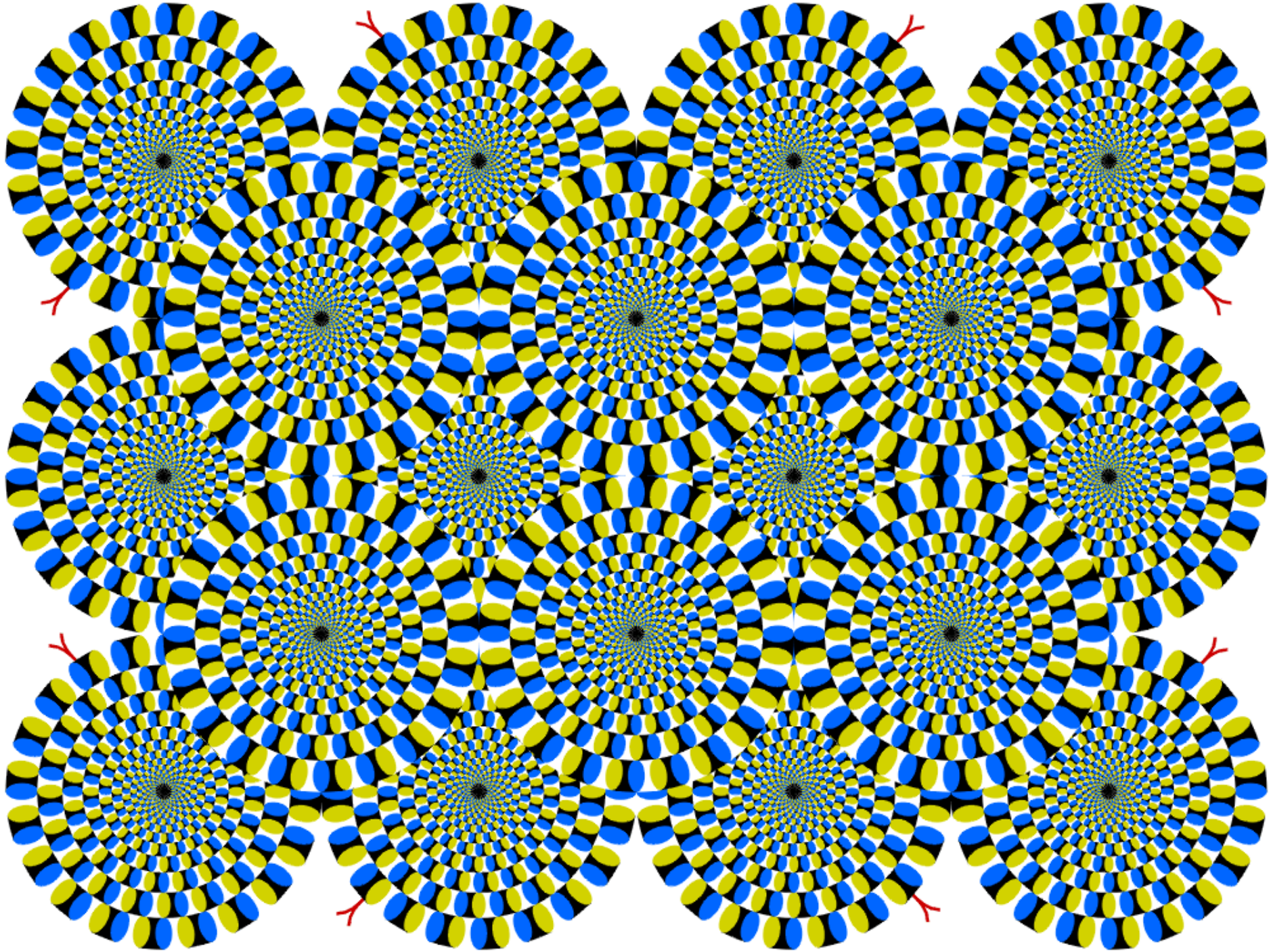
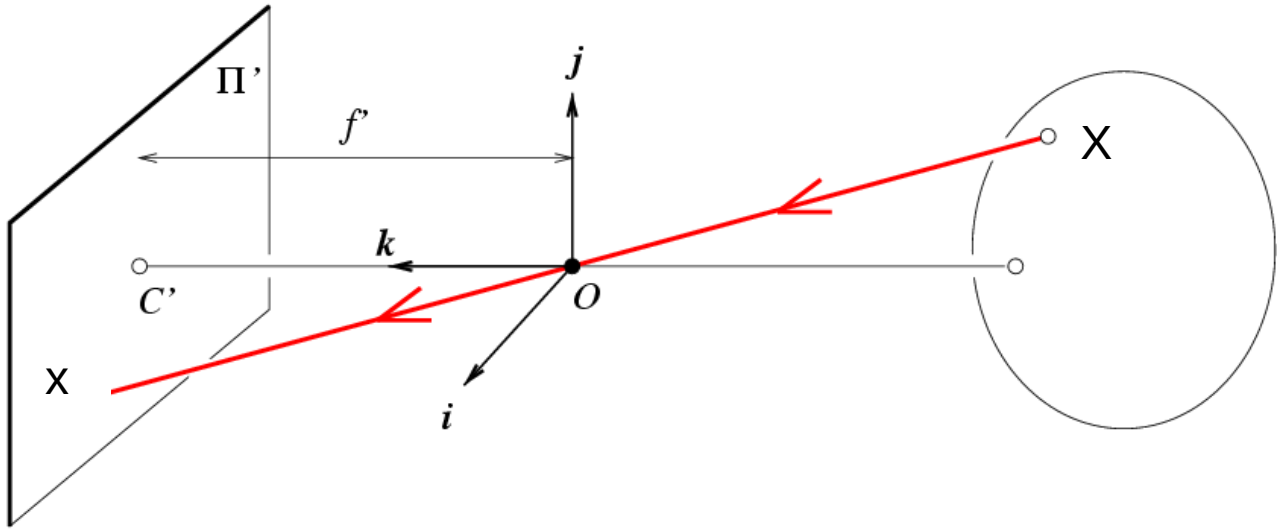


# Recap: projection




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

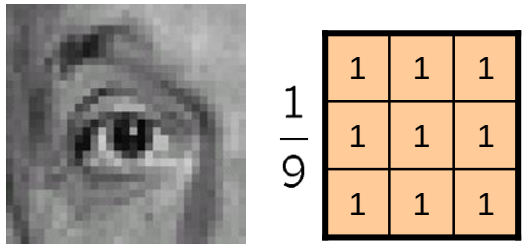
$$w\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \alpha & s & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \end{bmatrix}\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

# Relating multiple views

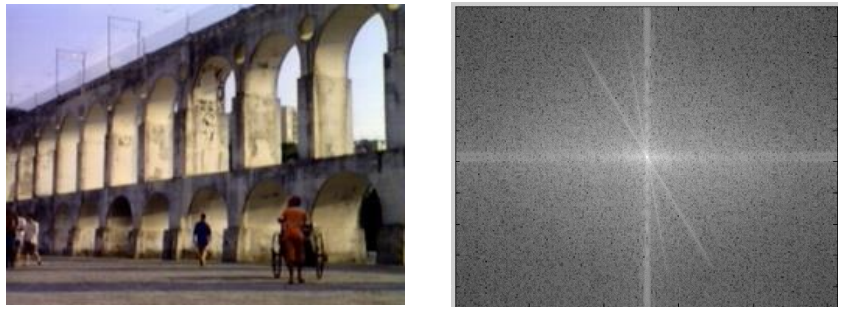
**Figure Credit: Bundler: Structure from Motion (SfM) for Unordered Image Collections**

# Recap of Filtering

- Linear filtering is dot product at each position
  - Not a matrix multiplication
  - Can smooth, sharpen, translate (among many other uses)



