

Color and Images

CS425: Computer Graphics I

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Overview

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

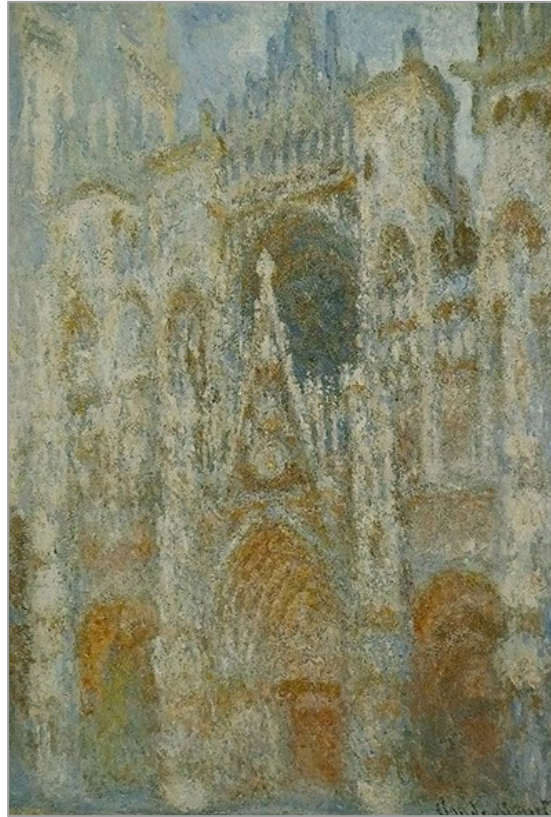
Colors



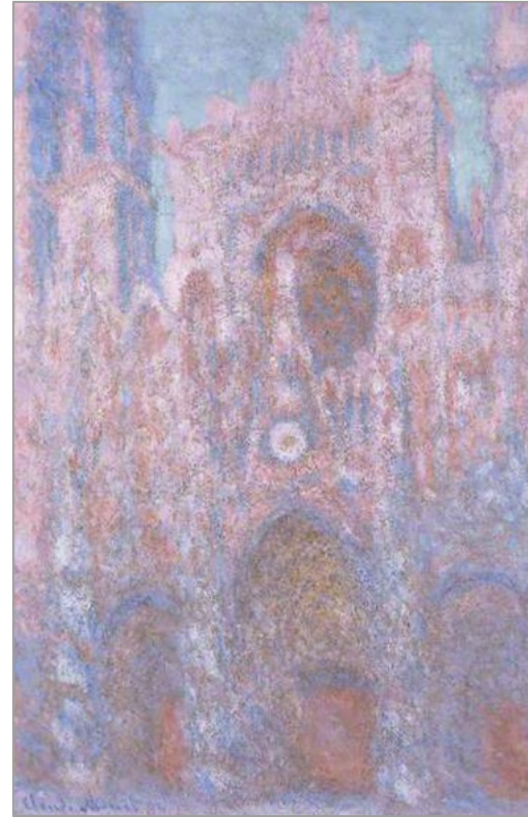
Color perception depends on context (especially lighting)



Full Sun



Morning Sun



Setting Sun



Grey Weather

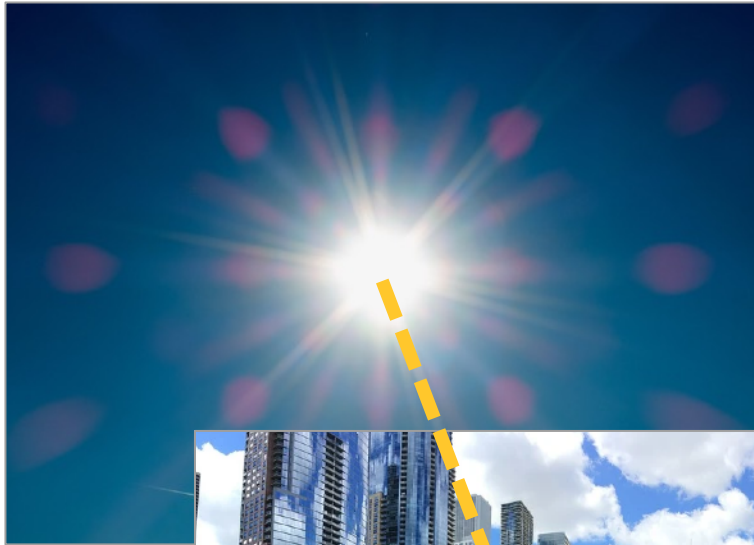
Rouen Cathedral (Monet series)

Color

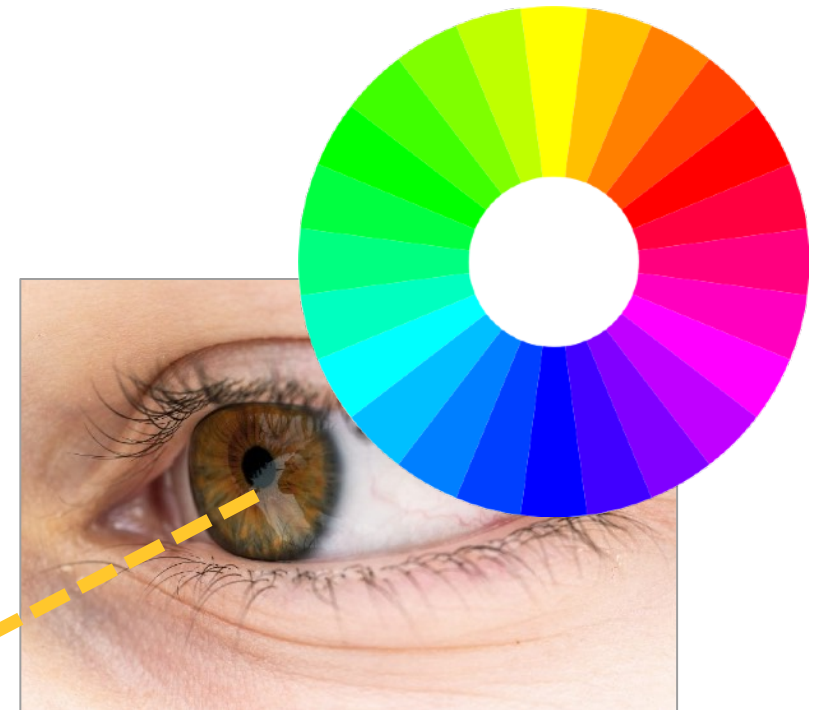
- Color is a product of visual perception.
- “Our perception of color is a purely psychological phenomenon” (Real-time Rendering, 3rd Ed.).
- **“Color is a perceptual sensation from seeing light of different spectral power distributions” (Kayvon Fatahalian).**

Light and color

1. Light source emits photons

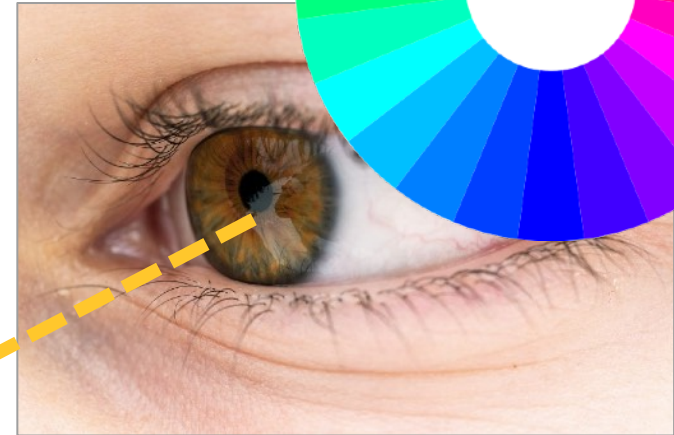
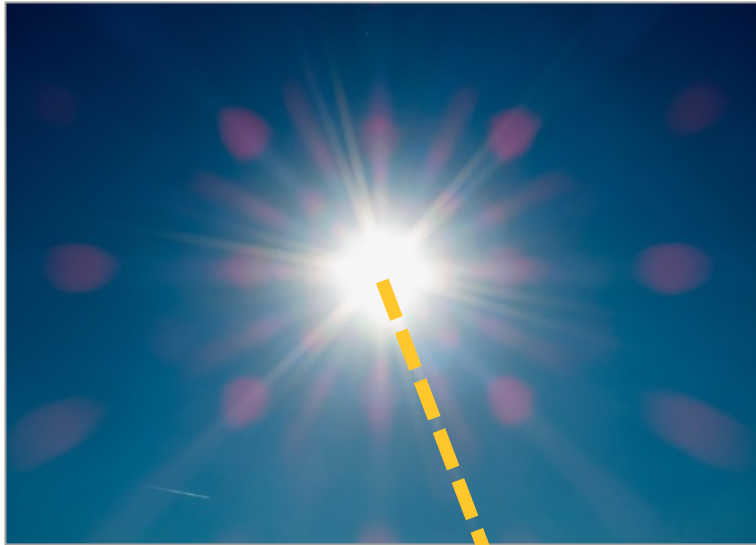


2. Photons interact with the environment: absorption, reflection



3. Some are captured by eye / camera

Light and color

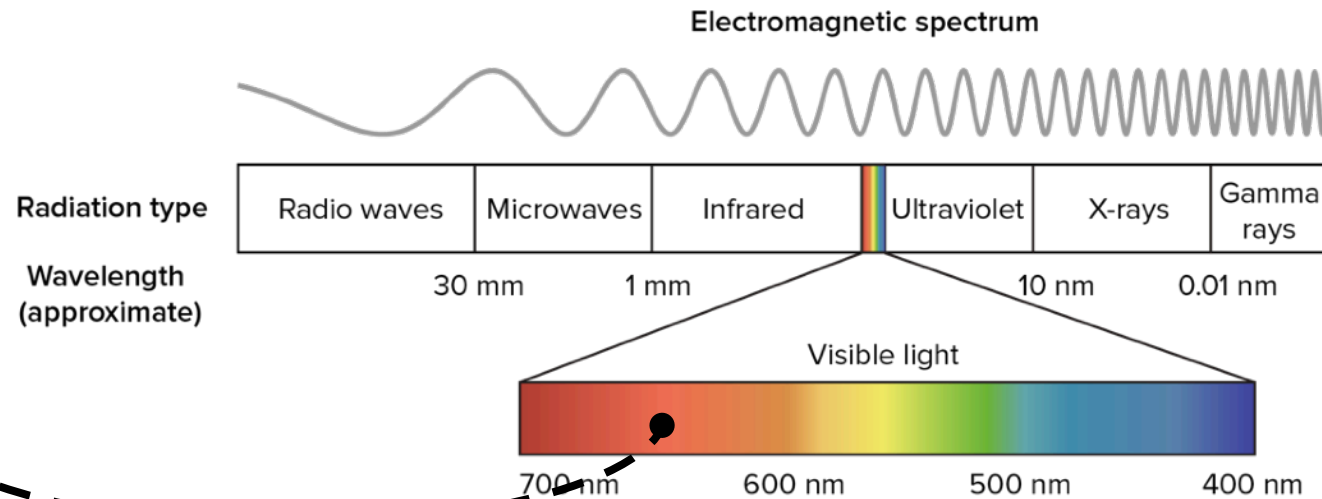


Illumination

Physics of light

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

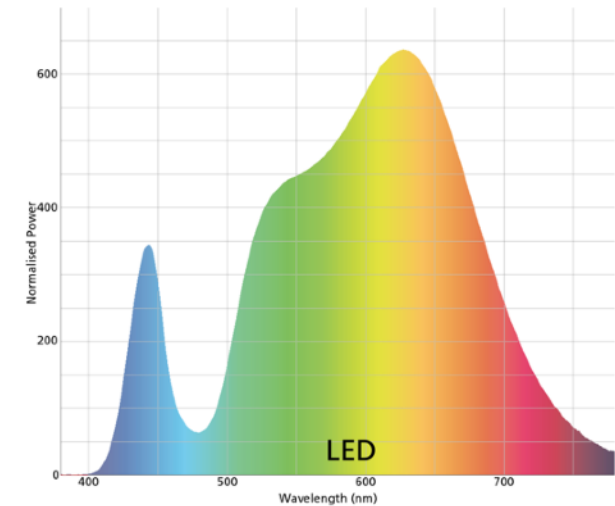
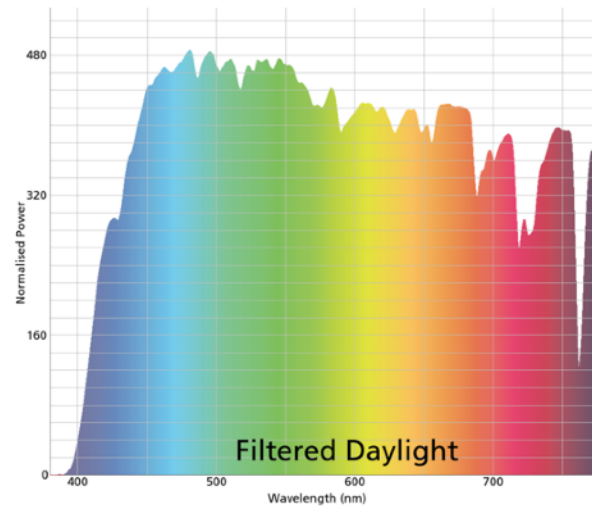
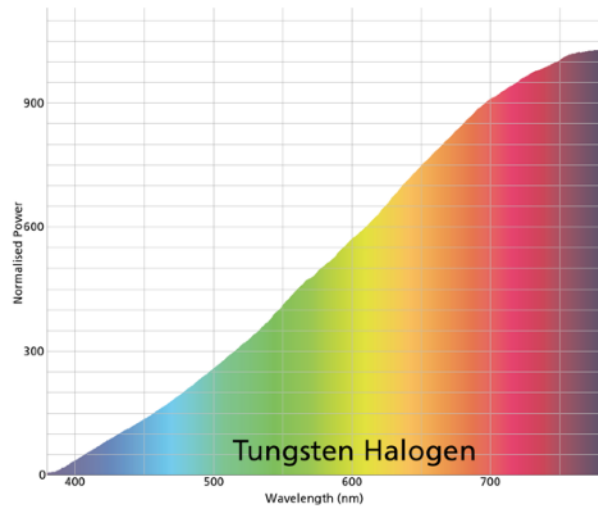
Light that is visible to the human eye



From: Wikipedia – EM spectrum

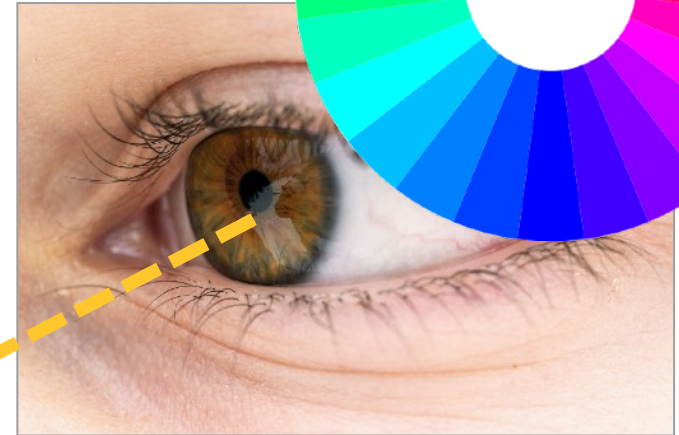
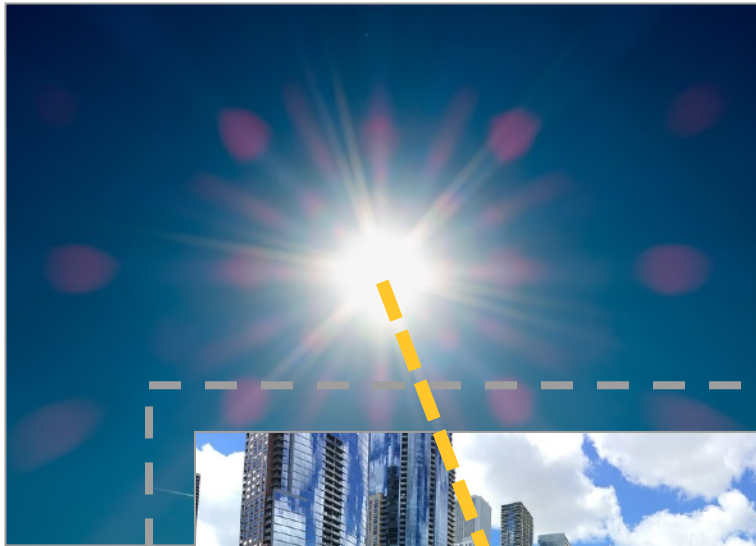
Spectral power distribution

- Each light source emits a different distribution of wave lengths (power spectra)
- Fingerprint of a light source.



