Network & Media Laboratory

Fundamentals of Multimedia

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3. Color in Image and Video

Content

Network & Media Laboratory

1. Color Science

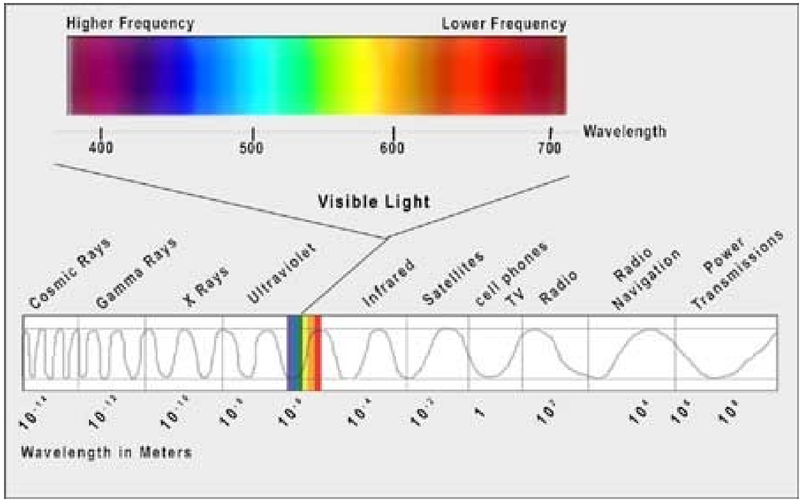
Light and Spectra； Gamma Correction

L*a*B*(CIELAB) Color Model

CMY(CMYK)； HSV； Other Color Models

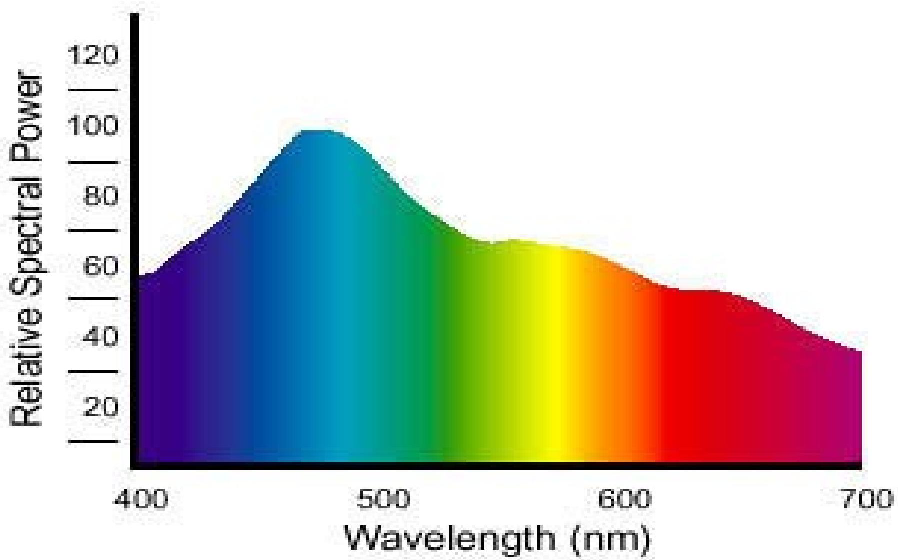
1.1 Light and Spectra

- Light is an electromagnetic wave, its color characterized by the wavelength
  - Laser Light -- a single wavelength
  - Most light sources -- Contributions over many wavelengths
  - Short wave – Blue, Long wave -- Red
  - Visible light in the range: 400-700nm (Nanometer, 10^{-9} M)



1.1 Light and Spectra

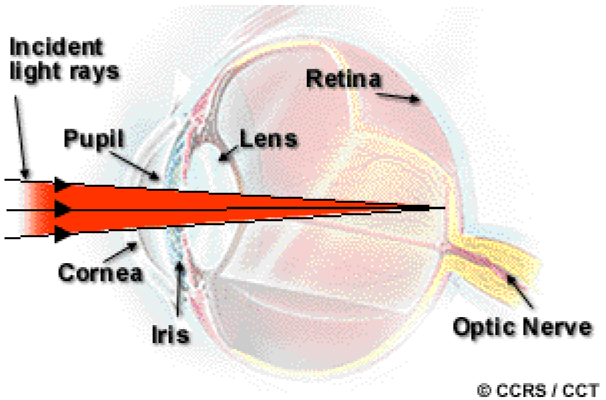
- Spectral Power Distribution (SPD)
  - The relative power in each wavelength interval

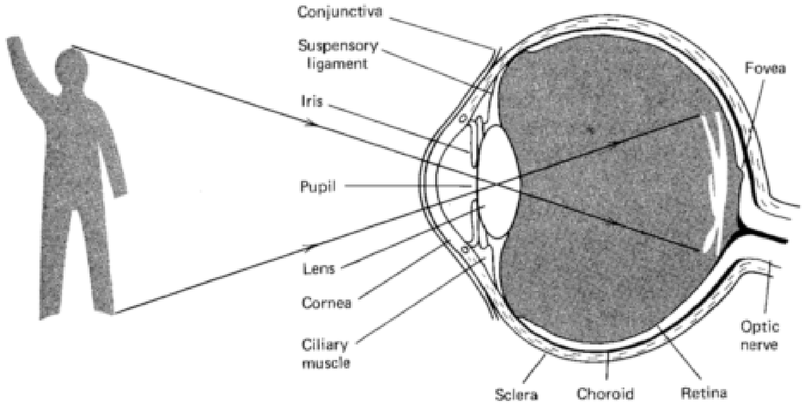


Spectral Power Distribution of Daylight

1.1 Light and Spectra

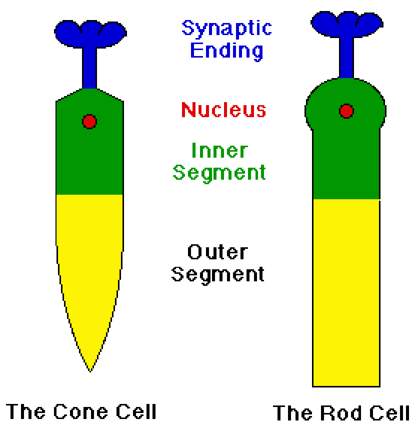
- Human Vision
  - Works like a camera
  - Lens focusing an image onto the retina