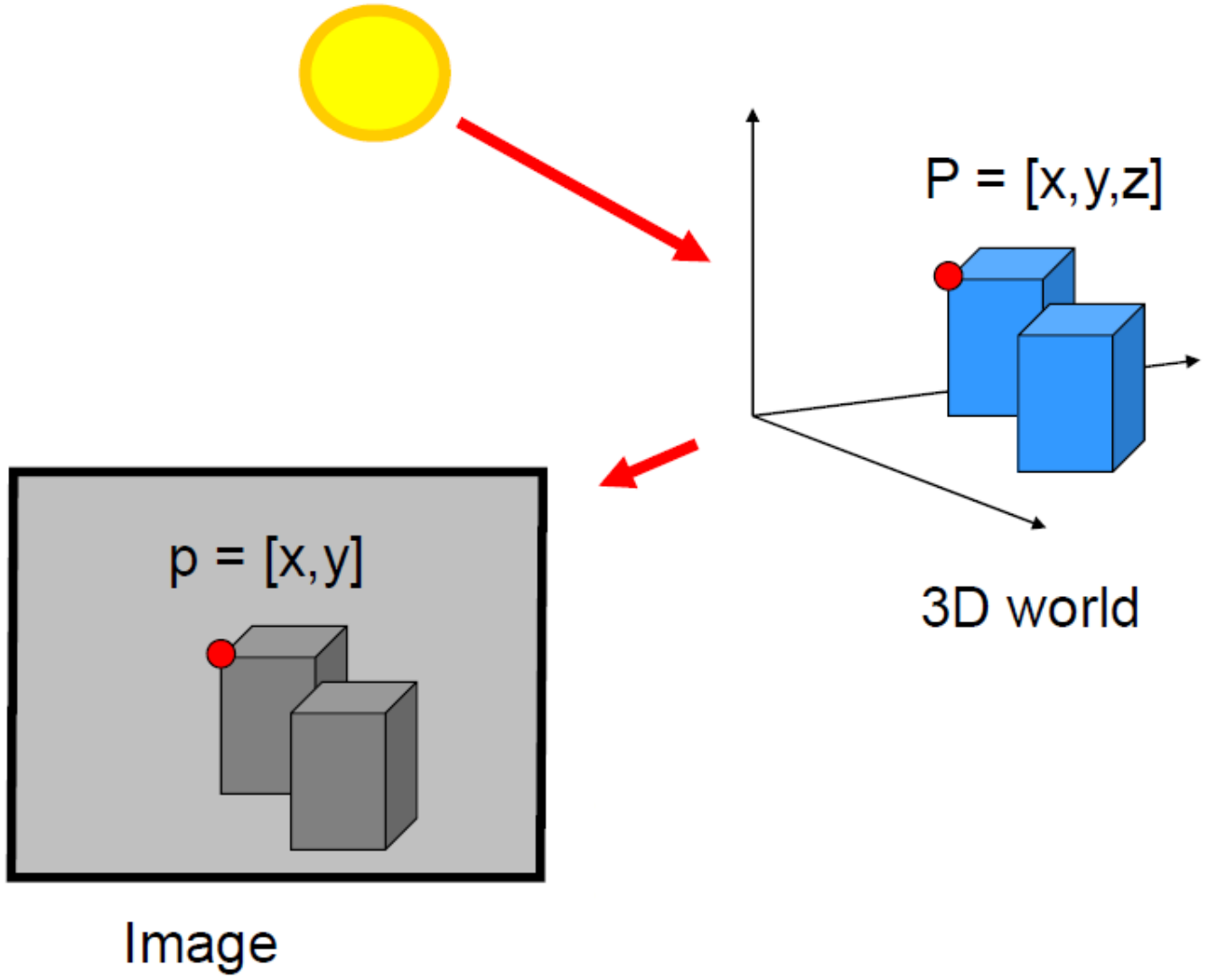

- We can use the Fourier transform to represent images in the frequency domain.
  - Filtering in the spatial domain is multiplication in the frequency domain.



# This lecture

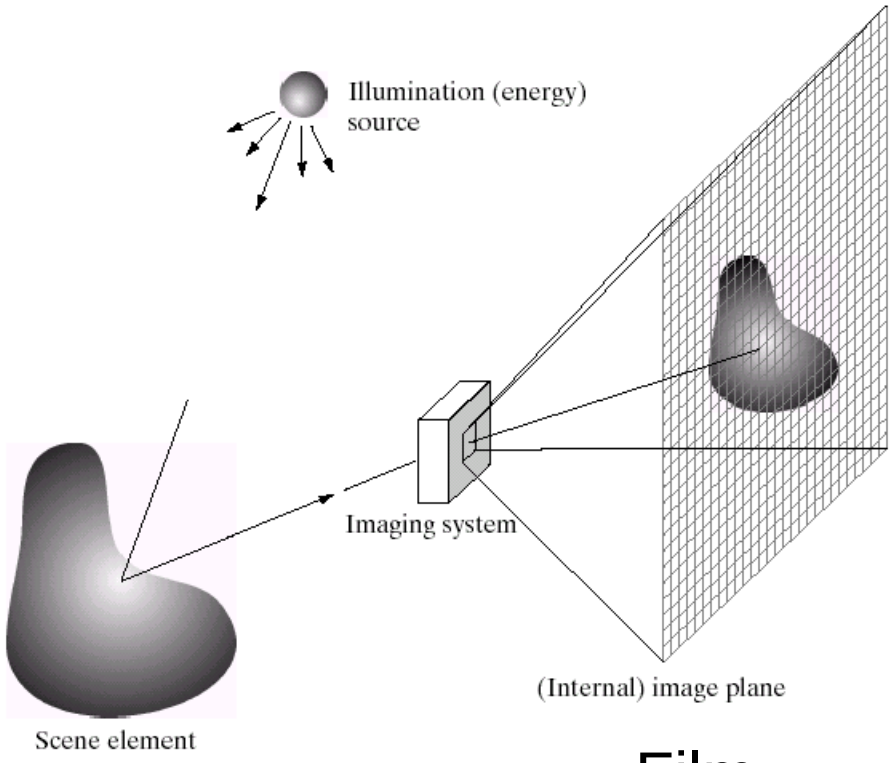
- Image Formation
- Biological Vision
- Light and Color

