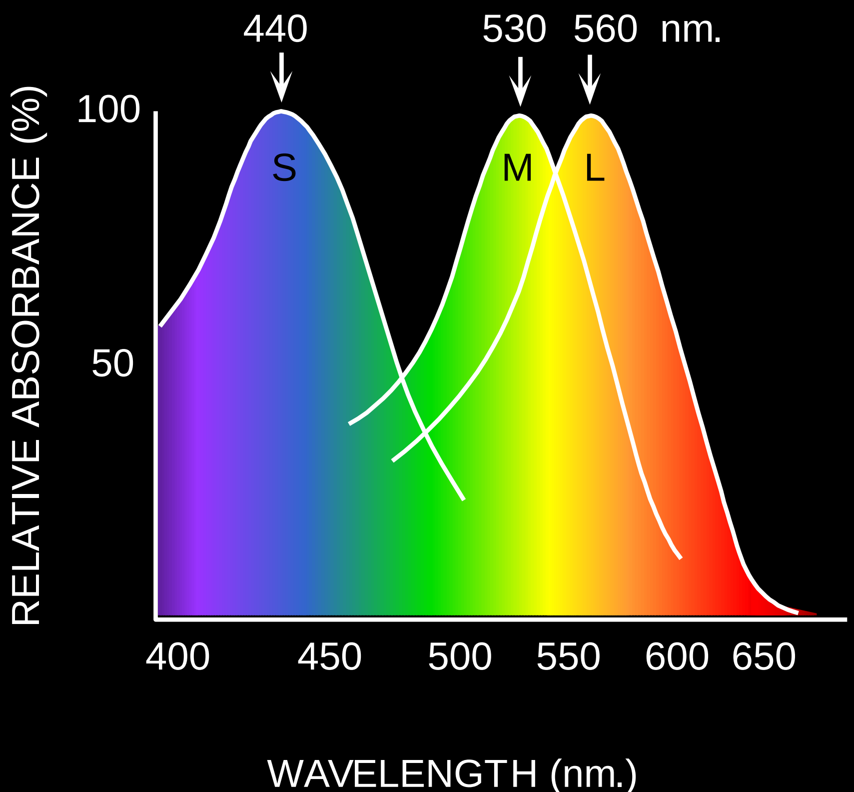
The Psychophysical Correspondence

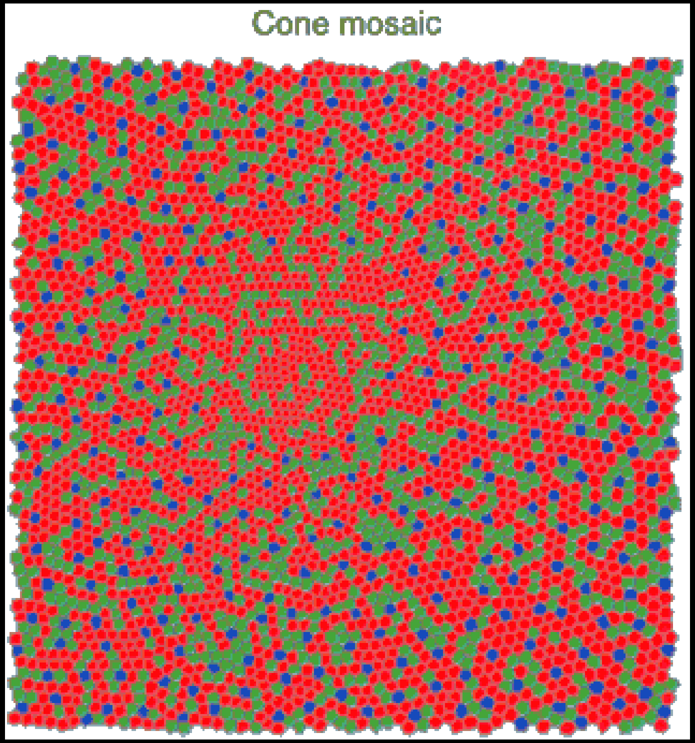
Area ⟷ Brightness



Physiology of Color Vision

Three kinds of cones:



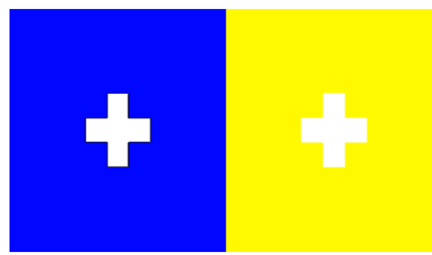


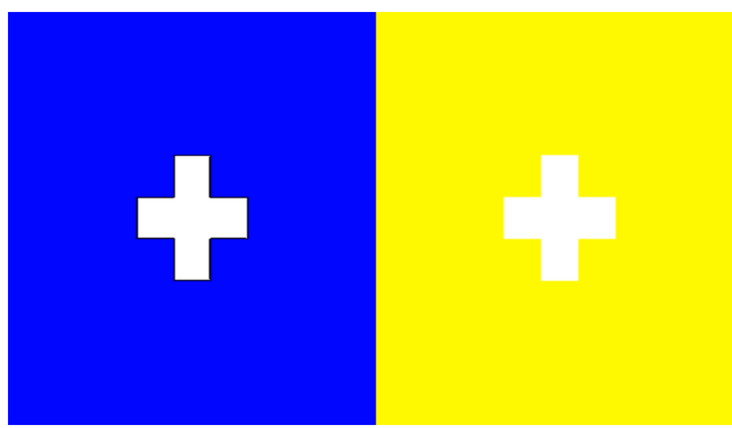
- Why are M and L cones so close?
- Why are there 3?

