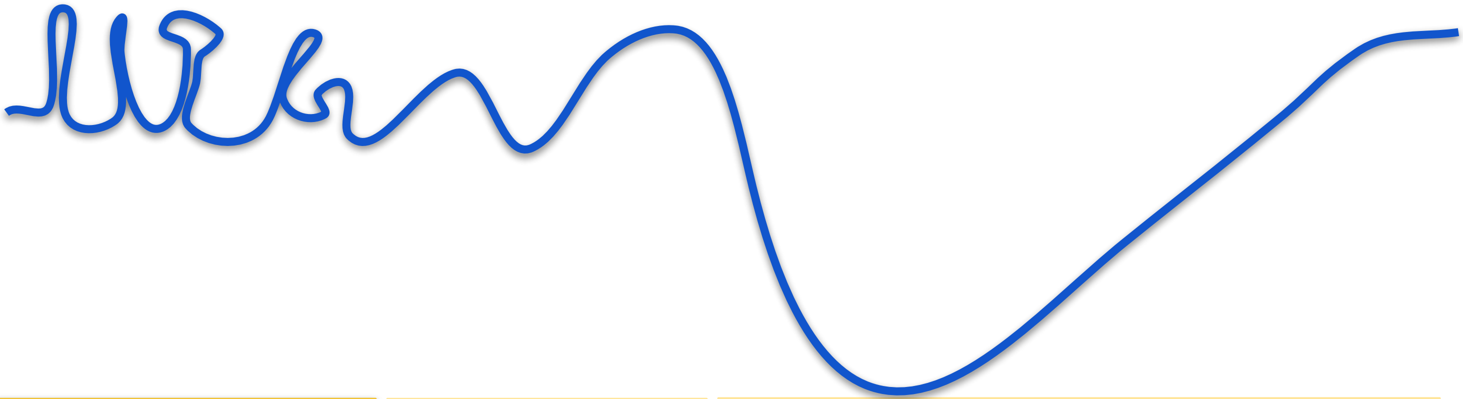
Computing with Signals



DA 623

Jan - May 2024

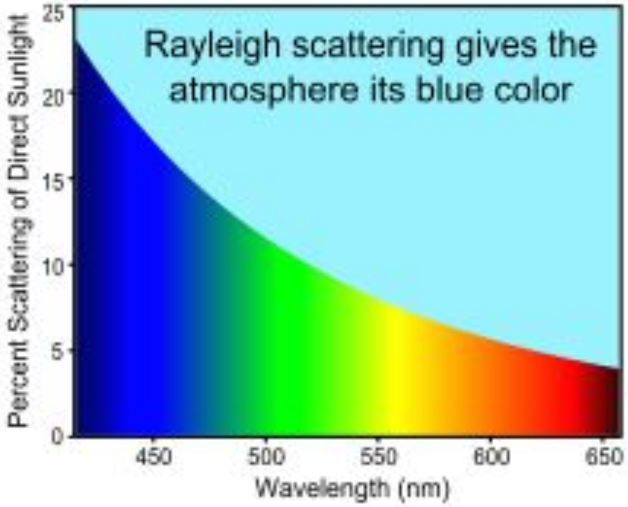
IIT Guwahati

Instructors: Neeraj Sharma

Lecture-15
(and more)

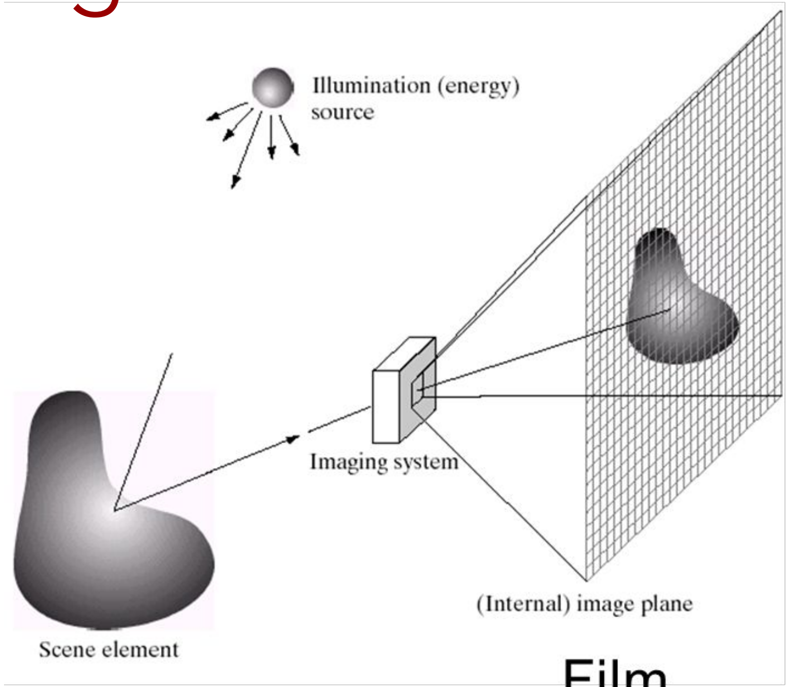
Why are car tails lights red?

Why are car tails lights red?

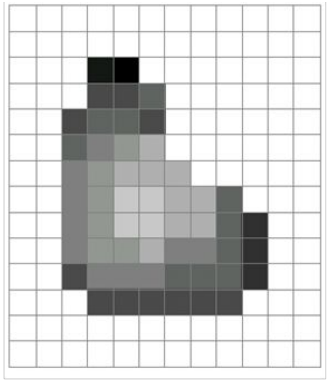


- Amount of scattering inversely proportional to fourth power of the wavelength
- Red light scattered least (in fog and rain), travels farthest

