

Color Fundamentals

The experiment of Sir Isaac Newton, in 1666.

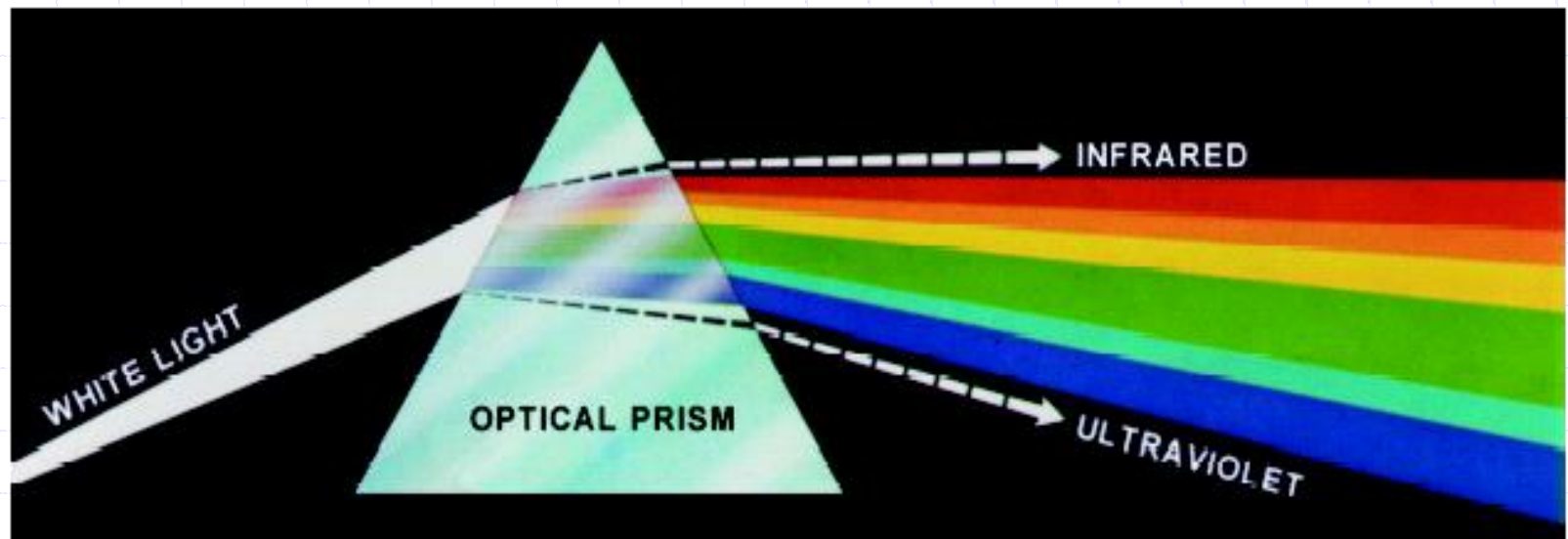
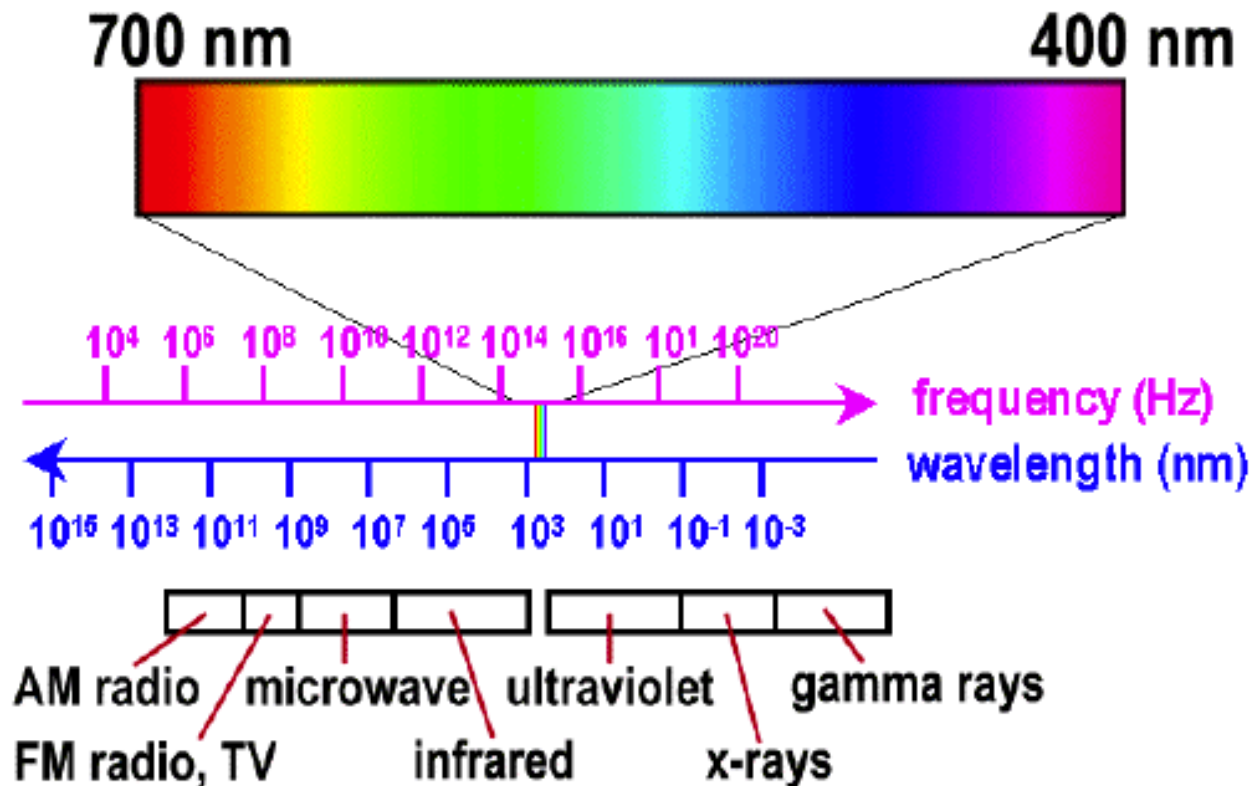


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Visible Light



Color Fundamentals (con't)

