影像處理
Chapter 5 色彩影像處理

Chien-Chang Chen
Tamkang University
Department of Computer Science and Information Engineering

色彩理論

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

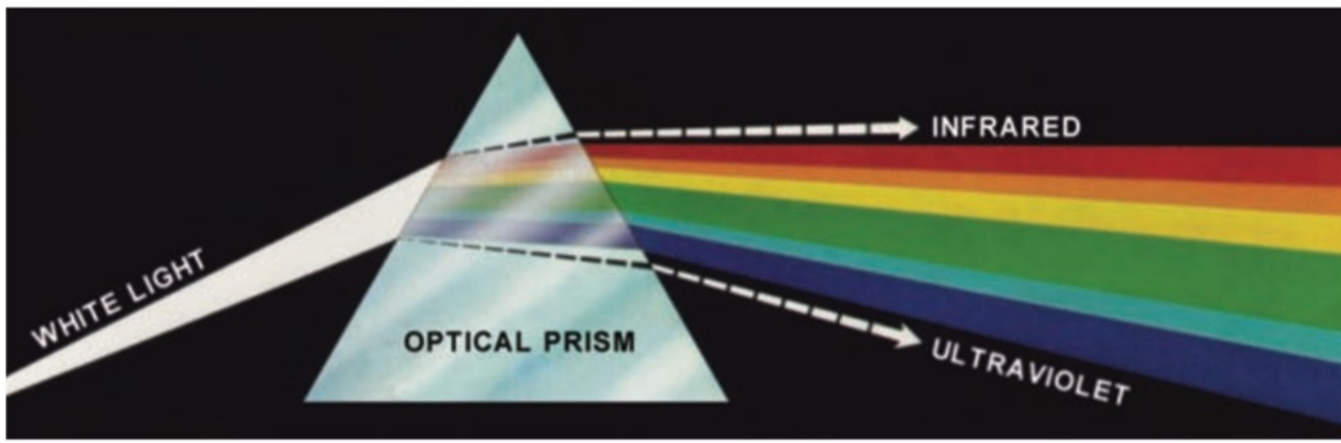
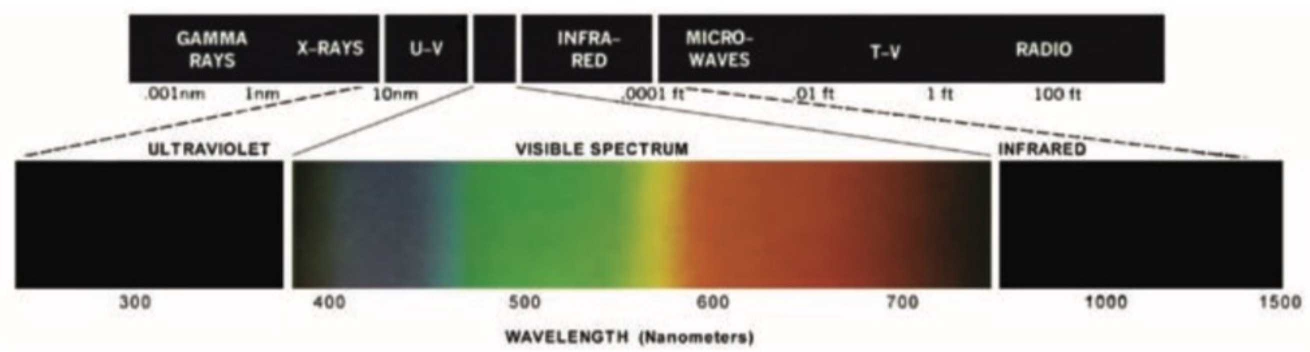


FIGURE 6.2
Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lighting Division.)



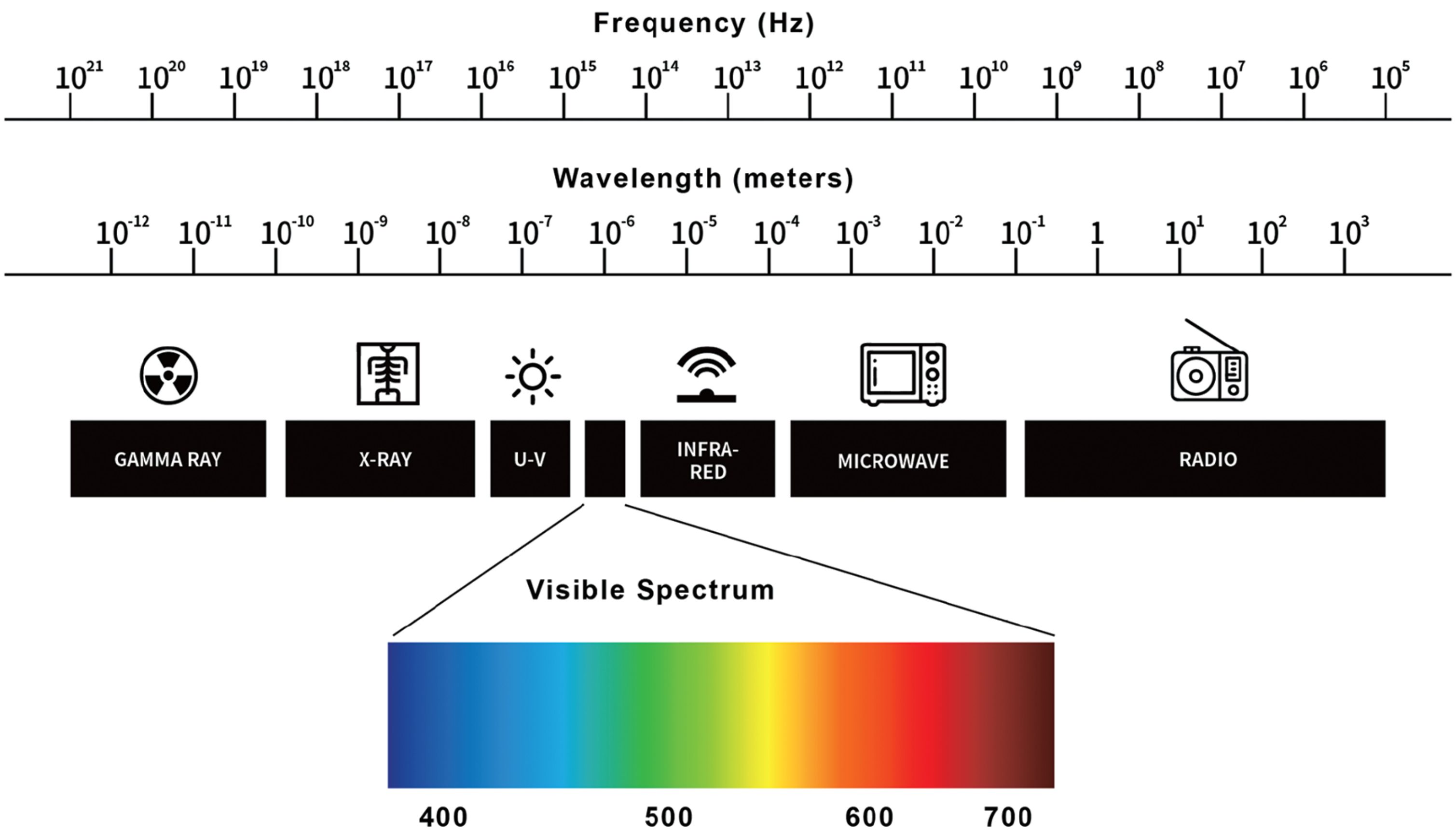

Frequency (Hz)
10^21 10^20 10^19 10^18 10^17 10^16 10^15 10^14 10^13 10^12 10^11 10^10 10^9 10^8 10^7 10^6 10^5
Wavelength (meters)
10^-12 10^-11 10^-10 10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3
GAMMA RAY
X-RAY
U-V
INFRA-RED
MICROWAVE
RADIO
Visible Spectrum
400
500
600
700

圖 8-1　電磁波頻譜

光的混合　　顏料的混合

圖 8-2　光或顏料的混合

- The amounts of red(X), green(Y), and blue(Z) form any particular color are called the *tristimulus* values.
- A color is then specified by its trichromatic coefficients, defined as
- $\boldsymbol{x = \frac{X}{X+Y+Z}}$
- $\boldsymbol{y = \frac{Y}{X+Y+Z}}$
- $\boldsymbol{z = \frac{Z}{X+Y+Z}}$
- and
- $\boldsymbol{x + y + z = 1}$

1. CIE *chromaticity diagram* shows color composition as a function of *x* (red) and *y* (green)

2. *z* (blue) is obtained by $z = 1 - (x + y)$

3. A point marked green in Fig. 6.5 has approximately 62% green and 25% red content, the composition of blue is approximately 13%

4. The positions of the various spectrum colors—from violet at 380 nm to red at 780 nm—are indicated around the boundary of the tongue-shaped chromaticity diagram

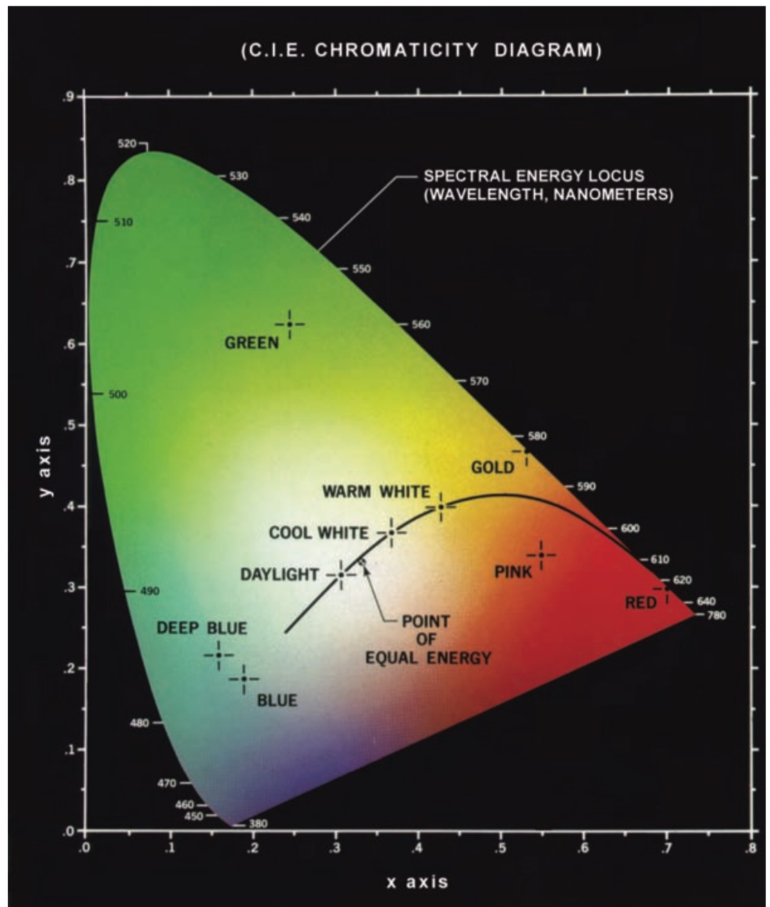
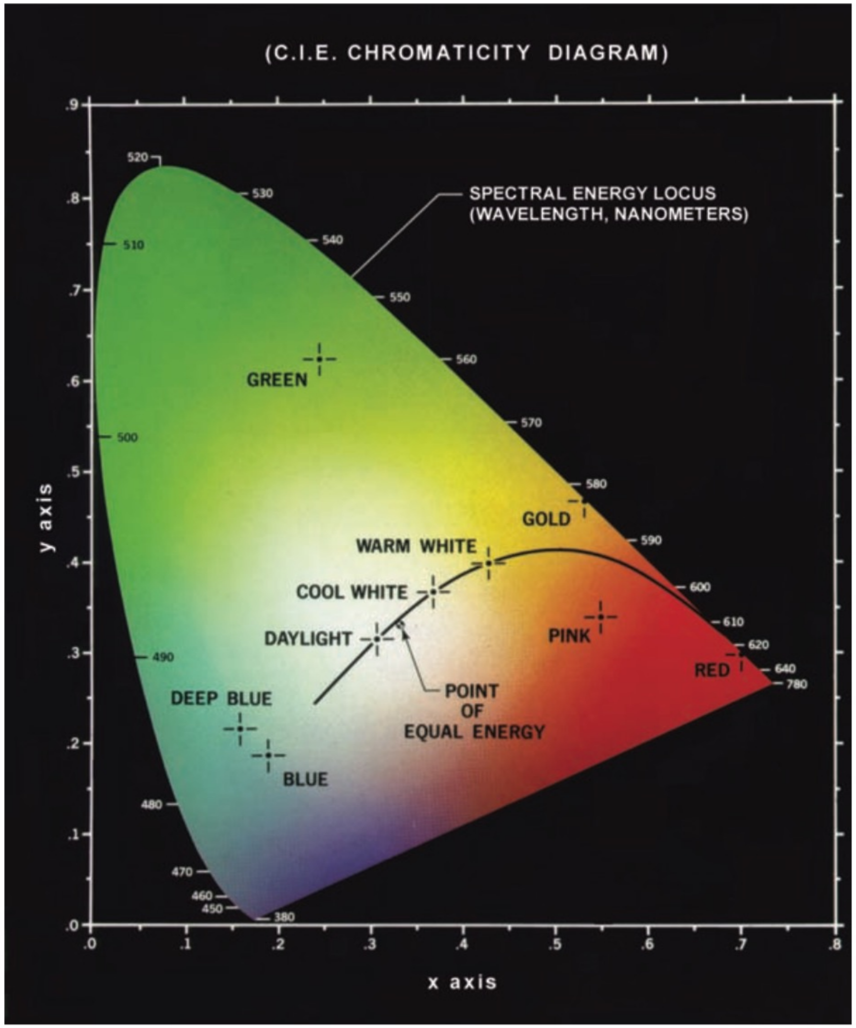


FIGURE 6.5
The CIE chromaticity diagram. (Courtesy of the General Electric Co., Lighting Division.)

