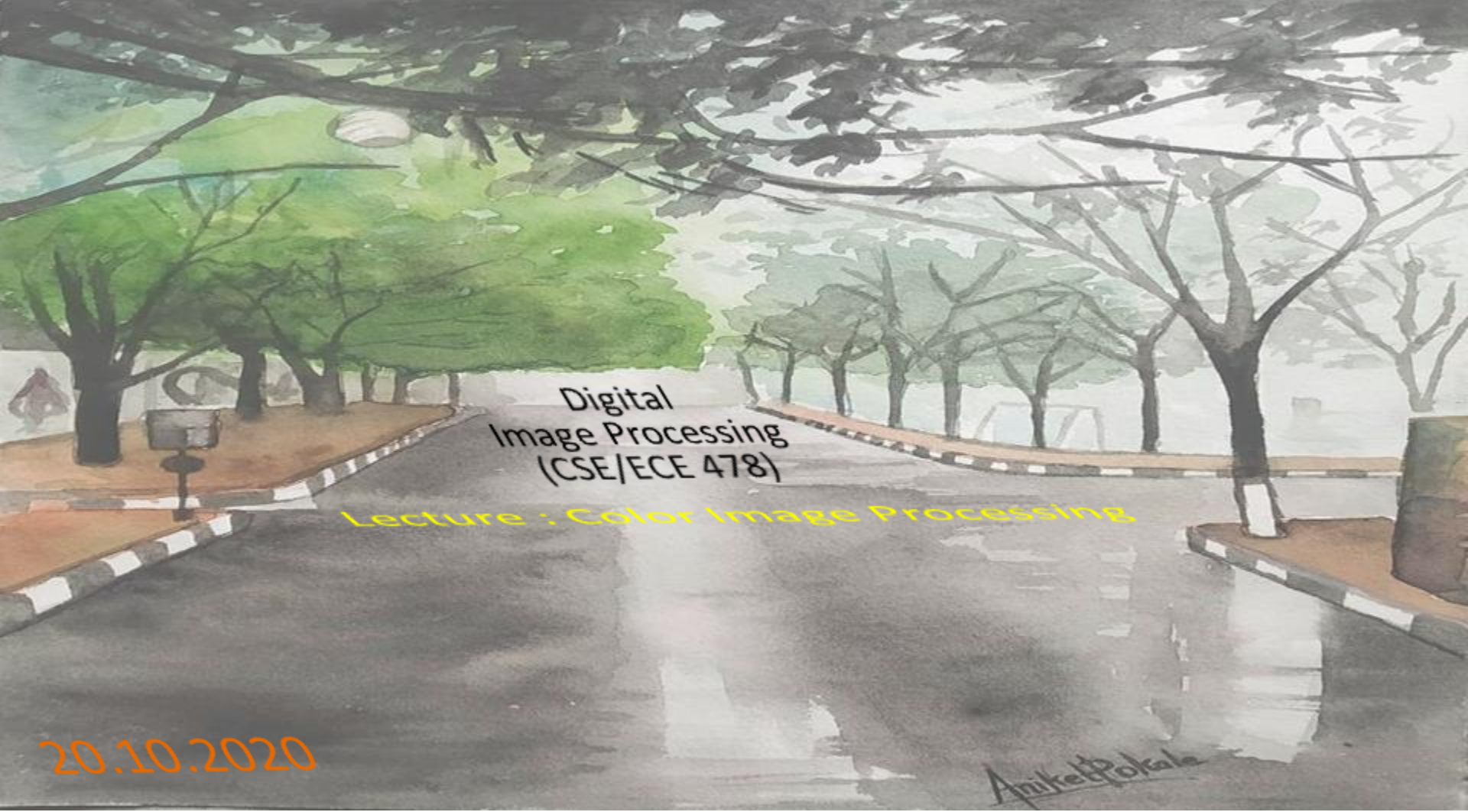
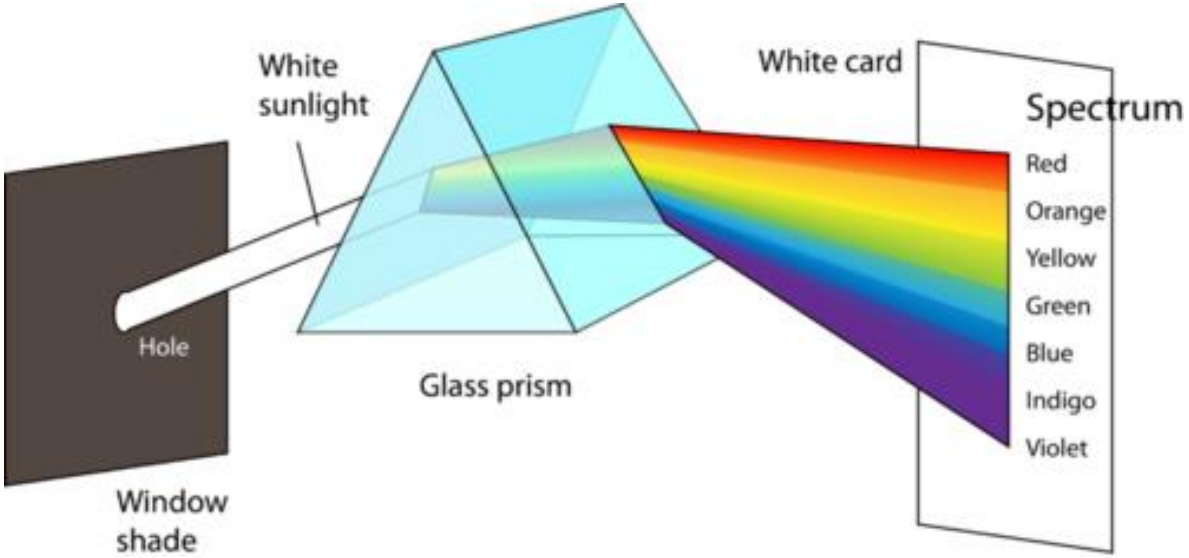

Digital
Image Processing
(CSE/ECE 478)
Lecture : Color Image Processing
20.10.2020
Anirudh Pokala

What is Color?

- Physical Phenomenon

- Physiopsychological Phenomenon

Color as a Physical Phenomenon



Color as a Physical Phenomenon

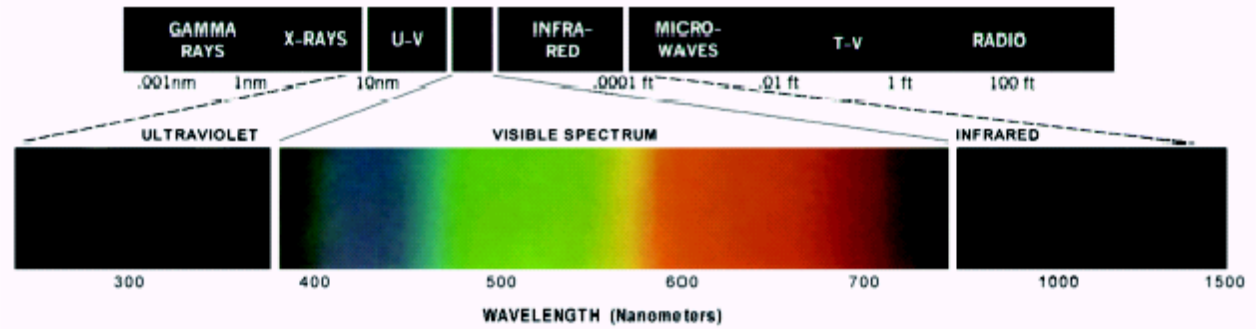
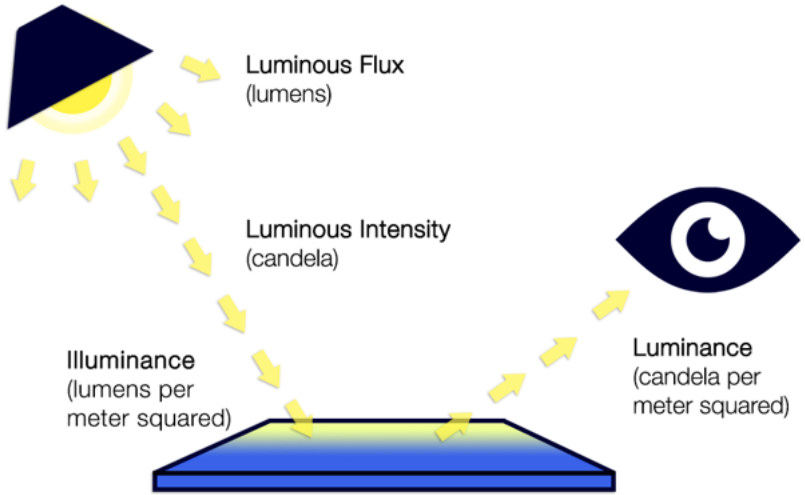


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Physical Quantities

- Radiance: Total amount of energy flow from the light source, measured in watts (W)
- Luminance: amount of energy an observer *perceives* from a light source, measured in candela/m^2
  - Far infrared light: high radiance, but 0 luminance
- Brightness: subjective descriptor that is hard to measure, (similar to the achromatic notion of intensity)

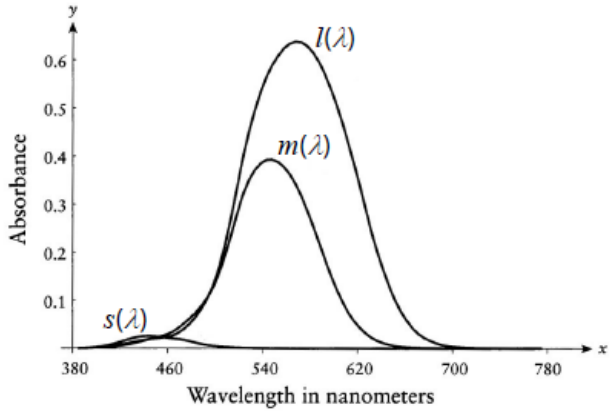


What is Color?

