Lecture 4 - Image Fundamentals – Color space

This lecture will cover:

- Color fundamentals
  - Primary colors
  - Secondary colors
  - Color gamut
- Color models
  - RGB model
  - CMY and CMYK model
  - HSI model
- Pseudocolor image processing
- Color transformation

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Primary colors (原色)

- **Three basic quantities to describe the quality of chromatic light source:**
  - Radiance (辐射): the total amount of energy from the light source, in watt
  - Luminance (光强): the amount of energy perceived by an observer, in lumen
  - Brightness (亮度): achromatic notion of intensity, subjective descriptor, key factor in describing color sensation.

- **CIE RGB Standard**
  - Blue = 435.8 nm
  - Green = 546.1 nm
  - Red = 700 nm

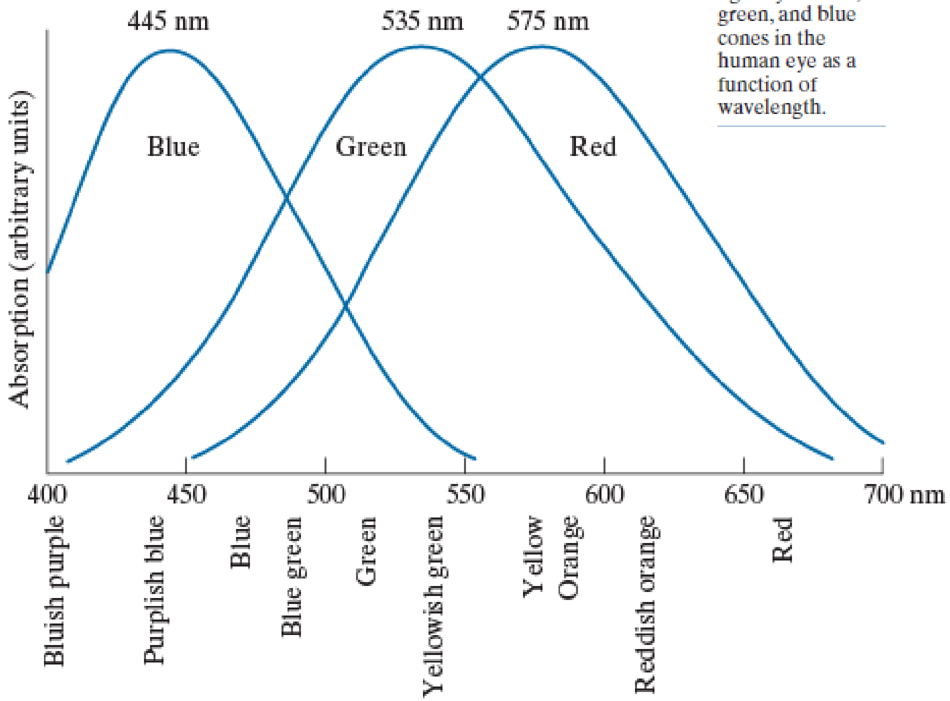


FIGURE 7.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

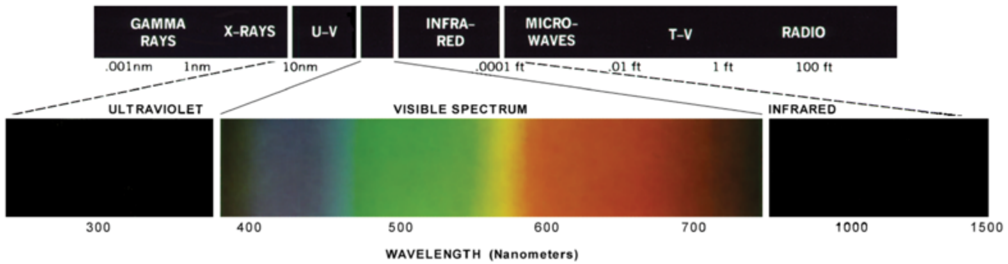


FIGURE 7.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lighting Division.)

Secondary colors (二次色)