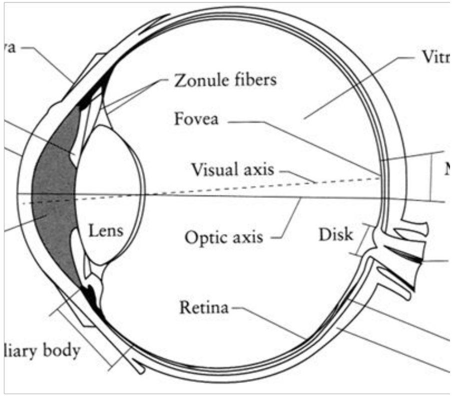
Imaging



Film



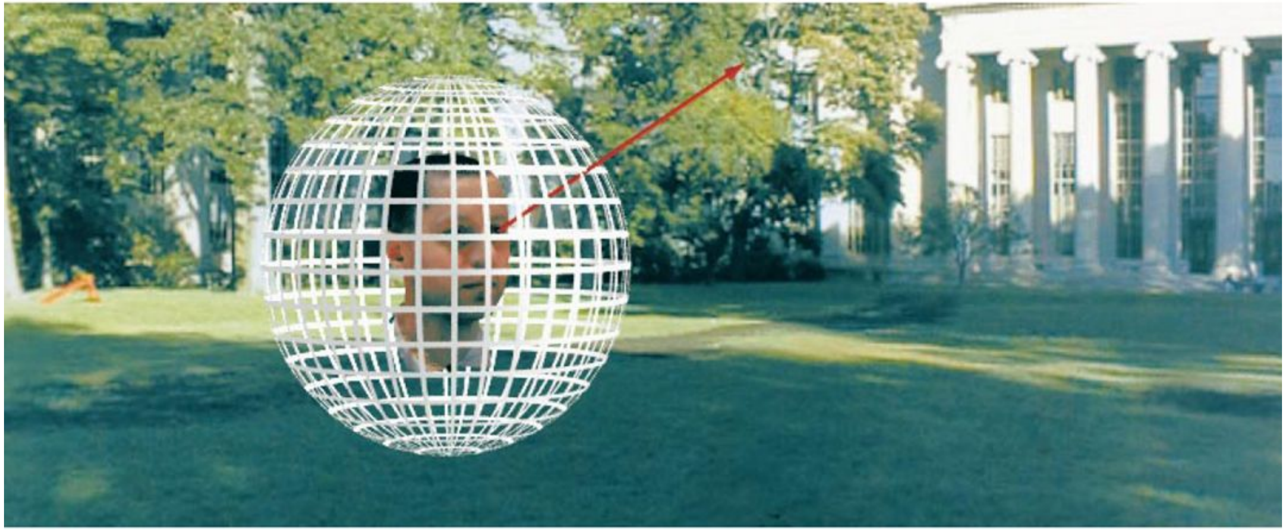
Digital Camera



The Eye

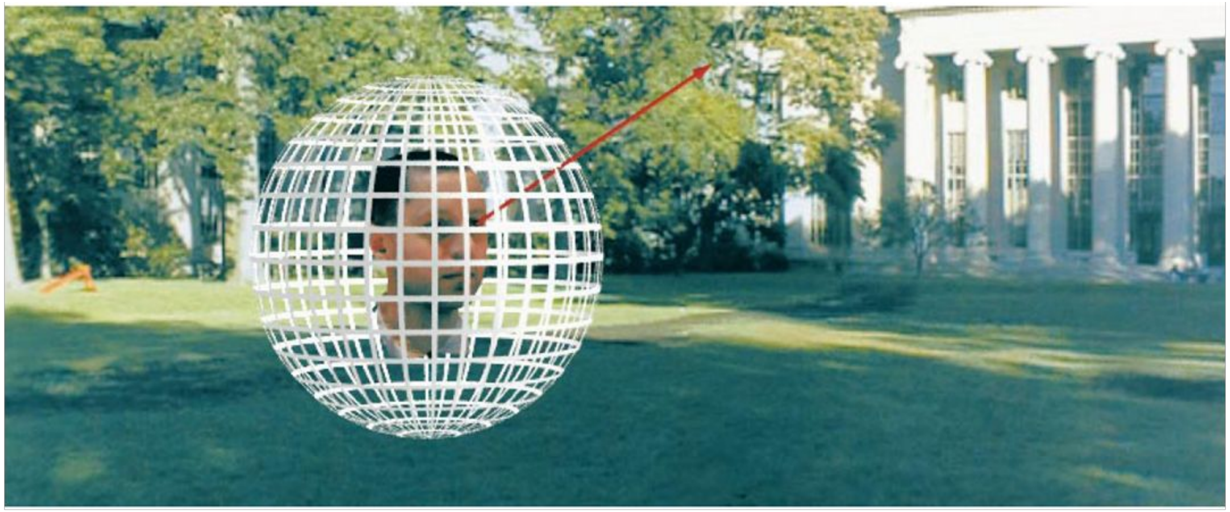
The Plenoptic Function

A hypothetical function representing the intensity or chromacity of the light observed from every position and direction in 3-dimensional space.



Let’s start with a stationary person and try to parameterize <u>everything</u> what they (usually) see …

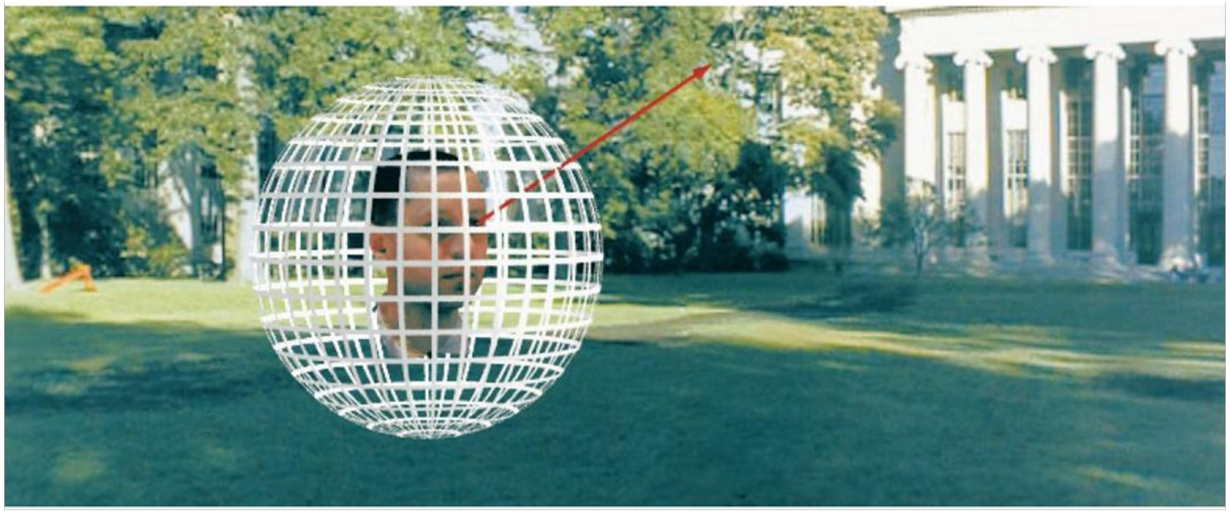
$$P(.,..,..) = \text{what they see}$$



$$P(\theta,\phi,\lambda)$$

is intensity of light

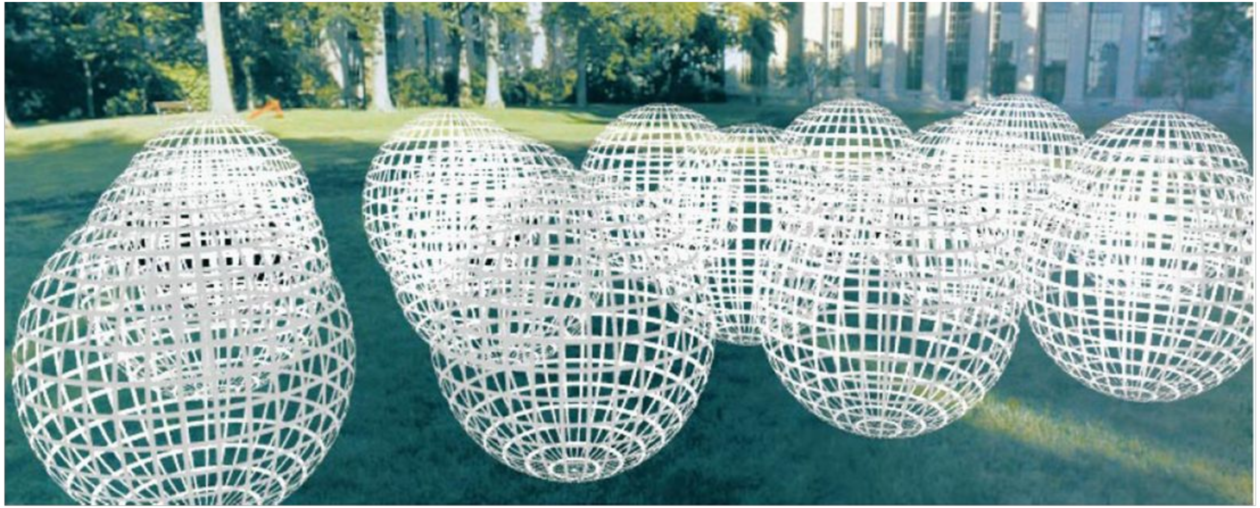
- Seen from a single view point
- At a single time
- As a function of wavelength



$$P(\theta,\phi,\lambda,t)$$

is intensity of light

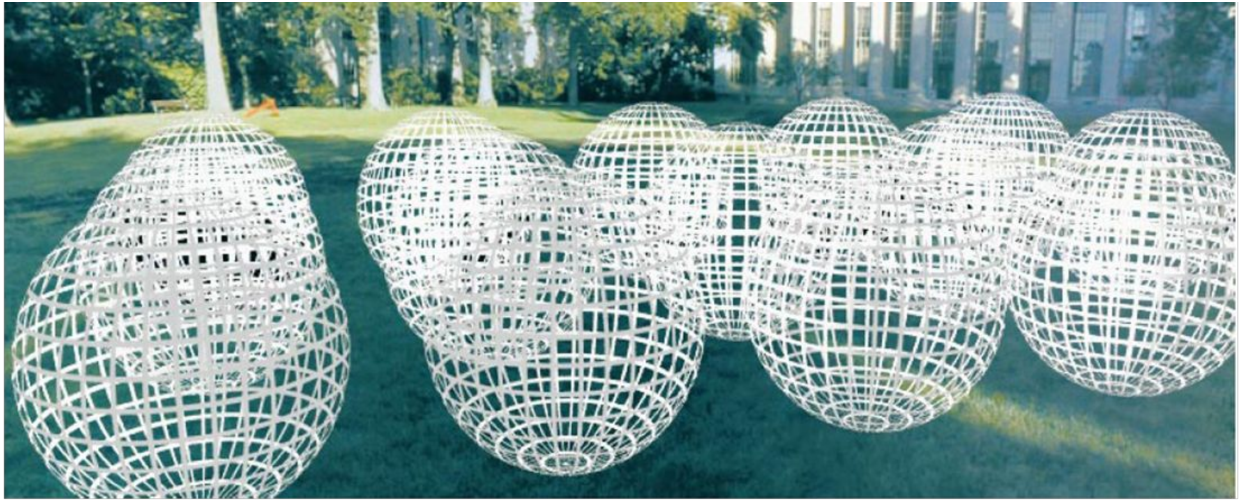
- Seen from a single view point
- Over time
- As a function of wavelength



