Vision and Color

Human Vision Influences Graphics

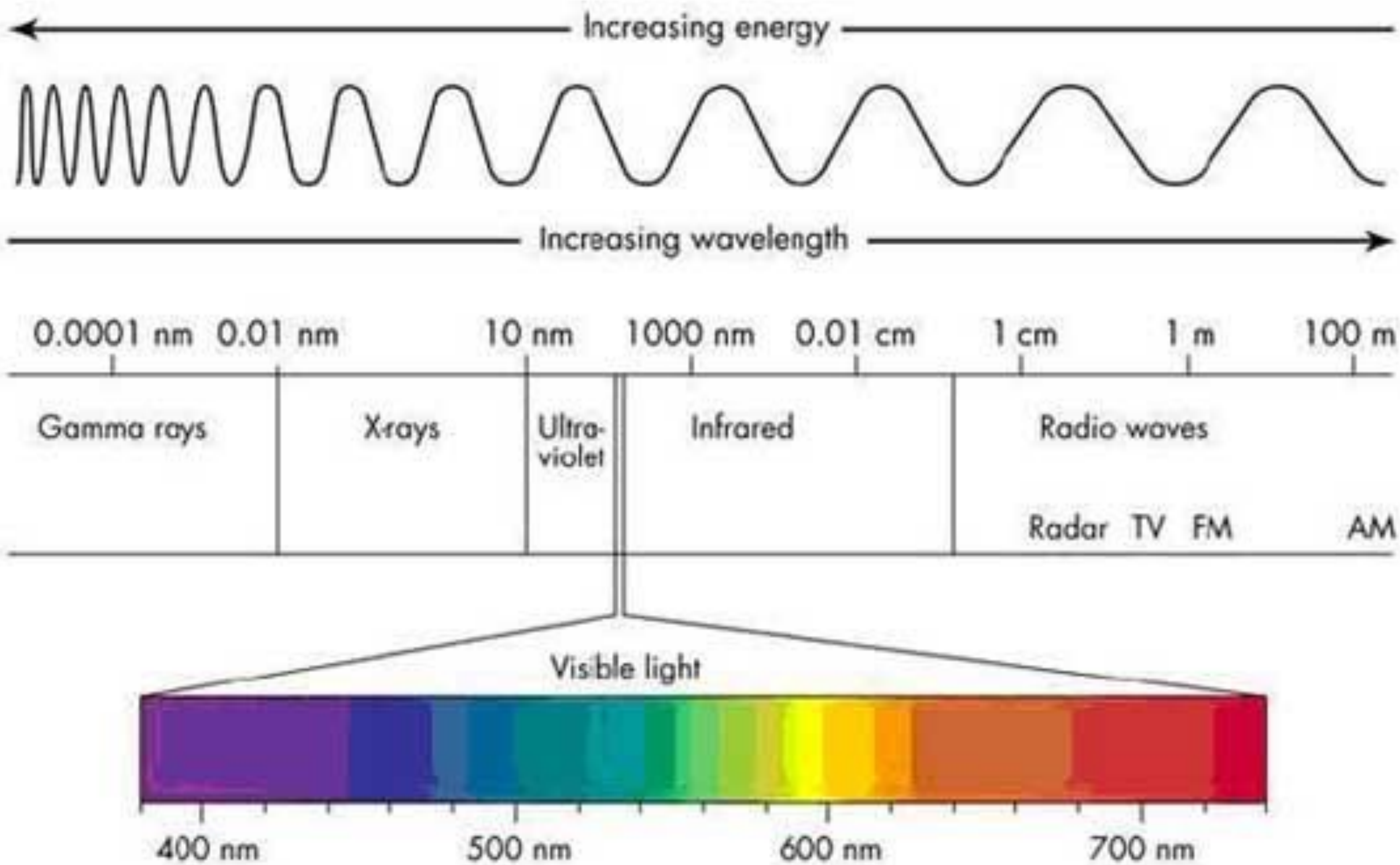
Human vision is quirky

- What we render is **not** what we see

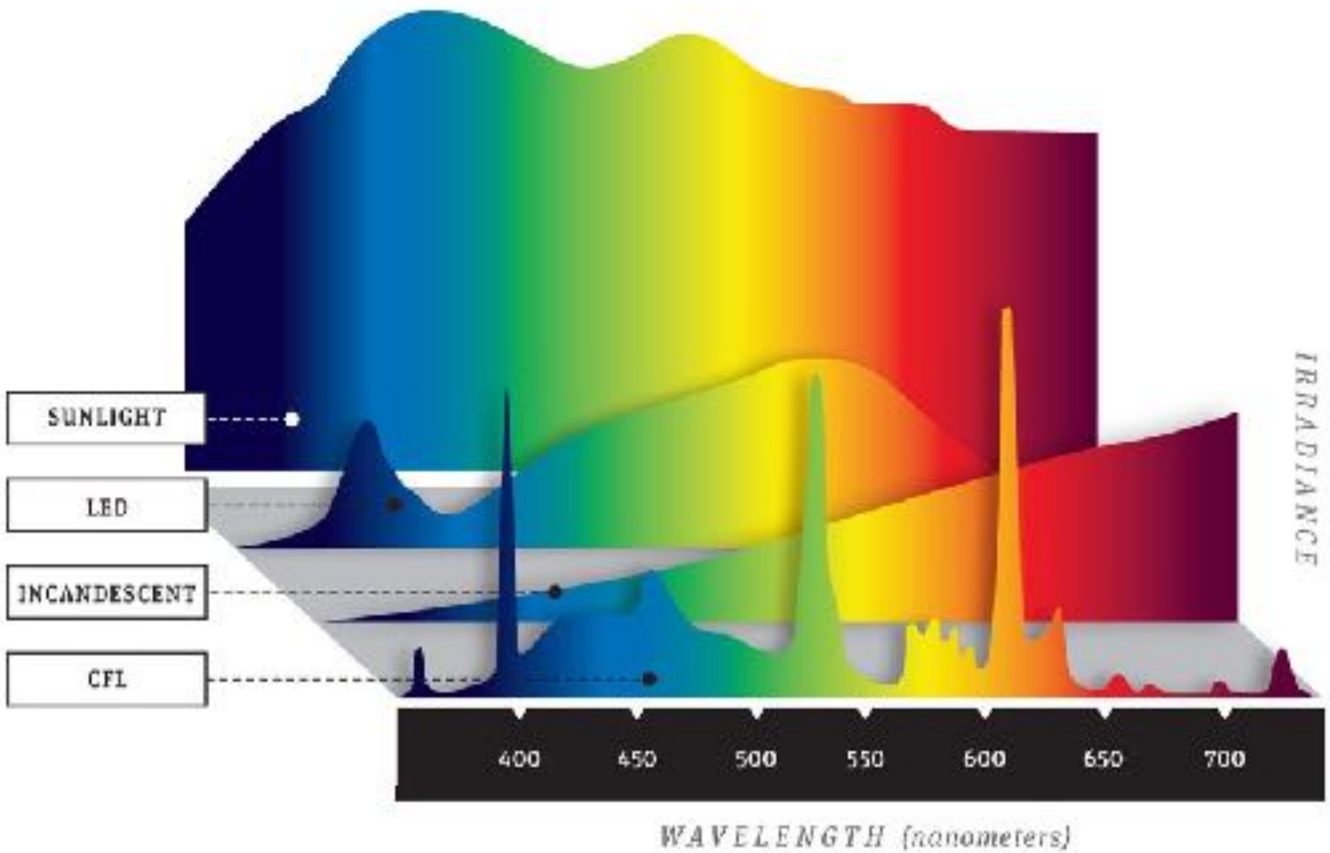
Errors (artifacts) can be more or less noticeable

