COMP3271 Computer Graphics

Color Spaces

2019-20

Objectives

Human Visual System

Color Representations

- Physical color spaces: RGB, CMY
- Perceptual color space: HSV

Examining Color Representation

We've generally treated colors solely as RGB triples

- with an optional alpha value
- perform almost all operations on each channel separately
- but usually treat them as identical
  - trace one transmission ray, despite wavelength dependence

But RGB is not the only representation and we'll explore other color representations

Spectral Distribution of Light

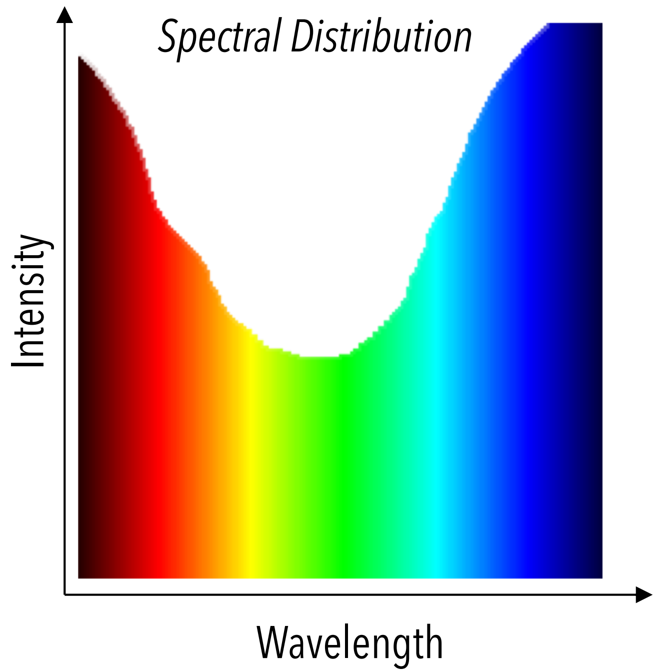
"Light" is a mixture of many wavelengths

- represented by continuous function
  $P(\lambda)$ =intensity at wavelength λ
- spectral distribution: intensity as a function of wavelength over the entire spectrum

We perceive these distributions as colors

- largely an artifact of our visual system

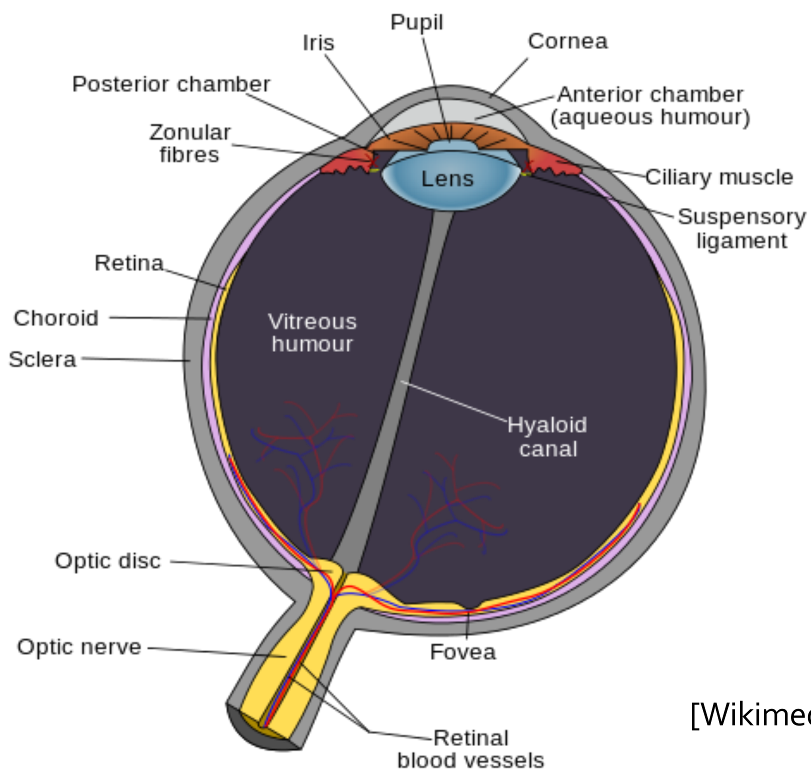
Sample Color



The Visual System

How do we see?

