Digital Image Processing

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COLOR FUNDAMENTALS

- Although the process employed by the human brain in perceiving and interpreting color is a physio-psychological phenomenon that is not fully understood, the physical nature of color can be expressed on a formal basis supported by experimental and theoretical results.
- In 1666, Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging light is not white, but consists instead of a continuous spectrum of colors ranging from violet at one end to red at the other.
- the color spectrum may be divided into six broad regions: violet, blue, green, yellow, orange, and red.
- No color in the spectrum ends abruptly; each color blends smoothly into the next.

Color fundamentals (cont.)

- 1666, Isaac Newton

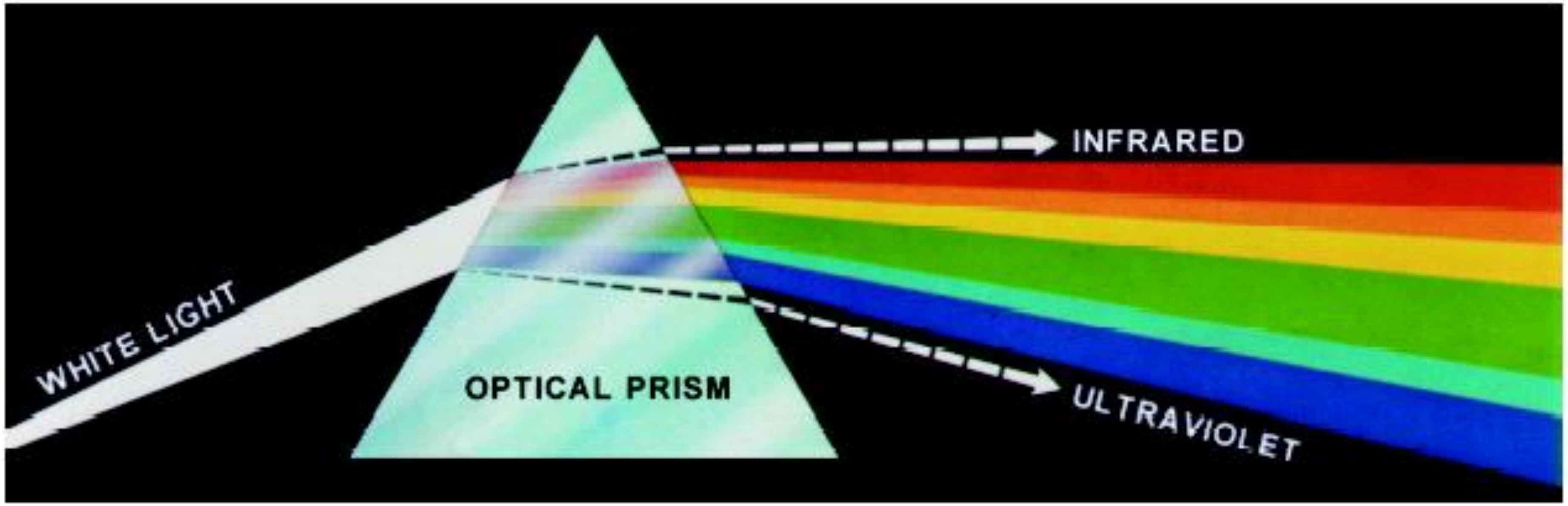


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Color fundamentals (cont.)

- In color image processing, "nm" typically refers to nanometers, which is a unit of measurement used to specify the wavelength of light. The visible spectrum of light ranges from approximately 400nm (violet) to 700nm (red).
- In this context, nm is often used to describe the color properties of light or filters used in image processing. For example, a camera or a display may have filters that allow only certain wavelengths of light to pass through, resulting in specific color reproduction. In such cases, the filters may be described in terms of their cutoff wavelengths in nm.

