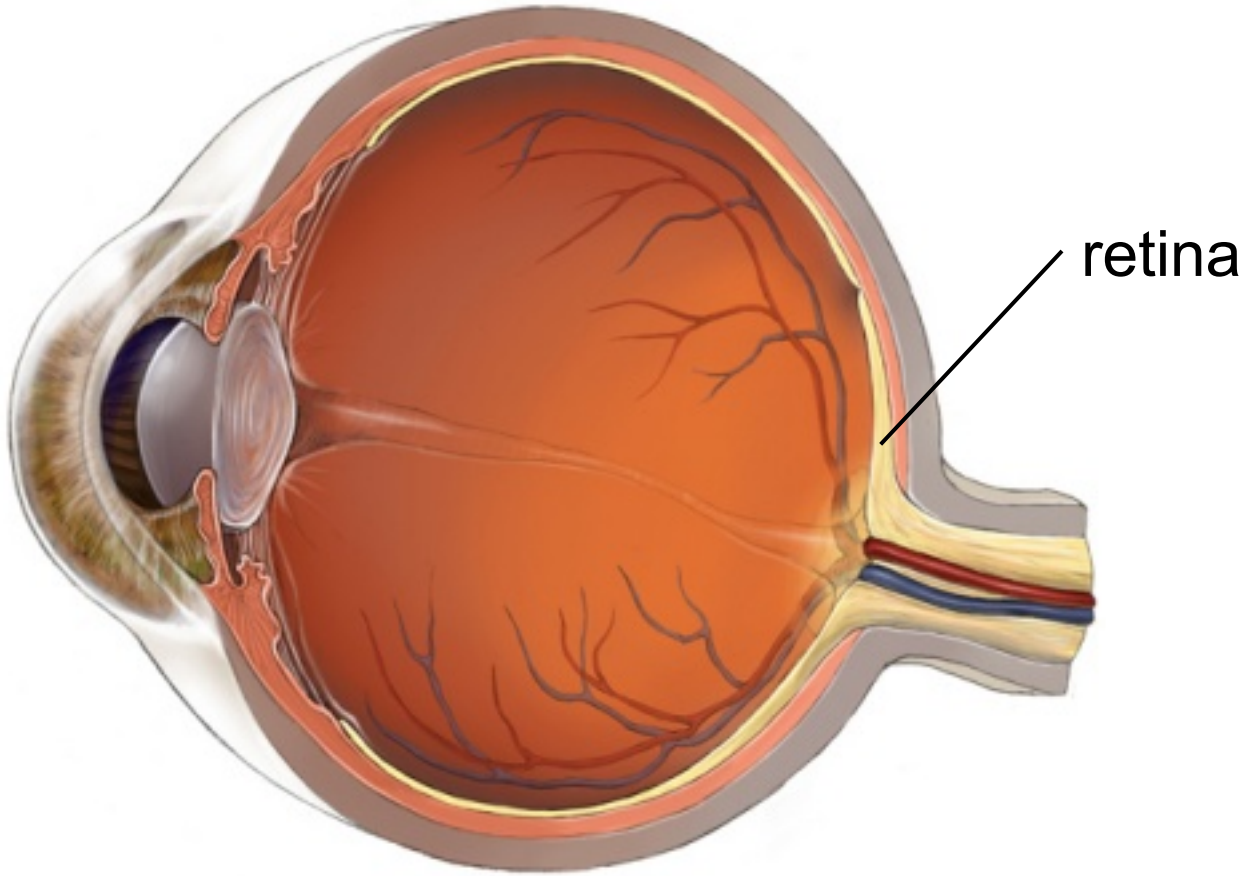
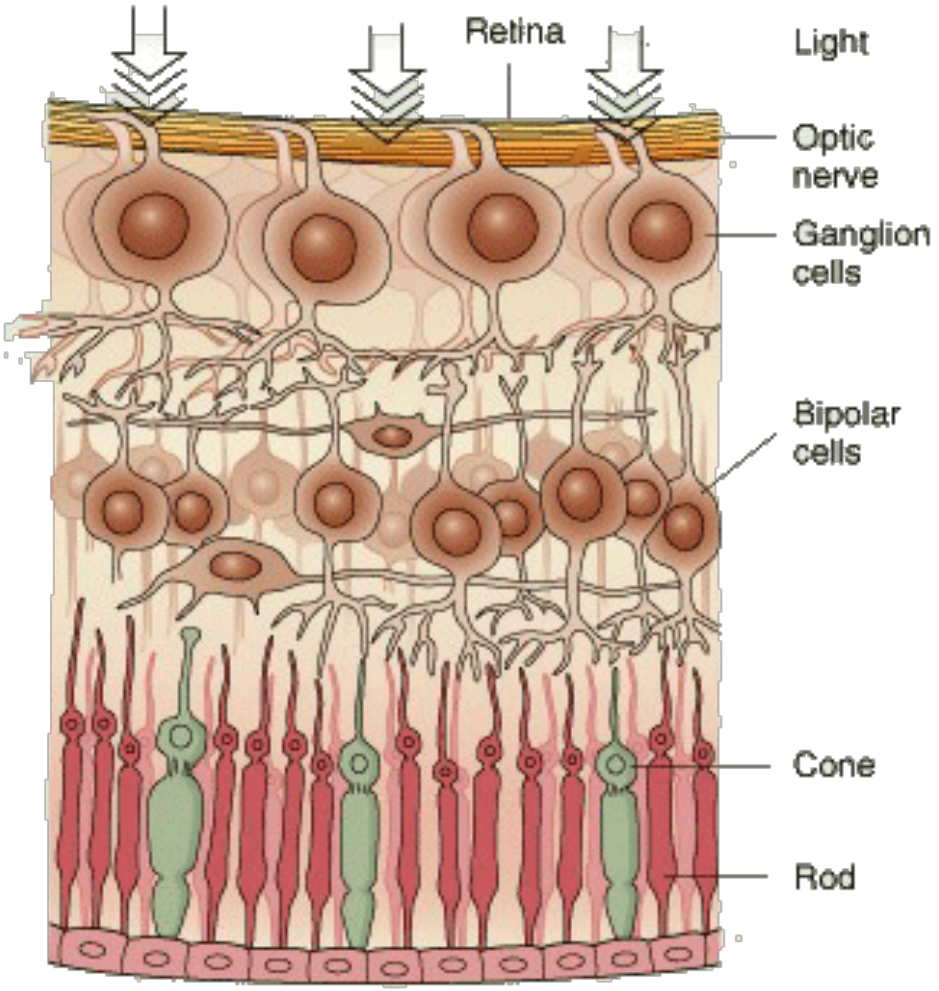
Colour Spaces