From: The National Gallery

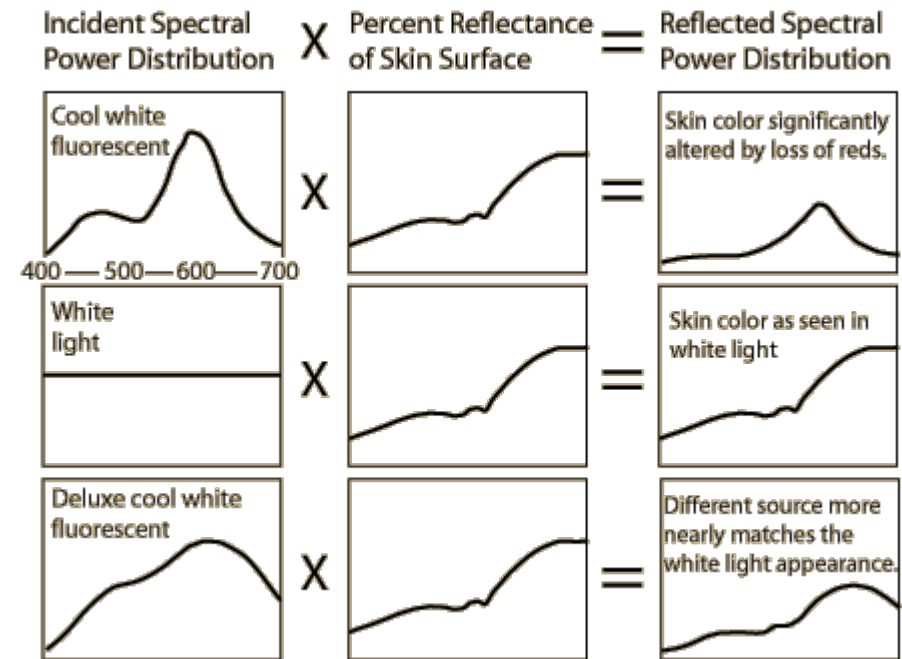
Light and color



Surface interaction

Emission and reflection

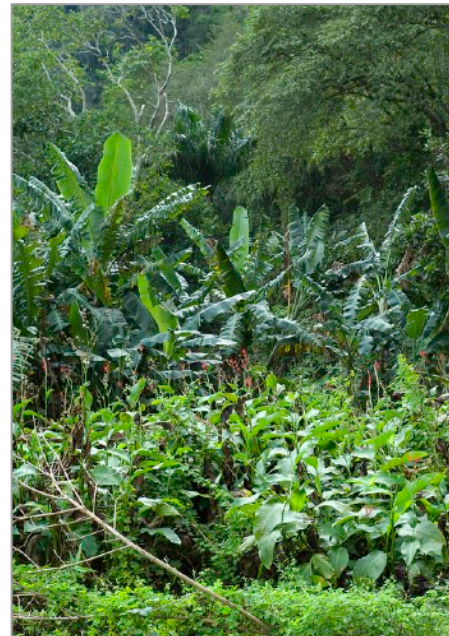
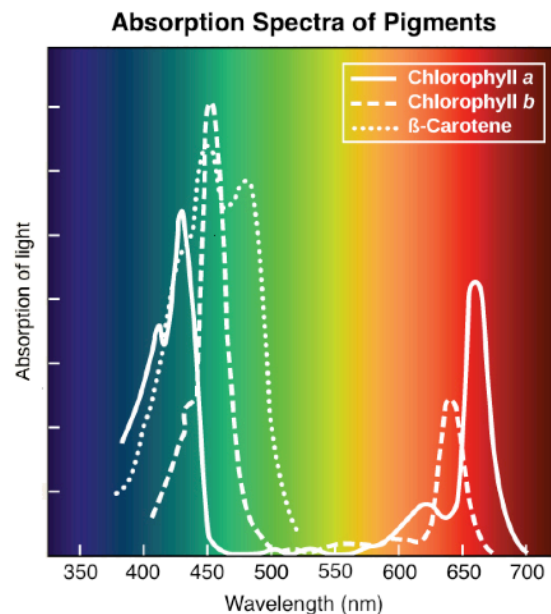
- Light reflected from a surface
- Light source emission spectrum: $f(\nu)$
- Surface reflection spectrum: $g(\nu)$
- Intensity reflected: $f(\nu)g(\nu)$



After Williamson and Cummins

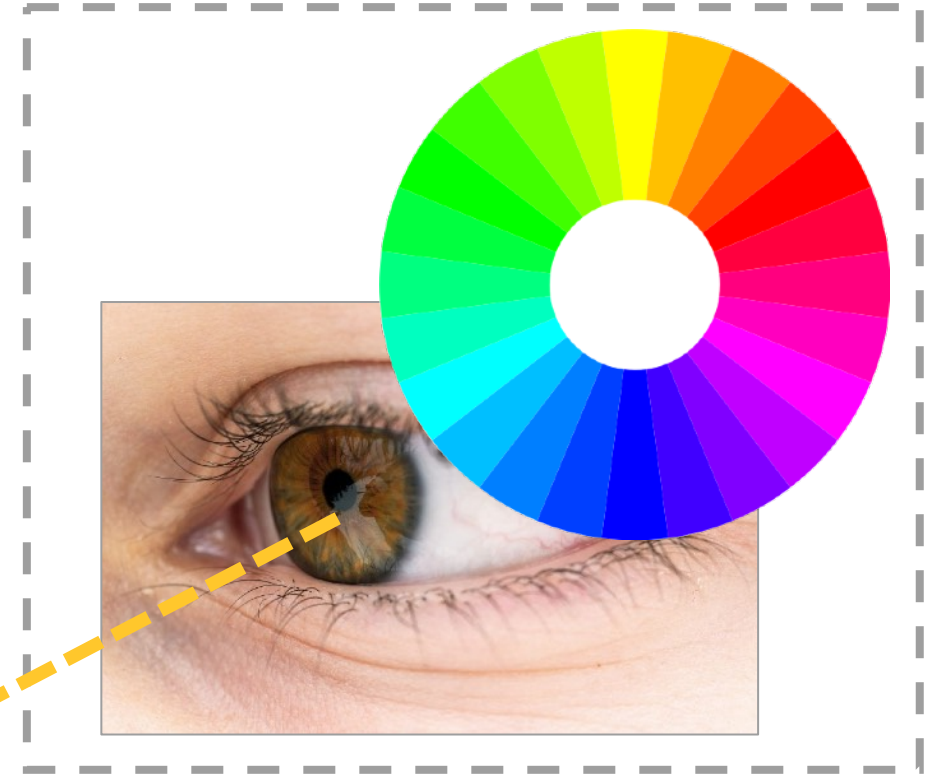
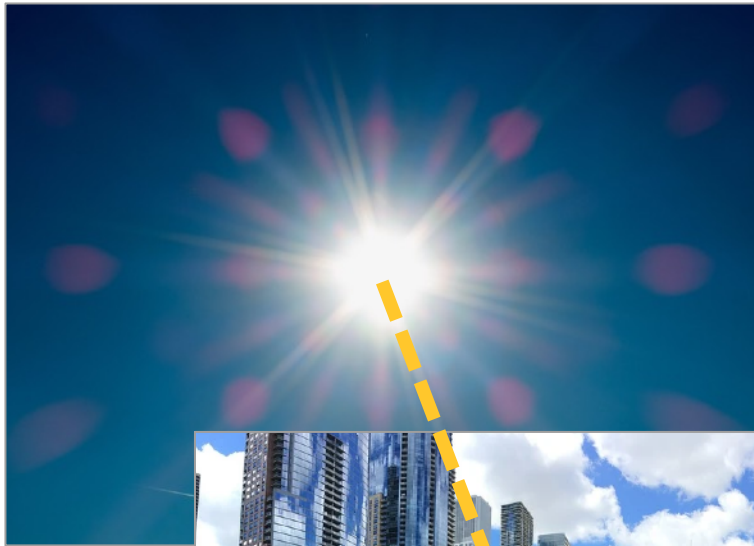
Absorption spectrum

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



From:
CNX.org
Wikipedia - Frankemann

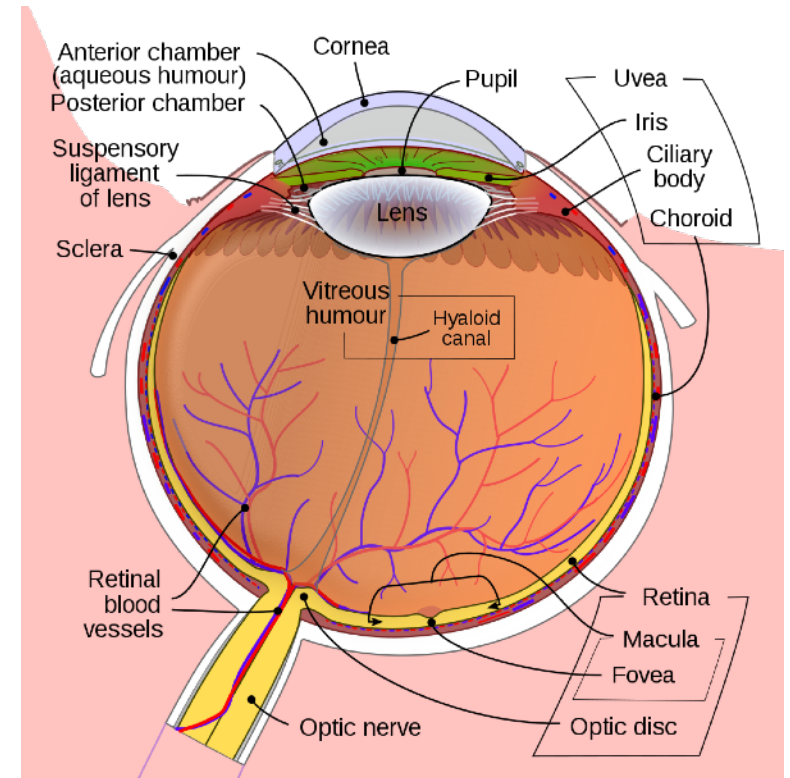
Light and color



Perception

Perception of color

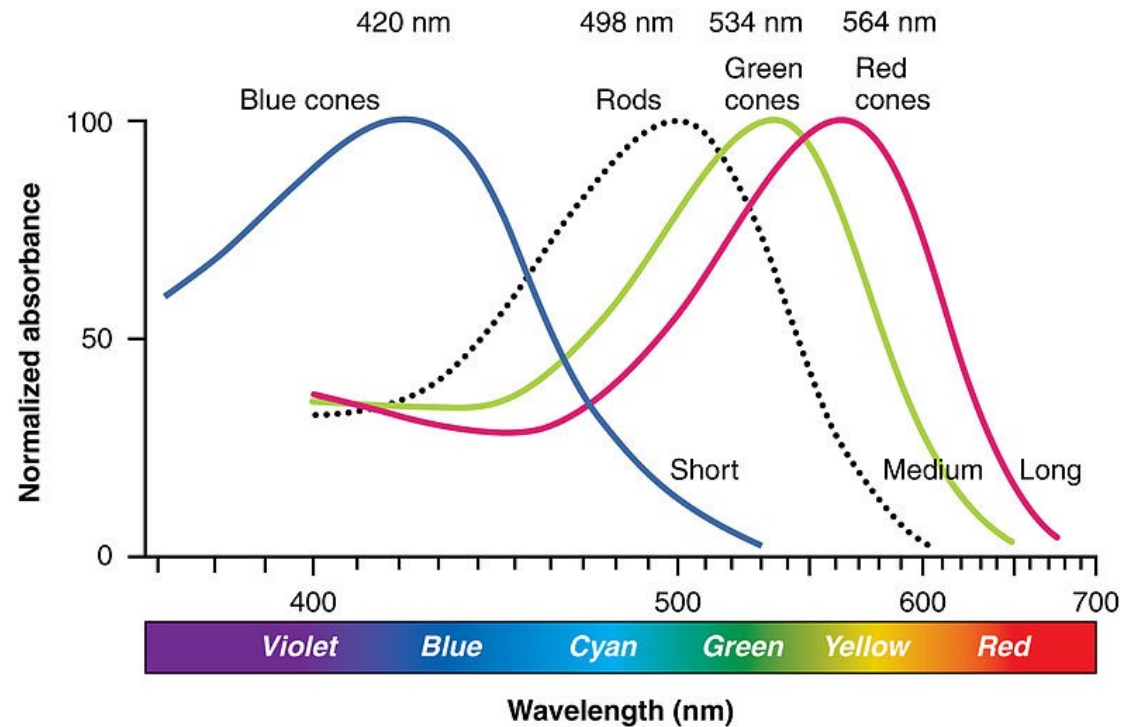
- Humans can distinguish about 10 million different colors.
- Three different types of cone receptors in the retina. Each receptor responds differently to various wavelengths.
- The brain receives three different signals.



From: Wikipedia – Human Eye

Perception of color

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



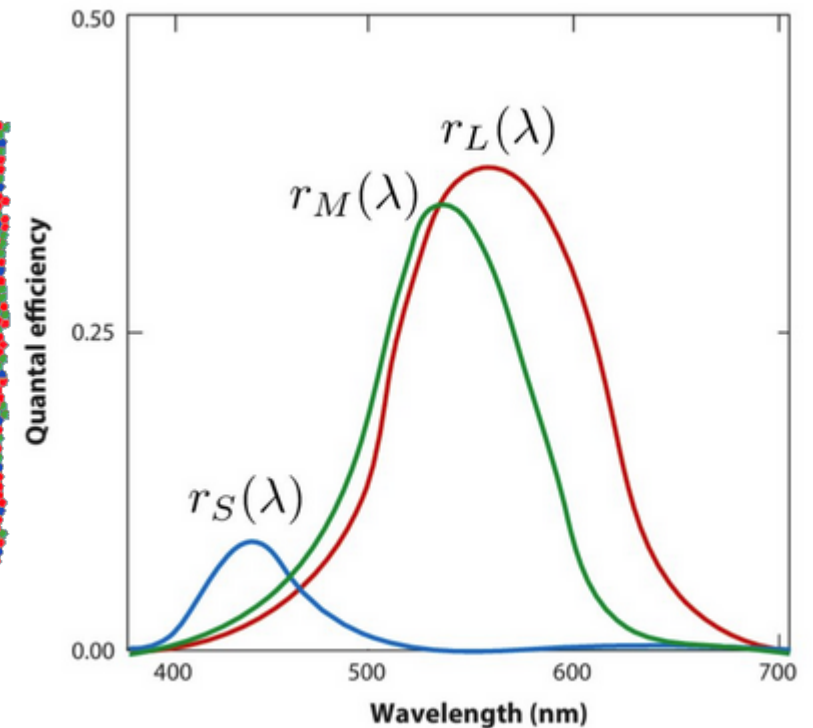
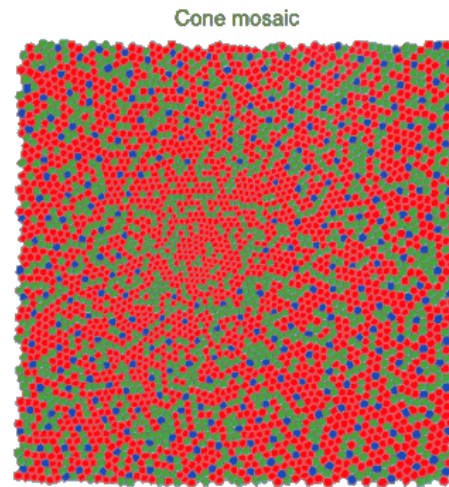
Perception of color