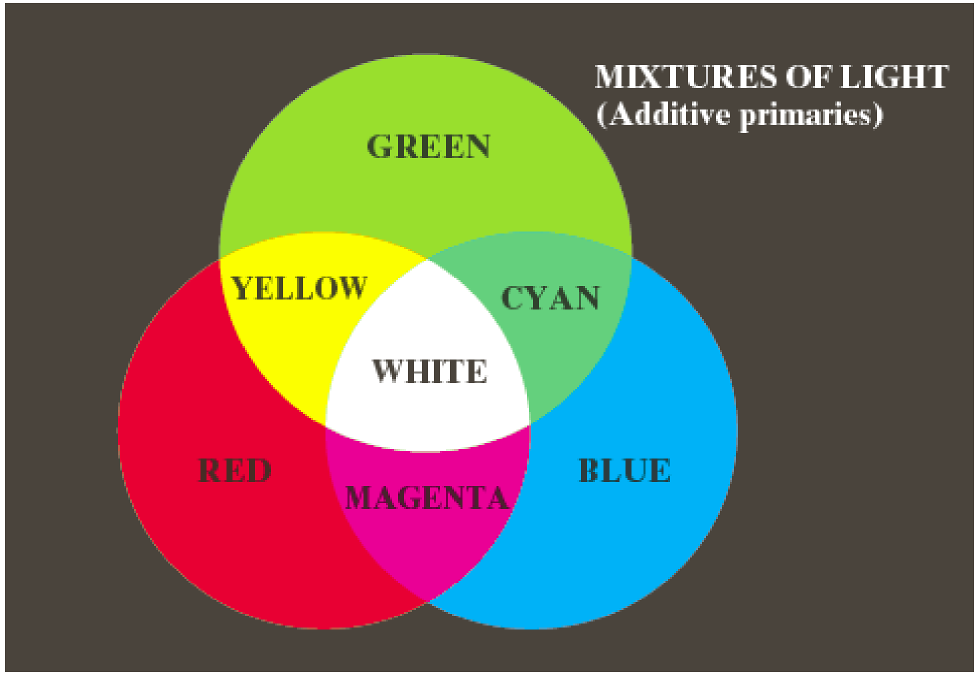
CMY and CMYK color

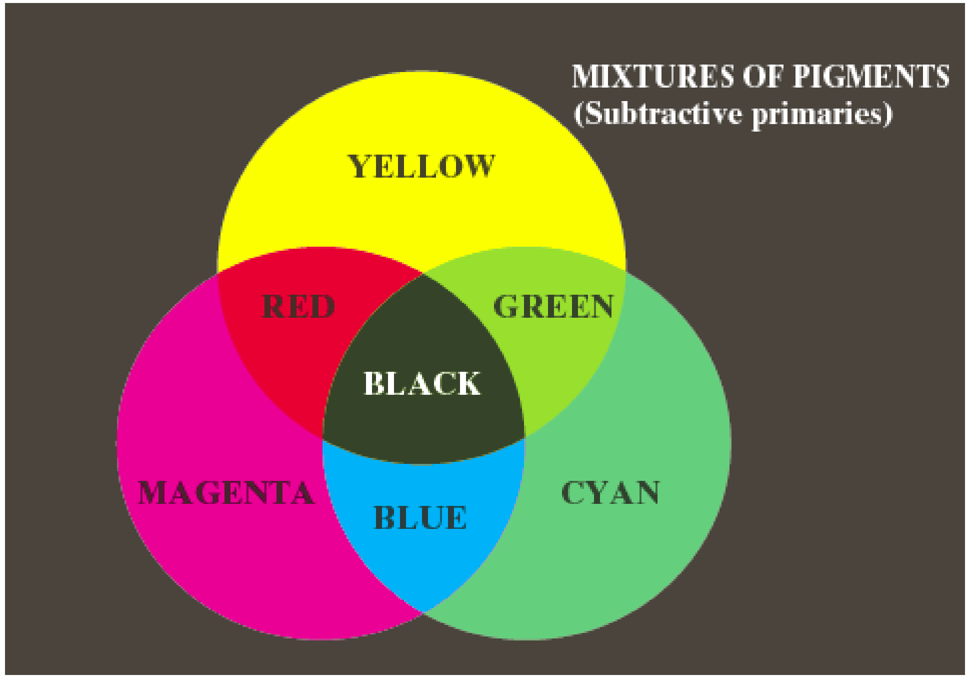
Cyan = White – Red

Magenta = White – Green

Yellow = White – Blue

Black = White – Red - Green - Blue





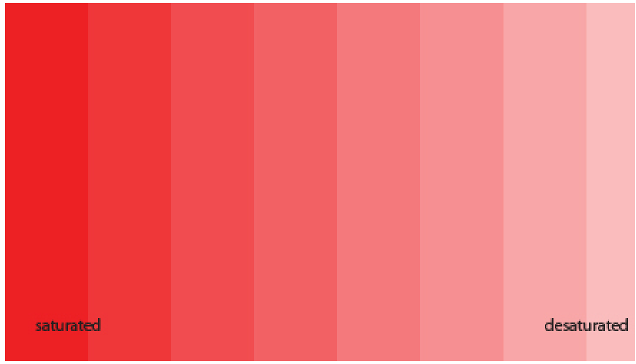
Color characteristics

- **The characteristics to distinguish colors:**
  - Brightness (亮度): achromatic notion of intensity;
  - Hue (色调): dominant color, associate with dominant wavelength of light;
  - Saturation (饱和度): relative purity, the amount of white light mixed with a hue.
  - Chromaticity (色度): Hue + Saturation

- **Color: Chromaticity + brightness**

  Trichromatic coefficients (三色值系数):

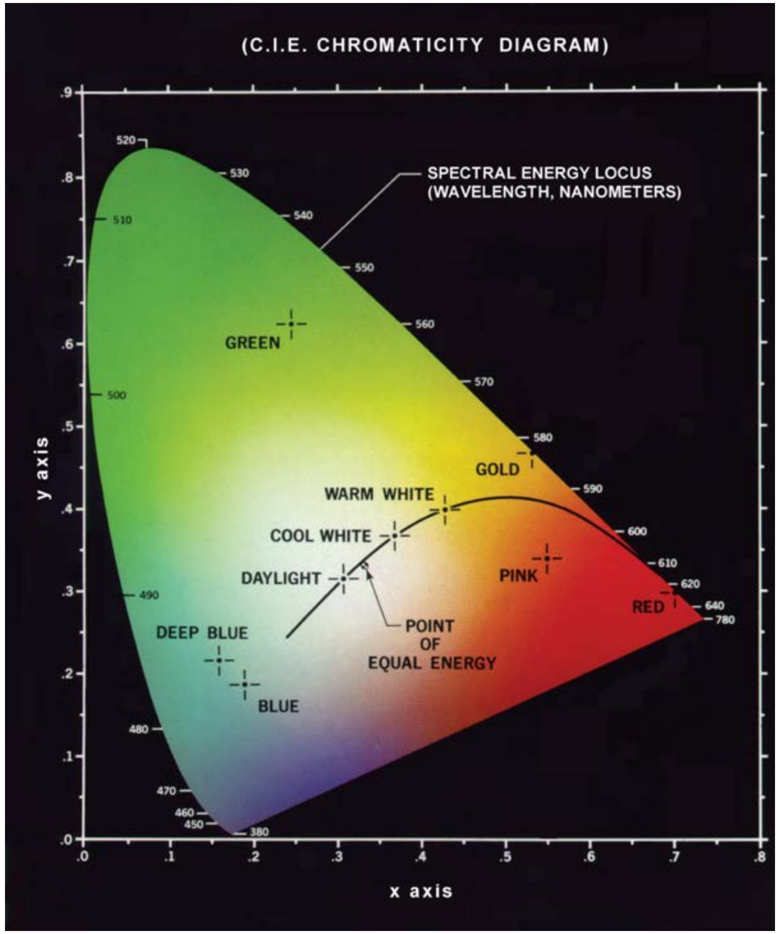
$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad z = \frac{Z}{X+Y+Z}$$



Saturation of color

Color Gamut (色域)

FIGURE 7.5 The CIE chromaticity diagram. (Courtesy of the General Electric Co., Lighting Division.)