Visible light

- Chromatic light span the electromagnetic spectrum (EM) from 400 to 700 nm

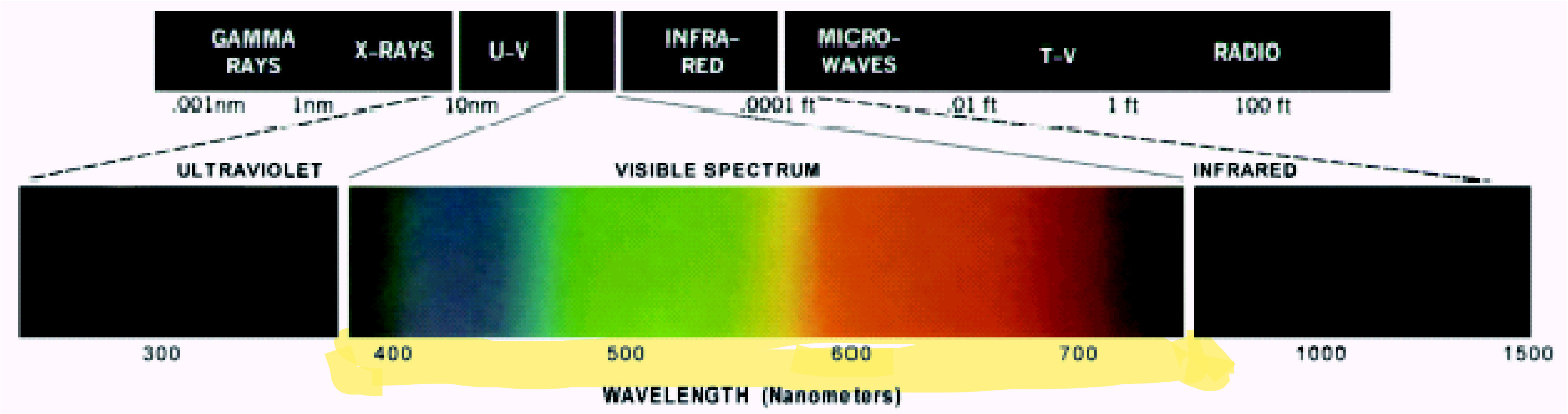


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

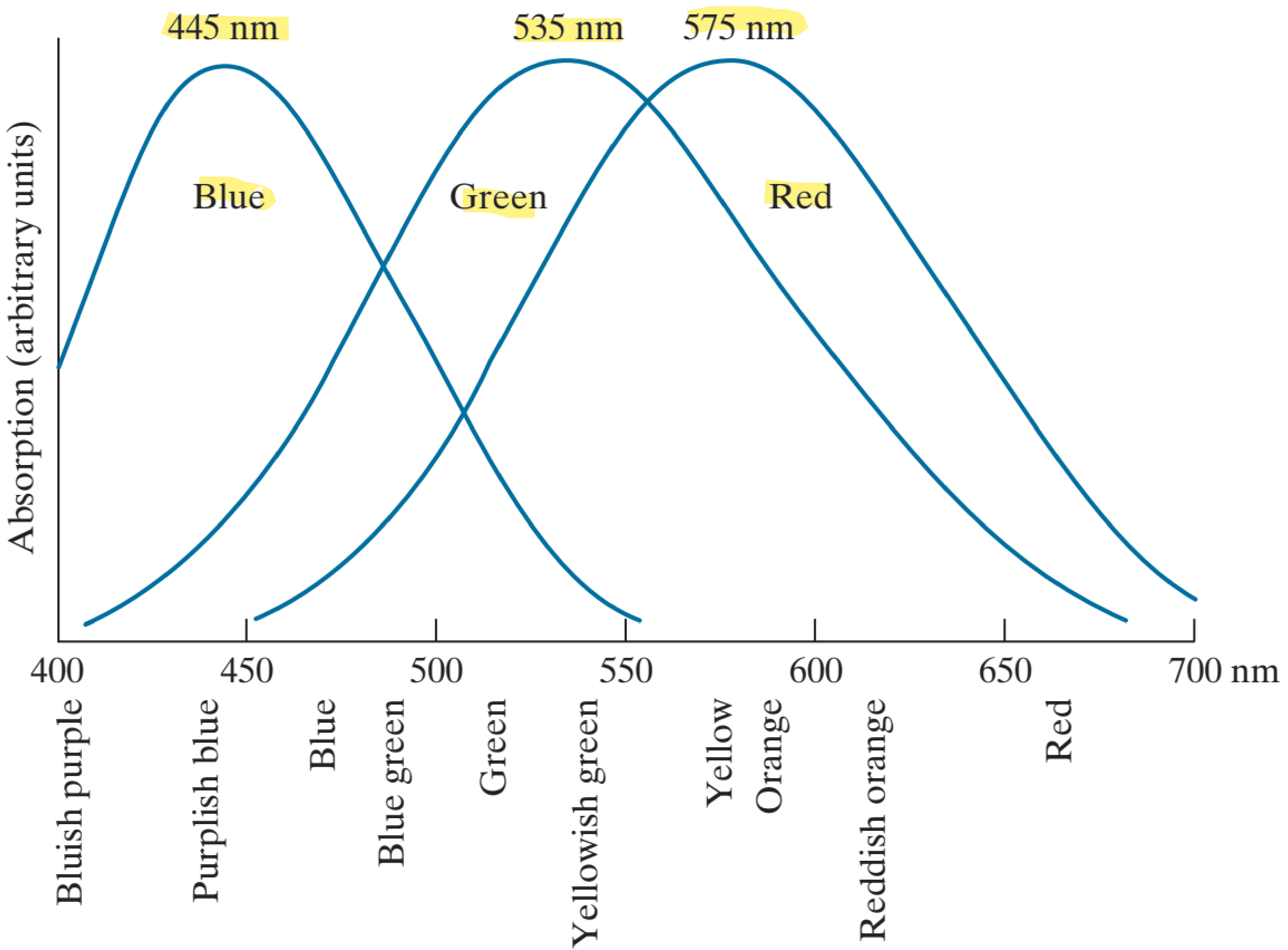
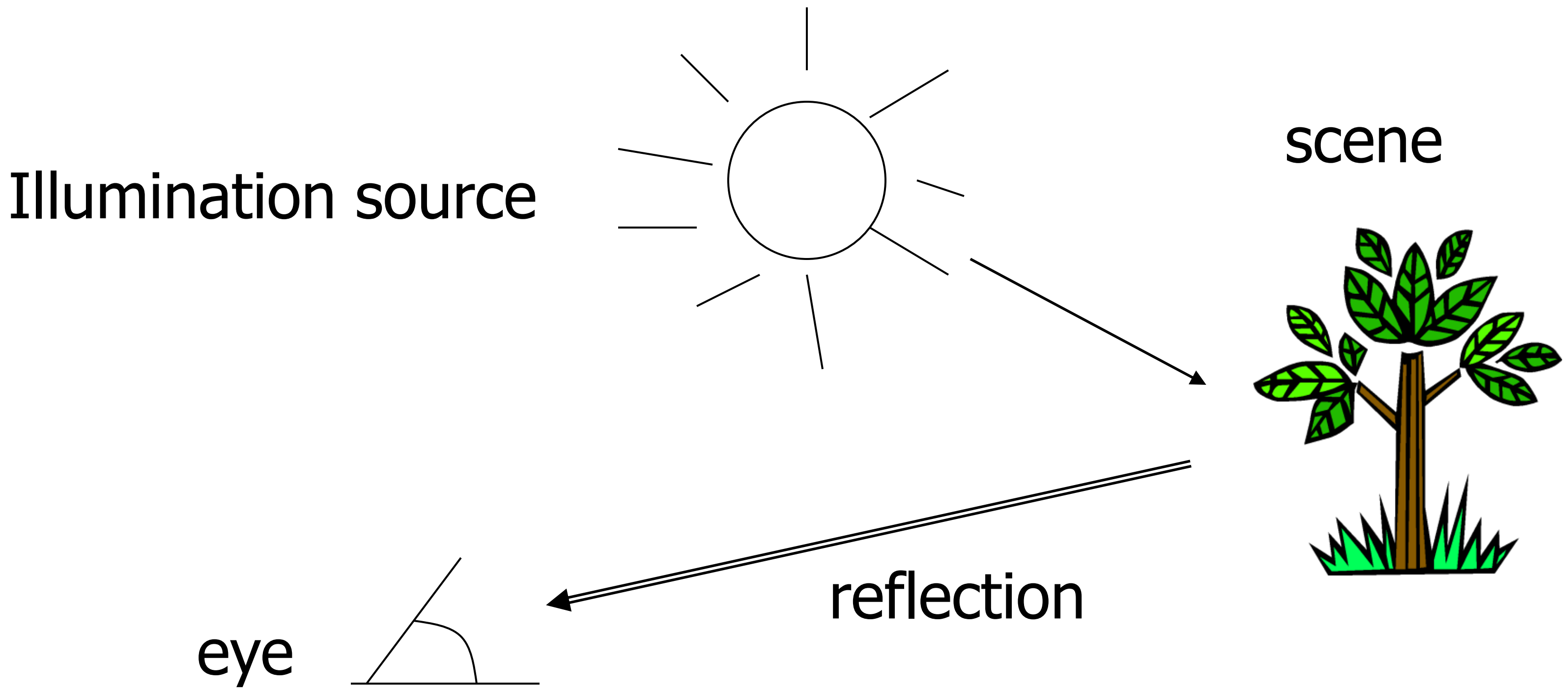


FIGURE 6.3
Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Color fundamentals (cont.)

- The color that human perceive in an object = the light reflected from the object



Physical quantities to describe a chromatic light source

- Radiance: total amount of energy that flow from the light source, measured in watts (W)
- Luminance: amount of energy an observer *perceives* from a light source, measured in lumens (lm)
  - Far infrared light: high radiance, but 0 luminance
- Brightness: subjective descriptor that is hard to measure, similar to the achromatic notion of intensity

How human eyes sense light?

- 6~7M Cones are the sensors in the eye
- 3 principal sensing categories in eyes
  - Red light 65%, green light 33%, and blue light 2%

