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Digital Image Processing

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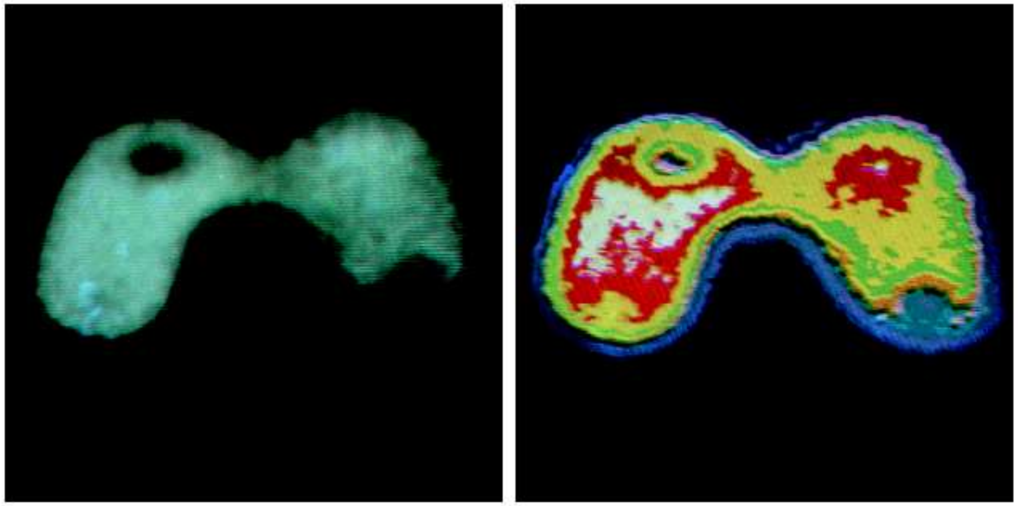
Color Image Processing

- For a long time I limited myself to one color – as a form of discipline.
    - Pablo Picasso
- It is only after years of preparation that the young artist should touch color – not color used descriptively, that is, but as a means of personal expression.
    - Henri Matisse

Preview

- Why use color in image processing?
  - Color is a powerful descriptor
    - Object identification and extraction
    - eg. Face detection using skin colors
  - Humans can discern thousands of color shades and intensities
    - c.f. Human discern only two dozen shades of grays



Preview (cont.)

- Two category of color image processing
  - Full color processing
    - Images are acquired from full-color sensor or equipments
  - Pseudo-color processing
    - In the past decade, color sensors and processing hardware are not available
    - Colors are assigned to a range of monochrome intensities

Outline

- Color fundamentals
- Color models
- Pseudo-color image processing
- Basics of full-color image processing
- Color transformations
- Smoothing and sharpening

Color fundamentals

- Physical phenomenon
  - Physical nature of color is known
- Psysio-psychological phenomenon
  - How human brain perceive and interpret color?

Color fundamentals (cont.)

- 1666, Isaac Newton 三稜鏡

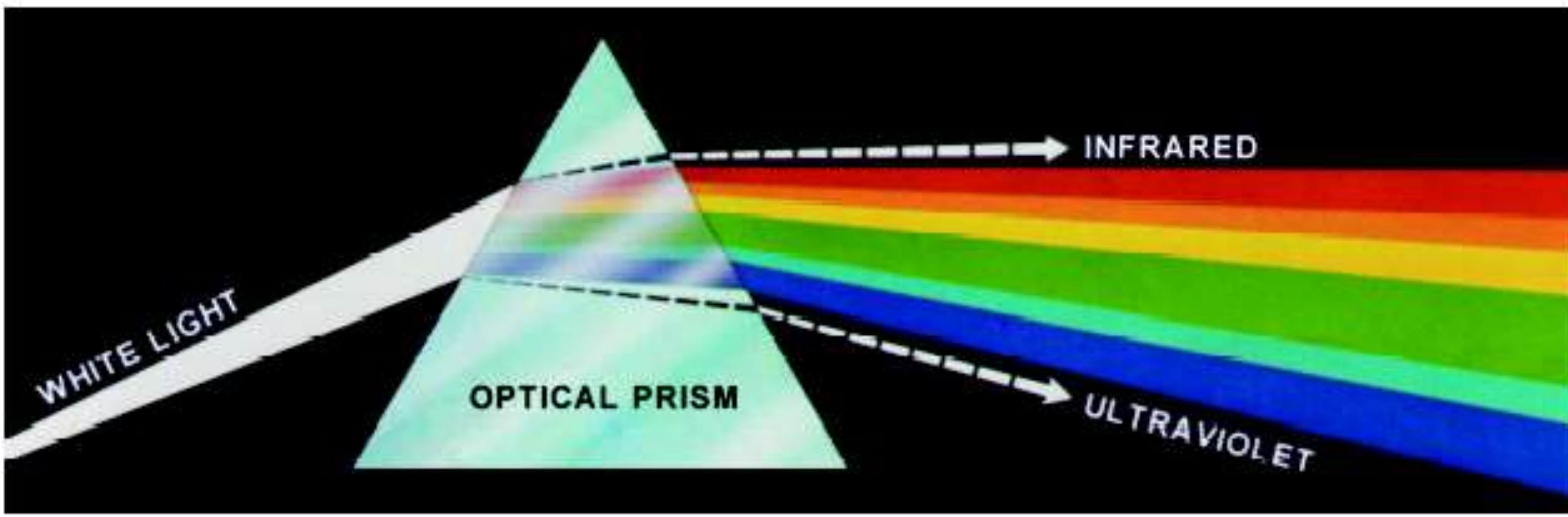


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Visible light

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

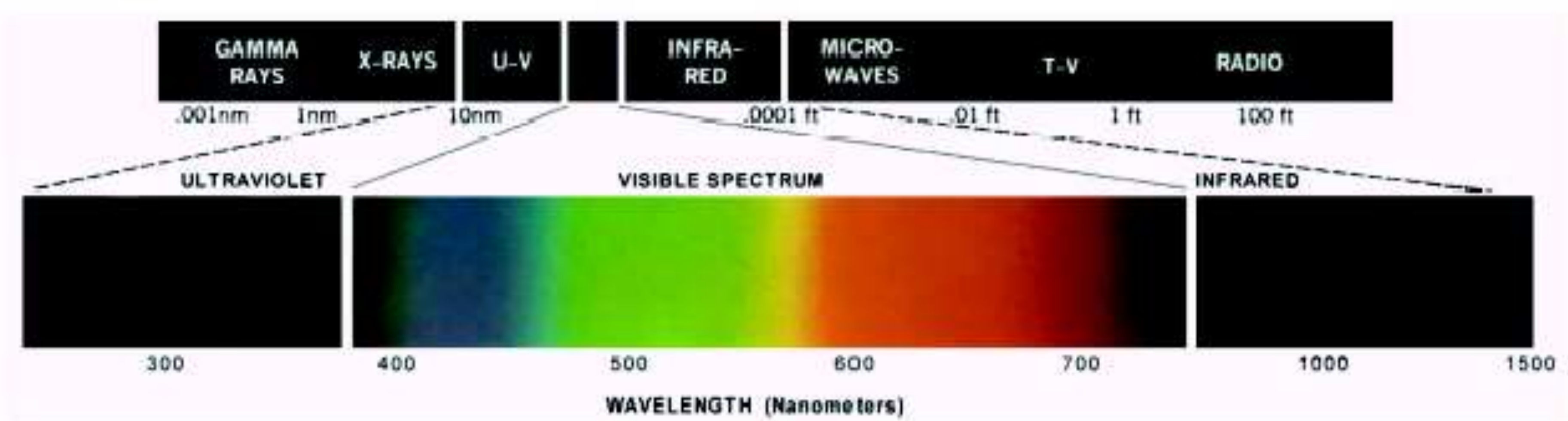
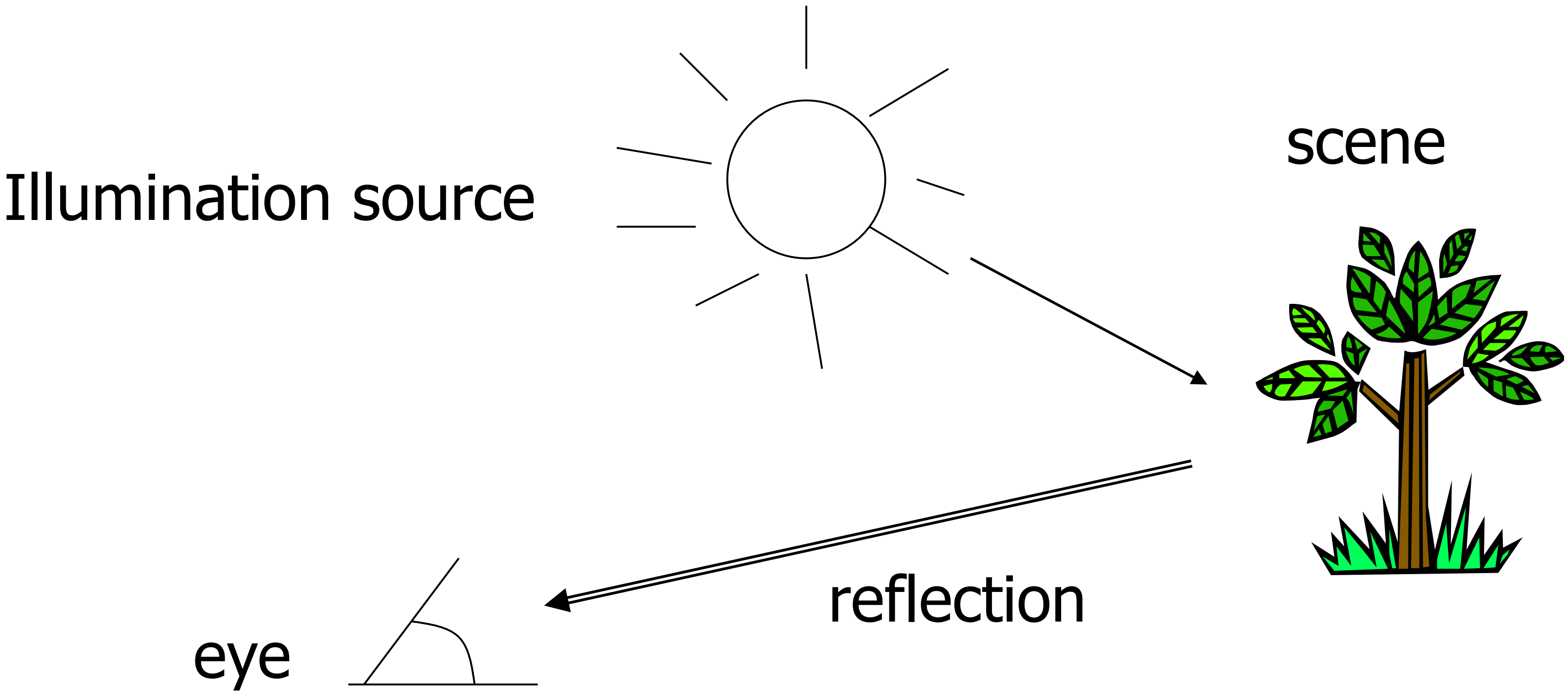