- Understanding vision can help with minimizing these

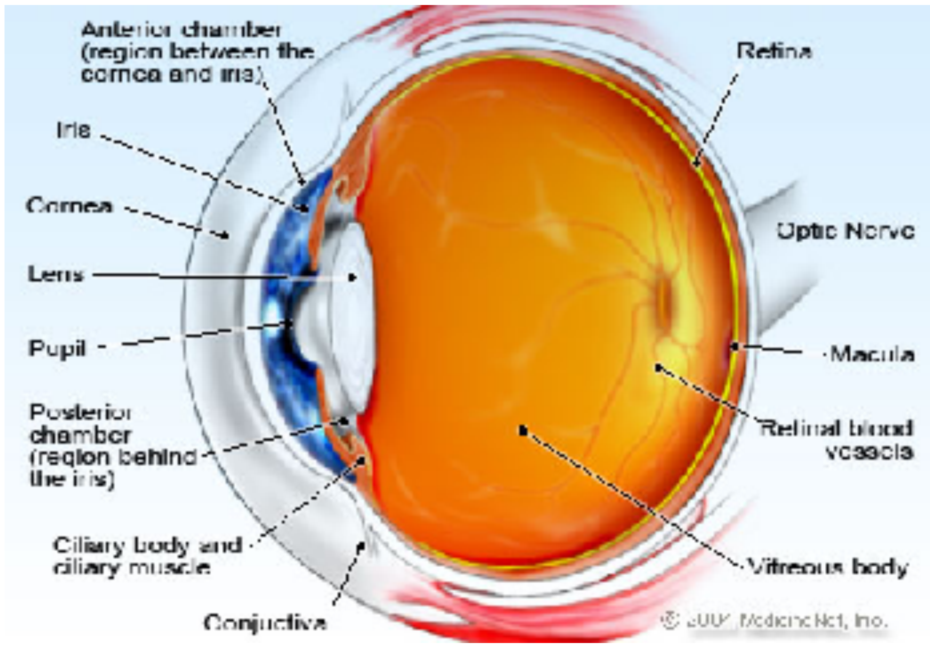
Visible Light



Spectral Power Distribution



The Eye



Light enters pupil, focused by lens, strikes retina (back of eye)

We see **blend of photons** that hit retina

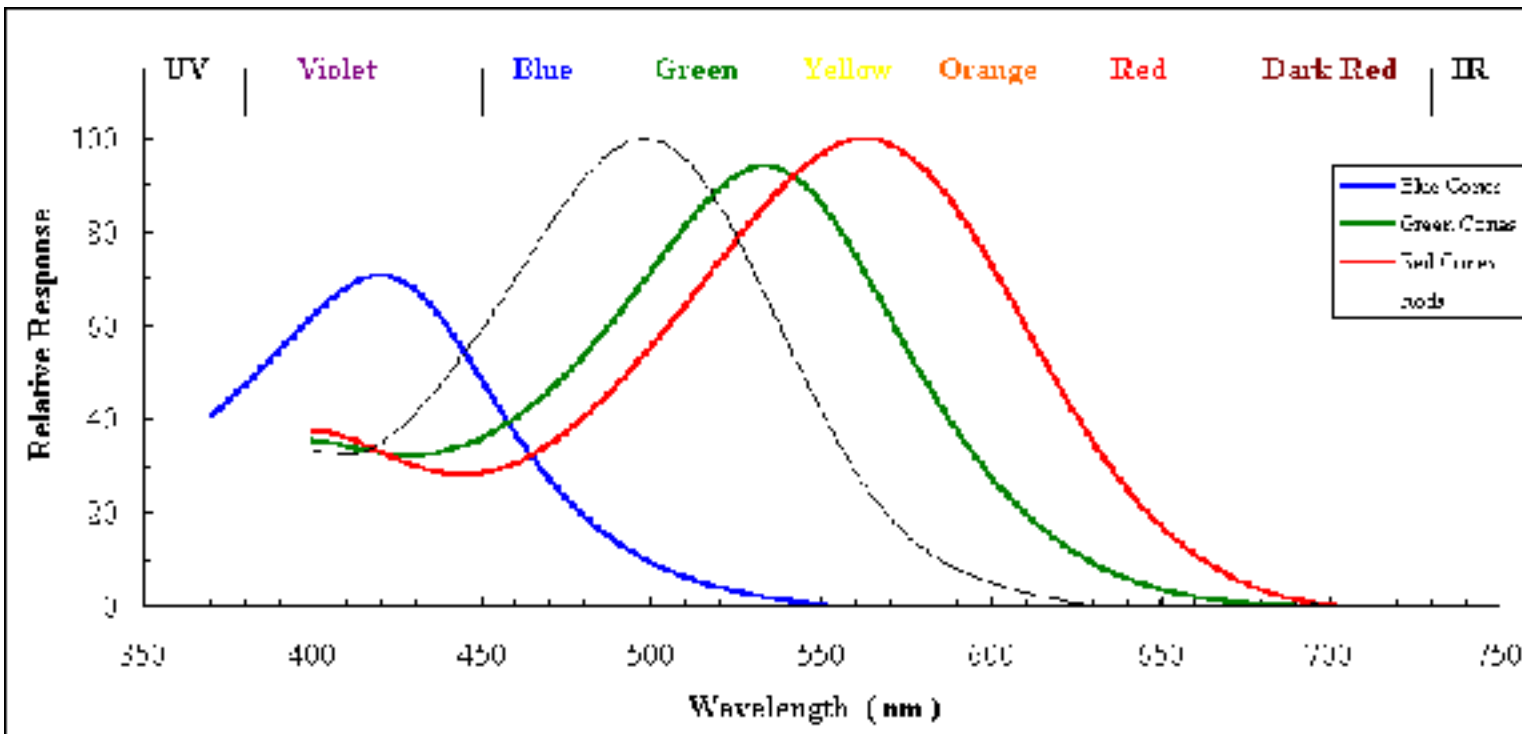
Retina

Two sensors in retina

- **cones** (4.5 million)
  - three kinds (red, green, blue)
  - work best in bright light
- **rods** (11 million)
  - monochrome
  - work in dim light

