

## **Chapter Four**

### **Image and Video**

#### **4.1 Color Science**

##### **Light and Spectra**

Light is an electromagnetic wave. Its color is characterized by the wavelength content of the light.

- a) Laser light consists of a single wavelength: e.g., a ruby laser produces a bright, scarlet-red beam.
- b) Most light sources produce contributions over many wavelengths.
- c) However, humans cannot detect all light, just contributions that fall in the "visible wavelengths".
- d) Short wavelengths produce a blue sensation, long wavelengths produce a red one.

**Spectrophotometer:** 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 in the range 400 nm to 700 nm (where nm stands for nanometer,  $10^{-9}$  meters).

Fig. 4.1 shows the relative power in each wavelength interval for typical outdoor light on a sunny day. This type of curve is called a Spectral Power Distribution (SPD) or a **spectrum**.

The symbol for wavelength is  $\lambda$ . This curve is called  $E(\lambda)$ .

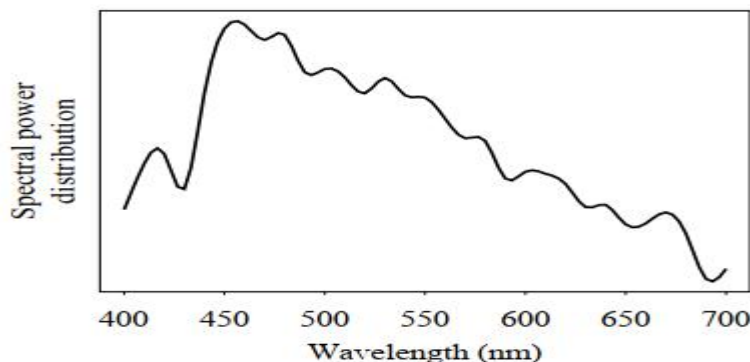


Fig. 4.1: Spectral power distribution of daylight.

## Human Vision

The eye works like a camera, with the lens focusing an image onto the retina (upside-down and left-right reversed).

The retina consists of an array of *rods* and three kinds of cones. The rods come into play when light levels are low and produce a 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, the three kinds of cones are most sensitive to red (*R*), green (*G*), and blue (*B*) light. It seems likely that the brain makes use of *differences* *R-G*, *G-B*, and *B-R*, as well as combining all of *R*, *G*, and *B* into a high-light-level achromatic channel.

## Spectral Sensitivity of the Eye

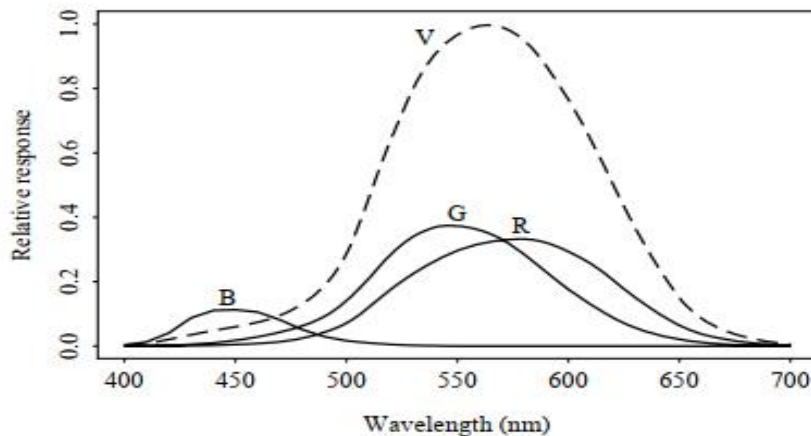
- ❖ The eye is most sensitive to light in the middle of the visible spectrum.
- ❖ The sensitivity of our *receptors* is also a function of wavelength (Fig. 4.2 below).
- ❖ The Blue receptor sensitivity is not shown to scale because it is much smaller than the curves for Red or Green | Blue is a late addition, in evolution.

*Statistically, Blue is the favorite color of humans, regardless of nationality | perhaps for this reason: Blue is a latecomer and thus is a bit surprising!*

- ❖ Fig. 4.2 shows the overall sensitivity as a dashed line | this important curve is called the luminous-efficiency function.

*It is usually denoted  $V(\lambda)$  and is formed as the sum of the response curves for Red, Green, and Blue.*

- ❖ The rod sensitivity curve looks like the luminous-efficiency function  $V(\lambda)$  but is shifted to the red end of the spectrum.
- ❖ The achromatic channel produced by the cones is approximately proportional to  $2R + G + B=20$



❖

Fig. 4.2: R,G, and B cones, and Luminous Efficiency curve  $V(\lambda)$ .