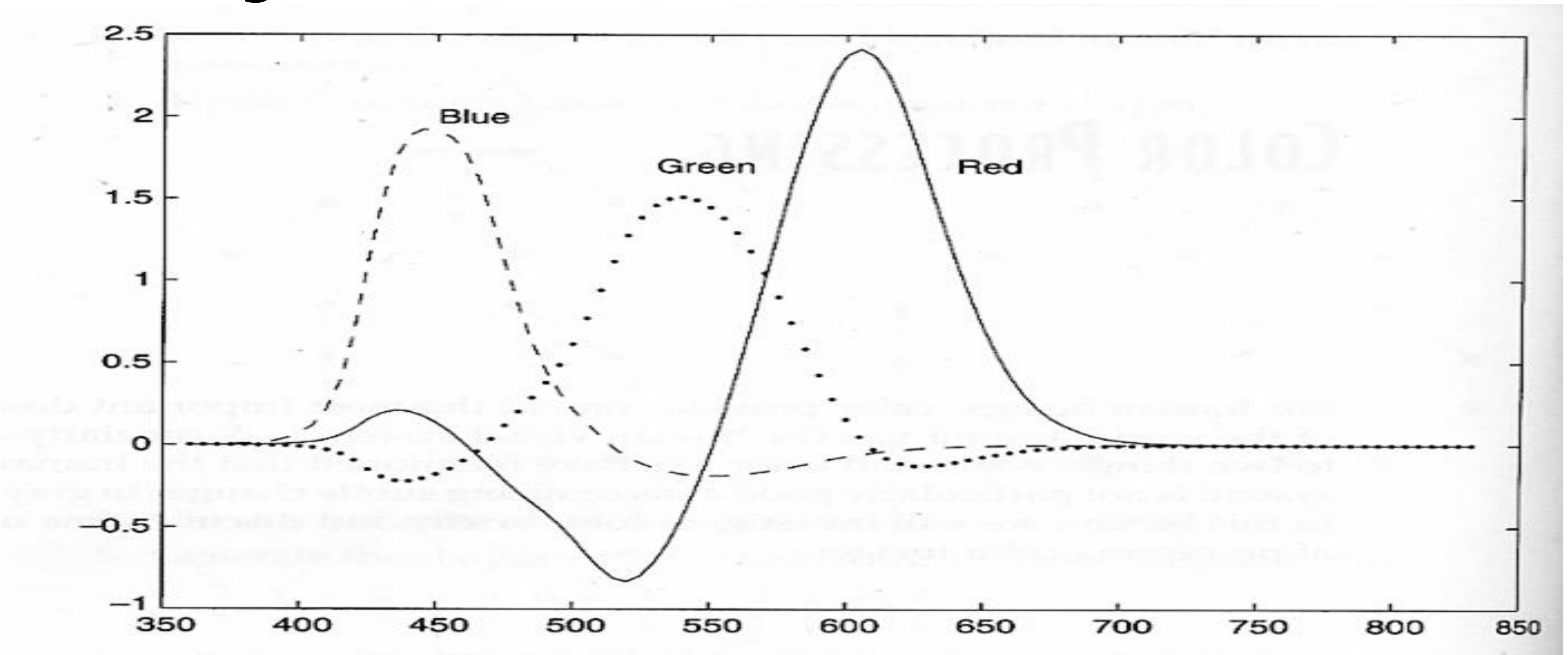
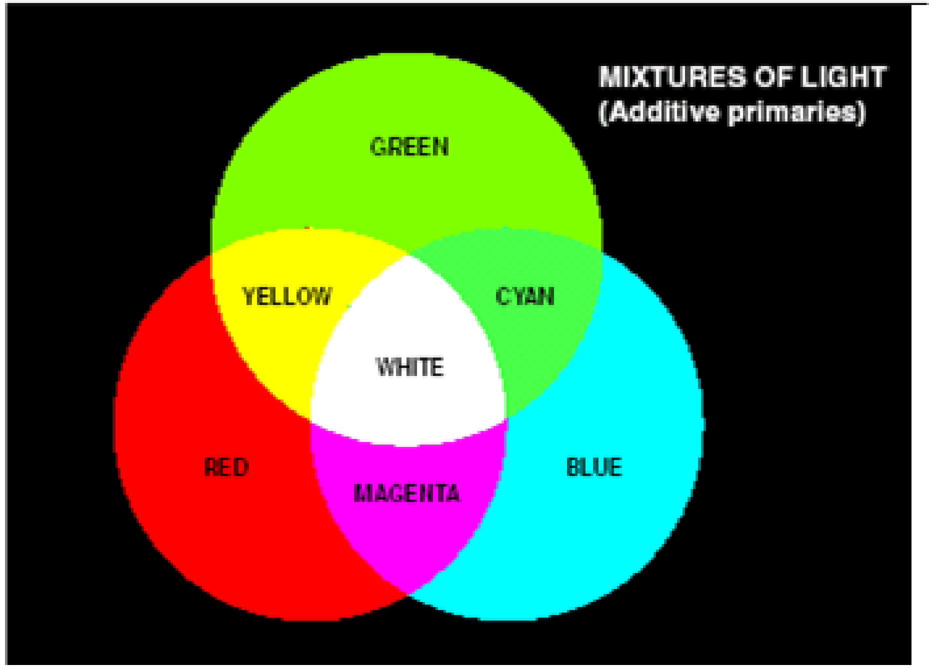
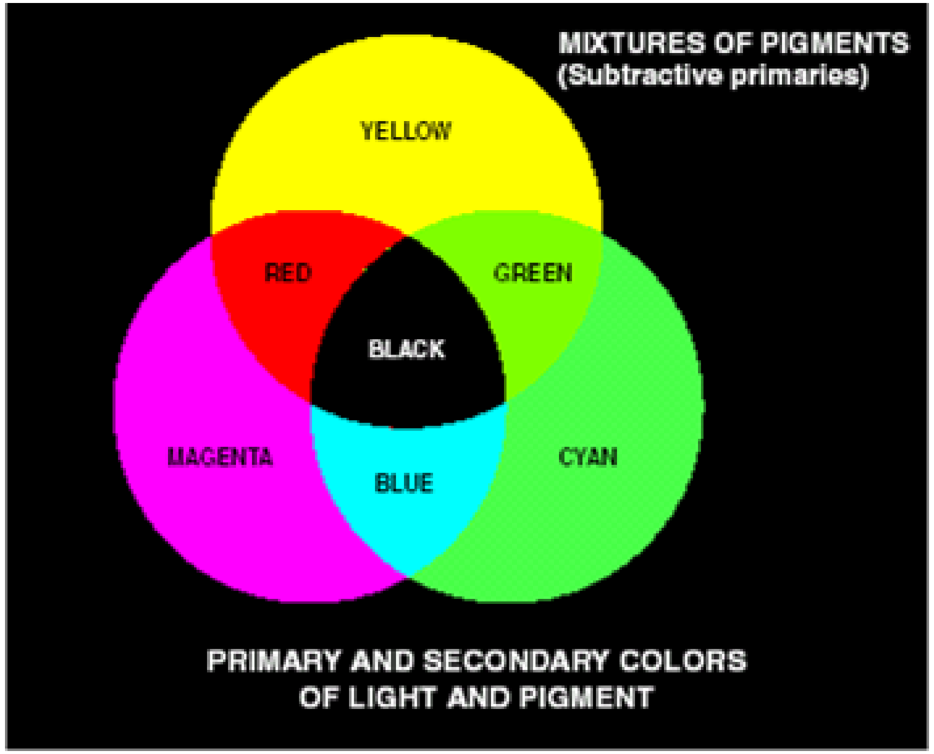


FIGURE B.1 *RGB color-matching functions (CIE, 1931).*

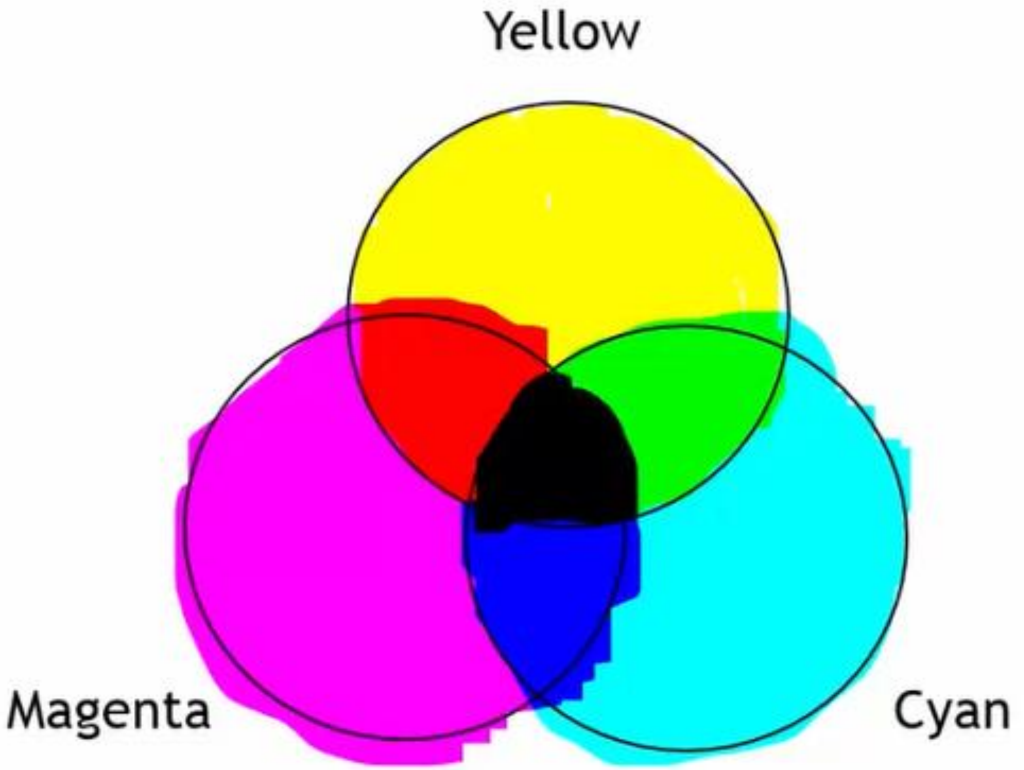
Primary and secondary colors

- In 1931, CIE(International Commission on Illumination) defines specific wavelength values to the primary colors
  - B = 435.8 nm, G = 546.1 nm, R = 700 nm
  - However, we know that no single color may be called red, green, or blue
- Secondary colors: G+B=Cyan, R+G=Yellow, R+B=Magenta





