

# How Do We See?

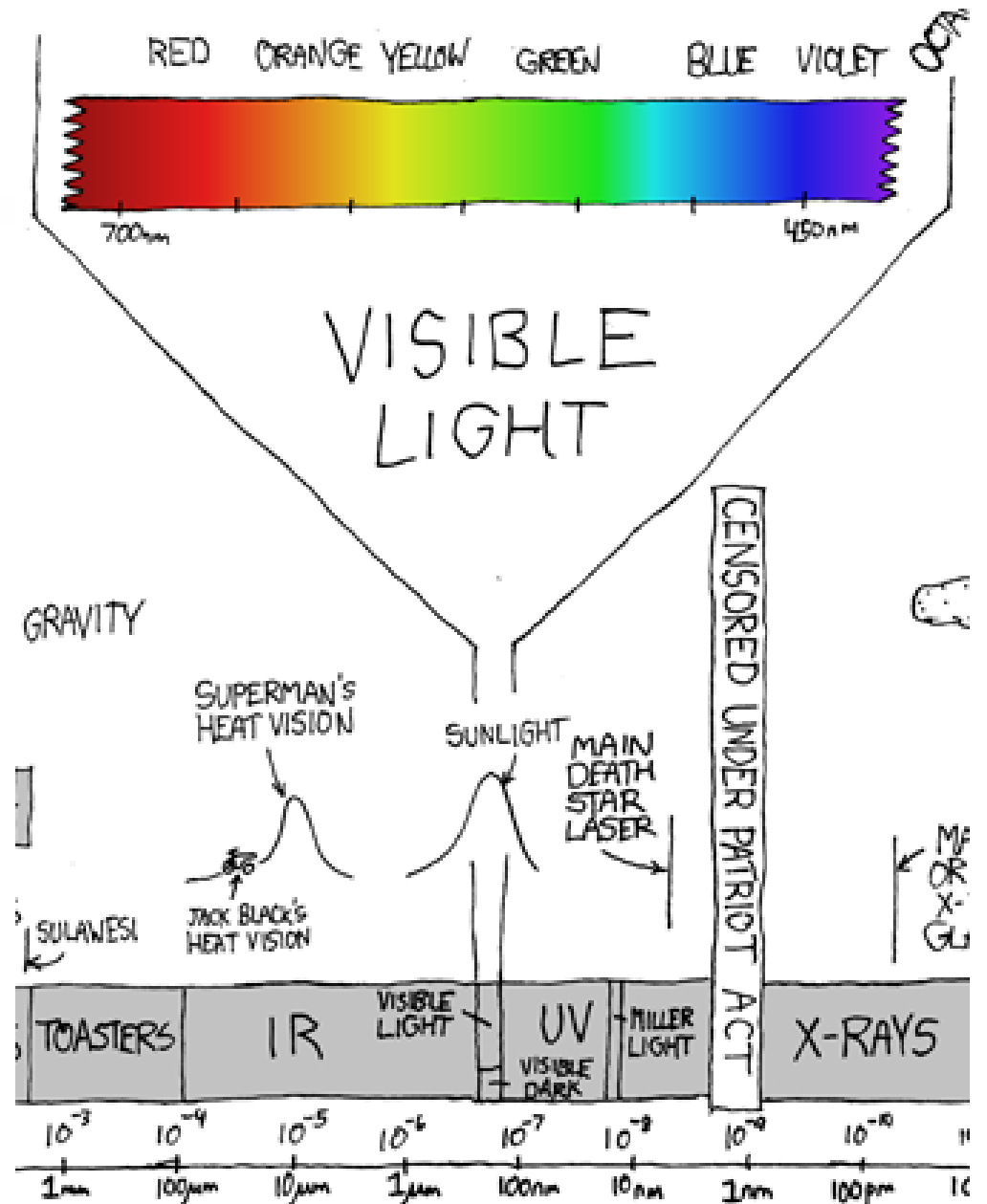
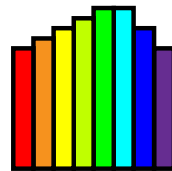
CS418 Computer Graphics

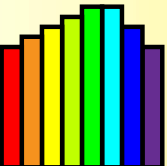
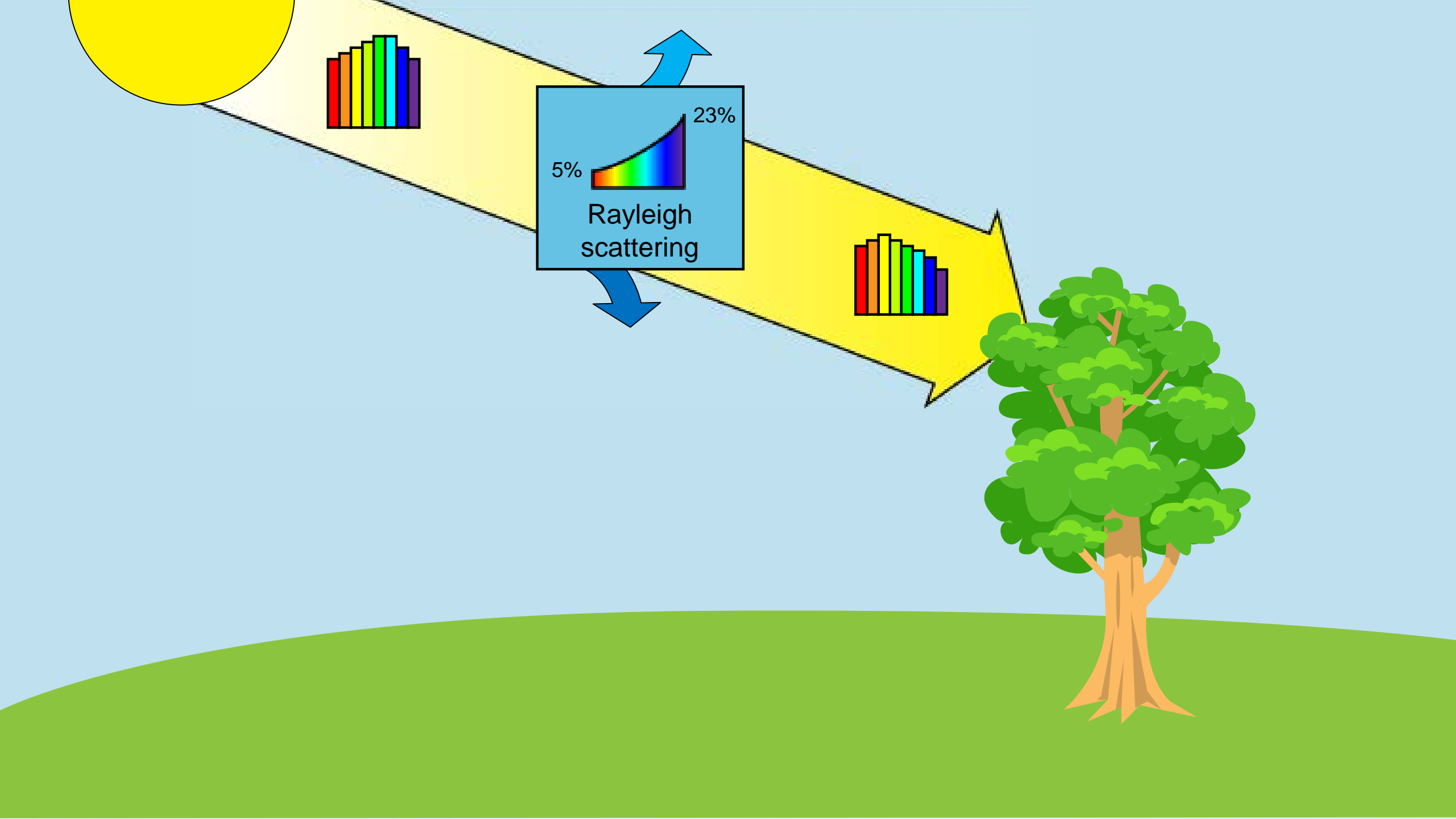
John C. Hart

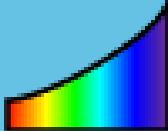


# Light

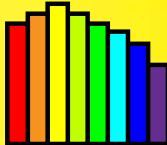
- Computer graphics focuses largely on the computational simulation of our visual perception of the world
- We see because we sense energy in a portion of the electromagnetic spectrum
- Energy carried by photons
- The energy of each photon is proportional to its frequency, inverse of its wavelength
- The number of photons is related to the intensity of light
- The “color” of light is the distribution of the rate of photons at each wavelength
- For example, this is a histogram of the rate of photons of different wavelengths emitted by the sun