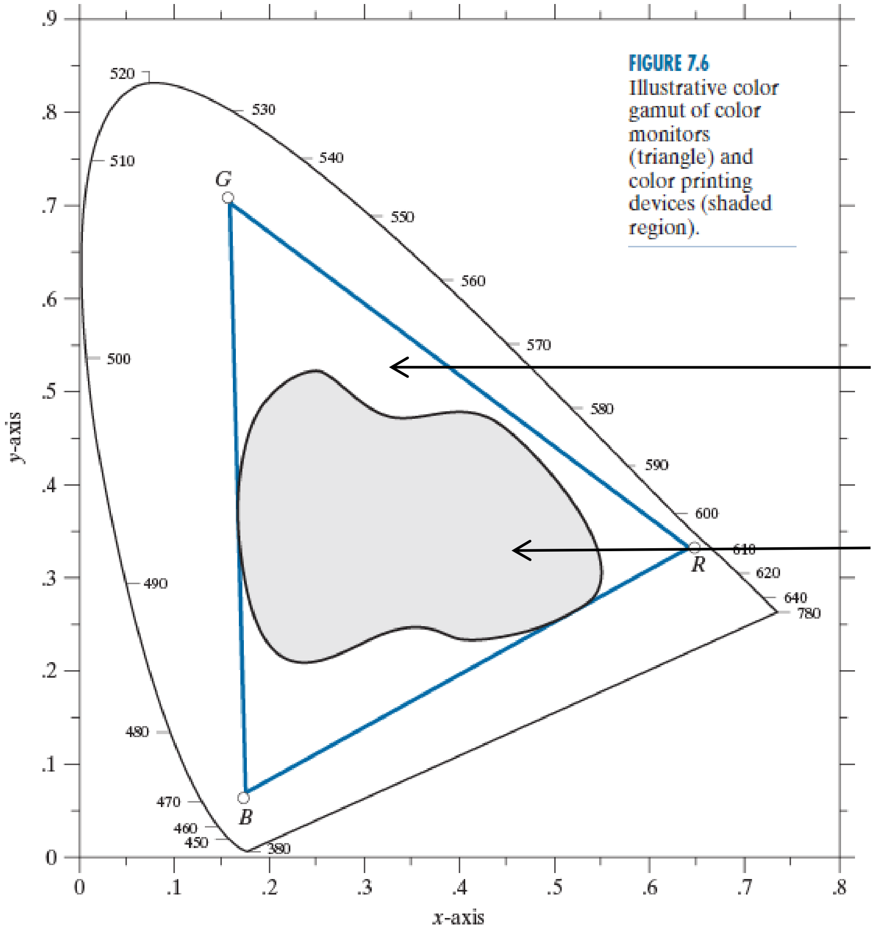


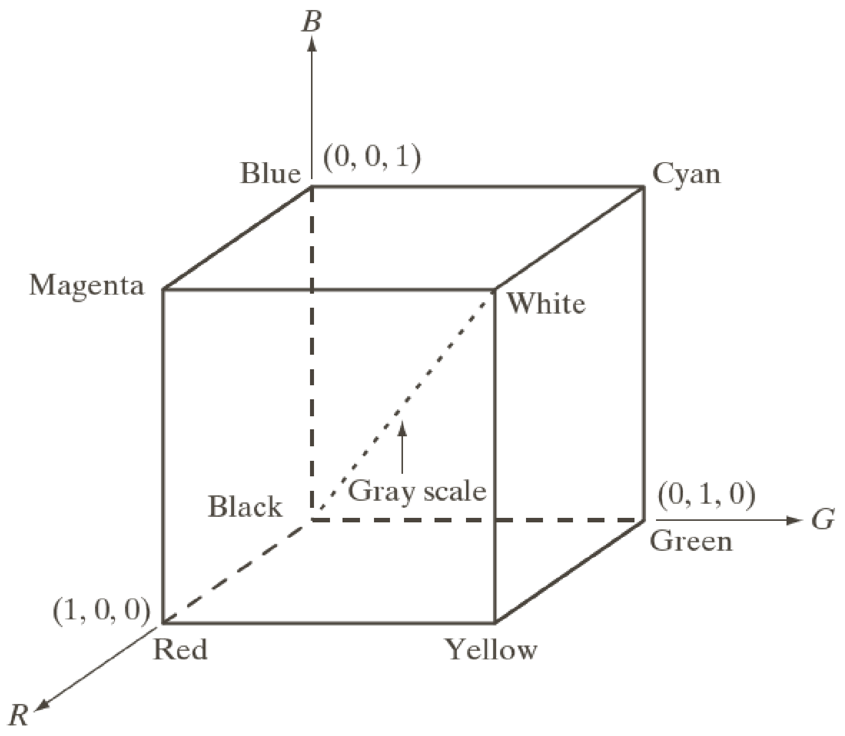
FIGURE 7.6 Illustrative color gamut of color monitors (triangle) and color printing devices (shaded region).