PRIMARY AND SECONDARY COLORS
OF LIGHT AND PIGMENT

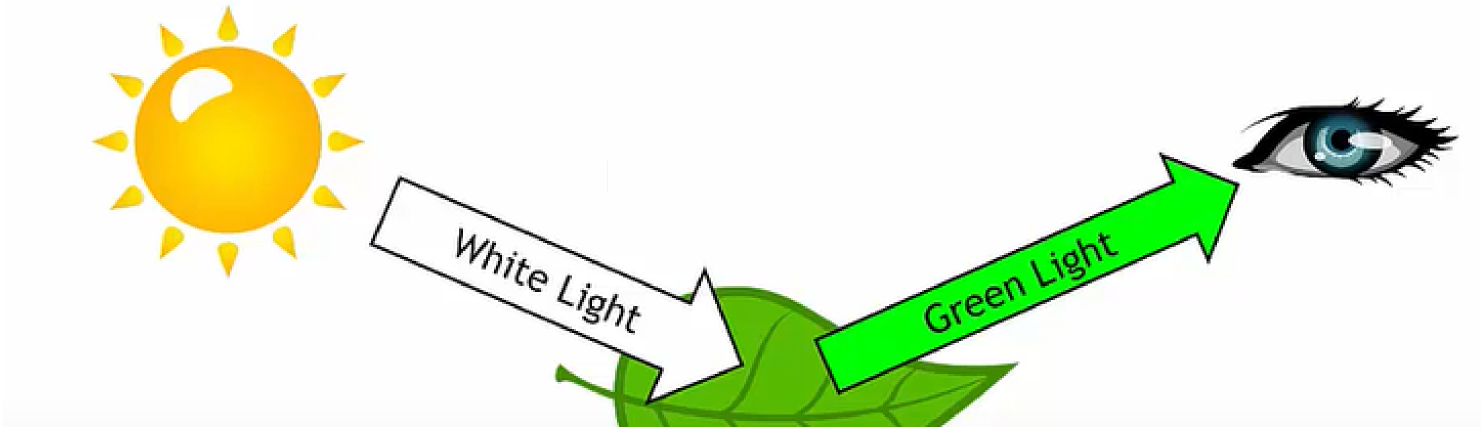

Yellow
Magenta
Cyan

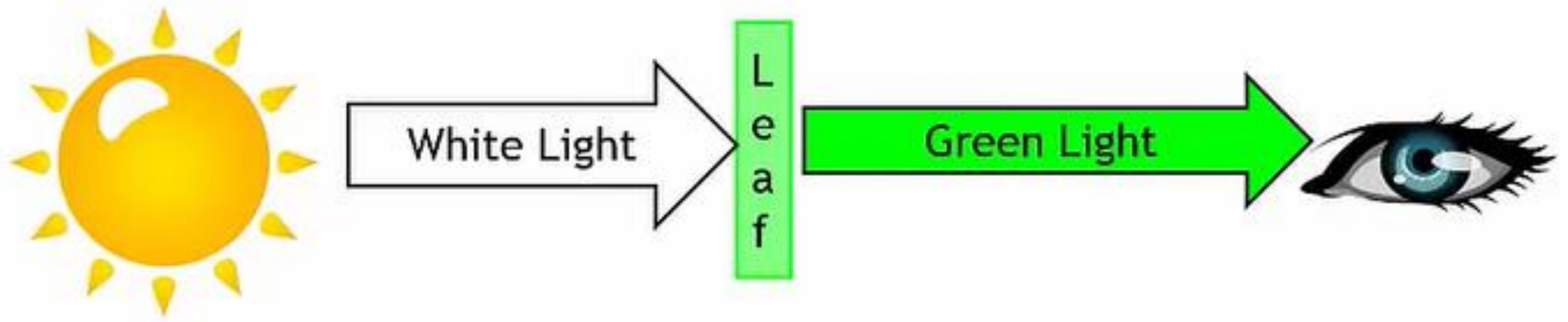
Mixing of colors

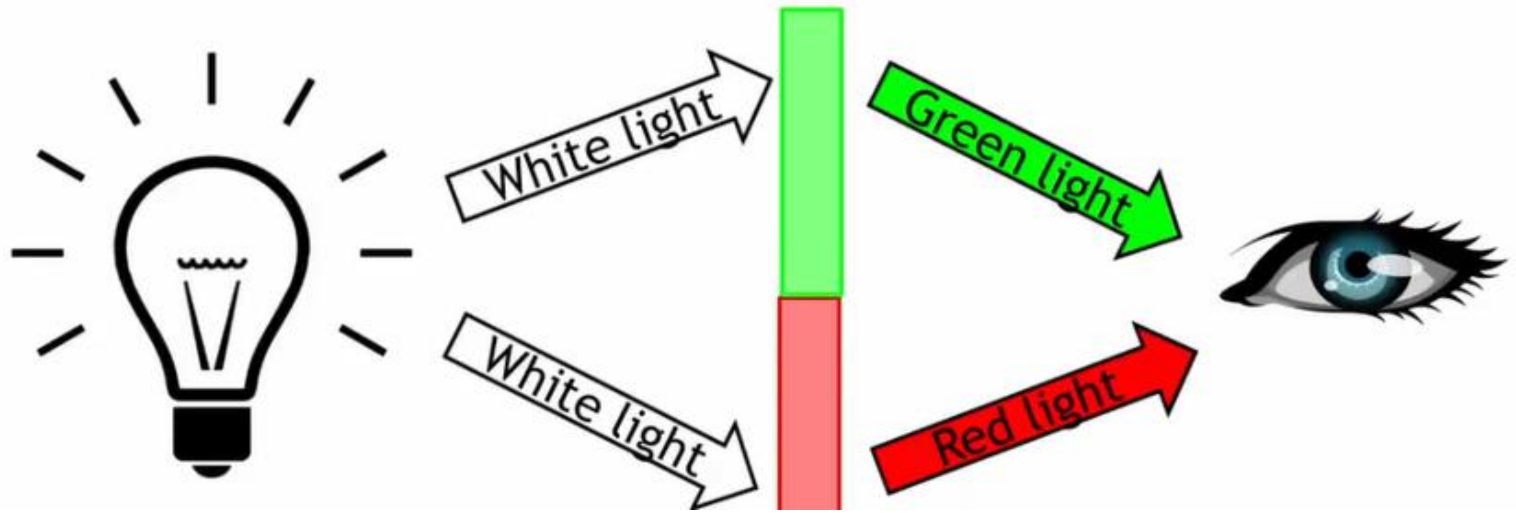
- 2 types of mixing of colors.
- Mixing of colors using LIGHT
- Mixing of colors using PAINT
    - For example, using paints, color pencils, crayons etc.
- When we mix colors using light, it is as standard primary color addition diagram.
- All TV, laptop, tablets and handphone screens' colors are obtained using this concept of different RGB light levels as taught in the previous lesson.

Mixing colors using paints

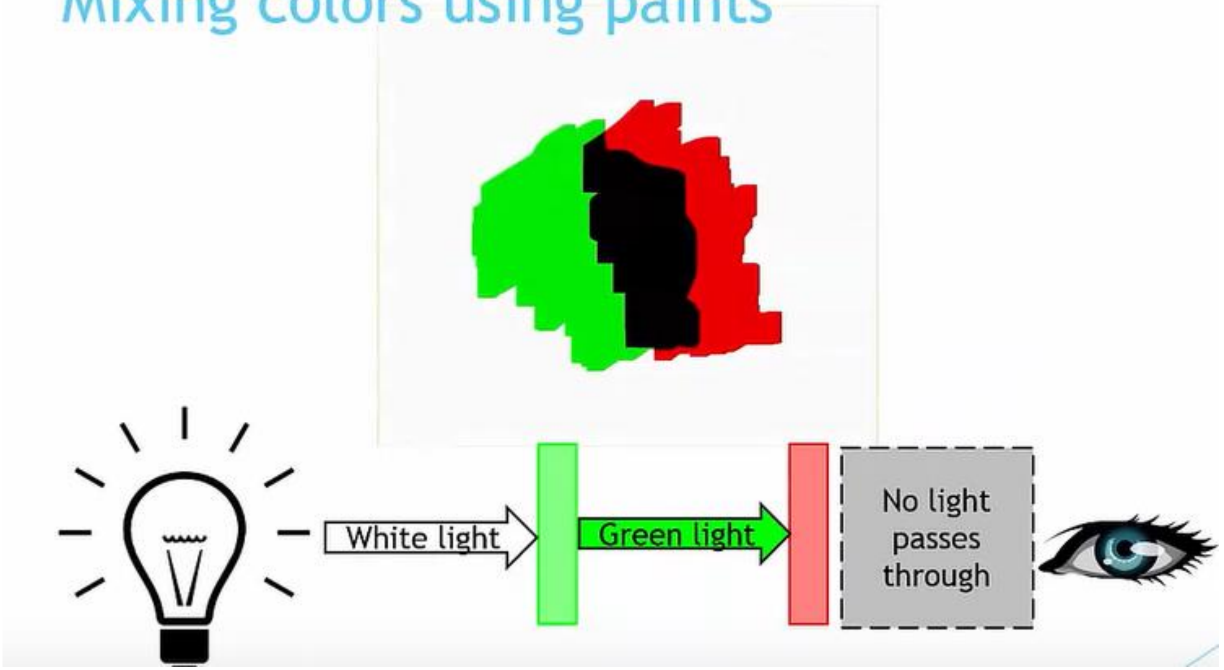
- To explain why mixing color using paints differ from using light, we have to first understand why how do we see colors of an object.