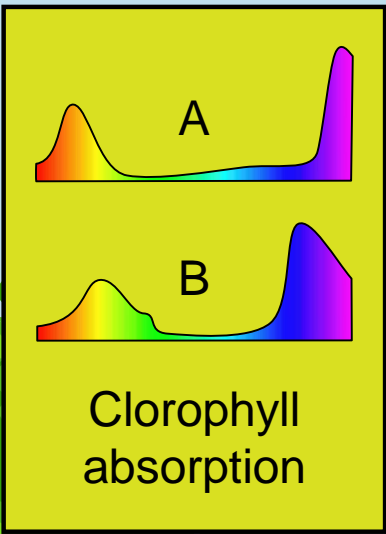
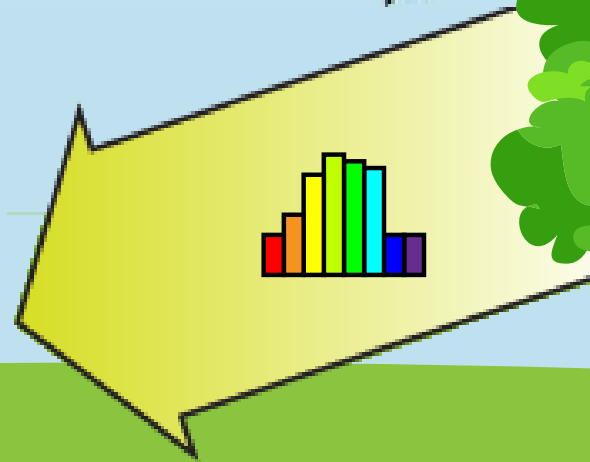
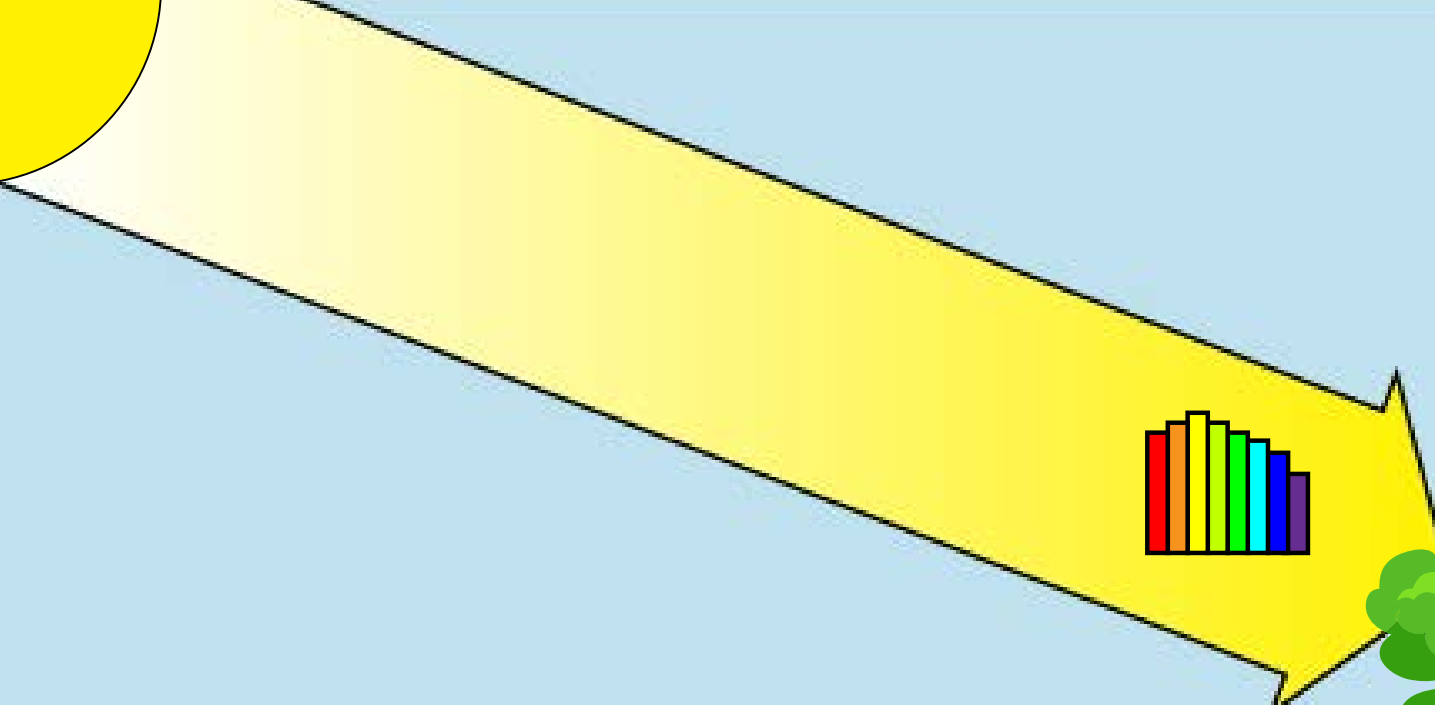
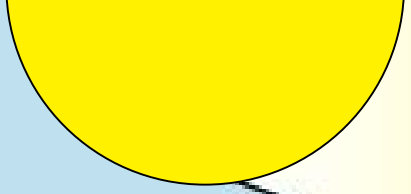




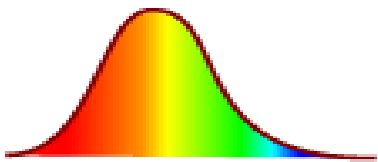
5%  23%

Rayleigh scattering

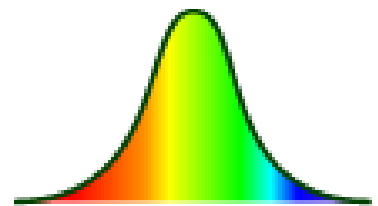




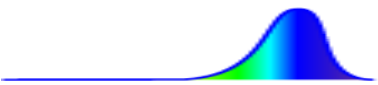
Eye cone responses



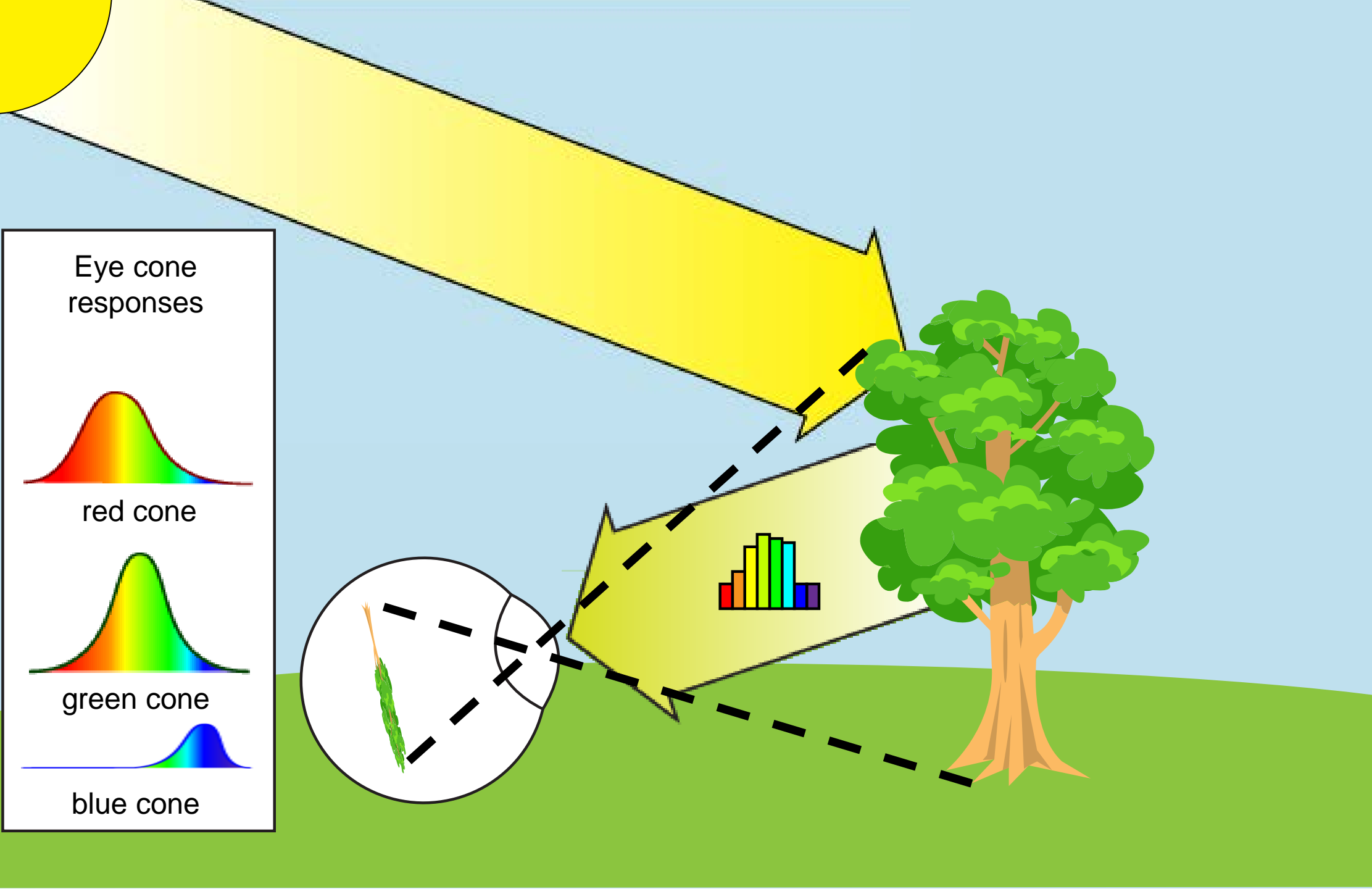
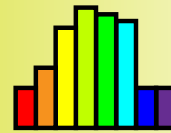
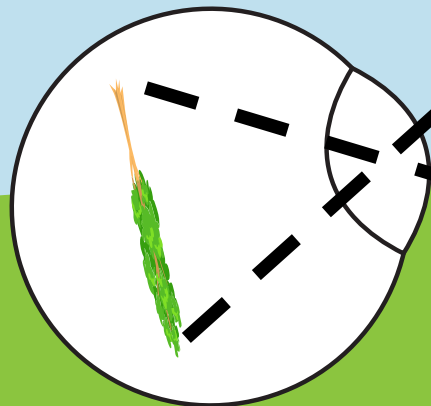
red cone