Trichromatic Vision

Each cone responds to different wavelengths

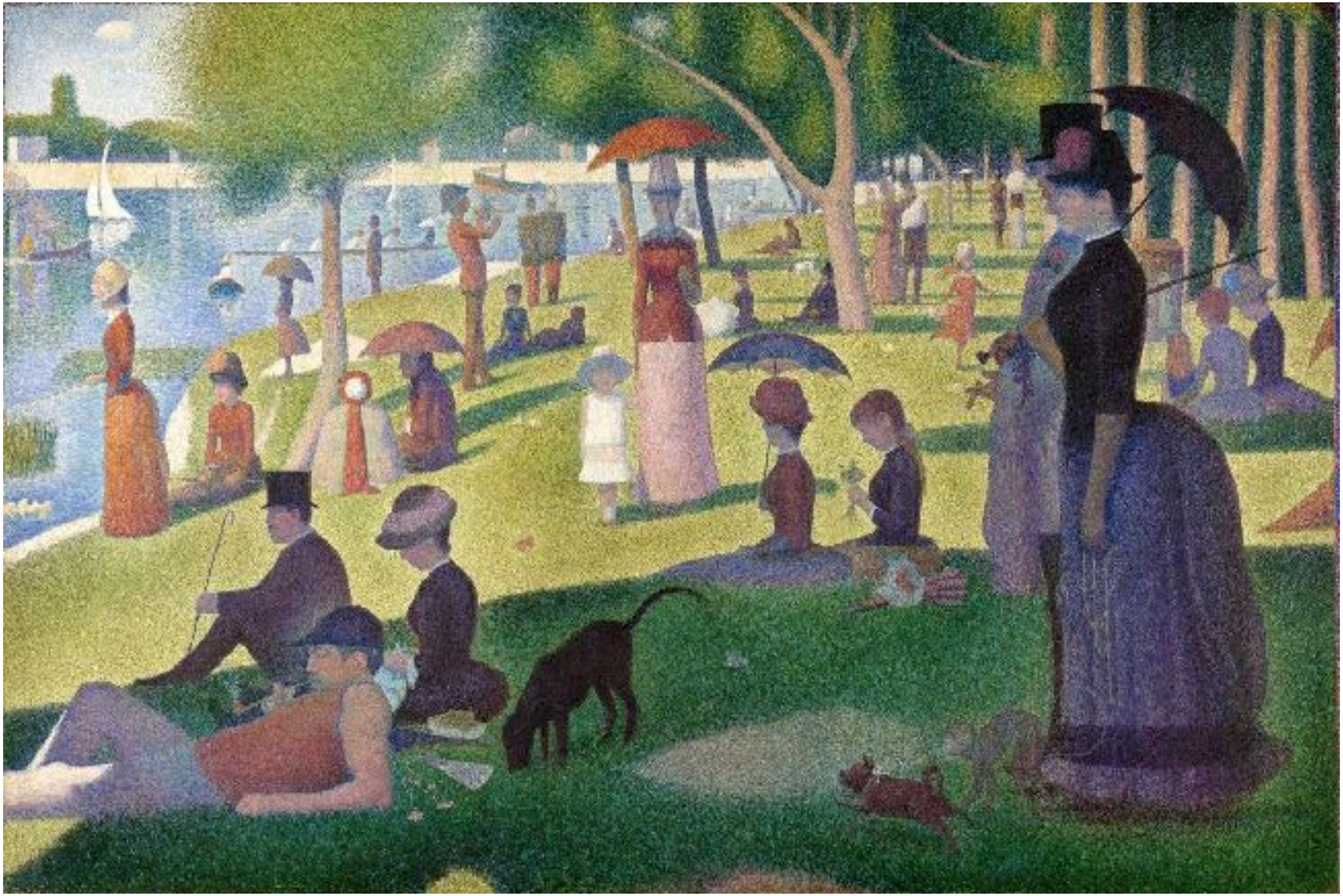


Trichromatic Vision

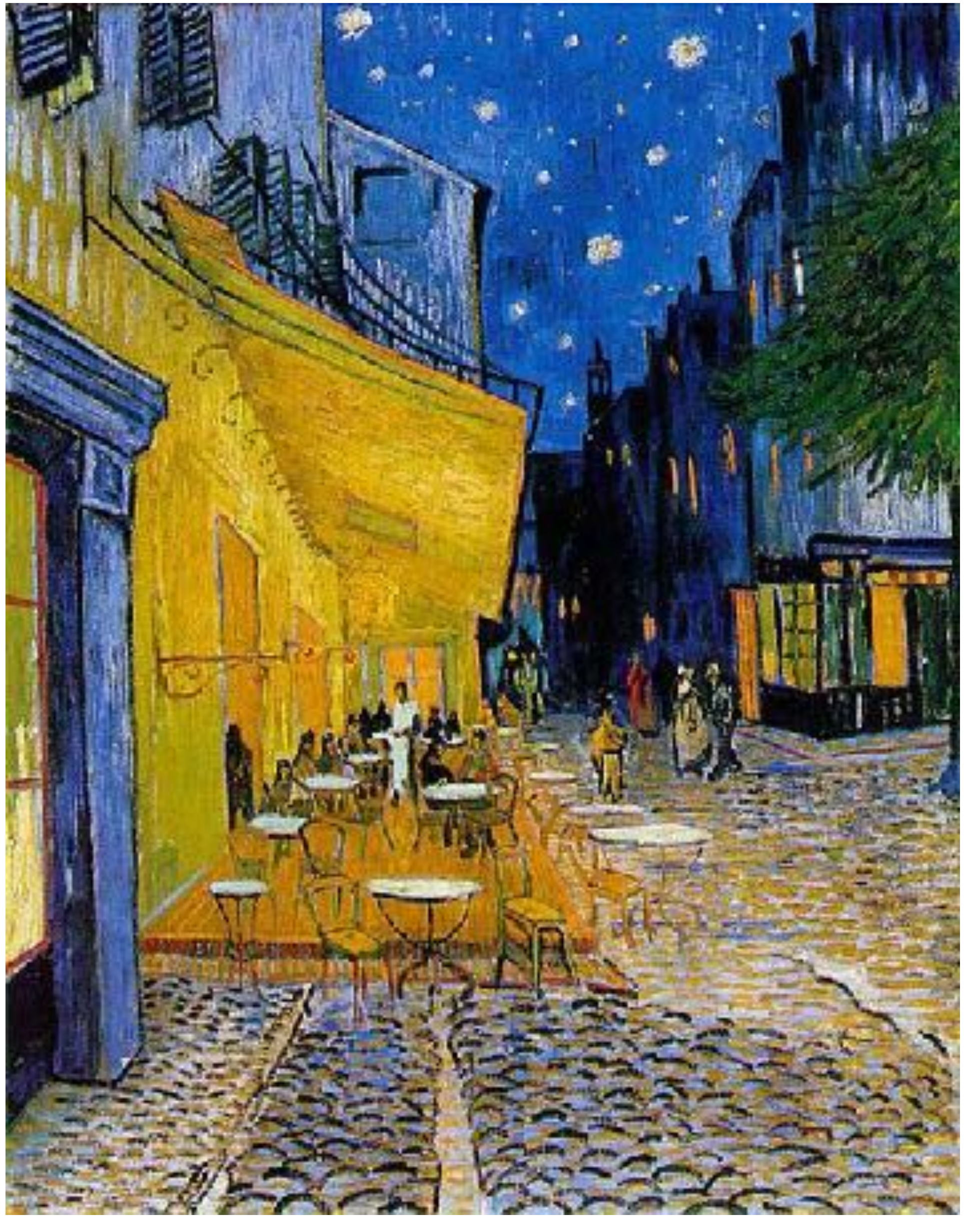
Key Point: many combinations of wavelengths **look** the same