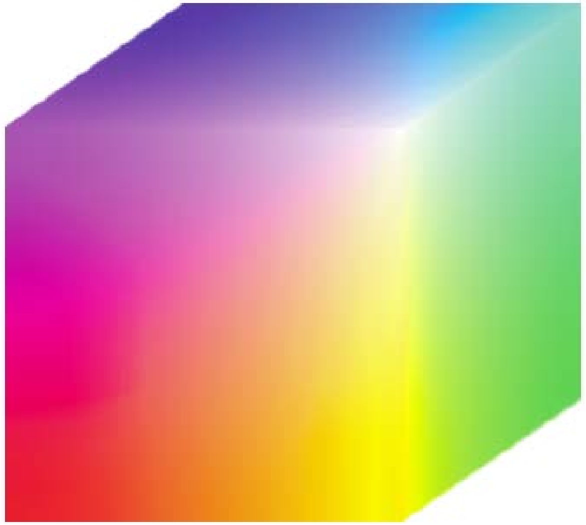
Color gamut for monitor

Color gamut for printer

RGB Color Model

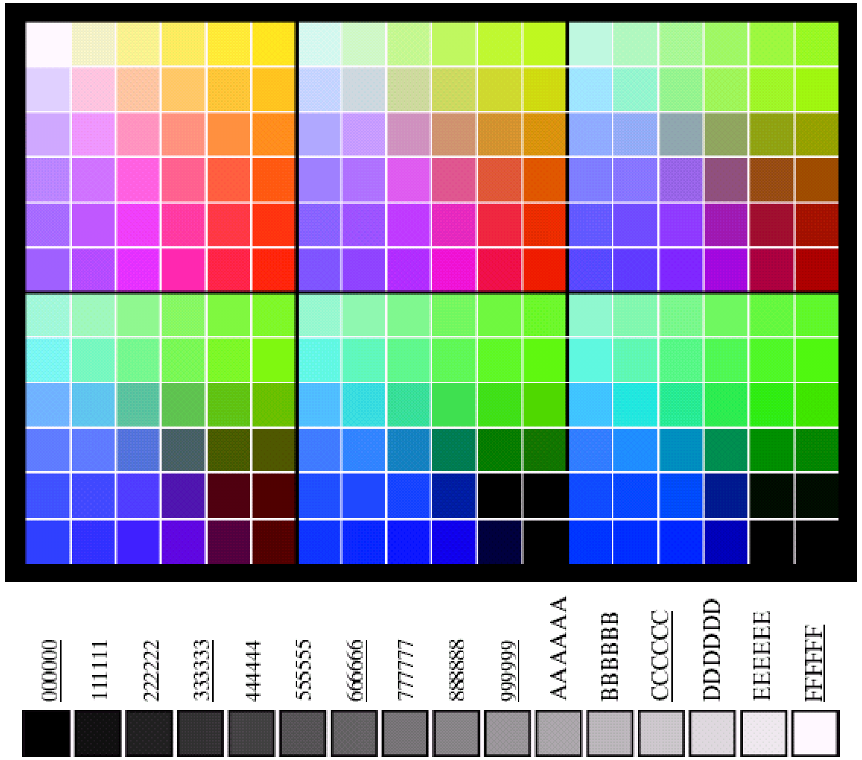
- Towards hardware: color monitor, color video camera;
- Primary spectral components of red, green and blue;
- Based on Cartesian coordinate system;

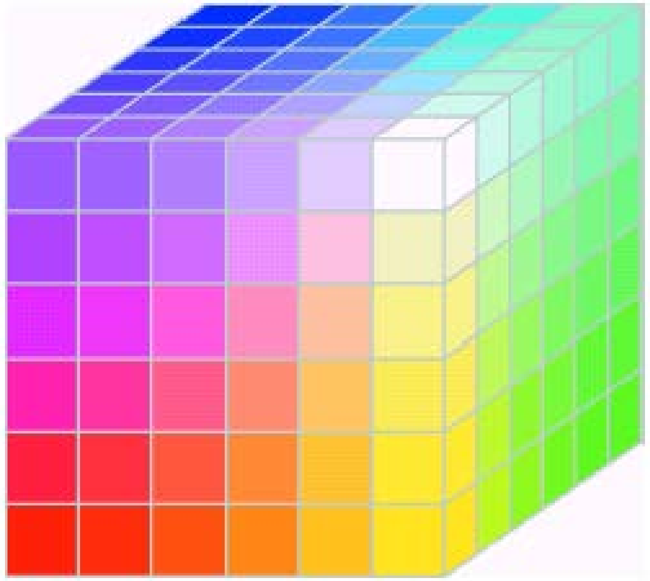




Safe RGB Color (稳定色)

Number System			Color Equivalents			
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255





CMY Color Model

- RGB to CMY conversion

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

- CMYK: In order to produce true black in printing, a fourth color, black, is added into the CMYK color model:

CMY to CMYK:

- when K=1, $C=M=Y=0$
- Otherwise: $K=\min(C,M,Y)$ $C=(C-K)/(1-K)$ $M=(M-K)/(1-K)$ $Y=(Y-K)/(1-K)$

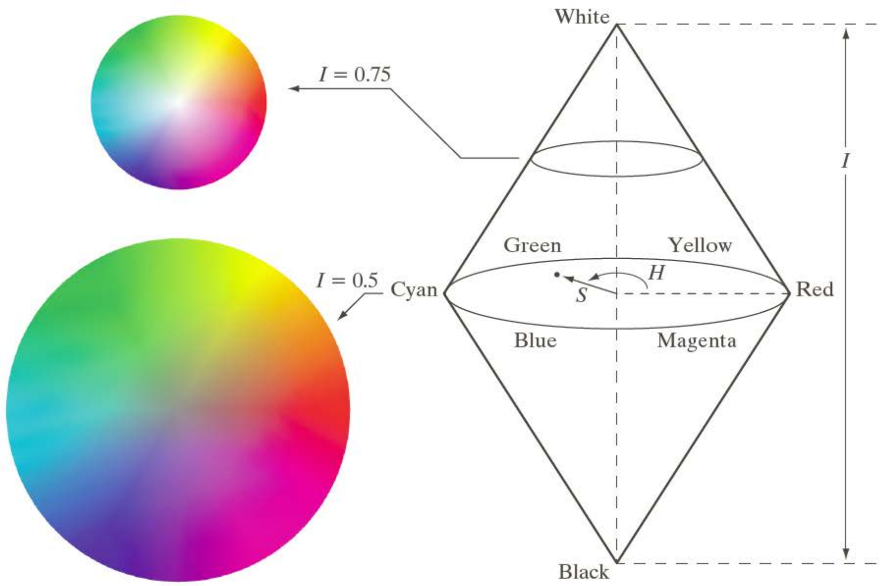
CMYK to CMY:

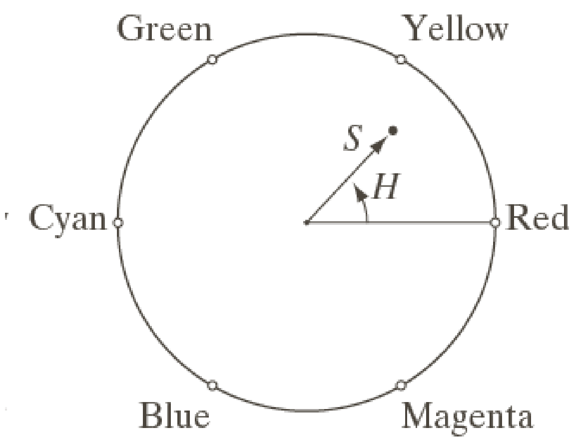
$C=C*(1-K)+K$ $M=M*(1-K)+K$ $Y=Y*(1-K)+K$

HSI Color Model

➢ **HSI Color Model:**

- Hue: Dominant color associated with wavelength
- Saturation: relative purity, the amount of white light mixed with a hue
- Intensity: brightness (V: value, L: lightness)