Impossible Colors

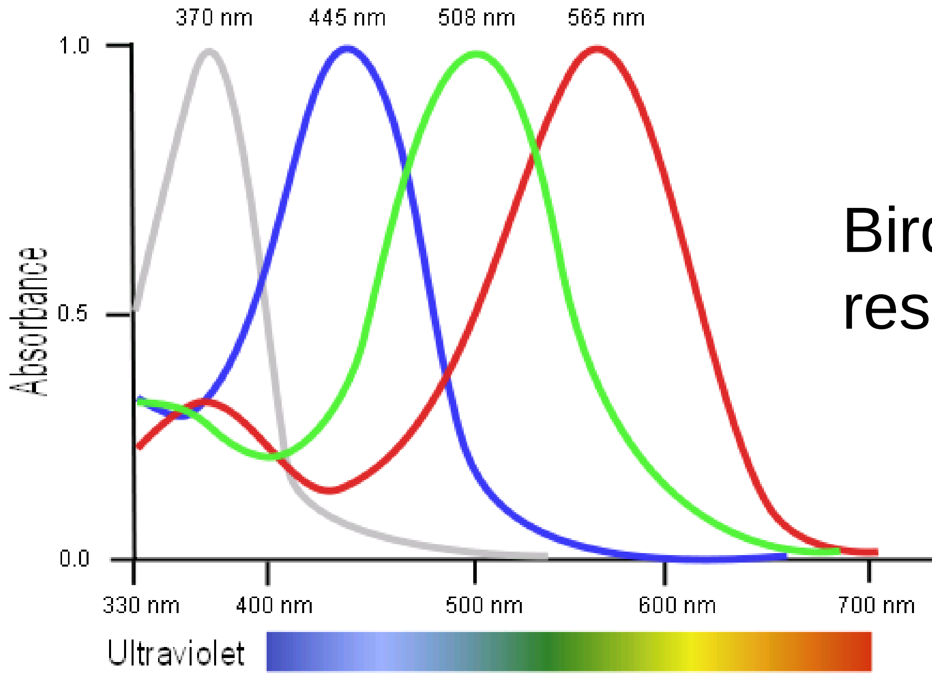
Can you make the cones respond in ways that typical light spectra never would?

http://en.wikipedia.org/wiki/Impossible_colors





Tetrachromatism

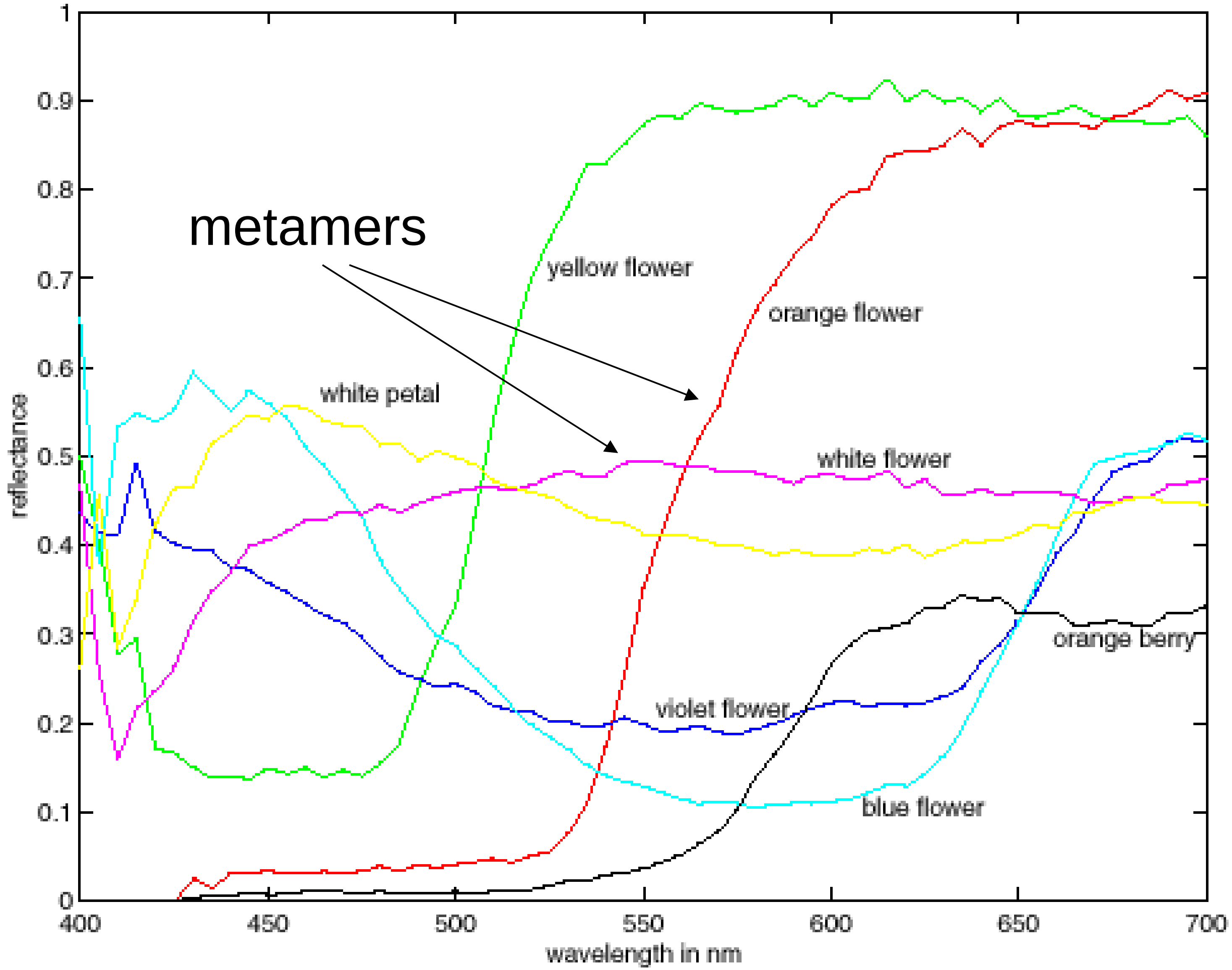


Bird cone responses

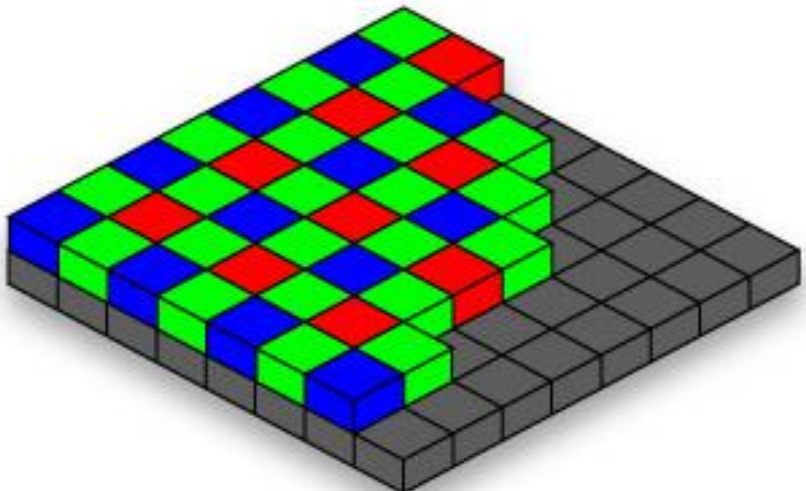
Most birds, and many other animals, have cones for ultraviolet light.

