Image Processing
INT3404 20
Week 8:
Color Image Processing

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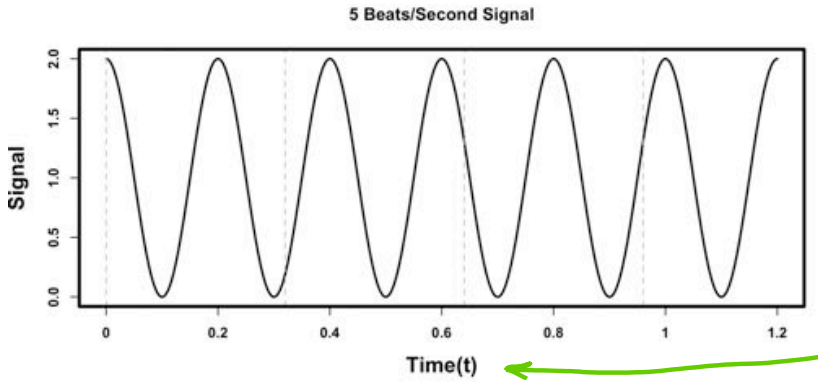
Slide & code: https://github.com/chupibk/INT3404_20

Schedule

Week	Content	Homework
1	Introduction	Set up environments: Python 3, OpenCV 3, Numpy, Jupyter Notebook
2	Digital image – Point operations Contrast adjust – Combining images	HW1: adjust gamma to find the best contrast
3	Histogram - Histogram equalization – Histogram-based image classification	Self-study
4	Spatial filtering - Template matching	Self-study
5	Feature extraction Edge, Line, and Texture	Self-study
6	Morphological operations	HW2: Barcode detection → Require submission as mid-term test
7	Filtering in the Frequency domain Announcement of Final project topics	Final project registration
8	Color image processing	HW3: Conversion between color spaces, color image segmentation
9	Geometric transformations	Self-study
10	Noise and restoration	Self-study
11	Compression	Self-study
12	Final project presentation	Self-study
13	Final project presentation Class summarization	Self-study

Recall week 7: Frequency domain Fourier transform

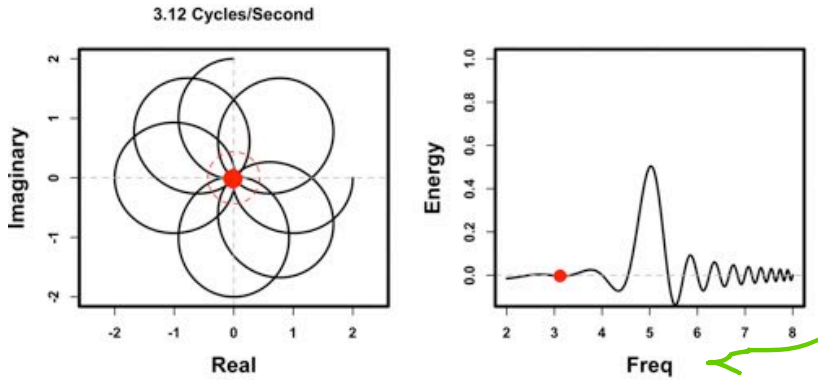


Transform the "Signal-Time" space

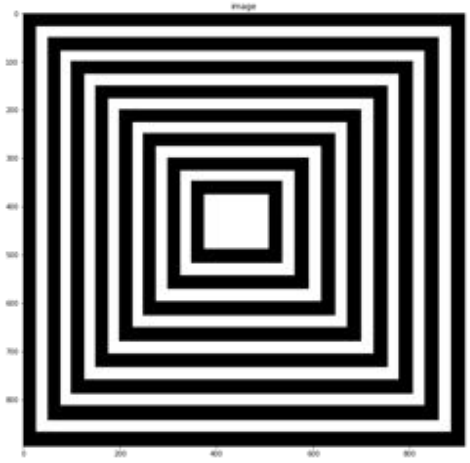
g(t)

To "Energy-Frequency" space

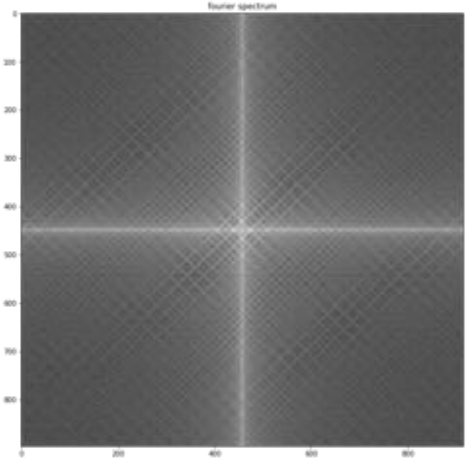
G(f)

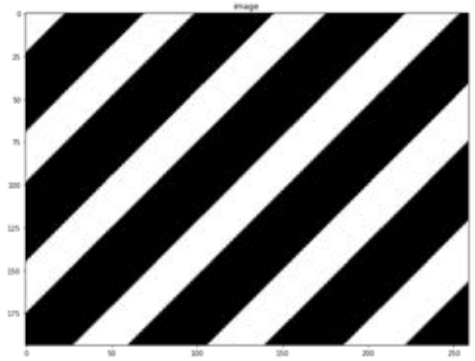


$$\hat{g}(f) = \frac{1}{N}\sum_{k=1}^{N} g(t_k)e^{-2\pi i f t_k}$$



image


fourier spectrum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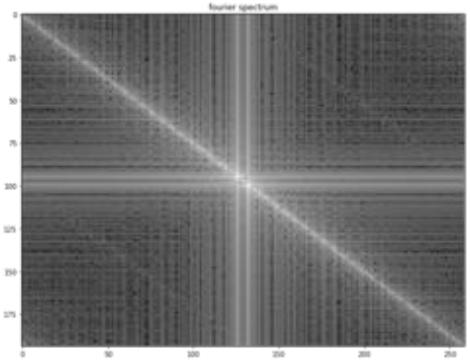
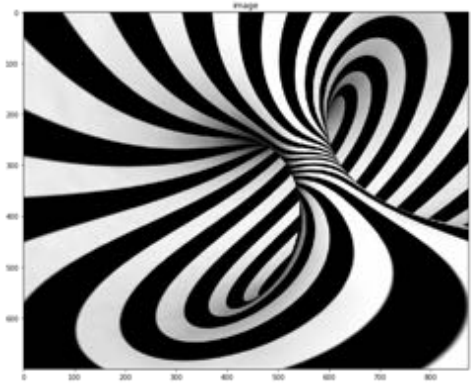

fourier spectrum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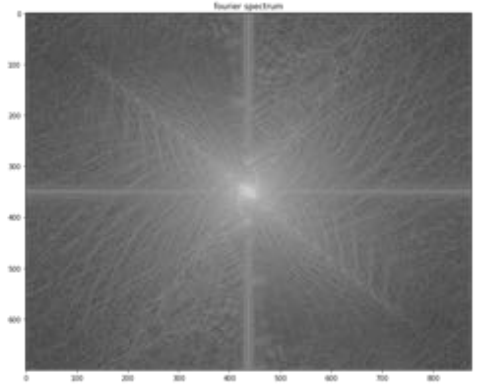
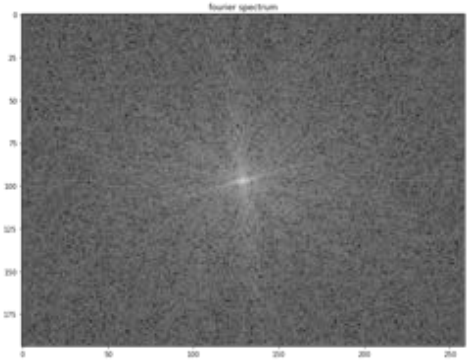

fourier spectrum


image

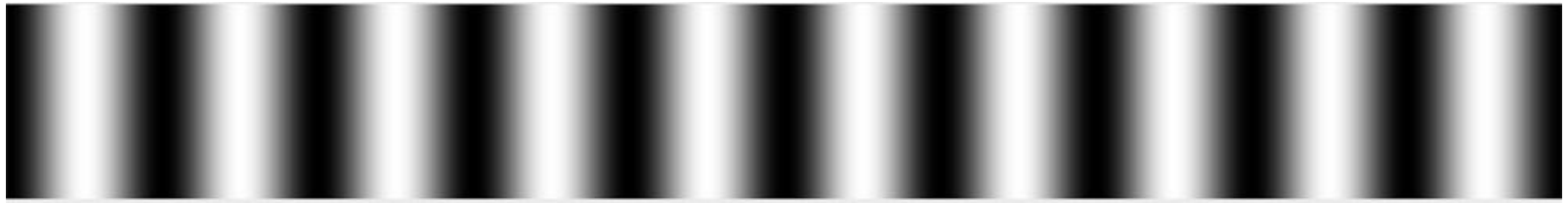

fourier spectrum

Fourier Transform references

- Great reference links:
- Euler's formula: https://www.mathsisfun.com/algebra/eulers-formula.html
- Interactive Fourier transforms: http://www.jezzamon.com/fourier/
- Intuitive Fourier transforms: https://sites.northwestern.edu/elannesscohn/2019/07/30/developing-an-intuition-for-fourier-transforms/
- Explanation video: https://www.youtube.com/watch?v=spUNpyF58BY

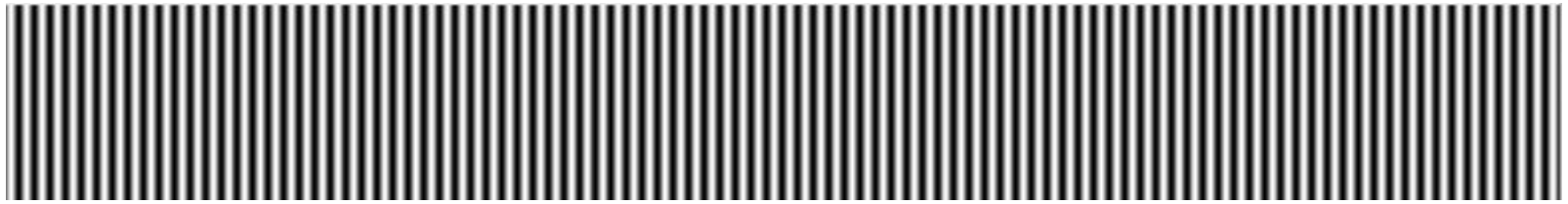
Low frequency, High frequency?

800px X 100px grayscale image
Generated using $I(x) = \sin(2\pi fx)$
where f = 10repetitions/800px = 0.0125 repetitions/px



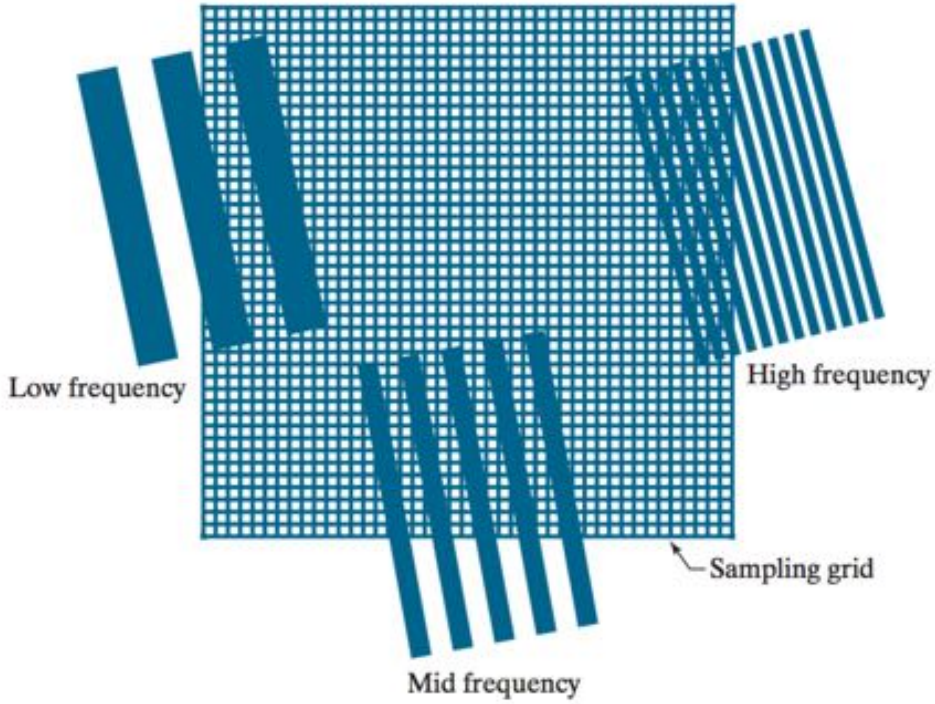
Smooth

increase the frequency by a factor of 10, so that n = 100 repetitions
f = 100/800 = 1/8 = 0.125 repetitions/px

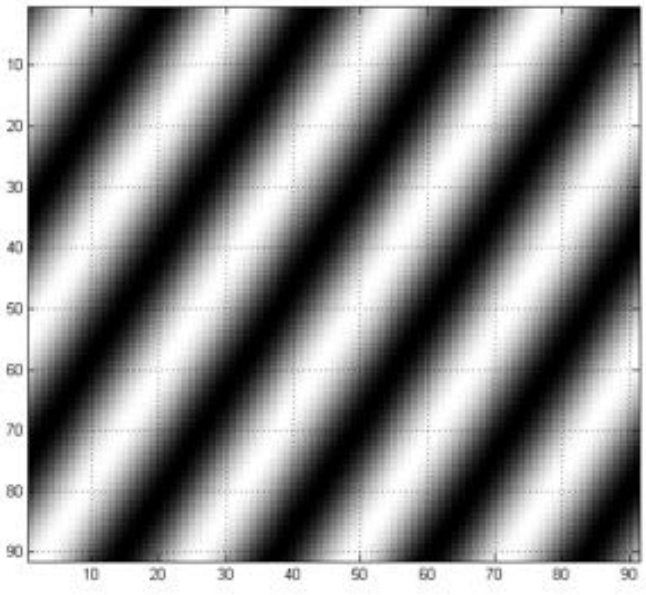


Finer details,
many edge

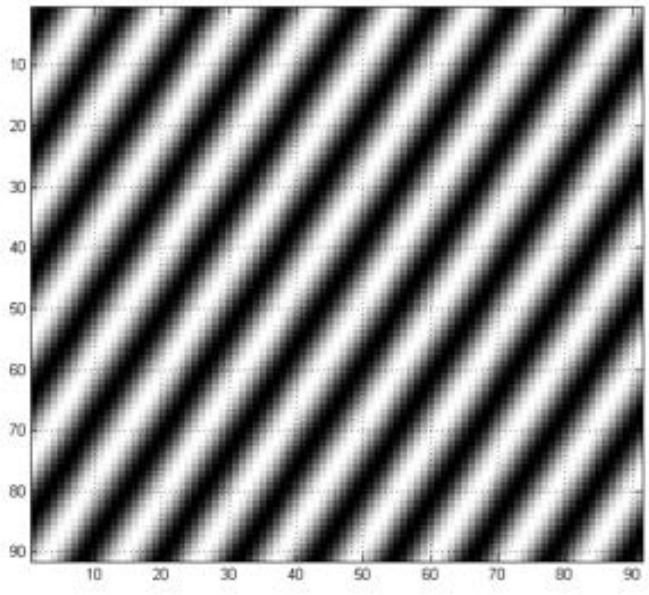
Low frequency, High frequency?



Low frequency, High frequency?

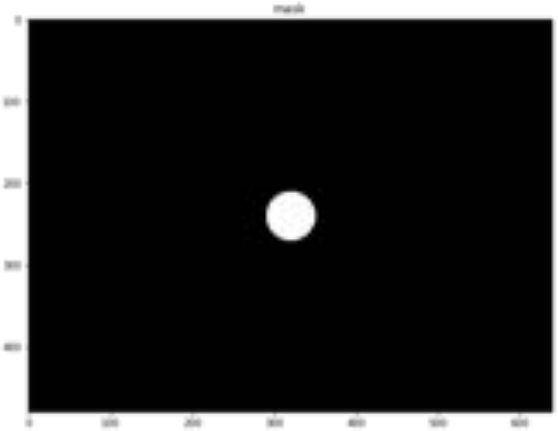


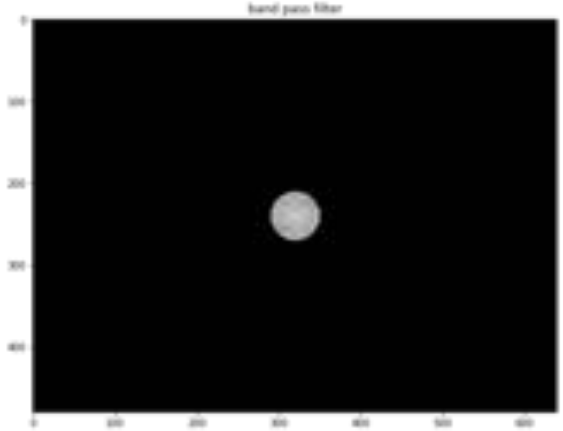
Low frequency

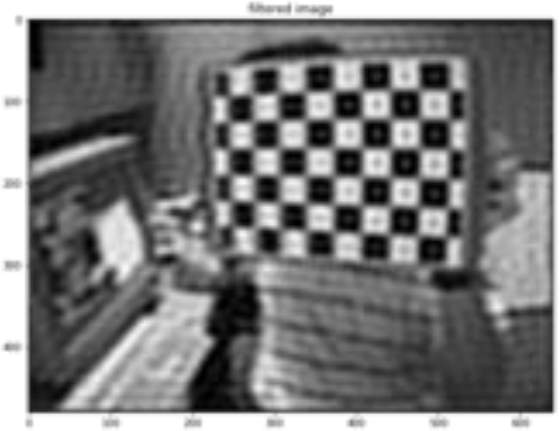


High frequency

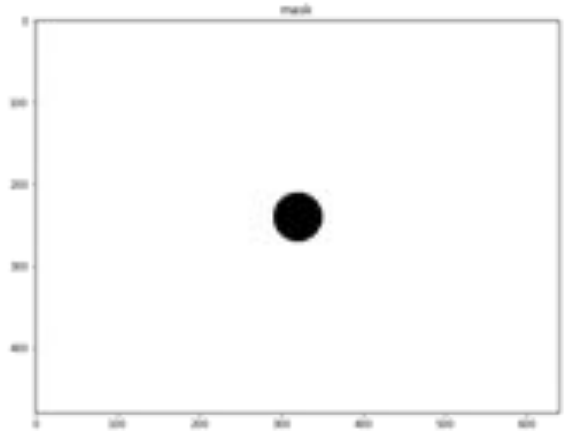
Low pass filter

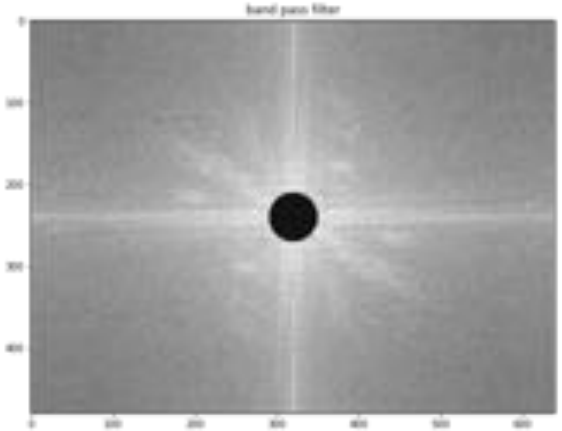


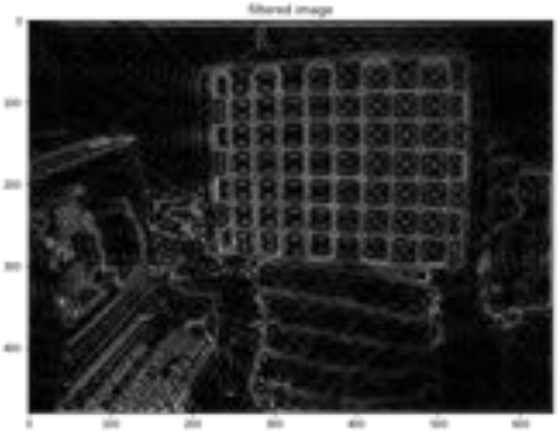




High pass filter







Filtering in Frequency domain

- Ideal low/high pass
- Butterworth low/high pass
- Gaussian low/high pass

Color image processing

- What is color
- How to create color
- How to encode color
- Color spaces

Colors

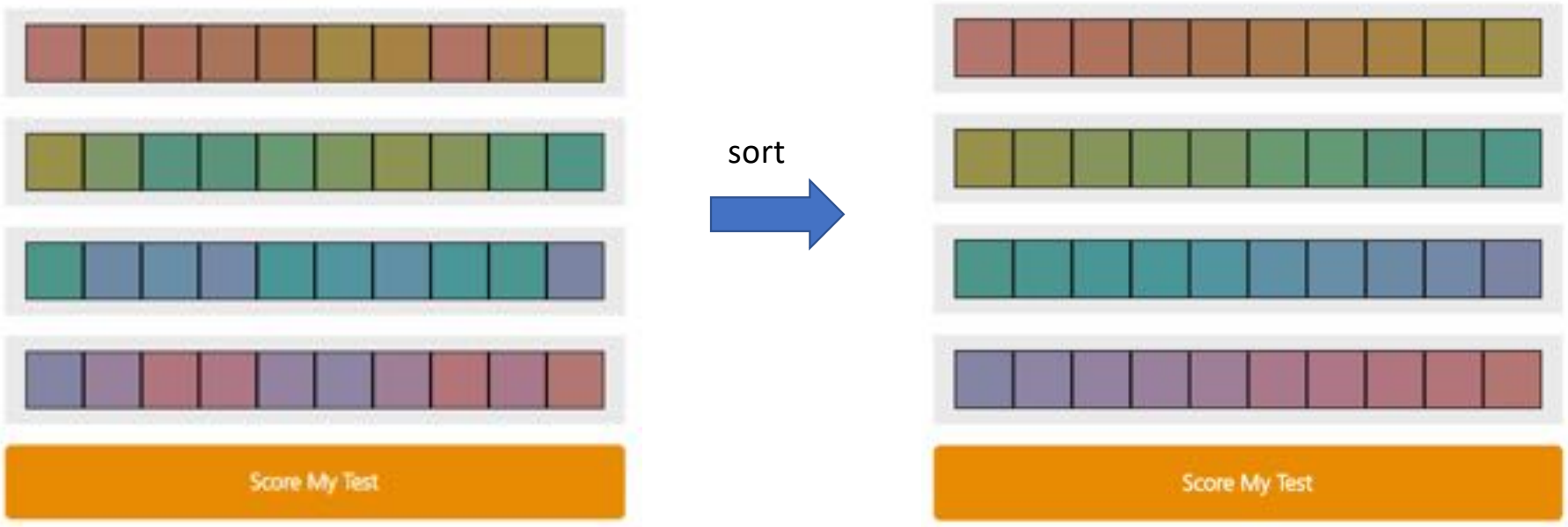
- Color exists only in light, but light itself seems colorless to the human eyes

- What is color and how we perceive colors?

