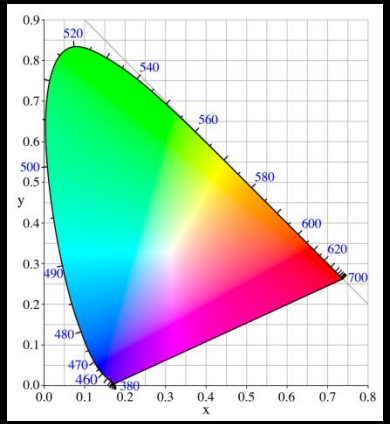
CS4495/6495
Introduction to Computer Vision

9A-L1 *Color spaces*



Light Detection: Rods and Cones

Cones:

- 6-7 million cones in the retina
- Responsible for high-resolution vision
- Discriminate colors
- Three types of color sensors (64% red, 32% green, 2% blue)

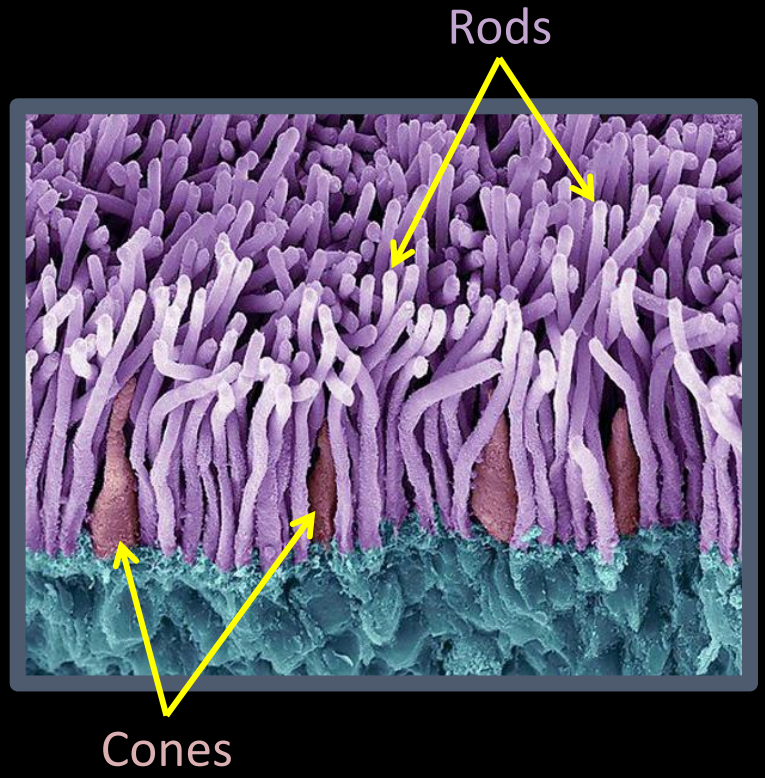
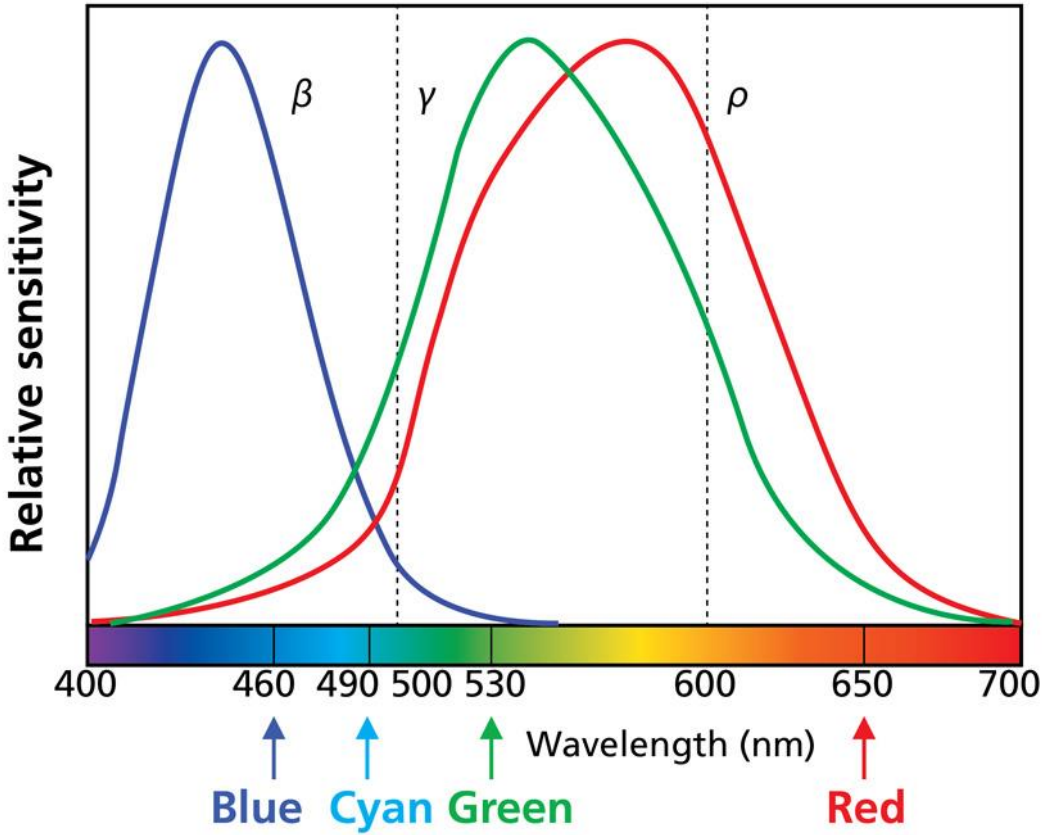


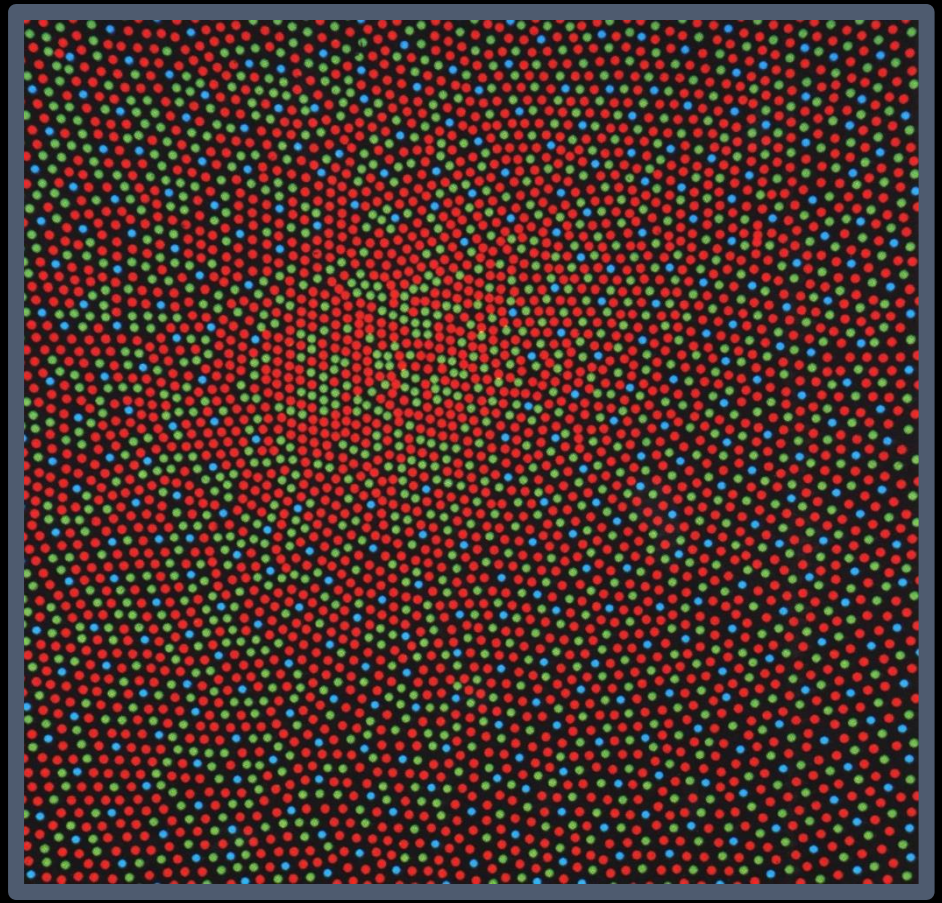
Image: anatomybox.com/retina-sem

Human spectral sensitivity to color

Three cone types (ρ, γ, β) correspond roughly to R, G, B.



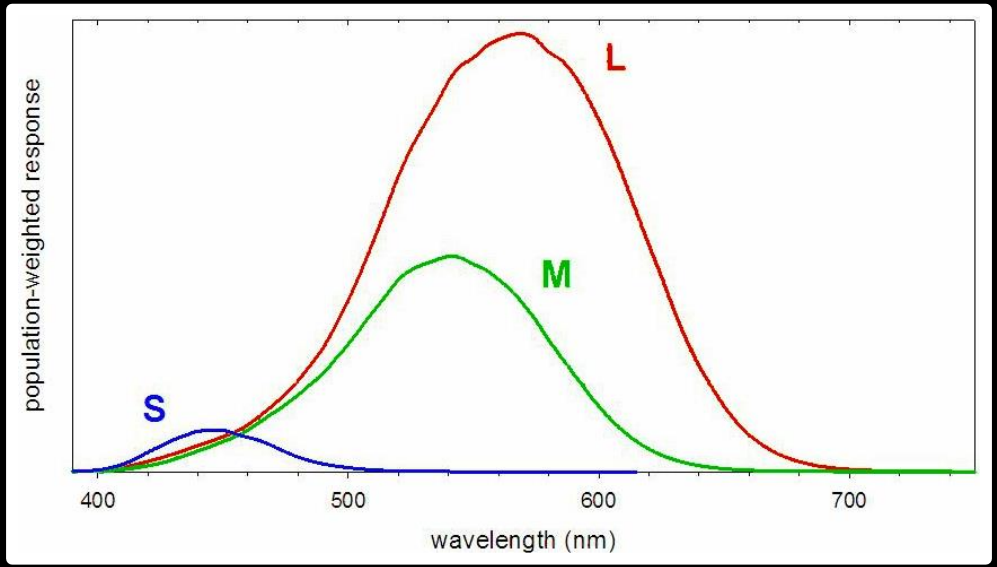
Retina Mosaic



Tristimulus Color Theory

Spectral-response functions of each of the three types of cones

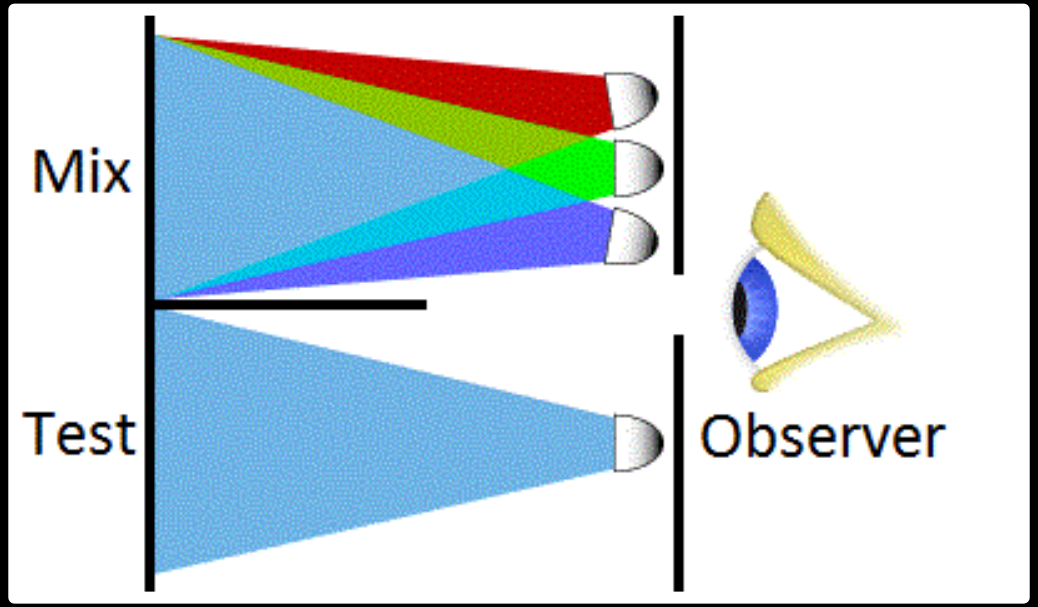
- Can we use them to match any spectral color?