Human Colour Perception

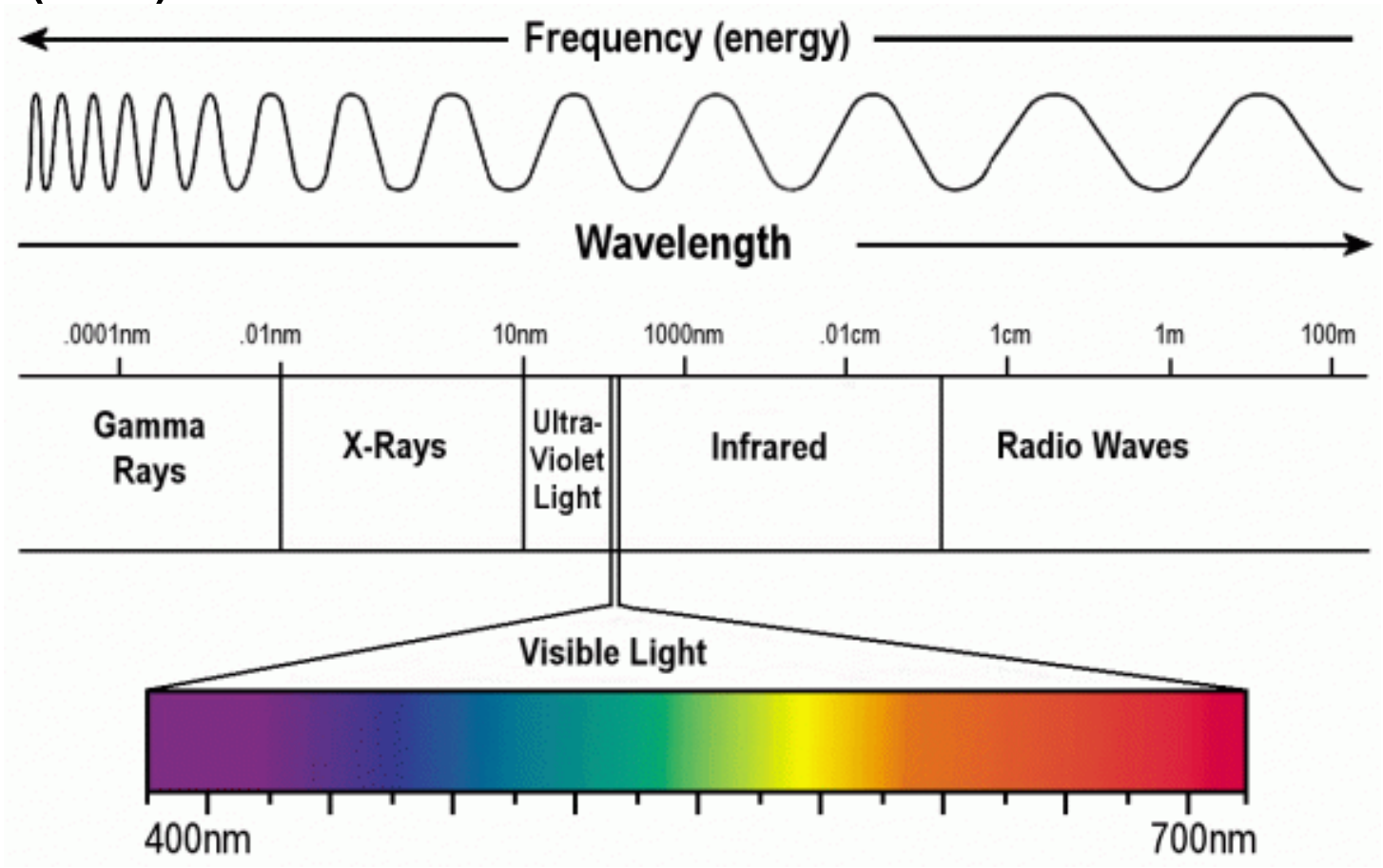
- Human's eye has retina that senses light.



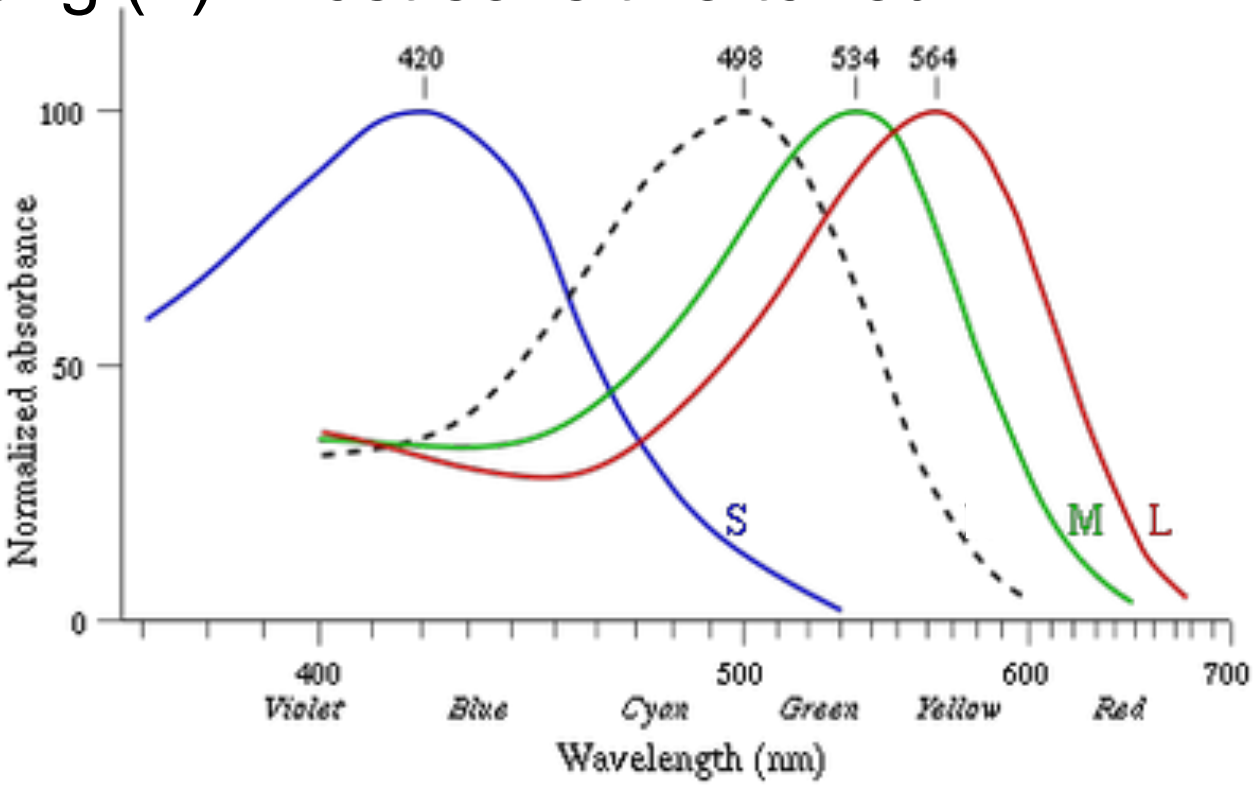
- Human's retina has 2 kinds of light receptors:
  - Rods: sensitive to amount of light
  - Cones: sensitive to wavelengths of light



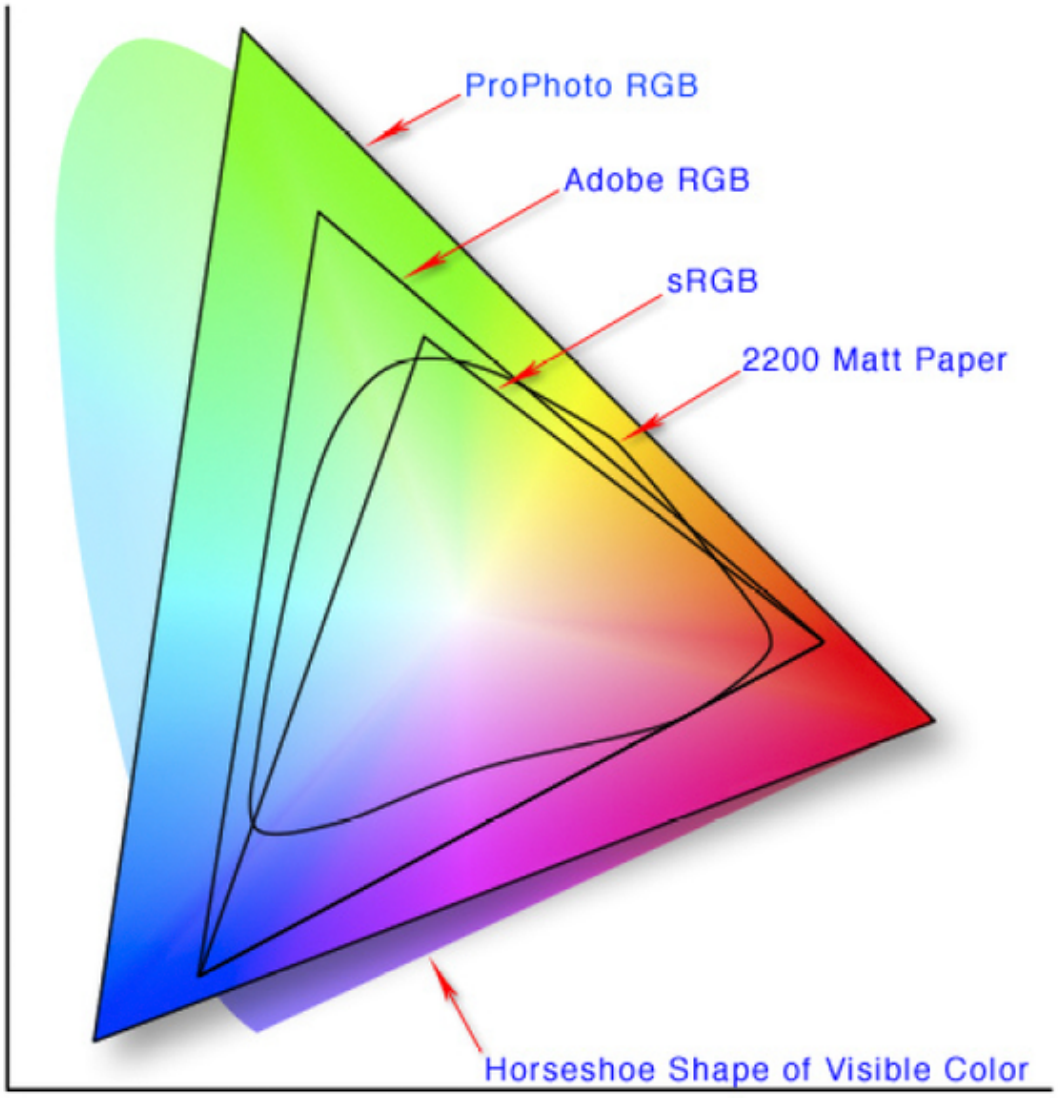
- Cones are sensitive to various colours
  - Wavelengths from 400nm (violet) to 700nm (red)



