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Computer Vision

Color vision

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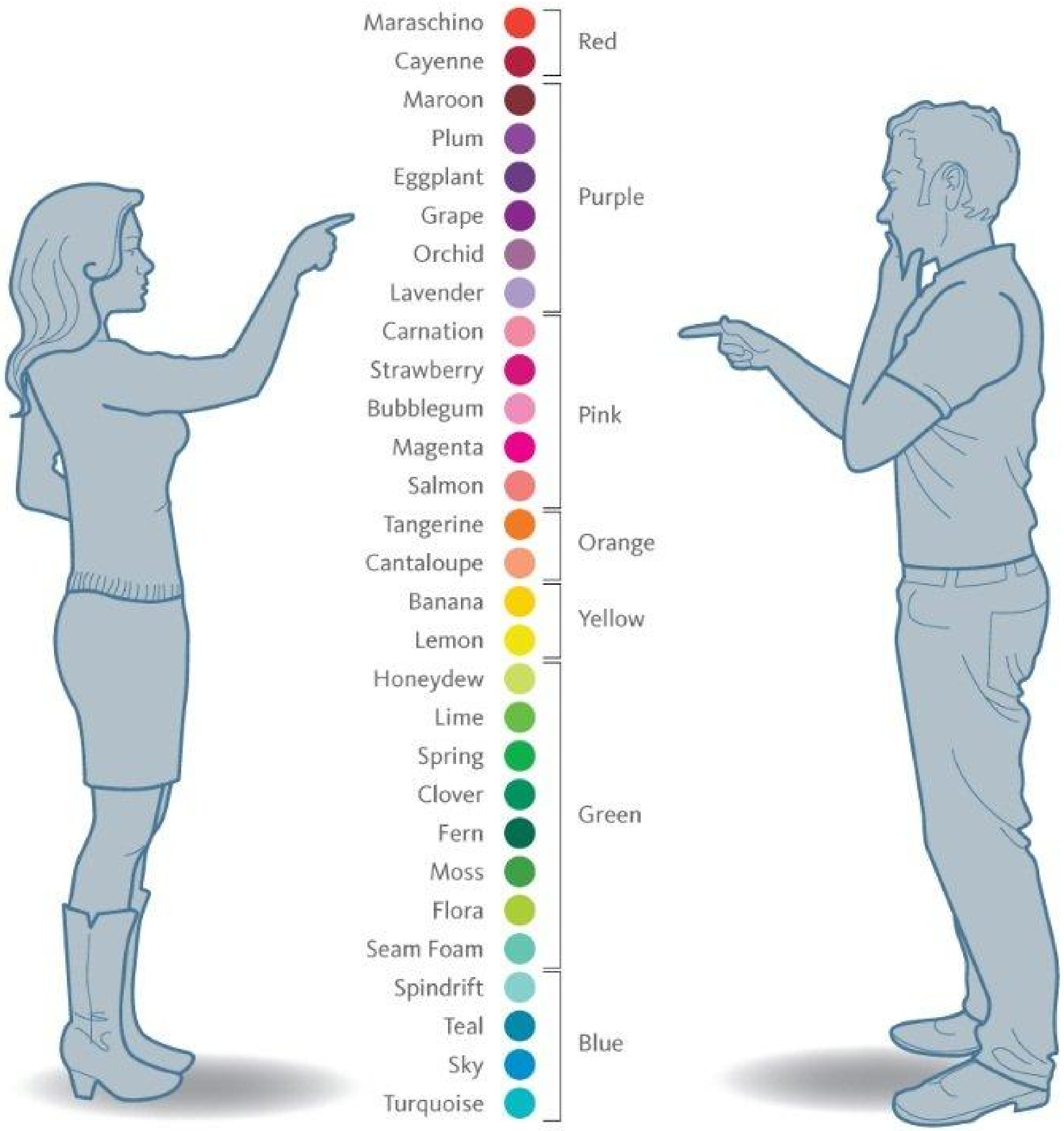
Color Vision



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Color Fundamentals

We have seen that we perceive light radiation which is characterized by a certain intensity and wavelength

In 1660 Newton discovered that If we let white light go through a prism, the light is separated in various colors

Newton's intuition is that white is not a “pure” color, but is the **composition** of several colors.

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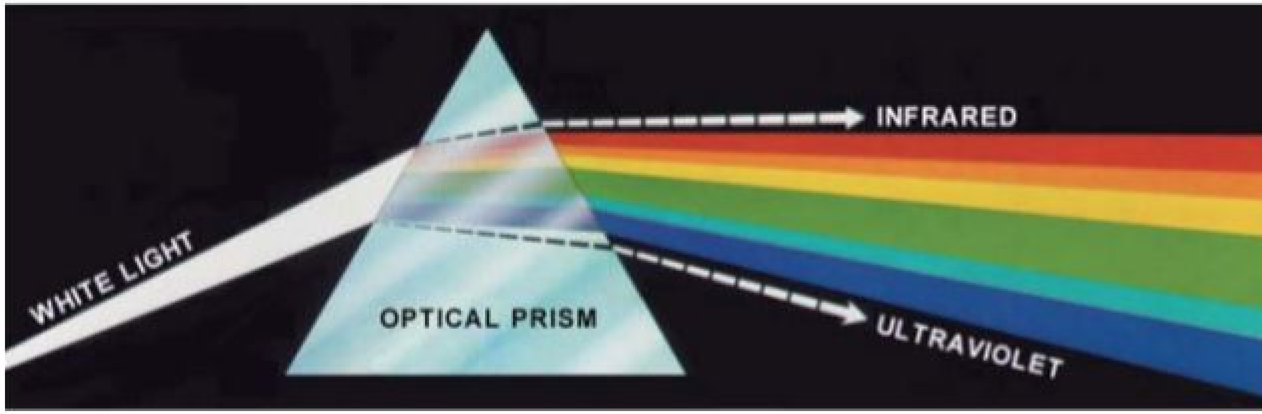
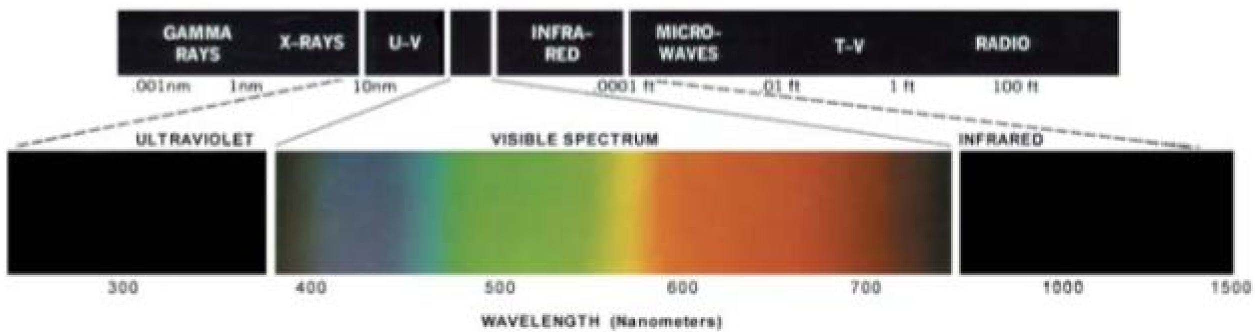
Color Fundamentals

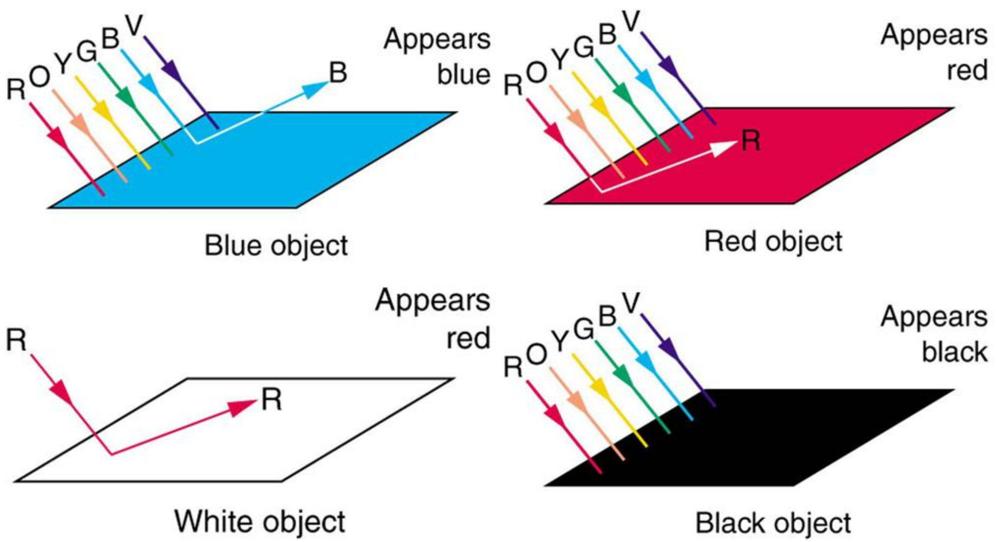




Color Fundamentals

The colors that humans and animals perceive in an object are determined by the nature of the light (wavelength) reflected from the object

- A body that favors reflectance in a limited range of the visible spectrum exhibits some shades of color