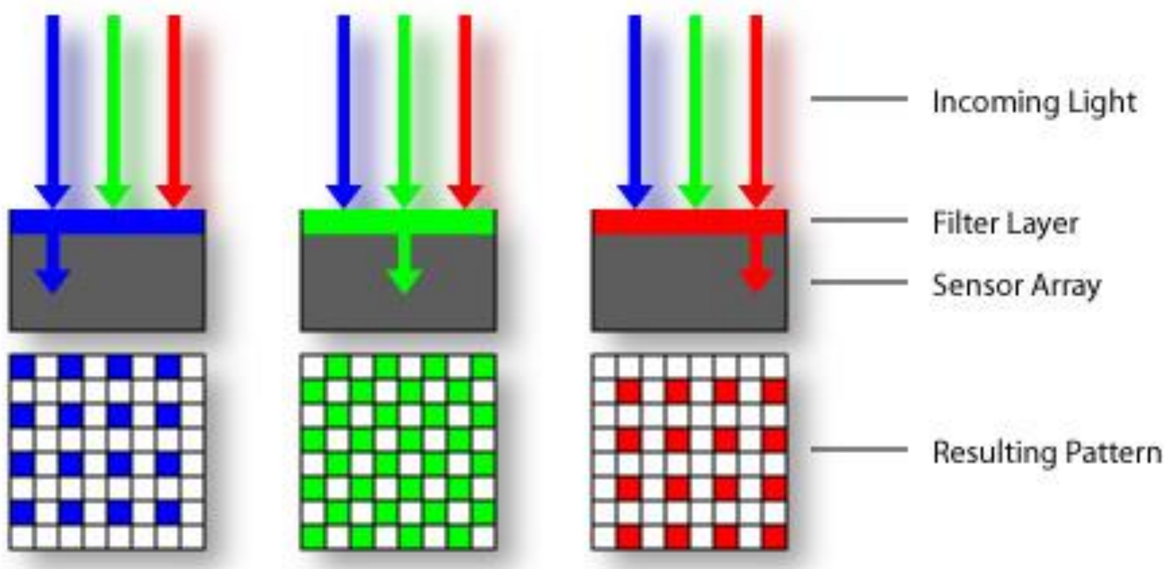
Some humans, mostly female, seem to have slight tetrachromatism.

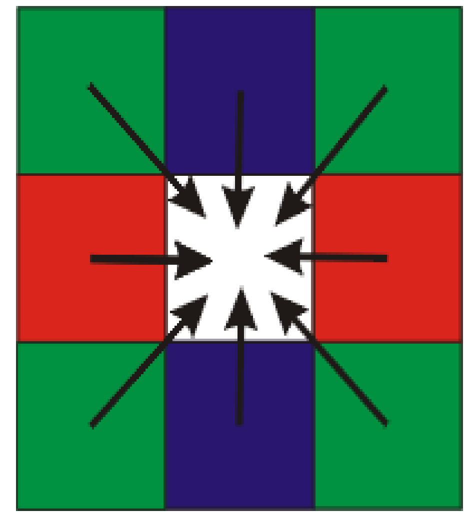
More Spectra



Practical Color Sensing: Bayer Grid







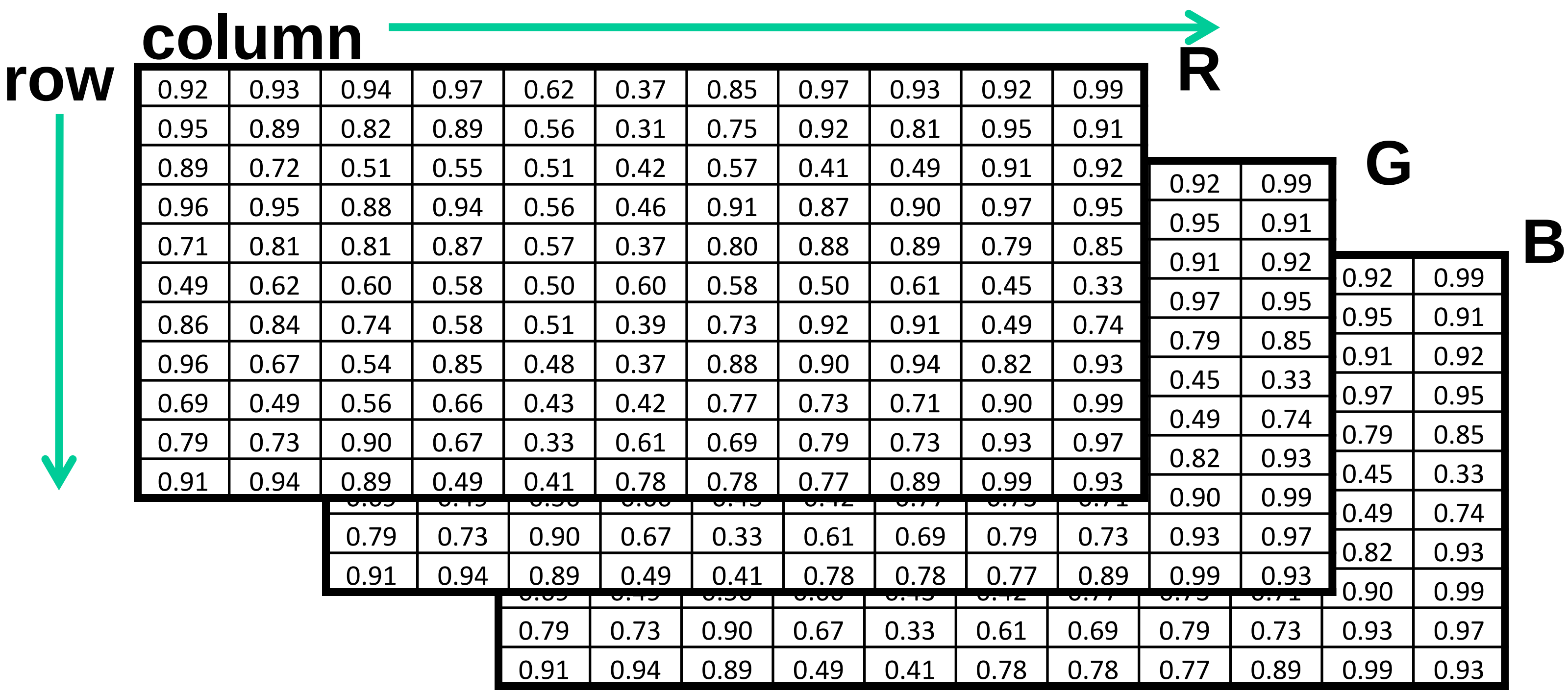
Estimate RGB at ‘G’ cells from neighboring values