Percentage of light absorbed by each cone

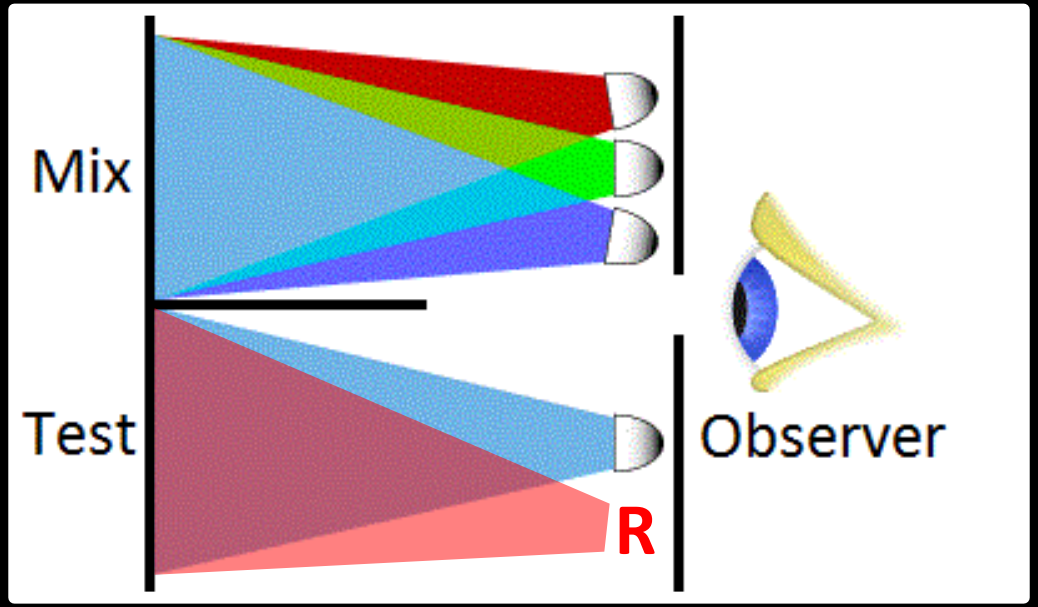
Color matching function based on RGB

Most spectral color can be represented as a positive linear combination of these primary colors (but…)

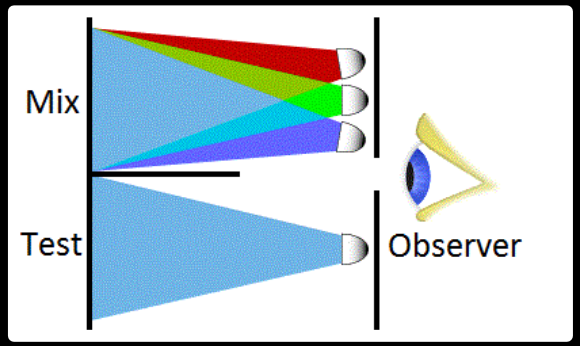


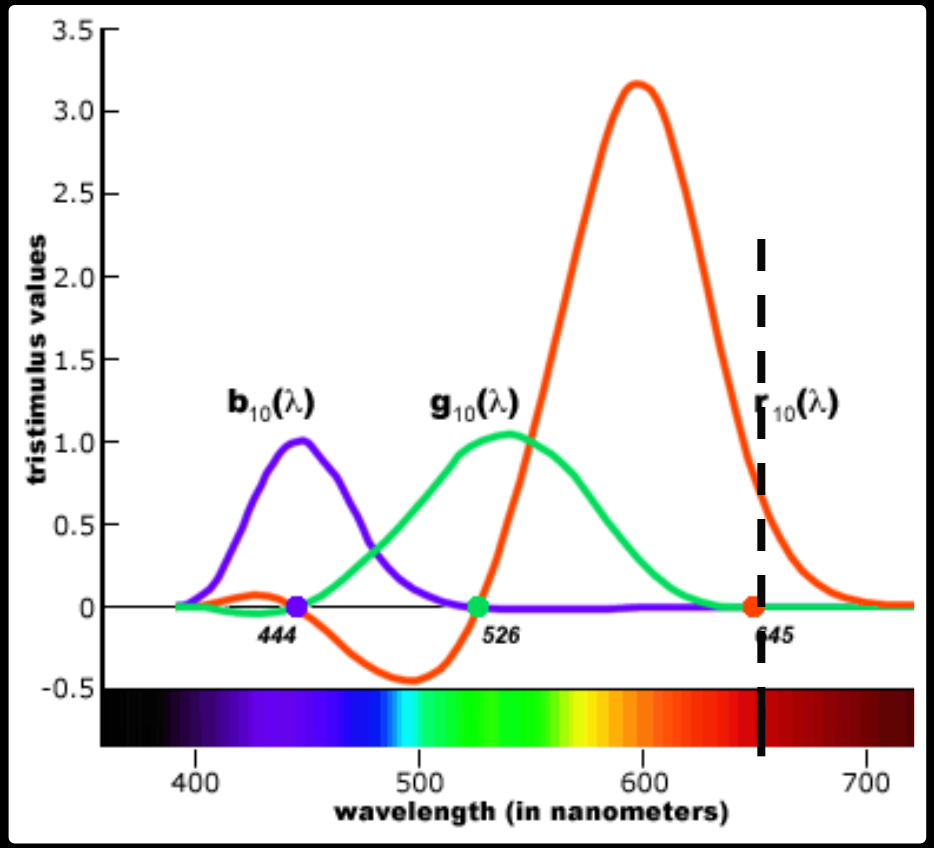
Color matching function based on RGB

But some spectral cannot – need to add some red

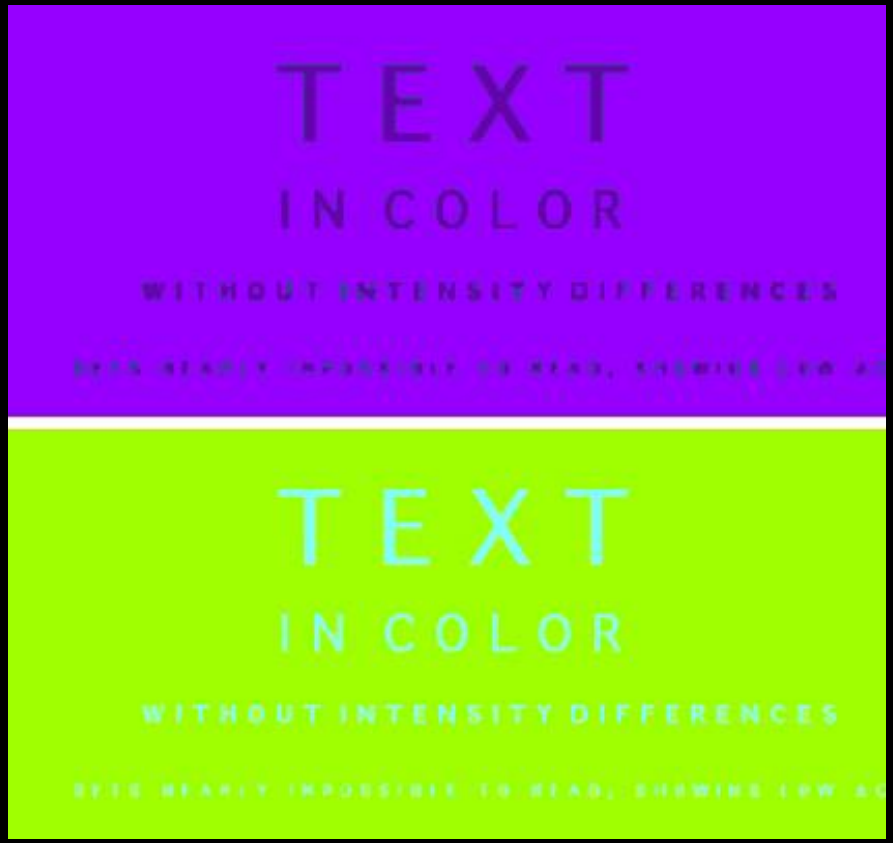


Color matching function based on RGB





Luminance vs color

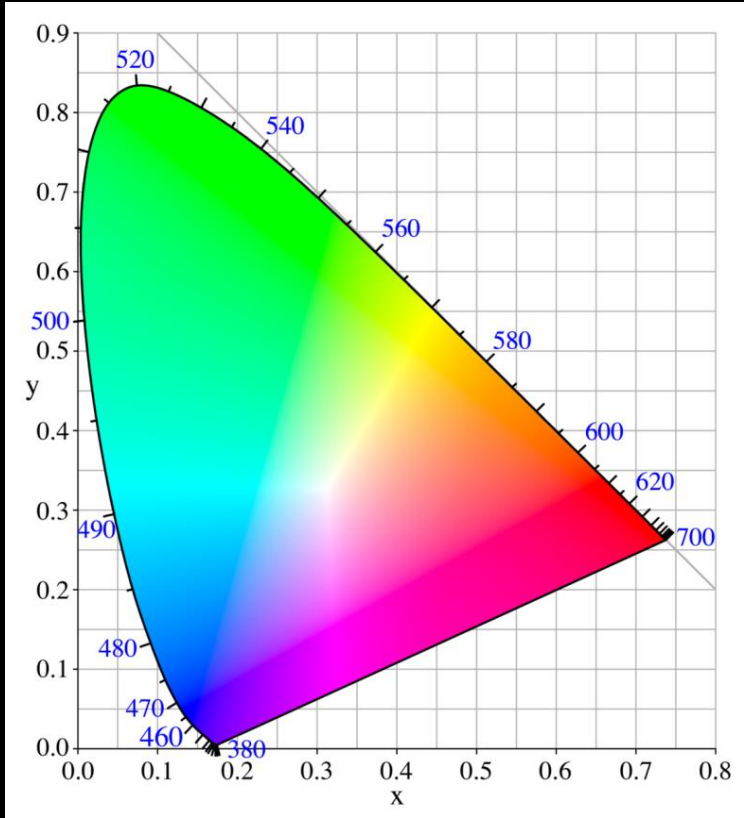


CIE RGB color space

Color matching experiments [Wright & Guild 1920s]

- Mapped physical wavelengths to perceived colors
- Identified relative similarity and difference between colors
- Result: CIE RGB space defined

Colors perceivable by the human eye



CIE xy chromaticity diagram, 1931

CIE XYZ color space

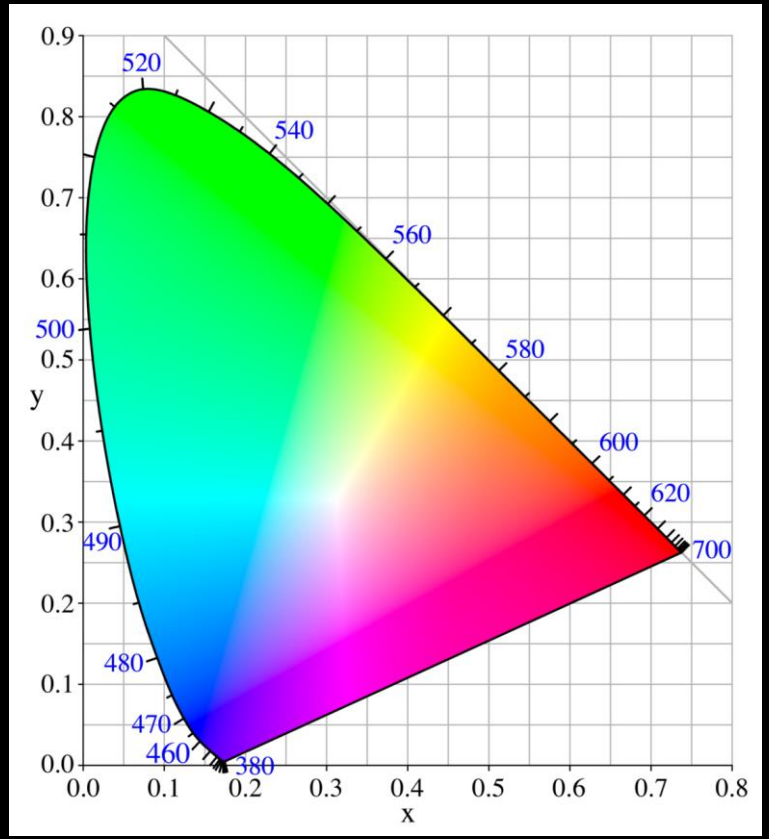
A new space with desired properties

- Easy to compute – linear transform of CIE RGB
- Y: Perceived luminance
- X, Z: Perceived color
- Represents a wide range of colors