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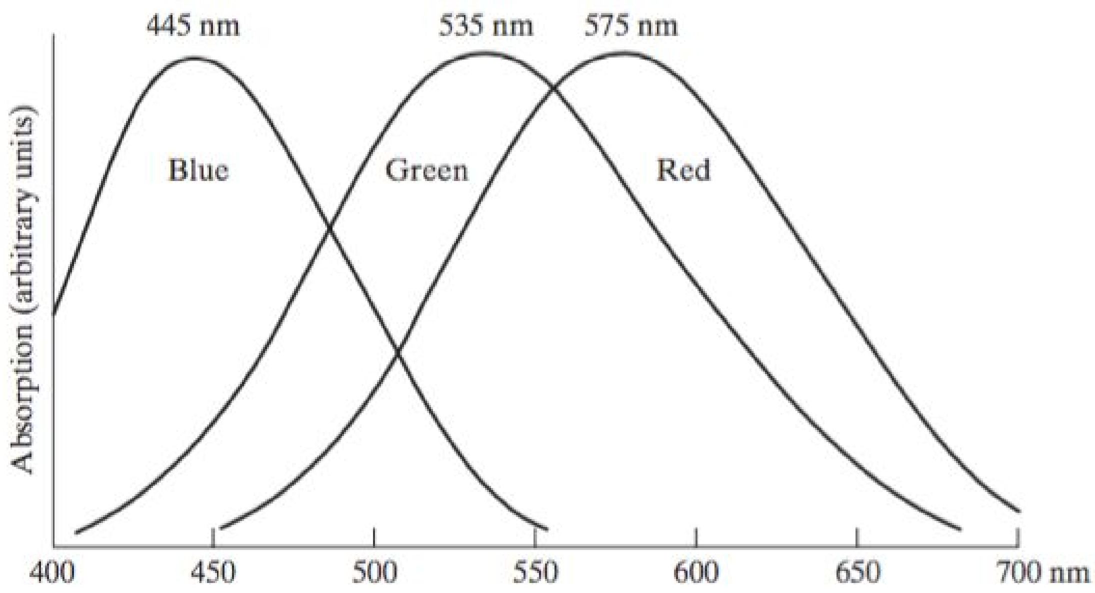
Human Vision

Physiologic research showed that in the human cornea there are three types of receptors for daylight vision (cones) sensible in different ways to the various frequencies of the electromagnetic radiation



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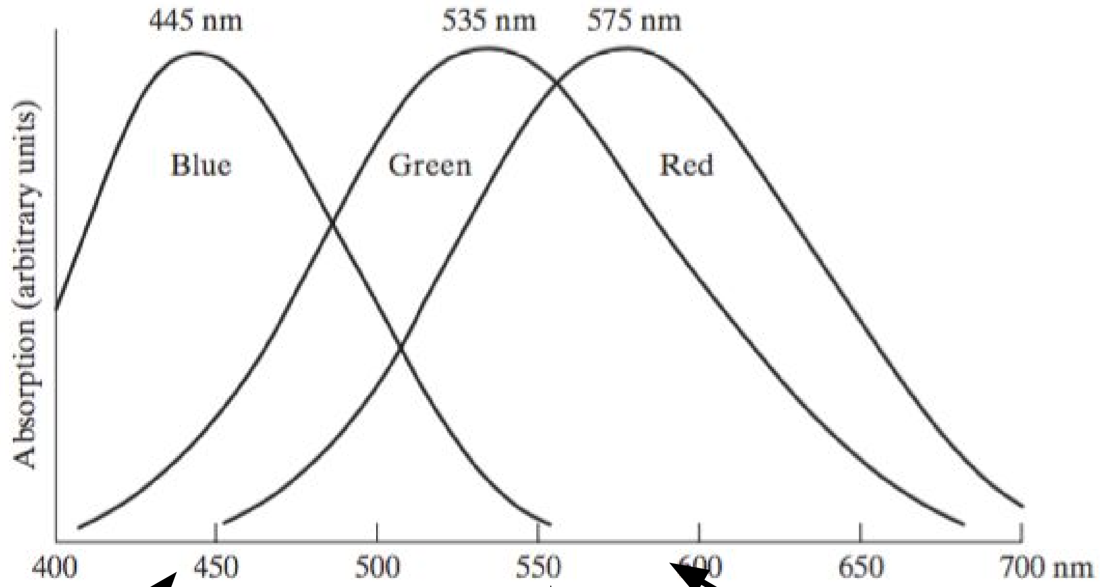
Human Vision



2% of the cones are sensitive to blue light (but are the most sensible)

33% of the cones are sensitive to green light

65% of the cones are sensitive to red light

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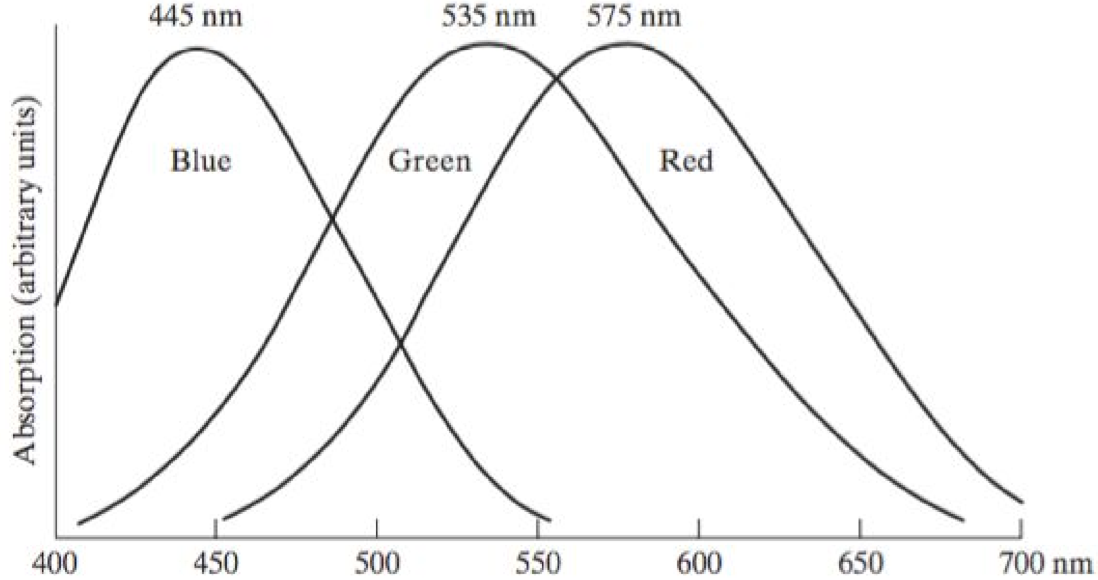
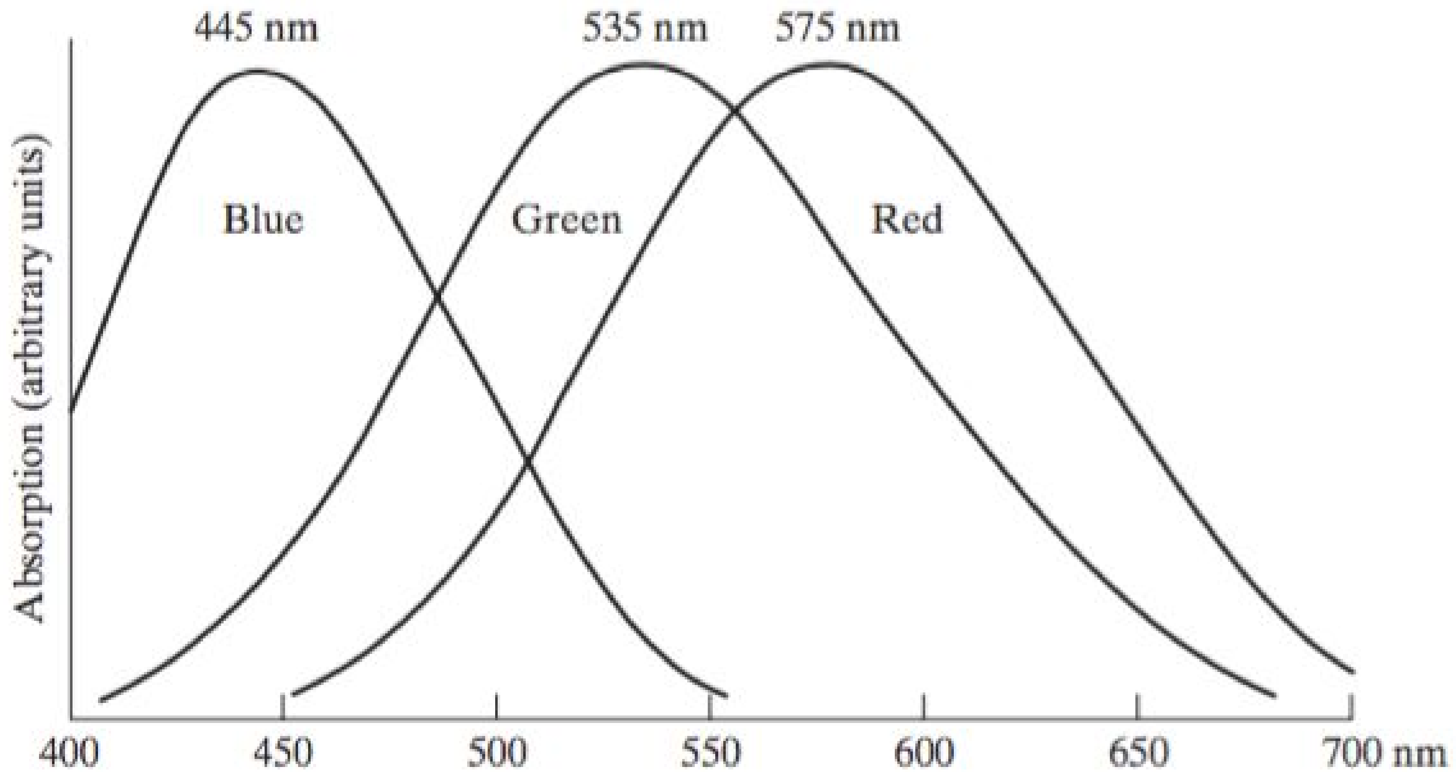
Human Vision



Our perception of colors is the result of the simultaneous stimulus (tri-stimulus) of the 3 different classes of cones

- Two lights with different spectra that produce the same response from these 3 types of receptors are perceived being of the same color.