- Physical Phenomenon
- Physiopsychological Phenomenon

Biology of Color Vision

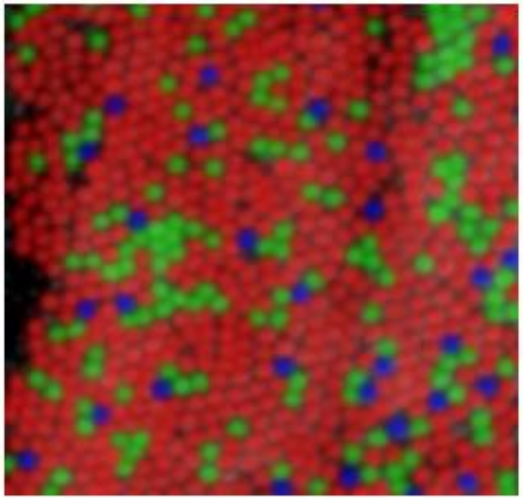
Cones come in three varieties: L, M, and S.

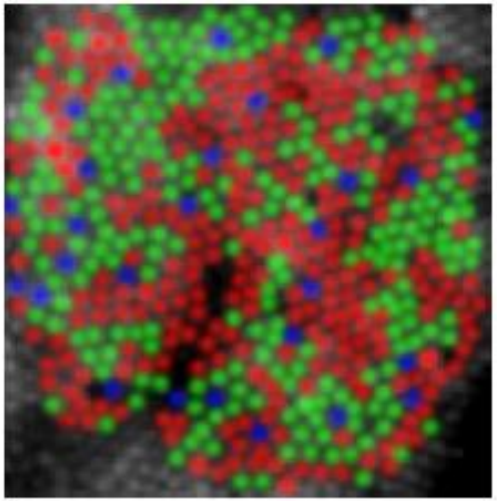


Cone photopigment absorption (Glassner, 1.1)

Cones are active under high light levels, i.e., they are responsible for **photopic** vision.

Cone distribution

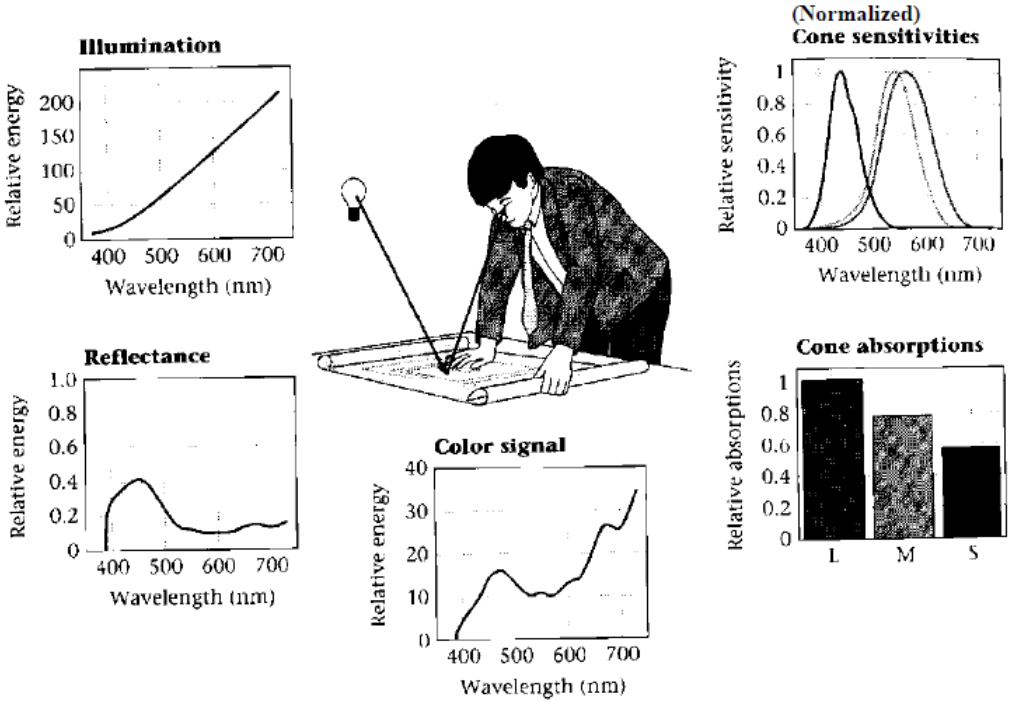




Here are images of near-fovea regions for two different human subjects, with colors to indicate the L (red), M (green) and S (blue) cones:

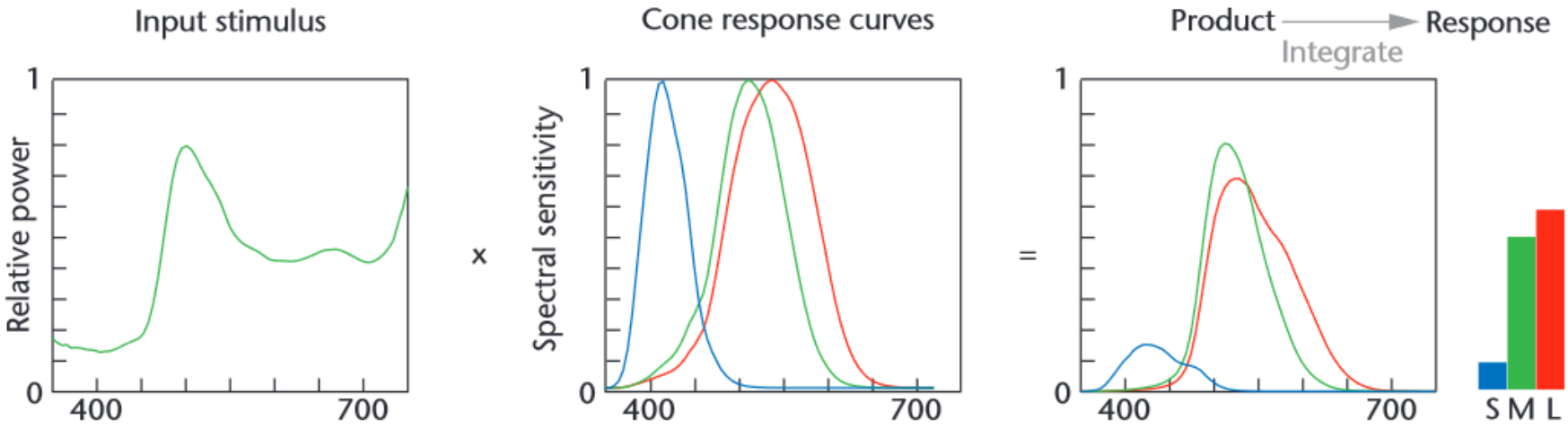
Remarkably, both subjects have normal color vision!

Light source vs. reflected light



How light and reflectance become cone responses (Wandell, 9.2)

Color signal to the brain

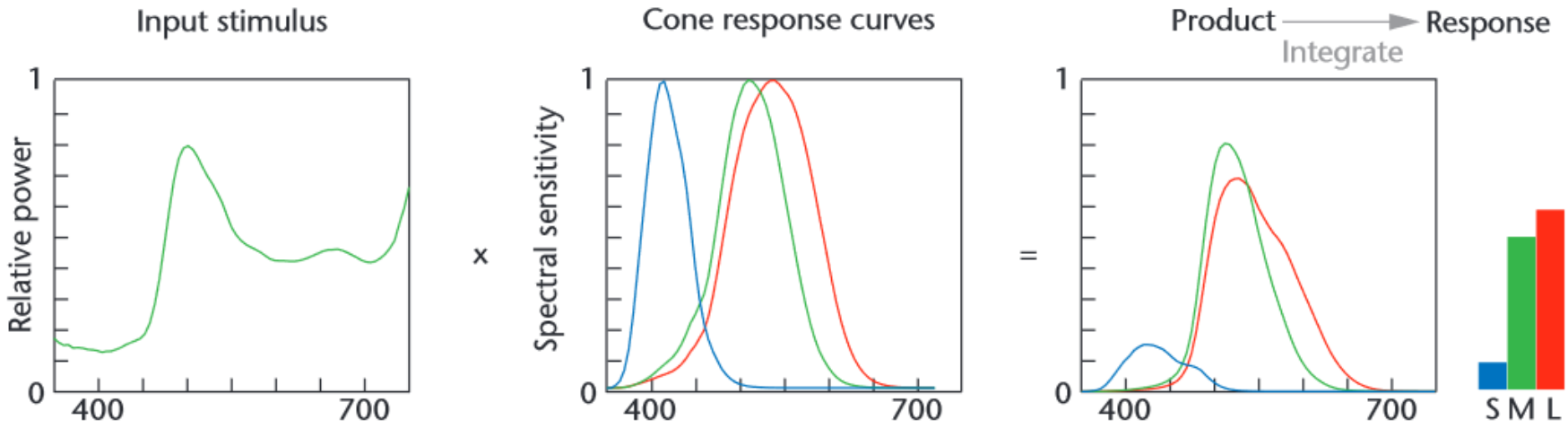


Note that intensity is a weighted function of the r, g, b values.