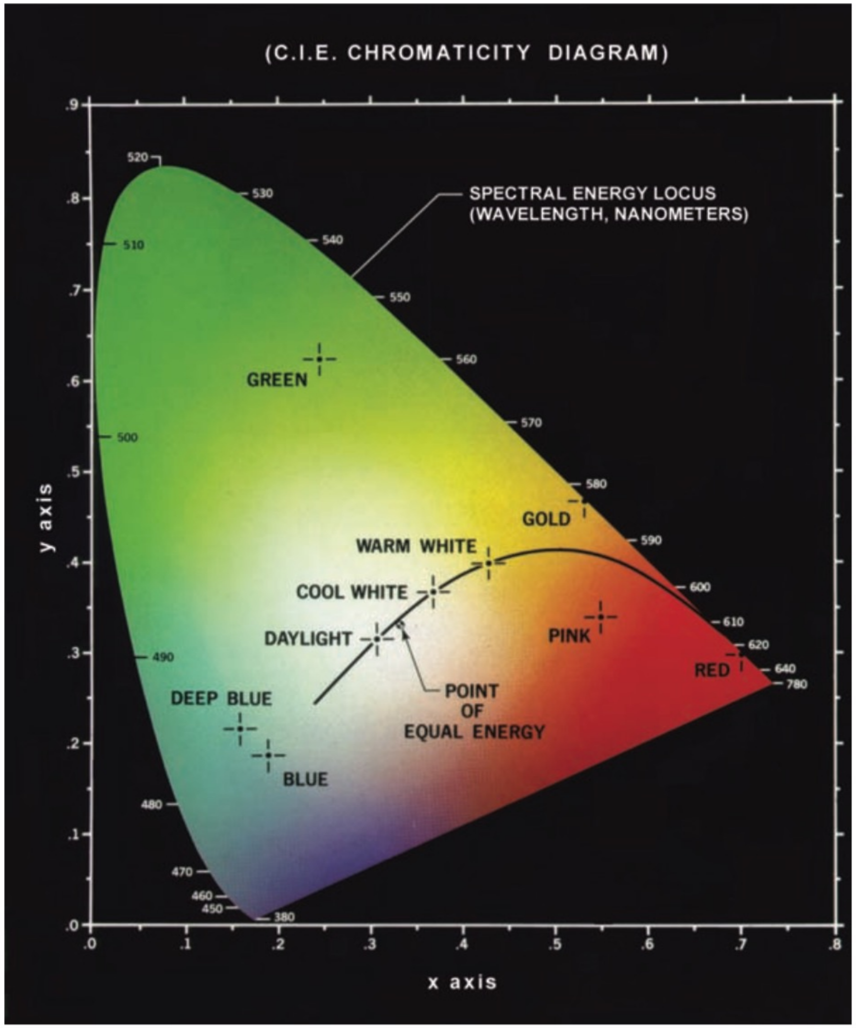
5. The point of equal energy is equal fractions of the three primary colors; it represents the CIE standard for white light
6. Any point located on the boundary of the chromaticity chart is fully saturated
7. A point approaches the point of equal energy, more white light is added to the color, and it becomes less saturated

FIGURE 6.5 The CIE chromaticity diagram. (Courtesy of the General Electric Co., Lighting Division.)



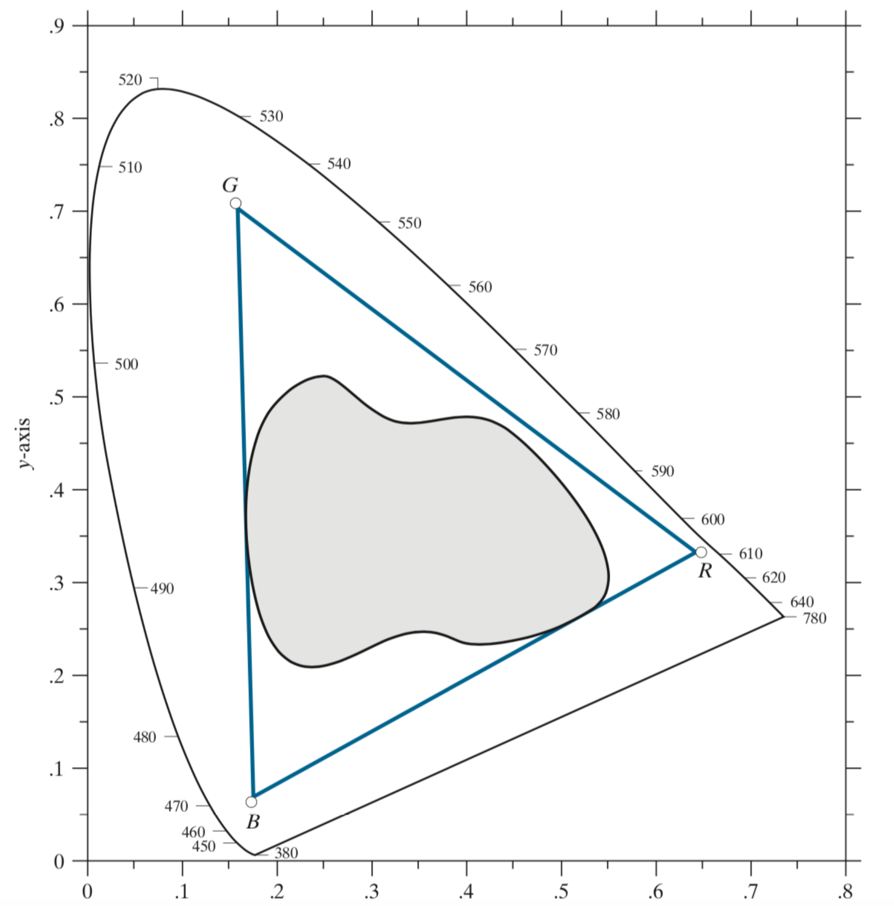
8. The saturation at the point of equal energy is zero
9. A straight-line segment joining any two points in the diagram defines all the different color variations that can be obtained by combining these two colors additively

FIGURE 6.5 The CIE chromaticity diagram. (Courtesy of the General Electric Co., Lighting Division.)



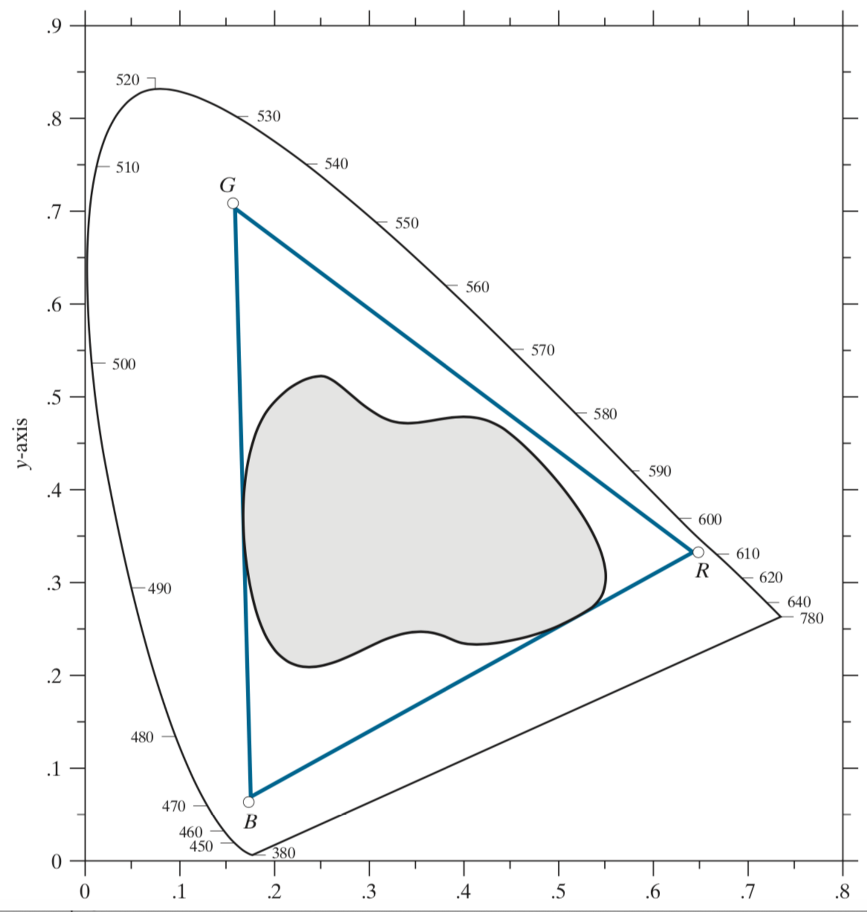
1. A triangle acquired from drawing connecting lines of three color points, can produce any color inside the triangle by various combinations of the three vertex colors
2. A triangle with vertices at any three fixed colors cannot enclose the entire color region
3. The shaded region inside the triangle illustrates the color gamut of today's high-quality color printing devices

FIGURE 6.6 Illustrative color gamut of color monitors (triangle) and color printing devices (shaded region).



4. The boundary of the color printing gamut is irregular
5. Color printing is a combination of additive and subtractive color mixing
6. The process is much more difficult to control than displaying colors on a monitor

FIGURE 6.6 Illustrative color gamut of color monitors (triangle) and color printing devices (shaded region).



色彩模型

- 色彩模型(color model)
- 色彩空間(color space)
- 色彩系統(color system)
- Color properties:
- Luminance(亮度), Chrominance(色度)
- 人類對於亮度的敏感度高於色度的敏感度

1. A color image can be acquired by using three filters, sensitive to red, green, and blue, respectively. 2. When we view a color scene with a monochrome camera equipped with one of these filters, the result is a monochrome image whose intensity is proportional to the response of that filter