- 3 kinds of cones:
  - Short (S): most sensitive to blue
  - Medium (M): most sensitive to green
  - Long (L): most sensitive to red



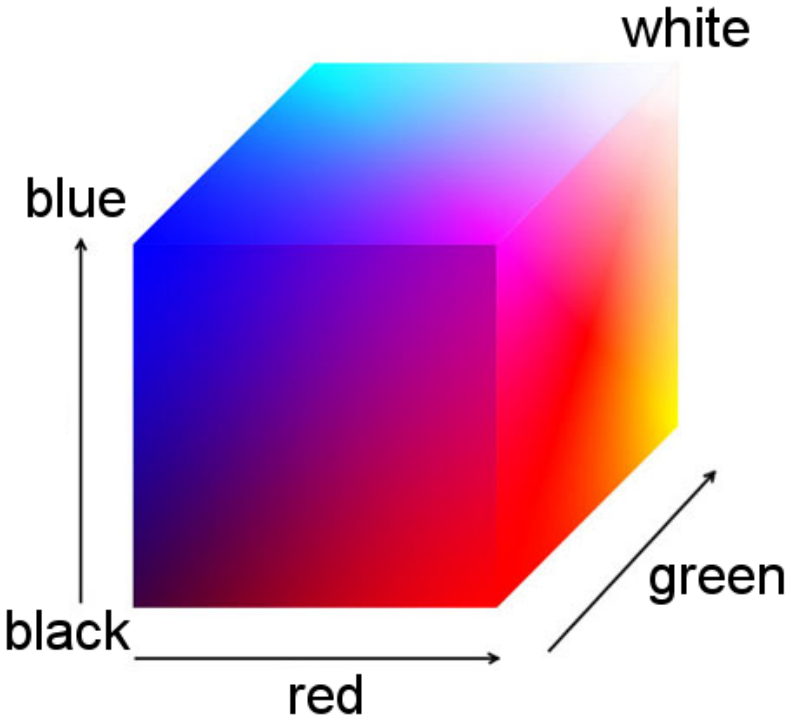
- Cones send signals to brain.
- Brain interprets mixture of signals as colours.
- That's why colours are coded with 3 values.
- Different coding schemes give different colour spaces.


ProPhoto RGB
Adobe RGB
sRGB
2200 Matt Paper
Horseshoe Shape of Visible Color

RGB Colour Space

- Colour is coded with 3 values

  (red, green, blue)

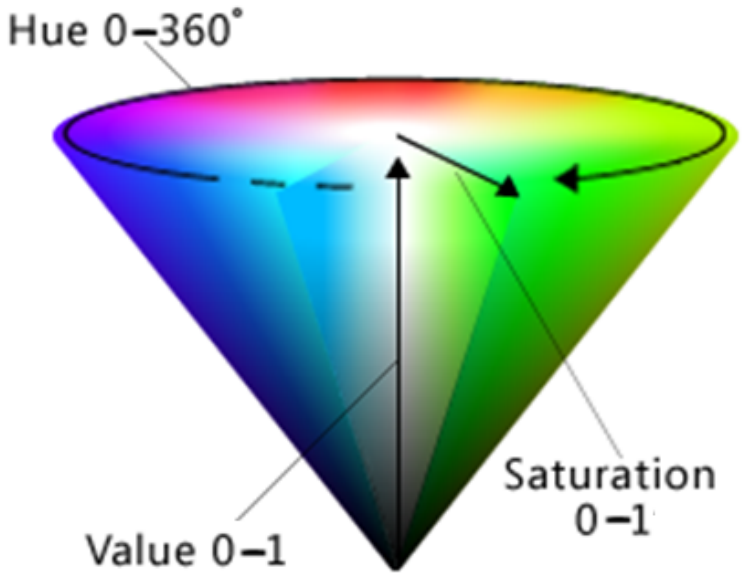


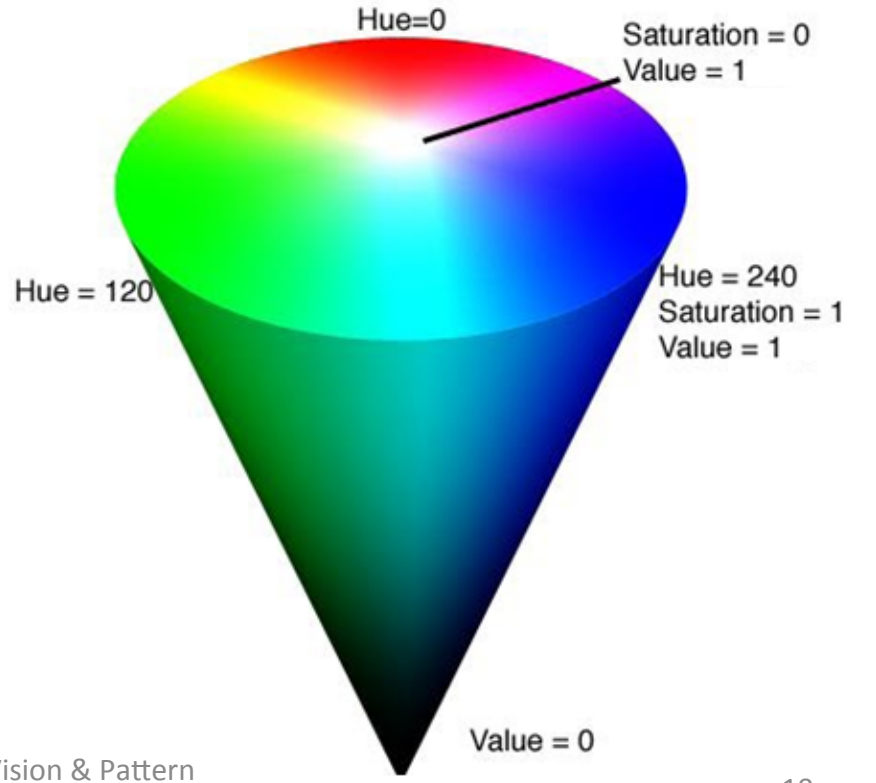
- Each value is an unsigned 8-bit value:
  - (0, 0, 0) is black
  - (255, 0, 0) is red
  - (0, 255, 0) is green
  - (0, 0, 255) is blue
  - (128, 128, 128) is gray
  - (255, 255, 255) is white

note that in opencv, colors are represented as (B,G,R)