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

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 流明)
  - 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%

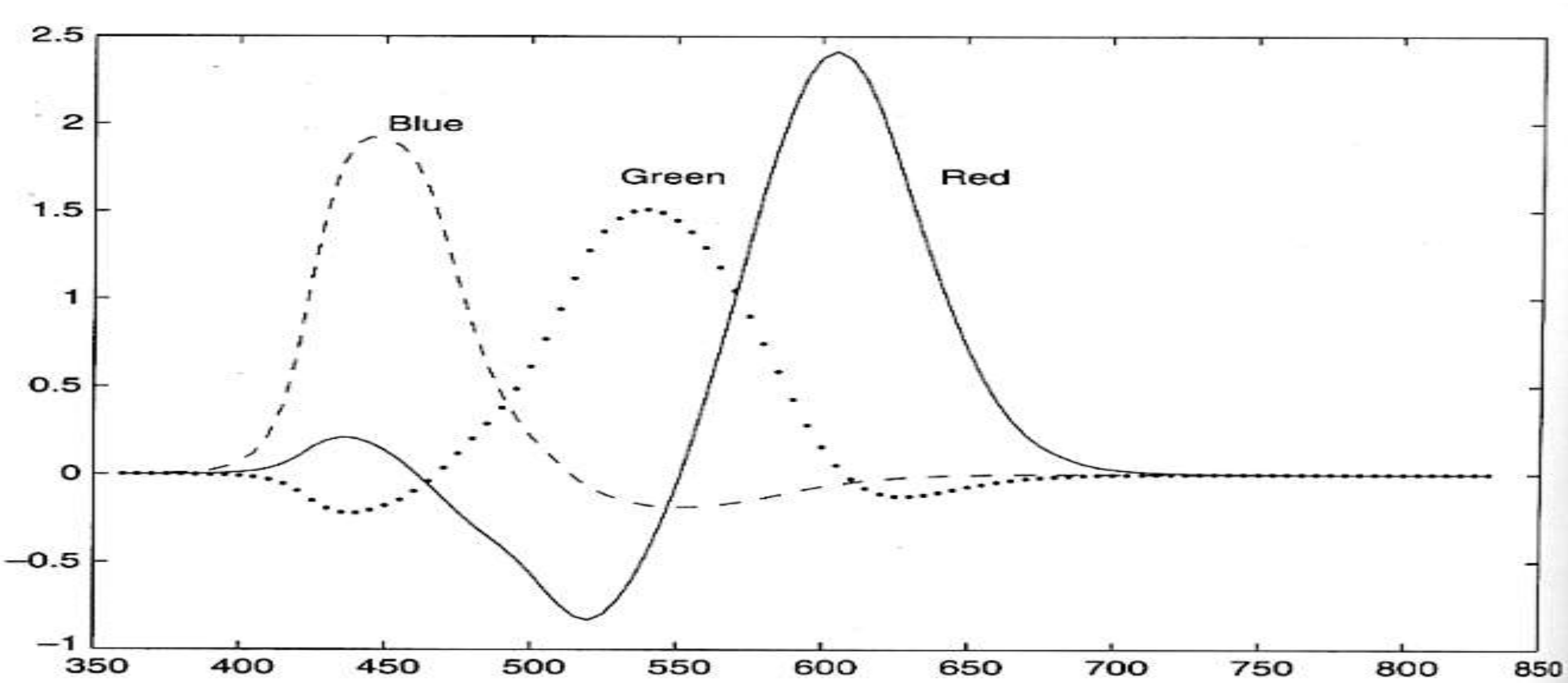
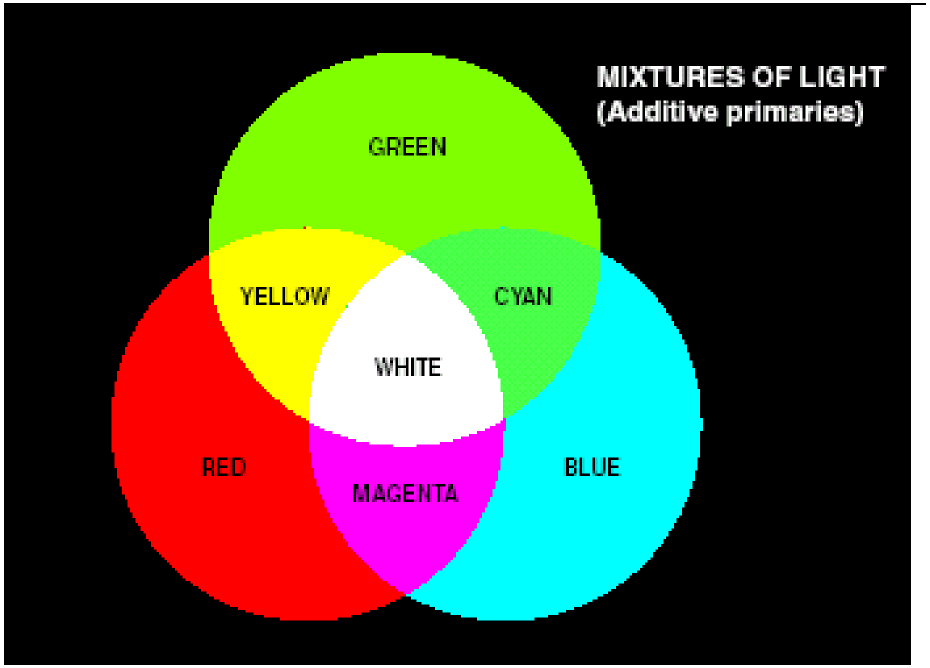
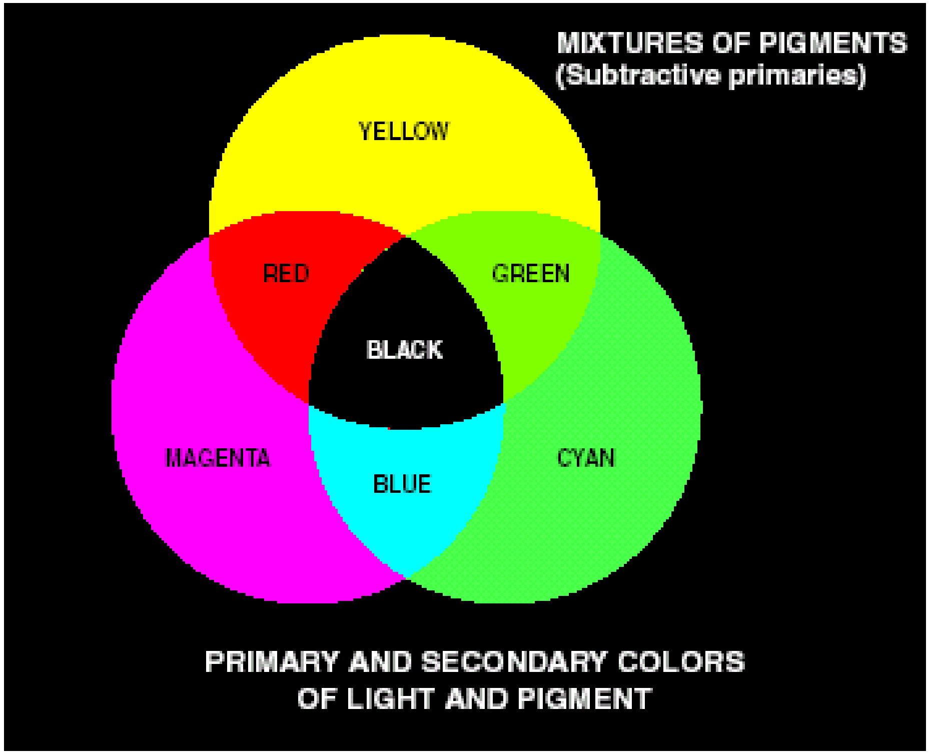


FIGURE B.1 *RGB color-matching functions (CIE, 1931).*

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


MIXTURES OF LIGHT
(Additive primaries)
GREEN
YELLOW
CYAN
WHITE
RED
MAGENTA
BLUE


MIXTURES OF PIGMENTS
(Subtractive primaries)
YELLOW
RED
GREEN
BLACK
MAGENTA
BLUE
CYAN
PRIMARY AND SECONDARY COLORS
OF LIGHT AND PIGMENT

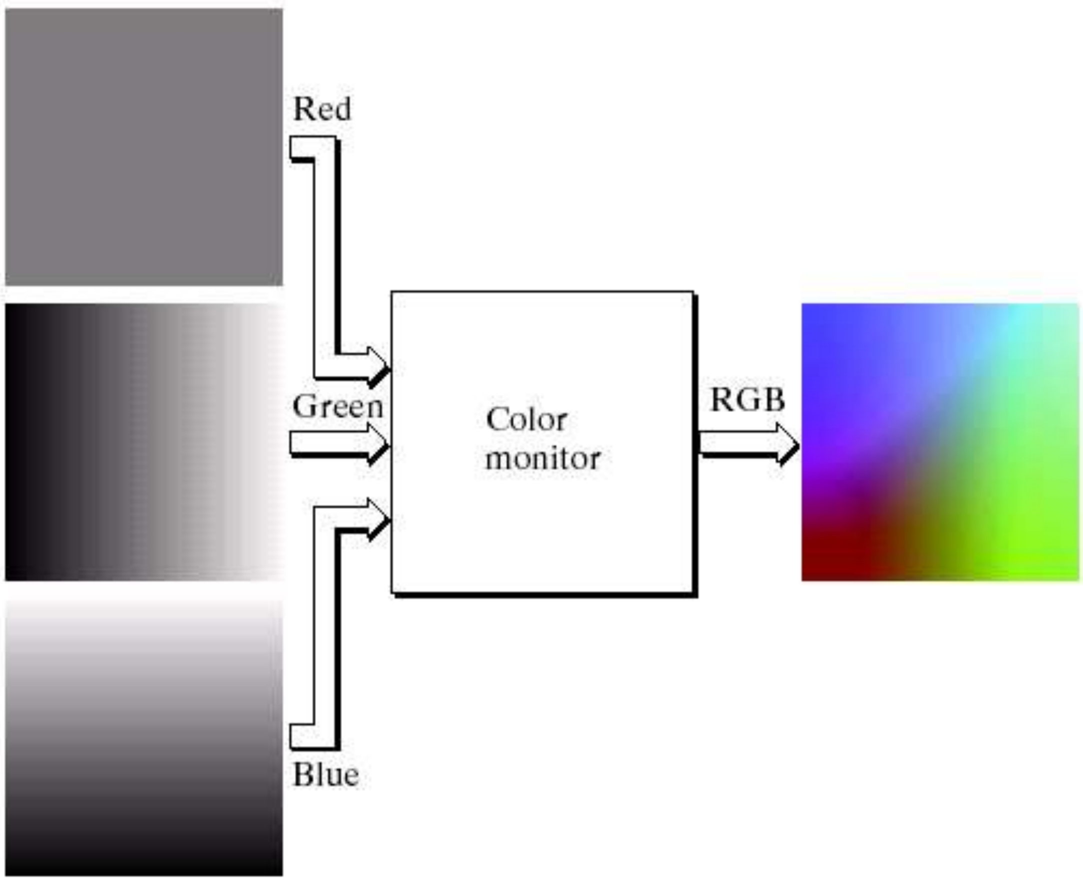
Primary colors of light v.s. primary colors of pigments