$$P(\theta,\phi,\lambda,t,V_X,V_Y,V_Z)$$

is intensity of light

- Seen from ANY viewpoint
- Over time
- As a function of wavelength

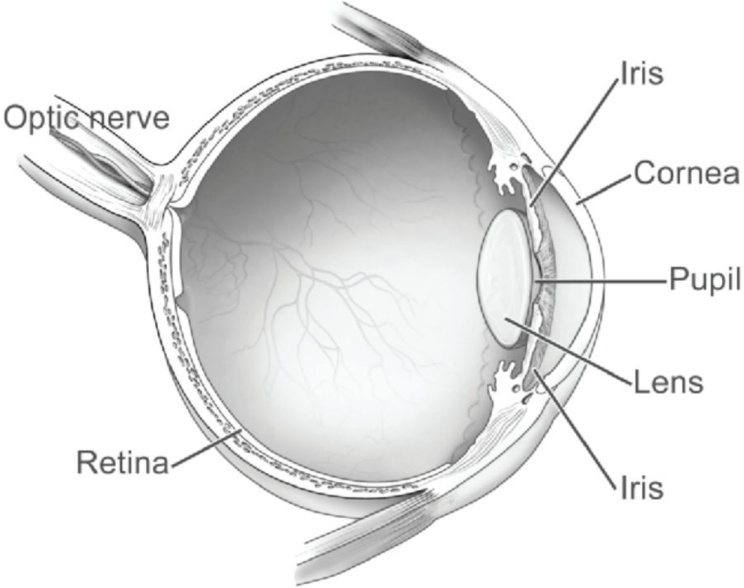


$$P(\theta,\phi,\lambda,t,V_X,V_Y,V_Z)$$

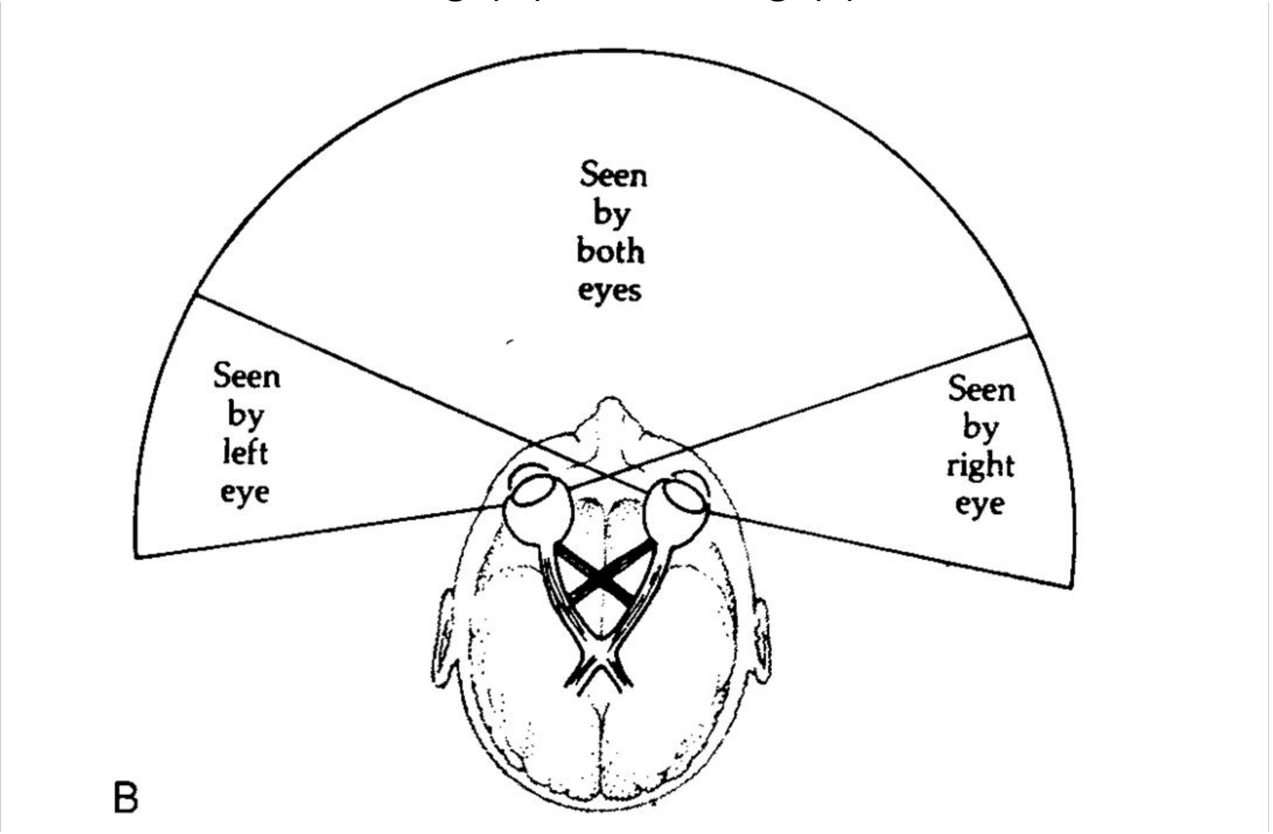
- This can reconstruct every possible view, at every moment, from every position, at every wavelength

- Contains every photograph, every movie, everything that anyone has ever seen! it completely captures our visual reality!

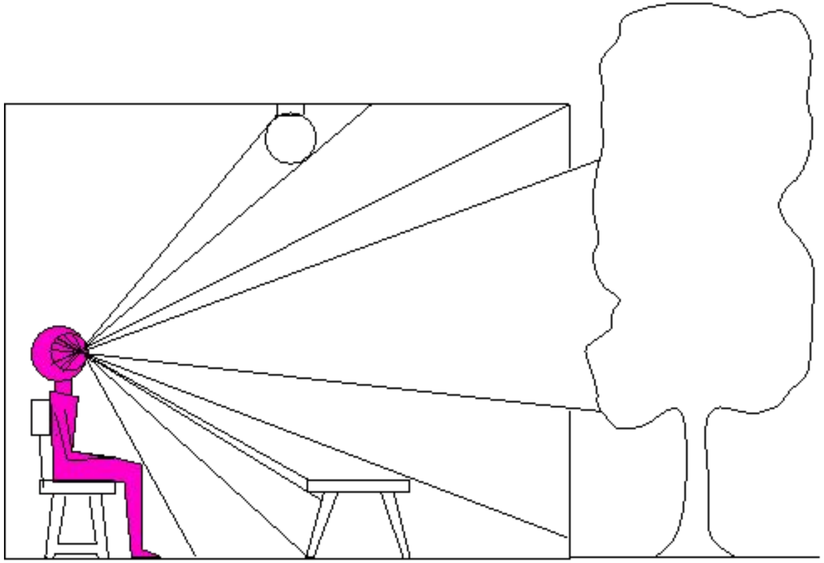
Human Eye



Monocular Visual Field: 160 deg (w) X 135 deg (h)
Binocular Visual Field: 200 deg (w) X 135 deg (h)



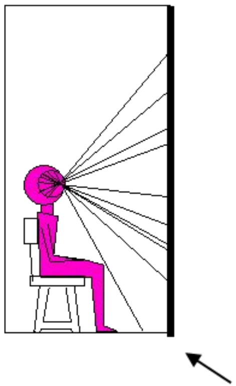
3D world



Point of observation

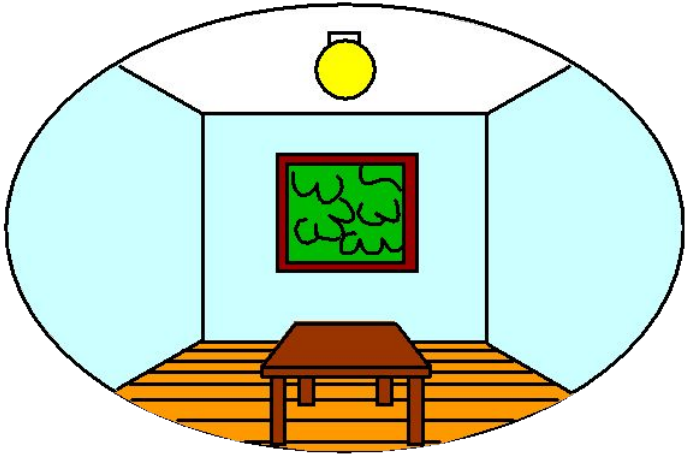
What do we see?

