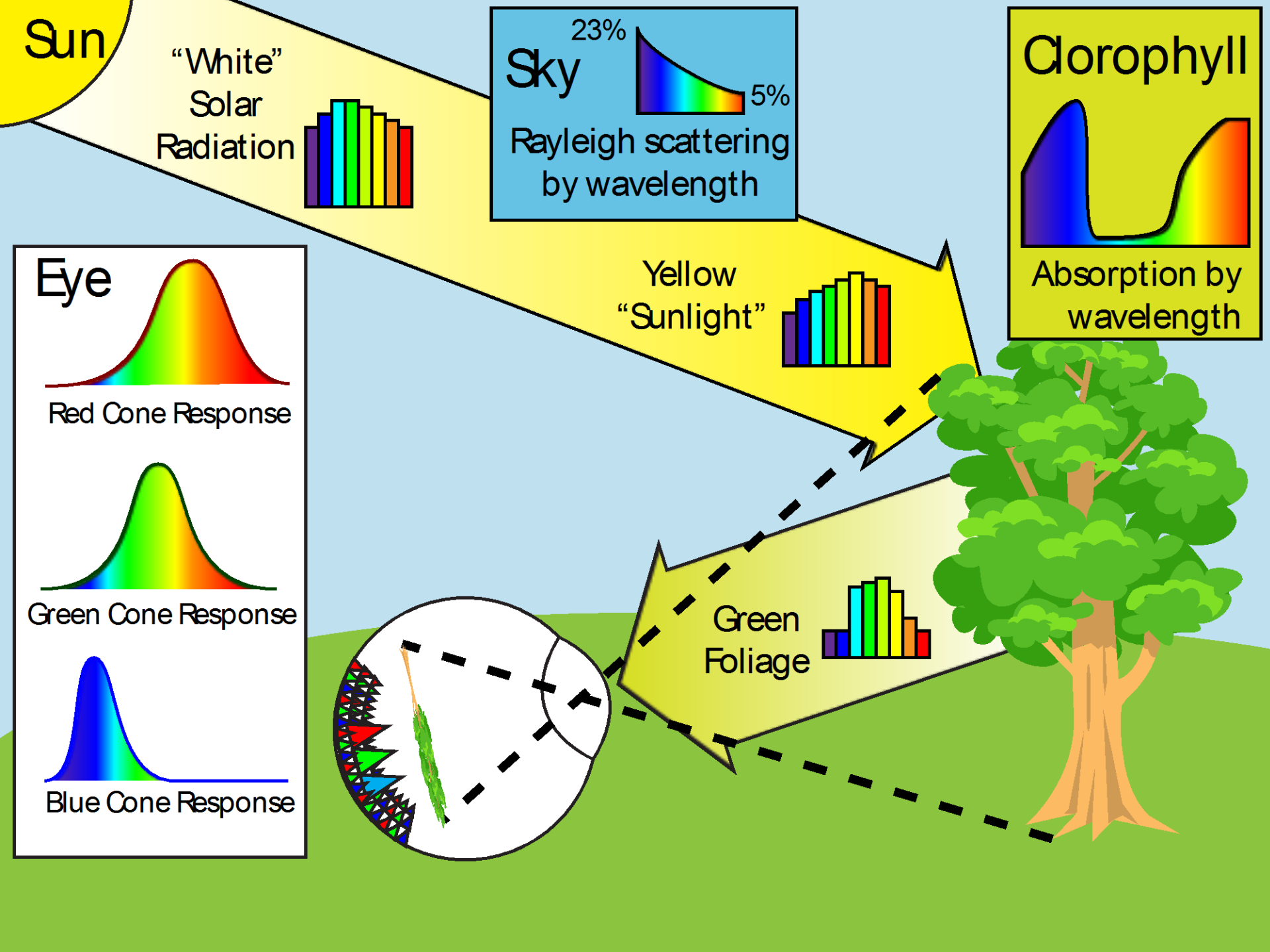
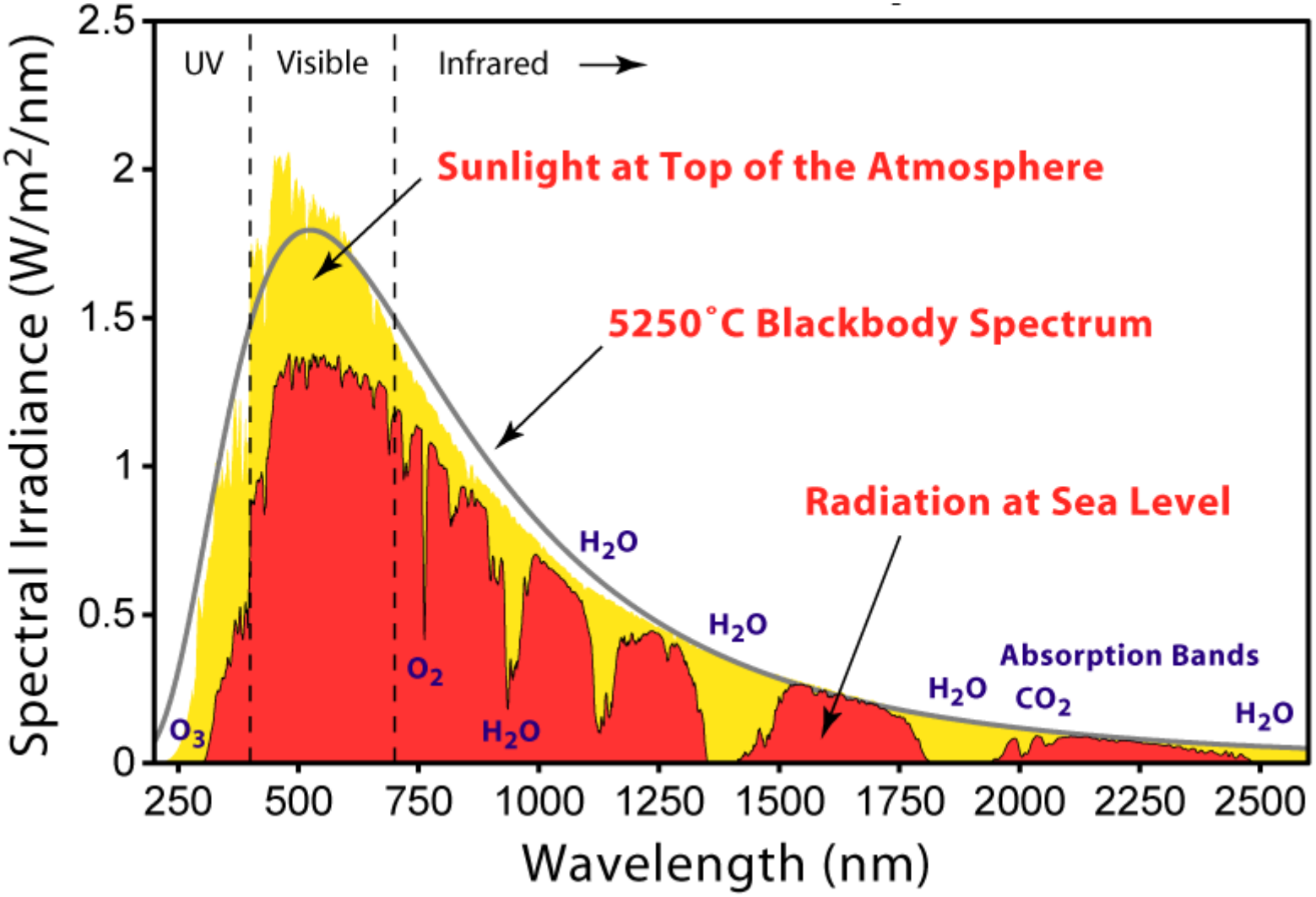
Image Formation

CS418 Computer Graphics

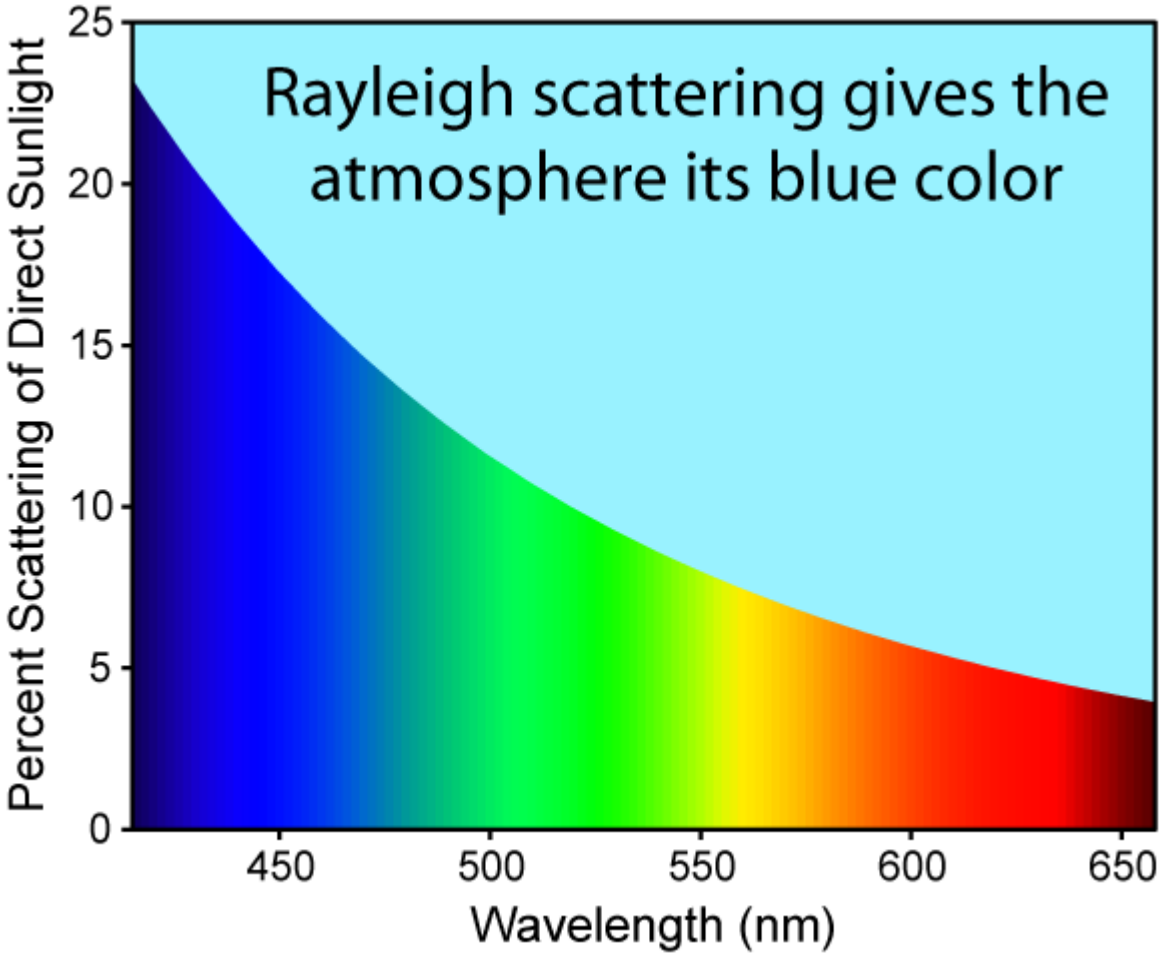
John C. Hart


Sun
"White"
Solar
Radiation
Sky
23%
5%
Rayleigh scattering
by wavelength
Clorophyll
Absorption by
wavelength
Yellow
"Sunlight"
Eye
Red Cone Response
Green Cone Response
Blue Cone Response
Green
Foliage

