Colors and Images

CS425: Computer Graphics I

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COMPUTER SCIENCE

Overview

- Colors
- Physics of light
- Perception of color
- Image formation
- Synthetic camera model

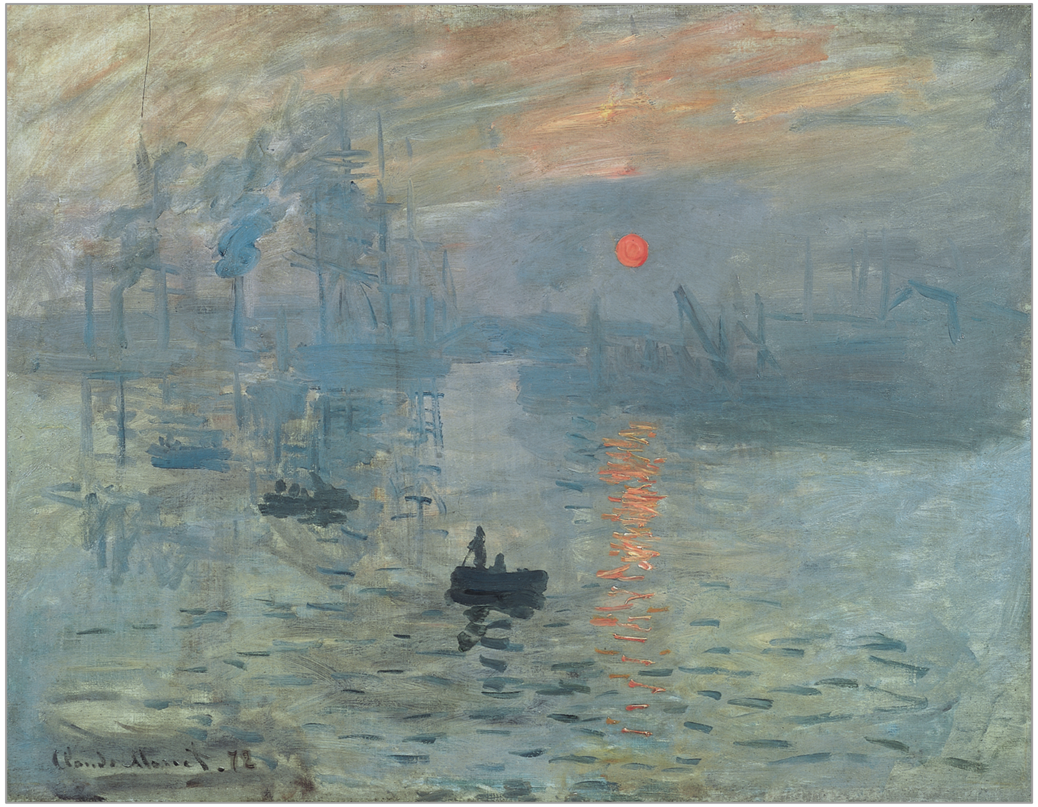
Colors

From: Wikipedia – Atishay Photography

Colors

From: Wikipedia – Terry George

Colors



Monet – Impression, Sunrise

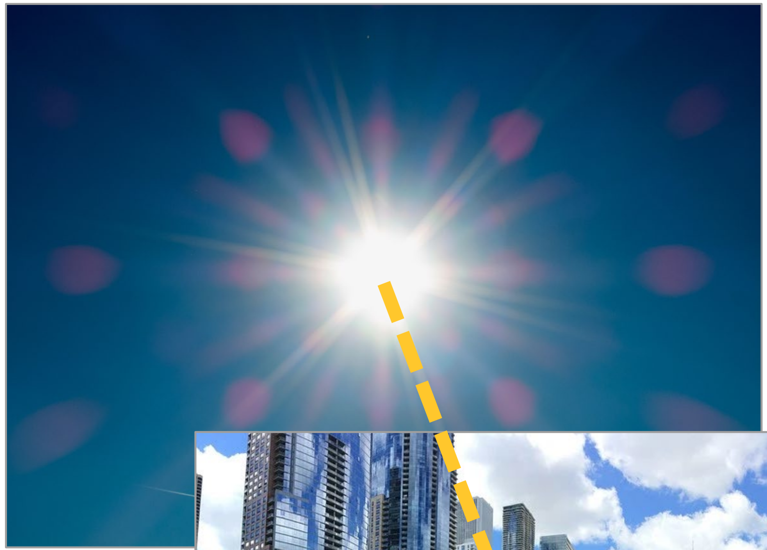
Picasso – Painting of a Lover

Color

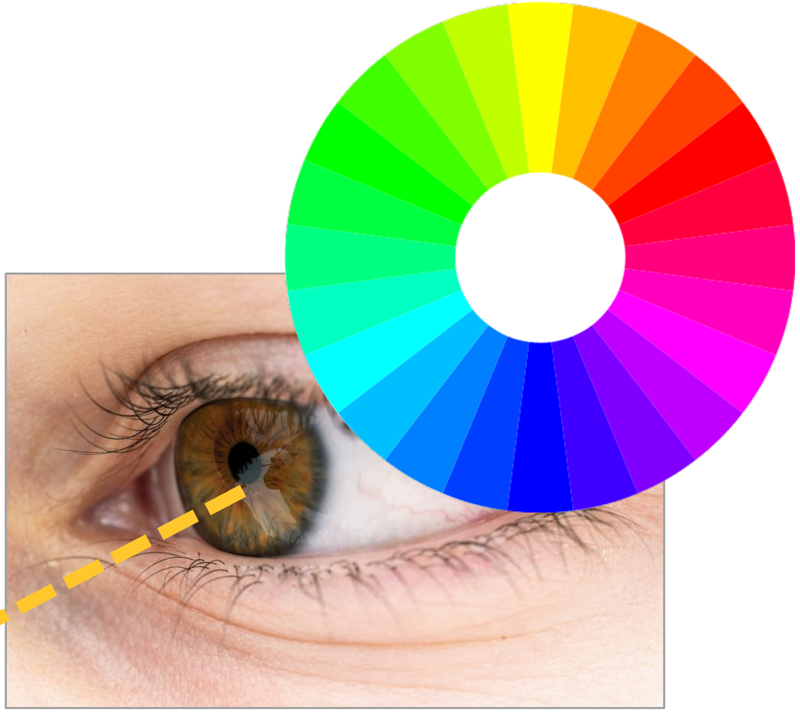
- Color is a product of visual perception.
- “Our perception of color is a purely psychological phenomenon” (Real-time Rendering, 3rd Ed.).
- **“Color is a perceptual sensation from seeing light of different spectral power distributions” (Kayvon Fatahalian).**
- Color is not a universal property of light.
  i.e., objects do not have a color

