Research Institute for Future Media Computing 未来媒体技术与研究所
Institute of Computer Vision 计算机视觉研究所

图像和视频中的颜色
Color in Image and Video

授课教师：张小燕
邮箱：xyzhang15@szu.edu.cn

Outline of Lecture 03

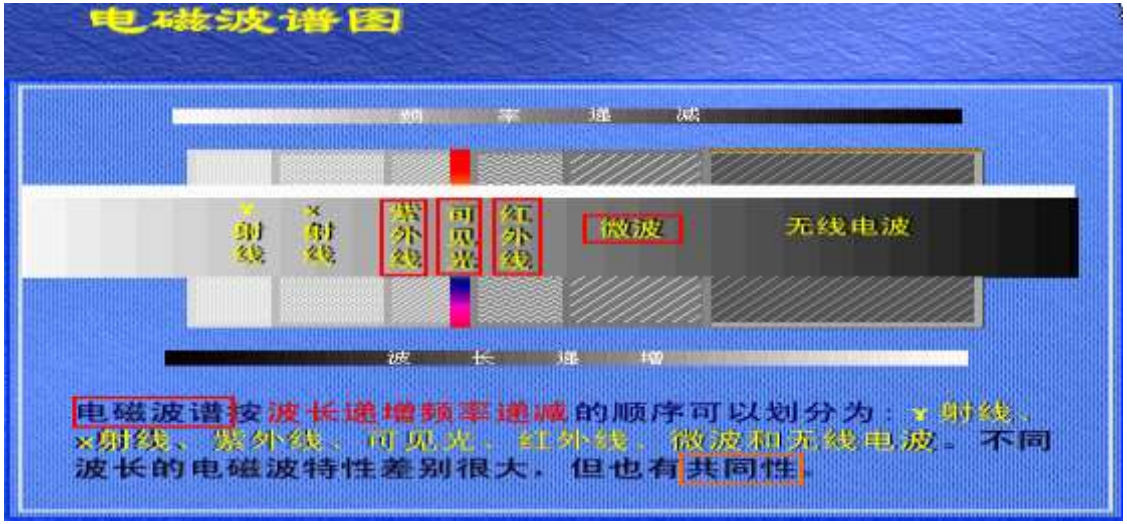
- Color Science
  - Light and Spectra
  - Human Vision
  - Image Formation
  - Color-Matching Functions
  - CIE Chromaticity Diagram
  - Out-of-Gamut Colors
  - Color Coordinate Schemes
- Color Models in Image
- Color Models in Video
- Demo

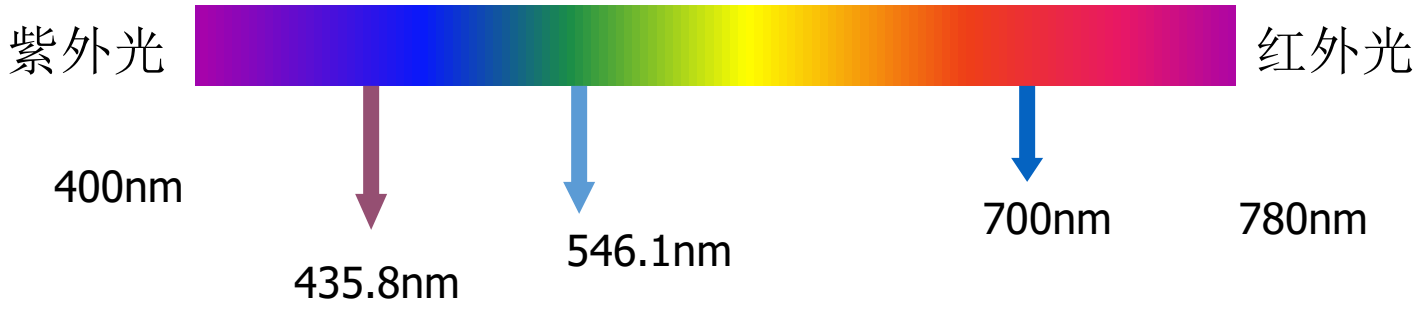
Color Science

- What is color?

Color Science

- **Light and Spectra**
  - Light is an electromagnetic wave (电磁波).

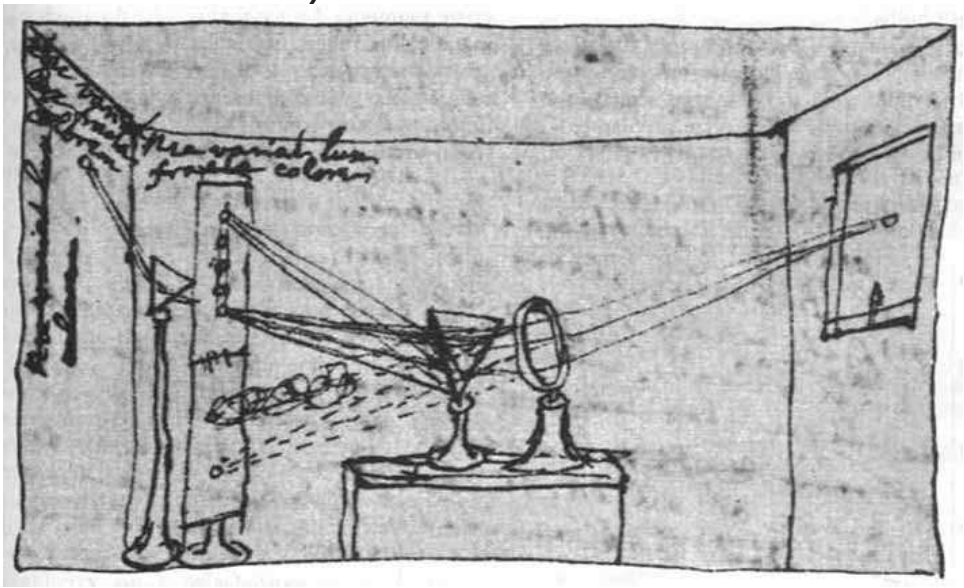


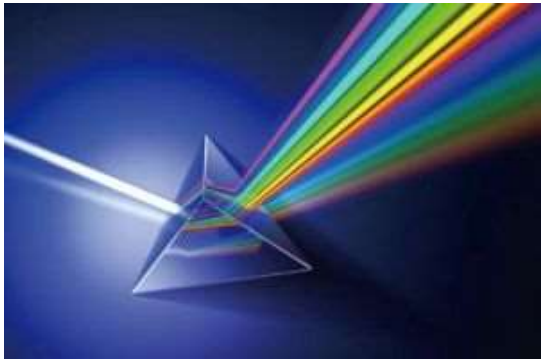


Color Science

Light and Spectra

- Spectrophotometer (分光光度计): a device used to measure visible light by reflecting light from a diffraction grating (a ruled surface) that spreads out the different wavelengths.
- Visible light is an electromagnetic wave (电磁波) in the range 400 nm to 700 nm (where nm stands for nanometer, 10^{-9} meters).