Color IQ: How well do you see color

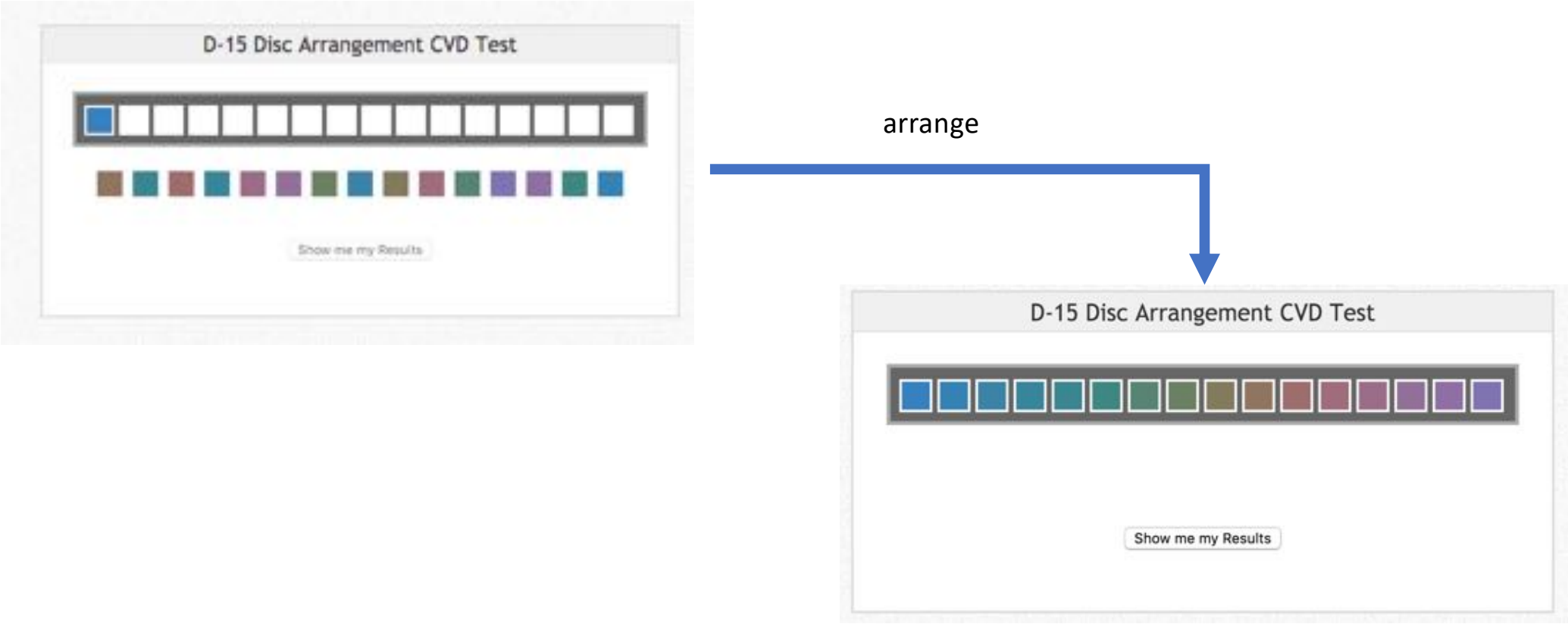
- Do you know
  - 1 out of 255 women and 1 out of 12 men have some form of color vision deficiency?
- Color vision test examples:
  - Farnsworth Munsell 100 Hue Test (1949)
    - http://goo.gl/Nj6mBi
  - Farnsworth D15 arrangement test (1947)
    - http://goo.gl/OL1k6o

Farnsworth Munsell 100 Hue Test (1949)

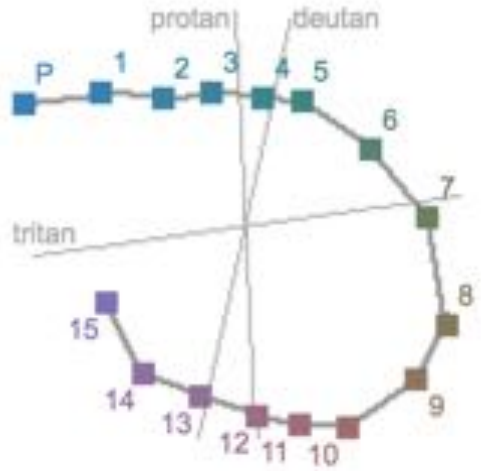


Farnsworth Munsell 100 Hue test result

Farnsworth D15 arrangement test (1947)



Farnsworth D15 arrangement results



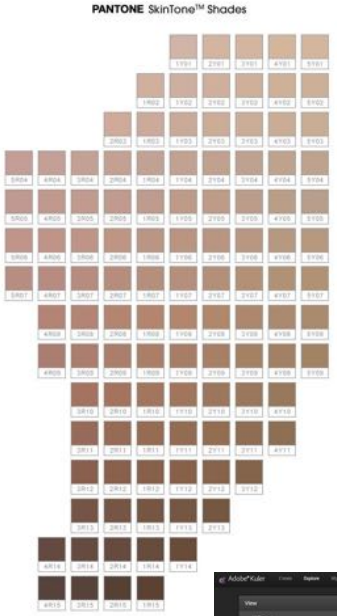
The thick line describes your order of the test plates. People with normal color vision order them in a circle (P, 1, 2, ..., 15). Crossings indicate some form of color blindness. Paralleslism of crossings to a confusion line (protan, deutan, tritan) is a clue for the type of your color blindness.

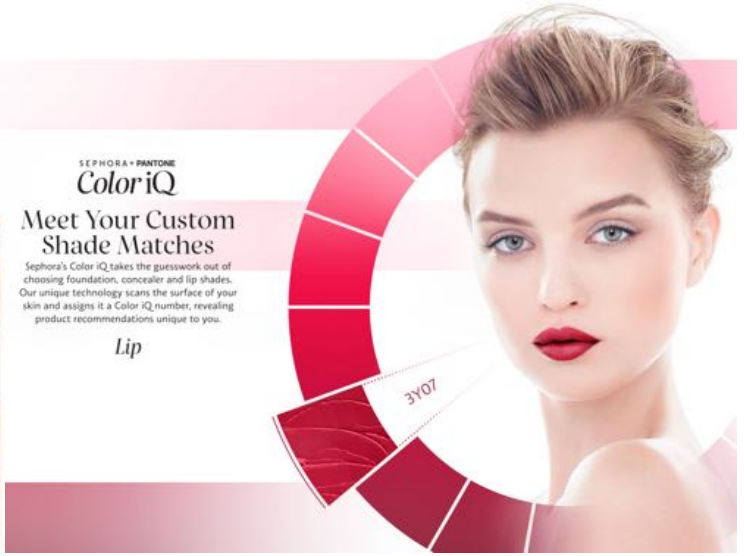
Give me more detailed Results

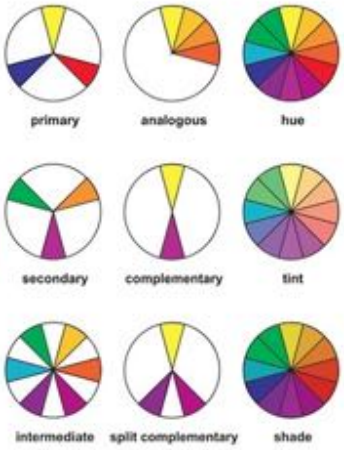
Color IQ: it is not just for fun

- Color vision can indicate certain medical conditions
- In industries, where color decisions are critical
  - E.g., Product sales, Design, Cosmetics
- In art

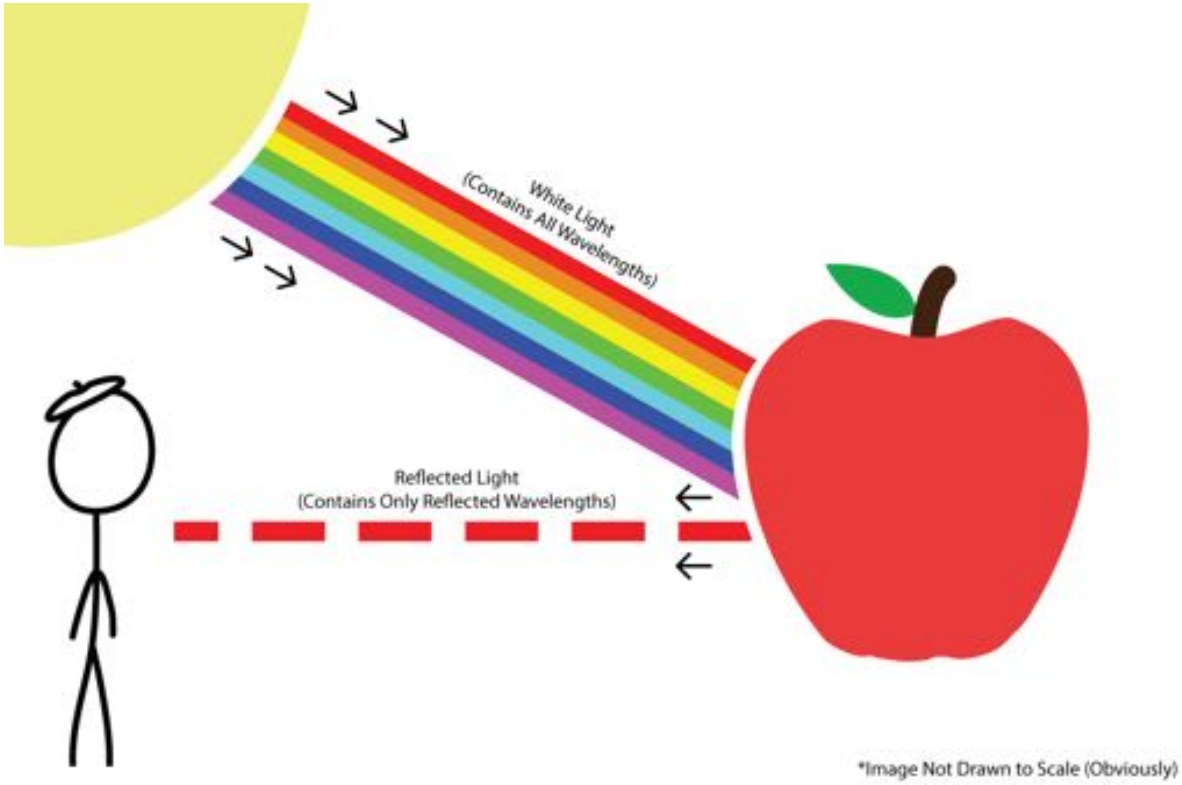
Applications





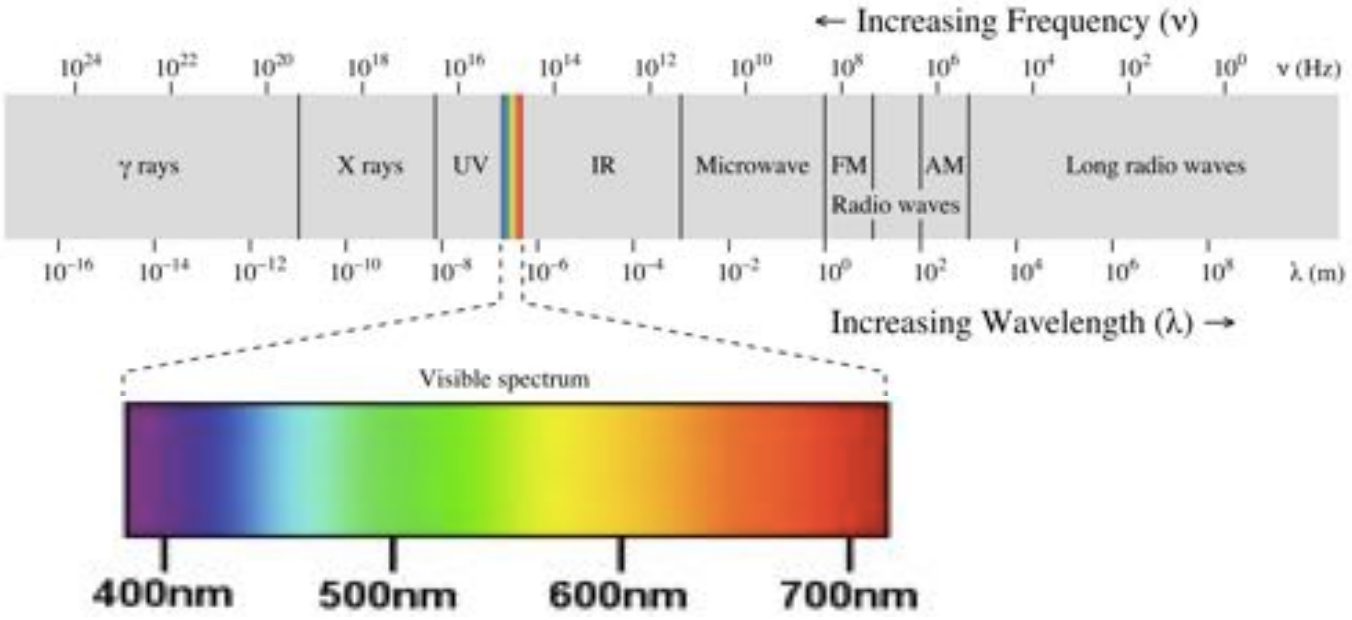


Seeing colors



Electromagnetic spectrum

Electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation



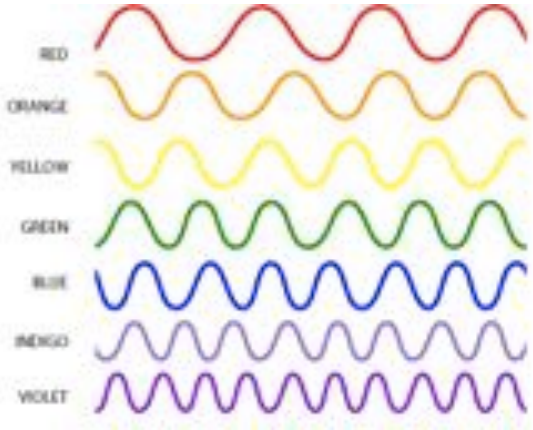
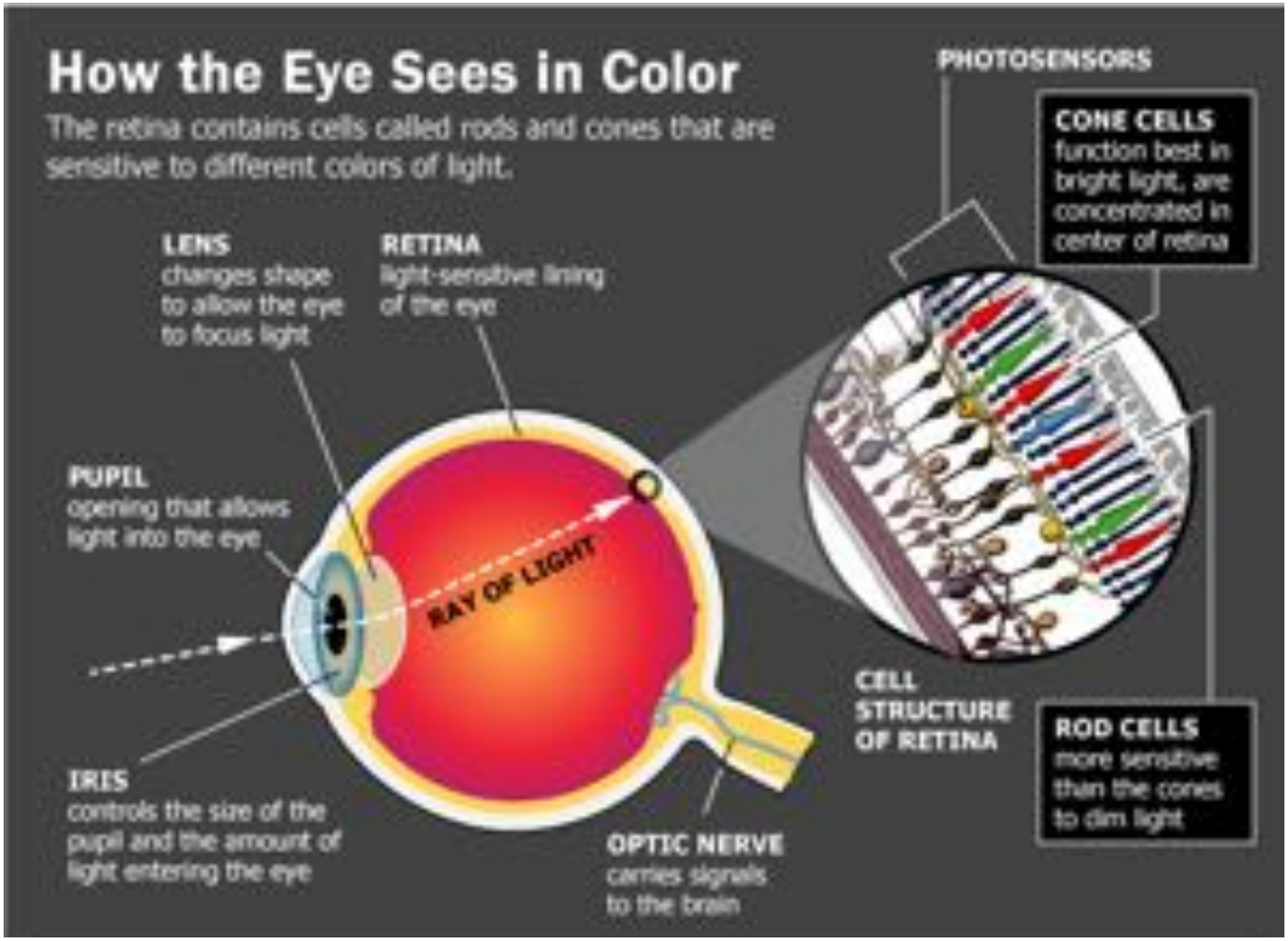


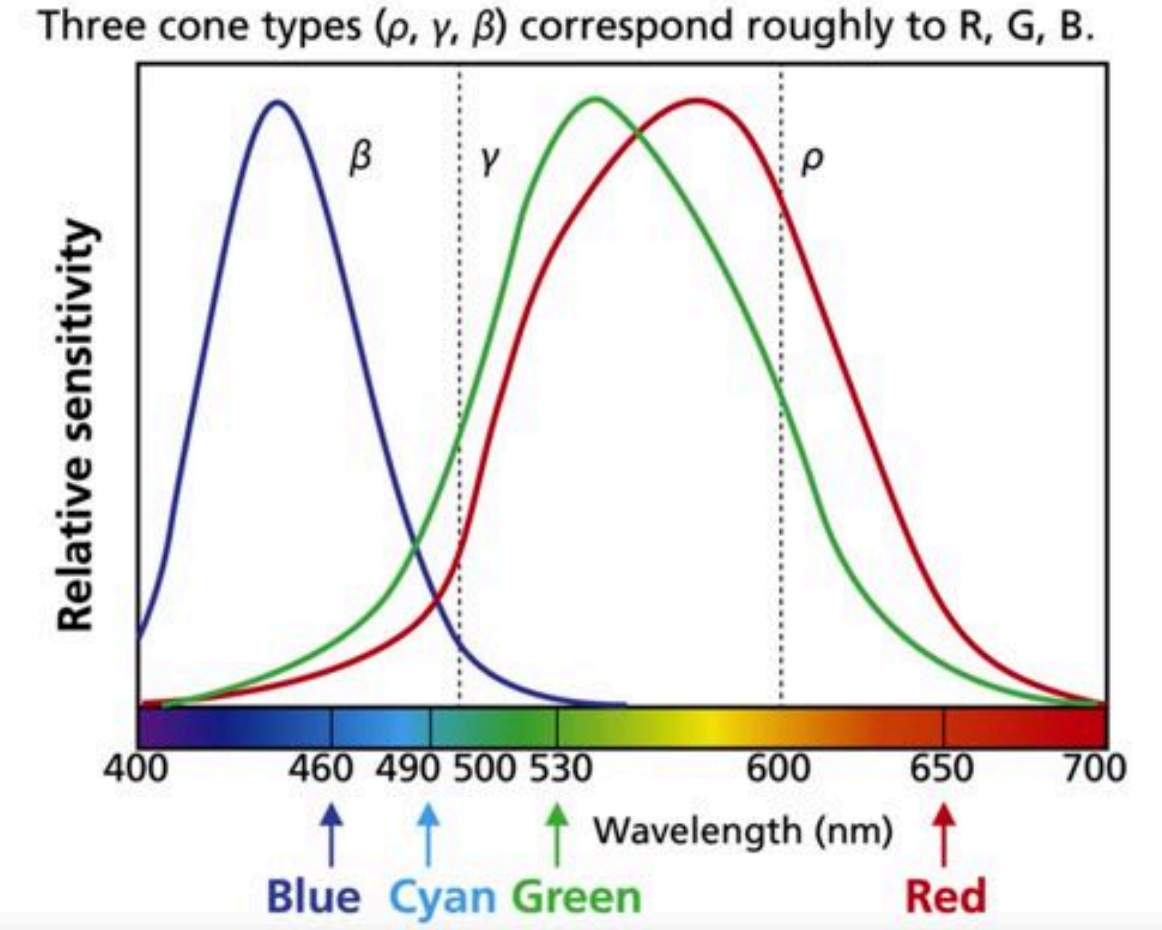
Image credit: wikipedia.org
nasa.gov


Absorbs All
Reflects Red
Reflects All



Source: National Library of Medicine, photos8.com

Human spectral sensitivity to color



Three types of cone cells:
(named after their sensitivity at wavelengths)

- Long (L)
- Medium (M)
- Short (S)

In principle, three parameters, corresponding to levels of stimulus to the three types of cone cells, can describe any color sensation