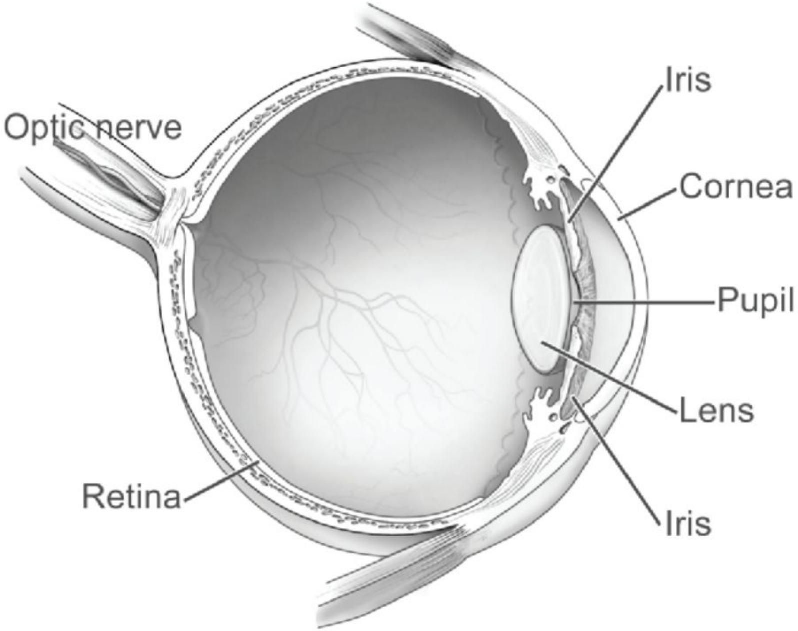
3D world



Painted
backdrop

2D image

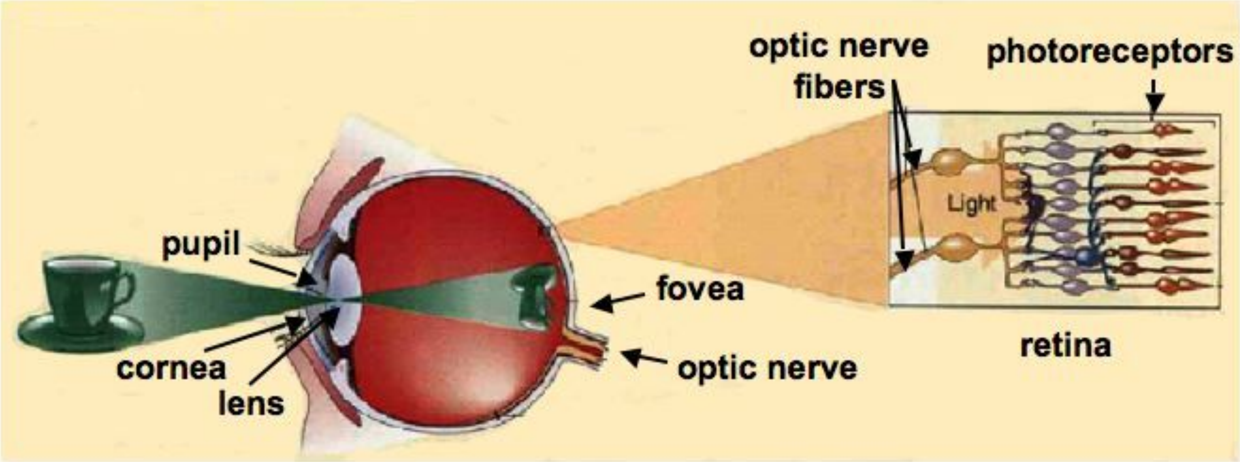


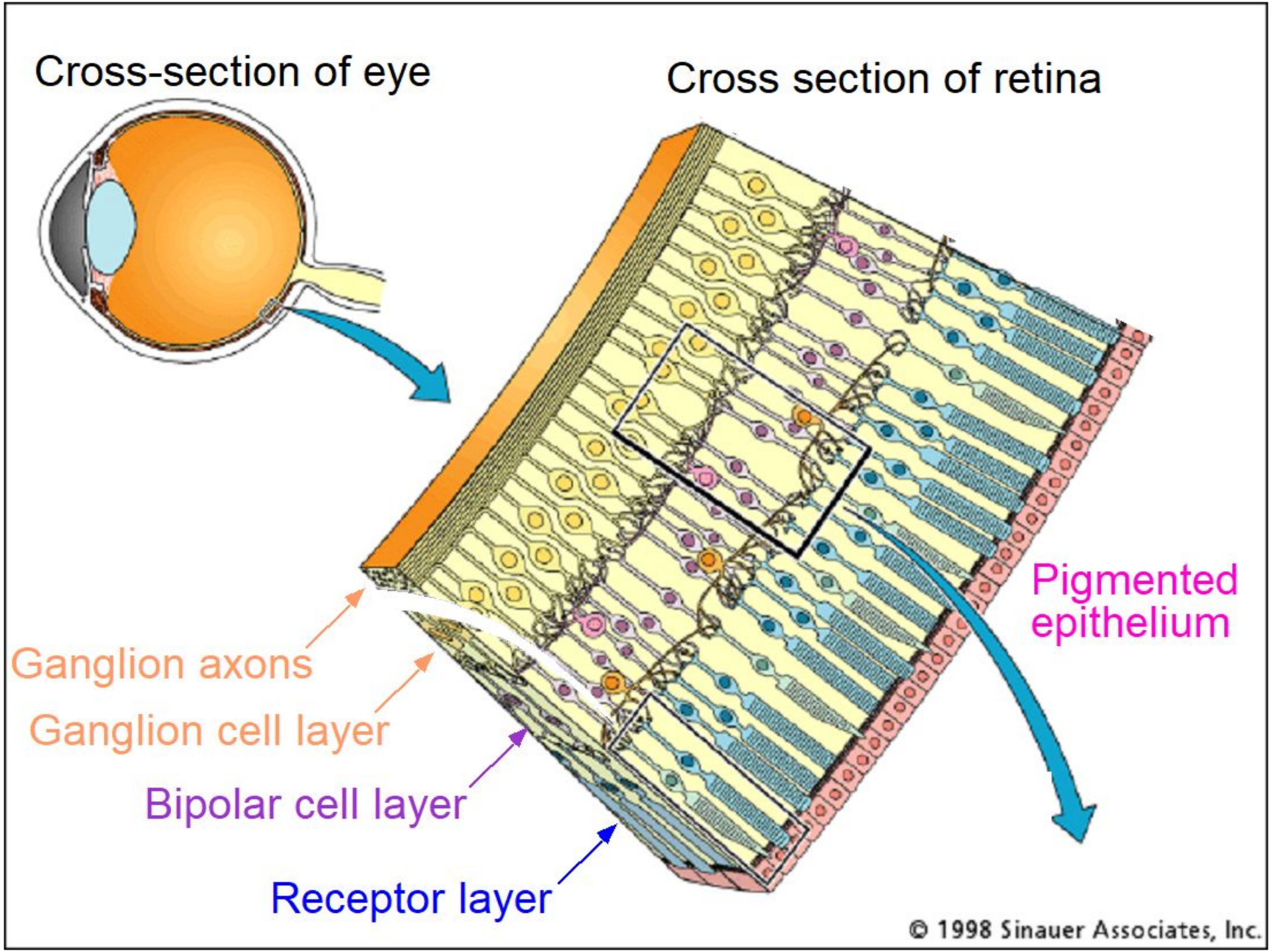


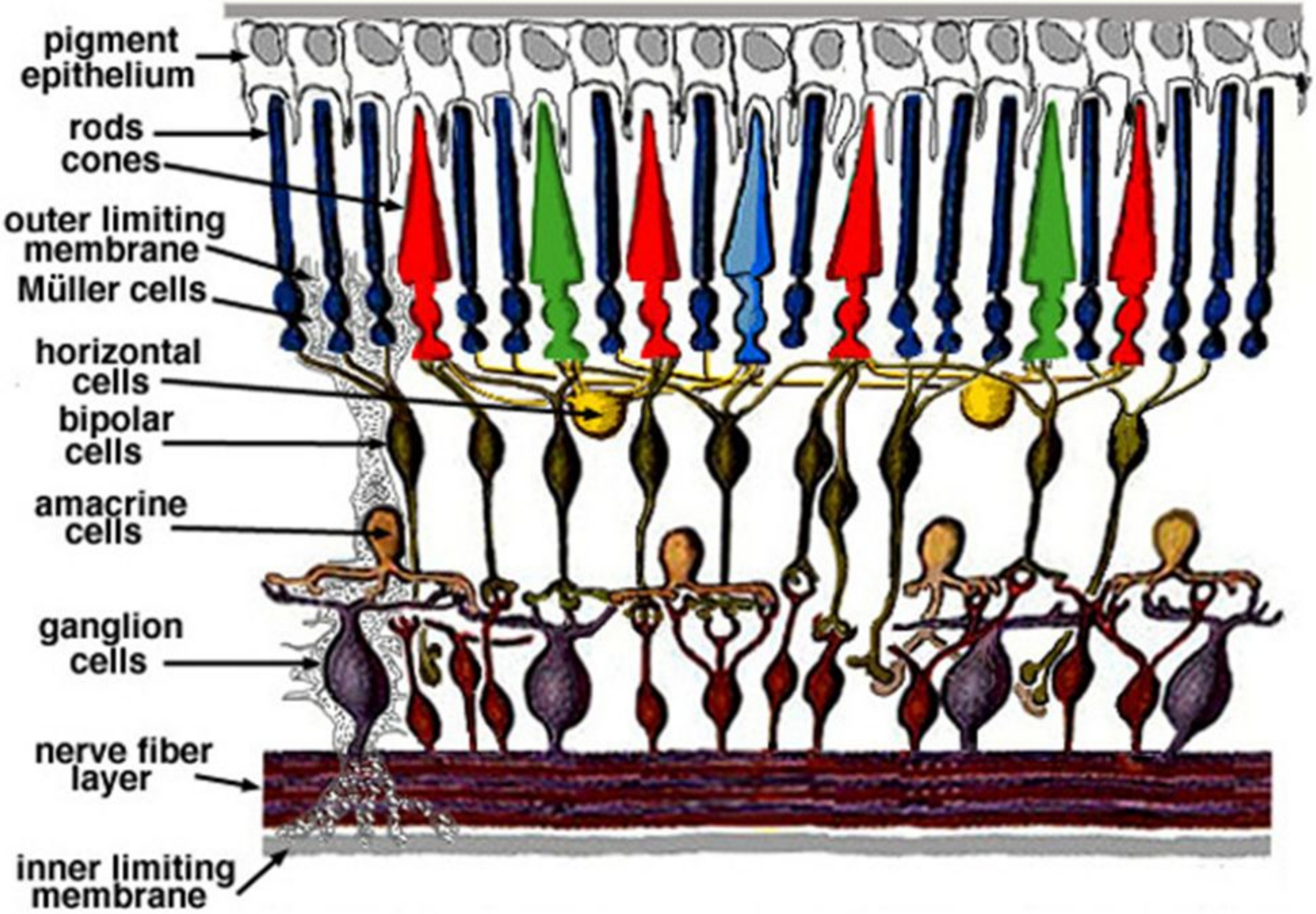
The human eye can be understood as a camera

- Iris - colored annulus with radial muscles
- Pupil - the hole (aperture) whose size is controlled by the iris
- What about the “film”?
  - Photoreceptor cells (rods and cones) in the retina

The eye


optic nerve
fibers
photoreceptors
Light
pupil
fovea
cornea
lens
optic nerve
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.