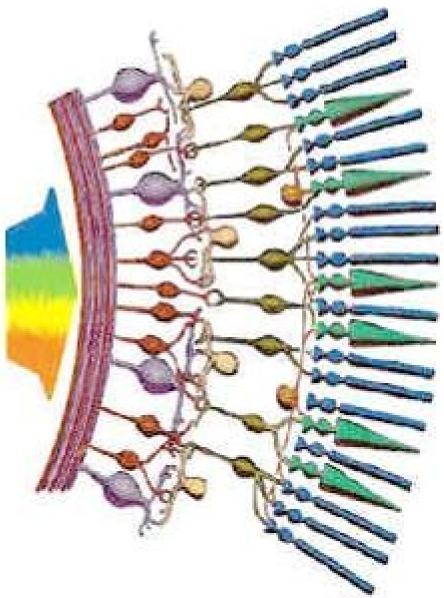




1.1 Light and Spectra

- Human Vision (Conti.)
  - The retina – Rods and Cones

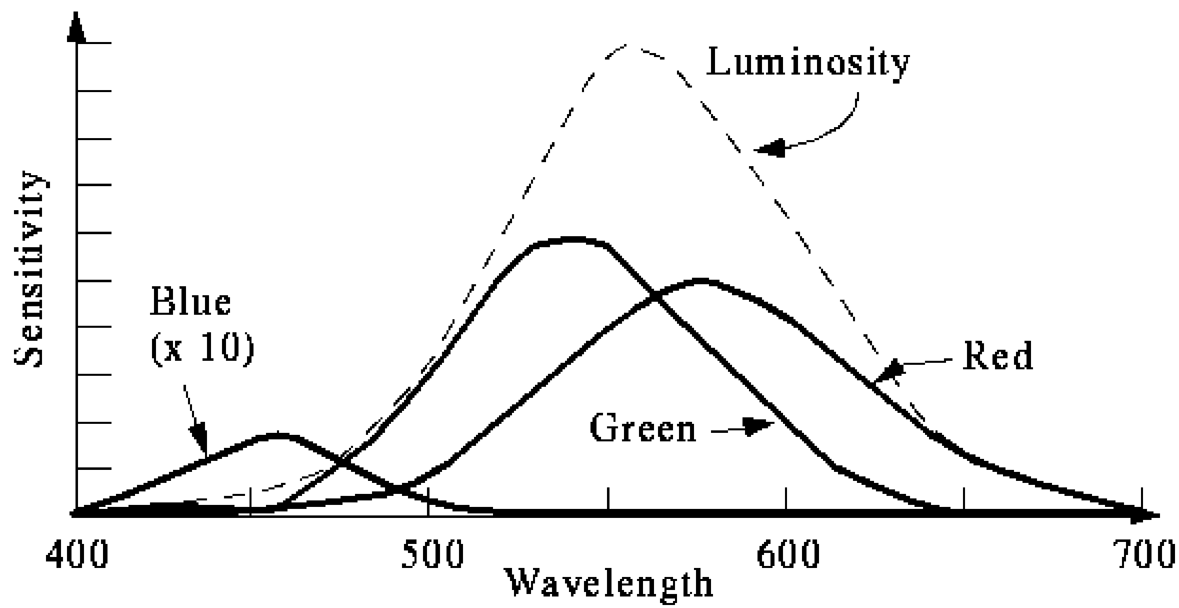




Rods and Cones

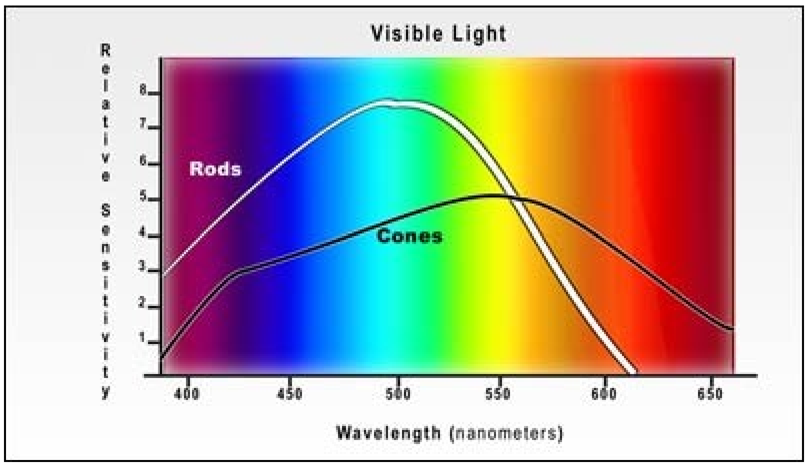
1.1 Light and Spectra

- **Spectral Sensitivity of the Eye**
  - Most Sensitive to the middle of the visible spectrum
  - Luminous-efficiency function showing the overall sensitivity