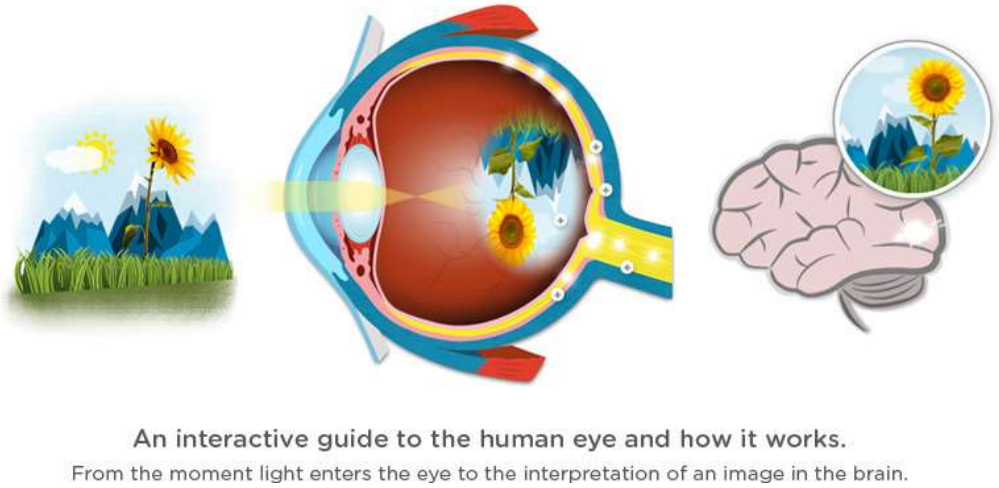




Sir Isaac Newton's experiments.

Color Science

- **Human Vision**



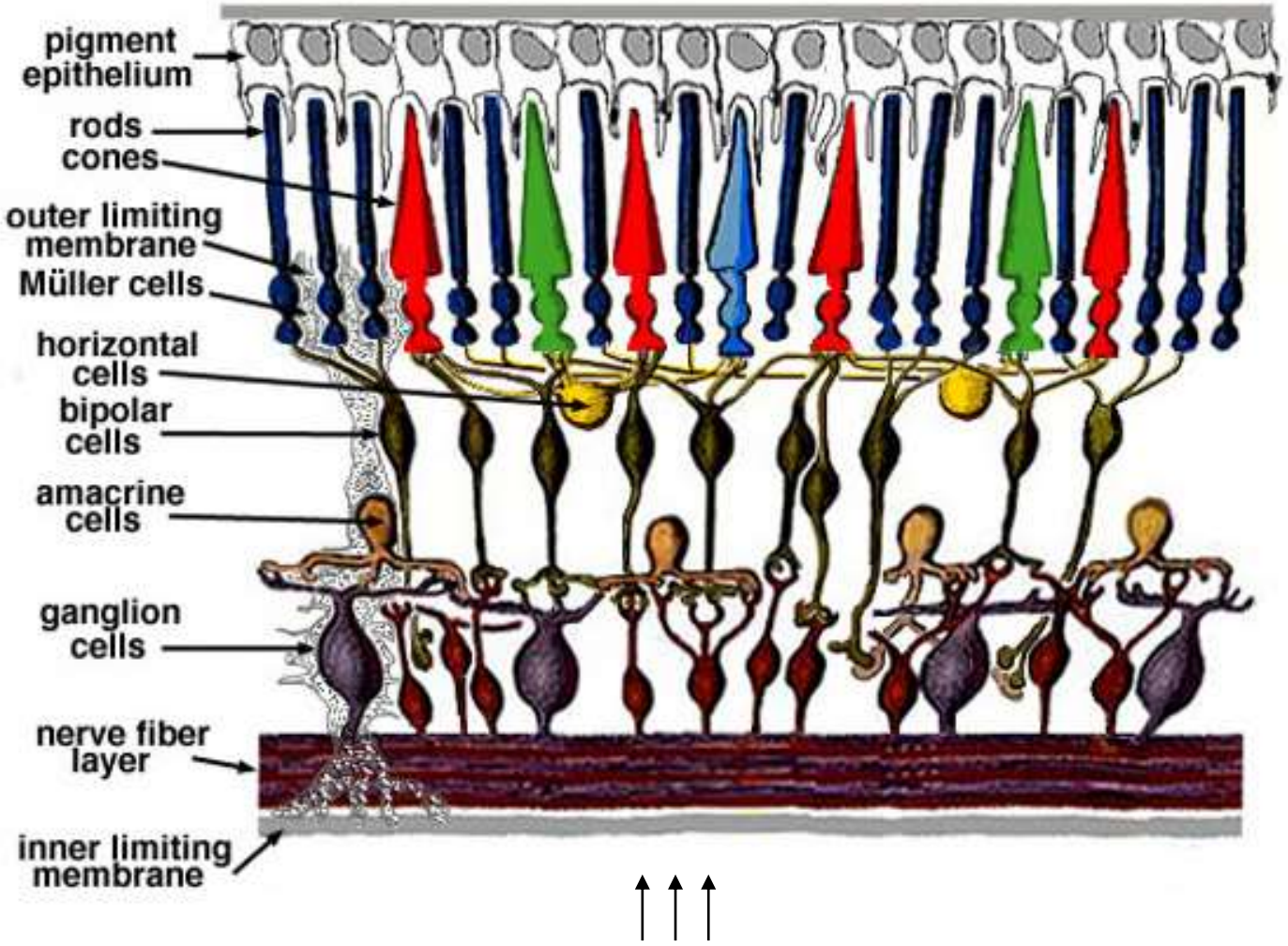
- The retina（视网膜）consists of an array of rods（柱状细胞）and three kinds of cones (视锥细胞).

- The rods come into play when light levels are low and produce an image in shades of gray (“all cats are gray at night!”).

- For higher light levels, the cones each produce a signal. Because of their differing pigments（色素）, the three kinds of cones are most sensitive to red (R), green (G), and blue (B) light.