Color blindness

One or more cone types are defective

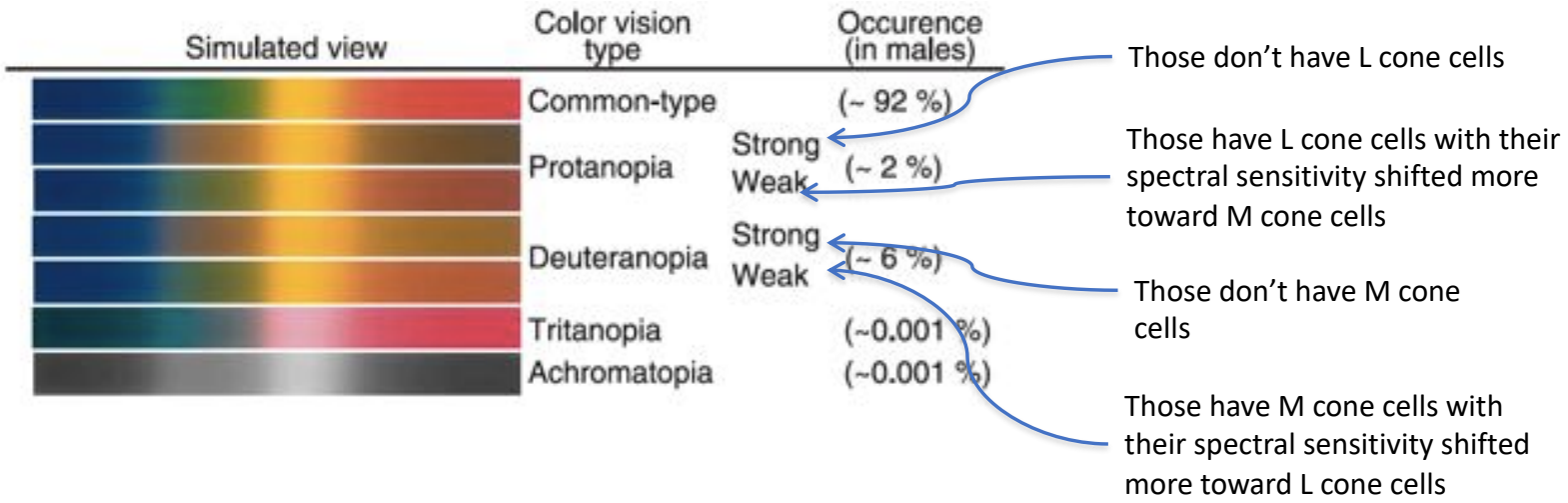


Image credit: www.cudo.jp

Example of color vision deficiency

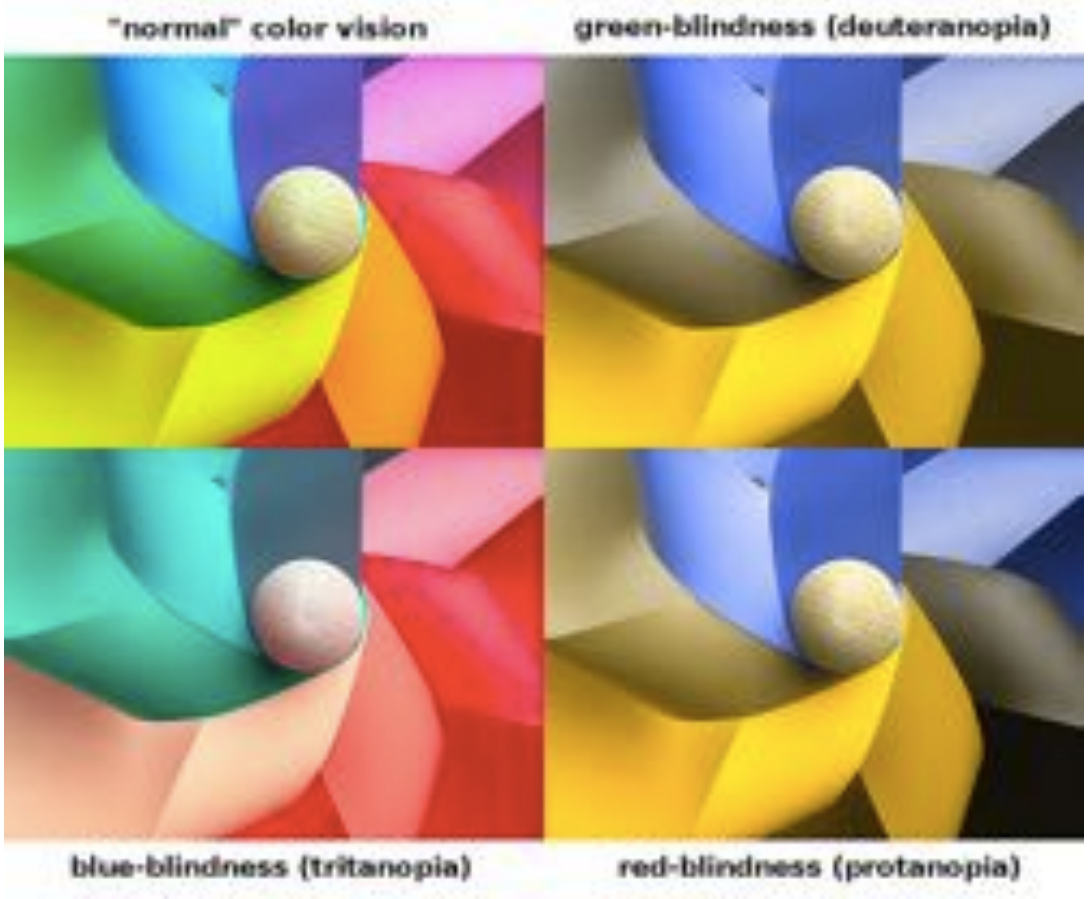
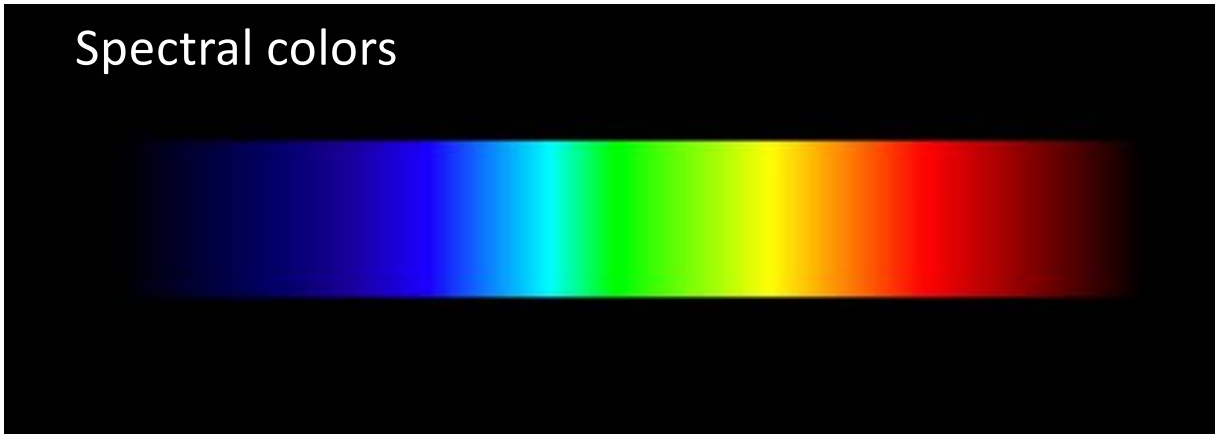


Image credit: flickr.com

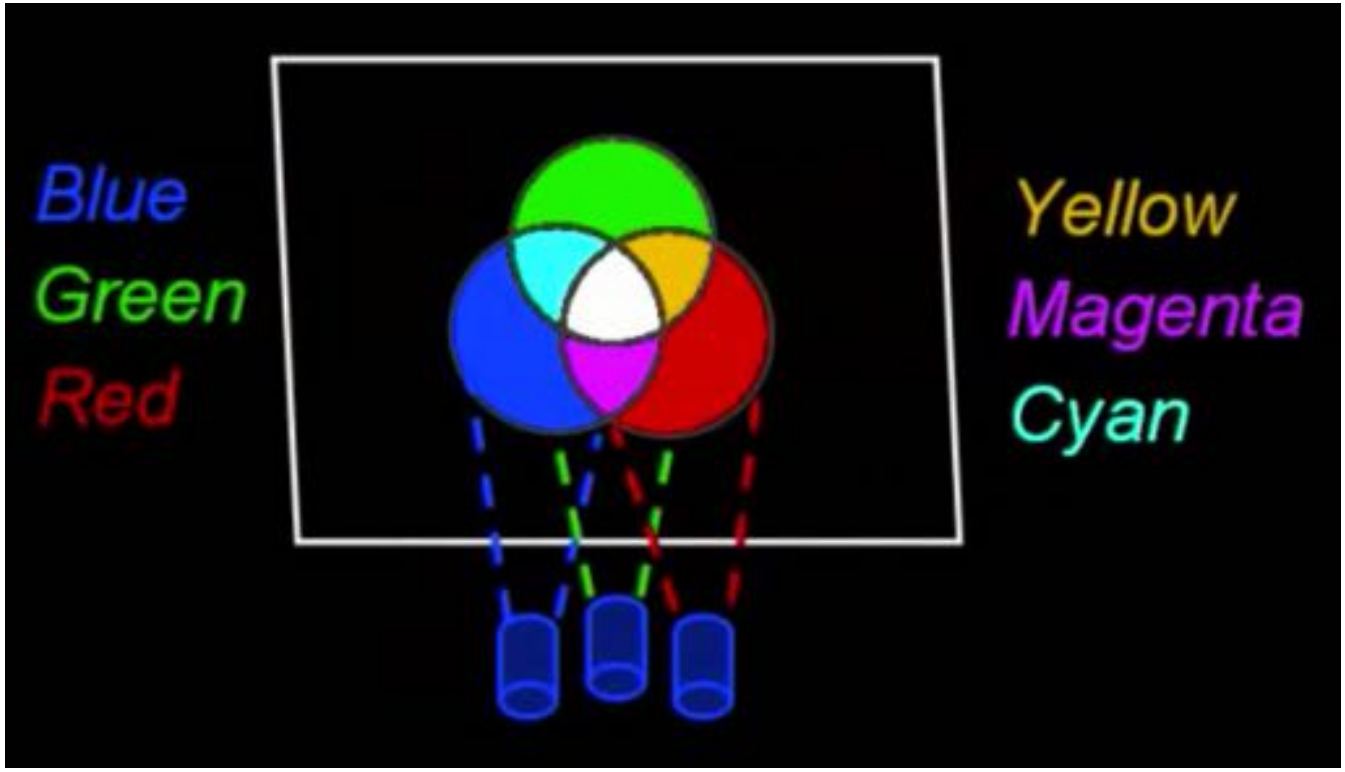
Color creation

Colors

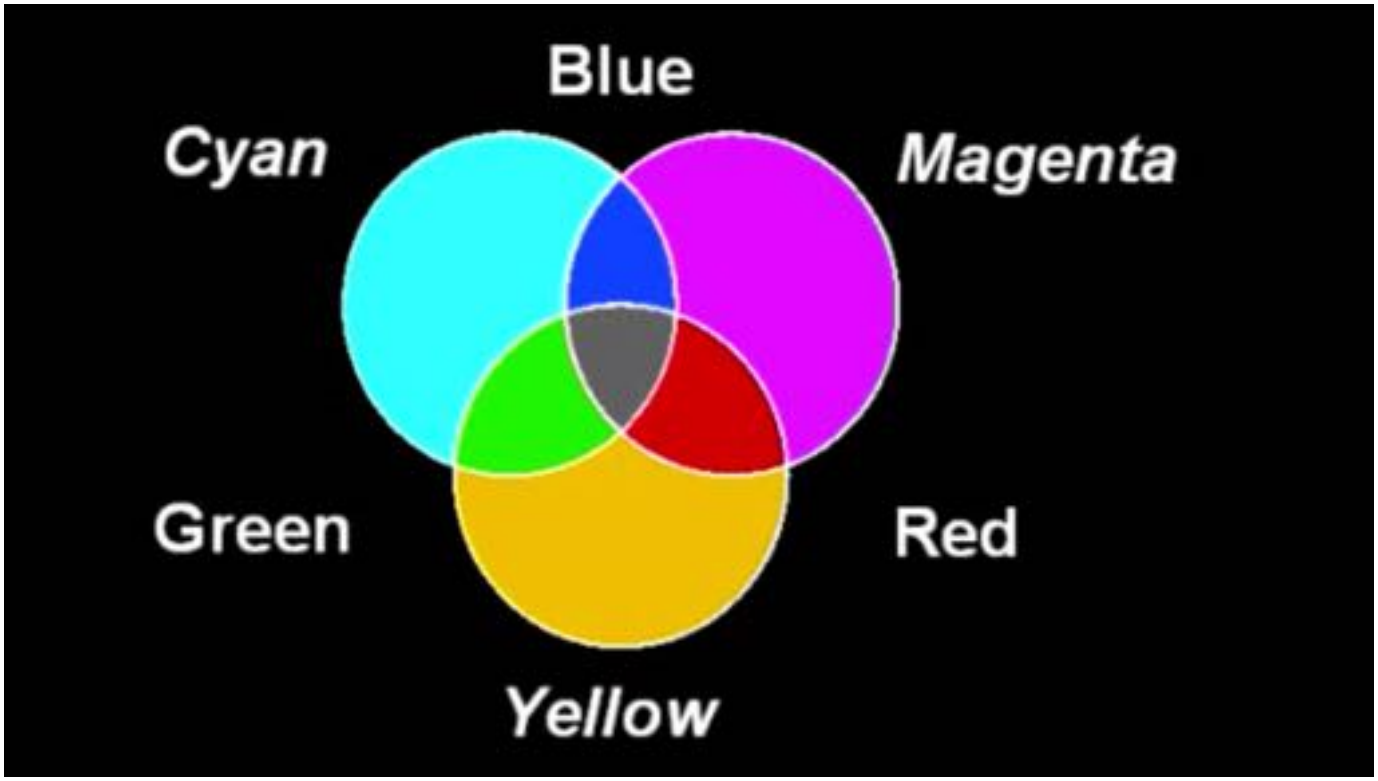
Newton 1666-72



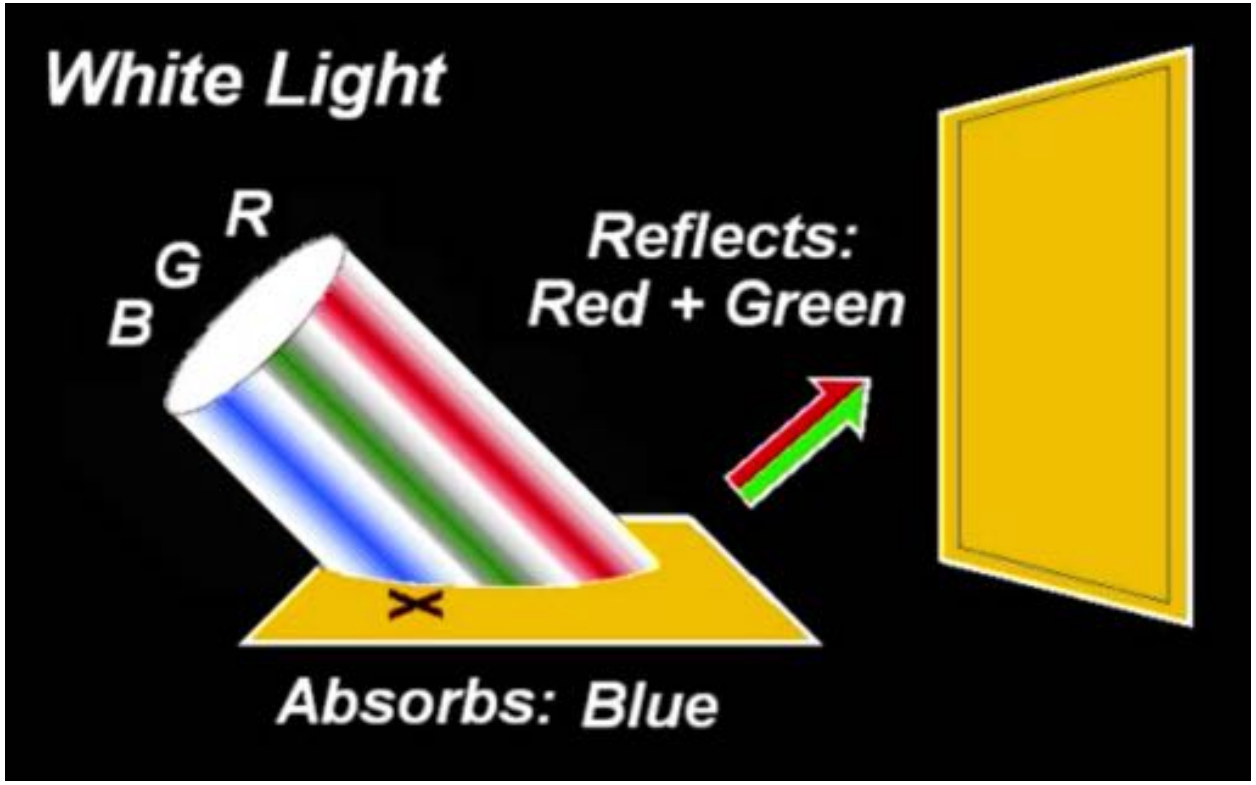
Additive color



Subtractive color

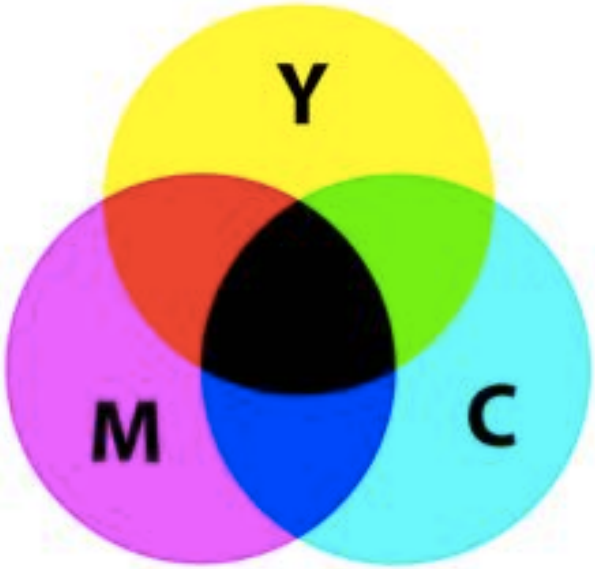


Subtractive color with filter



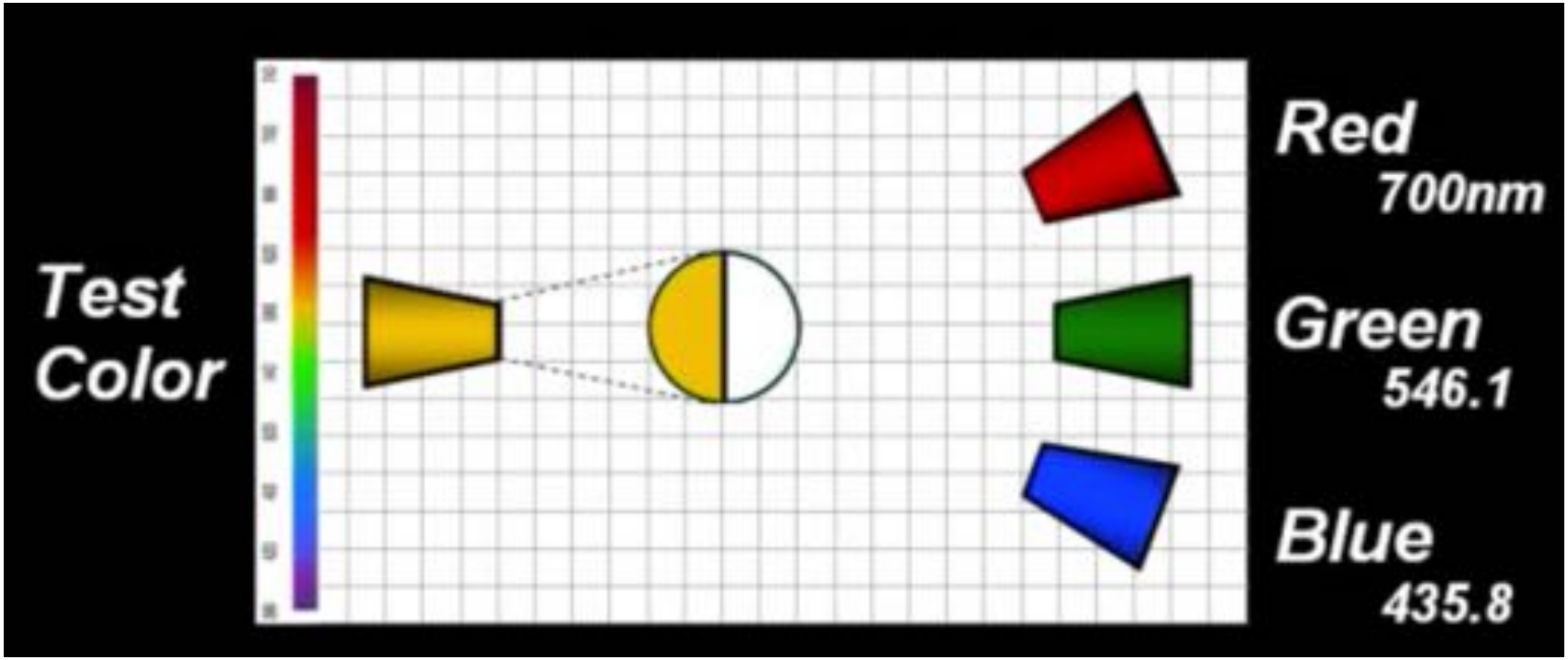
Additive vs Subtractive color creation

Your add light to make the color brighter



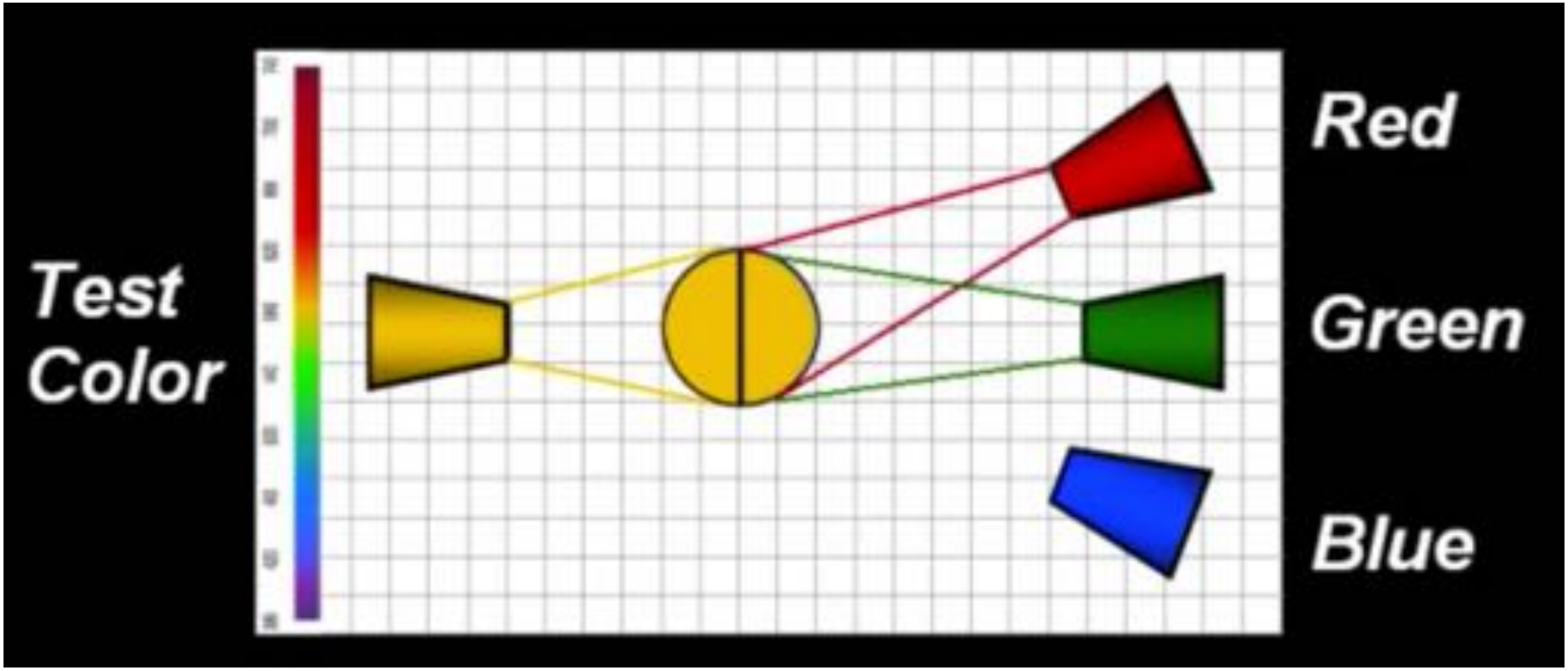
You subtract the light from the paper by adding more color