Standard wavelength values for the primary colors

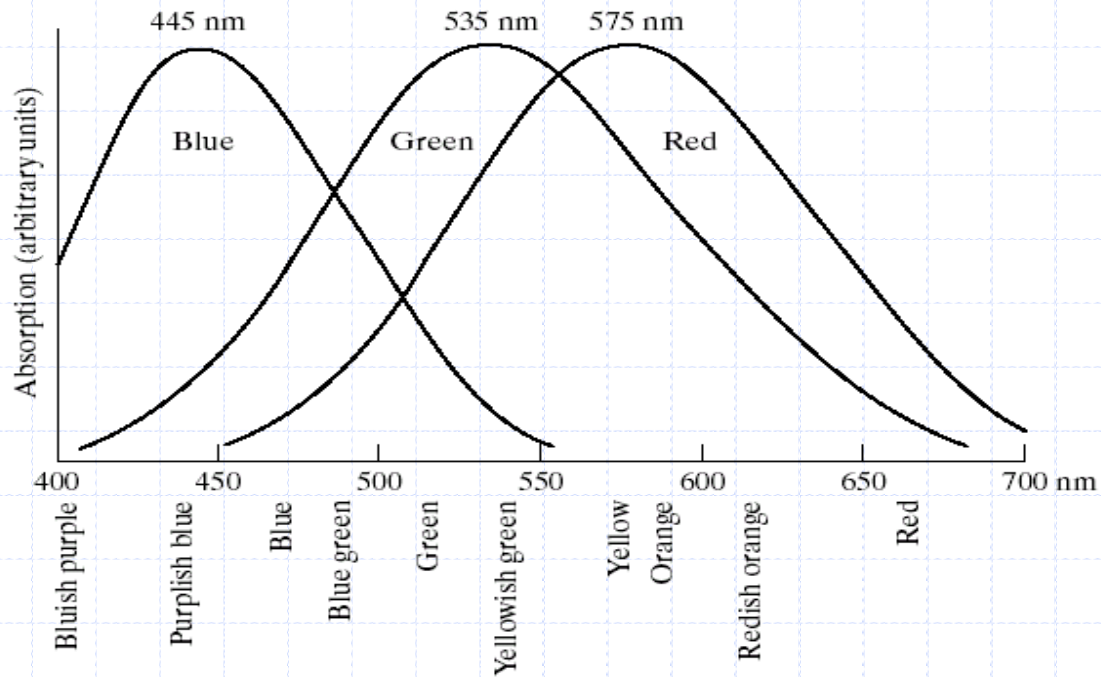
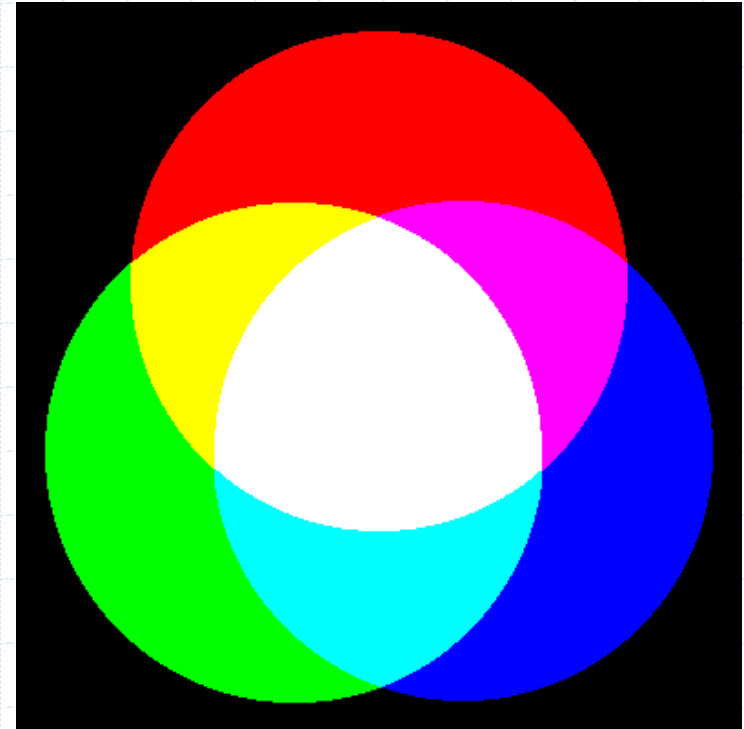


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Color Fundamentals (con't)

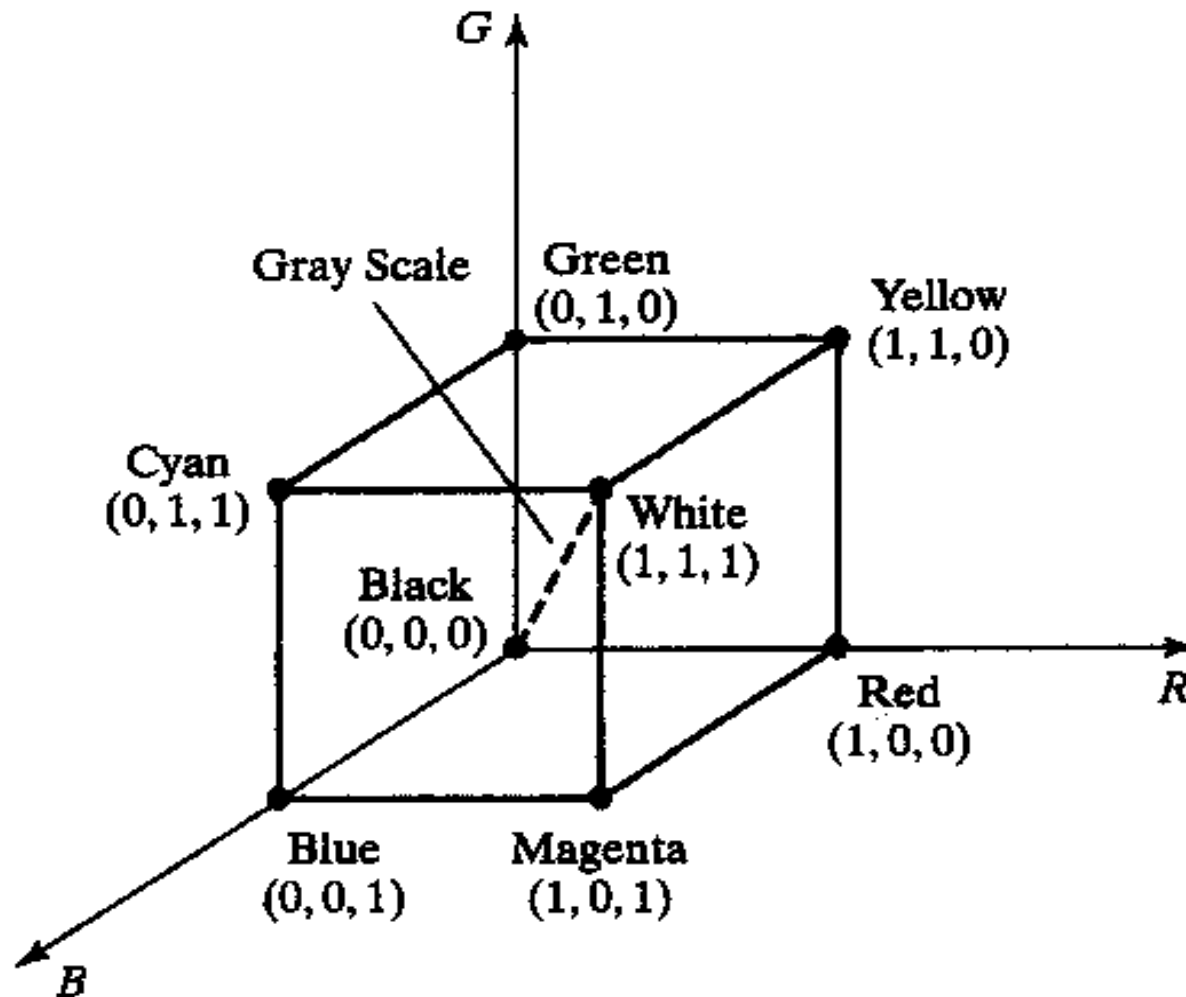
- **Basic quantities to describe the quality of light source:**
 - **Radiance:** Total amount of energy that flows from the light source (in W)
 - **Luminance:** A measure of the amount of energy an observer perceives from the light source (in lm)
 - **Brightness:** A subjective descriptor that embodies the achromatic notion of intensity and is practically impossible to measure