Human Vision



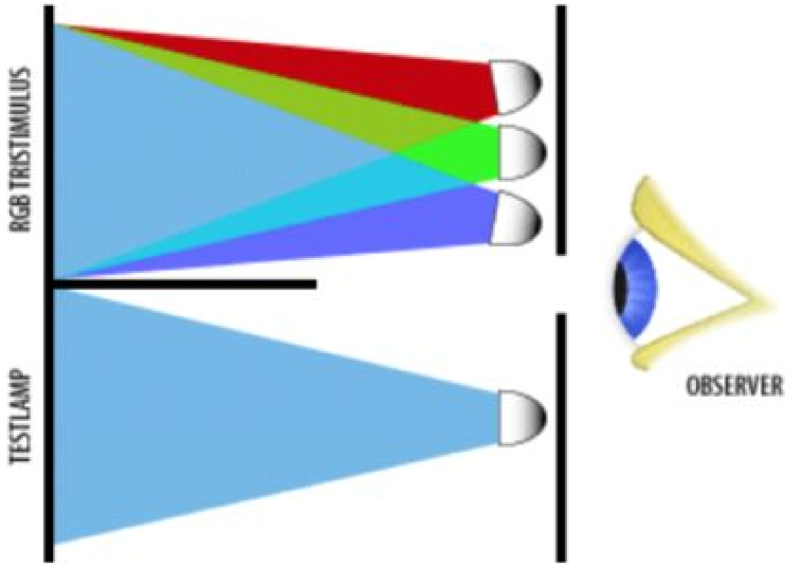
Our perception of colors is the result of the simultaneous stimulus (tri-stimulus) of the 3 different classes of cones

Color Matching

We can try to characterize every monochromatic (single wavelength) color as a mixture of three suitably chosen primaries.

In the 1930s, the CIE defined the 3 primary colors:

1. RED: 700.0 nm
2. GREEN: 546.1 nm
3. BLUE: 435.8 nm



The function mapping the 3 primaries to any visible single wavelength was performed via color matching

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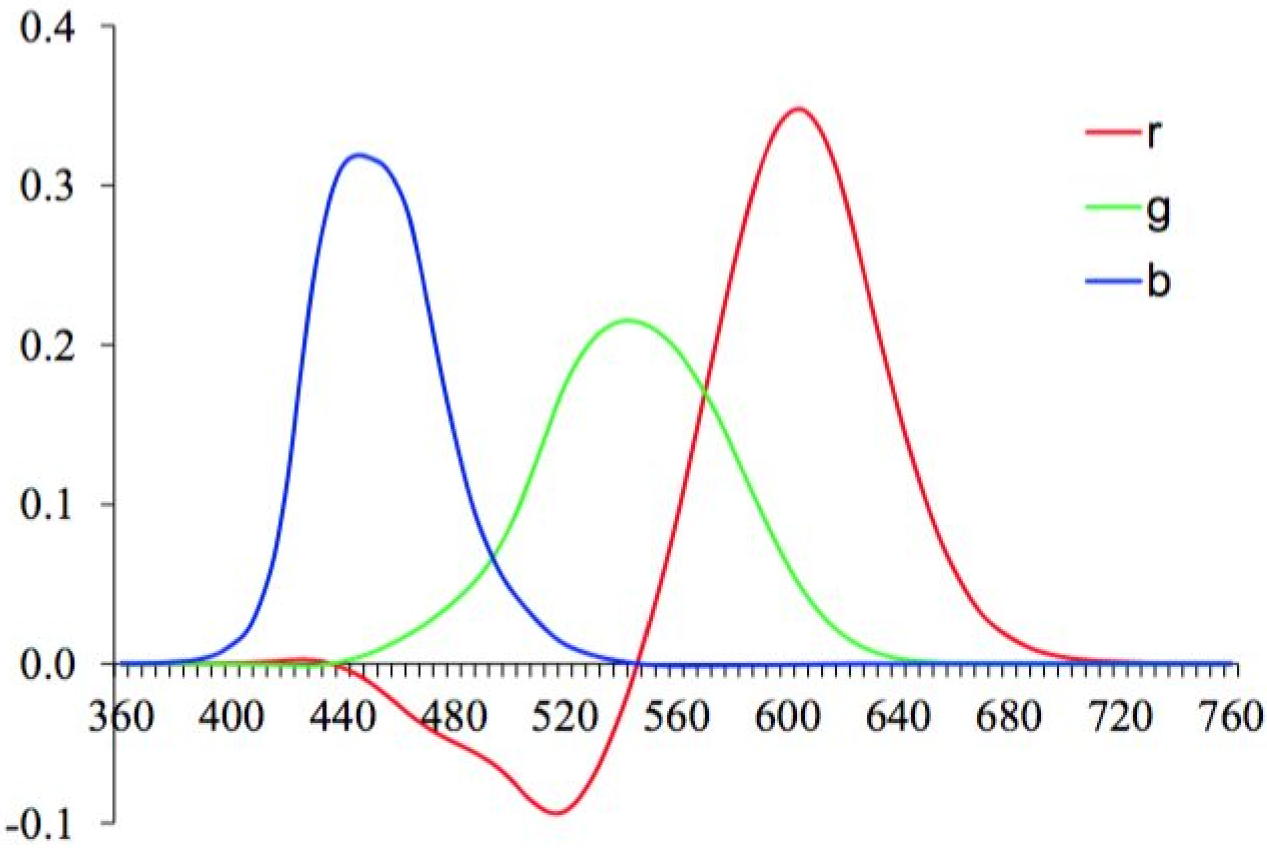
Color Matching function



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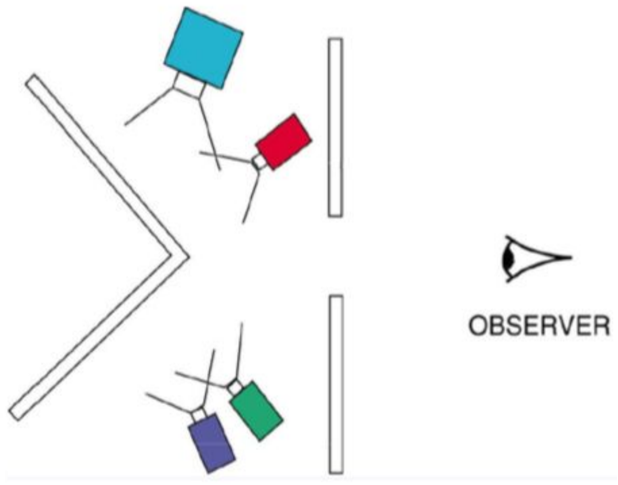
Color Matching

Almost all colors can be matched this way, except some shades between blue and green that cannot be reproduced

If we add some red to the test light, than we can match it using only green and blue.

> We need a negative amount of red to obtain some colors!

...Why?



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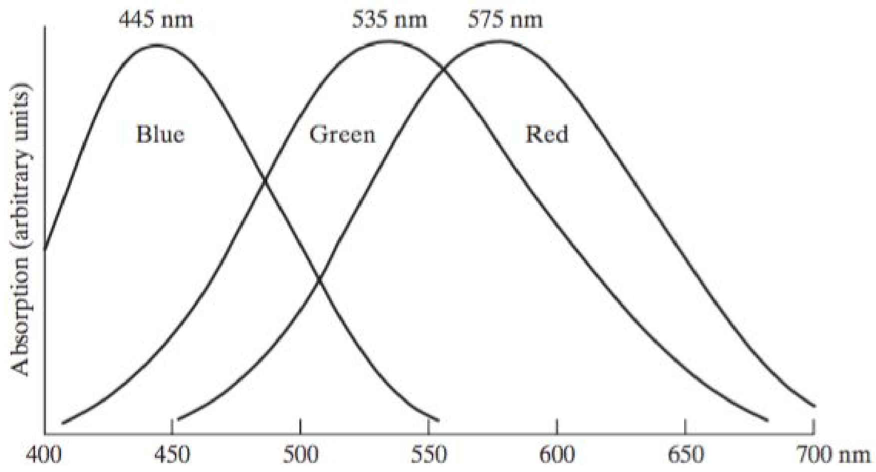
Color Matching

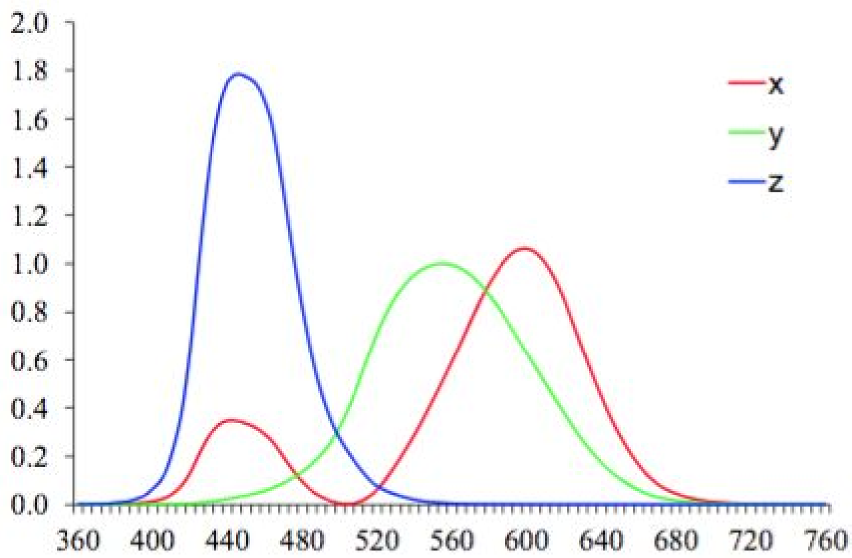
- The sensitivity regions of the three classes of cones overlap.