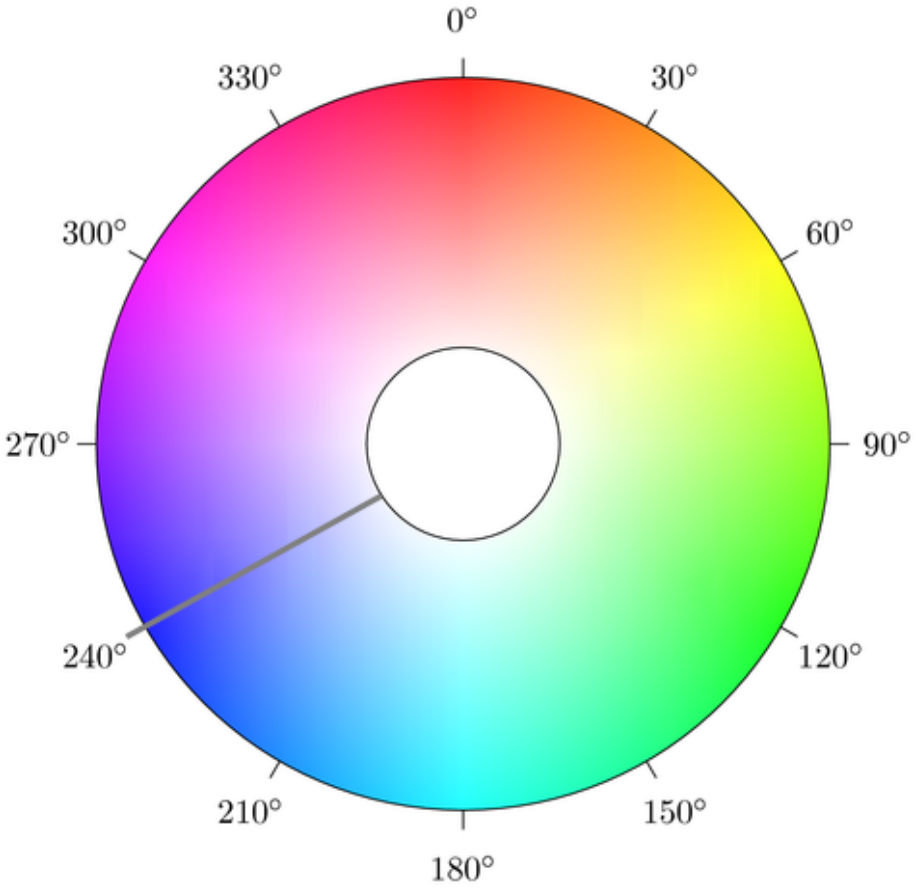
HSV Colour Space

- Code colour as hue, saturation, value.
  - Also called HSB (B for brightness).





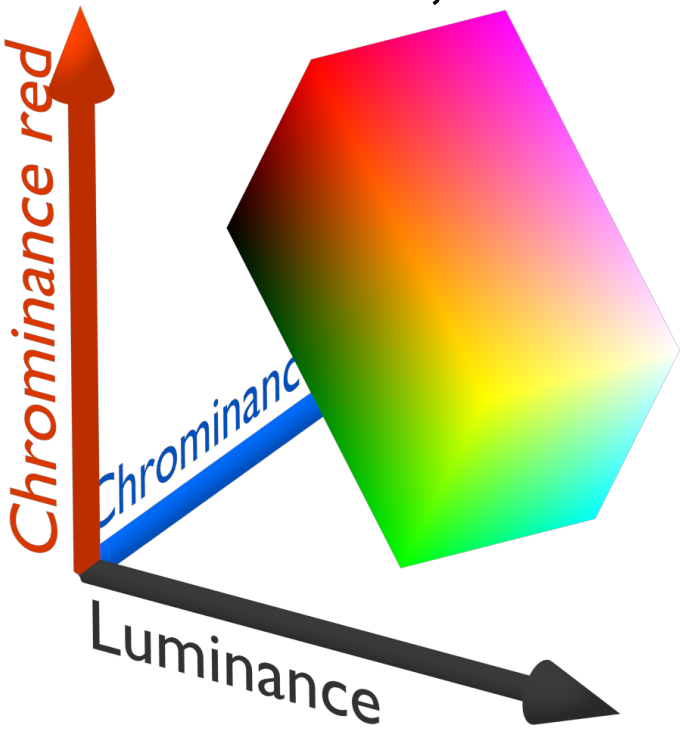
- Hue
  - colour type
  - 0° (red) to 360°
- Saturation
  - Colourfulness
  - 0 to 1 (full colour)
- Value
  - Brightness
  - 0 (black) to 1 (white)

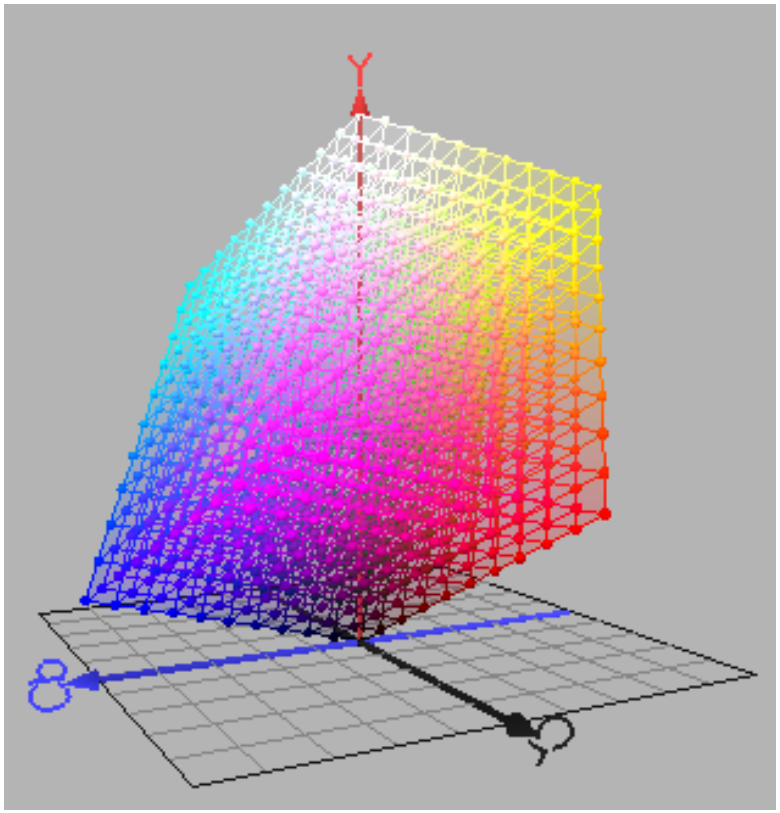


⊙More intuitive than RGB.

YCbCr Colour Space

- Code colour as Y, Cb, Cr.
  - Used for TV, video.





- Y: luminance
- Cb: blue difference
- Cr: red difference
- For unsigned 8-bit encoding, these values range from 0 to 255.

Primary Colors:

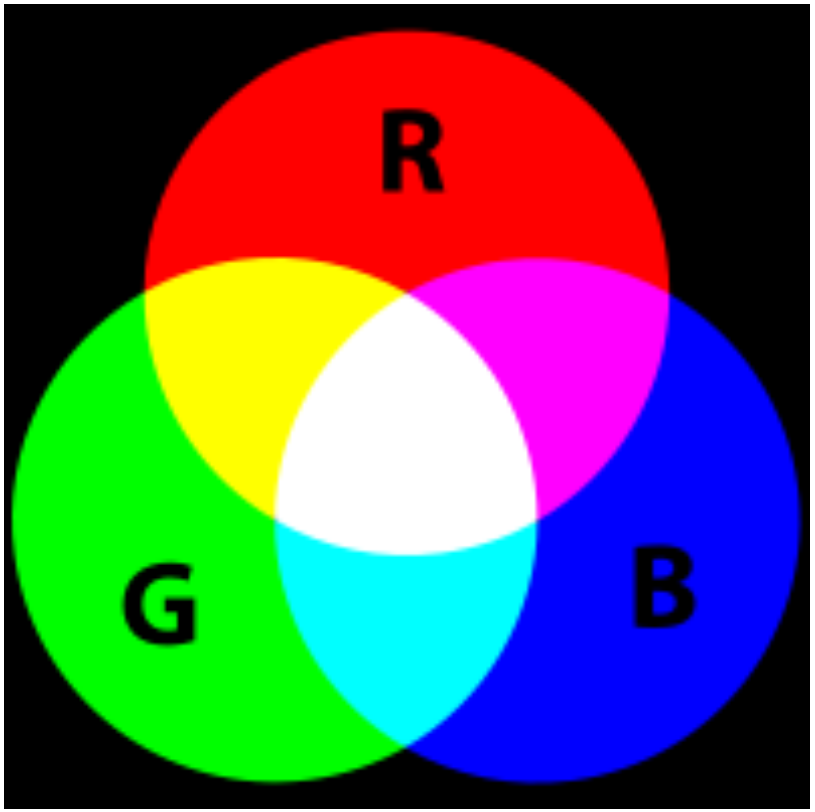
Sets of colors that can be combined to make a range of colors. Since human vision is trichromatic, for human consumption, we need only to use 3 primary colors.

The result of combining primary colors depend on whether the combination is additive or subtractive.