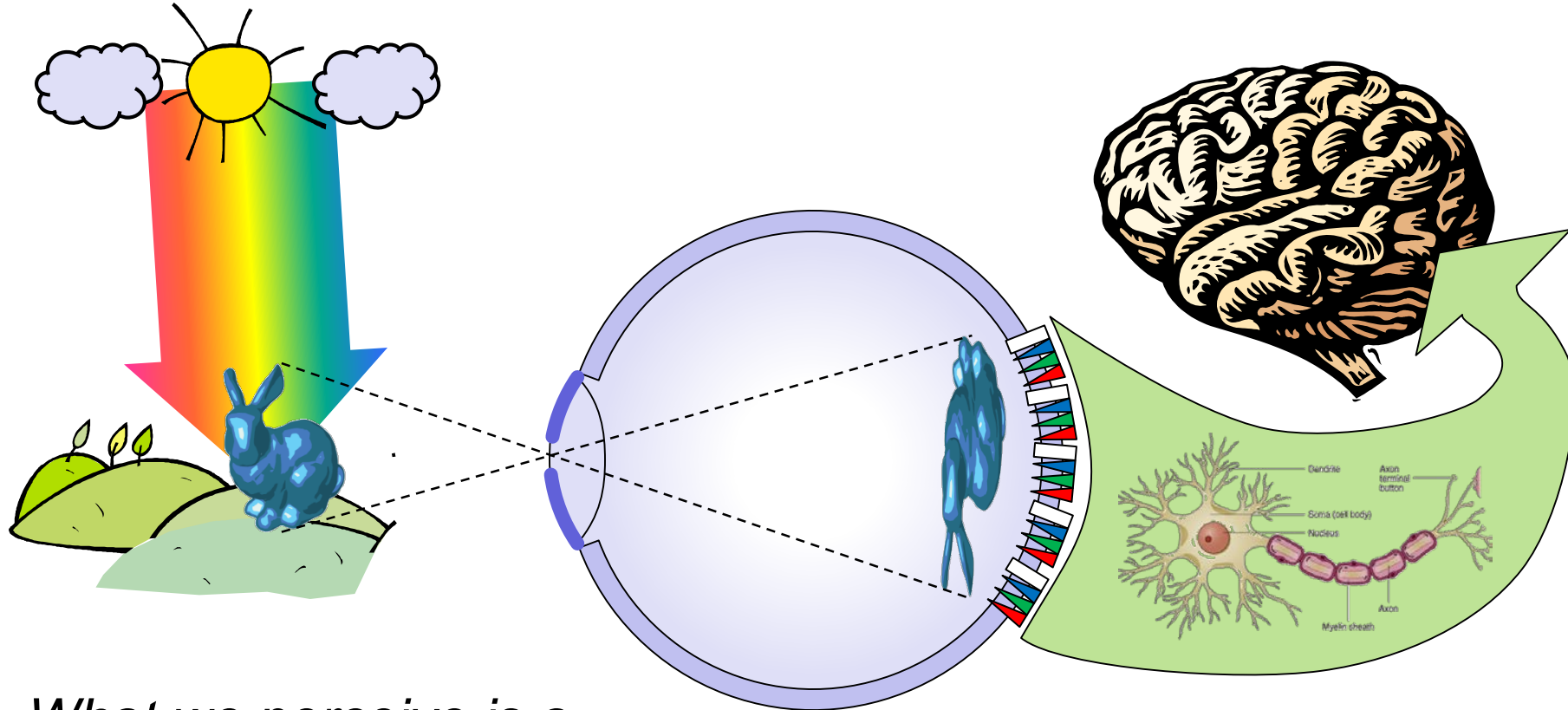
green cone



blue cone



# The Human Visual System

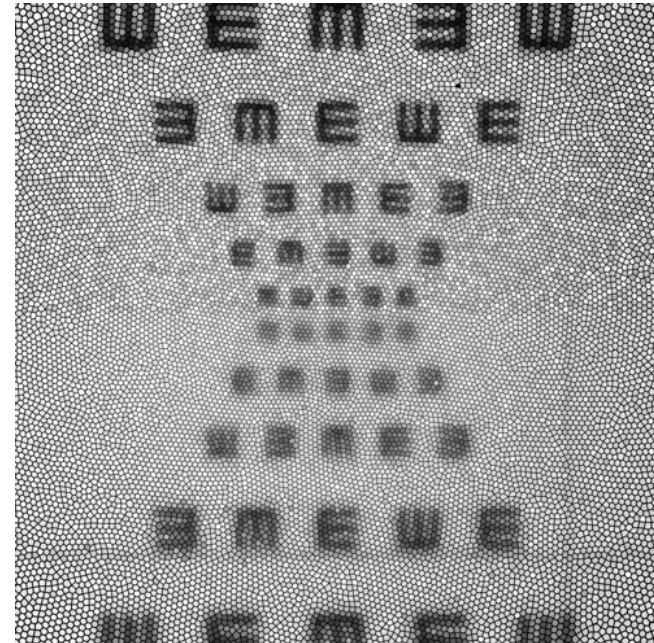
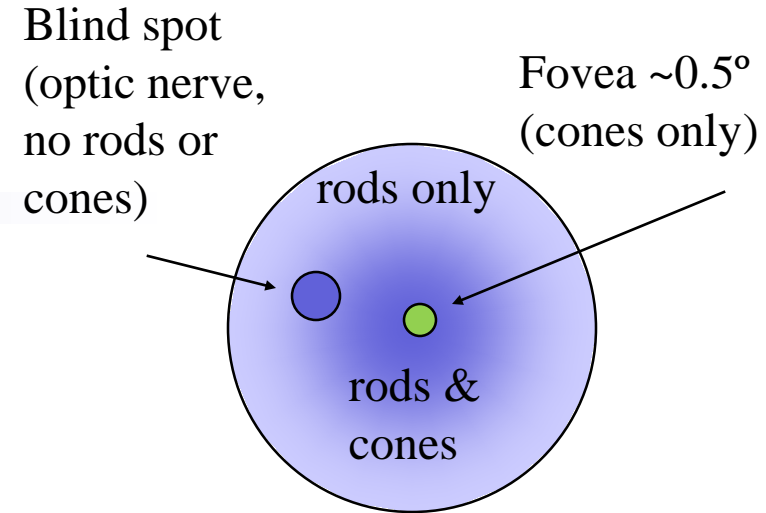


