Color Theory

- What is color?
- How do we perceive it?
- How do we describe and match colors?
- Color spaces

What is color?

- Interaction of light and eye-brain system
- Light: electromagnetic phenomenon
  - Discerned by different wavelength

Color Spectra

Pure colors - single wavelength

Sample lights:
How do we perceive them?
Human Visual System

Rods
- black & white receptors
- peripheral vision
- sensitive

Cones
- 3 type tuned to different frequencies
- 3 cones have different sensitivities
- central vision
- less sensitive

Tristimulus Theory of Color

Important principle:
Any color spectra is perceived by sensors with 3 different response frequencies!

Tristimulus theory of color:
Color is inherently a three-dimensional space

Metamers:
If two colors produce the same tristimulus values, then they are visually indistinguishable

Spectral Response of Human Visual System

Color Spectra

Sample lights:
How to describe them numerically?
**Color Spectra**

Important principle:

Any color spectra is perceived as:
- a single dominant wavelength - its hue
- mixed with a certain amount of white light (saturation)
- of a certain intensity or brightness

**Dominant Wavelength**

- Stating the numbers
  - Dominant wavelength (hue)
  - Luminance (total power)
  - Saturation (purity)

**Luminance and Saturation**

- Luminance \( (L) = (D-A)B + AW \)
- Saturation = \( (D-A)B/L \times 100\% \)
  - White light: \( D = A \), i.e., Sat. = 0

**RGB color description**

- Use three primary color \((r,g,b)\)
  - \( C(L) = r(L)R + g(L)G + b(L)B \)

negative!!
RGB Primary Colors

- RGB Color Space

CMY Color Model

- C: Cyan; M: Magenta; Y: Yellow
- Subtractive primaries - Cyan, Magenta, and Yellow are the compliment of Red, Green Blue
- Specified by what is being removed from white
- Example: Cyan color = (1,0,0) means red is removed; CMY: (1,1,0) -> red and green is removed => what color?
- Sometimes CMYK - K: Black

CMY <-> RGB

\[
\begin{align*}
C & = 1 - R \\
M & = 1 - G \\
Y & = 1 - B
\end{align*}
\]
CIE Primary “Colors”

- \((X,Y,Z)\) - Not real colors
- The combination coefficients are positive
- Perceptual space

\[
C(\cdot) = x(\cdot)X + y(\cdot)Y + z(\cdot)Z
\]

CIE Chromaticity Chart

- Project to xy plane

CIE Gamut

- The range of colors that can be produced on a device
Color Spaces

- CIE model is a good color reference
- Not necessarily the most natural one
- Many other color spaces are used
  - RGB
  - HLS
  - CMY
  - HSV
  - YIQ
  - ...

HLS Color Space

HLS Color Space (2)