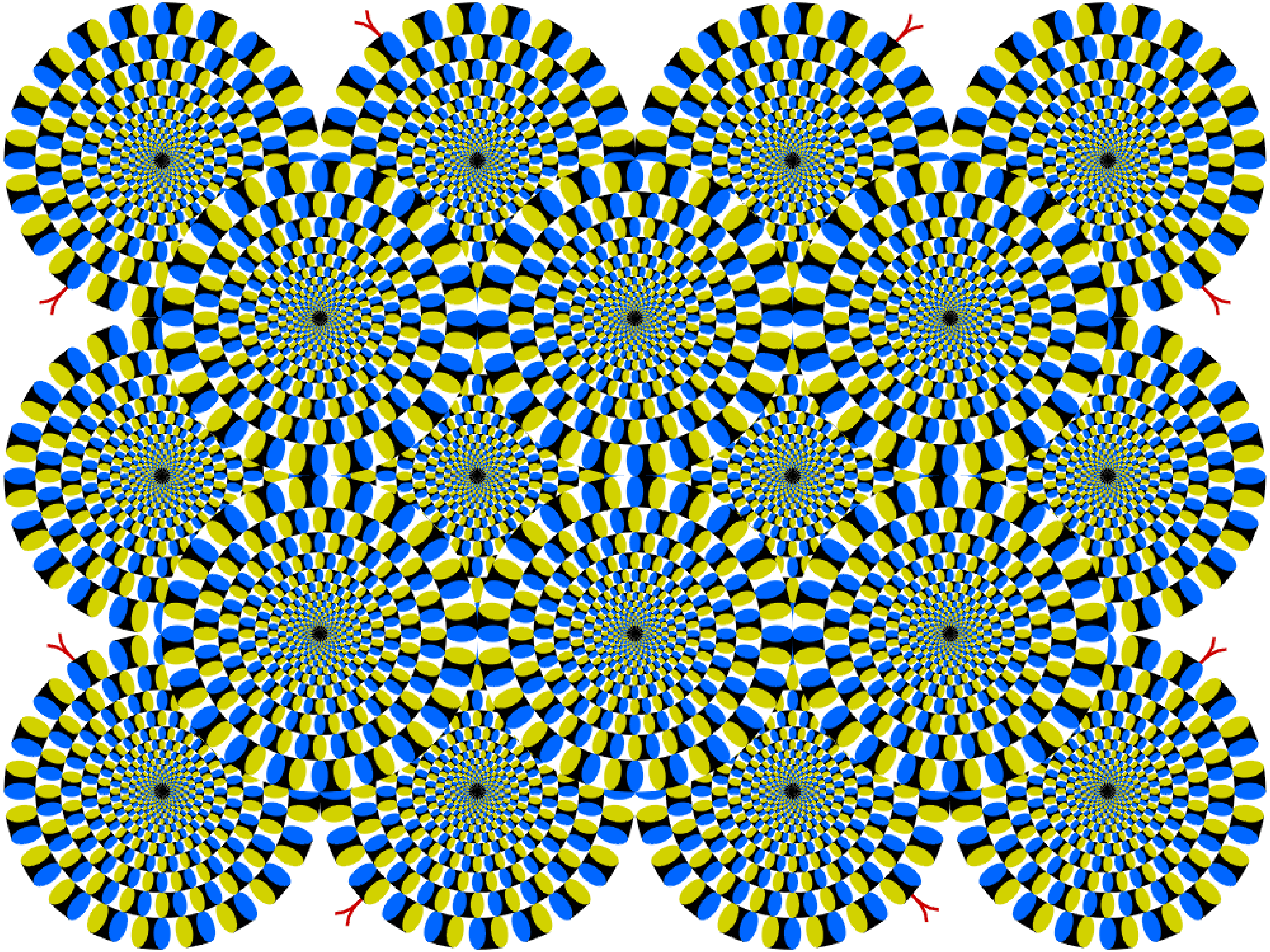
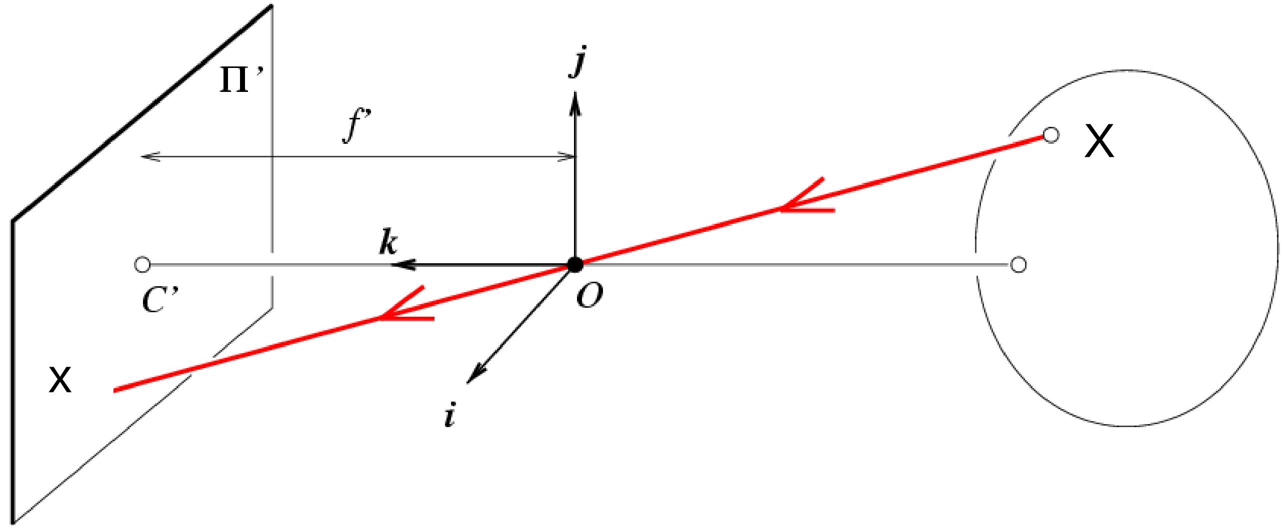


Recap: projection



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

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

Relating multiple views

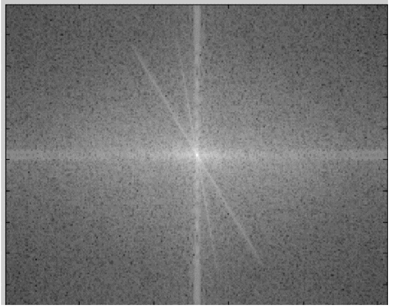
Figure Credit: Bundler: Structure from Motion (SfM) for Unordered Image Collections

Recap of Filtering

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

$$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

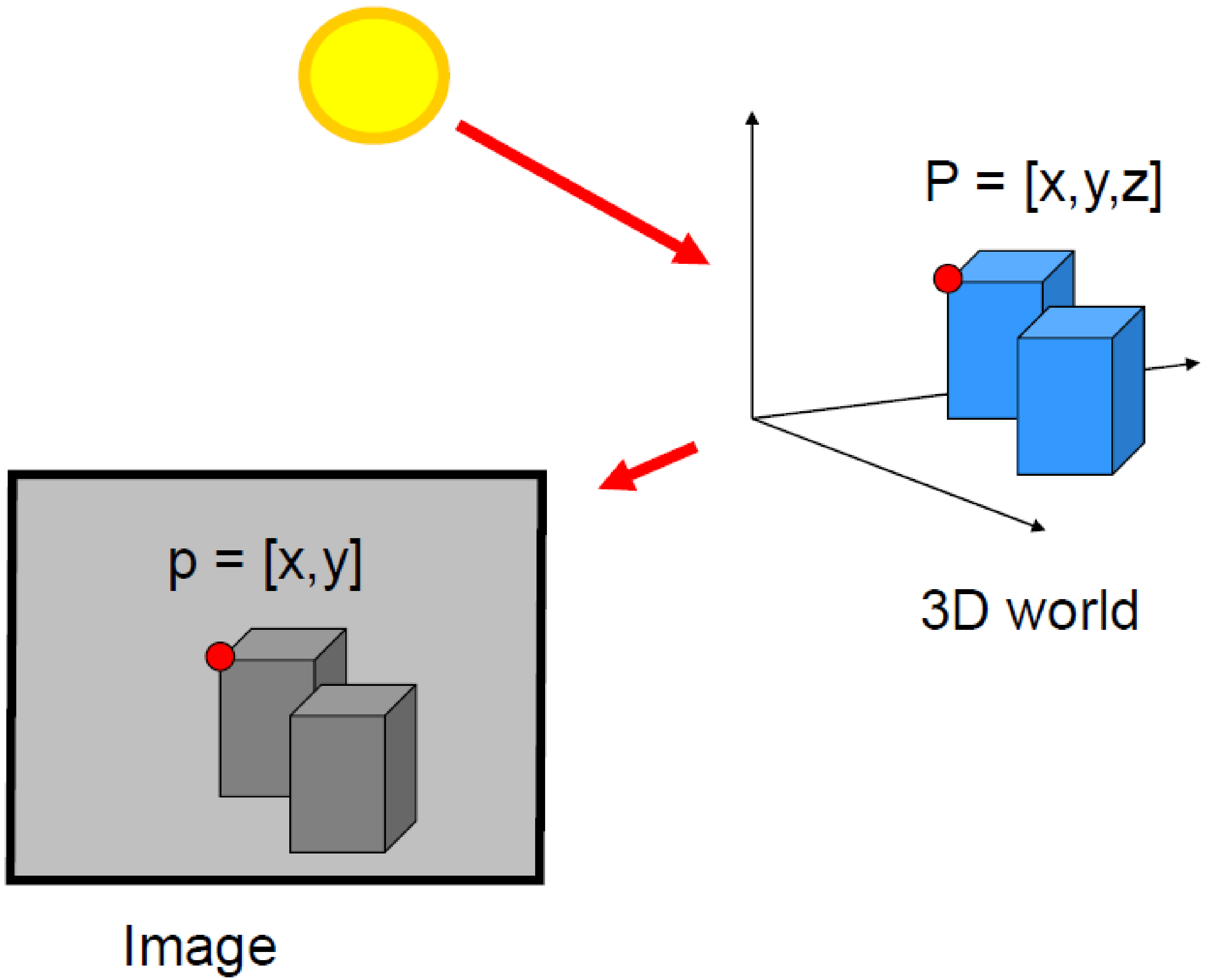
- We can use the Fourier transform to represent images in the frequency domain.
  - Filtering in the spatial domain is multiplication in the frequency domain.