- 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. “

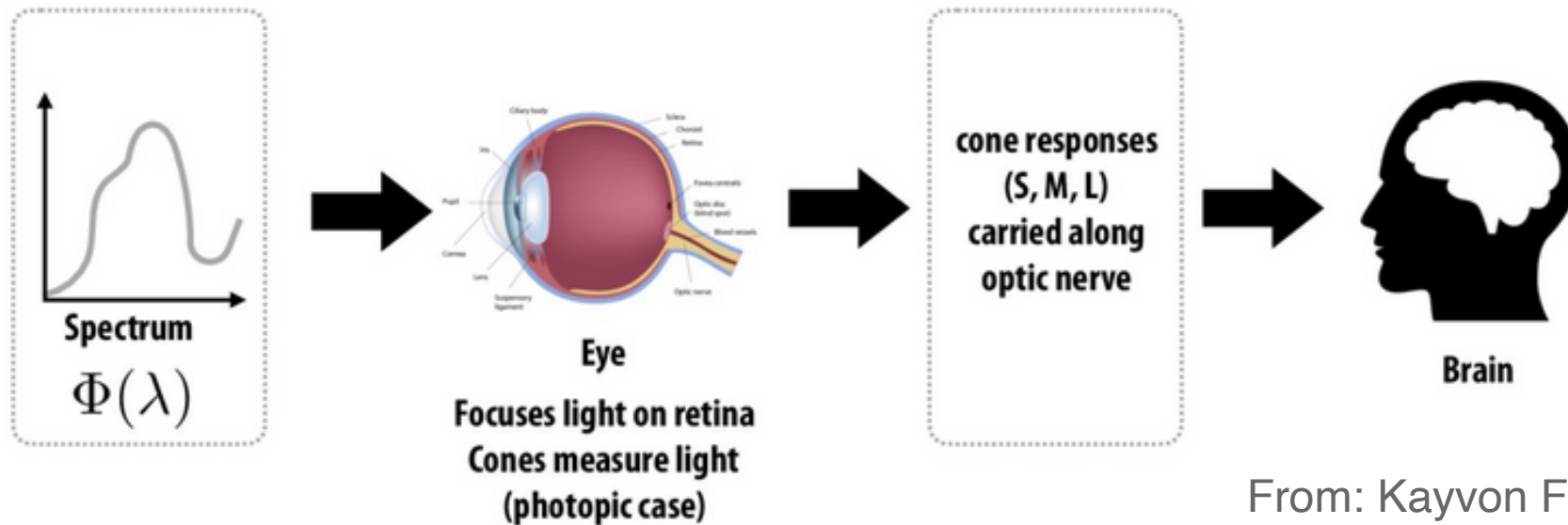
HyperPhysics, Georgia State



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

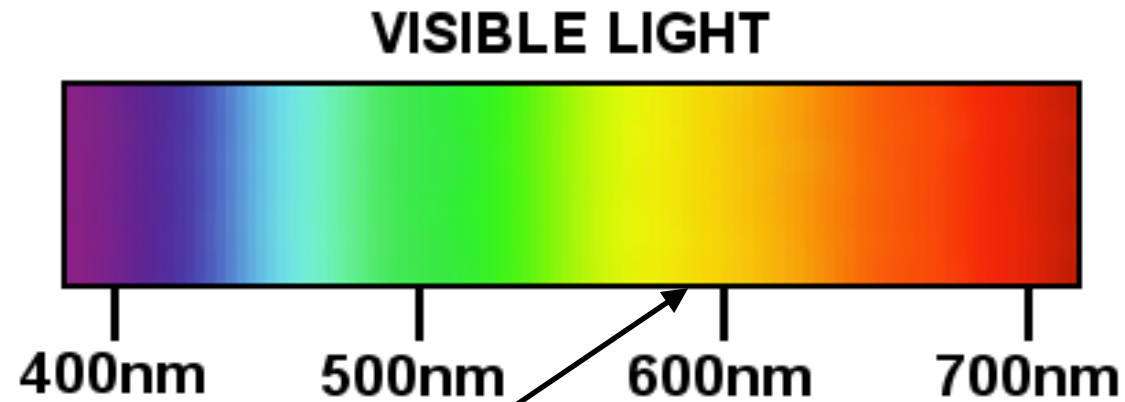
Color models

How do we represent color precisely?

We need a method that allow us to reproduce colors precisely

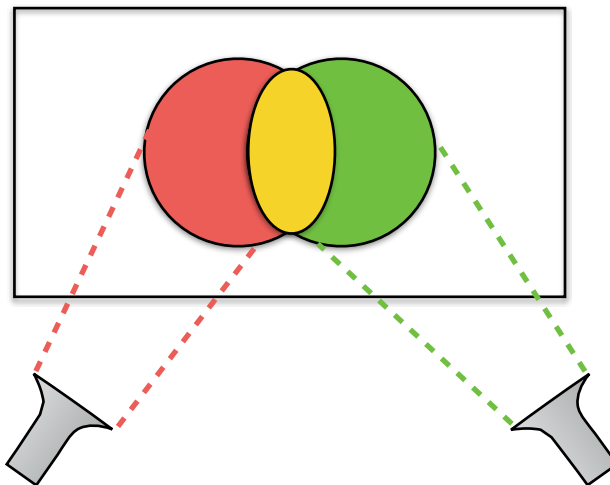
Would be nice if it is intuitive (i.e., align with our perception of color)

light

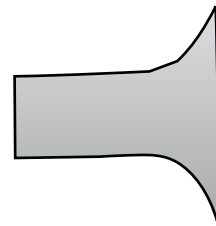


1. pure yellow: 580 nm

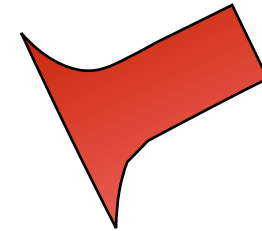
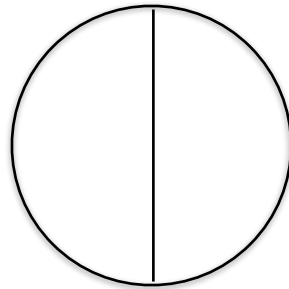
2. color matching
yellow