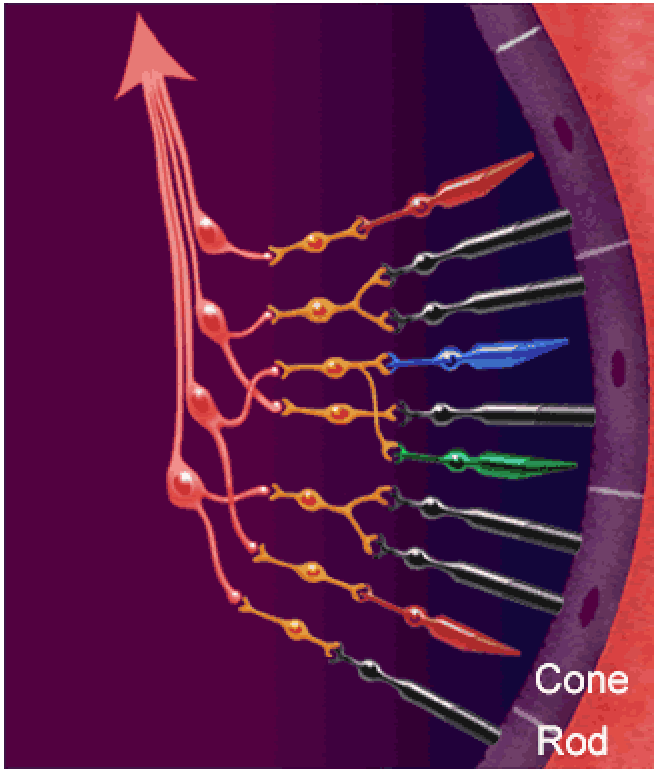


1.1 Light and Spectra

- Spectral Sensitivity of the Eye (Conti.)
  - Rods – broad range wavelengths, perception of Black-White
  - About 6 million cones – color R:G:B=40:20:1



Spectral Sensitivity of Rods and Cones



Response in the eye to the falling light

1.2 Gamma Correction

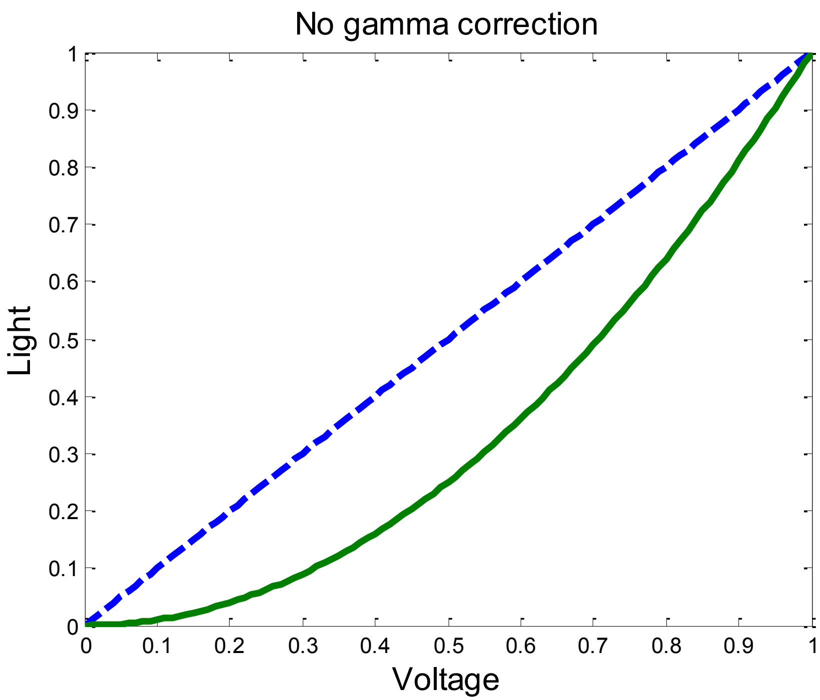
- Image Display
  - Convert RGB number back to analog (voltage), driving the electron gun in CRT (Cathode Ray Tube)
  - !! Light linearly related to the voltage
- CRT's light not linear to the driving voltage
  - Proportional to the voltage raised to a power

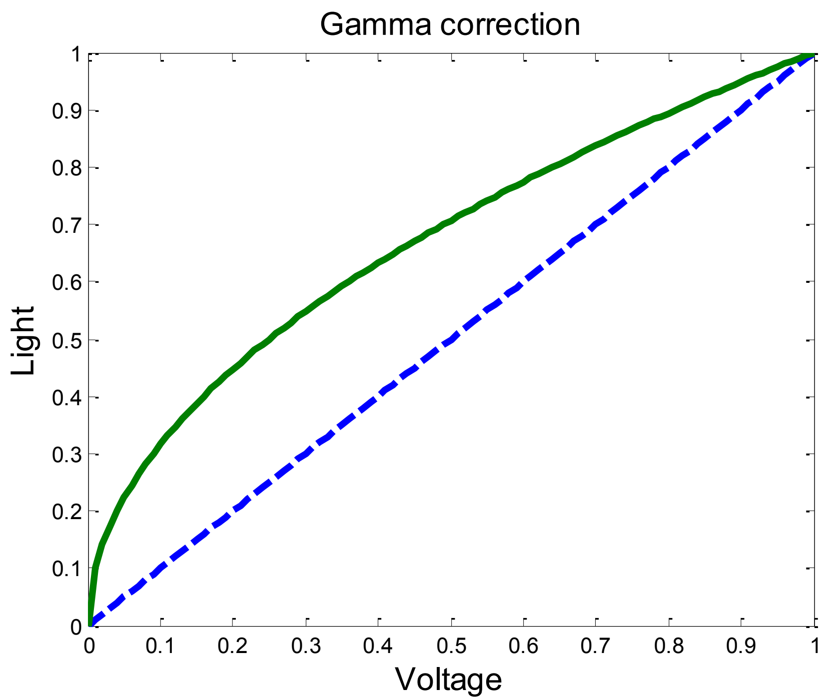
    $$R \rightarrow R' = R^{1/\gamma} => (R')^{\gamma} \rightarrow R$$