Slide by Steve Seitz

Color Image

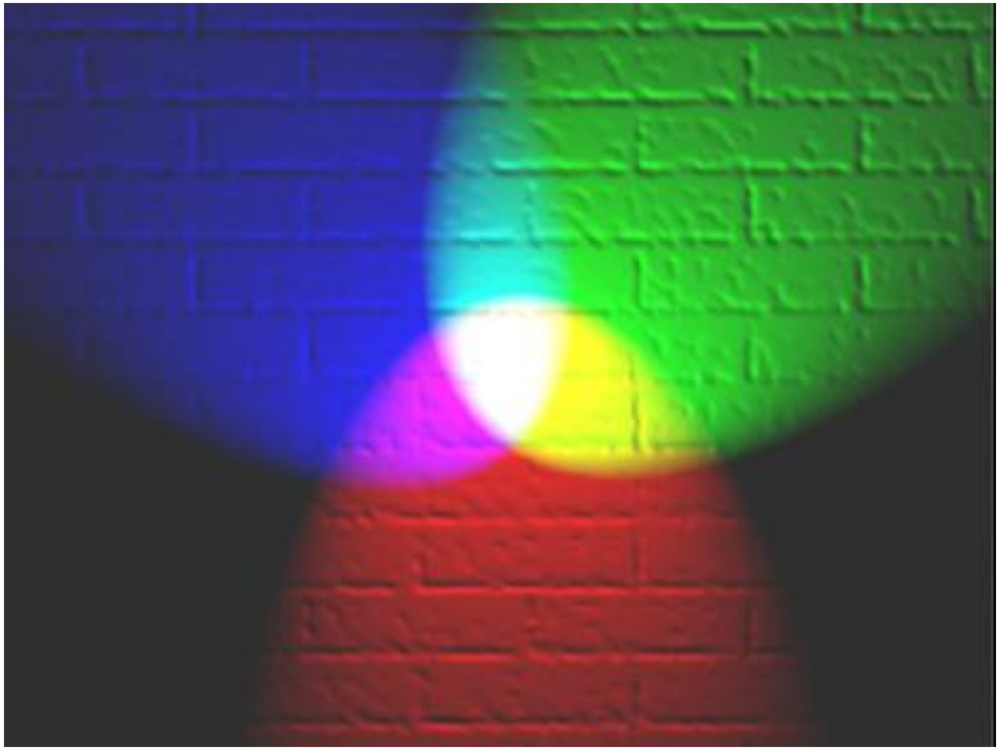
Images in Matlab

- Images represented as a matrix
- Suppose we have a NxM RGB image called “im”
  - im(1,1,1) = top-left pixel value in R-channel
  - im(y, x, b) = y pixels down, x pixels to right in the b^{th} channel
  - im(N, M, 3) = bottom-right pixel in B-channel
- imread(filename) returns a uint8 image (values 0 to 255)
  - Convert to double format (values 0 to 1) with im2double



Color spaces

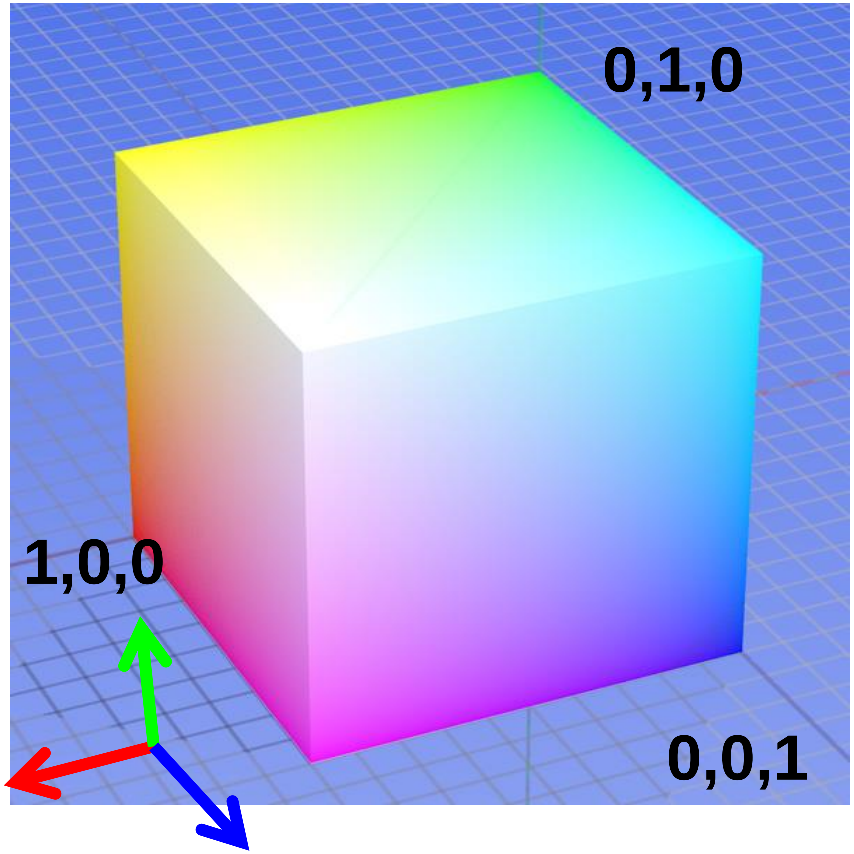
How can we represent color?