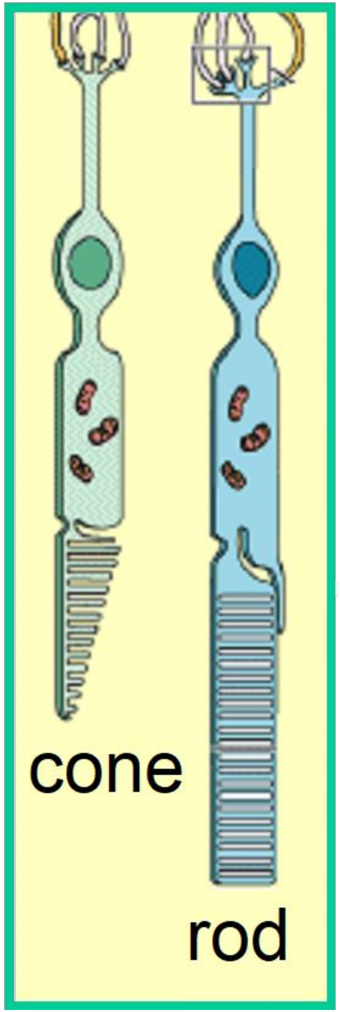

pigment epithelium
rods
cones
outer limiting membrane
Müller cells
horizontal cells
bipolar cells
amacrine cells
ganglion cells
nerve fiber layer
inner limiting membrane

Cones

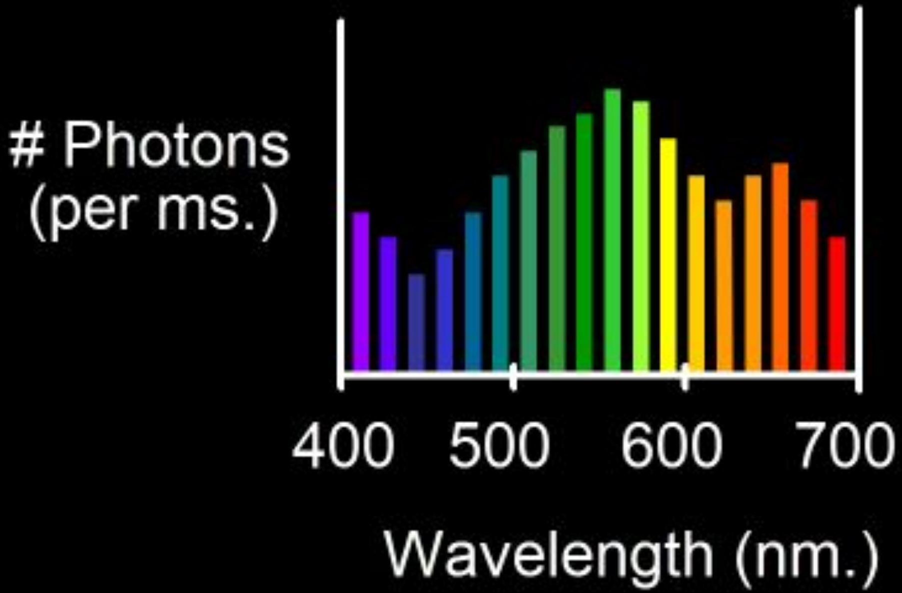
- cone-shaped
- less sensitive
- operate in high light
- color vision