The human eye doesn't weight each component identically!

```
intensity = 0.299*Red + 0.587*Green + 0.144*Blue
```

Color signal to the brain



"... the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour." - Isaac Newton, *Opticks, 1704*

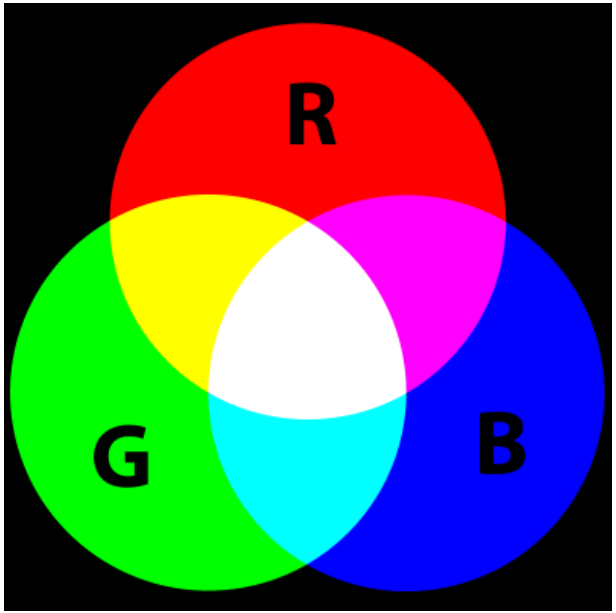
- The perception of colour is an entirely arbitrary creation of our nervous system
- It is not contained in the wavelengths themselves

The Matrix

Primary Colors (color as three numbers)

- Additive (CRT displays, projectors etc.)
  - Combining red, green and blue light produces lighter colors, offering a good contrast to dark screens.
  - (Usually) Combined on a surface which reflects all light that falls on it

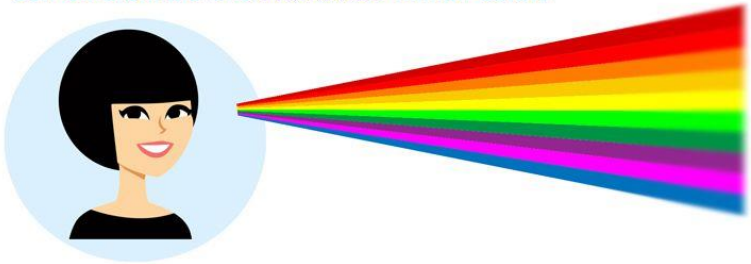
Magenta = Red + Blue
Cyan = Blue + Green
Yellow = Green + Red



TETRACHROMATS

SEE 10 COLORS IN THE RAINBOW

can differentiate one HUNDRED million colors



Mrs M - an English social worker, and the first known human "tetrachromat", discovered at Cambridge in 1993.

ORDINARY PEOPLE

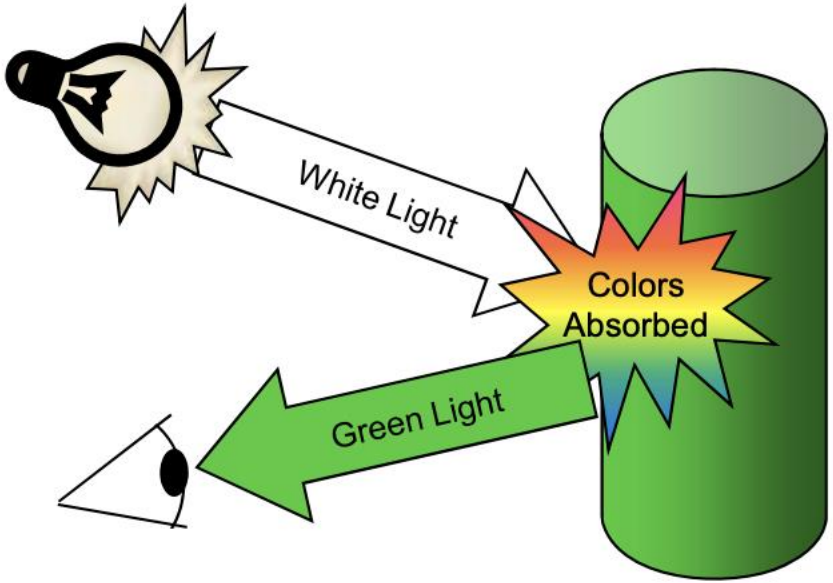
SEE 5 COLORS IN THE RAINBOW

can differentiate one million colors

Mantis shrimp
12 primary color receptors

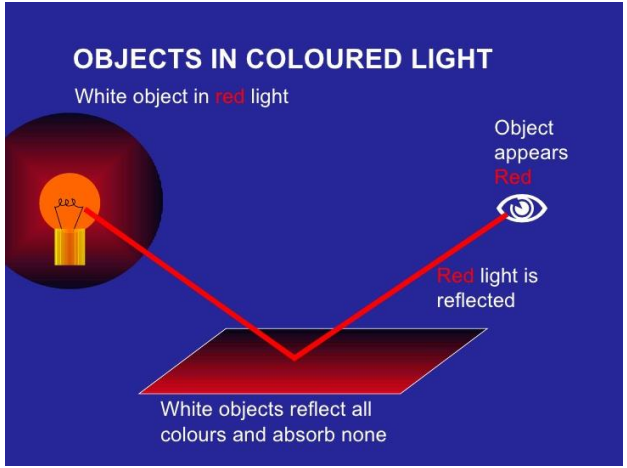
'Perceived' color

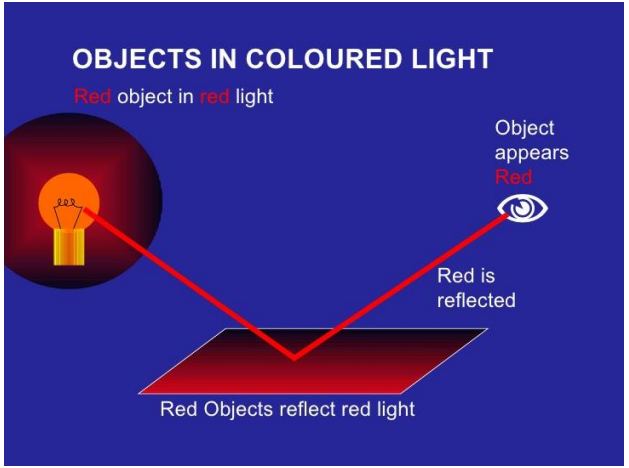
- Color is determined by nature of light reflected from an object
- E.g. green object reflects light from 500-570nm wavelength, absorbs other wavelengths

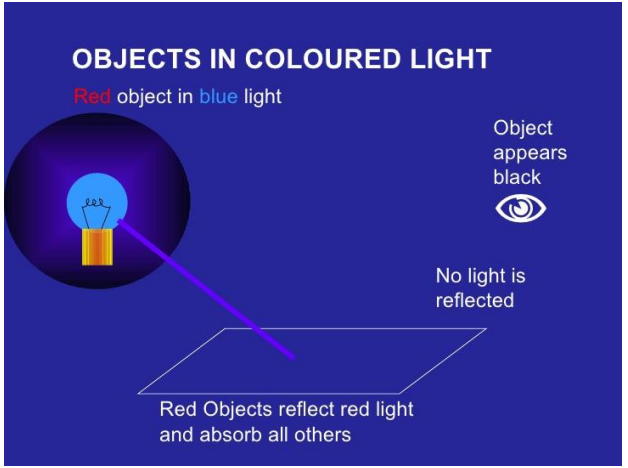


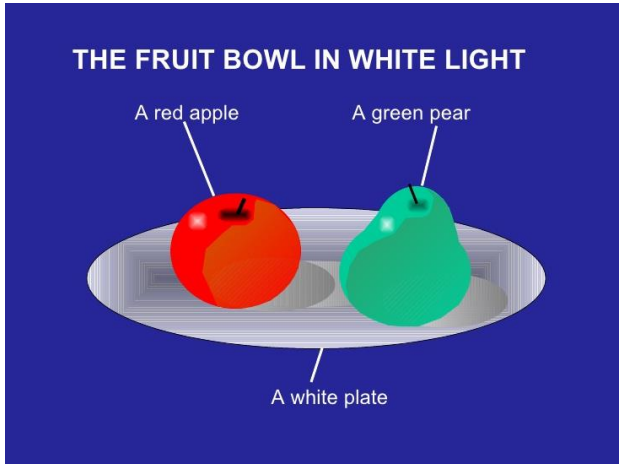
Courtesy: CNikou

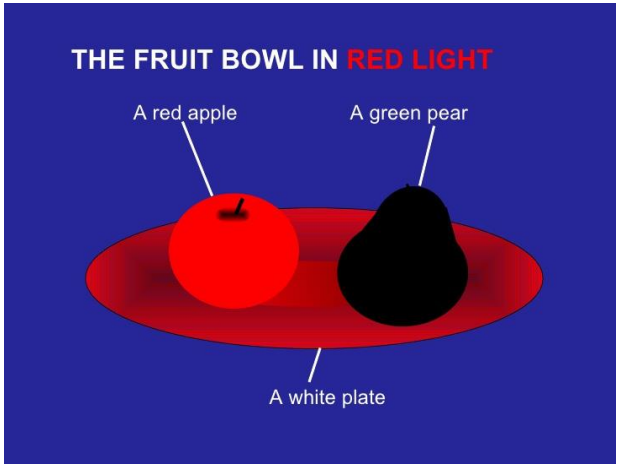
Perceived Color = f(Light, Object)