This lecture

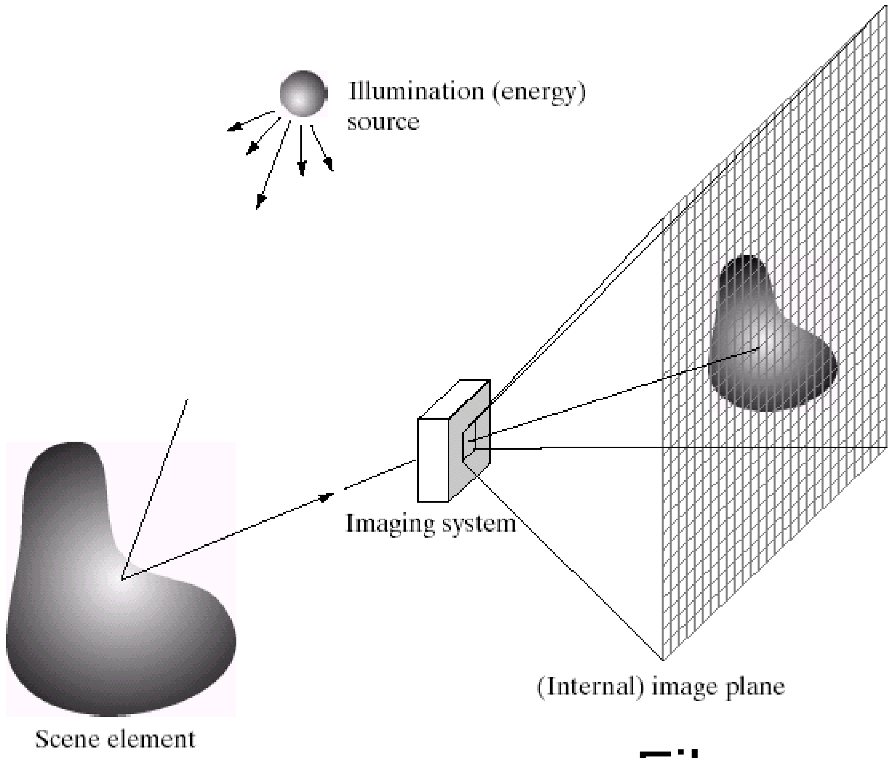
- Image Formation
- Biological Vision
- Light and Color