- The green light activates the red receptor more than the test light (cyan).
- To obtain the same response we need to reduce the activation of the red cones
(subtract some red)

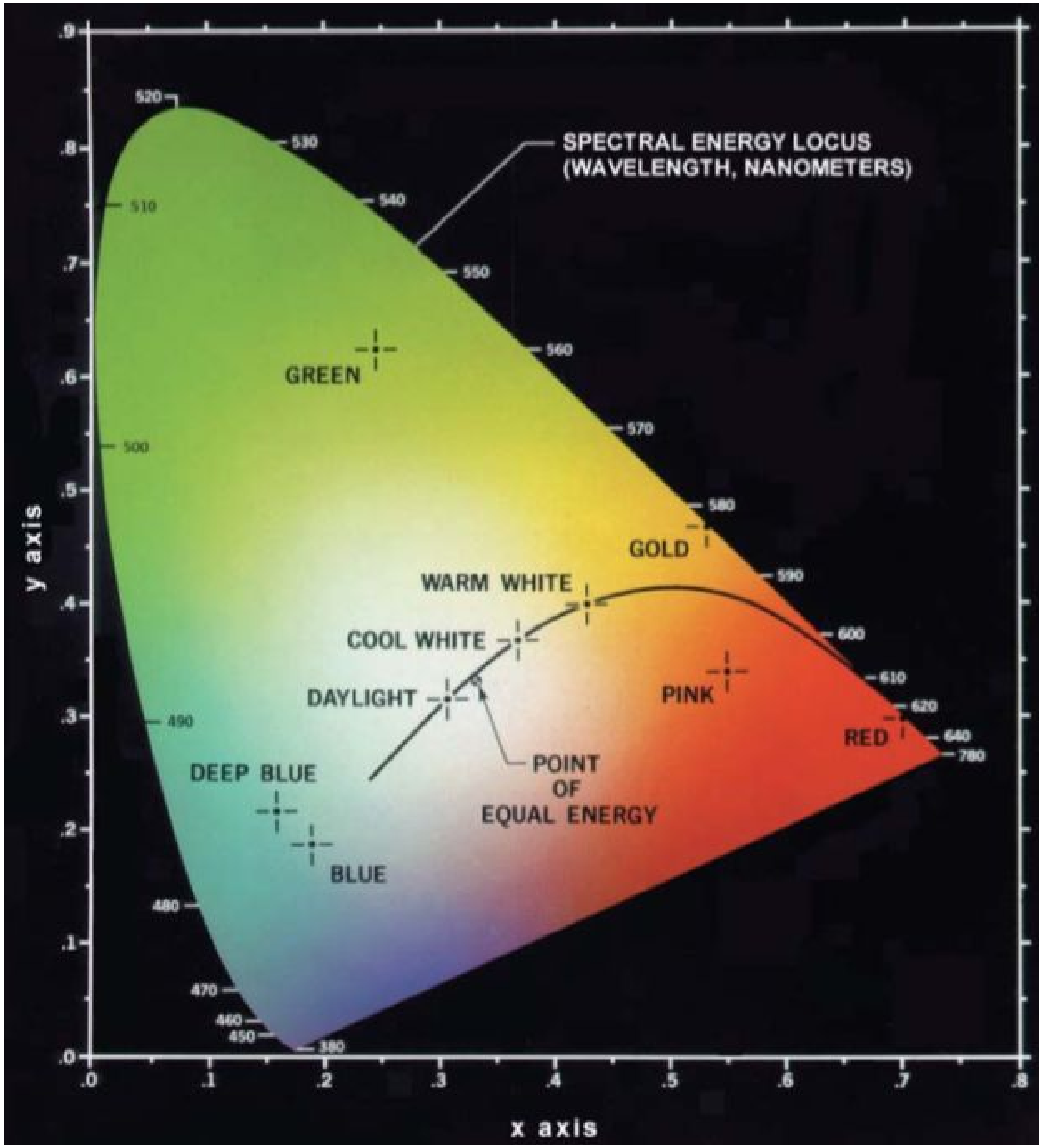
XYZ Color Space

To overcome the problem of mixing negative amount of red light, CIE Standard defined a new color space created by the combination of 3 virtual colors: X Y Z



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Cromaticity Diagram



$$z = 1 - (x + y)$$

Useful for color mixing because a straight-line segment joining any two points in the diagram defines all the different color variations that can be obtained by combining these two colors additively

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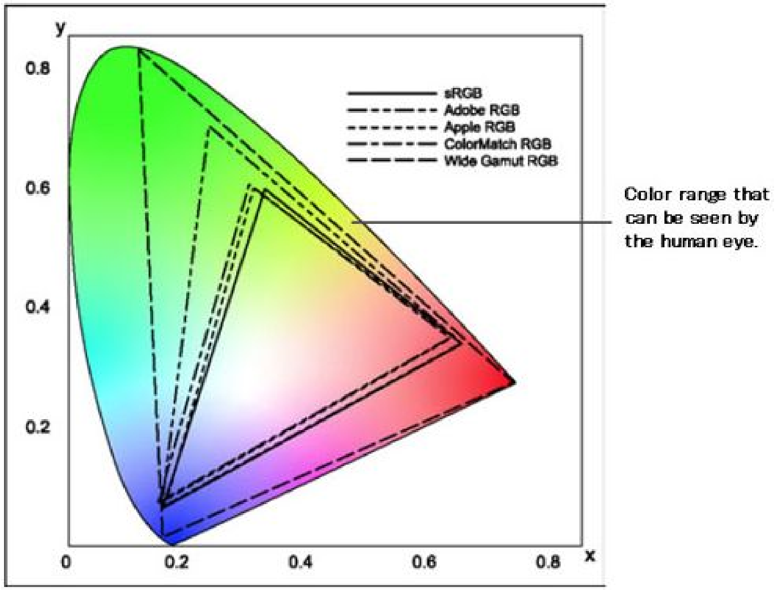
Color Gamut

Any device that reproduces colors by mixing a fixed set of basic colors can only reproduce the colors within the convex envelope of their basis



The area of the envelope measures the quantity of reproducible colors and is called **Gamut**

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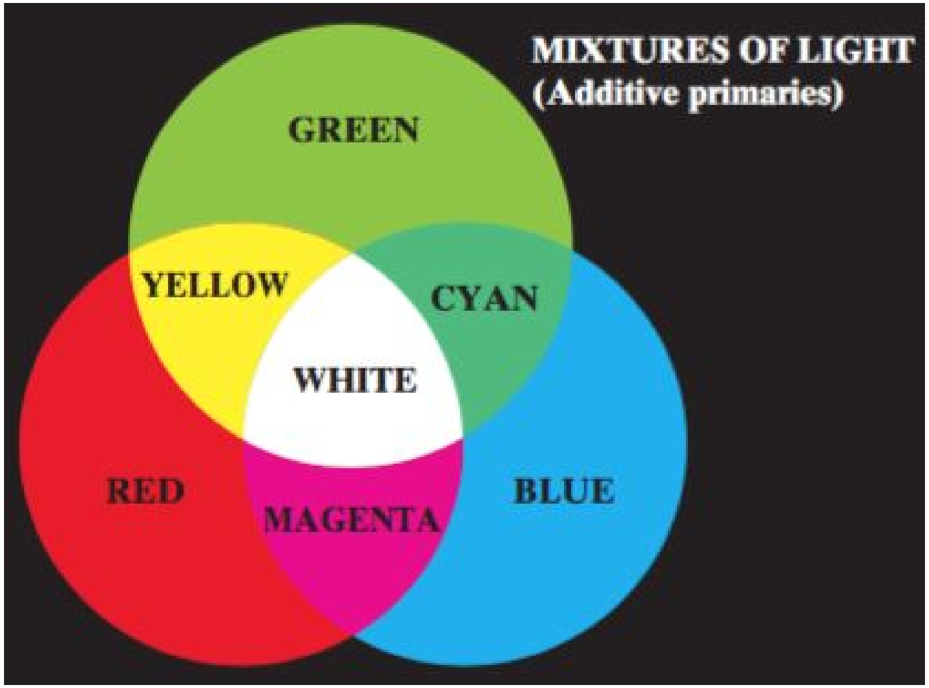
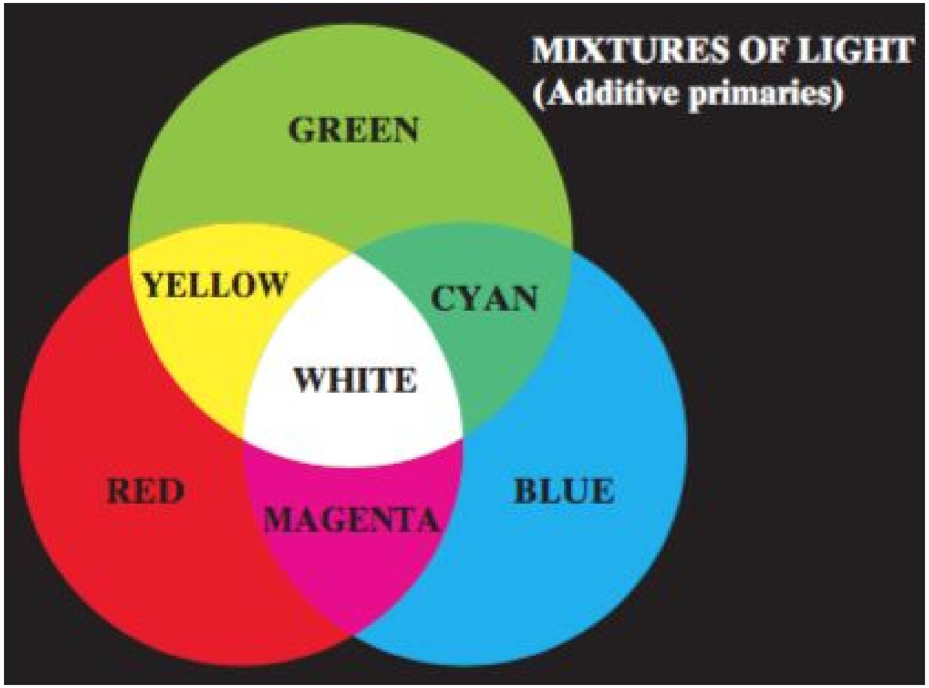
Mixing colors