Light and color

1. Light source emits photons

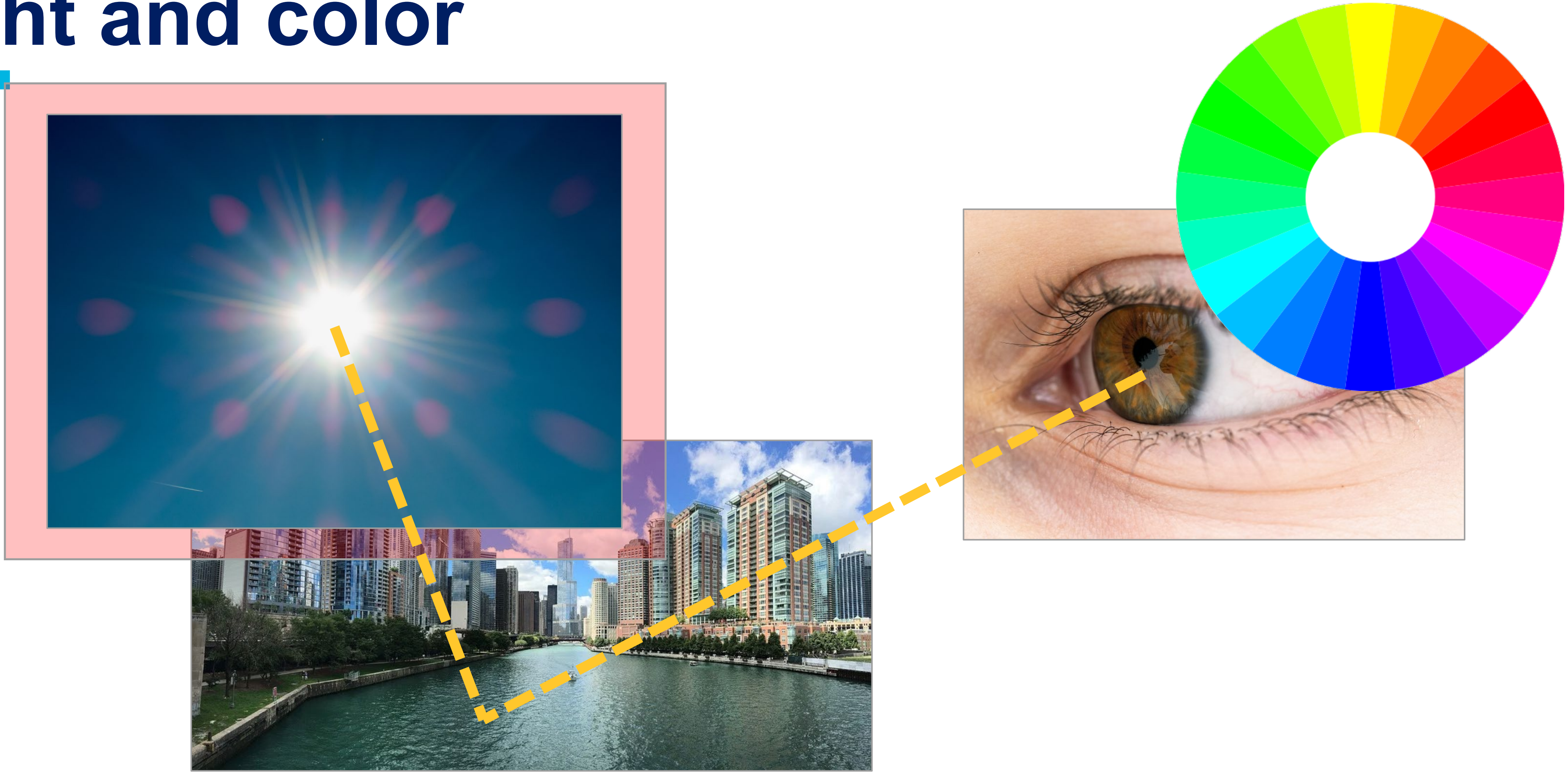


2. Photons interact with the environment: absorption, reflection



3. Some are captured by eye / camera

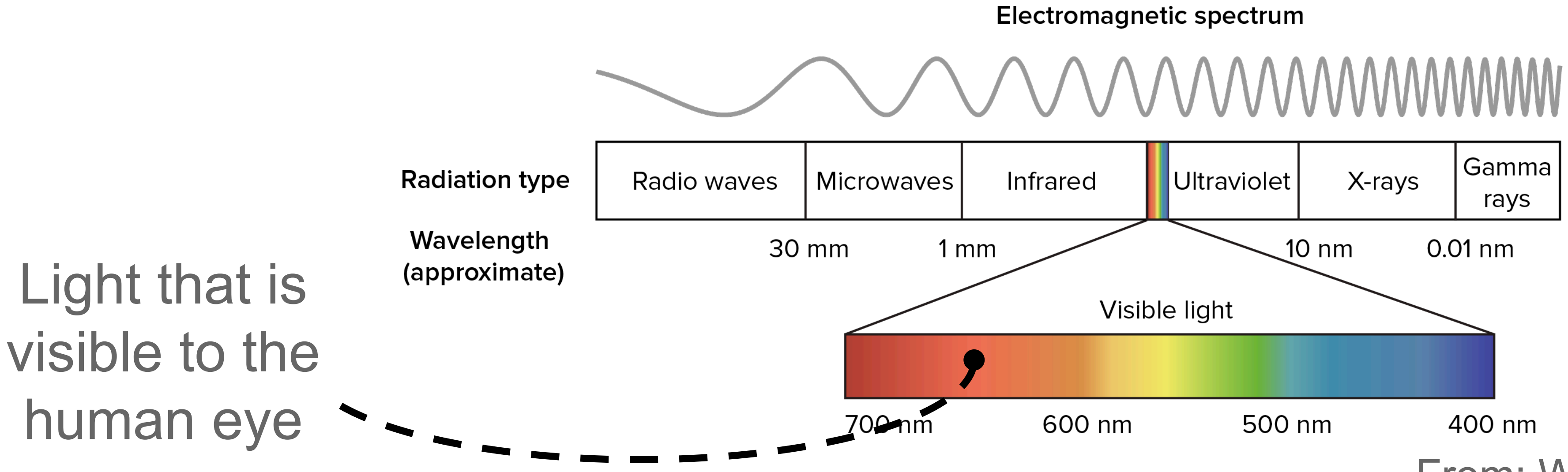
Light and color



Illumination

Physics of light

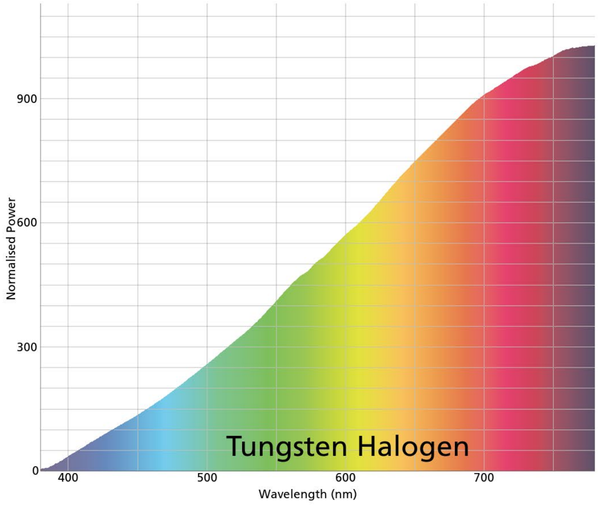
- Light: electromagnetic radiation.
- Radiometry: measurement of electromagnetic radiation.

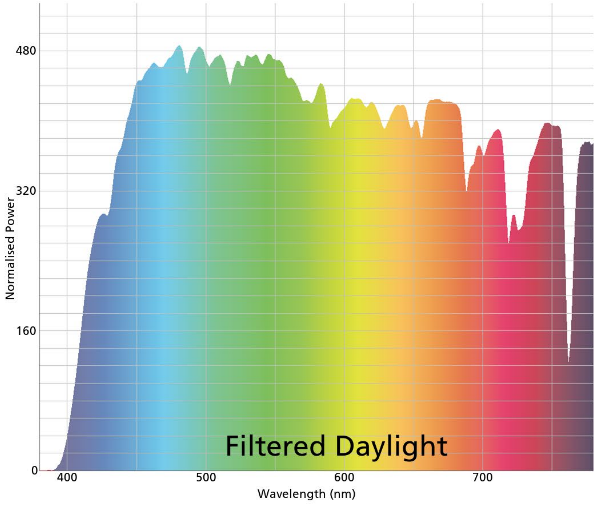


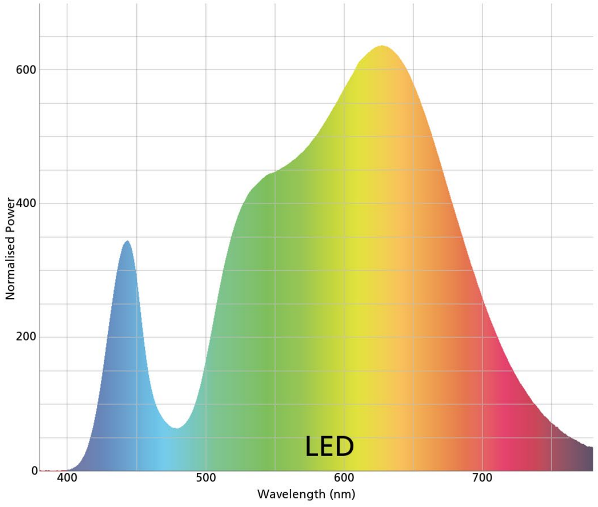
From: Wikipedia – EM spectrum

Spectral power distribution

- Amount of light energy at each wavelength.
- Fingerprint of a light source.
- Intensity as a function of frequency.

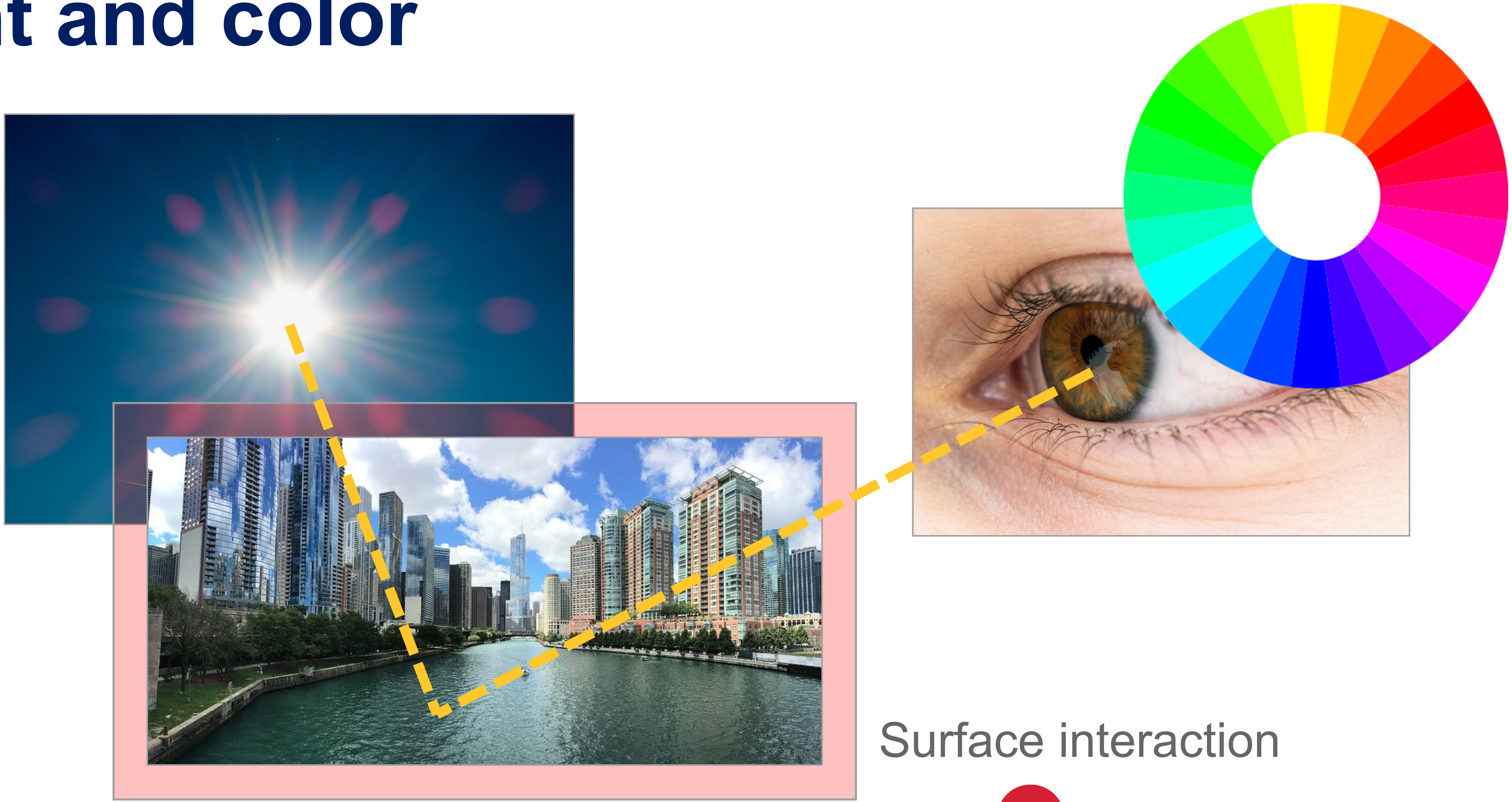






From: The National Gallery

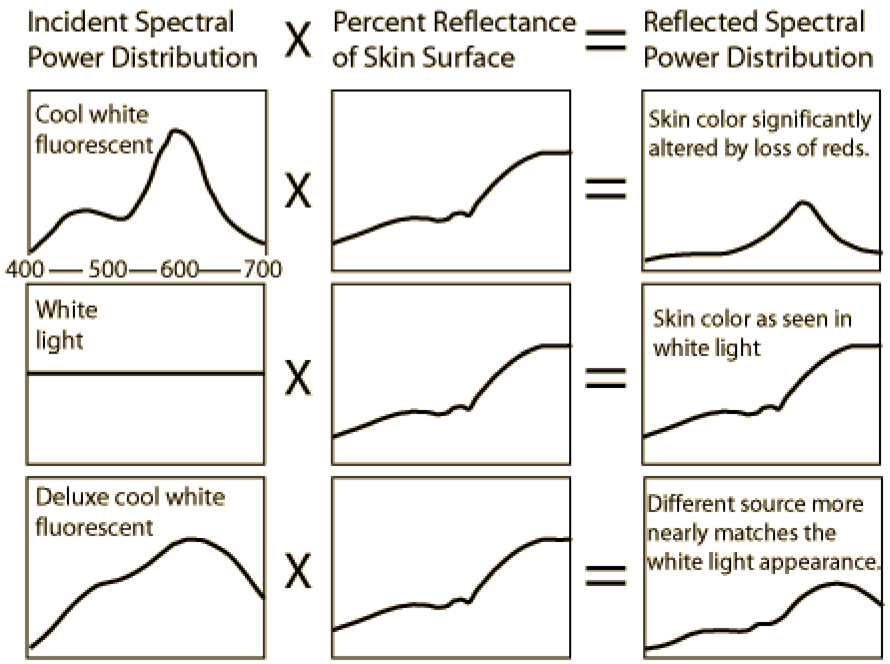
Light and color



Surface interaction

Emission and reflection

- Light reflected from a surface
- Light source emission spectrum: f(v)
- Surface reflection spectrum: g(v)
- Intensity: f(v)g(v)