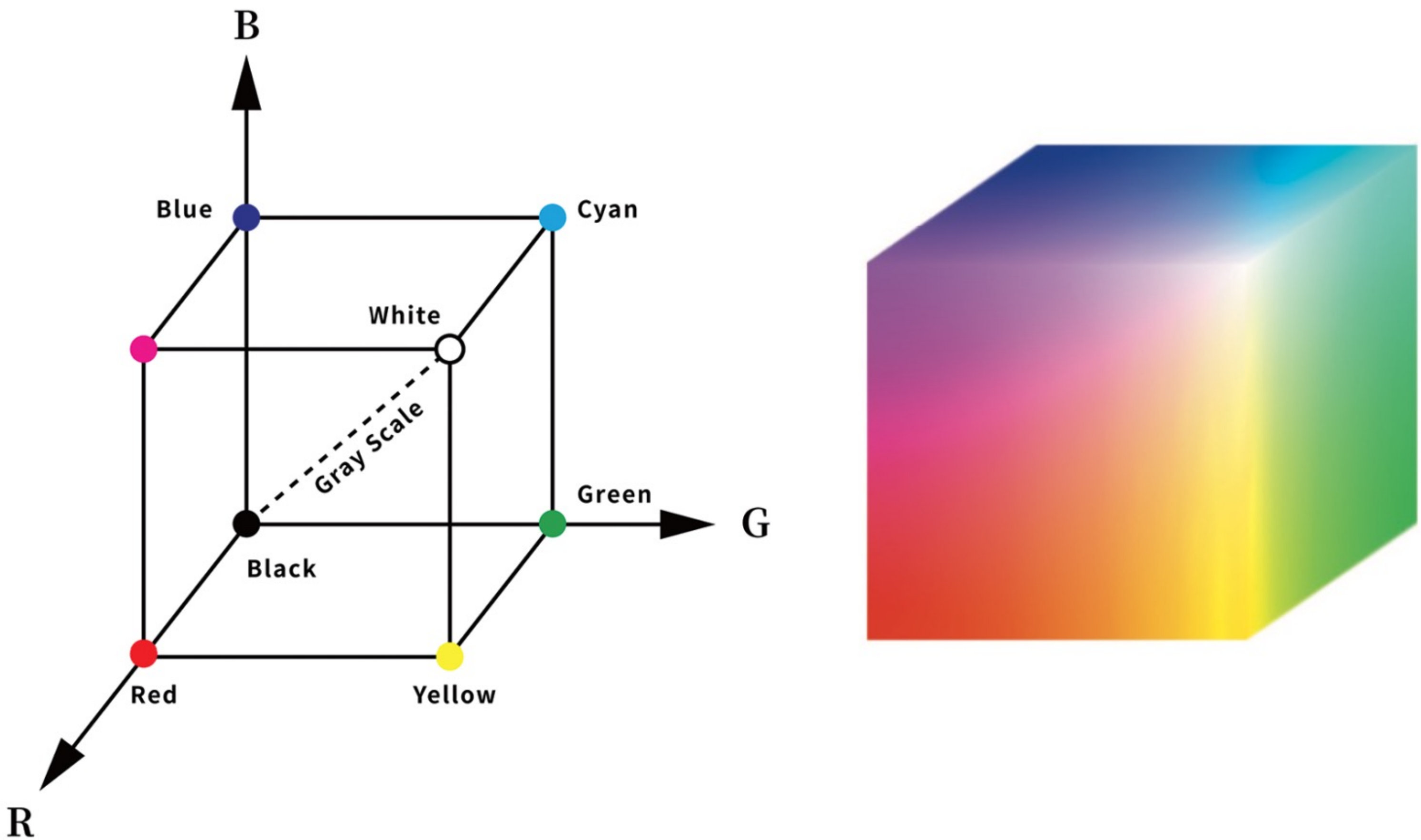


圖 8-3 RGB 色彩模型

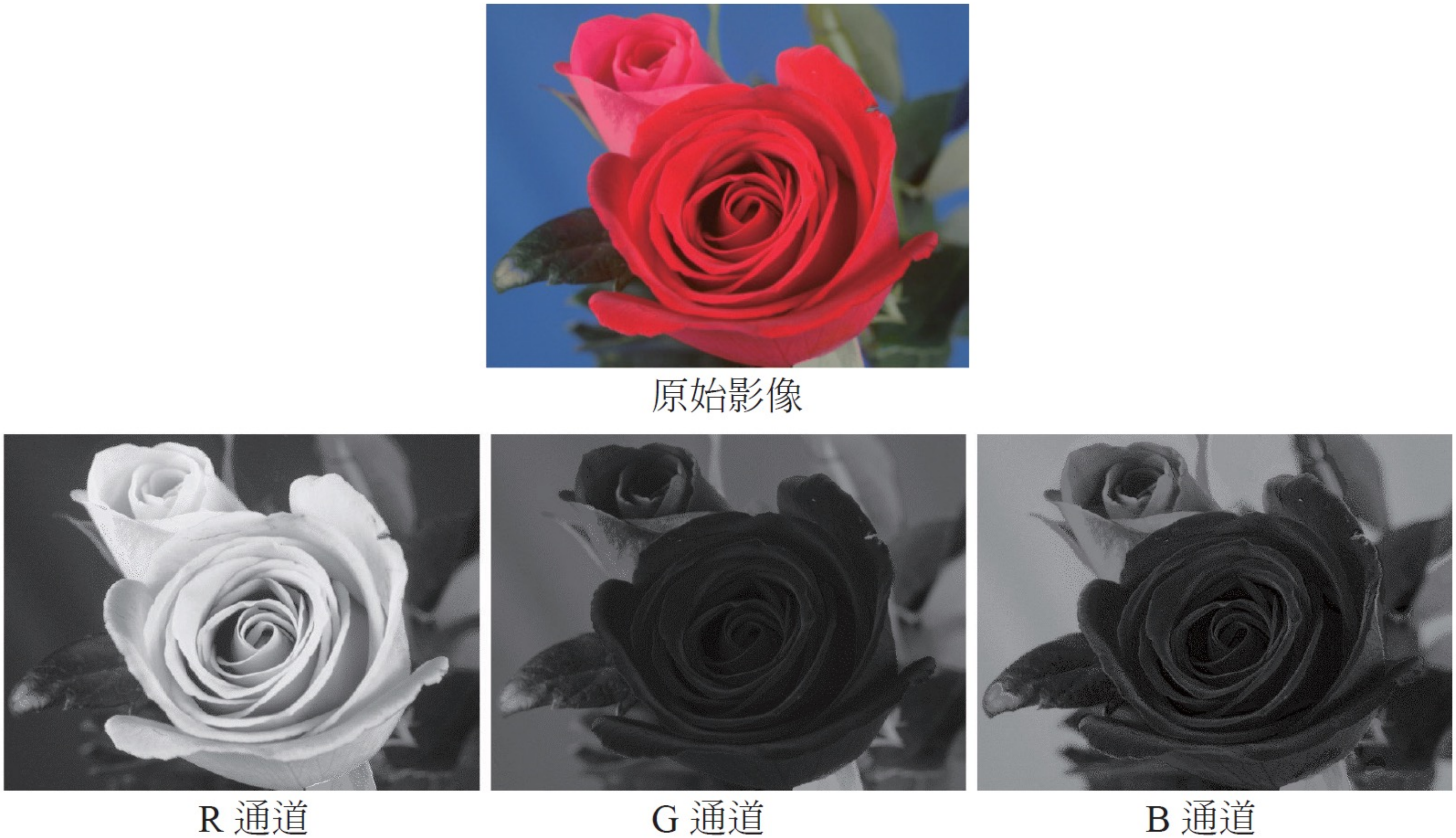


圖 8-4　RGB 色彩模型

Check IP05.ipynb

- 5.1 show RGB channels

CMY Model

- $$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$
- 1. all RGB color values have been normalized to the range [0, 1]
- 2. (C,M,Y) model is (R,G,B) model's complement
- 3. cyan, magenta, and yellow are the secondary colors of light
- 4. cyan, magenta, and yellow are the primary colors of pigments
- 5. pure cyan does not contain red ($C=1-R$)
- 6. pure magenta does not reflect green
- 7. pure yellow does not reflect blue

圖 8-5　CMY 色彩模型

Check IP05.ipynb

- 5.2 show CMY channels

CMYK Model from CMY model

- $K = min(C, M, Y)$
- $\begin{bmatrix} C_K \\ M_K \\ Y_K \end{bmatrix} = \begin{bmatrix} C - K \\ M - K \\ Y - K \end{bmatrix}$

- If K=1, C=M=Y=1
- The color is black
- $C_K = M_K = Y_K = 0$

CMYK Model from CMY model

- If K=1, C=M=Y=1
- The color is black
- $C_K = M_K = Y_K = 0$
- Others
- $$\begin{bmatrix} \boldsymbol{C_K} \\ \boldsymbol{M_K} \\ \boldsymbol{Y_K} \end{bmatrix} = \begin{bmatrix} \frac{C-K}{1-K} \\ \frac{M-K}{1-K} \\ \frac{Y-K}{1-K} \end{bmatrix}$$

Recover CMY model from CMYK model

- $$\begin{bmatrix} C_K \\ M_K \\ Y_K \end{bmatrix} = \begin{bmatrix} \frac{C-K}{1-K} \\ \frac{M-K}{1-K} \\ \frac{Y-K}{1-K} \end{bmatrix}$$
- $$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} C_K * (1-K) + K \\ M_K * (1-K) + K \\ Y_K * (1-K) + K \end{bmatrix}$$
- (R, G, B), (C, M, Y), (C, M, Y, K)同一種計算關係

Check IP05.ipynb

- 5.3 show CMYK channels

HSI model

- Hue(色調)
- 與光波的波長有關，它表示人的感官對不同顏色的感受，例如：紅橙黃綠藍紫等。0^{o}~360^{o}
- Saturation(飽和度)
- 純色與白色的混合比例。純光譜色是完全飽和的，加入白光會稀釋飽和度。飽和度越大，顏色看起來就會越鮮艷，反之亦然。 [0, 1](或0%~100%)
- Intensity(強度)
- 亮度。 [0, 1](或0%~100%)
- 例如：人的膚色是『不飽和的紅色』

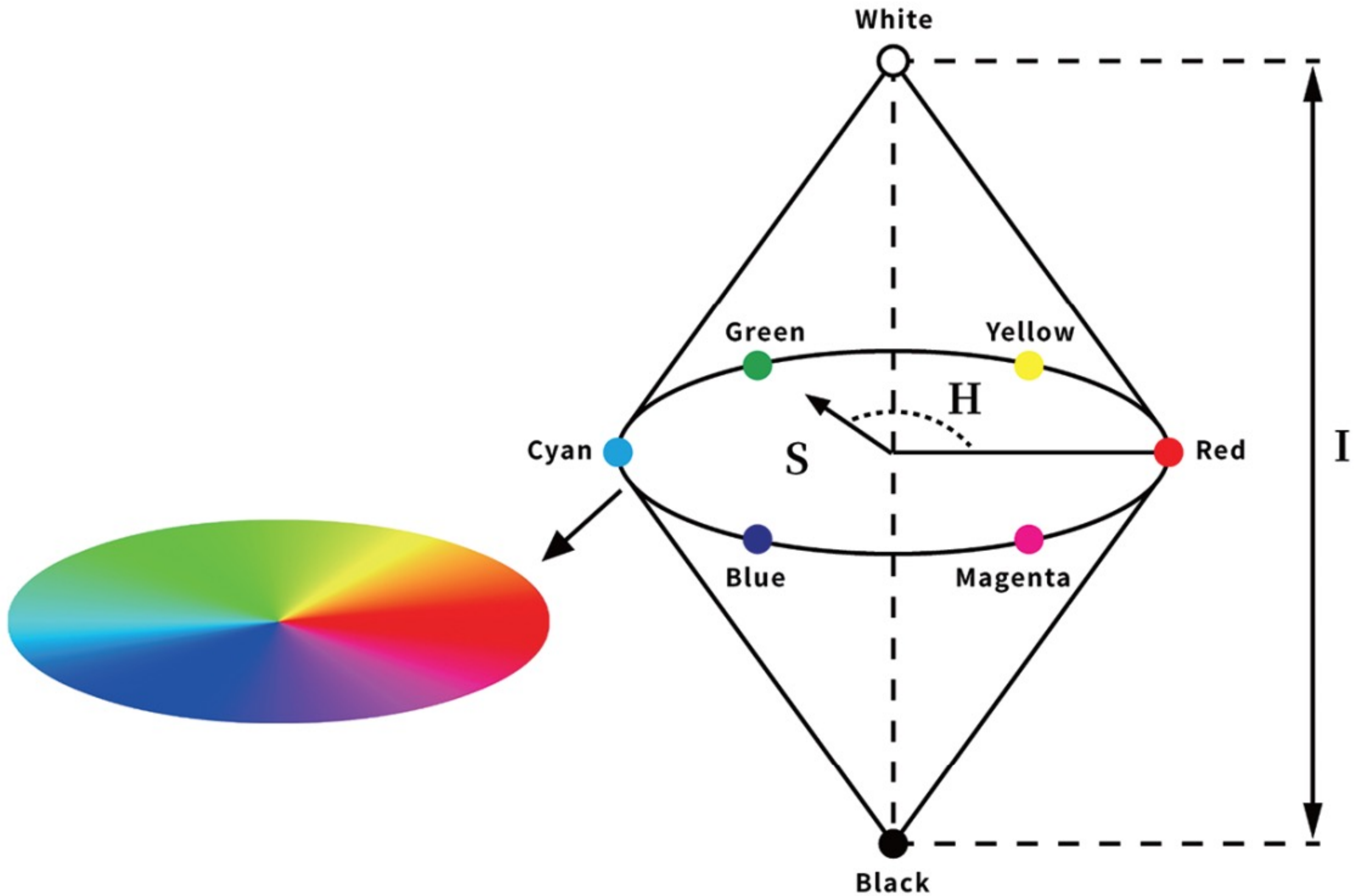
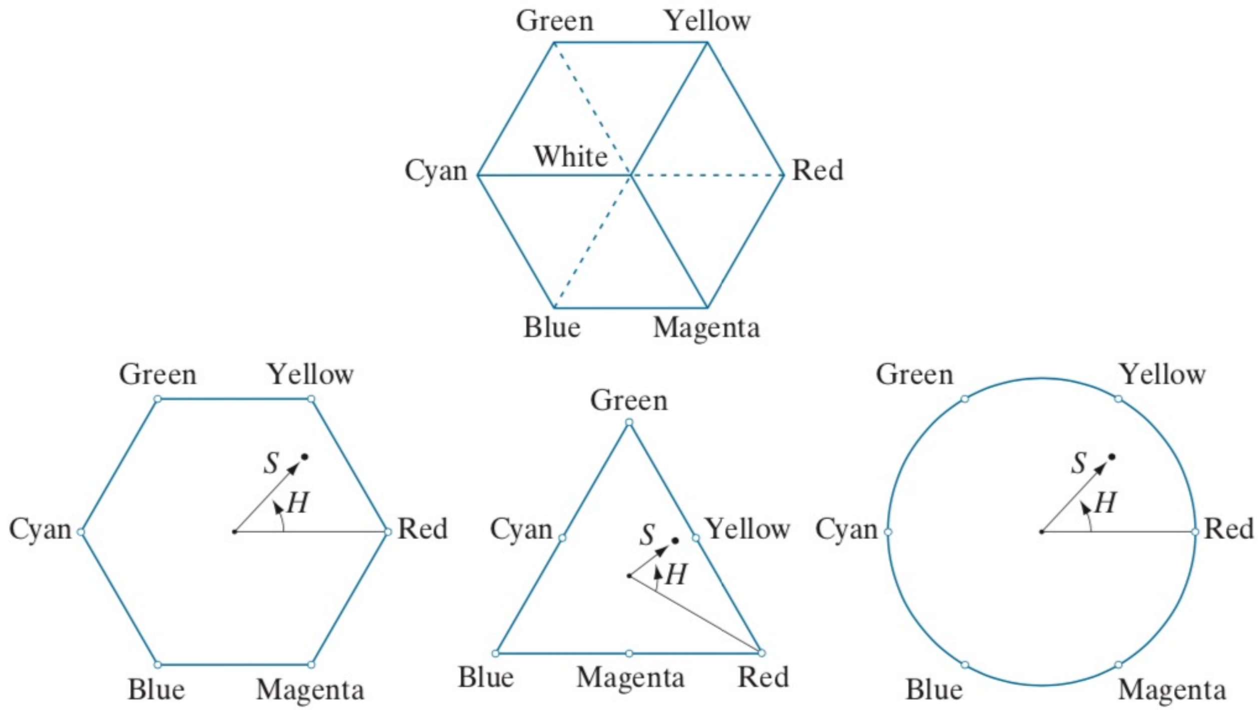