- 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



CIE XYZ model

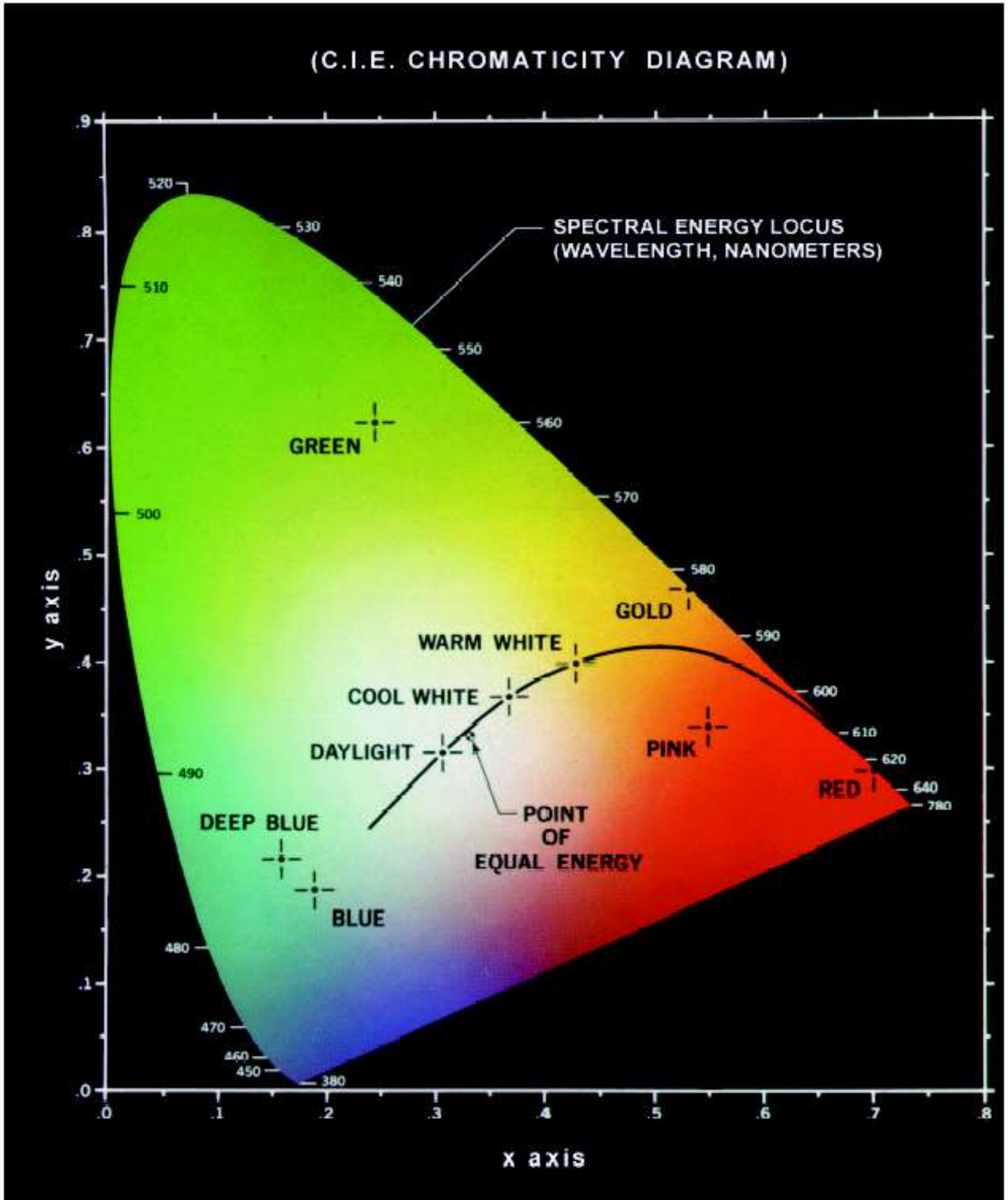
- RGB -> CIE XYZ model

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.431 & 0.342 & 0.178 \\ 0.222 & 0.707 & 0.071 \\ 0.020 & 0.130 & 0.939 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Normalized tristimulus values

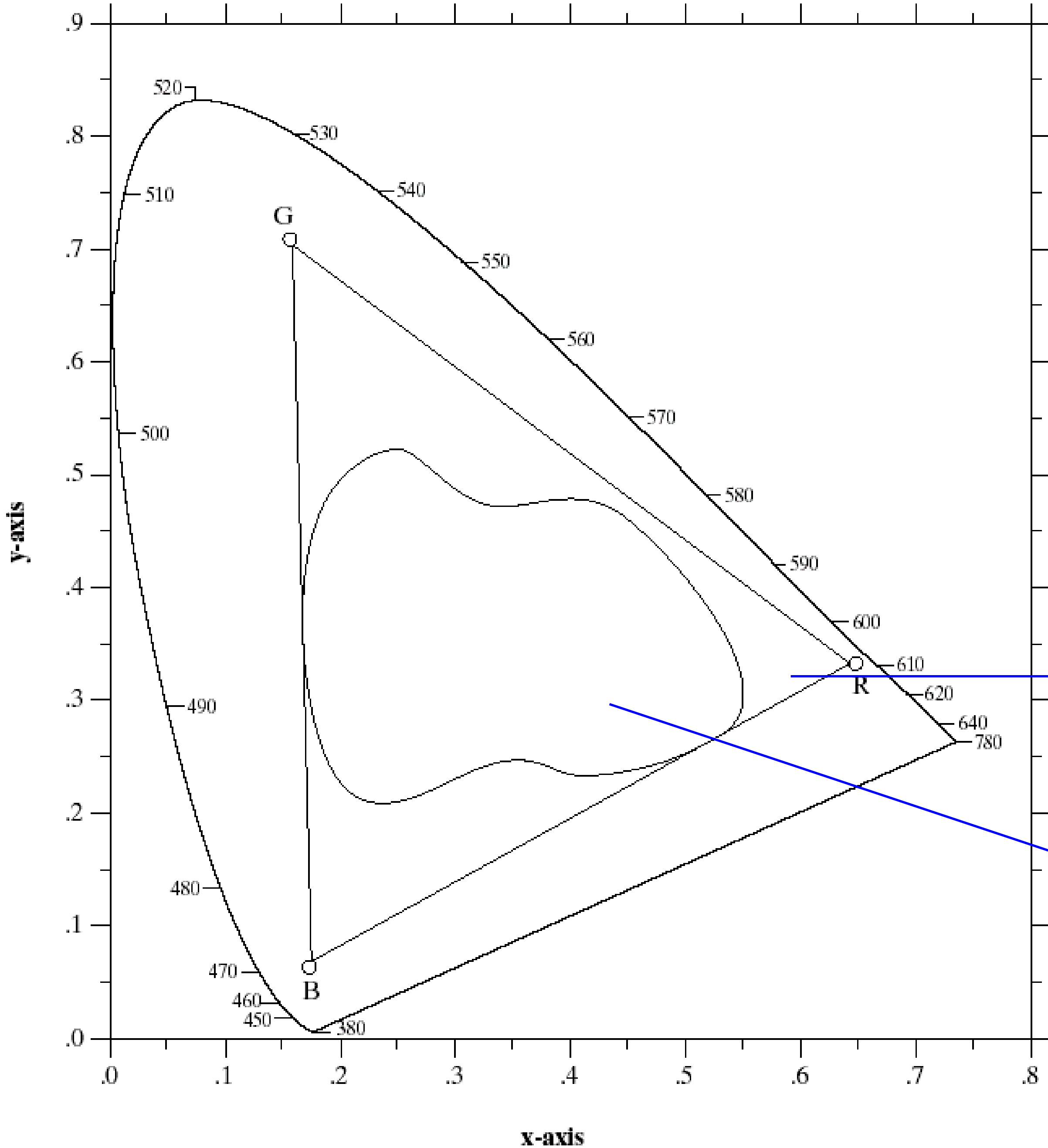
$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad z = \frac{Z}{X+Y+Z}$$

=> x+y+z=1. Thus, x, y (chromaticity coordinate) is enough to describe all colors


(C.I.E. CHROMATICITY DIAGRAM)
SPECTRAL ENERGY LOCUS
(WAVELENGTH, NANOMETERS)
520
530
540
510
550
560
GREEN
570
500
580
GOLD
590
WARM WHITE
600
COOL WHITE
610
PINK
DAYLIGHT
620
490
RED
640
780
POINT
OF
EQUAL ENERGY
DEEP BLUE
BLUE
480
470
460
450
380
y axis
x axis
.0
.1
.2
.3
.4
.5
.6
.7
.8
.9

色度圖

By additivity of colors: Any color inside the triangle can be produced by combinations of the three initial colors