RGB Color model



Active displays, such as computer monitors and television sets, emit combinations of red, green and blue light. This is an **additive** color model

The RGB Color Spaces



The RGB Color Models (con't)

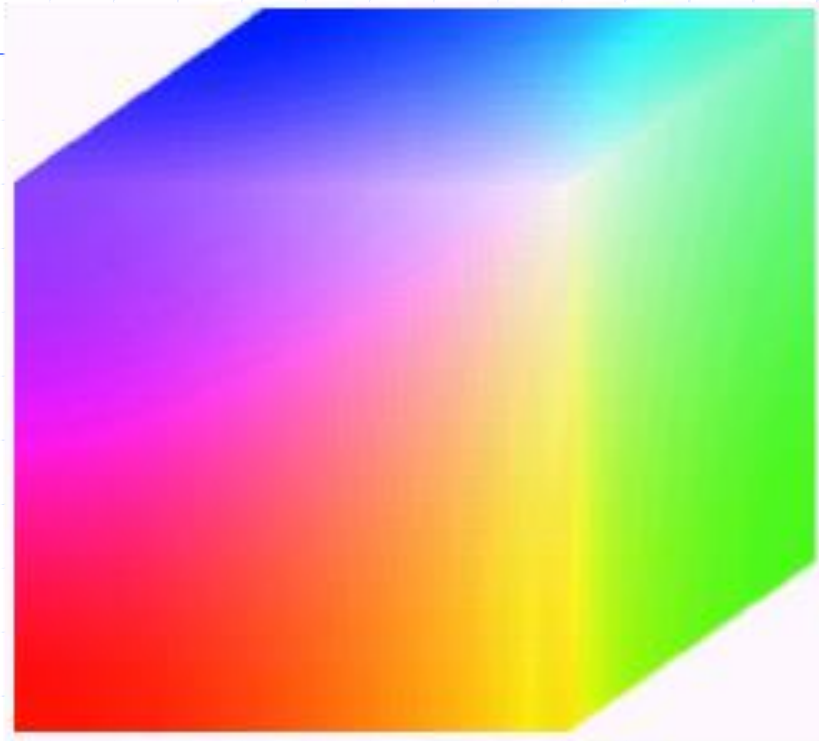


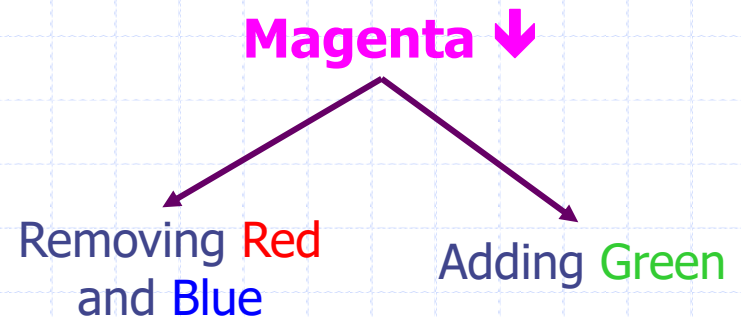
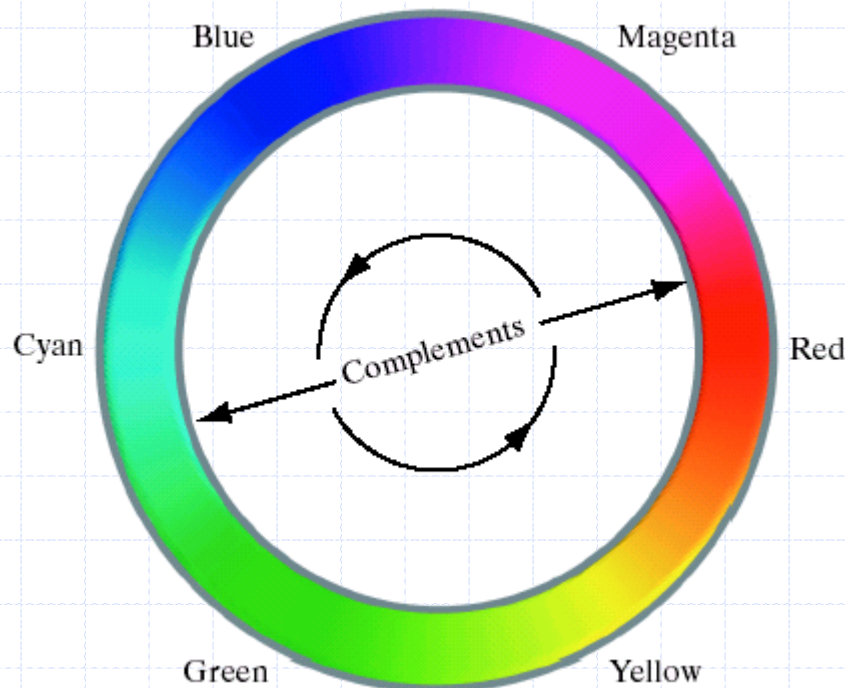
FIGURE 6.8 RGB 24-bit color cube.

$$(2^8)^3 = 16,777,216 \text{ Colors}$$

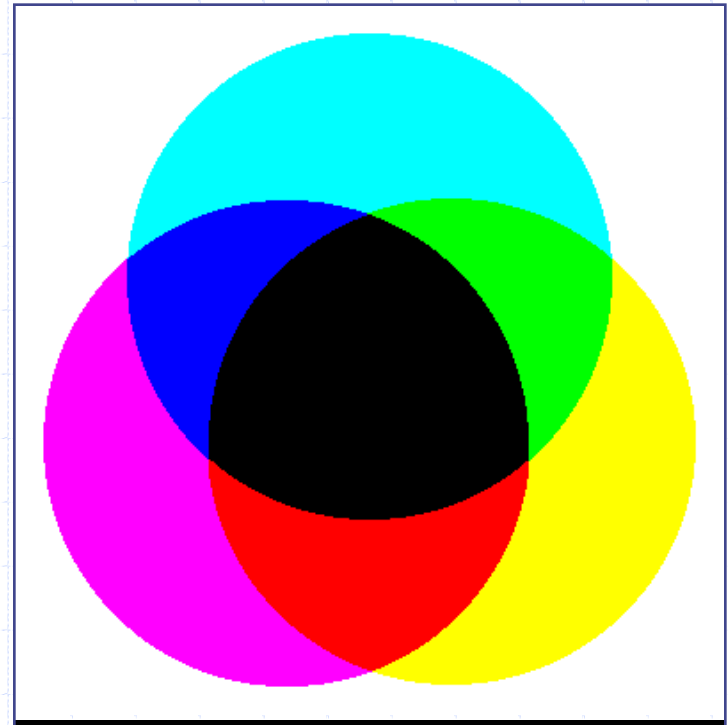
Color Image Processing

Color Transformation: Color Correction

The proportion of any color can be increased by decreasing the amount of the opposite (or complementary) color in the image or by raising the proportion of the two immediately adjacent colors or decreasing the percentage of the two colors adjacent to the complement.