From the 3D to 2D

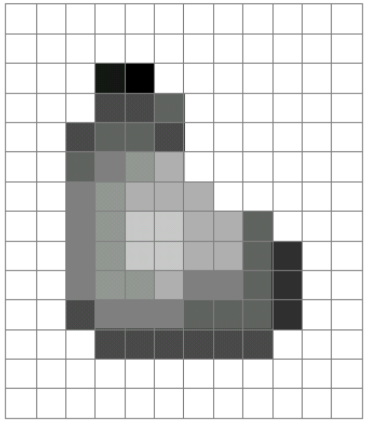


Slide credit Fei Fei Li

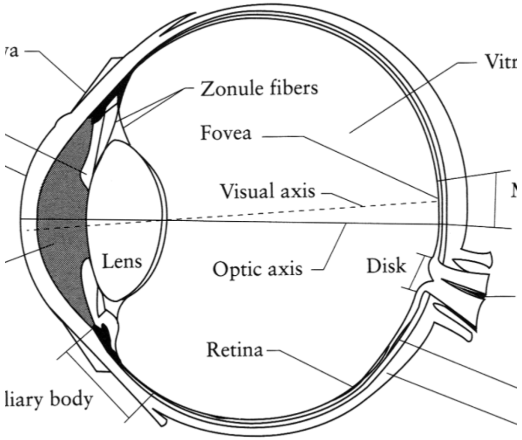
Image Formation



Film



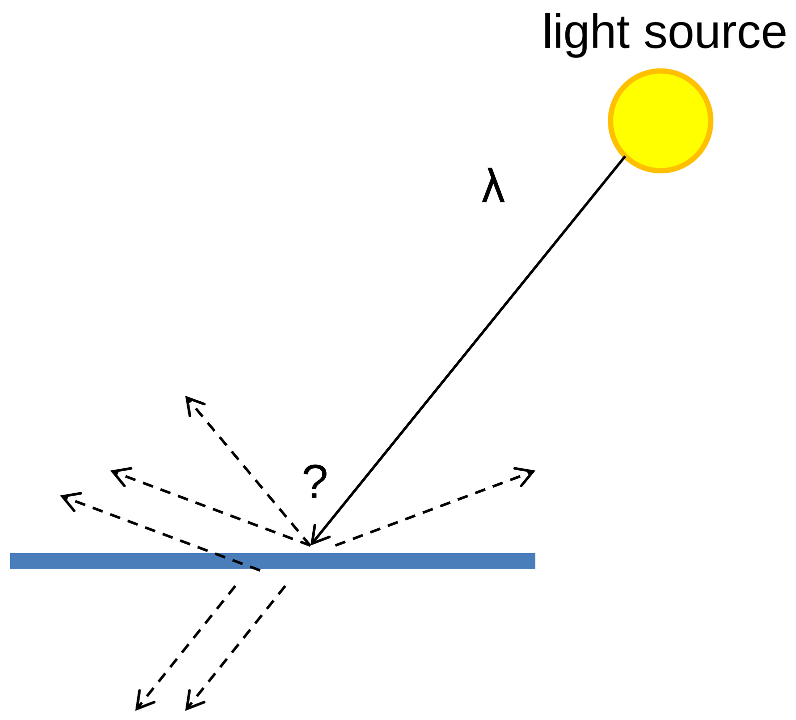
Digital Camera



The Eye

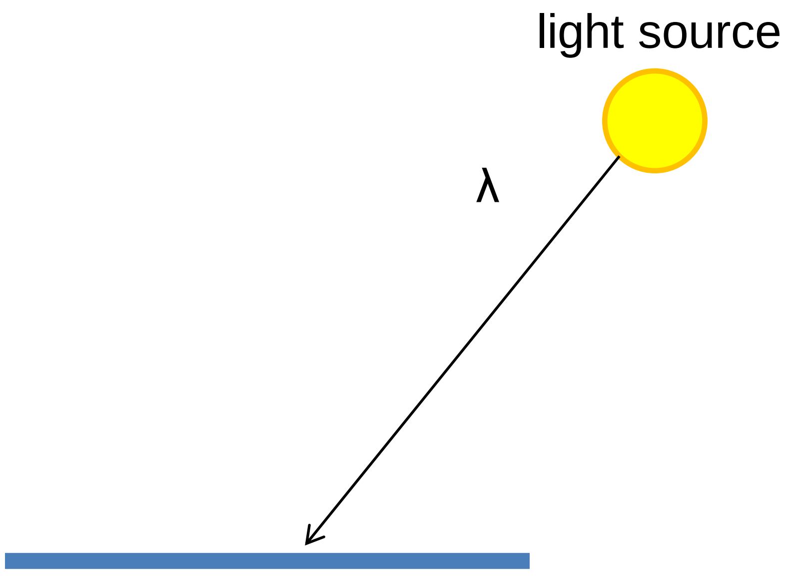
A photon's life choices

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



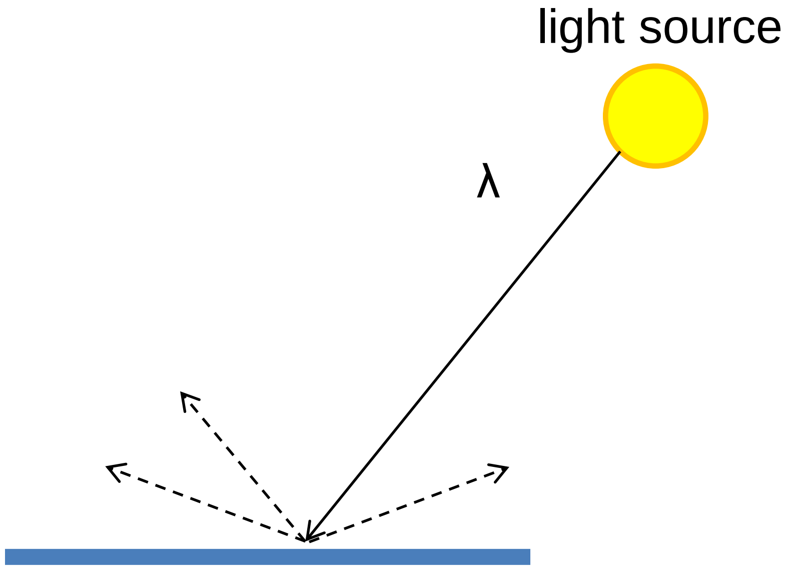
A photon’s life choices

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



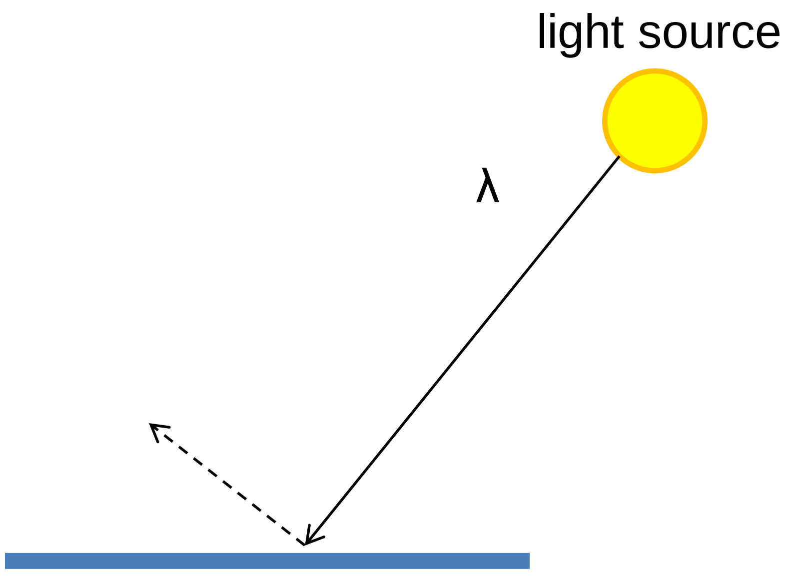
A photon’s life choices

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



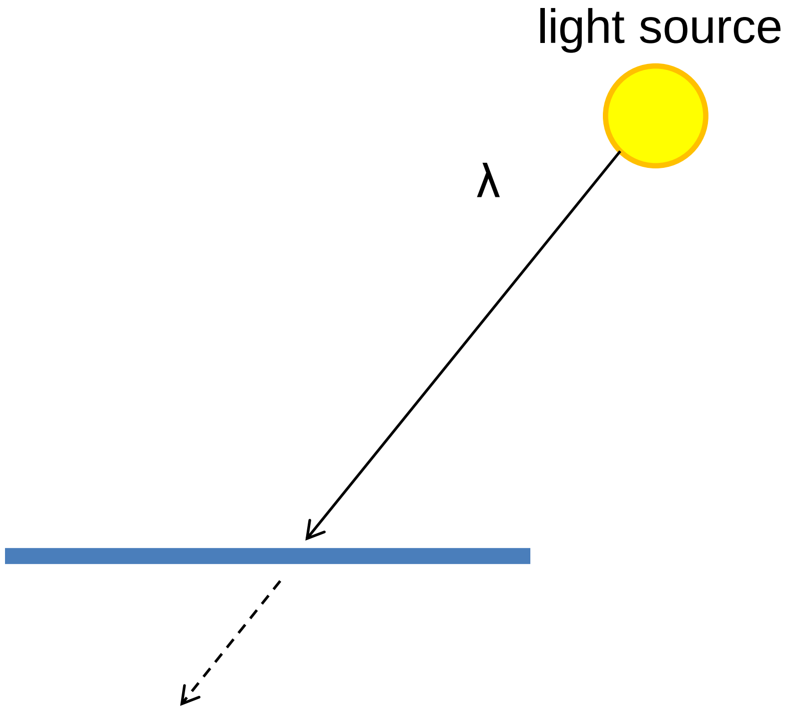
A photon's life choices

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



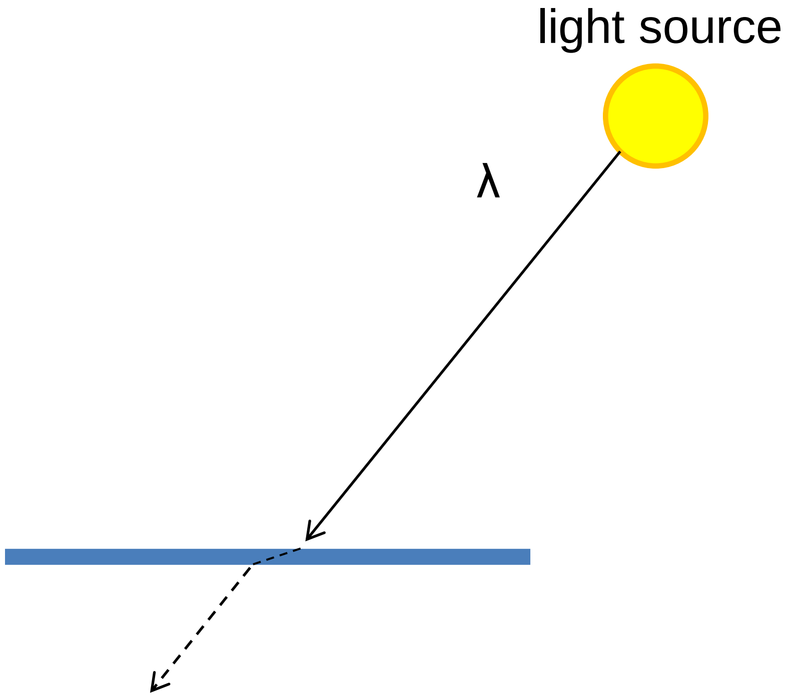
A photon’s life choices

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