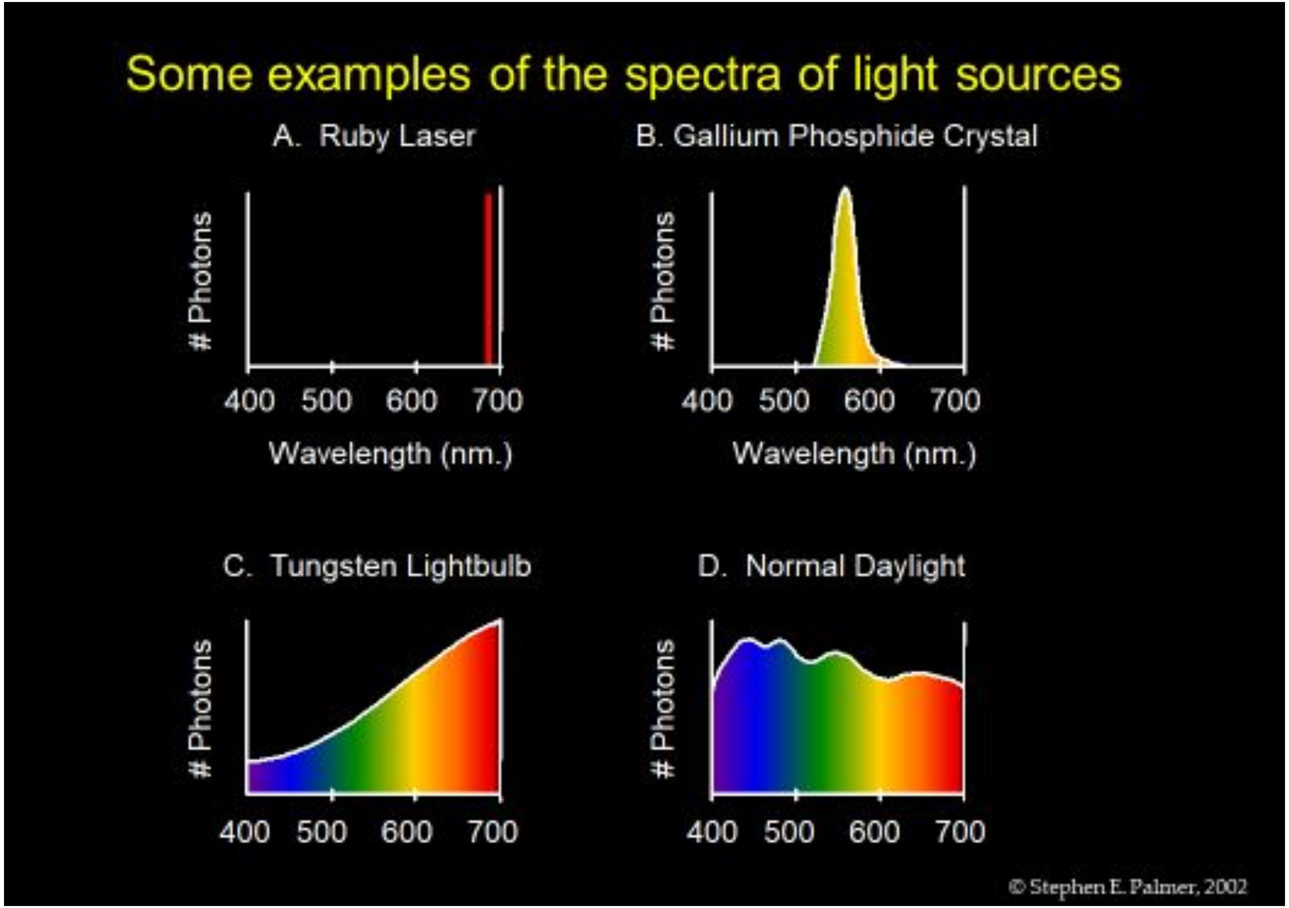
Rods

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

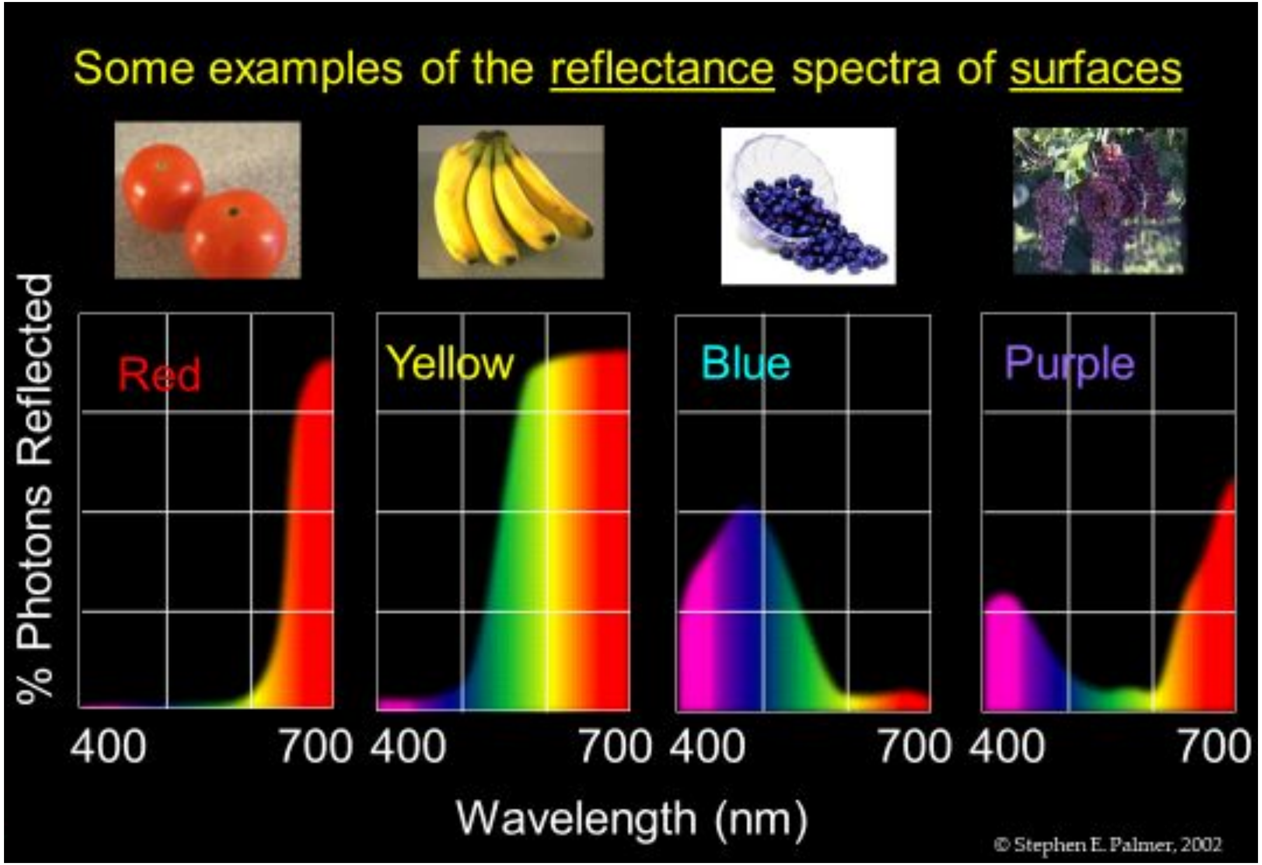


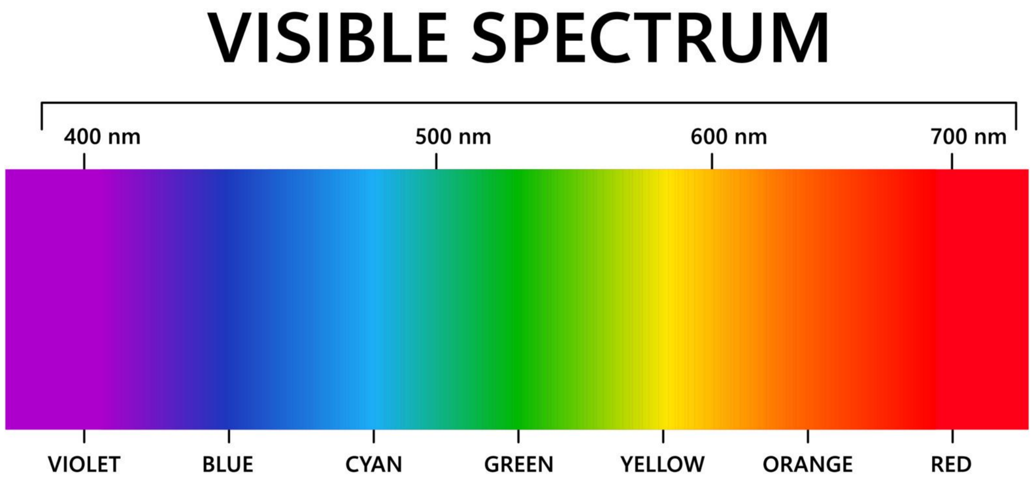
Any patch of light can be completely described physically by its spectrum: the number of photons (per time unit) at each wavelength 400 - 700 nm.





Some examples of the spectra of light sources
A. Ruby Laser
B. Gallium Phosphide Crystal
C. Tungsten Lightbulb
D. Normal Daylight
Photons
400 500 600 700
Wavelength (nm.)
© Stephen E. Palmer, 2002


Some examples of the reflectance spectra of surfaces
Red
Yellow
Blue
Purple
% Photons Reflected
400
700
400
700
400
700
400
700
Wavelength (nm)
© Stephen E. Palmer, 2002



The continuous visible spectrum

Color spaces: RGB

- Every natural object reflects a continuous spectrum of colors.
- However, the human eye only has three color sensors:
  - Red cones are sensitive to lower frequencies
  - Green cones are sensitive to intermediate frequencies
  - Blue cones are sensitive to higher frequencies

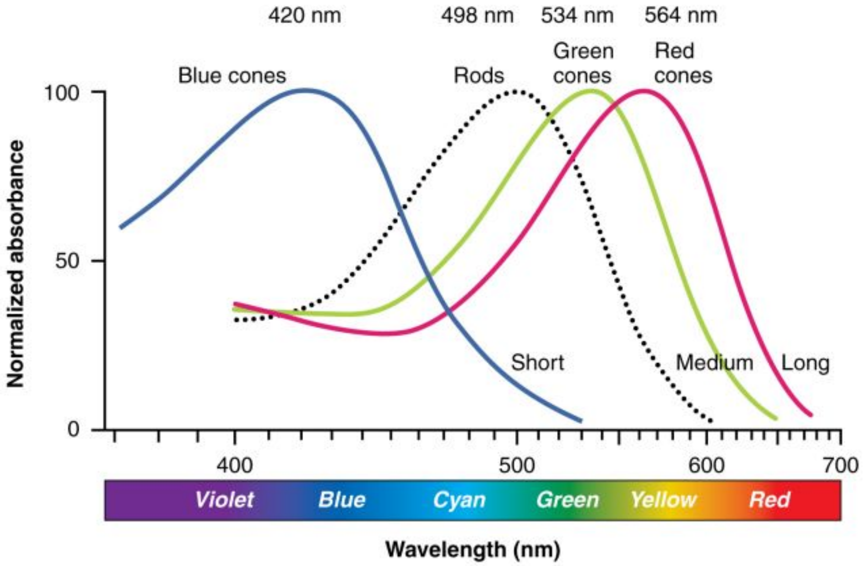
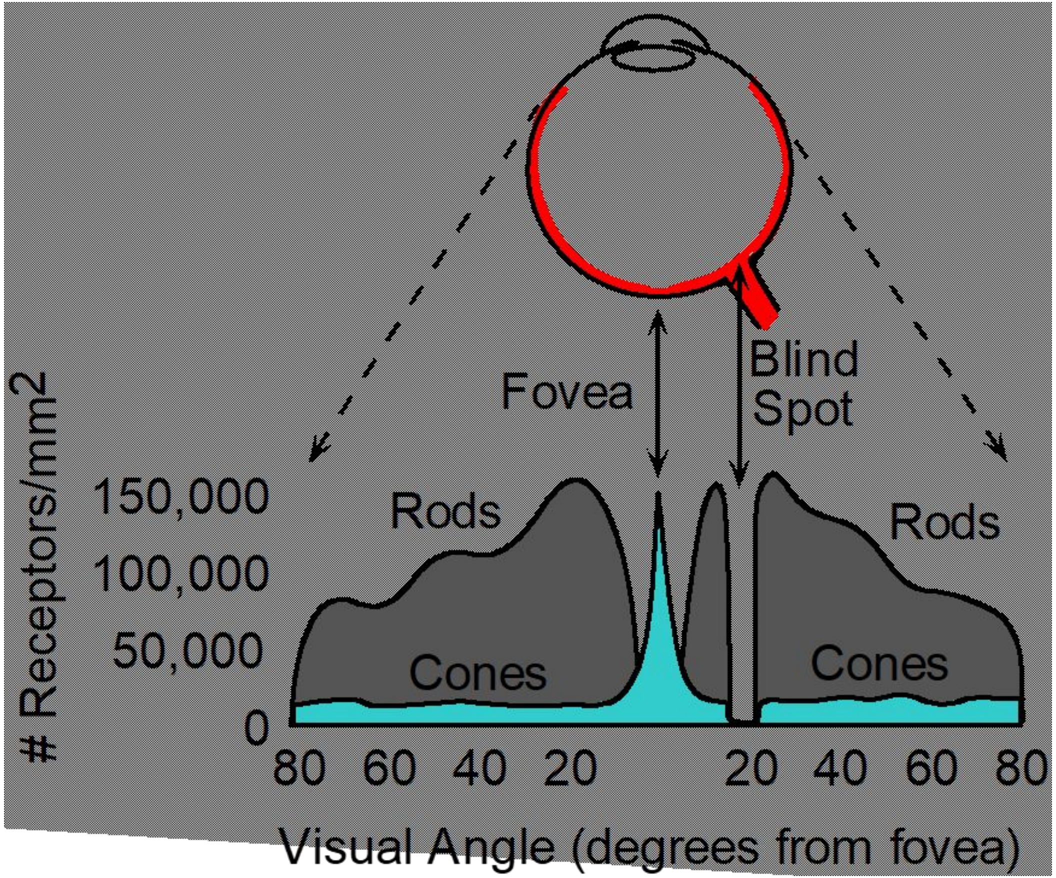


Illustration from Anatomy & Physiology, Connexions Web site. http://cnx.org/content/col11496/1.6/, Jun 19, 2013.

