How Do We See?

CS418 Computer Graphics
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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

xkcd.com/273
Clorophyll absorption

A

B

Clorophyll absorption
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/mm² 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’ = 1/60th of a deg.).

\[
\theta = 2 \tan^{-1}\left(\frac{h}{2d}\right)
\]

\[
h \approx \tan(\theta) \quad \text{for small } \theta
\]

\[
\tan(1') = 0.03\%
\]

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 $15.15° = 909’$.

• 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

from Gray’s Anatomy
Mach Bands

- Adjacent solid gray quads in increasing brightness
- Intensity on the retina
- Intensity perceived
What We Learned

- 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

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

xkcd.com/1080