Mixing colors using paints



Mixture of Light and Pigment

- The mixture of light and pigment refers to the combination of these two elements in the context of color perception. Light and pigment are two different ways in which colors can be produced and perceived.
- Light is composed of different wavelengths, and when all the wavelengths of visible light are combined, they create white light. The primary colors of light are red, green, and blue (RGB), and by combining different intensities of these colors, a wide range of colors can be created. This is the additive color model, commonly used in electronic displays such as computer monitors and televisions.
- On the other hand, pigment refers to colored substances that selectively absorb certain wavelengths of light and reflect others. When pigments are mixed or applied to a surface, they absorb certain colors of light and reflect the remaining ones, creating the perception of color. The primary colors of pigments are cyan, magenta, and yellow (CMY), and by mixing different amounts of these pigments, a variety of colors can be obtained. This is the subtractive color model, used in mediums like paint, ink, and printing.

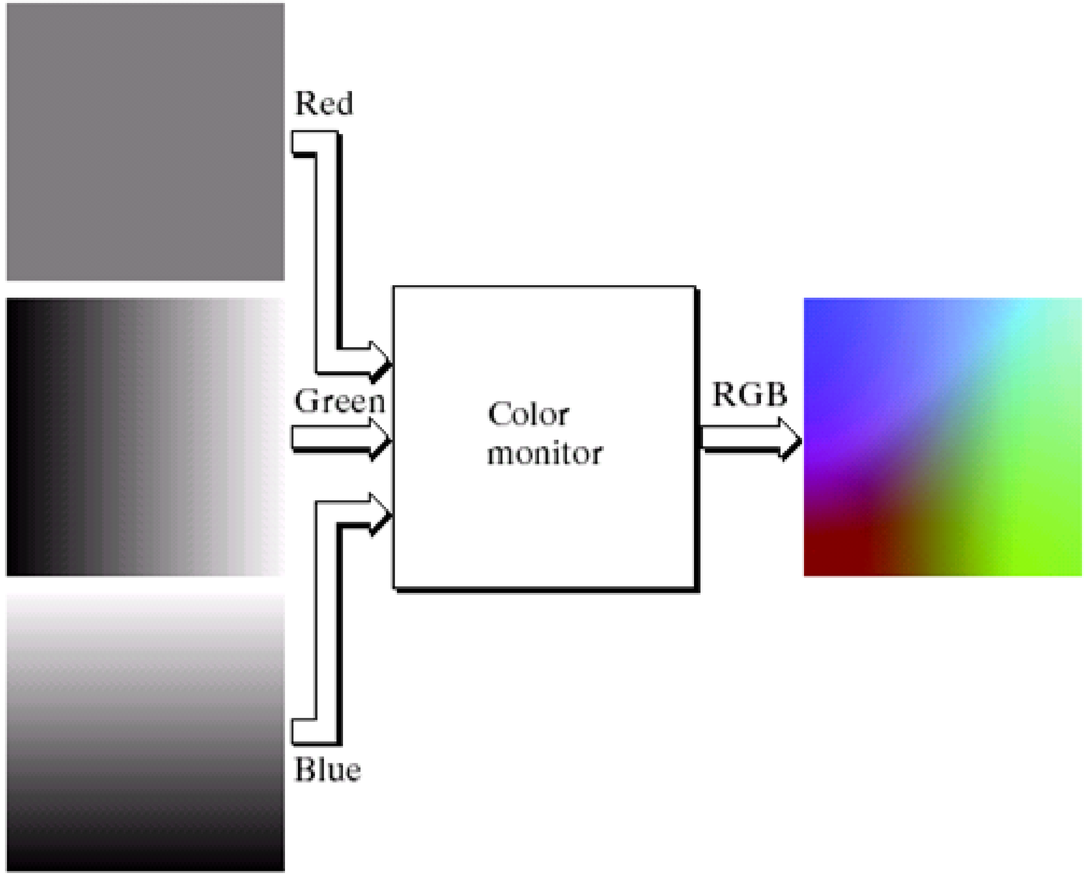
Primary colors of light v.s. primary colors of pigments

- Primary color of pigments
  - Color that subtracts or absorbs a primary color of light and reflects or transmits the other two

Color of light:	R	G	B
	↓	↓	↓
Color of pigments:	absorb R Cyan	absorb G Magenta	absorb B Yellow

Application of additive nature of light colors

- Color TV



Color models

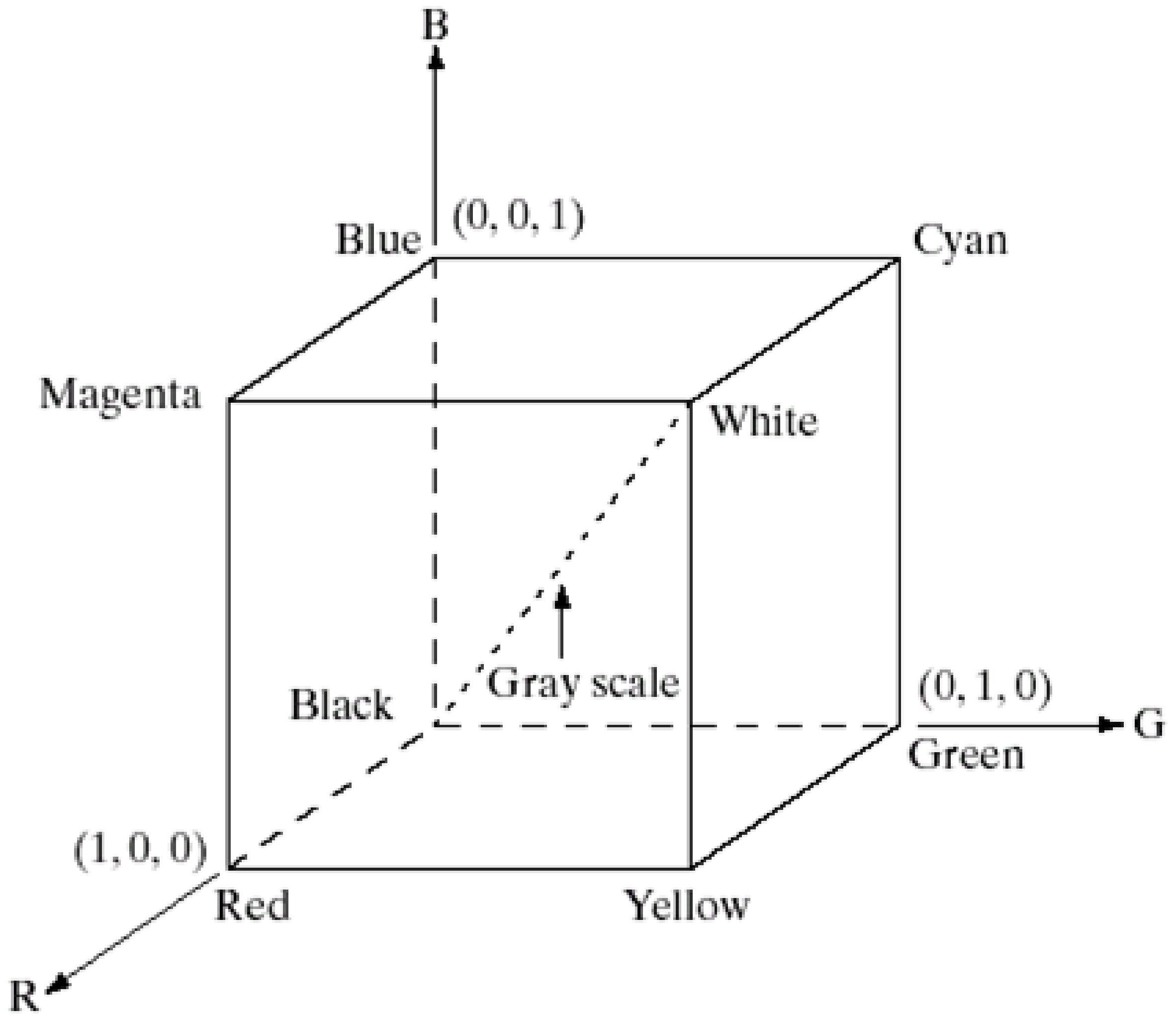
- Color model, color space, color system
  - Specify colors in a standard way
  - A coordinate system that each color is represented by a single point