RGB gamut of monitors

Color gamut of printers

FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

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Color models

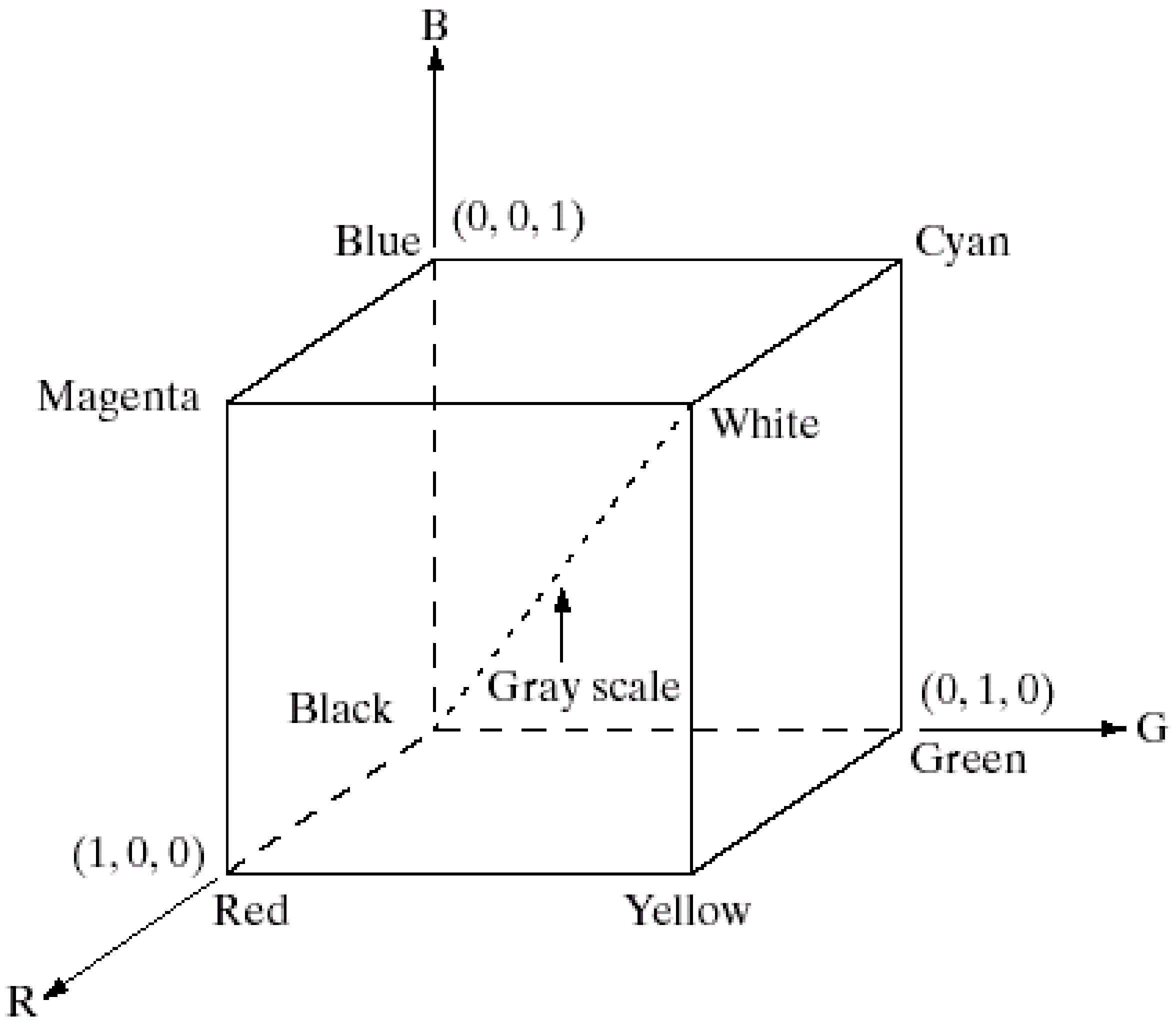
- Color model, color space, color system
  - Specify colors in a standard way
  - A coordinate system that each color is represented by a single point

- RGB model
- CYM model
- CYMK model
- HSI model

} Suitable for hardware or applications (RGB, CYM, CYMK models)

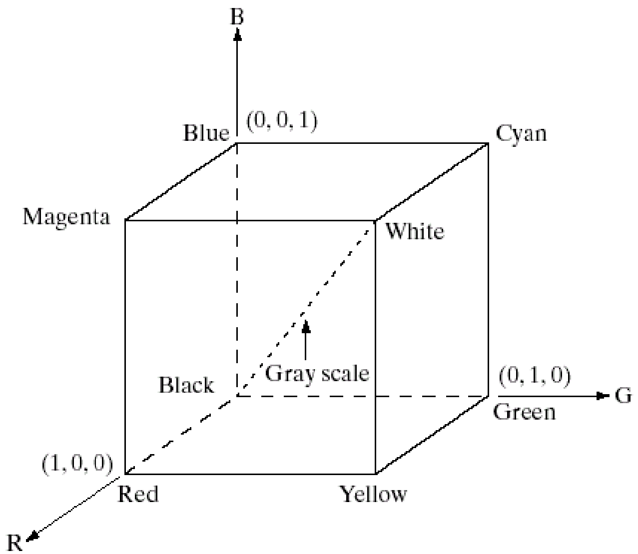
- match the human description (HSI model)

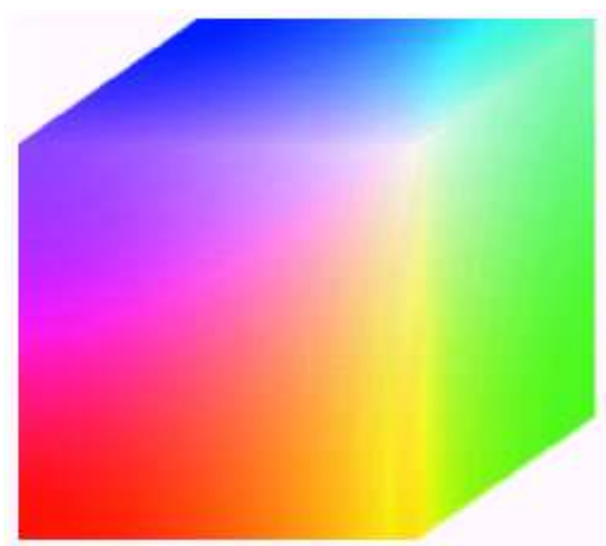
RGB color model



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)





Safe RGB colors

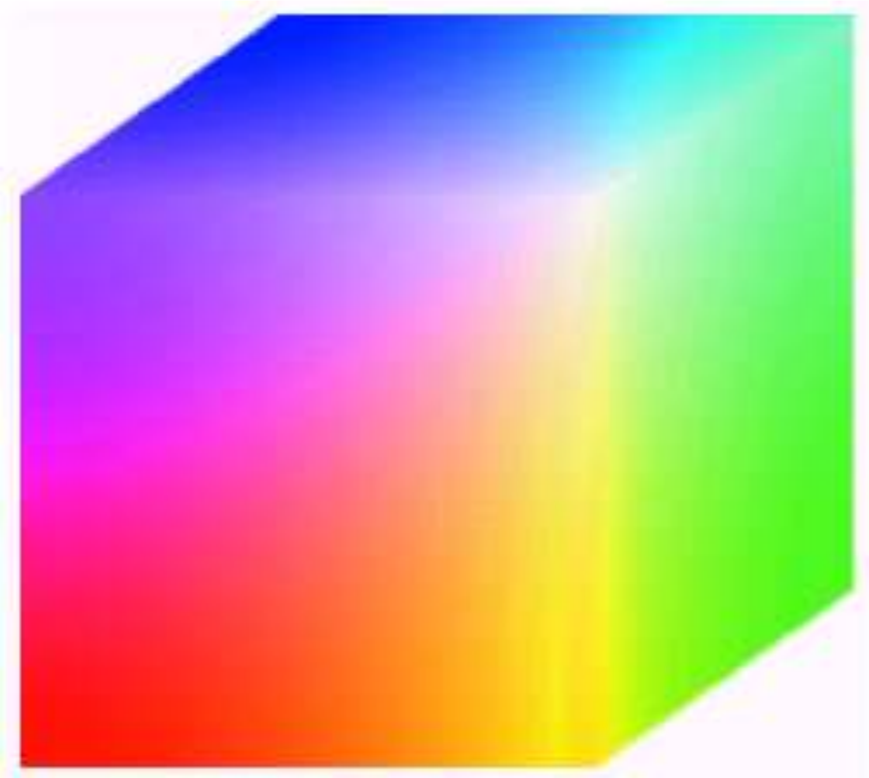
- Subset of colors is enough for some application
- Safe RGB colors (safe Web colors, safe browser colors)

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

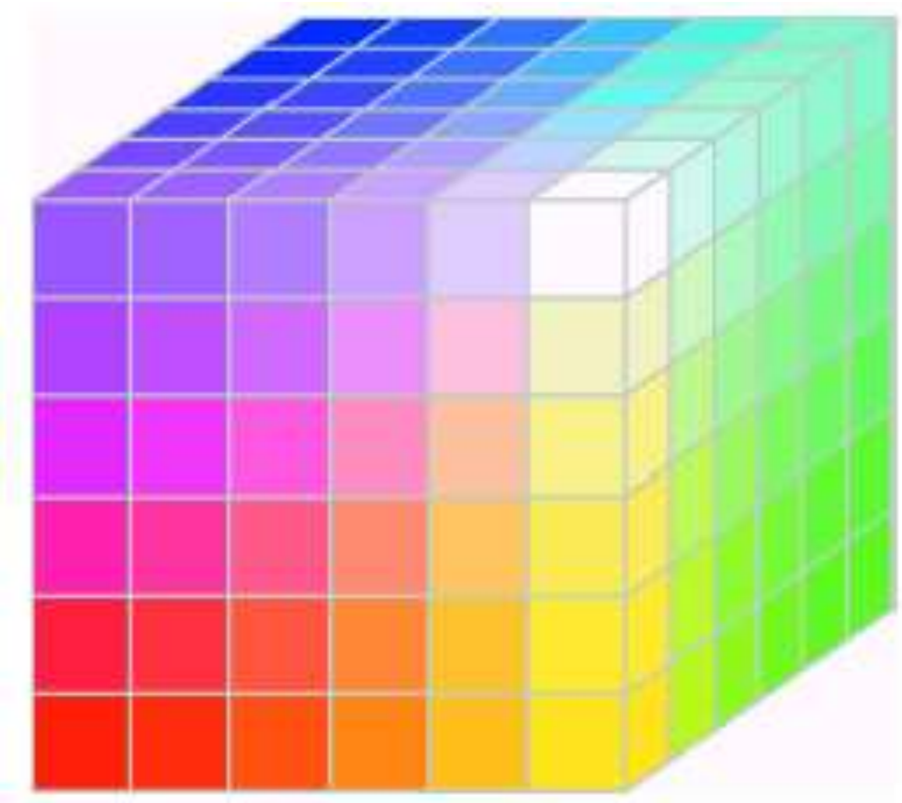
TABLE 6.1 Valid values of each RGB component in a safe color.

$(6)^3 = 216$

Safe RGB color (cont.)