- red & yellow blend == “pure” orange

Basis of color displays, print dithering, etc

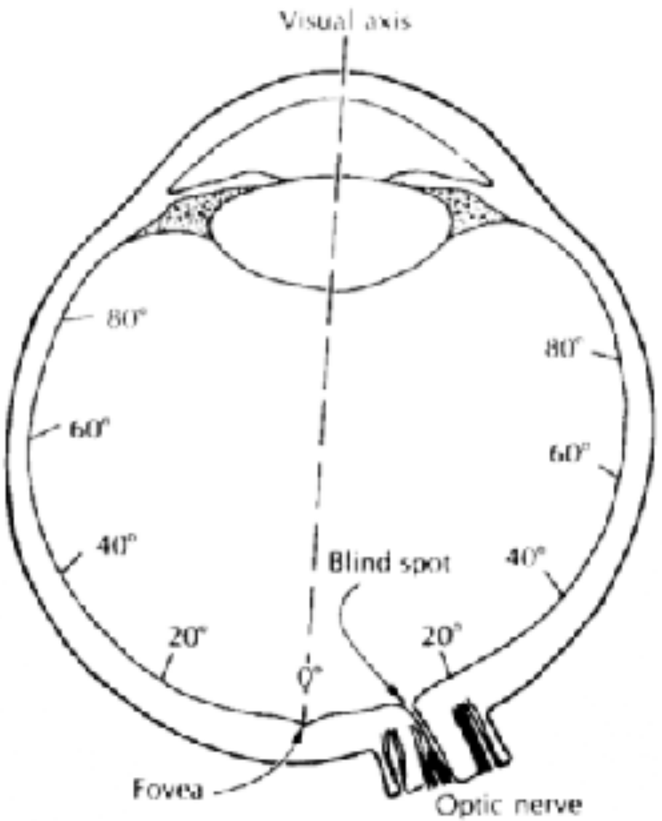


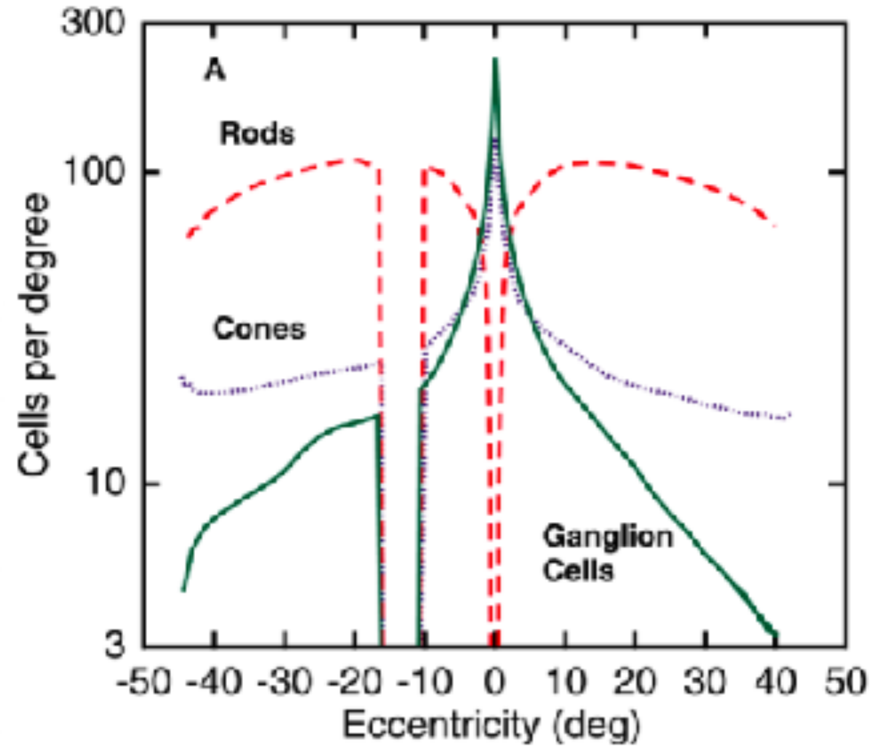
George Seurat, A Sunday Afternoon on the Island of la Grande Jatte