Color matching

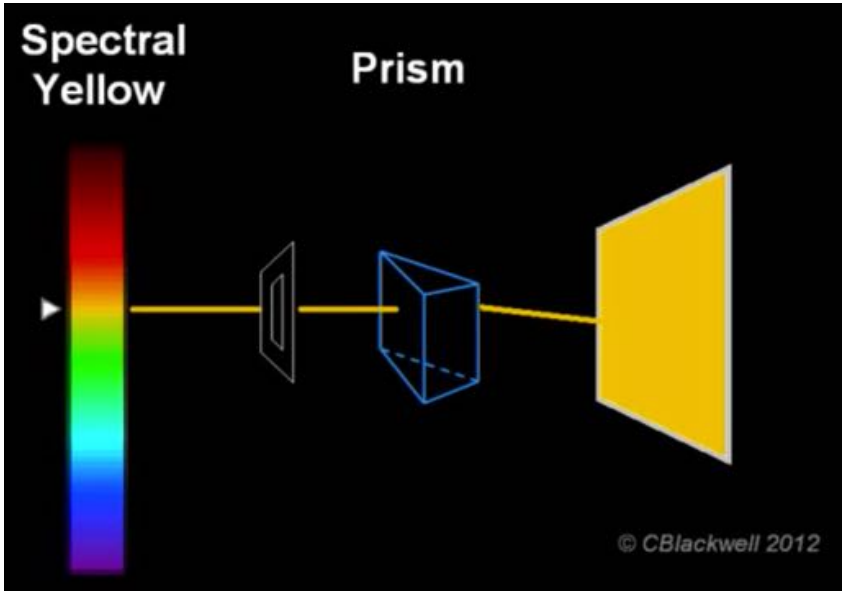


The amount of three colors: tristimulus values

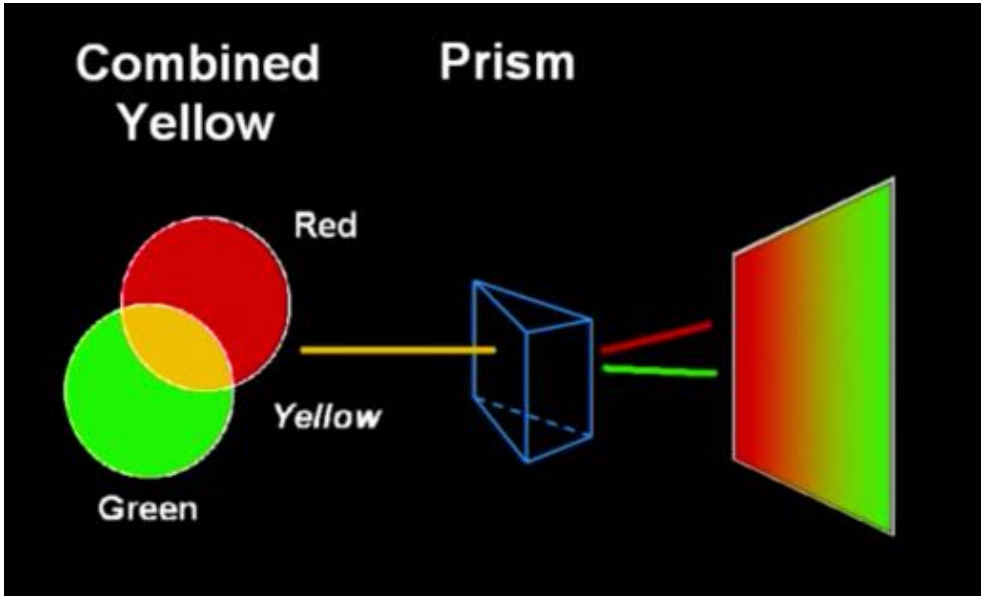
Color matching



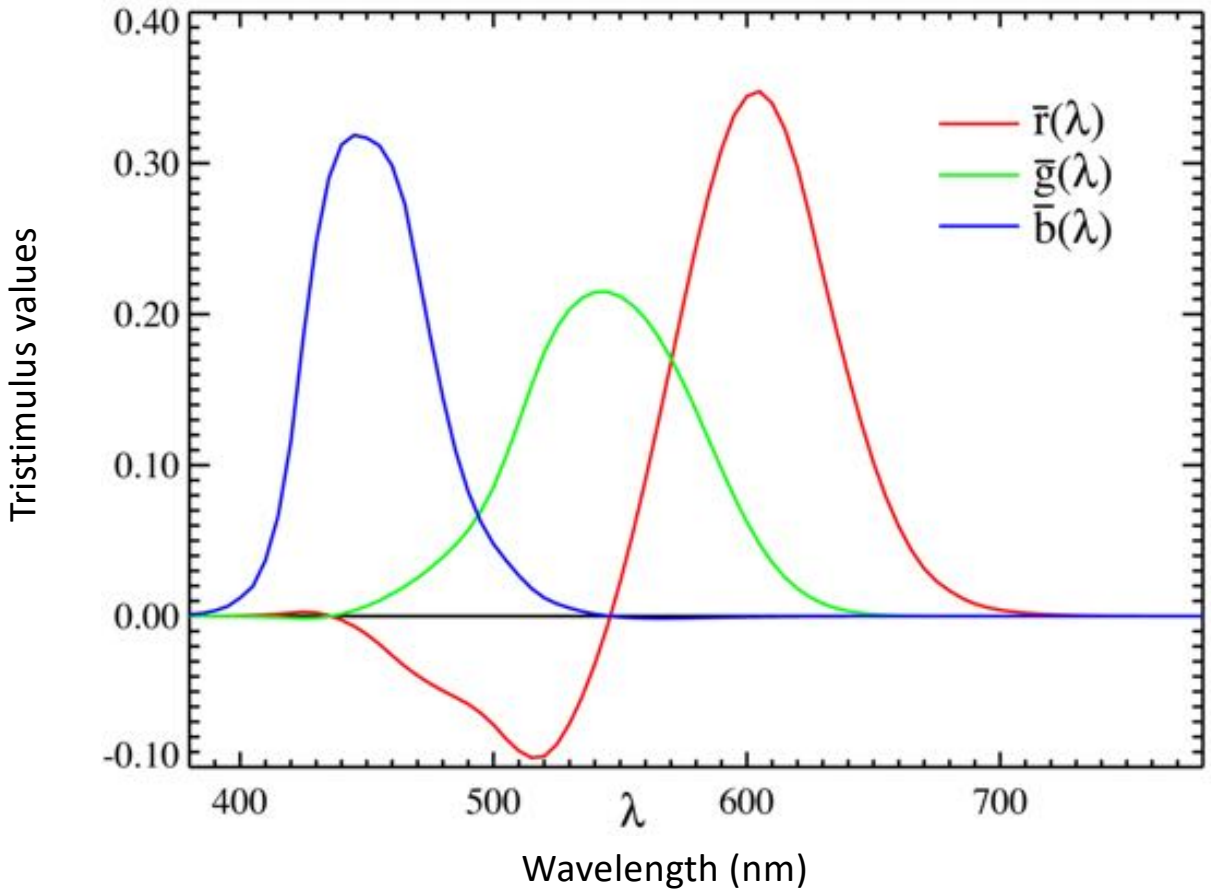
Note: color is in your mind



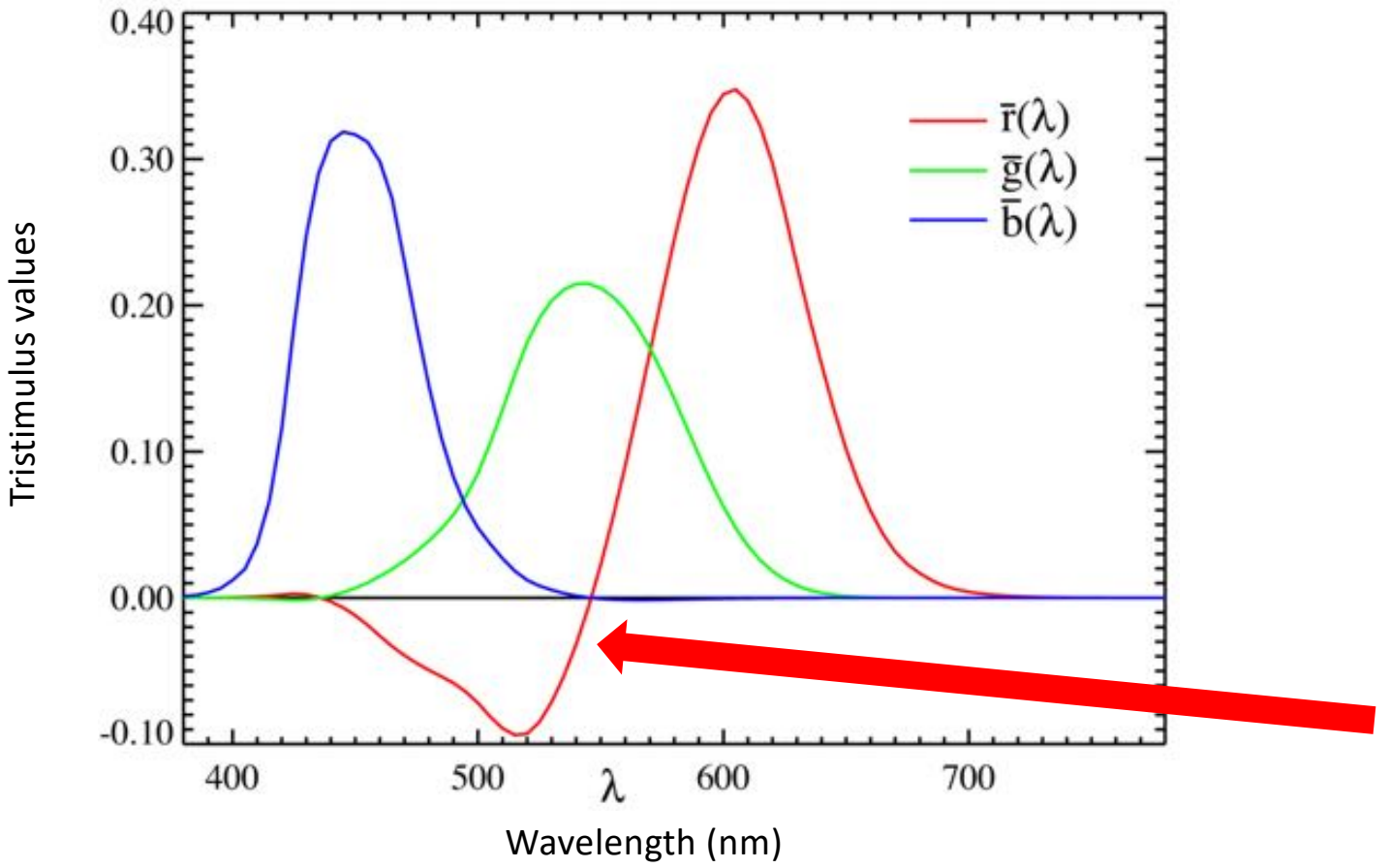
But...



Color matching RGB

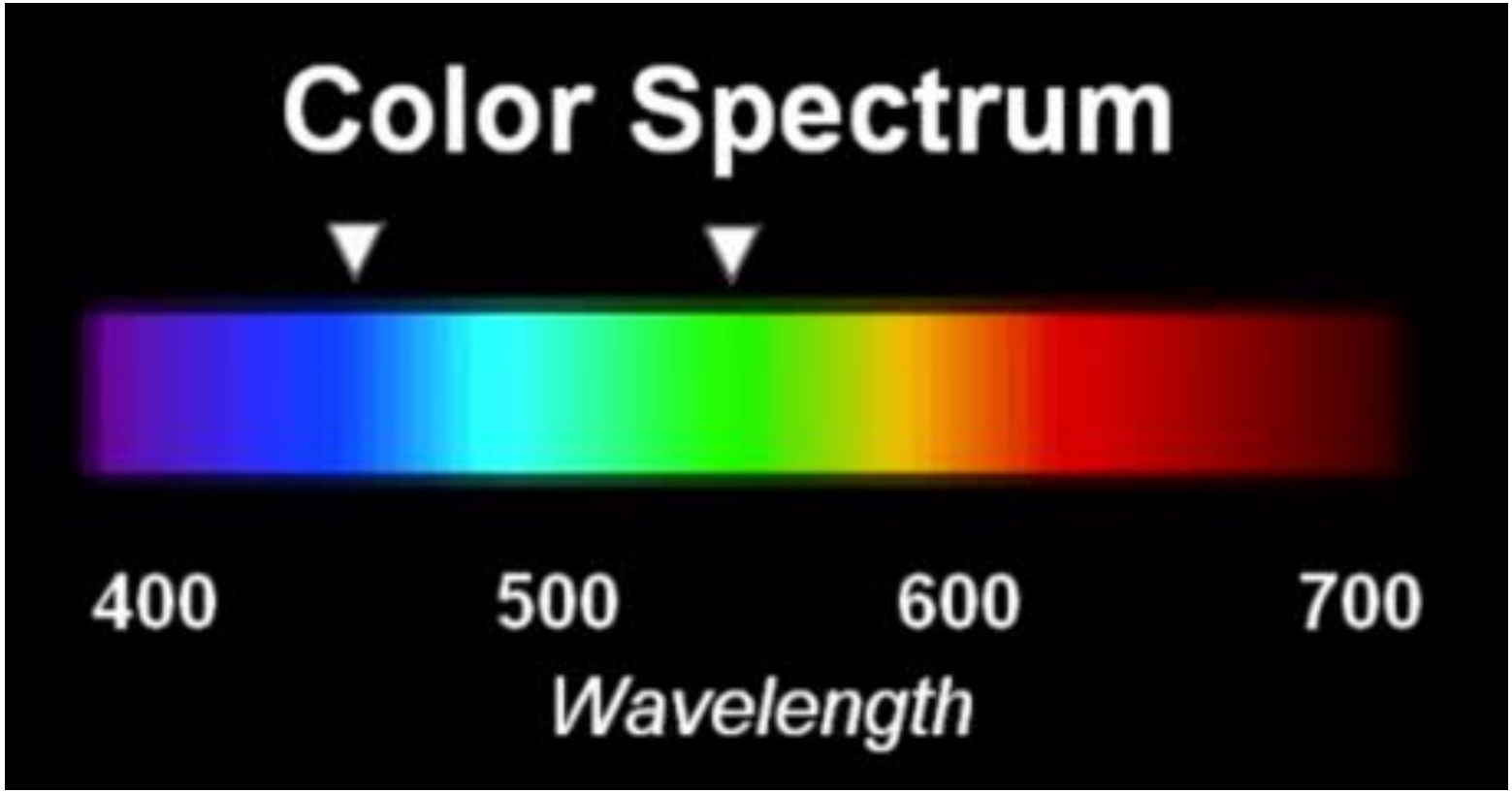


Color matching RGB

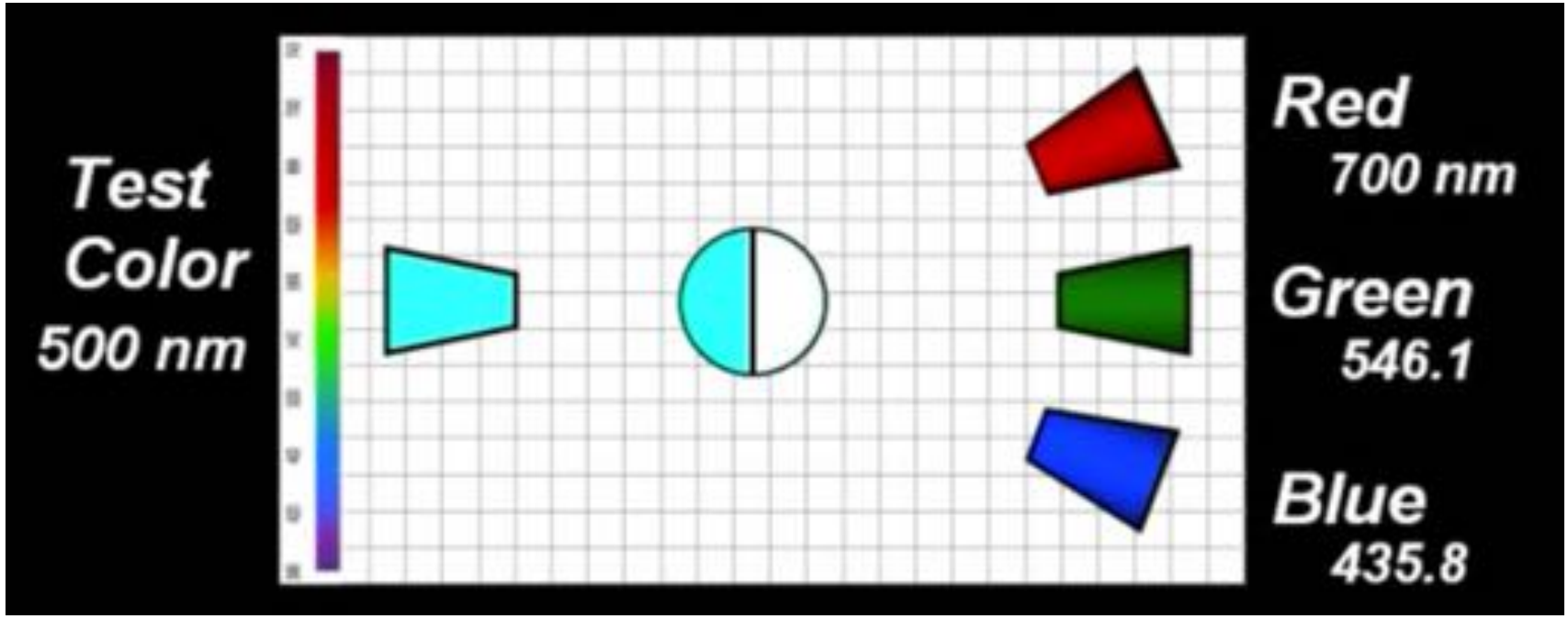


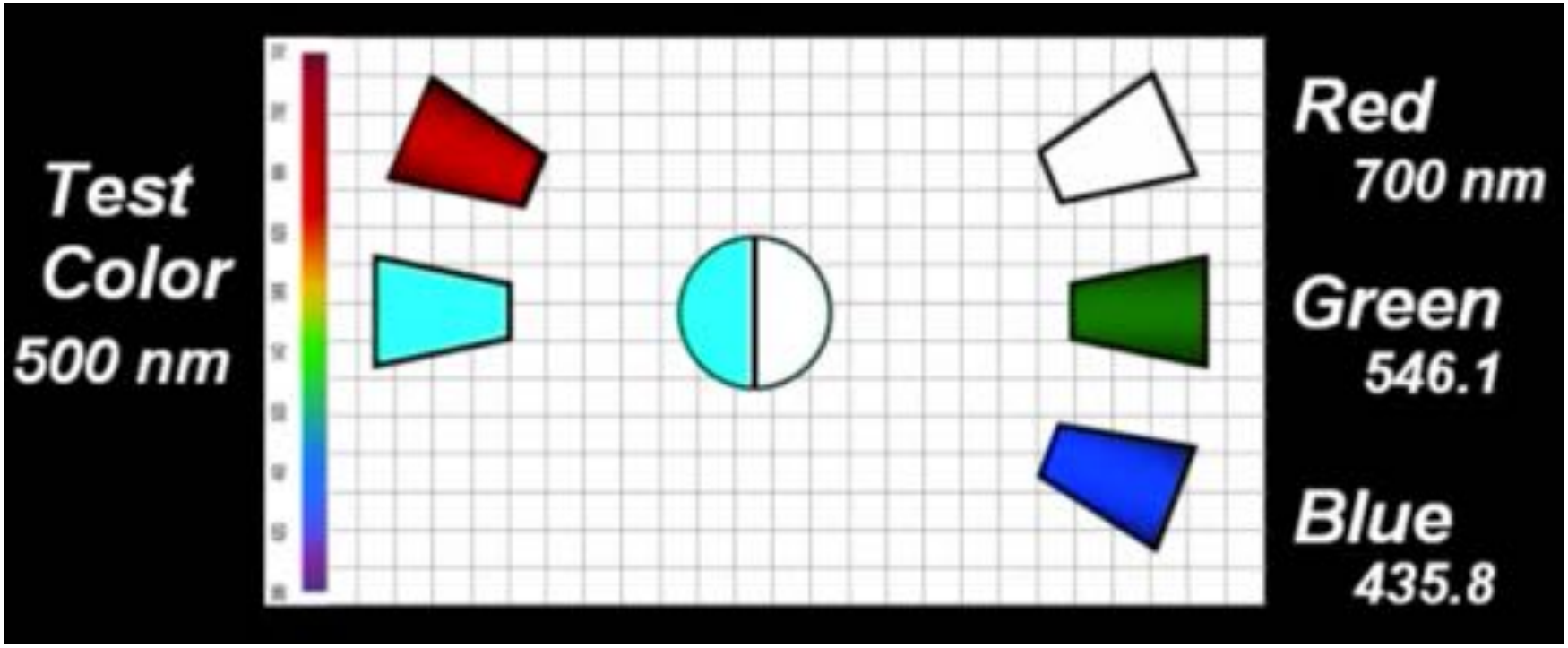
Negative amounts?