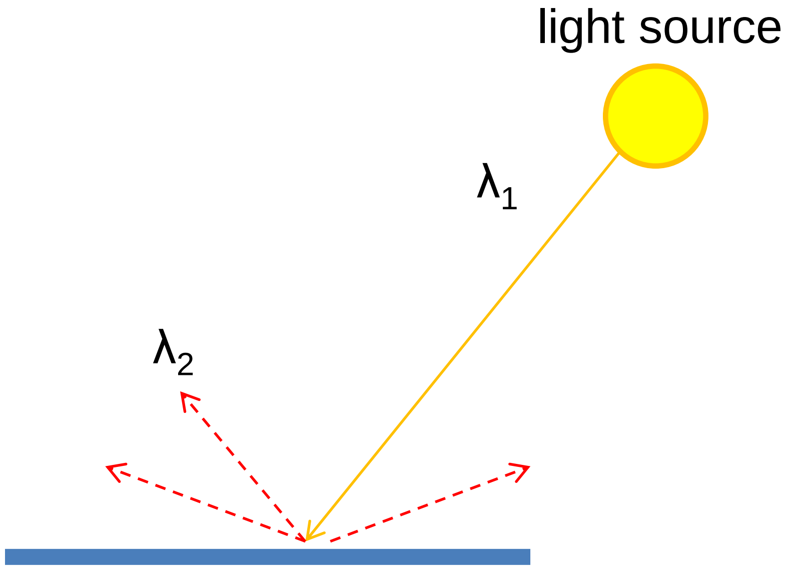
A photon’s life choices

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



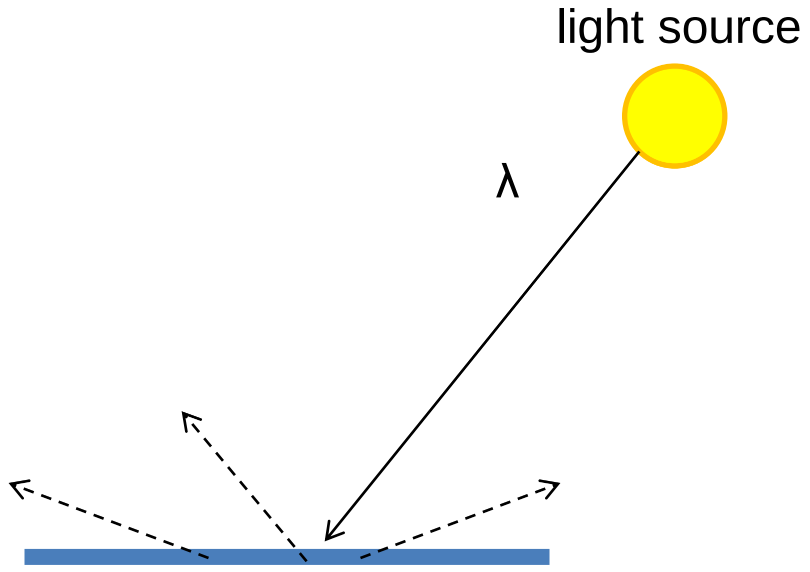
A photon's life choices

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



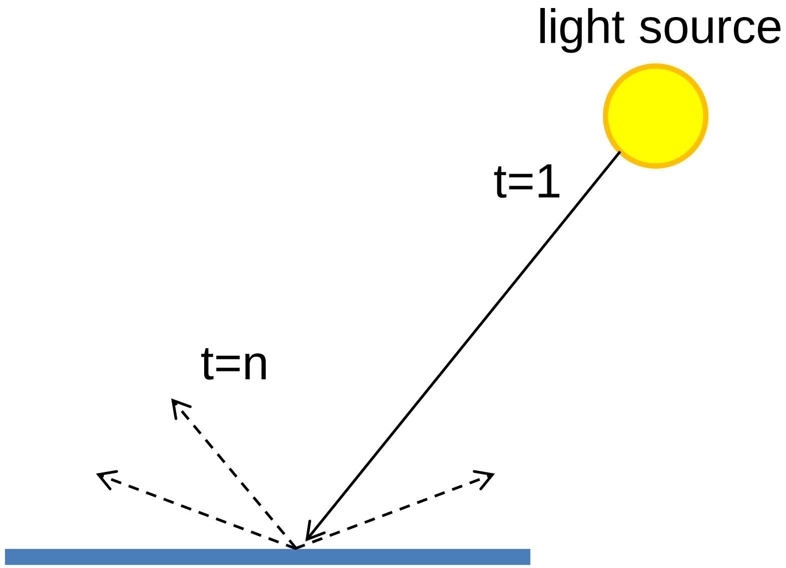
A photon's life choices

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



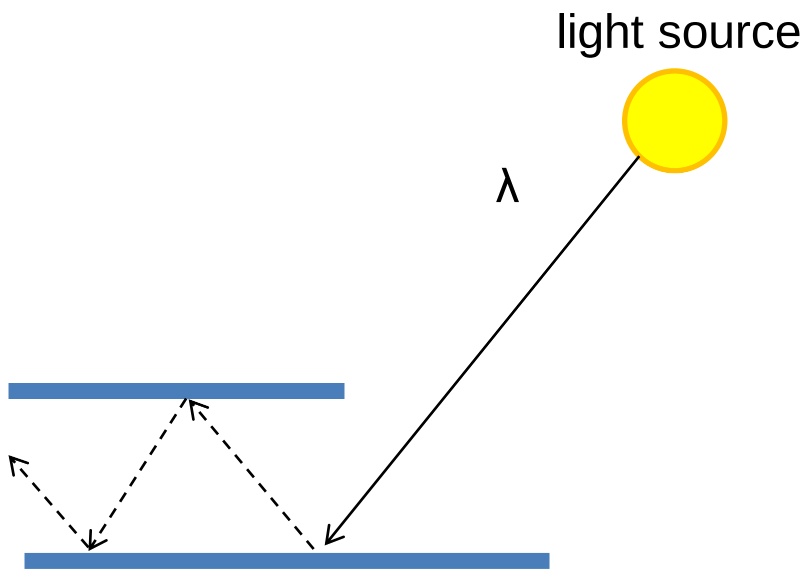
A photon's life choices

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



A photon's life choices

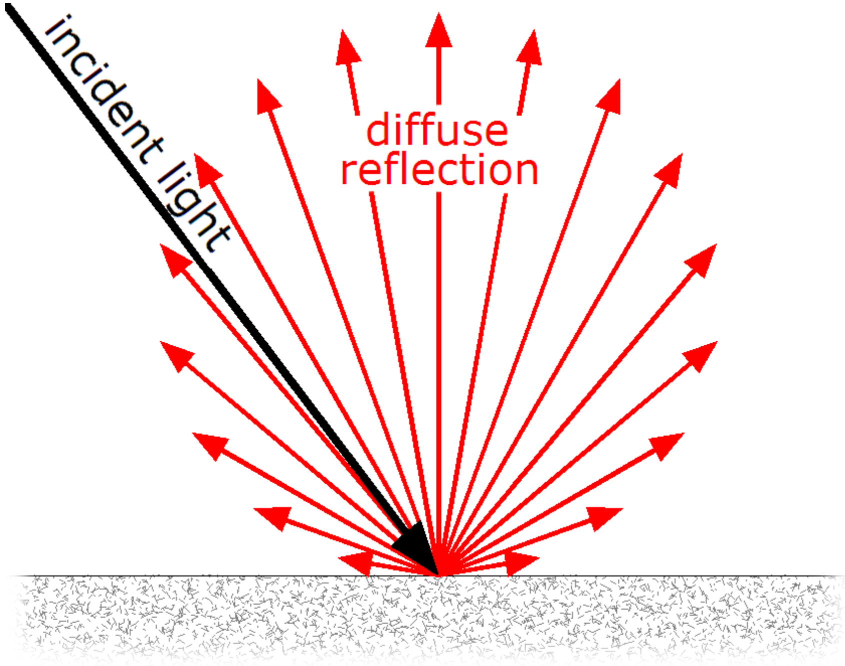
- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- **Interreflection**



(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.



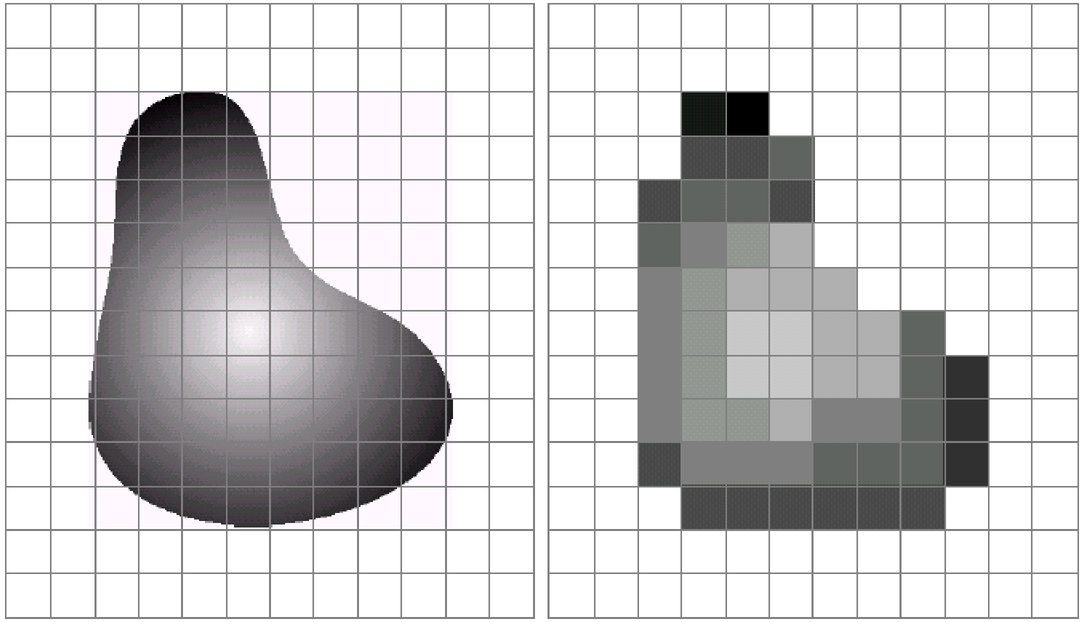
https://en.wikipedia.org/wiki/Lambertian_reflectance