Vincent Van Gogh, Café Terrace on the Place du Forum

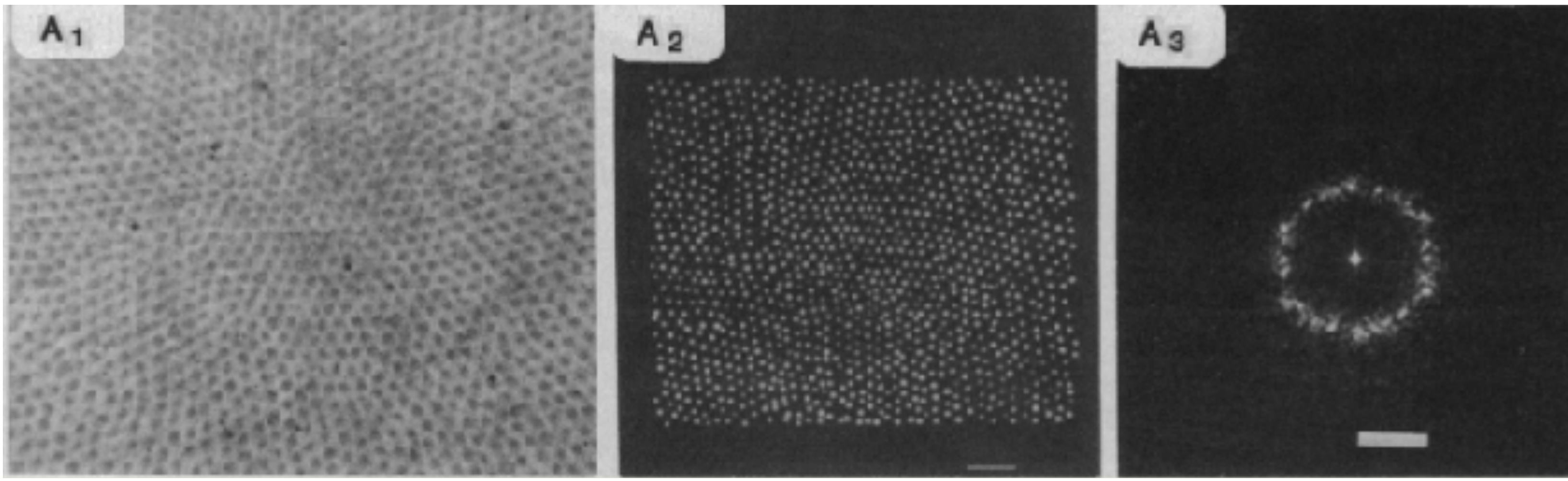
Retinal Density





Visual acuity drops off past two degrees

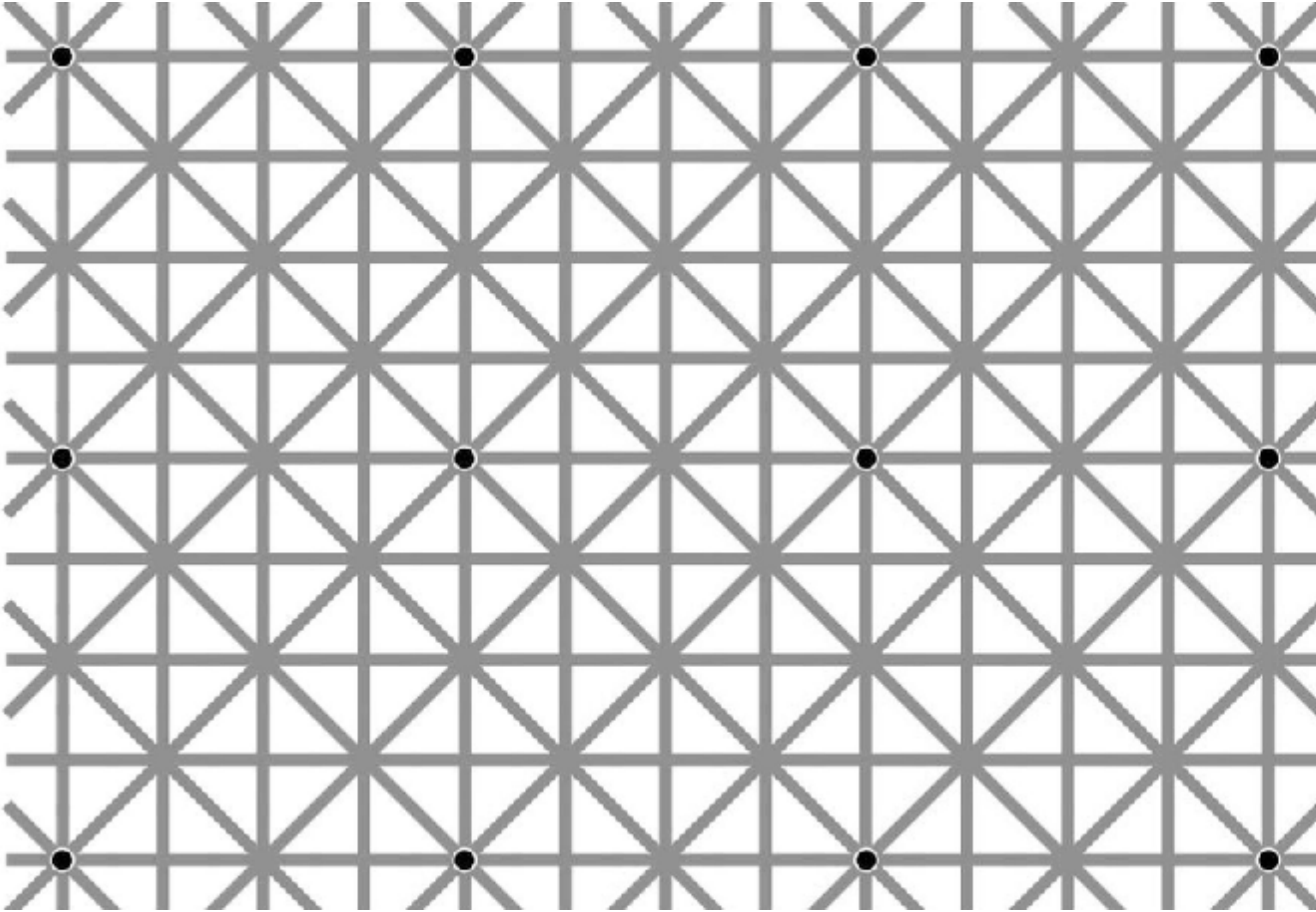
Sensor Distribution



Random, but **isotropic**

- “same in all directions”

This randomness called **blue noise**



Dealing with Limitations

Saccades: short, quick jumps

Vergence: both eyes focus on a point

Pursuit: follow moving objects

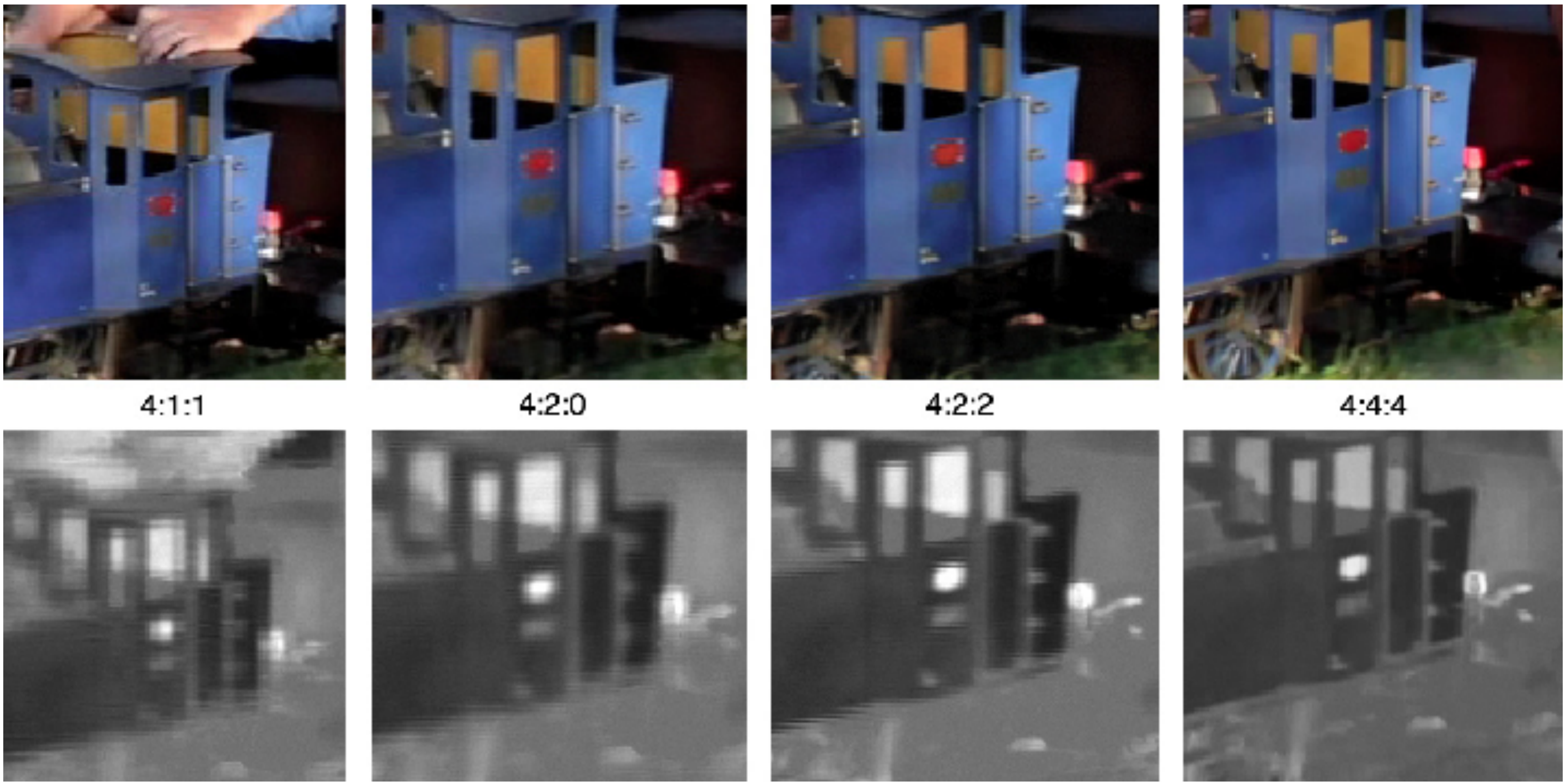
Vestibulo-ocular reflex: compensate for head motion