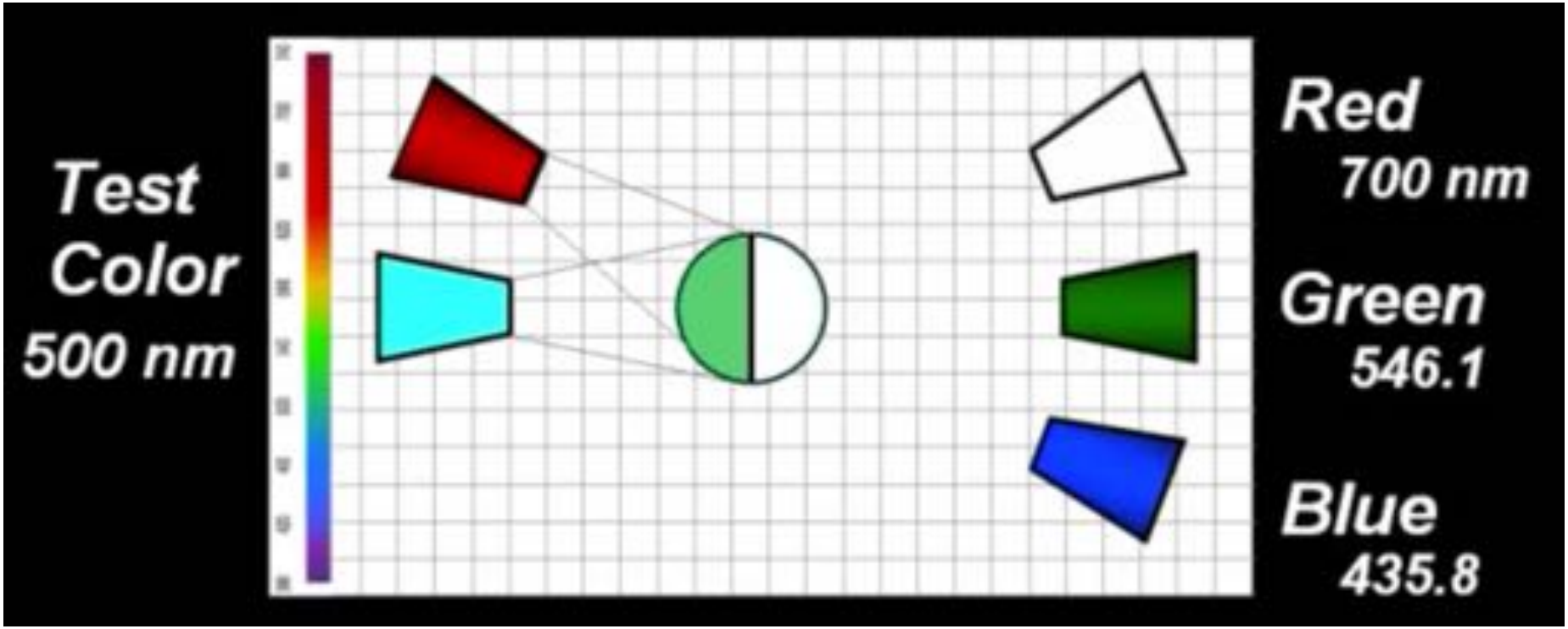
Unmatch-able examples using RGB



How is it matched?




Test
Color
500 nm
Red
700 nm
Green
546.1
Blue
435.8


Test
Color
500 nm
Red
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546.1
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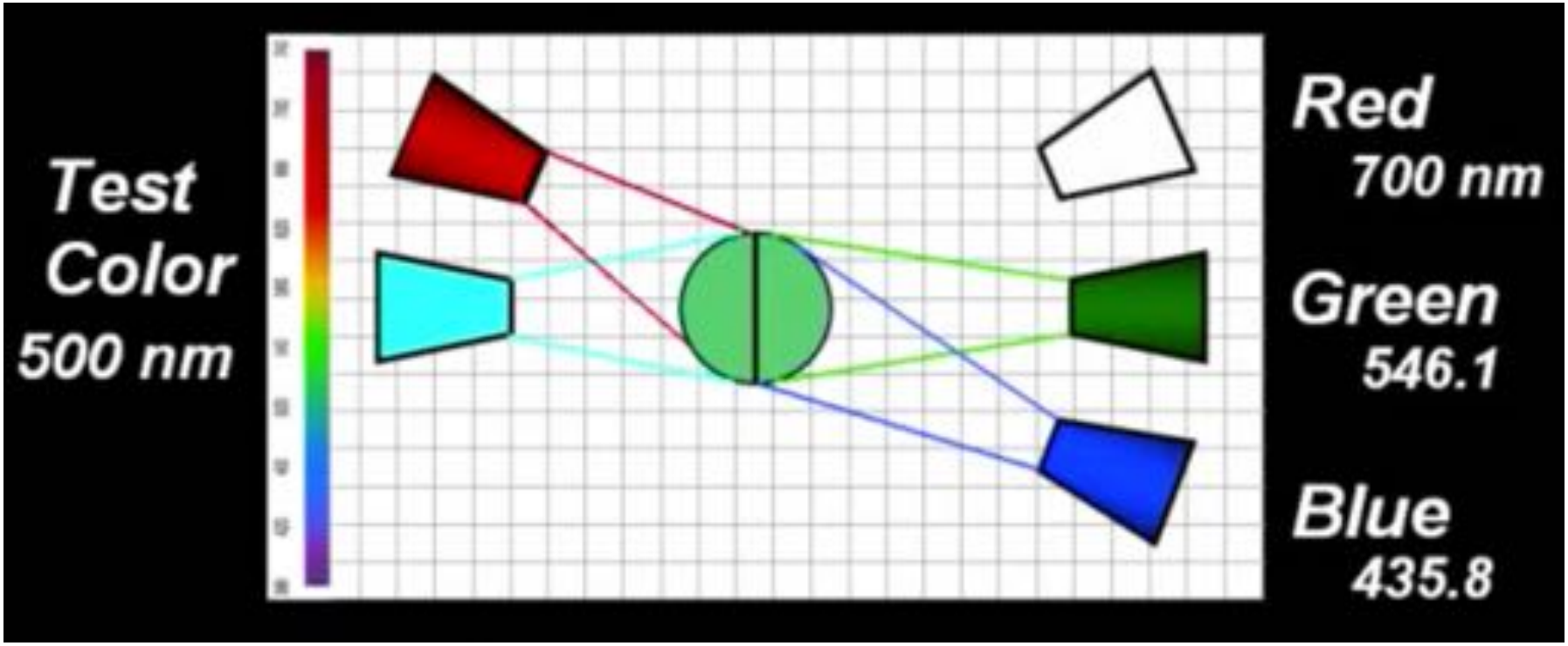
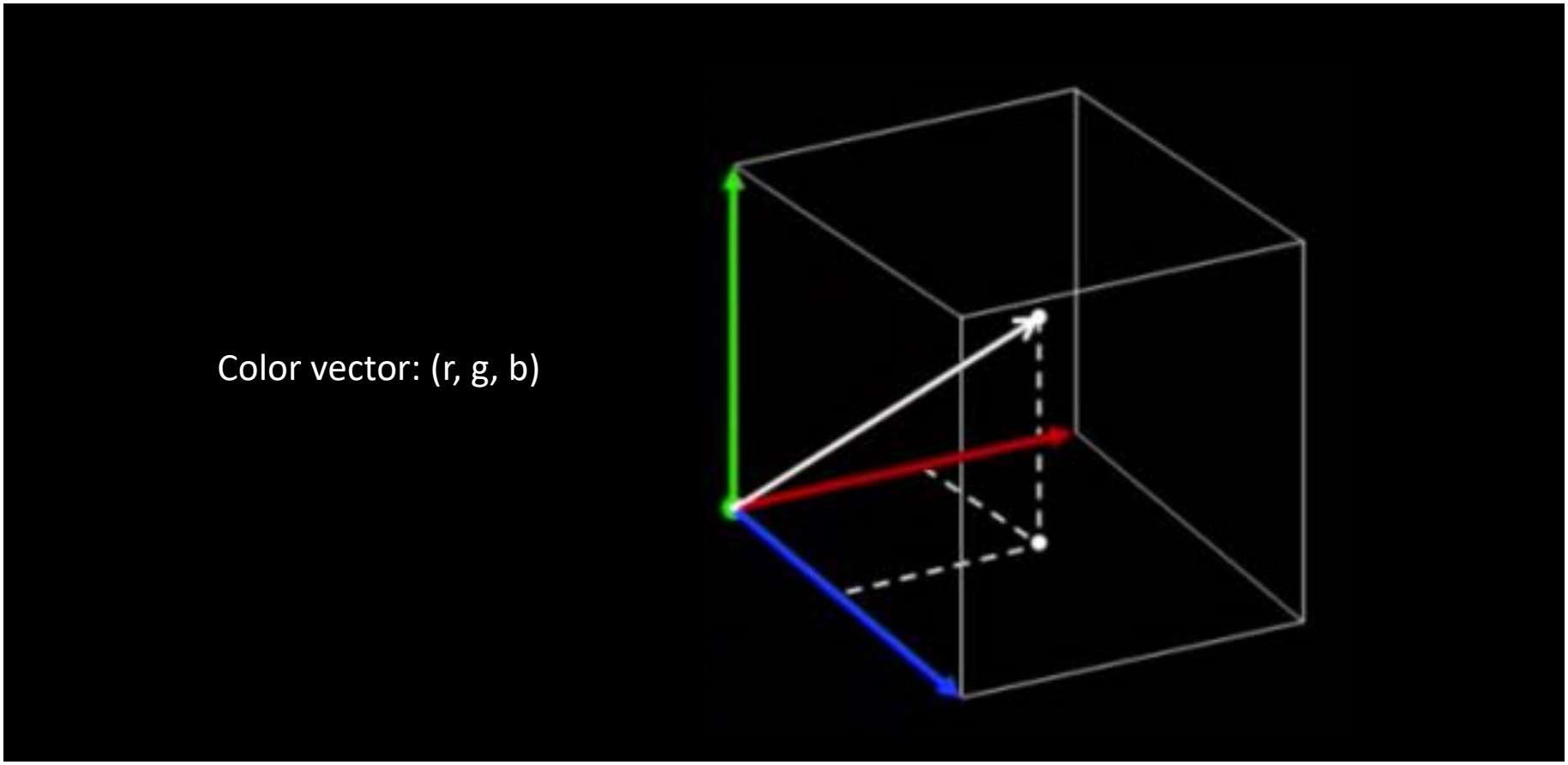
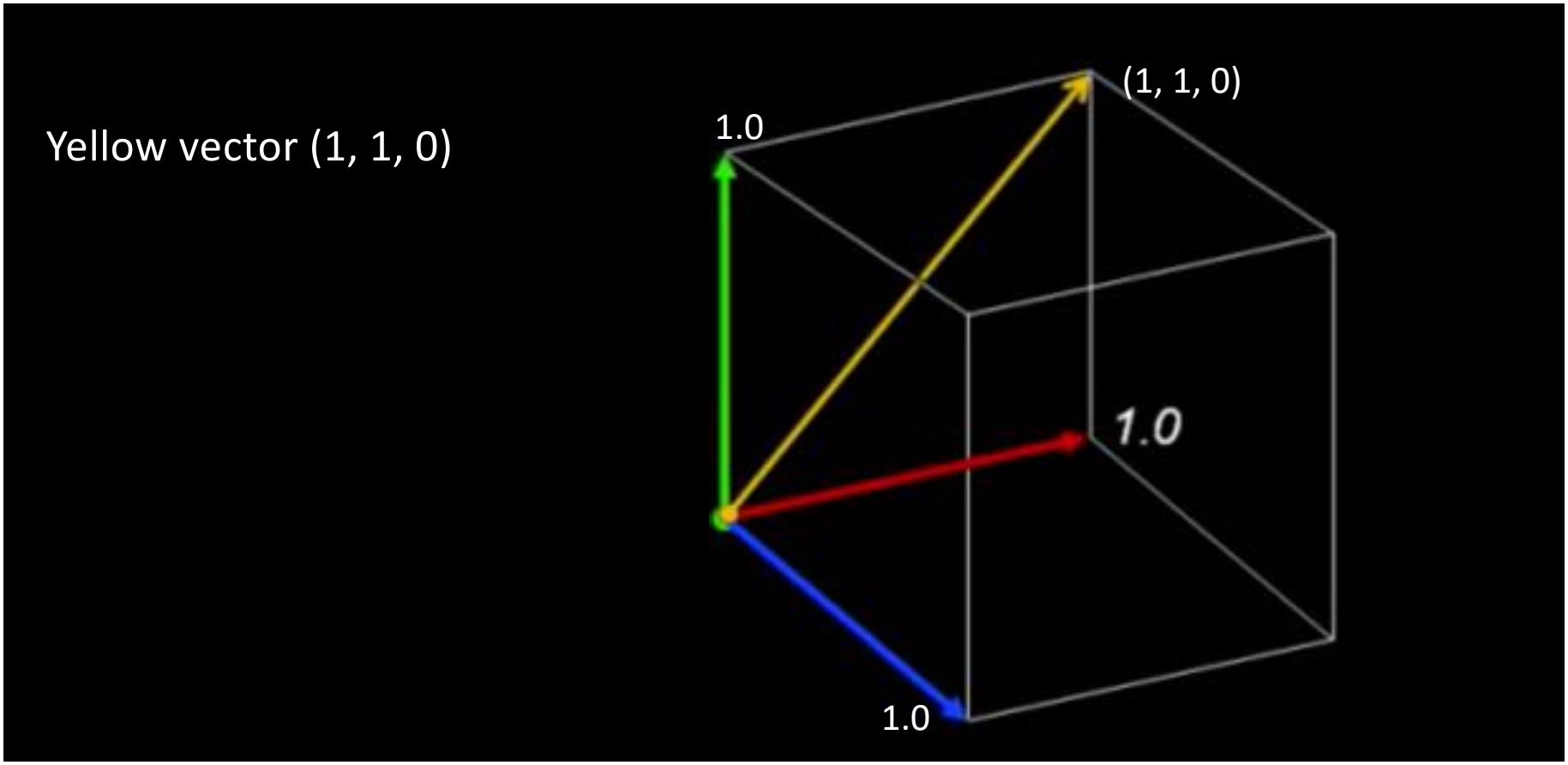
435.8


Test
Color
500 nm
Red
700 nm
Green
546.1
Blue
435.8

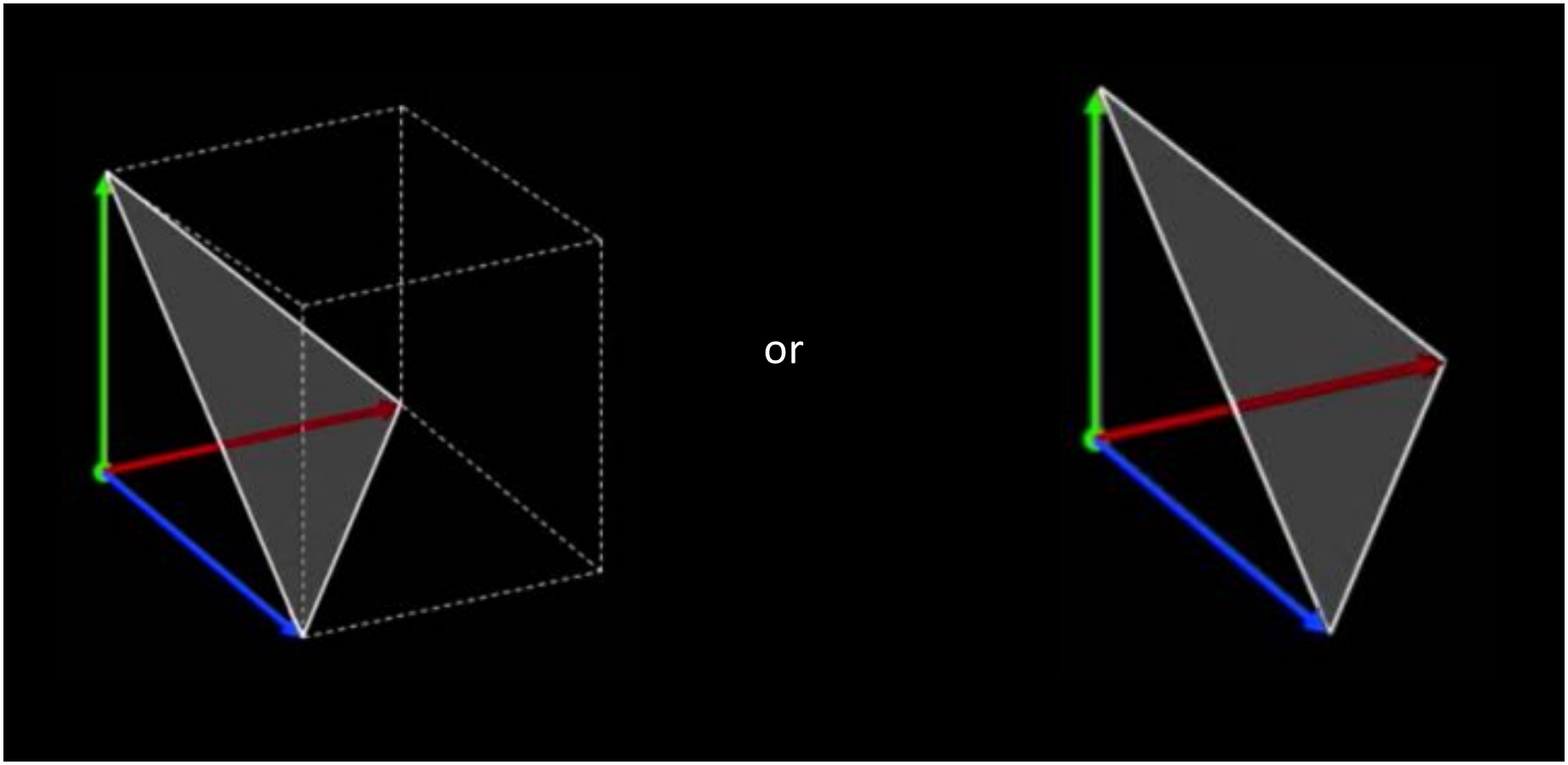
Color space: R-G-B



Color space RGB

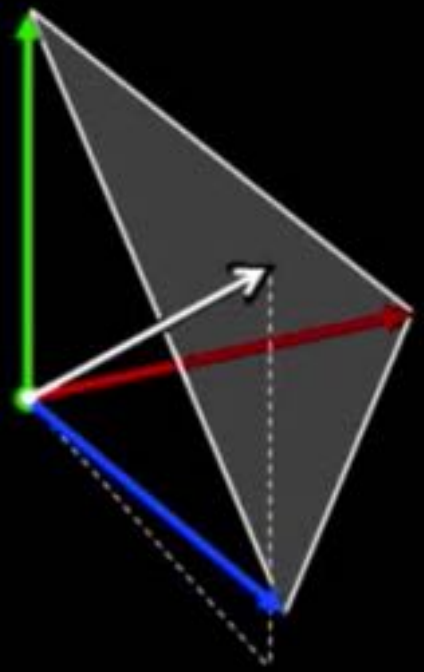


Unit plane



Negative red?

Vector outside of Unit Plane

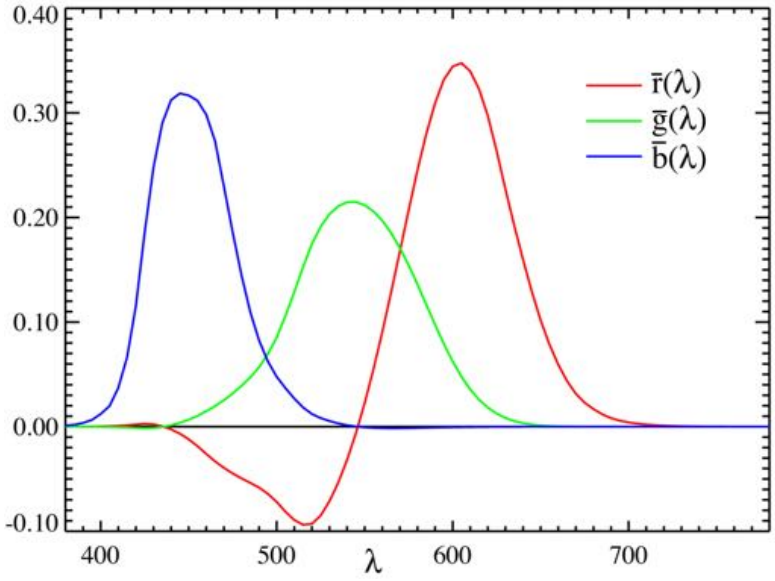


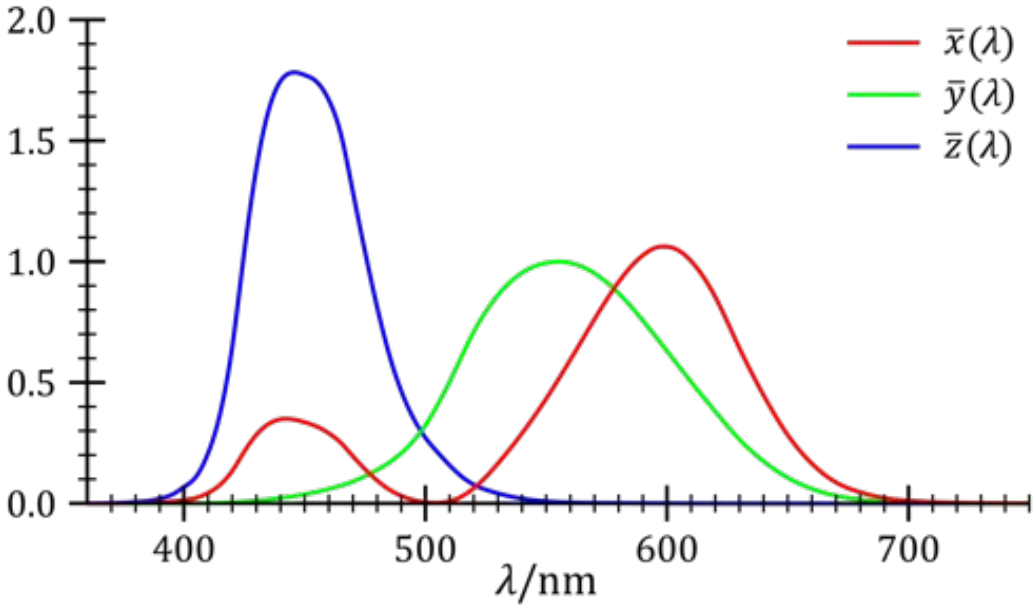
RGBA color space

RGB color model supplemented with a fourth *alpha channel*. Alpha indicates how opaque each pixel is and allows an image to be combined over others using alpha compositing, with transparent areas and anti-aliasing of the edges of opaque regions.