圖 8-6　HSI 色彩模型

RGB to HSI

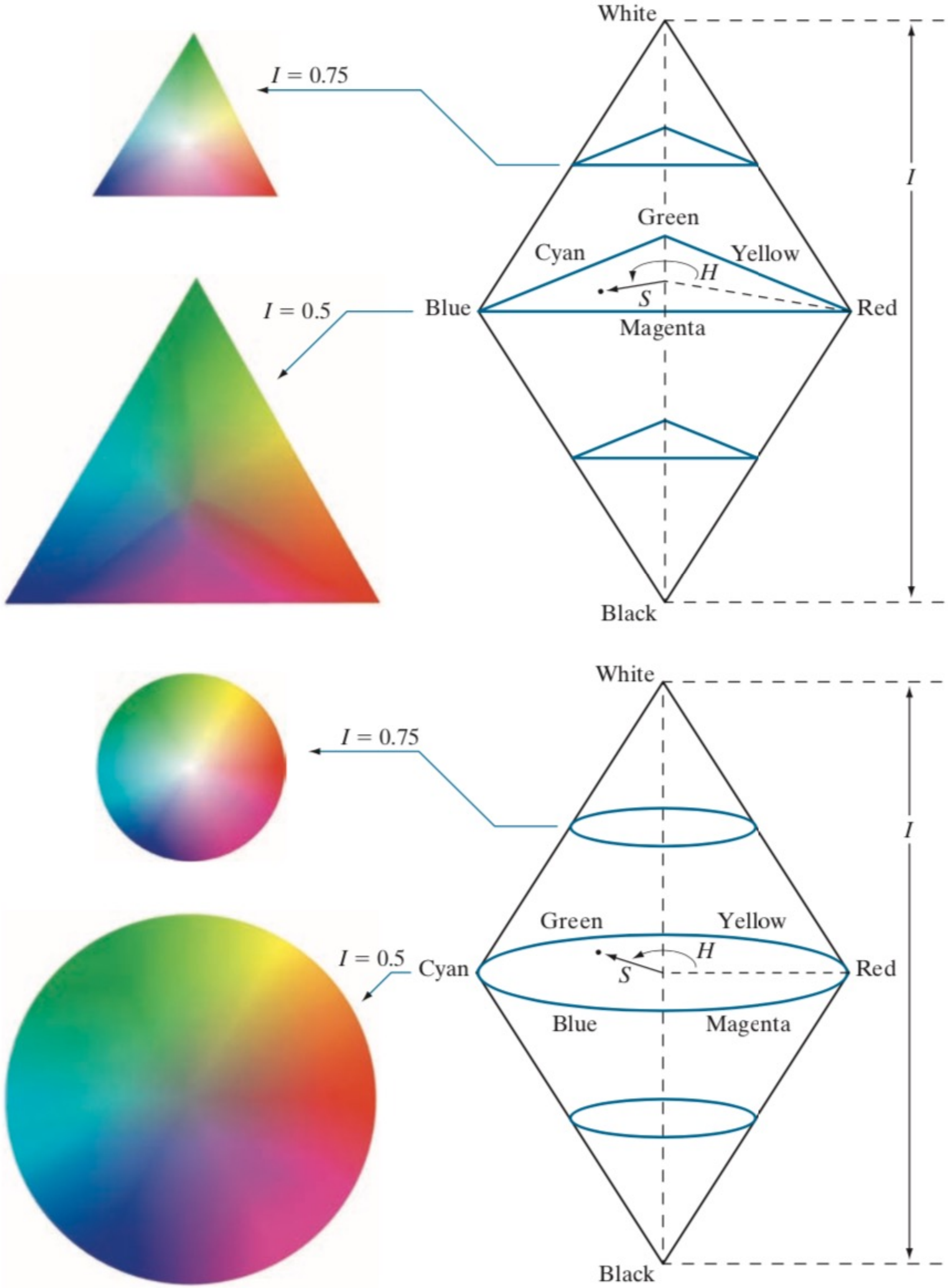


a
b c d

FIGURE 6.11 Hue and saturation in the HSI color model. The dot is any color point. The angle from the red axis gives the hue. The length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

a
b

FIGURE 6.12 The HSI color model based on (a) triangular, and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.



RGB to HSI

Converting Colors from RGB to HSI

Given an image in RGB color format, the H component of each RGB pixel is obtained using the equation

$$H = \begin{cases} \theta & \text{if } B \leq G \\ 360 - \theta & \text{if } B > G \end{cases} \tag{6-16}$$

with†

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\} \tag{6-17}$$

The saturation component is given by

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R,G,B)\right] \tag{6-18}$$

Finally, the intensity component is obtained from the equation

$$I = \frac{1}{3}(R+G+B) \tag{6-19}$$

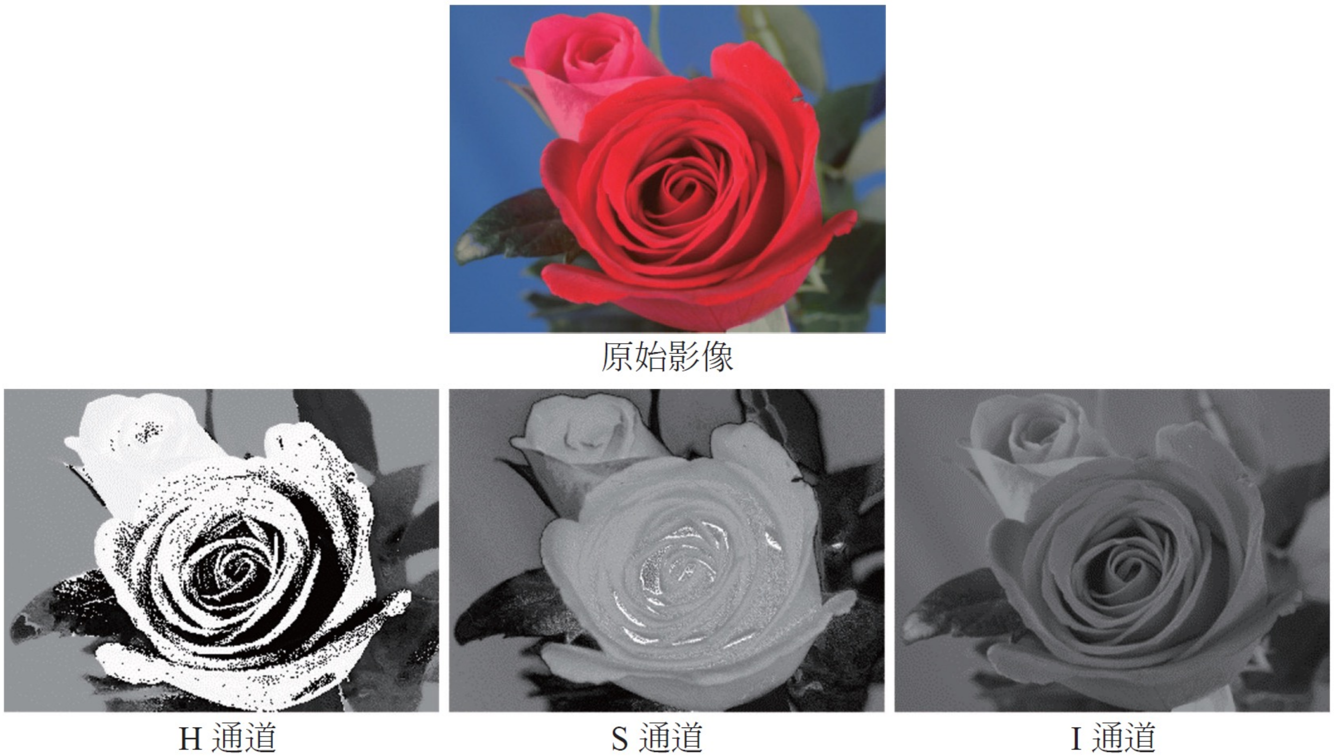


圖 8-7　HSI 色彩模型

Check IP05.ipynb

- 5.4 RGB to HSI model

HSI to RGB

RG sector $(0° \leq H < 120°)$: When H is in this sector, the RGB components are given by the equations

$$B = I(1 - S) \tag{6-20}$$

$$R = I\left[1 + \frac{S\cos H}{\cos(60° - H)}\right] \tag{6-21}$$

and

$$G = 3I - (R + B) \tag{6-22}$$

GB sector $(120° \leq H < 240°)$: If the given value of H is in this sector, we first subtract 120° from it:

$$H = H - 120° \tag{6-23}$$

Then, the RGB components are

$$R = I(1 - S) \tag{6-24}$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60° - H)}\right] \tag{6-25}$$

HSI to RGB

and

$$B = 3I - (R + G) \tag{6-26}$$

BR sector $(240° \le H \le 360°)$: Finally, if H is in this range, we subtract $240°$ from it:

$$H = H - 240° \tag{6-27}$$

Then, the RGB components are

$$G = I(1 - S) \tag{6-28}$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60° - H)}\right] \tag{6-29}$$