Chroma and Luma

luminance = “brightness”

chrominance = “color”

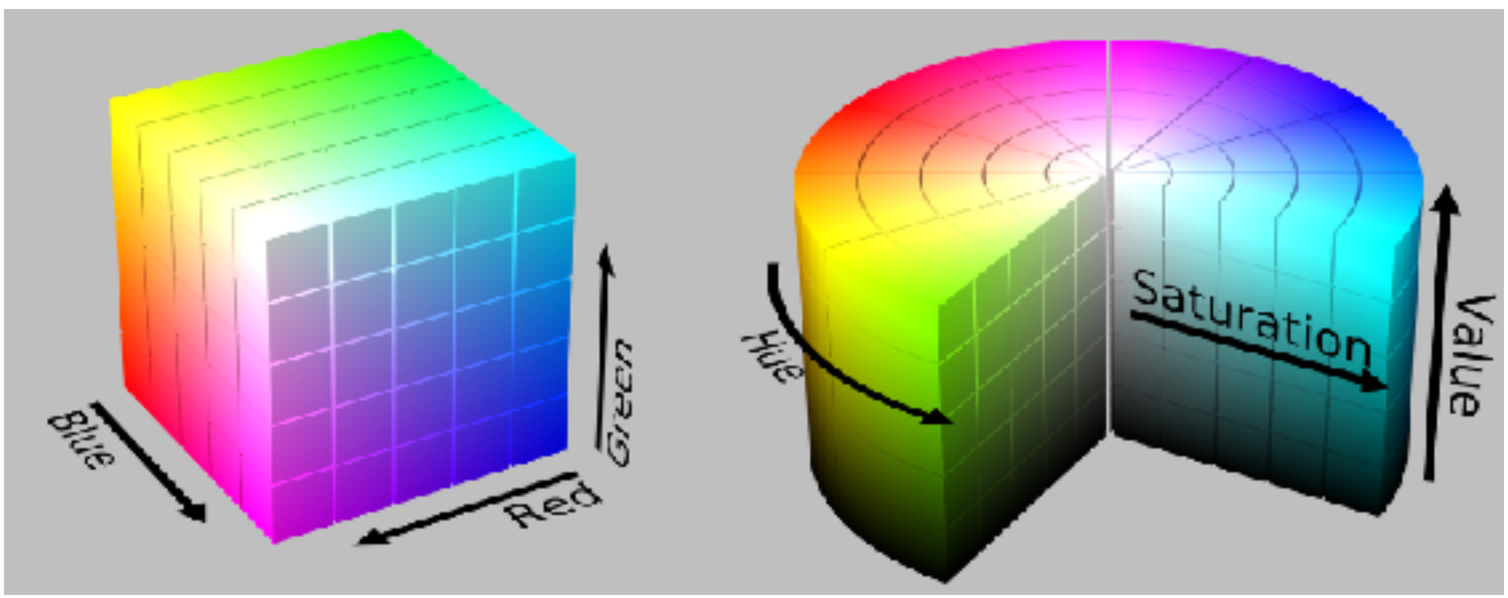
Eye Much More Luma-Sensitive



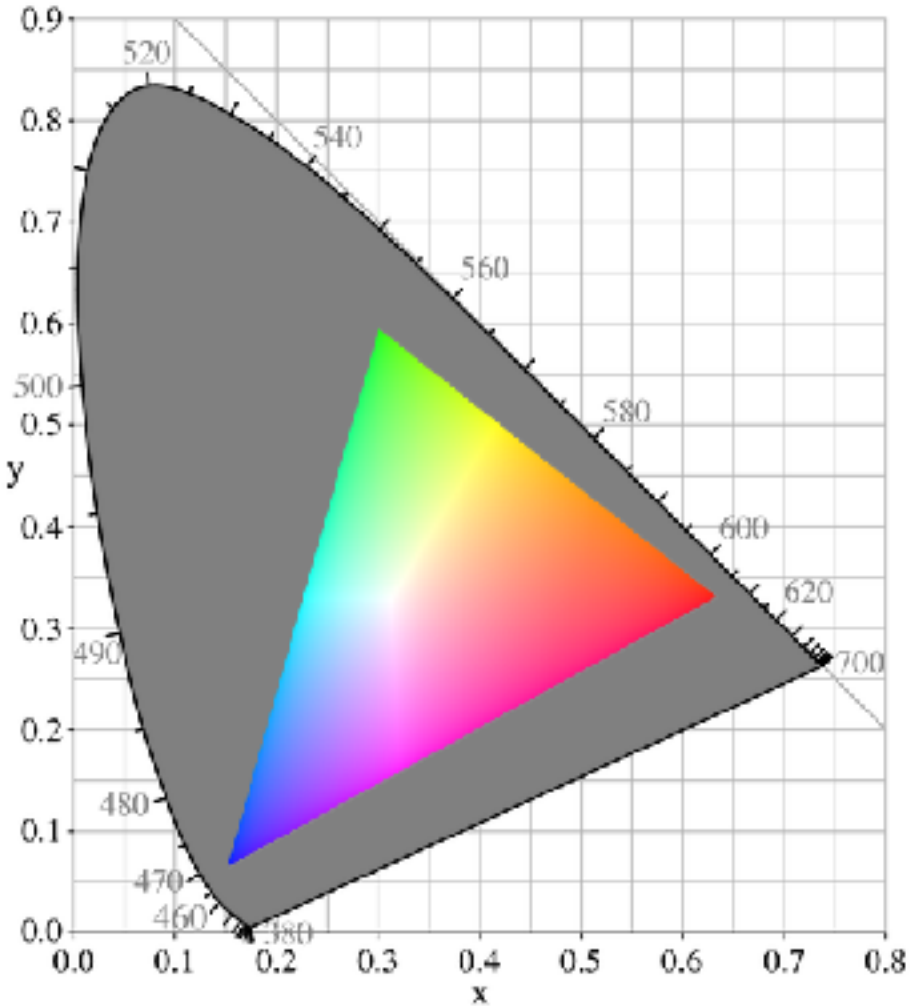
Color Spaces

Many ways to encode color

- RGB, HSV, CMYK most common



Human Visible Space



- True color can encode 16M values
- Human eye can discriminate around 10M colors
- But visible spectrum much broader than RGB…