Example of an RGBA image with translucent and transparent portions, composited over a checkerboard background

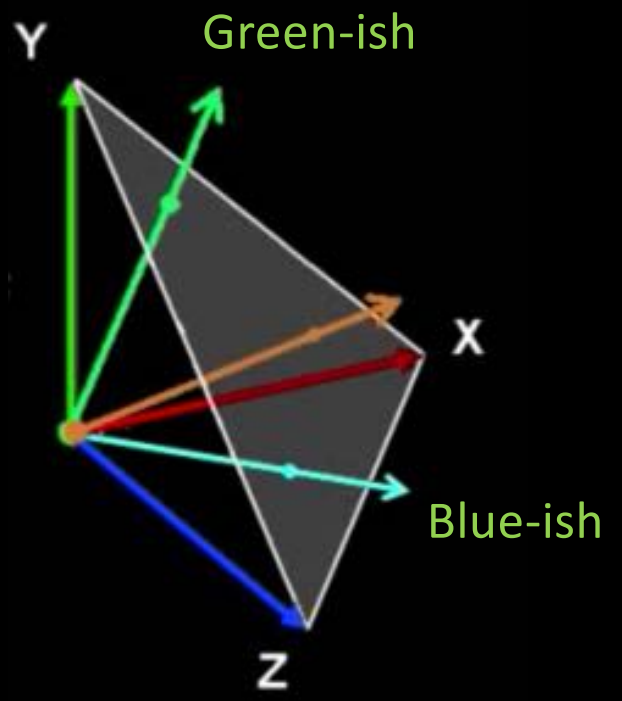
RGB to XYZ


0.40
0.30
0.20
0.10
0.00
-0.10
400
500
λ
600
700
r̄(λ)
ḡ(λ)
b̄(λ)


2.0
1.5
1.0
0.5
0.0
400
500
600
700
λ/nm
$\bar{x}(\lambda)$
$\bar{y}(\lambda)$
$\bar{z}(\lambda)$

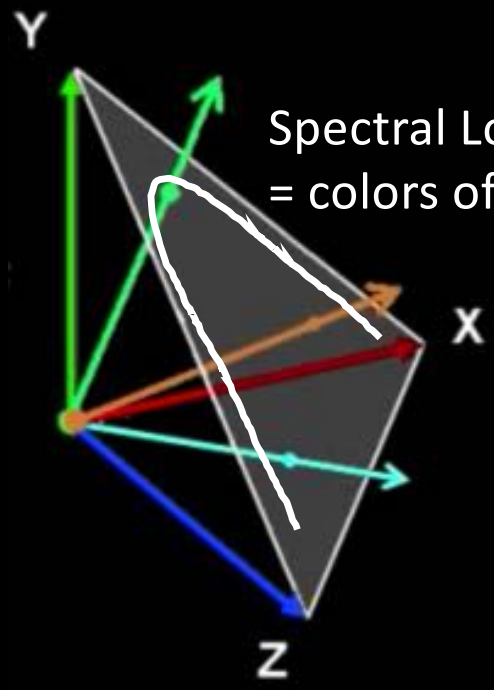
Color space X-Y-Z

Series of tristimulus vectors map out the chromaticity diagram



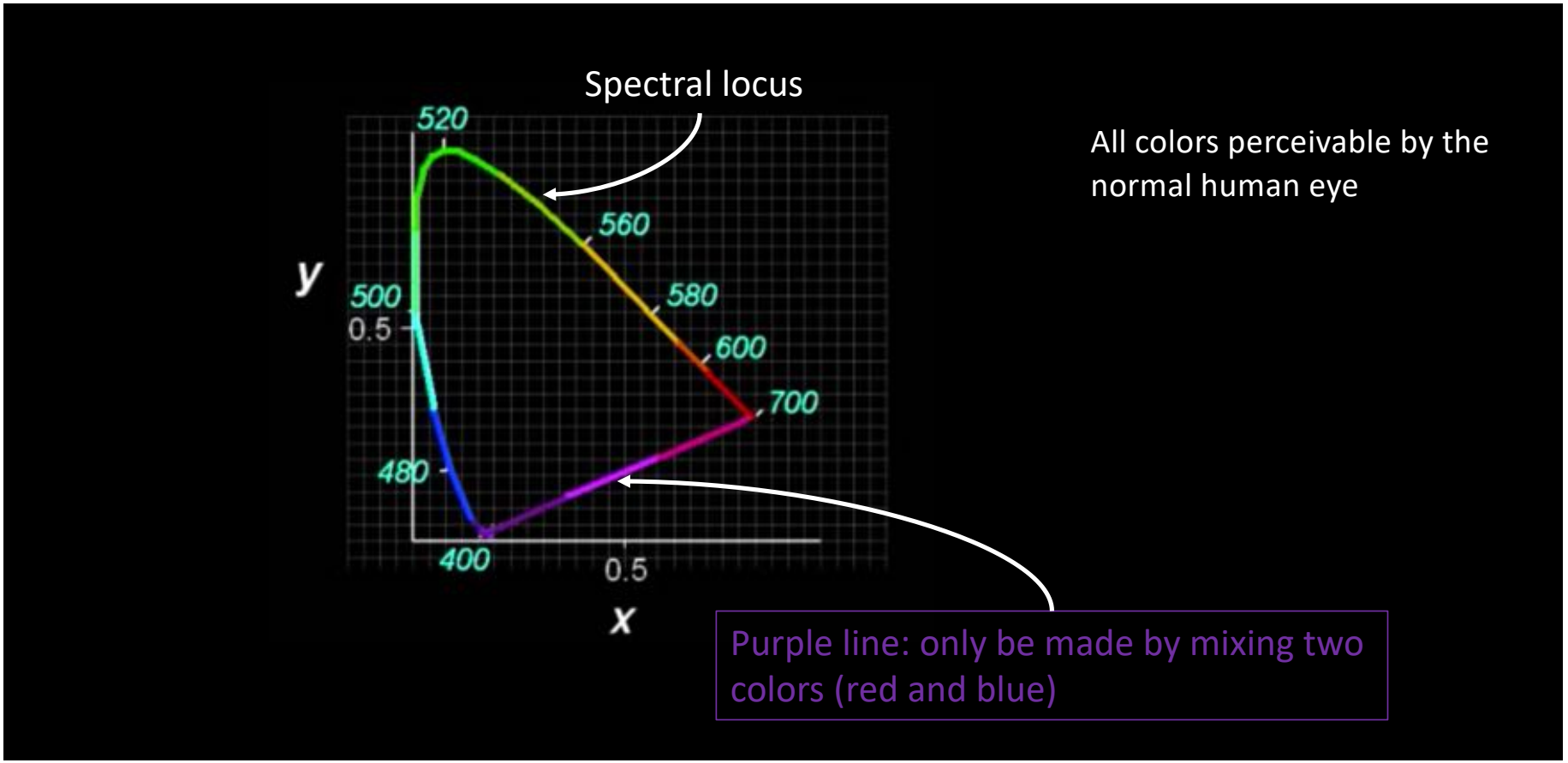
Color space X-Y-Z

Series of tristimulus vectors map out the chromaticity diagram



Spectral Locus
= colors of the spectrum

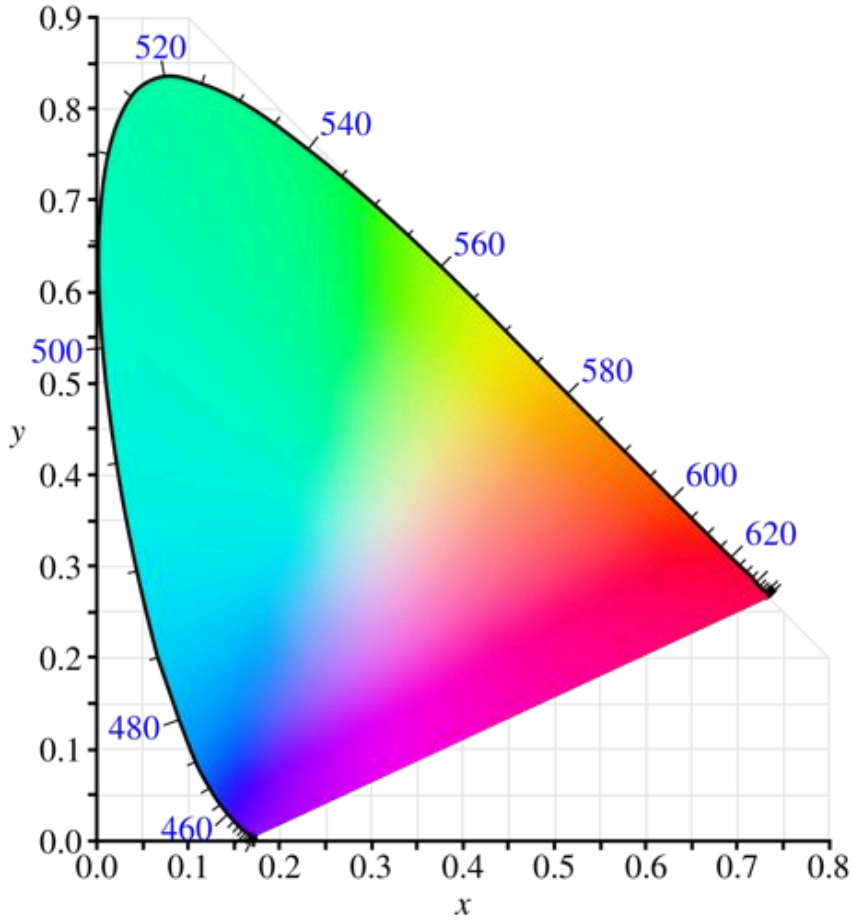
Chromaticity Diagram



CIE chromaticity diagram (1931)

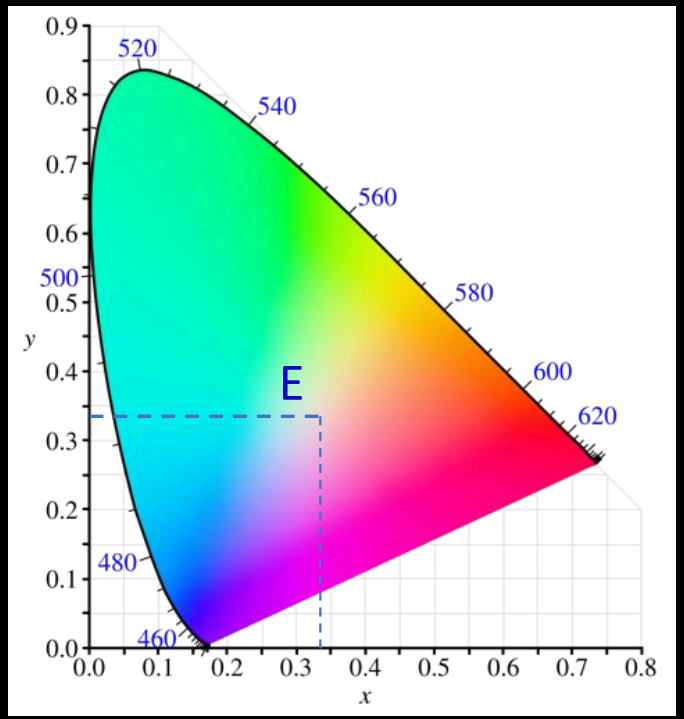
By the International Commission on Illumination

(French name: *"Commission internationale de l'éclairage"*)



White

Equal energy white
x = 0.33
y = 0.33



Traffic lights: green color

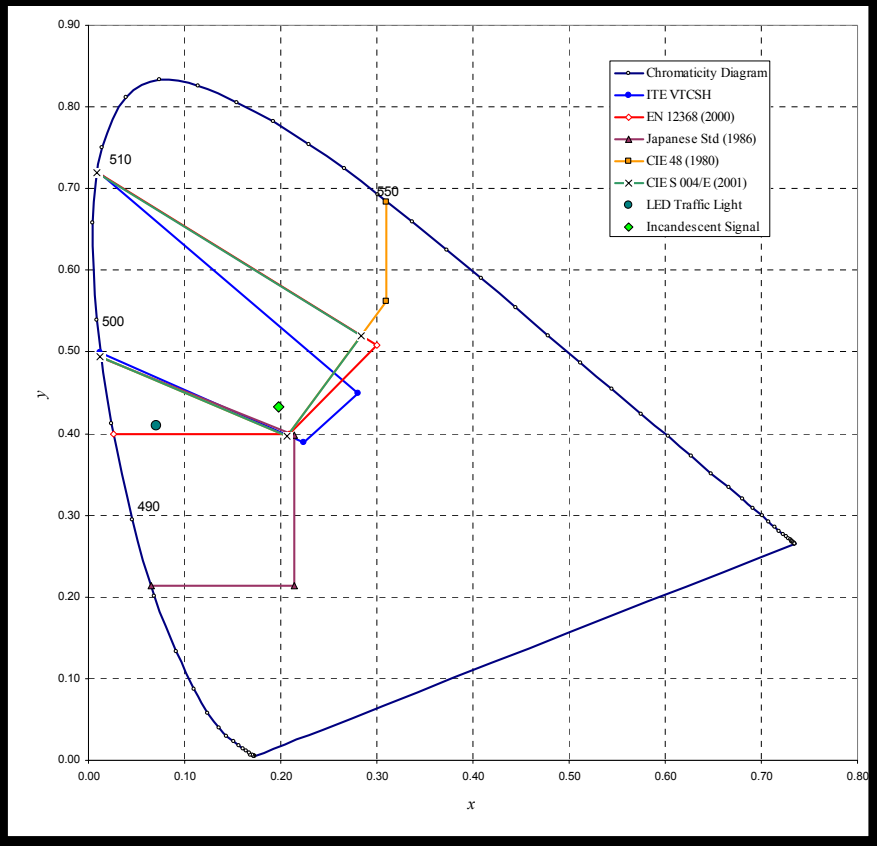
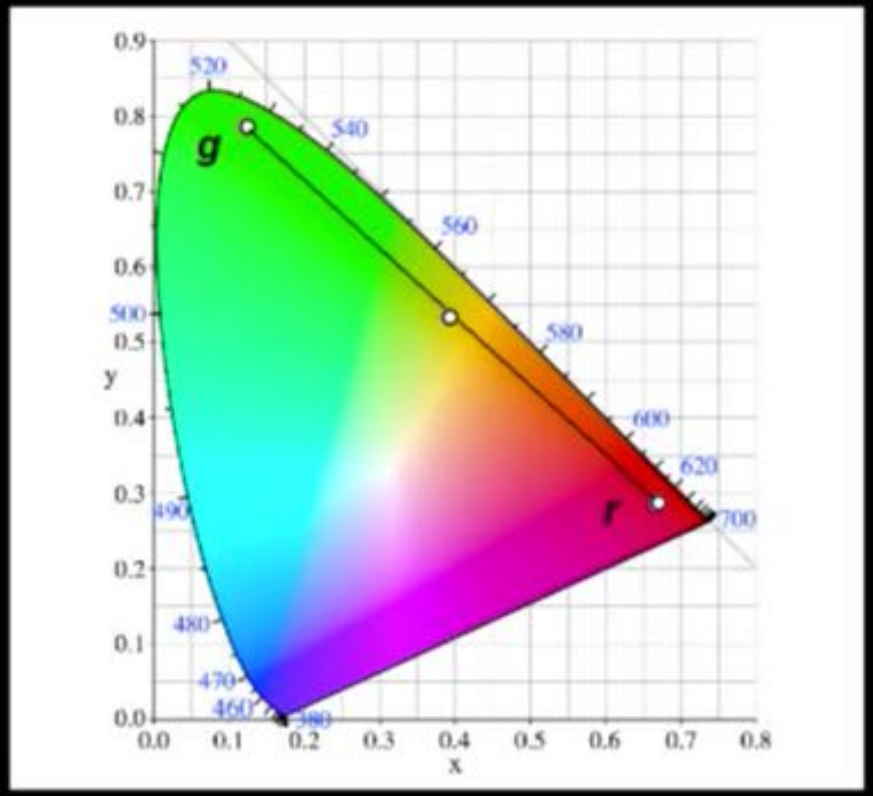


Figure 2c – Color Regions for Green Traffic Lights

CIE color mix

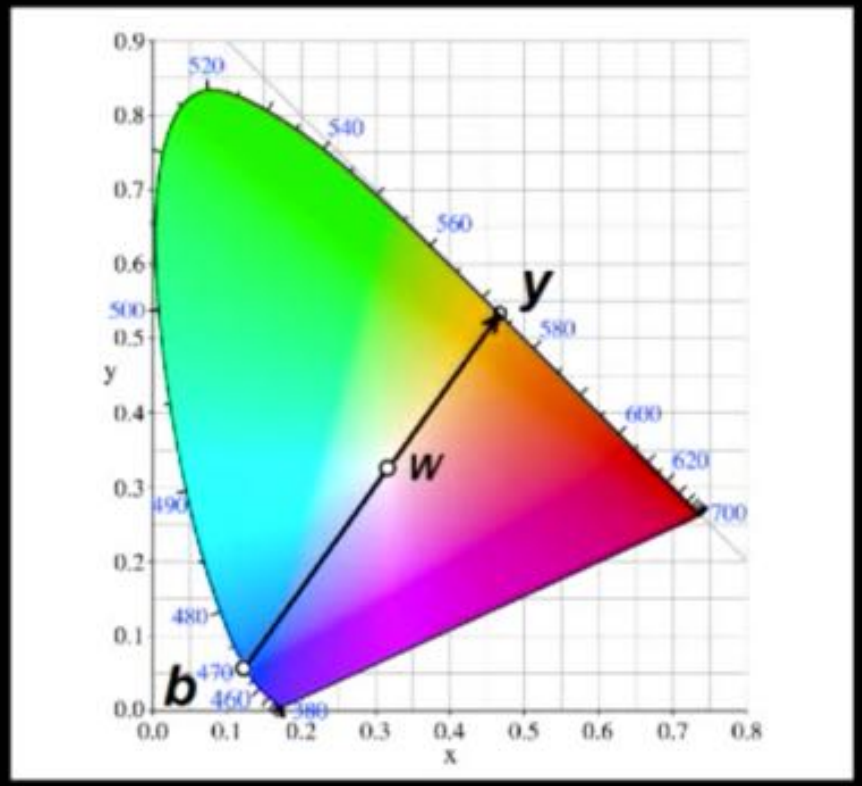
Midpoint: mixing of two colors



CIE color compliments

Opposite of “blue” via “White” is “yellow”

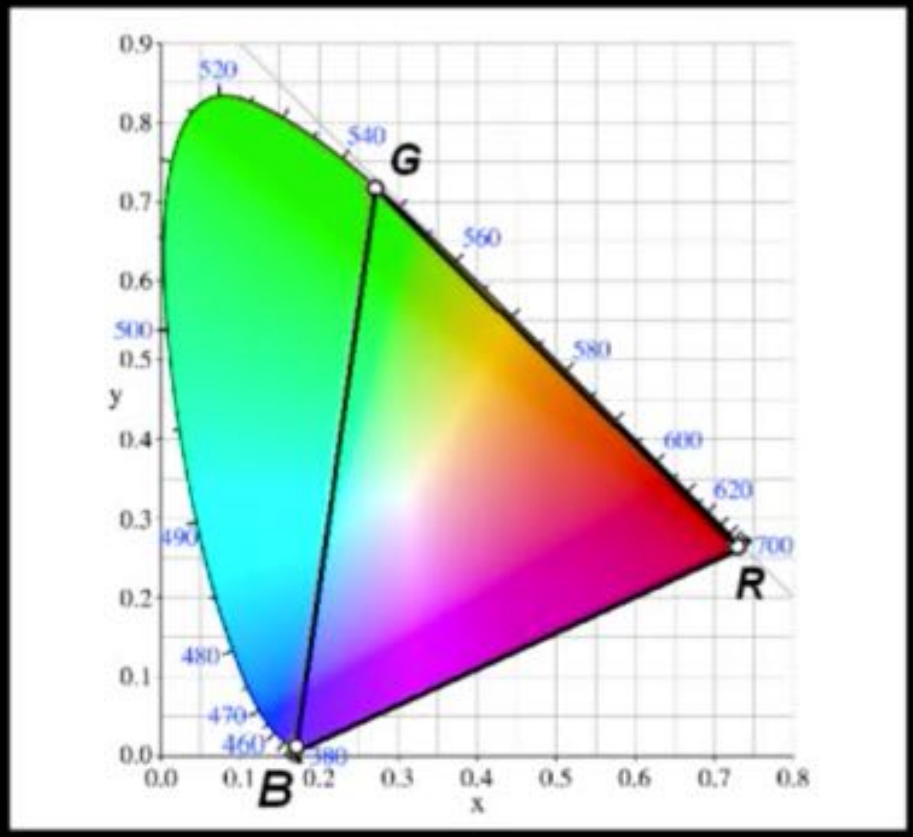
Or: adding “blue” and “yello” makes “white”