  - The power called "gamma", with the symbol γ
- Signal "Gamma Corrected" before transmission,
  - Obtaining "linear signal"

1.2 Gamma Correction

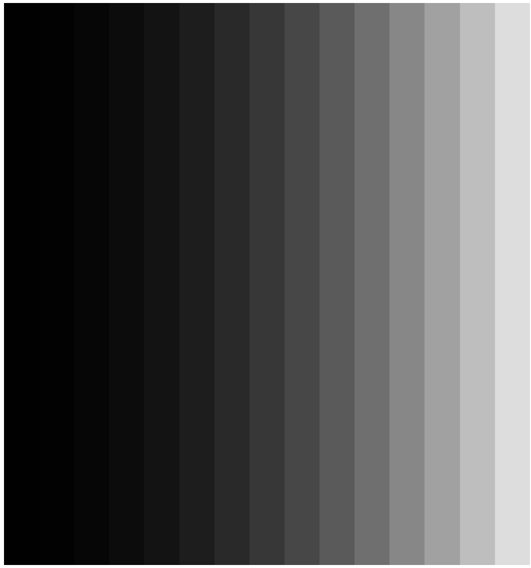
- Voltage normalized to maximum 1



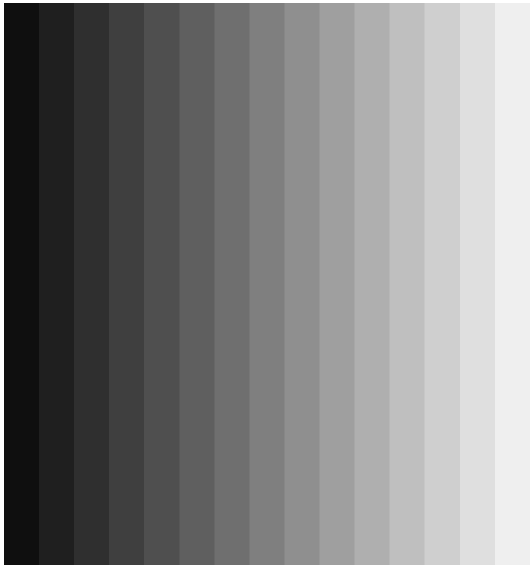


1.2 Gamma Correction

- Gamma Correction Effect
  - Example – Display of ramp from 0 to 255

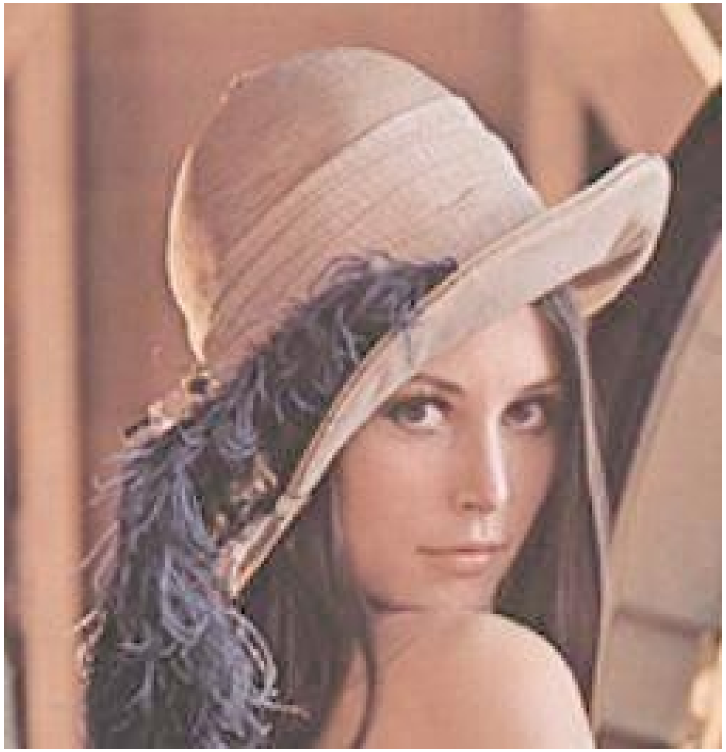


With no gamma Correction



Applying gamma correction

1.2 Gamma Correction



Original image

After gamma correction

1.2 Gamma Correction

- Camera transfer function: One practical method
  - R→R'＝a×$R^{1/\gamma}$＋b, with special care at the origin

$$V_{out} = \begin{cases} 4.5 \times V_{in} & \text{Vin} < 0.018 \\ 1.099 \times (Vin - 0.099) & \text{Vin} >= 0.018 \end{cases}$$

  - Recommended by SMPTE（The Society of Motion Picture and Television）as standard SMPTE-170