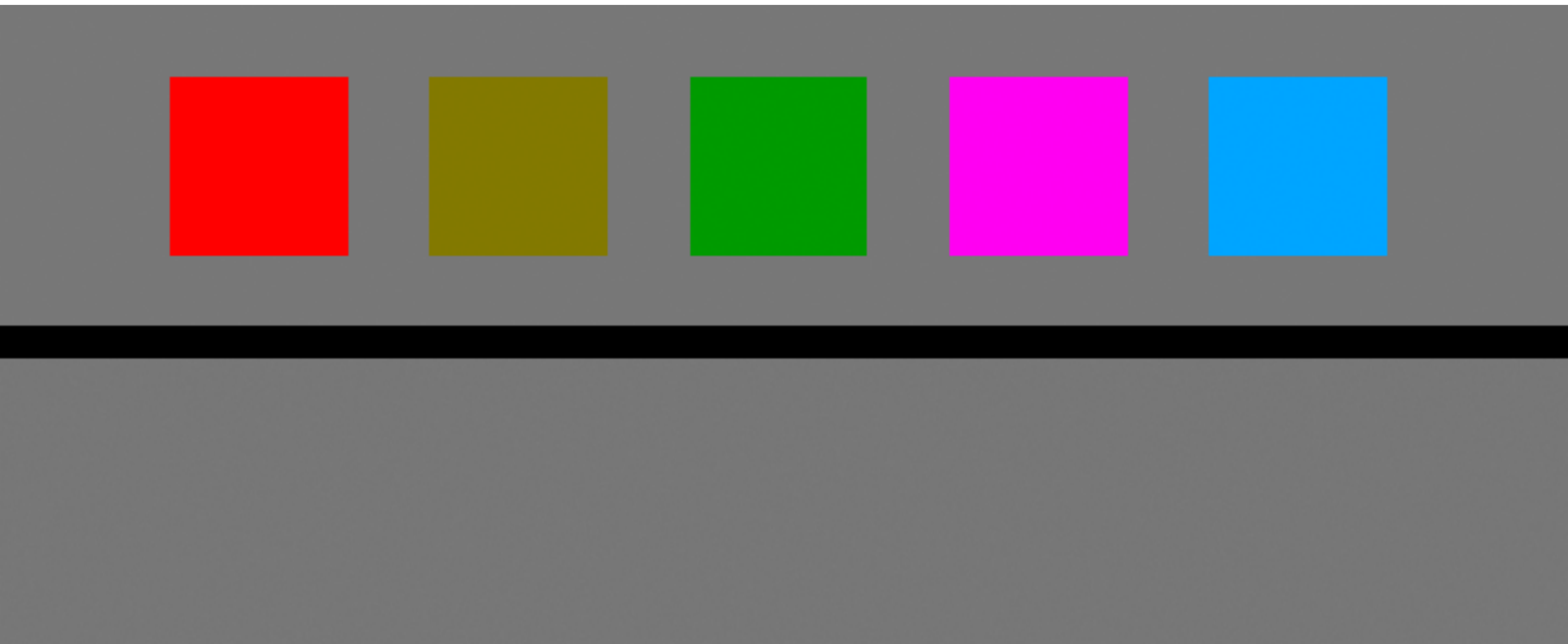
Perceptually Normalized Colors

Idea: represent colors based on how they will be perceived

- CIE 1931 color space based on empirical studies of human perception
- Lab color space describes all perceptible colors in terms of (L) light, (a) green-red and (b) blue-yellow

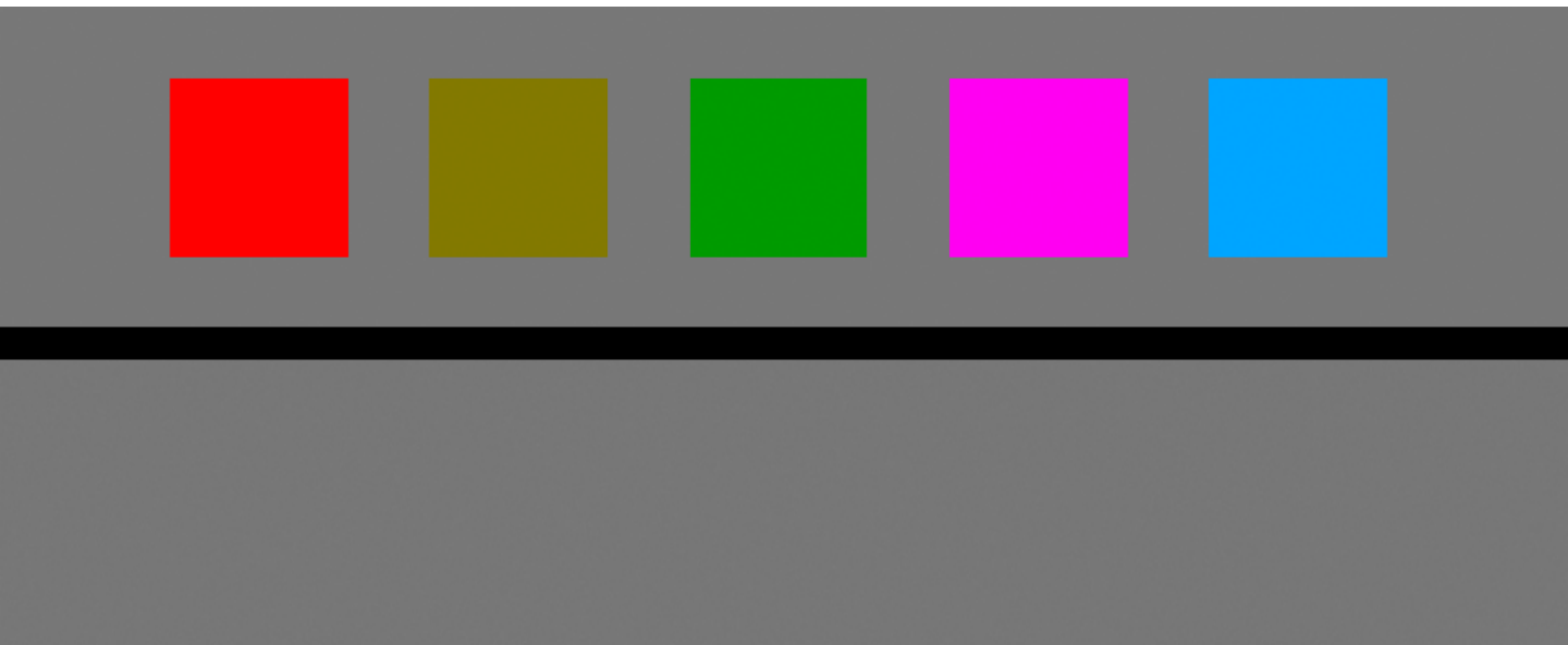
Helmholtz–Kohlrausch Effect

Which color is the brightest? (e.g. most luminance)



Same Luminance!