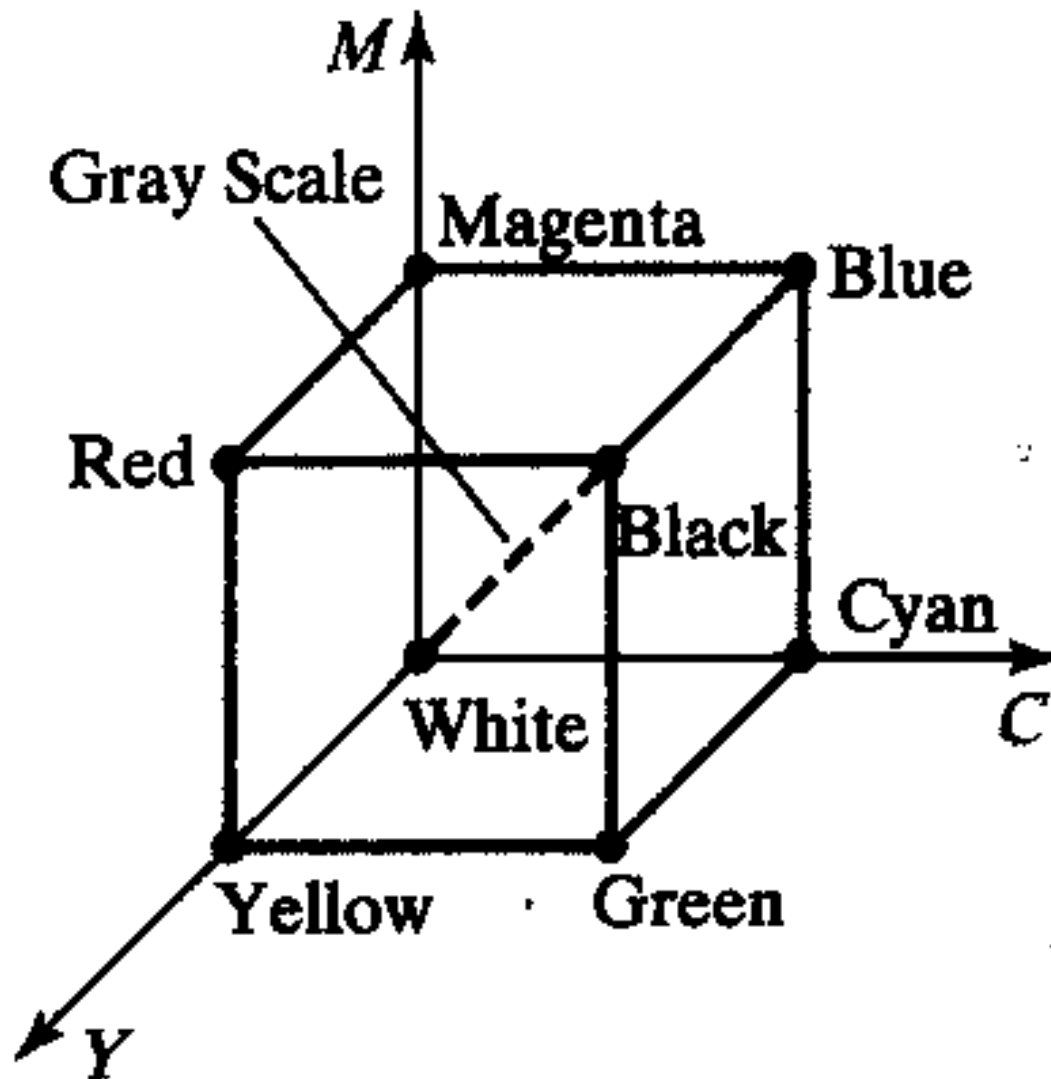


CMY Color model



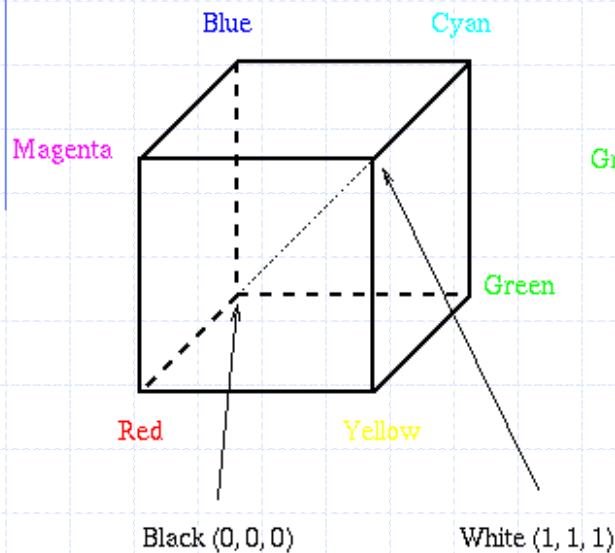
Passive displays, such as color inkjet printers, **absorb** light instead of emitting it. Combinations of **cyan**, **magenta** and **yellow** inks are used. This is a **subtractive** color model.

The CMY and CMYK Color Spaces

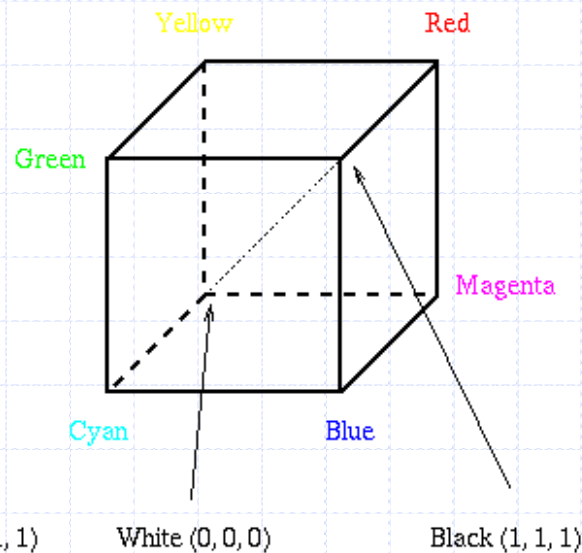


RGB and CMY

◆ Converting between RGB and CMY



The RGB Cube



The CMY Cube

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

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

The CMY and CMYK Color Models

- Cyan, Magenta and Yellow are the **secondary colors** of light
- Most devices that deposit colored pigments on paper, such as color printers and copiers, require CMY data input.

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

The conversion from RGB to CMY is given by the formula

$$\begin{bmatrix} c \\ m \\ y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

Example: The red colour is written in RGB as (1,0,0). In CMY it is written as

$$\begin{bmatrix} c \\ m \\ y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}$$

that is, magenta and yellow.

CMYK model

For printing and graphics art industry, CMY is not enough; a fourth primary, K which stands for black, is added.

Conversions between RGB and CMYK are possible, although they require some extra processing.

YIQ Color Coordinate System

- ◆ YIQ is defined by the National Television System Committee (NTSC)

- ◆ Y describes the **luminance**

- ◆ I and Q describes the **chrominance**

***Luminance** information is contained on the Y-channel, whereas **color** information is carried on I and Q channels (in-phase and in-quadrature) , in-short YIQ(Luminance, In-phase, Quadrature)*

- ◆ A more compact representation of the color.