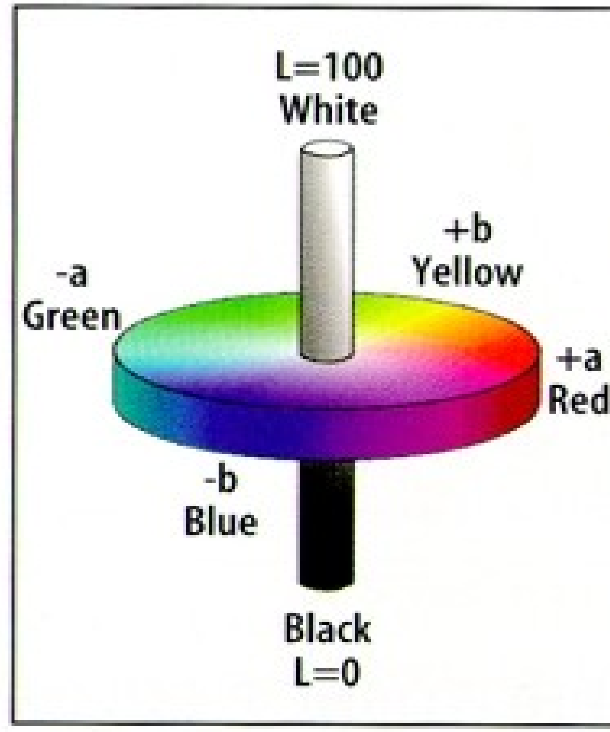
- Why a gamma of 2.2?（NTSC）
  - Actual be close to 2.8 (About = 1.25 * 2.2)
- An issue related to gamma Correction
  - What intensity level – what bit pattern in the pixel values
  - Most sensitive to ratios of level rather than absolute intensities

1.3 L*a*b*(CIELAB) Color Model

- **Weber's Law（From psychology）**
  - **The more there is of a quantity，the more changes there must be to perceive a difference**
  - **Changes are about equally perceived if the ratio of the change is the same**
    - **A logarithmic approximation**

1.3 L*a*b*(CIELAB) Color Model

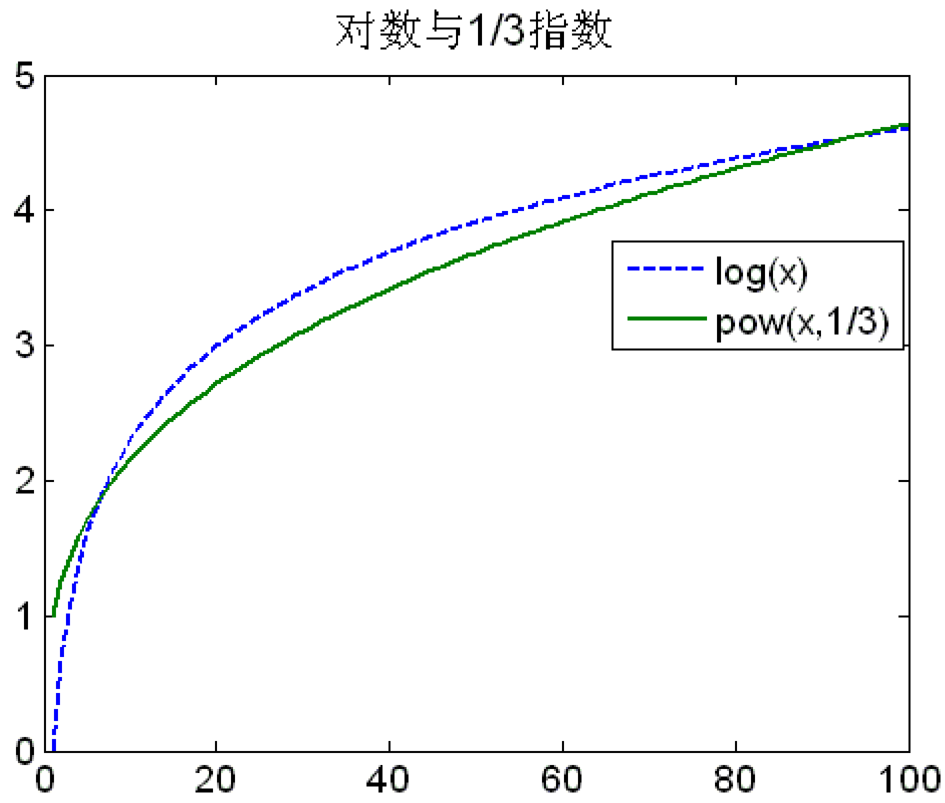
- CIE – Human vision: CIELAB space, called L*a*b*
  - Three value – Luminance, Colorfulness and Hue
  - Using Power law of 1/3 – instead of logarithm



Lab model

1.3 L*a*b*(CIELAB) Color Model

- Logarithm close to the power law of 1/3



1.3 L*a*b*(CIELAB) Color Model

- The color difference is defined as

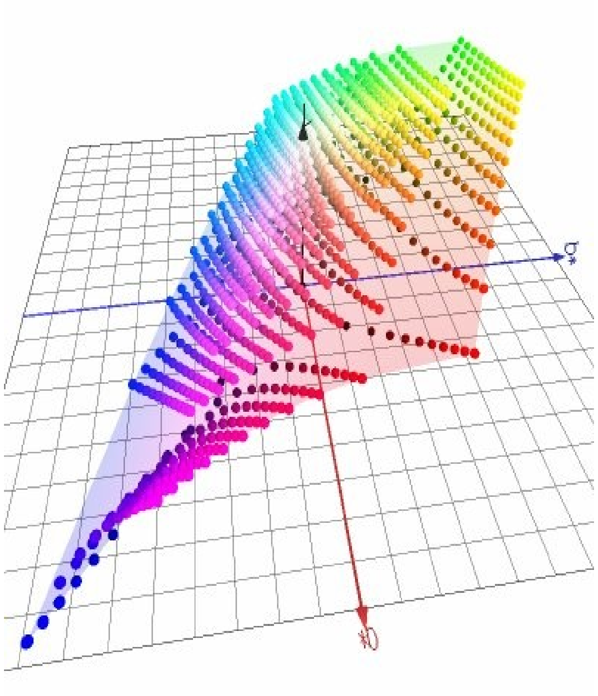
$$\Delta E = \sqrt{(L*)^2 + (a*)^2 + (b*)^2}$$

where,

$$L* = 116\left(\frac{Y}{Yn}\right)^{(1/3)} - 16$$

$$a* = 500\left[\left(\frac{X}{Xn}\right)^{(1/3)} - \left(\frac{Y}{Yn}\right)^{(1/3)}\right]$$

$$b* = 200\left[\left(\frac{Y}{Yn}\right)^{(1/3)} - \left(\frac{Z}{Zn}\right)^{(1/3)}\right]$$