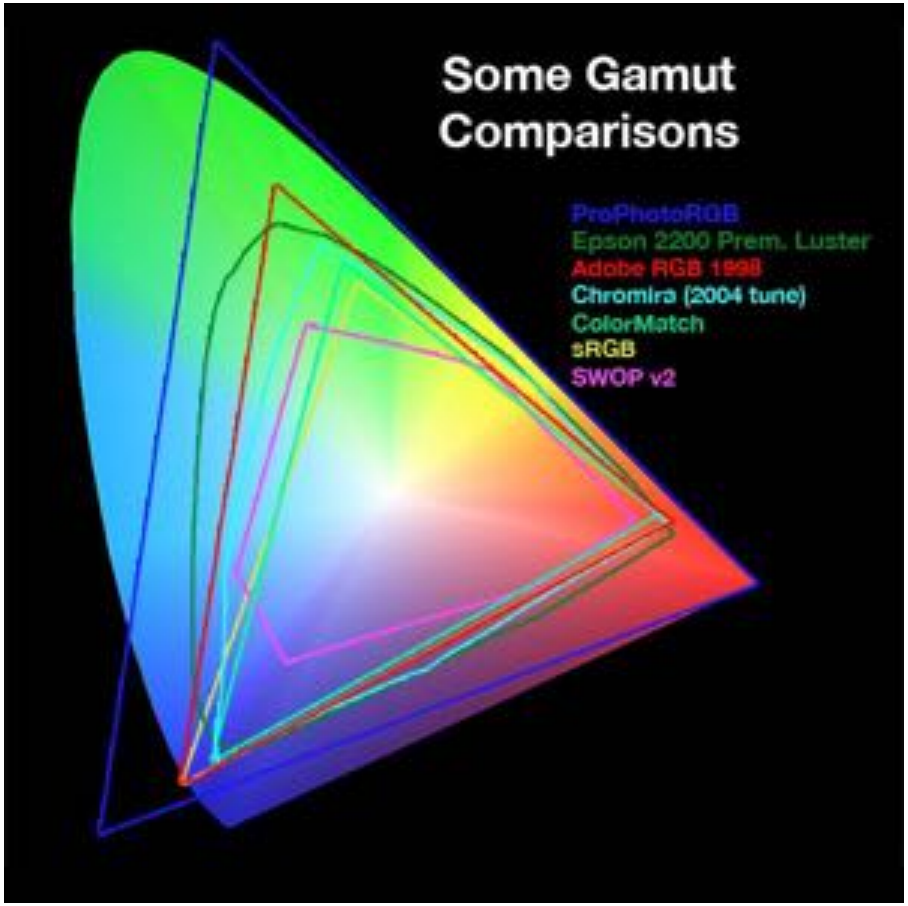
CIE color gamut

Red: 700.0 nm
Green: 546.1 nm
Blue: 435.8

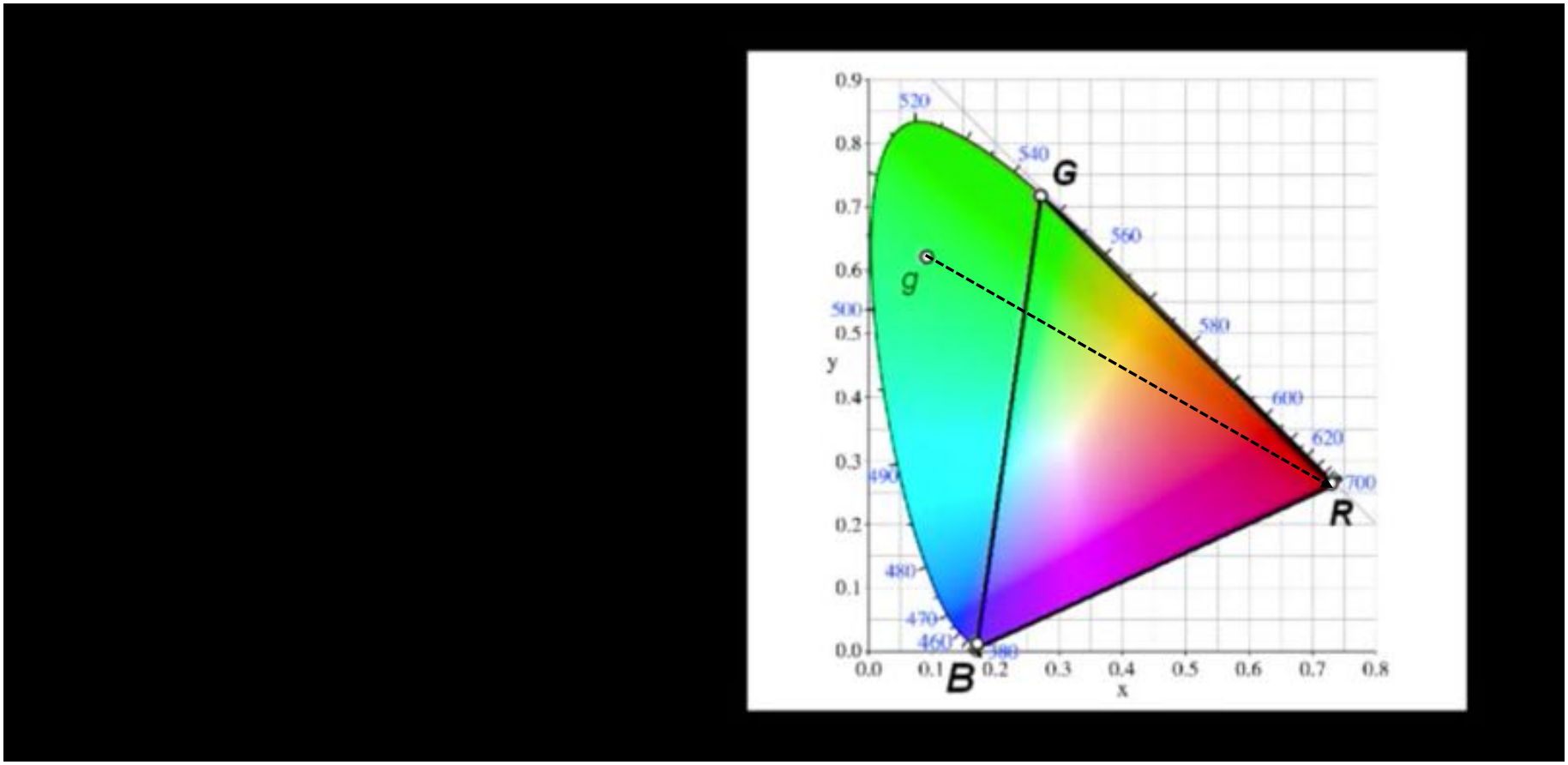
All colors can be made using those primary colors are in the triangle



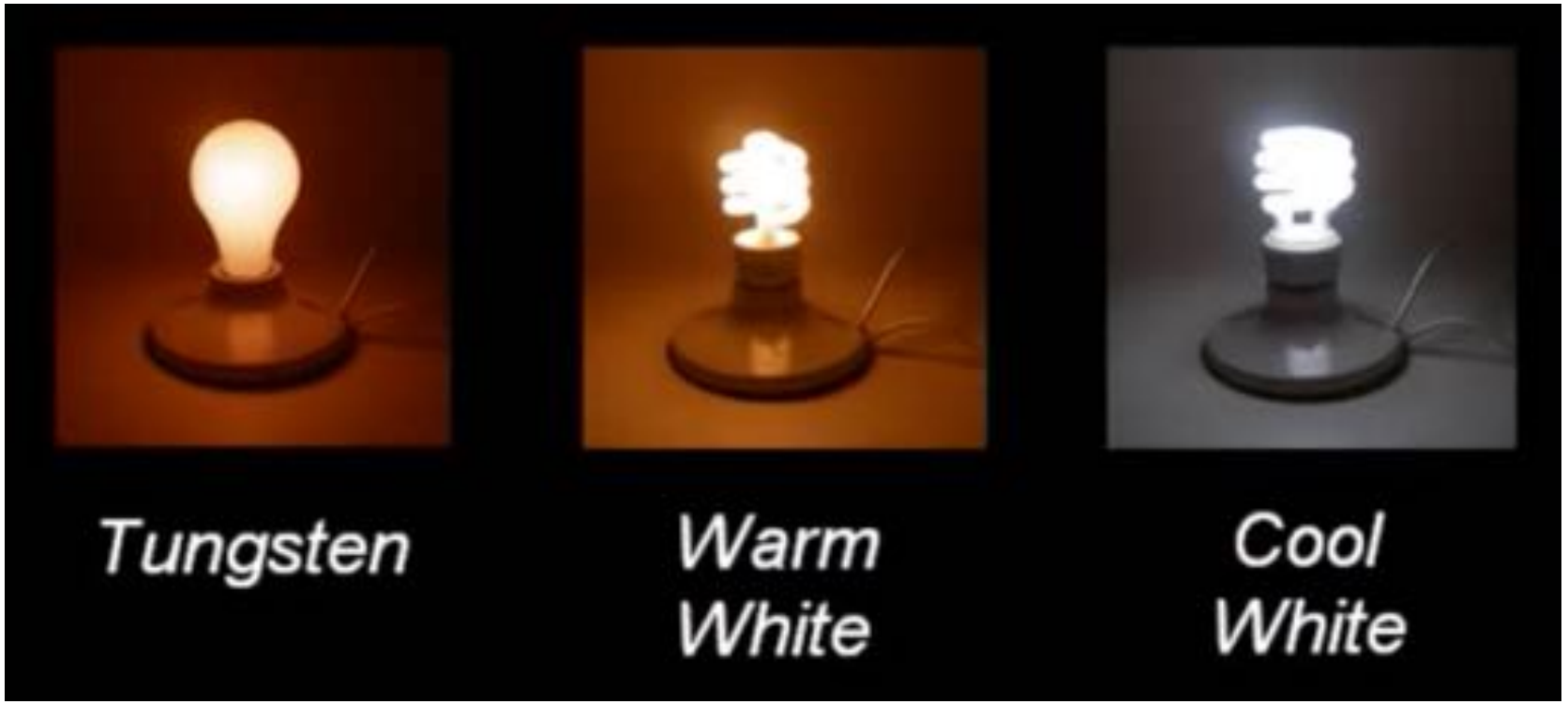
Some color gamuts



How to match color outside the triangle?

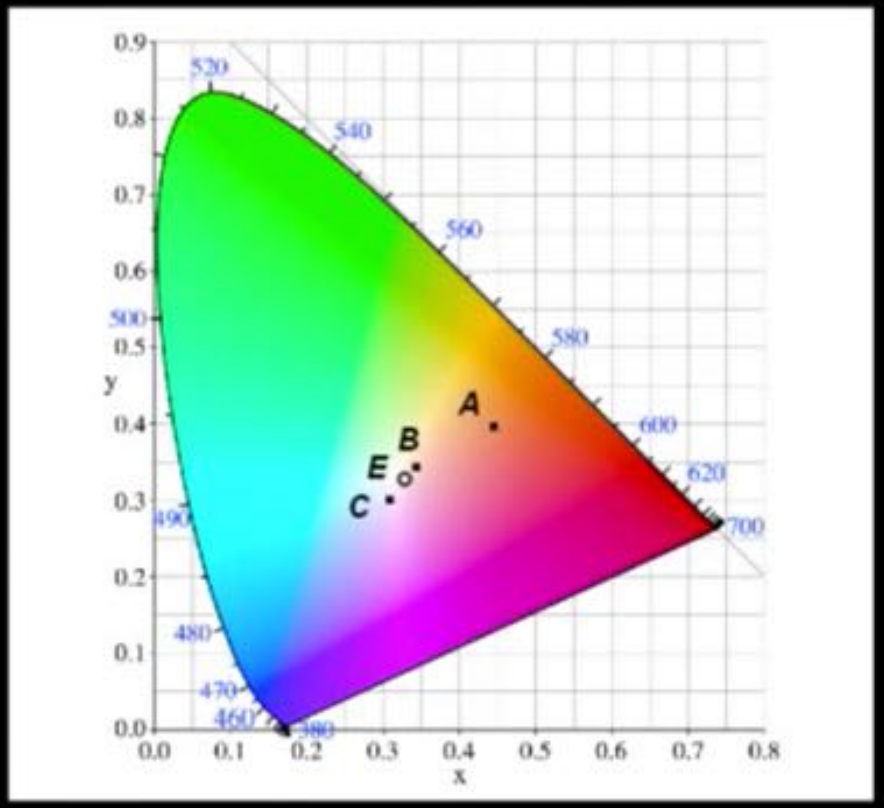


Many whites



CIE Standard Illuminants

A: Tungsten
B: Direct Sun
C: Average daylight

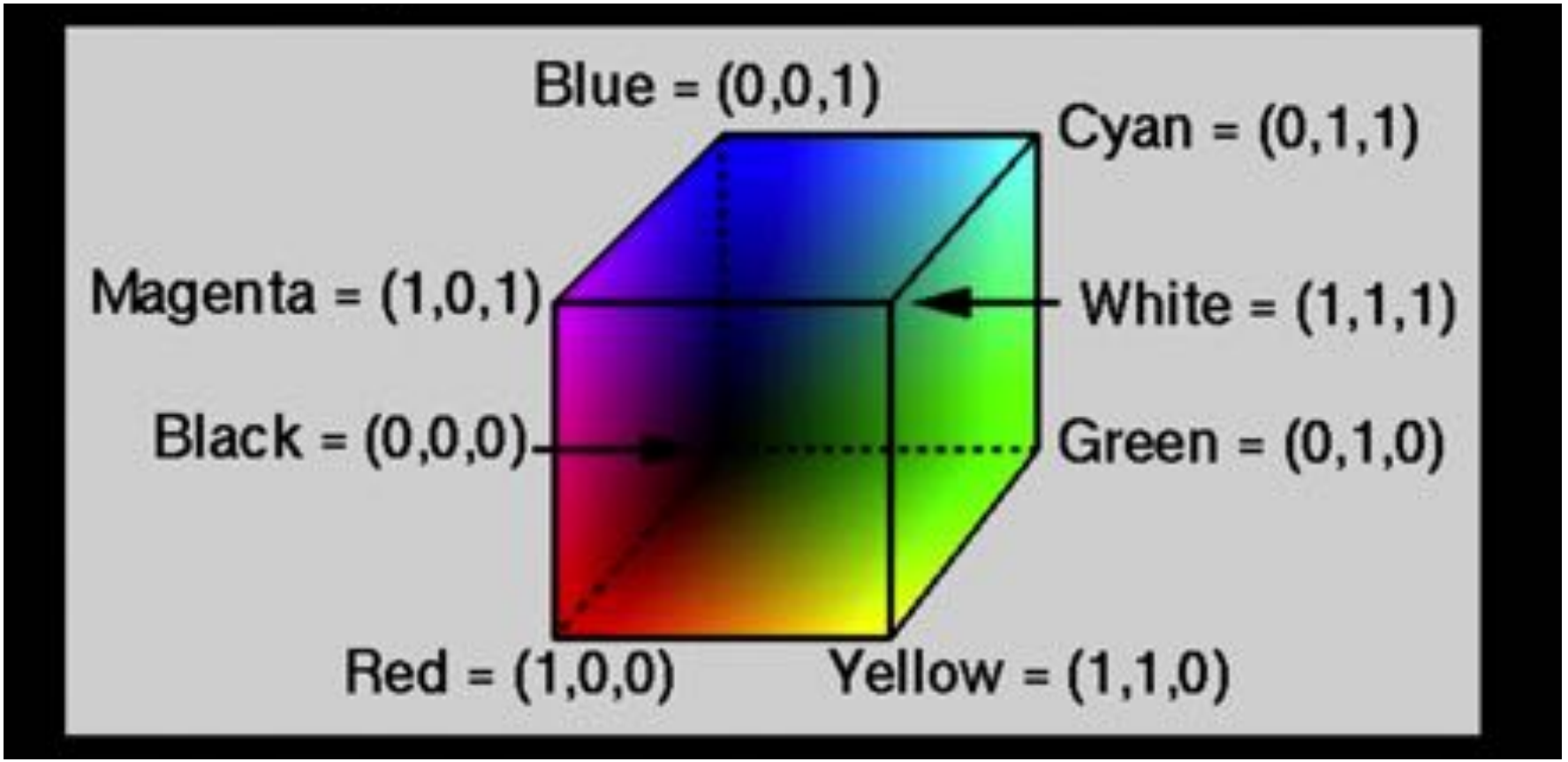


Color model

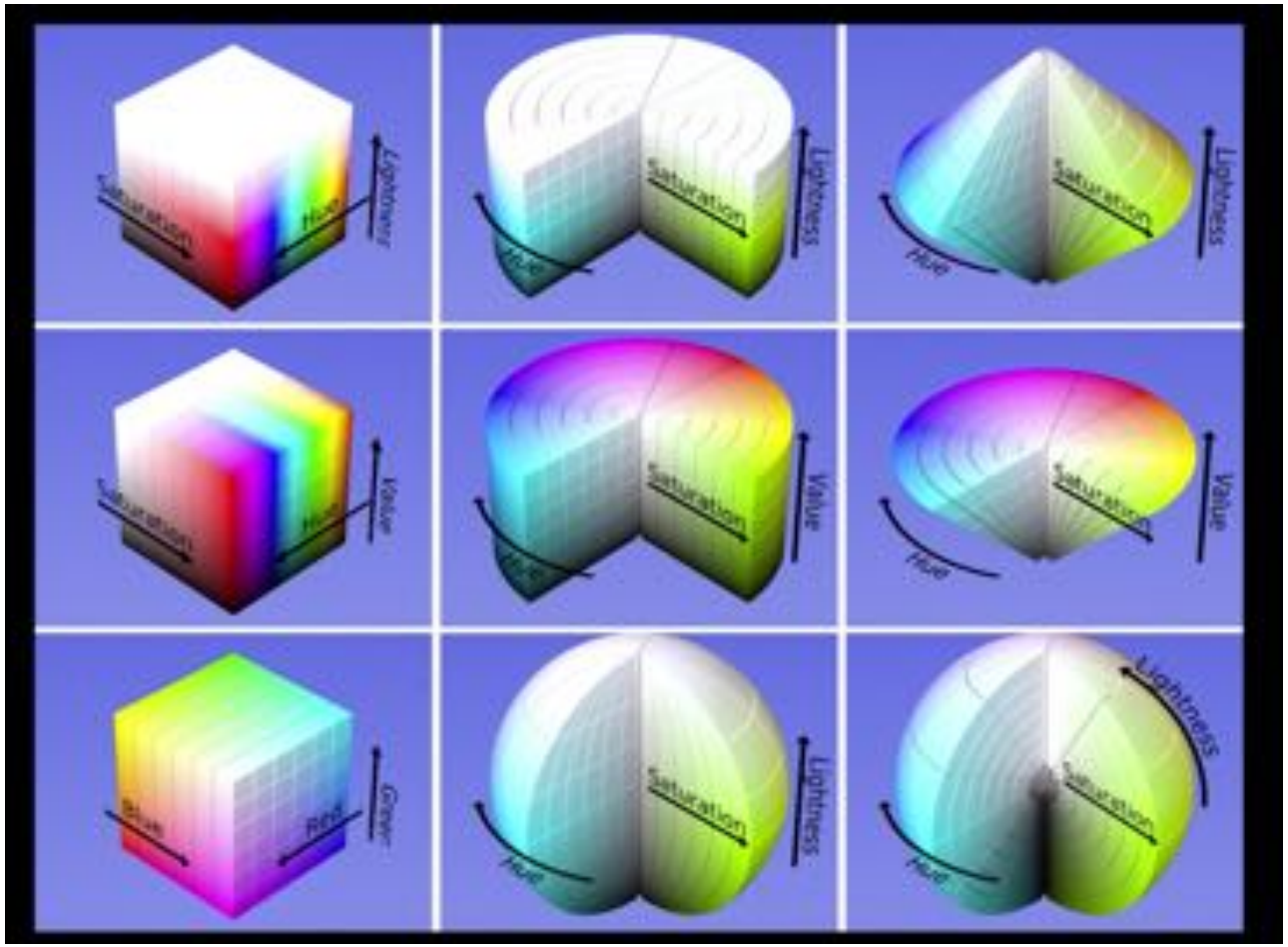
Color model

- A mathematical way to map wavelengths to certain colors
- A color model describes a coordinate system where each color is represented by a single point
- Each color model is used for different purpose
- For example:
  - RGB: computer graphics, image processing, image storage
  - HSV, HSL: human visual perception, human vision, computer vision
  - Y’CbCa: image compression
  - CMYK: printing
  - YIQ: television broadcasting systems and video systems

RGB color space

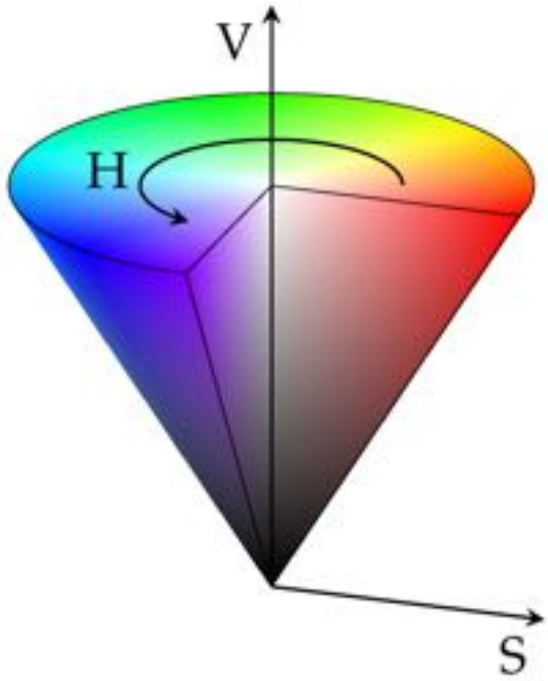


A lot of color spaces



HSV color model

- Hue: wavelength of color
  - Is presented by an angle from 0 to 360
- Value: value of brightness
  - Ranging in [0, 1]
  - V=0 → black
- Saturation: purity of color
  - Ranging in [0, 1]



Quiz: Hue difference

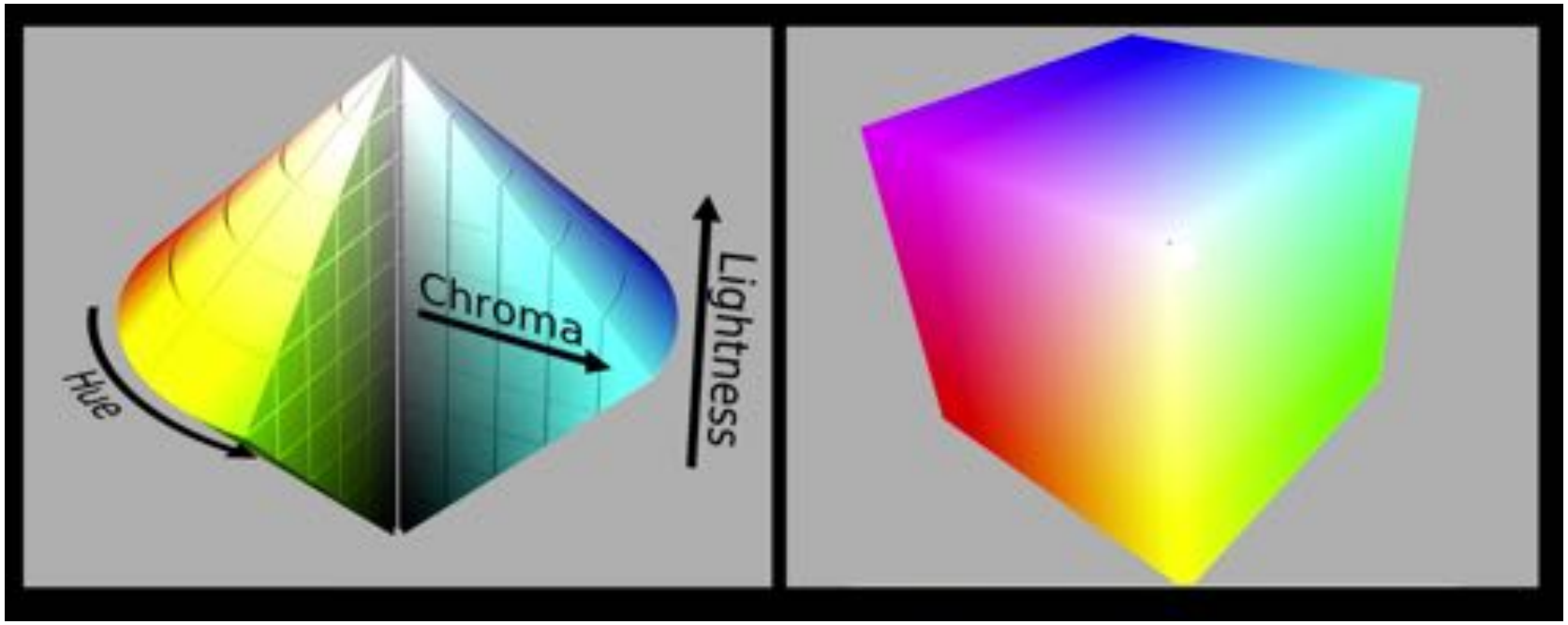
If hue values range in [0, 360], what is the absolute difference between the following pairs of hues?