- RGB model
- CMY model
- CMYK model
- HSI model

Suitable for hardware or applications

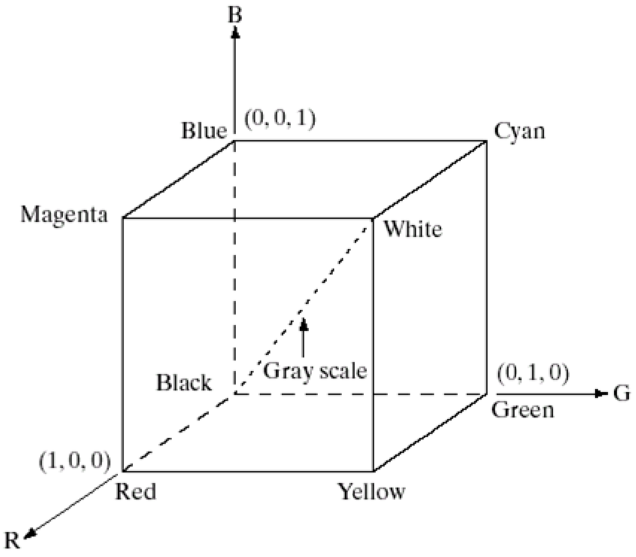
- match the human description

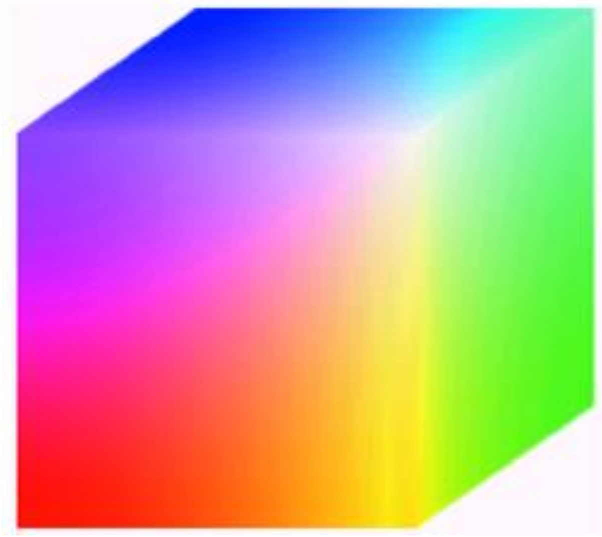
RGB color model



Pixel depth

- Pixel depth: the number of bits used to represent each pixel in RGB space
- Full-color image: 24-bit RGB color image
  - (R, G, B) = (8 bits, 8 bits, 8 bits)

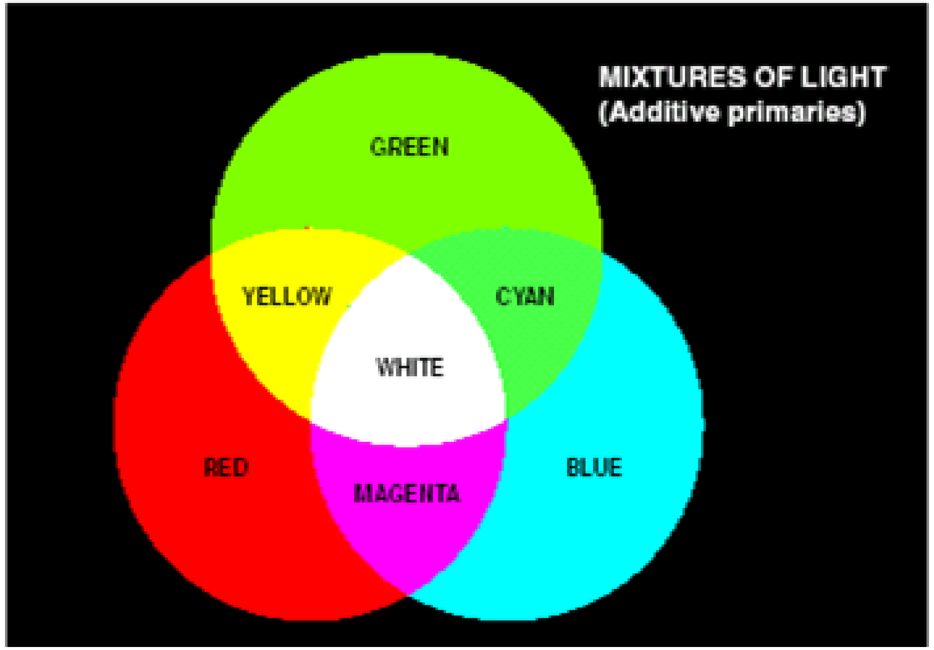




CMY model (+Black = CMYK)

- CMY: secondary colors of light, or primary colors of pigments.
- Used to generate hardcopy output

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



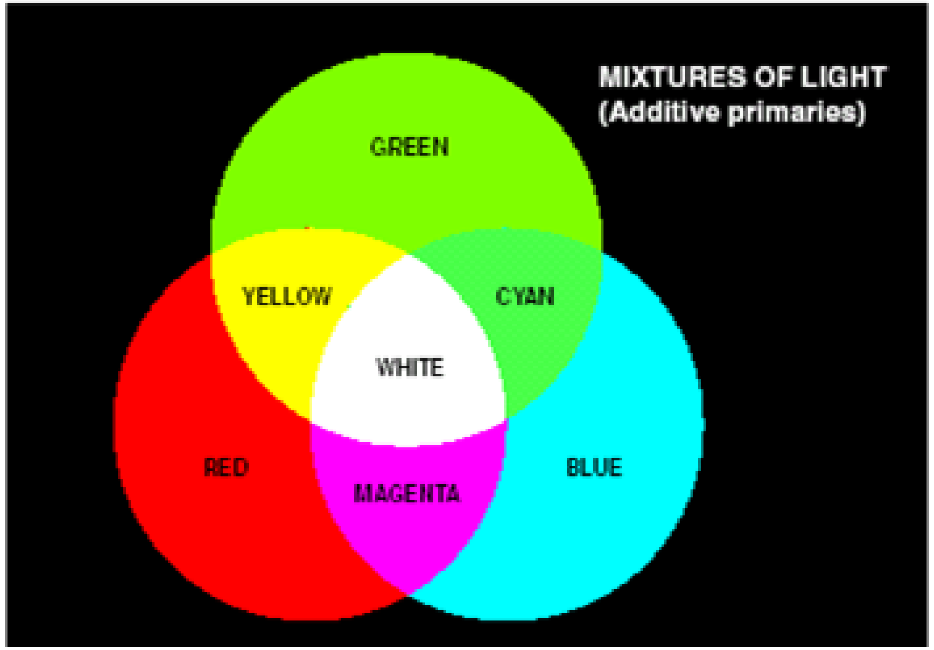
RGB to CMY conversion

- RGB vales(29, 98, 128)
- First convert it into double by dividing 255.
- R = 29/255 = 0.113
- G = 98/255 = 0.384
- B = 128/255 = 0.501
- Now calculate the C M Y
- C = Blue + Green OR White – R = 1 – 0.113 = 0.887
- M = Red + blue OR White – G = 1 – 0.384 = 0.616
- Y = Green + Red OR white – Blue = 1 – 0.51 = 0.499

CMY model (+Black = CMYK)

- CMY: secondary colors of light, or primary colors of pigments.
- Used to generate hardcopy output

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



HSI color model

- Will you describe a color using its R, G, B components?
- Humans describe a color by its hue, saturation, and brightness
  - Hue: color attribute
  - Saturation: purity of color
  - Brightness: the achromatic notion of intensity

RGB to HSI conversion

- R = 28
- G = 98
- B = 118
- Divide each value by 255
- R = 28/255 = 0.1098
- G = 98/255 = 0.3843
- B = 118/255 = 0.4627
- Now calculate the value of HSI