# From the 3D to 2D

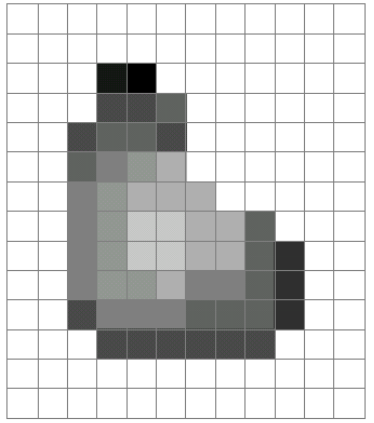



Slide credit Fei Fei Li

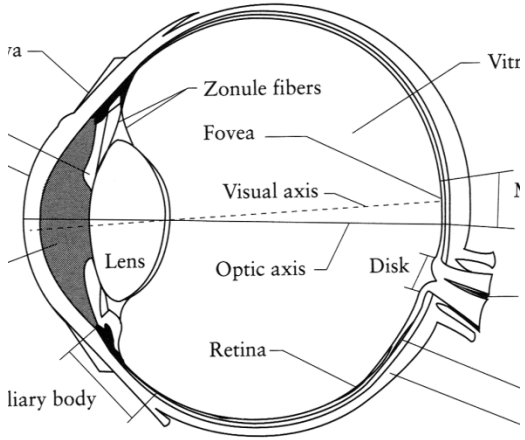
# Image Formation




Film



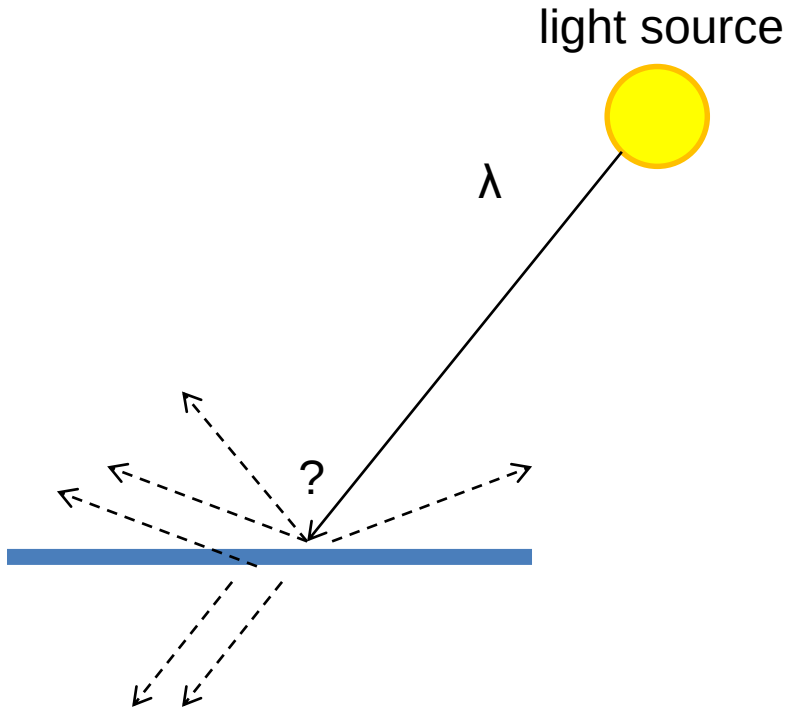
Digital Camera




The Eye

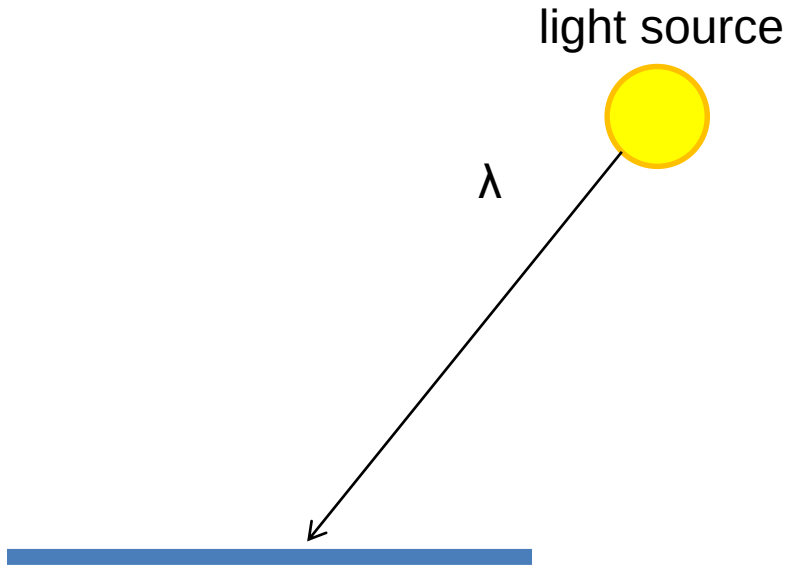
# A photon’s life choices

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



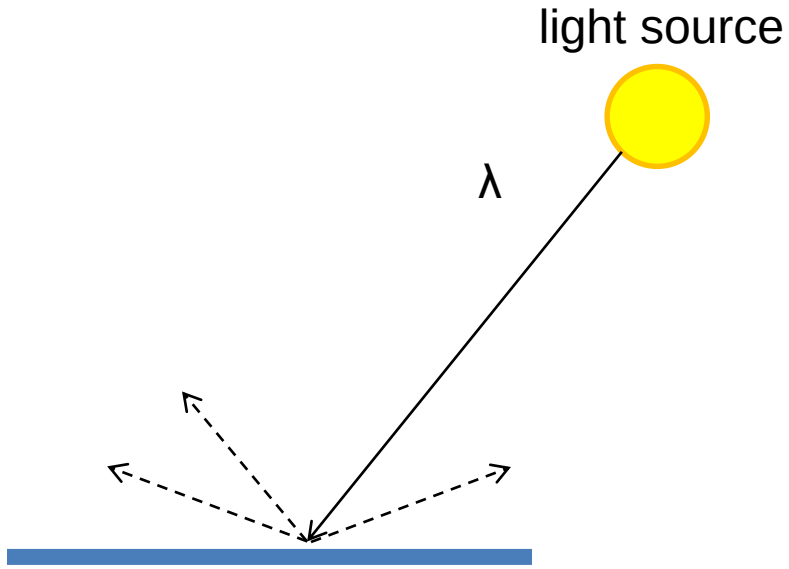
# A photon’s life choices

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



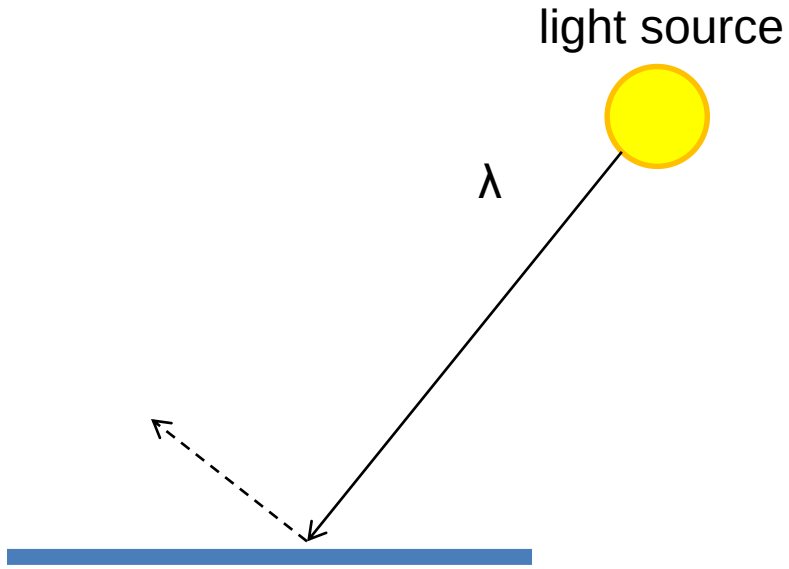
# A photon’s life choices

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



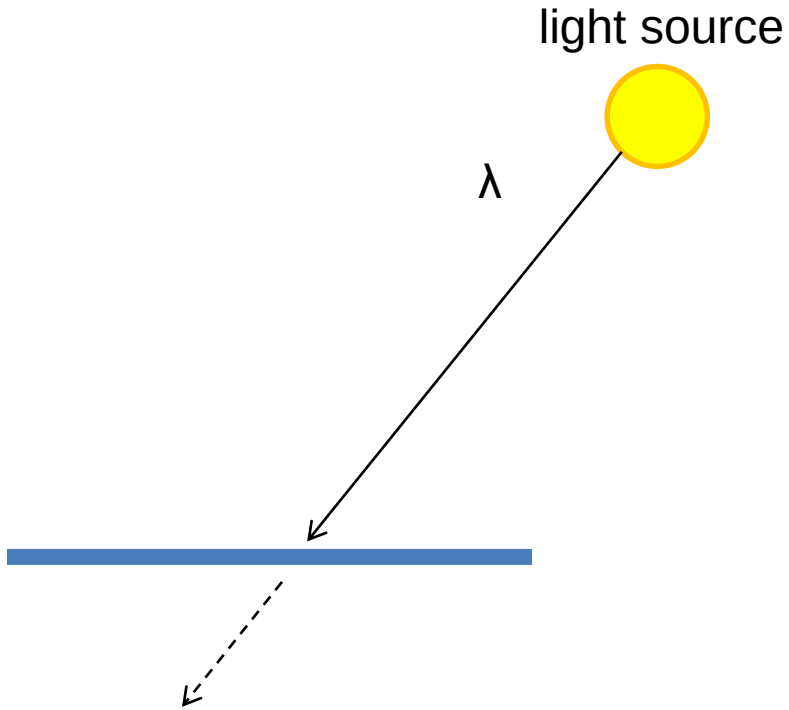
# A photon’s life choices

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



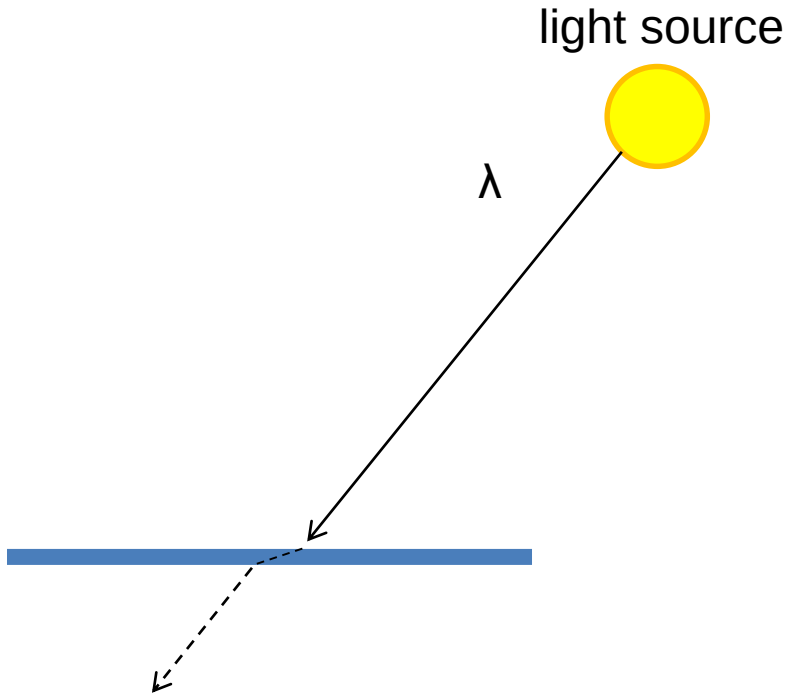
# A photon’s life choices

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