*What we perceive is a heavily processed version of what we physically sense*

Perceptual nerves process edges and motion before the signal even gets to the brain

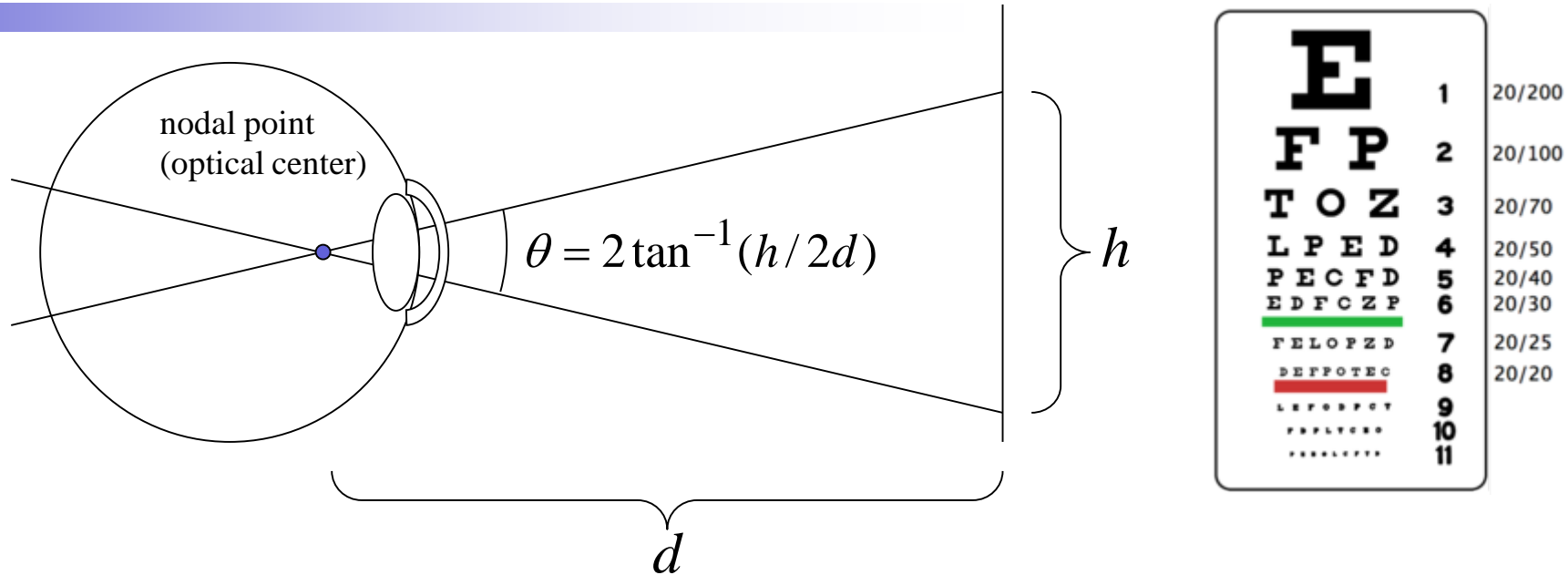
# Rods & Cones

- Rods measure intensity
  - 80 million
  - Denser away from fovea
  - Astronomers learn to glance off to the side of what they are studying
  - sensitive, shut down in daylight
- R,G and B cones
  - 5 million total
  - 100K – 325K cones/mm<sup>2</sup> in fovea
  - 150 hues
- Combined
  - 7 million shades



Deering's Photon Accurate  
Model of the Human Retina  
from SIGGRAPH 2005

# Visual Acuity



- Visual acuity measures the angular perceptual resolution of the retina
- Snellen Ratio: “20/X” means “subject can resolve at 20 feet what average person can resolve at X feet”
- **20/20** vision means can resolve **one arc minute** ( $1' = 1/60^{\text{th}}$  of a deg.)

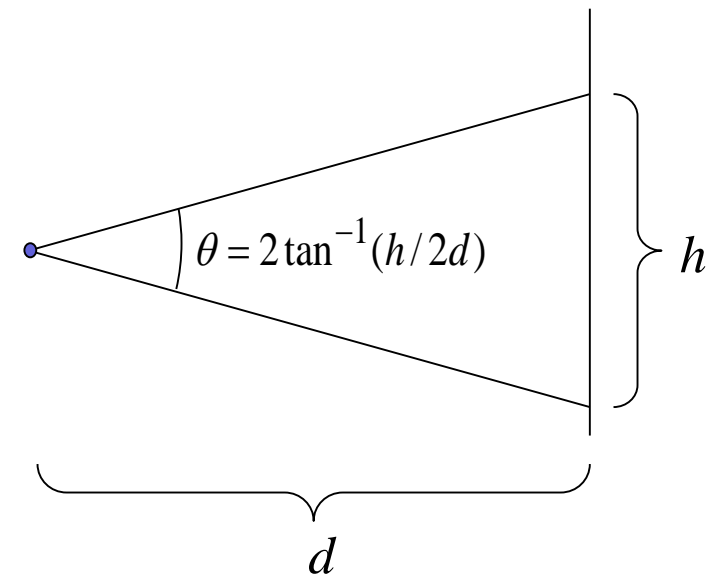
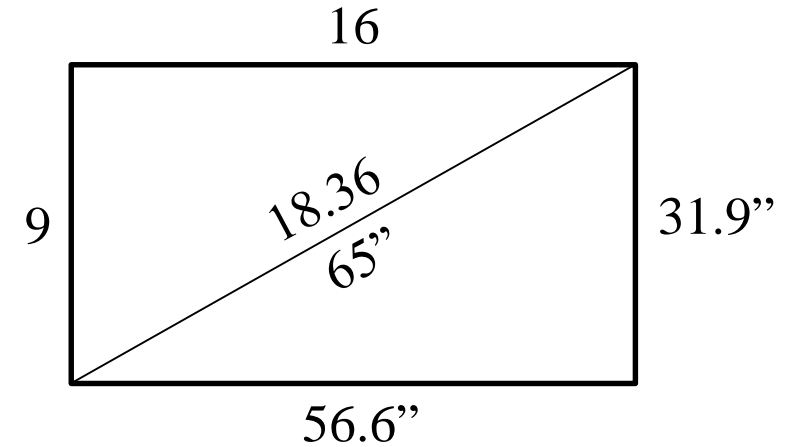
$$h/d \approx \tan(\theta) \text{ for small } \theta$$
$$\tan(1') = 0.03\%$$

A 20/20 viewer can resolve laterally about 0.03% of the distance to the target



# Buying a Home Theater Display

- Do you need a 4K HDTV with 2,160 lines of resolution, or can you get away with 1,080 or even 720?
- Displays are measured diagonally, so the height  $h$  of a 16:9 display is about half (49%) of the diagonal
- So a 65" display extends 31.9" vertically. This display would subtend a visual angle for a viewer 10' = 120" away of  $15.15^\circ = 909'$ .
- A viewer with 20/20 vision can resolve 1', so a vertical resolution of 720 might look a little blurry, but at that distance the viewer probably couldn't tell the difference between 1080 and 4K (2,160)