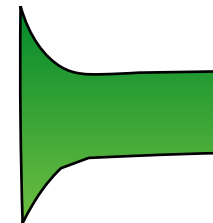
Tristimulus color matching



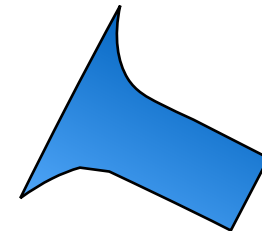
test color



red

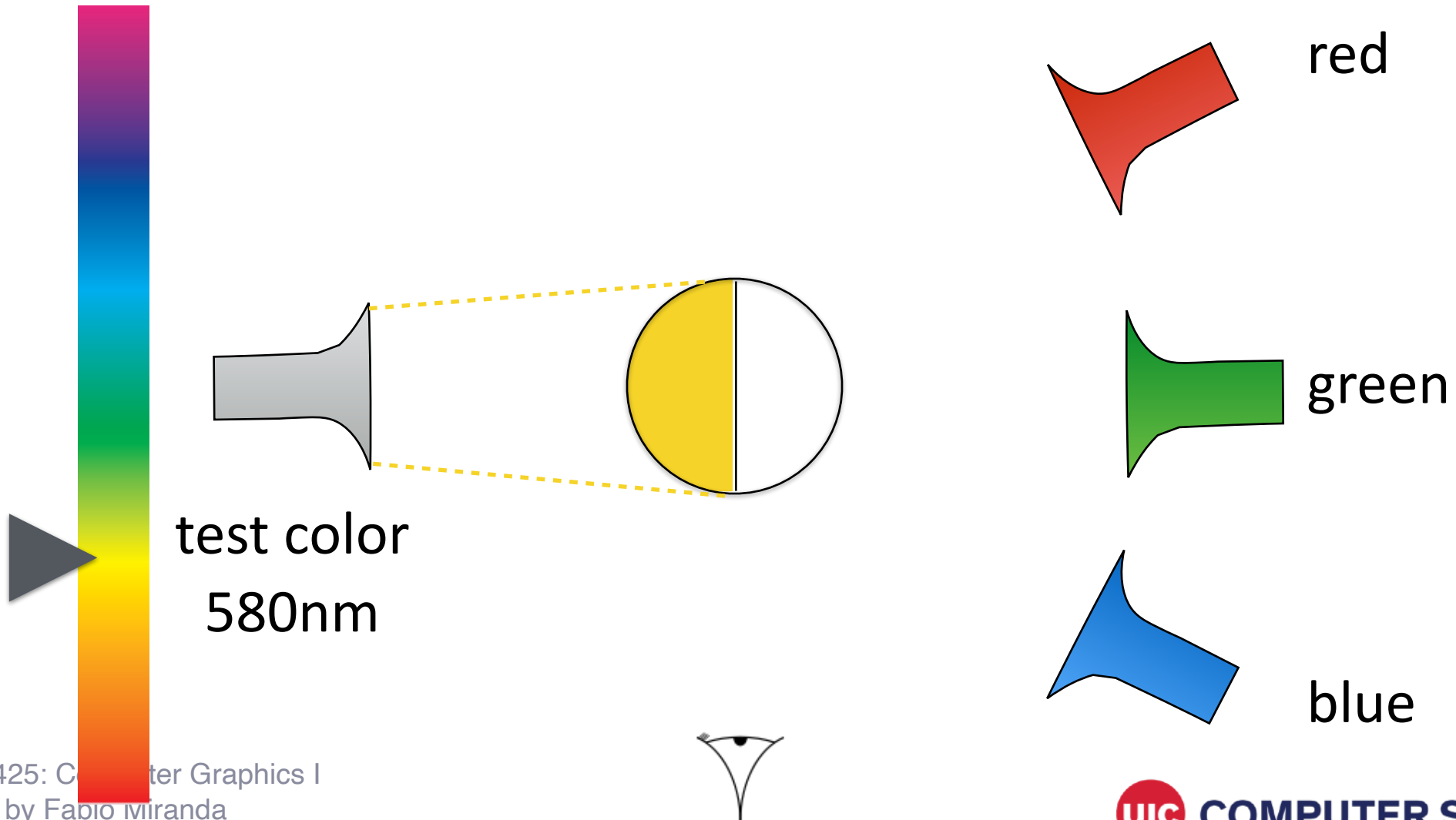


green

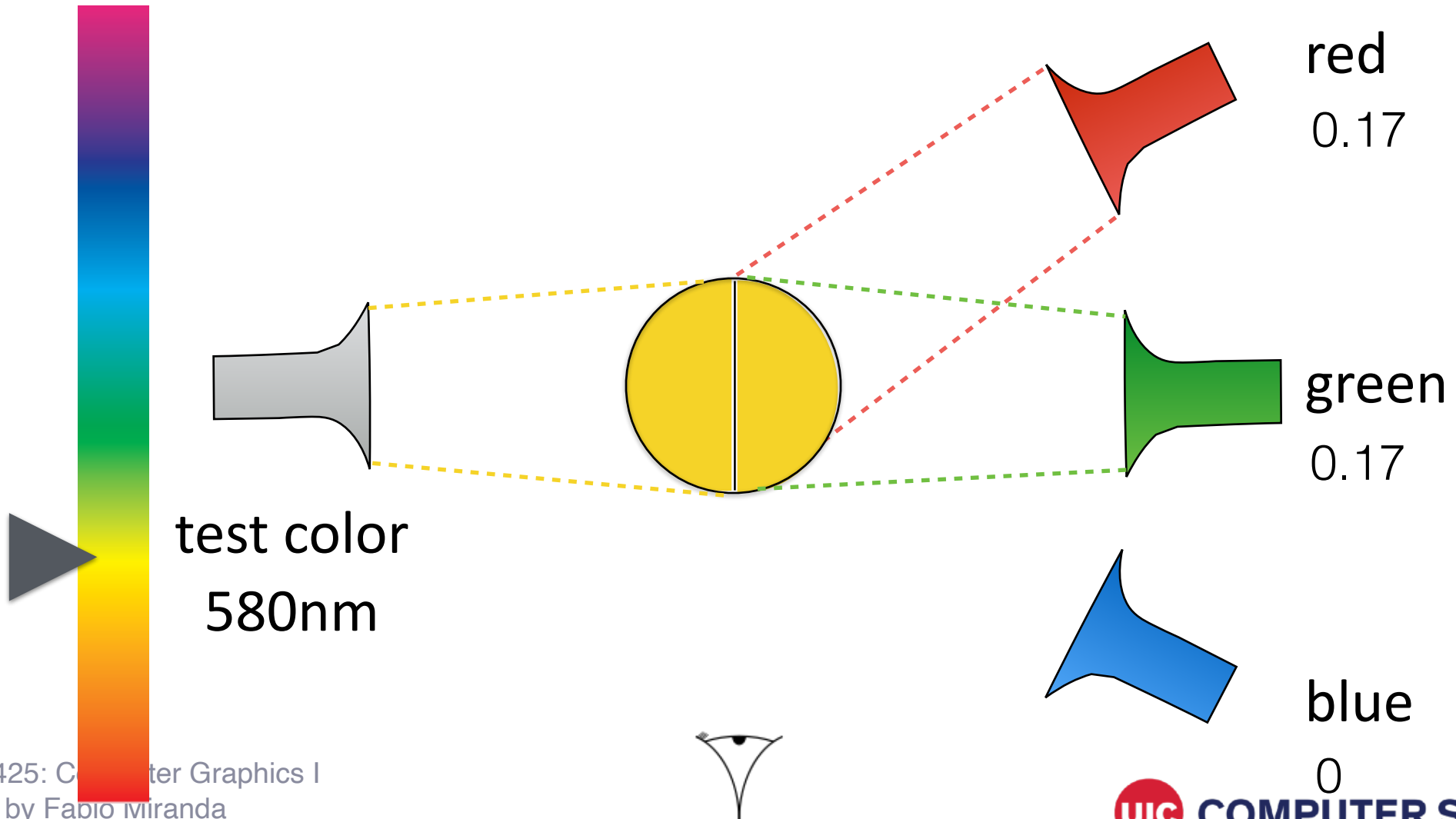


blue

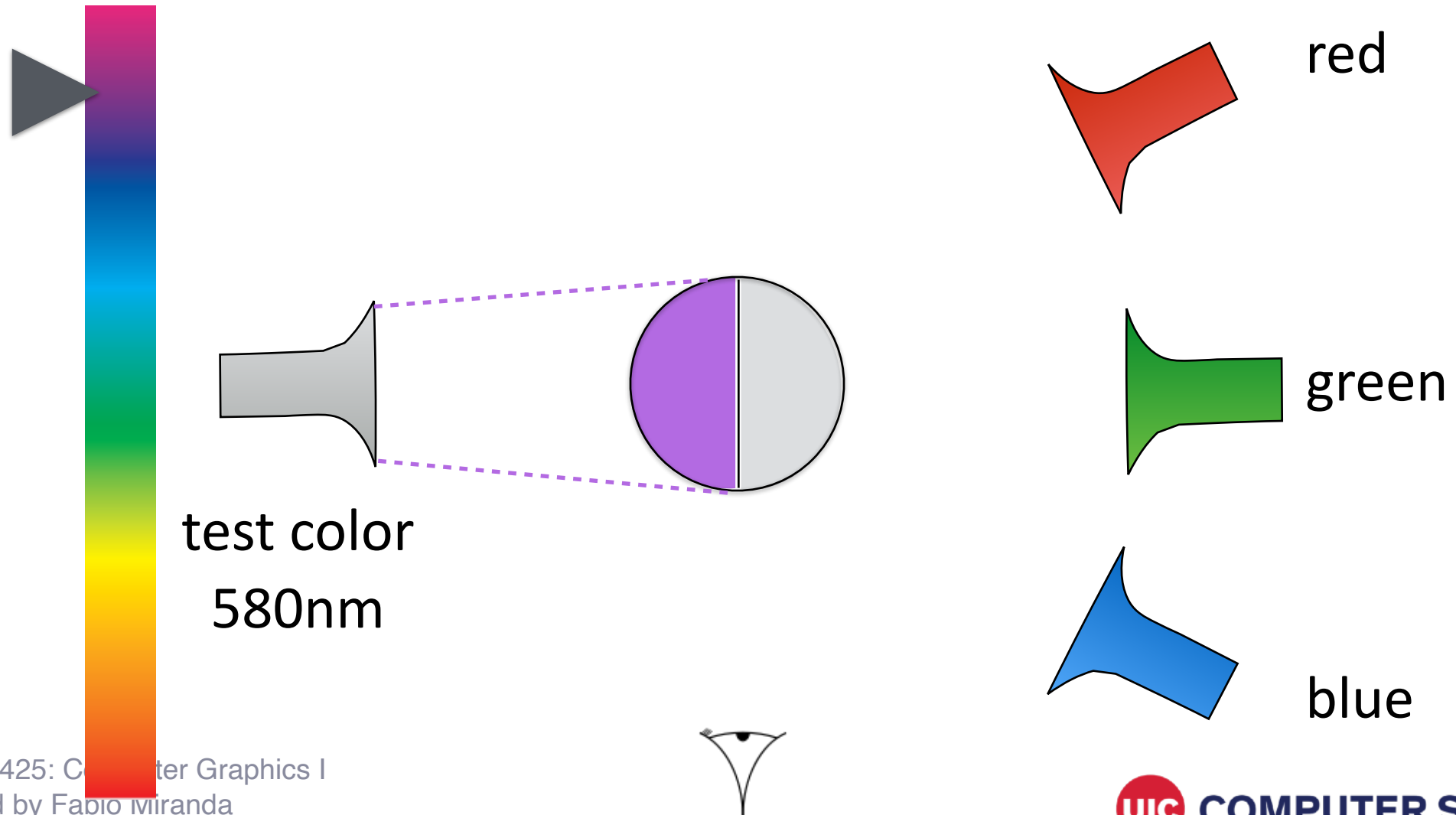
Tristimulus color matching



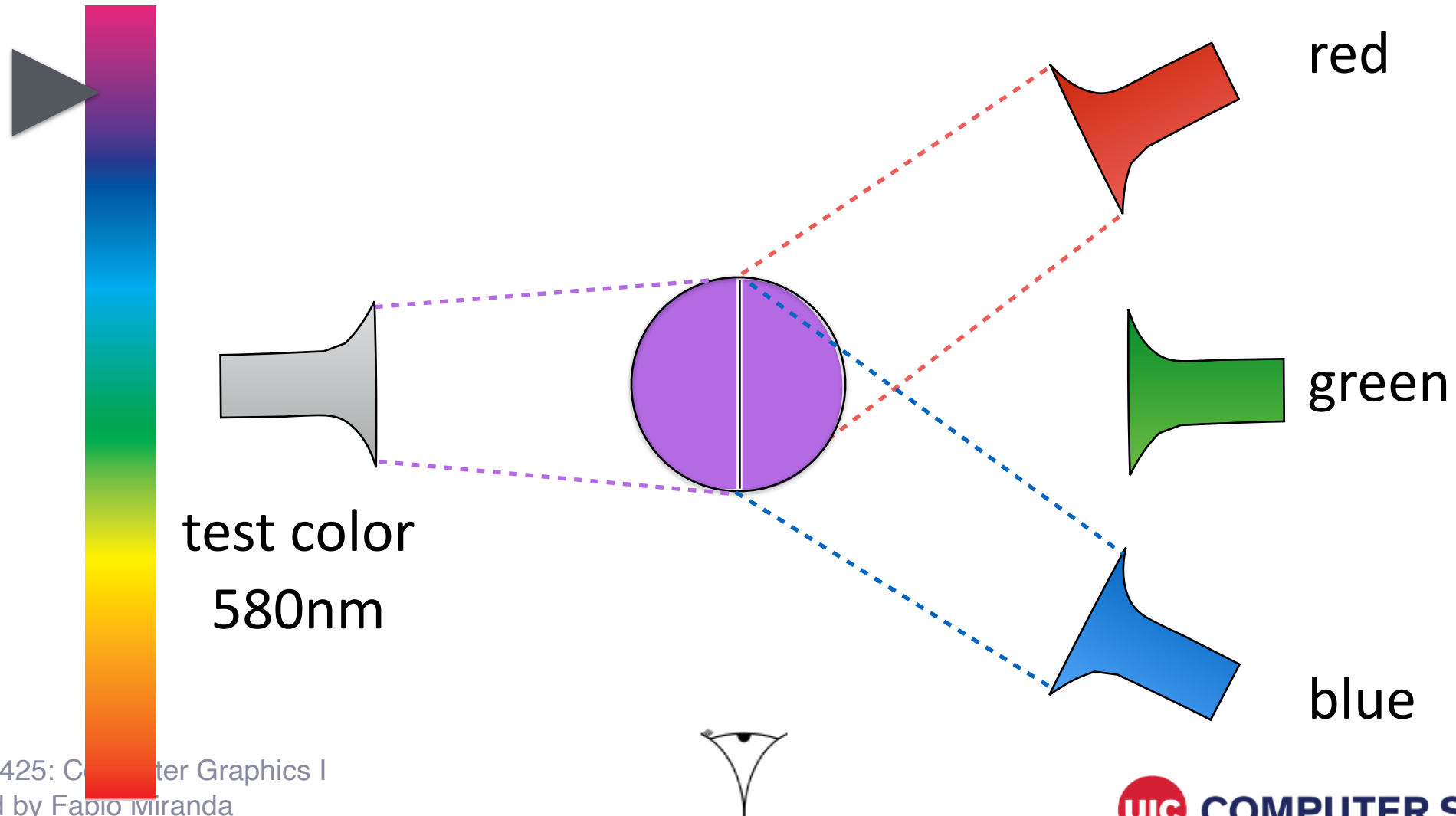
Tristimulus color matching

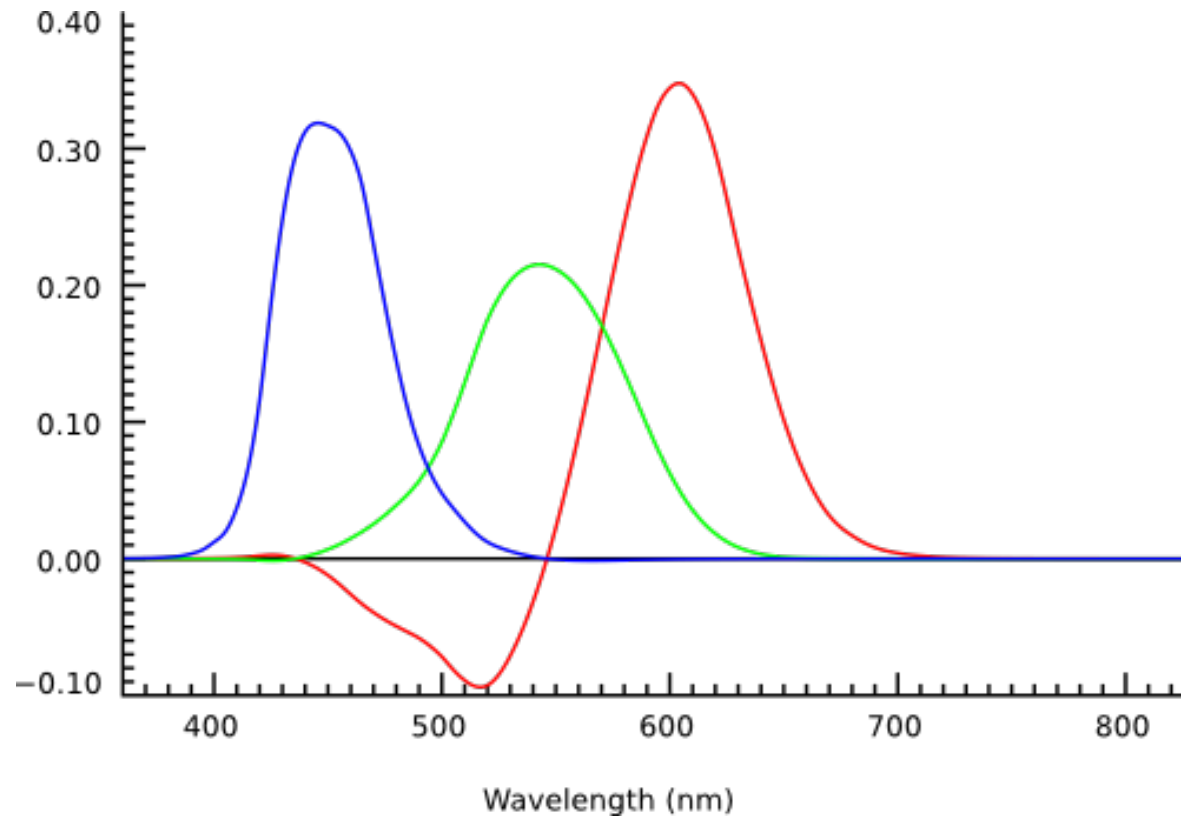


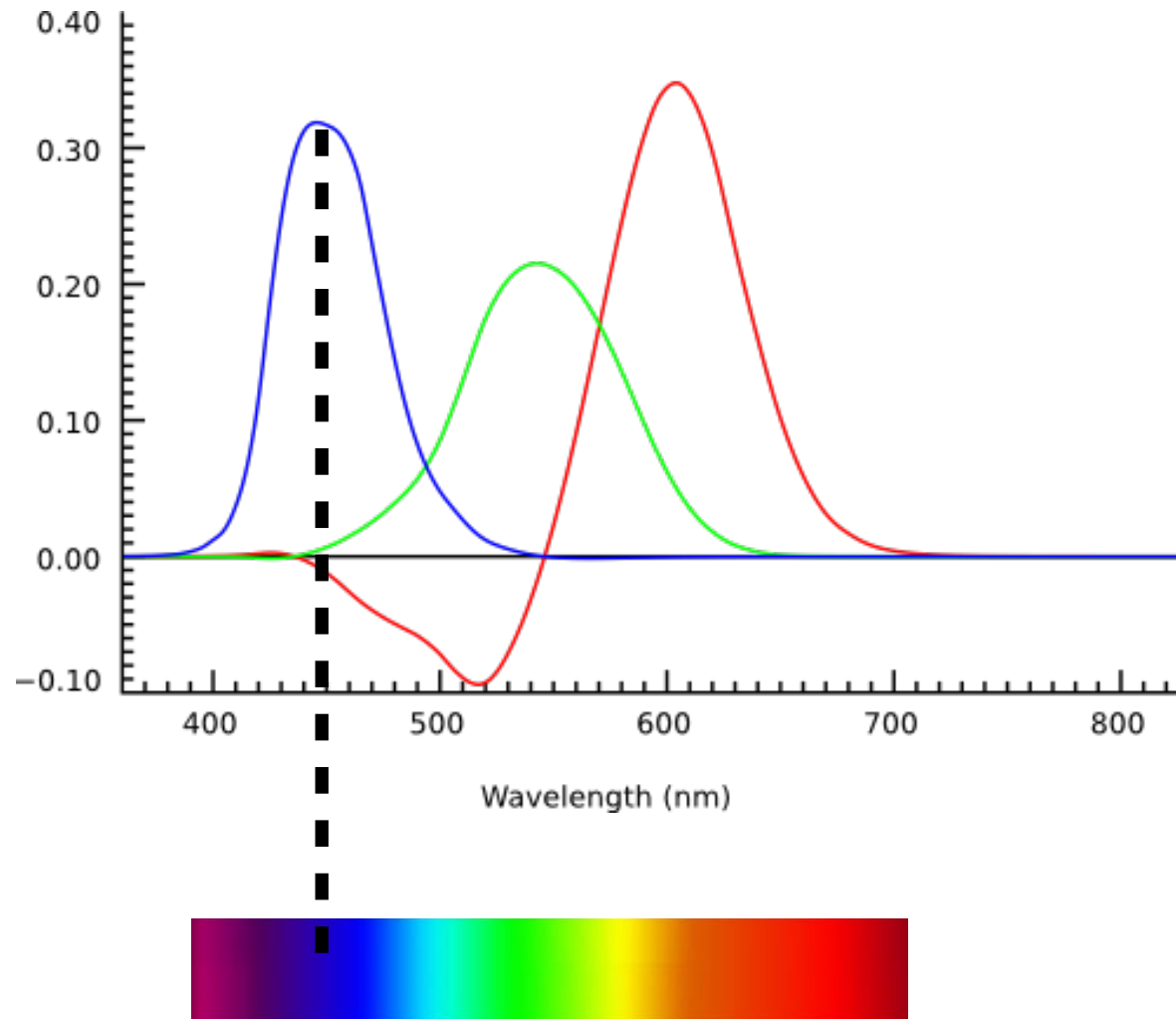
Tristimulus color matching

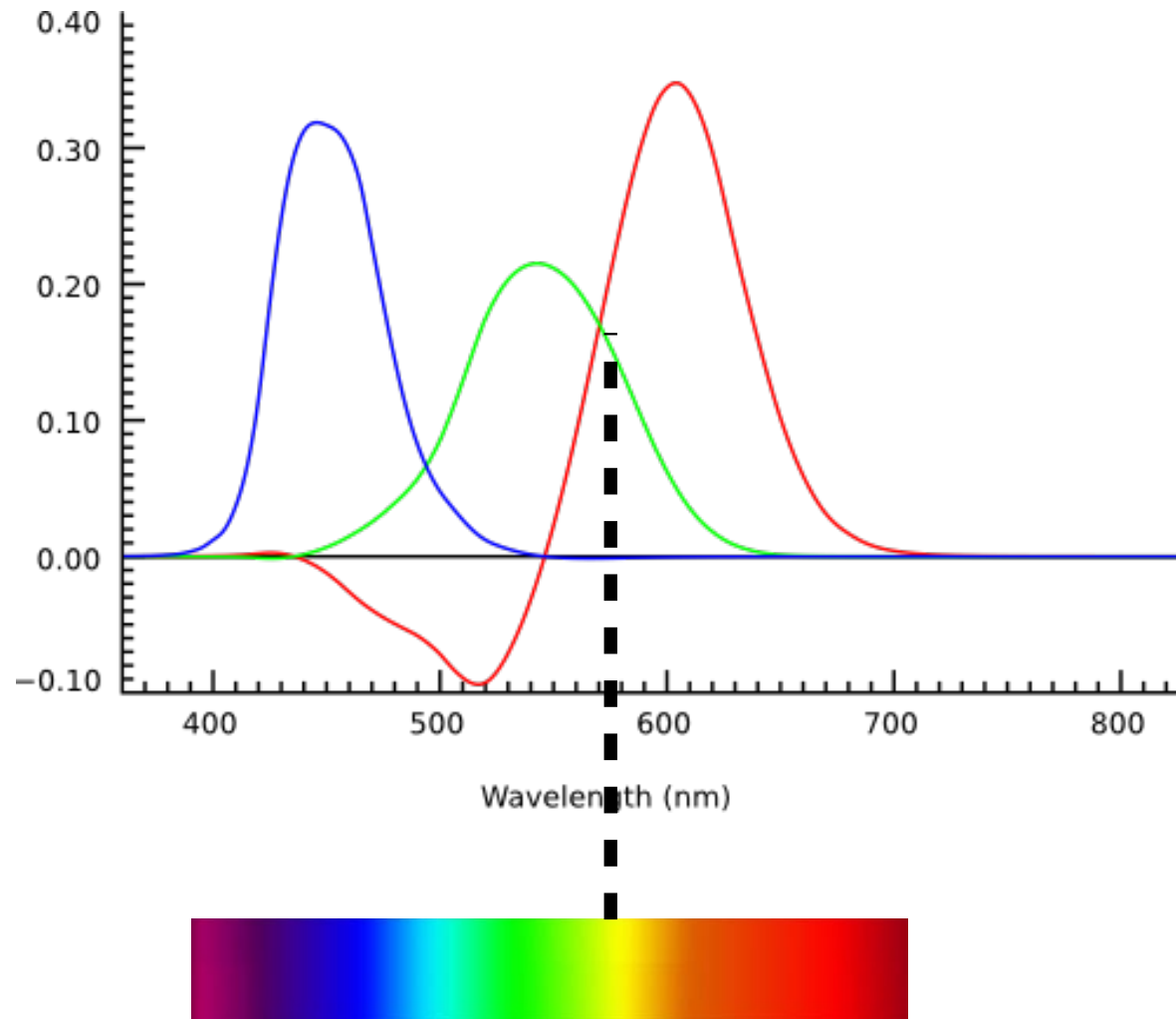


Tristimulus color matching





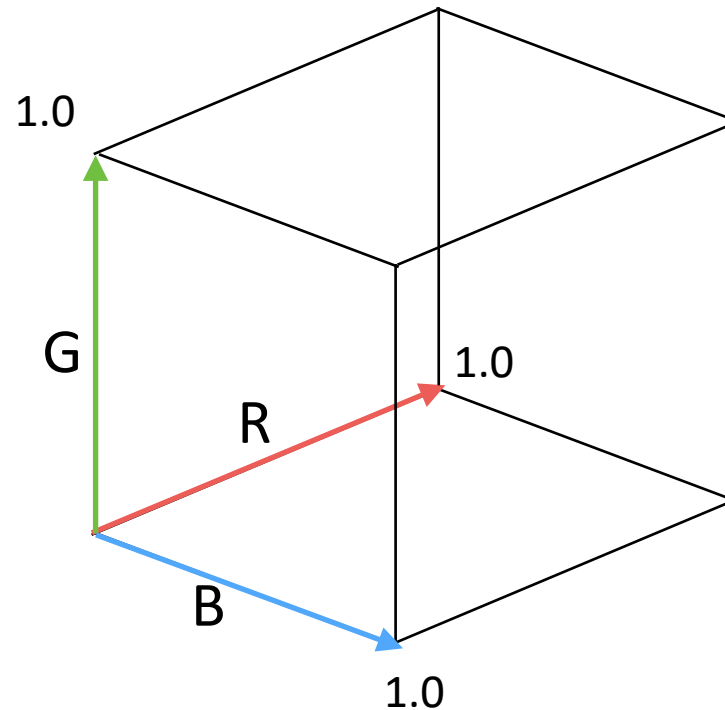




RGB color space

Each point within the cube is defined by a 3D vector (r, g, b) and represents a unique color