Color Fundamentals (con't)

- The characteristics generally used to distinguish one color from another are **Brightness, Hue, and Saturation**.
 - Hue: Represents dominant color as perceived by an observer
 - Saturation: Relative purity or the amount of white light mixed with a hue
- Hue and saturation taken together are called ***Chromaticity***, and therefore, a color may be characterized by its **Brightness and Chromaticity**.

YUV/YCbCr Coordinate

- ◆ YUV is the color coordinate used in color TV in PAL system, somewhat different from YIQ

*(//Phase Alternating Line (PAL) is a colour encoding system for **analogue television**. It was one of three major analogue colour television standards, the others being NTSC and SECAM//)*

- ◆ YCbCr is the digital equivalent of YUV, used for digital TV, with 8 bit for each component, in range of 0-255

YCbCr Color Space is used in MPEG video compression standards

- Y is luminance
- Cb is blue chromaticity
- Cr is red chromaticity

$$Y = 0.257*R + 0.504*G + 0.098*B + 16$$

$$Cr = 0.439*R - 0.368*G - 0.071*B + 128$$

$$Cb = -0.148*R - 0.291*G + 0.439*B + 128$$

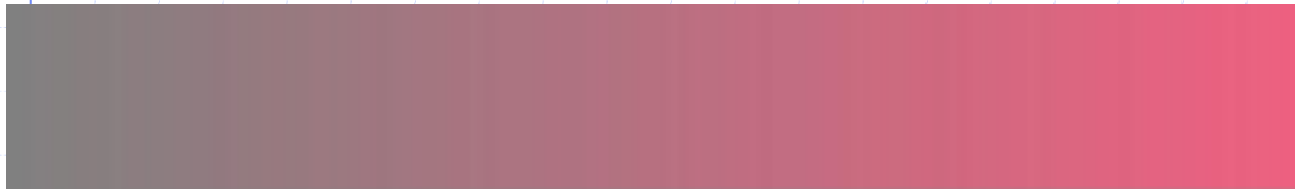
- **More bits of bandwidth are used to represent Y than to represent I and Q, because our eye is more sensitive to changes in luminance**
- YIQ color space (Matlab conversion function: `rgb2ntsc`):

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.528 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

HSI Color Model



H
*dominant
wavelength*



S
*purity
% white*

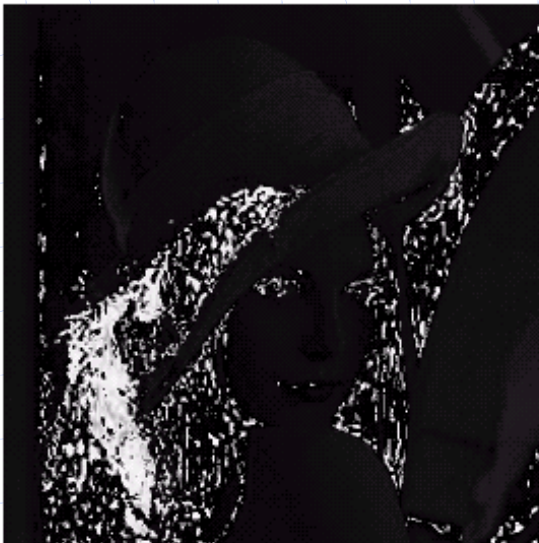


I
Intensity

Color Image Processing

Color Image Smoothing

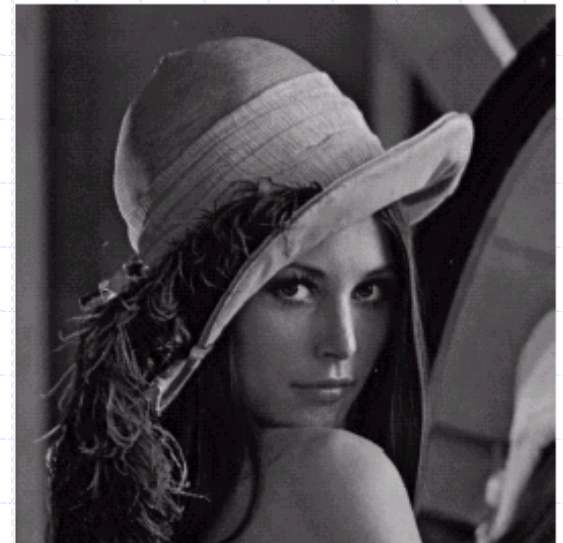
Hue



Saturation



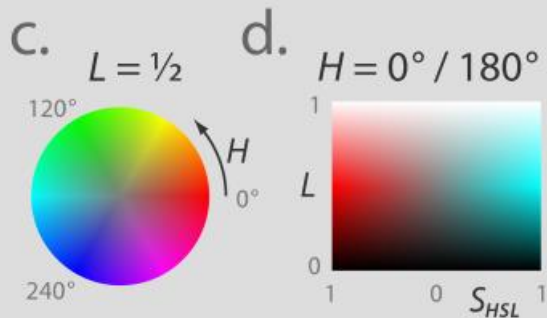
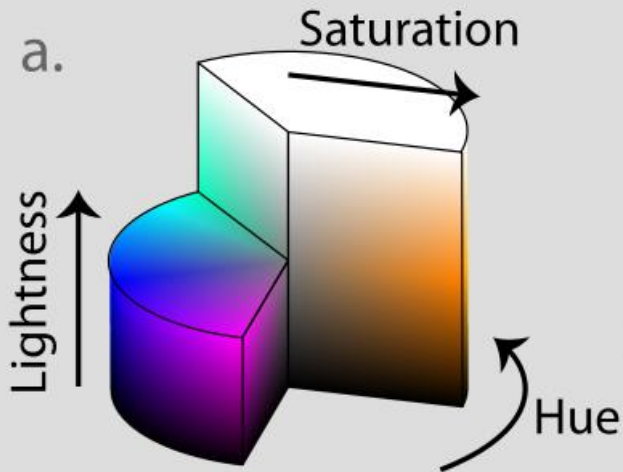
Intensity



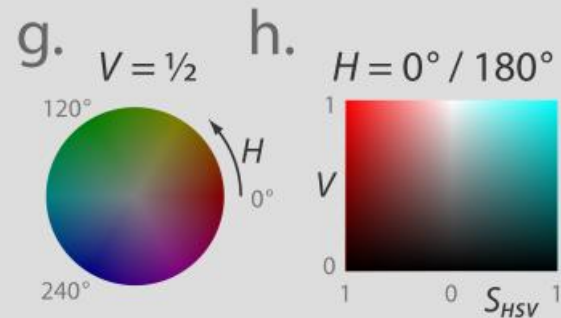
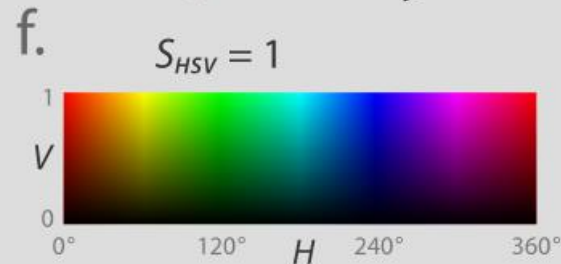
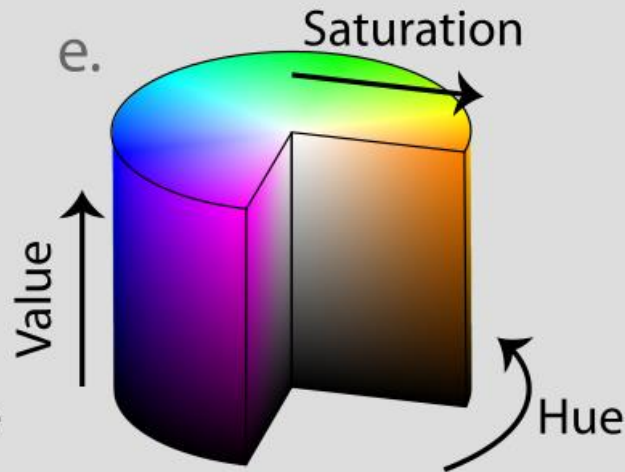
a b c

FIGURE 6.39 HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.

