

Wireless Communication Systems

@CS.NCTU

Lecture 4: Color

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Chap. 4 of “Fundamentals of Multimedia”

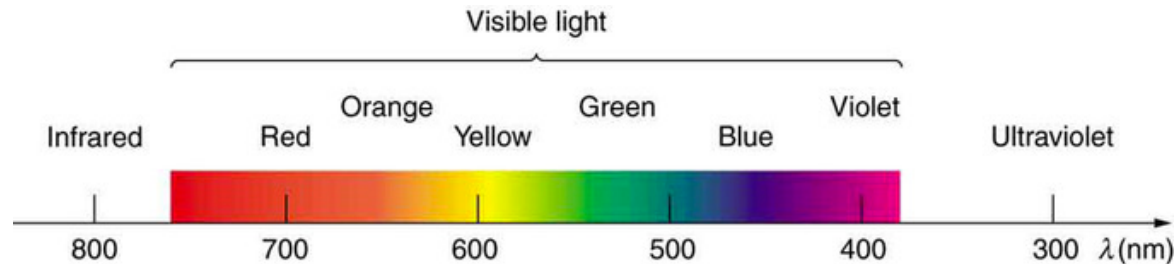
Some reference from <http://media.ee.ntu.edu.tw/courses/dvt/15F/>

Outline

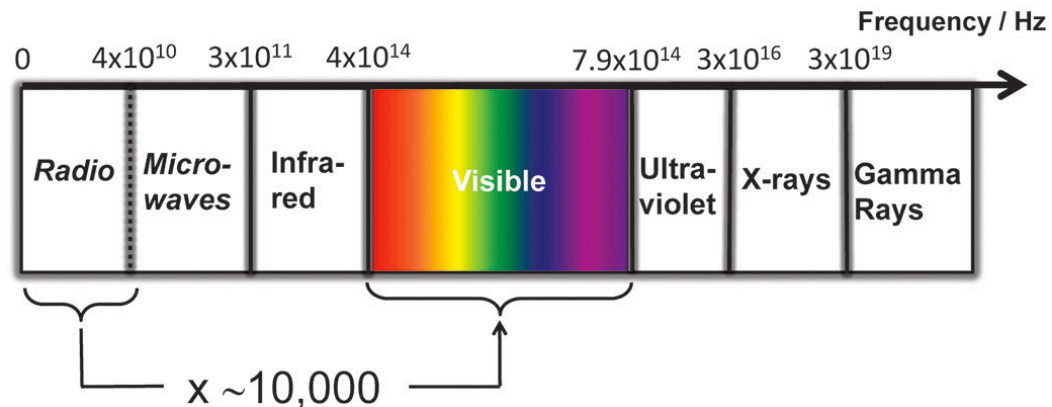
- **Human Vision**
- Color model
- Attributes

Colors

- Light is an electromagnetic wave
- Color is the wavelength of the light wave
- Human visible light
 - wavelength 370 – 780 nm