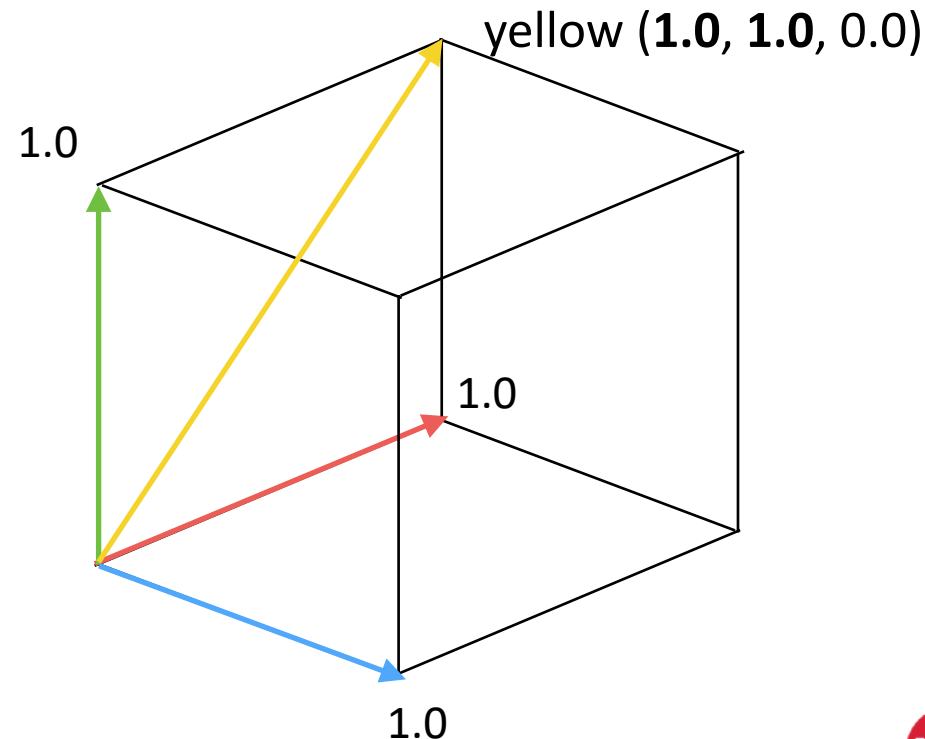
The **r**, **g**, **b** coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



RGB color space

Each point within the cube is defined by a 3D vector (r, g, b) and represents a unique color

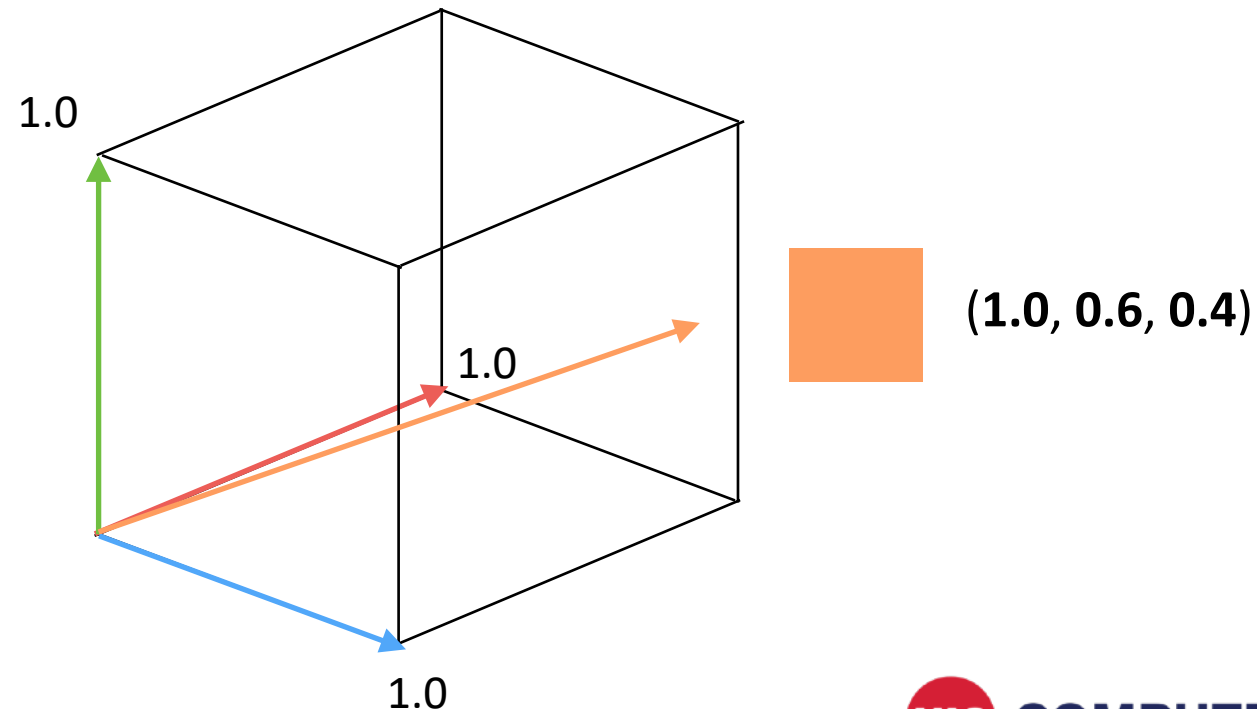
The r , g , b coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



RGB color space

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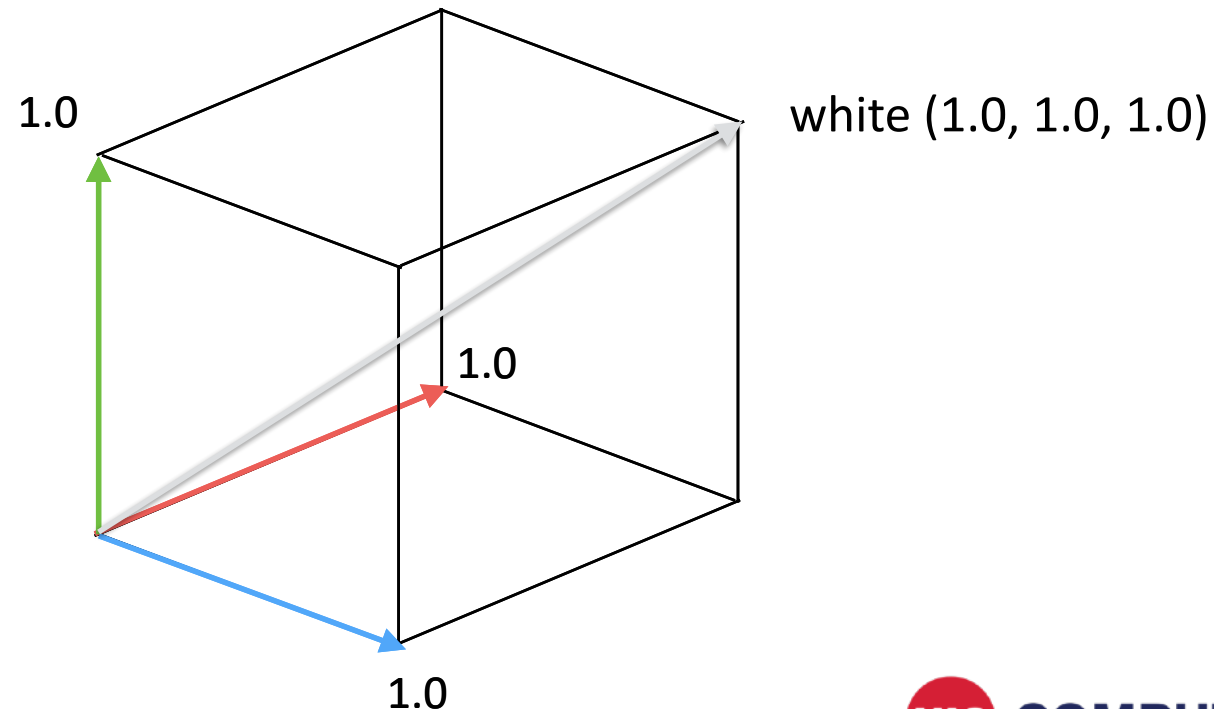
The **r**, **g**, **b** coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



RGB color space

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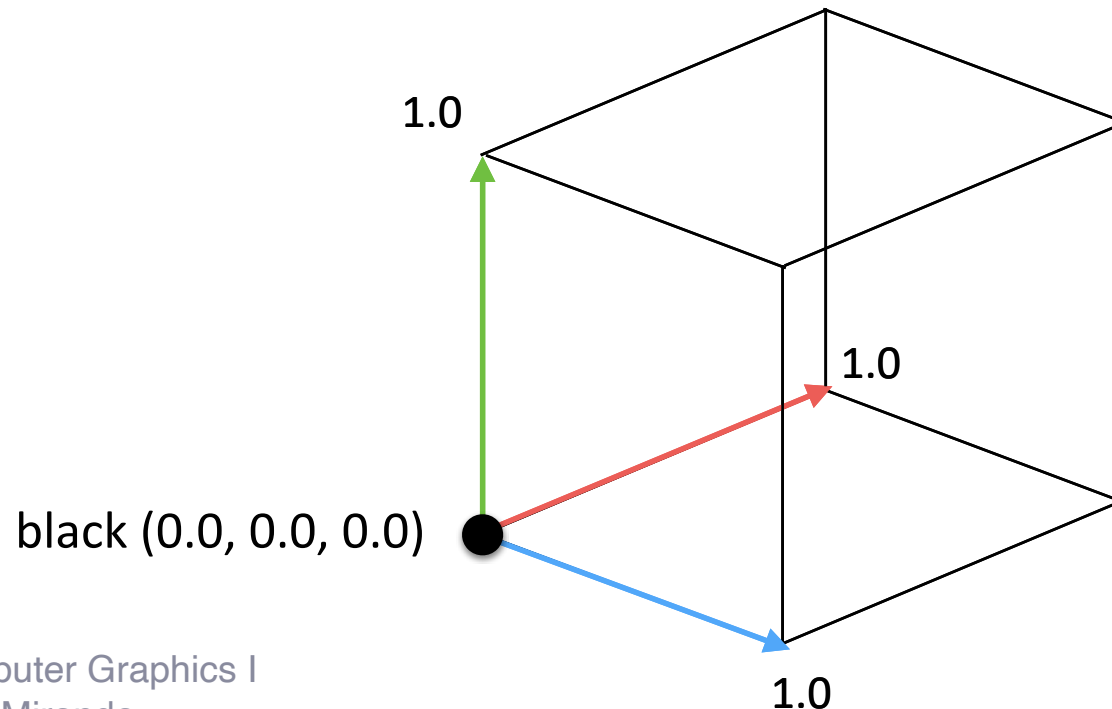
The **r**, **g**, **b** coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



RGB color space

Each point within the cube is defined by a 3D vector (r, g, b) and represents a unique color

The **r**, **g**, **b** coordinates of the vector reflect a combination of red, green, and blue primaries needed to reproduce the color



What primary colors should I use to reproduce the visible light spectrum by mixing?

- red, yellow, blue
- red, green, blue
- orange, green, violet
- cyan, magenta, yellow
- all of the above

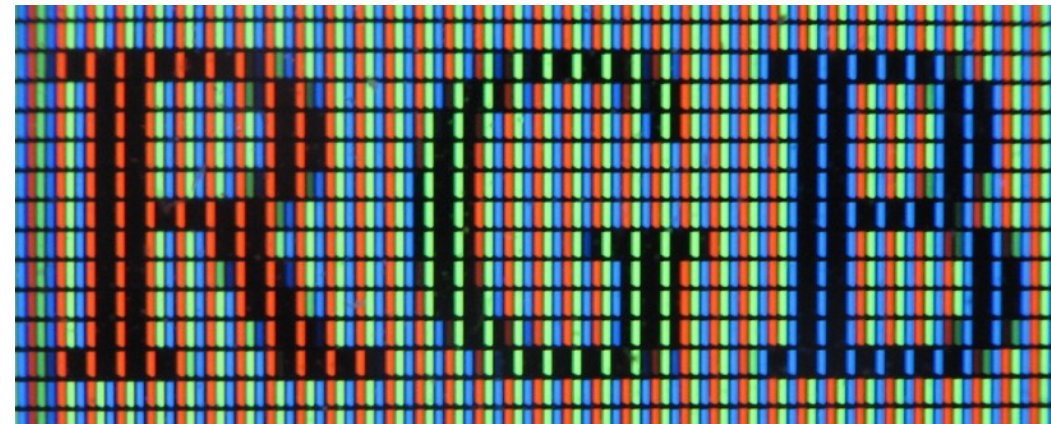
Light mixing (RGB)

Additive mixing of colored lights



Light mixing (RGB)

LCD display closeup



Wikipedia

Ink mixing (CMY / CMYK)

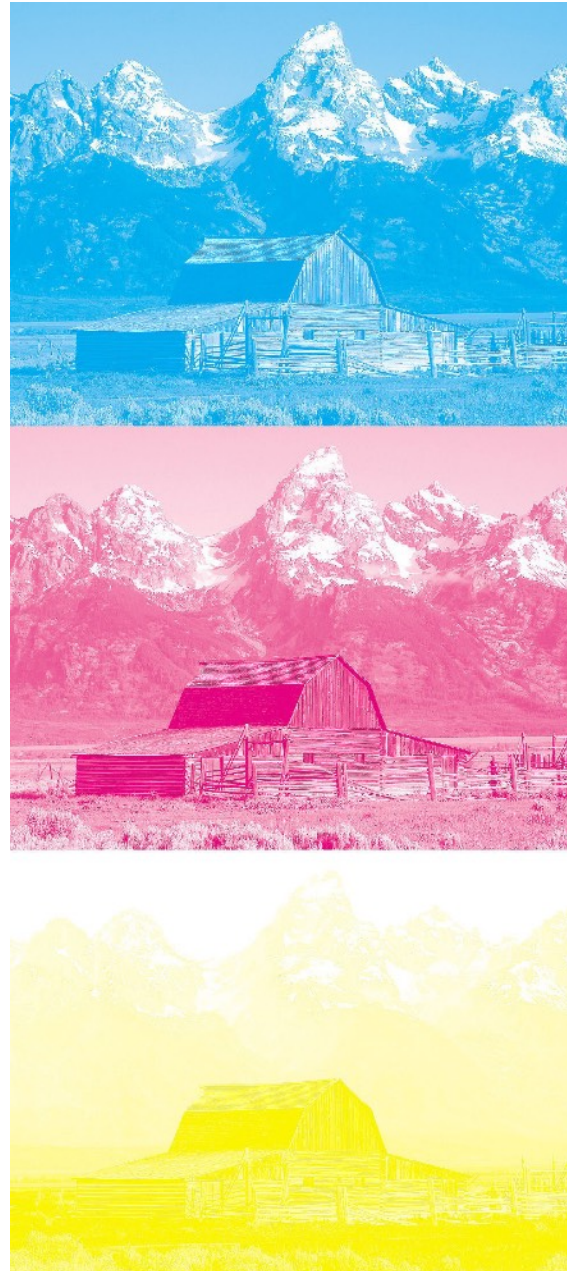
Subtractive mixing of inks printed on white paper



Color picture



CMY composite

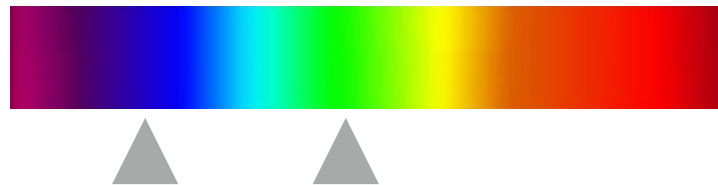
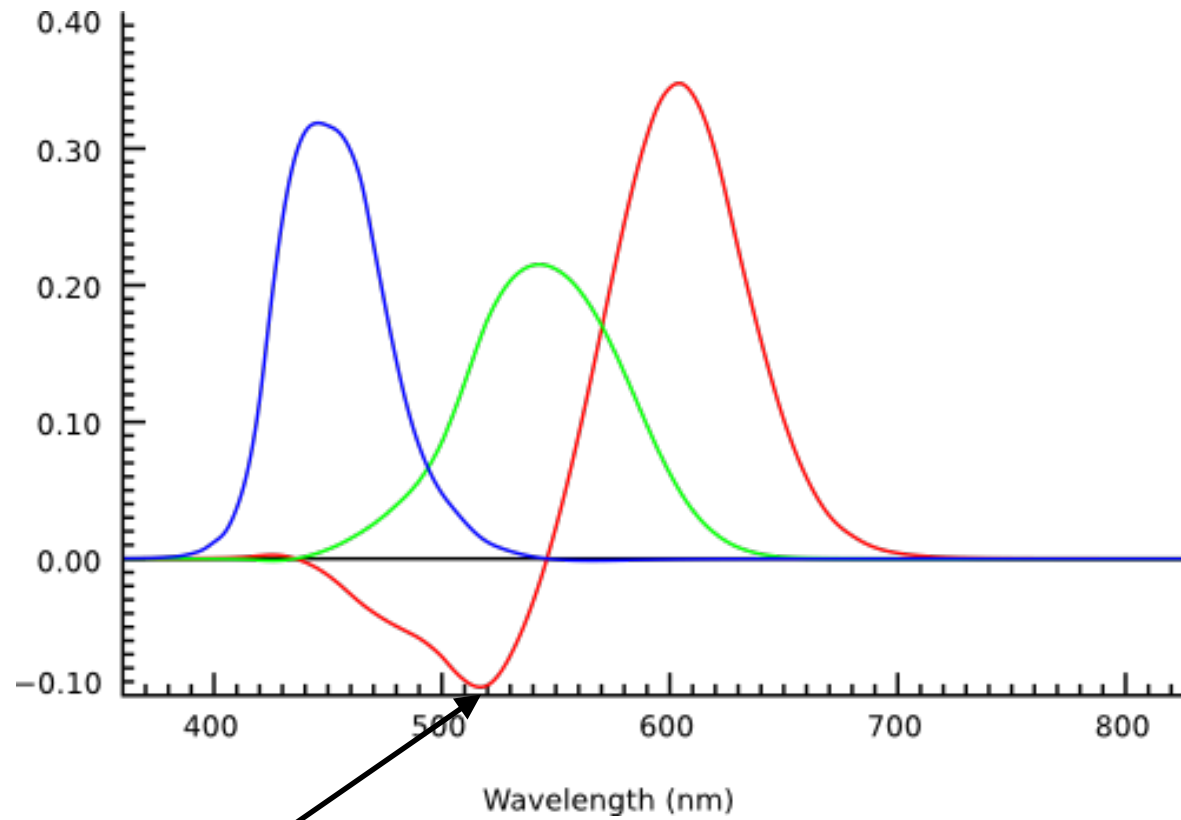