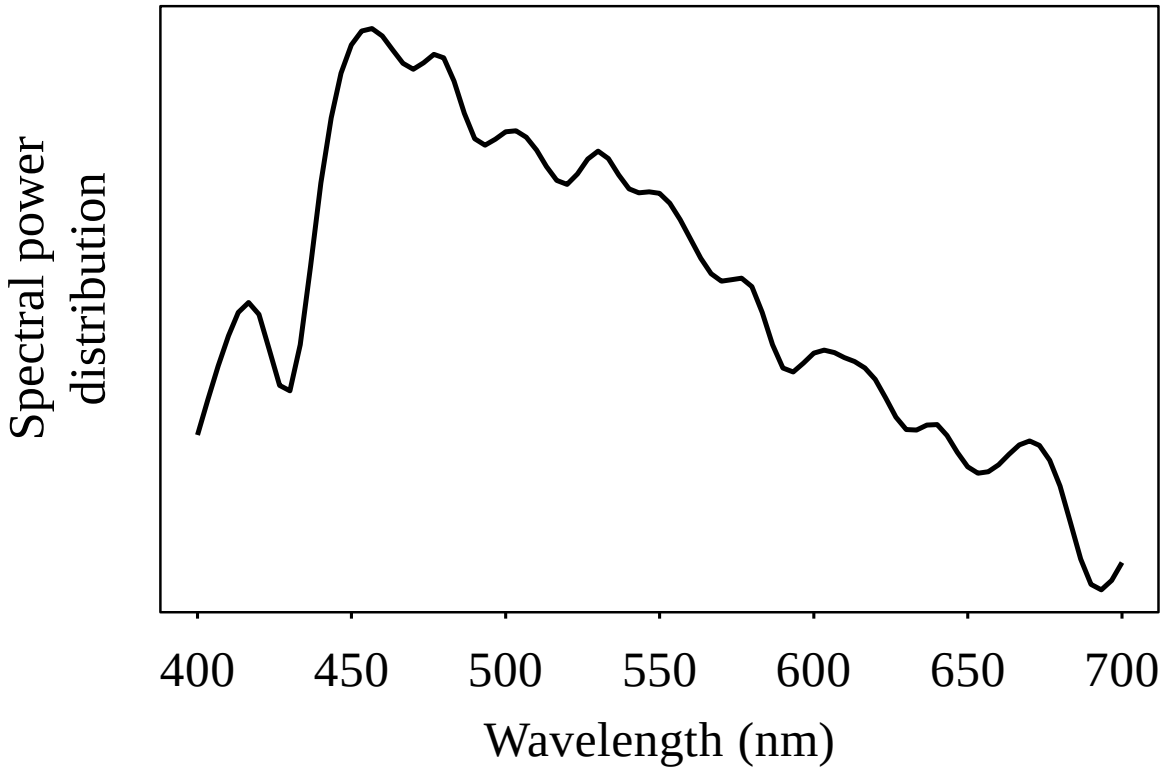
Color Science

- Human Vision



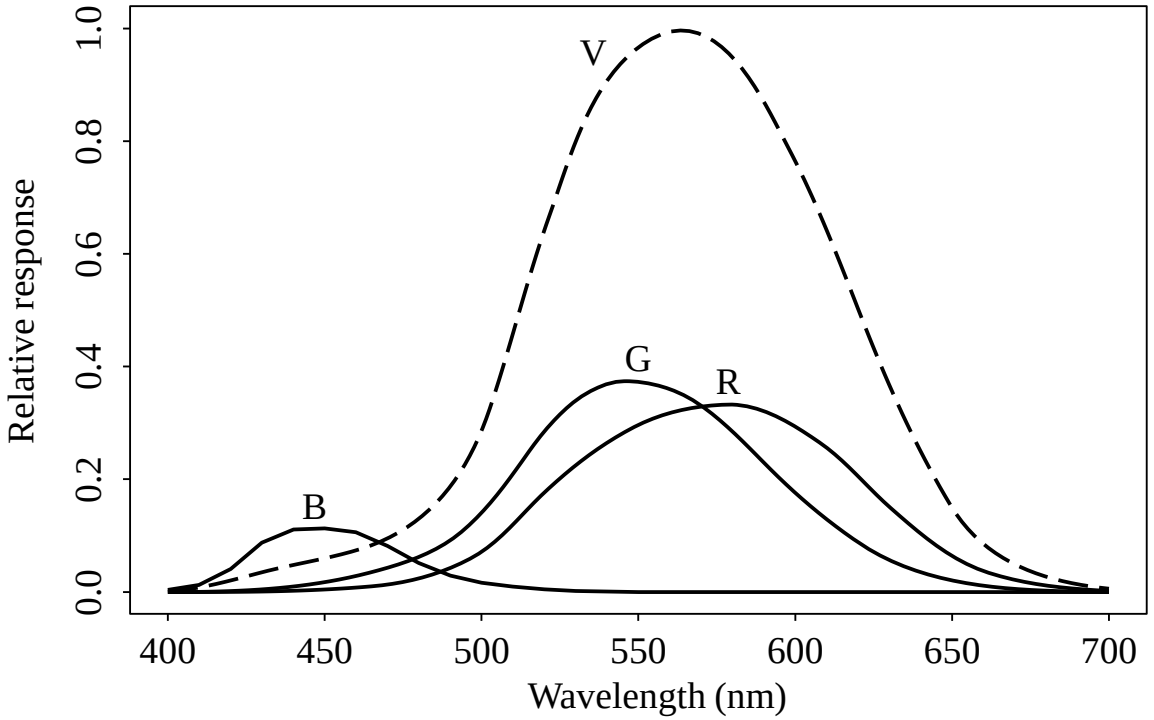
Color Science

- **Human Vision**
  - Spectral Power Distribution (**SPD,**光谱能量分布) or a **spectrum,** shows the relative power in each wavelength interval
  - The symbol for wavelength is λ. This curve is called E(λ).



Color Science

- **Human Vision**
  - **Spectral Sensitivity of the Eye(眼睛的光谱灵敏度)**
  - R, G, and B cones, and Luminous Efficiency curve V(*λ*).
- 光的颜色由光的波长决定，短波产生蓝色感觉，长波产生红色感觉



Color Science

Human Vision

- These spectral sensitivity functions are usually denoted by a vector function q(λ), with components

$$\boldsymbol{q}(\lambda) = (q_R(\lambda), q_G(\lambda), q_B(\lambda))^T$$

- The response in each color channel in the eye is proportional to the number of neurons firing.
- We can succinctly write down this idea in the form of an integral:

$$R = \int E(\lambda)\, q_R(\lambda)\, d\lambda$$

$$G = \int E(\lambda)\, q_G(\lambda)\, d\lambda$$

$$B = \int E(\lambda)\, q_B(\lambda)\, d\lambda$$

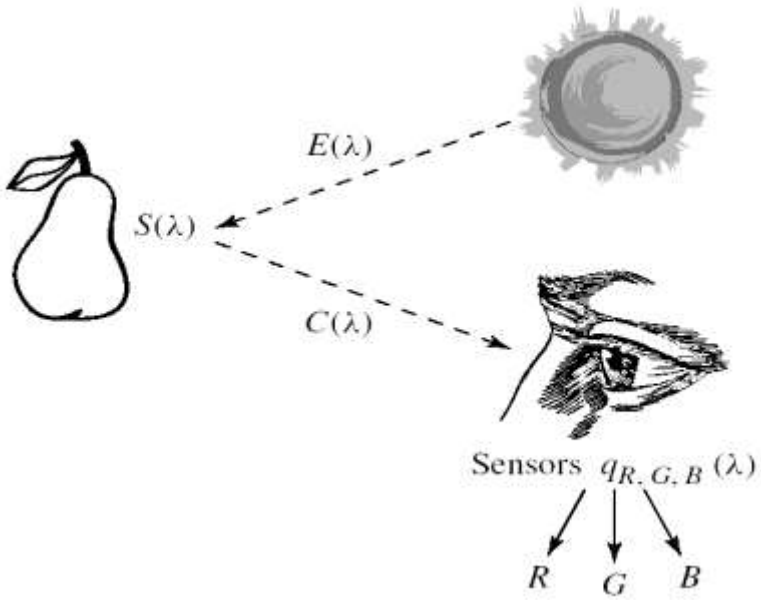
Color Science

- **Image Formation**
  - The equations that take into account the image formation model are:

$$R = \int E(\lambda)S(\lambda)q_R(\lambda)\, d\lambda$$

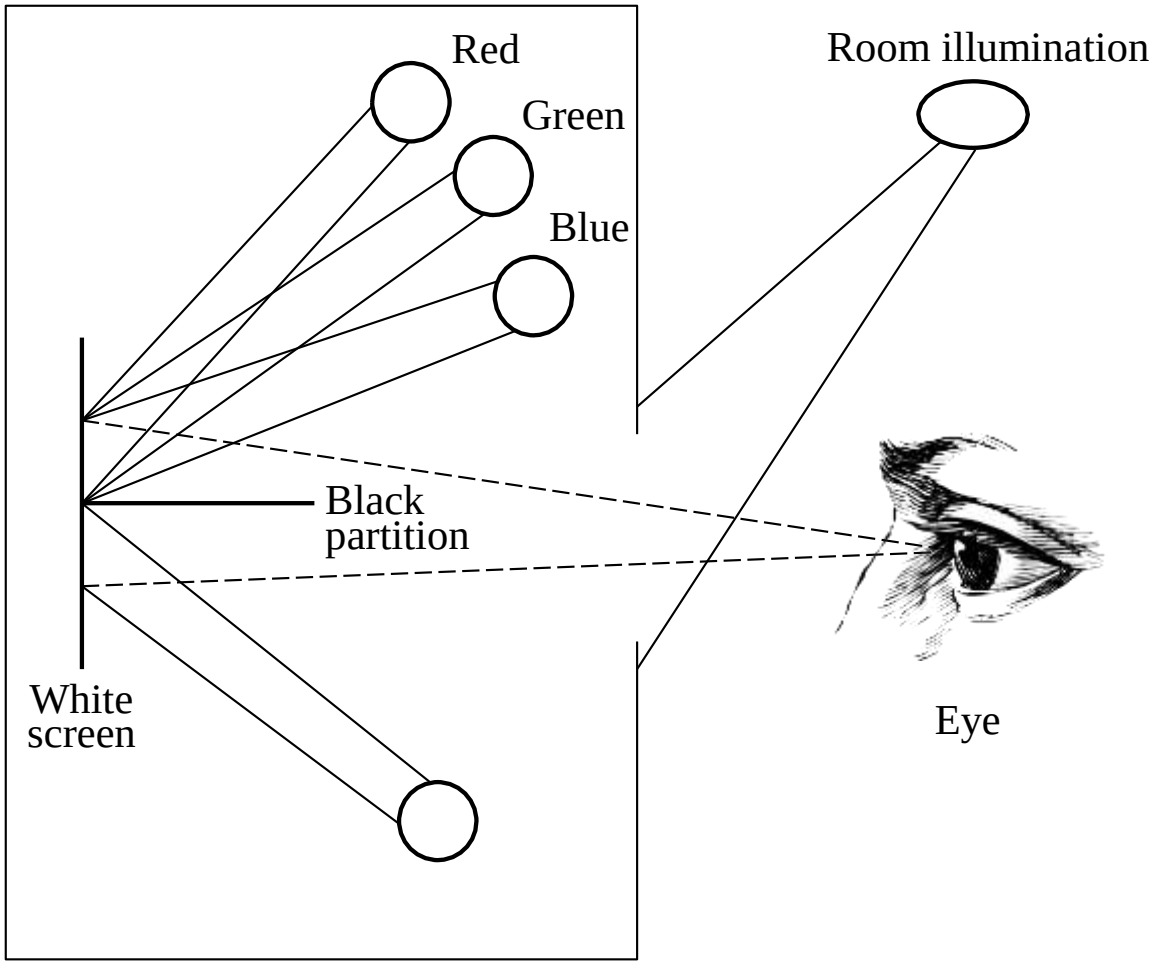
$$G = \int E(\lambda)S(\lambda)q_G(\lambda)\, d\lambda$$

$$B = \int E(\lambda)S(\lambda)q_B(\lambda)\, d\lambda$$



Color Science

- **Color-Matching Functions**



Color Science

◆ Color-Matching Functions

- The particular set of three basic lights used in an experiment are called the set of **color primaries**.

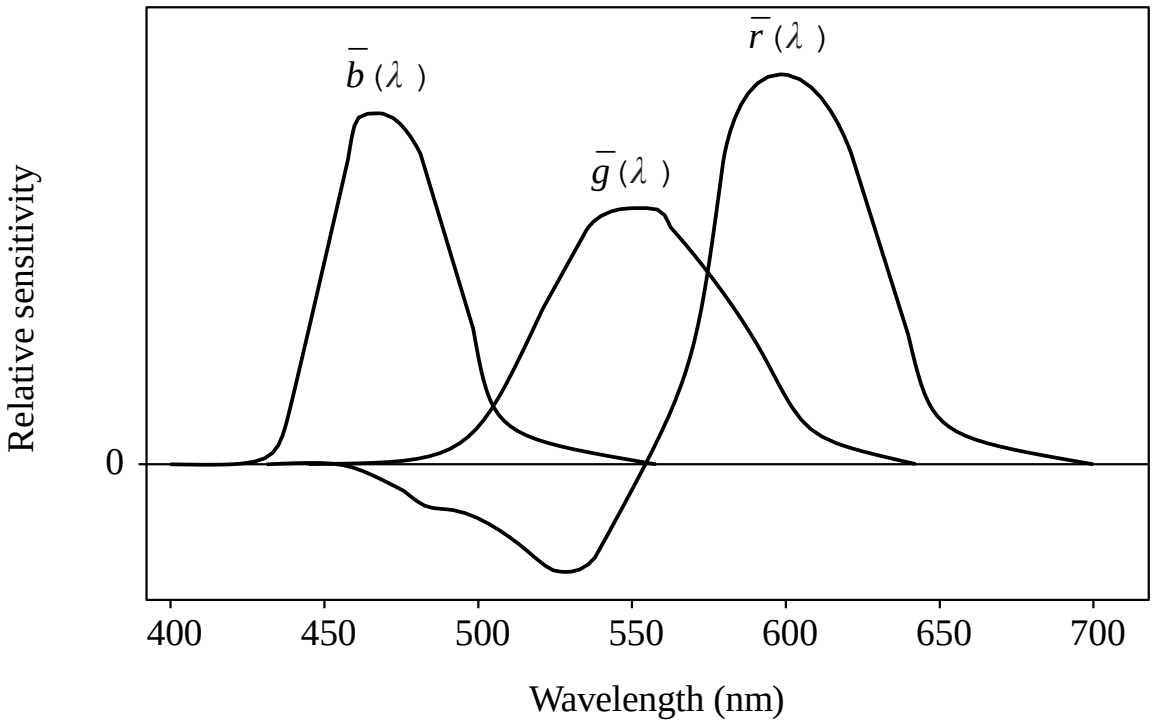
- To match a given color, a subject is asked to separately adjust the brightness of the three primaries using a set of controls until the resulting spot of light most closely matches the desired color.

- A device for carrying out such an experiment is called a colorimeter(色度计).

Color Science

◆ Color-Matching Functions

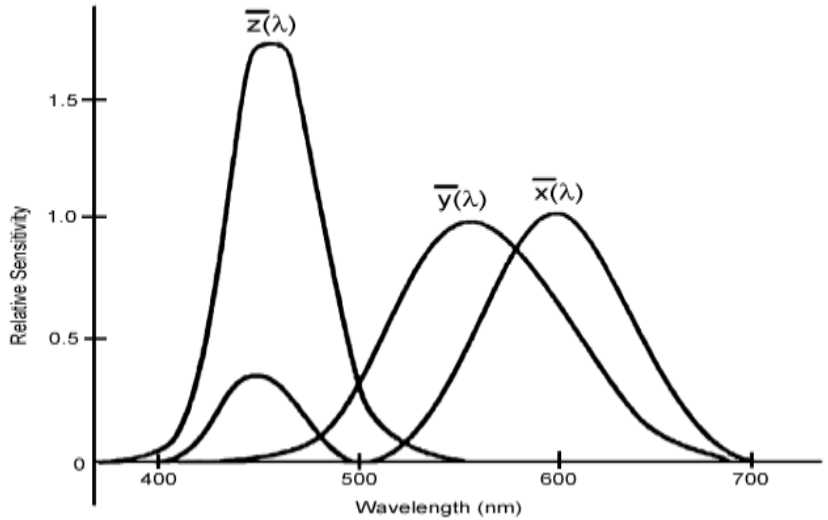
- The amounts of R, G, and B the subject selects to match each single-wavelength light forms the color-matching curves. These are denoted $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, $\bar{b}(\lambda)$
- CIE(国际照明委员会) RGB color-matching functions.



Color Science

◆ CIE Chromaticity Diagram

- Since the $\bar{r}(\lambda)$ color-matching curve has a negative lobe, a set of fictitious primaries were devised that lead to color-matching functions with only positives values.
- They are a 3×3 matrix away from $\bar{r}, \bar{g}, \bar{b}$ curves, and are denoted $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$.
- CIE standard XYZ color-matching functions $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$.