RGB to HSI

$$\theta = \arccos\left\{\frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-G)(G-B)]^{\frac{1}{2}}}\right\}$$

$$H = \begin{cases} \theta, & G \geq B \\ 360-\theta, & G < B \end{cases}$$

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

$$I = \frac{R+G+B}{3}$$

Two special cases:

$$S = 0 \rightarrow H = 0$$

$$I = 0 \rightarrow S = 0, H = 0$$

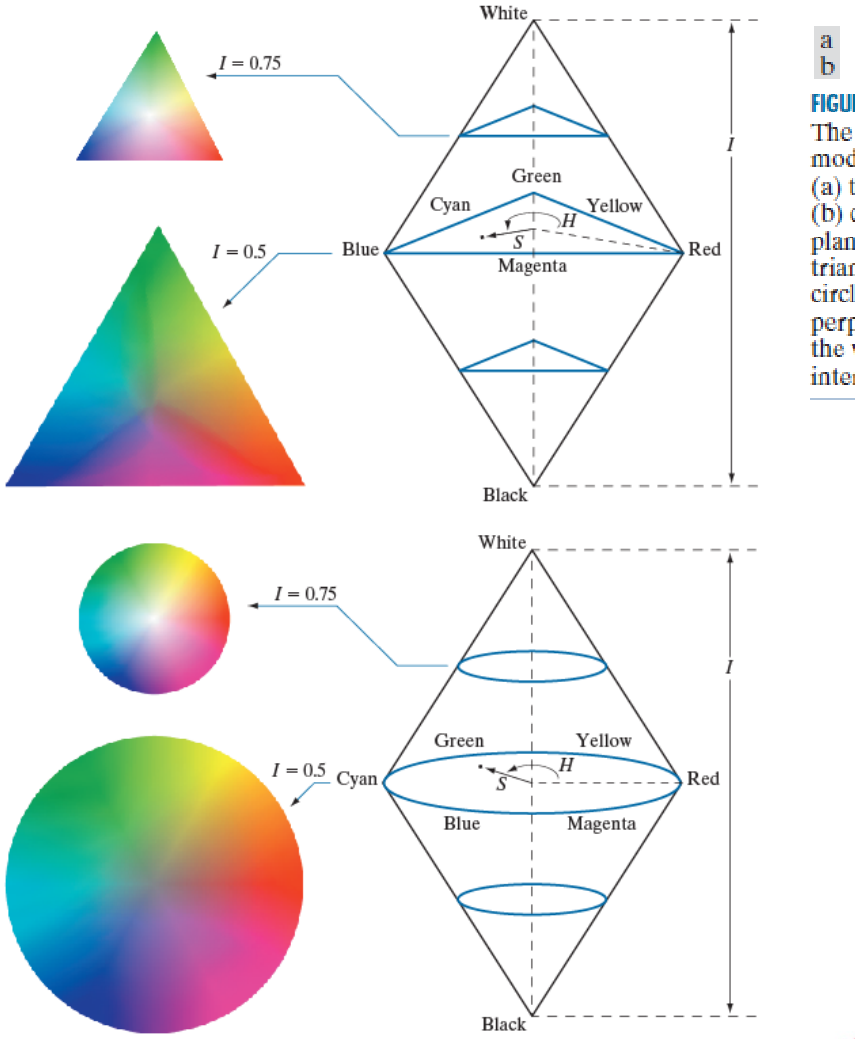


FIGURE 7.12 The HSI color model based on (a) triangular, and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

HSI to RGB

- $0° \leq H < 120°$

$$B = I(1 - S), \qquad R = I\left[1 + \frac{S\cos(H)}{\cos(60° - H)}\right], \qquad G = 3I - (R + B)$$

- $120° \leq H < 240°$

$$R = I(1 - S), \qquad G = I\left[1 + \frac{S\cos(H - 120°)}{\cos(180° - H)}\right], \qquad B = 3I - (R + G)$$

- $240° \leq H < 360°$

$$G = I(1 - S), \qquad B = I\left[1 + \frac{S\cos(H - 240°)}{\cos(300° - H)}\right], \qquad R = 3I - (G + B)$$

Pseudocolor image processing

- **Pseudocolor(伪彩色)**: assigning colors to gray values based on specified criterion

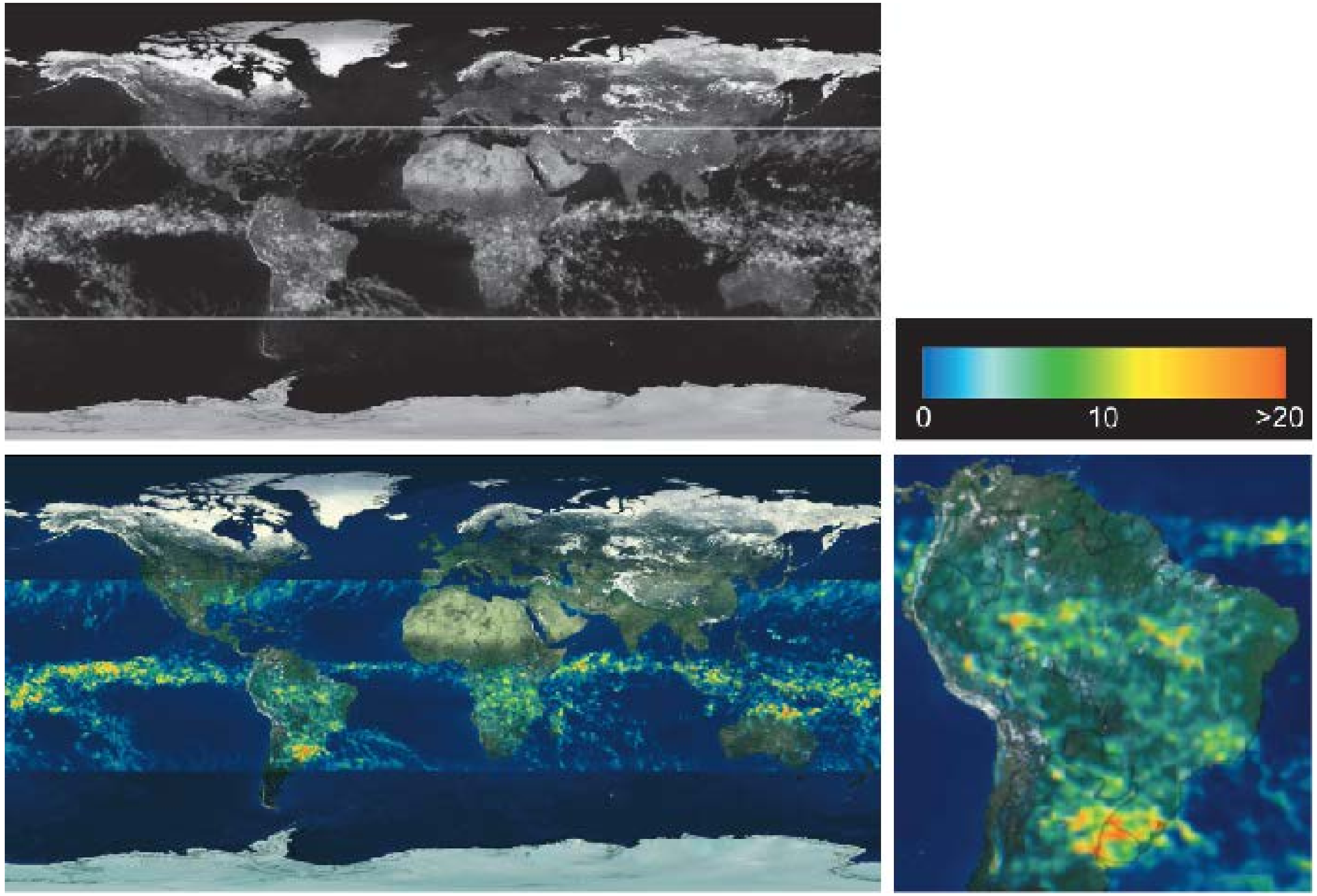
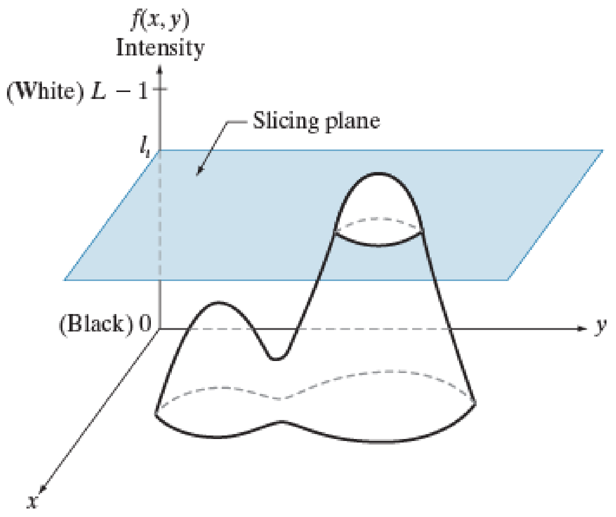