CMYK

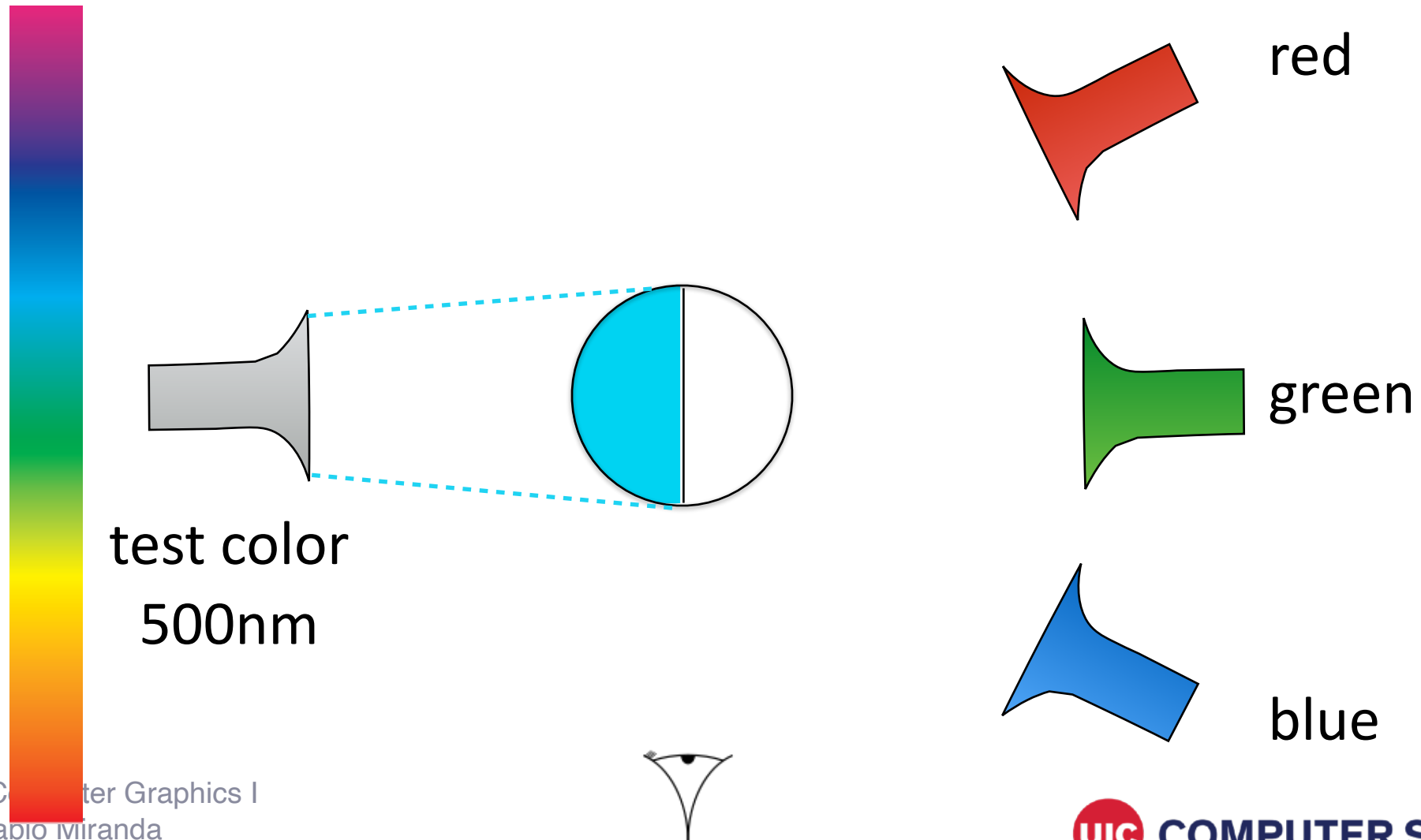


what colors combination can be used to re-producing the visible light spectrum by mixing?

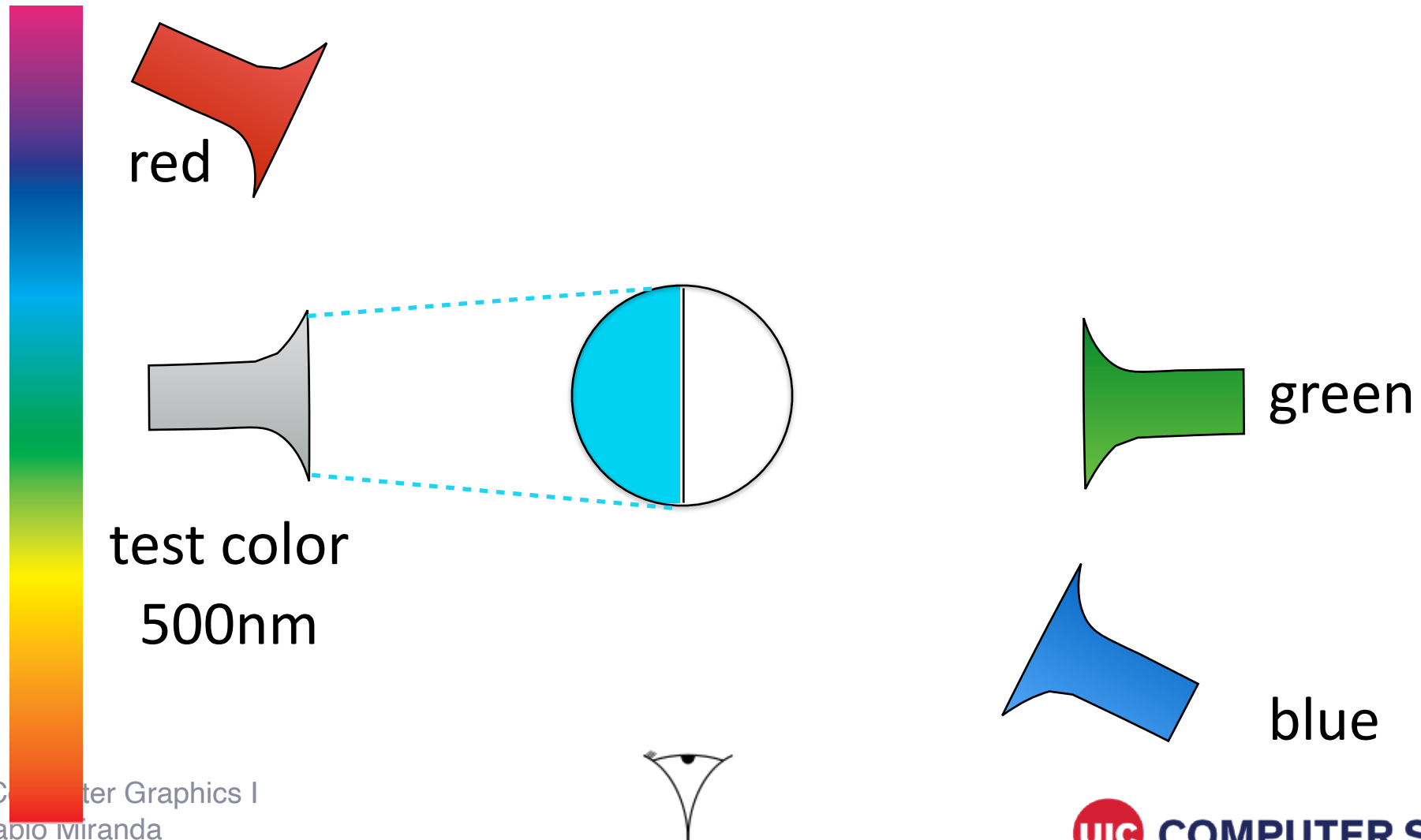
- red, yellow, blue
- red, green, blue
- orange, green, violet
- cyan, magenta, yellow
- **all of the above , almost**