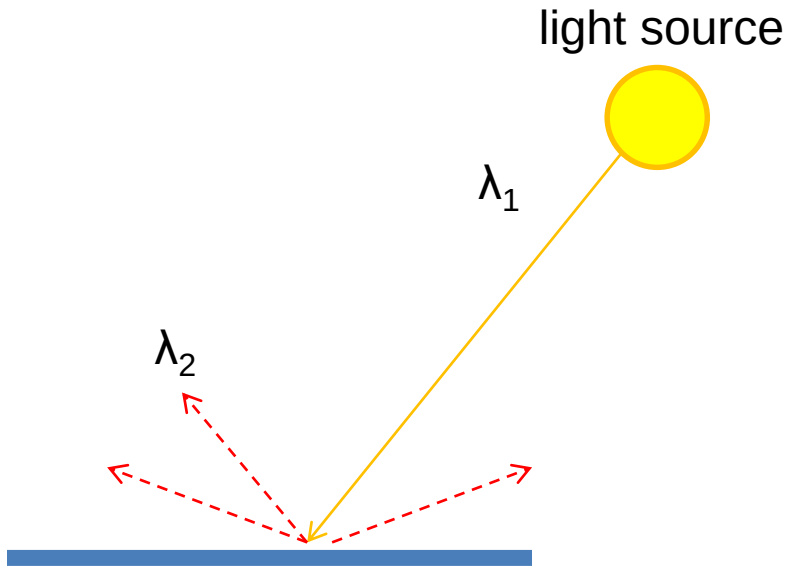
# A photon’s life choices

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



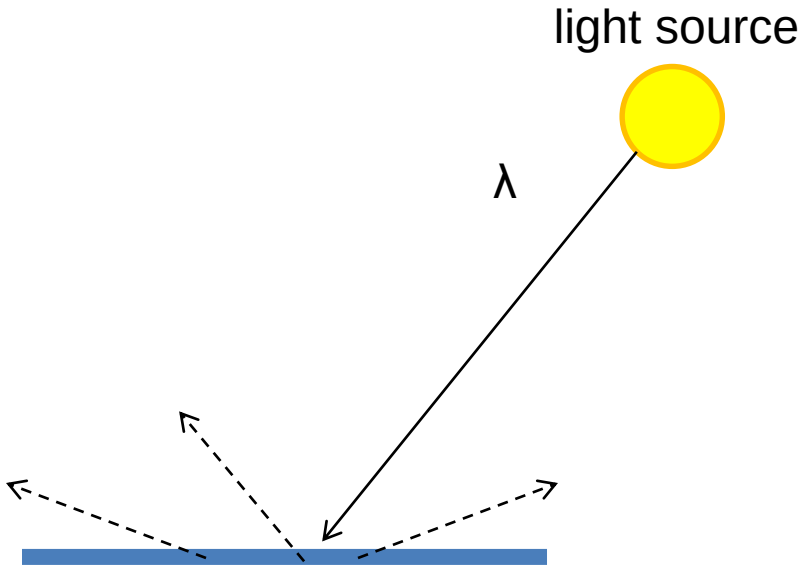
# A photon’s life choices

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



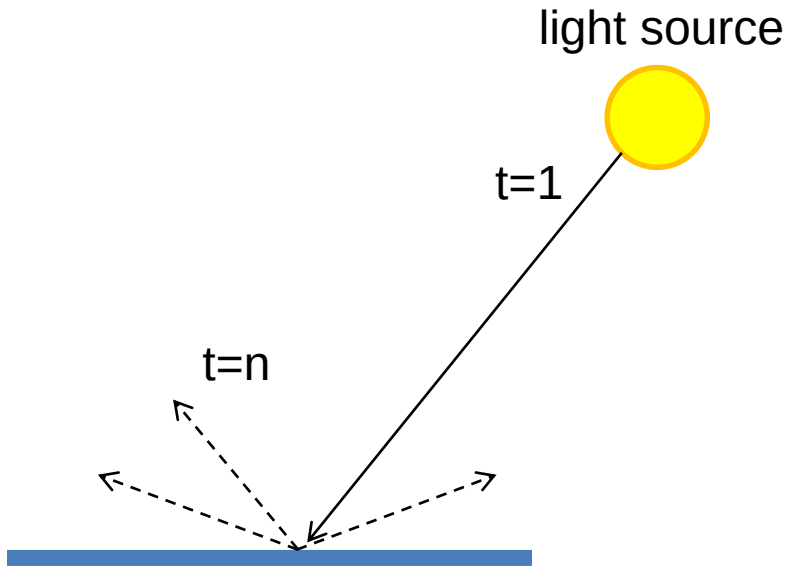
# A photon’s life choices

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



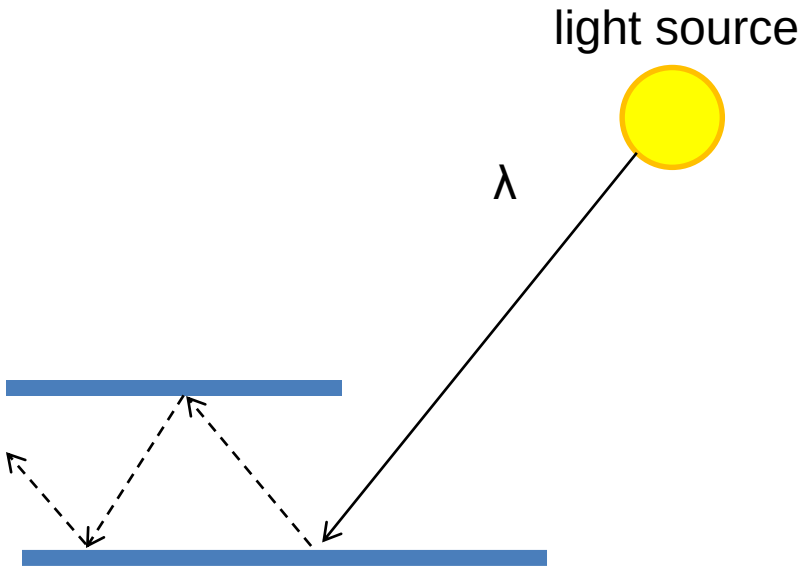
# A photon’s life choices

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



# A photon’s life choices

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




(Specular Interreflection)

# Lambertian Reflectance

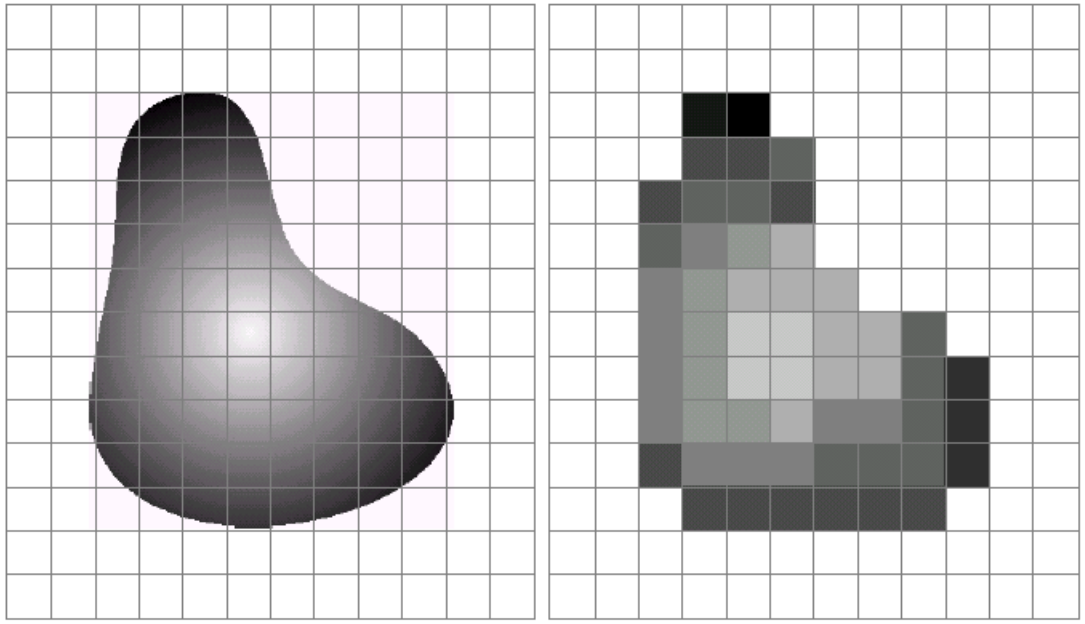
- In computer vision, the complexity of light transport is mostly ignored.
- Surfaces are often assumed to be ideal diffuse reflectors with no dependence on viewing direction.