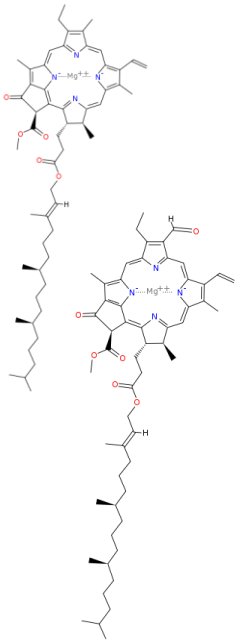
Solar Radiation

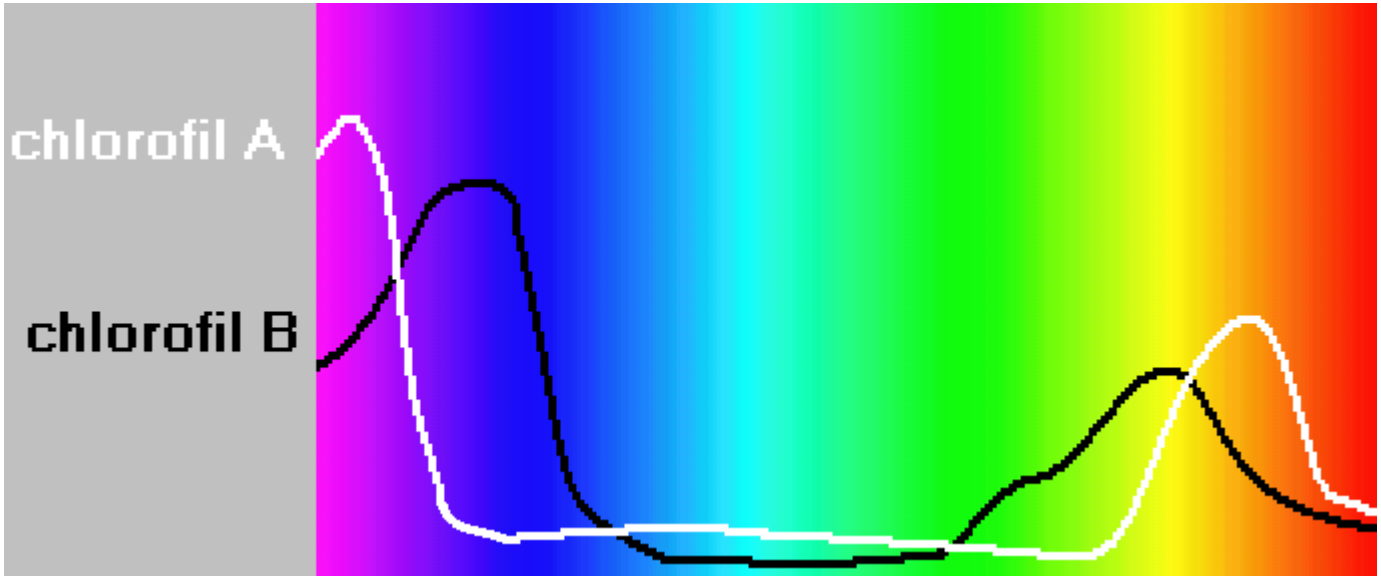


Rayleigh Scattering



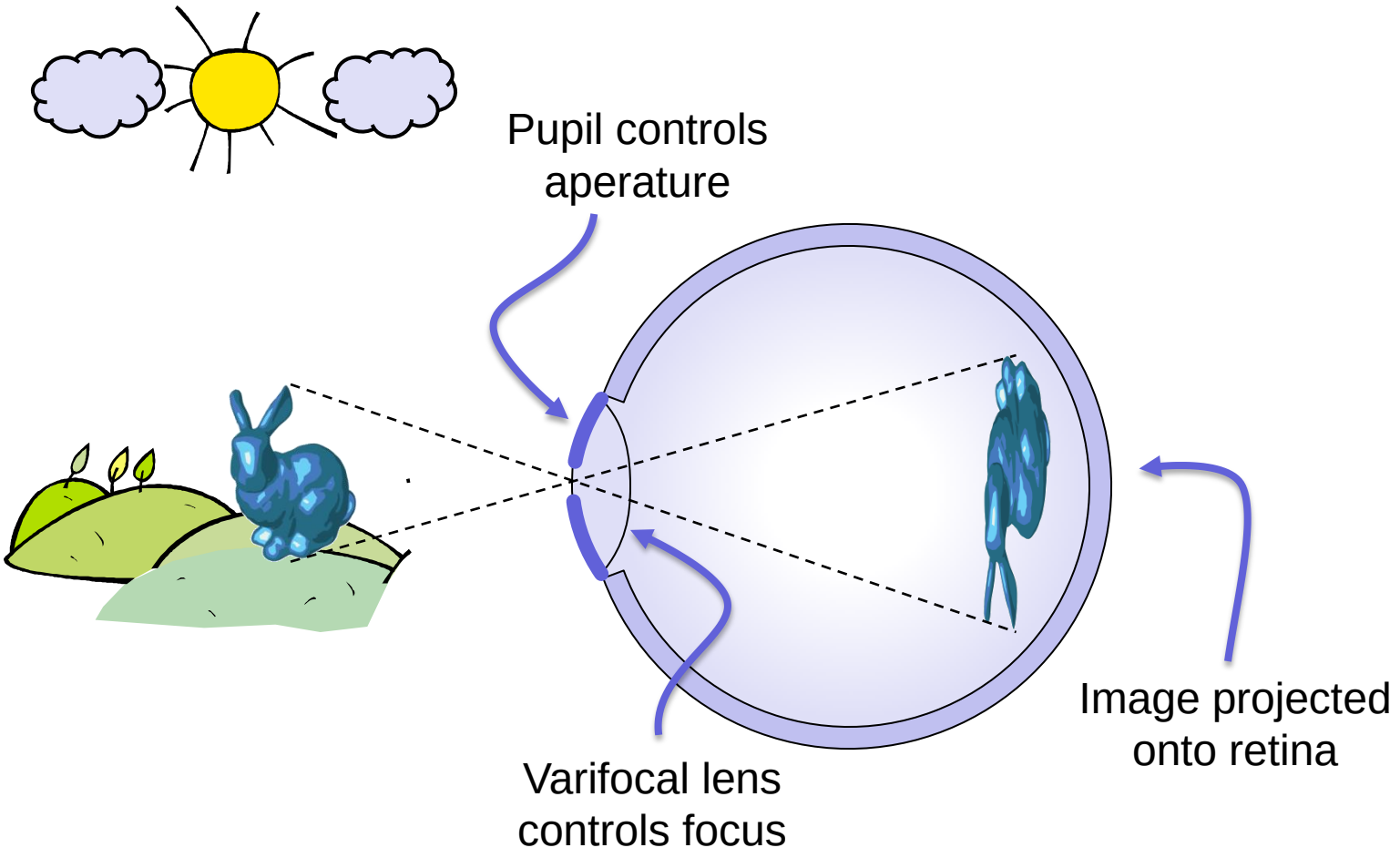
Chlorophyll





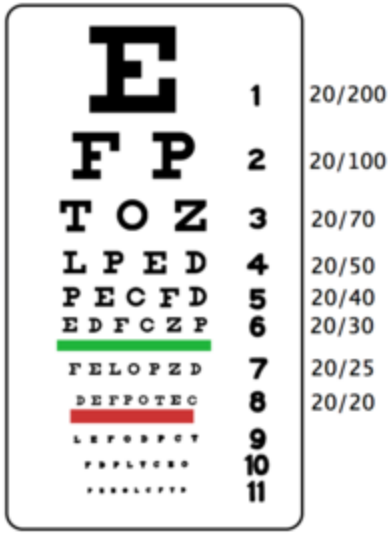
The Human Eye

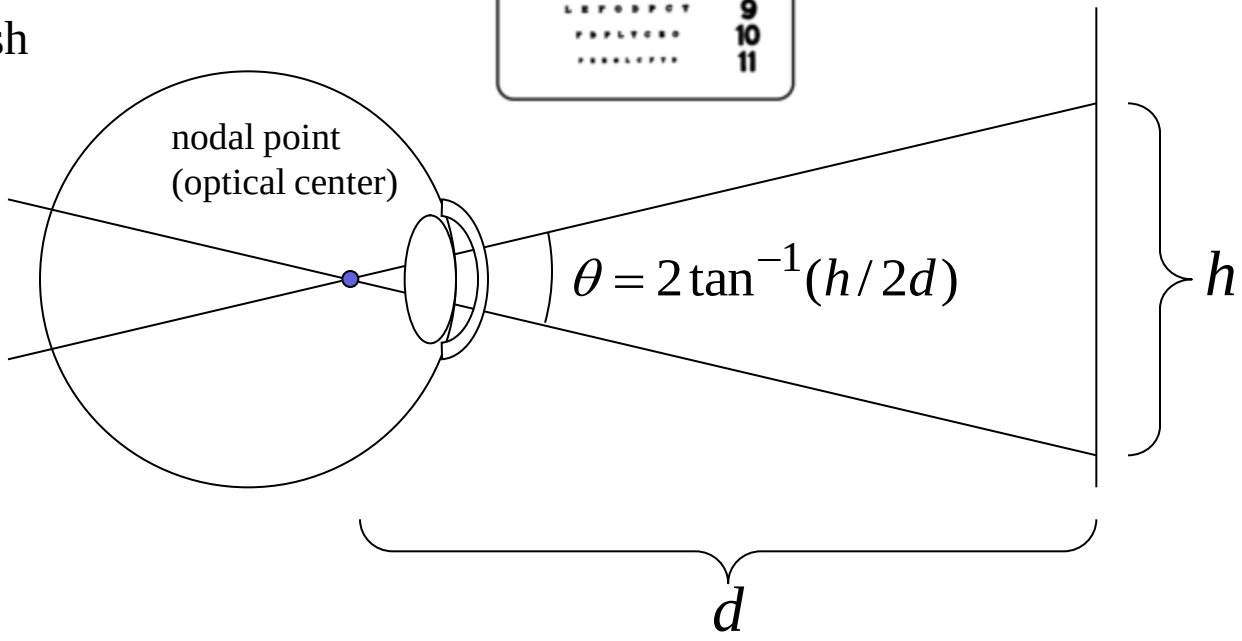
We perceive the world around us largely through images