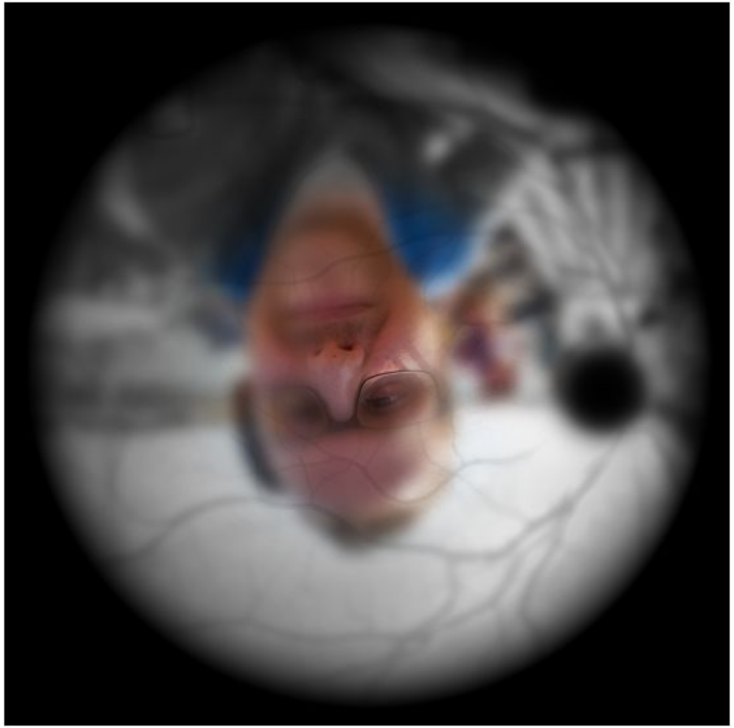


Fovea
Blind
Spot
Receptors/mm2
150,000
100,000
50,000
0
Rods
Rods
Cones
Cones
80 60 40 20 20 40 60 80
Visual Angle (degrees from fovea)

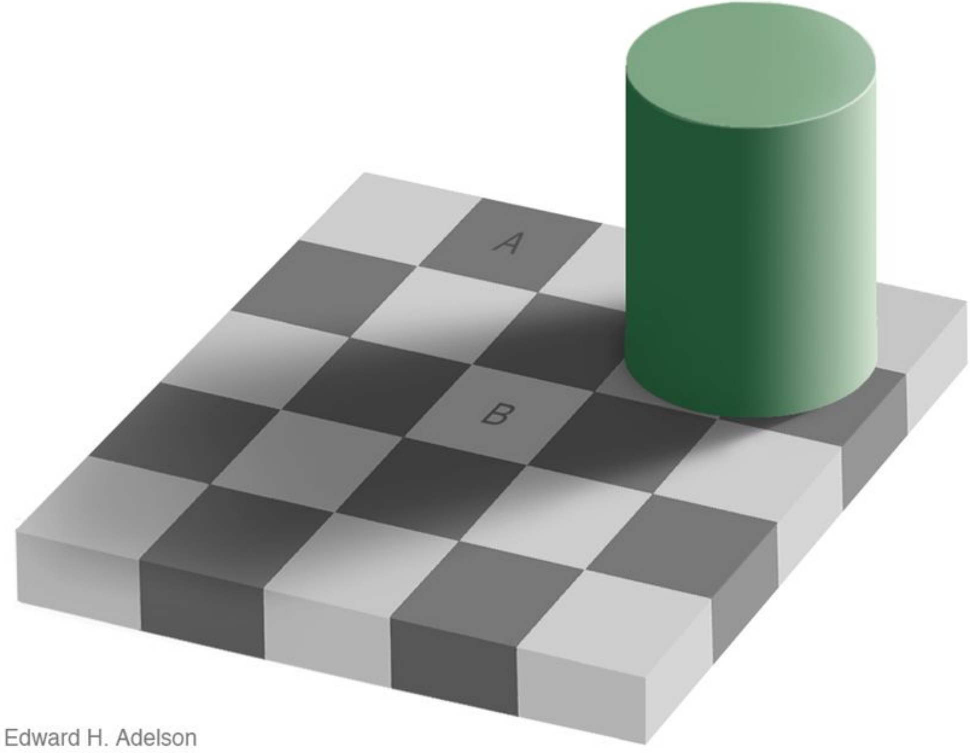
Structure of the eye

- Because we only have cones in the center of the eye, we can only actually see color in the center.
- The colors that you believe you see, in the periphery of your vision, are being filled in from memory by your pre-conscious visual processes (optic nerve and striate cortex).

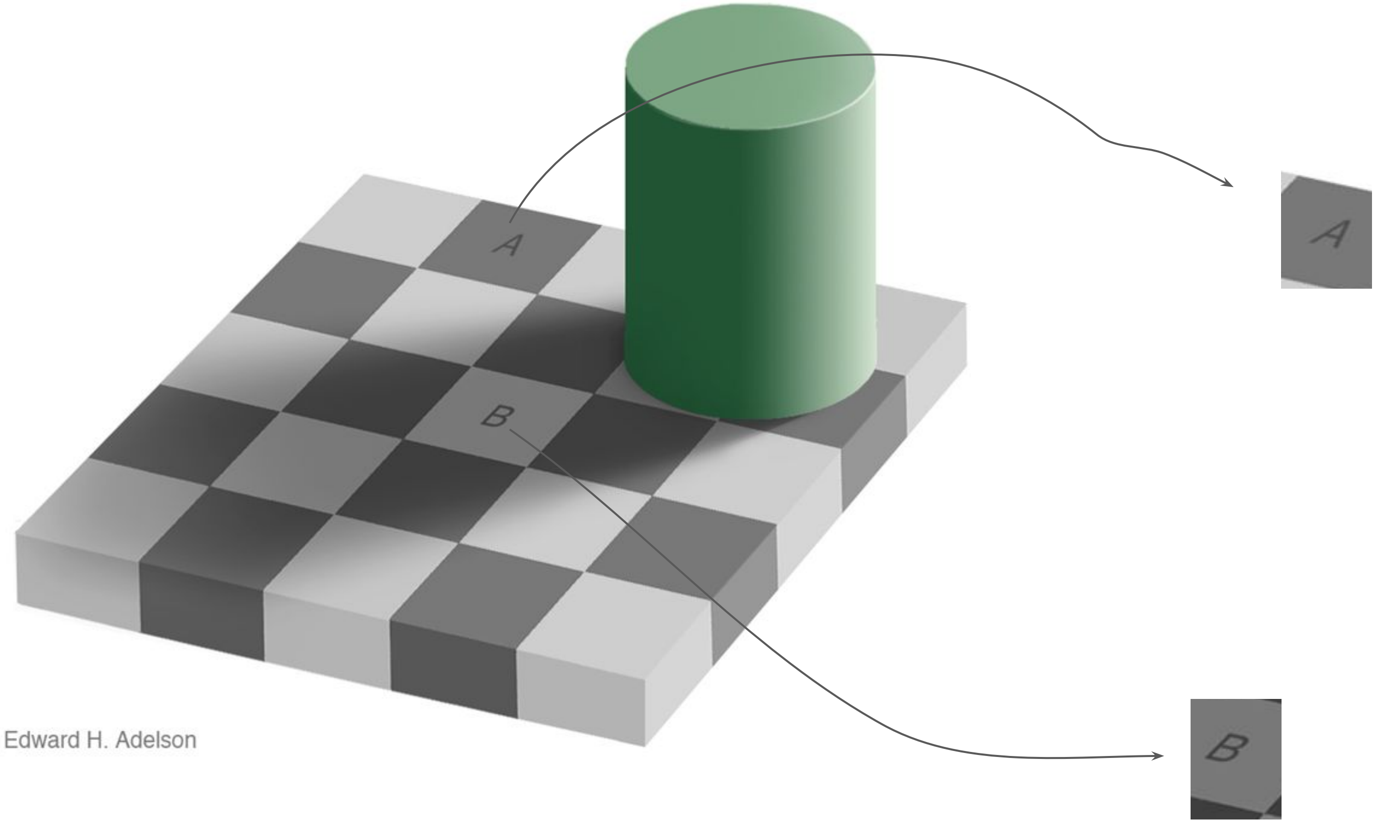
Illustration of image as 'seen' by the retina independent of optic nerve and striate cortex processing.