Additive combination

- eg. overlapping projected lights, CRT displays
- primary colors normally used are red, green, blue

Additive Colour Mixing

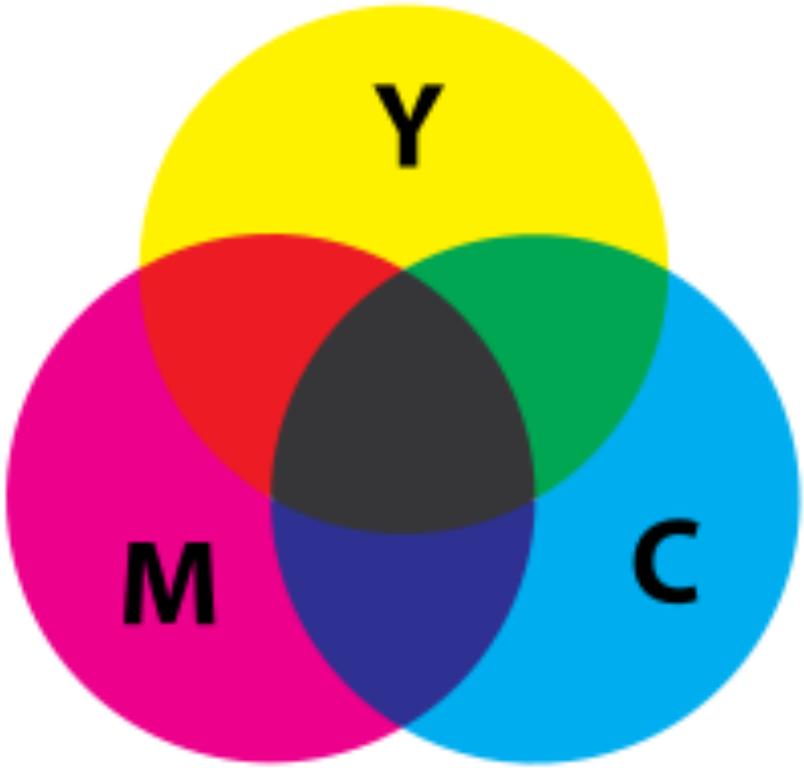


RGB:
color system used for computer monitor displays

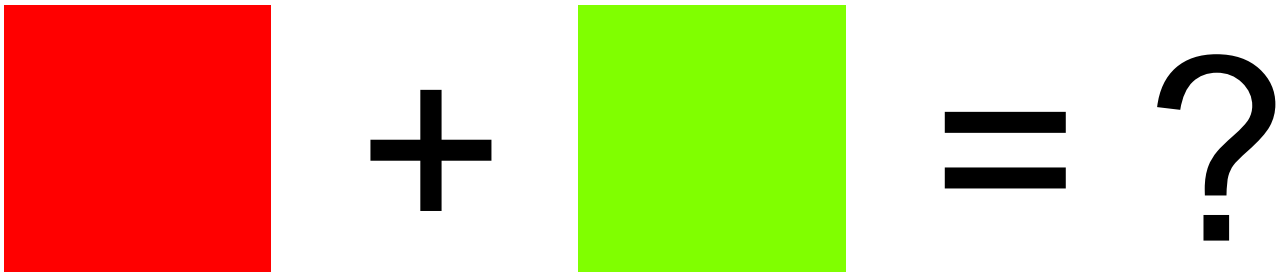
Subtracting combination

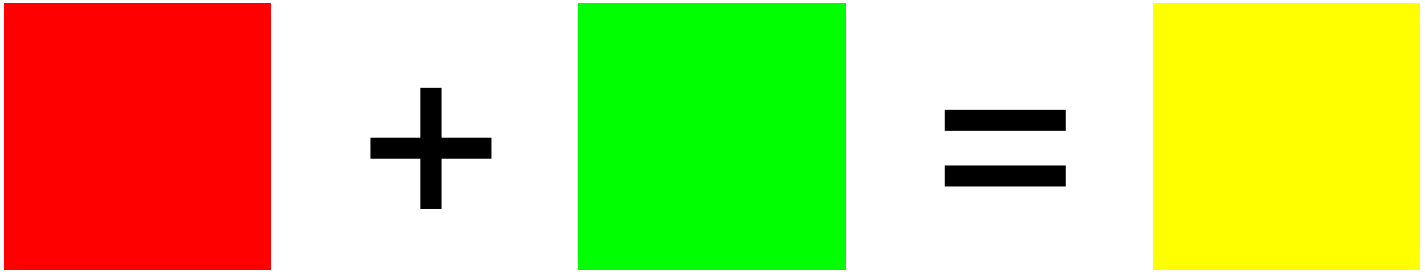
- eg. mixing of color pigments or dyes such as in printing
- primary colors normally used are cyan, magenta, and yellow.
- red, yellow, blue is popular among artists

Subtractive Colour Mixing

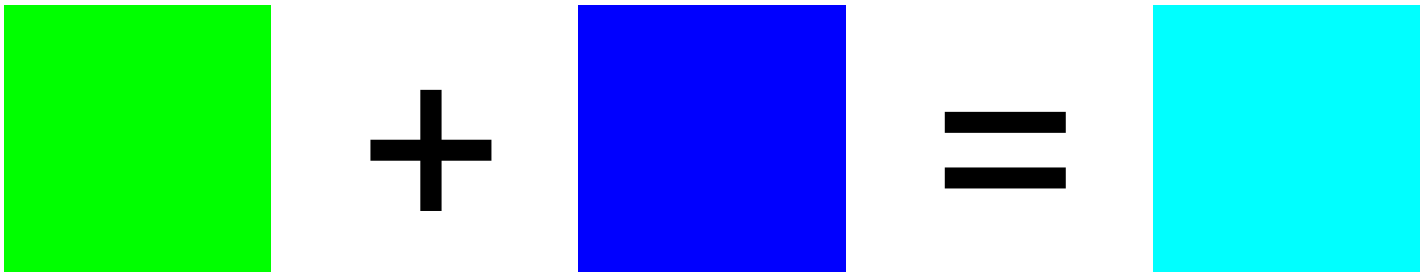


CMYK:
color system used for printing.

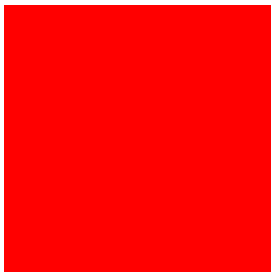




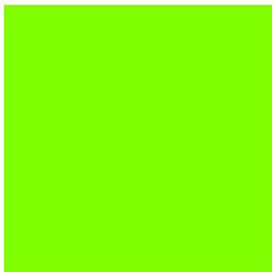
If you say “yellow,” that’s correct!



If you say “cyan,” you are very clever!



+



= ?

(255, 0, 0)

(128, 255, 0)

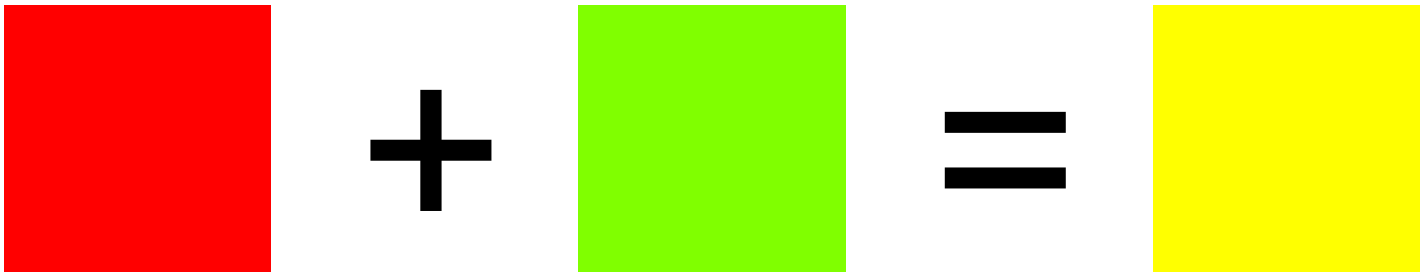
Not a valid colour!

Why?

(383, 255, 0)

out of range!

- Most software will clip to maximum value:



(255, 0, 0) (128, 255, 0) (255, 255, 0)

Colour Difference

- Consider two colours C_1 and C_2.
- How to measure difference between C_1 and C_2?
- Simplest difference measure: Euclidean distance

$$d(C_1, C_2) = \sqrt{(R_1 - R_2)^2 + (G_1 - G_2)^2 + (B_1 - B_2)^2}$$

  – Straight line distance in RGB space.

Let's do a test…

Which colour looks more similar to the middle colour, left or right?

Perceptually Uniform Colour Spaces

- RGB space is not perceptually uniform
  - Equal colour distance ≠ equal perceptual difference
  - Inappropriate if need to match human perception.
- HSV, YCbCr also not perceptually uniform.
- Perceptually (more) uniform colour spaces:
  - Munsell colour space
  - CIELAB
  - CIELUB

Colour Arithmetic

- How to add, subtract, average colours correctly?
- If not careful, can produce invalid colours.