- Light travels through cornea, pupil, lens, retina, optical nerves, then brain
- Imaging sensors on the retina: rods & cones



[Wikimedia Commons]

Rods and Cones

Cones

- active at normal light levels
- color vision involves cone only

Rods

- sensitive at low light levels
- not sensitive to color
- responsible for our dark-adapted vision
- low influence on color perception

There is an uneven distribution of cones and rods in the retina

Cone Response

Three kinds of cones: S, L, and M

- S cones respond to blue
- M cones respond to green
- L cones respond to red
- much less sensitive to blue

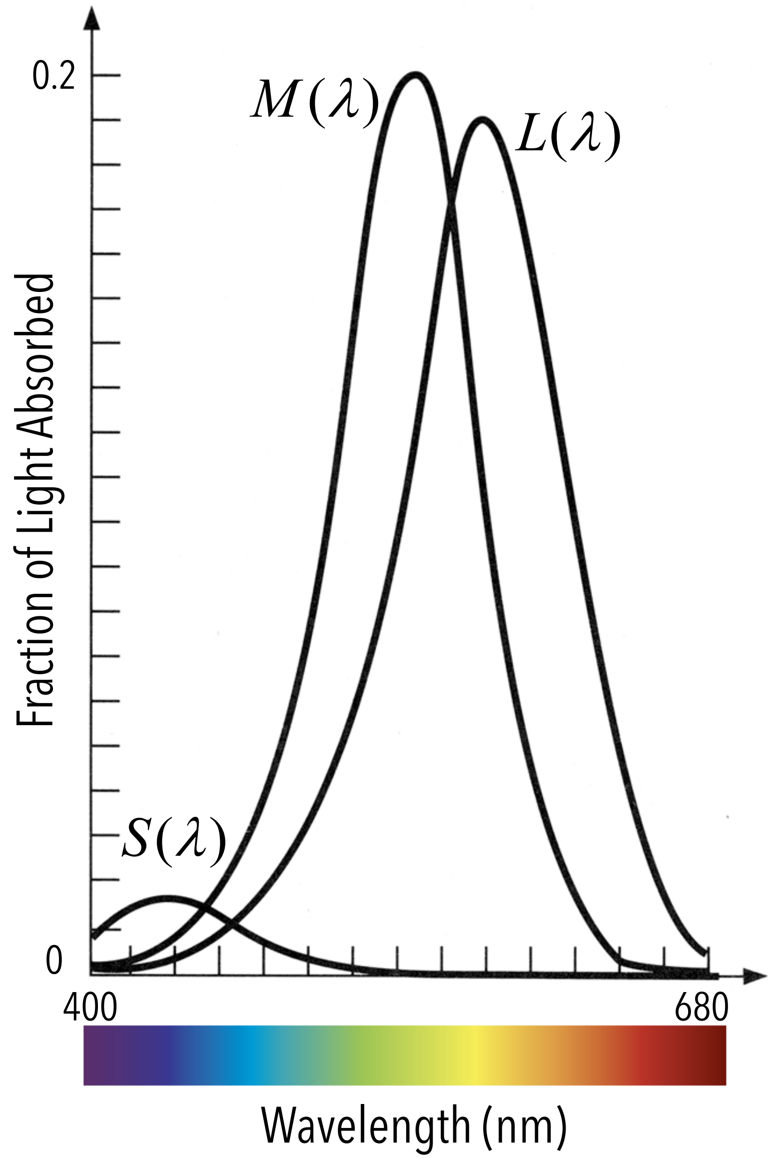
Response levels to illumination are

$$s = \int S(\lambda)P(\lambda)d\lambda$$

$$m = \int M(\lambda)P(\lambda)d\lambda$$

$$l = \int L(\lambda)P(\lambda)d\lambda$$

This implies that we humans perceive light as a 3D space only because we have 3 cone types