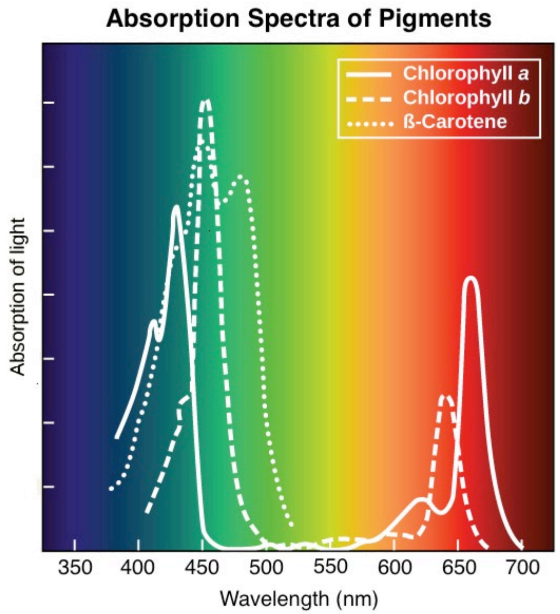


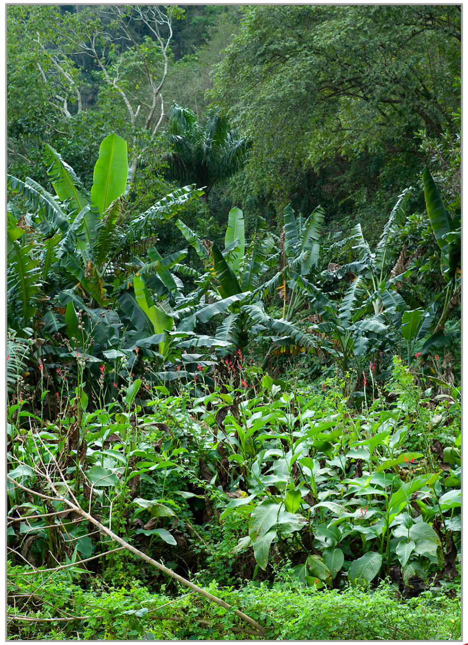
After Williamson and Cummins

UIC COMPUTER SCIENCE

Absorption spectrum

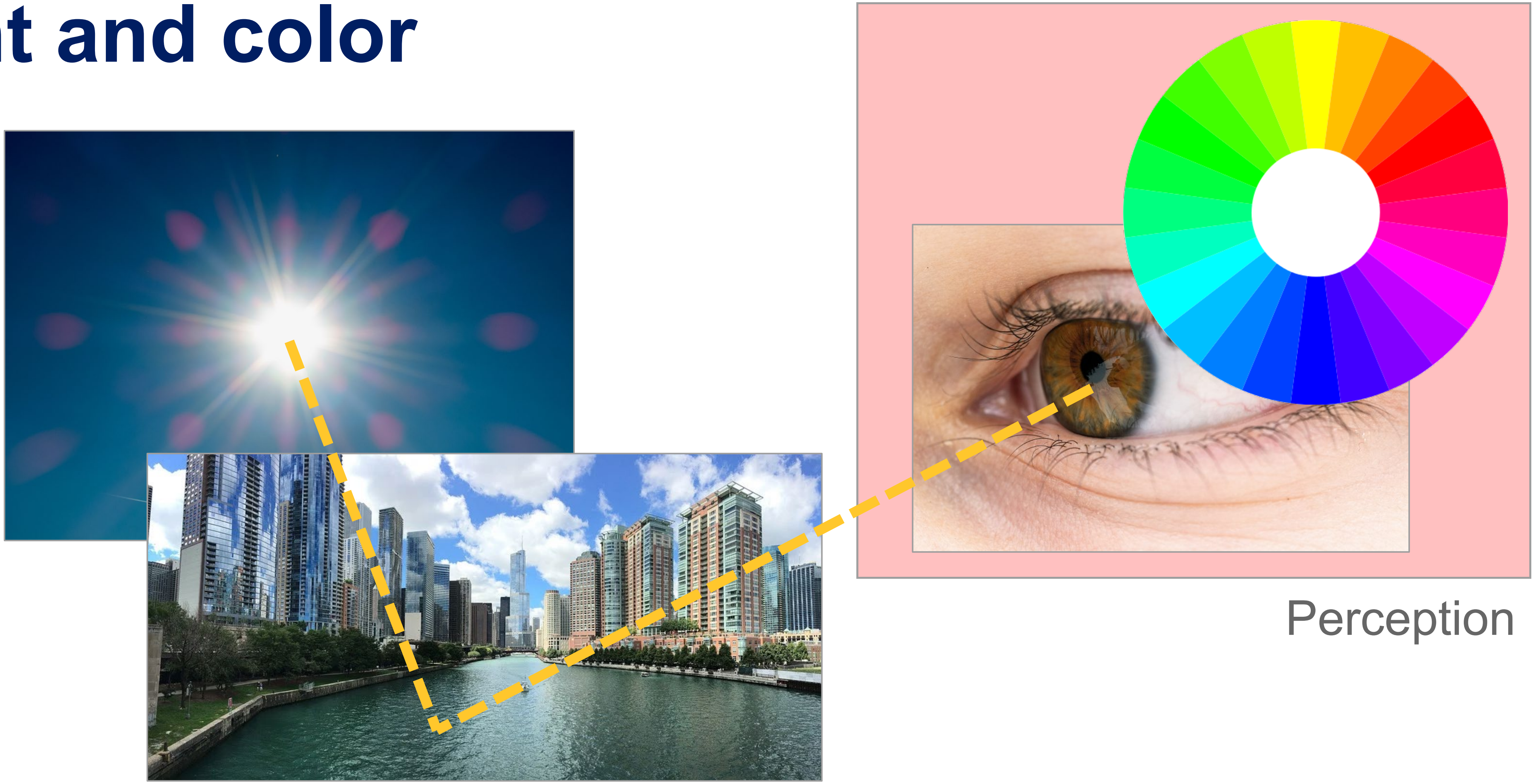
- Wavelength absorbed by object.
- Fraction absorbed as function of frequency





From:
CNX.org
Wikipedia - Frankemann

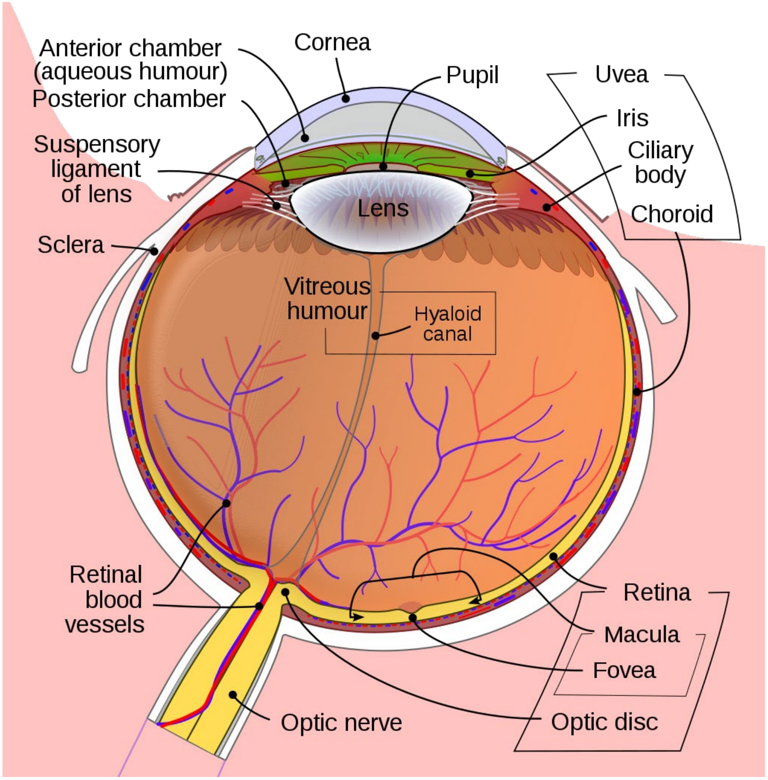
Light and color



Perception

Perception of color

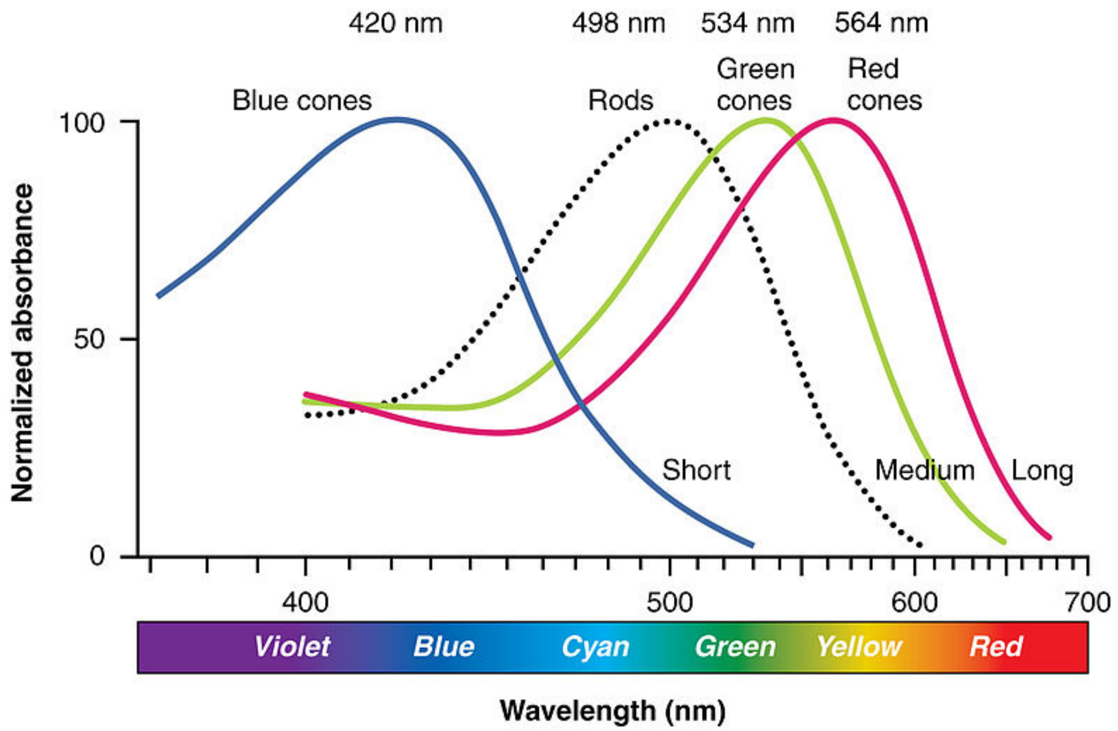
- Humans can distinguish about 10 million different colors.
- Three different types of cone receptors in the retina. Each receptor responds differently to various wavelengths.
- The brain receives three different signals.