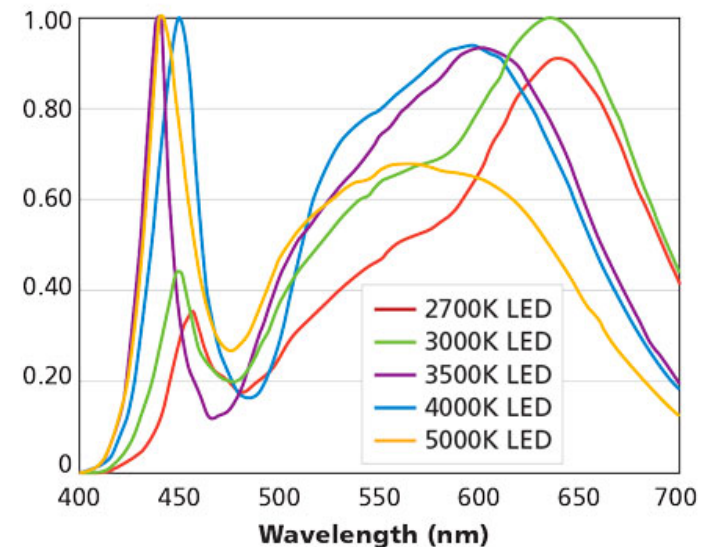
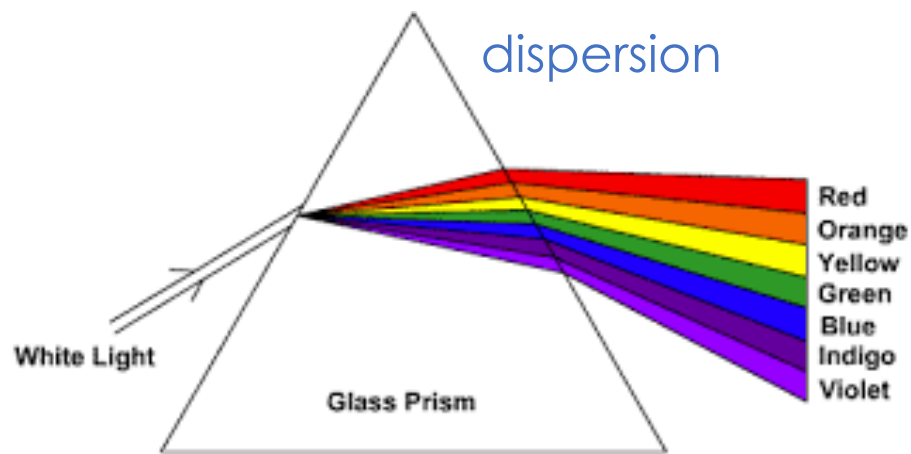


- Frequency spectrum



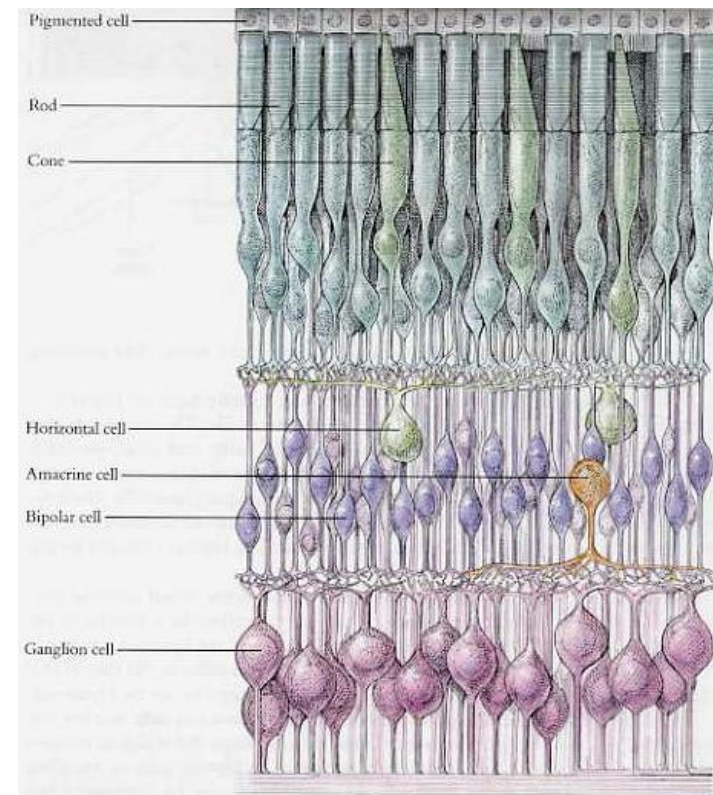
Colors

- Laser light consists of a single wavelength
 - Pure color
- Most light sources are a combination of wavelength
 - Spectral analysis via [spectrophotometer](#) shows the contribution of each wavelength



Human Vision

- Human eye likes a camera
 - Lens focusing an image onto the *retina*
- Retina consists of
 - An array of rods
 - Three kinds of cones, sensitive to R, G, B, respectively
 - ~6 million cones, proportion of R, G, and B cones is 40:20:1
- Eye is most sensitive to light in the middle of the visible spectrum