Humans perceive a color’s saturation as a part of its brightness



Eye FPS?

How fast can the human eye see?

Eye FPS

Anywhere between 20Hz and 200Hz

What does this imply for rendering in terms of:

- A video?
- A game?
- A VR system?

Temporal Aliasing

Same signal processing issue as with regular aliasing

- Number of frames too low wrt the speed of the object

Wagon Wheel Effect

Ganglia

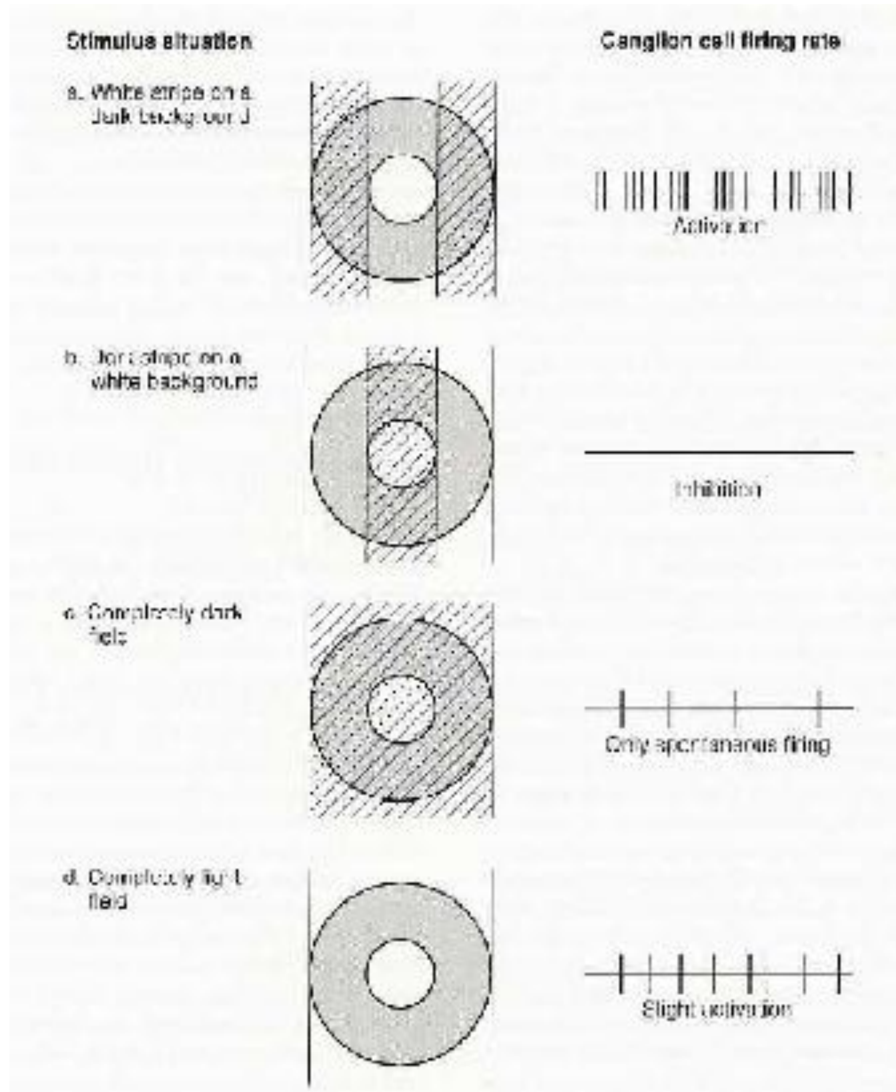
Connect rods & cones to optic nerve

- Optic nerve sends signal to brain

Perform blending of signals, and some other preprocessing before signal reaches brain

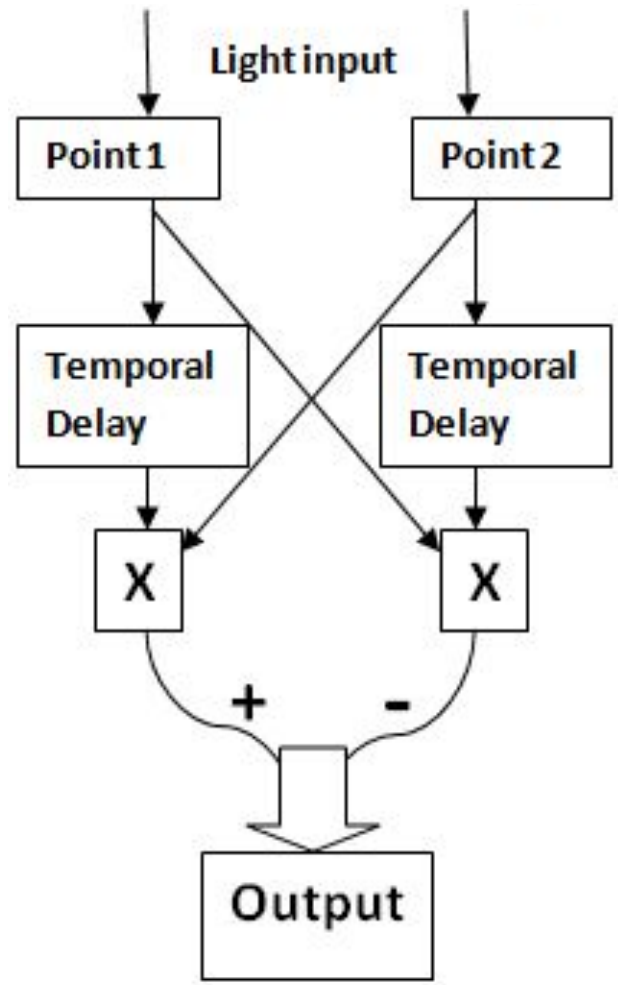
Ganglion Function

Edge detection



Ganglion Function

Motion detection



Computer Vision

“Inverse” problem to computer graphics:
  Computers must process image or video to understand content

What are some computer vision tasks?

How Can Computers See?

How Can Computers See?

Similar to ganglion!

Process scene information by breaking down signals into features and patterns

- Key concept of convolutional neural networks (CNNs)

Basic CNN Concept

- Inspired by biological neurons
- Each perceptron (neuron) applies a function to input data
- This function “classifies” the data in one of two categories
- Multiple perceptrons on multiple layers* can lead to very sophisticated forms of classification

* Deep learning refers to CNNs with a large number of “hidden” layers