# 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

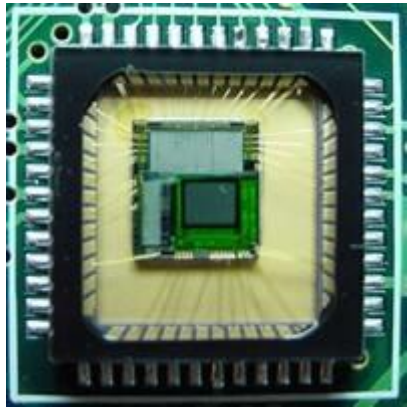
Slide by Steve Seitz

# Sensor Array



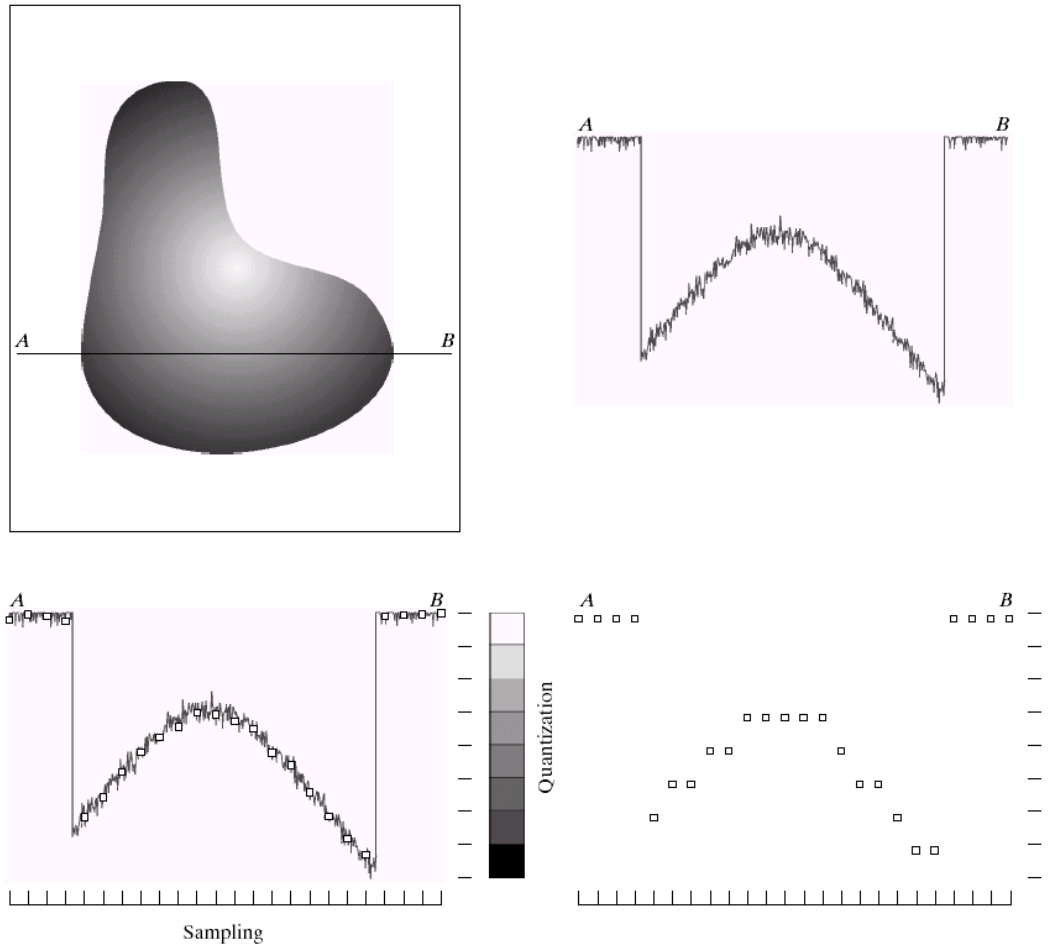
a b

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



CMOS sensor

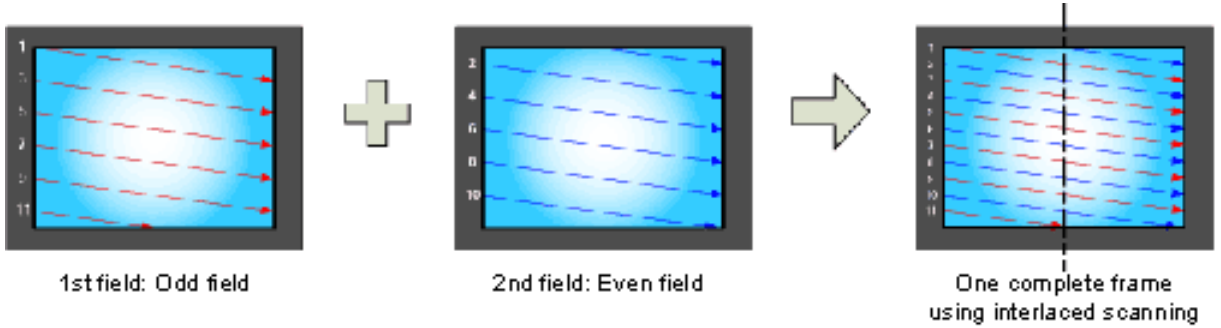
# Sampling and Quantization

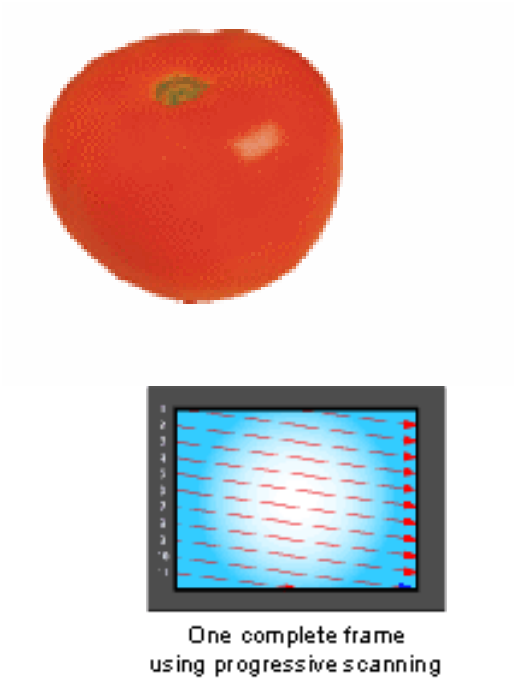



a b
c d

**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




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

Slide by Steve Seitz

# Progressive scan or Global shutter

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

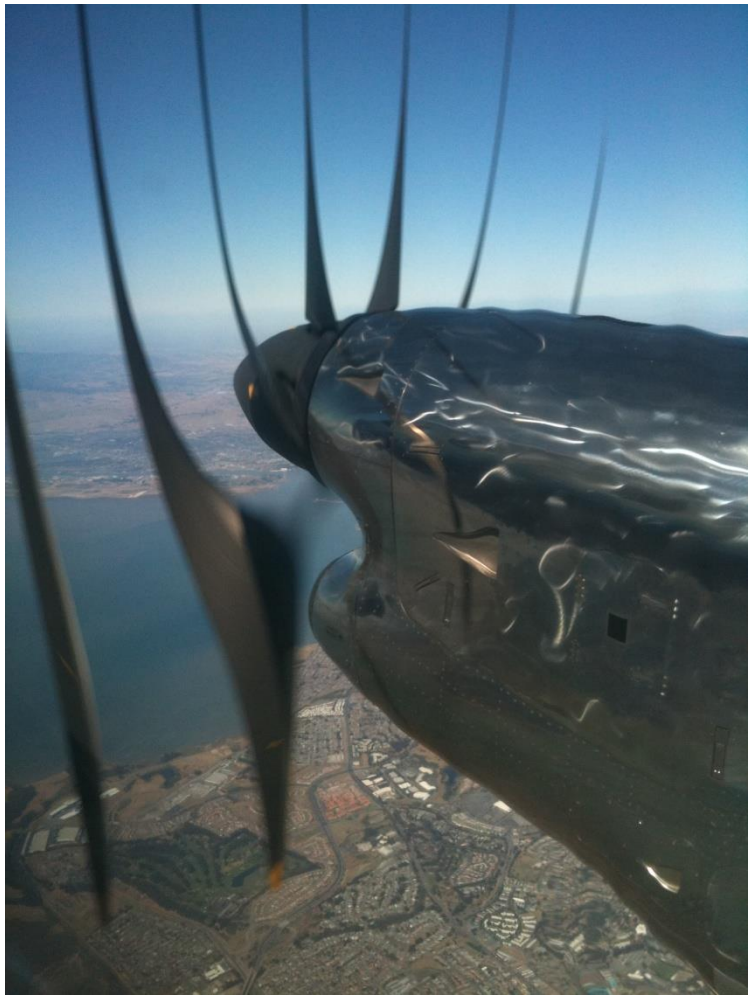
Slide by Steve Seitz

# Interlaced

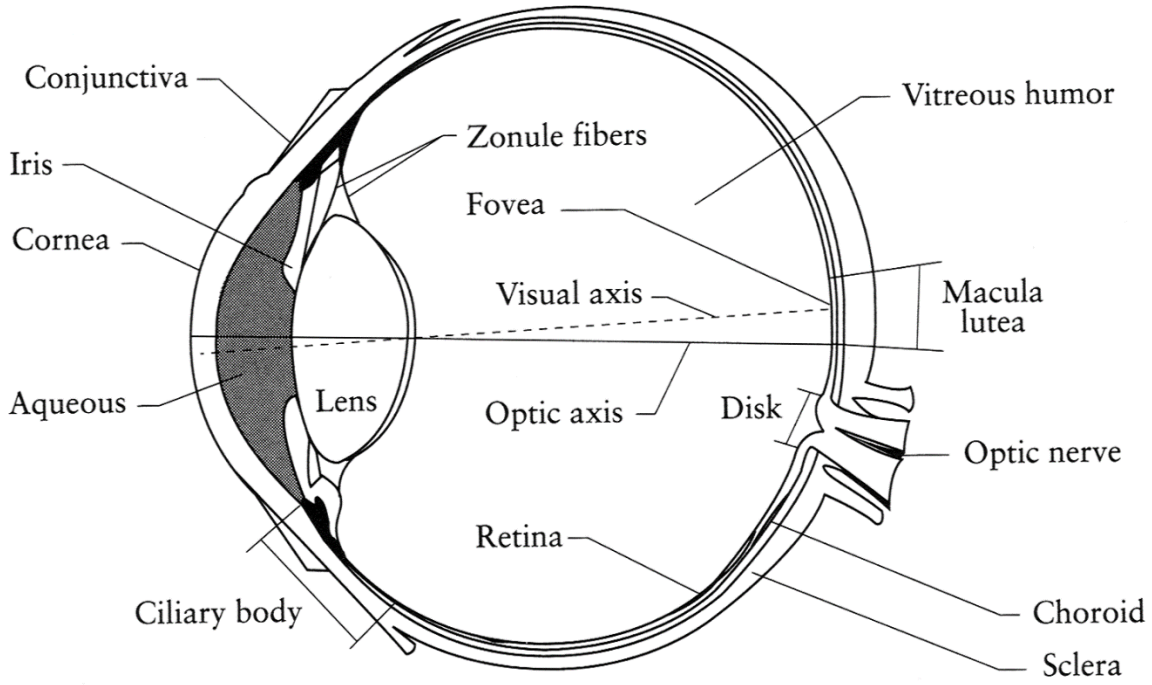
http://www.axis.com/products/video/camera/progressive_scan.htm