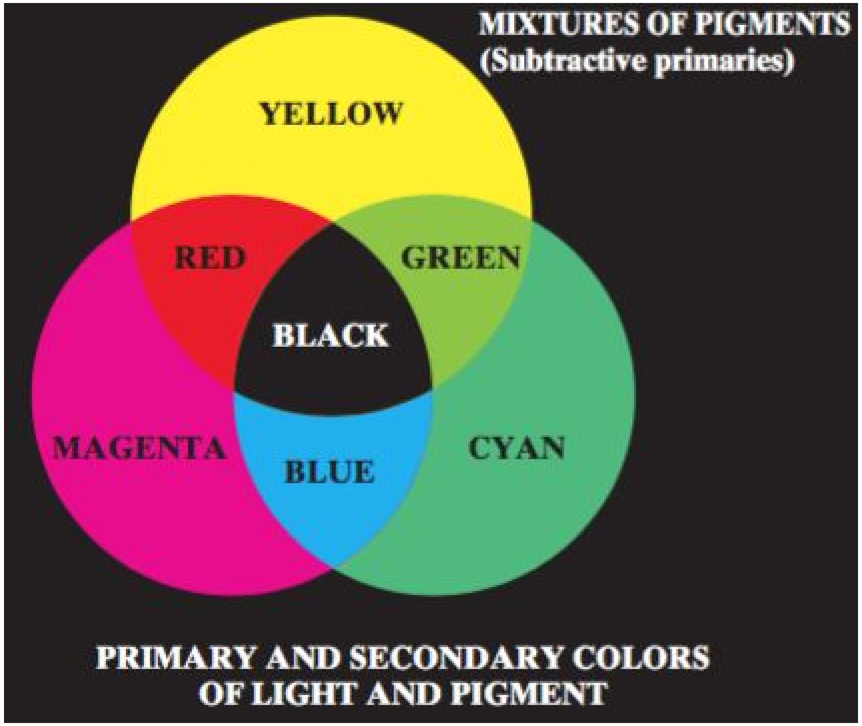
3 monochromatic lights with the R,G,B primary colors respectively can be mixed together (added) to produce what are called **secondary colors**

Mixing colors RGB



This is the basic technology behind LCD screens which use polarized filters to block or pass light through the screen

Mixing colors CMY(K)



When talking about pigments, it is useful to reason by means of subtractive synthesis. In this model, a primary color is defined as one that subtracts or absorbs a primary color of light and reflects or transmits the other two

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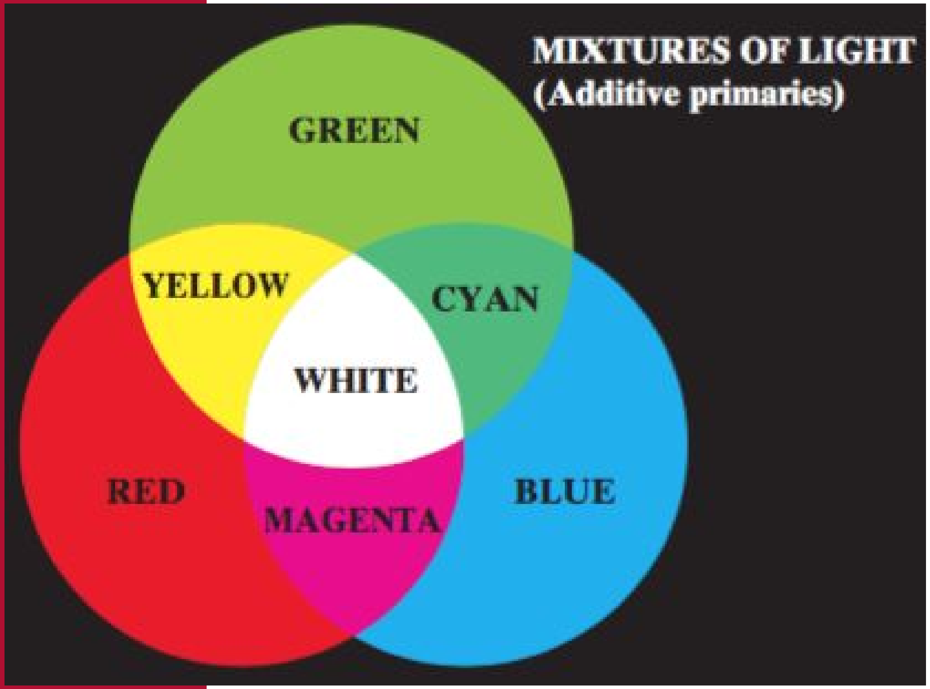
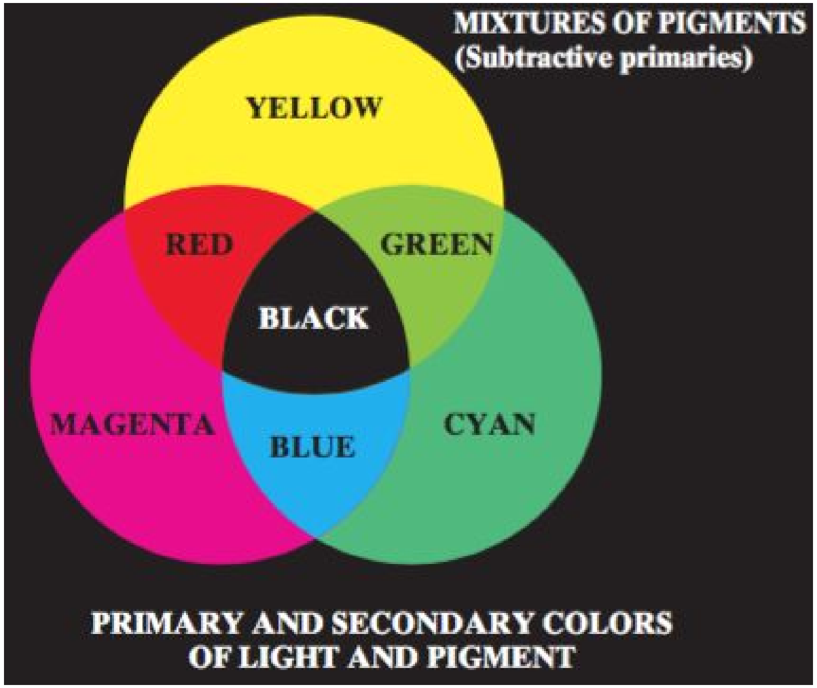
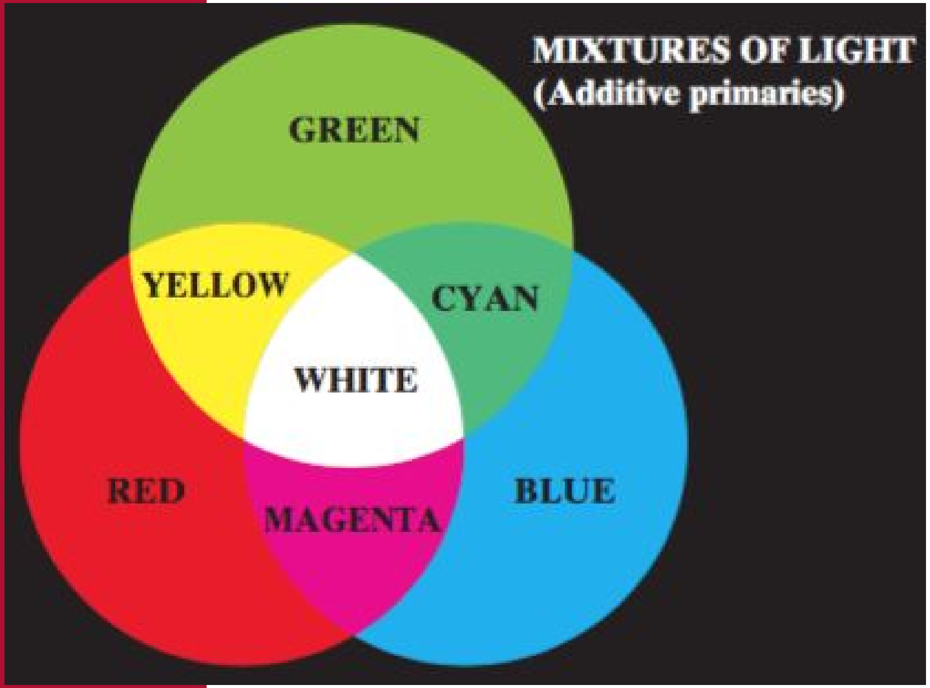
Mixing colors

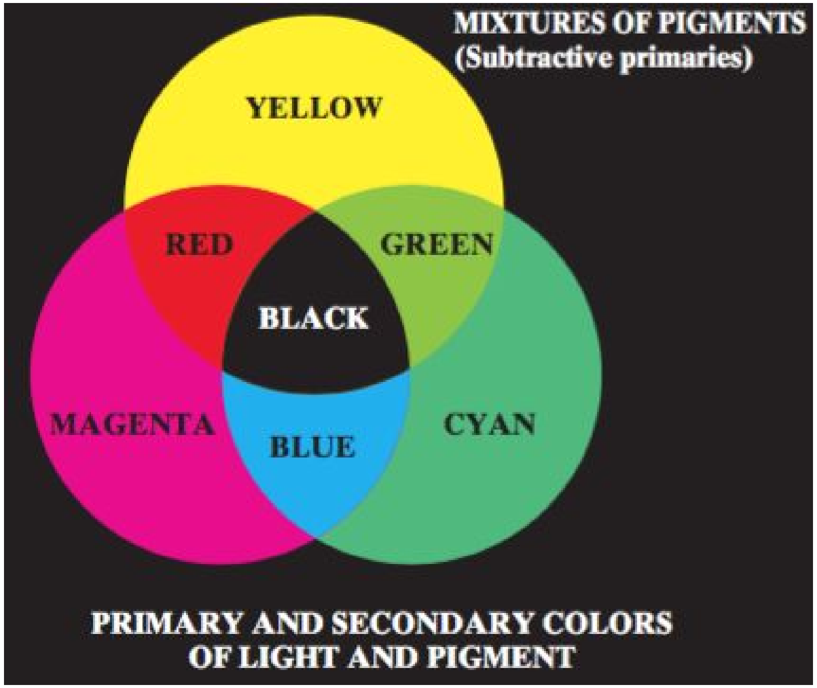




For example, yellow completely absorbs blue and reflects red and green. Hence, mixing yellow (absorbing blue) with cyan (absorbing red) transmits only green

Mixing colors





Odd fact: The secondary color "magenta" is not in the spectrum of colors (ie. there is no wavelength associated to magenta that is always a result of red-blue mix).