L*a*b* space

With Xn, Yn, Zn the XYZ (CIE Chromaticity Diagram) value of the white point

1.3 L*a*b*(CIELAB) Color Model

- In NTSC system, the conversion of XYZ from RGB as follows:

$$X = 0.607\,R + 0.174\,G + 0.200\,B$$
$$Y = 0.299\,R + 0.587\,G + 0.114\,B$$
$$Z = 0.000\,R + 0.066\,G + 1.116\,B$$

- Choosing R， G， B as the maximum
  - （Notice: here RGB's maximum=1)
  - Obtaining the **white point XYZ value**

1.3 L*a*b* Color Model

$$chroma = C^* = \sqrt{(a^*)^2 + (b^*)^2}$$

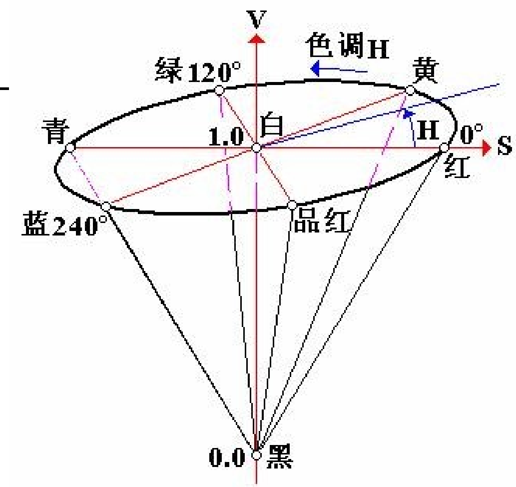
$$Hue - angle = h^* = \arctan \frac{b^*}{a^*}$$

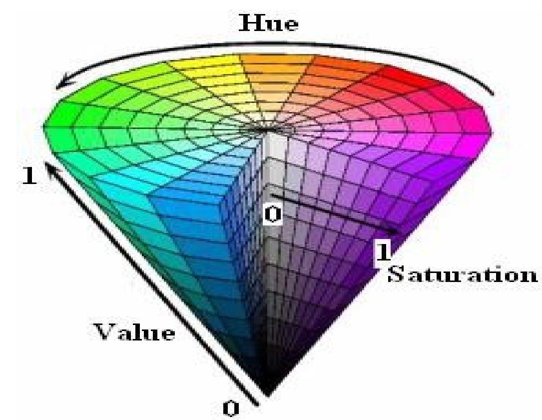
- Roughly, the maximum and minimum of a* correspond to red and green
- The maximum and minimum of b* correspond to yellow and blue

- Chroma -- a scale of colorfulness
- Hue angle – "the color"

1.4 Other color models

- HSL(HSB)－hue, Saturation, Lightness/Brightness.
- HSV --Hue Saturation Value
- HIS -- Hue，Saturation and Intensity
- HCI -- C= Chroma
- HVC -- V＝value
- HSD -- D=Darkness
- CMY
- http://learn.colorotate.org/color-models.html