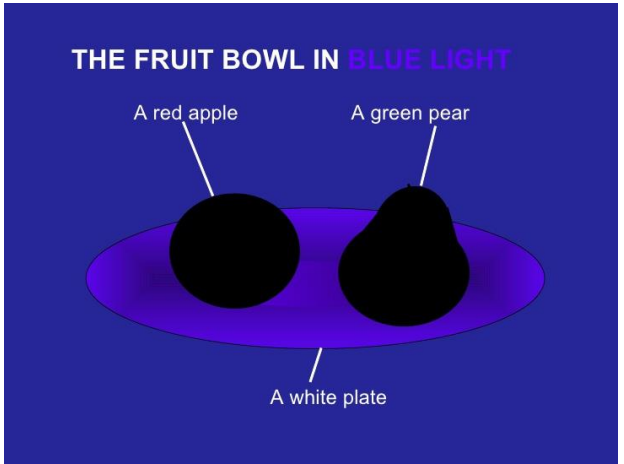












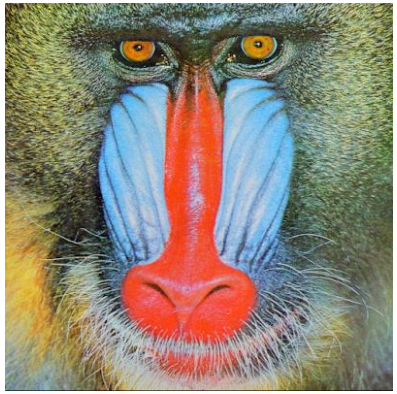
Full color

Red

Green

Blue

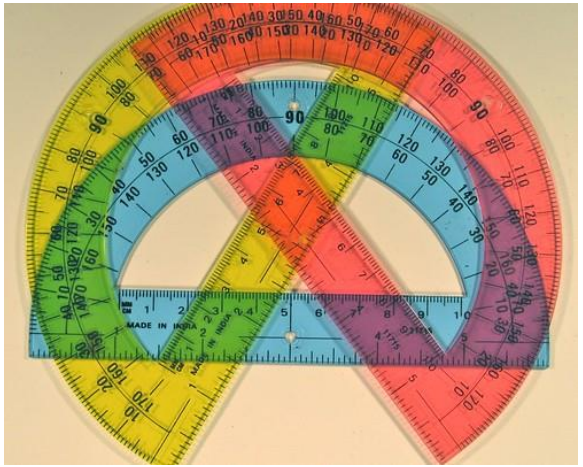
RGB channels

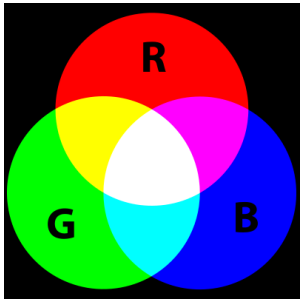


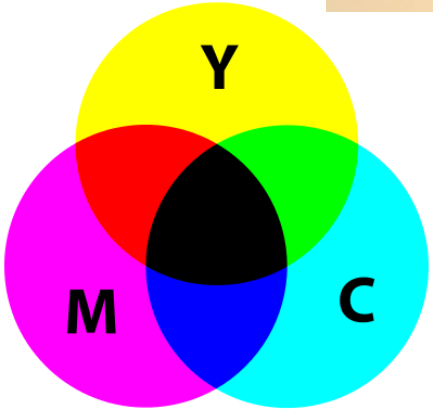
Primary Colors

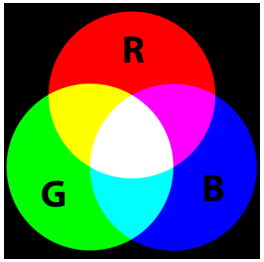
- Subtractive
  - Paints, Printing
  - Starting with white paper, each addition of a colored ink "subtracts" available color from the starting medium.
  - For pure white , leave the paper unprinted (nothing can be whiter than the paper it is printed upon).