and

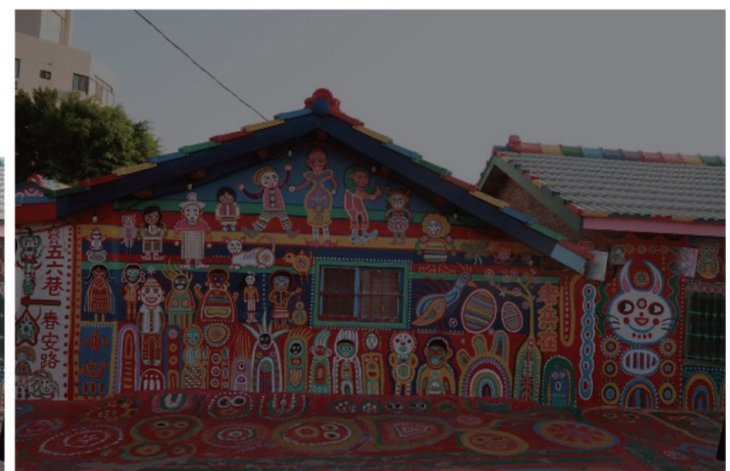
$$R = 3I - (G + B) \tag{6-30}$$

HSI 色彩影像處理

原始影像

色調 (Hue) 旋轉 180°

飽和度 (Saturation) 降爲 50%



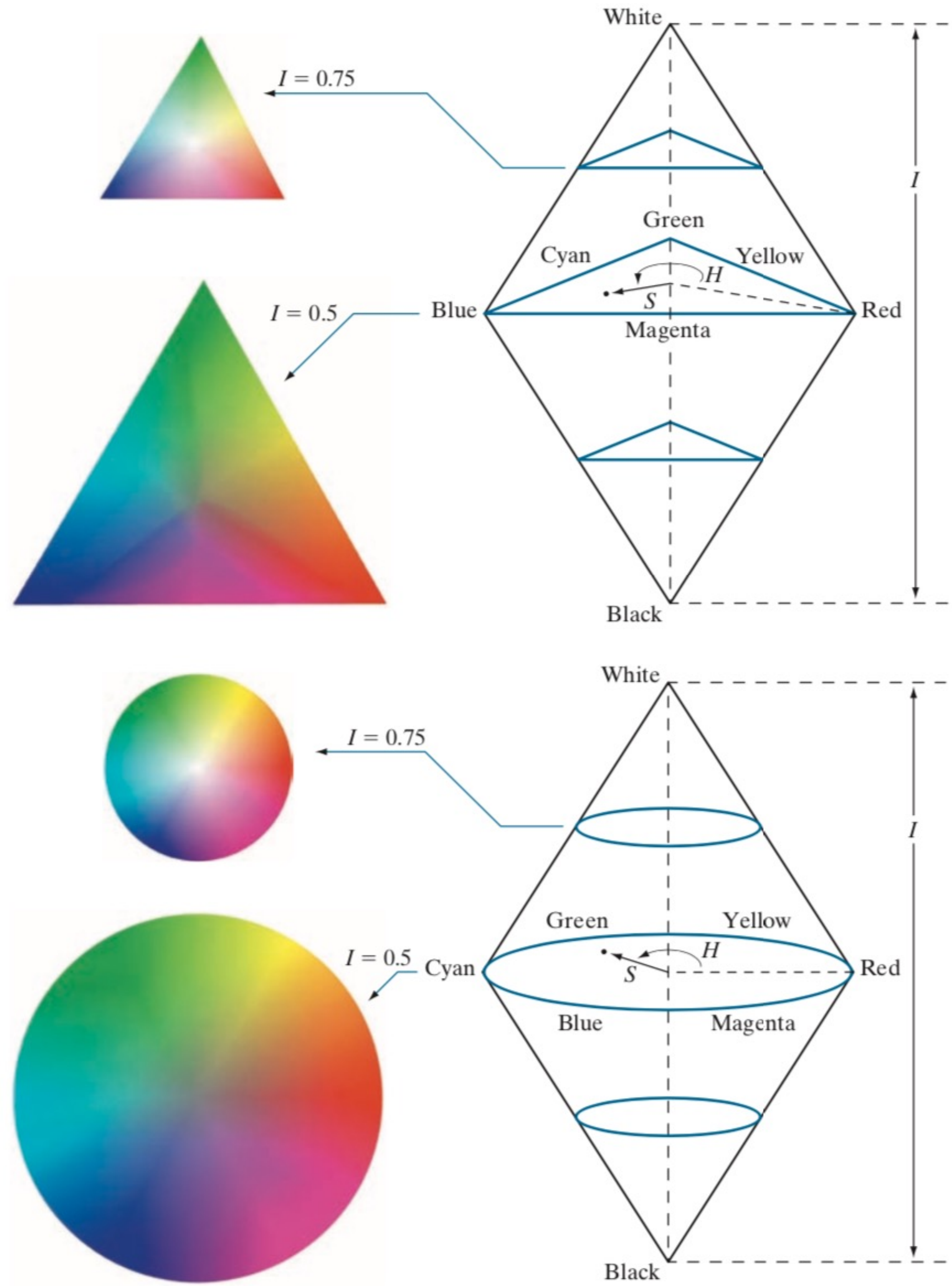
亮度 (Intensity) 降爲 50%

Check IP05.ipynb

- 5.5 HSI to RGB model
  - recover original RGB images from HSI images

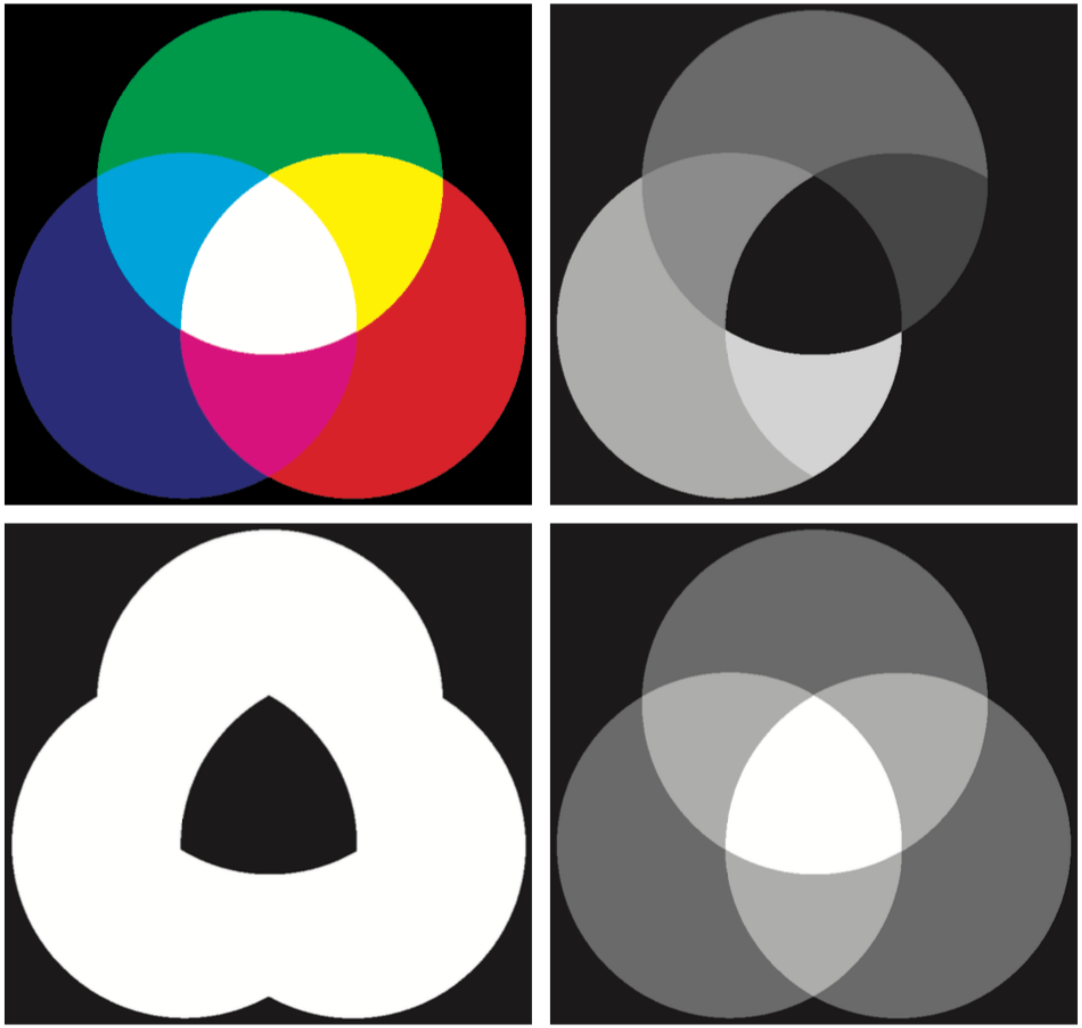
a
b

FIGURE 6.12
The HSI color model based on (a) triangular, and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.



a b
c d

FIGURE 6.14 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.



1. red corresponds to 0°, the red region is mapped to a black region in the hue image

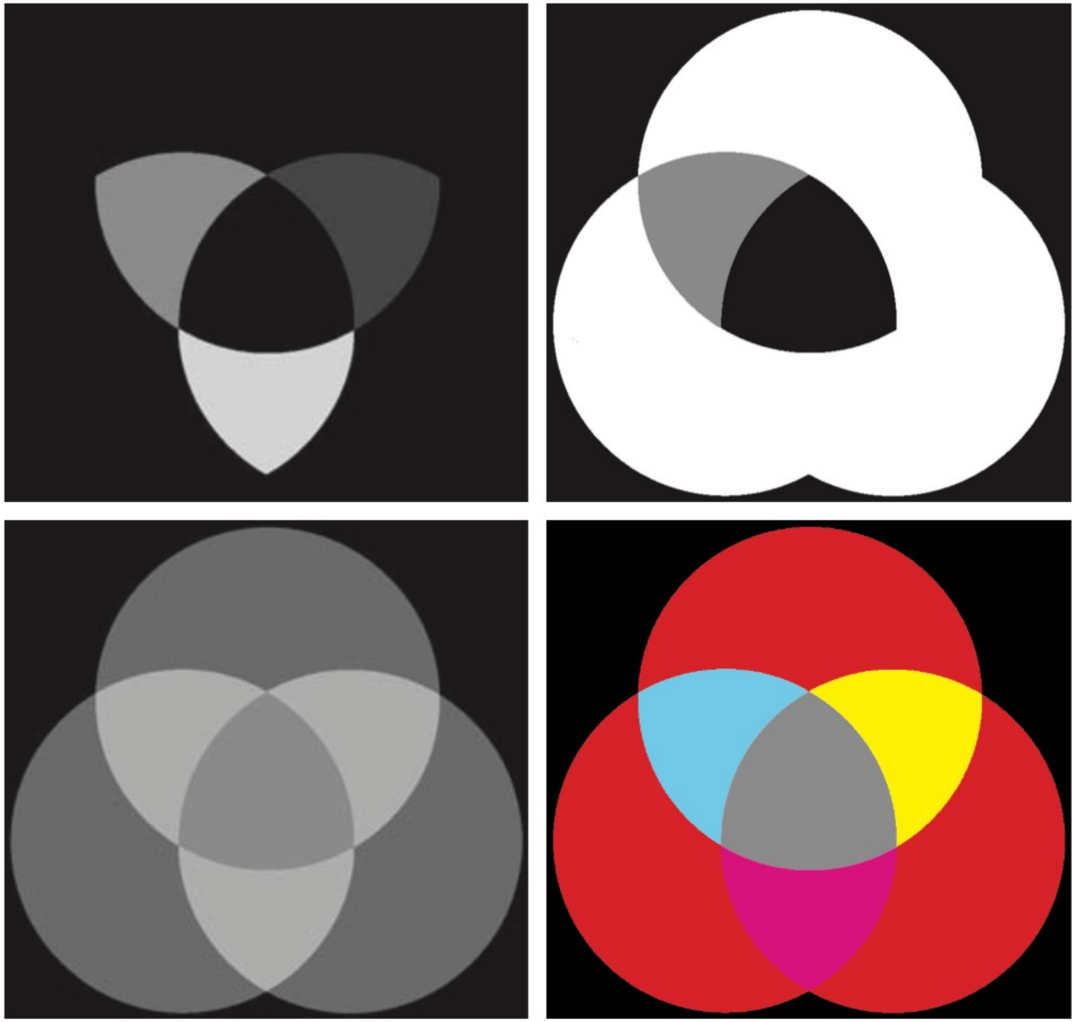


FIGURE 6.15
(a)-(c) Modified HSI component images.
(d) Resulting RGB image. (See Fig. 6.14 for the original HSI images.)

1. the image in (a) was obtained by changing to 0 the pixels corresponding to the blue and green regions in Fig. 6.14(b)
2. (b) is reduced by half the saturation of the cyan region in component image S from Fig. 6.14(c)
3. (c) is reduced by half the intensity of the central white region in the intensity image of Fig. 6.14(d)
4. The result of converting this modified HSI image back to RGB is shown in Fig. 6.15(d).