Colors perceivable by the human eye

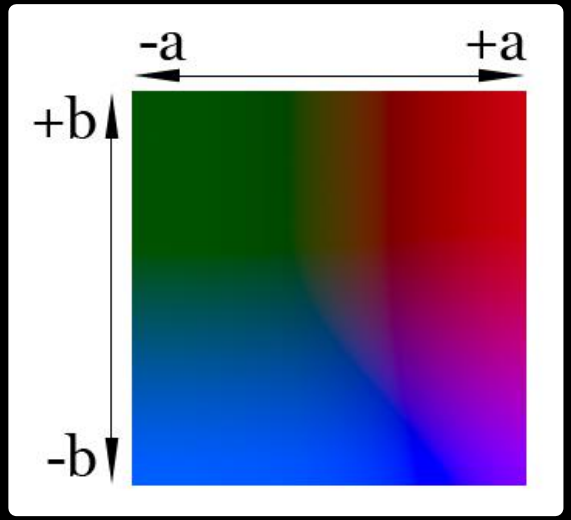
$$y = \frac{X}{X + Y + Z}$$

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

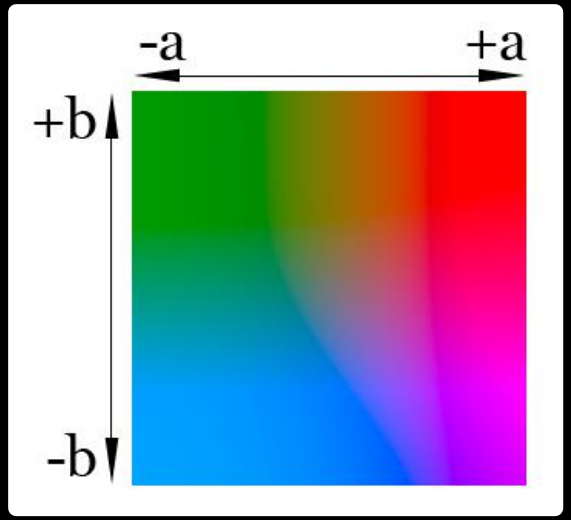


CIE xy chromaticity diagram, 1931

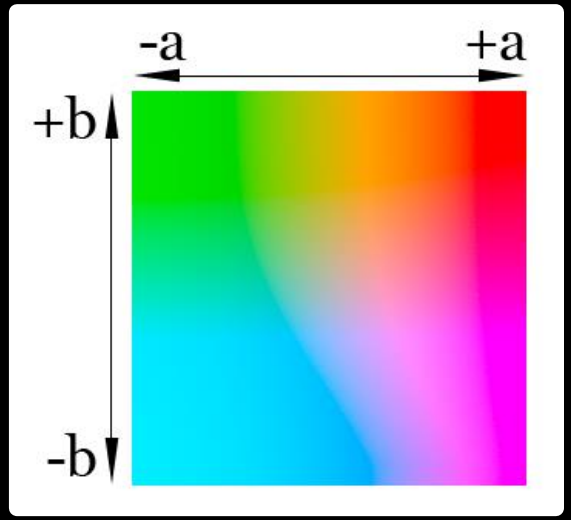
CIE L*a*b* color space



L = 25%



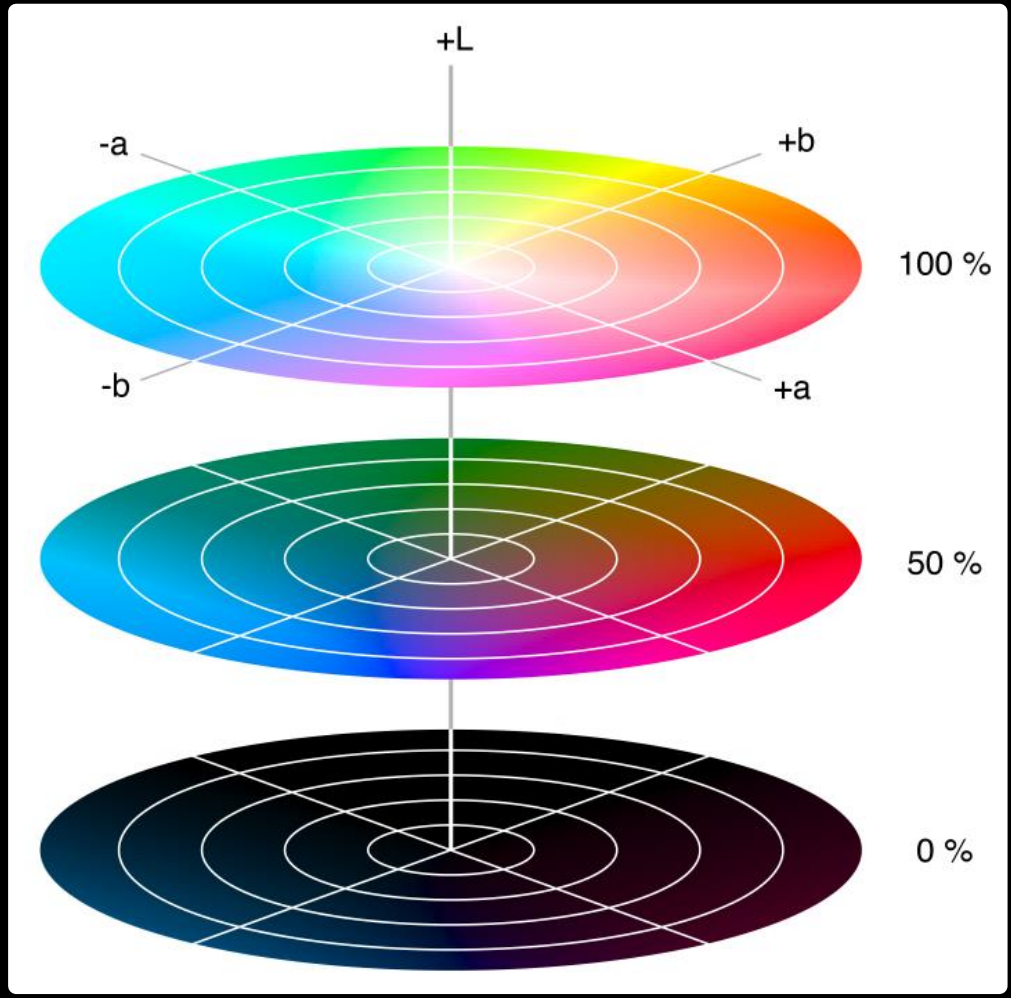
L = 50%



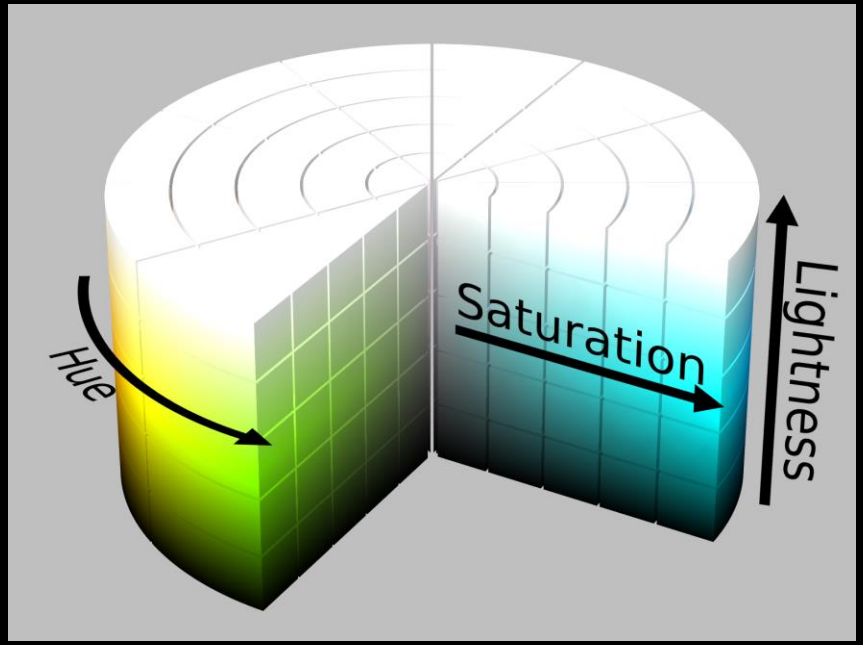
L = 75%

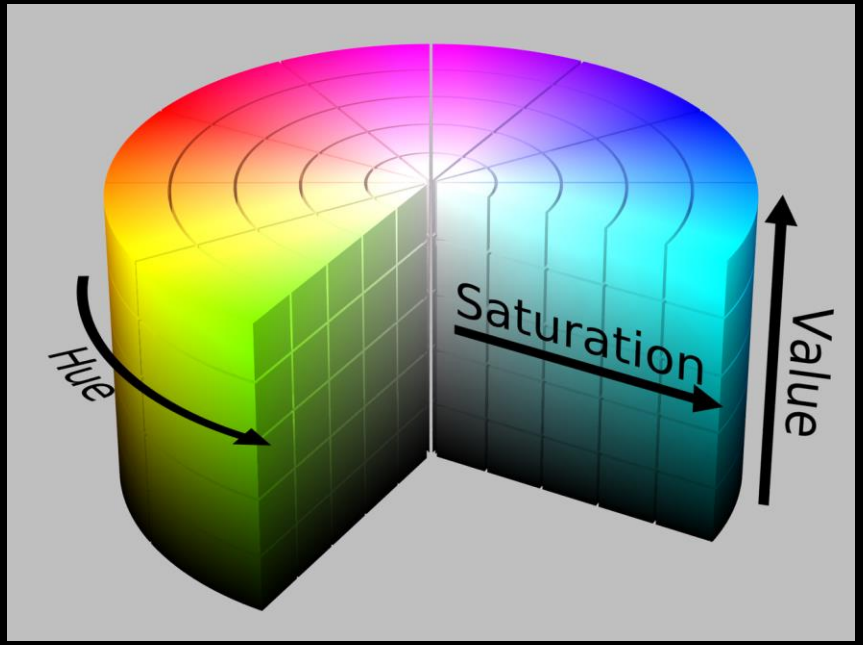
Cylindrical view

Think of chroma (here a*, b*) defining a planar disc at each luminance level (L)