RGB to HSI

- I = 1/3[(R+G+B)] = 1/3(0.1098 + 0.3843 + 0.4627) = 0.93/3 = 0.3190
- S = 1 – (3/R+G+B) min(R,G,B) = 1 – (3/(0.1098 + 0.3843 + 0.4627)* (0.1098) = 0.6557

$$\text{theta} = \cos^{-1}\left(\frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\sqrt{(R-G)^2+(R-B)(G-B)}}\right) \quad \begin{cases} \text{theta} & B \le G \\ 360 - \text{thets} & B > G \end{cases}$$

RGB to HSI

$$\cos^{-1}\left[\frac{1/2\left(\left(0.1098-0.3843\right)+\left(0.1098-0.4627\right)\right)}{\sqrt{\left(\left(0.1098-0.3843\right)+\left(0.1098-0.4627\right)*\left(0.3843-0.4627\right)\right)}}\right]$$

$$\text{Theta} = \cos^{-1}\left(-0.9774\right) = 167.78$$

$$\text{Theta} = 360 - 167.78 = 192.21$$

RGB to YUV

- Step 1: Write down the RGB values The RGB values for this example are as follows:
- R=49, G=128, B=98.
- Step 2: Convert RGB to YUV using the following formulas:
- $Y = 0.299R + 0.587G + 0.114B$
- $U = -0.147R - 0.289G + 0.436B$
- $V = 0.615R - 0.515G - 0.100B$
- Step 3: Calculate YUV values Using the formulas above, we can calculate the YUV values as follows:
- $Y = 0.299(49) + 0.587(128) + 0.114(98) = 97.732$
- $U = -0.147(49) - 0.289(128) + 0.436(98) = -14.701$
- $V = 0.615(49) - 0.515(128) - 0.100(98) = 48.272$
- RGB stands for red, blue and green and YUV stands for **(Y) luma, or brightness**, (U) blue projection and (V) red projection.

RGB to YUV

- Step 4: Round the YUV values to integers The YUV values are typically rounded to the nearest integer to simplify processing and reduce memory requirements. In this case, we would round Y to 98, U to -15, and V to 48.
- Step 5: Write down the YUV values The final YUV values for this example are as follows: Y=98, U=-15, V=48.

Color pixel

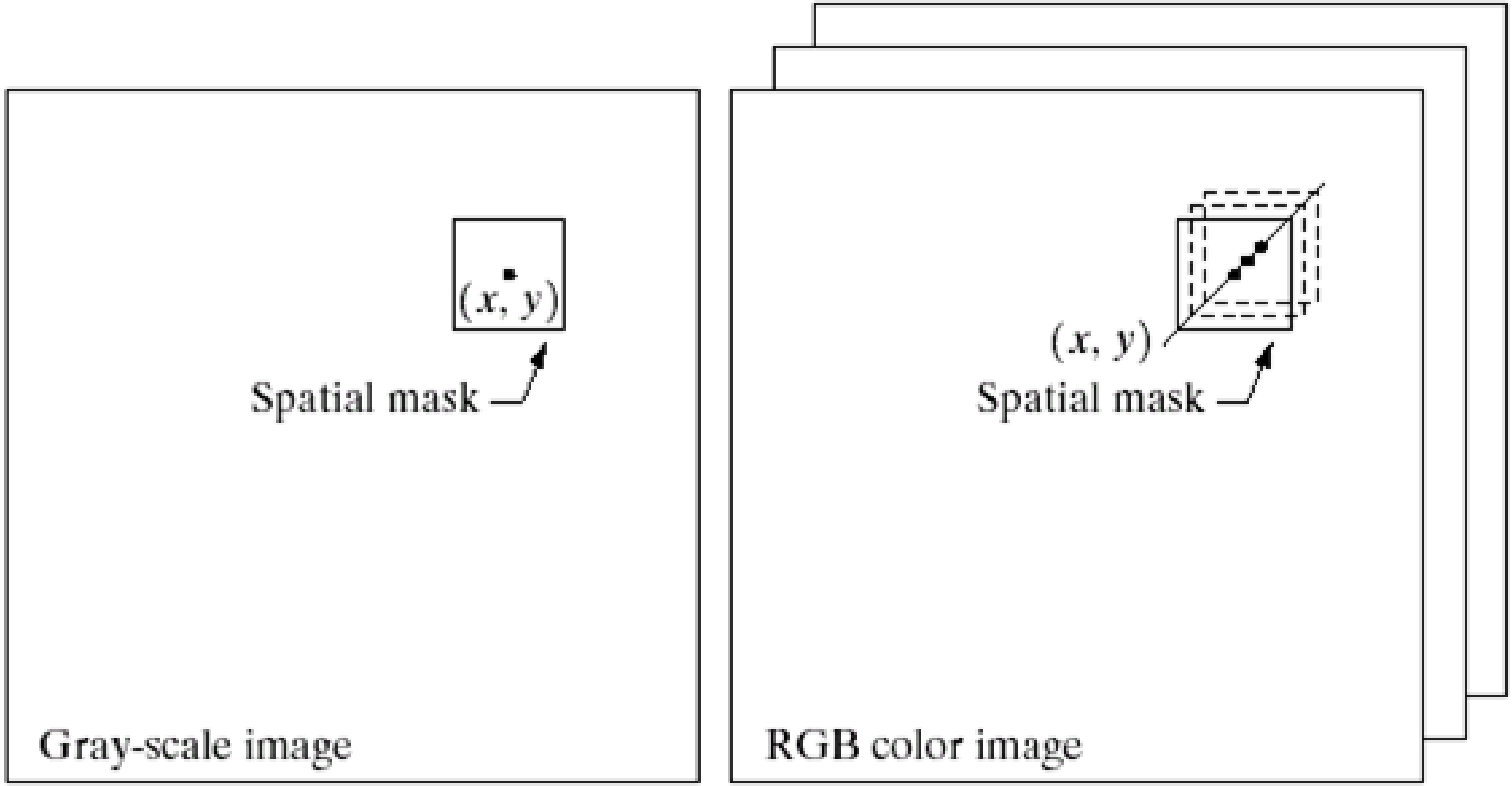
- A pixel at (x,y) is a vector in the color space
  - RGB color space

$$\mathbf{c}(x,y) = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

c.f. gray-scale image

f(x,y) = I(x,y)

Example: spatial mask



How to deal with color vector?

- Per-color-component processing
  - Process each color component
- Vector-based processing
  - Process the color vector of each pixel
- When can the above methods be equivalent?
  - Process can be applied to both scalars and vectors
  - Operation on each component of a vector must be independent of the other component

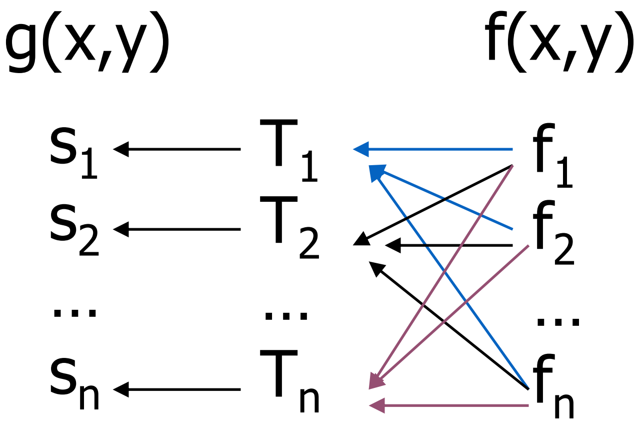
Two spatial processing categories

- Similar to gray scale processing studied before, we have to major categories
- Pixel-wise processing
- Neighborhood processing