Full color cube

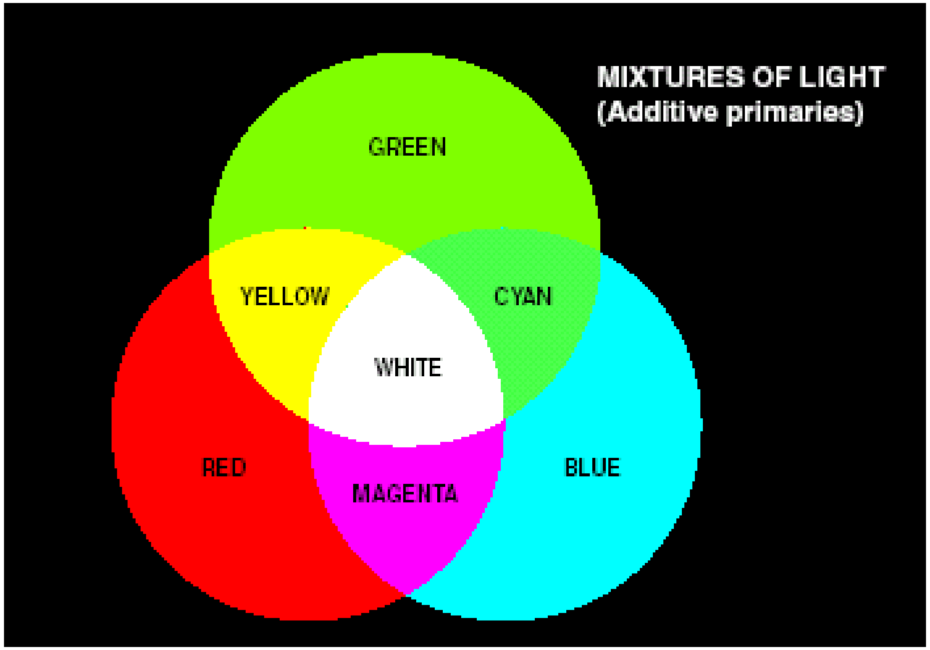


Safe color cube

CMY model (+Black = CMYK)

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

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

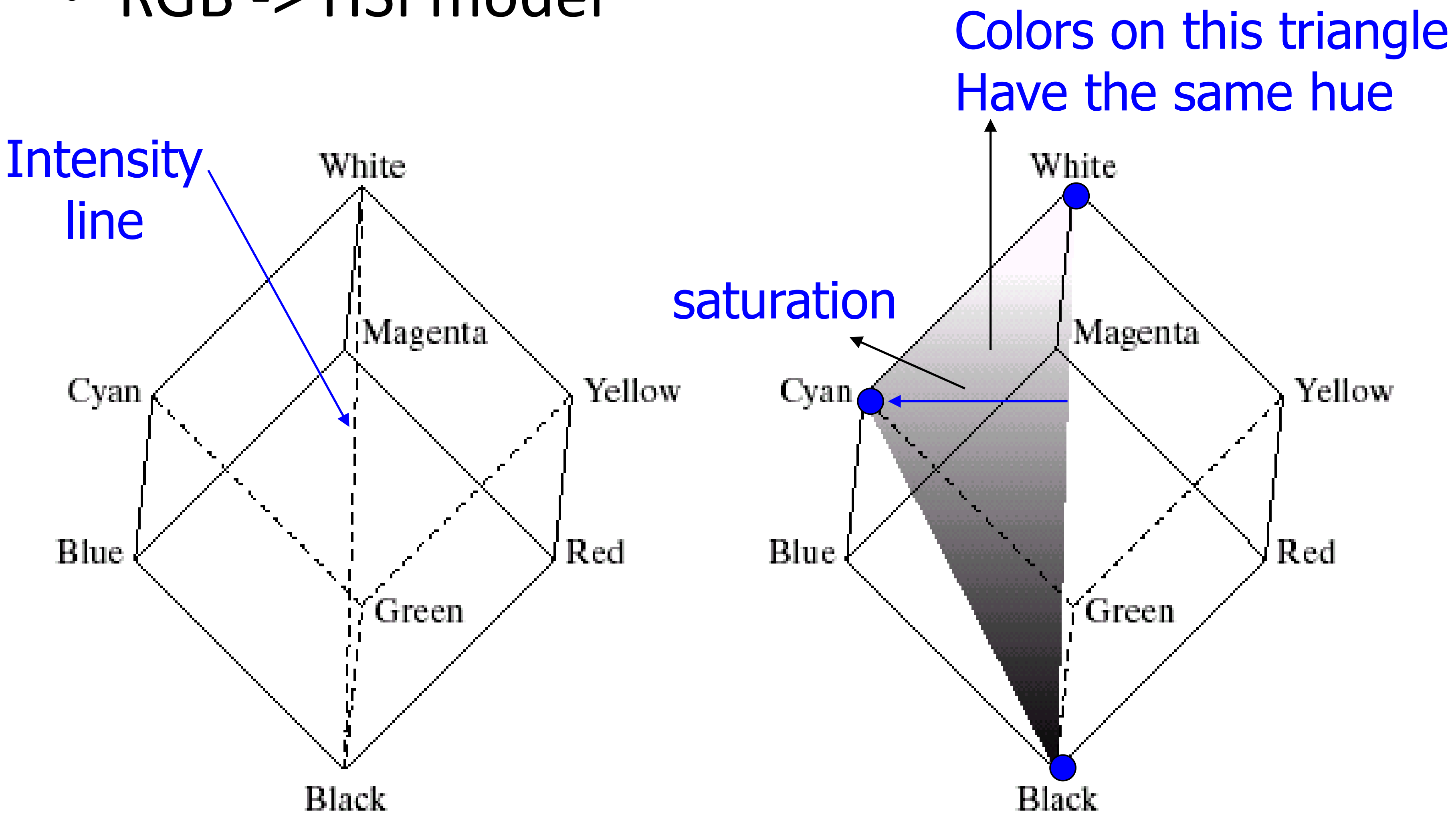


HSI color model

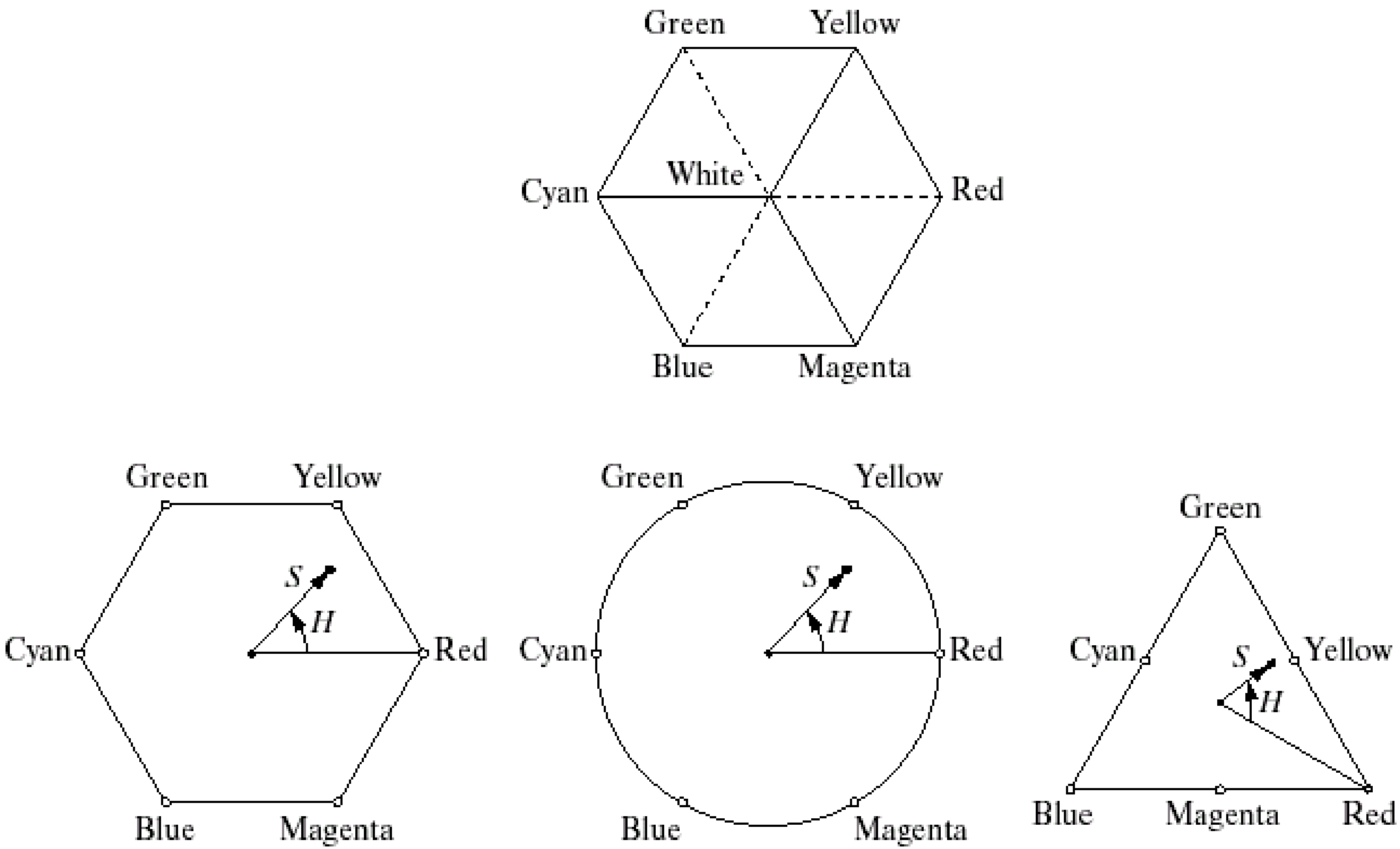
- Will you describe a color using its R, G, B components?
- Human describe a color by its hue, saturation, and brightness
  - Hue 色度: color attribute
  - Saturation: purity of color (white->0, primary color->1)
  - Brightness: achromatic notion of intensity

HSI color model (cont.)