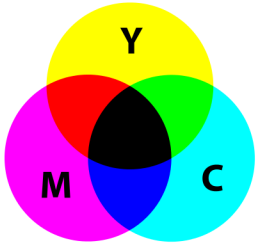
Viewed under white light

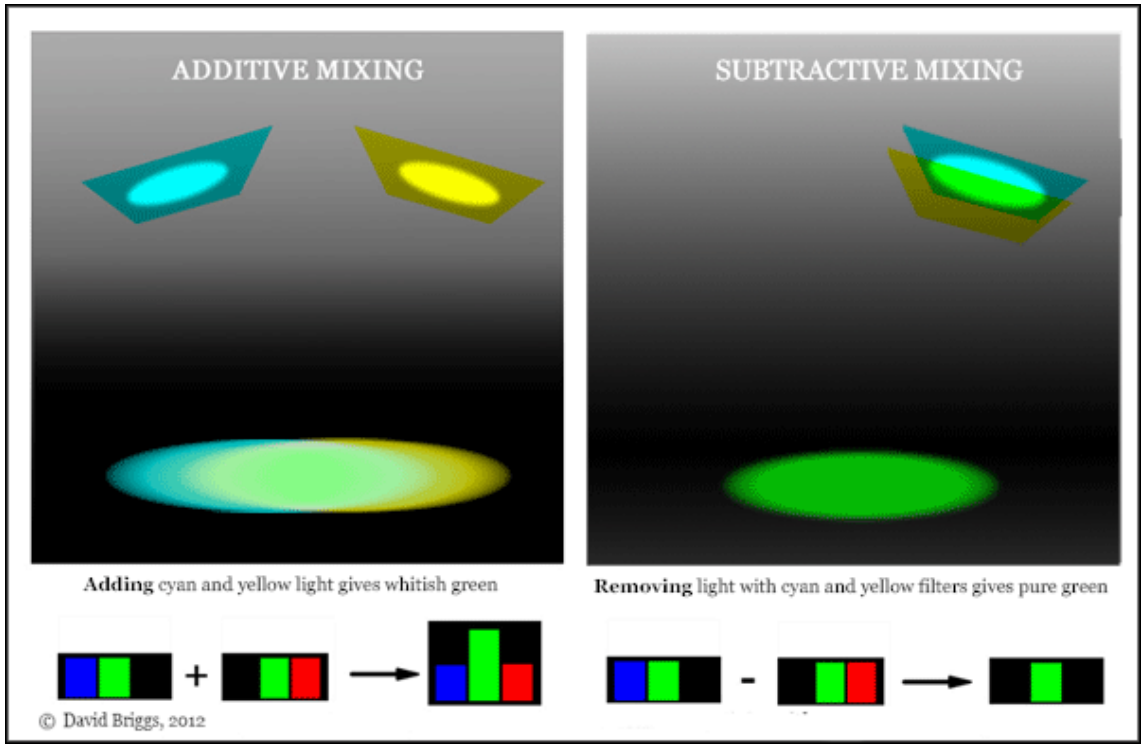


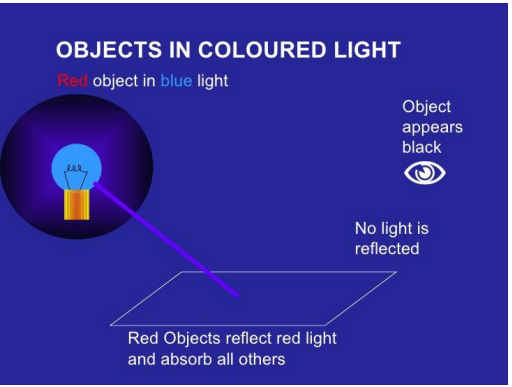


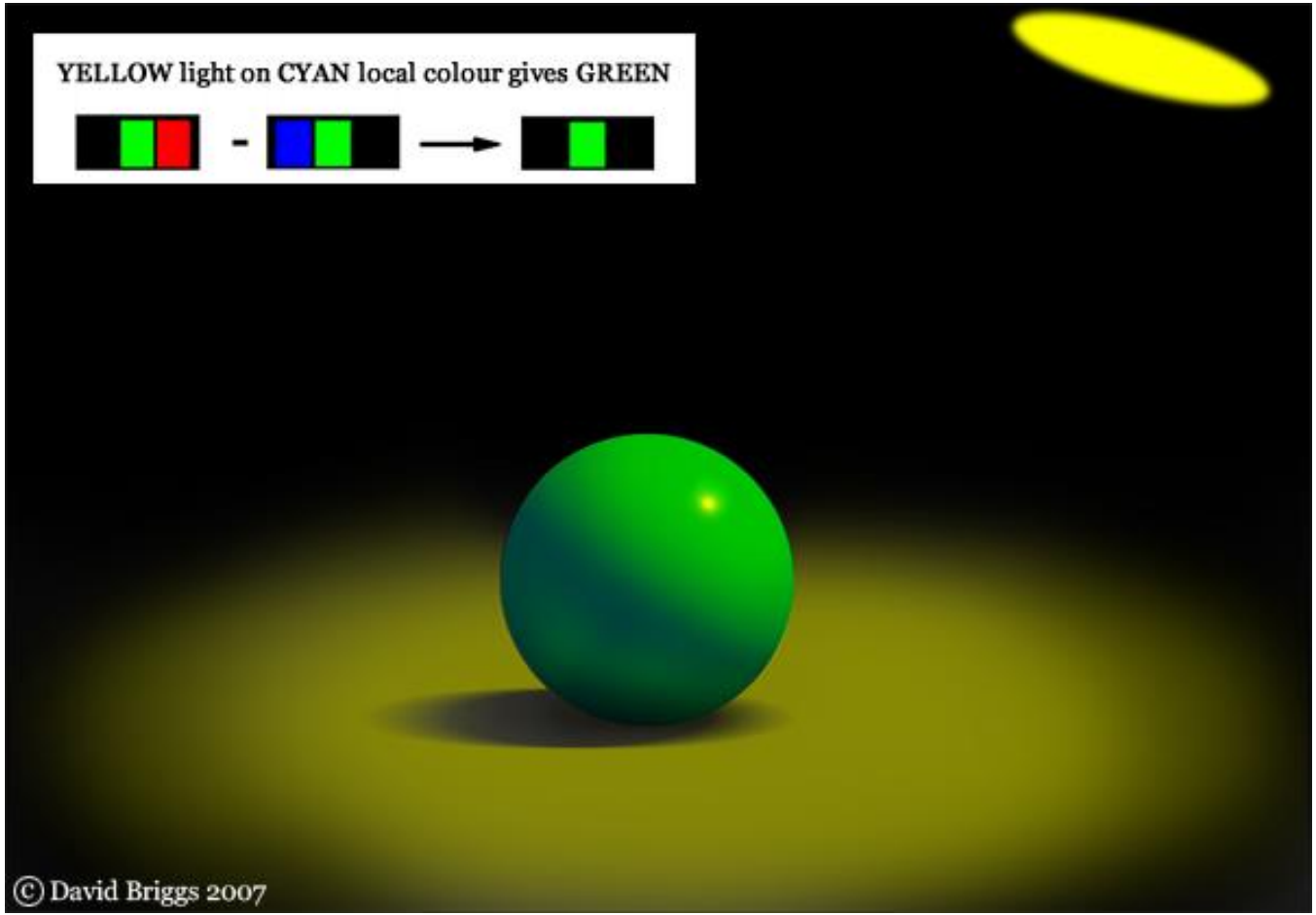



R
G
B

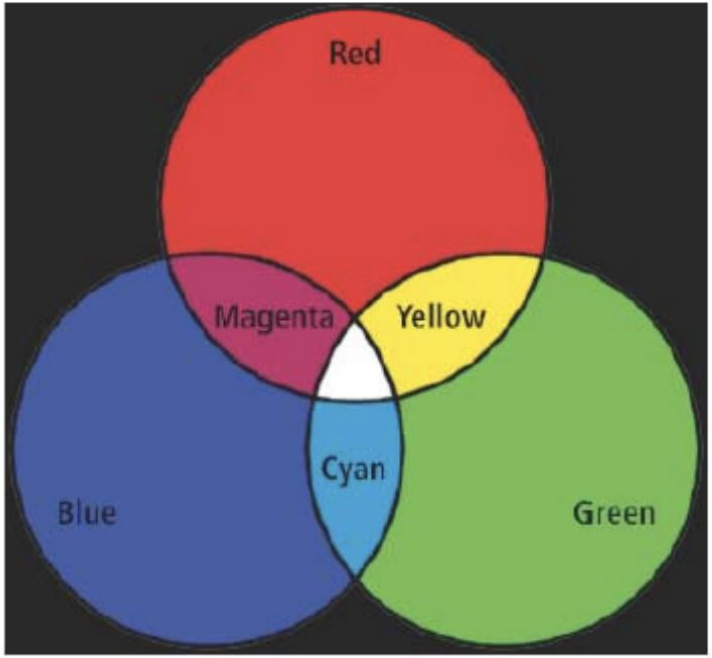

Y
M
C


ADDITIVE MIXING
SUBTRACTIVE MIXING
Adding cyan and yellow light gives whitish green
Removing light with cyan and yellow filters gives pure green
© David Briggs, 2012


OBJECTS IN COLOURED LIGHT
Red object in blue light
Object appears black
No light is reflected
Red Objects reflect red light and absorb all others

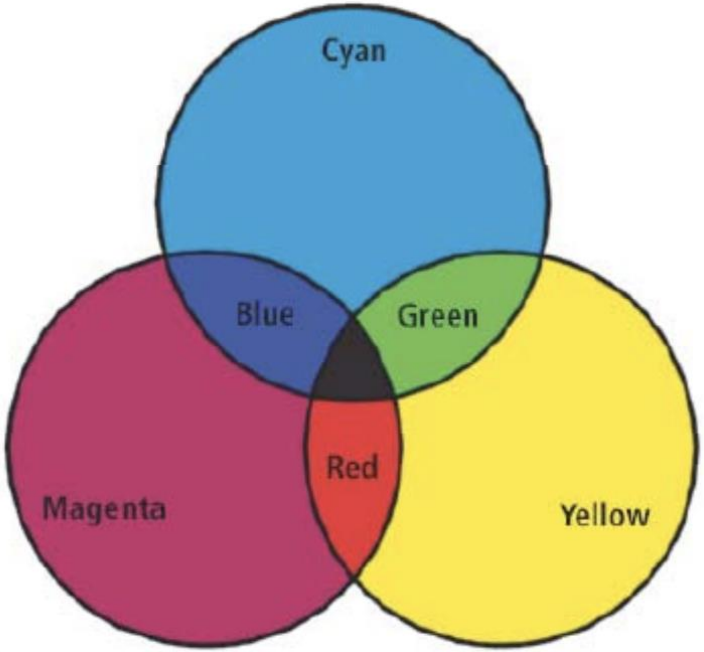

YELLOW light on CYAN local colour gives GREEN
© David Briggs 2007

Additive

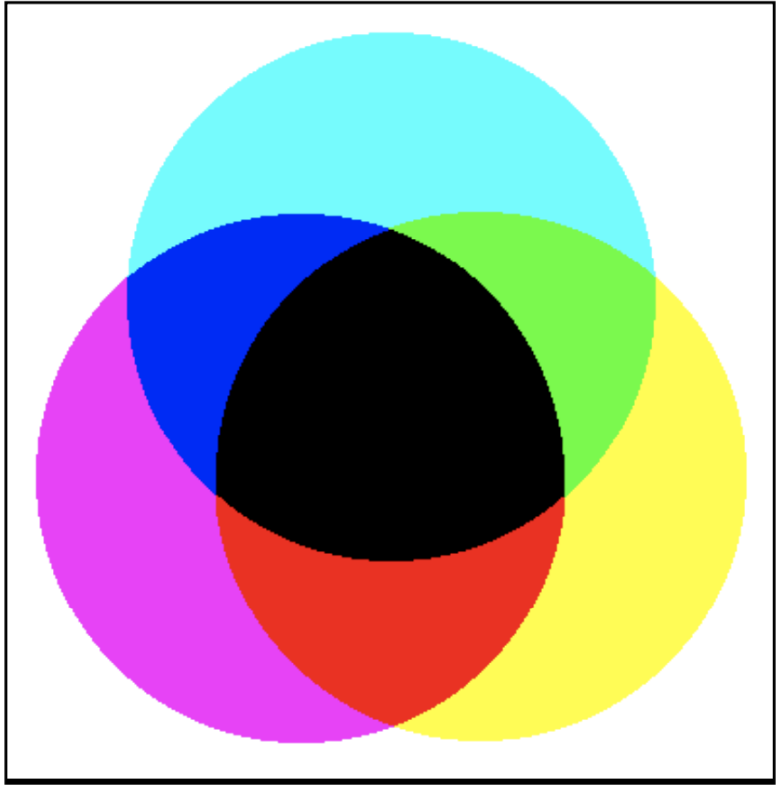


Magenta = Red + Blue
Cyan = Blue + Green
Yellow = Green + Red

Subtractive



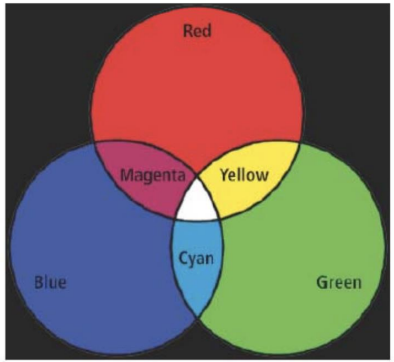
Magenta = White - Green
Cyan = White - Red
Yellow = White - Blue



Passive displays, such as color inkjet printers, **absorb** light instead of emitting it. Combinations of **cyan**, **magenta** and **yellow** inks are used. This is a **subtractive** color model.

Why CMYK in printers

- RGB colors already dark to begin with.
- Layering RGB inks produces even darker colors.
- Inks only absorb, reflect colors in the light spectrum, not emit them.
- This makes it difficult to produce lighter colors (yellow, lime green)



Magenta = Red + Blue
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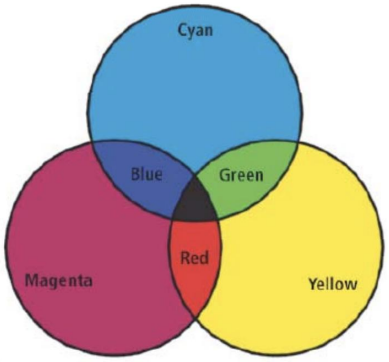
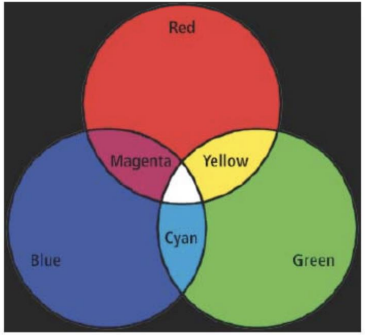


Magenta = White - Green
Cyan = White - Red
Yellow = White - Blue

Why CMYK in printers

- Cyan, Magenta, and Yellow are lighter than red, green, and blue.
- CMY cover most lighter color ranges quite easily compared to RGB.
- BUT CMY by itself will not be able to create very deep dark colors (e.g. “true black,”)
- Black (designated “K” for “key color”) is added to CMY to achieve a much wider range of colors.