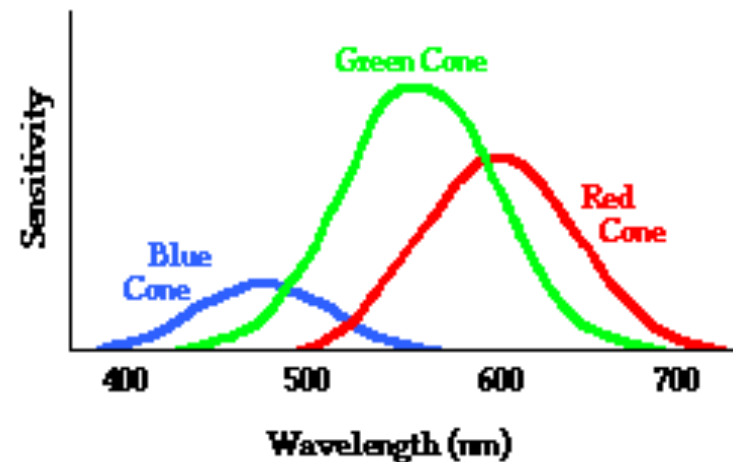
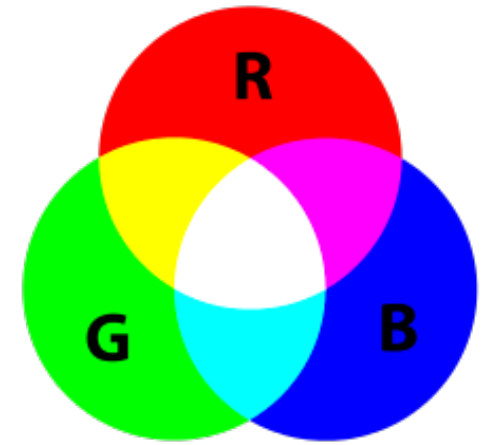


Outline

- Human Vision
- **Color model**
- Attributes

RGB Color model

- Additive color model
 - $Y=R+G$, $M=B+R$, $C=B+G$
- Create a wide range of color by combining the three primary colors
 - Primary colors: cannot be generated from each other
- Human eyes are most sensitive to RGB
 - The retina consists of sensing cells known as rods and cones.
 - More sensitive to green
 - Less sensitive to blue



RGB Color Model

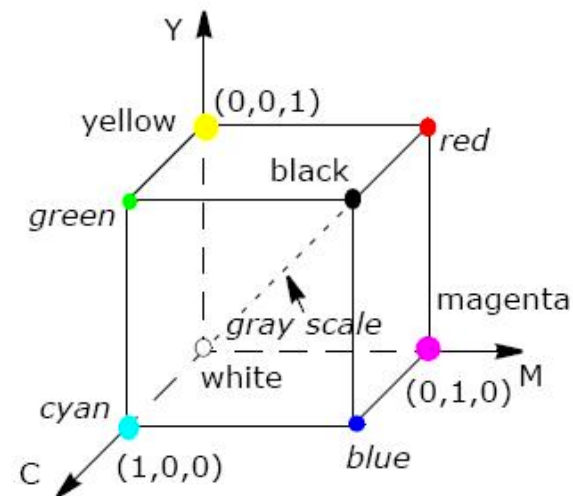
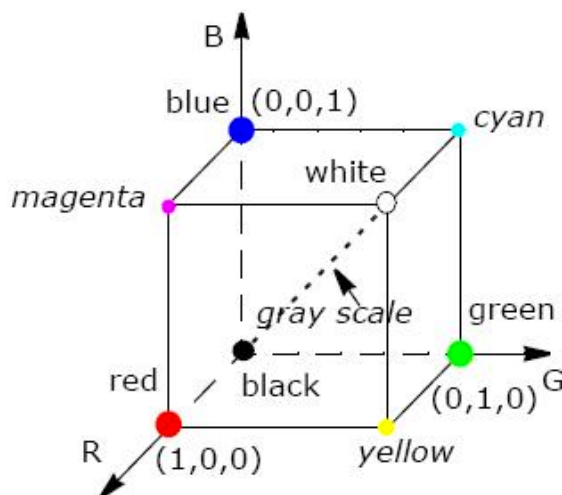
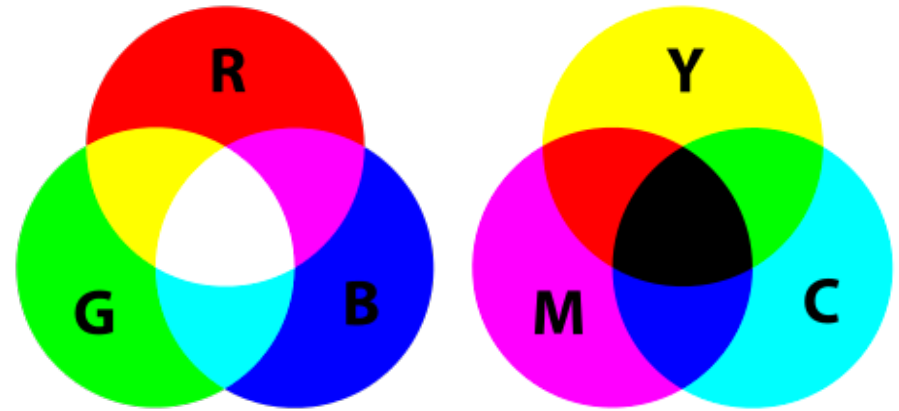
- Usually 8 bits per color channel
- How to increase brightness (intensity)?
 - Increase each component with the same ratio
 - RGB(50,100,200) RGB(25,50,100)