Slide by Steve Seitz

# Rolling Shutter



# The Eye



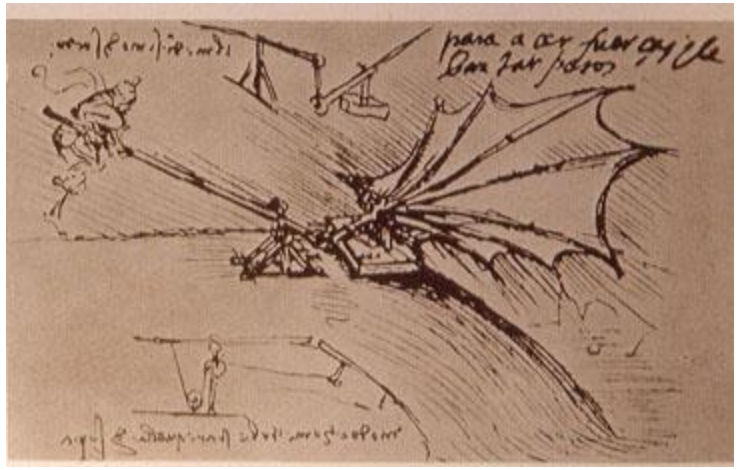

- The human eye is a camera!
  - **Iris** - colored annulus with radial muscles
  - **Pupil** - the hole (aperture) whose size is controlled by the iris
  - What's the "film"?
    - photoreceptor cells (rods and cones) in the **retina**

Slide by Steve Seitz

# Aside: why do we care about human vision in this class?

- We don’t, necessarily.

# Ornithopters



# Why do we care about human vision?

- We don’t, necessarily.
- But cameras necessarily imitate the frequency response of the human eye, so we should know that much.
- Also, computer vision probably wouldn’t get as much scrutiny if biological vision (especially human vision) hadn’t proved that it was possible to make important judgements from 2d images.

# Does computer vision “understand” images?

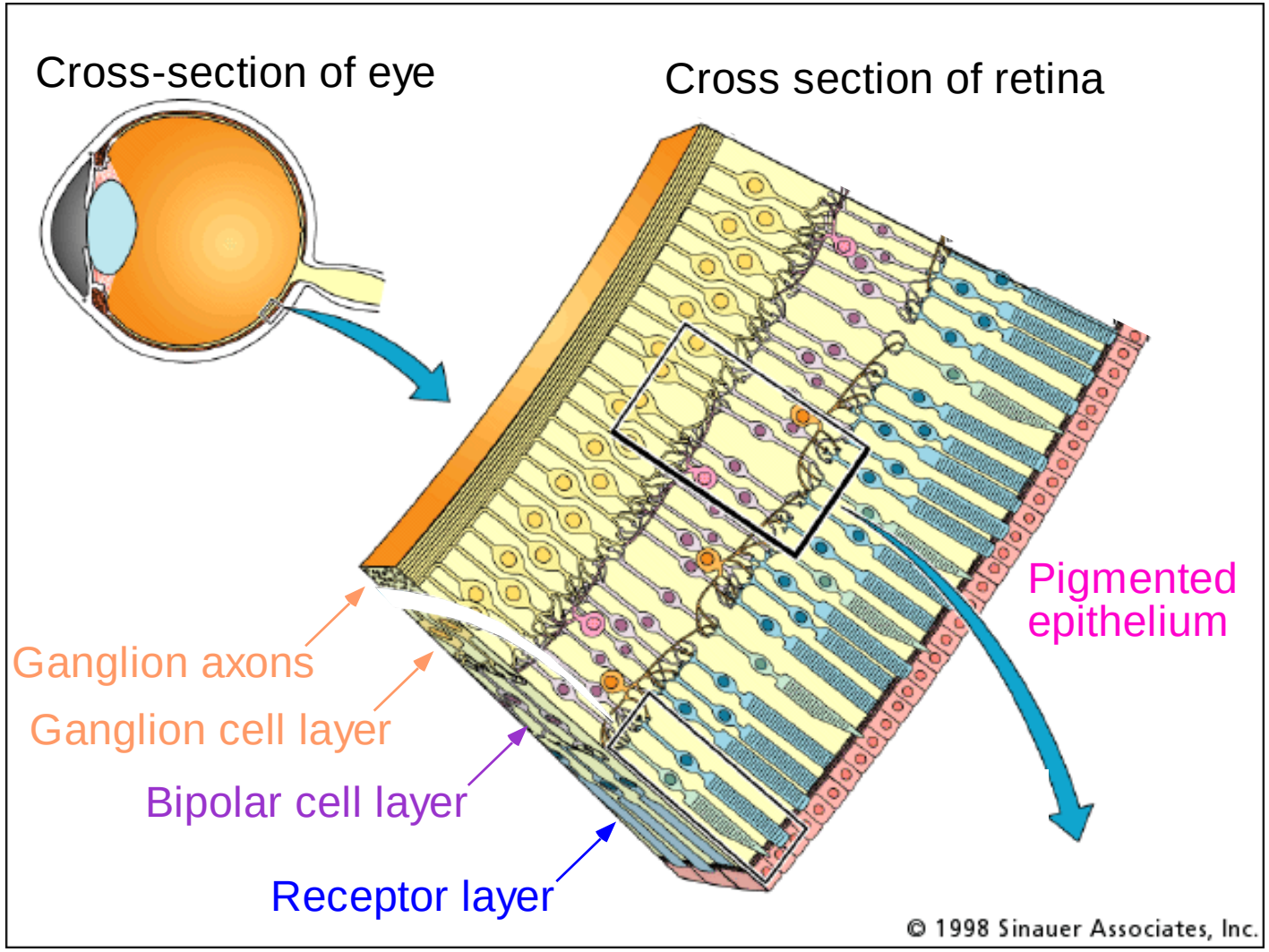
"Can machines fly?" The answer is yes, because airplanes fly.

"Can machines swim?" The answer is no, because submarines don't swim.

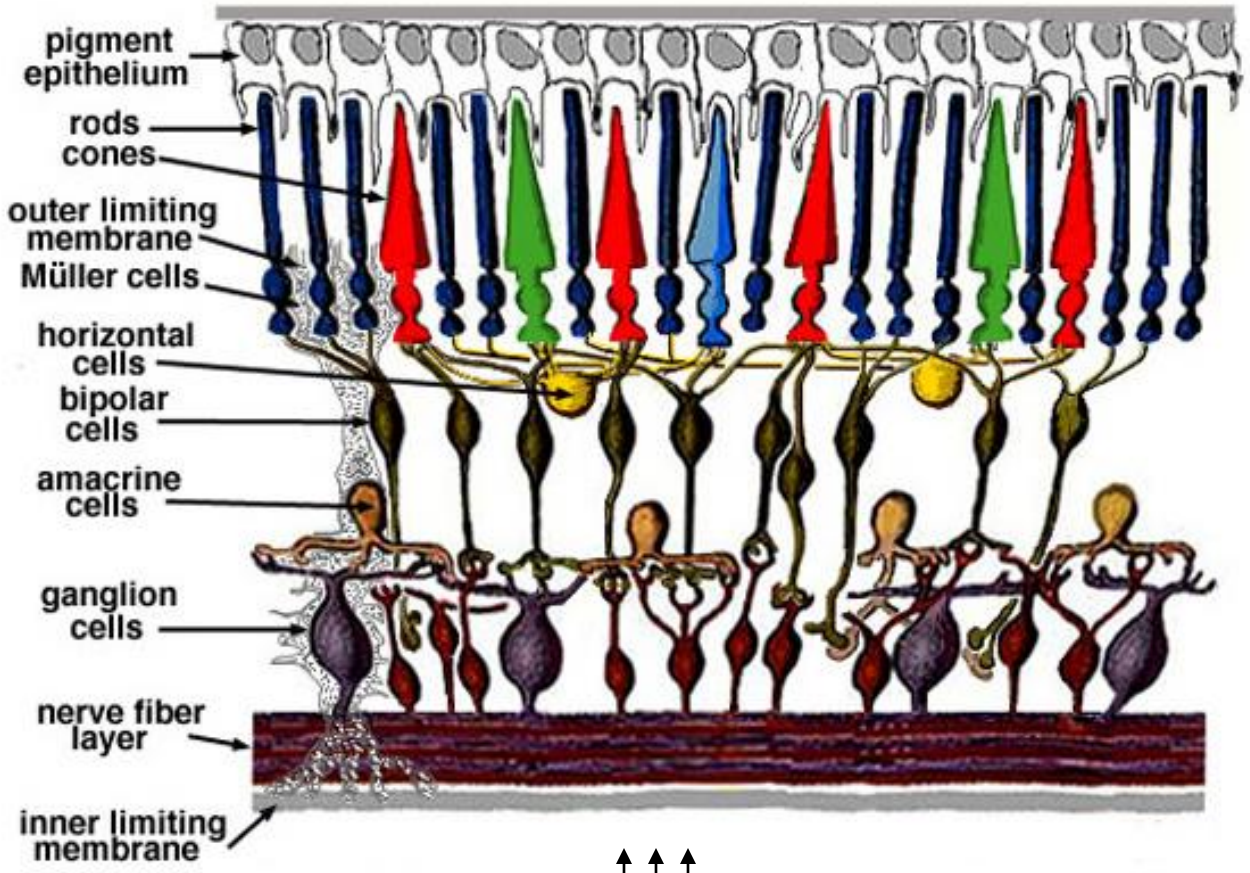
"Can machines think?" Is this question like the first, or like the second?