Our brain interpolates the two signals to produce the sensation of magenta

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Color characteristics

The characteristics generally used to distinguish one color from another are **brightness**, **hue**, and **saturation**.

Brightness: achromatic notion of intensity

Hue: dominant wavelength in a mixture of light waves (represents dominant color as perceived by an observer)

Saturation: the “relative purity” or the amount of white light mixed with a hue

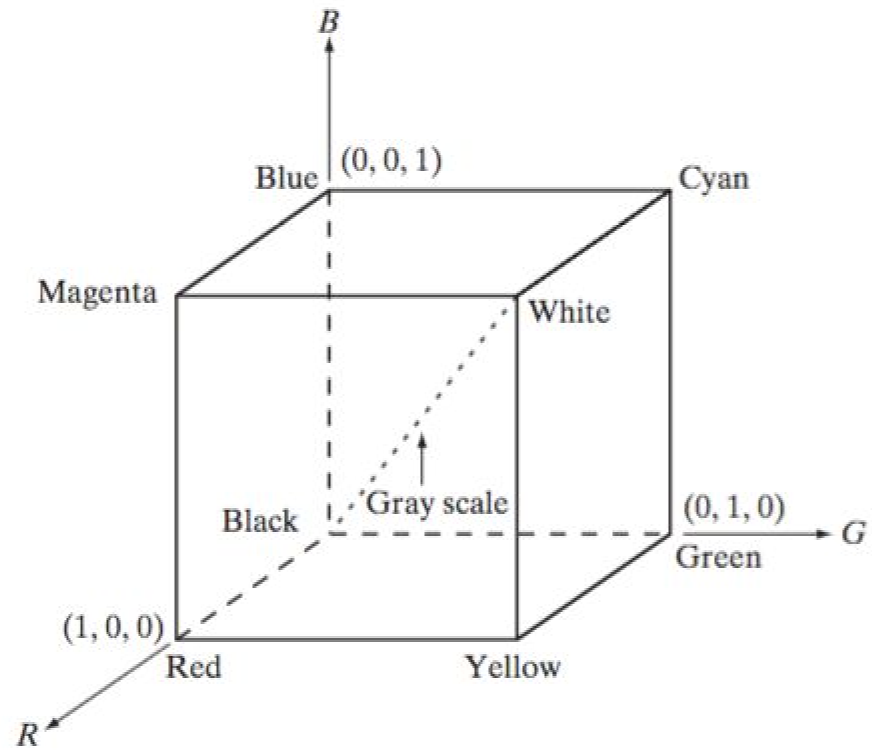
Color Models

The purpose of a color model (also called color space or color system) is to facilitate the specification of colors in some standard, generally accepted way.

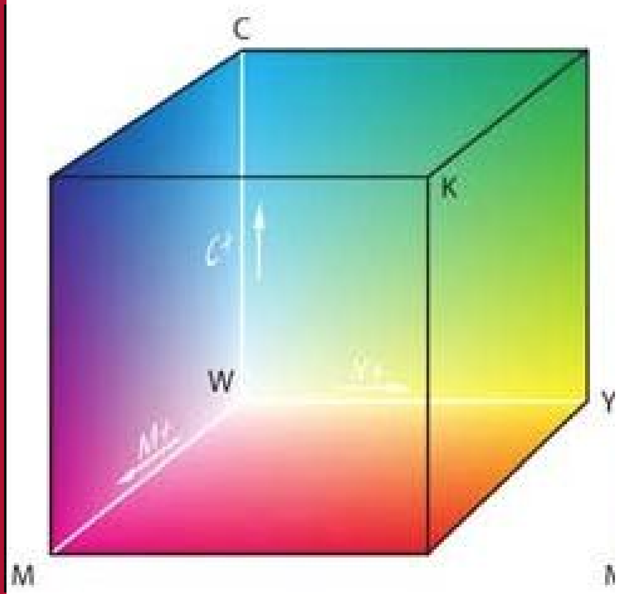
A color model is a specification of:

1. A coordinate system
2. A subspace within that system where each color is represented by a single point.

RGB

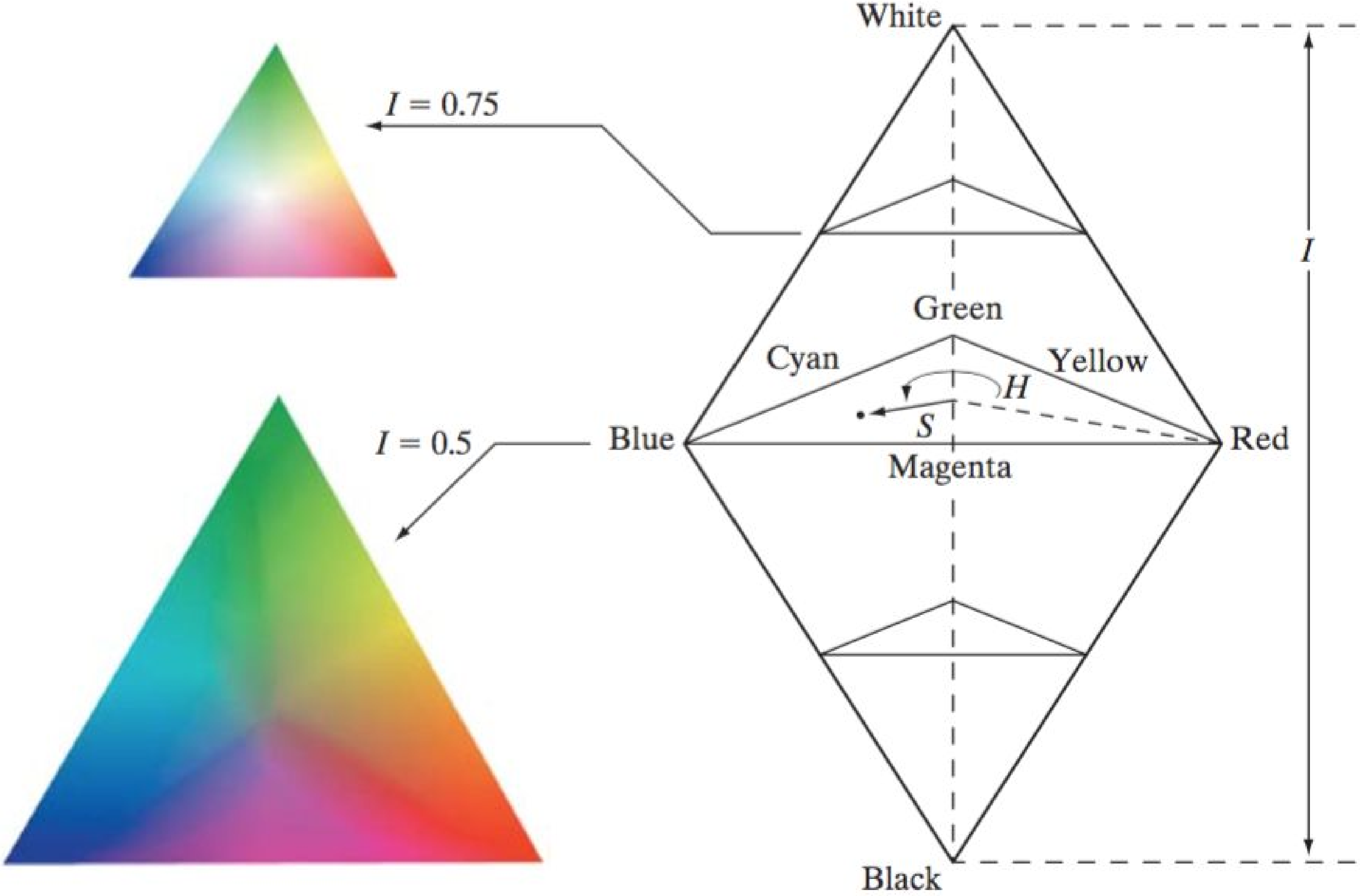

B
Blue
(0, 0, 1)
Cyan
Magenta
White
Gray scale
Black
(0, 1, 0)
G
Green
(1, 0, 0)
Red
Yellow
R

CMY and CMYK



- In real-world printing, combining cyan magenta and yellow produces a muddy-looking black
- In order to produce true black (which is the predominant color in printing), a fourth color, black, is added, giving rise to the CMYK color model