Addition

- With unsigned 8-bit, cannot have value > 255.
- Usually clip to maximum value.
- For example,

$$R = \begin{cases} R_1 + R_2 & \text{if } R_1 + R_2 < 255 \\ 255 & \text{otherwise} \end{cases}$$

- Similarly for *G*, *B*.

image 2

image 2

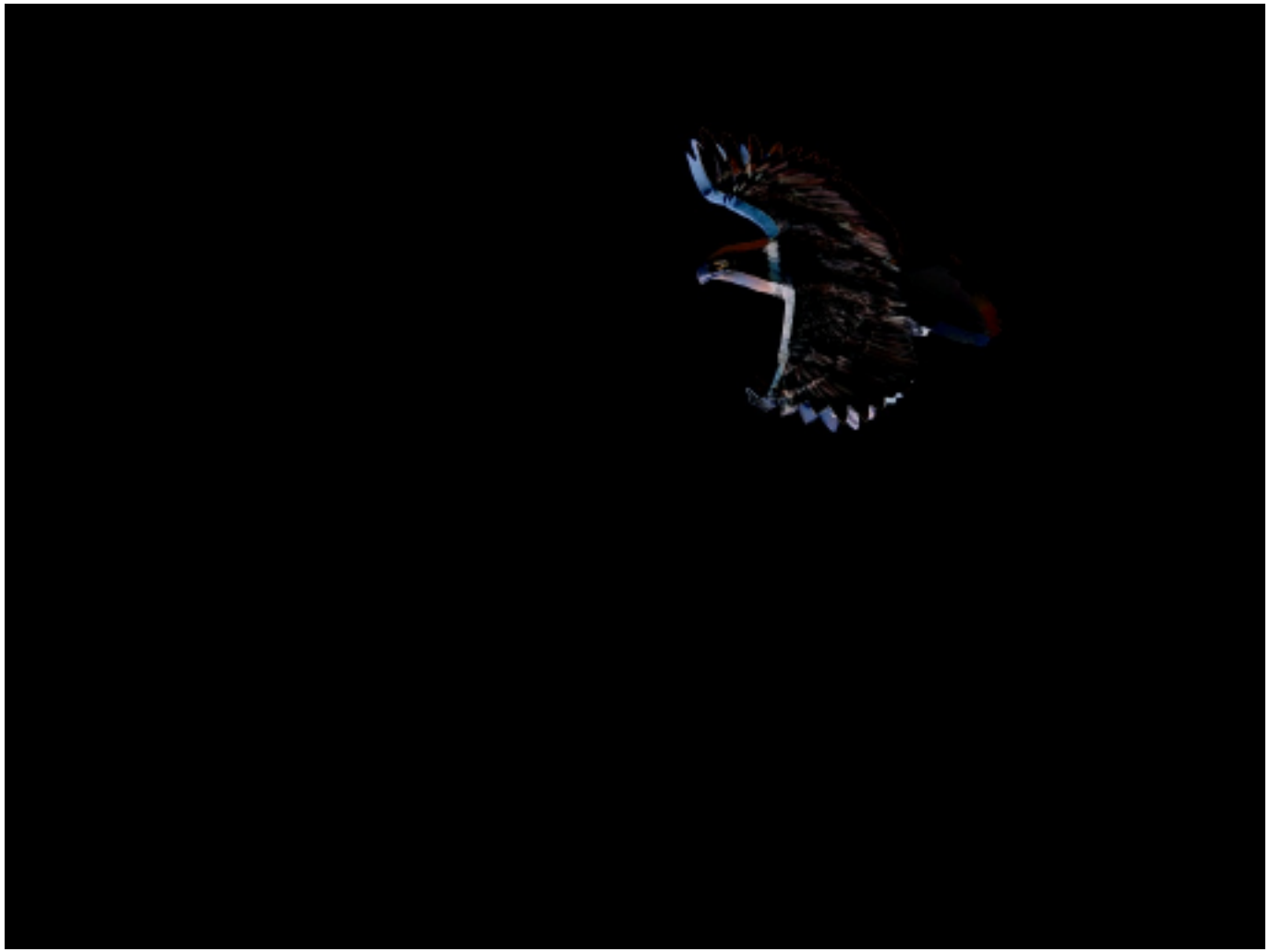
Subtraction

- With unsigned 8-bit, cannot have value < 0.
- Usually clip to minimum value.
- For example,

$$R = \begin{cases} R_1 - R_2 & \text{if } R_1 - R_2 > 0 \\ 0 & \text{otherwise} \end{cases}$$

- Similarly for *G*, *B*.

difference 2



difference

Average

- Usual way of computing mean:

sum $$S = \sum_{i=1}^{n} R_i$$

divide $$M = \frac{1}{n} S$$

- With unsigned 8-bit, S can overflow even for small n
- Clipping S produces inaccurate average.
- Need better methods.

Average

- Method 1: Floating point representation.
  - Then, S doesn't overflow unless n is very large.
  - S is not a valid colour value.
  - Mean $M = \frac{1}{n} S$ truncated to unsigned 8-bit is valid.

Average

- Method 2: Incremental average
  - With only 1 colour R_1, mean = R_1 $\quad M_1 = R_1$
  - With two colours R_1, R_2,

$$M_2 = \frac{1}{2}\left(R_1 + R_2\right) = \frac{1}{2}M_1 + \frac{1}{2}R_2$$

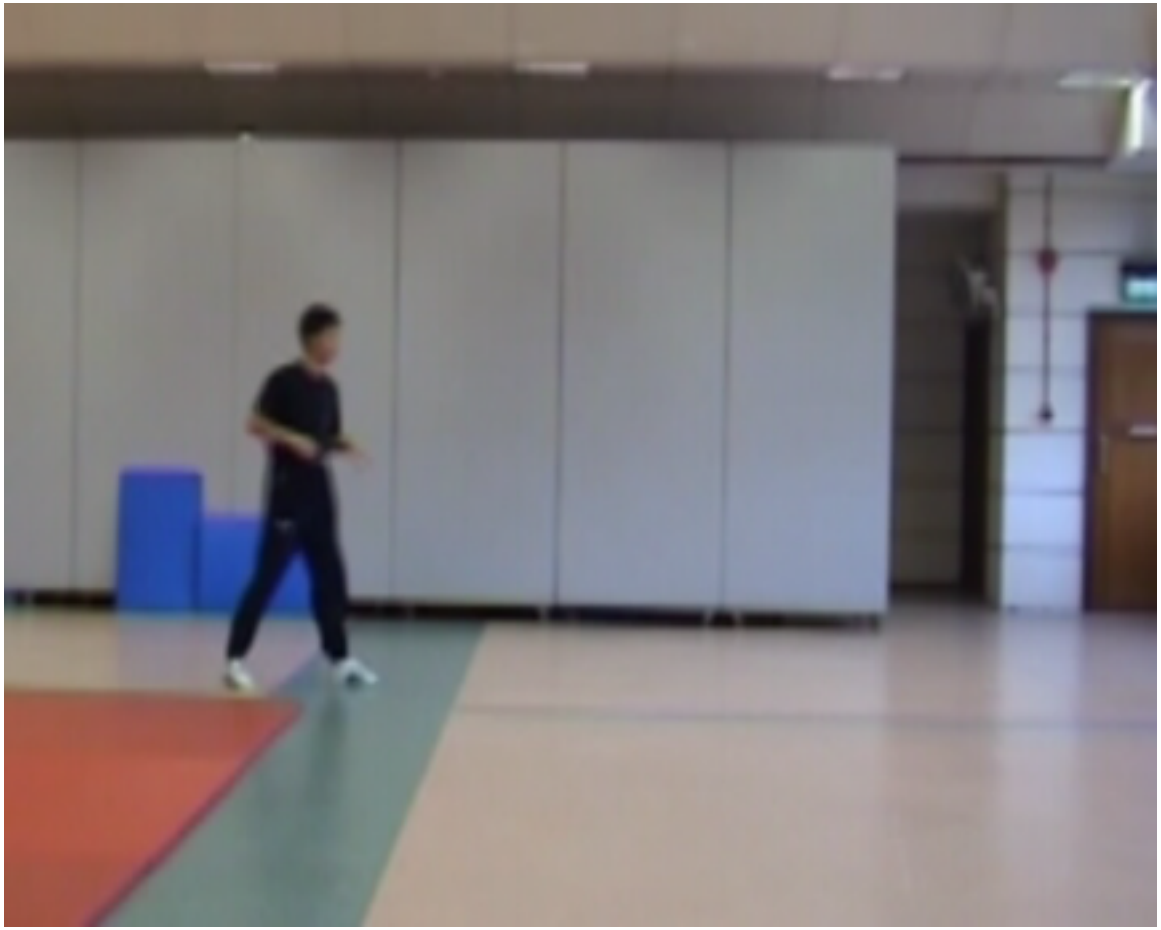
  - With k colours R_1, R_2,…, R_k,

$$M_k = \frac{1}{k}\left(R_1 + \cdots + R_k\right) = \frac{k-1}{k}M_{k-1} + \frac{1}{k}R_k$$