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

Color spaces: RGB

Default color space



R
(G=0,B=0)

G
(R=0,B=0)

B
(R=0,G=0)

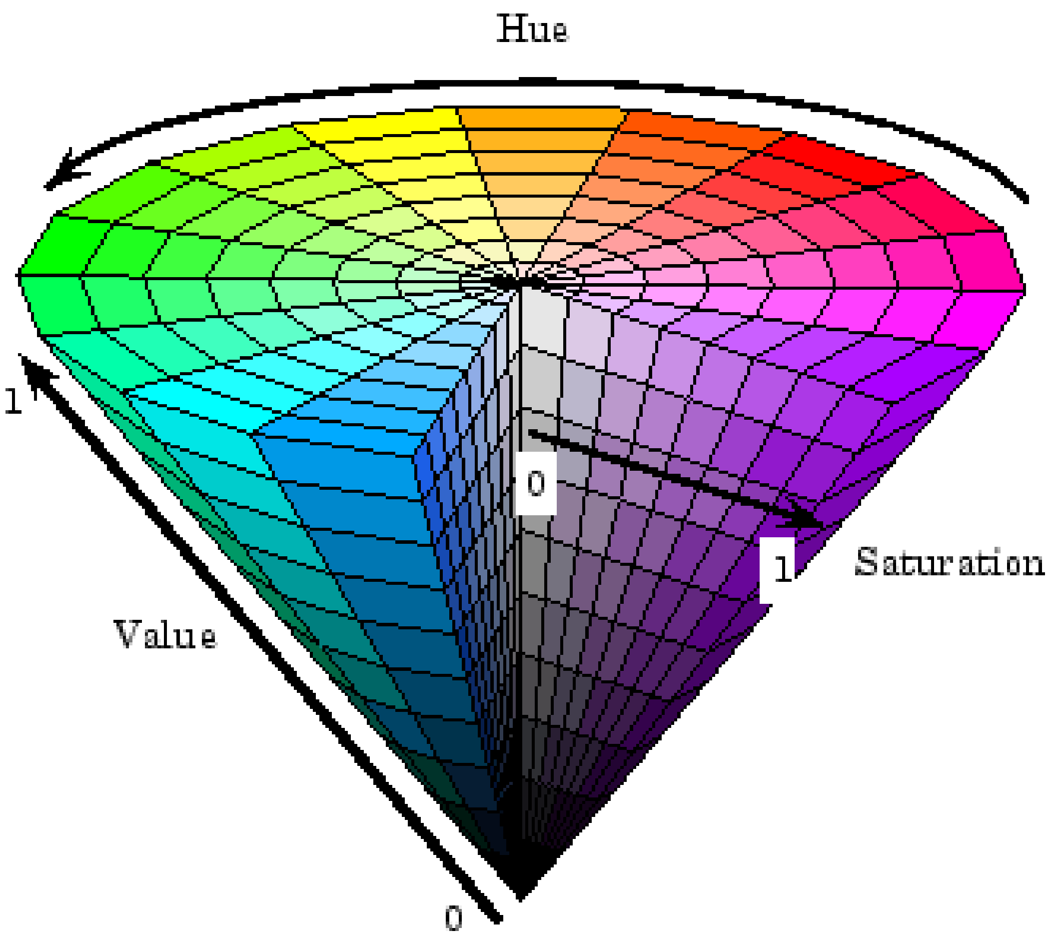
Some drawbacks

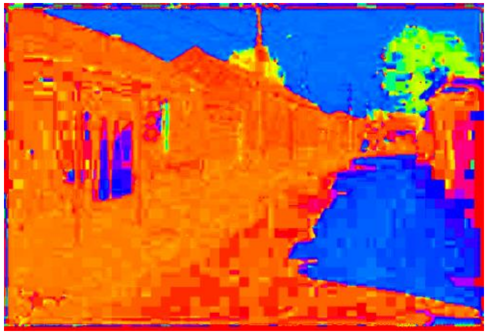
- Strongly correlated channels
- Non-perceptual