Color Science

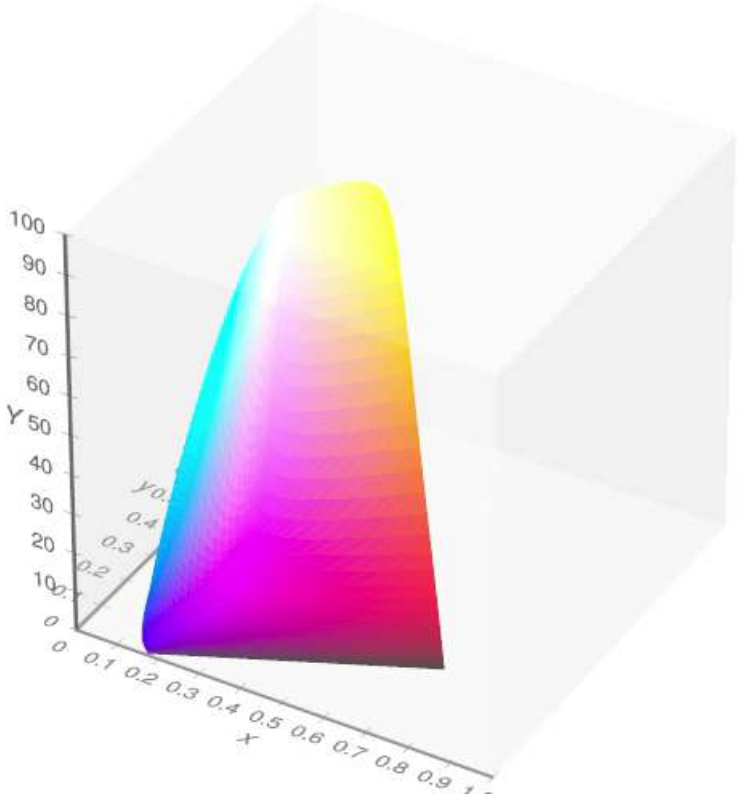
- **CIE Chromaticity Diagram(色度图)**

  - A color is the set of tristimulus *values* X, Y, Z defined

$$X = \int E(\lambda)\,\bar{x}(\lambda)\,d\lambda$$

$$Y = \int E(\lambda)\,\bar{y}(\lambda)\,d\lambda$$

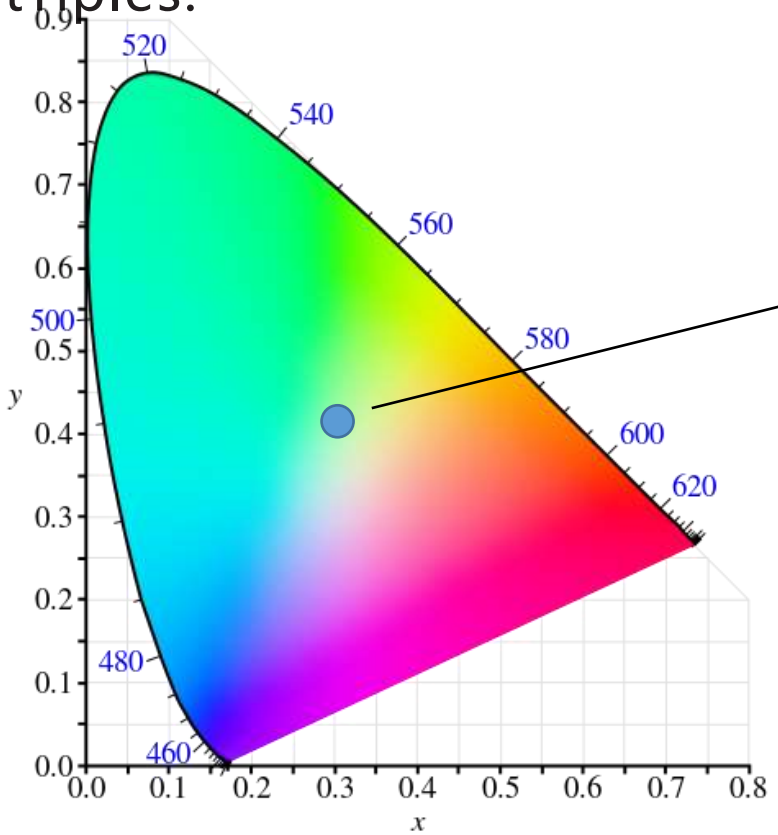
$$Z = \int E(\lambda)\,\bar{z}(\lambda)\,d\lambda$$



Color Science

- **CIE Chromaticity Diagram**

  - CIE chromaticity diagram
  - CIE devised a 2D diagram based on the values of (X, Y, Z) triples.



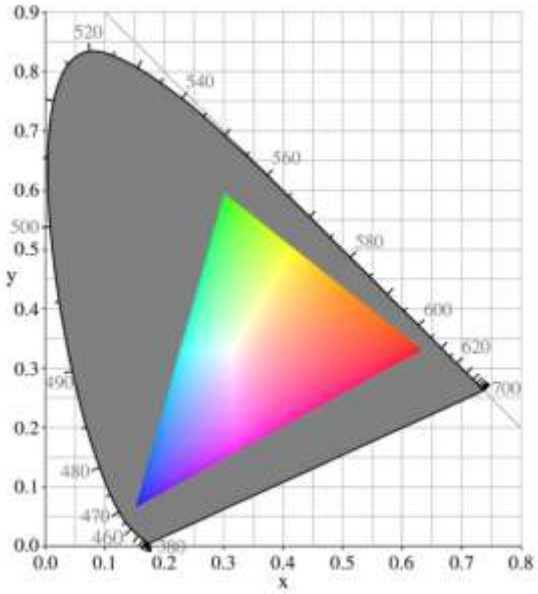
White point

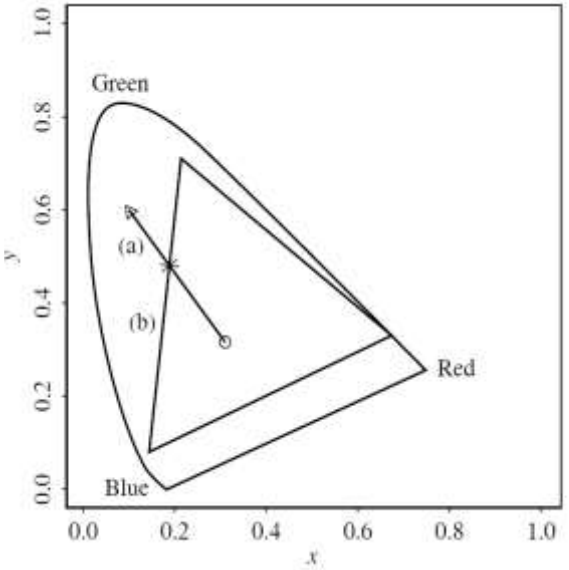
Color monitors are specified in part by the white point chromaticity

Color Science

◆ Out-of-Gamut Colors

- **Gamut(色彩空间，色域)**: refers to the subset of colors which can be accurately represented in a given circumstance, such as within a given **color space** or by a certain **output device**.
- The out-of-gamut（超色域）color shown by a triangle is approximated by the intersection of (a) the line from that color to the white point with (b) the boundary of the device color gamut.