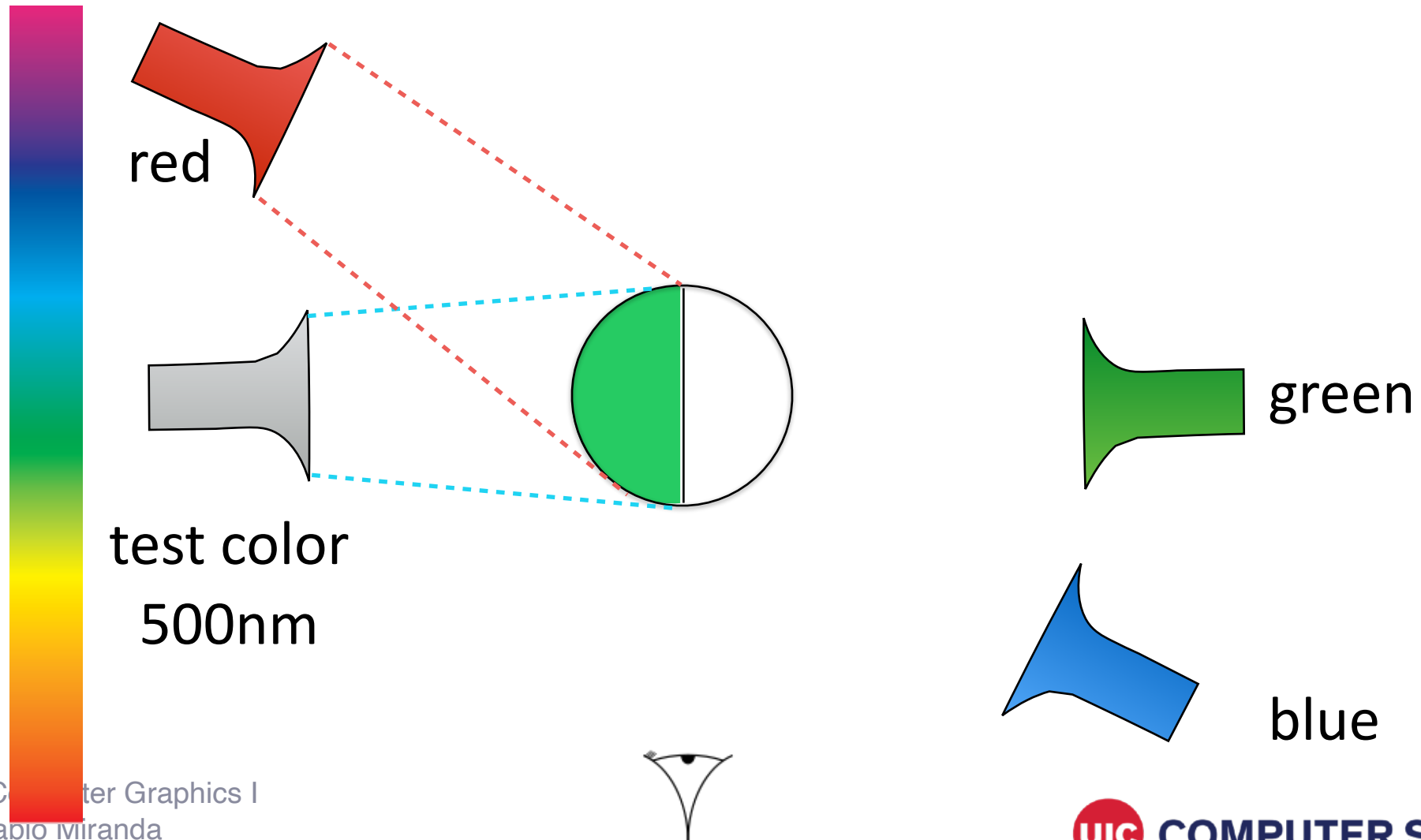
Tristimulus color matching



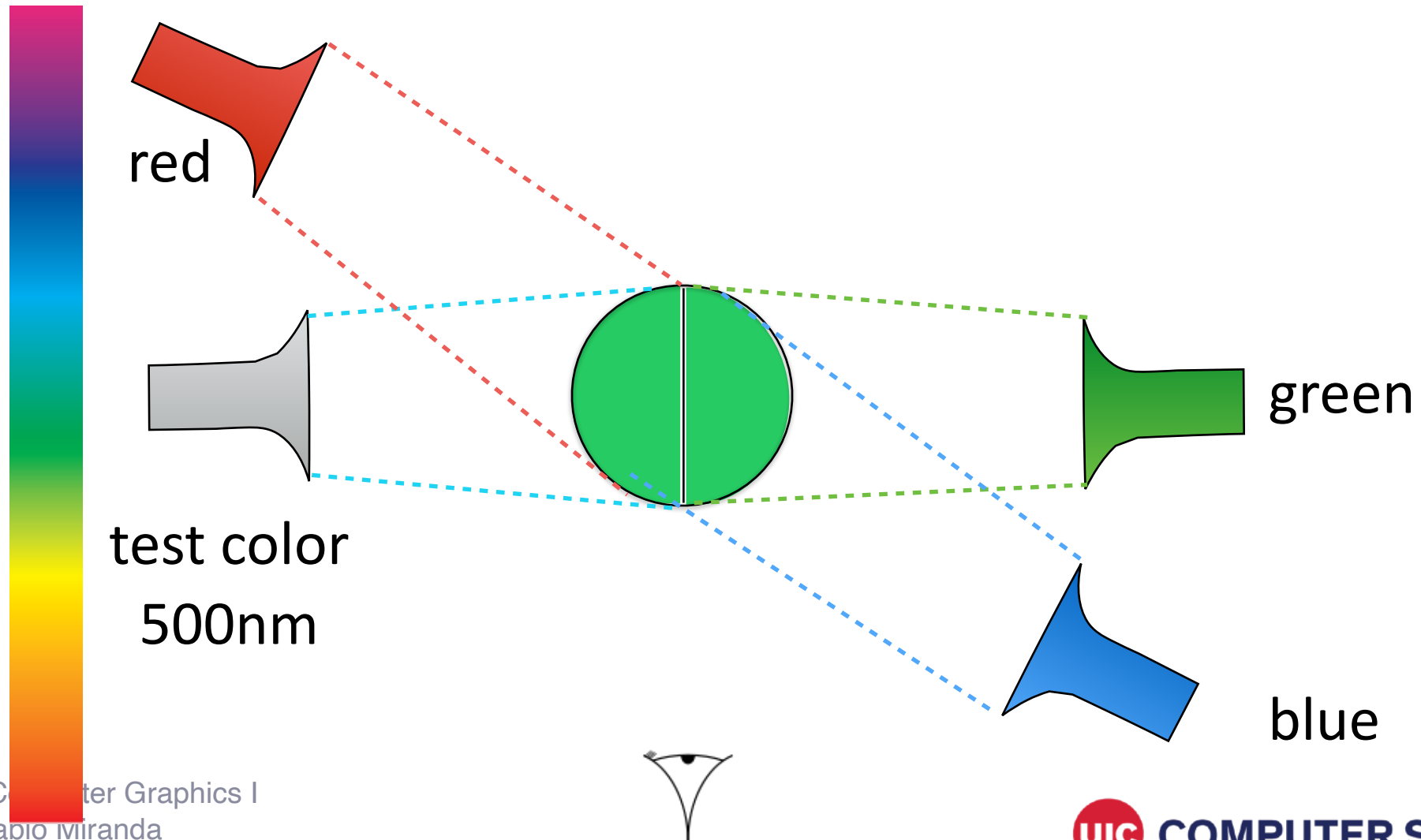
Tristimulus color matching

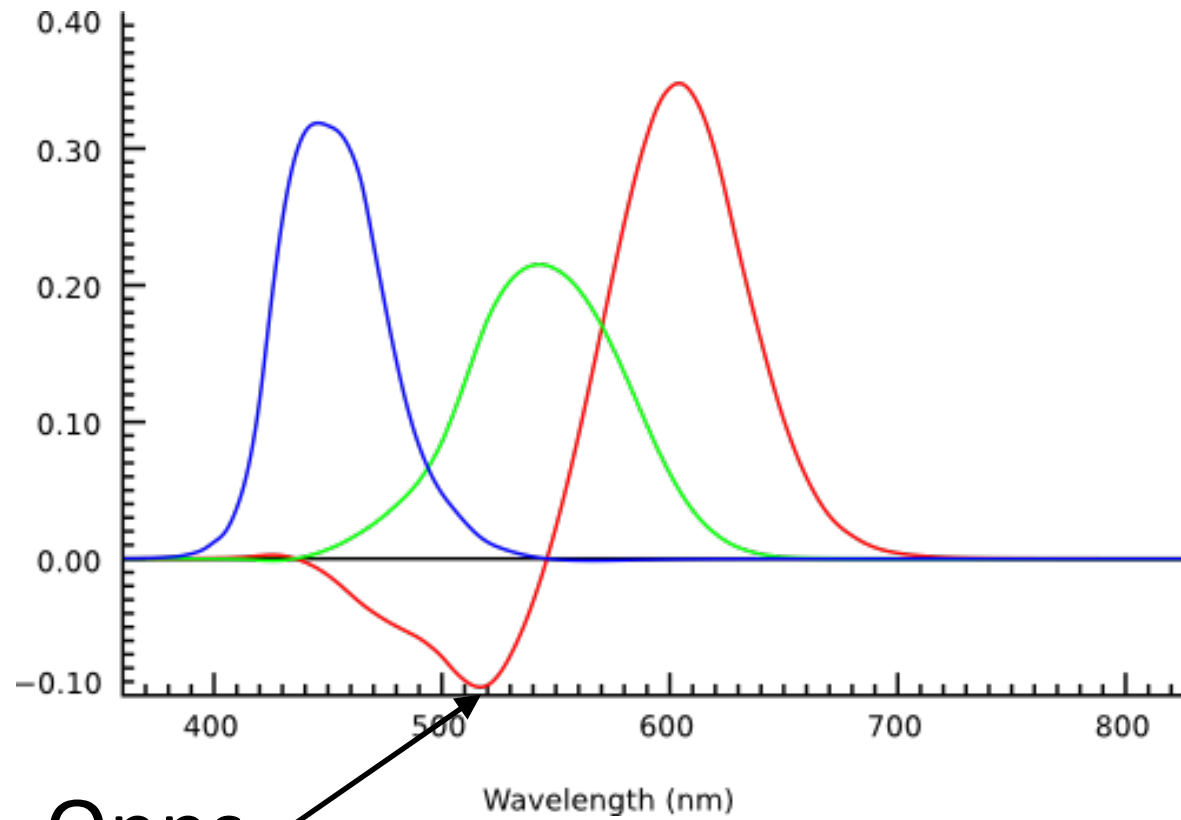


Tristimulus color matching

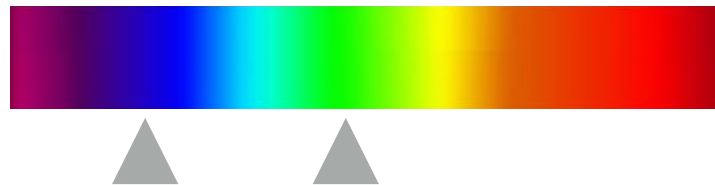


Tristimulus color matching

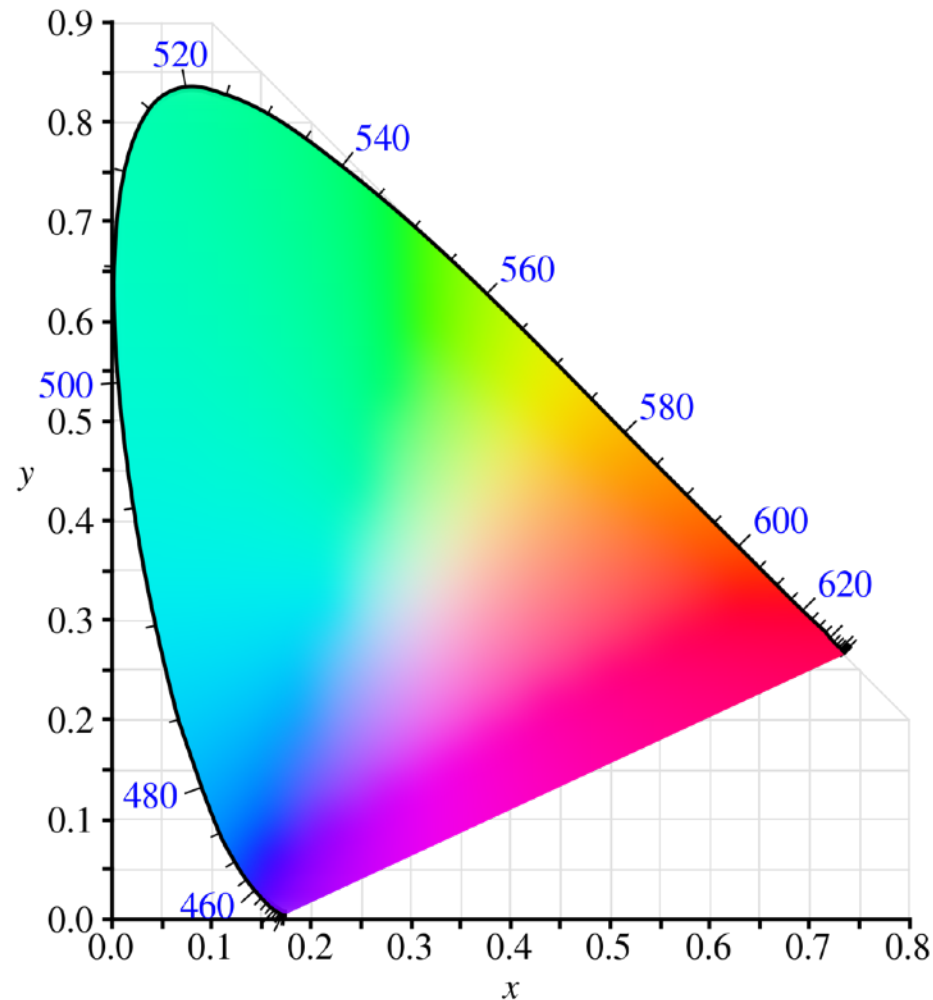




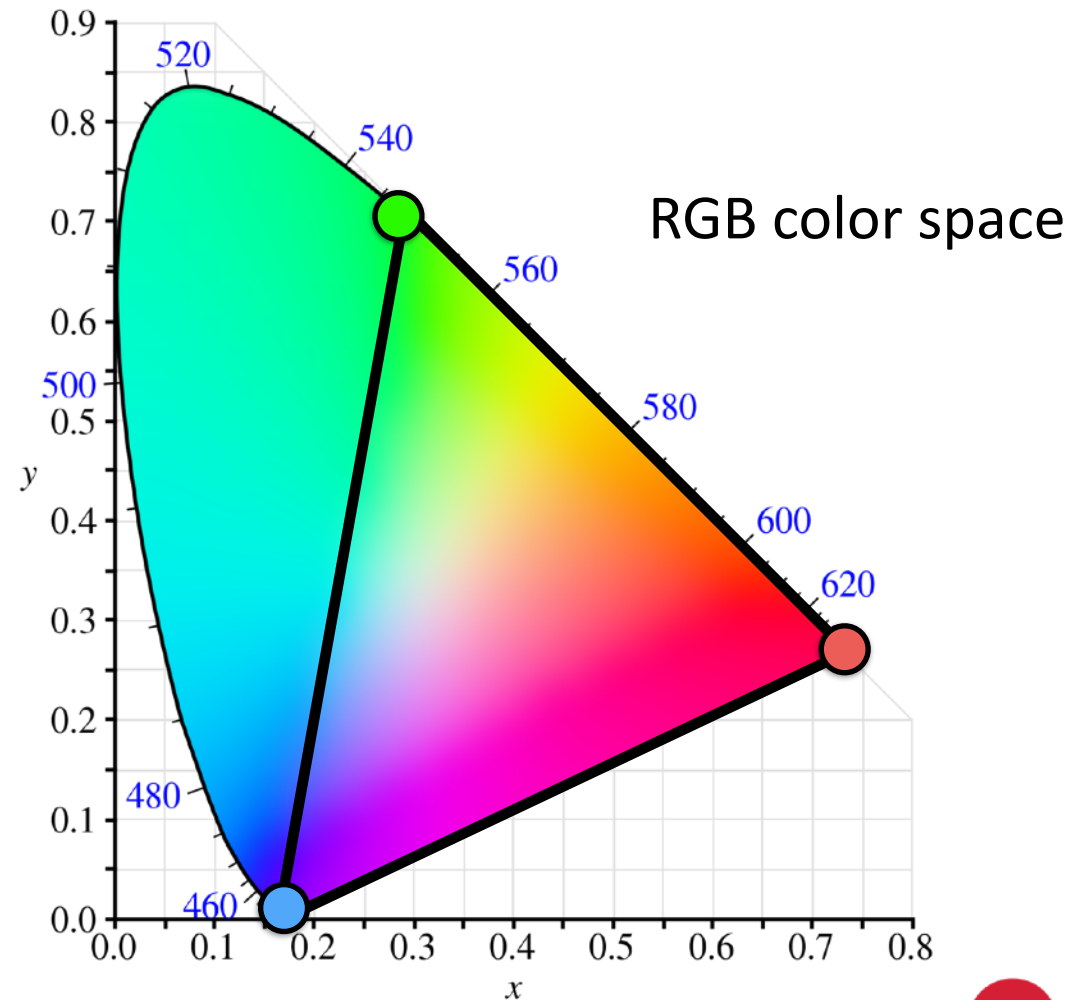
Opps



CIE chromaticity diagram

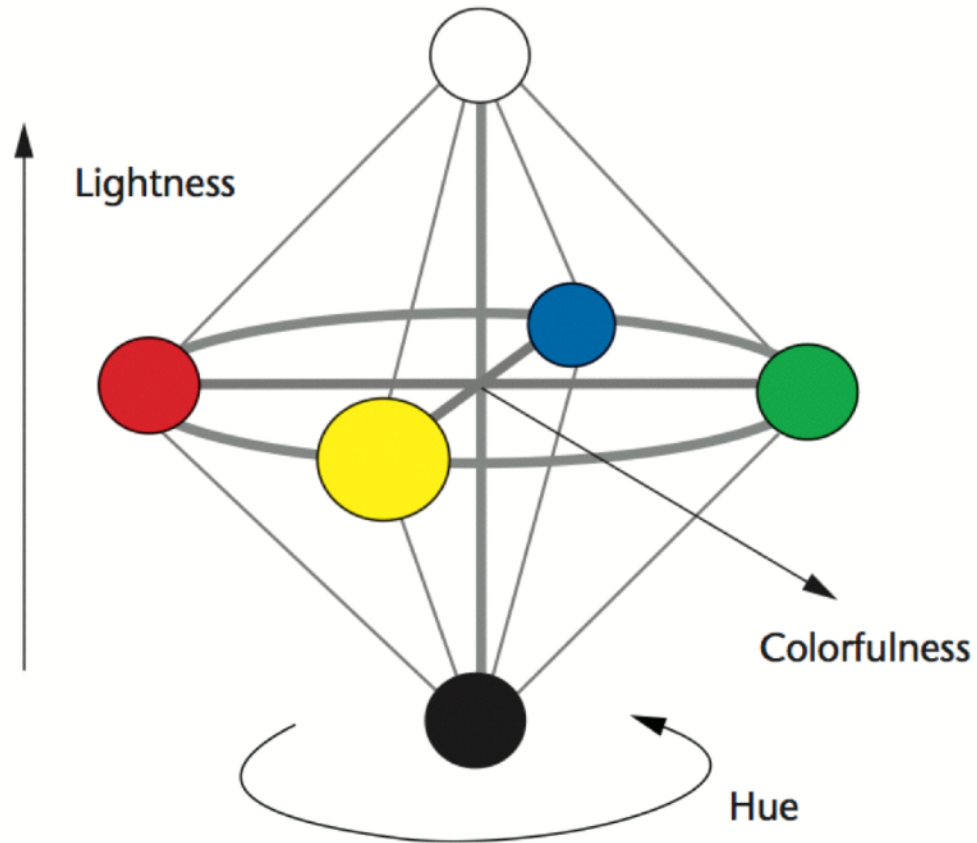


CIE chromaticity diagram



Perceptual color spaces

A change in the amount of color value should produce a proportional change in the way we see the color





hue



saturation



luminance

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.

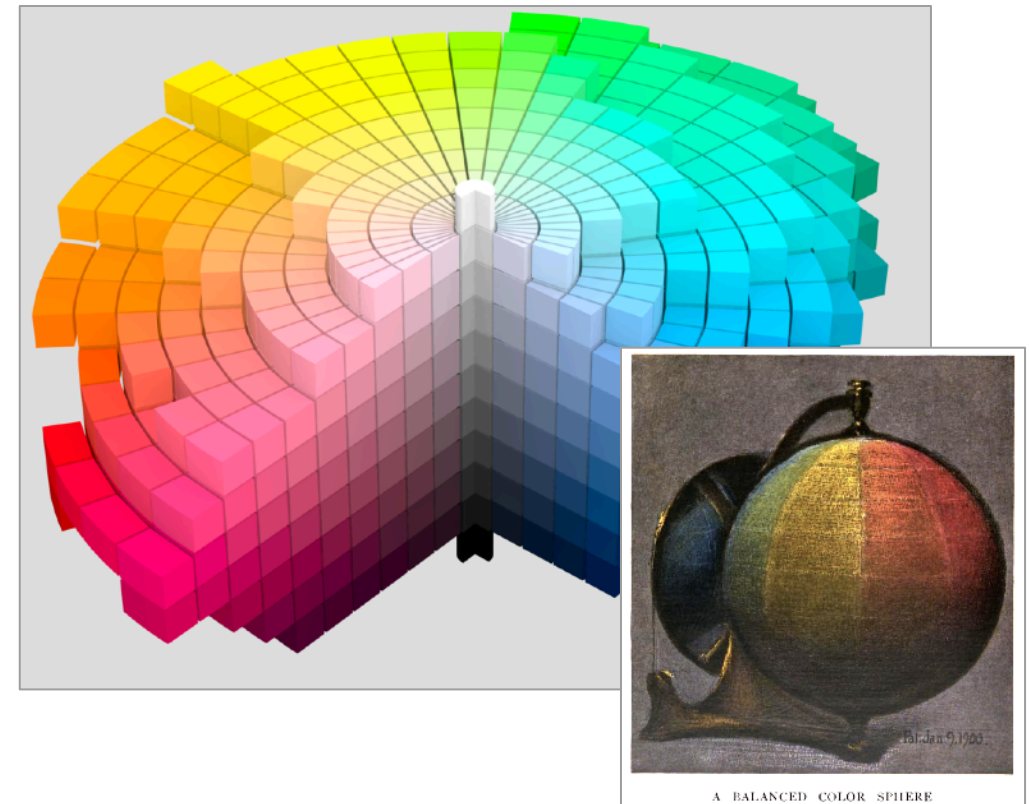
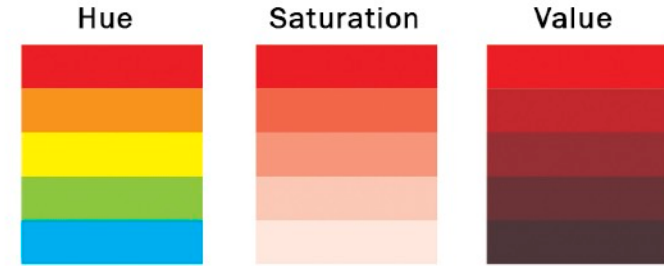