- Grayscale values on the cube's diagonal from (0,0,0) to (1,1,1)
 - Same value for RGB(L, L, L), $0 \leq L \leq 1$
- RGB to grayscale conversion
 - $(R, G, B) \rightarrow (L, L, L)$ $L = 0.30 R + 0.59 G + 0.11 B$
 - Because human eyes are more sensitive to green

CMY Color Model

- CMY (Cyan, Magenta, Yellow) are complements of R,G,B
 - $C=1-R$, $M=1-G$, $Y=1-B$
- Subtractive color model
 - The origin of the cube is white
- CMYK is used in color printers
 - K: black
 - Lay down transparent layers of ink onto a white paper

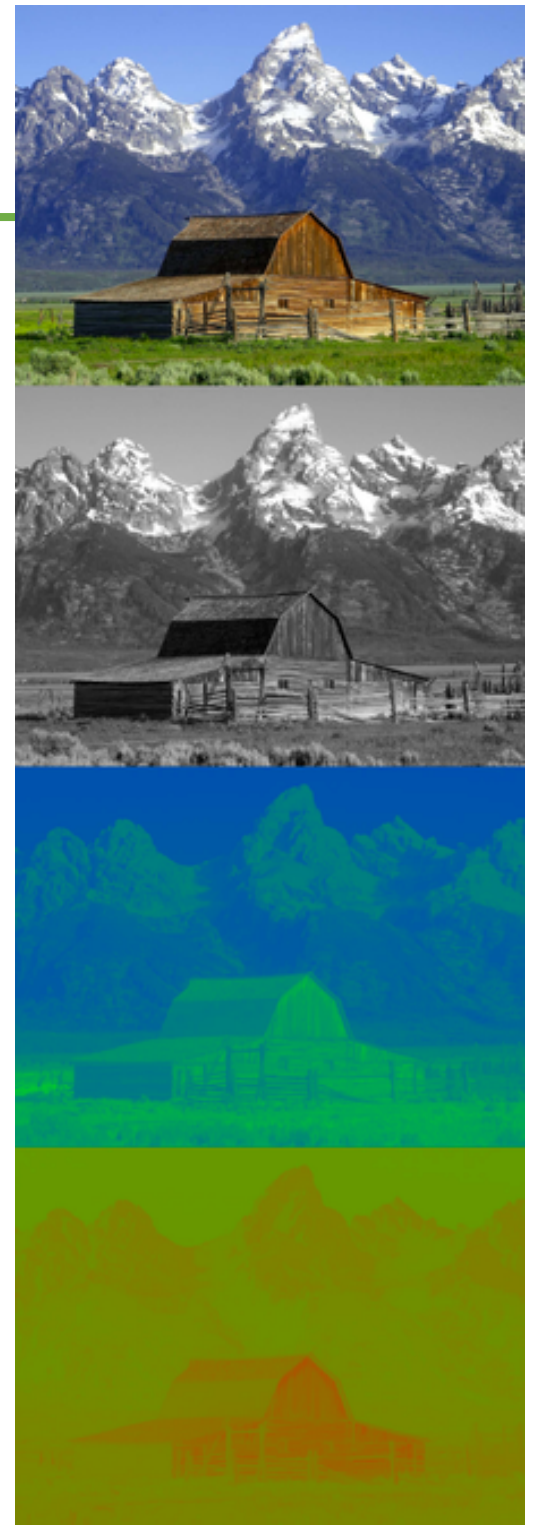


YUV Color Model

- Historically, the terms YUV were used for *analog encoding* in television systems