HSL



HSV



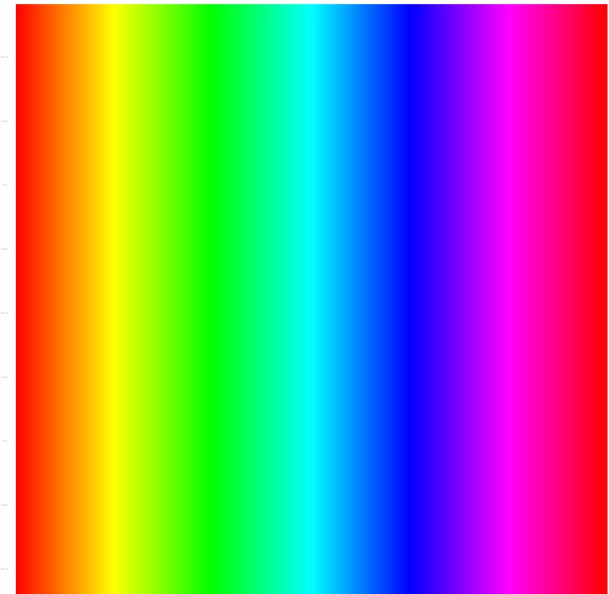
Designers use the HSV color model **when selecting colors for paint or ink** because HSV better represents how people relate to colors than the RGB color model does. **The HSV color wheel also contributes to high-quality graphics.**

Hue

The HSV spectrum of bright pure colours ($s = 1, v = 1$).

Notice the cyclicality of the hue.

The red corresponds both to $h=0$ and $h=1$.

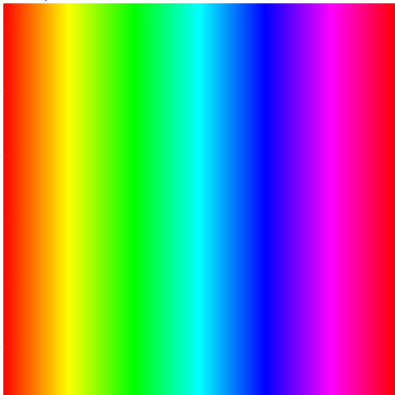


$h = 0$

$h = 1$

Saturation

Bright colours ($v=1$) with decreasing values of saturation.



$s = 1$



$s = 0.75$



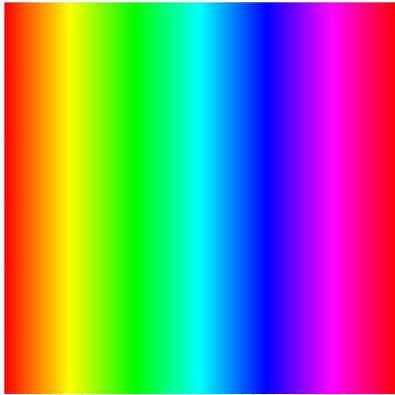
$s = 0.5$



$s = 0.25$

Value

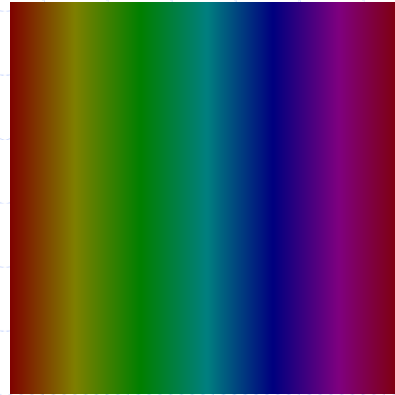
Pure colours ($s=1$) with decreasing values of “value” (brightness).