From: Wikipedia – Human Eye

Perception of color

- Spectral curves of the short (S), medium (M), and long (L) wavelength pigments in human cone.

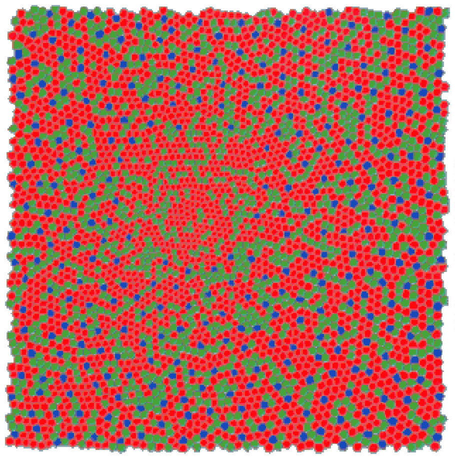


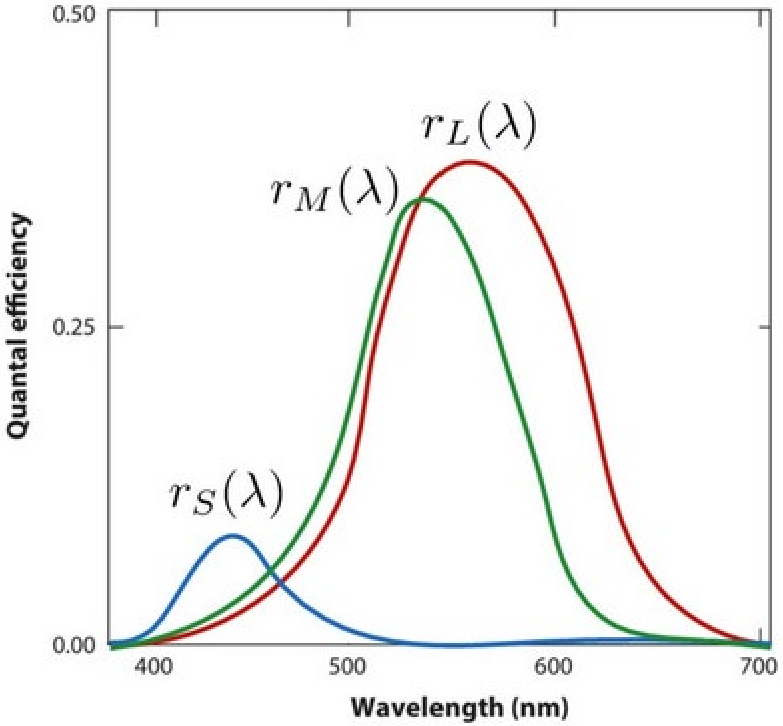
Perception of color

- 6-7 million cones:
  - 64% red
  - 32% green
  - 2% blue

"However, the blue sensitivity of our final visual perception is comparable to that of red and green, suggesting that there is a somewhat selective "blue amplifier" somewhere in the visual processing in the brain. "

HyperPhysics, Georgia State

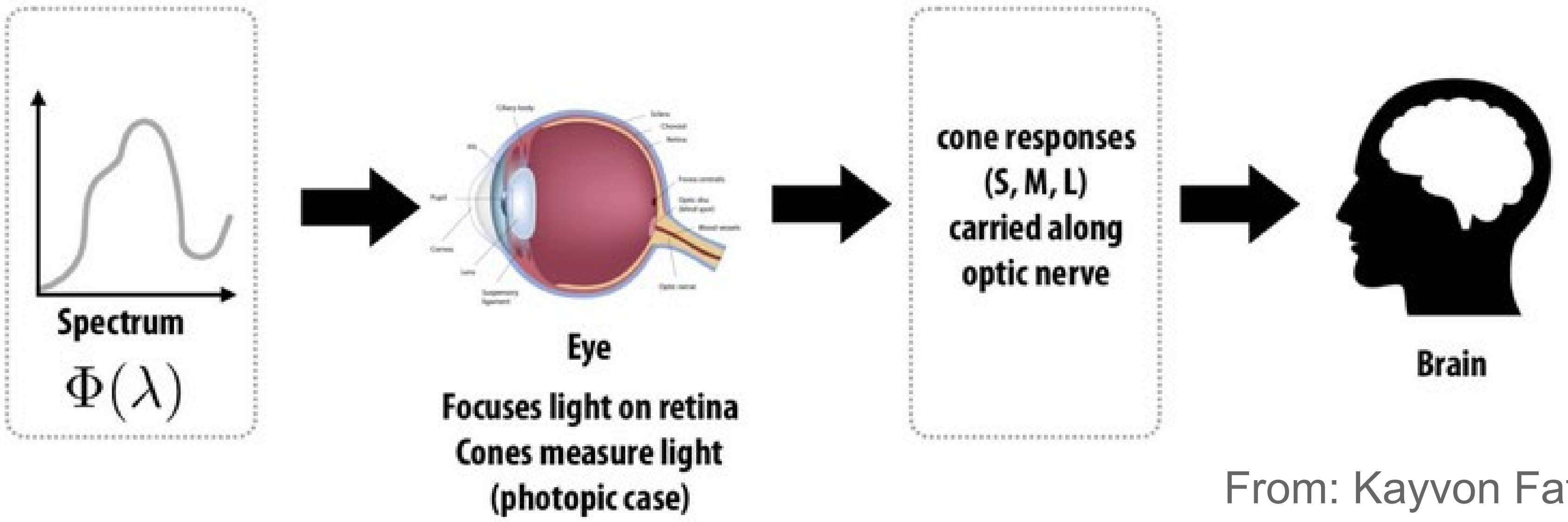




Brainard, Color and the Cone Mosaic, 2015.

Perception of color

- The brain receives only the response of three values (S, M, L).



From: Kayvon Fatahalian – Interactive Computer Graphics

Color blindness

“People with normal color vision have all three types of cone/pathway working correctly but color blindness occurs when one or more of the cone types are faulty” (Colourblindawareness.org)

Normal vision

Deuteranopia

Tritanopia

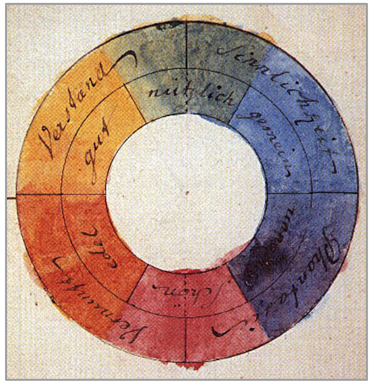
Color theory

Opticks **(1704) by Isaac Newton:** white light is a combination of all colors across the spectrum.

Additive approach: darkness is the absence of light.

Theory of Colors **(1810) by Wolfgang von Goethe:** dark light is a combination of all colors.

Subtractive approach: whiteness is the absence of light.



From: Programmingdesignsystems.com

Color theory

***Opticks* (1704) by Isaac Newton:**

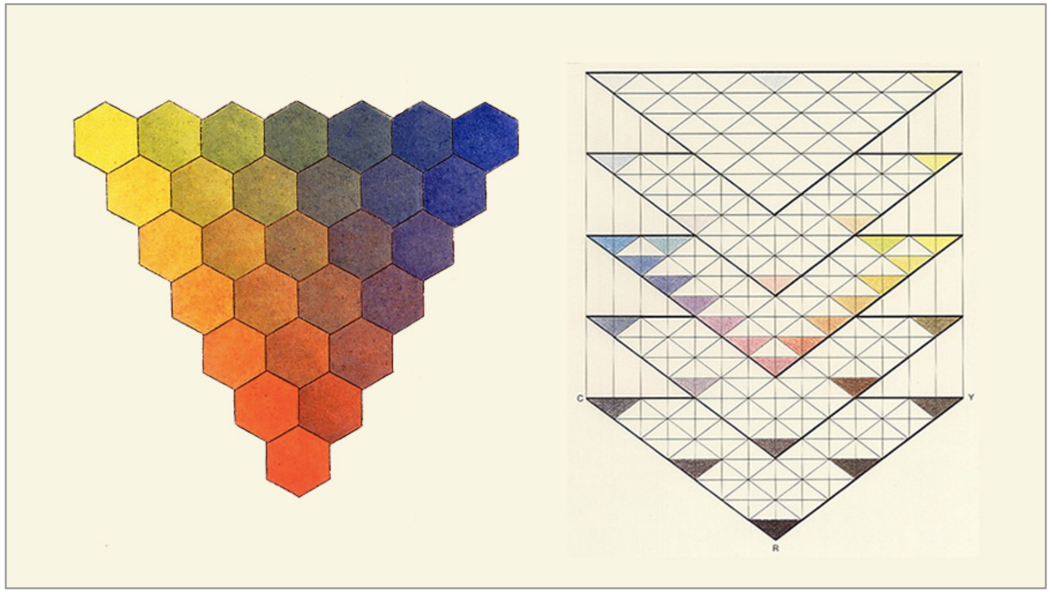
Light mixes in an additive way, i.e., combining light of different colors will result in white light.