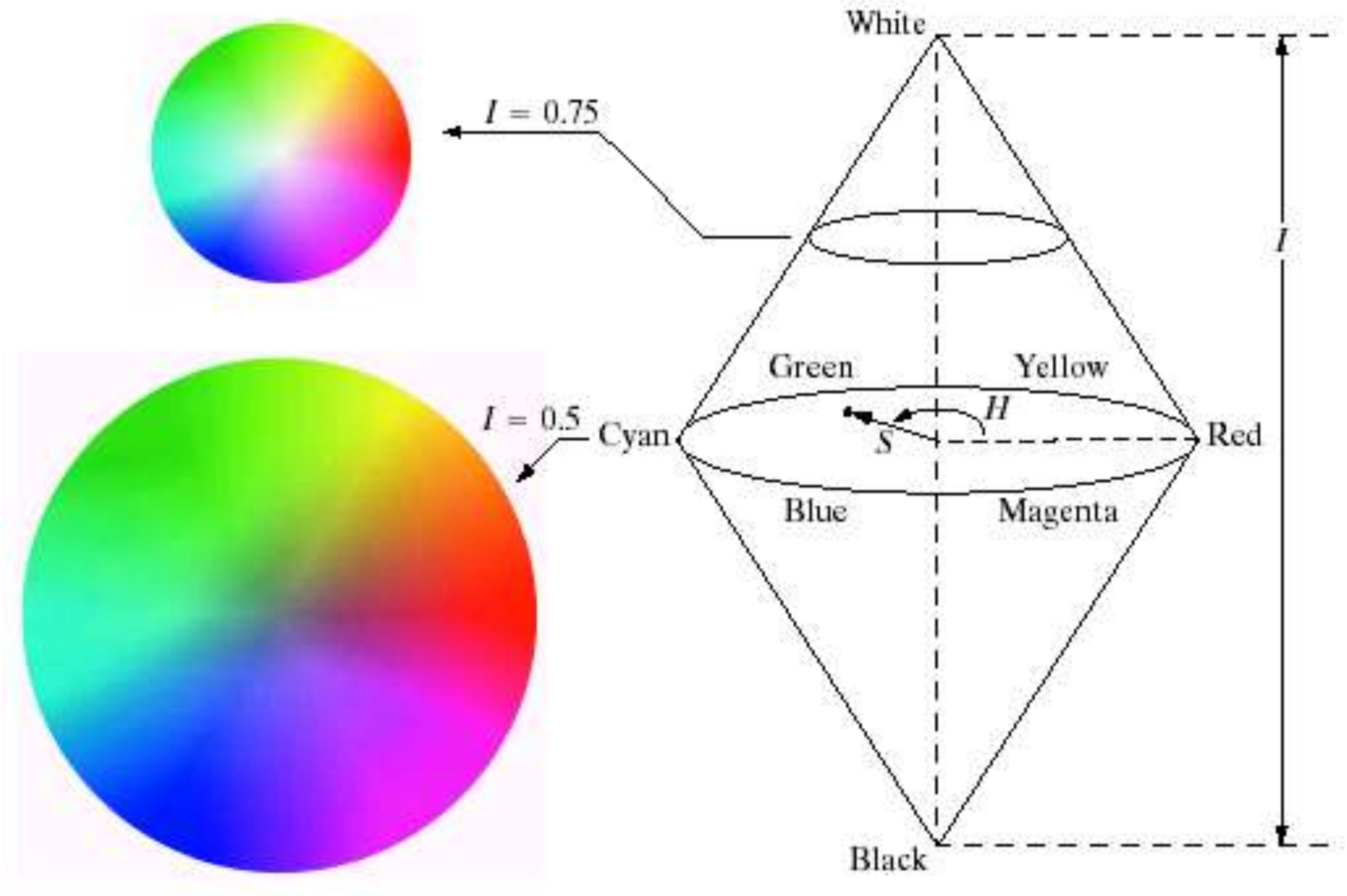
- RGB -> HSI model



HSI model: hue and saturation



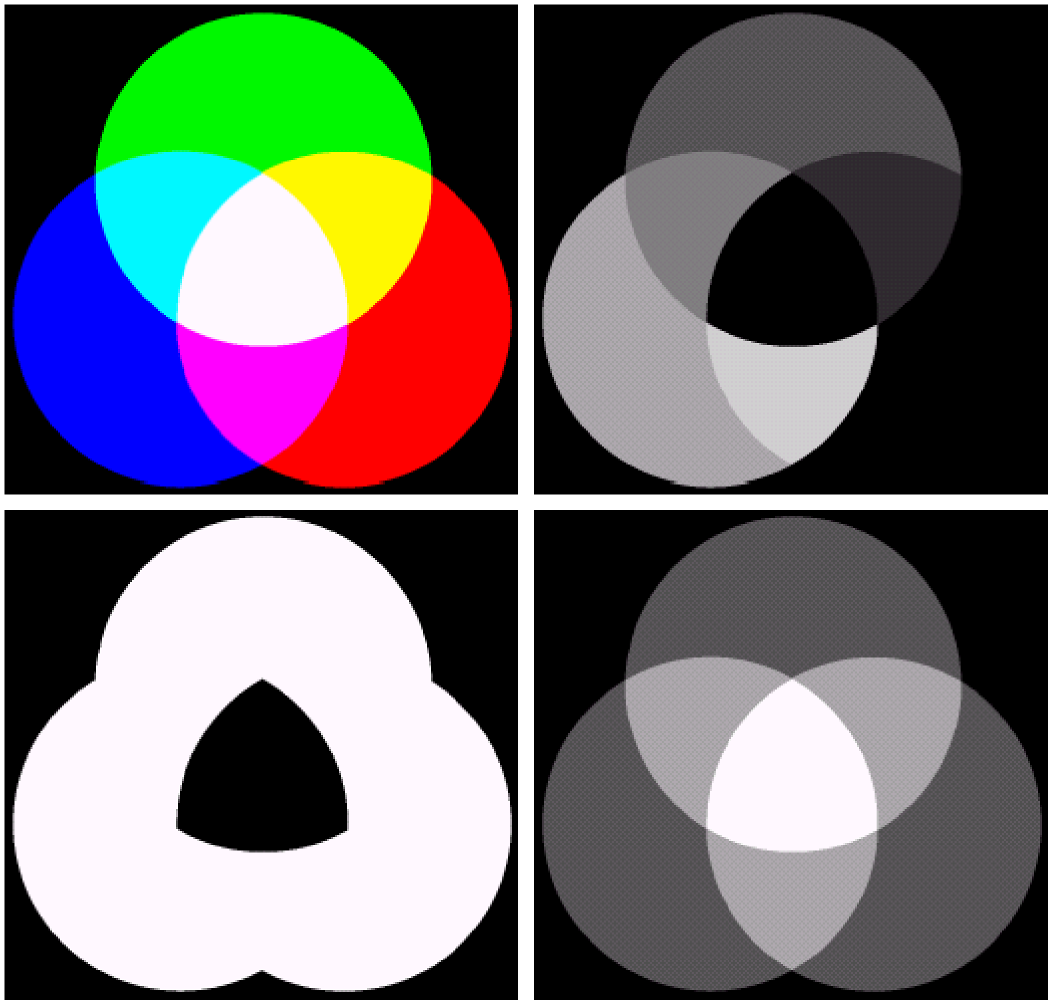
HSI model



HSI component images

R,G,B

Hue



saturation

intensity

Outline

- Color fundamentals
- Color models
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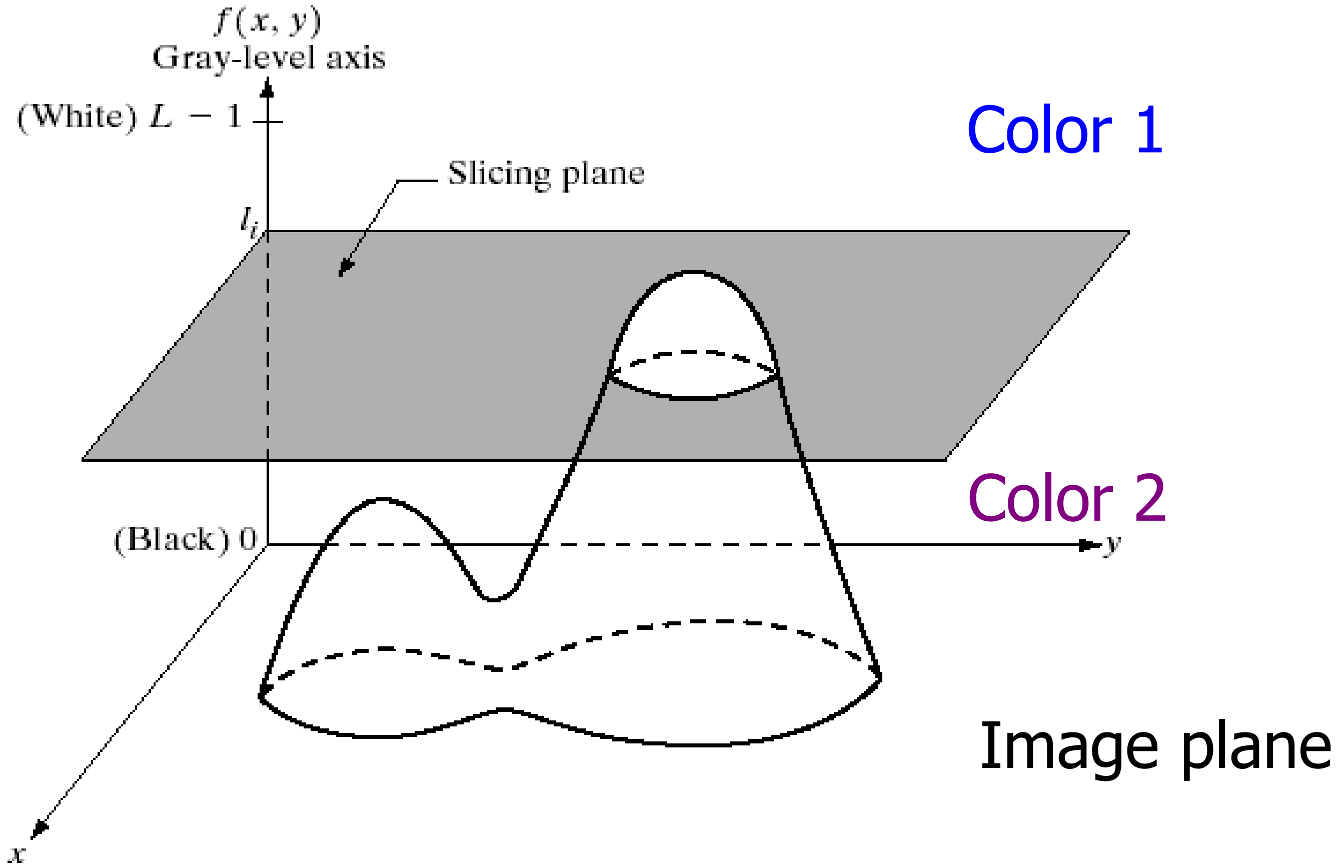
Pseudo-color image processing

- Assign colors to gray values based on a specified criterion
- For human visualization and interpretation of gray-scale events
- Intensity slicing
- Gray level to color transformations