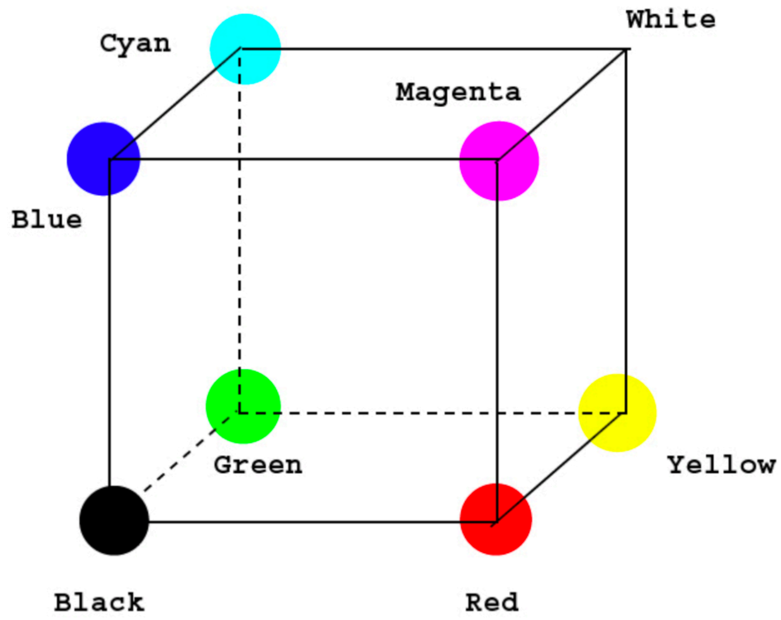
The RGB Color Space

We've represented colors as combinations of three primaries

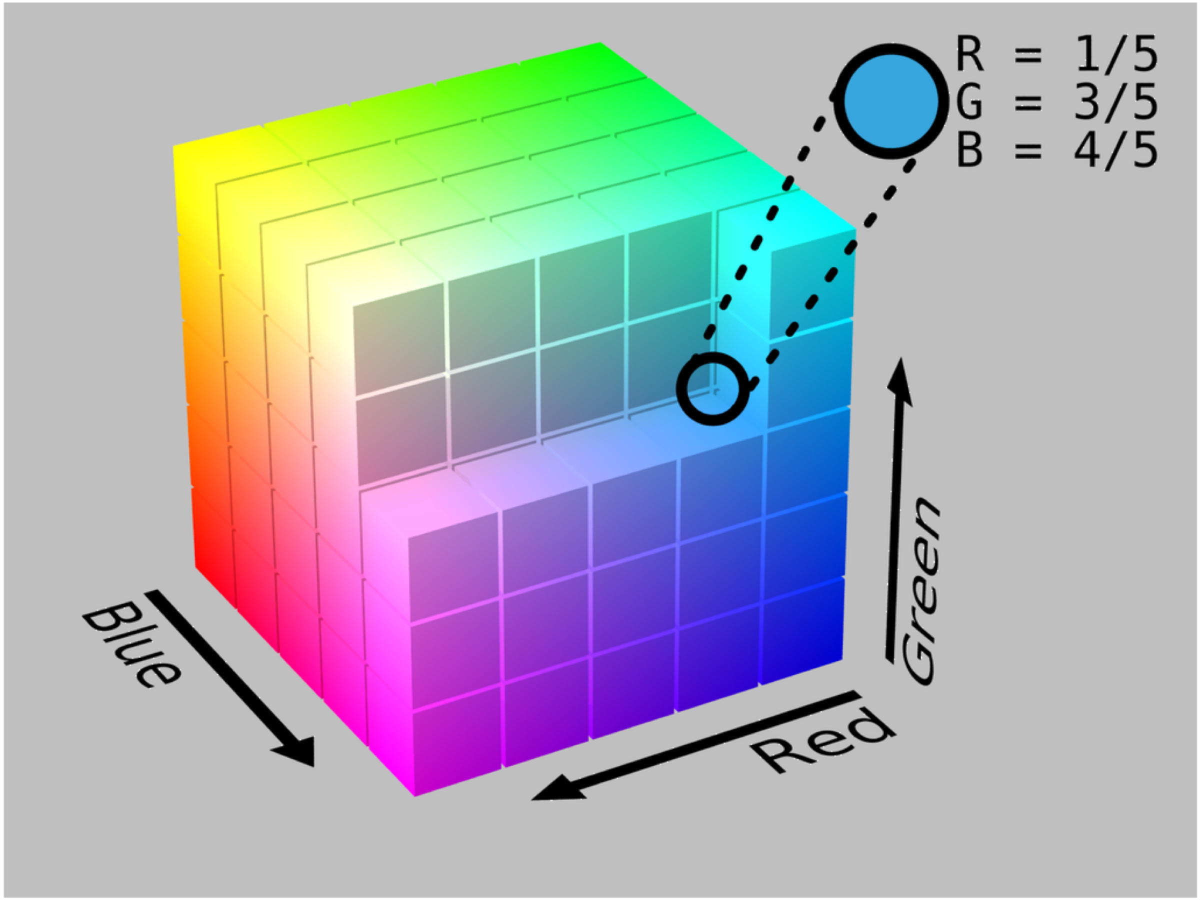
- established 3 special colors (red, green, blue)
- compose all colors by weighted combinations of these