***Theory of Colors* (1810) by Wolfgang von Goethe:**

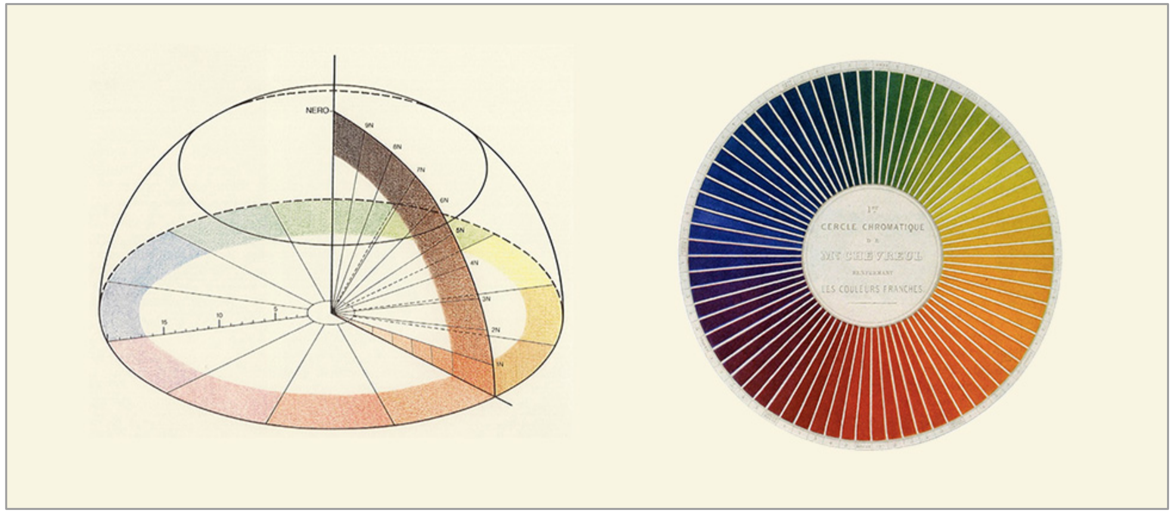
Pigments mix in a subtractive way, i.e., combining paints of different colors will eventually result in black paint.

Color solids

Unified notation for color: proposal of color spectrum as 3D solids



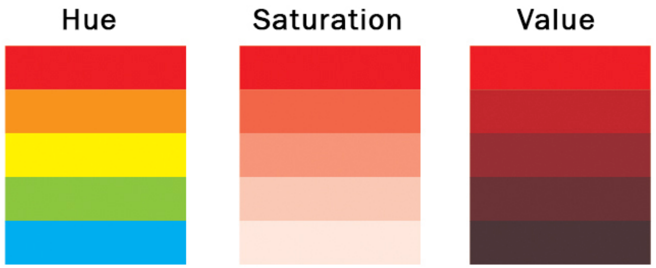
Tobias Mayer's color triangles

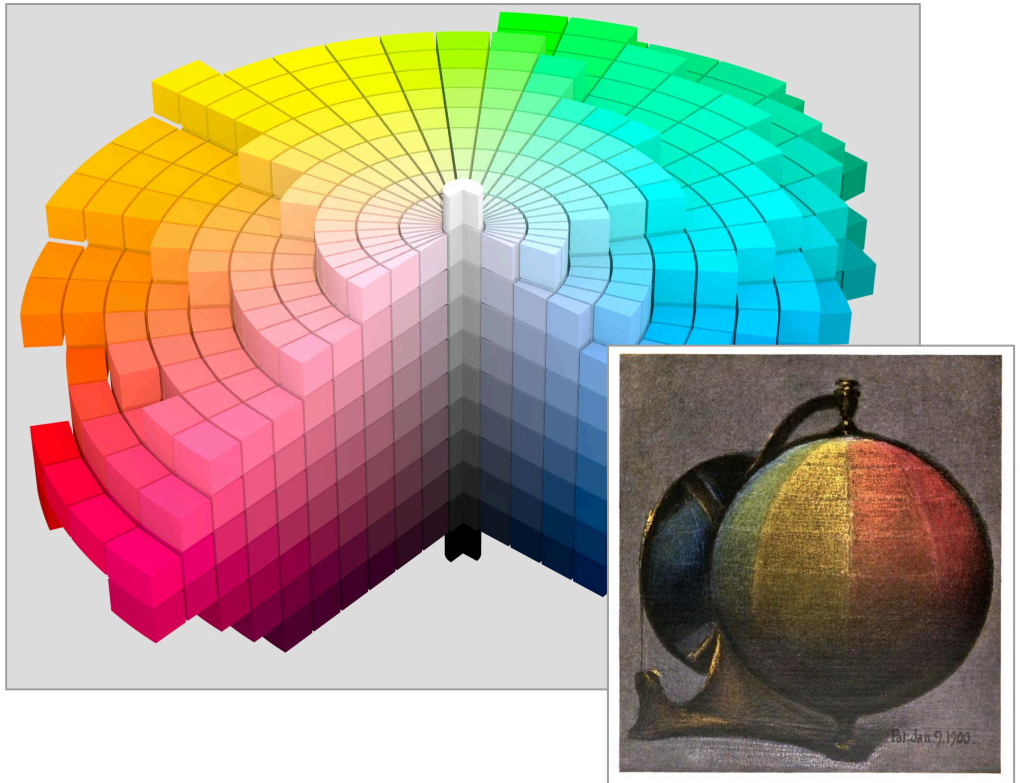


Philipp Otto Runge's color sphere

Munsell color system

- Three independent properties of color: hue, chroma/saturation, value.
- Mathematical syntax over color names.
- Perceptually uniform: a change of length x in any direction of the color space would be perceived by a human as the same change.





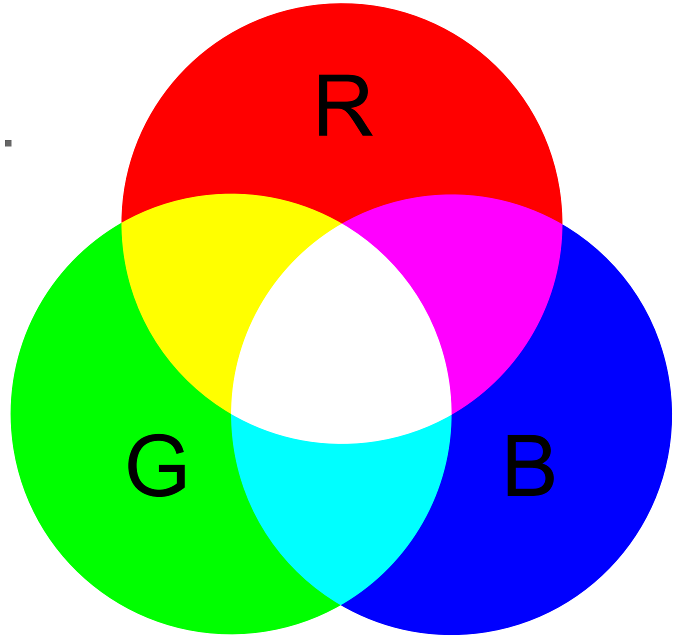
A BALANCED COLOR SPHERE

Color models

- Description of how colors can be represented as a combination of numbers.
- Combination of how many numbers?
    - Three: RGB, HSV, HSL color models
    - Four: CMYK

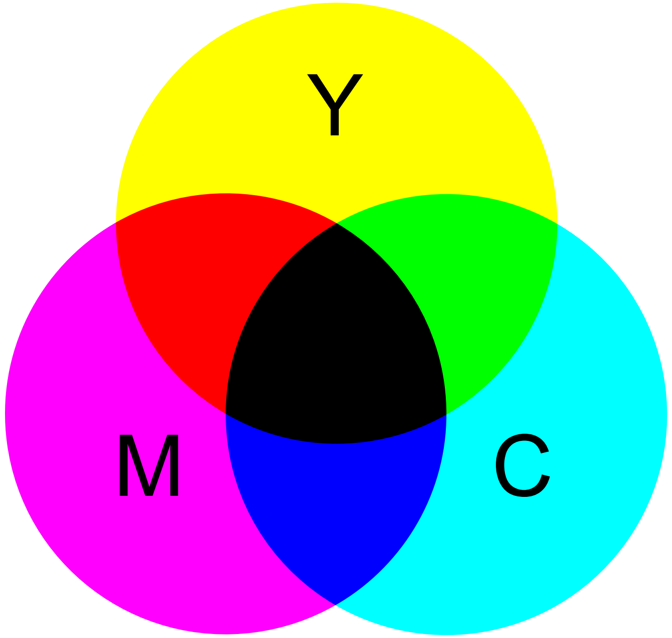
RGB color model

- Additive color model: combination of red, green, and blue.
- Overlap of three light beams.
- Based on the cone cells of the human retina.
- Common in display devices.



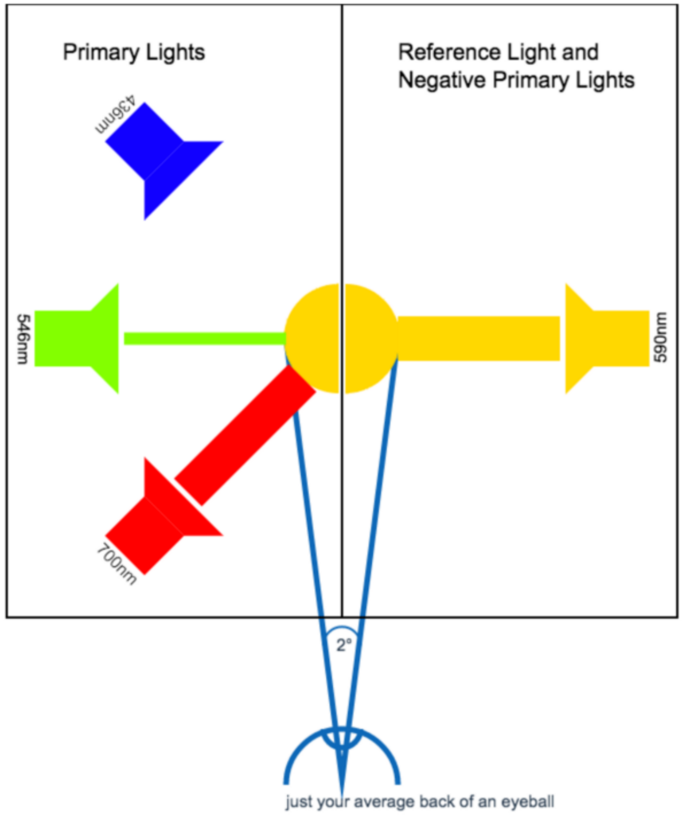
CMY color model

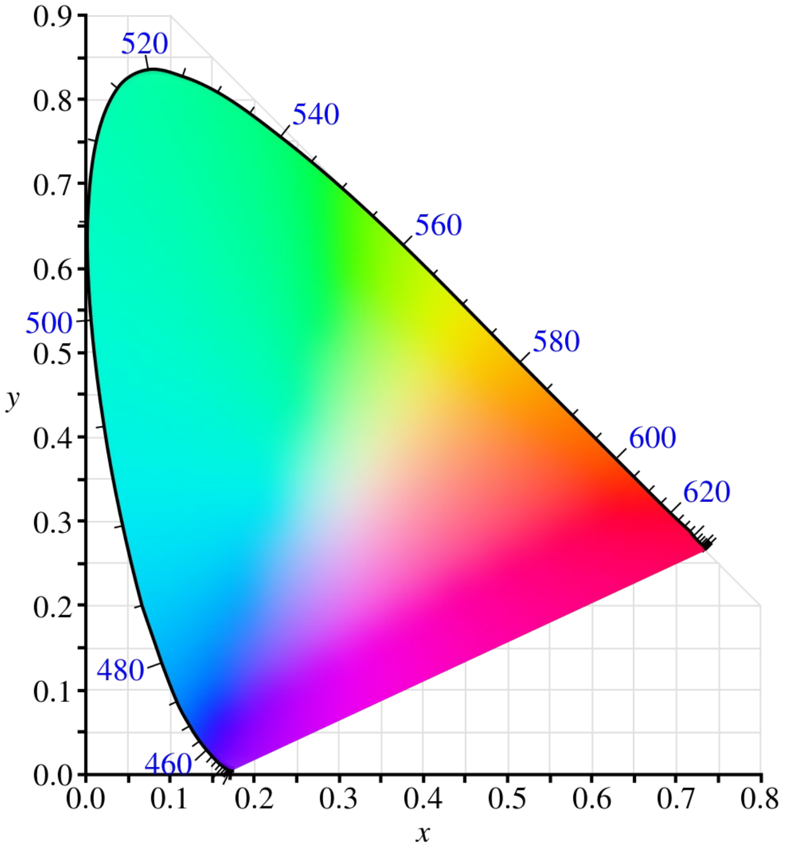
- Subtractive color model: combination of cyan, magenta and yellow.
- Mixing of paints and pigments
  (or colored filters).
- Base of CMYK model (used in printing).