$v = 1$



$v = 0.75$



$v = 0.5$



$v = 0.25$

The HSI Color Models

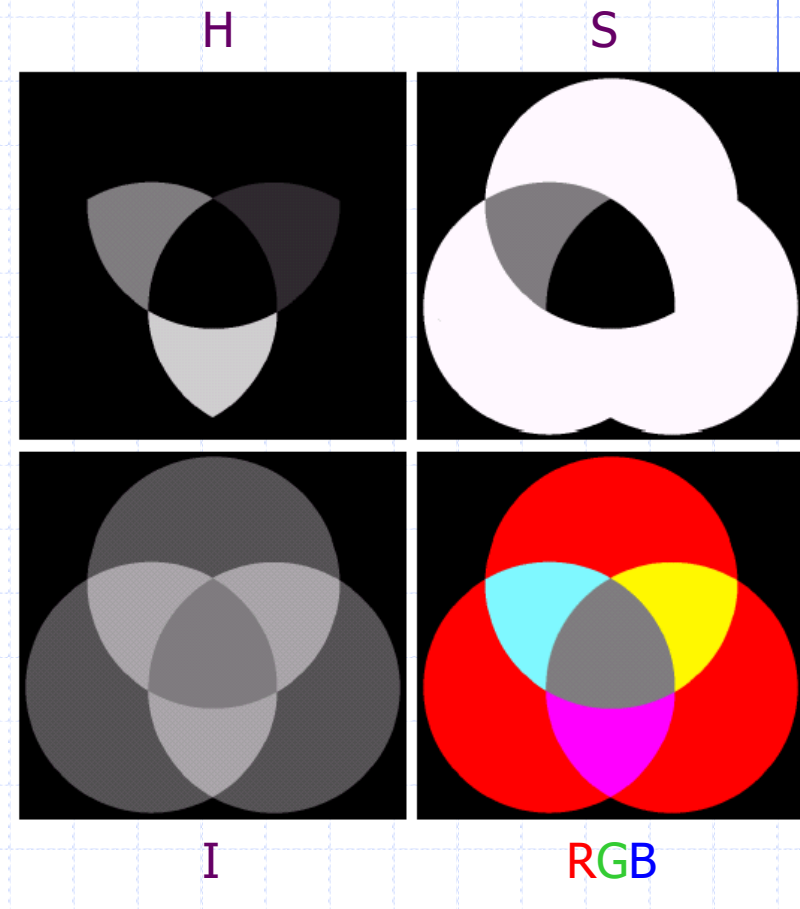
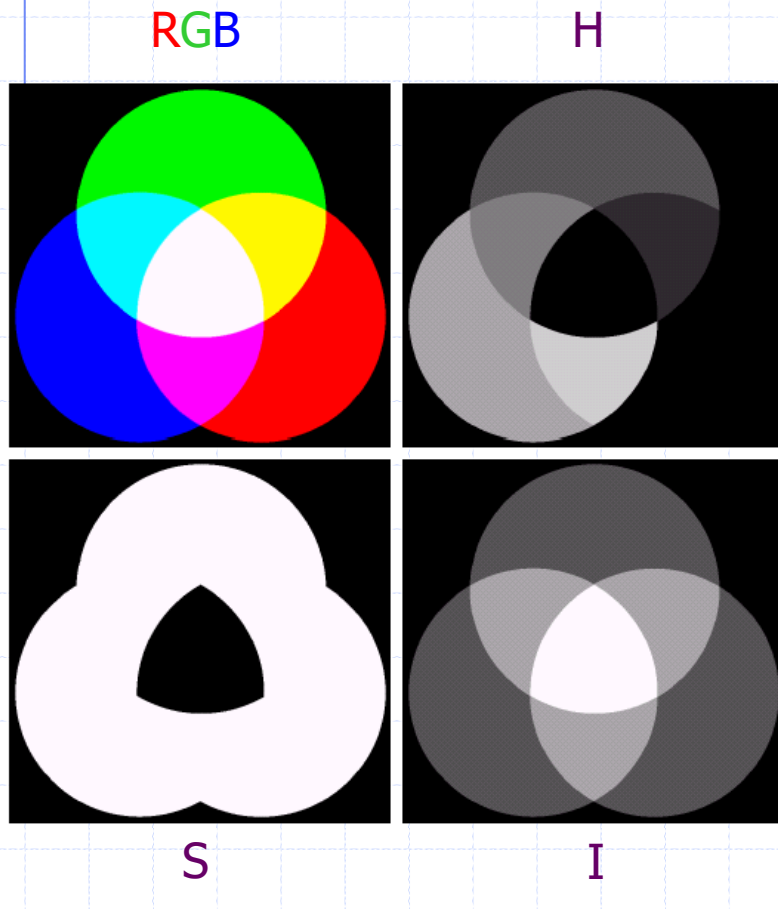
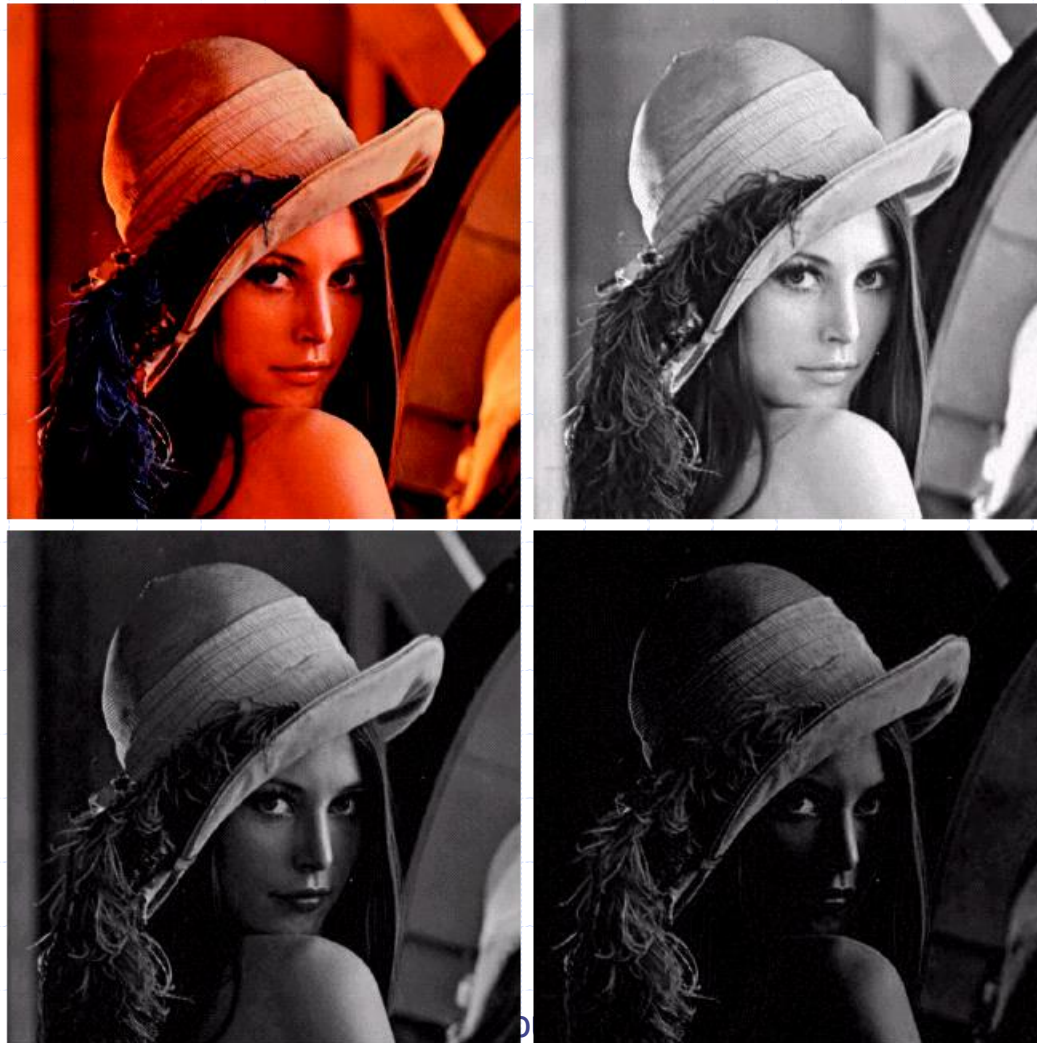


FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.

FIGURE 6.17 (a)–(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)

Color Image Processing

Color Image Smoothing



a	b
c	d

FIGURE 6.38

(a) RGB image.
(b) Red component image.
(c) Green component.
(d) Blue component.

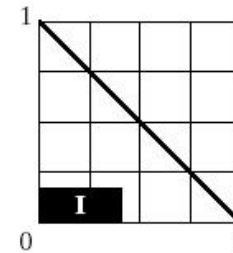
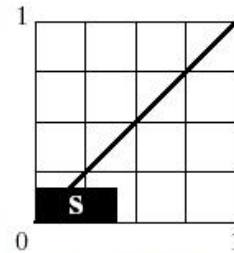
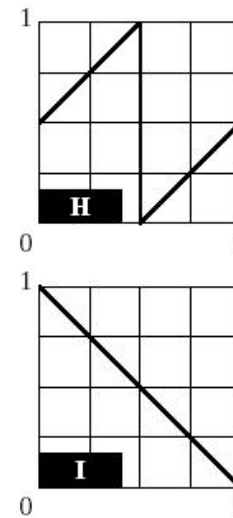
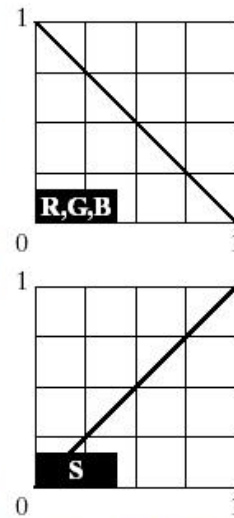
Red