HSL and HSV color spaces





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

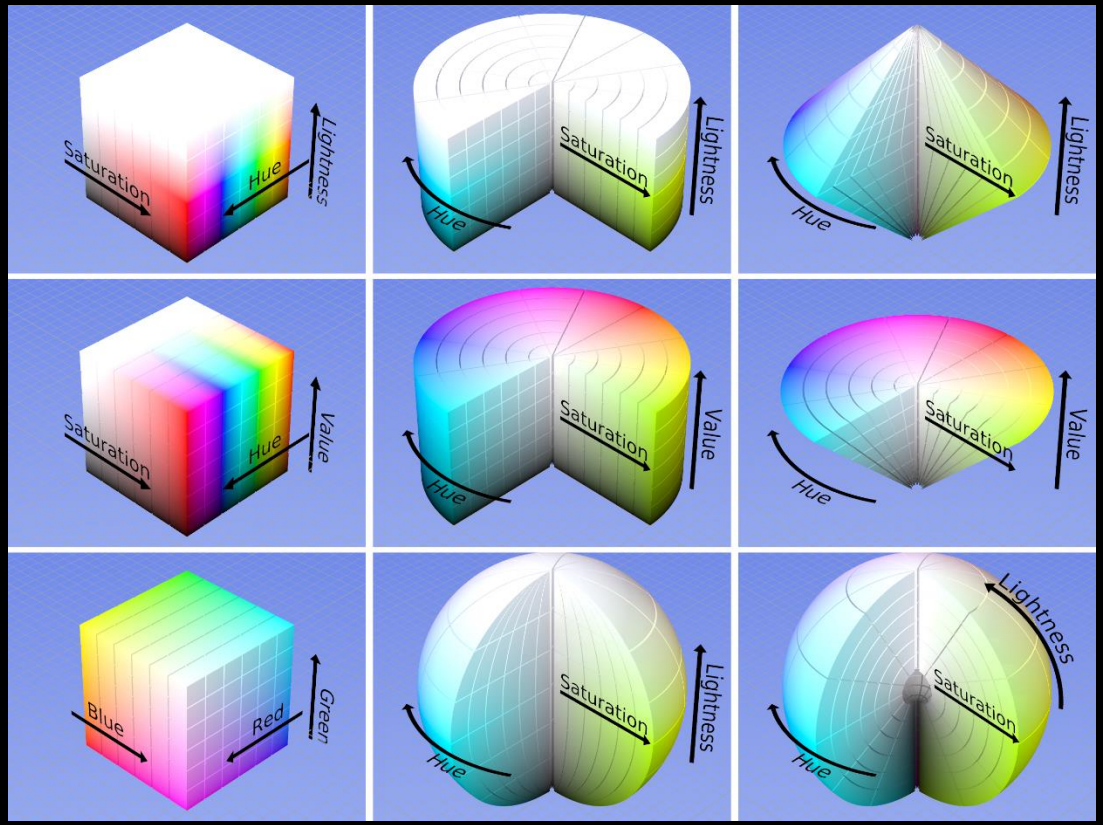
Quiz: Hue difference

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

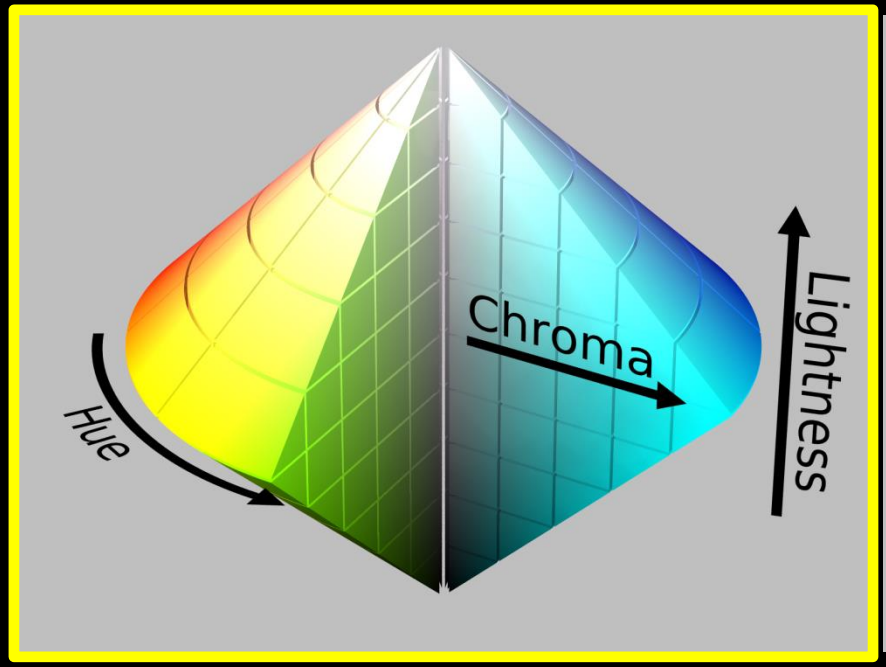
- 225 and 75 — 150
- 45 and 315 — 90

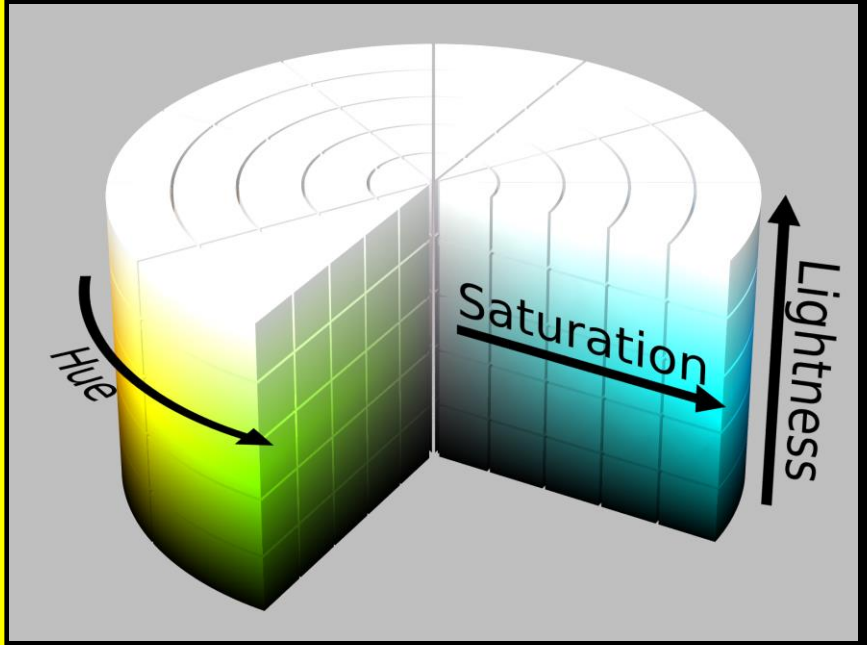
Hue is an angular measure, it "wraps around" at 0/360

But there are lots of color spaces



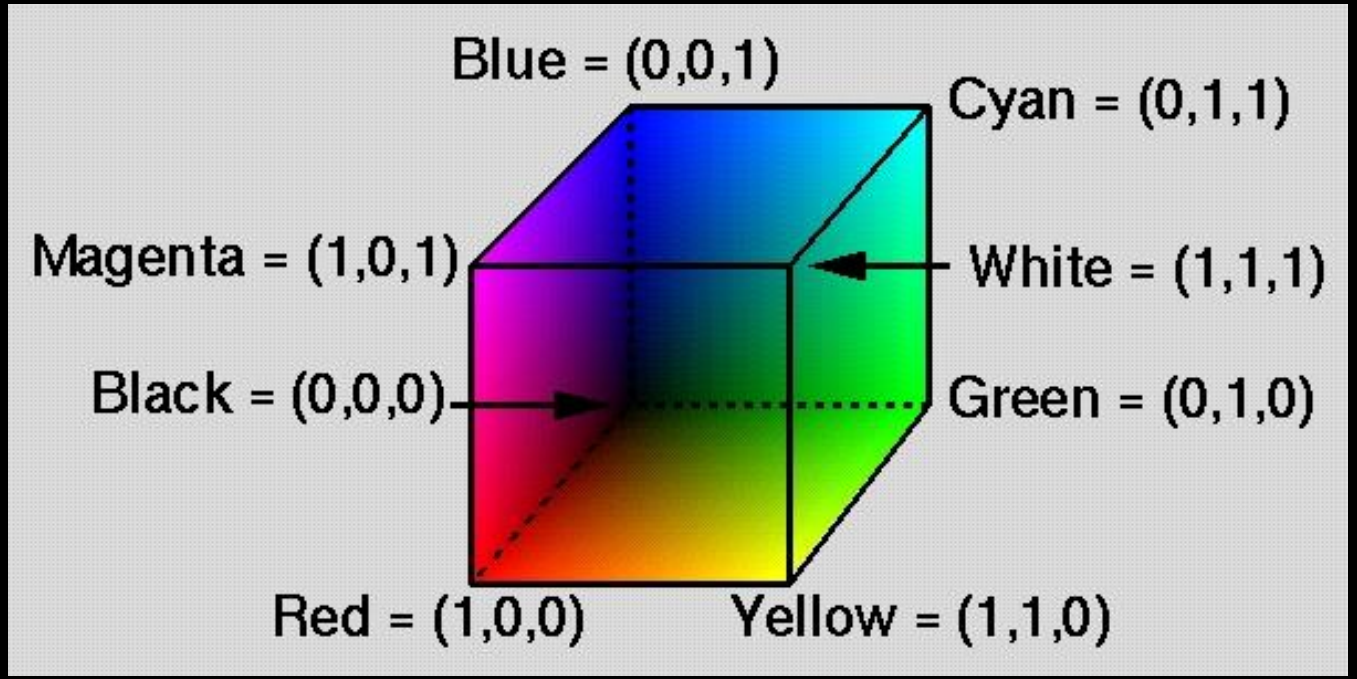
My favorite



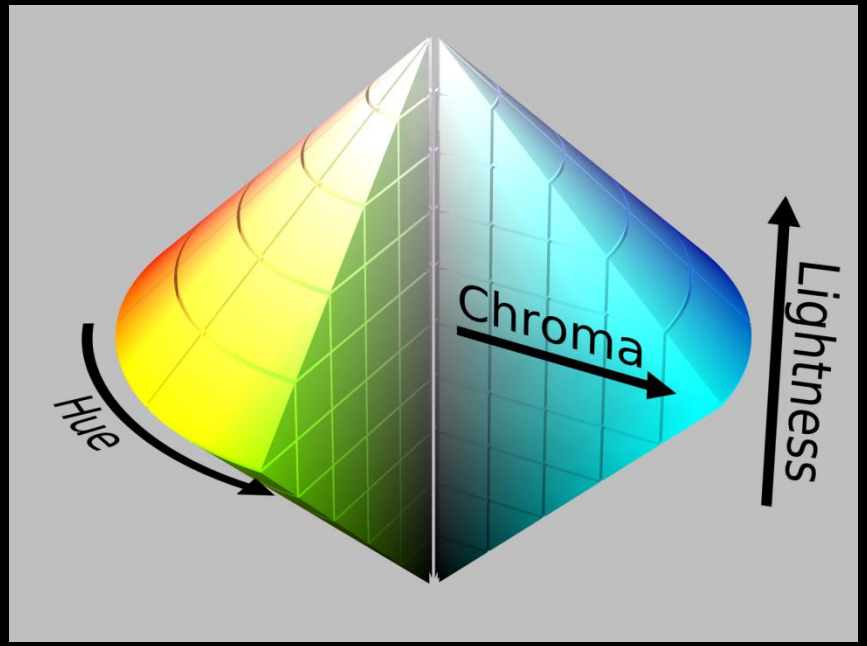


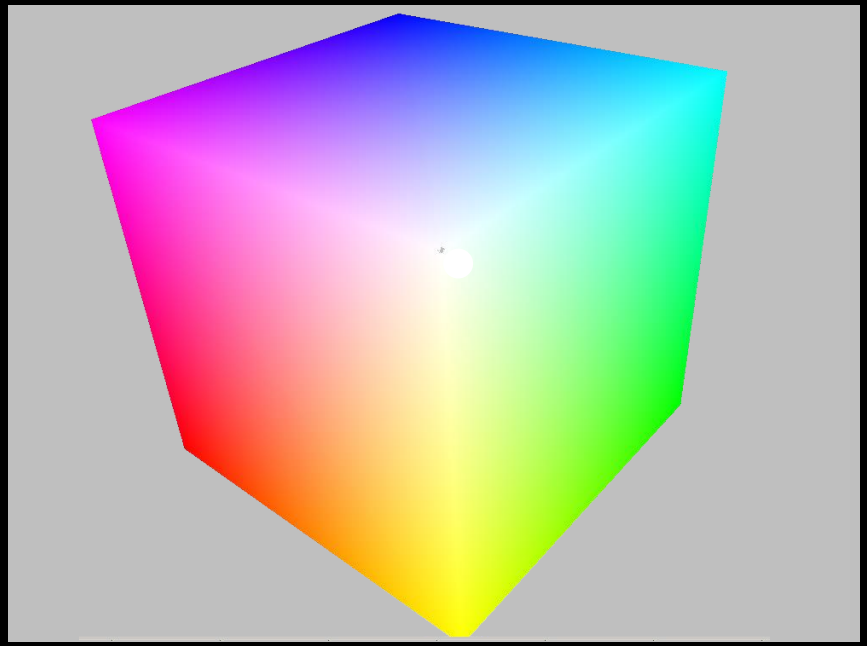
The one we know best…

- RGB color space

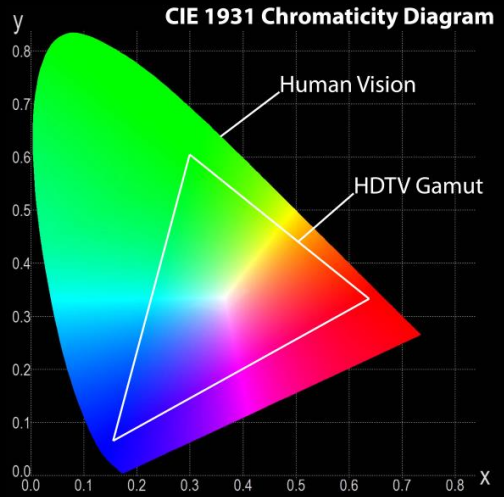


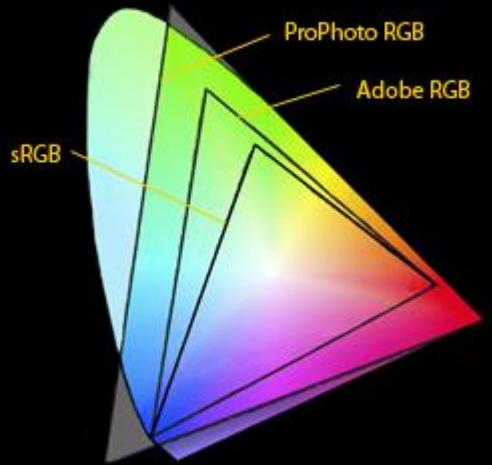
Like a squared double cone?