$$C = rR + gG + bB, \text{ where } (r, g, b) \in [0,1]^3$$

- and why did we pick red, green, and blue?
  - essentially because of the structure of our visual system
  - roughly correspond to peaks of cone response curves



The RGB Color Space



Not intuitive to describe a color

Looking Towards Other Color Spaces

Our choice of RGB color space is fairly arbitrary

- it's loosely based on our perceptual system

We could in principle select any 3 primaries we like

- and continue to represent colors as weighted combinations

We can also construct other 3-D color spaces

- where the dimensions are no longer primary colors
- but have some other physical meaning

As we'll see, RGB color space is not always the best choice

- different color spaces lend themselves to different tasks

Other Primary Colors

Red, Green, Blue

- liquid crystal, CRT displays

Red, Yellow, Blue

- paint

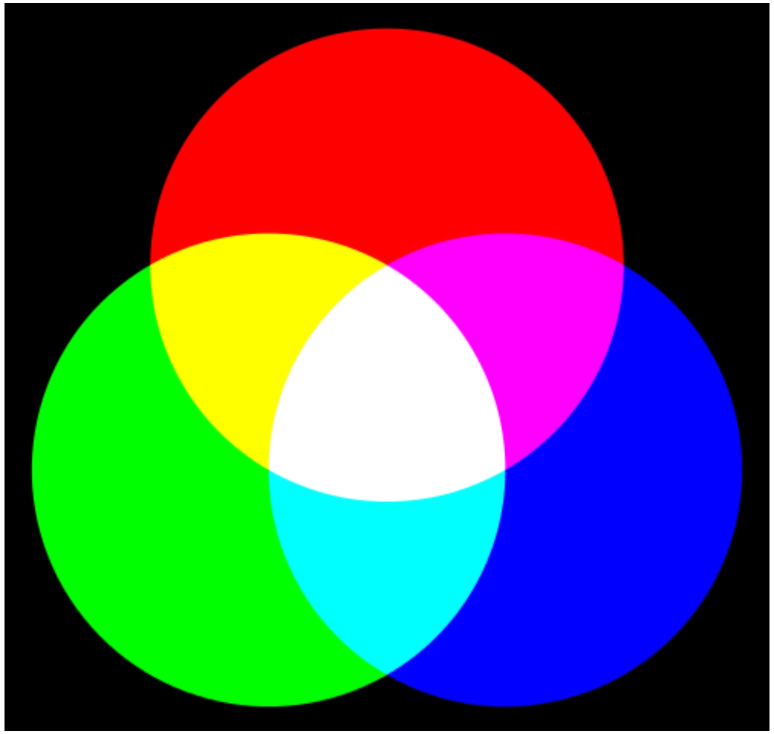
Cyan, Magenta, Yellow

- color printing

Orange, Green, Violet

- color photography

Physical Color Spaces



Additive, RGB

For media that emits light

Subtractive, CMY

For media that reflects light

The CMY Color Space

The other most common set of primaries besides RGB

- cyan, magenta, and yellow — complements of red, green, blue

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

These are the so-called subtractive primaries

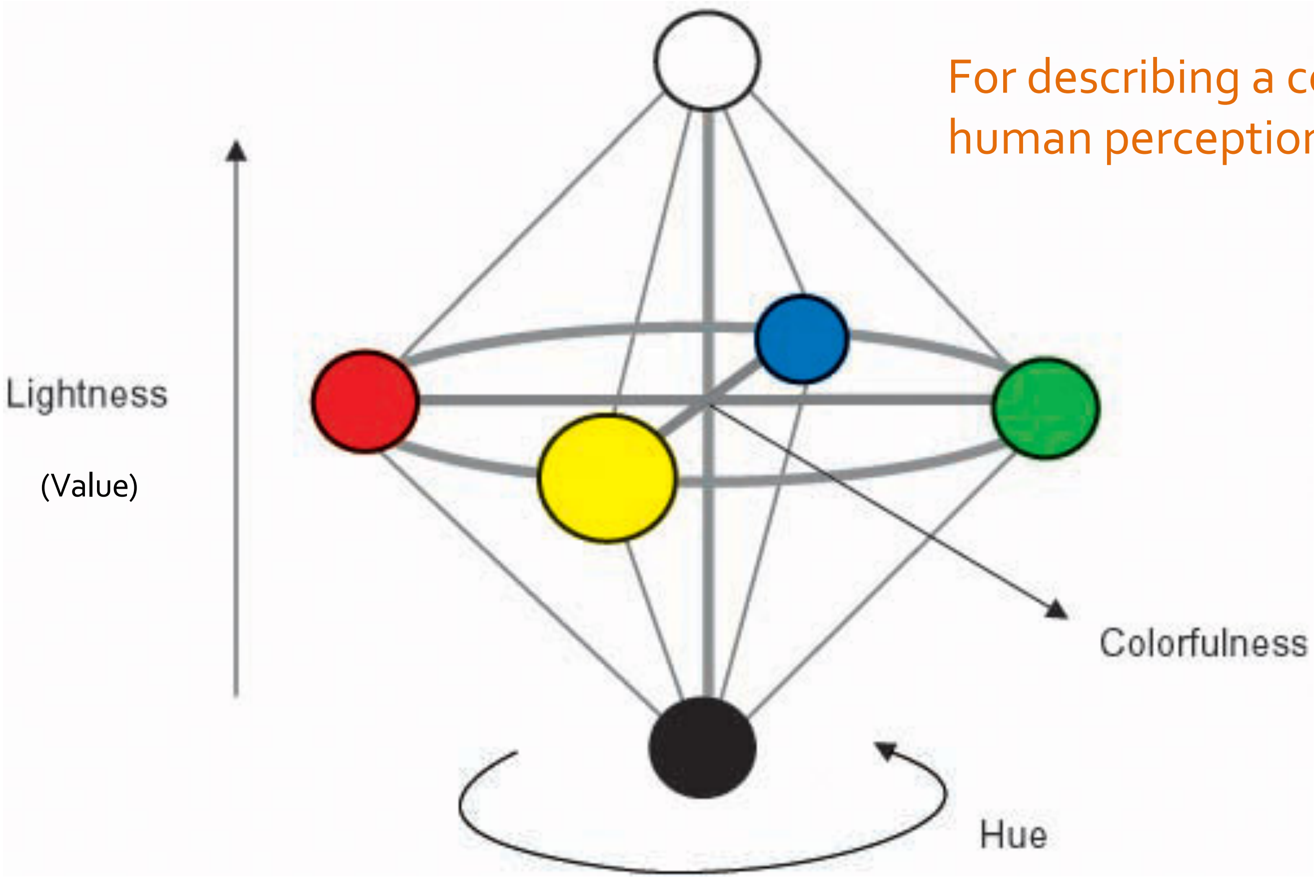
- RGB are additive primaries — start with black, add up to white
  - appropriate when dealing with emitted light
- CMY — start with white and subtract colors from white
  - appropriate when dealing with inks/pigments
  - each ink absorbs some part of the spectrum (subtracts light)

A Color Puzzle

A piece of paper appears green in yellow light, cyan in cyan light, and black in red light.