Green

Blue

Color Image Processing

Color Transformation: Color Complement



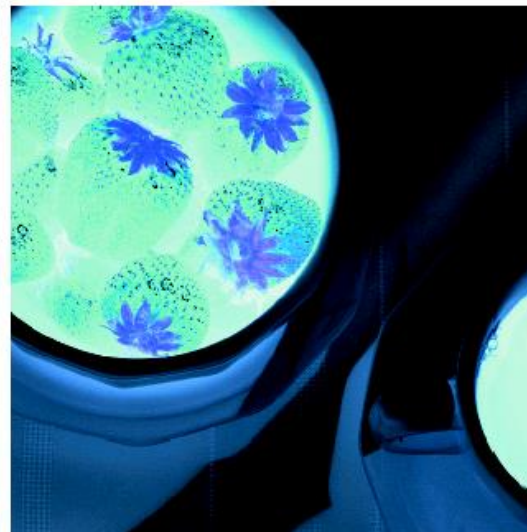
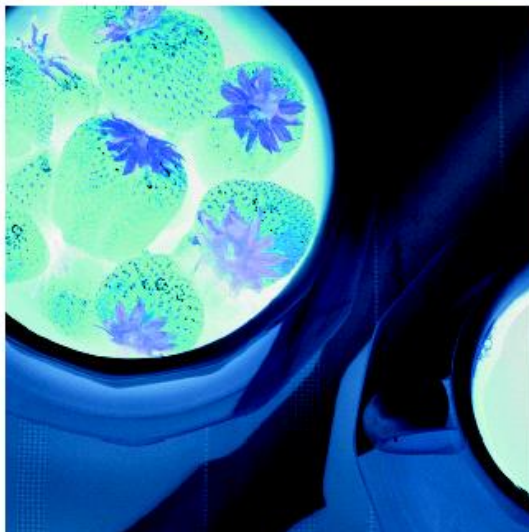
a	b
c	d

FIGURE 6.33

Color complement transformations. (a) Original image.

(b) Complement transformation functions.

(c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.



Color Image Processing

Noise in Color Images



a	b
c	d

FIGURE 6.50

(a) RGB image with green plane corrupted by salt-and-pepper noise.

(b) Hue component of HSI image.

(c) Saturation component.

(d) Intensity component.

Color Image Processing

Color Transformation: Tonal Correction

Middle-key Image



Flat



Corrected

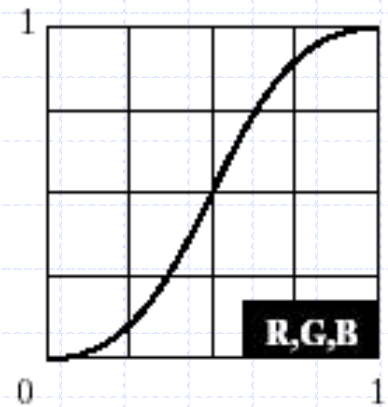
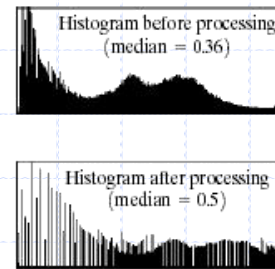
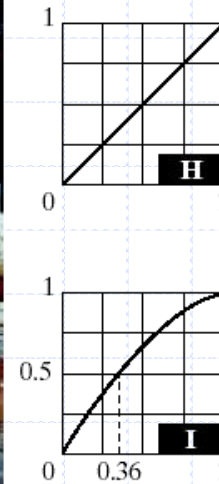


FIGURE 6.35 Tonal corrections for flat, light (high key), and dark (low key) color images. Adjusting the red, green, and blue components equally does not alter the image hues.

Color Image Processing

Color Transformation: Histogram Processing



a b
c d

FIGURE 6.37
Histogram equalization
(followed by saturation
adjustment) in the
HSI color space.

Histogram
Equalizing the
Intensity



Saturation
Adjustment



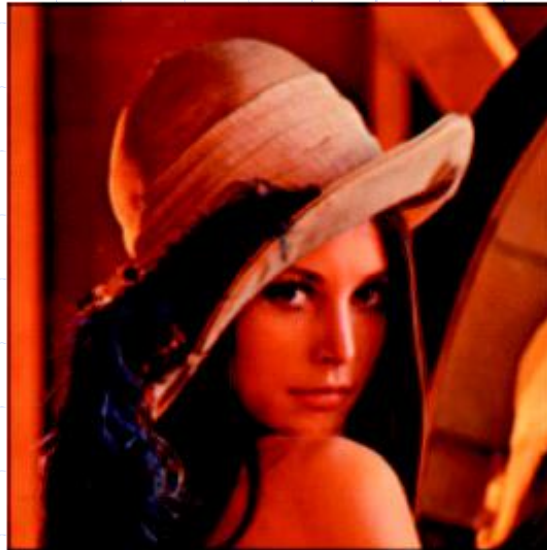
Color Image Processing

Color Image Smoothing

Averaging R,G and B



Averaging Intensity



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.

Color Image Processing

Color Image Sharpening

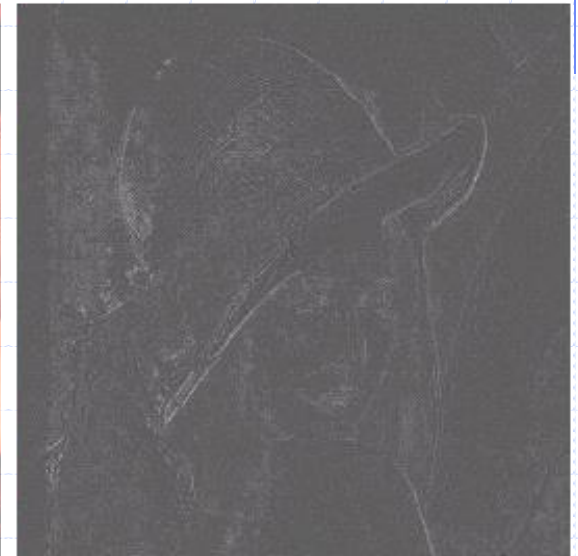
Sharpening R,G and B



Sharpening Intensity



Difference



a b c

FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the intensity component and converting to RGB. (c) Difference between the two results.

Color Image Processing

Color Segmentation: Color Edge Detection

a	b
c	d

FIGURE 6.46

- (a) RGB image.
- (b) Gradient computed in RGB color vector space.
- (c) Gradients computed on a per-image basis and then added.
- (d) Difference between (b) and (c).



Color Image Processing

Color Segmentation: Color Edge Detection



a b c

FIGURE 6.47 Component gradient images of the color image in Fig. 6.46. (a) Red component, (b) green component, and (c) blue component. These three images were added and scaled to produce the image in Fig. 6.46(c).

Color Image Processing

Noise in Color Images

a b
c d

FIGURE 6.48
(a)–(c) Red, green, and blue component images corrupted by additive Gaussian noise of mean 0 and variance 800. (d) Resulting RGB image. [Compare (d) with Fig. 6.46(a).]



Color Image Processing

Noise in Color Images



a b c

FIGURE 6.49 HSI components of the noisy color image in Fig. 6.48(d). (a) Hue. (b) Saturation. (c) Intensity.