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

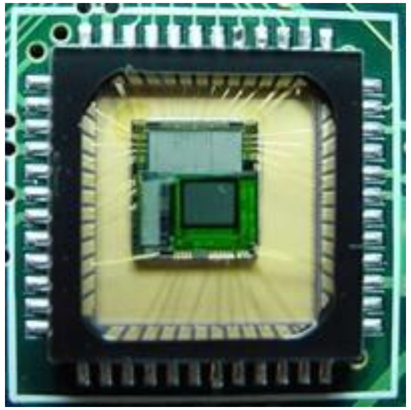
Slide by Steve Seitz

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

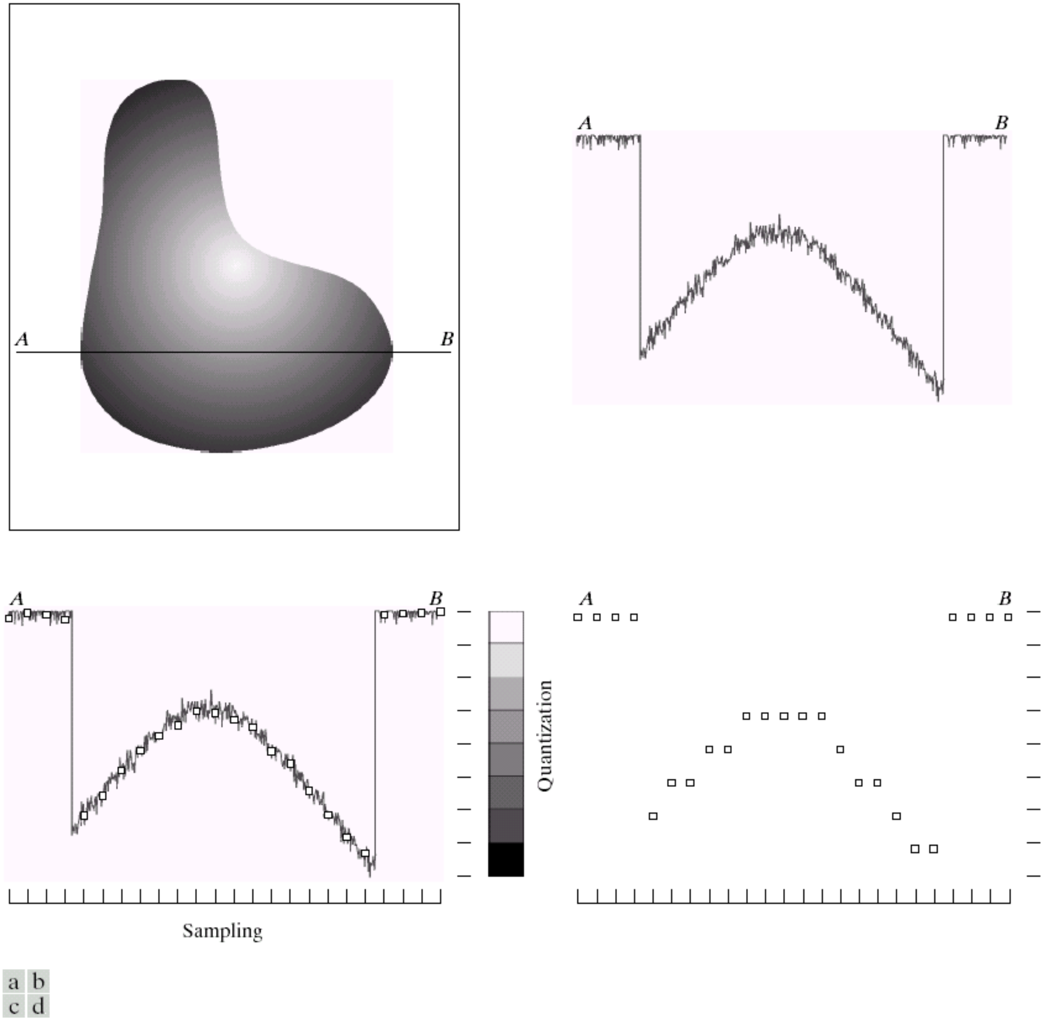
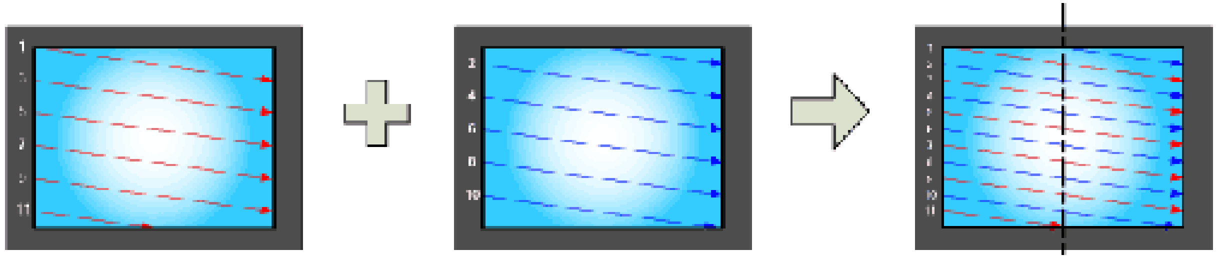


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

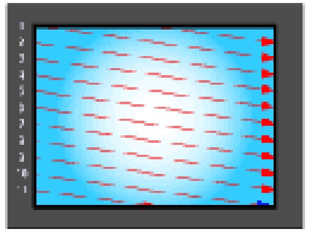
Interlace vs. progressive scan



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 or Global shutter

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

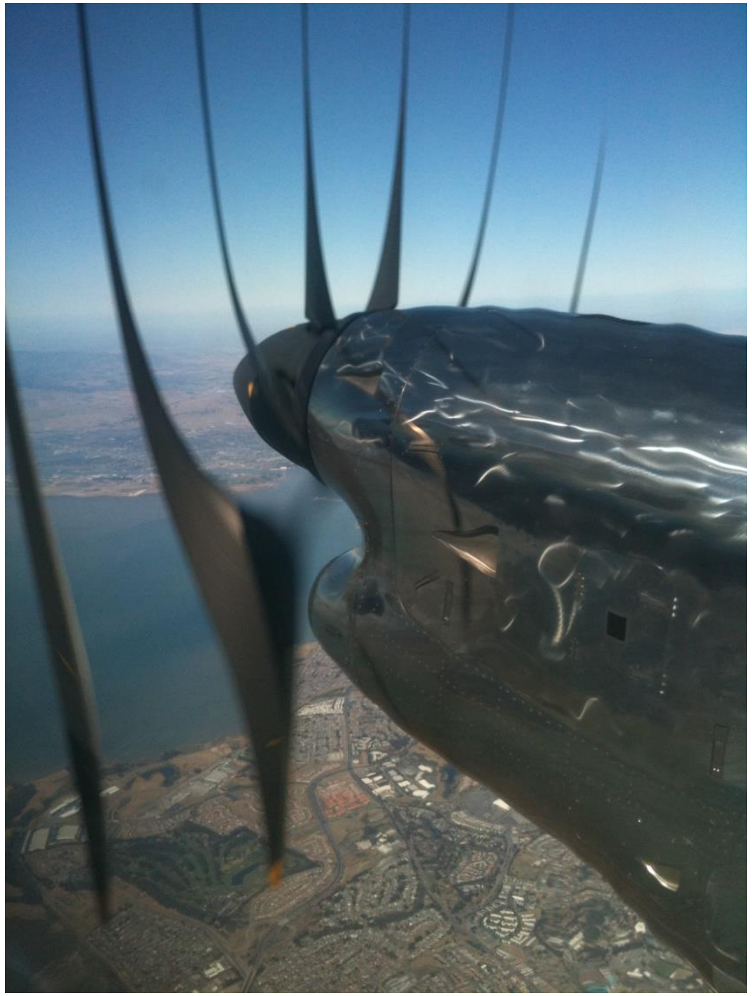
Slide by Steve Seitz

Interlaced

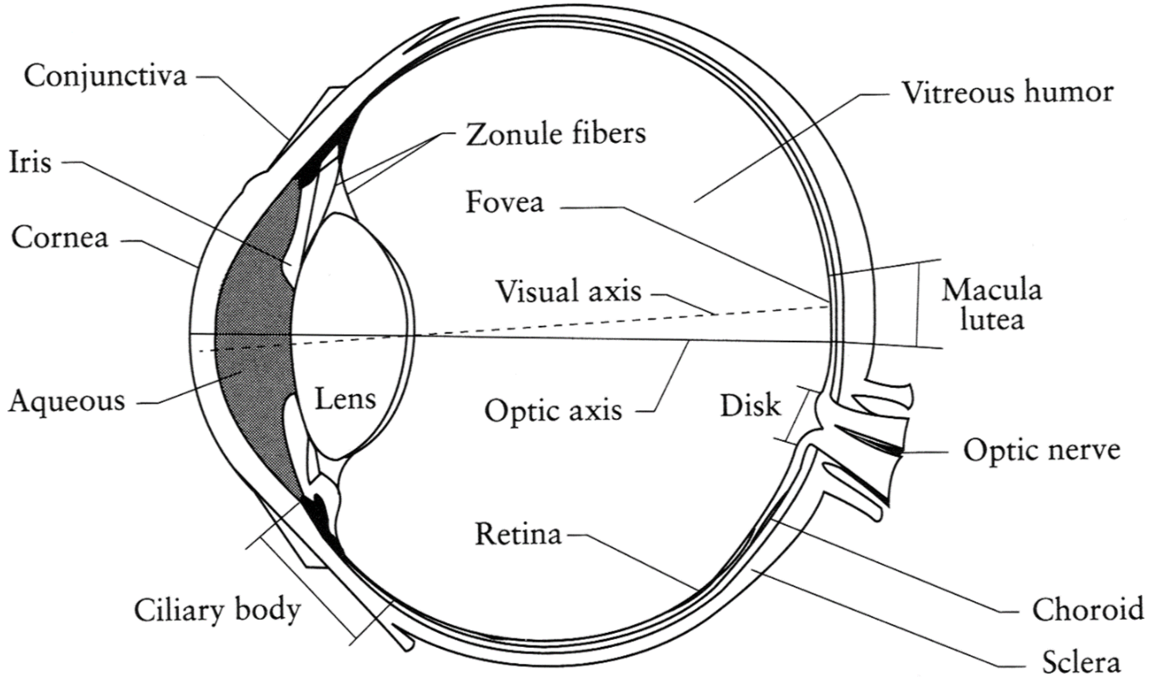
http://www.axis.com/products/video/camera/progressive_scan.htm