Color Science

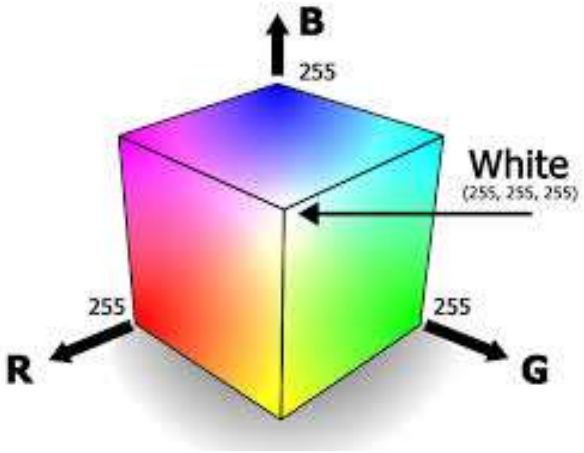
Color Coordinate Schemes

- **RGB**：an additive color model（加性颜色模型），in which red, green, and blue light are added together in various ways to reproduce a broad array of colors.
- RGB color model is used for the sensing, representation, and display of images in electronic systems, such as televisions and computers.
- **XYZ to RGB Transform**

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \boldsymbol{T} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

For the SMPTE specification, we arrive at:

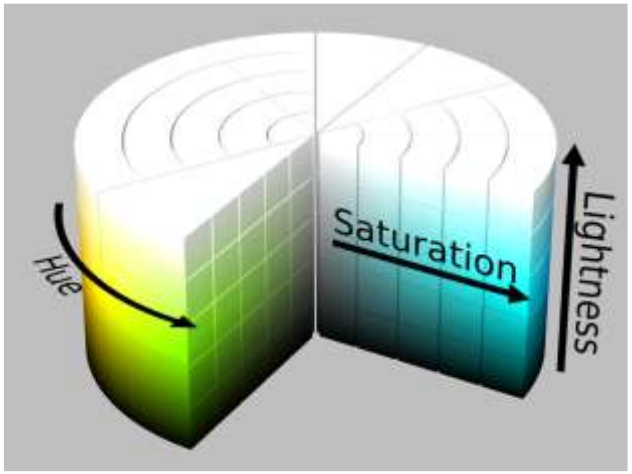
$$\boldsymbol{T} = \begin{bmatrix} 0.3935 & 0.3653 & 0.1916 \\ 0.2124 & 0.7011 & 0.0866 \\ 0.0187 & 0.1119 & 0.9582 \end{bmatrix}$$

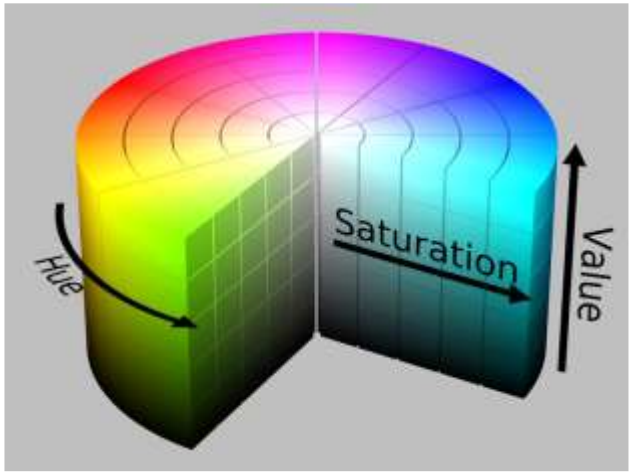


Color Science

Color Coordinate Schemes

- HSL — Hue（色调）, Saturation （饱和度）and Lightness;
- HSV — Hue, Saturation and Value;
- They are more closely align with the way human vision perceives color-making attributes

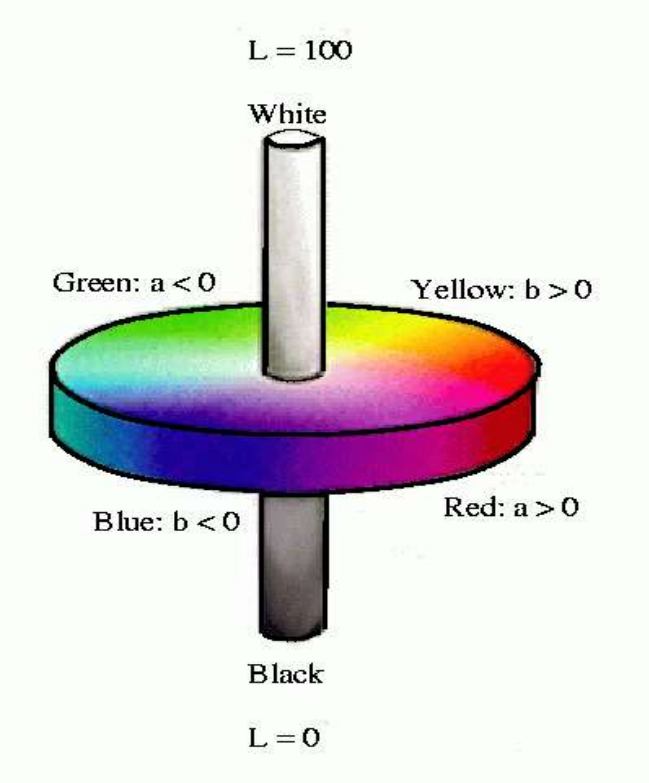




Color Science

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

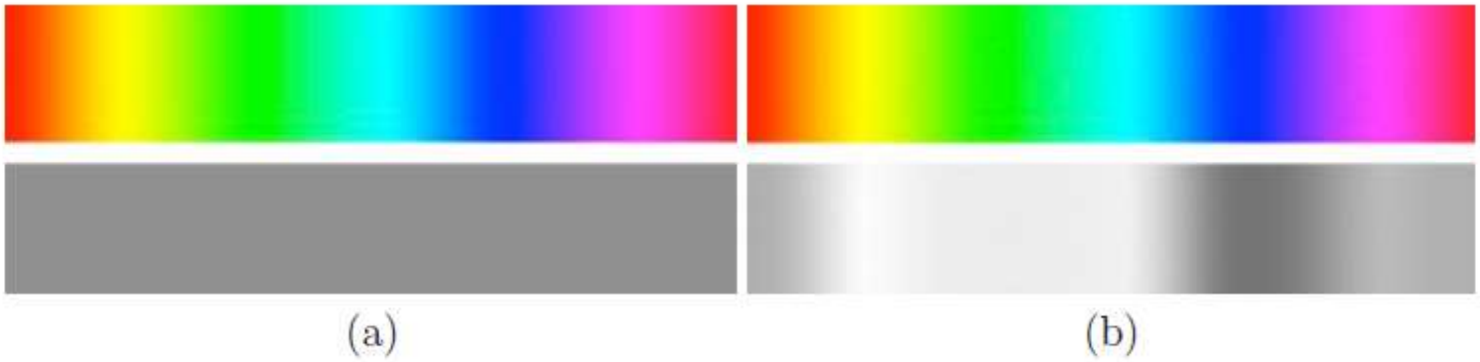
  - L* for the lightness from black (0) to white (100), a* from green (−) to red (+), and b* from blue (−) to yellow (+).



Color Science

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

  - CIELAB was designed so that the same amount of numerical change in these values corresponds to roughly the same amount of visually perceived change (**Weber's Law（韦伯定理）**).



(a) Hue ramp and L channel of HSL space, (b) Hue ramp and L channel of CIELAB space.

Outline of Lecture 03

- Color Science
  - Light and Spectra
  - Human Vision
  - Image Formation
  - Color-Matching Functions
  - CIE Chromaticity Diagram
  - Out-of-Gamut Colors
  - Color Coordinate Schemes
- Color Models in Image
- Color Models in Video
- Demo

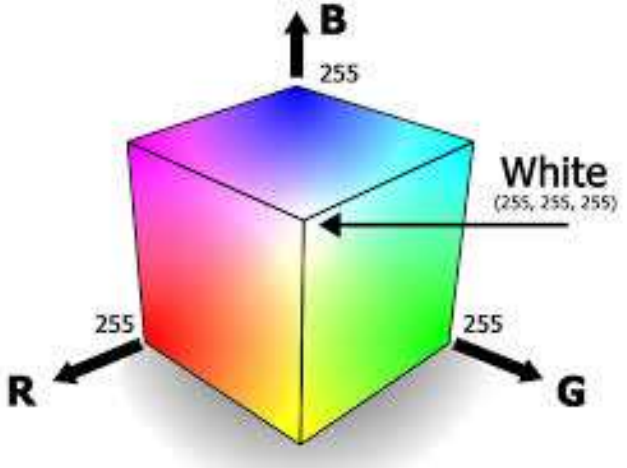
Color Models in Image

- **RGB Color Model**

- Usually used for storing color information

- Used for the sensing, representation, and display of images in electronic systems.