HSI



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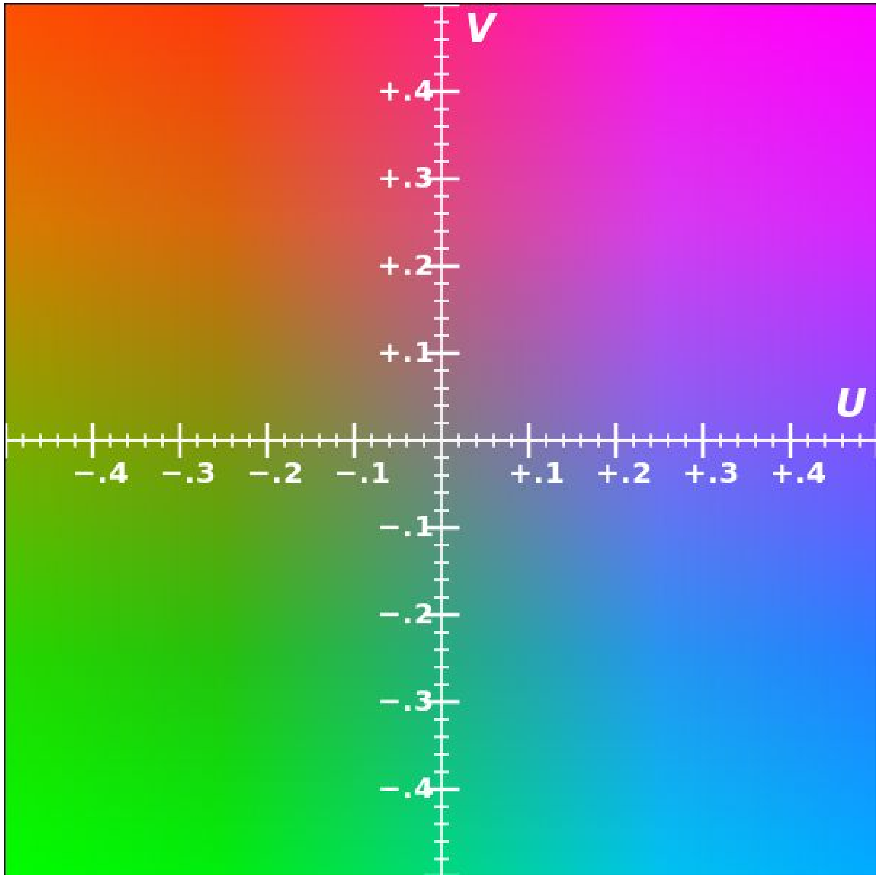
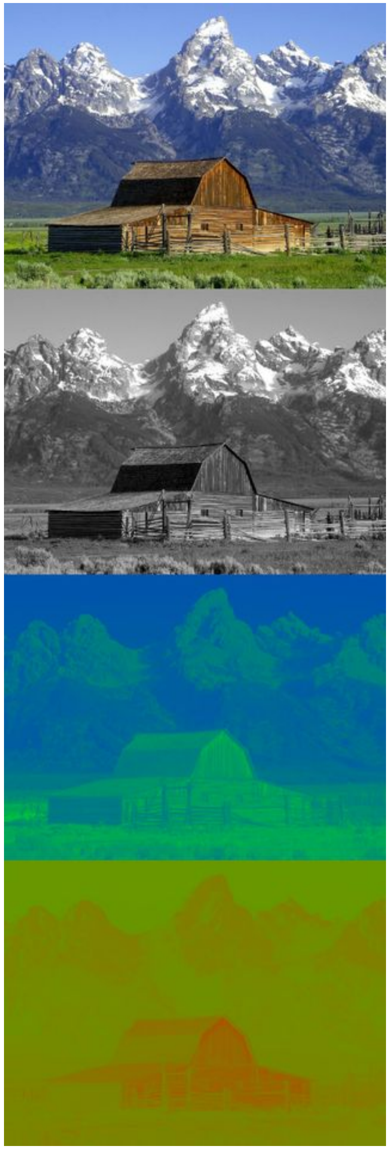
YUV



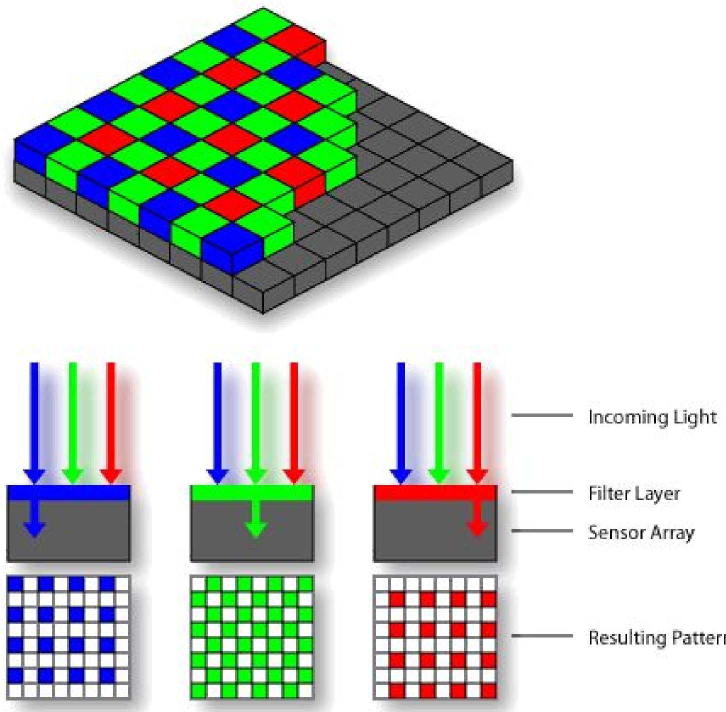


Similar to HSI but the color vector is parametrized by uv components instead by hue (angle) saturation (length)

Color Cameras

Color digital cameras use a color filter array (CFA), where alternating sensors are covered by different colored filters.

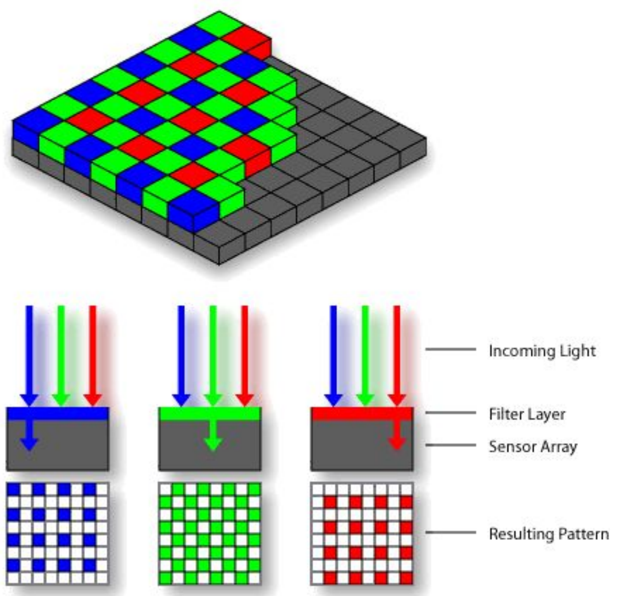
The most commonly used pattern in color cameras today is the **Bayer pattern**



Bayer Pattern

Twice as many green filters as red and blue because the luminance signal is mostly determined by green

The process of interpolating the missing color values so that we have valid RGB values for all the pixels is known as **demosaicing**



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Demosaicing

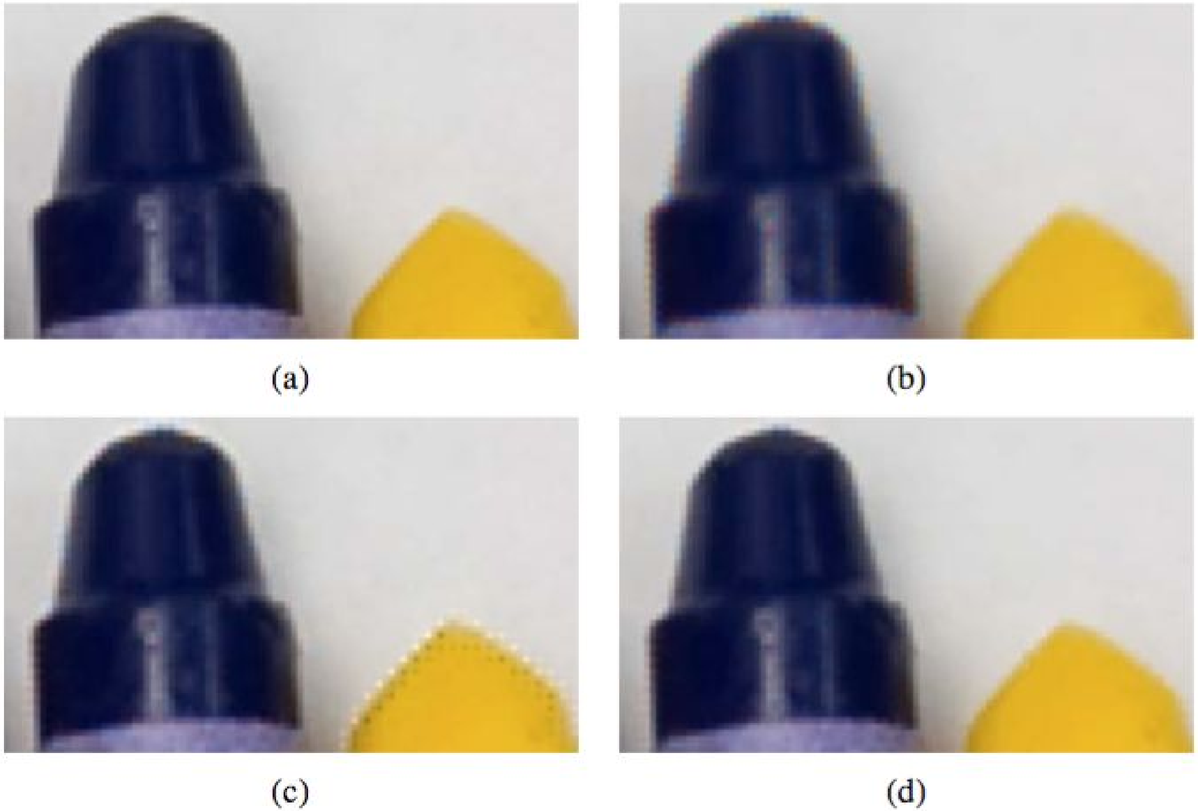

Figure 10.35 CFA demosaicing results (Bennett, Uyttendaele, Zitnick *et al.* 2006) © 2006 Springer: (a) original full-resolution image (a color subsampled version is used as the input to the algorithms); (b) bilinear interpolation results, showing color fringing near the tip of the blue crayon and zippering near its left (vertical) edge; (c) the high-quality linear interpolation results of Malvar, He, and Cutler (2004) (note the strong halo/checkerboard artifacts on the yellow crayon); (d) using the local two-color prior of Bennett, Uyttendaele, Zitnick *et al.* (2006).

Color transformations

When working with color images, we can operate on each channel individually and perform intensity transformations.