Slide by Steve Seitz

Rolling Shutter



The Eye



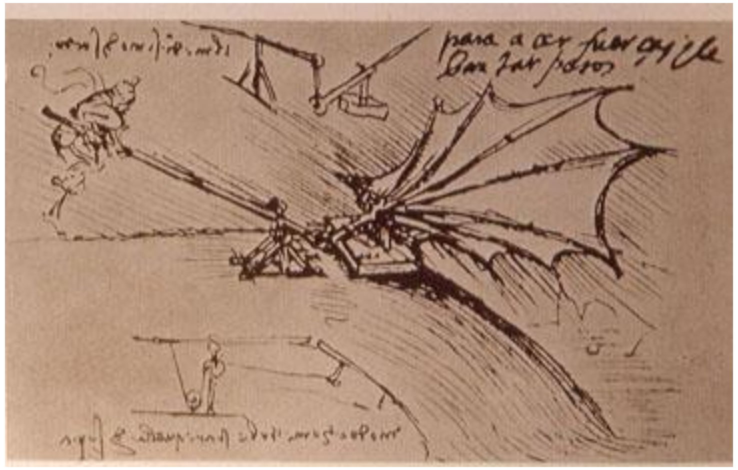
- The human eye is a camera!
  - **Iris** - colored annulus with radial muscles
  - **Pupil** - the hole (aperture) whose size is controlled by the iris
  - What's the "film"?
    - photoreceptor cells (rods and cones) in the **retina**

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?

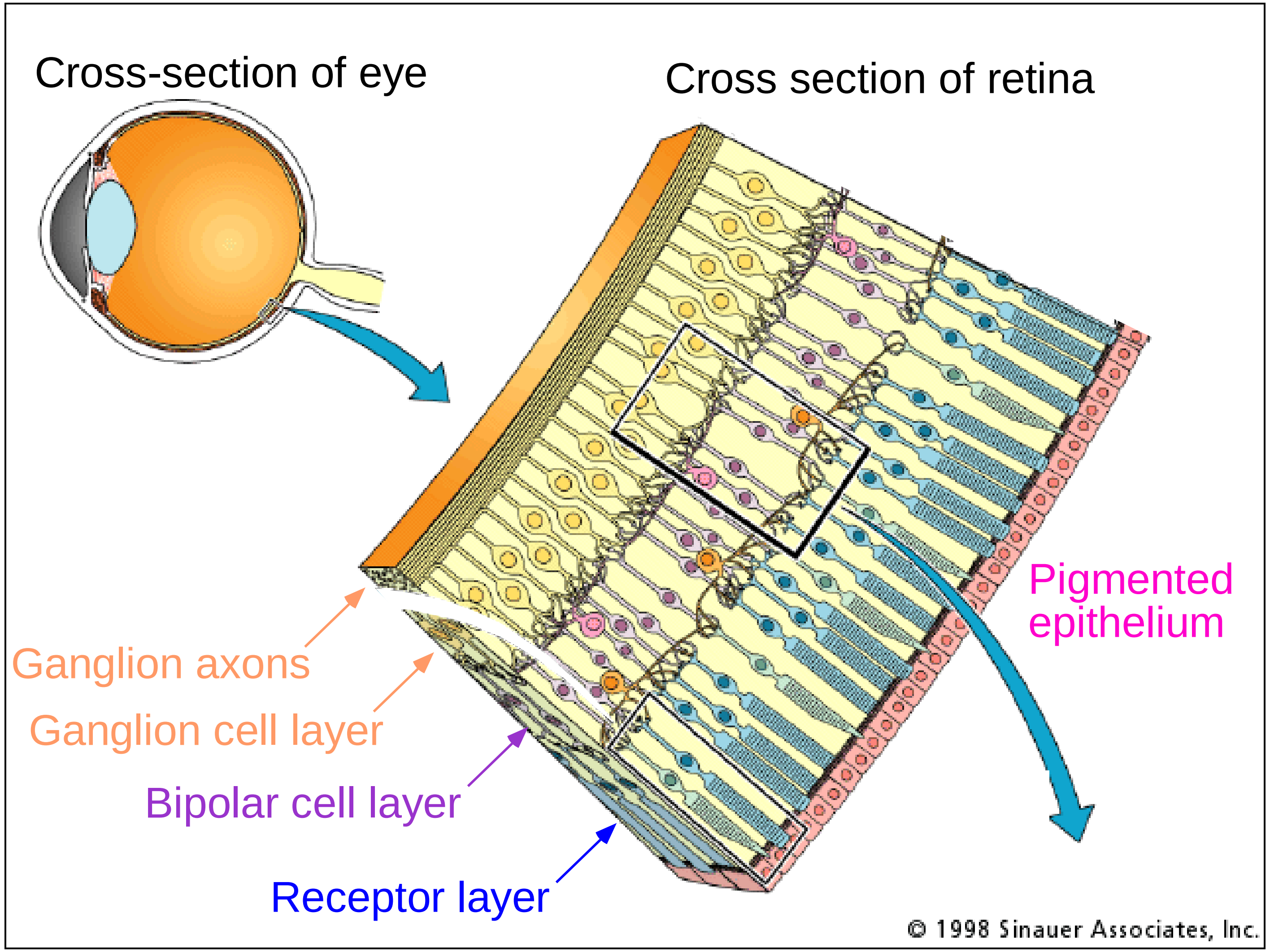
"Can machines fly?" The answer is yes, because airplanes fly.

"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?

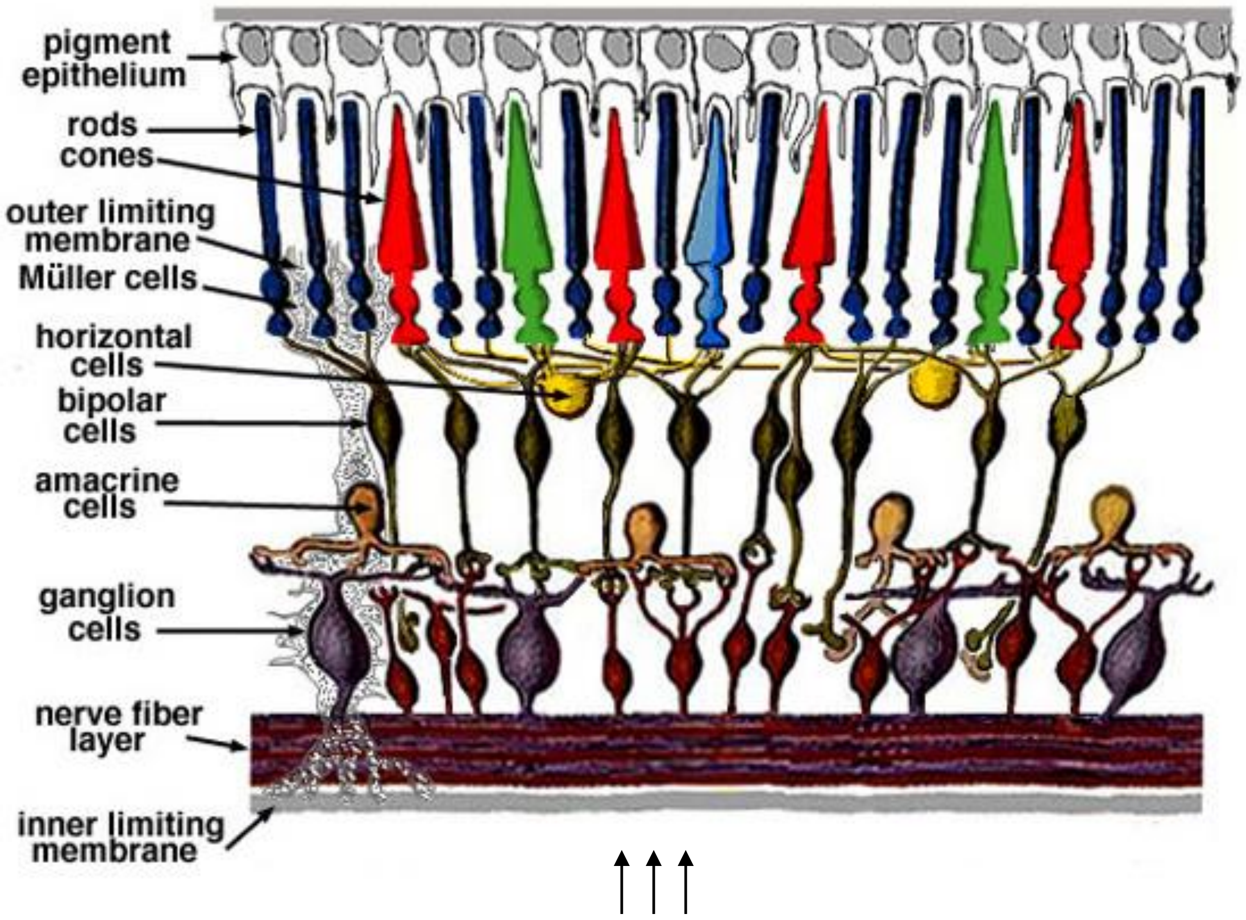
Source: Norvig

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.