What color does it appear to have in magenta light?

Perceptual Color Spaces

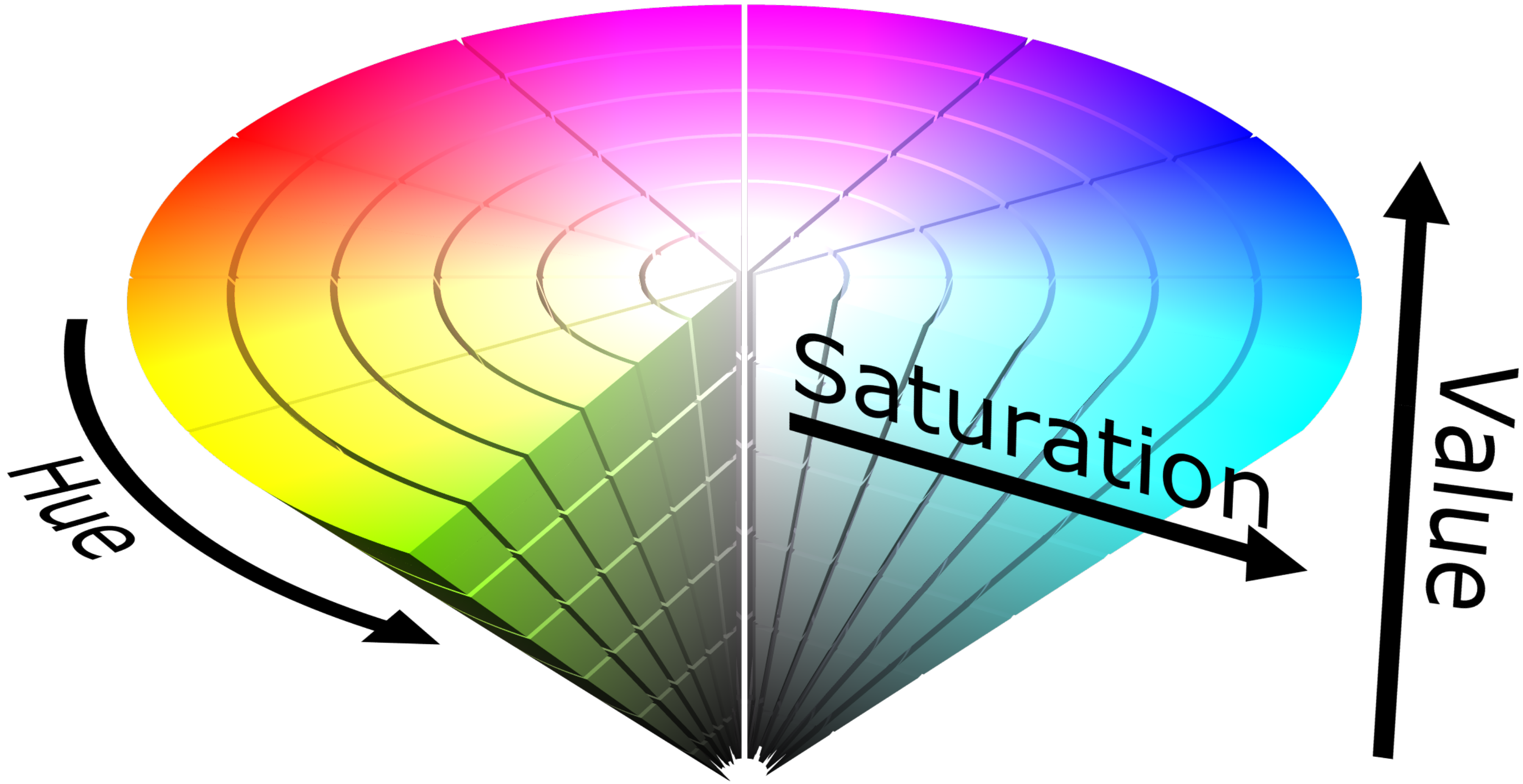


For describing a color based on human perception

[Stone]

How human perceive a color:
hue, **lightness** and **colorfulness (color saturation)**

The HSV Color Space



HSV is Common in User Interfaces