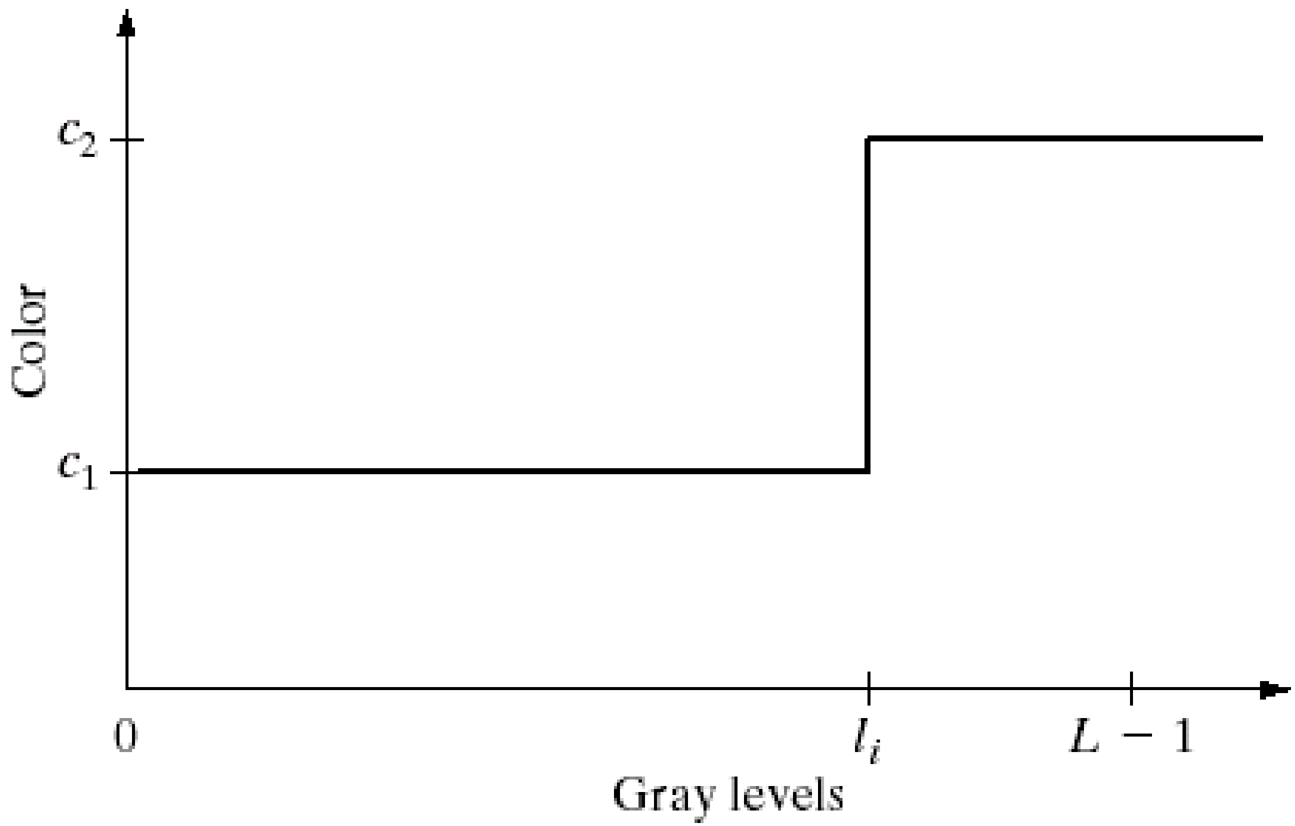
Intensity slicing

- 3-D view of intensity image



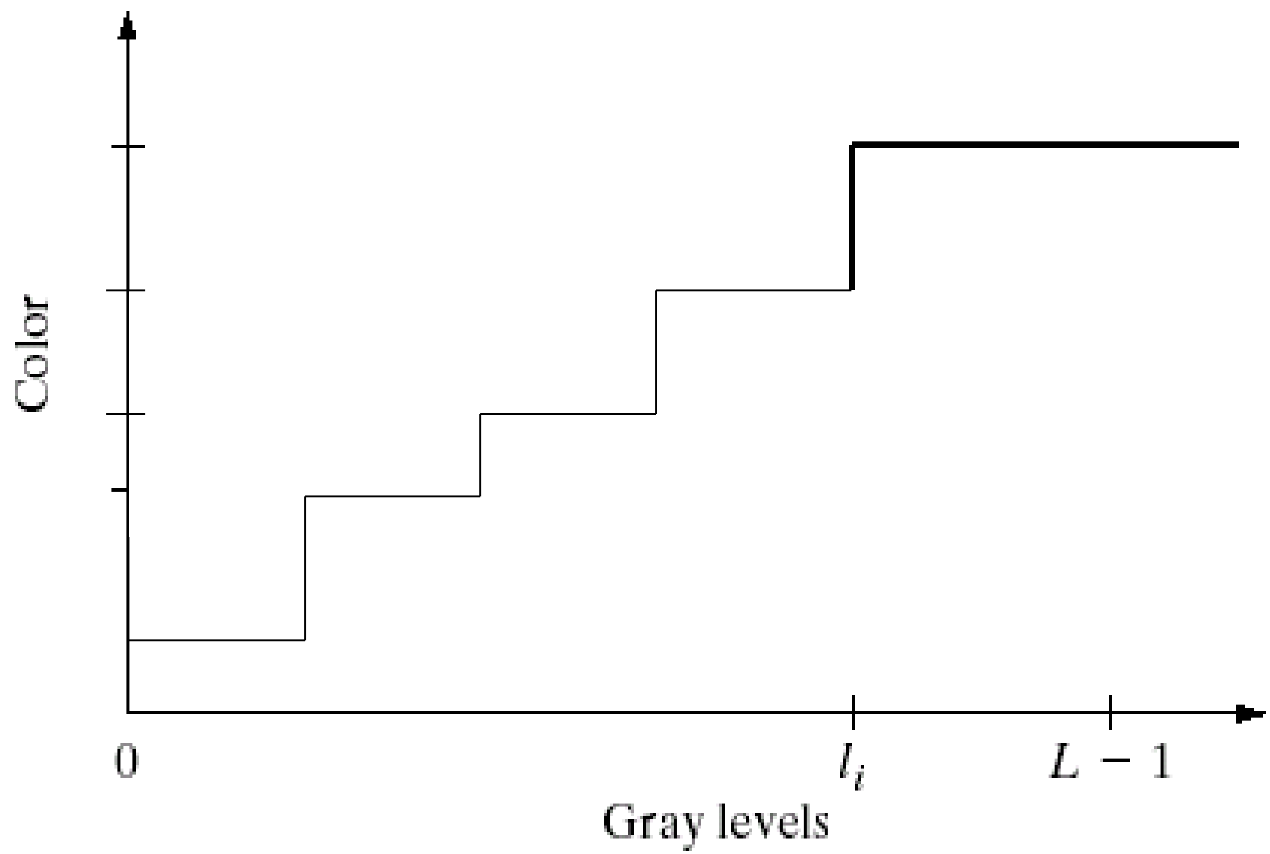
Intensity slicing (cont.)

- Alternative representation of intensity slicing

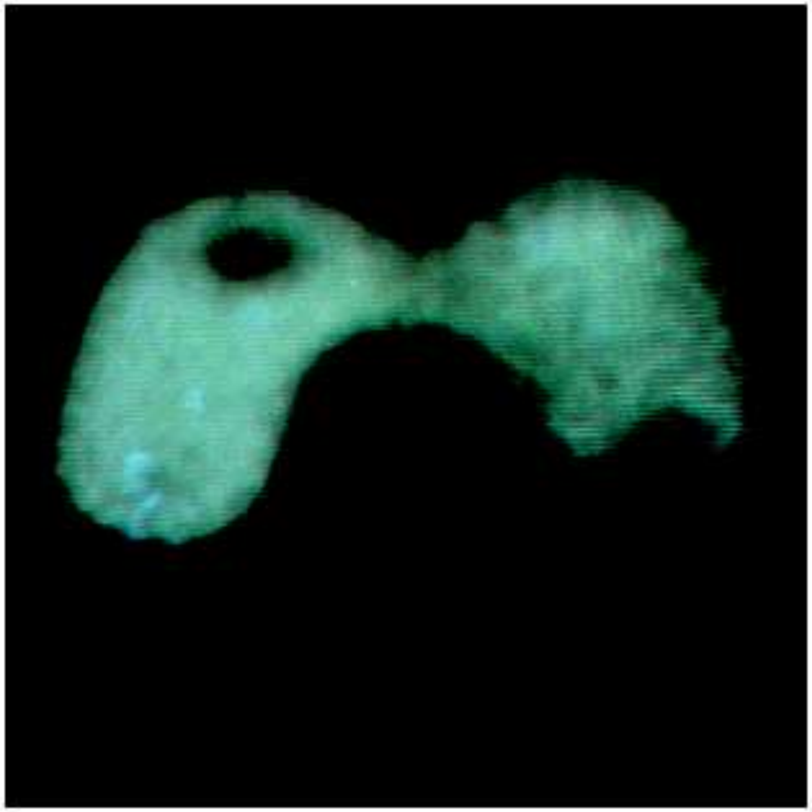


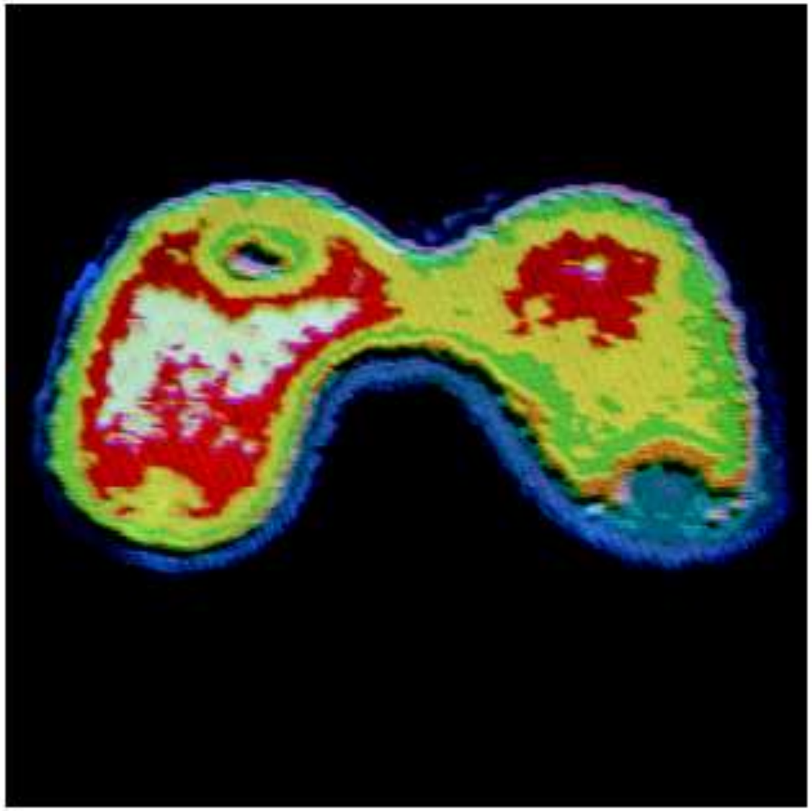
Intensity slicing (cont.)