❖ These spectral sensitivity functions are usually denoted by letters other than  $\{R; G; B\}$ ; here let's use a vector function  $\mathbf{q}(\lambda)$ , with components

$$\mathbf{q}(\lambda) = (qR(\lambda); qG(\lambda); qB(\lambda))T \quad (4:1)$$

❖ The response in each color channel in the eye is proportional to the number of neurons firing.

❖ A laser light at wavelength  $\lambda$  would result in a certain number of neurons firing. An SPD is a combination of single frequency lights (like "lasers"), so we add up the cone responses for all wavelengths, weighted by the eye's relative response at that wavelength.

❖ We can succinctly write down this idea in the form of an integral:

$$R = \int R E(\lambda) qR(\lambda) d\lambda$$

$$G = \int R E(\lambda) qG(\lambda) d\lambda$$

$$B = \int R E(\lambda) qB(\lambda) d\lambda$$

### Image Formation

Surfaces reflect different amounts of light at different wavelengths, and dark surfaces reflect less energy than light surfaces.

Fig. 4.3 shows the surface spectral reflectance from (1) orange sneakers and (2) faded bluejeans. The reflectance function is denoted  $S(\lambda)$ .

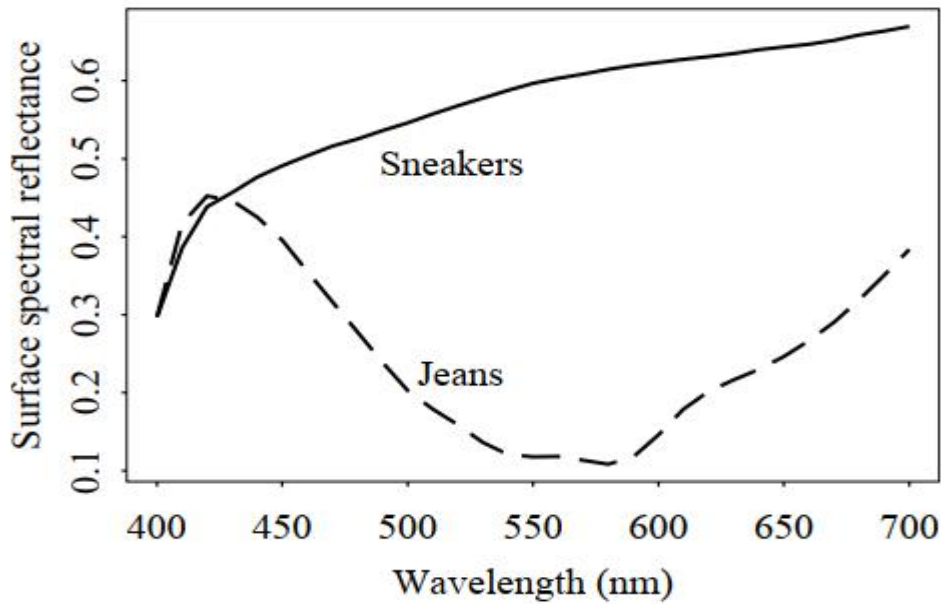


Fig. 4.3: Surface spectral reflectance functions  $S(\lambda)$  for objects.

❖ Image formation is thus:

- Light from the illuminant with SPD  $E(\lambda)$  impinges on a surface, with surface spectral reflectance function  $S(\lambda)$ , is reflected, and then is filtered by the eye's cone functions  $q(\lambda)$ .
- Reflection is shown in Fig. 4. 4 below.
- The function  $C(\lambda)$  is called the *color signal* and consists of the product of  $E(\lambda)$ , the illuminant, times  $S(\lambda)$ , the reflectance:  
$$C(\lambda) = E(\lambda) S(\lambda).$$