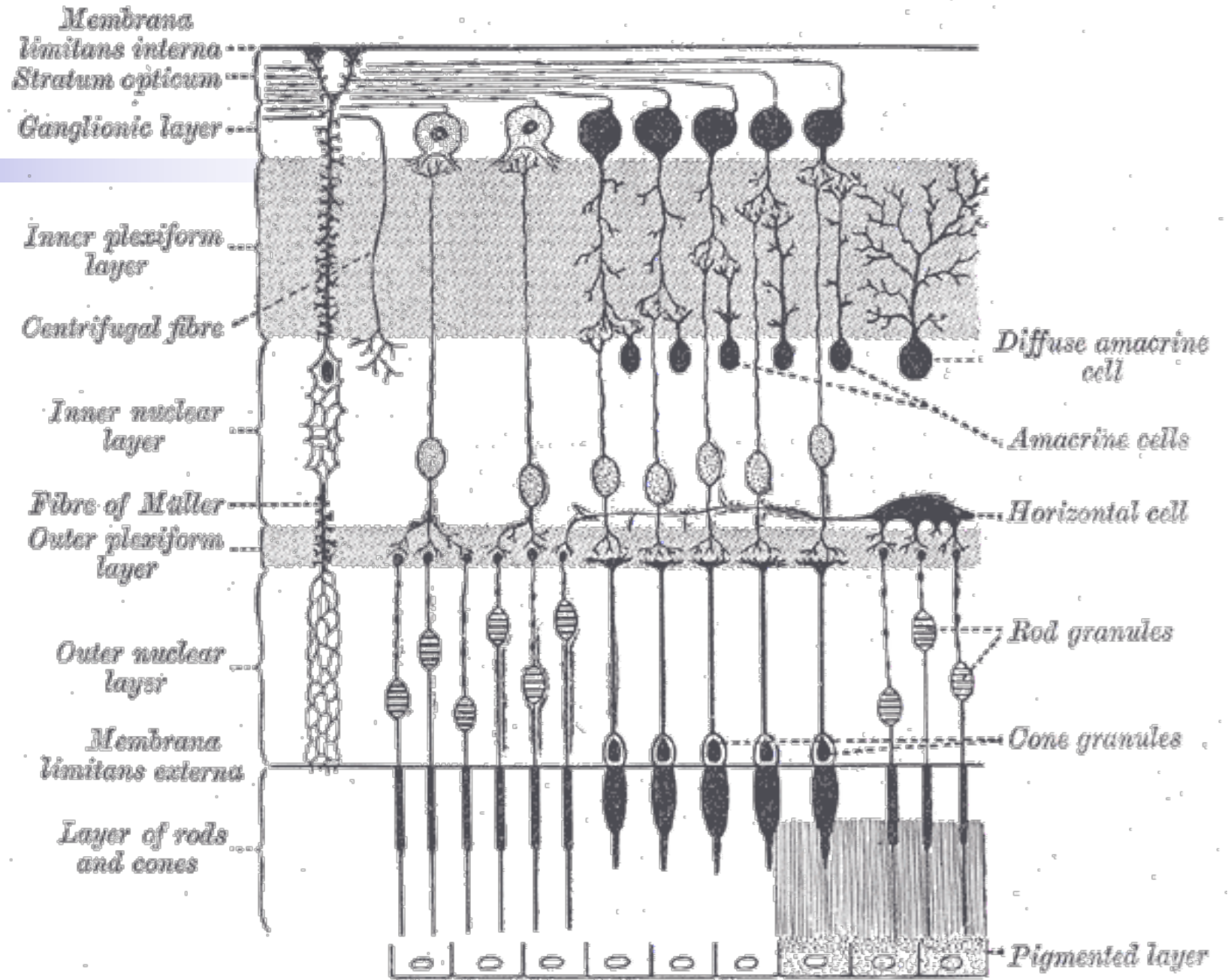


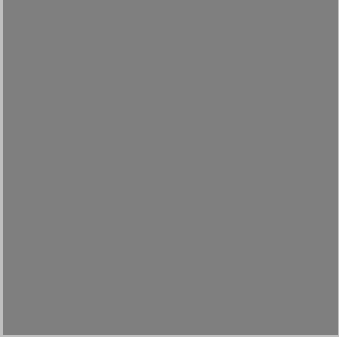
# Ganglions

nerve cells that preprocess sensory signals for visual perception

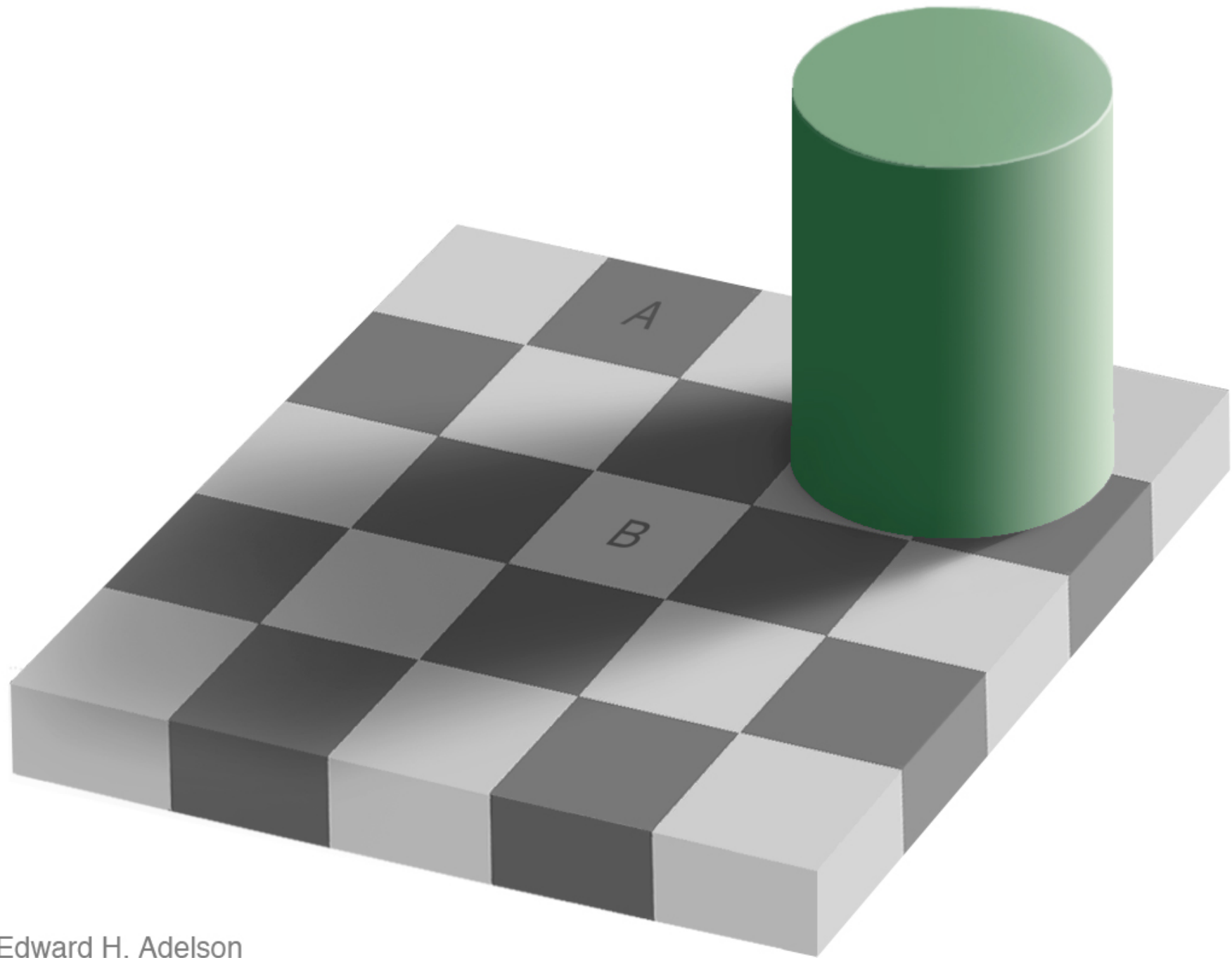
- *X-cells*
  - detect patterns
  - spatial differences
- *Y-cells*
  - detect motion
  - temporal differences