- RGB is a device-dependent color model: different devices detect or reproduce a given RGB value differently.

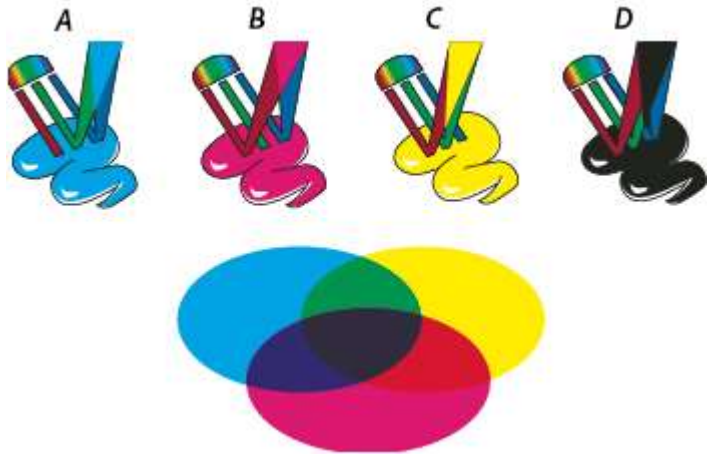


Color Models in Image

- **Subtractive Color: CMY Color Model**

- Additive color. When two light beams impinge on a target, their colors add; when two phosphors on a CRT screen are turned on, their colors add.

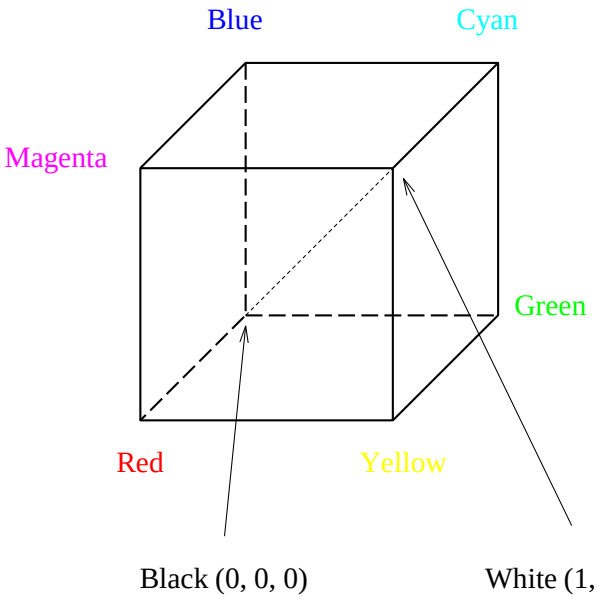
- But for ink deposited on paper, the opposite situation holds: yellow ink subtracts blue from white illumination, but reflects red and green; it appears yellow.

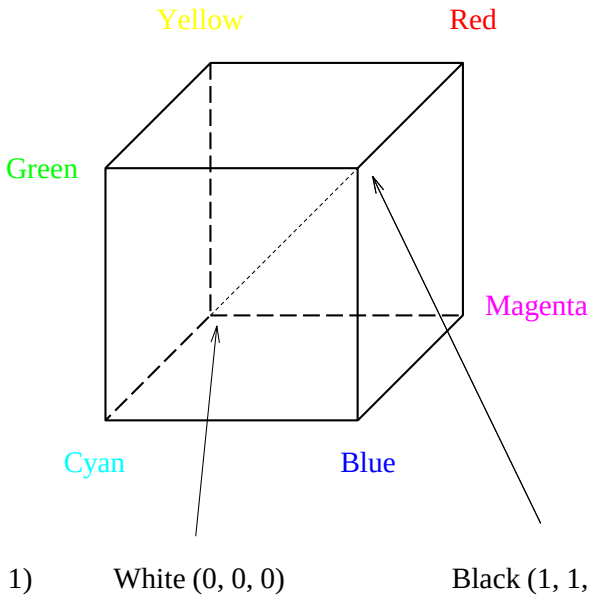


Color Models in Image

- **Subtractive Color: CMY Color Model**

  - These subtractive color primaries are Cyan (C), Magenta (M) and Yellow (Y) inks.





Color Models in Image

- **Subtractive Color: CMY Color Model**

- Transformation from RGB to CMY

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

Then the inverse transform is:

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

Truly "black" black ink is in fact cheaper than mixing colored inks to make black. Therefore, we use **CMYK** system in real color printer (K represents black).

Color Models in Image

- **Subtractive Color: CMY Color Model**

  - 思考题

  - 彩色喷墨打印机使用CMY模型，当青色墨水喷洒在一片白纸上时，在蓝色光线下他看起来像什么颜色？
  - （蓝色）

  - 在白色光线下他看起来像什么颜色？
  - （青色）

Outline of Lecture 03

- Color Science
  - Light and Spectra
  - Human Vision
  - Image Formation
  - Color-Matching Functions
  - CIE Chromaticity Diagram
  - Out-of-Gamut Colors
  - Color Coordinate Schemes
- Color Models in Image
- Color Models in Video
- Demo

Color Models in Video

- Methods of dealing with color in digital video largely derive from older analog methods of coding color for TV.

  - In Europe, video tape uses the PAL or SECAM codings, which are based on TV that uses a matrix transform called YUV.

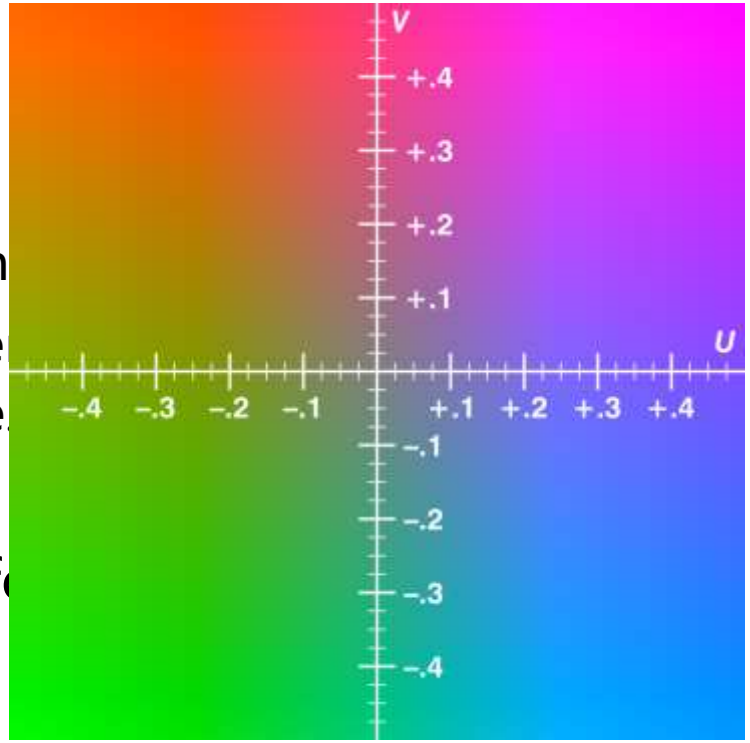
  - YIQ is used to transmit TV signals in North America and Japan.

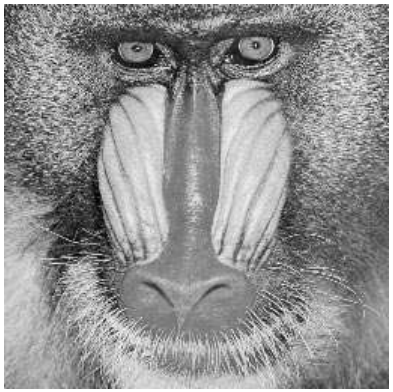
  - Another video color model YCbCr is closely related to YUV.