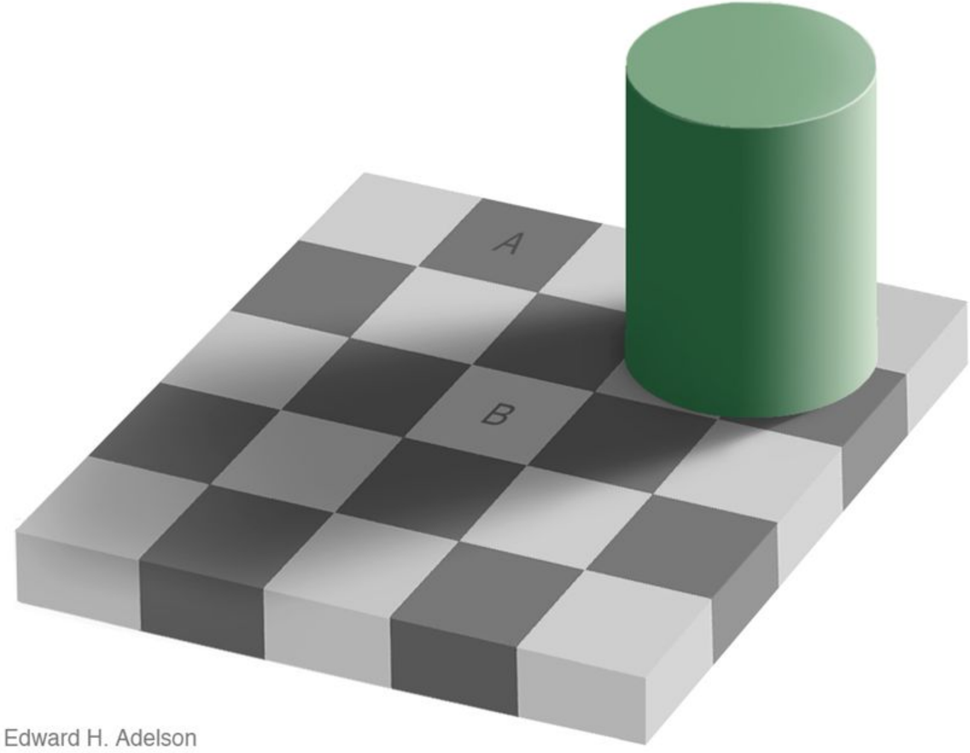


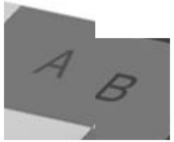
Do we see what is out there?



Tiles at A and B are of different color?


A
B
A
B
Edward H. Adelson



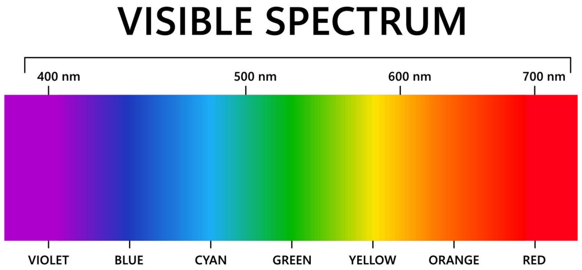


They are same color!

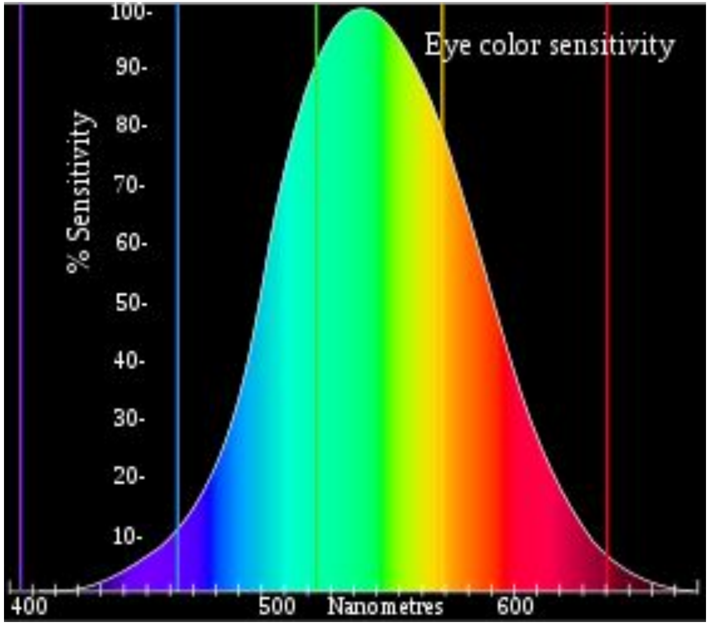
Capturing image using sensor

Human vision

Cone cells help
to see color



Human color vision has
highest sensitivity to green



Color spaces: RGB

A photograph of Mohammed Alim Khan (1880–1944), Emir of Bukhara, taken in 1911 by Sergey Prokudin-Gorsky using three exposures with blue, green, and red filters.

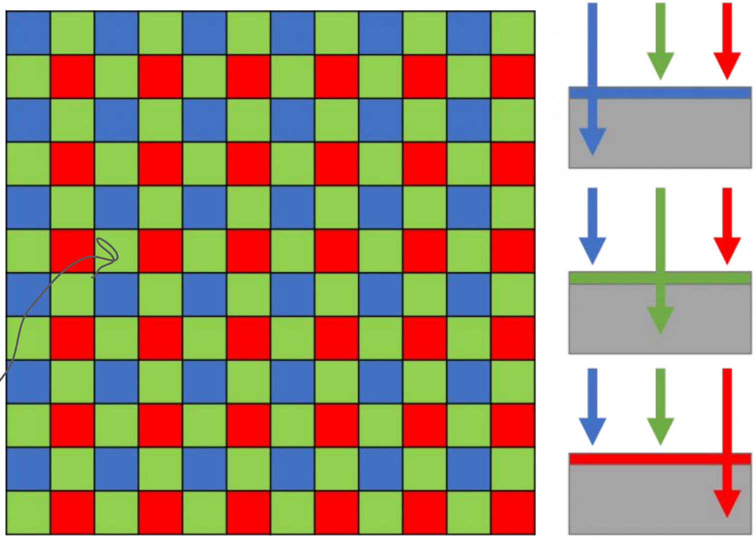
- By activating LED or other display hardware at just three discrete colors (R, G, and B), it is possible to fool the human eye into thinking that it sees a continuum of colors.
- Therefore, a so-called “color” camera is really three different black-and-white photographs:
  - R(x’,y’) is the brightness of red light at position (x’,y’)
  - G(x’,y’) is brightness of green.
  - B(x’,y’) is brightness of blue.

By Sergei Prokudin-Gorskii - Taken from the Library of Congress' website and converted from TIFF to PNG.TIFF file from LOC, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1470606

How does camera capture a scene?

- cone cells help to see color
- primarily sense red, green, and blue light
- RGB!

Bayer Filter

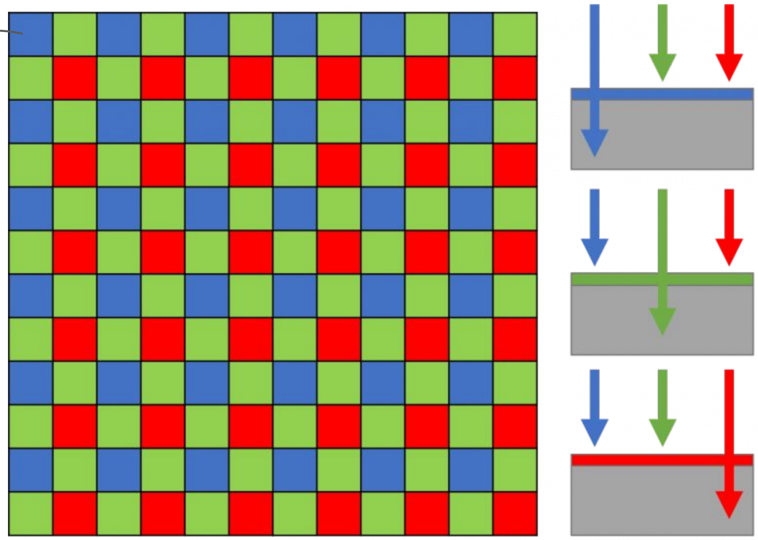


https://www.photometrics.com/

How does camera capture color?

Bayer Filter

How much blue has been captured?



- Count the number of photons falling for Blue - in a time interval T
- This quantifies the reflected blue light from a specific point on the object being photographed
- Quantize the count using N-bit number (bit depth)

note: measurements are (again) discrete

https://www.photometrics.com/

Combined image

Only R

Only G

Only B

https://en.wikipedia.org/wiki/RGB_color_model