Acuity

- Angular resolution of retina
- Snellen ratio:
  20/X means you distinguish at X feet what the average person distinguishes at 20 feet.
- 20/20 = distinguish two points 1 arc minute apart





Focus

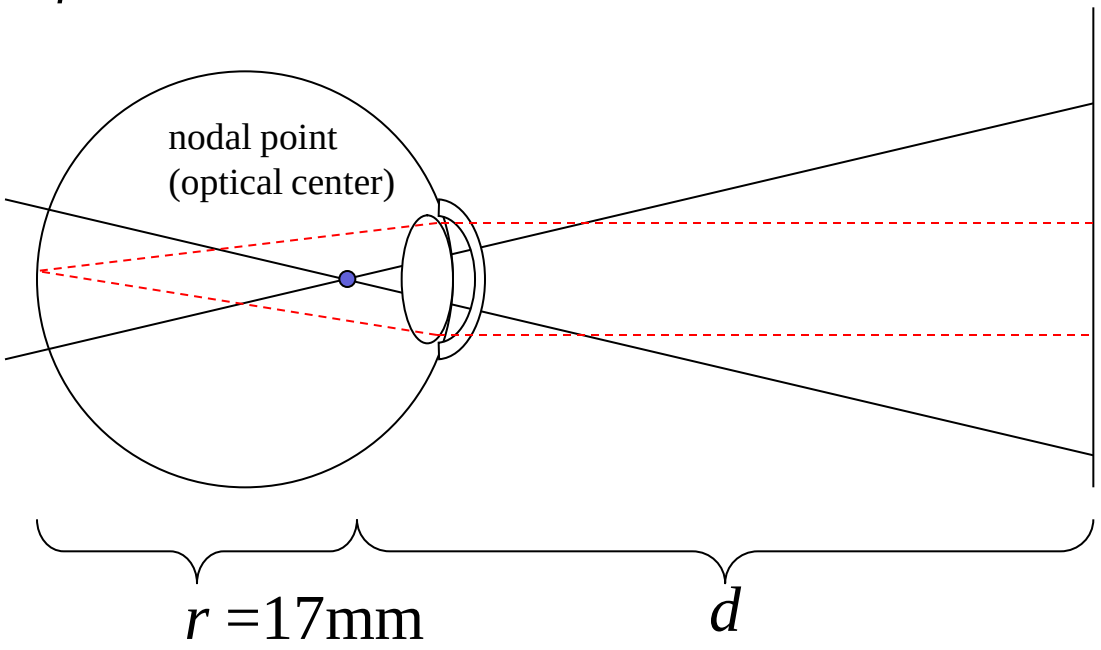
Simple lens

- Focal length: f
- Power: $1/f$ diopters
- When $d = \infty$

  $f = r = 17\text{mm}$

  $1\text{m}/f = 59$ diopters

$$\frac{1}{f} = \frac{1}{d} + \frac{1}{r}$$

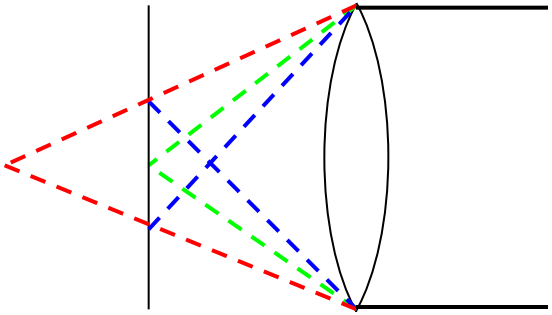


Compound lens

- cornea: 40 diopters
- lens: 12 diopters (kids)
- lose ~ 0.2 diopters/year
- lens rigid by age 60

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

Chromatic Aberration



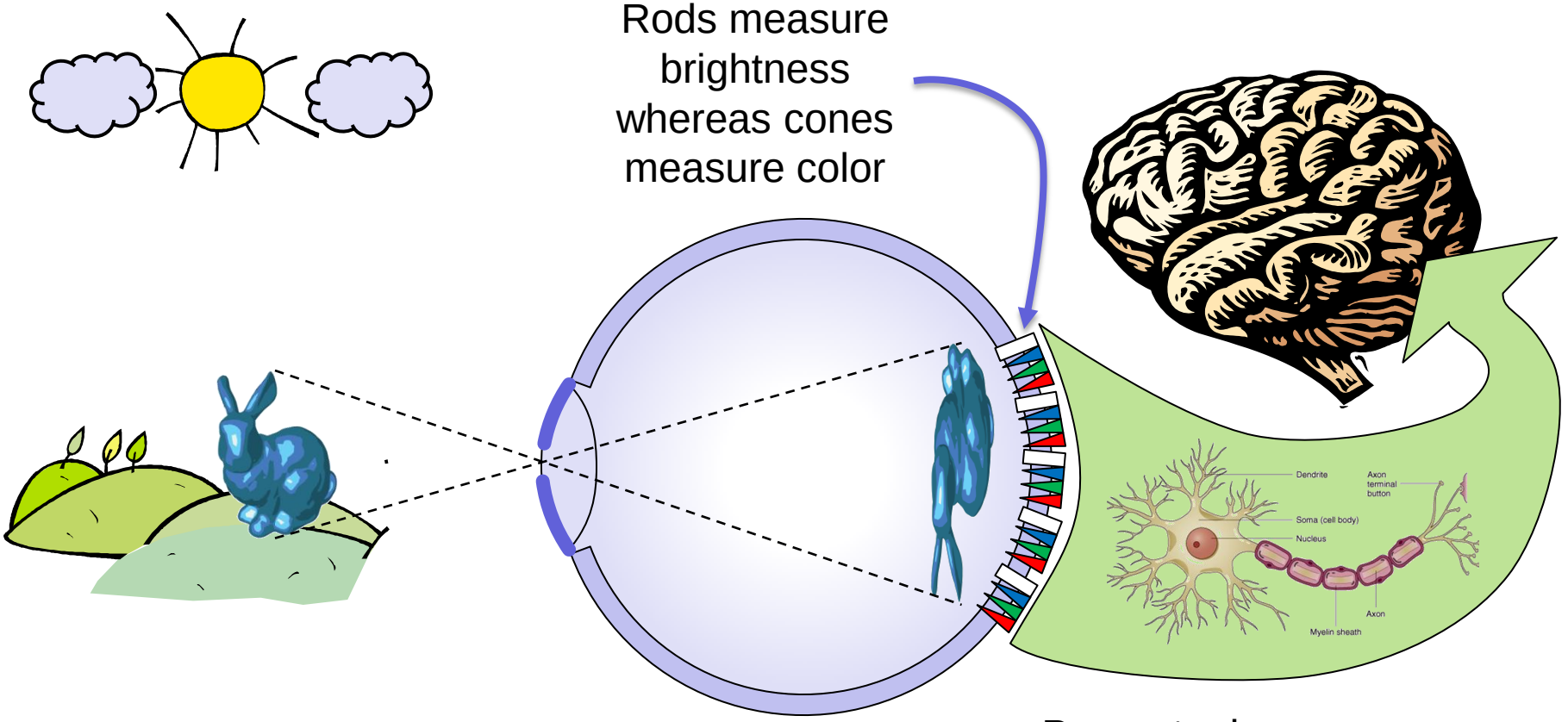
- Refractive index of lens material varies by wavelength
- Resulting dispersion causes focal plane to vary by color
- Need 1.5 diopters to focus red and blue to the same depth
- Never use pure blue (add a bit of red or green to aid in focusing on edges)
- Warm colors close, cool colors far

Most people see the red,
Closer than the blue.
Others see the opposite.
How about you?

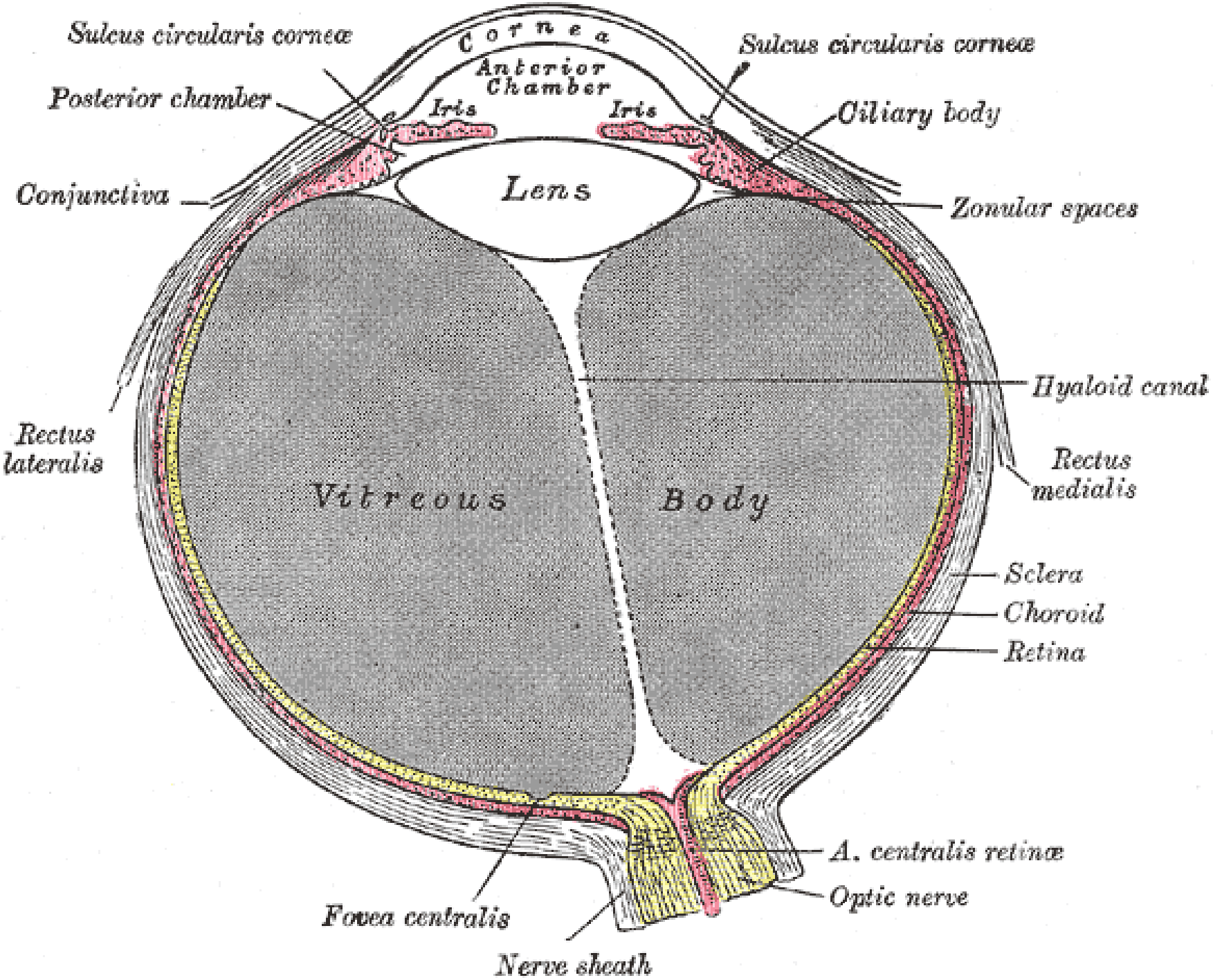
The Human Eye

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

Rods measure brightness whereas cones measure color



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


Sulcus circularis corneæ
Cornea
Anterior Chamber
Sulcus circularis corneæ
Posterior chamber
Iris
Iris
Ciliary body
Conjunctiva
Lens
Zonular spaces
Hyaloid canal
Rectus lateralis
Vitreous Body
Rectus medialis
Sclera
Choroid
Retina
A. centralis retinæ
Optic nerve
Fovea centralis
Nerve sheath