- YUV used for TV in Europe (PAL)
- Also known as **Luminance** and **Chrominance**
Color Models
 - Put all luminance information in one value (Y)
 - All color (chrominance) information in other two (UV)
 - Human eyes are more sensitive to Y than UV

Y'UV Color Model

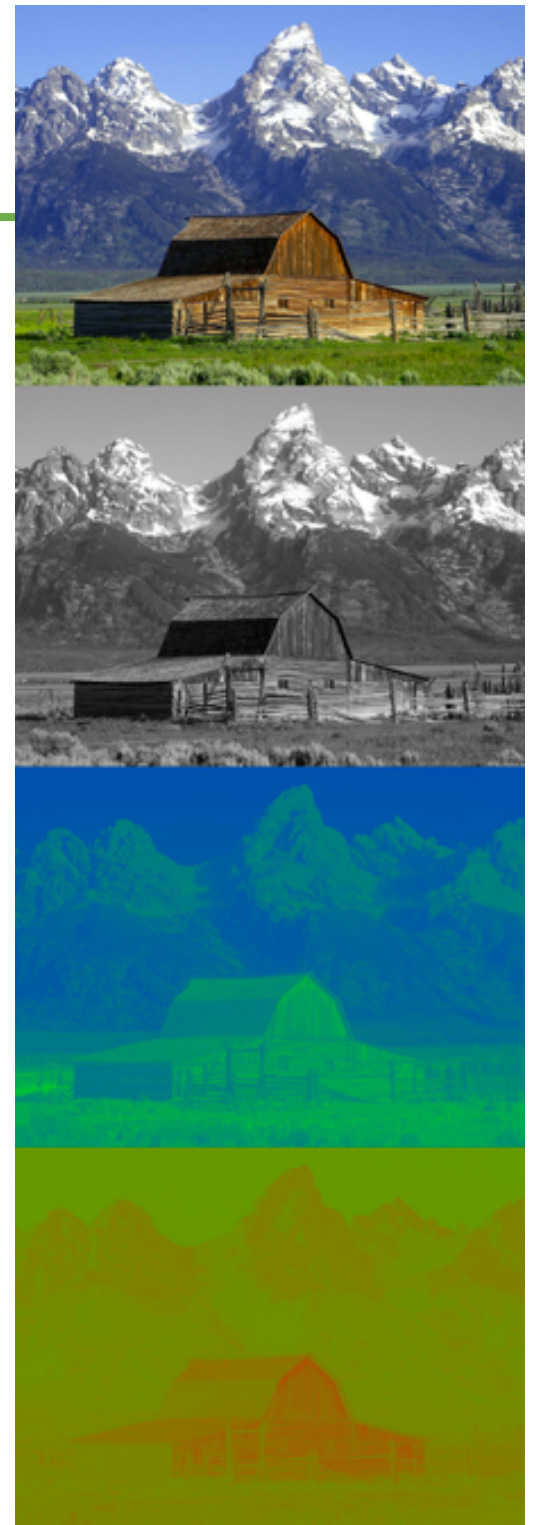
- Y': **luma** (electronic brightness)
 - <https://en.wikipedia.org/wiki/YUV>
 - Grey value of an image
 - An image becomes gray level if U and V are set to zero
- UV: **chrominance**
 - Difference between a color and a reference white are the same luminance
 - $U = B' - Y'$
 - $V = R' - Y'$
 - B', R' are B and R after gamma correction