  - $M_k, \frac{k-1}{k}M_{k-1}, \frac{1}{k}R_k$ are all valid colours.

image 2

image 2



mean over 8-sec video

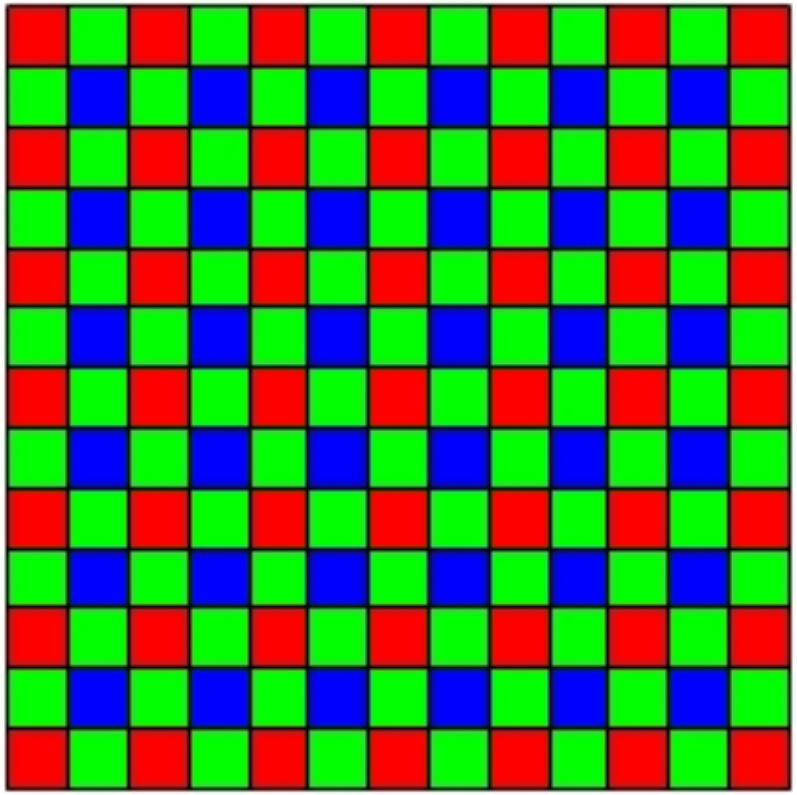
Summary

- We use 3 colour components as primary colours
- choice of primary colors depend on whether it is subtractive or additive mixing
- Some colour spaces are more perceptually uniform than others
- Be careful with colour arithmetic

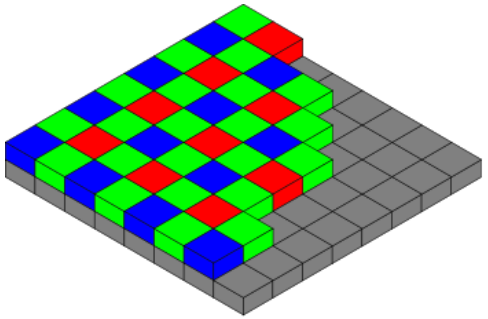
References

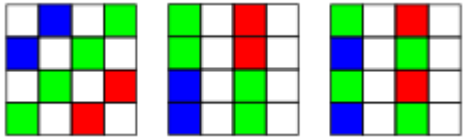
- R. S. Berns. Billmeyer and Saltzman's Principles of Color Technology. John Wiley & Sons, 3 edition, 2000.
- W. K. Leow, Color Spaces and Color-Difference Equations. Tech Report, NUS, 2002.

How does a Digital Camera Sense Color ?