Source: Norvig

# The Retina

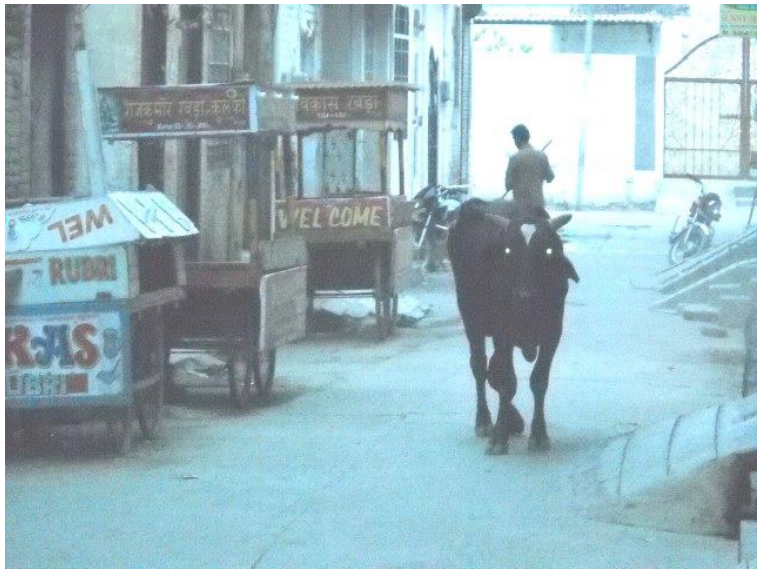

Cross-section of eye
Cross section of retina
Pigmented epithelium
Ganglion axons
Ganglion cell layer
Bipolar cell layer
Receptor layer
© 1998 Sinauer Associates, Inc.

# Retina up-close



# What humans don’t have: tapetum lucidum

Human eyes can reflect a tiny bit and blood in the retina makes this reflection red.



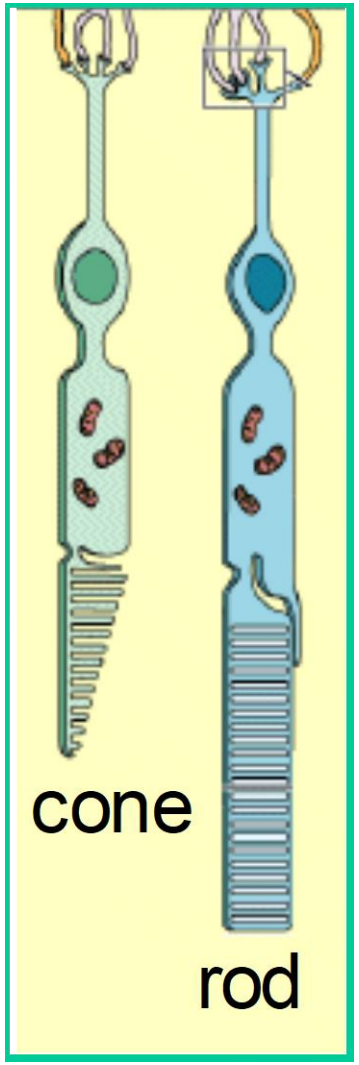
# Two types of light-sensitive receptors

**Cones**

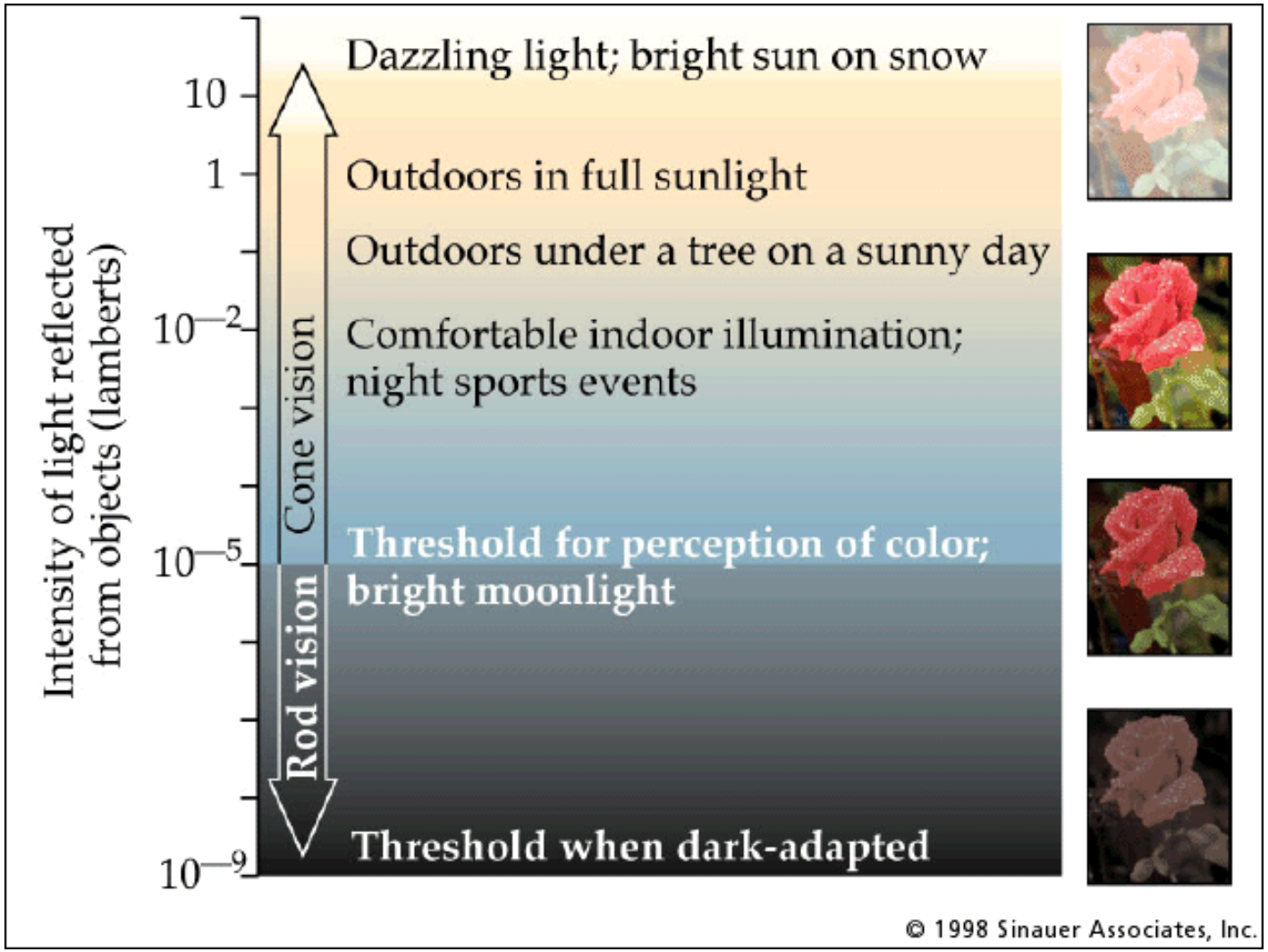
- cone-shaped
- less sensitive
- operate in high light
- color vision