Y'UV Color Model

- Y'UV and RGB conversion

$$\begin{bmatrix} Y' \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.58060 \\ 1 & 2.03211 & 0 \end{bmatrix} \begin{bmatrix} Y' \\ U \\ V \end{bmatrix}$$



YIQ Color Model

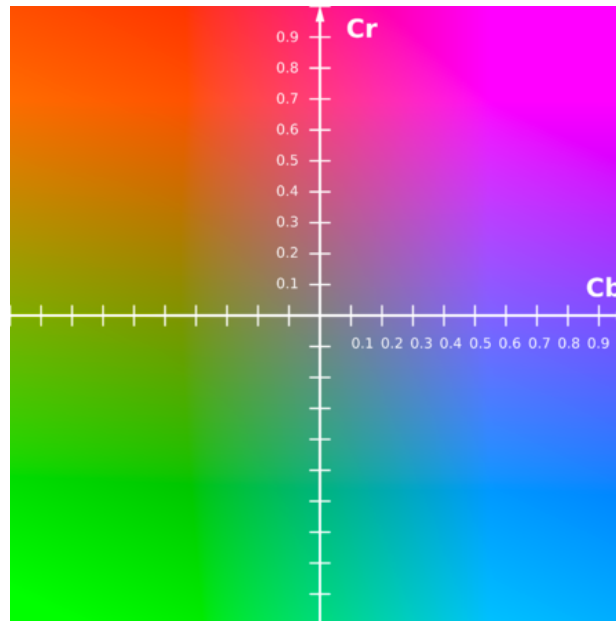
- Actually Y'IQ model
- YIQ used for TV in North America and Japan
 - I: In-phase chrominance
 - Q: quadrature chrominance
- A version of YUV, with the same Y' but with U and V rotated by 33°

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0.956 & 0.621 \\ 1 & -0.272 & -0.647 \\ 1 & -1.106 & 1.703 \end{bmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix} \quad \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \implies \begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

YCbCr

- Used in **digital** image/video (JPEG and MPEG)
- When refer to signals in video or digital form, the term YUV mostly means YCbCr
- Cb and Cr are just U and V, but with scaling and shift such that the values are between 0 and 255
- The CbCr plane at constant luma $Y'=0.5$



Outline

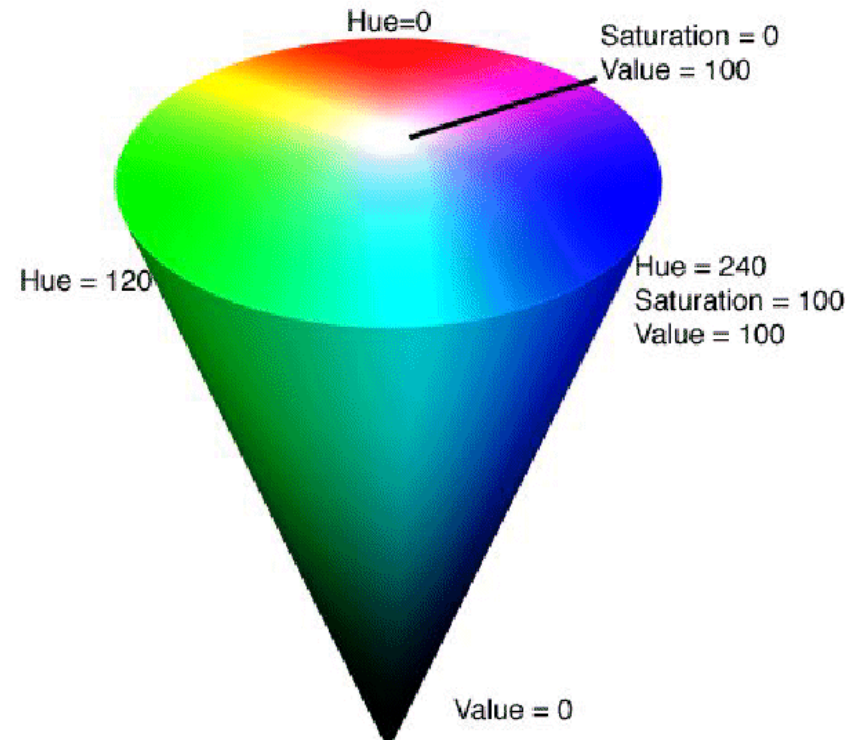
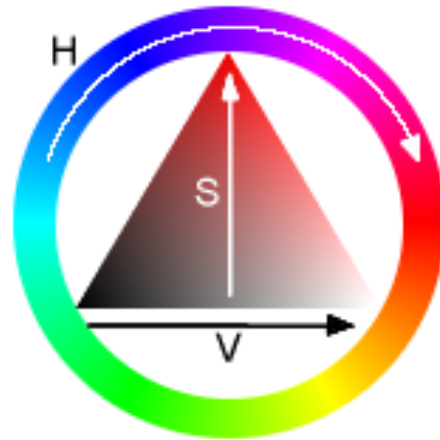
- Human Vision
- Color model
- **Attributes**