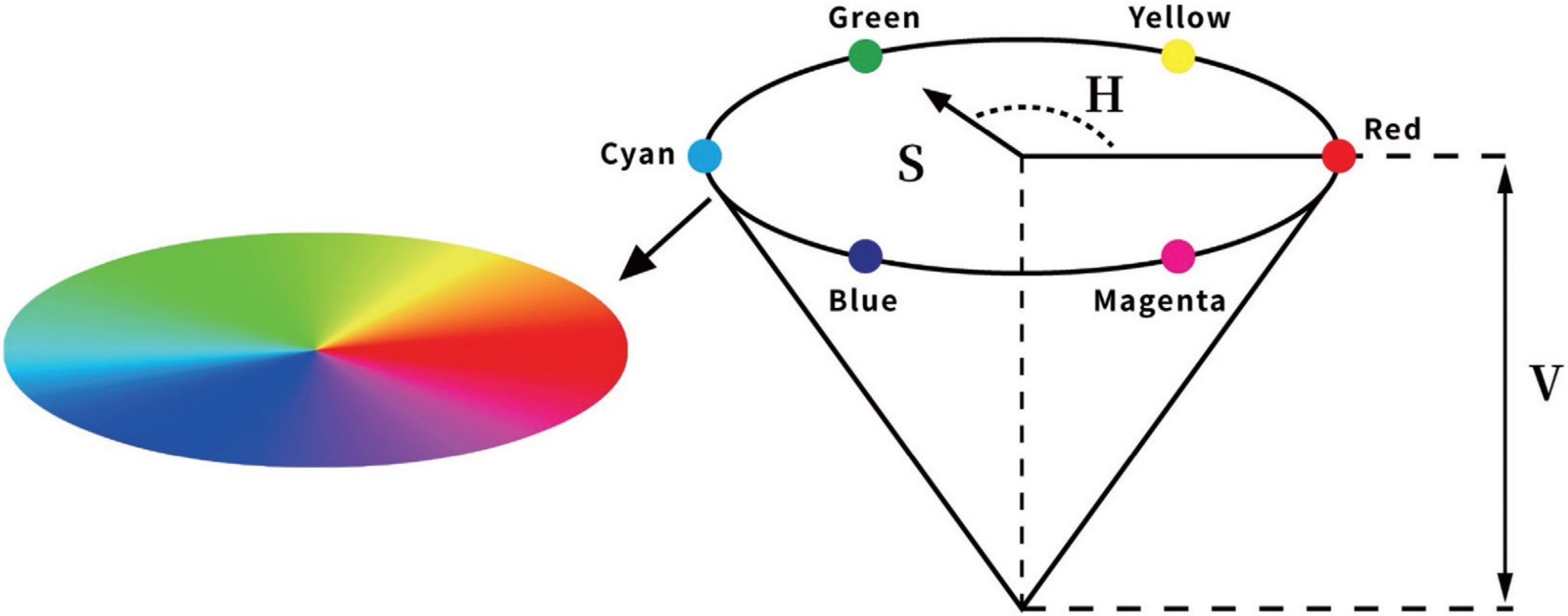
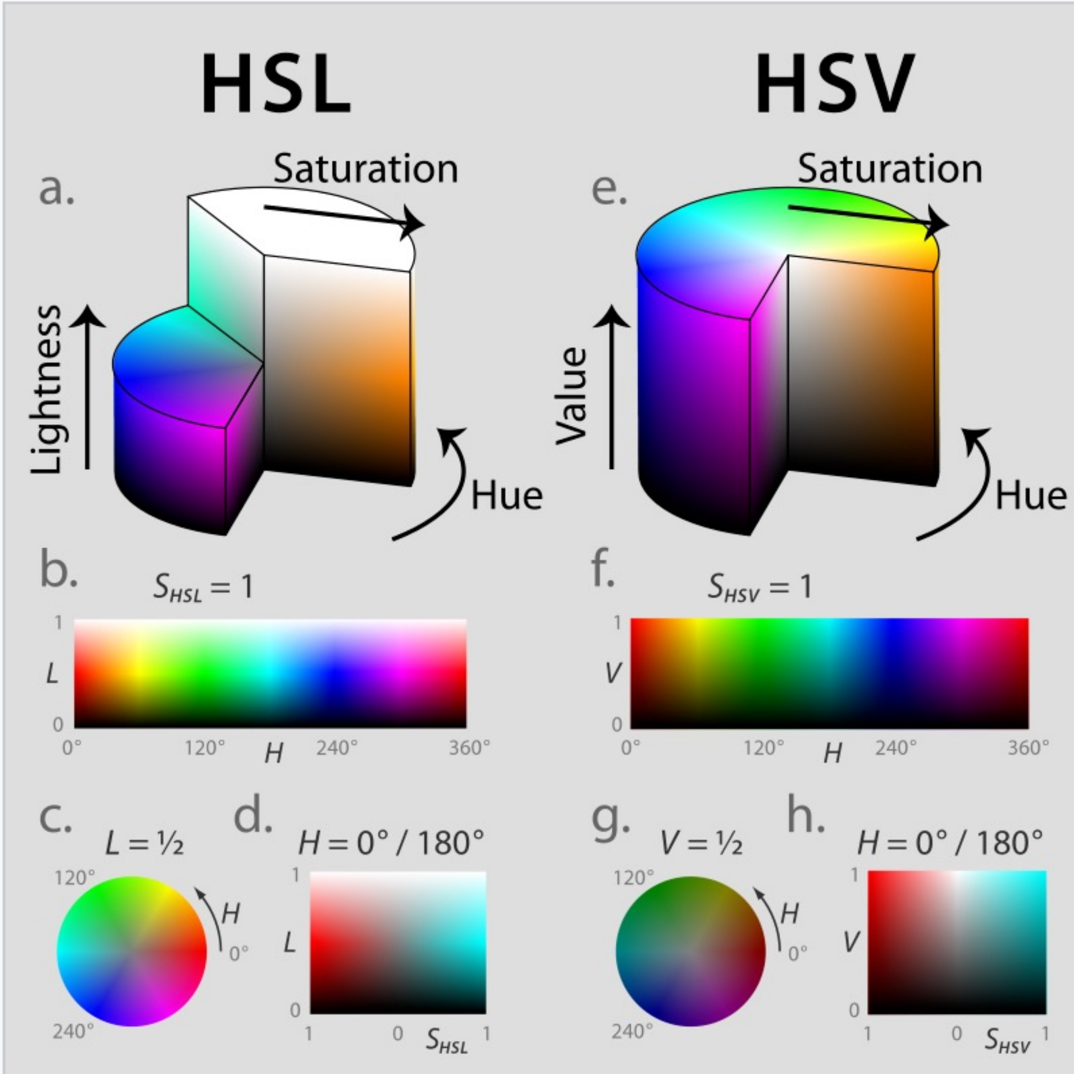


圖 8-8　HSV 色彩模型



HSL（a~d）和HSV（e~h）。上半部分（a、e）：兩者的3D模型截面。下半部分：將模型中三個參數的其中之一固定為常量，其它兩個參數的圖像。

from Wikipedia

原始影像

H 通道

S 通道

V 通道

圖 8-9　HSV 色彩模型

YCbCr

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 0 \\ 128 \\ 128 \end{bmatrix} \quad \begin{matrix} Y \in [0, 255] \\ C_b \in [0, 255] \\ C_r \in [0, 255] \end{matrix} \tag{F.15}$$

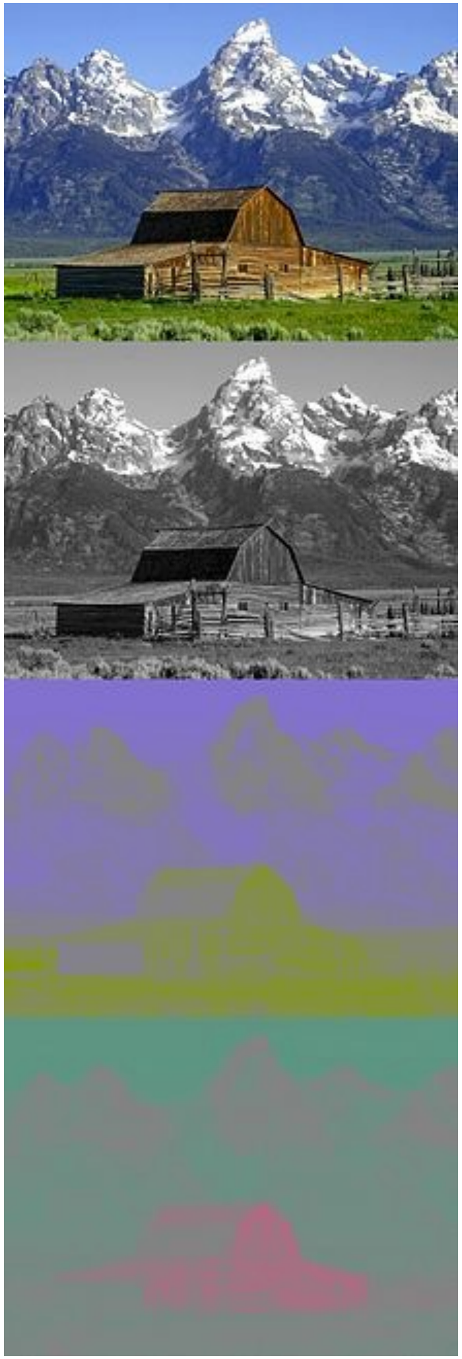


圖 8-10　YCrCb 色彩模型

Basics of Full-Color Image Processing

- Full-color image processing approaches fall into two major categories
- 1. process each grayscale component image individually, then form a composite color image from the individually processed components
- 2. work with color pixels directly

a b

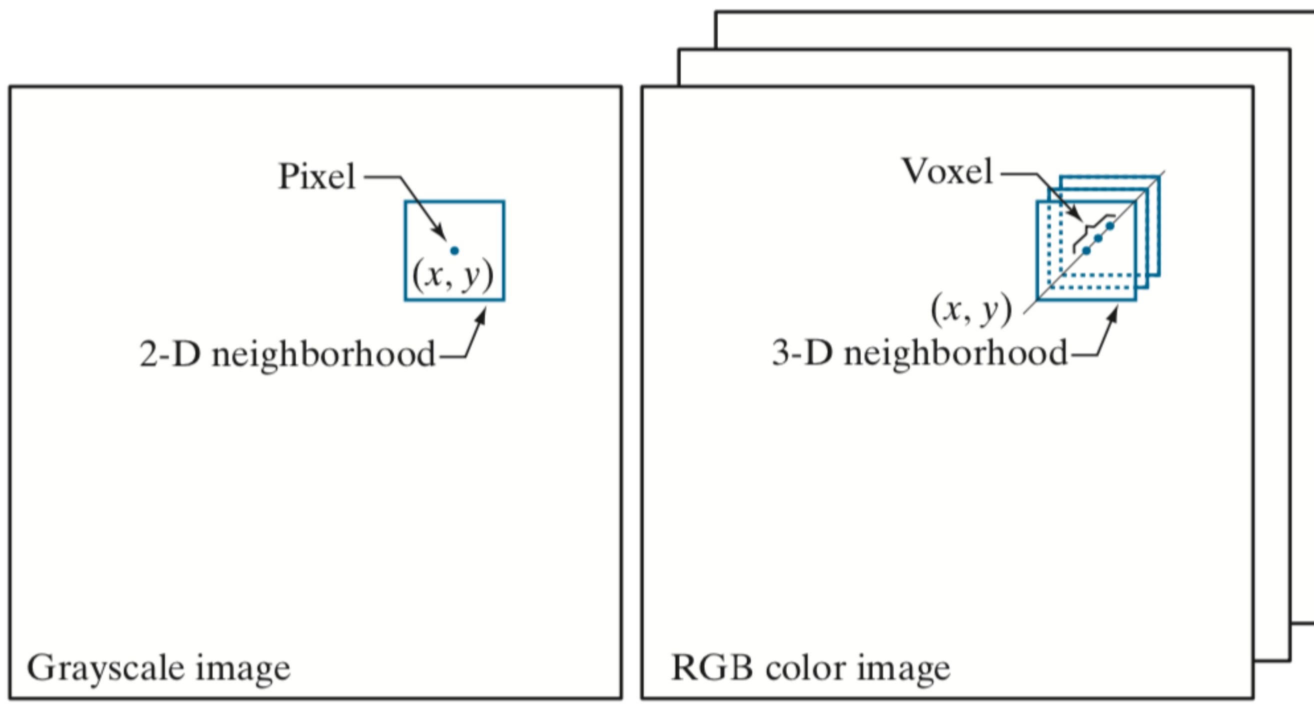


FIGURE 6.27 Spatial neighborhoods for grayscale and RGB color images. Observe in (b) that a *single* pair of spatial coordinates, (x, y), addresses the same spatial location in all three images.