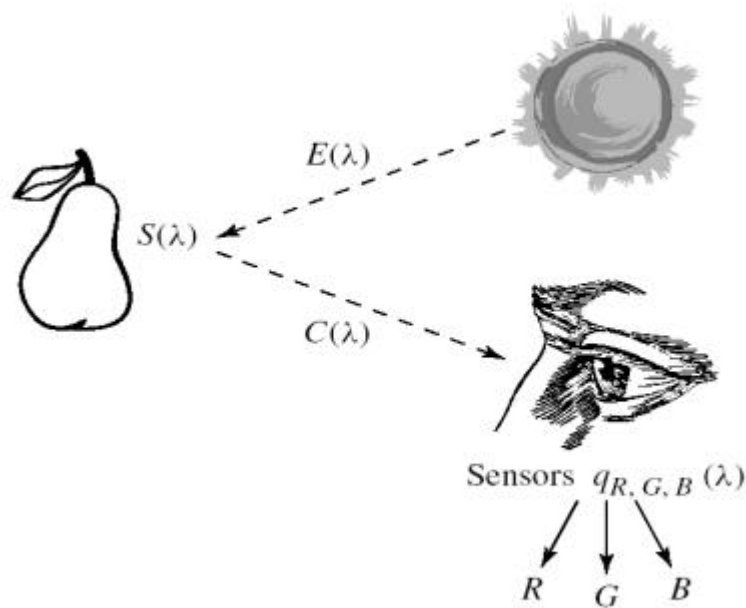


Figure 4.4 Image formation model

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

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

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

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

### Camera Systems

- Camera systems are made in a similar fashion; a studio quality camera has three signals produced at each pixel location (corresponding to a retinal position).
- Analog signals are converted to digital, truncated to integers, and stored. If the precision used is 8-bit, then the maximum value for any of  $R$ ;  $G$ ;  $B$  is 255, and the minimum is 0.
- However, the light entering the eye of the computer user is that which is emitted by the screen – the screen is essentially a self-luminous source. Therefore we need to know the light  $E(\lambda)$  entering the eye.

### Gamma Correction

The light emitted is in fact roughly proportional to the voltage *raised to a power*; this power is called **gamma**, with symbol  $\gamma$ .

- (a) Thus, if the file value in the red channel is  $R$ , the screen emits light

proportional to  $R^\gamma$ , with SPD equal to that of the red phosphor paint on the screen that is the target of the red channel electron gun. The value of gamma is around 2.2.

(b) It is customary to append a prime to signals that are **gamma-corrected** by raising to the power  $(1/\gamma)$  before transmission. Thus we arrive at **linear signals**:

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

### 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.

The basic situation is shown in the following figure. A device for carrying out such an experiment is called a **colorimeter**.

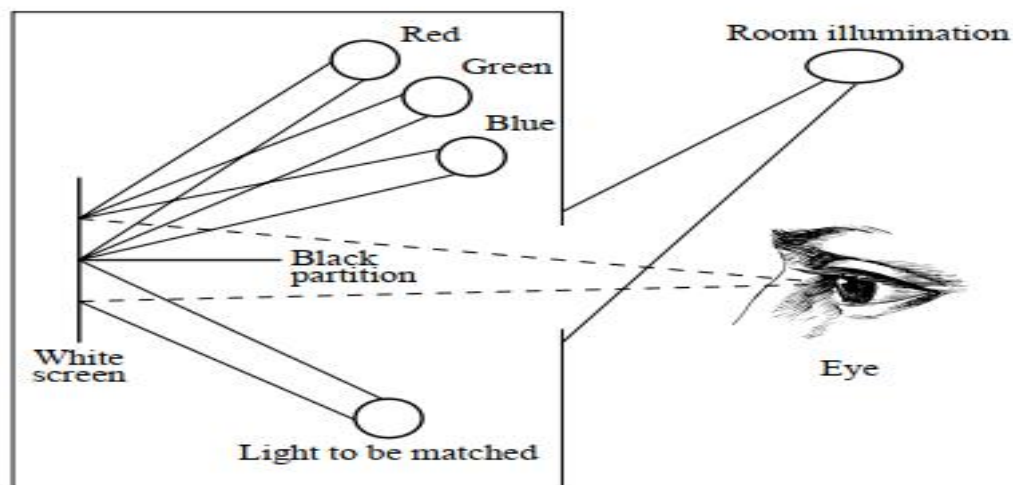


Fig. 4.8: Colorimeter experiment

## 4.2 Color Models in Images

Colors models and spaces used for stored, displayed, and printed images

### RGB Color Model for CRT Displays

- We expect to be able to use 8 bits per color channel for color that is accurate enough.
- However, in fact we have to use about 12 bits per channel to avoid an

aliasing effect in dark image areas | contour bands that result from gamma correction.