Magenta = Red + Blue
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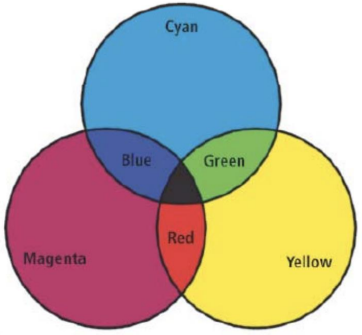
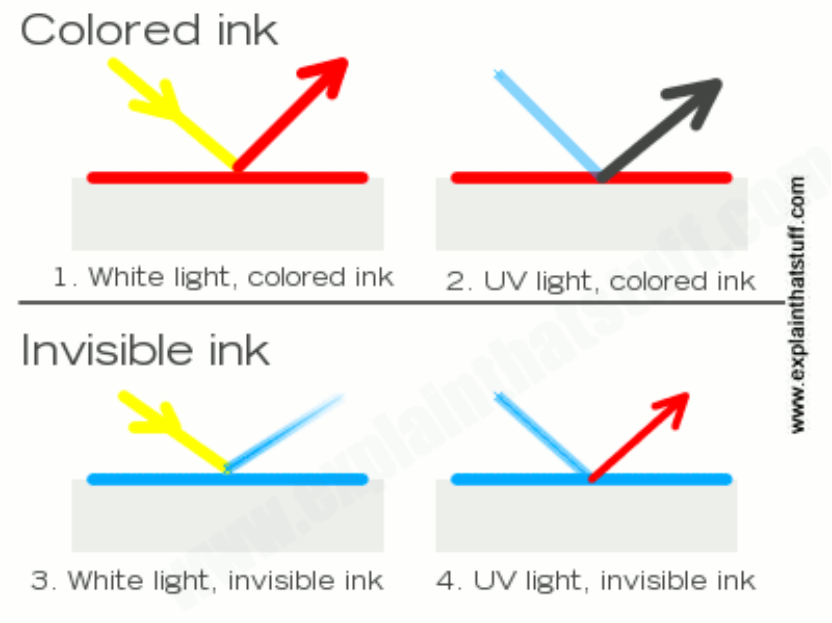


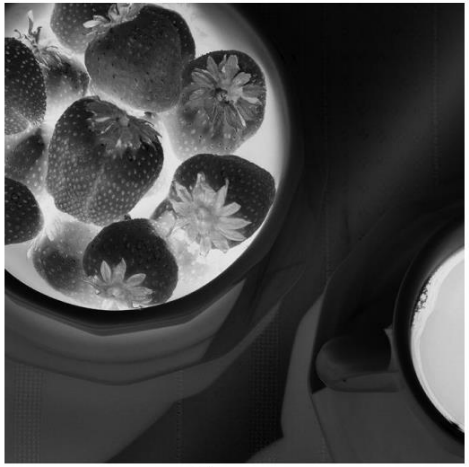
Magenta = White - Green
Cyan = White - Red
Yellow = White - Blue