The Human Eye

Cornea, *lens* focus light onto *Retina*

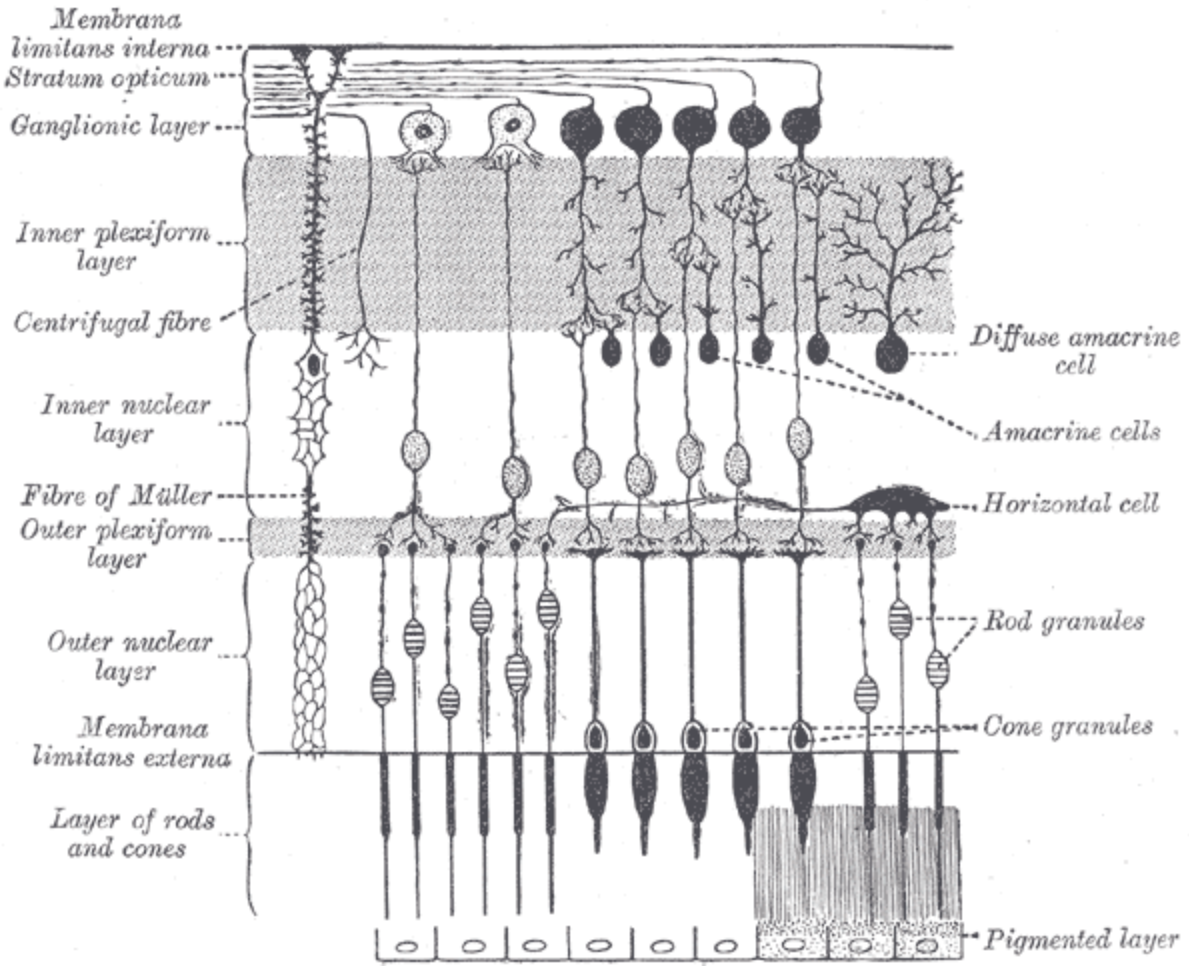
from Gray's Anatomy

Photoreceptors

- *rods* - brightness
- *cones* – color (red, green, blue)

Ganglions – nerve cells

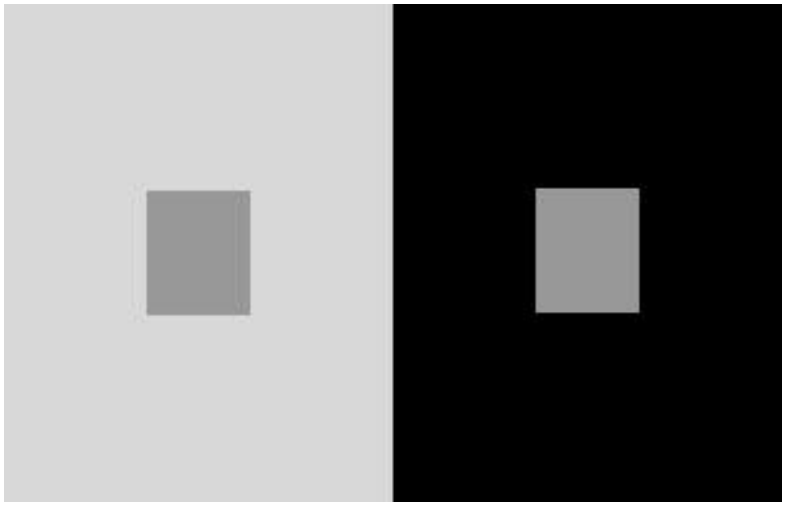
- (*X-cells*) detect pattern
- (*Y-cells*) detect movement