Color transformation

- Similar to gray scale transformation
  - g(x,y)=T[f(x,y)]
- Color transformation

$$s_i = T_i(r_1, r_2, \ldots, r_n), \quad i = 1,2,\ldots,n$$

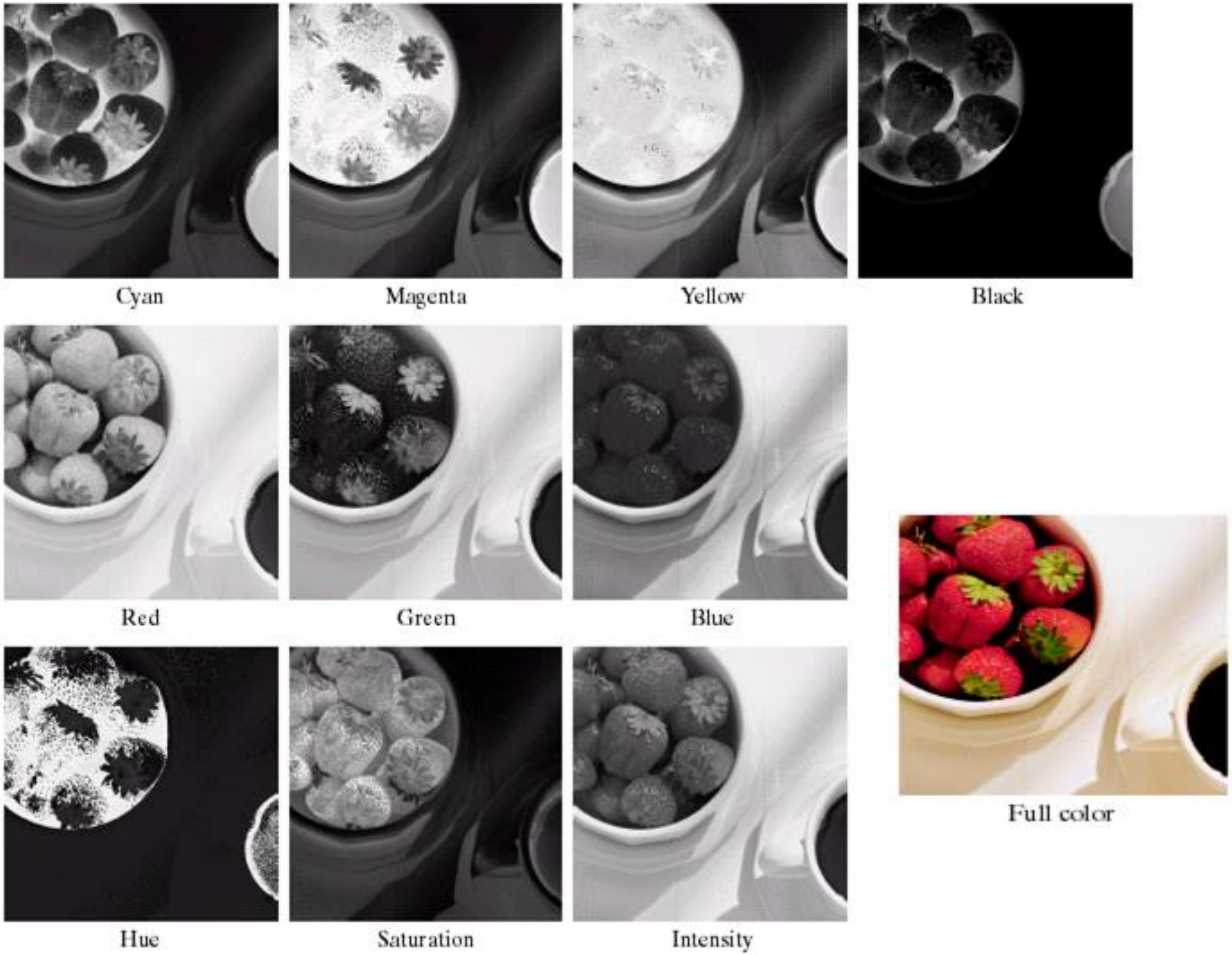


Use which color model in color transformation?

- RGB ⇔CMY(K) ⇔ HSI
- Theoretically, any transformation can be performed in any color model
- Practically, some operations are better suited to specific color model

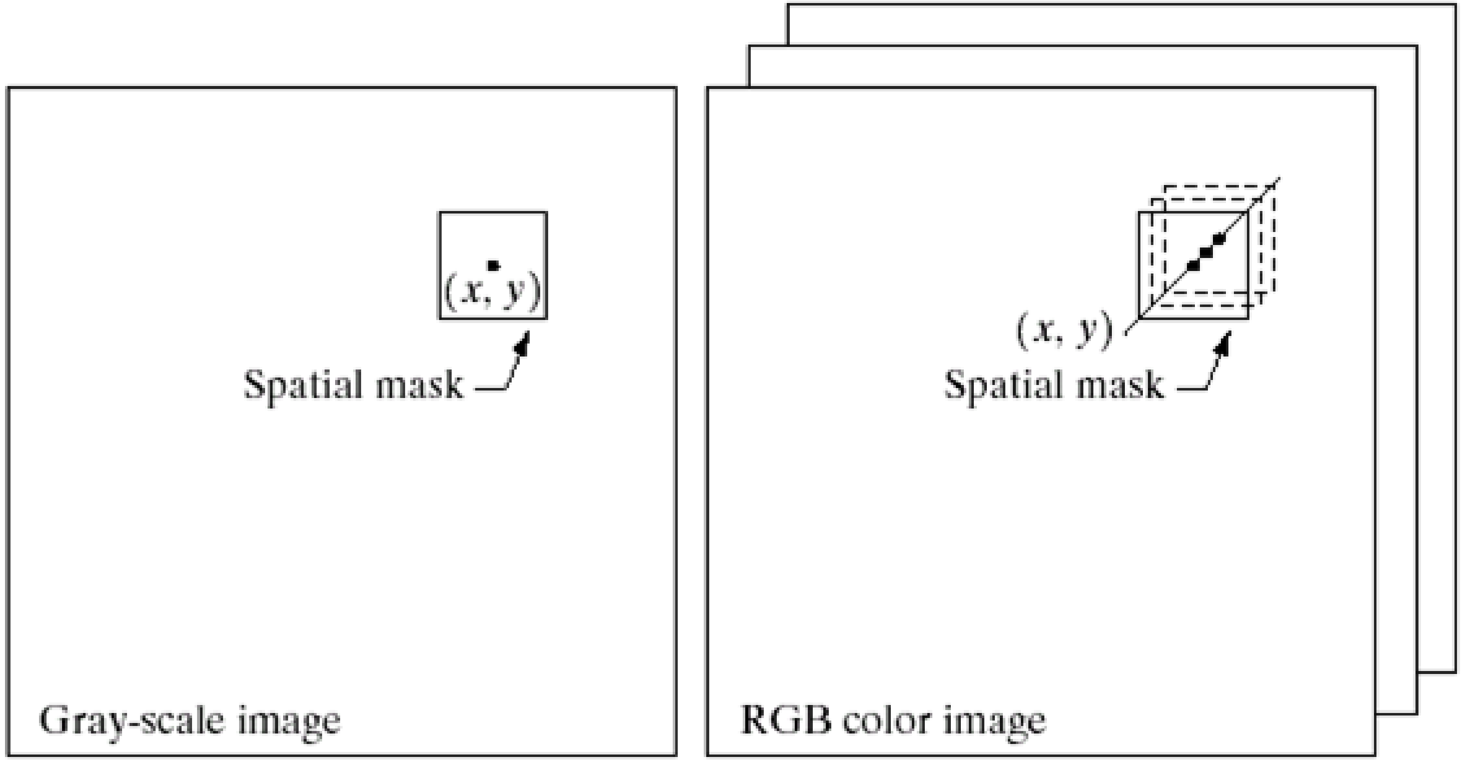
Conversion of RGB to Grayscale

- The formula for converting RGB to grayscale using weighted averages is:
- $\text{Grayscale} = 0.2989 \times \text{Red} + 0.5870 \times \text{Green} + 0.1140 \times \text{Blue}$


Cyan
Magenta
Yellow
Black
Red
Green
Blue
Hue
Saturation
Intensity
Full color

Color image smoothing

- Neighborhood processing



Color image smoothing: averaging mask

$$\bar{\mathbf{c}}(x,y) = \frac{1}{K} \sum_{(x,y)\in S_{xy}} \mathbf{c}(x,y)$$

vector processing

Neighborhood
Centered at (x,y)

$$\bar{\mathbf{c}}(x,y) = \begin{bmatrix} \frac{1}{K} \sum_{(x,y)\in S_{xy}} R(x,y) \\ \frac{1}{K} \sum_{(x,y)\in S_{xy}} G(x,y) \\ \frac{1}{K} \sum_{(x,y)\in S_{xy}} B(x,y) \end{bmatrix}$$

per-component processing


original
R
G
B
H
S
I

Example: 5x5 smoothing mask

RGB model

Smooth I
in HSI model

difference

a b c

FIGURE 6.40 Image smoothing with a 5×5 averaging mask. (a) Result of processing each RGB component image. (b) Result of processing the intensity component of the HSI image and converting to RGB. (c) Difference between the two results.