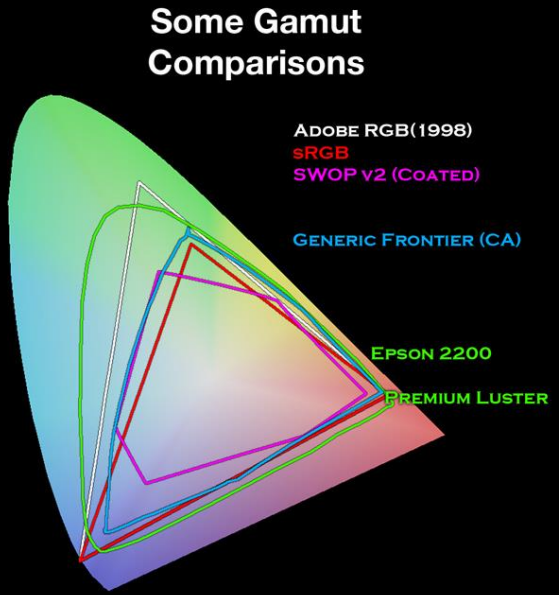


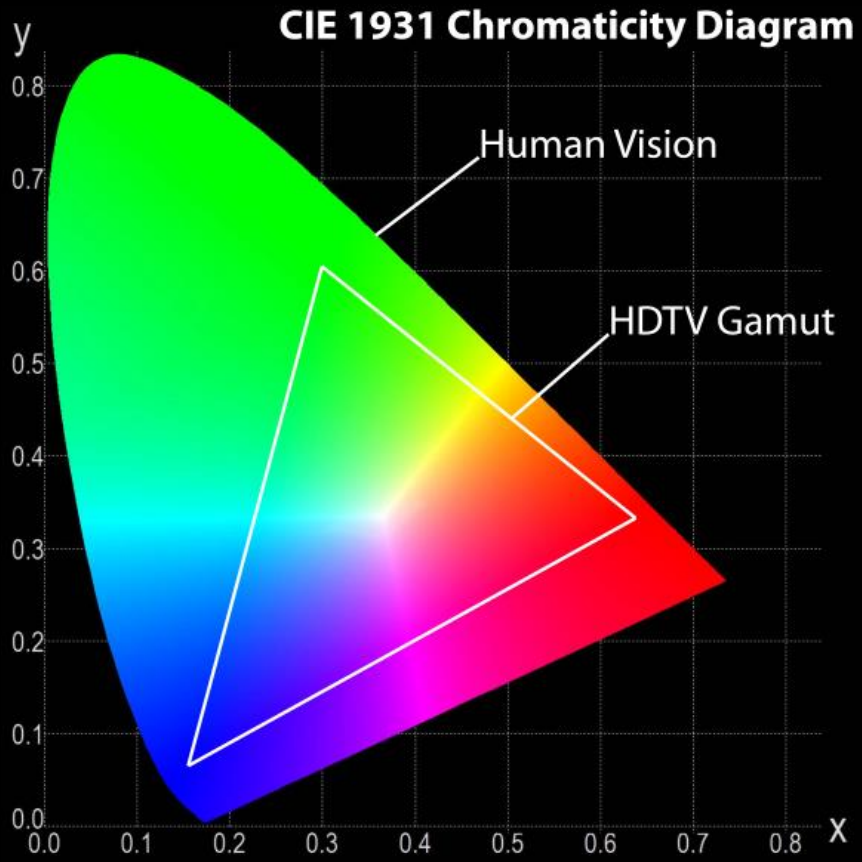


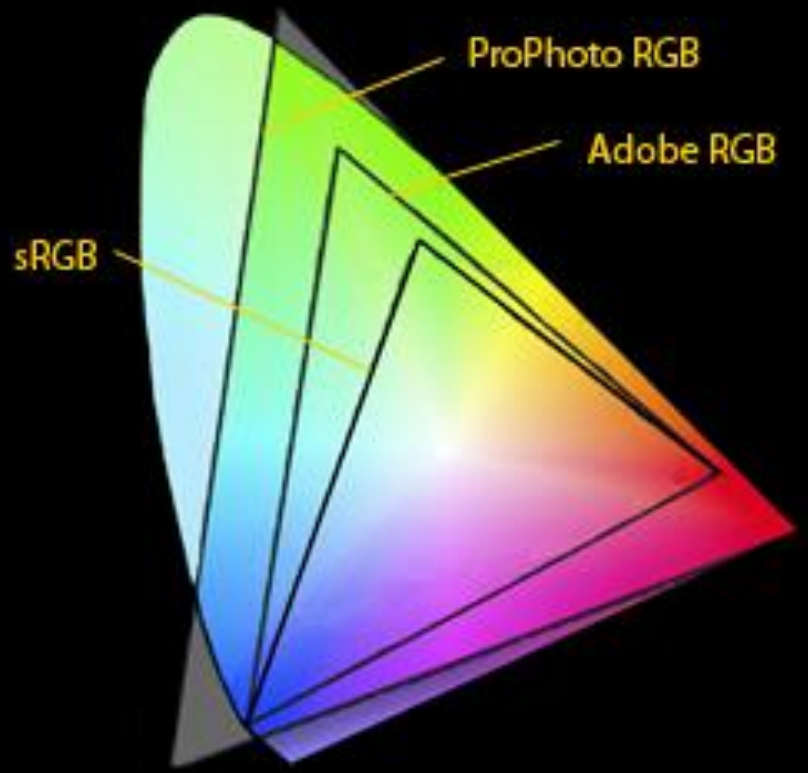
Color gamuts



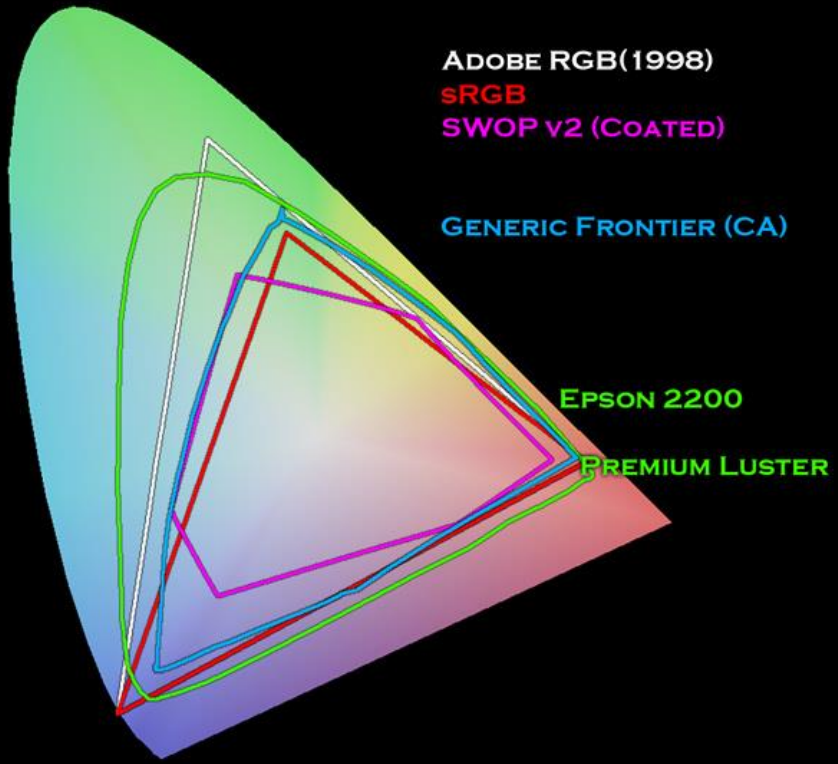





CIE 1931 Chromaticity Diagram
y
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Human Vision
HDTV Gamut
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x

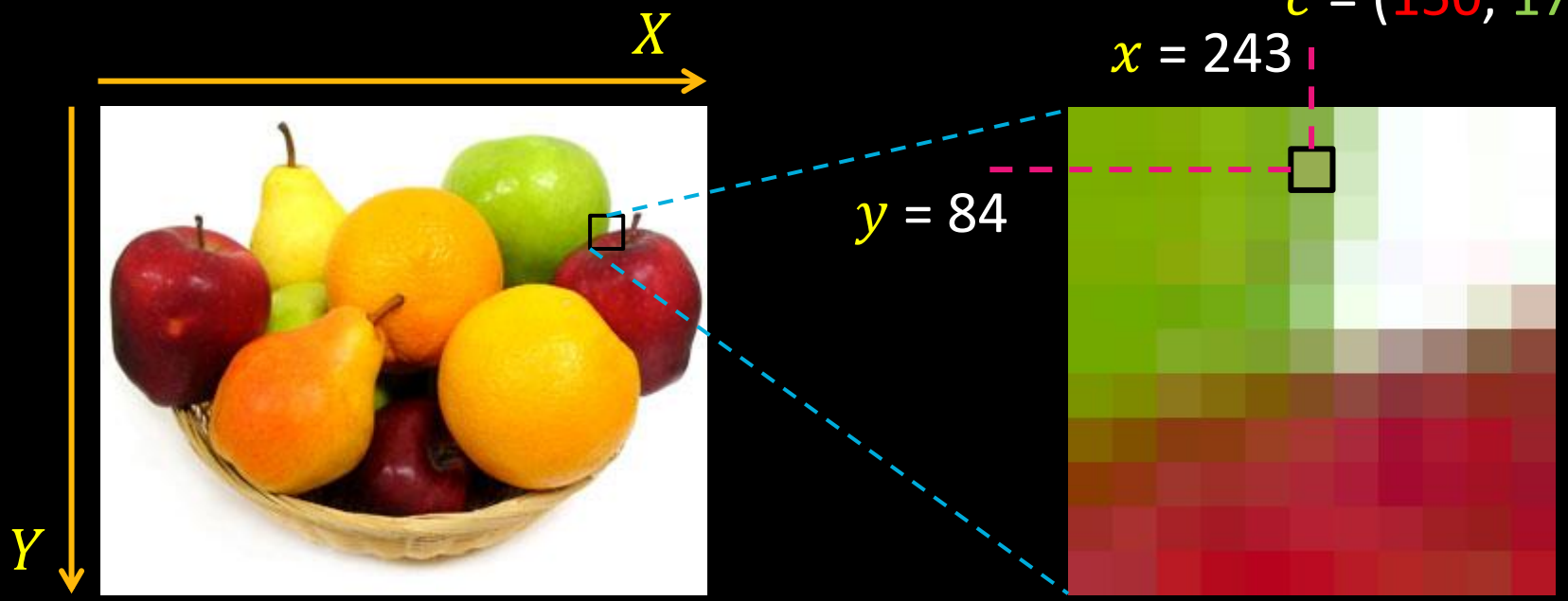

ProPhoto RGB
Adobe RGB
sRGB

Some Gamut Comparisons

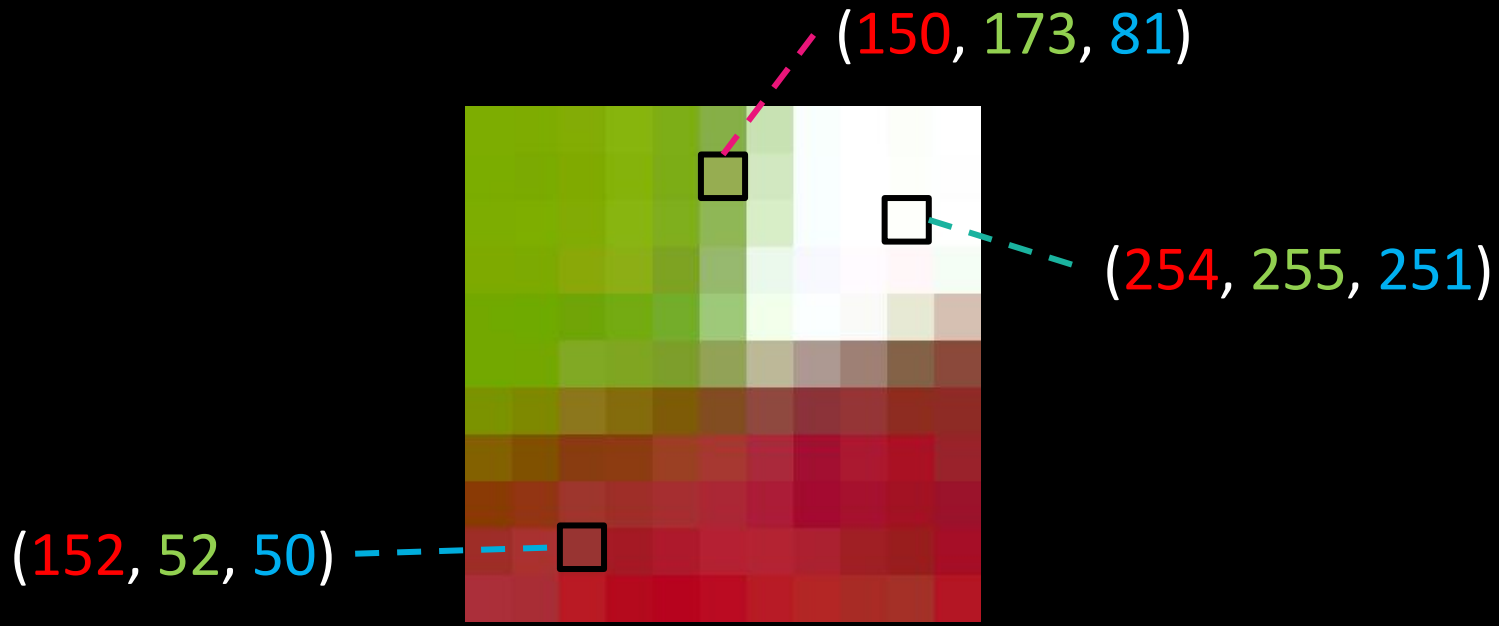


Revisiting pixels

"Picture element" at location (x, y), value or color c



Color values are vectors, here (R, G, B)