Color Models in Video

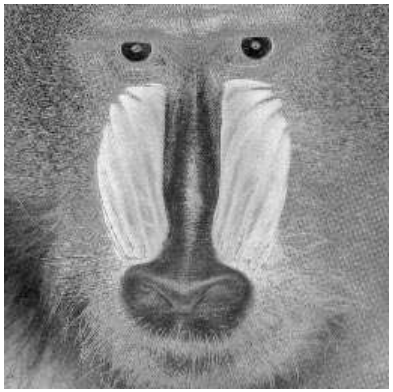
- **YUV Color Model**
  - Y is luminance (Y′ is "Luma", gamm
  - Chrominance U, V refers to the differe reference white at the same luminance

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \mathrm{T} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$, T is the transf

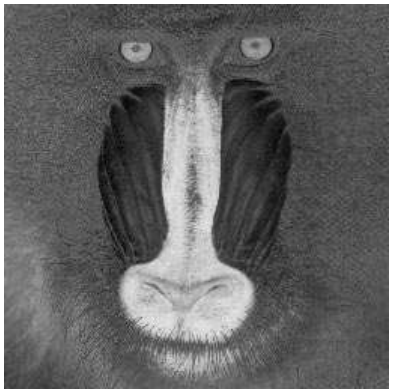




Y

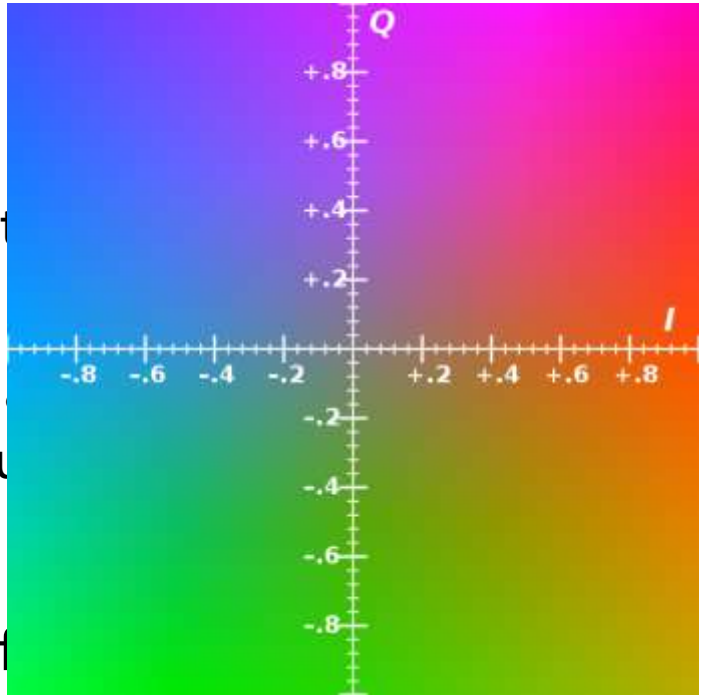


U



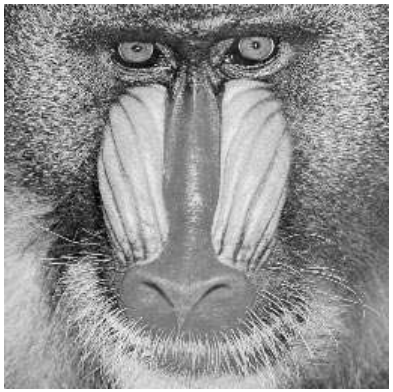
V

Color Models in Video

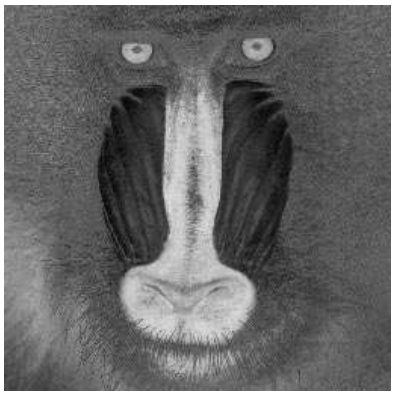


- **YIQ Color Model**
  - YIQ is used in NTSC color TV broadcast
  - Y is the same with that in YUV
  - Chrominance I, Q are generated by U
    to better match actual human perceptu

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \mathrm{M} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$, M is the transf



Y

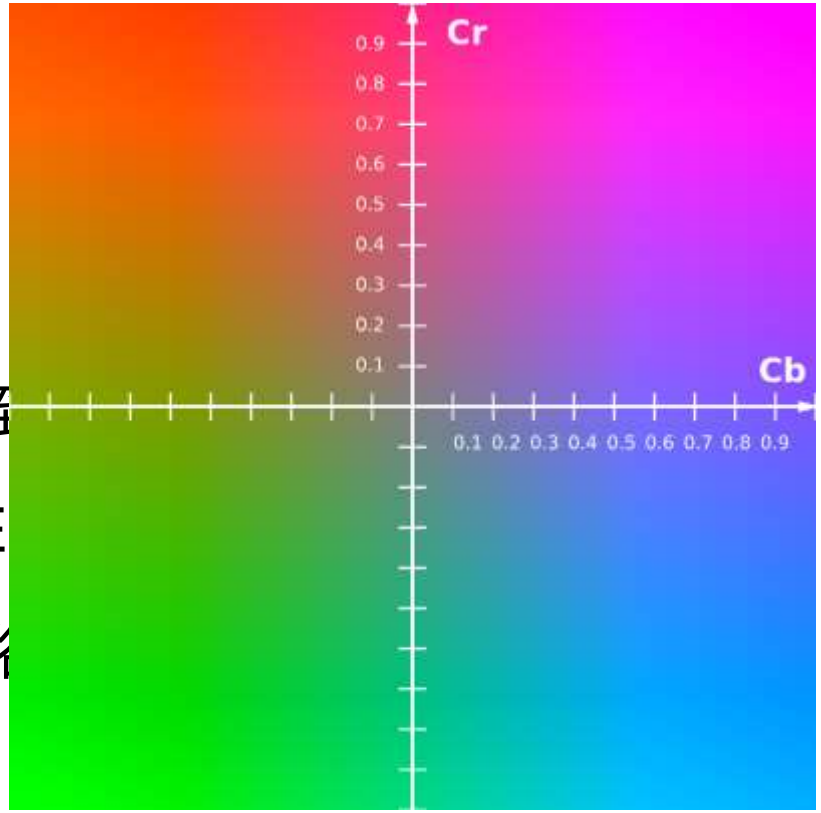


I

Q

Color Models in Video

- **YCbCr Color Model**



- YCbCr不是一种绝对色彩空间，
- YCbCr的Y与YUV中的Y含义一
- 在应用上很广泛，JPEG、MPE

  视等皆采此一格式。因此一般

- $\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix}$ = A $\begin{bmatrix} R \\ G \\ B \end{bmatrix}$ + b, A is the transformation matrix, and b is translation vector.

Outline of Lecture 03

- Color Science
  - Light and Spectra
  - Human Vision
  - Image Formation
  - Color-Matching Functions
  - CIE Chromaticity Diagram
  - Out-of-Gamut Colors
  - Color Coordinate Schemes
- Color Models in Image
- Color Models in Video
- Demo

Demo

- Color space conversion *run demoRGB.m*
  - HSV = rgb2hsv(RGB)
  - labI=rgb2lab(RGB);
  - xyz = rgb2xyz(RGB);

- RGB to YUV
  - *Run mlhdlc_rgb2yuv_tb.m*

- Gamma correction
  - *Run gammaCorrection.m*

课后练习

- 1. 调研伽马矫正（Gamma correction）的作用、用途、原理

- 2. 调研相机为什么可以感应红绿蓝
  - 相机工作原理
  - 感光器件
  - 色彩滤镜矩阵（Color Filter Array）