The human visual system not only detects differences, it *exaggerates* them

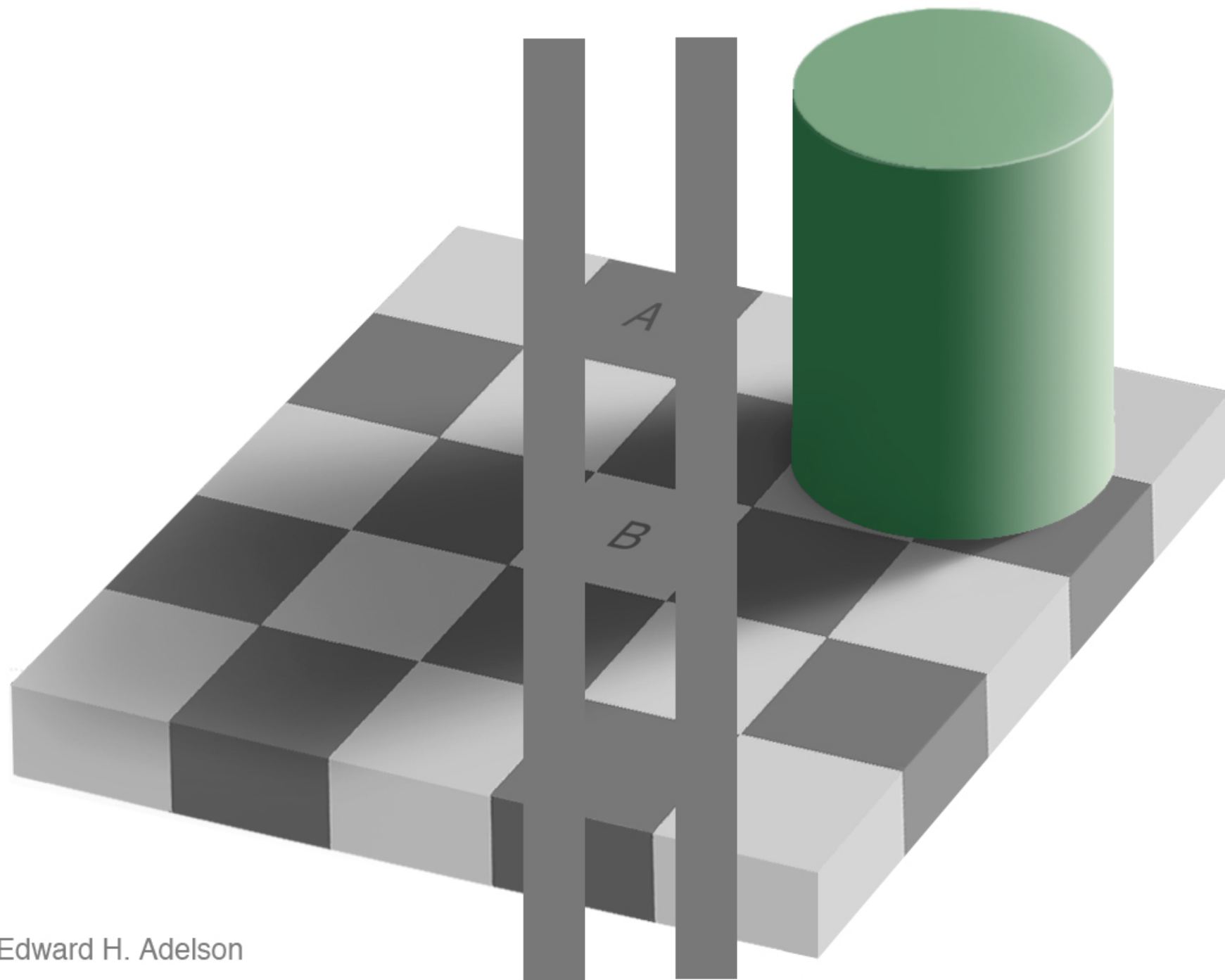




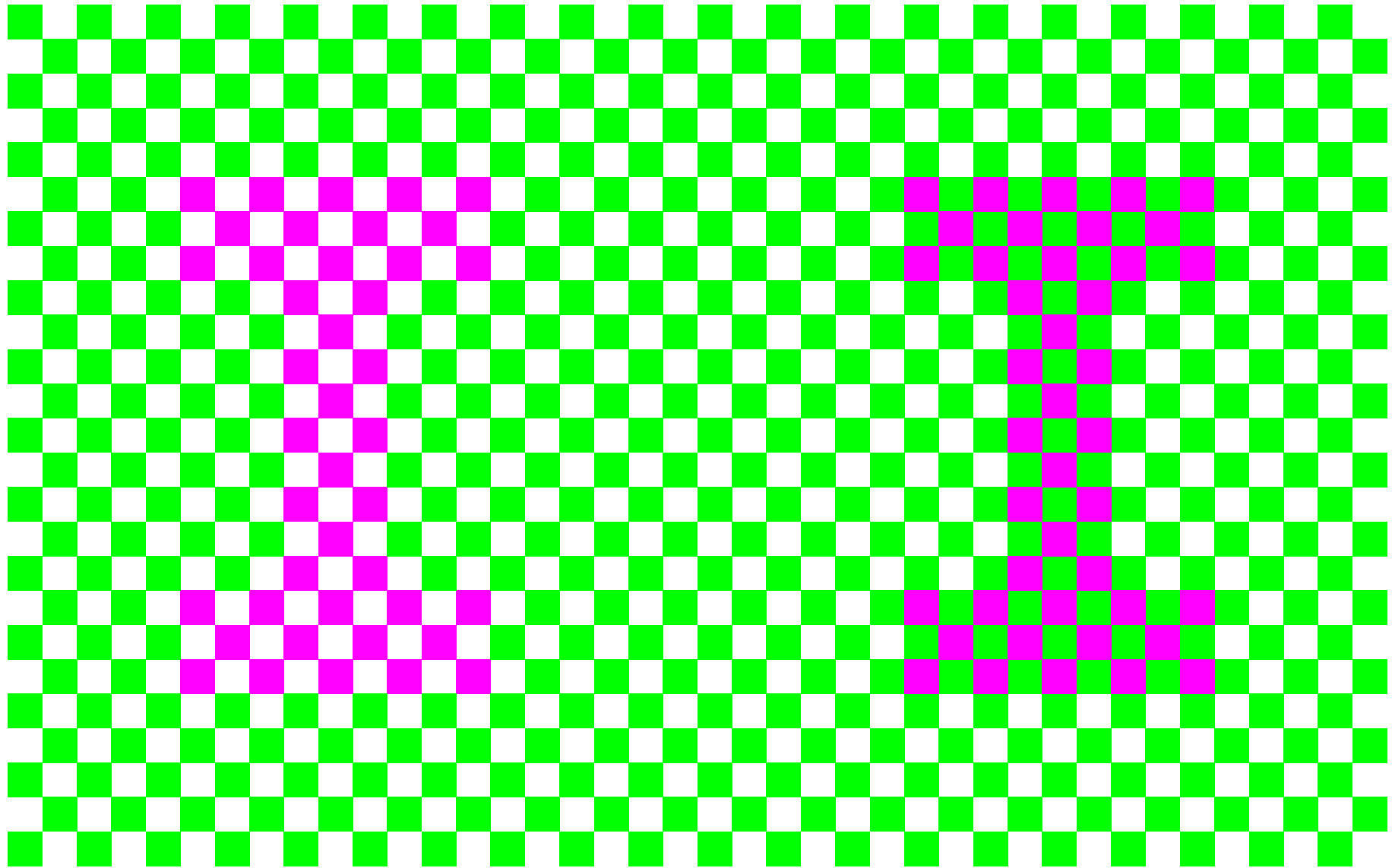


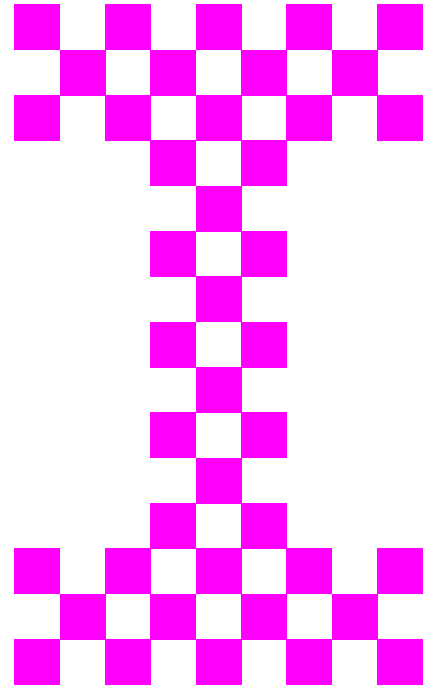
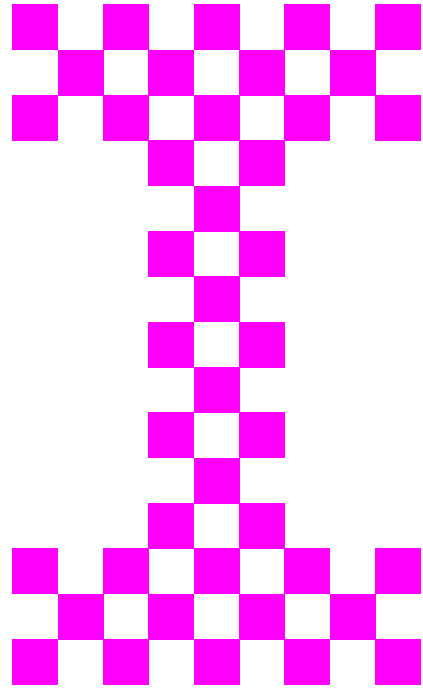