灰階與色彩轉換

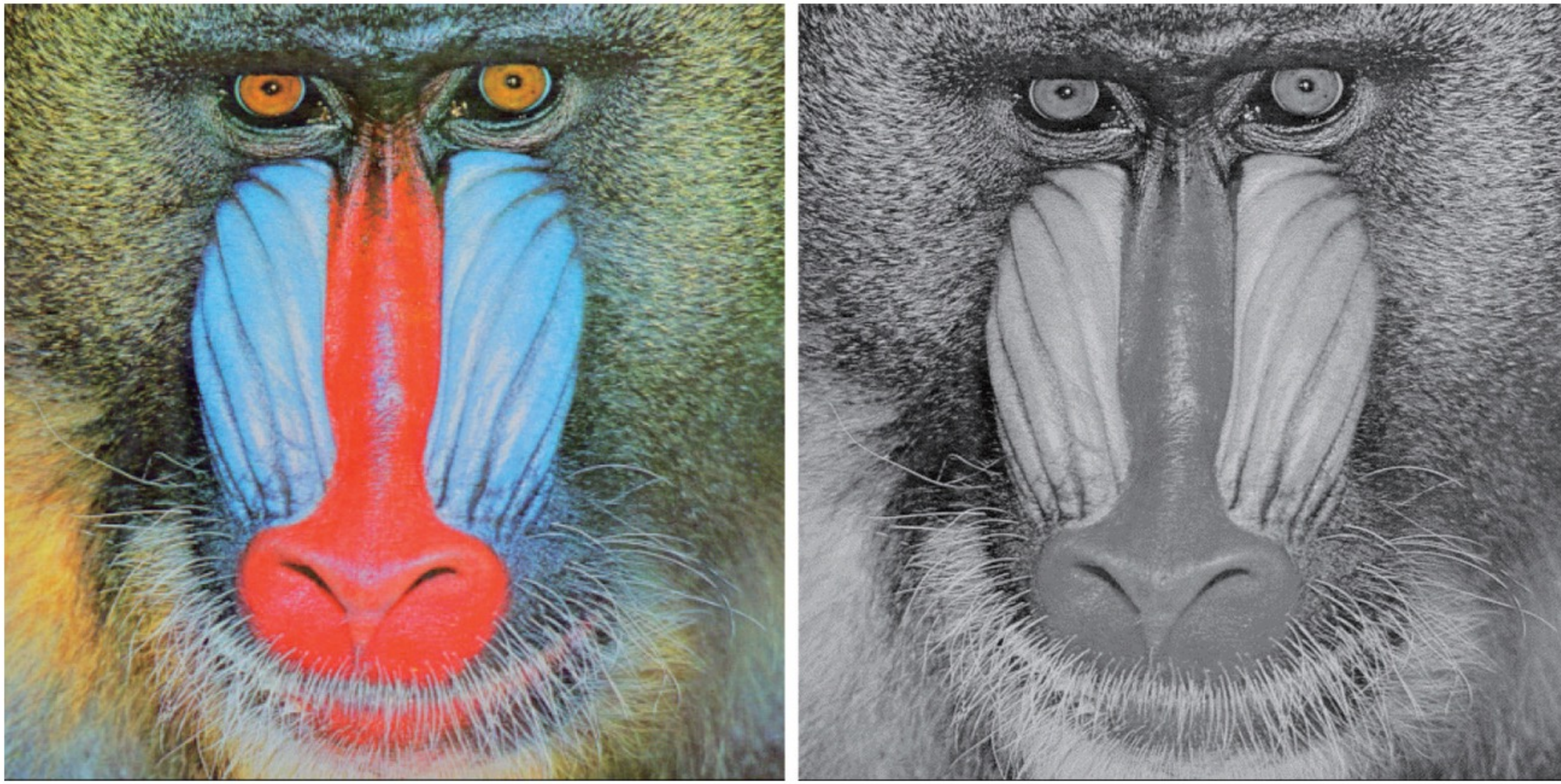
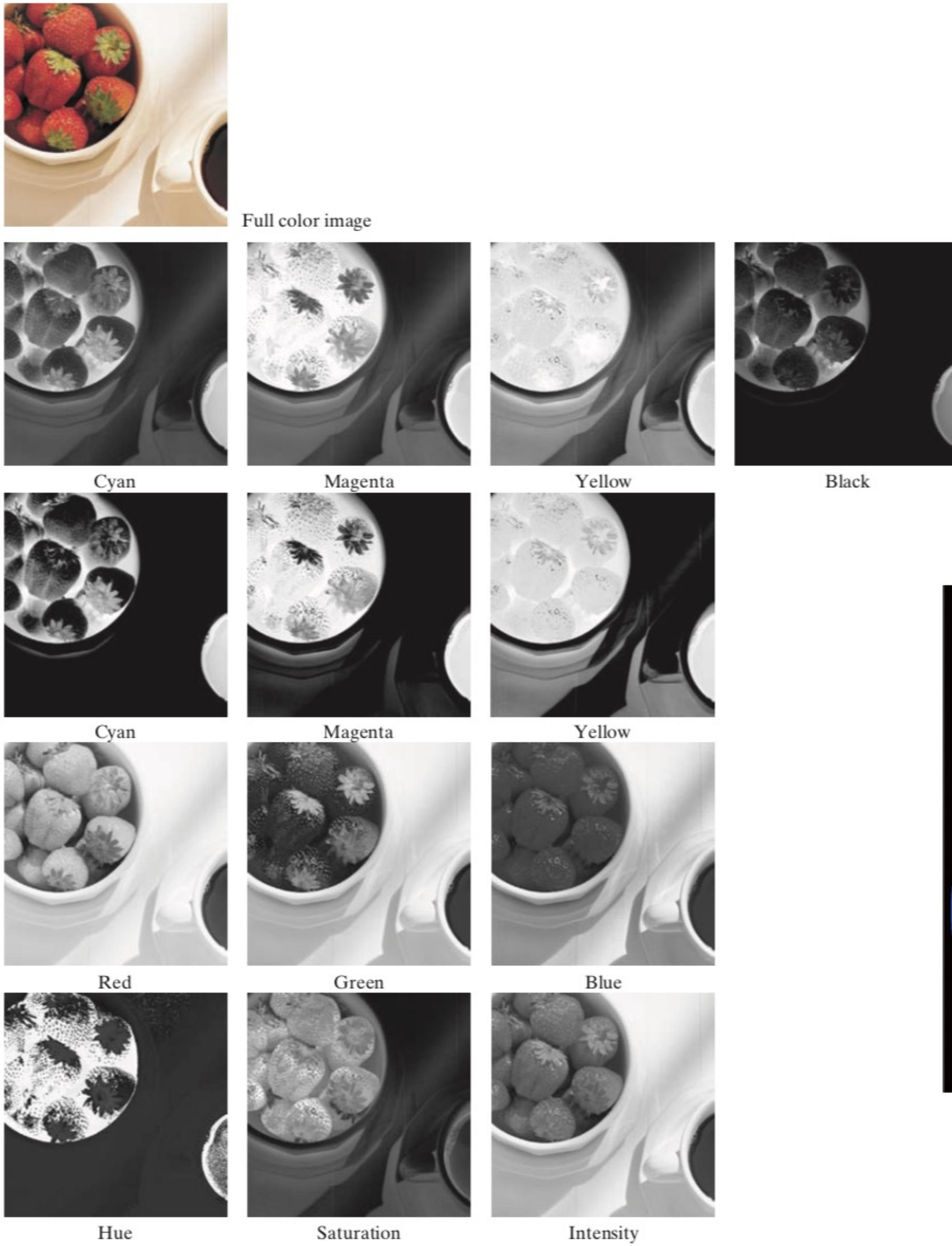


圖 8-11　灰階轉換

- model color transformations for multispectral images using the general expression
  - $s_i = T_i(r_i) \qquad i = 1, 2, \ldots, n$
- n is the total number of component images
- r_i are the intensity values of the input component images
- s_i are the spatially corresponding intensities in the output component images
- T_i are a set of *transformation* or *color mapping functions* that operate on r_i to produce s_i
  - applied individually to all pixels in the input image
- For example, in the case of RGB color images, n = 3, r_1 , r_2, r_3 are the intensities values at a point in the input components images, and s_1 , s_2 , s_3 are the corresponding transformed pixels in the output image



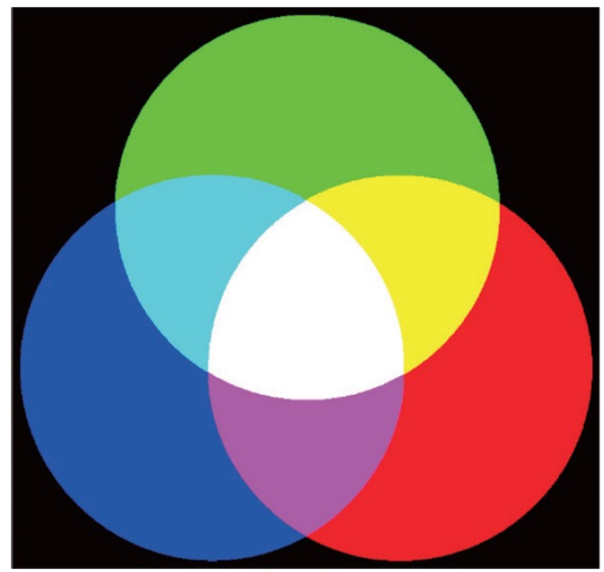
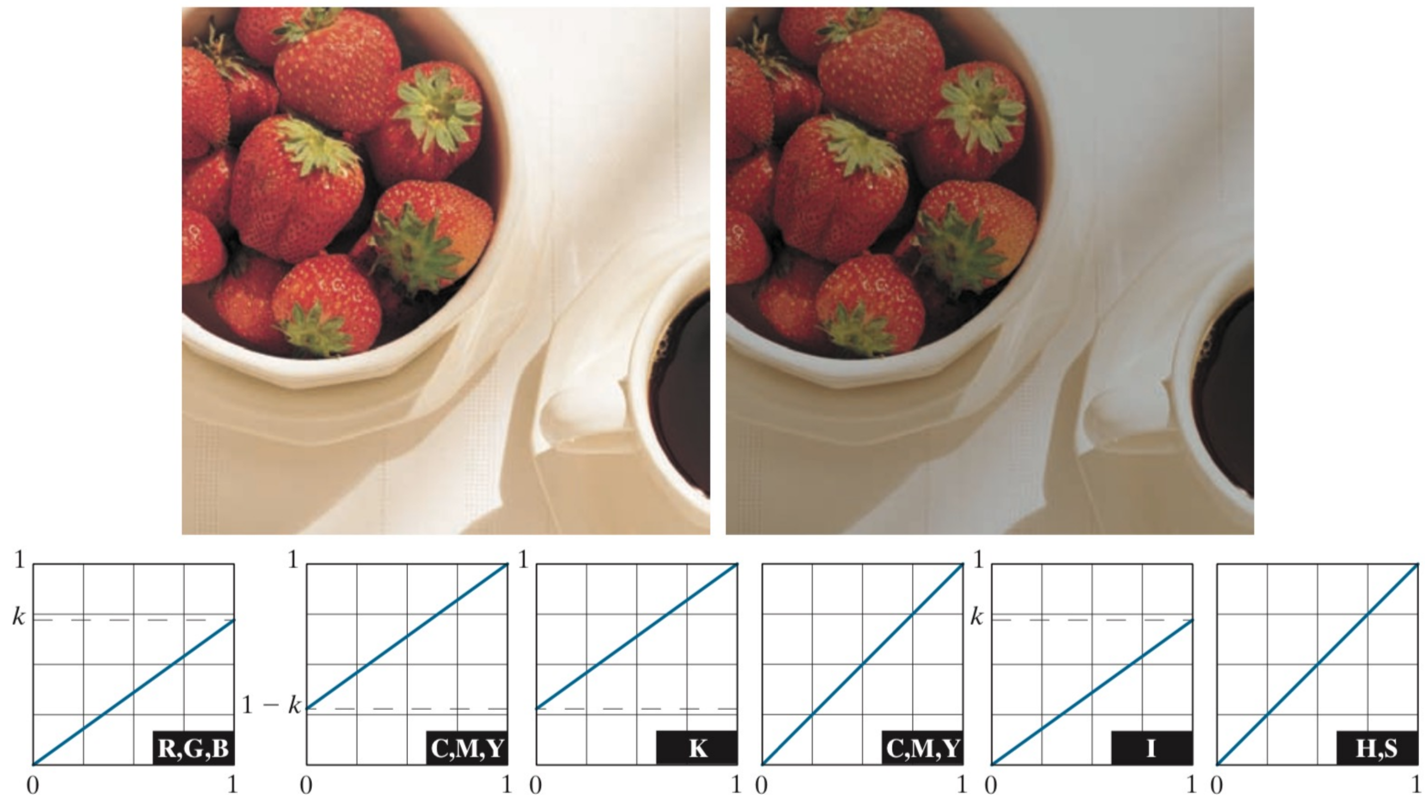


FIGURE 6.28 A full-color image and its various color-space components. (Original image courtesy of MedData Interactive.)

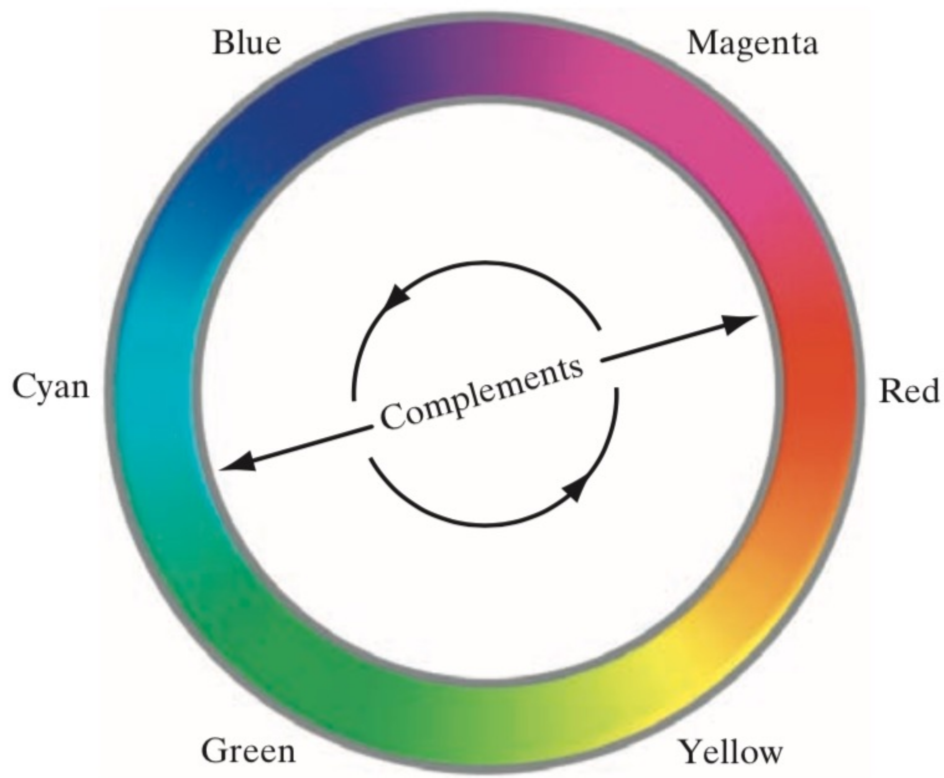
- modify the intensity of the full-color image
- 1. HSI color space: only modify the intensity component image
  - $s_3 = kr_3$
- and $s_1 = r_1$ and $s_2 = r_2$
- 2. RGB color space:
  - $s_i = kr_i \quad i=1,2,3$
- 3. CMY color space:
  - $s_i = kr_i + (1-k) \quad i=1,2,3$
- 4. CMYK color space:
  - $$s_i = \begin{cases} r_i & i = 1,2,3 \\ kr_i + (1-k) & i = 4 \end{cases}$$



a b
c d e f g h

FIGURE 6.29 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c) The required RGB mapping function. (d)–(e) The required CMYK mapping functions. (f) The required CMY mapping function. (g)–(h) The required HSI mapping functions. (Original image courtesy of MedData Interactive.)

FIGURE 6.30
Color complements on the color circle.