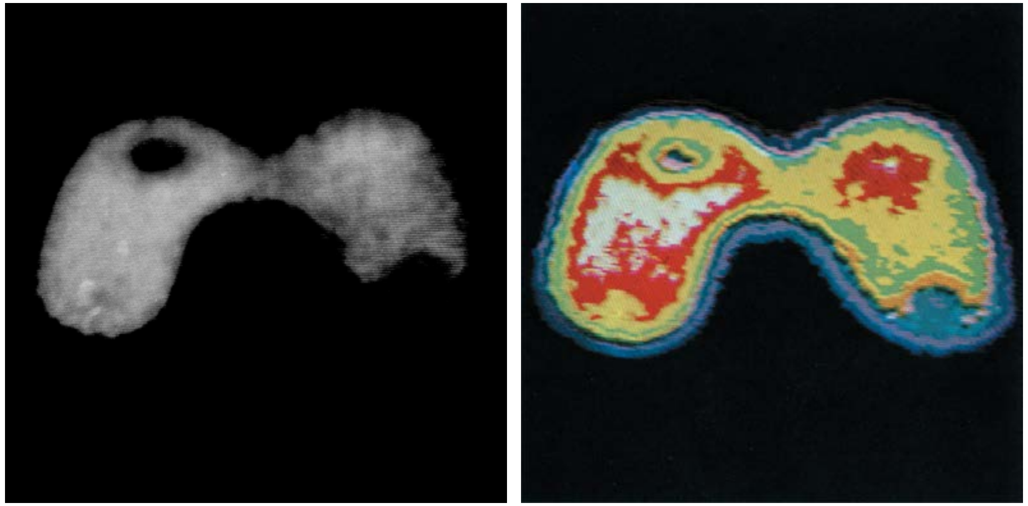
FIGURE 7.20 (a) Grayscale image in which intensity (in the horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South American region.(Courtesy of NASA.)

Intensity slicing

➢ **Intensity slicing (灰度分层):** the gray level was assigned to a different color;

FIGURE 7.16 Graphical interpretation of the intensity-slicing technique.





a b

FIGURE 7.18 (a) Grayscale image of the Picker Thyroid Phantom. (b) Result of intensity slicing using eight colors. (Courtesy of Dr. J. L. Blankenship, Oak Ridge National Laboratory.)

Intensity to color transformation

- Three independent transformations on the intensity of any pixel for red, green and blue channels

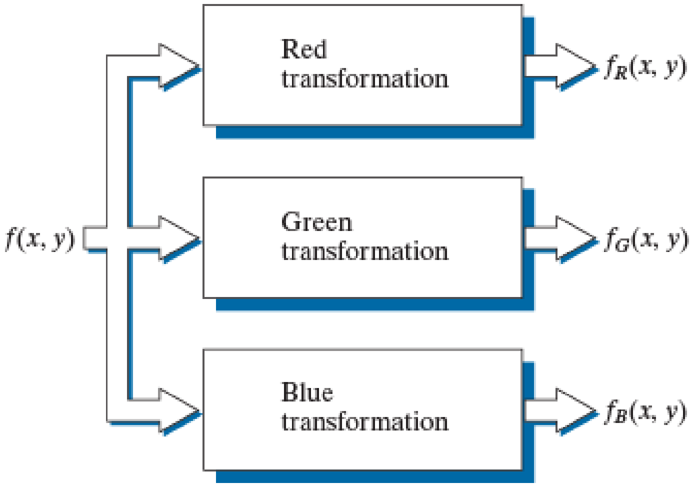
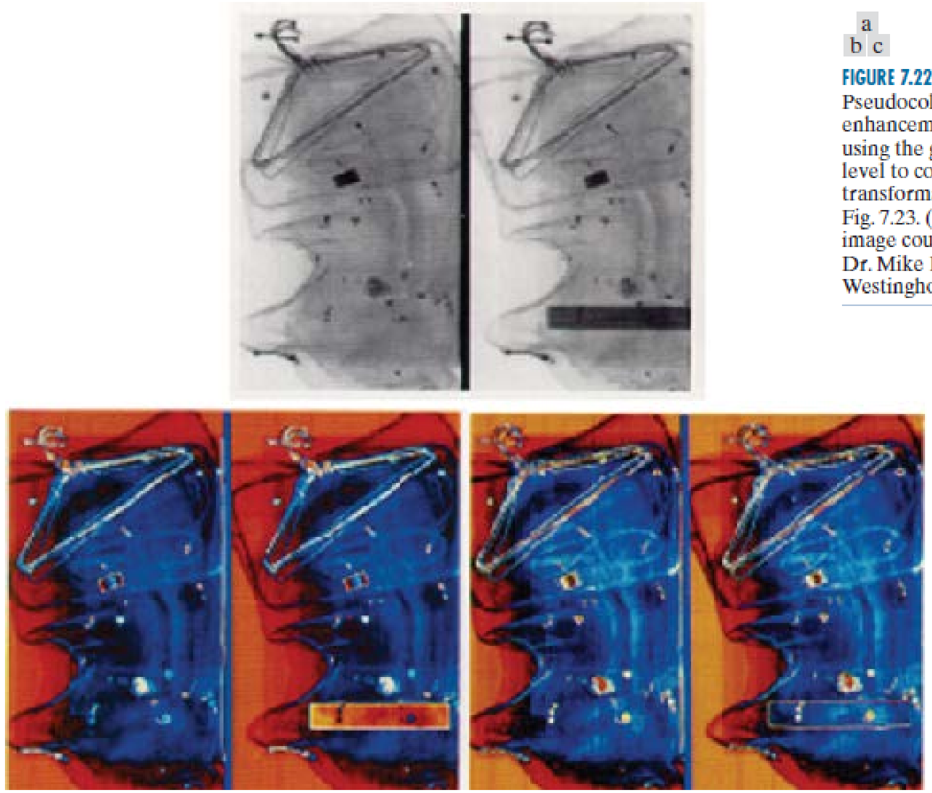