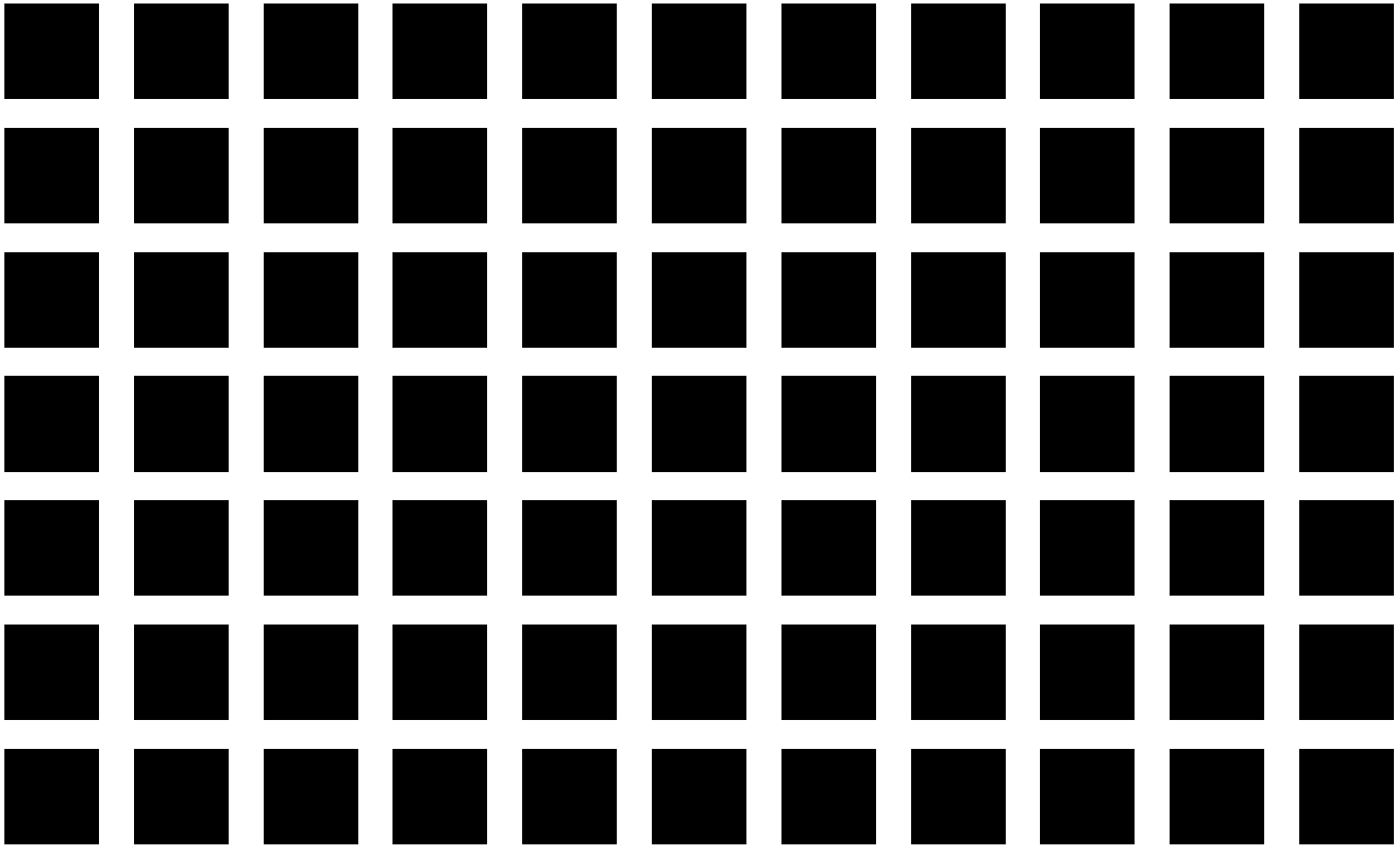


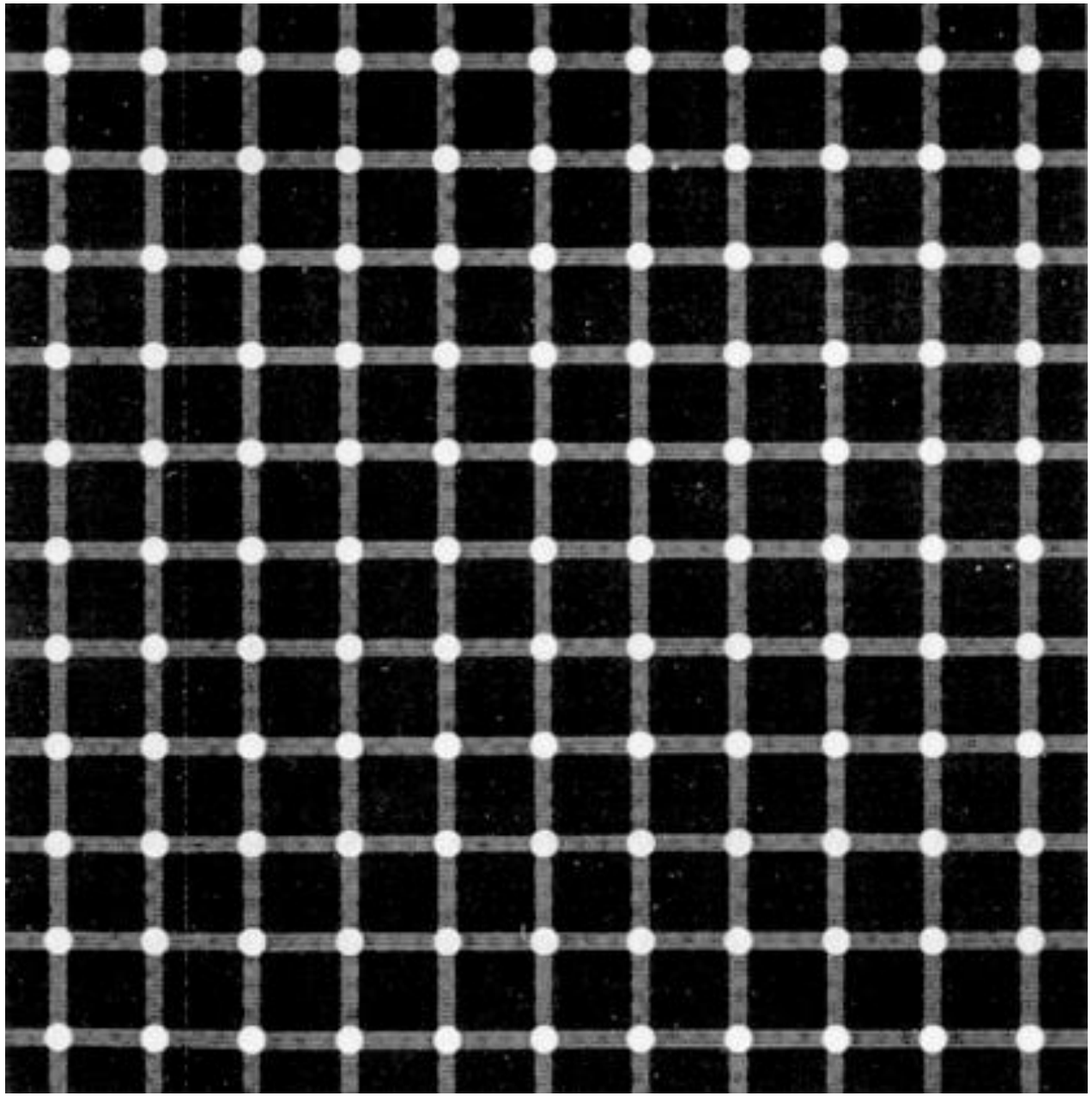
Lateral Inhibition

- Rods accentuates and exaggerates differences in space and time
- Eye's internal real-time edge and motion detector
- Used to detect predators like tigers in the bushes
- Middle squares same shade of gray

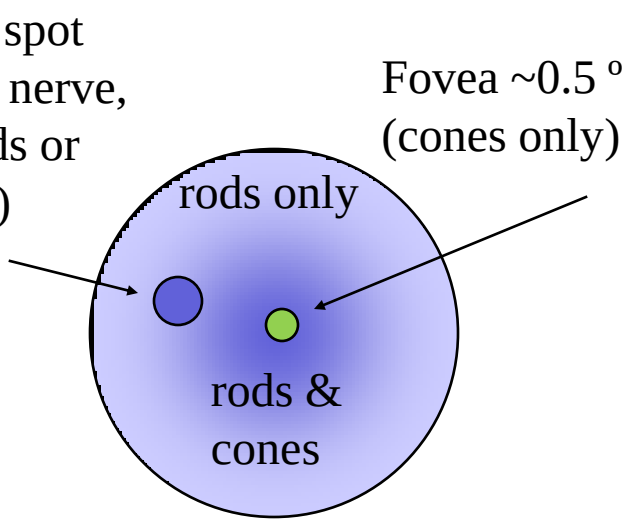
-1	-1	-1
-1	8	-1
-1	-1	-1





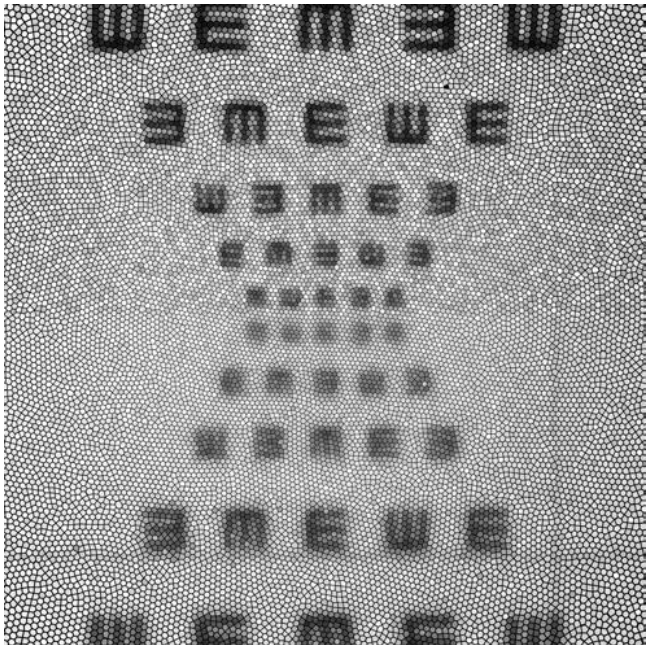


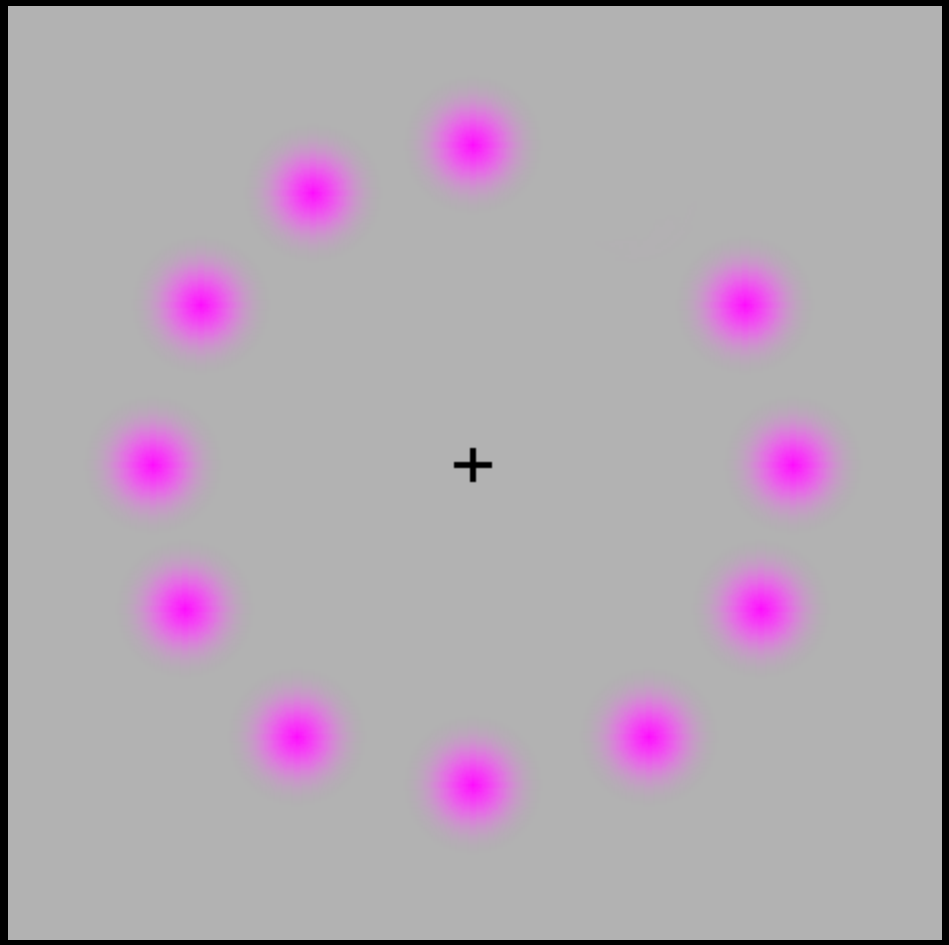
Rods & Cones



- 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^2 in fovea
  - 150 hues
- Combined
  - 7 million shades

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

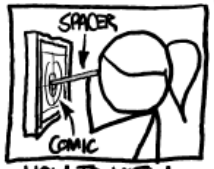




LOOK AT THE CENTER WITH YOUR EYES THIS FAR FROM THE SCREEN

(YOU CAN ROLL UP A SHEET OF PAPER AND CUT IT—OR ZOOM THE PAGE—SO IT MATCHES THIS IMAGE.)

YOUR CENTRAL VISUAL FIELD



HOW TO VIEW

COLOR VISION:

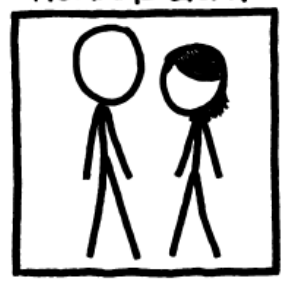
WE DON'T SEE MUCH COLOR OUTSIDE THE CENTER OF OUR VISION — OUR BRAINS KEEP TRACK OF WHAT COLOR THINGS ARE AND FILL IT IN FOR US.

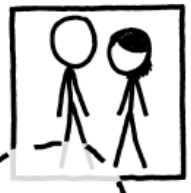
SATURATION INDICATES COLOR RECEPTOR DENSITY

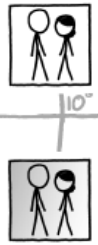
DETAIL

WE ONLY SEE AT HIGH RESOLUTION OVER A SMALL AREA IN THE CENTER OF OUR VISION WHERE RETINAL CELLS ARE DENSEST (THE FOVEA).

IF YOU STARE AT THE CENTER OF THIS CHART, YOUR EYES ARE SEEING ALL THESE PANELS AT ROUGHLY THE SAME LEVEL OF DETAIL.







WE HAVE FEW BLUE-SENSITIVE CONE CELLS, BUT THEY'RE FOUND OUT TO THE EDGE OF OUR VISION.

LEFT EYE* BLIND SPOT

RIGHT EYE BLIND SPOT

BLUE-SKY SPRITES

THESE TINY, DARTING BRIGHT SPOTS, VISIBLE AGAINST SMOOTH BLUE BACKGROUNDS, ARE WHITE CELLS MOVING IN THE BLOOD VESSELS OVER THE RETINA.

RED AND GREEN-SENSITIVE CONES ARE MAINLY LIMITED TO THE CENTER OF OUR VISION.

FLOATERS

SOME TYPES OF FLOATERS ARE CAUSED BY BREAKDOWN OF YOUR EYEBALL GOOP AS YOU AGE, BUT THIS TYPE IS SOME OTHER KIND OF DEBRIS NEAR THE RETINA.