**Rods**

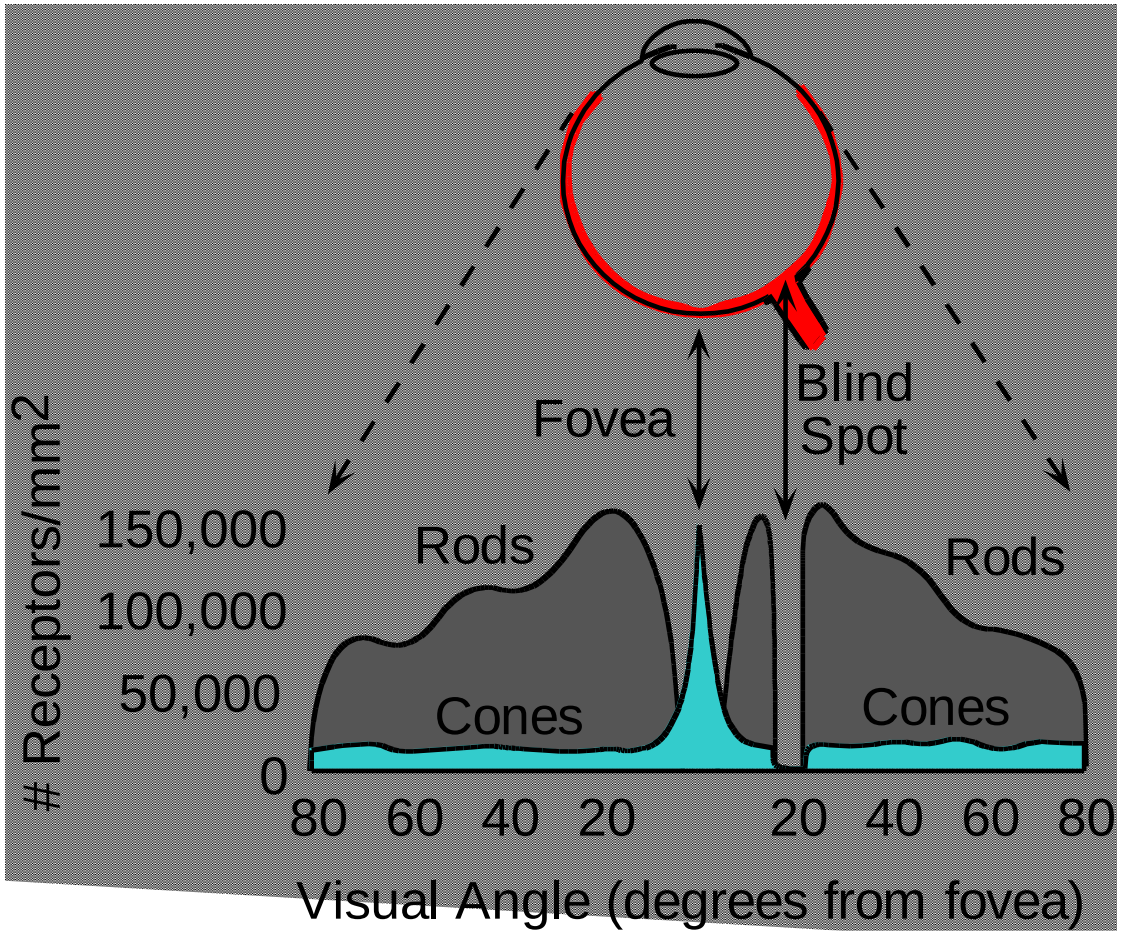
- rod-shaped
- highly sensitive
- operate at night
- gray-scale vision



# Rod / Cone sensitivity



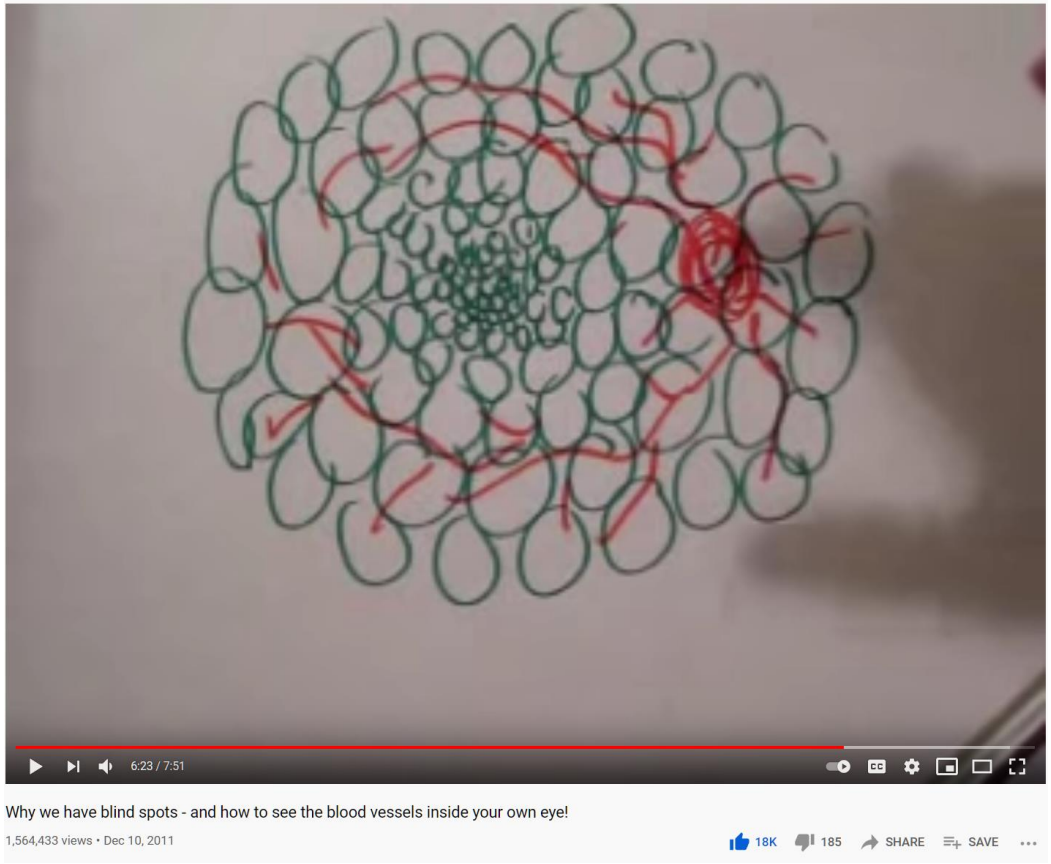
# Distribution of Rods and Cones




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

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

# Wait, the blood vessels are in front of the photoreceptors??




https://www.youtube.com/watch?v=L_W-IXqoxHA

# Eye Movements

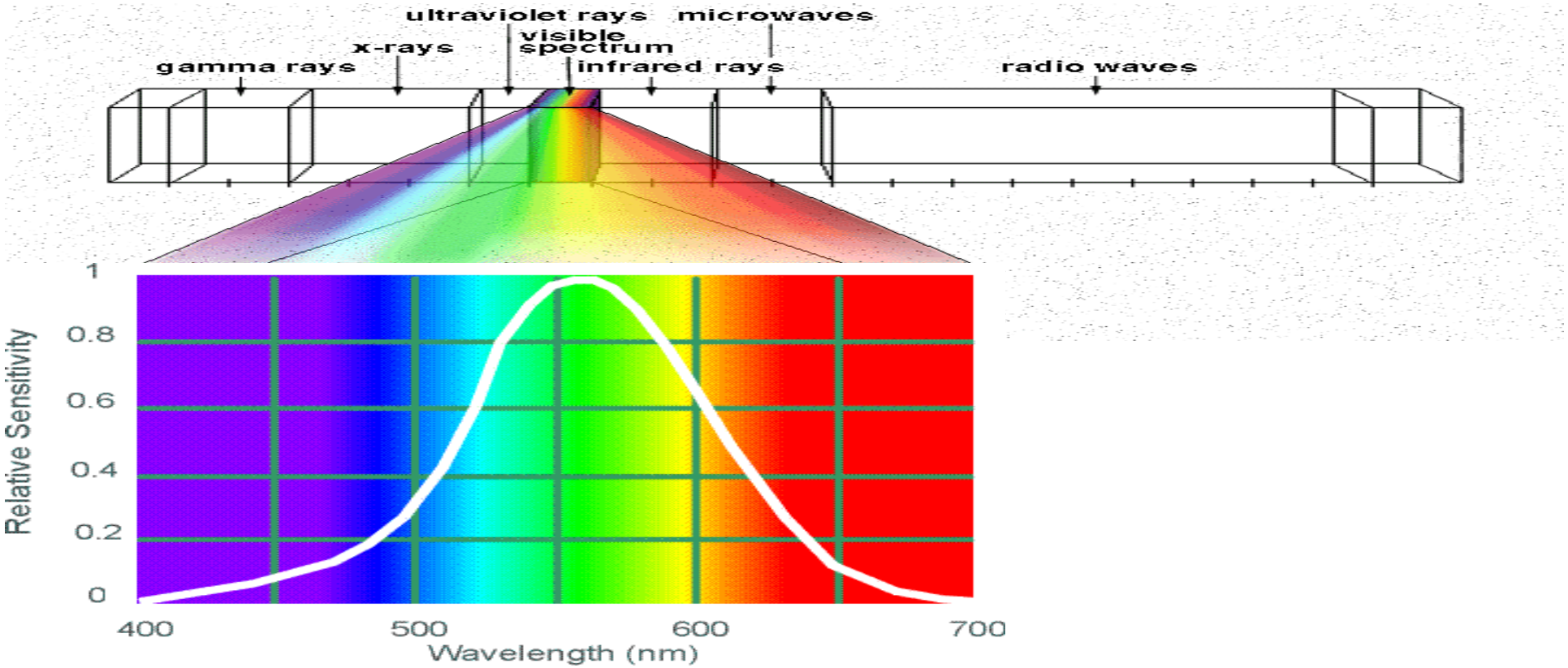
- Saccades
- Can be consciously controlled. Related to perceptual attention.
- 200ms to initiation, 20 to 200ms to carry out. Large amplitude.
- Microsaccades
- Involuntary. Smaller amplitude. Especially evident during prolonged fixation. Function debated.
- Ocular microtremor (OMT)
- Involuntary. high frequency (up to 80Hz), small amplitude.

- Smooth pursuit – tracking an object

# Slow mo guys – Saccades and CRTs

- https://youtu.be/Fmg9ZOHESgQ?t=21s
- https://youtu.be/3BJU2drrtCM

# Electromagnetic Spectrum




Human Luminance Sensitivity Function

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