FIGURE 7.21 Functional block diagram for pseudocolor image processing. Images f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.



a
b c

FIGURE 7.22 Pseudocolor enhancement by using the gray level to color transformations in Fig. 7.23. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

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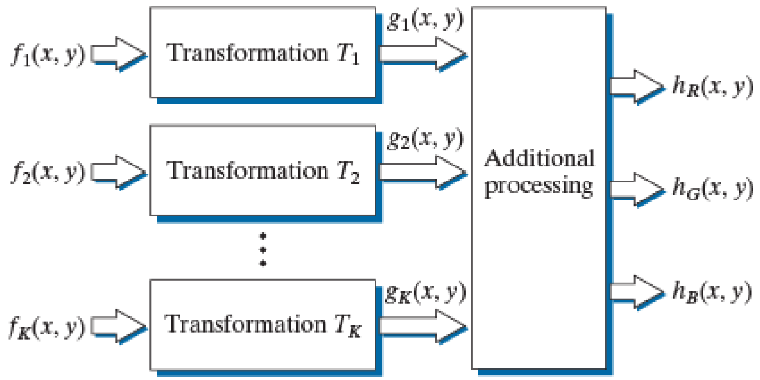
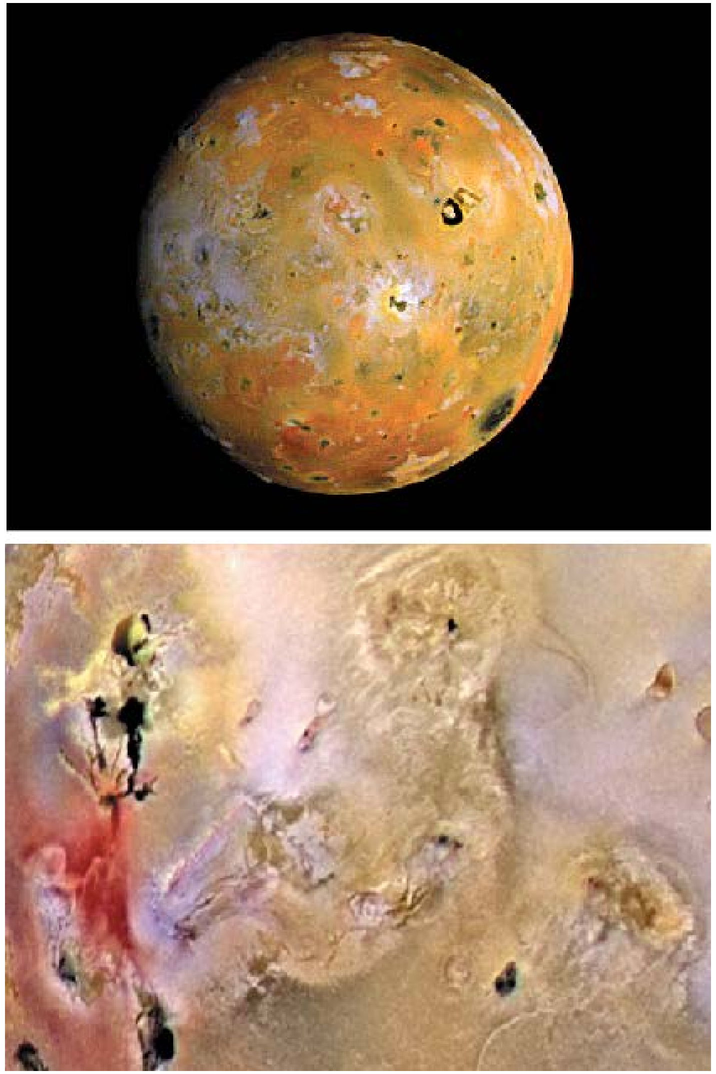
Intensity to color transformation

- **Color coding of multispectral images:** combine several monochrome images into a single color composite;

FIGURE 7.24 A pseudocolor coding approach using multiple grayscale images. The inputs are grayscale images. The outputs are the three components of an RGB composite image.





a
b

FIGURE 7.26 (a) Pseudocolor rendition of Jupiter Moon Io. (b) A close-up. (Courtesy of NASA.)