Different color spaces can be more or less adequate for different applications

Color transformations

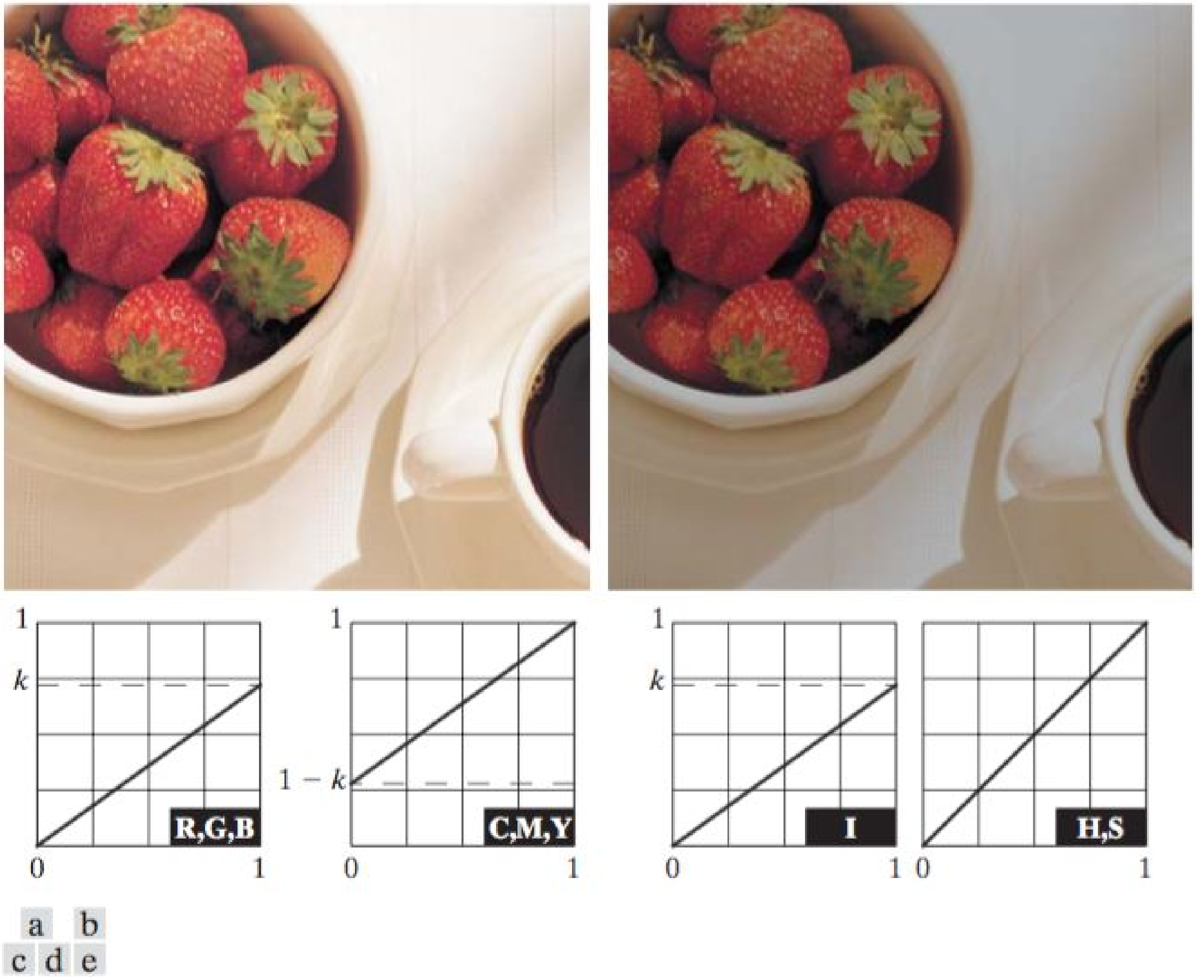

FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

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Tonal corrections

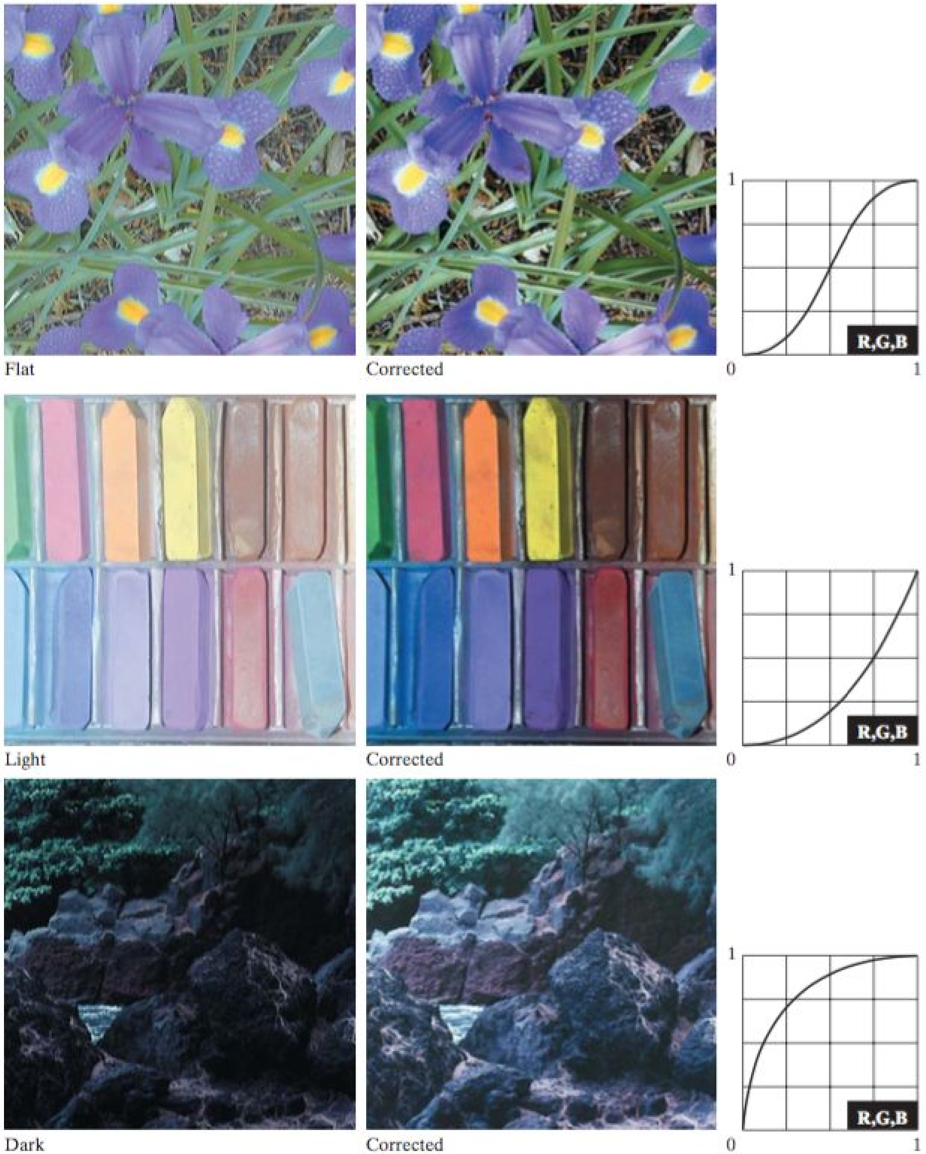

FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not always alter the image hues significantly.

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Tonal corrections

Transformation needed to correct the defect

Histogram equalization

Also for color images, we can perform histogram equalization to automatically determine a good transformation to enhance the image

What happen if we perform histogram equalization for each channel independently?

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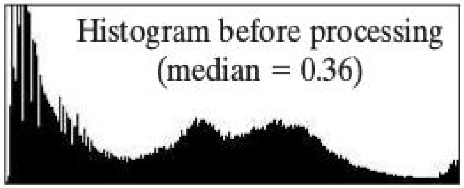
Histogram equalization

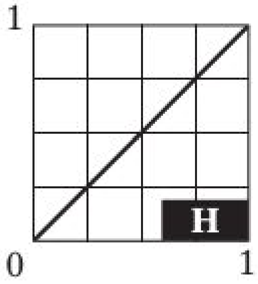
In general, it is not wise to equalize each channel (in any color space independently). This will result in erroneous colors.

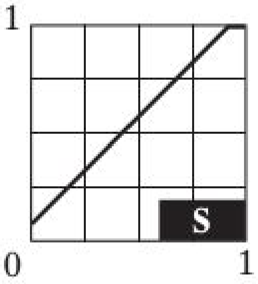
Usually we do the following:

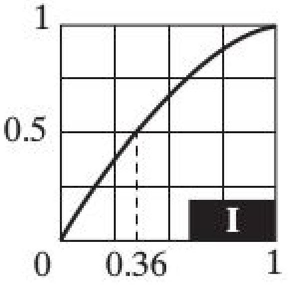
1. Transform the image in HSI color space
2. Equalize the Intensity channel
3. Increase the saturation to correct the perceived loss of vibrancy

Histogram equalization

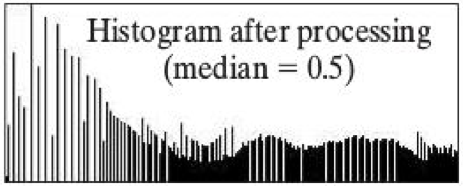


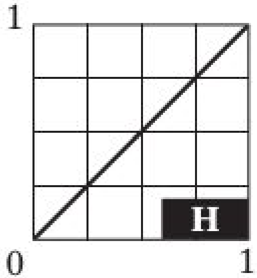


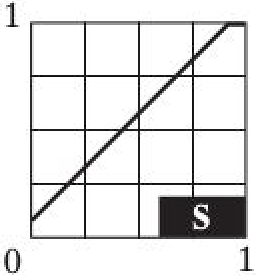


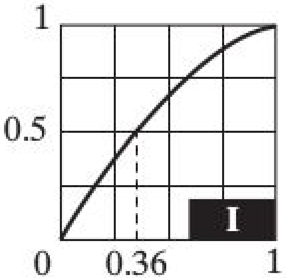


Histogram equalization









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Histogram equalization

Saturation adjustment

Chroma keying compositing

A known color is detected and considered transparent when mixing two video frames

- Typical colors are green or blue… why?
- What color space is better suited to this task?
- What would it be the general algorithm?