I DON'T KNOW WHAT.

HUMANS CAN SEE POLARIZATION—

STARE AT A WHITE AREA ON AN LCD DISPLAY WHILE ROTATING IT (OR YOUR HEAD)

LIKE THIS: (FAST)

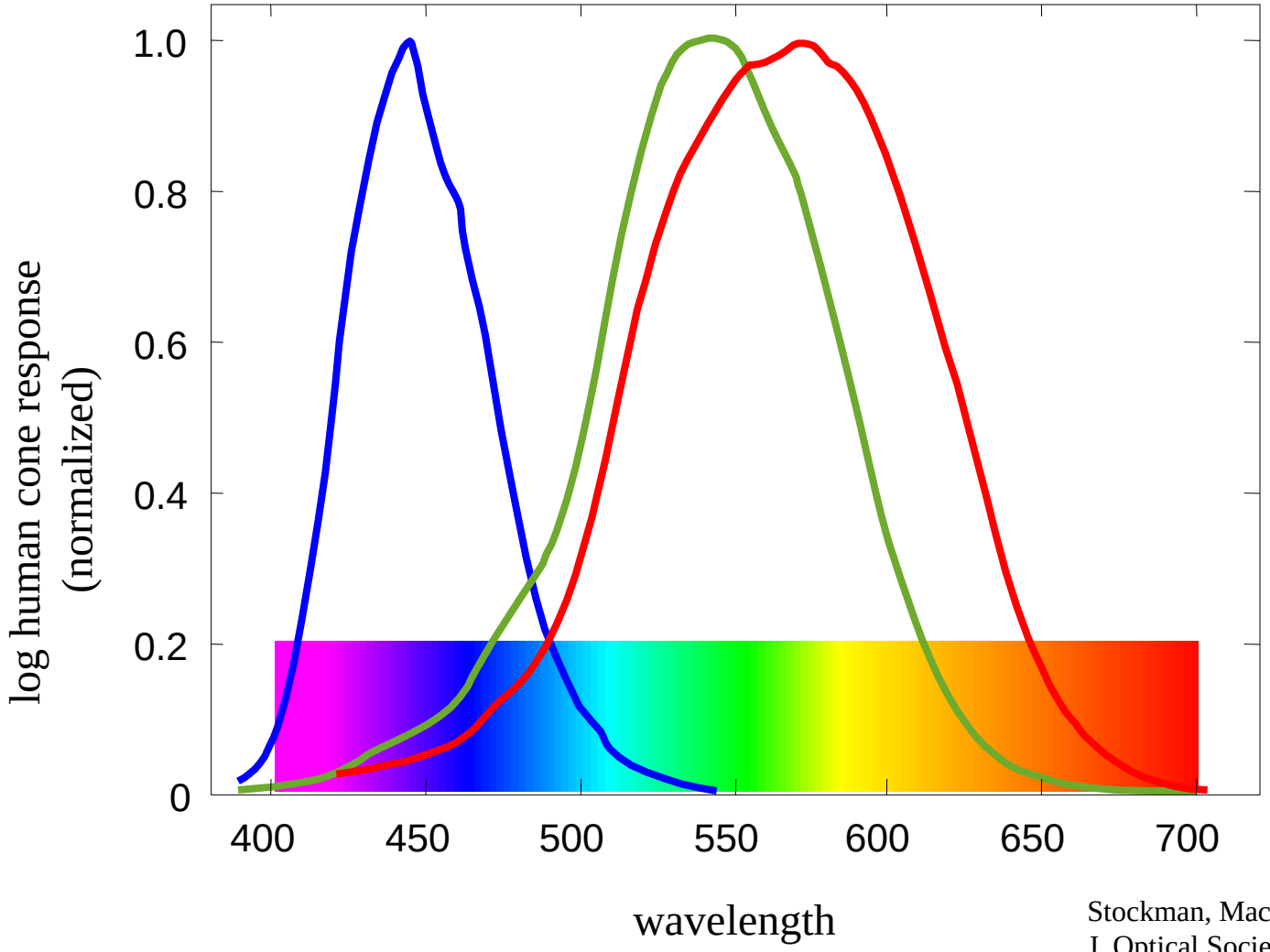
POLARIZATION DIRECTION IS SHOWN BY A FAINT CENTRAL YELLOW/BLUE SHAPE. (ALSO VISIBLE IN DEEP BLUE SKIES.)

NIGHT VISION

CONE CELLS (SHARP, CENTRAL COLOR VISION) DON'T WORK IN LOW LIGHT, BUT ROD CELLS (MONOCHROME, LOW-RES, NON-CENTRAL) DO. THIS IS WHY YOU CAN WALK AROUND IN DIM LIGHT, BUT NOT READ. IT'S ALSO WHY YOU CAN SPOT FAINTER STARS BY LOOKING NEXT TO THEM.

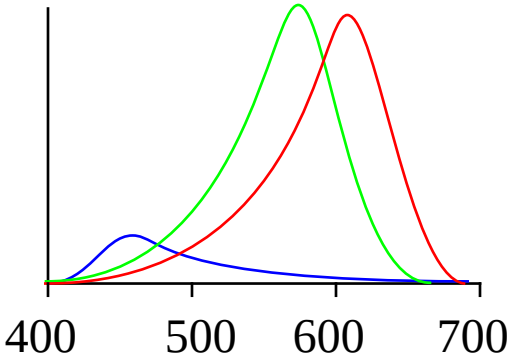
*NOT PICTURED: T-BOZ BLIND SPOT, CHILLI BLIND SPOT.

Cone Response



Stockman, MacLeod & Johnson (1993)
J. Optical Society of America A, 10,
2491-2521, via Wikipedia

Color Perception

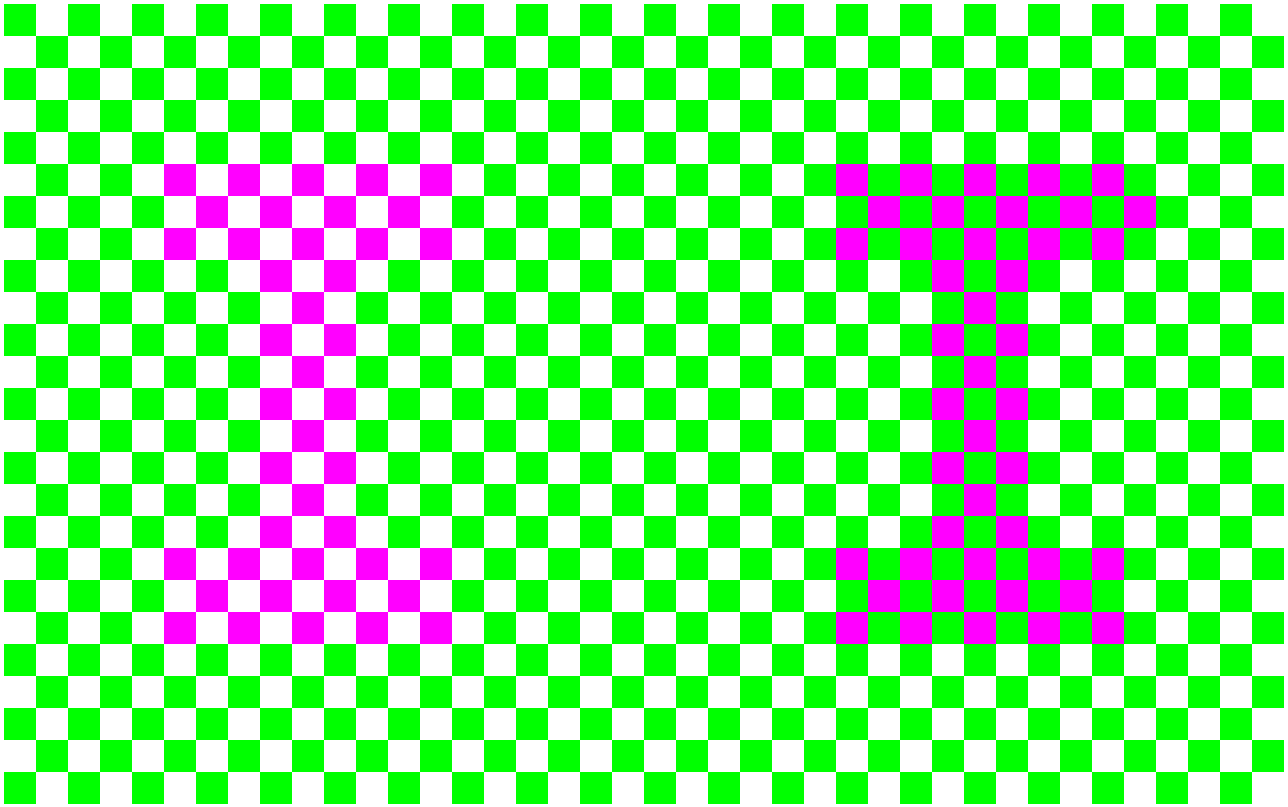


- L = 31% R + 59% G + 10% B
- 10% of males are color blind
- Pay attention to contrast!