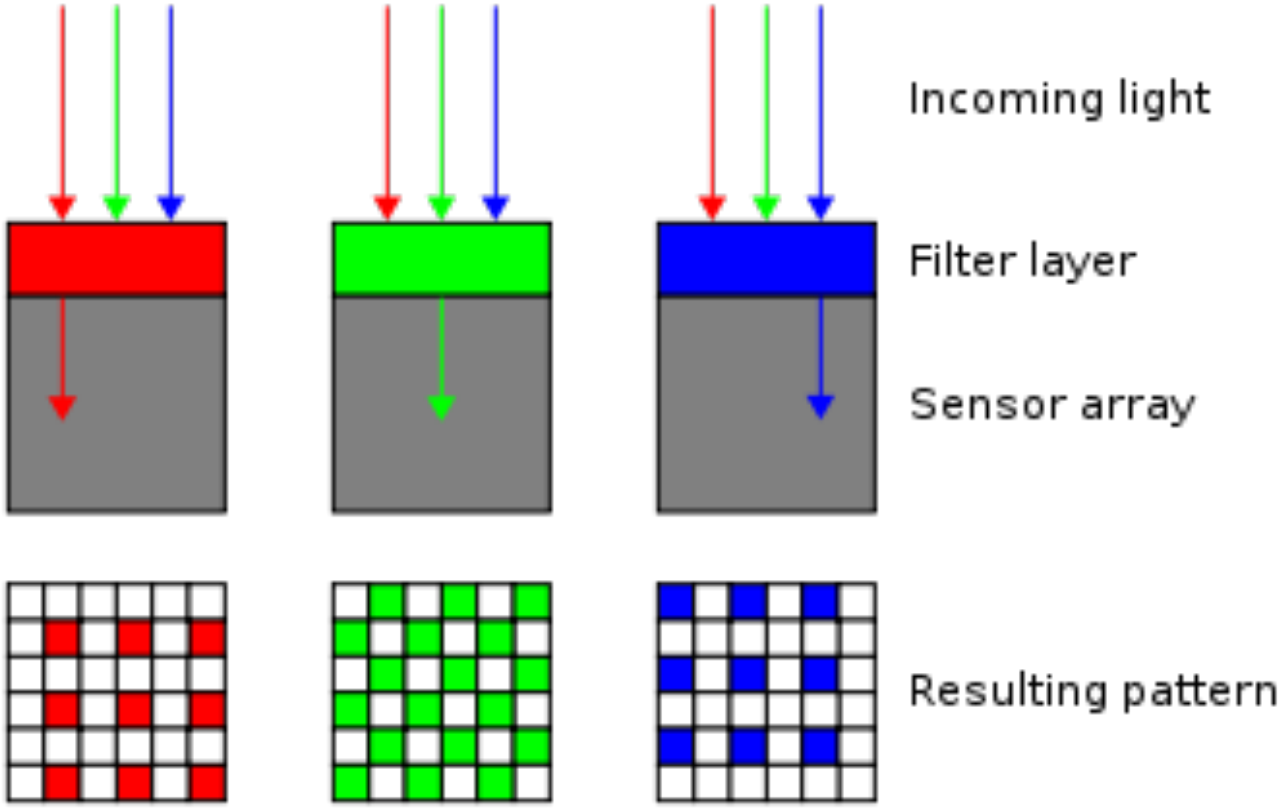


Bayer filter





picture taken from internet



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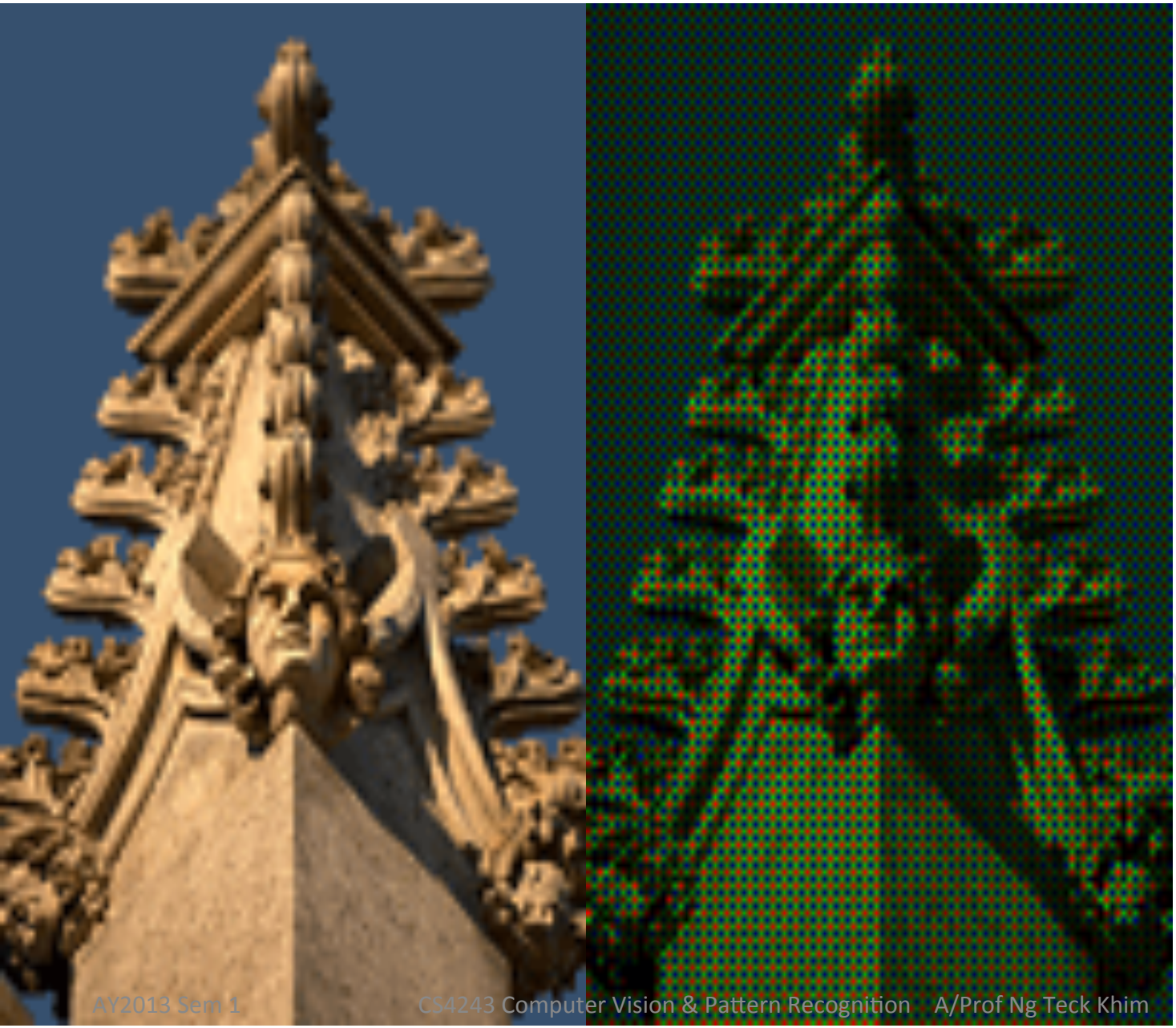

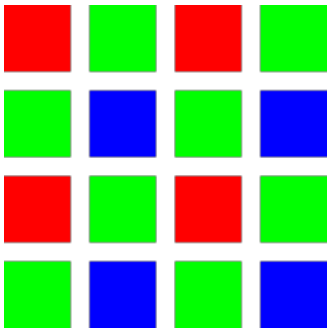

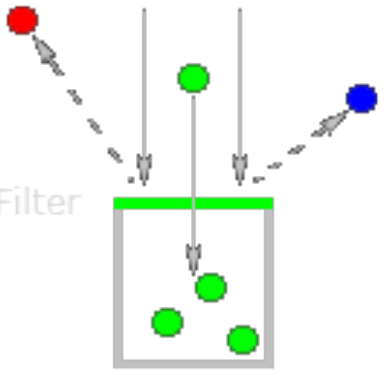

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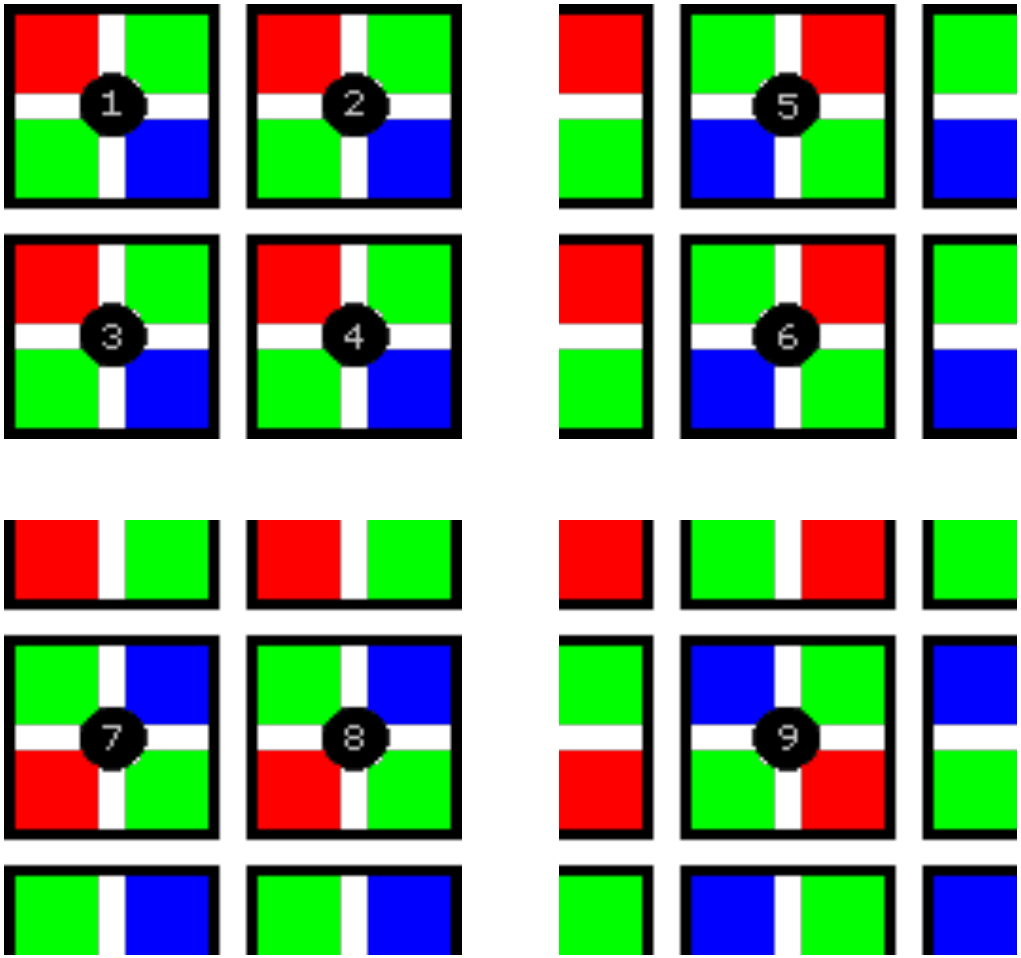

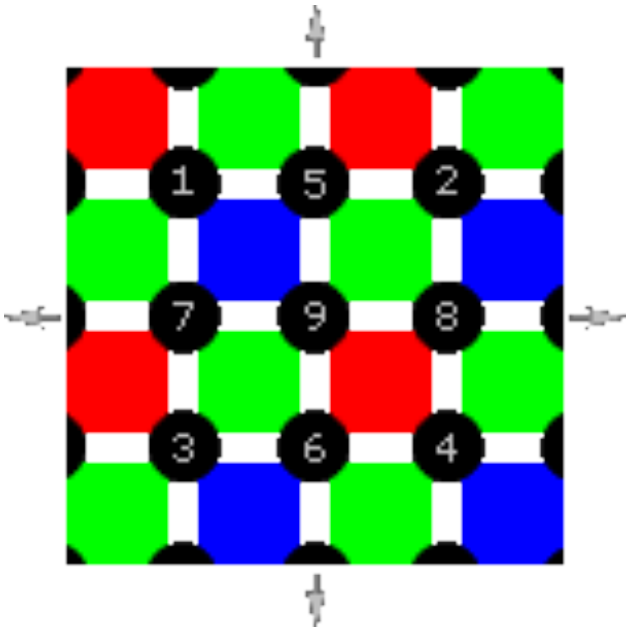

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