CIE 1931 XYZ

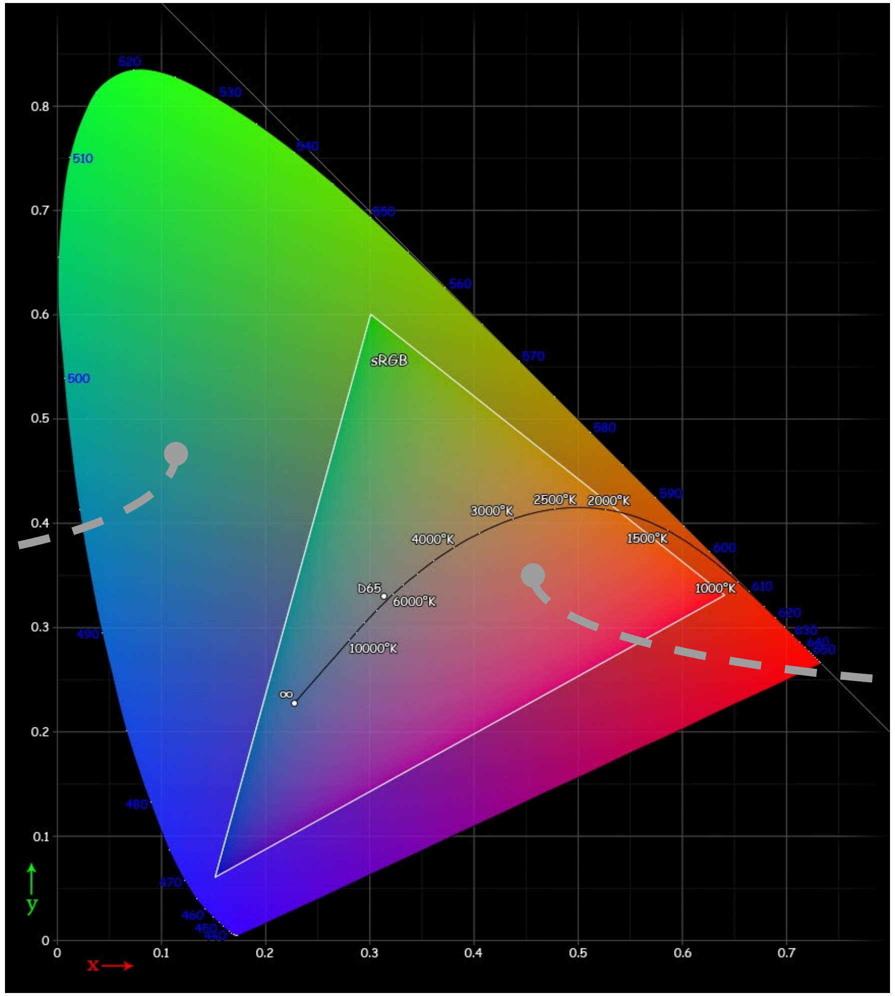
Color matching experiment





Chromaticity diagram

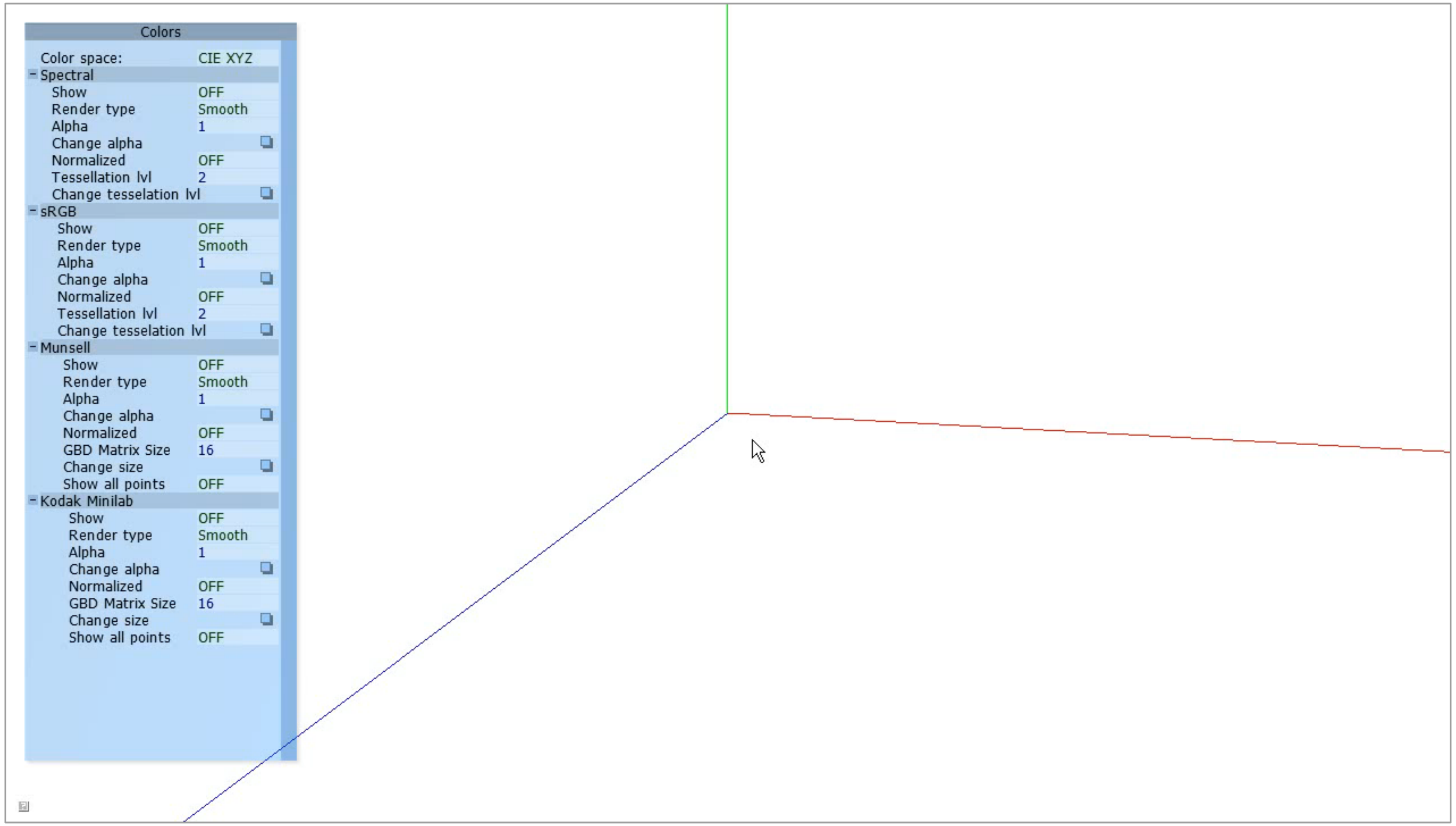
CIE 1931 xy chromaticity diagram. Note that luminance is not included.



Subset of colors (gamut) of the sRGB color space

Image drawn using sRGB

Color spaces



https://youtu.be/cvGCO9u_Ios
https://github.com/fabio-miranda/ColorGamut

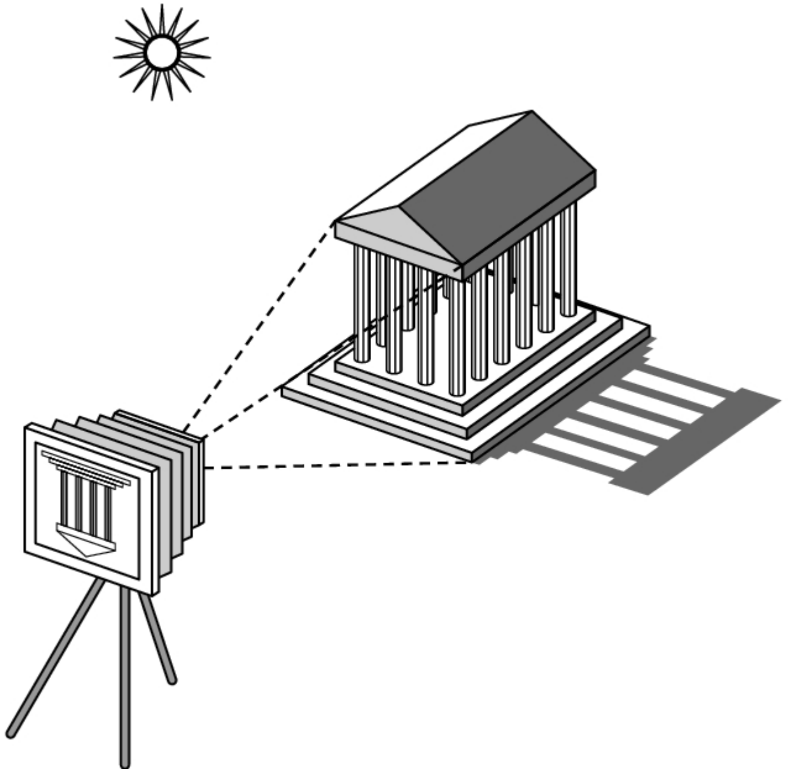
Image formation

In computer graphics, images are formed following the same process to how images are formed by physical imaging systems:

- Cameras
- Microscopes
- Telescopes
- Human visual system

Elements of image formation

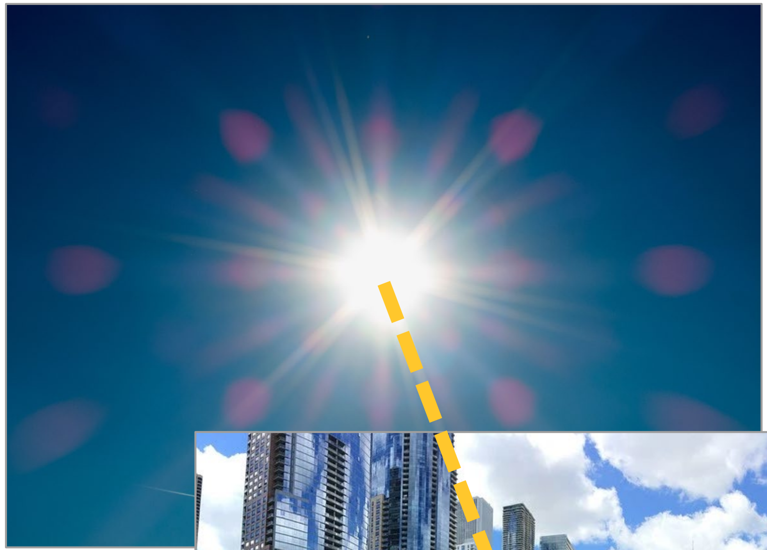
- Three independent elements:
  - Objects
  - Viewer
  - Light source
- Other attributes:
  - Material
  - Light color, direction



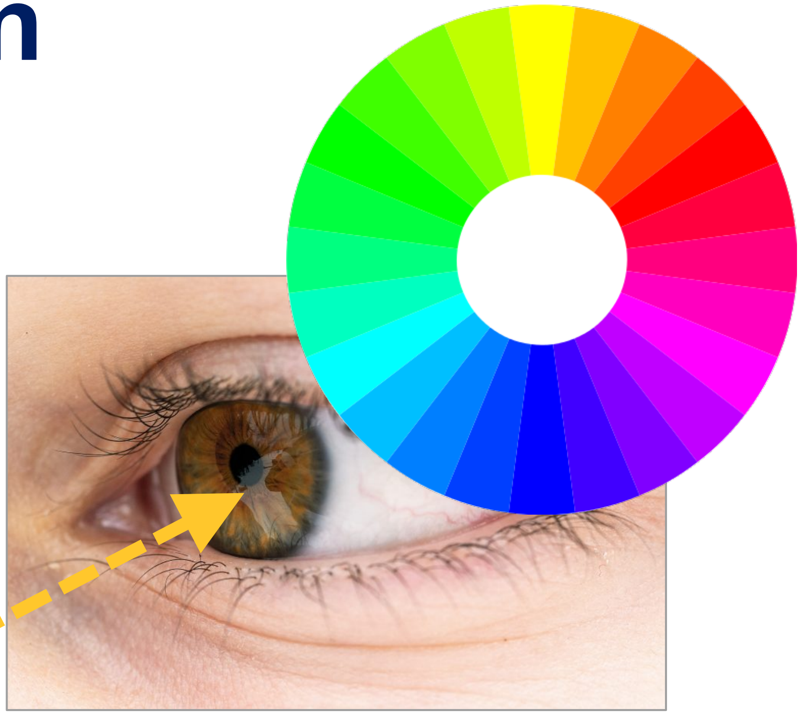
From: Interactive Computer Graphics 7th Ed.
by Professor Ed Angel and Dave Shreiner

Elements of image formation

1. Light source emits photons



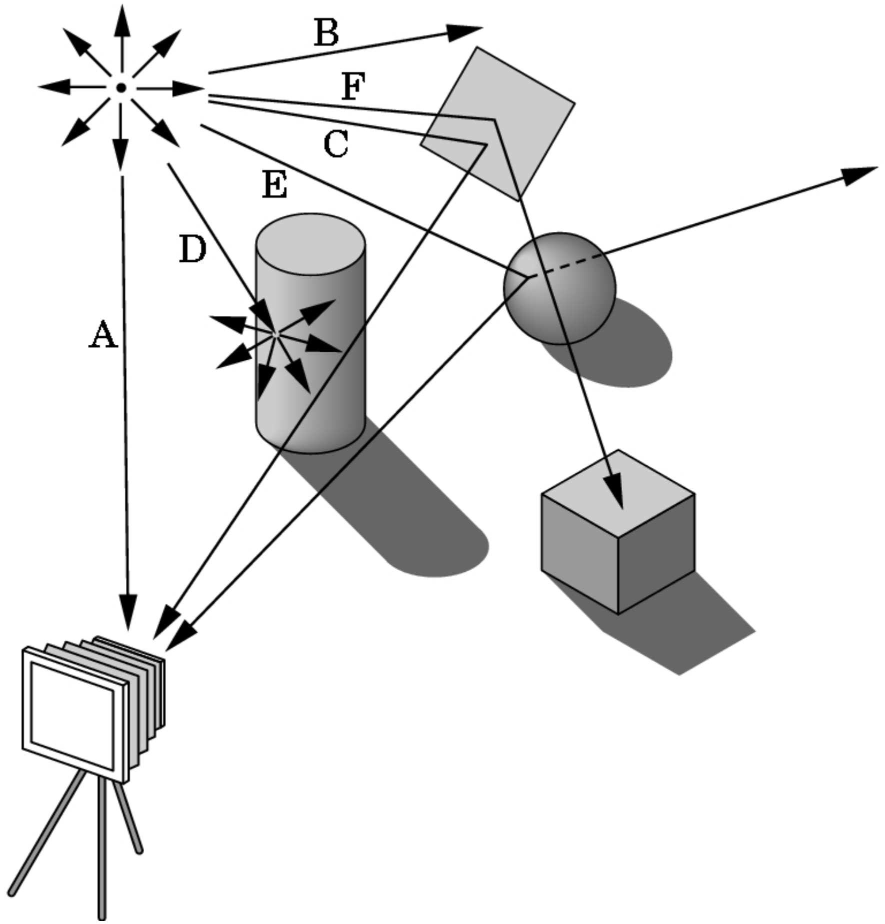
2. Photons interact with the environment: absorption, reflection



3. Some are captured by eye / camera

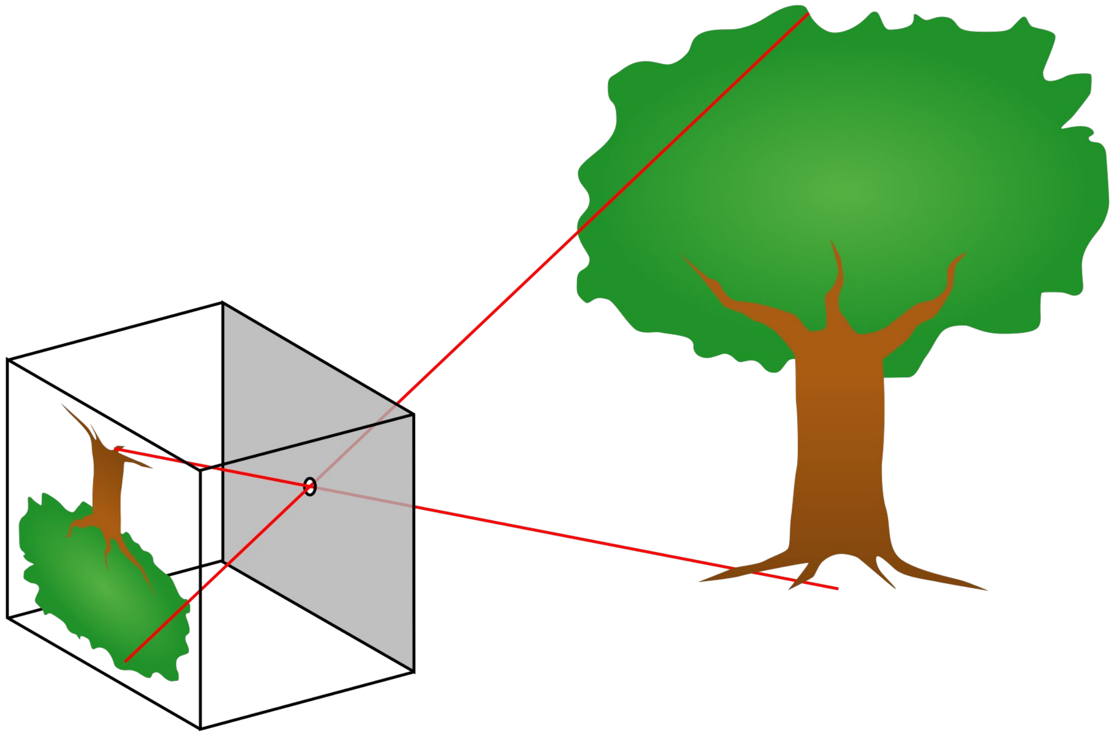
Tracing rays

Follow rays of light from a light source, intersecting objects, and finding which rays enter the lens of the camera.