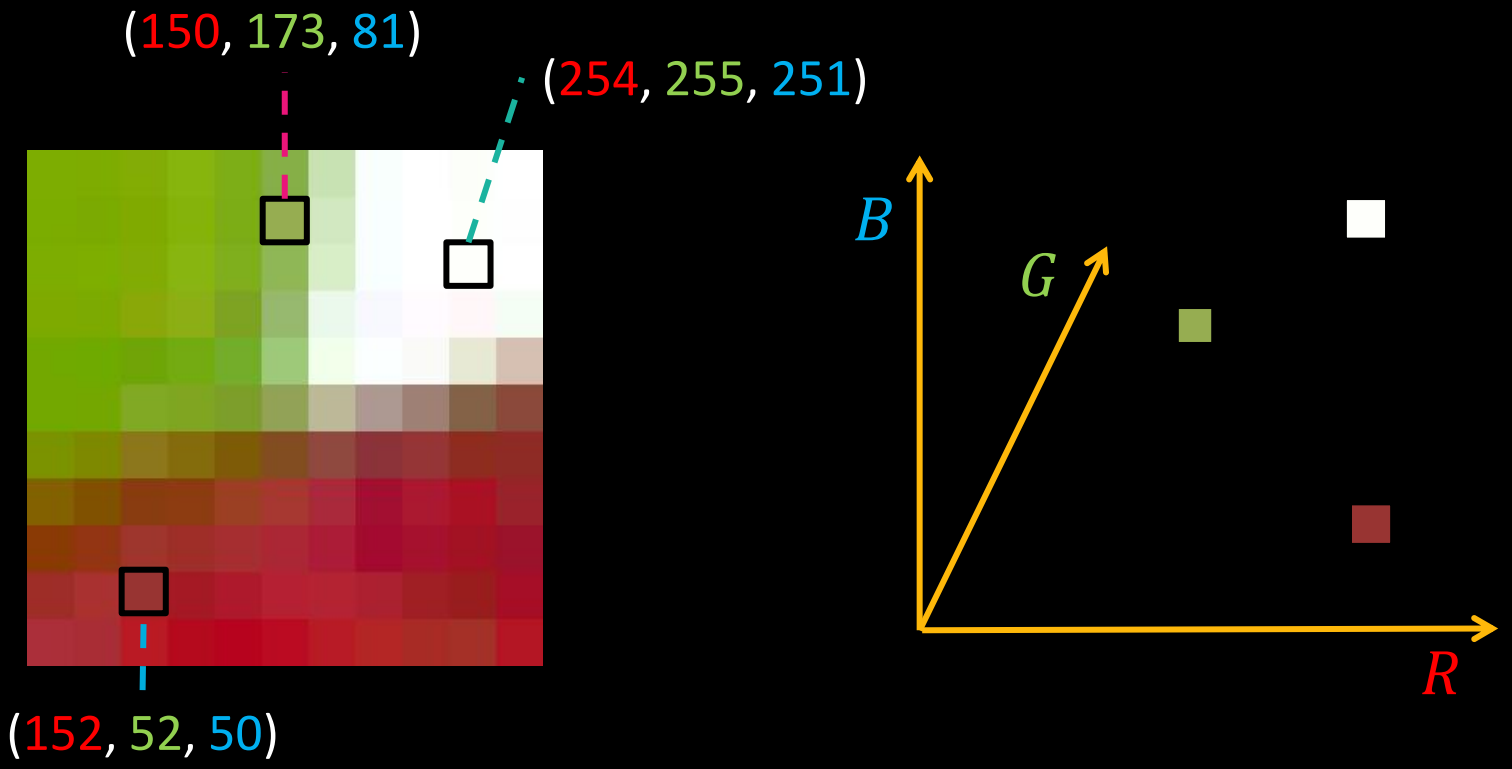
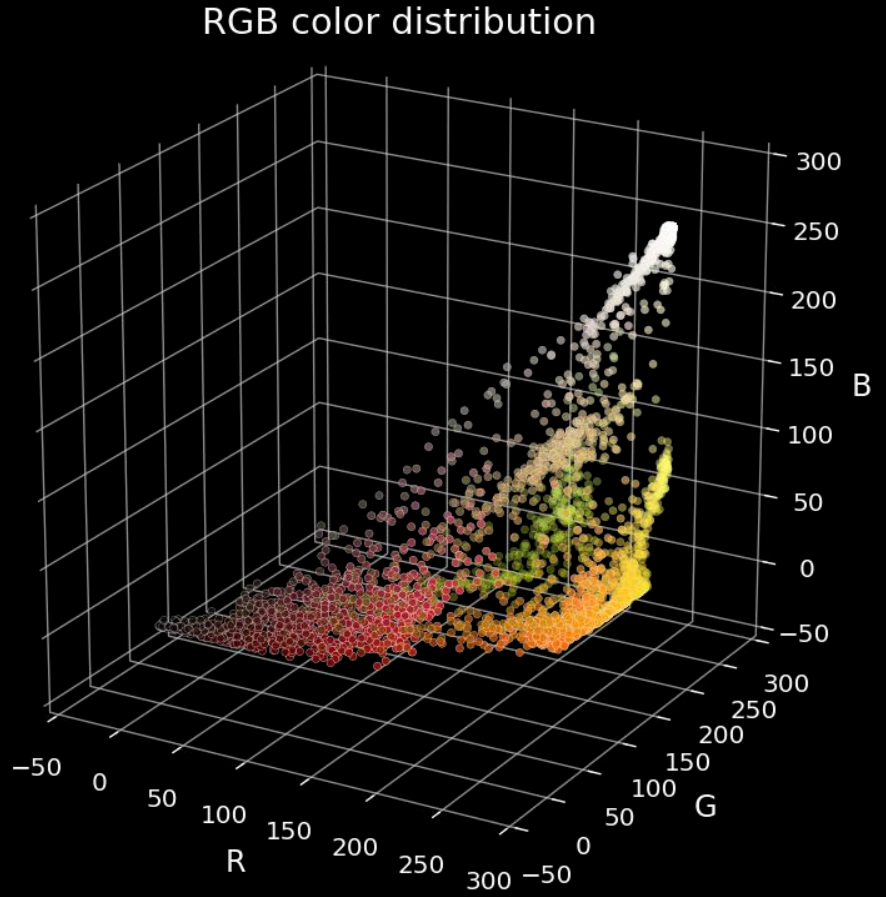


Image Space

RGB Color Space


RGB color distribution
300
250
200
150
100
50
0
−50
B
−50
0
50
100
150
200
250
300
R
300
250
200
150
100
50
0
−50
G

Quiz: Plotting pixels in a color space

What does this view enable us to do?

- Think about clusters of pixels that are similar in color
- Understand the shape and size of objects present
- Identify pixels that are different, and separate them
- Count how many pixels of each color there are

Quiz: Plotting pixels in a color space

What does this view enable us to do?

- ☑ Think about clusters of pixels that are similar in color
- ☐ Understand the shape and size of objects present
- ☑ Identify pixels that are different, and separate them
- ☐ Count how many pixels of each color there are

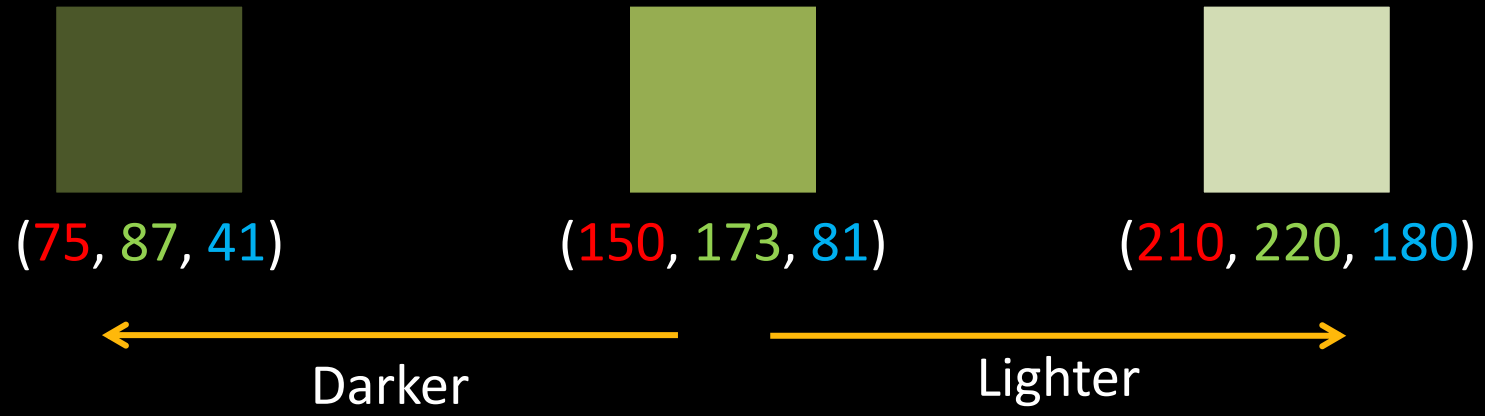
Example: Red filter

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!

Solution: Separate intensity and *color*

Define intensity (Y) as some combination of R, G, B

$$Y = W_R \times R + W_G \times G + W_B \times B$$
$$= 0.299 \times R + 0.587 \times G + 0.114 \times B$$

Solution: Separate intensity and *color*

Then compute new color values, taking out intensity

$$U = U_{max}\frac{B - Y}{1 - W_B} \approx 0.492 \times (B - Y)$$

$$V = V_{max}\frac{R - Y}{1 - W_R} \approx 0.877 \times (R - Y)$$

Assuming R, G, B and Y are in the range $[0,1]$

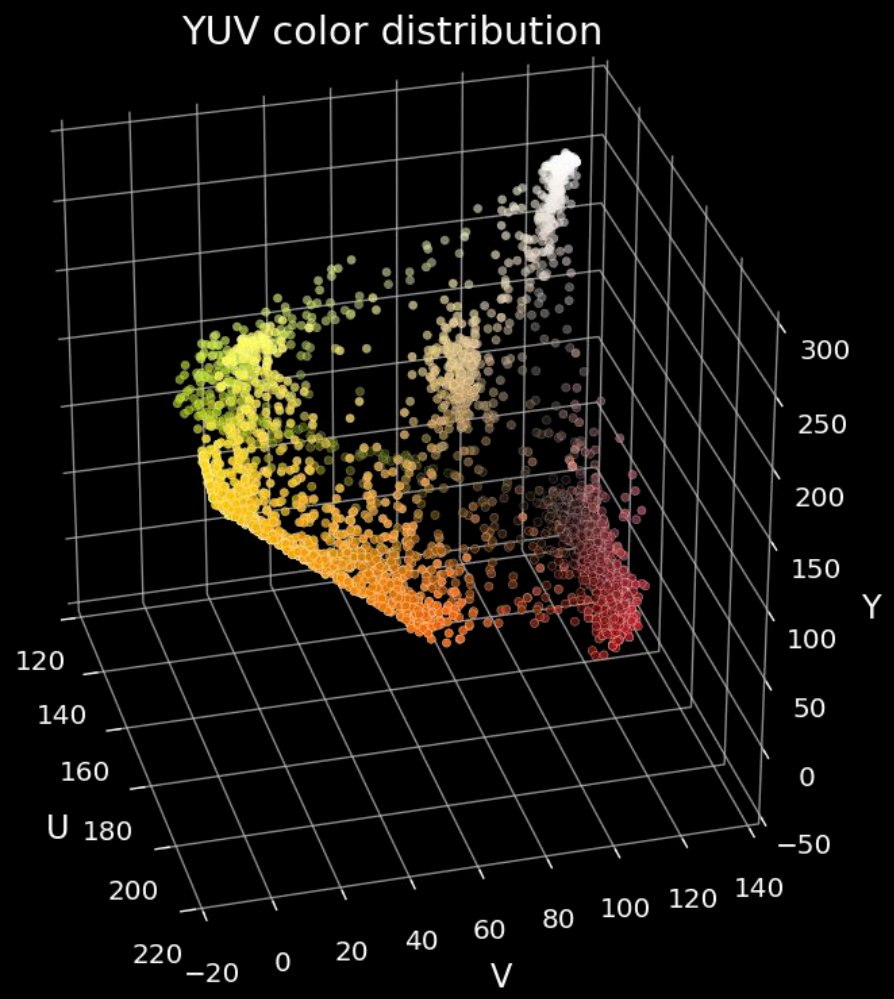
$U \in [-U_{max}, U_{max}]$ and $V \in [-V_{max}, V_{max}]$