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

Color spaces: HSV

Intuitive color space





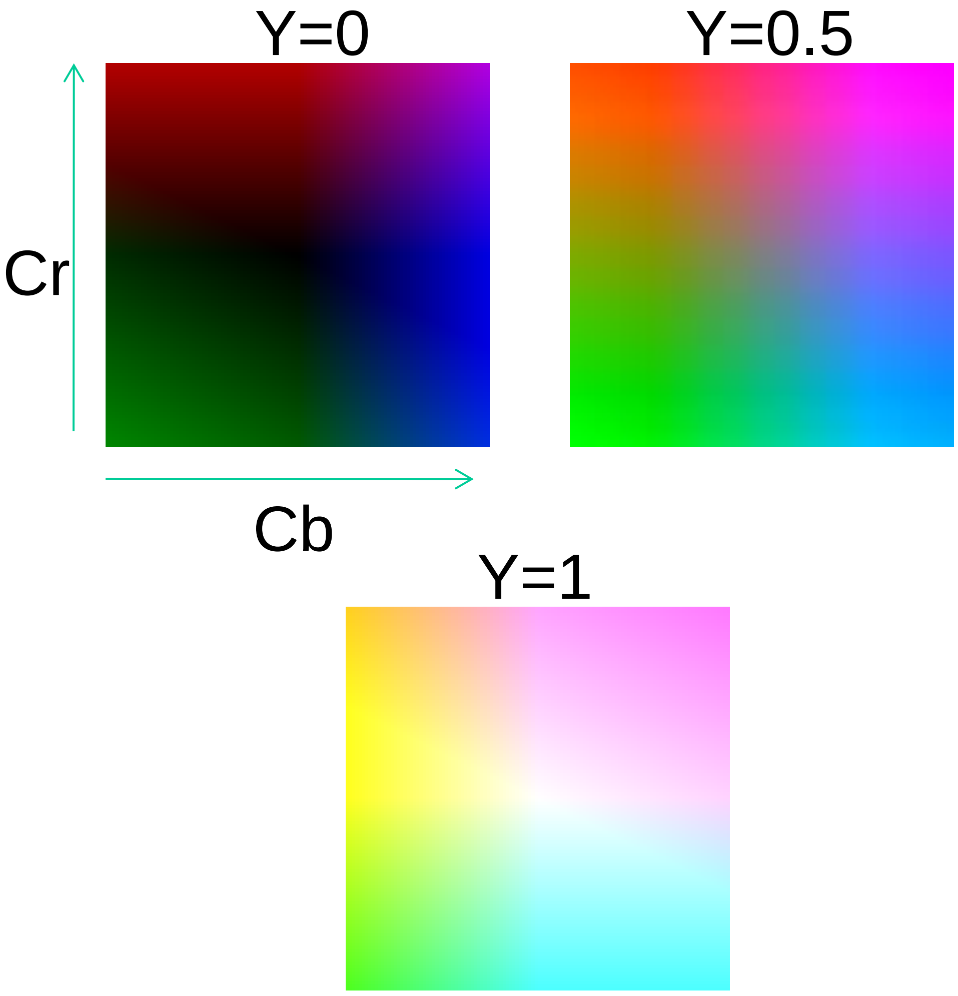
H
(S=1,V=1)

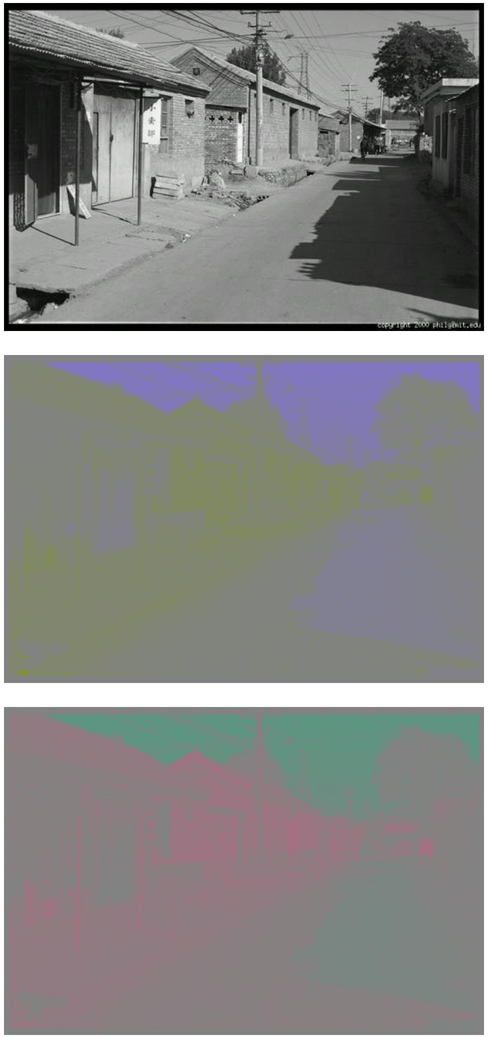
S
(H=1,V=1)

V
(H=1,S=0)

Color spaces: YCbCr

Fast to compute, good for compression, used by TV





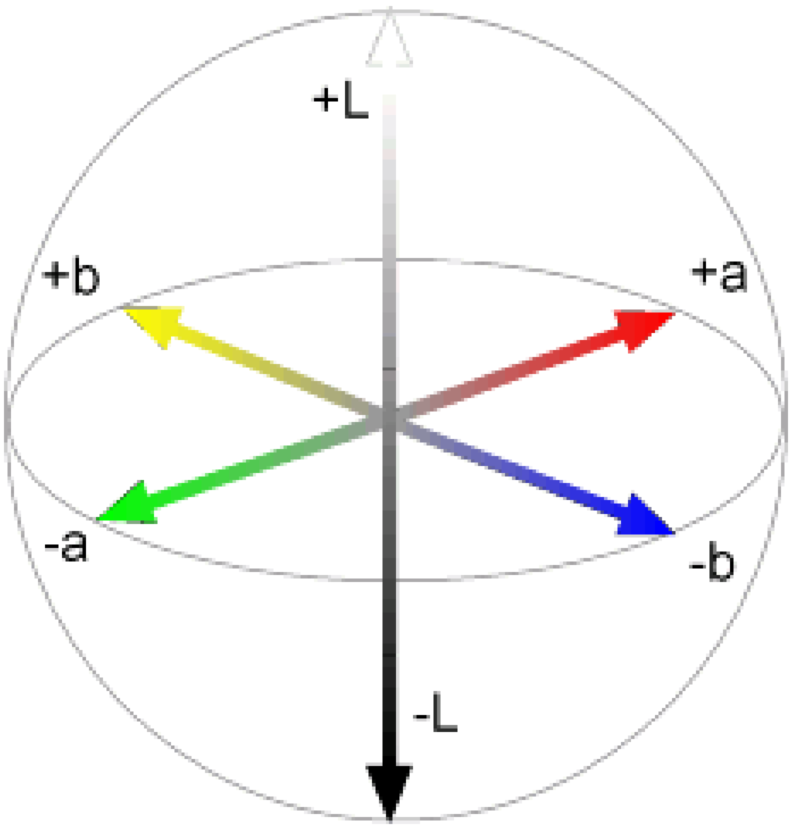
Y
(Cb=0.5,Cr=0.5)

Cb
(Y=0.5,Cr=0.5)

Cr
(Y=0.5,Cb=05)

Color spaces: L*a*b*

“Perceptually uniform”* color space



L
(a=0,b=0)

a
(L=65,b=0)

b
(L=65,a=0)