- For images produced from computer graphics, we store integers proportional to intensity in the frame buffer. So should have a gamma correction LUT between the frame buffer and the CRT.
- If gamma correction is applied to floats before quantizing to integers, before storage in the frame buffer, then in fact we can use only 8 bits per channel and still avoid contouring artifacts

### Subtractive Color: CMY Color Model

- So far, we have effectively been dealing only with **additive color**. Namely, 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.
- Instead of red, green, and blue primaries, we need primaries that amount to -red, -green, and -blue. I.e., we need to *subtract* R, or G, or B.
- These subtractive color primaries are Cyan (C), Magenta (M) and Yellow (Y) inks.

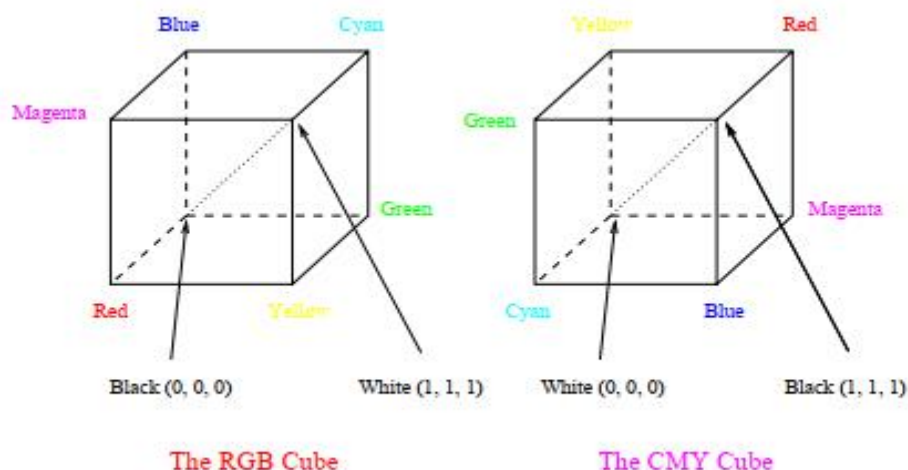


Fig. RGB and CMY color cubes.

**Transformation from RGB to CMY**

Simplest model we can invent to specify what ink density to lay down on paper, to make a certain desired RGB color:

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

Then the inverse transform is:

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

Fig.: color combinations that result from combining primary colors available in the two situations, additive color and subtractive color.

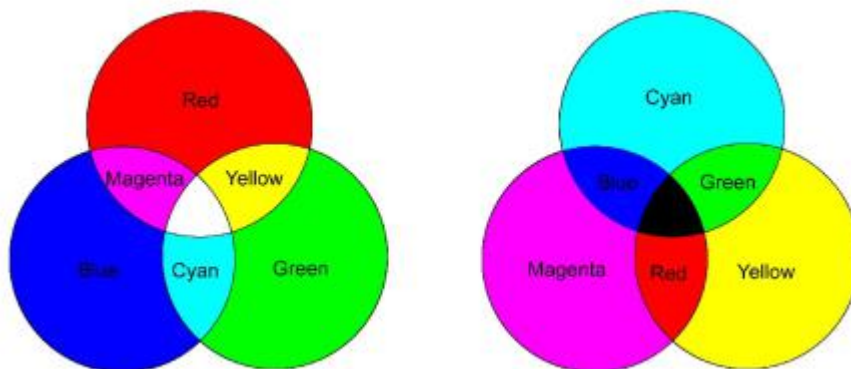


Fig. : Additive and subtractive color. (a): RGB is used to specify additive color. (b): CMY is used to specify subtractive color

**4.3 Color Models in Video****Video Color Transforms**

- Largely derive from older analog methods of coding color for TV. Luminance is separated from color information.
- For example, a matrix transform method called YIQ is used to transmit TV signals in North America and Japan.
- This coding also makes its way into VHS video tape coding in these countries since video tape technologies also use YIQ.



- In Europe, video tape uses the PAL or SECAM codings, which are based on TV that uses a matrix transform called YUV.
- Finally, digital video mostly uses a matrix transform called YCbCr that is closely related to YUV

**YUV Color Model**

- YUV codes a luminance signal (for gamma-corrected signals) equal to  $Y_0$  in the "luma".
- **Chrominance** refers to the difference between a color and a reference white at the same luminance. Use color differences  $U, V$ :  
$$U = B_0 - Y_0 ; V = R_0 - Y_0$$
- Fig. 4.18 shows the decomposition of a color image into its  $Y_0, U, V$  components. Since both  $U$  and  $V$  go negative, in fact the images displayed are shifted and rescaled.