White light shown as yellow for display

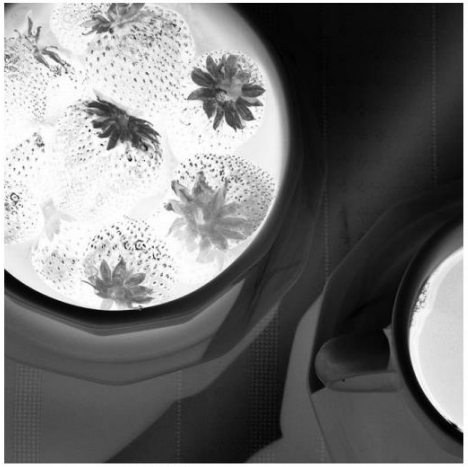


The Da Vinci Code

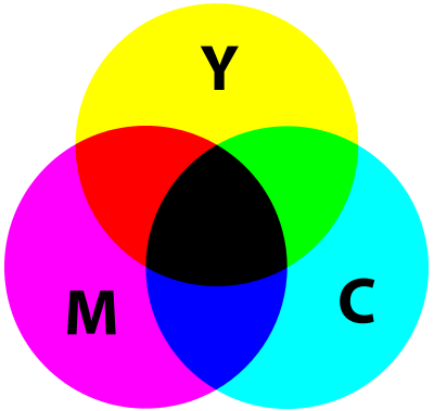
Full color

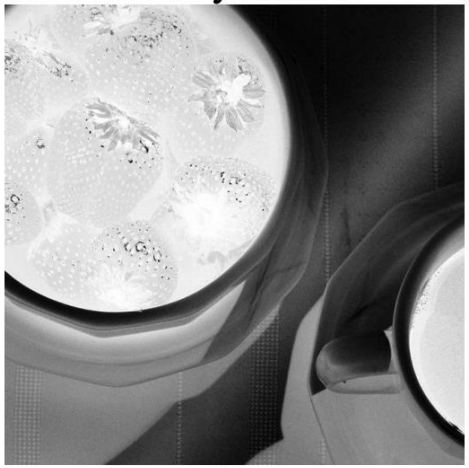


Cyan

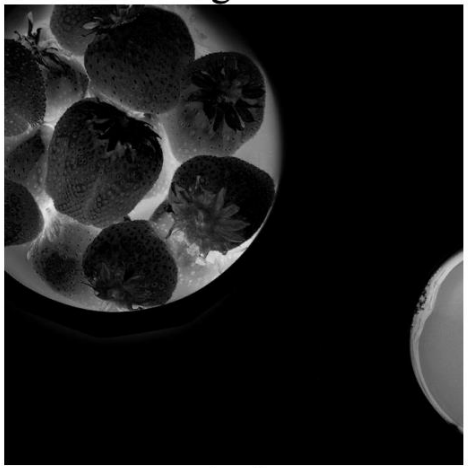


Magenta





Yellow



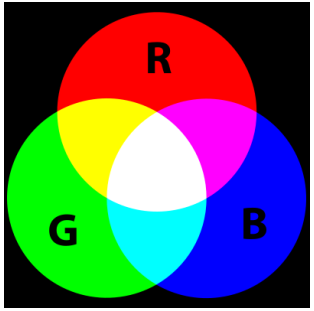
Black

Full color

Red

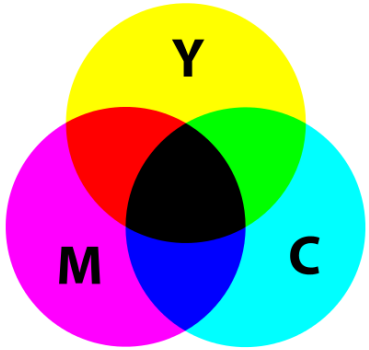
Green

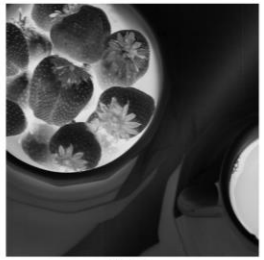
Blue



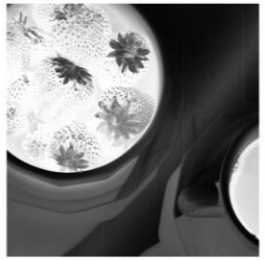
White

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



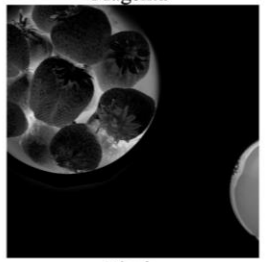


Cyan

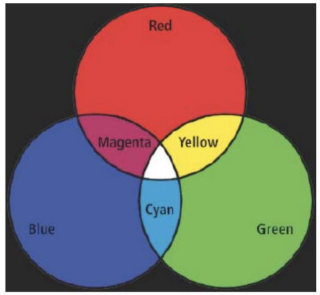


Magenta

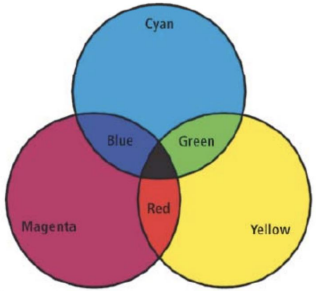
Yellow



Black

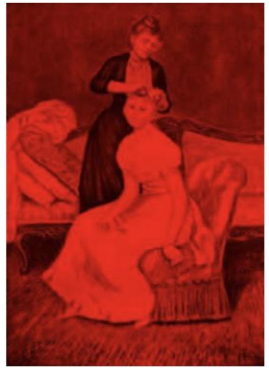


Magenta = Red + Blue
Cyan = Blue + Green
Yellow = Green + Red



Magenta = White - Green
Cyan = White - Red
Yellow = White - Blue

Original



Red Band

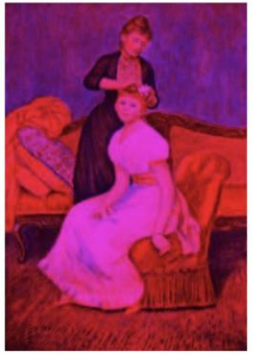
Green Band

Blue Band

Cyan

No Red

Magenta

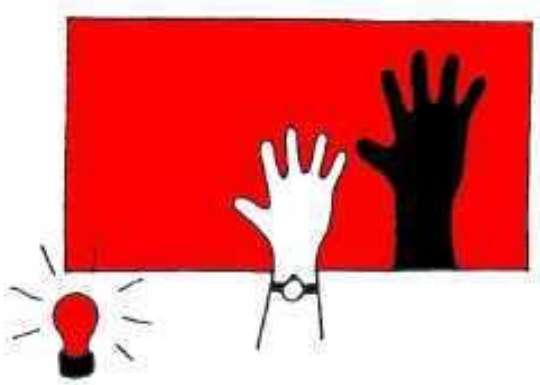


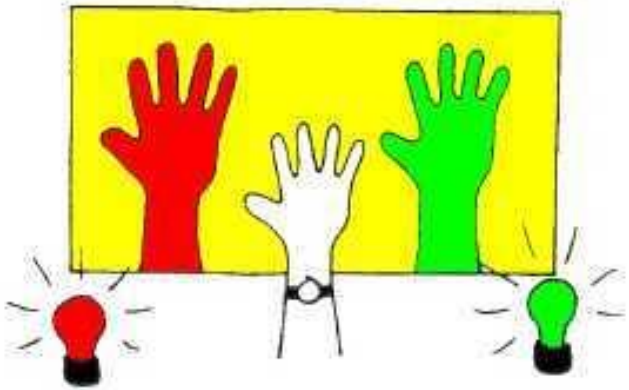
No Green

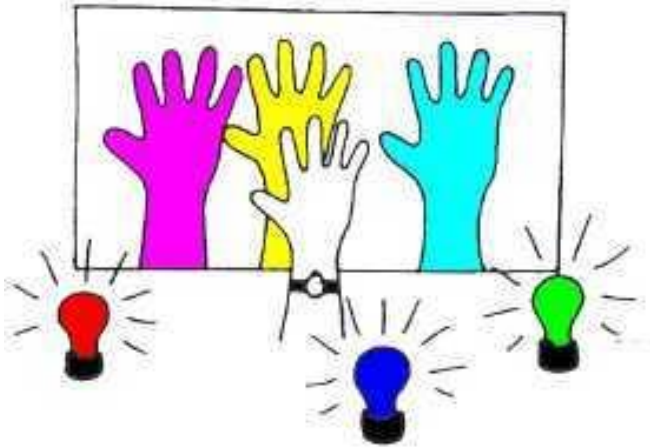
Yellow

No Blue

RGB and CMY





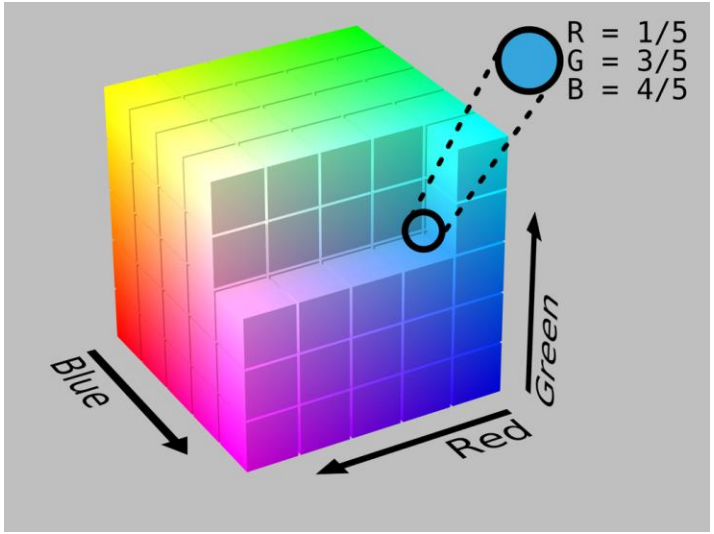


Color Models

- RGB
- HSI / HSY
- CIE LAB

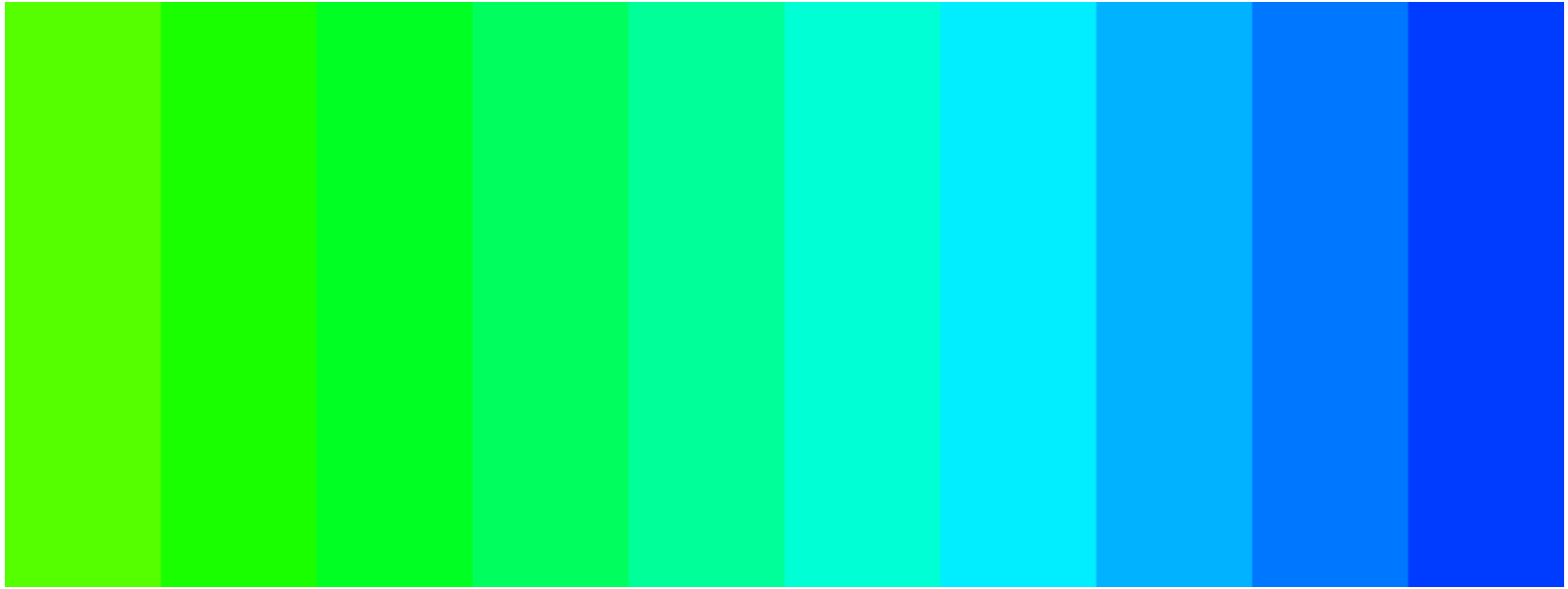
RGB color space

- Primary colors
- Additive color model $f(x, y) = \alpha_1 R + \alpha_2 G + \alpha_3 B$
- Perceptually non uniform