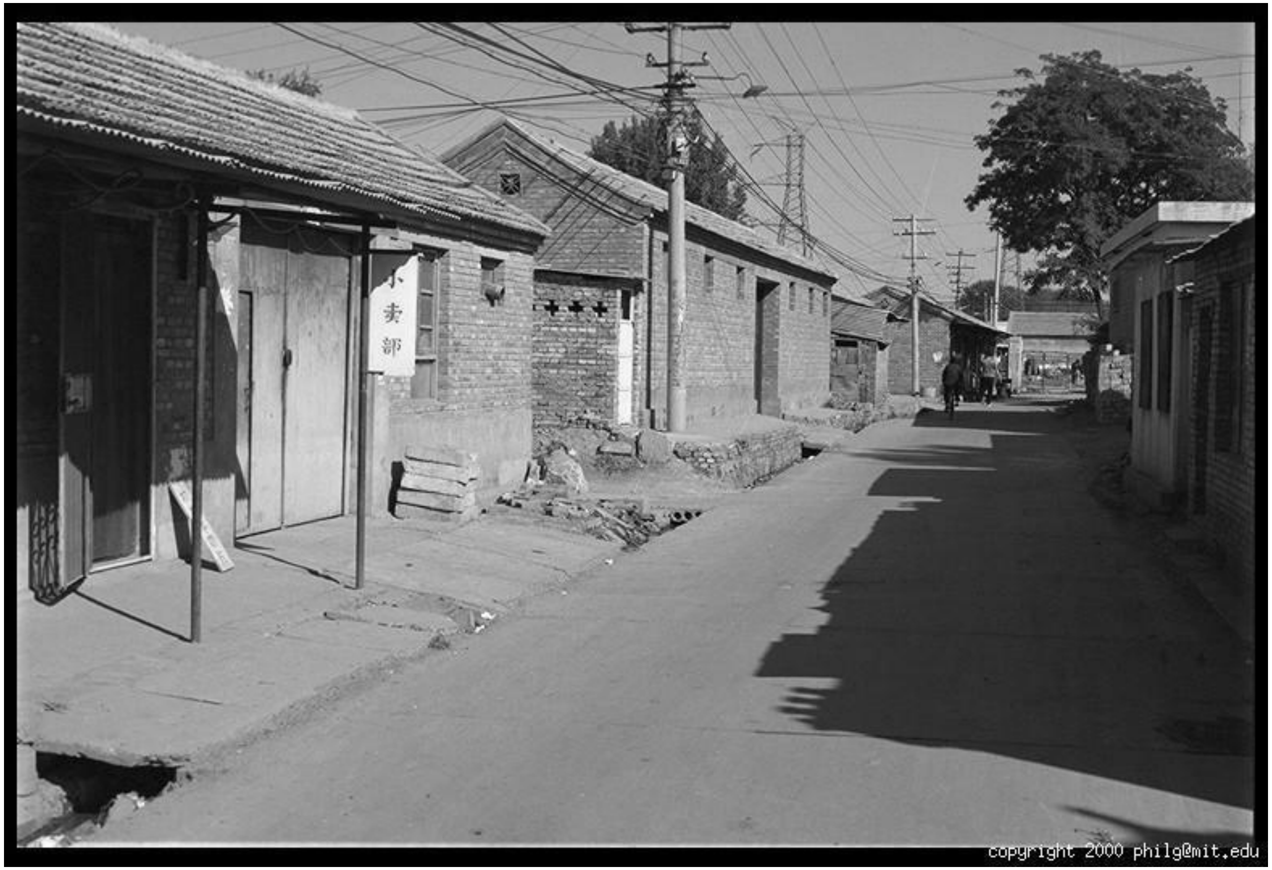
If you had to choose, would you rather go without luminance or chrominance?