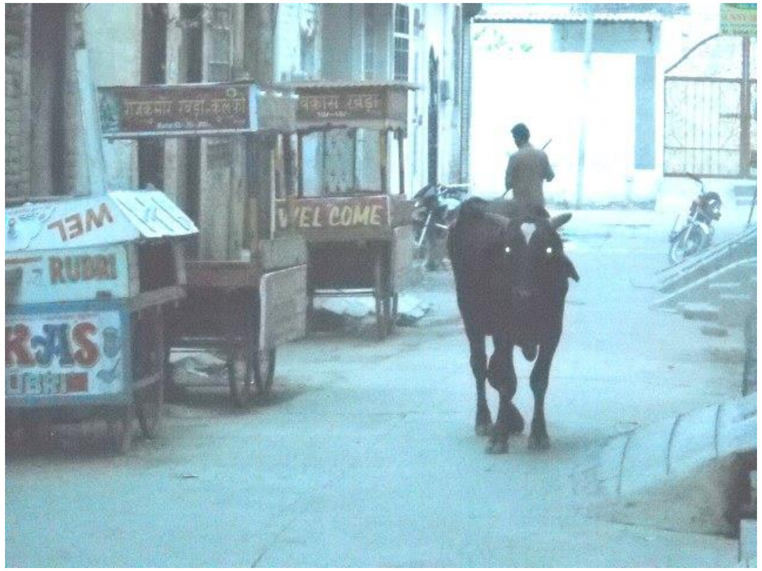
Retina up-close



Light

What humans don’t have: tapetum lucidum

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



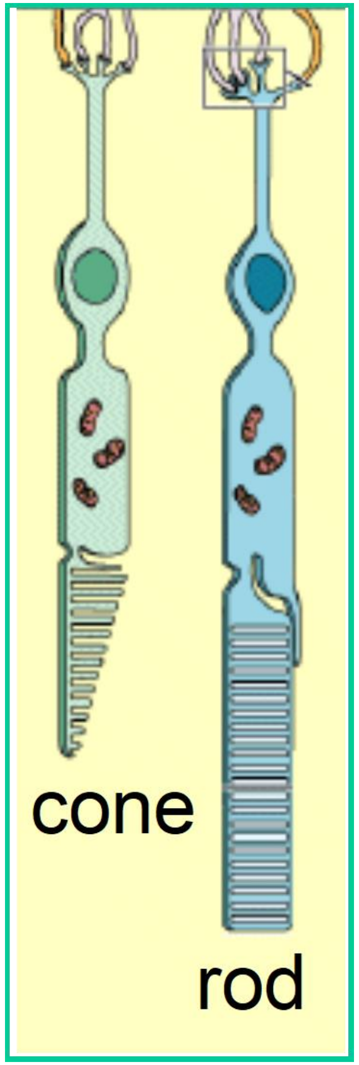
Two types of light-sensitive receptors

Cones

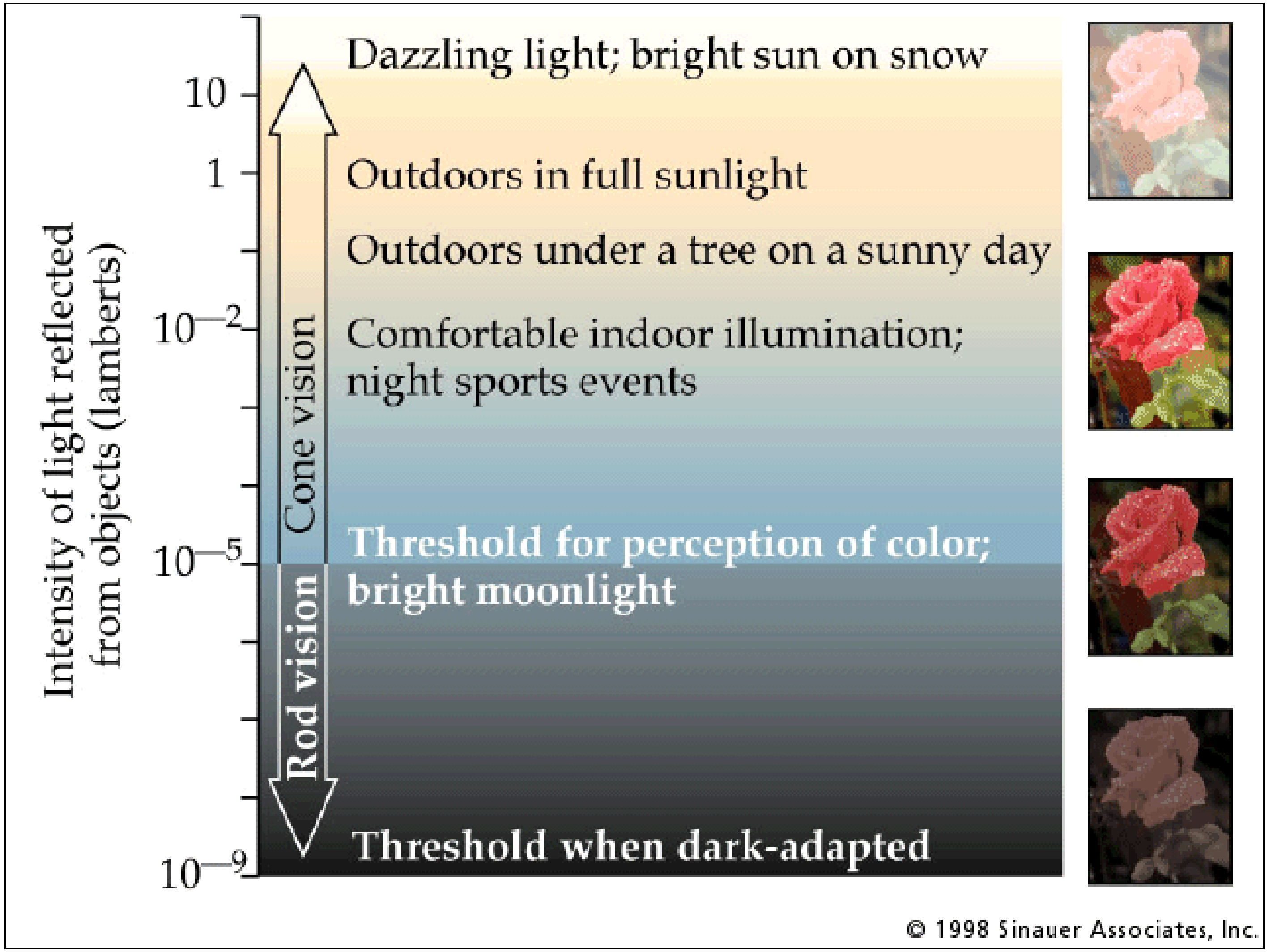
cone-shaped
less sensitive
operate in high light
color vision