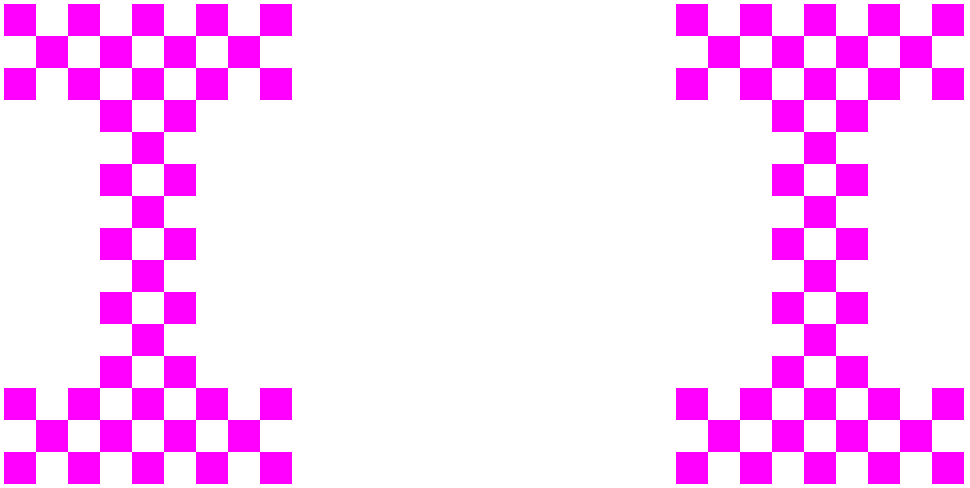
- Eye color space

  L, R + G – B, R – G
- Color space is black⇔white, yellow⇔blue, red⇔green

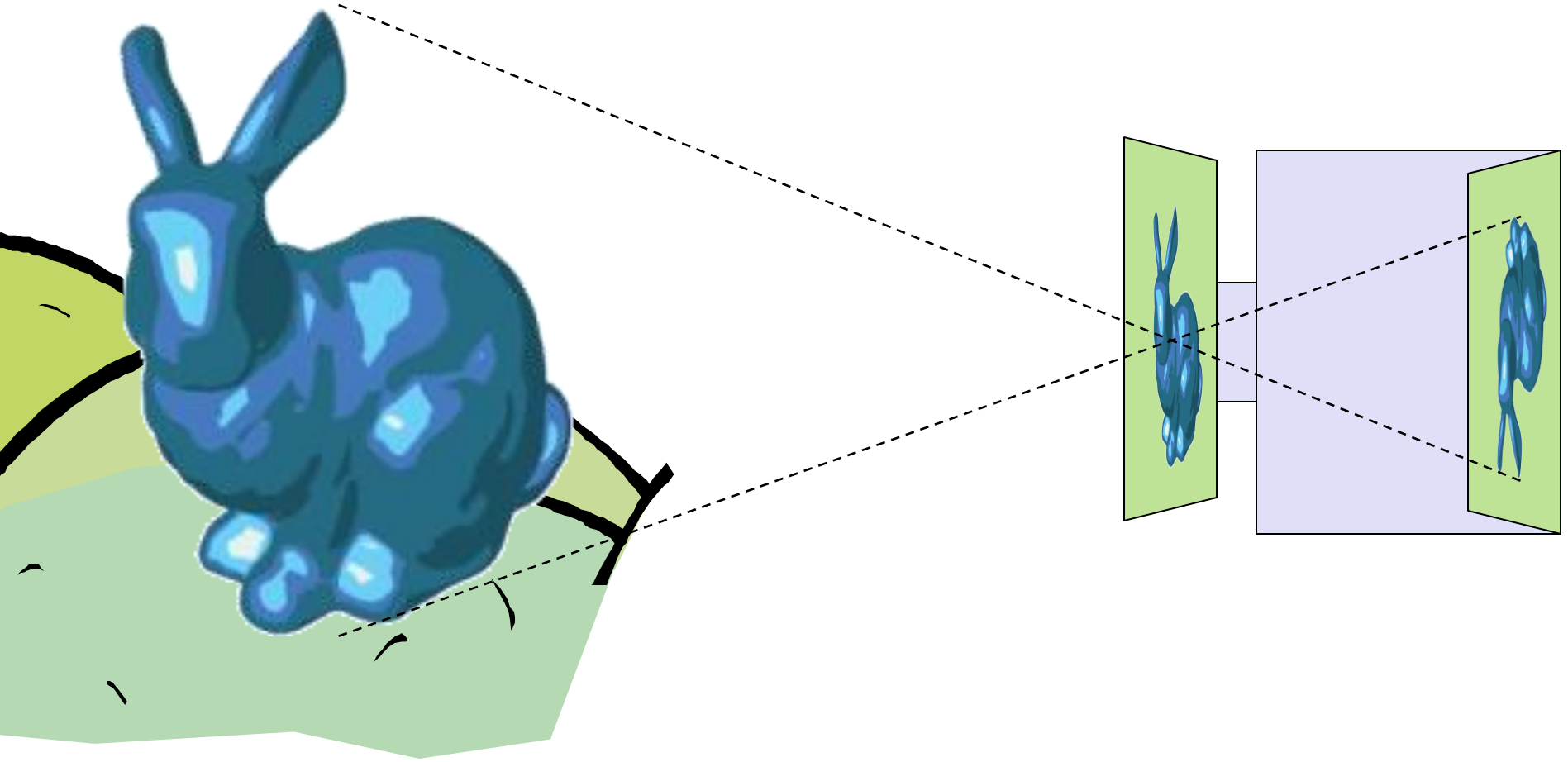
Color in Context



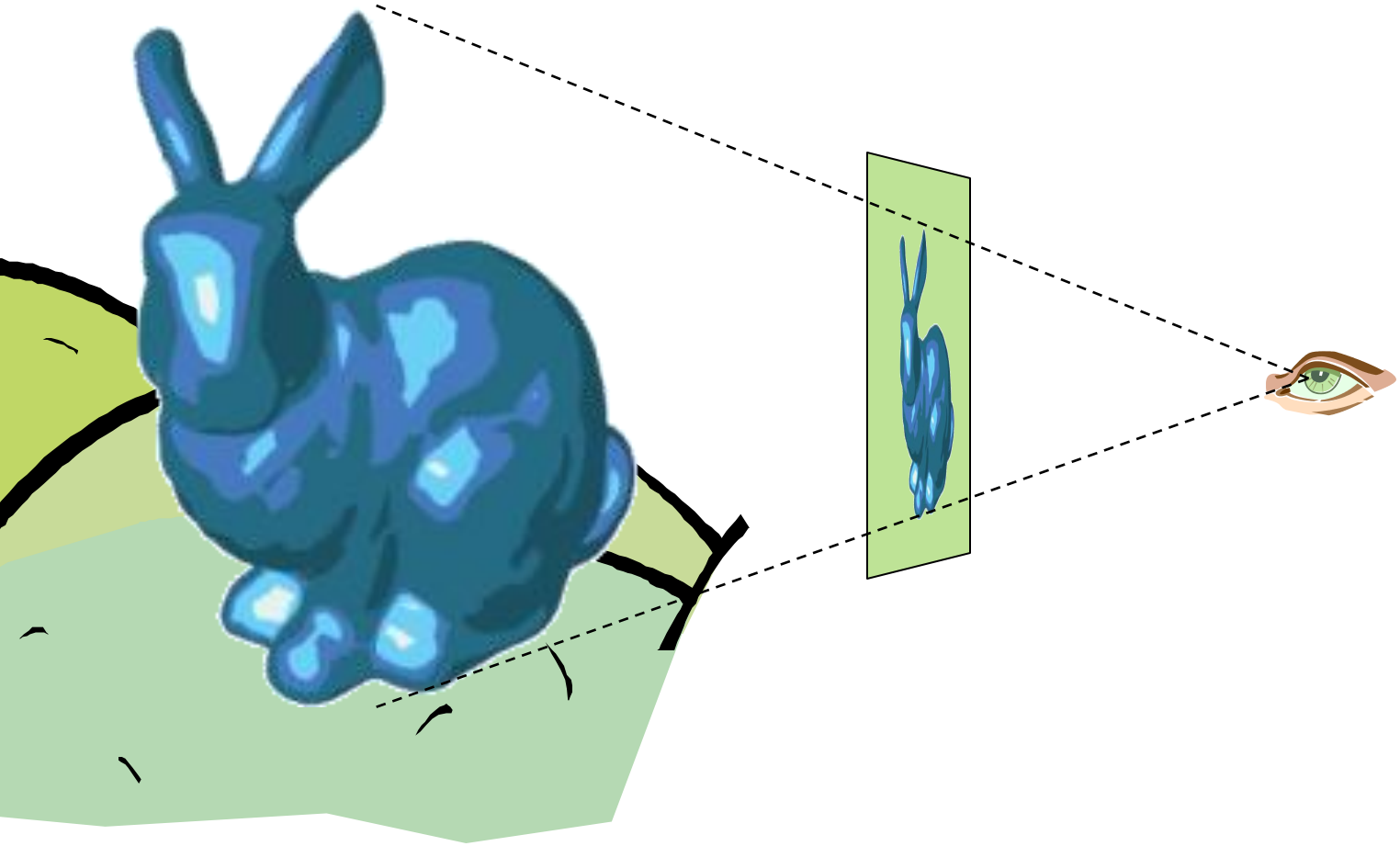
Color in Context



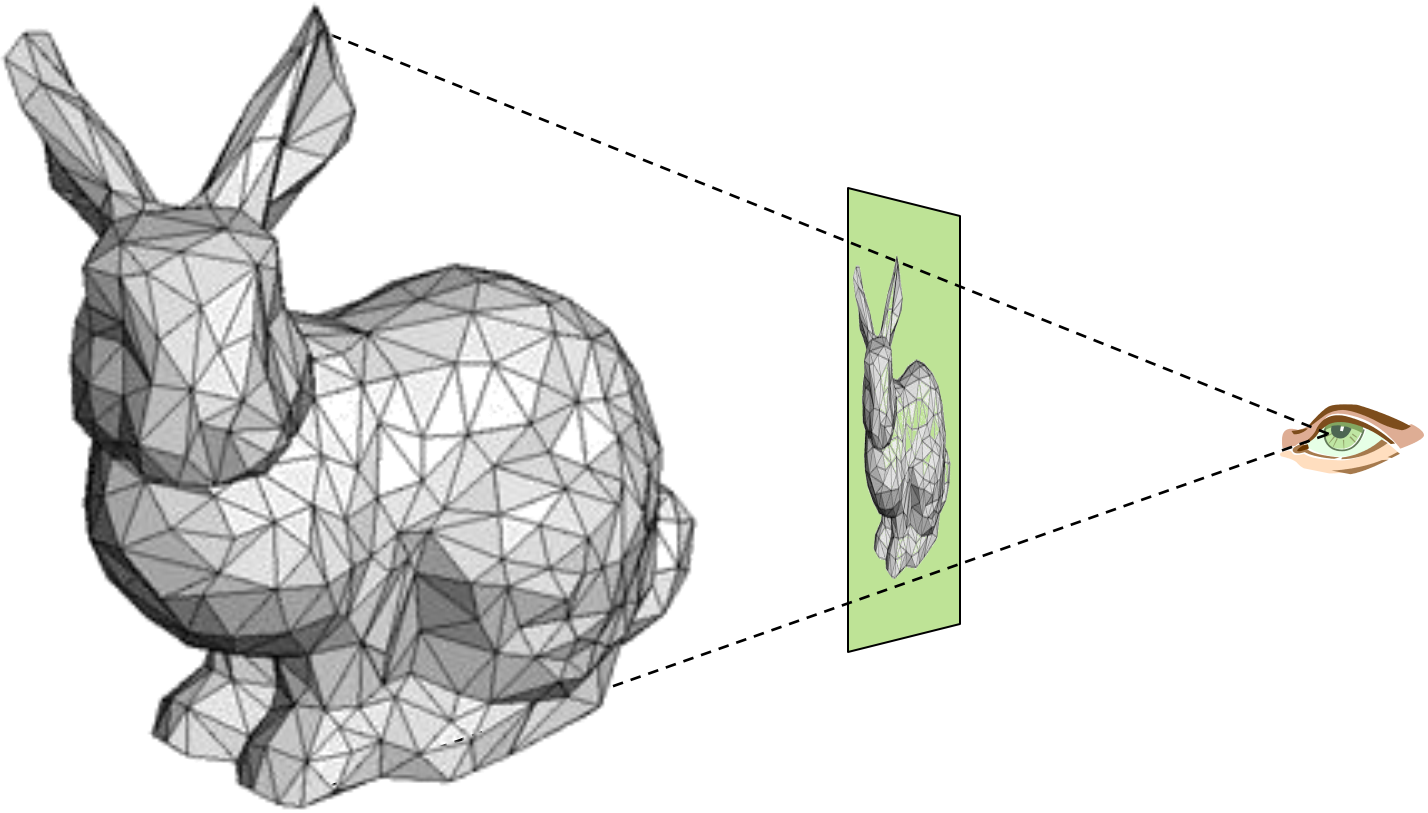
The Camera



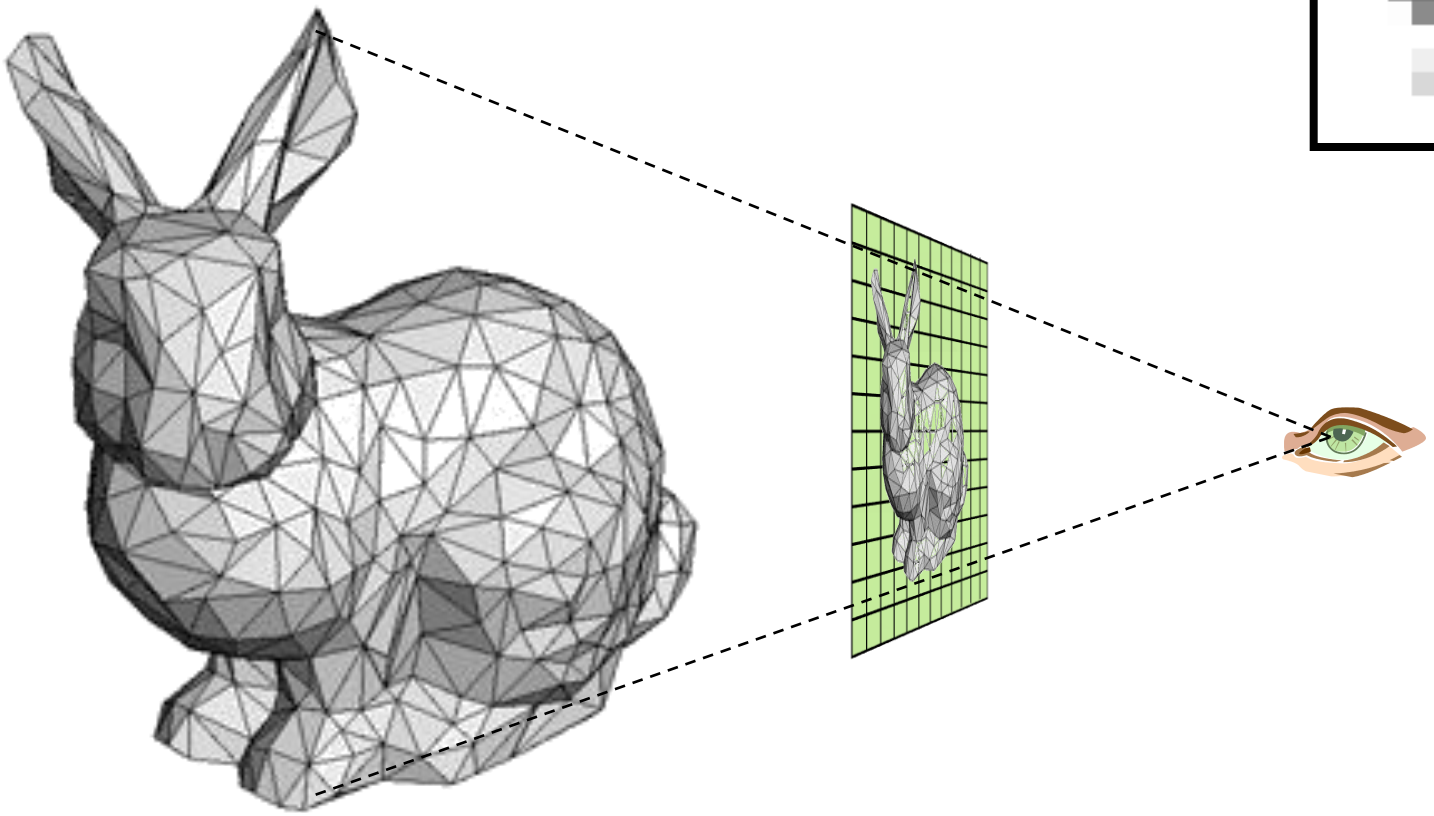
The Image Plane

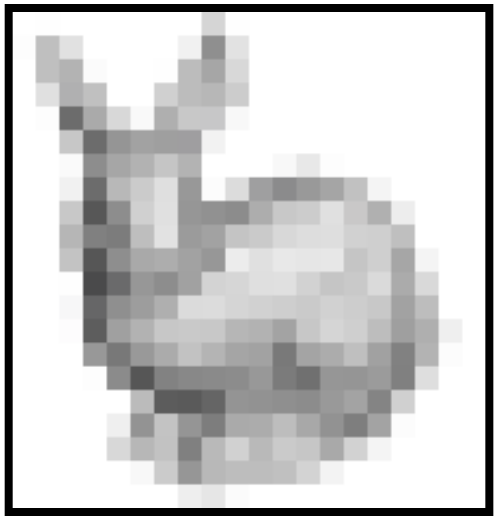


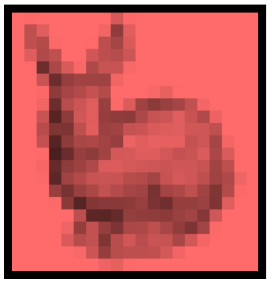
Polygonal Models

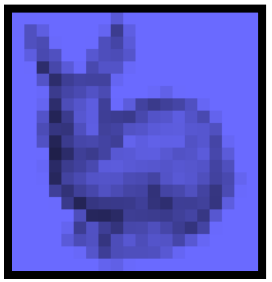


Pixel Discretization



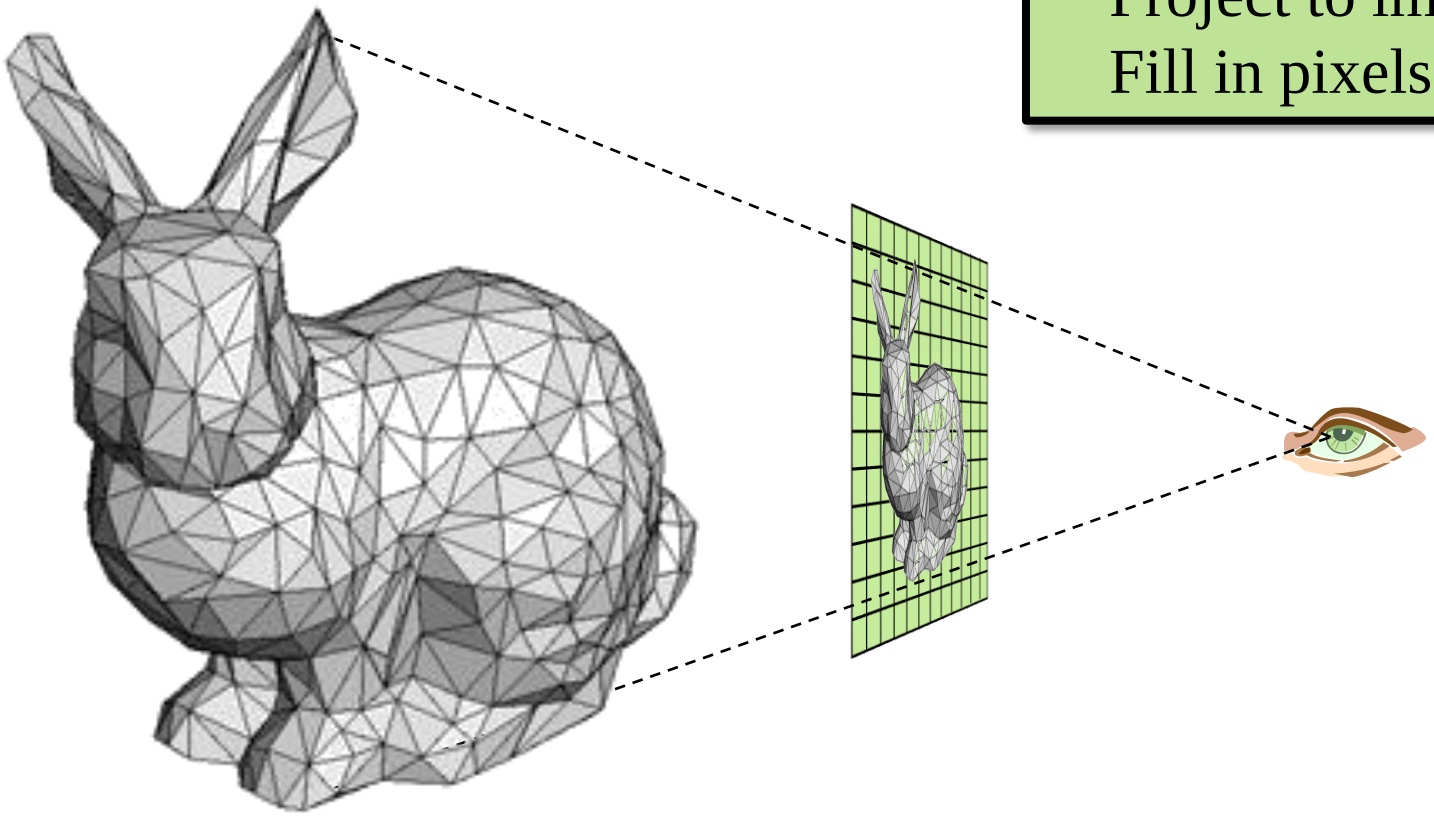






Raster Rendering

For each polygon:
- Compute illumination
- Project to image plane
- Fill in pixels



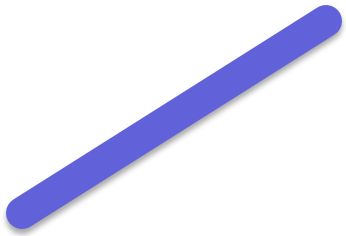
Raster Images

- (Spatial) Resolution
  - horizontal pixels x vertical pixels
- Image Aspect Ratio
  - width/height
  - HDTV = 1920/1080 = 1.78 = 16:9
- Pixel Aspect Ratio
  - (H/V) / (height/width) = (H/V) x (1/A)
  - Square pixels are 1:1
- Color resolution
  - Bits per pixel
  - 24 bpp = 8 bits red, green and blue
  - 8 bpp = 3 bits red, green, 2 bits blue

Vector v. Raster Graphics

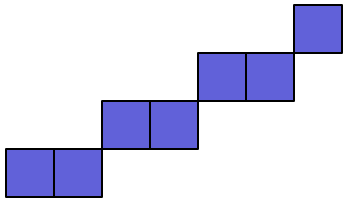
Vector Graphics

- Plotters, laser displays
- “Clip art,” illustrations
- PostScript, PDF, SVG
- Low memory (display list)
- Easy to draw line
- Solid/gradient/texture fills



Raster Graphics

- TV’s, monitors, phones
- Photographs
- GIF, JPG, etc.
- High memory (frame buffer)
- Hard to draw line
- Arbitrary fills



Getting a Line from 3-D to Screen