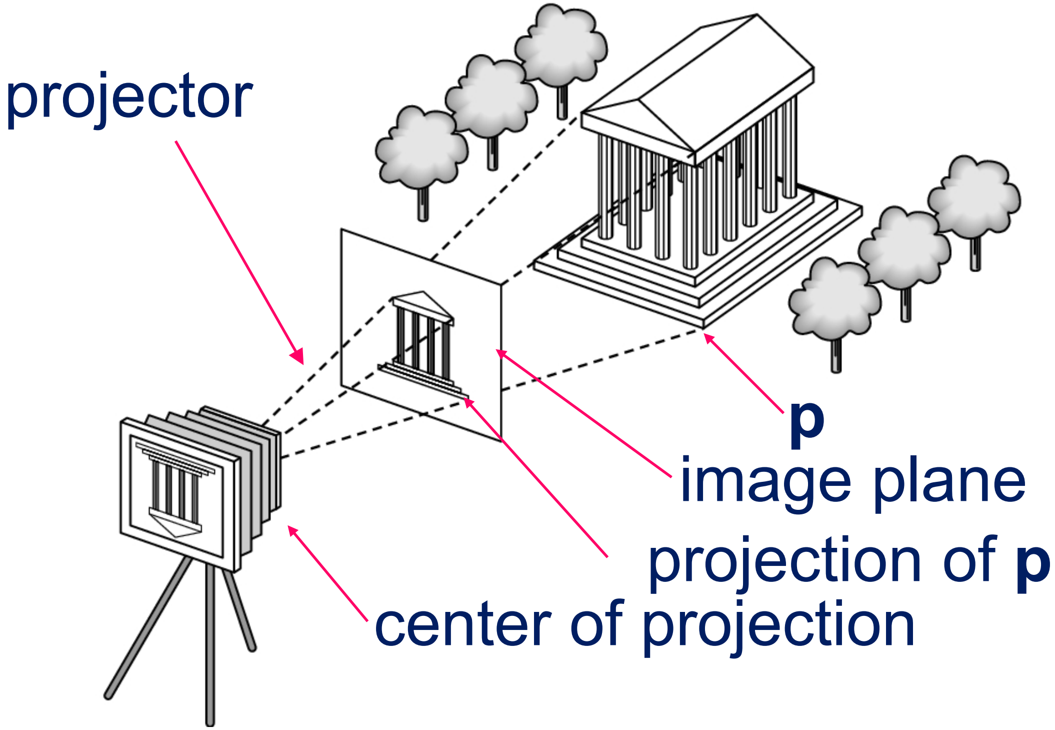


Pinhole camera

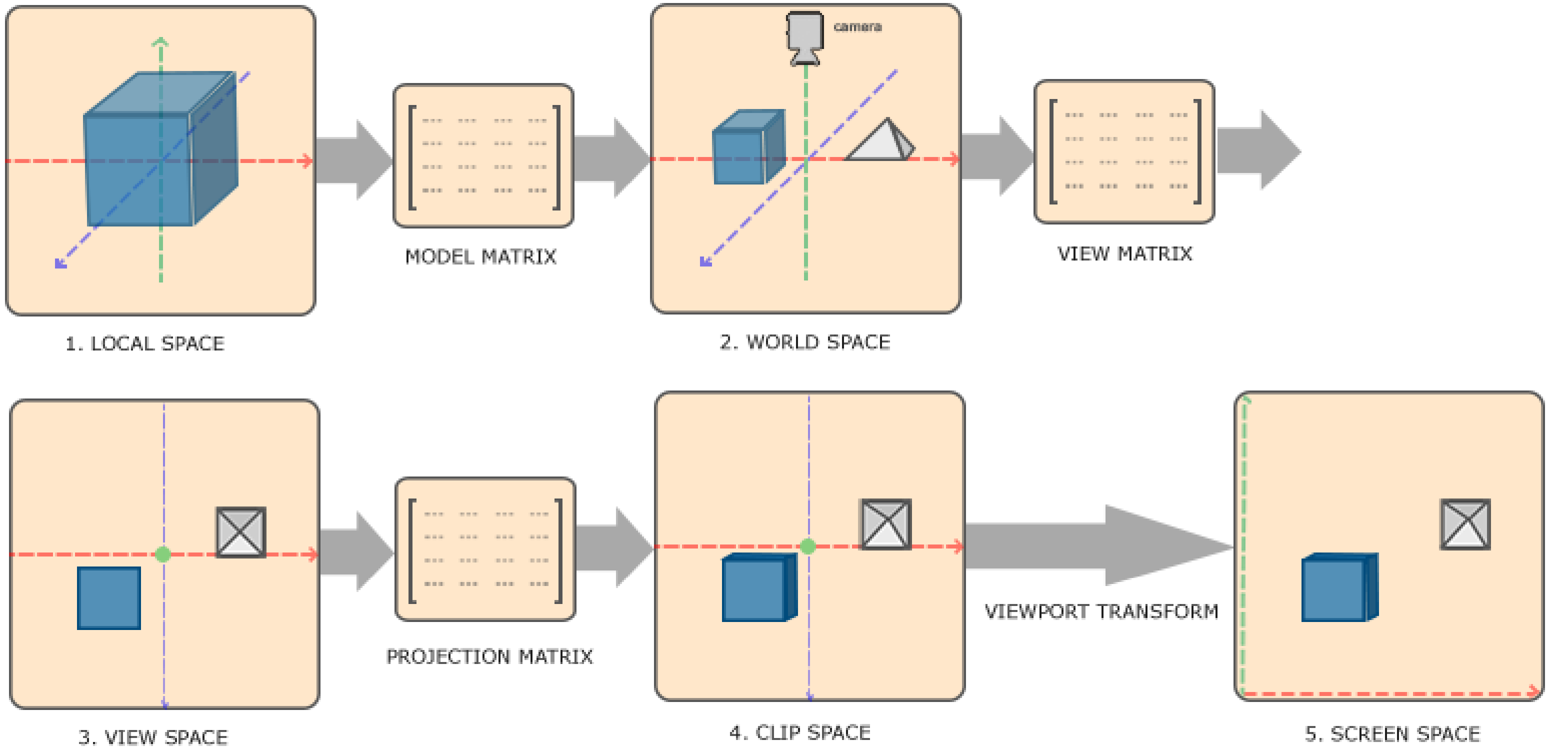
- Simple example of image formation
- A box with a small hole in the center of one side
- Film place inside the box on the side opposite the pinhole



Synthetic camera model

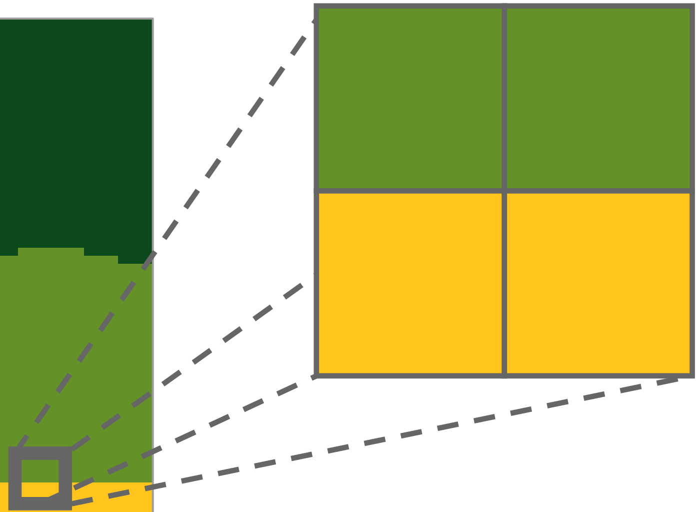


Transformations



From: learnopengl.com

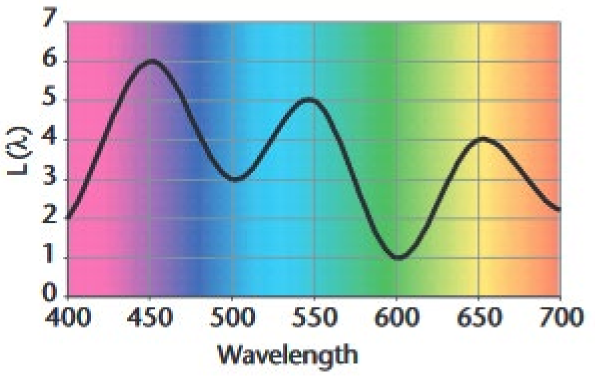
Images

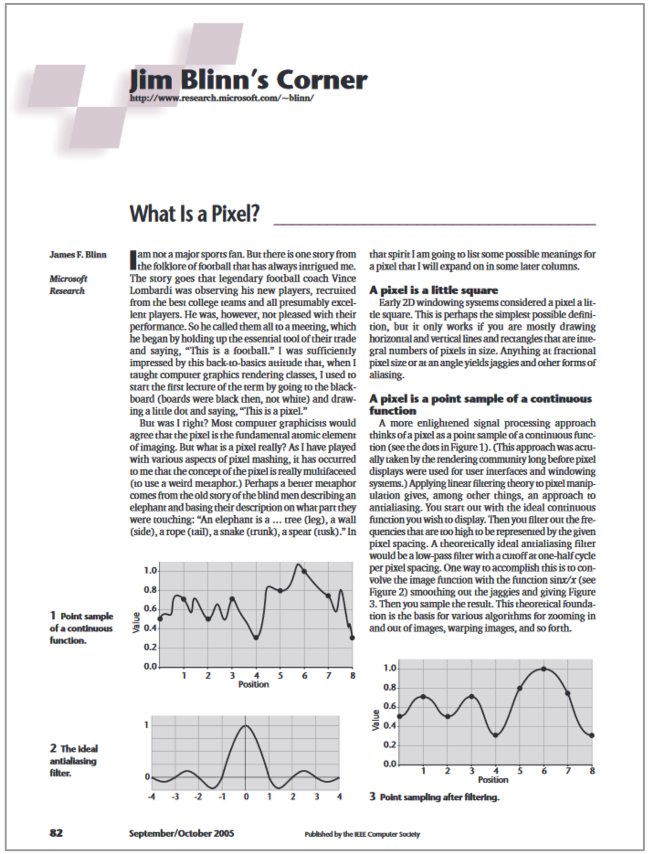


Frame buffer: a 2D array with color values

What is a Pixel? (Blinn, 2005)

- “An elephant is a … tree (leg), a wall (side), a rope (tail), a snake (trunk), a spear (tusk).”
- A pixel is a little square.
- A pixel is a projection of the color spectrum.





Jim Blinn’s Corner

http://www.research.microsoft.com/~blinn/

What Is a Pixel?

James F. Blinn

Microsoft Research

I am not a major sports fan. But there is one story from the folklore of football that has always intrigued me. The story goes that legendary football coach Vince Lombardi was observing his new players, recruited from the best college teams and all presumably excellent players. He was, however, not pleased with their performance. So he called them all to a meeting, which he began by holding up the essential tool of their trade and saying, “This is a football.” I was sufficiently impressed by this back-to-basics attitude that, when I taught computer graphics rendering classes, I used to start the first lecture of the term by going to the blackboard (boards were black then, not white) and drawing a little dot and saying, “This is a pixel.”

But was I right? Most computer graphicists would agree that the pixel is the fundamental atomic element of imaging. But what is a pixel really? As I have played with various aspects of pixel mashing, it has occurred to me that the concept of the pixel is really multifaceted (to use a weird metaphor.) Perhaps a better metaphor comes from the old story of the blind men describing an elephant and basing their description on what part they were touching: “An elephant is a … tree (leg), a wall (side), a rope (tail), a snake (trunk), a spear (tusk).” In that spirit I am going to list some possible meanings for a pixel that I will expand on in some later columns.

A pixel is a little square

Early 2D windowing systems considered a pixel a little square. This is perhaps the simplest possible definition, but it only works if you are mostly drawing horizontal and vertical lines and rectangles that are integral numbers of pixels in size. Anything at fractional pixel size or at an angle yields jaggies and other forms of aliasing.

A pixel is a point sample of a continuous function

A more enlightened signal processing approach thinks of a pixel as a point sample of a continuous function (see the dots in Figure 1). (This approach was actually taken by the rendering community long before pixel displays were used for user interfaces and windowing systems.) Applying linear filtering theory to pixel manipulation gives, among other things, an approach to antialiasing. You start out with the ideal continuous function you wish to display. Then you filter out the frequencies that are too high to be represented by the given pixel spacing. A theoretically ideal antialiasing filter would be a low-pass filter with a cutoff at one-half cycle per pixel spacing. One way to accomplish this is to convolve the image function with the function sin*x*/*x* (see Figure 2) smoothing out the jaggies and giving Figure 3. Then you sample the result. This theoretical foundation is the basis for various algorithms for zooming in and out of images, warping images, and so forth.

1 Point sample of a continuous function.

2 The ideal antialiasing filter.

3 Point sampling after filtering.

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