Edward H. Adelson



Edward H. Adelson

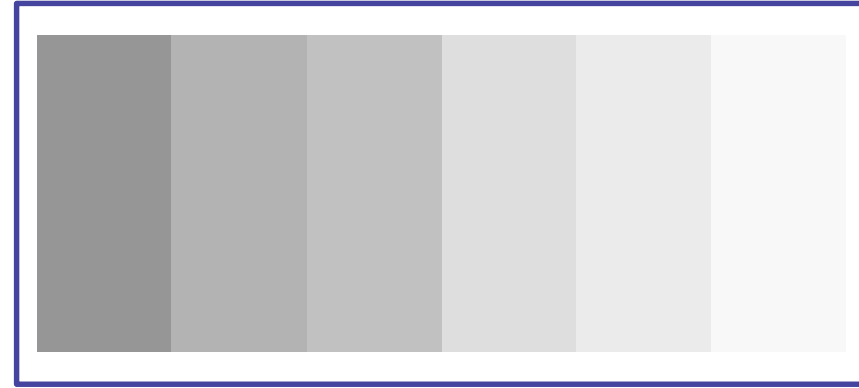




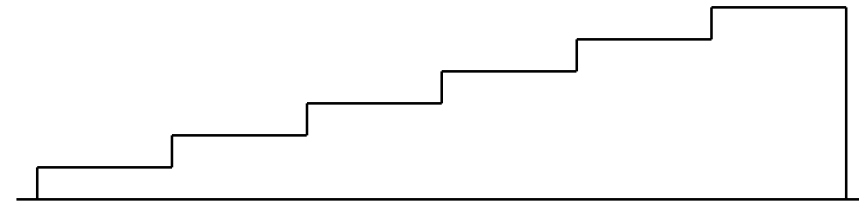


# Mach Bands

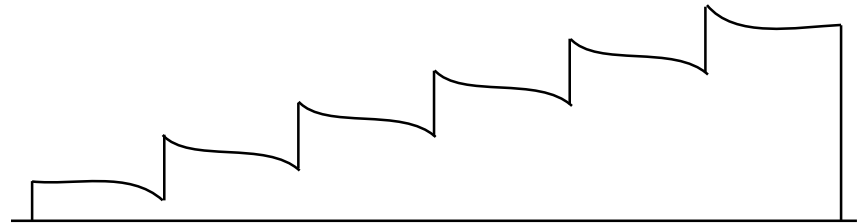
- Adjacent solid gray quads in increasing brightness