Color Appearance

- Five perceptual attributes
 - **Brightness:** the attribute according to which an area appears to more or less intense
 - **Lightness:** the brightness of an area relative to a similarly illuminated area that appears to be white
 - **Colorfulness (Chromaticness):** the attribute according to which an area appears to be more or less chromatic
 - **Chroma:** the colorfulness of an area relative to a similarly illuminated area that appears to be white
 - **Hue:** the attribute of a color denoted by its name such as blue, green, yellow, orange, etc
- Increasing the illumination increases the brightness and colorfulness of a stimulus, while the lightness and chroma remain approximately constant

Color Representation

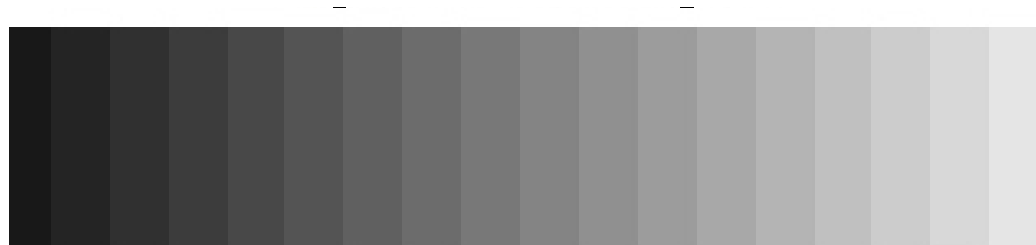
- There are three main perceptual attributes of colors: *brightness (V)*, *hue(H)*, and *saturation(S)*.



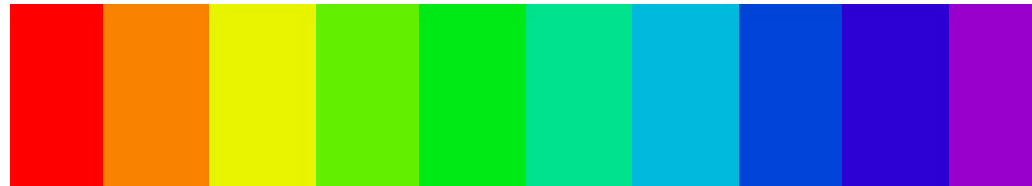
The HSV Cone

- Brightness is the perceived lumin
- Hue is an attribute we commonly describe as blue, red, green, etc
- Saturation is our impression how different the color is from achromatic (white or gray) color

Color Attributes



different brightness levels (dark to bright)



different hues (red to violet)



saturation (the dark blue at the left side is highly saturated whereas the faded blue at the right side has low saturation)

Summary

- Different methods for representing colors
 - Additive (three primary colors: R, G, B)
 - Used in digital cameras, monitors, TVs
 - Subtractive (three primary colors: C, M, Y Plus K)
 - Good for printers
 - Luminance & Chrominance: YIQ, YUV, YCbCr
 - Luminance component (Y) and two chrominance components
 - YIQ & YUV used in B&W and color TV (same signal)
 - YCbCr used in JPEG and MPEG compressions