2. Color Models in Images

RGB color model for CRT Display

CMY color model

Transformation from RBG to CMY

CMYK color system

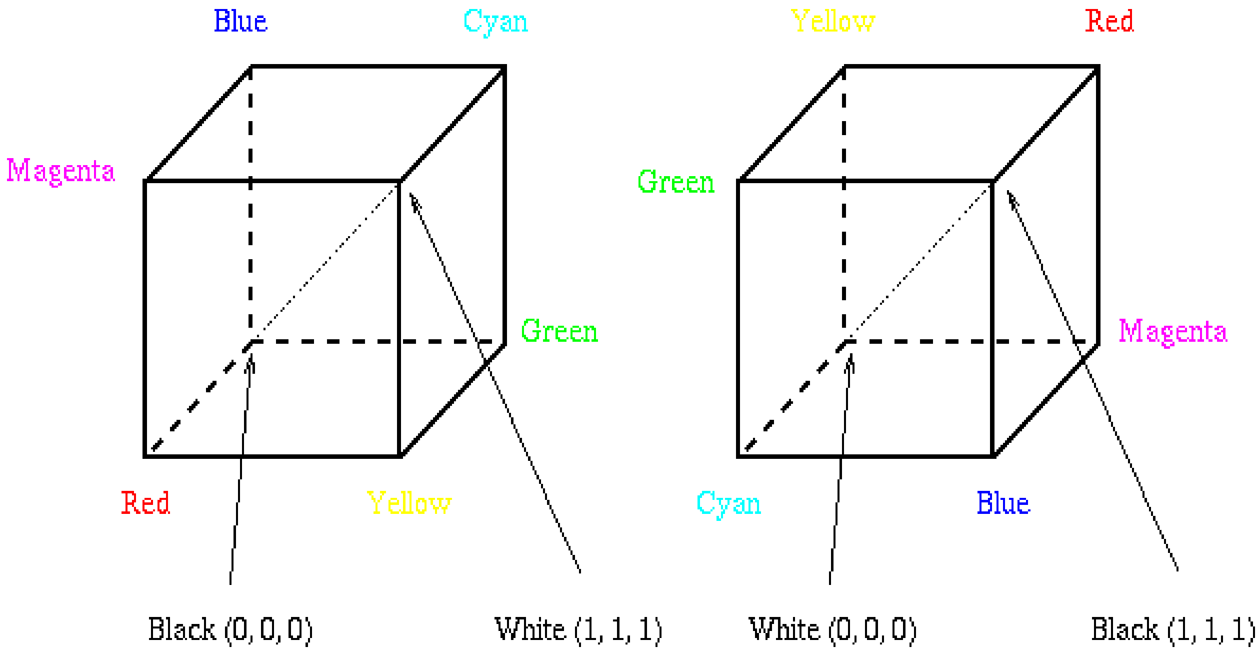
2.1 Additive Color Model

- Used by computers
- When light energy is added, a color appears brighter
- Different visible light wavelengths can be combined to create new colors

Image courtesy of Pat Ellison

2.1 RGB model for CRT display

- Store integers proportional to intensity in frame buffer
- Gamma Correction



The RGB Cube

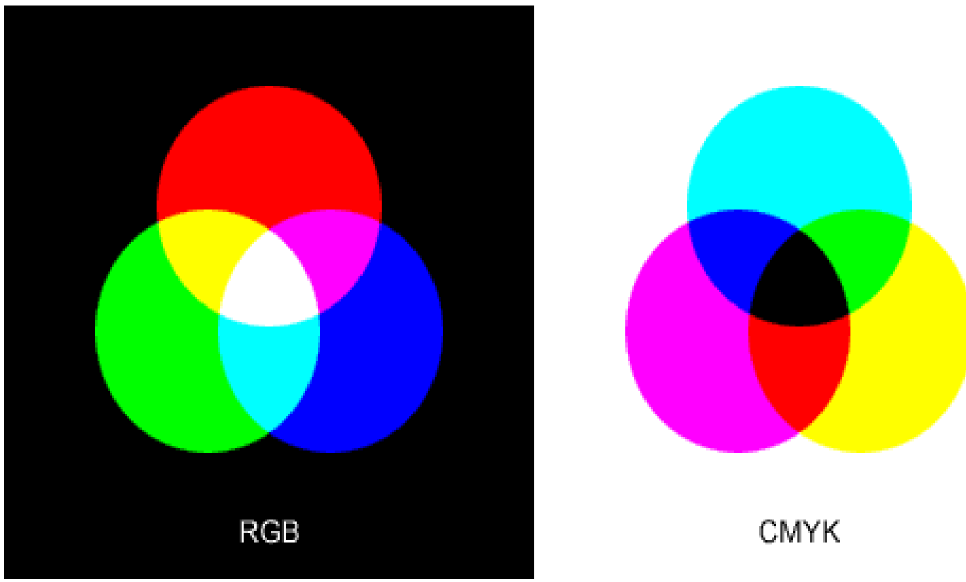
The CMY Cube

2.2 Subtractive Color Model

- Used in the print media
- When more color is added, a color appears darker
- Ink or paint can be thought of a filter that filters out all colors except the color being perceived, which is reflected

Image courtesy of Pat Ellison

2.2 Subtractive Color: CMY



Cyan – C

Magenta –M

Yellow --Y

Additive and subtractive color

RGB is additive color; CMYK is subtractive color

2.3 Transformation from RBG to CMY

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

The inverse transform

2.4 Under color Removal : CMYK

$$K \equiv \min\{\ C, M, Y\}$$

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} C - K \\ M - K \\ Y - K \end{bmatrix}$$

CMYK system get the “true” black by adding K component

3. Color Models in Video

YUV Color Model

YIQ Color Model

YCbCr Color Model

3.1 YUV Color Model

- YUV Model is invented because we needed a signal transmission method that was compatible with black-and-white (B&W) TV while being able to add color television.
- **YUV – for PAL analog video, also CCIR 601 standard for digital video**
  - $Y = 0.299R + 0.587G + 0.114B$ **: luma value**
  - ***Chrominance* as:**

$$U = B - Y$$
$$V = R - Y$$

  - **U = V = 0. No chrominance!**

3.1 YUV Color Model

- After gamma correction (R’, G’, B’)

$$U = B' - Y'$$

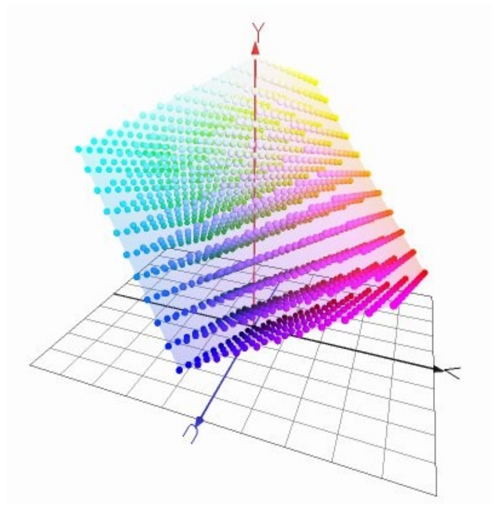
$$V = R' - Y'$$

$$\begin{bmatrix} Y' \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ -0.299 & -0.587 & 0.886 \\ 0.701 & -0.587 & -0.114 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