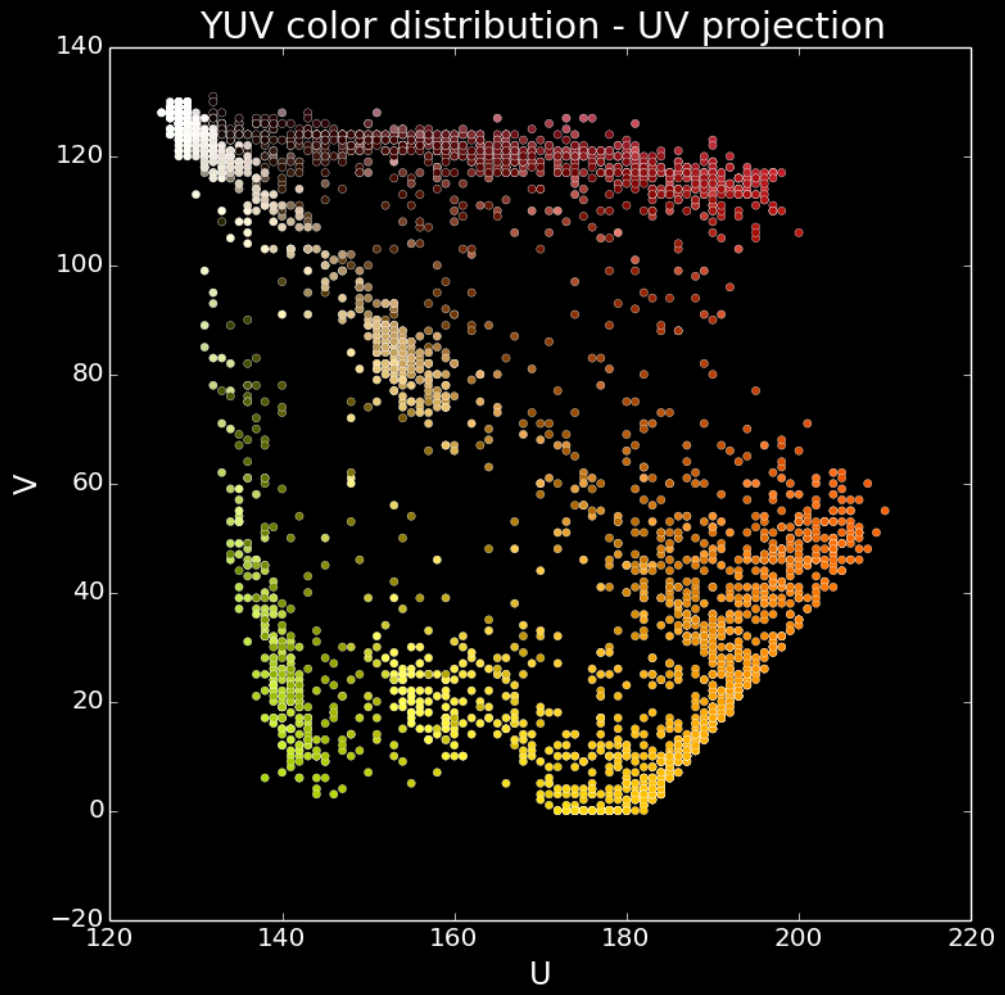
Together: YUV

Y

U

V


YUV color distribution
300
250
200
150
100
50
0
−50
Y
120
140
160
180
200
220
U
−20
0
20
40
60
80
100
120
140
V


YUV color distribution - UV projection
140
120
100
80
60
40
20
0
−20
V
120
140
160
180
200
220
U

Quiz: UV filter

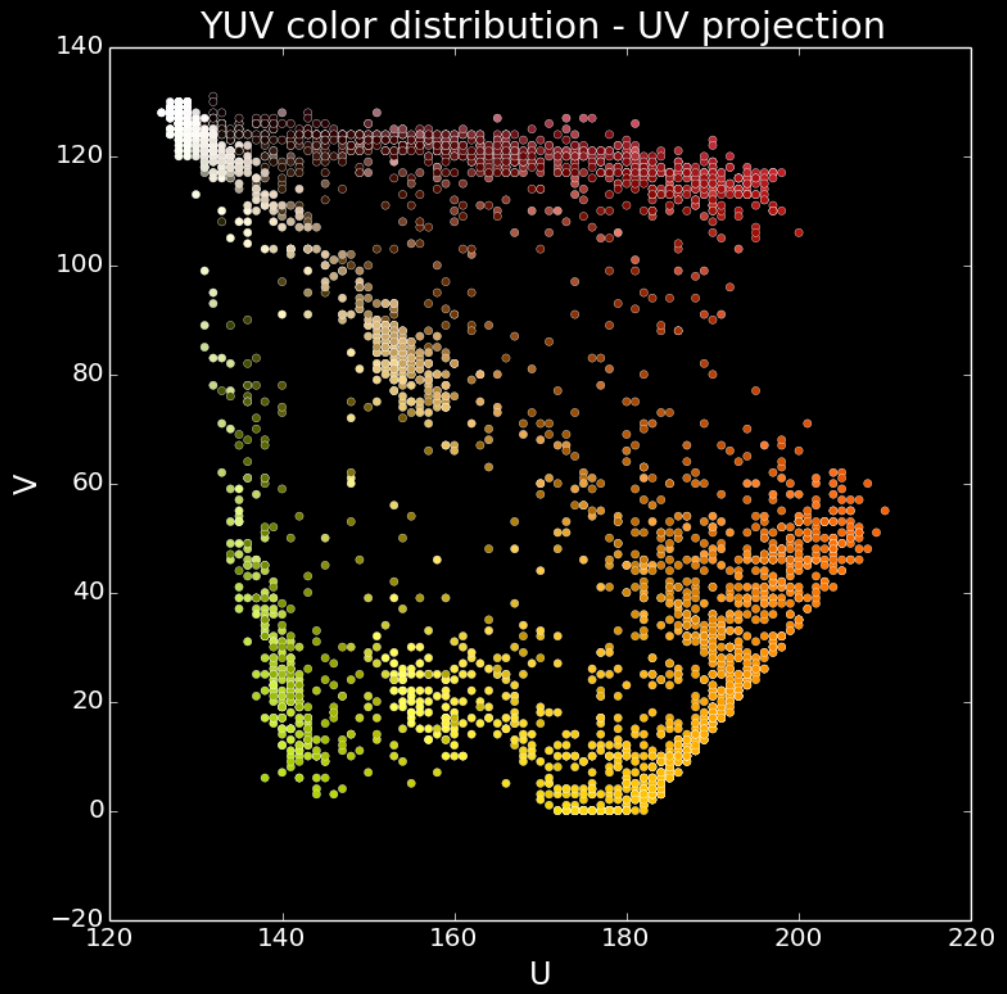
What UV limits should we use to extract red regions?

Filter:

$Y \in [0,255]$,

$U \in [\square, \square]$,

$V \in [\square, \square]$

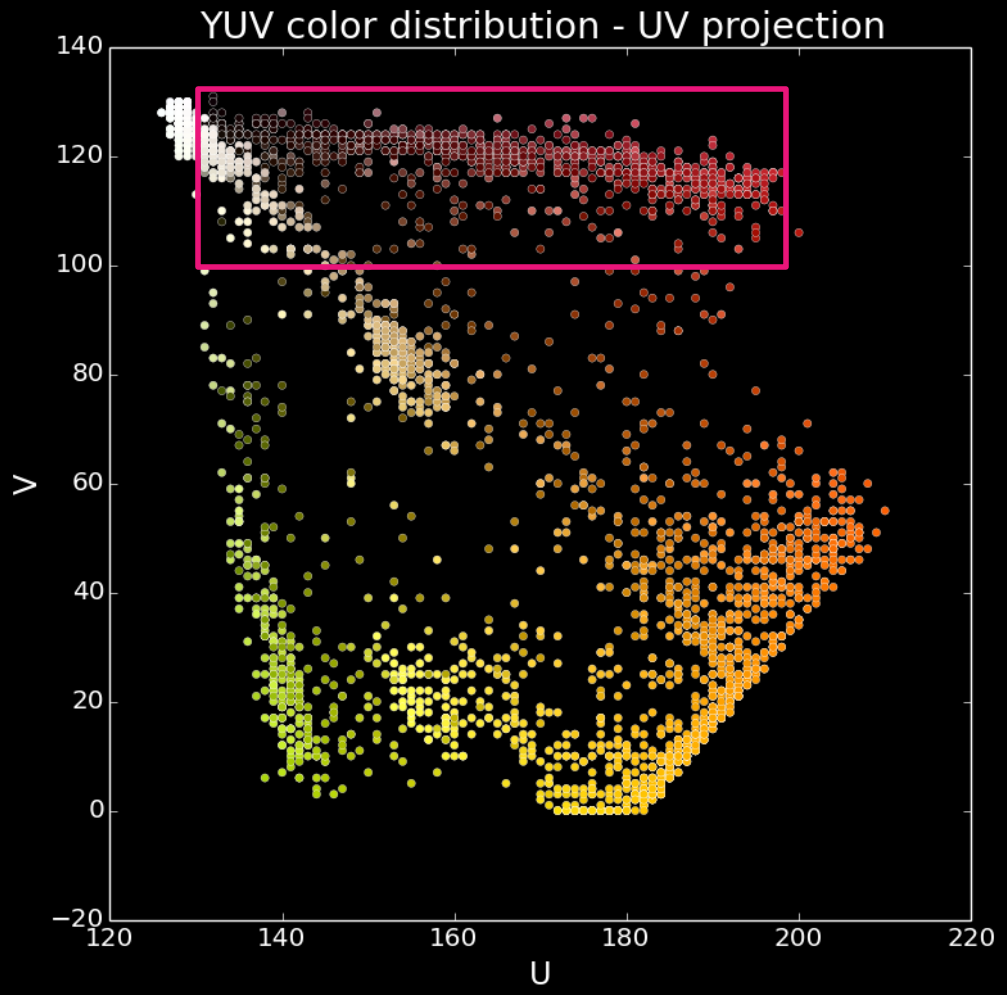


Quiz: UV filter

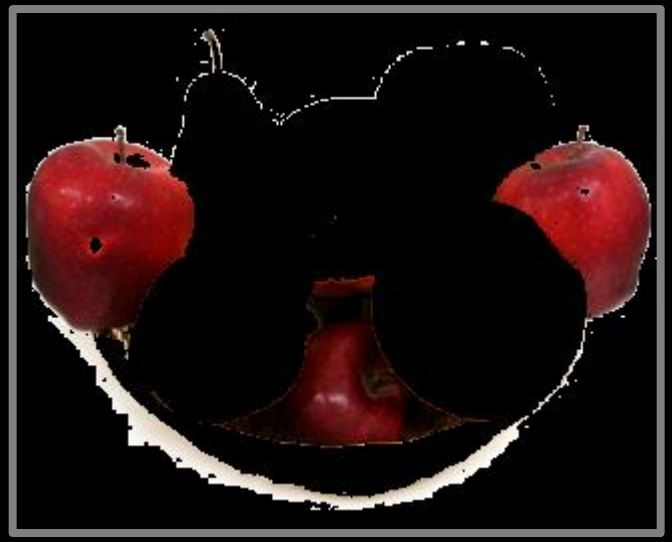
What UV limits should we use to extract red regions?

Filter:

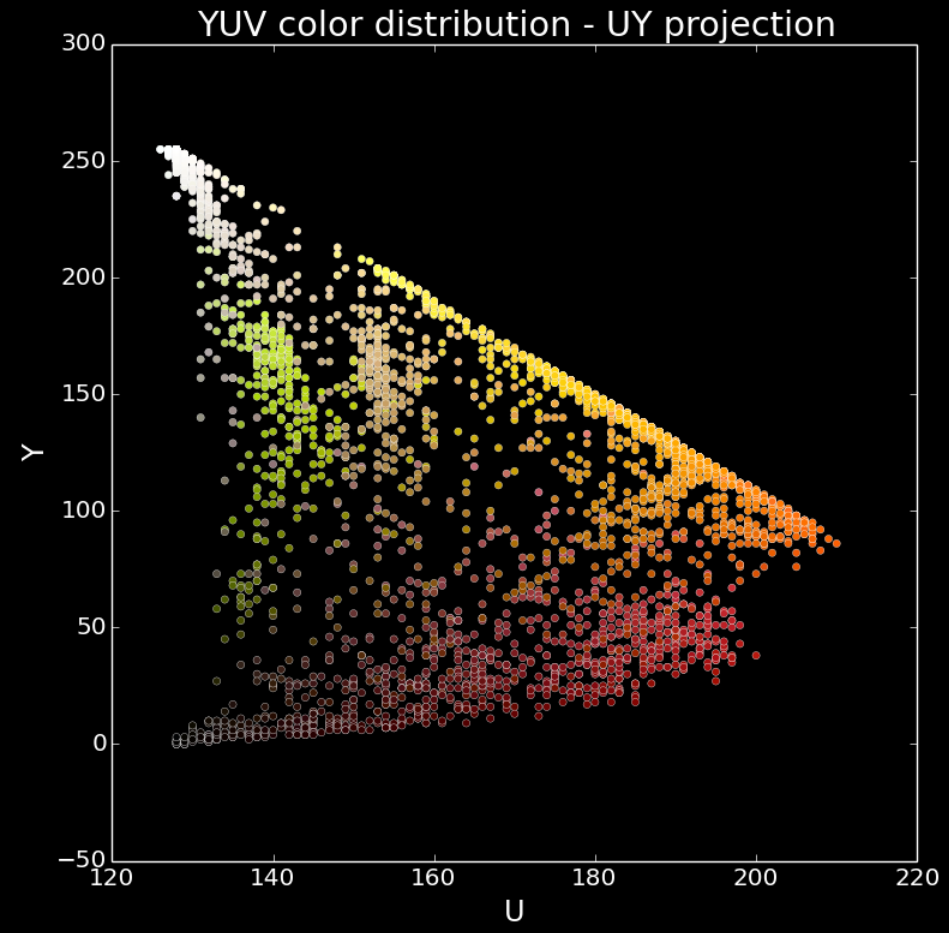
$$Y \in [0,255],$$
$$U \in [130,200],$$
$$V \in [100,130]$$