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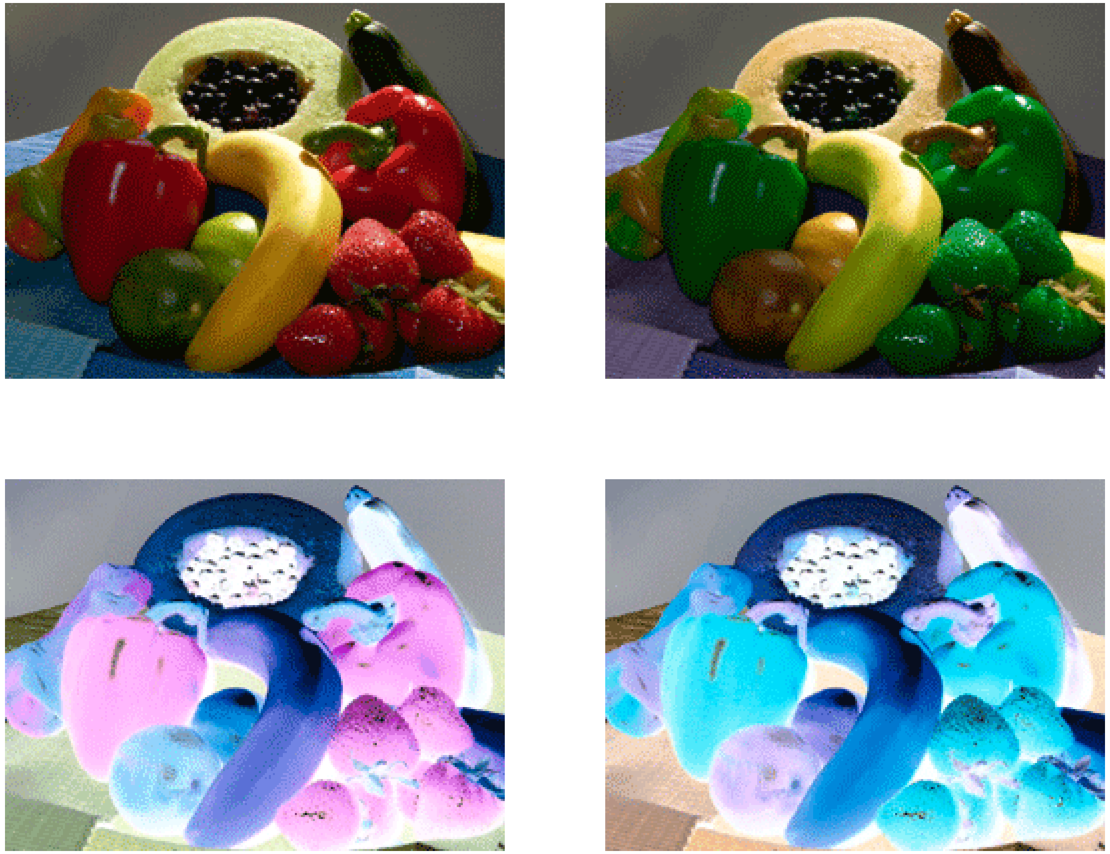
Inverse Color Transformation

$$\begin{bmatrix} g_R(x,y) \\ g_G(x,y) \\ g_B(x,y) \end{bmatrix} = \begin{bmatrix} 255 - f_R(x,y) \\ 255 - f_G(x,y) \\ 255 - f_B(x,y) \end{bmatrix}$$



RGB to Gray scale

- **Maximum value:**

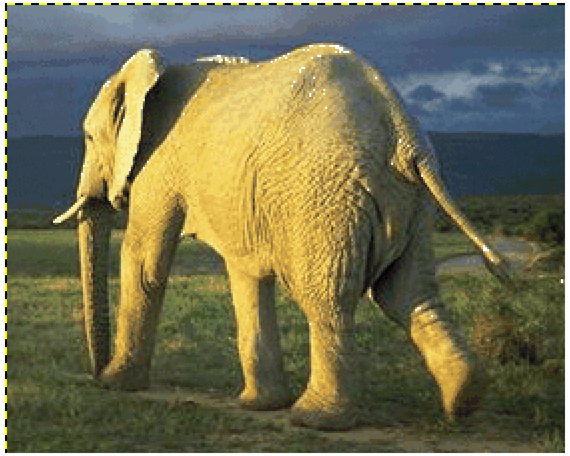
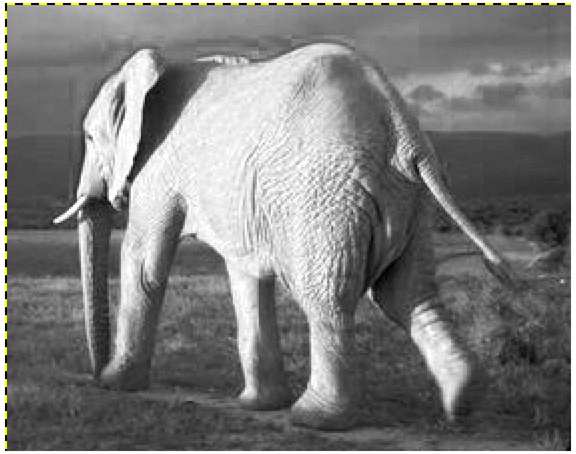
$$g_R(x,y) = g_G(x,y) = g_B(x,y) = \max[f_R(x,y), f_G(x,y), f_B(x,y)]$$

- **Average value**

$$g_R(x,y) = g_G(x,y) = g_B(x,y) = [f_R(x,y) + f_G(x,y) + f_B(x,y)]/3$$

- **Weighted value**

$$g_R(x,y) = g_G(x,y) = g_B(x,y) = 0.299 f_R(x,y) + 0.587 f_G(x,y) + 0.114 f_B(x,y)$$

Color Balance (彩色平衡)

- **White balance:**

$$I(x,y) = 0.299f_R(x,y) + 0.587f_G(x,y) + 0.114f_B(x,y)$$

$$k_R = \frac{\bar{I}}{\bar{\bar{R}}} \quad k_G = \frac{\bar{I}}{\bar{\bar{G}}} \quad k_B = \frac{\bar{I}}{\bar{\bar{B}}}$$

$$\begin{bmatrix} g_R(x,y) \\ g_G(x,y) \\ g_B(x,y) \end{bmatrix} = \begin{bmatrix} k_R & & \\ & k_G & \\ & & k_B \end{bmatrix} \begin{bmatrix} f_R(x,y) \\ f_G(x,y) \\ f_B(x,y) \end{bmatrix}$$

- **Maximum value balance**

$$S_{RGB} = \min[R_{max}, G_{max}, B_{max}]$$

$$k_R = \frac{S_{RGB}}{T_R} \quad k_G = \frac{S_{RGB}}{T_G} \quad k_B = \frac{S_{RGB}}{T_B}$$

$$\begin{bmatrix} g_R(x,y) \\ g_G(x,y) \\ g_B(x,y) \end{bmatrix} = \begin{bmatrix} k_R & & \\ & k_G & \\ & & k_B \end{bmatrix} \begin{bmatrix} f_R(x,y) \\ f_G(x,y) \\ f_B(x,y) \end{bmatrix}$$