- In PAL application

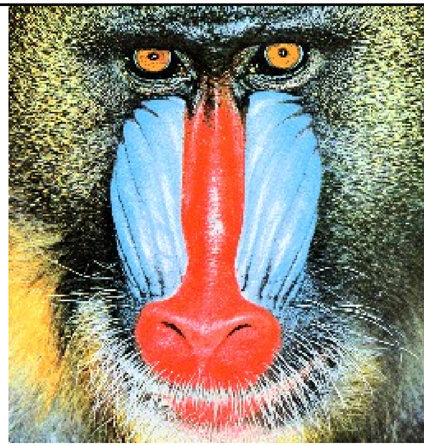
U = 0.492 (B’ – Y’)

V = 0.877 (R’ – Y’)

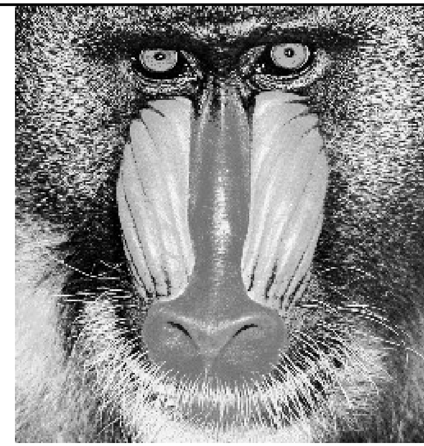


YUV space

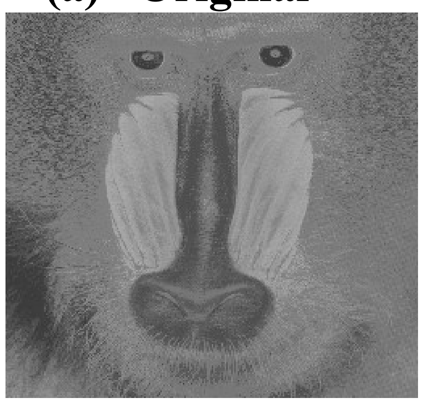
3.1 YUV Color Model



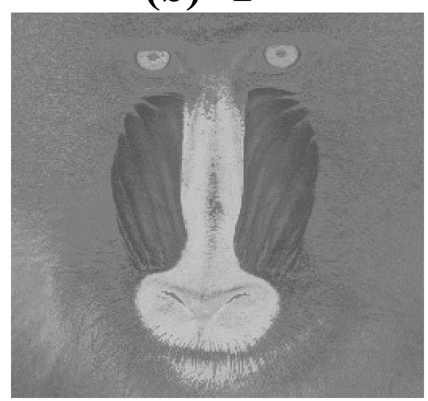
(a) Original



(b) Y'



(c) U



(d) V

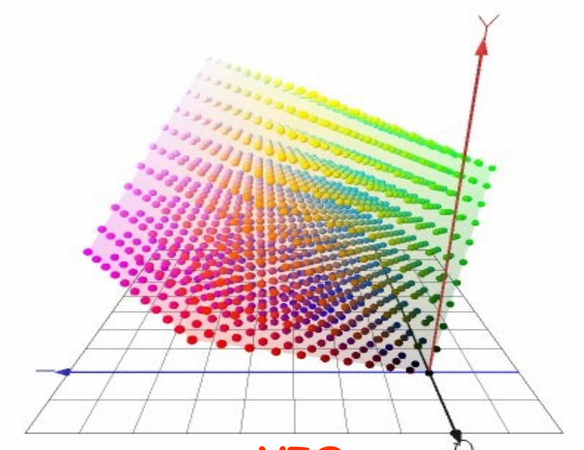
3.2 YIQ Color Model

- YIQ -- NTSC color TV broadcasting,
  - Adapt to black-white TV (only Y)
- U and V not capture the most-to-least hierarchy of human vision sensitivity
  - I and Q used in NTSC, instead of U,V.
- I -- orange-blue , Q -- purple-green
  - I and Q obtained by rotating R - Y and B – Y with 33° .

$$I = 0.877(R - Y)\cos 33^\circ - 0.492(B - Y)\sin 33^\circ$$
$$Q = 0.877(R - Y)\sin 33^\circ + 0.492(B - Y)\cos 33^\circ$$

3.2 YIQ color Model

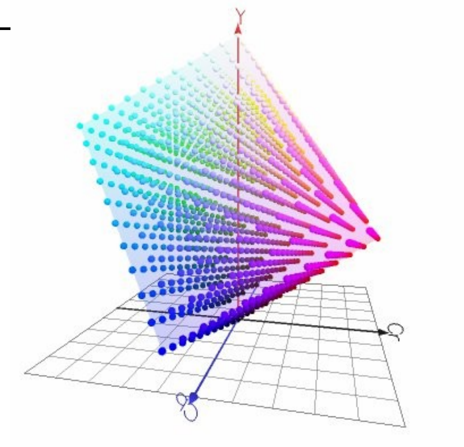
- Leading to the follow equations:
  - I = 0.736(R - Y) - 0.268(B - Y) = 0.596R - 0.275G - 0.321B
  - Q = 0.478(R - Y) + 0.413(B - Y) = 0.212R - 0.523G + 0.311B
- Most sensitivity to Y, then to I, Least to Q
  - In NTSC Broadcasting, the bandwidth for each components as follows:
    - 4.2 MHz is allocated to Y
    - 1.5 MHz to I
    - 0.55 MHz to Q



YIQ space

3.3 YCbCr Color Model

- YCbCr – ITU-R BT.601-4
- YCbCr model closely related to YUV
  - Cb = (B - Y) / 1.772 + 0.5
  - Cr = (R - Y) / 1.402 + 0.5
- The value Cb and Cr are between 0 and 1
- YCbCr widely used in JPEG and MPEG



YCbCr space

YCbCr is a scaled and offset version of the YUV color space.

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The End

Thanks !