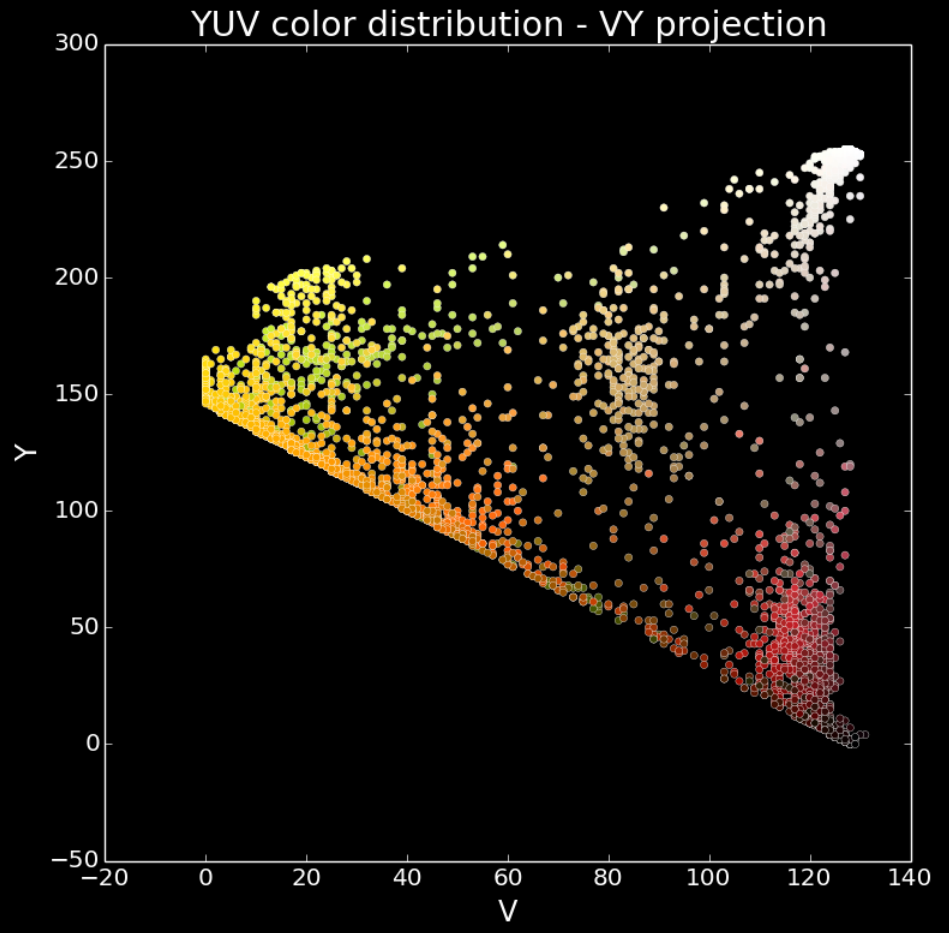


UV filter

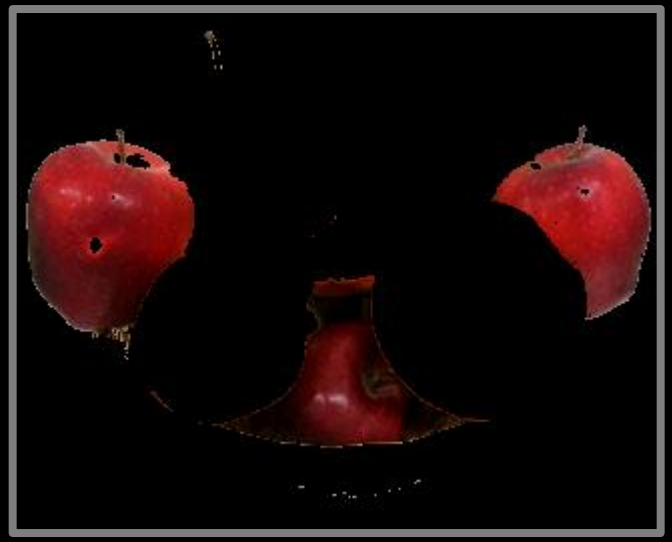


Filter: $Y \in [0,255]$,
$U \in [130,200]$,
$V \in [100,130]$


YUV color distribution - UY projection
300
250
200
150
100
50
0
−50
Y
120
140
160
180
200
220
U


YUV color distribution - VY projection
300
250
200
150
100
50
0
−50
Y
−20
0
20
40
60
80
100
120
140
V

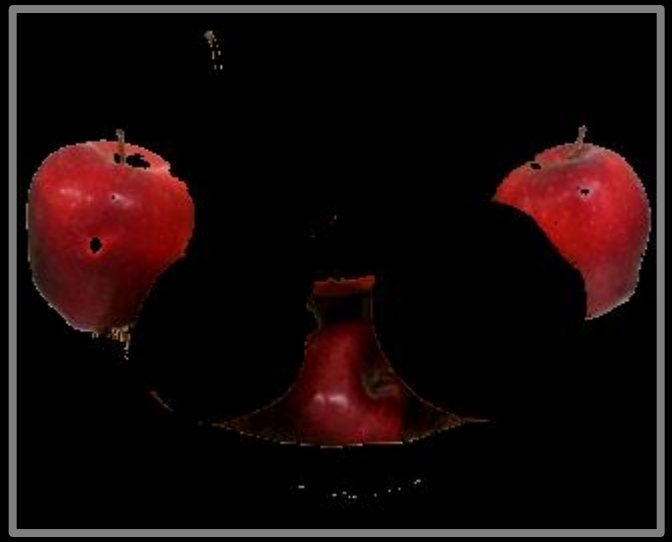
YUV filter



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

Other luma-chroma color spaces

- YC_bC_r/YP_bP_r – video transmission, compression
- CIE L*a*b*
  - Based on human perception
  - Intensity channel: L* = lightness
  - Color-opponent: a* = red-green, b* = blue-yellow
- CIE L*u*v* – like L*a*b* but easier to compute

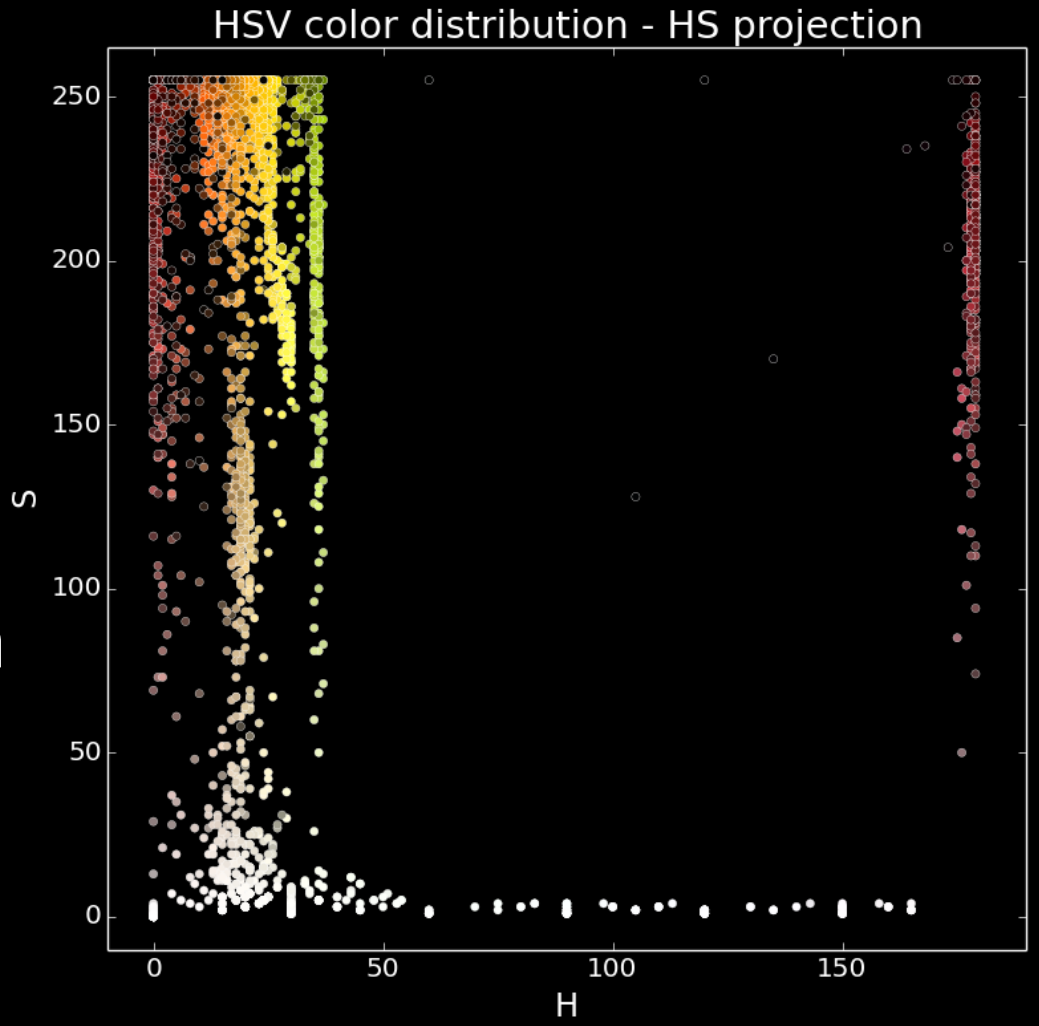
Back to plotting image pixels

Plotting in HSV

Focus on HS projection
– what do you see?

Colors spread along a single dimension!

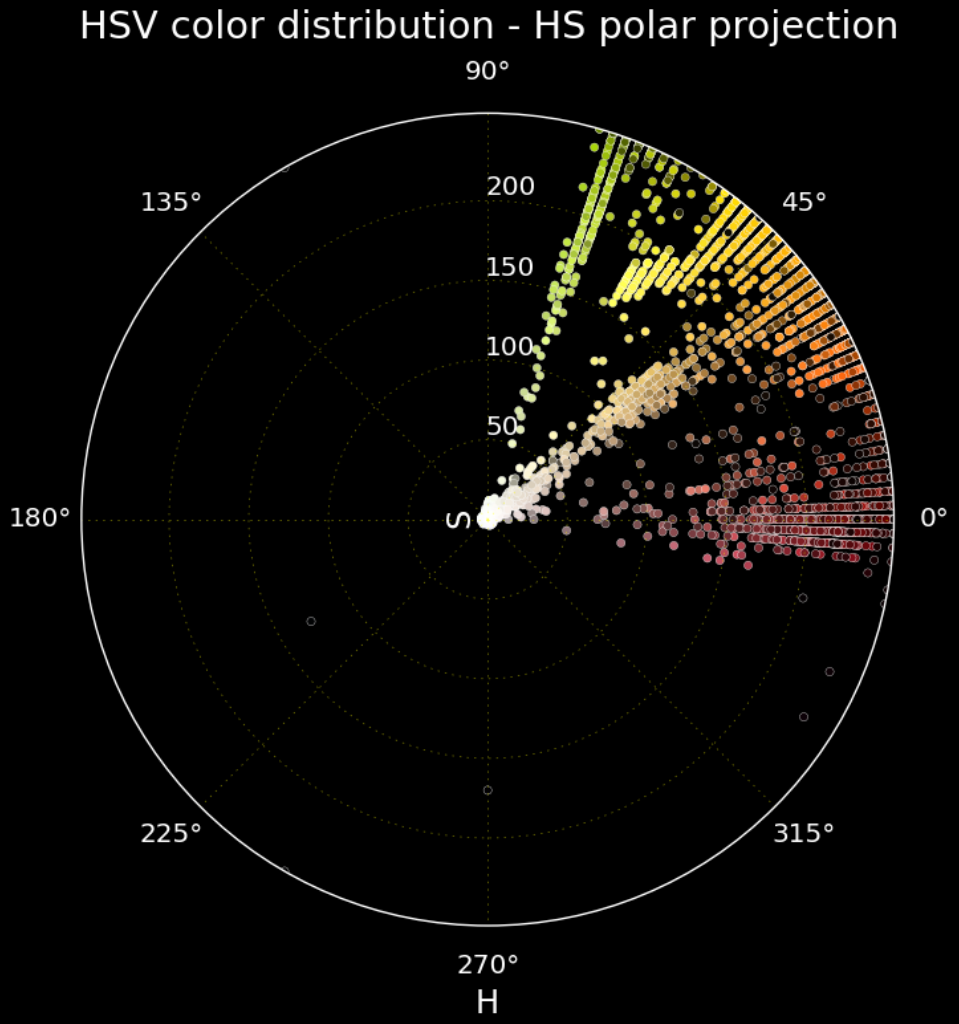
Hue



A better HS plot

Treat hue as an angle

- Reds from both ends of the spectrum now in proximity
- Better reflects the role of saturation (radius or distance from center)



Exercise: HSV filter

- Filter this image in HSV to select red apples
- Compare best results from RGB, YUV, L*a*b*