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

Most information in intensity

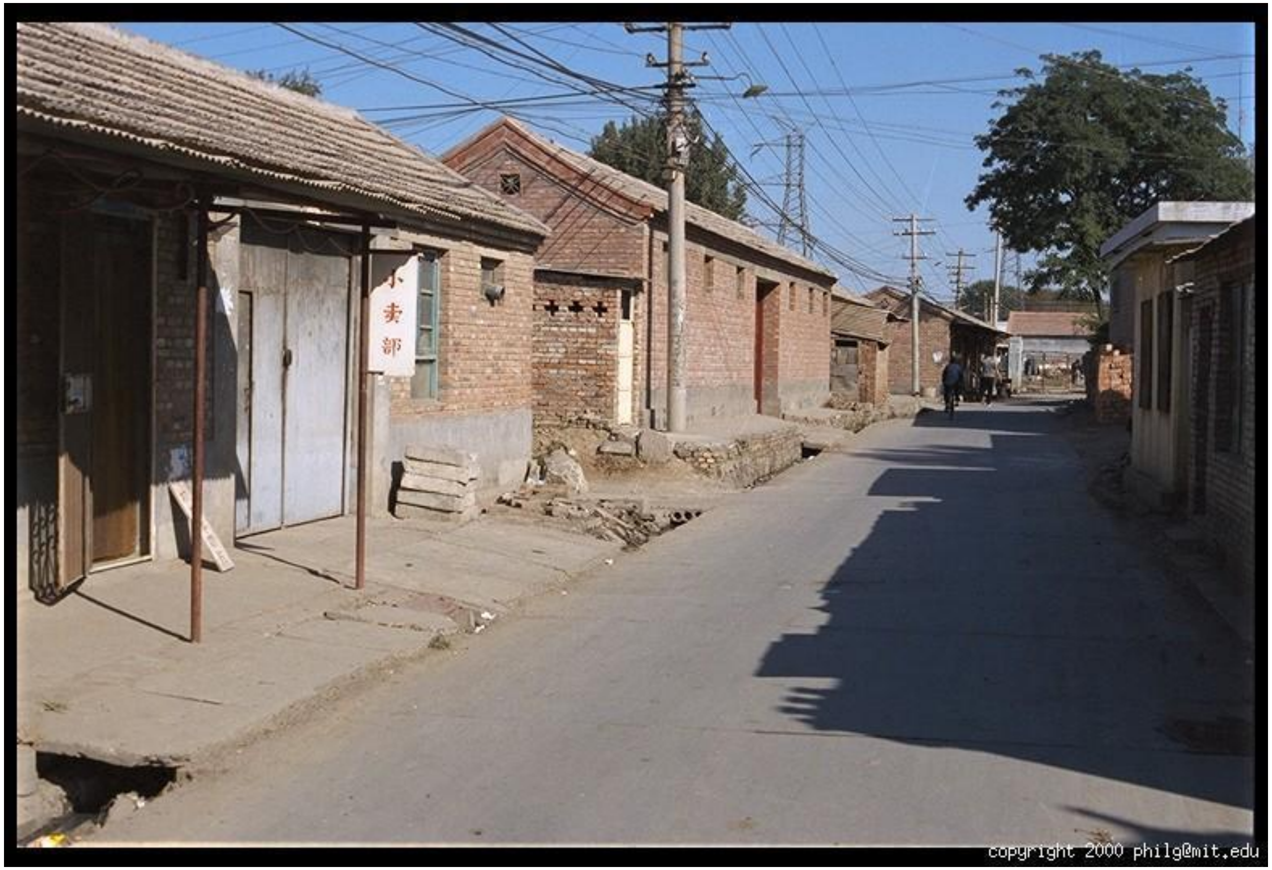
Only color shown – constant intensity

Most information in intensity



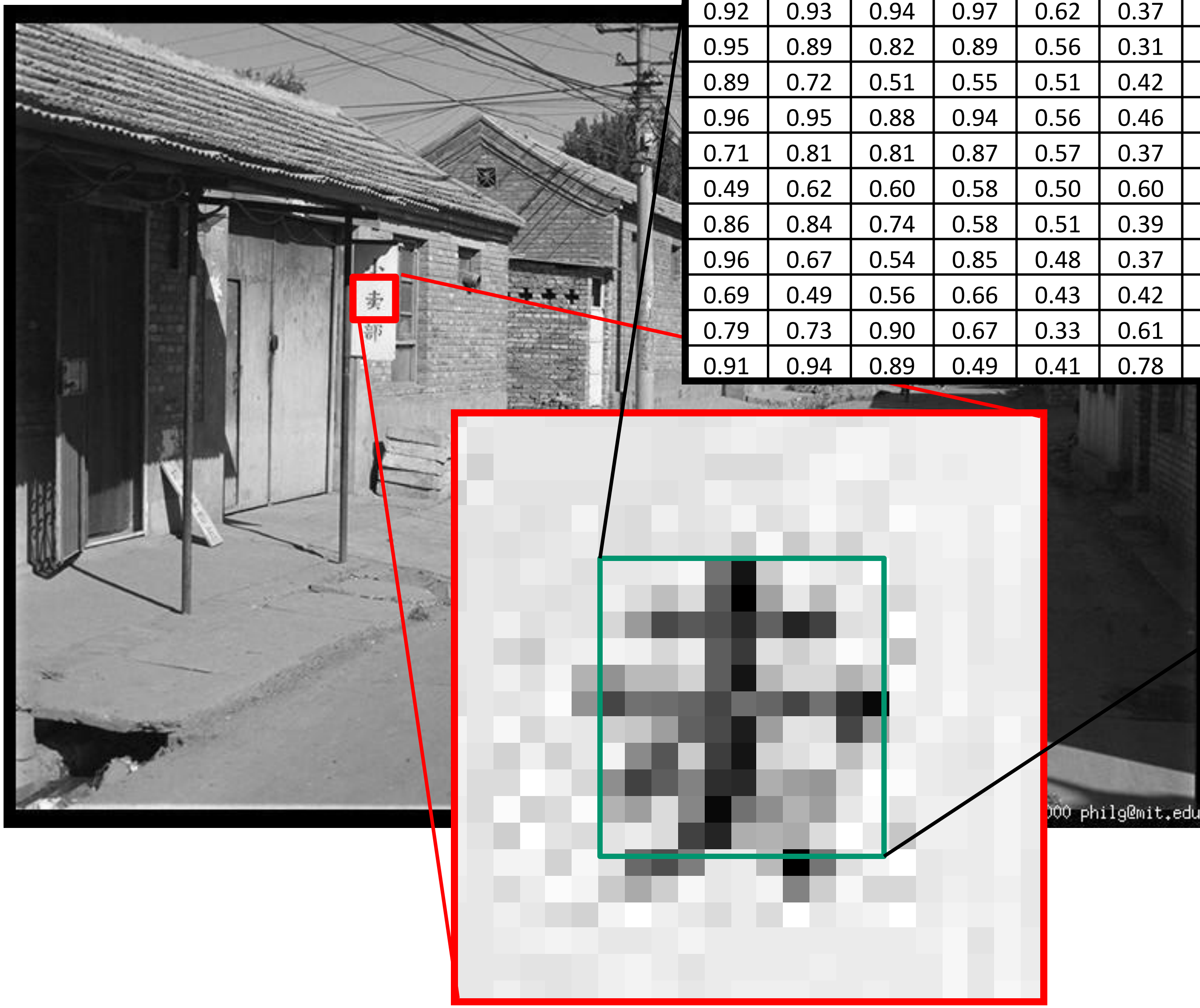
Only intensity shown – constant color

Most information in intensity



Original image

Back to grayscale intensity



0.92	0.93	0.94	0.97	0.62	0.37	0.85	0.97	0.93	0.92	0.99
0.95	0.89	0.82	0.89	0.56	0.31	0.75	0.92	0.81	0.95	0.91
0.89	0.72	0.51	0.55	0.51	0.42	0.57	0.41	0.49	0.91	0.92
0.96	0.95	0.88	0.94	0.56	0.46	0.91	0.87	0.90	0.97	0.95
0.71	0.81	0.81	0.87	0.57	0.37	0.80	0.88	0.89	0.79	0.85
0.49	0.62	0.60	0.58	0.50	0.60	0.58	0.50	0.61	0.45	0.33
0.86	0.84	0.74	0.58	0.51	0.39	0.73	0.92	0.91	0.49	0.74
0.96	0.67	0.54	0.85	0.48	0.37	0.88	0.90	0.94	0.82	0.93
0.69	0.49	0.56	0.66	0.43	0.42	0.77	0.73	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93

Next Lecture

Image Filtering - the core idea for project 1, and all of image processing.

Project 1 is much simpler than the remaining projects.