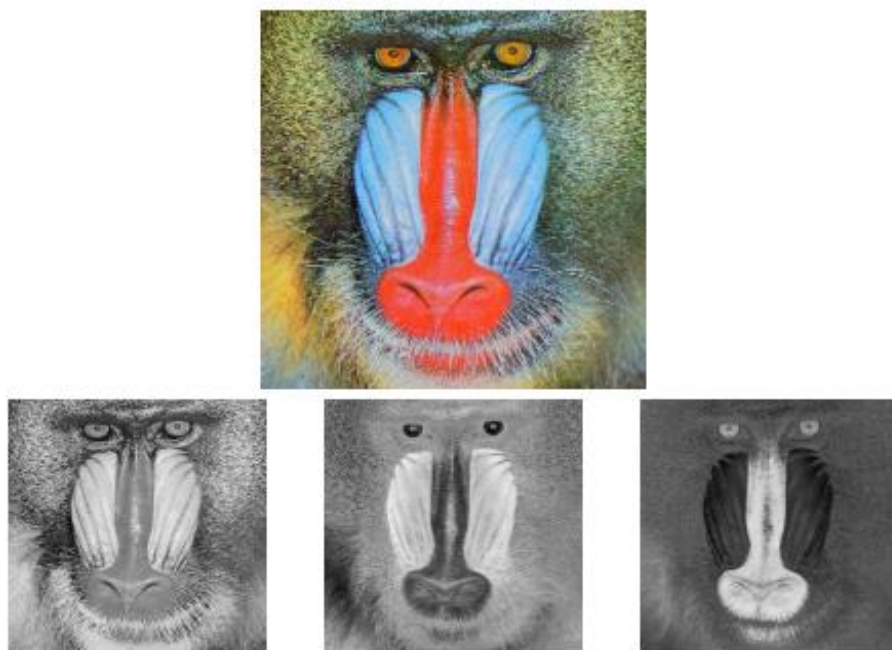


Fig. 4.18:  $Y_0UV$  decomposition of color image. Top image (a) is original color image; (b) is  $Y_0$ ; (c,d) are  $(U; V)$

## YIQ Color Model

YIQ is used in NTSC color TV broadcasting. Again, gray pixels generate zero ( $I$ ;  $Q$ ) chrominance signal.

- $I$  and  $Q$  are a rotated version of  $U$  and  $V$ .
- $Y'$  in YIQ is the same as in YUV;  $U$  and  $V$  are rotated by  $33^\circ$ :

$$I = 0.492111(R0 - Y0) \cos 33^\circ - 0.877283(B0 - Y0) \sin 33^\circ$$

$$Q = 0.492111(R0 - Y0) \sin 33^\circ + 0.877283(B0 - Y0) \cos 33^\circ$$

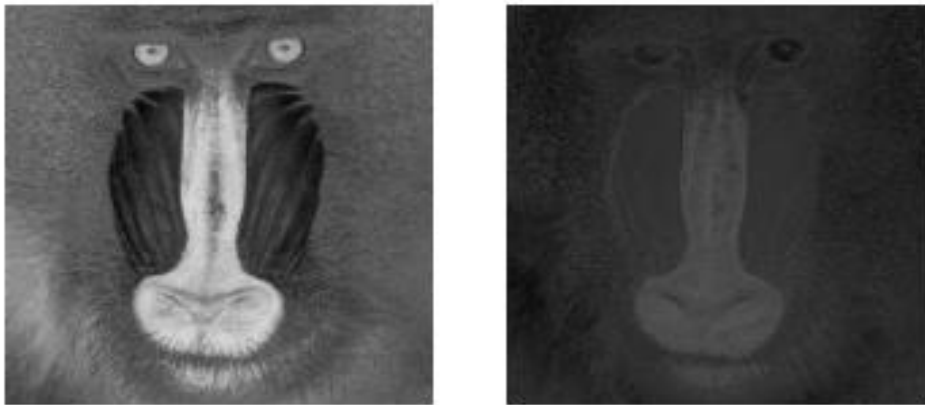


Fig.4.19:  $I$  and  $Q$  components of color image

## YCbCr Color Model

- The Rec. 601 standard for digital video uses another color space,  $YCbCr$ , often simply written YCbCr | closely related to the YUV transform.
- YUV is changed by scaling such that  $Cb$  is  $U$ , but with a coefficient of 0.5 multiplying  $B0$ . In some software systems,  $Cb$  and  $Cr$  are also shifted such that values are between 0 and 1.
- This makes the equations as follows:

$$Cb = ((B0 - Y0) = 1.772) + 0.5$$

$$Cr = ((R0 - Y0) = 1.402) + 0.5$$