Image formation



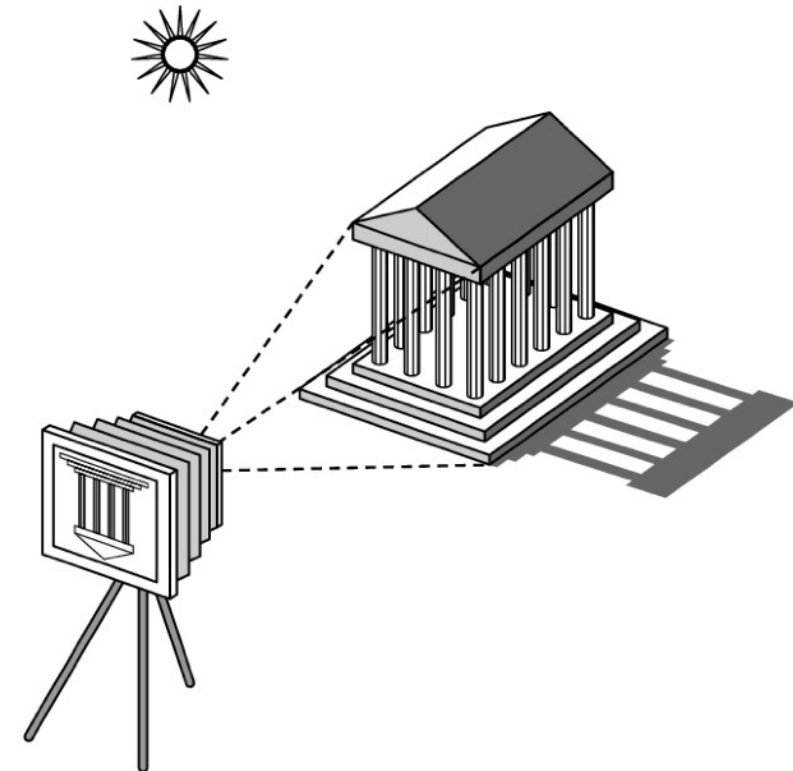
Image formation

In computer graphics, images are formed similarly to how we create images in the physical world:

- Objects
- Lights
- Human visual system (or a camera)

Elements of image formation

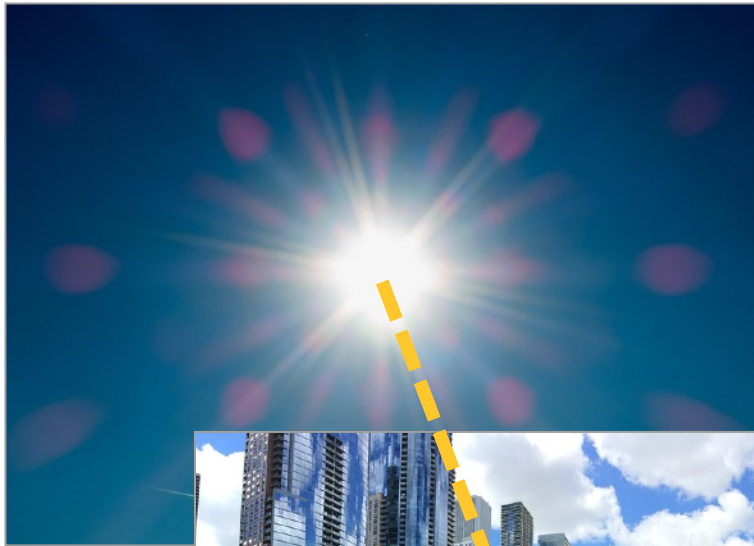
- Three independent elements:
 - Objects
 - Viewer
 - Light source
- Other attributes:
 - Material
 - Light color, direction



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

Elements of image formation

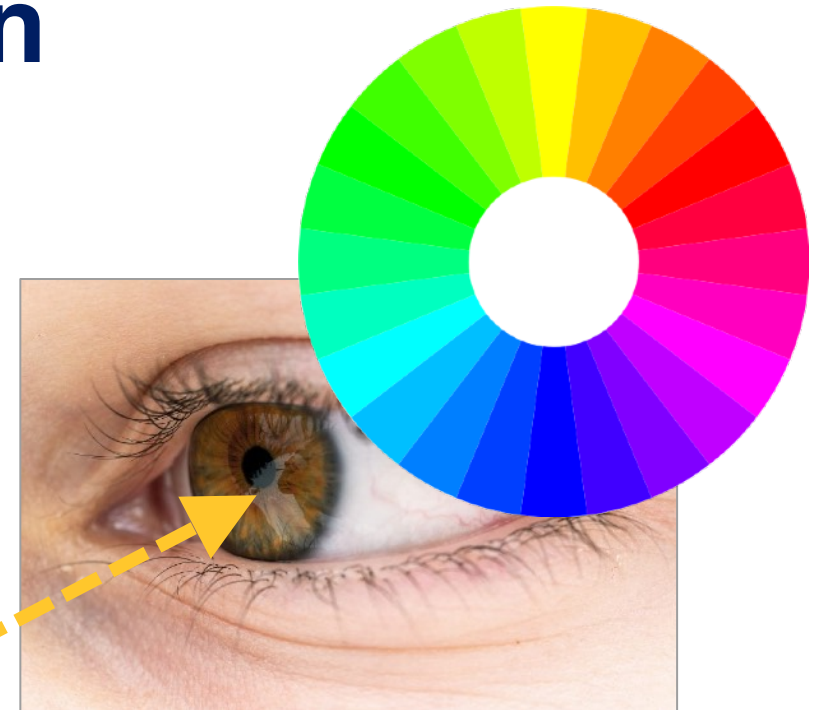
1. Light source emits photons



2. Photons interact with the environment: absorption, reflection



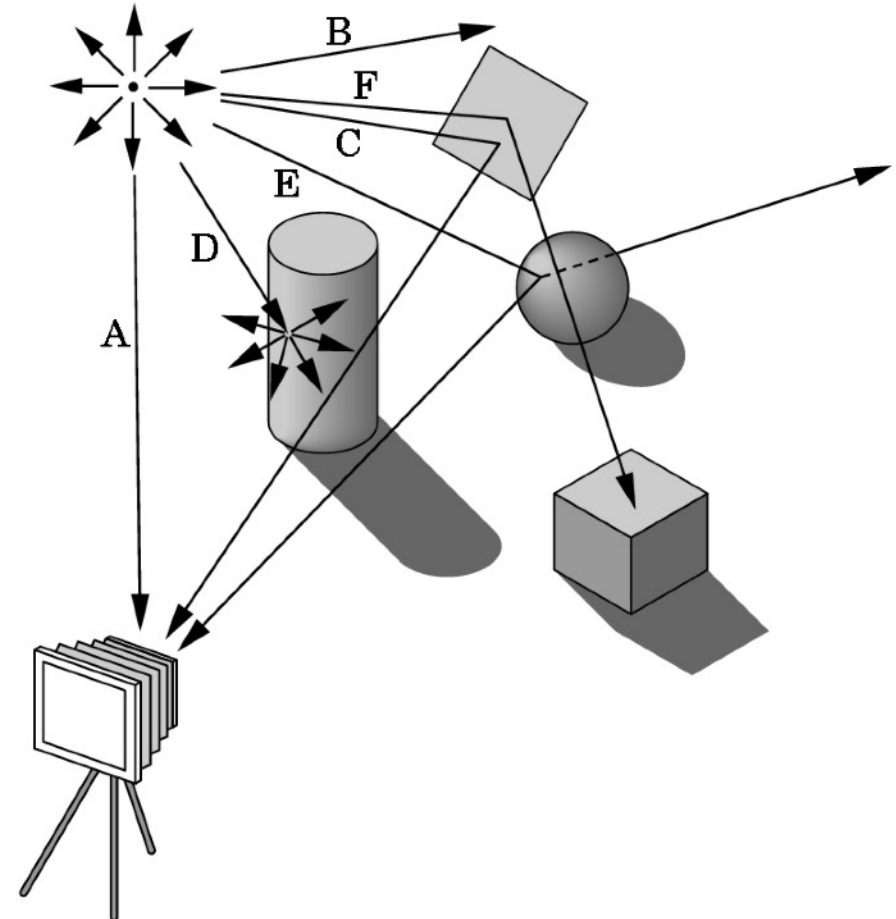
3. Some are captured by eye / camera



Tracing rays

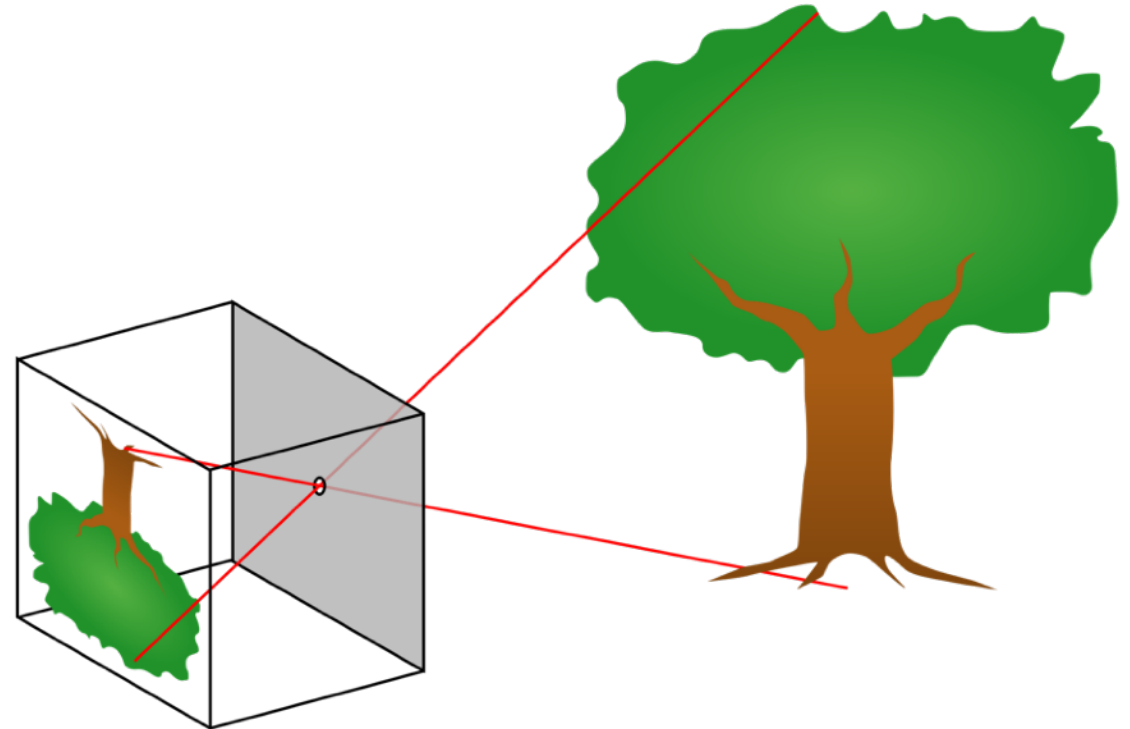
Follow rays of light from a light source, intersecting objects, and finding which rays enter the lens of the camera.

Computationally expensive!

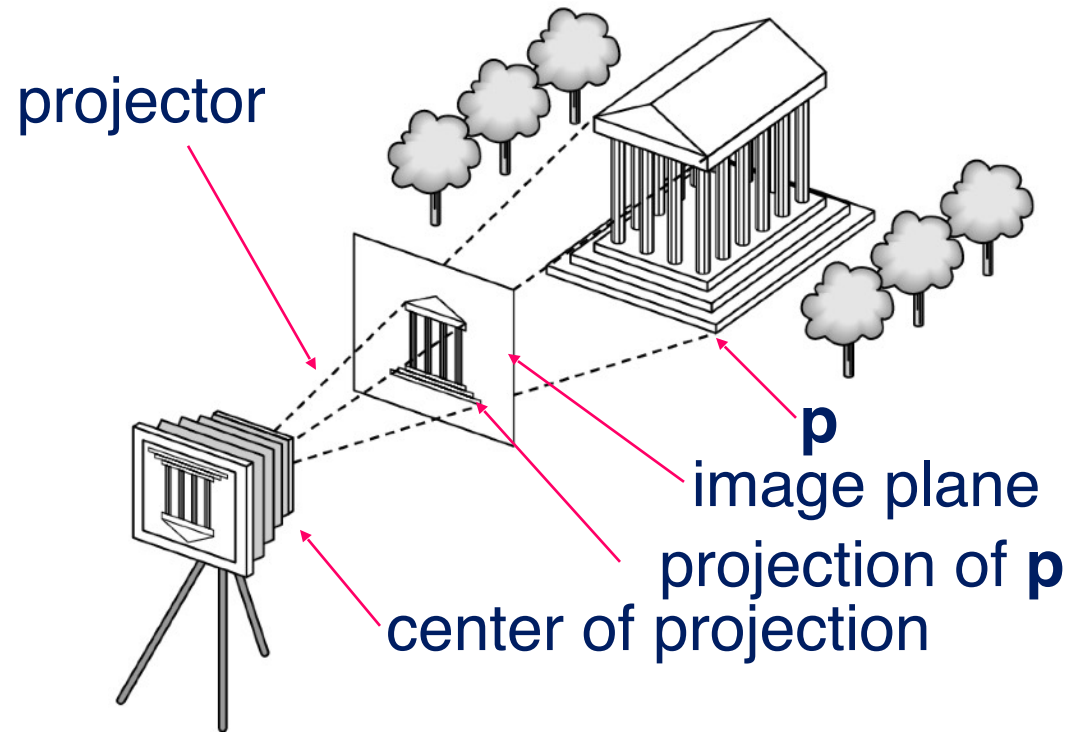


Pinhole camera

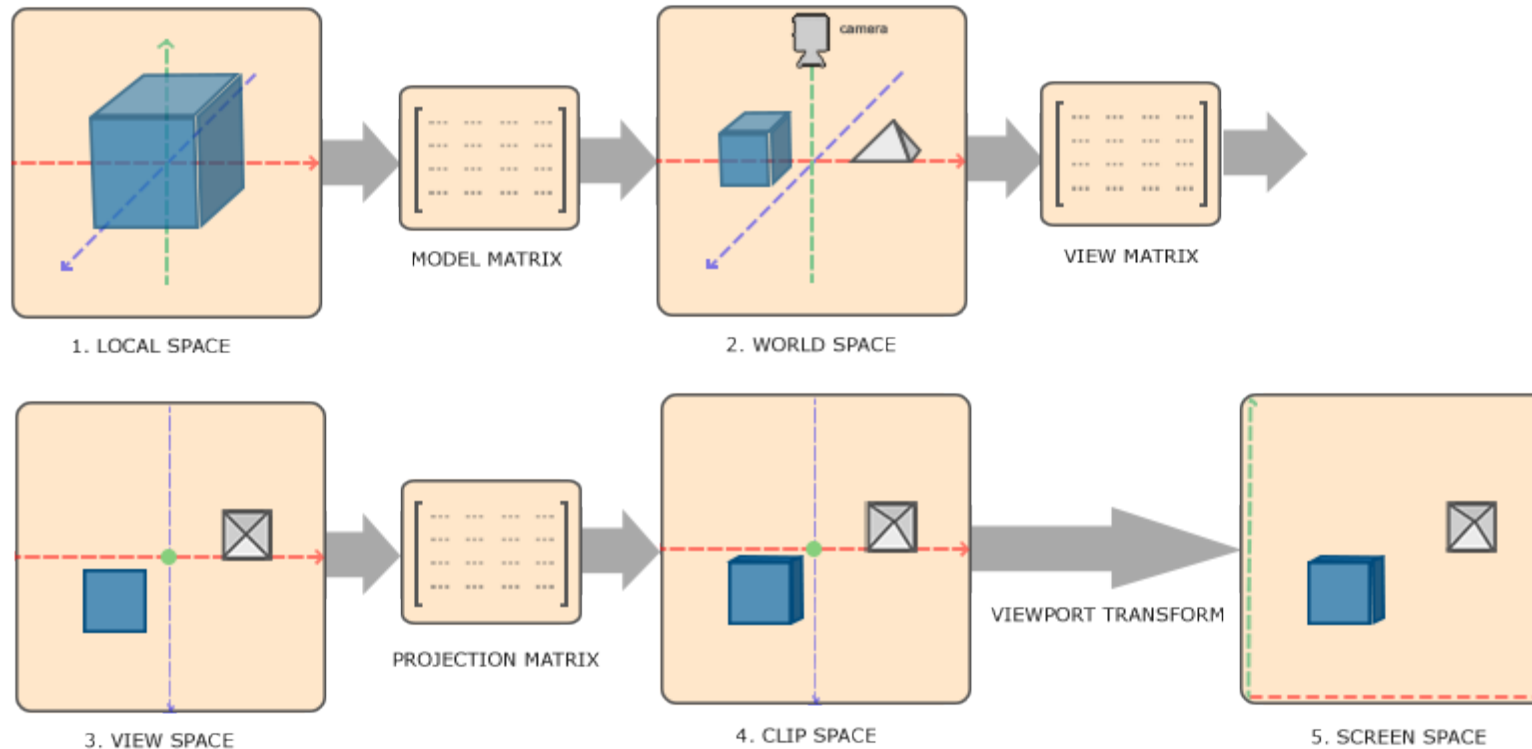
- Simple example of image formation
- A box with a small hole in the center of one side
- Film placed inside the box on the side opposite the pinhole



Synthetic camera model



Transformations



From: learnopengl.com

Images



Frame buffer: a 2D array with color values

Coming up next week...