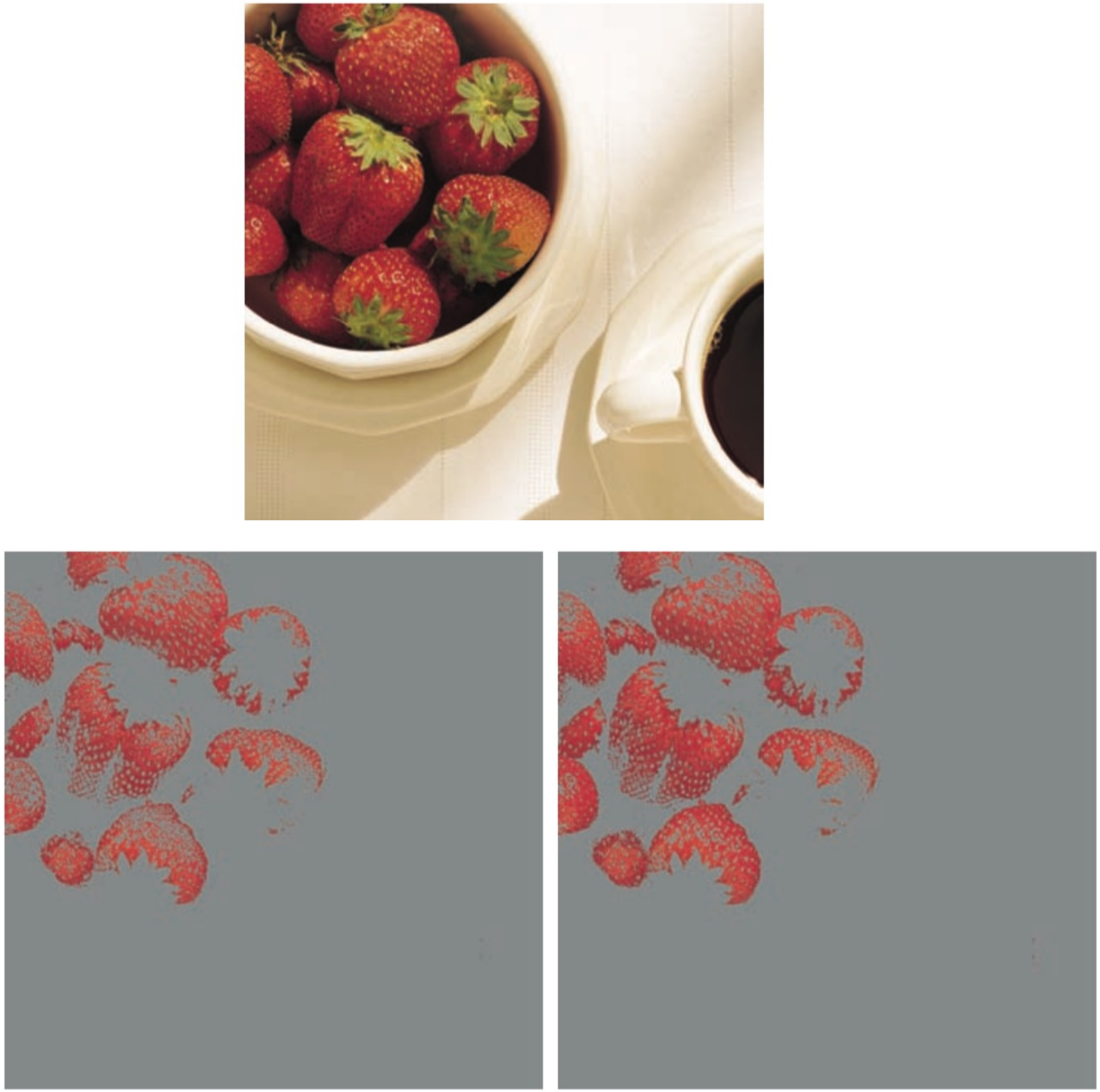
Color slicing

- Highlighting a specific range of colors in an image
- cube (or *hypercube* for $n > 3$)

$$s_i = \begin{cases} 0.5 & \text{if } \left[\left| r_j - a_j \right| > \dfrac{W}{2} \right]_{\text{any } 1 \le j \le n} \\ r_i & \text{otherwise} \end{cases} \qquad i = 1, 2, \ldots, n$$

- sphere (or hypersphere for $n > 3$)

$$s_i = \begin{cases} 0.5 & \text{if } \displaystyle\sum_{j=1}^{n} \left(r_j - a_j \right)^2 > R_0^2 \\ r_i & \text{otherwise} \end{cases} \qquad i = 1, 2, \ldots, n$$



a b

FIGURE 6.32 Color-slicing transformations that detect (a) reds within an RGB cube of width $W = 0.2549$ centered at $(0.6863, 0.1608, 0.1922)$, and (b) reds within an RGB sphere of radius 0.1765 centered at the same point. Pixels outside the cube and sphere were replaced by color $(0.5, 0.5, 0.5)$.

Tone and Color Corrections

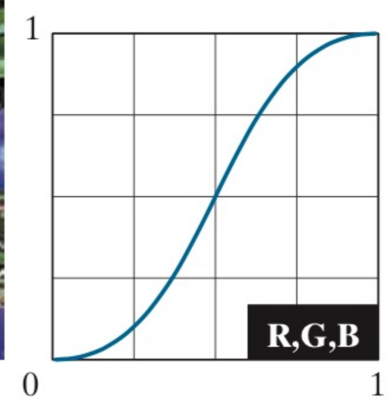
- over- and under-saturated colors
- *key type*: tonal range of an image
- general distribution of color intensities
- *high-key* images:
- most of information is concentrated at high (or light) intensities
- *low-key* images:
- are located predominantly at low intensities
- *middle-key* images lie in between

- Transformations for modifying image tones normally are selected interactively
- adjust experimentally the image's brightness and contrast to provide maximum detail over a suitable

Flat

Corrected

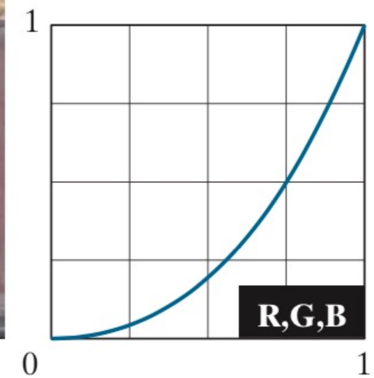
S 型曲線
固定中值，加強對比

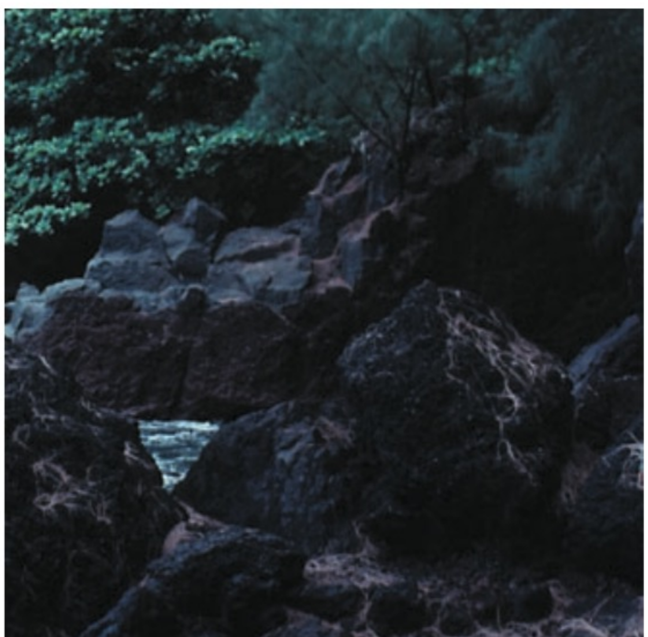


Light

Corrected

Exponential 曲線
修正太亮

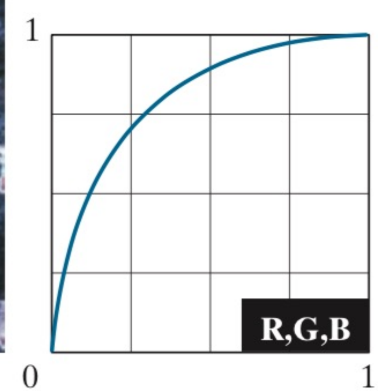




Dark

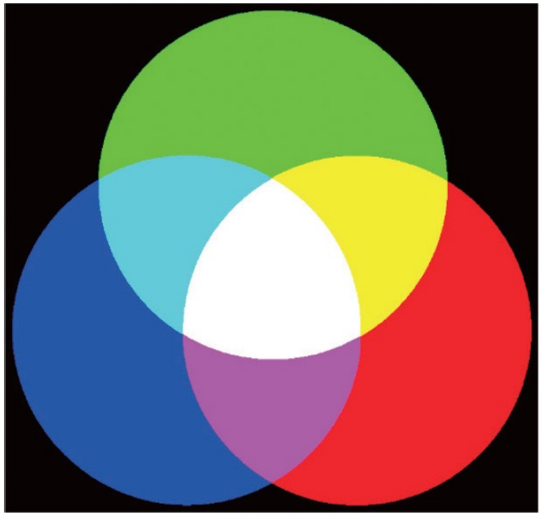
Corrected

Log 曲線
修正太暗



Color balancing

- A color proportional increase by color wheel
- decreasing the amount of the complementary color
- increasing the percentage of the two adjacent colors or decreasing the percentage of the two adjacent complement colors
- For instance, there is too much magenta in an RGB image. It can be decreased:
- (1) removing both red and blue
- (2) adding green



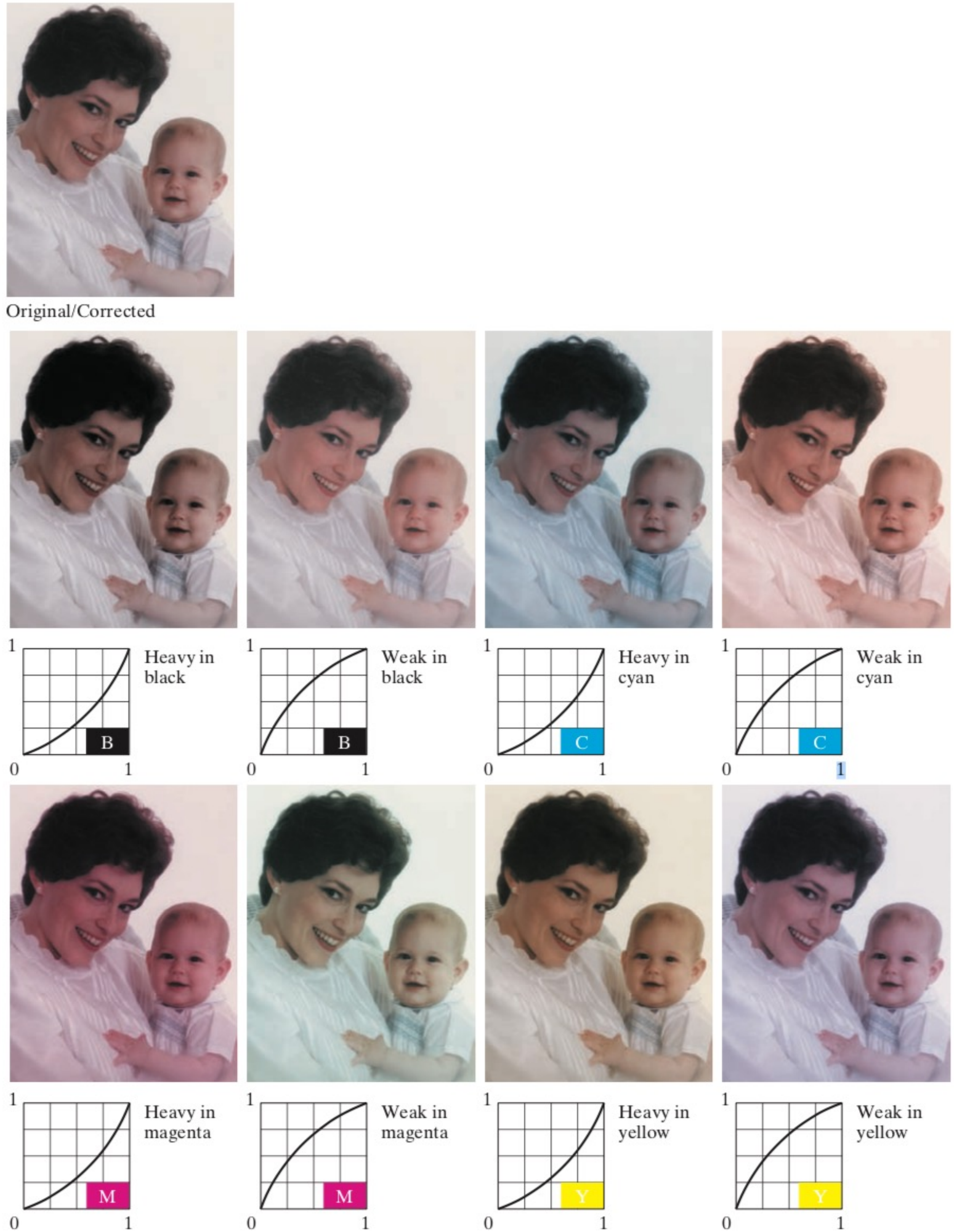


FIGURE 6.34 Color balancing a CMYK image.

Check IP05.ipynb

- 5.6 Image Brightness
  - Step 1: RGB to YCbCr
  - Step 2: apply gamma correction with gamma = 0.5 on plane Y
  - Step 3: recover YCbCr to RGB
  - Step 4: compare with gamma correction with gamma = 0.5 on planes RGB