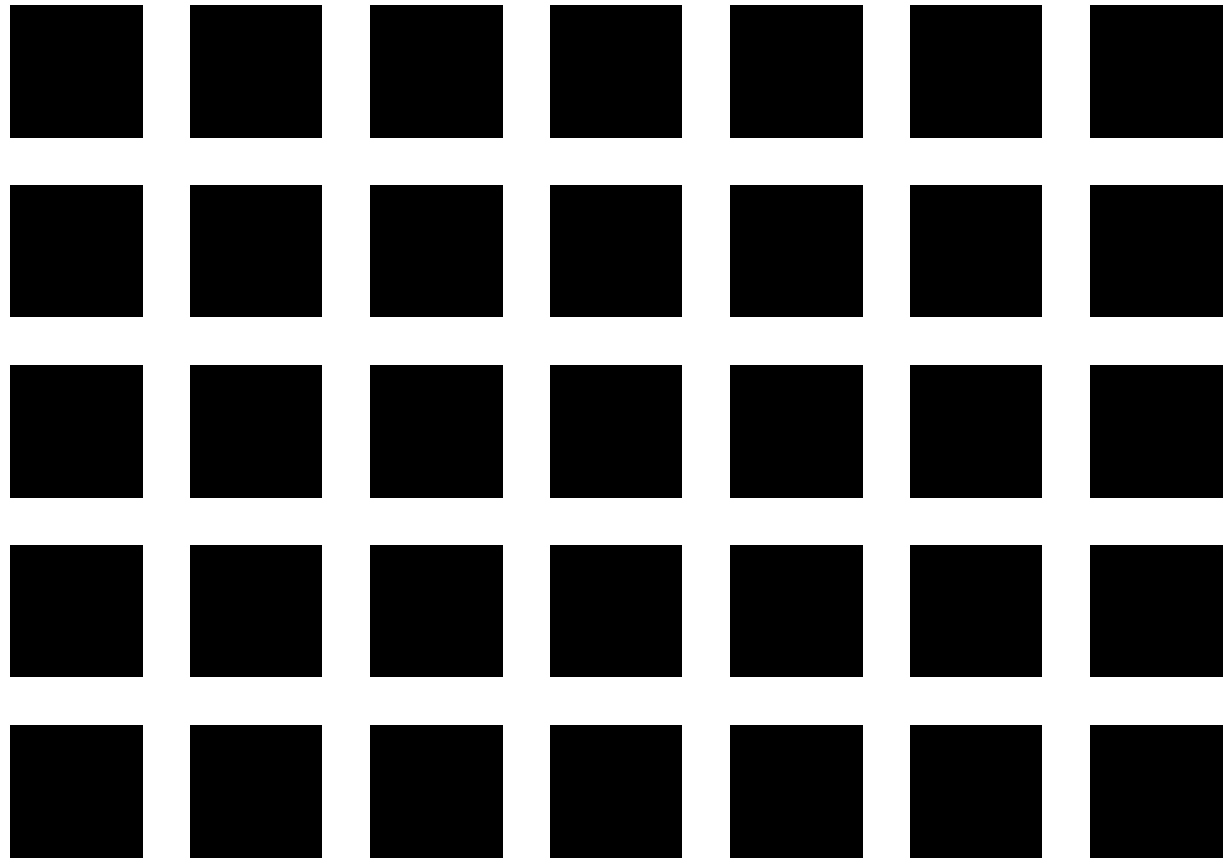


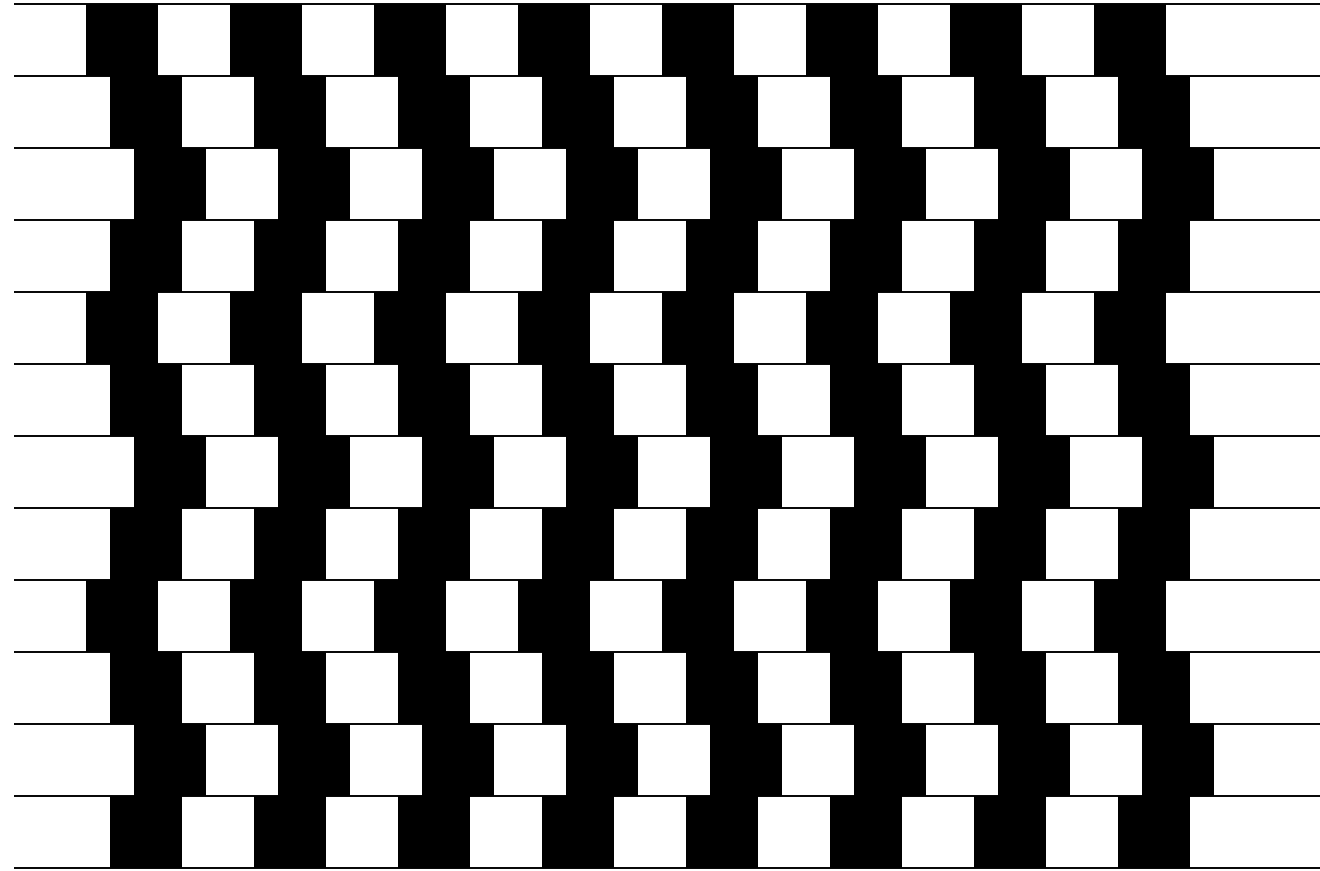
- Intensity on the retina



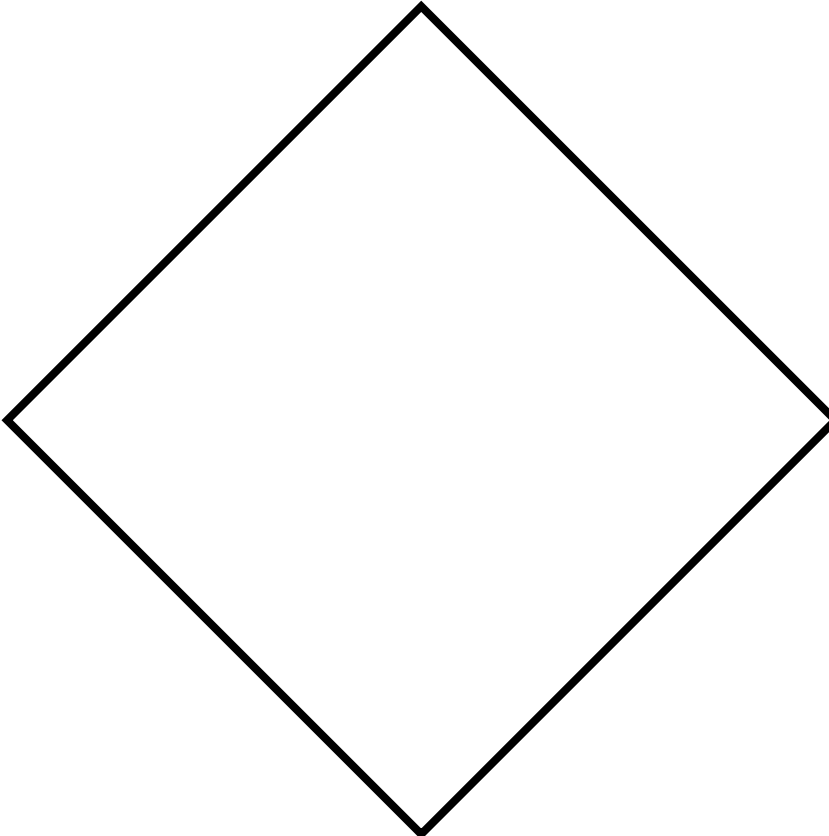
- Intensity perceived

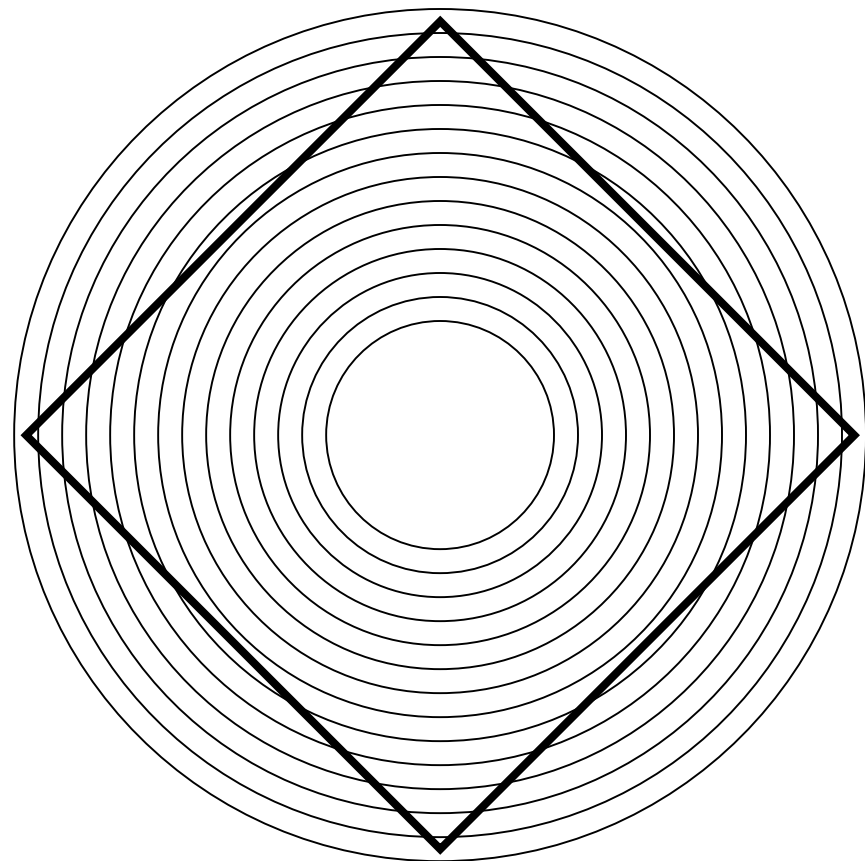


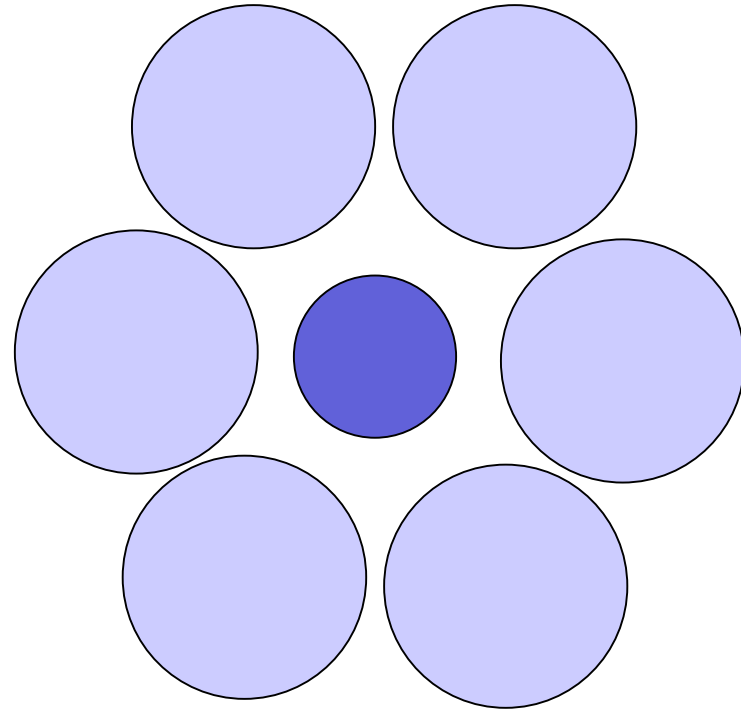
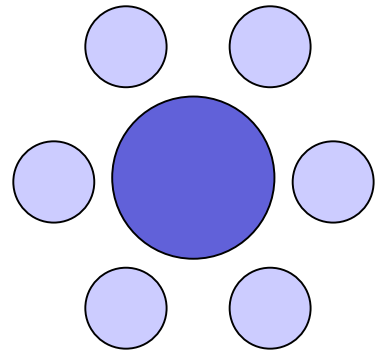


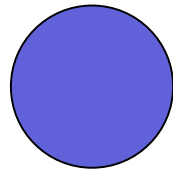
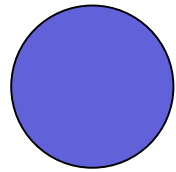














# What We Learned

*“Who you gonna believe, me or your lying eyes?”*

- The light reaching your eyes follows the laws of physics (e.g. scattering, absorption)
- The light perceived by the human visual system follows the laws of perceptual psychology (e.g. lateral inhibition)
- We have to understand both in computer graphics so we can take computational shortcuts when simulating the physics of light based on how the result will be perceived by the viewer