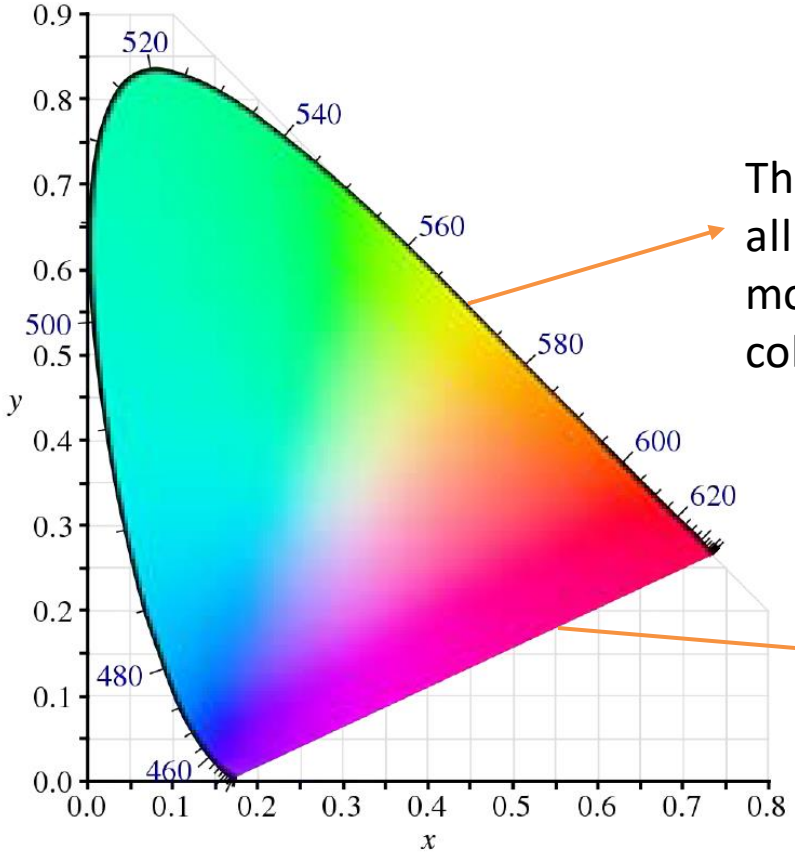
Courtesy: wikipedia

RGB : Non-Uniform Perceptual Space



CIE 1931 (x,y) chromaticity diagram

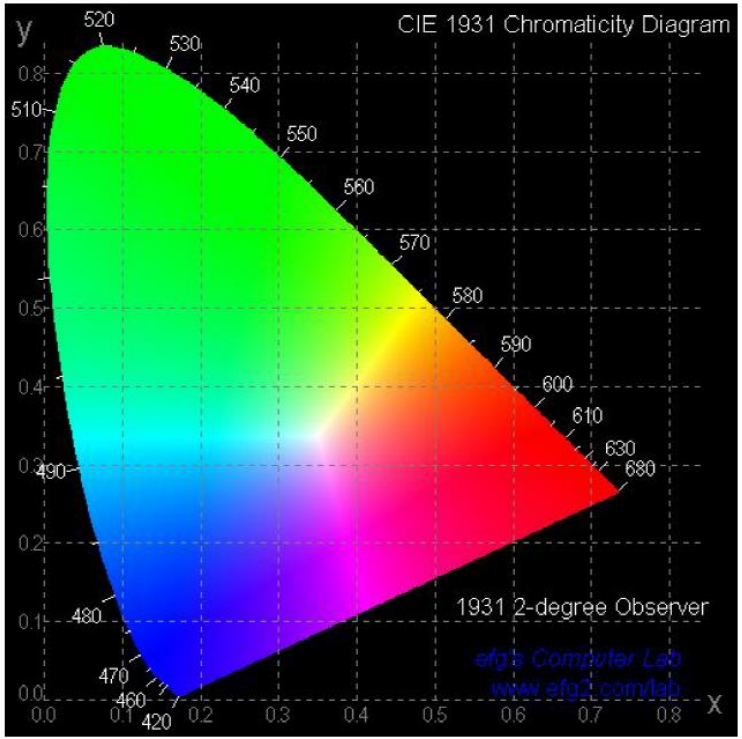
- Yxy - luminance + the two most distinctive chrominance components
- Helps separate luminance and chromaticity
- A convenient representation for color values



The rim represents all of the pure monochromatic colors

Purple Line

CIE 1931 (x,y) chromaticity diagram

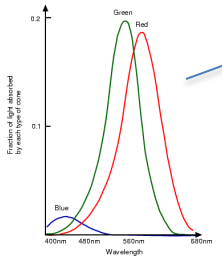


- Chromaticity coordinates:

$$x = \frac{X}{X+Y+Z}$$

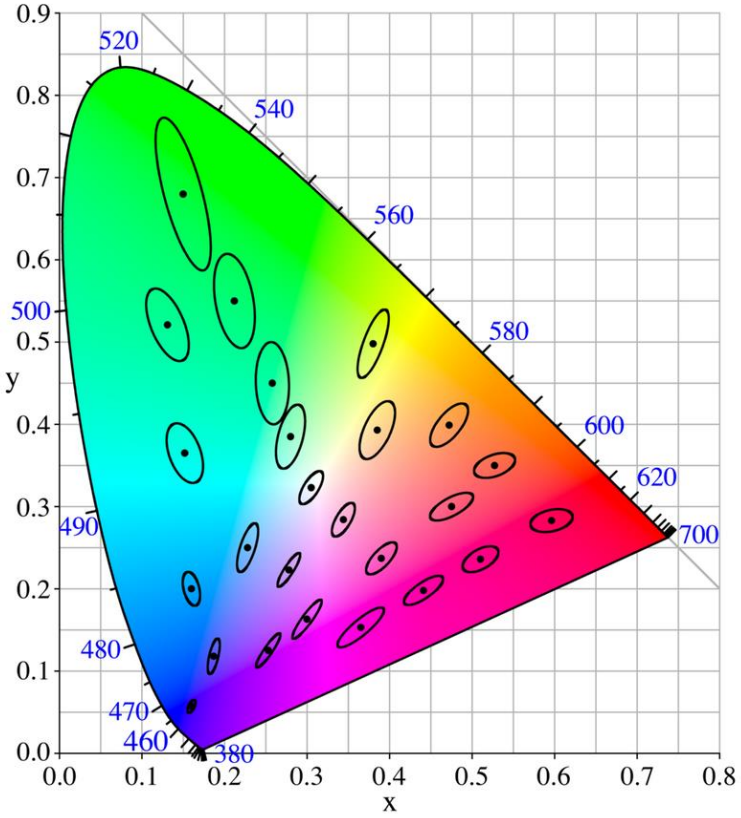
$$y = \frac{Y}{X+Y+Z}$$

- x and y are chromaticity coordinates
- Y is relative luminance
  - Chosen so that its colour matching function exactly matches the luminous-efficiency function for the human eye



Sum of these curves

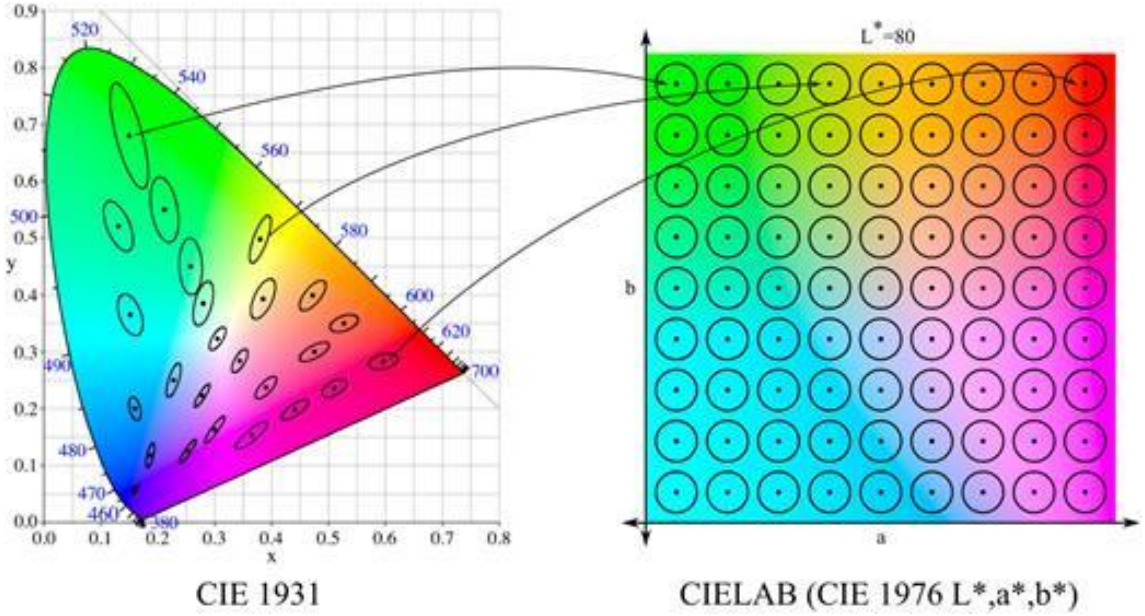
McAdam Ellipses



- **McAdam ellipses** refer to the region on a chromaticity diagram which contains all colors which are indistinguishable, to the average human eye, from the color at the center of the ellipse
- The contour of the ellipse represents the just noticeable differences of chromaticity

courtesy: wikipedia

CIE Lab color space

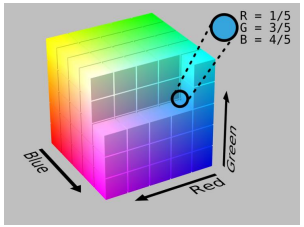


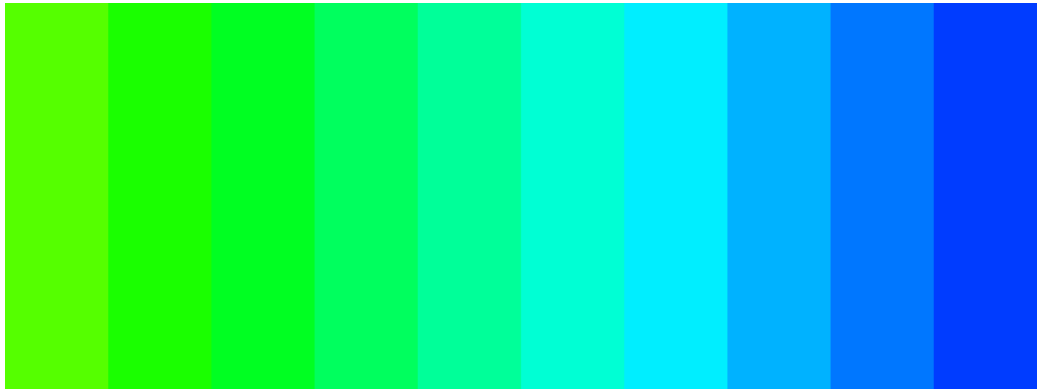
CIE 1931

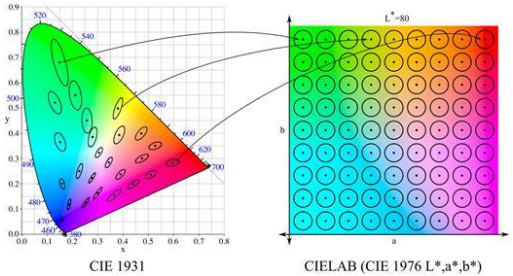
CIELAB (CIE 1976 L*,a*,b*)

Ideal scenario

Perceptually Uniform Color Spaces







https://matplotlib.org/3.1.1/tutorials/colors/colormaps.html