- 225 and 75

- 45 and 315

HCL color space

Like a squared double cone?



Color space conversion

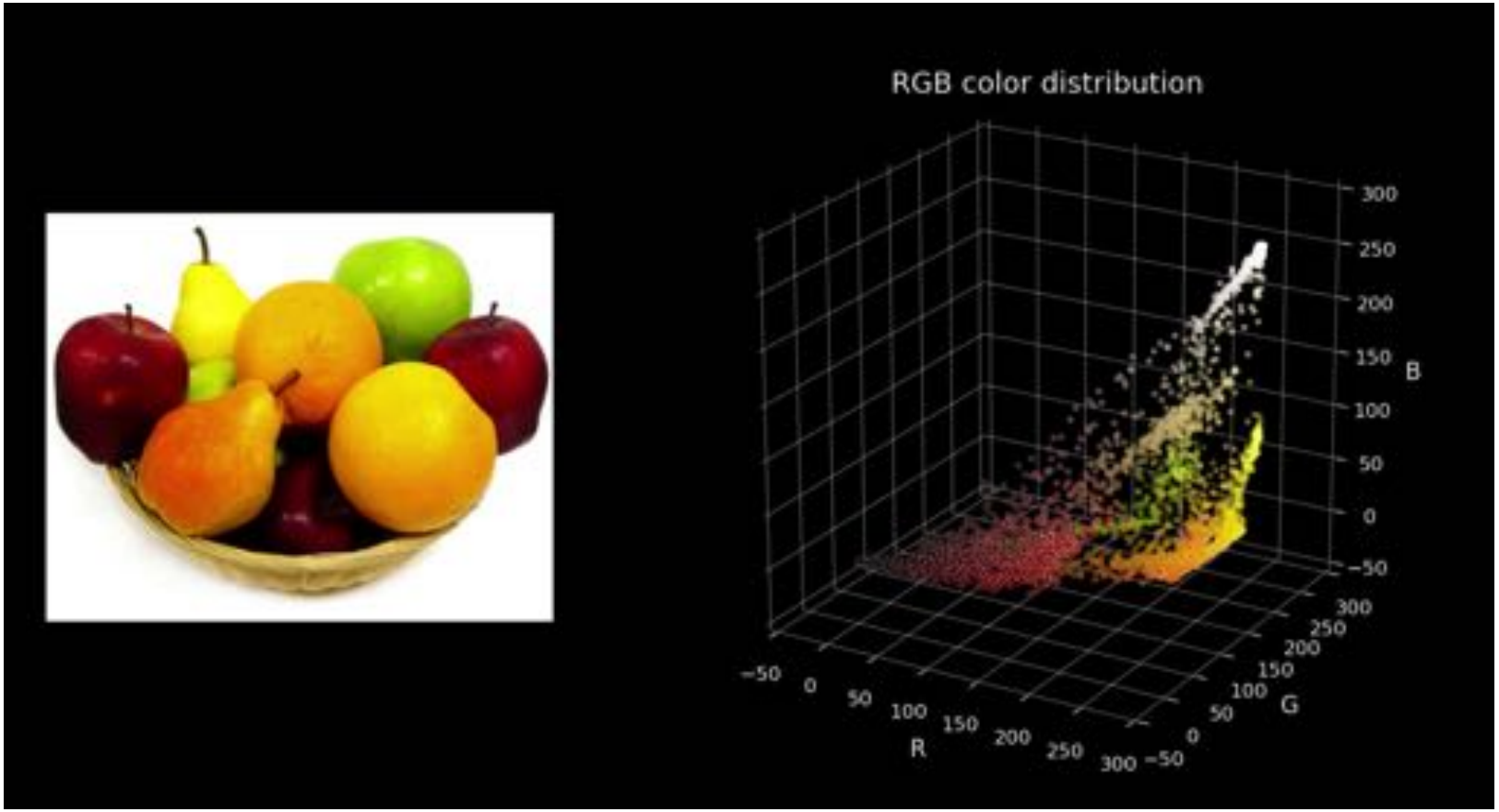
- Linear transformation
  - Transformation matrix
  - E.g.: XYZ <-> RGB

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{vmatrix} * \begin{vmatrix} R \\ G \\ B \end{vmatrix} \qquad \begin{vmatrix} R \\ G \\ B \end{vmatrix} = \begin{vmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{vmatrix} (-1) * \begin{vmatrix} X \\ Y \\ Z \end{vmatrix}$$

- Non-linear transformation
  - RGB <-> CMYK
  - RGB <-> HSV
  - RGB <-> Munsell

Color image processing

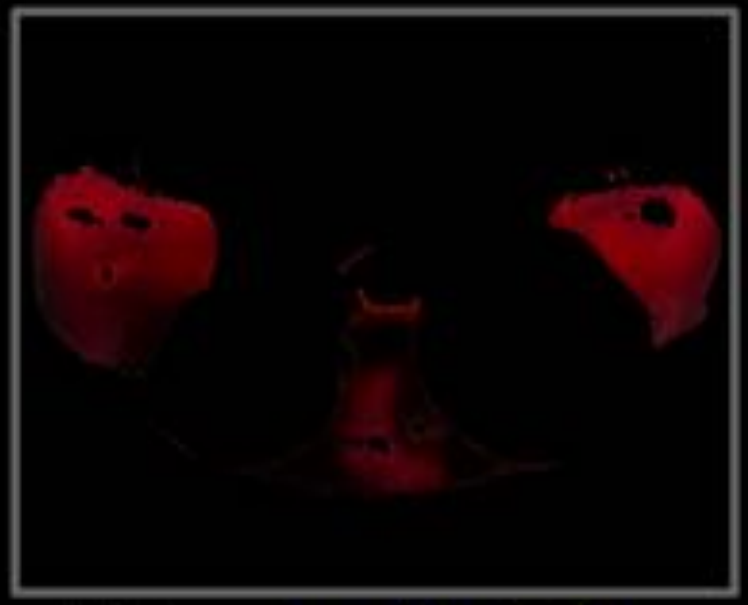
Color distribution



Example: Red filter

Filter: $R \in [0,255]$,
$G \in [0,100]$,
$B \in [0,100]$

Example: Red filter – more red!



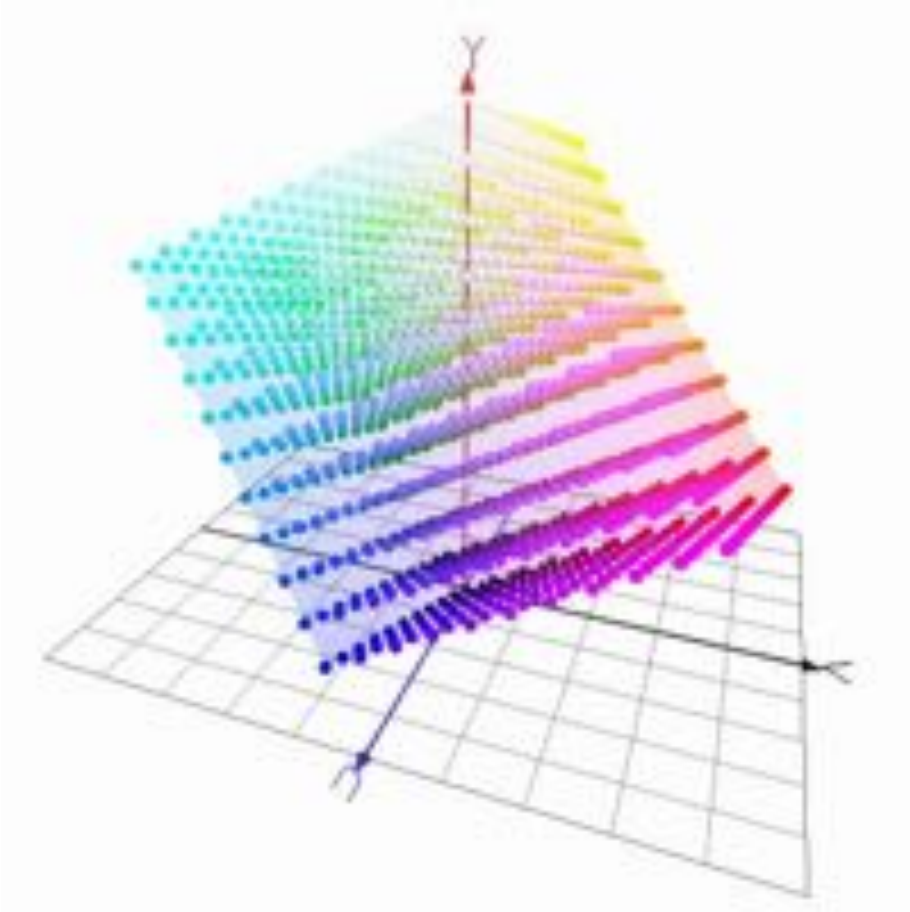
Filter: $R \in [0,255]$,
$G \in [0,50]$,
$B \in [0,50]$

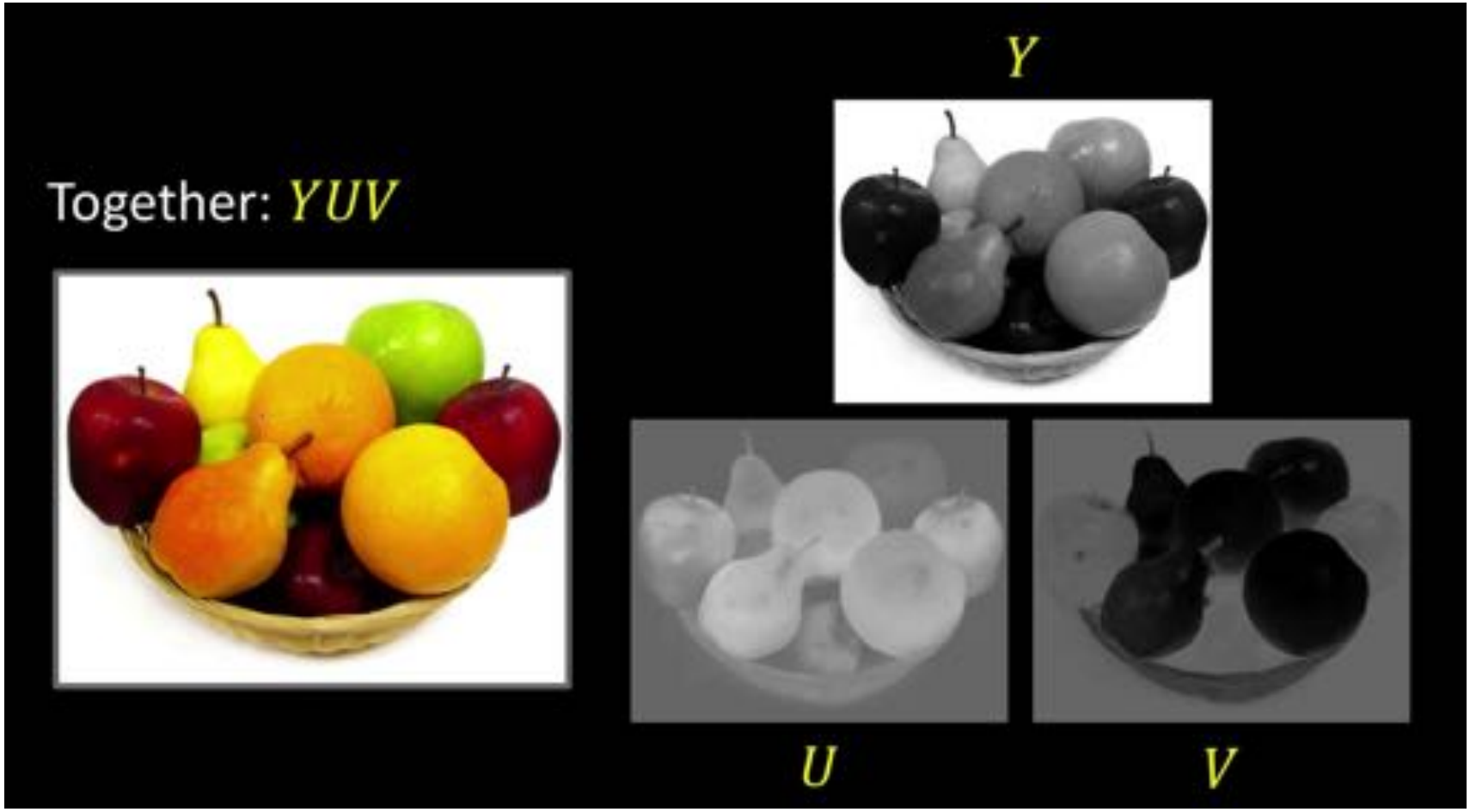
How intensity affects color values

Just different shades of green, but all 3 values change!

YUV color model

Y: luma component (the brightness)
U: blue projection
V: red projection




Y
Together: YUV
U
V

Quiz: UV filter

What UV limits should we use to extract red regio

Filter:

$Y \in [0,255]$

$U \in [\quad, \quad]$,

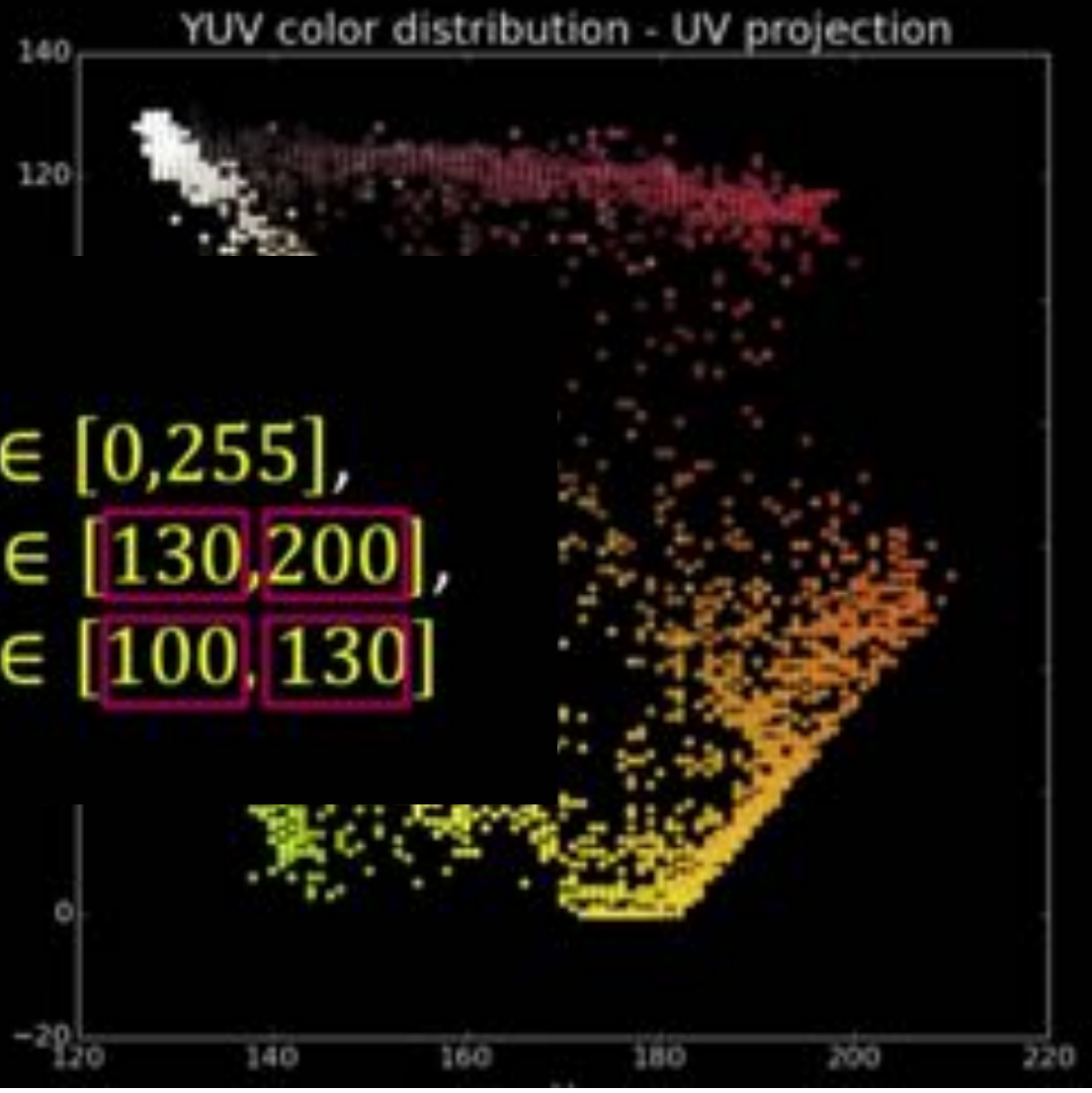
$V \in [\quad, \quad]$

Filter:

$Y \in [0,255]$,

$U \in [130,200]$,

$V \in [100,130]$



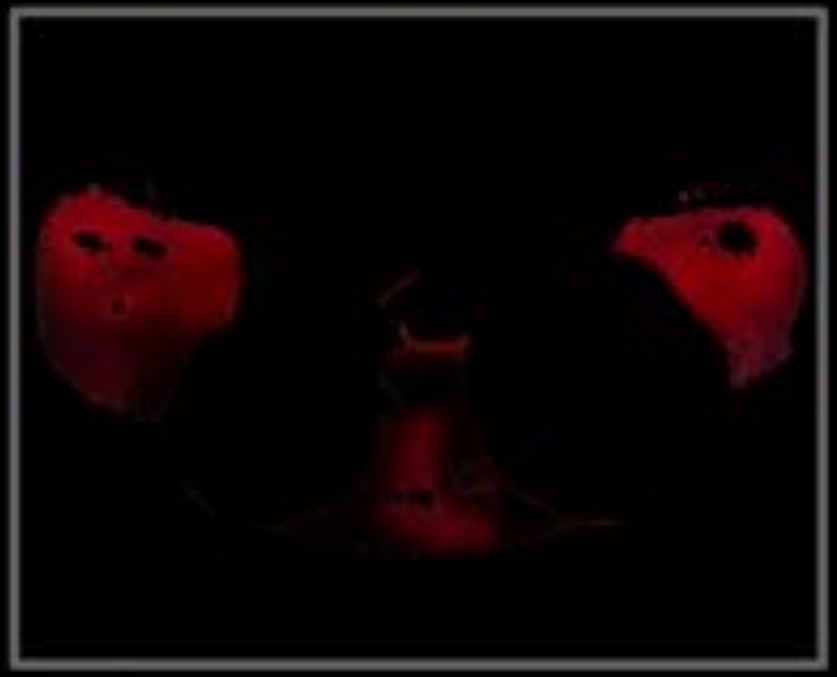
UV filter

Filter: $Y \in [0,255]$,
$U \in [130,200]$,
$V \in [100,130]$

YUV filter

Filter: $Y \in [0,150]$,
$U \in [130,200]$,
$V \in [100,130]$

Comparing RGB and YUV filters



Filter: $R \in [0,255]$,
$G \in [0,50]$,
$B \in [0,50]$

Filter: $Y \in [0,150]$,
$U \in [130,200]$,
$V \in [100,130]$

Intuition: Why YUV?

- Easier clustering of pixels
- Efficient encoding by *chroma subsampling*
  - Recall, human vision is more sensitive to intensity changes
  - Y channel can now use more bits
- E.g., YUV422 – to represent 2 image pixels, it uses 2 bytes for Y, and 1 byte each for U and V

References

- Youtube: Craig Blackwell channel
  - “Color vision” series
- Udacity: “Introduction to computer vision” course