Rods

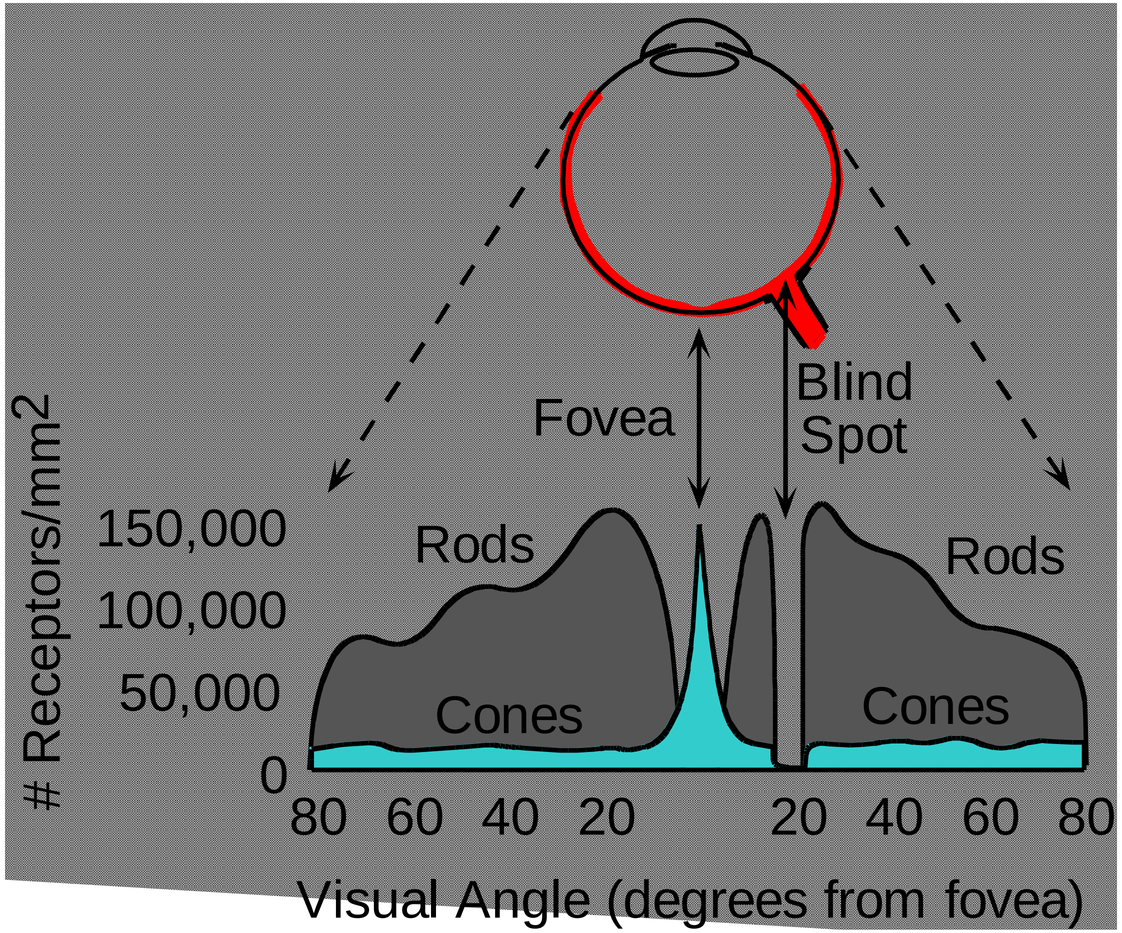
rod-shaped
highly sensitive
operate at night
gray-scale vision



Rod / Cone sensitivity



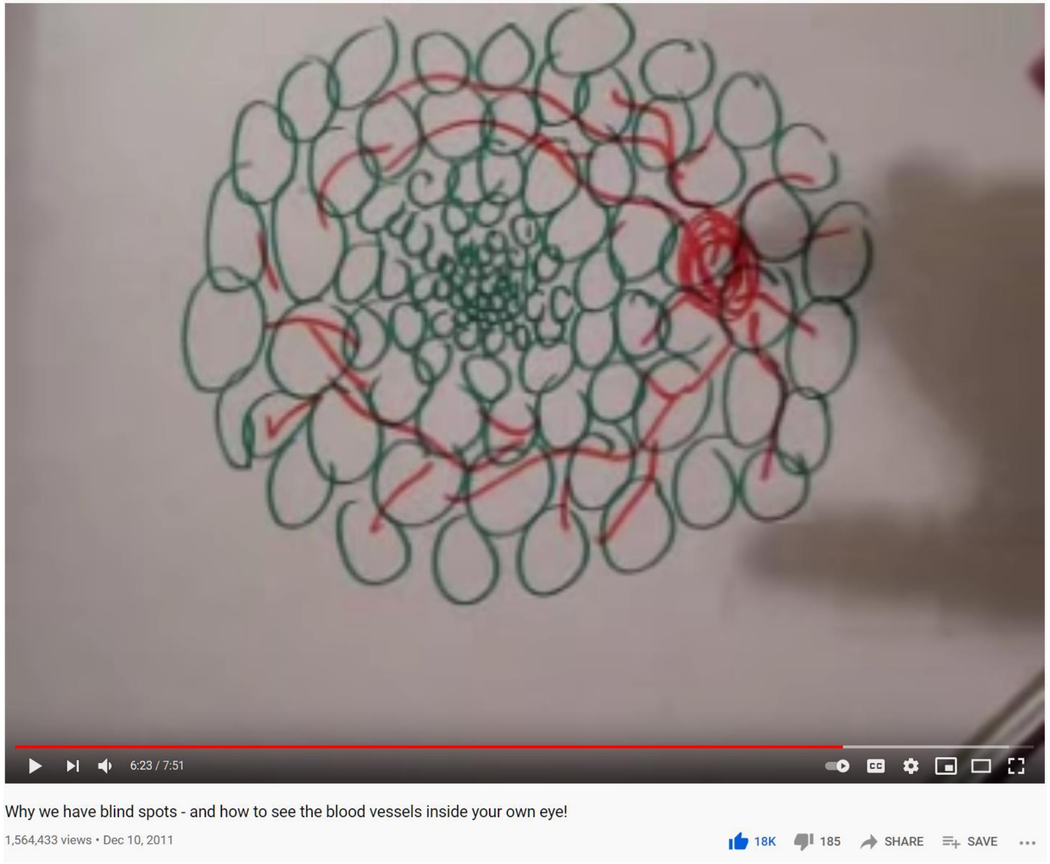
Distribution of Rods and Cones



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

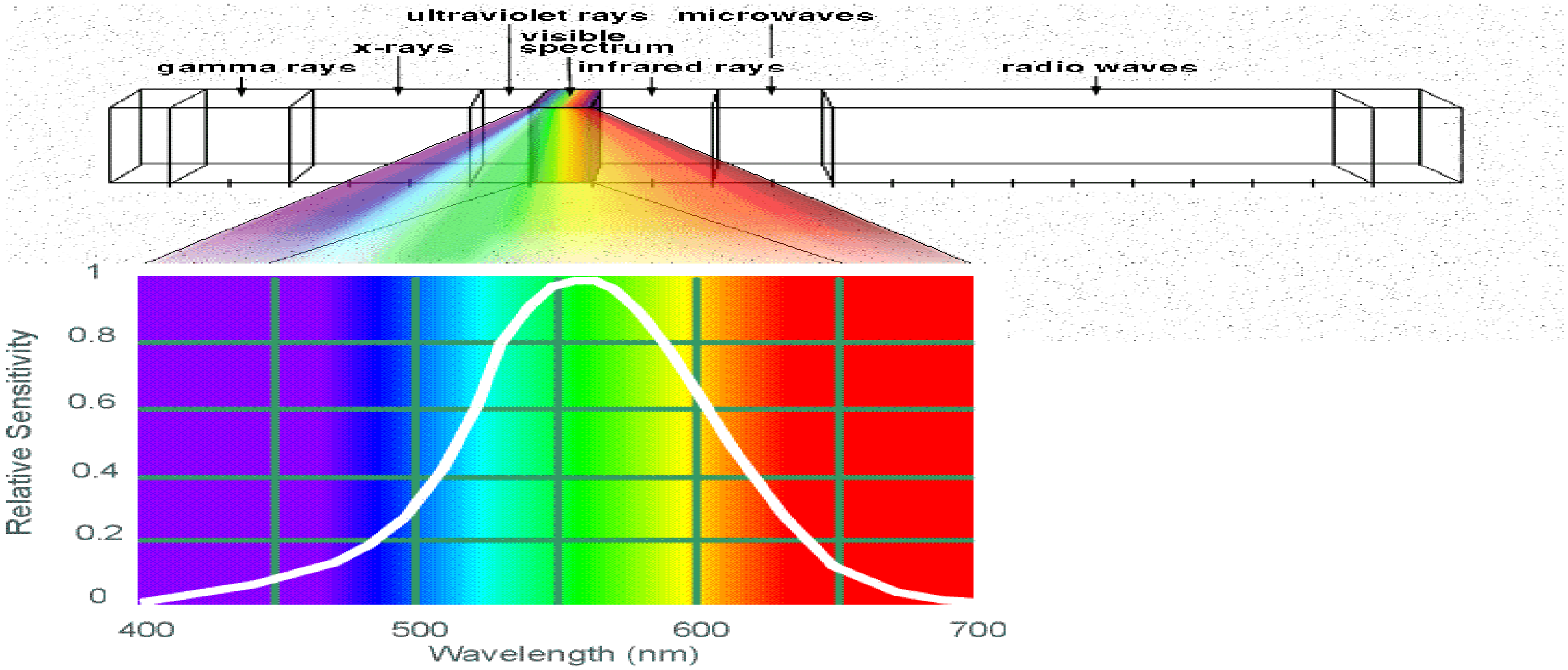
- Saccades
- Can be consciously controlled. Related to perceptual attention.
- 200ms to initiation, 20 to 200ms to carry out. Large amplitude.
- Microsaccades
- Involuntary. Smaller amplitude. Especially evident during prolonged fixation. Function debated.
- Ocular microtremor (OMT)
- Involuntary. high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