- More slicing plane, more colors



Application 1

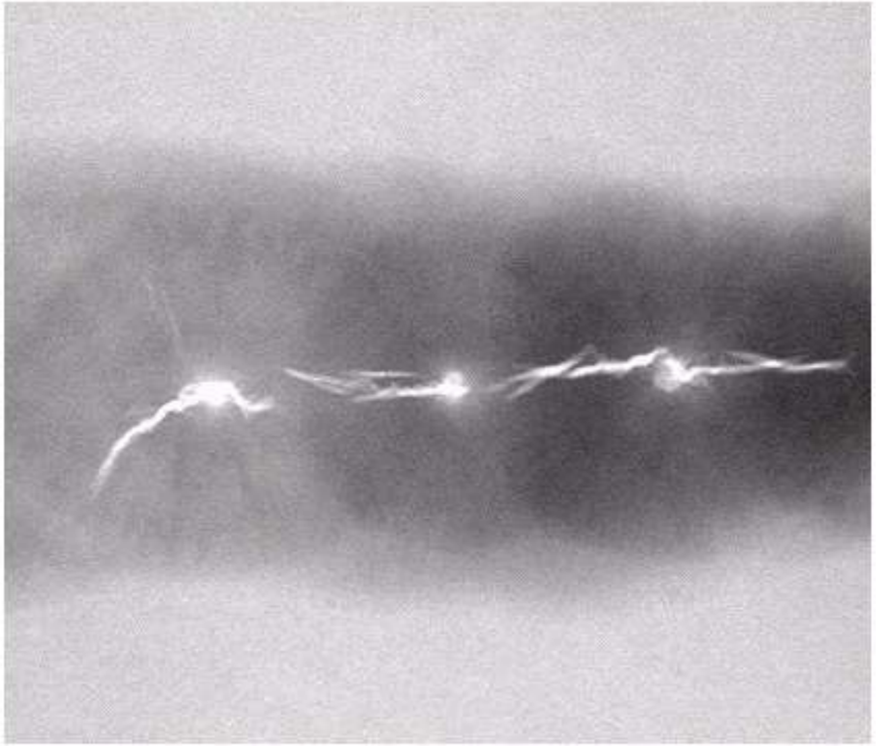


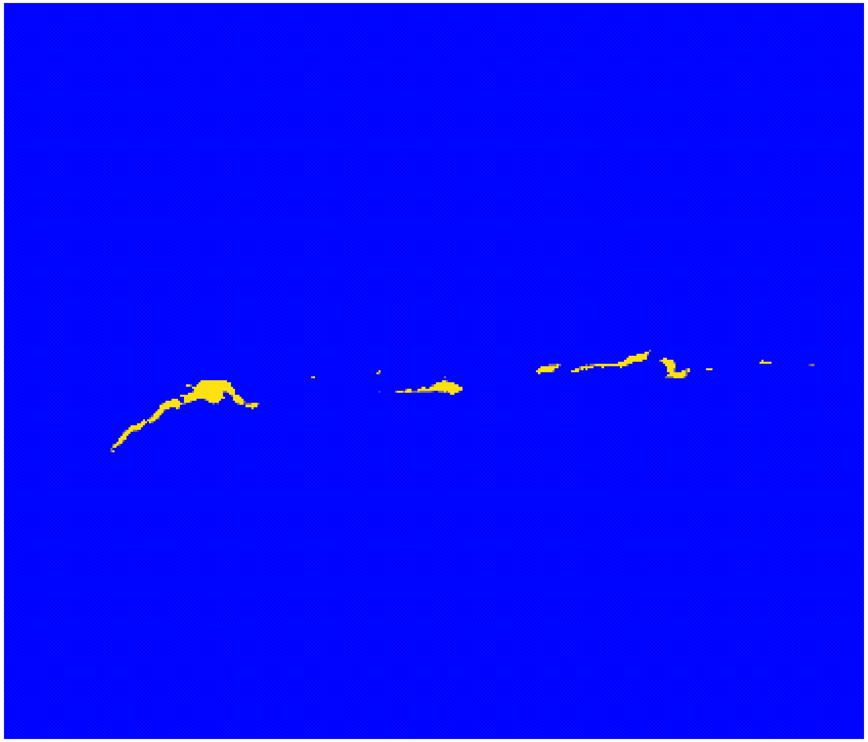


Radiation test pattern → 8 color regions

* See the gradual gray-level changes

Application 2

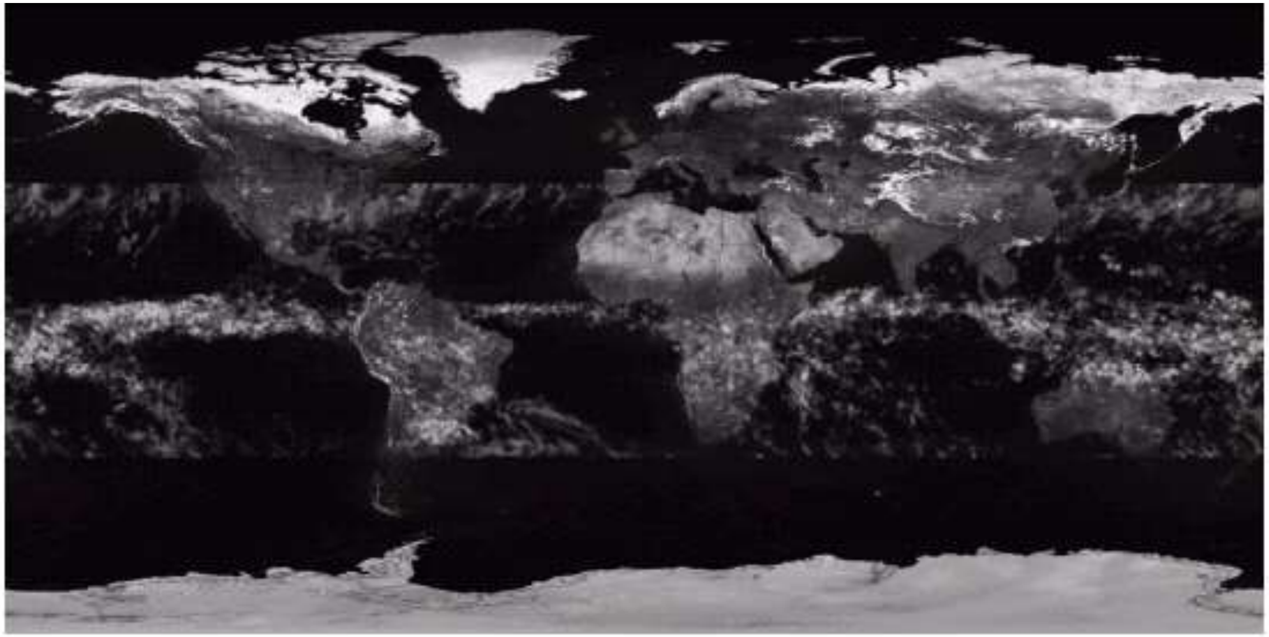




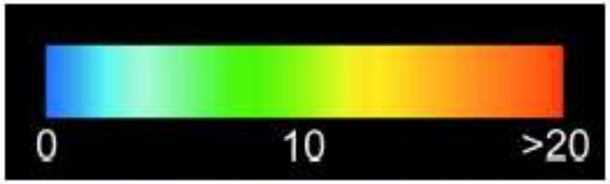
X-ray image of a weld

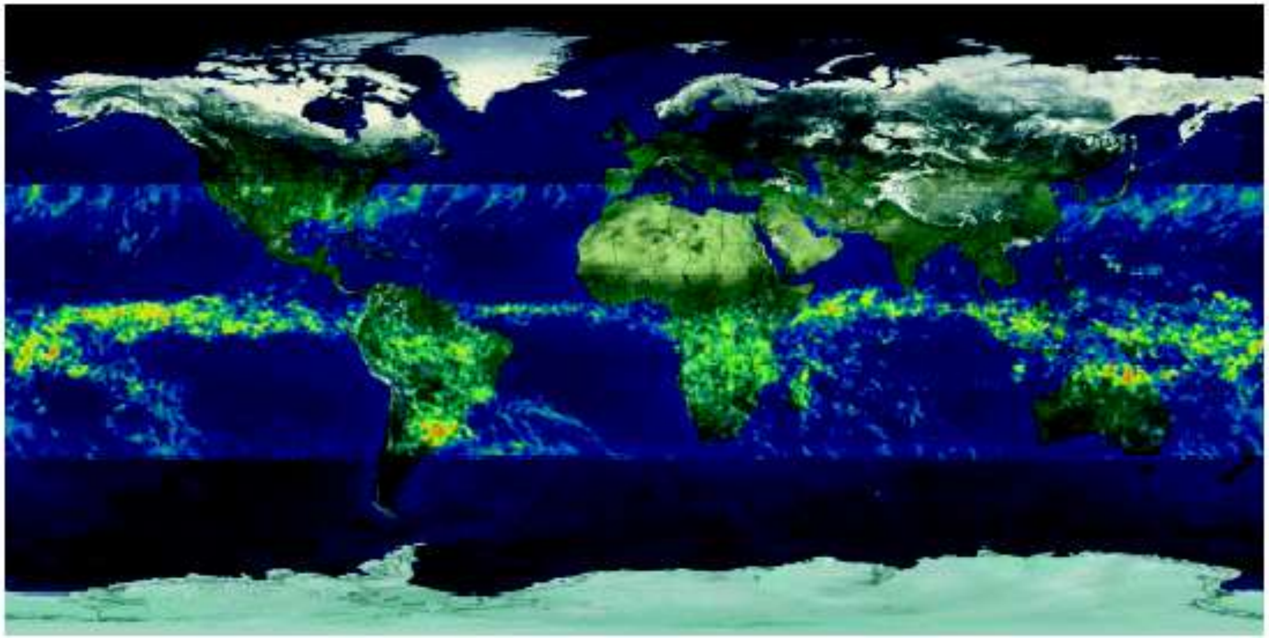
焊接物

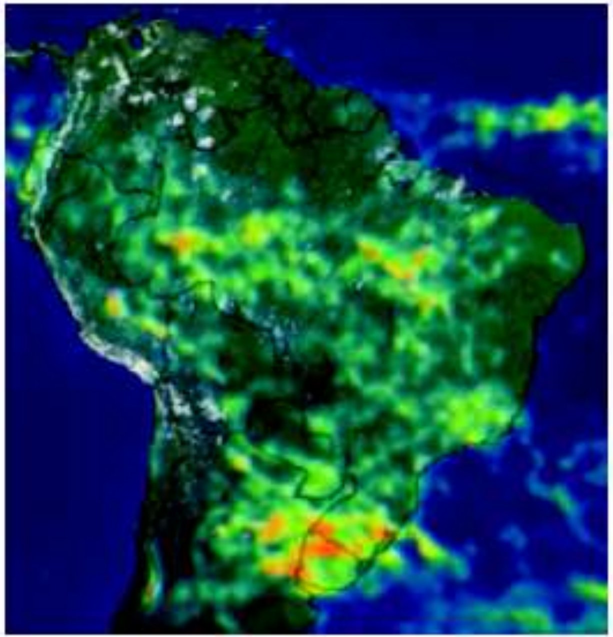
Application 3



Rainfall statistics

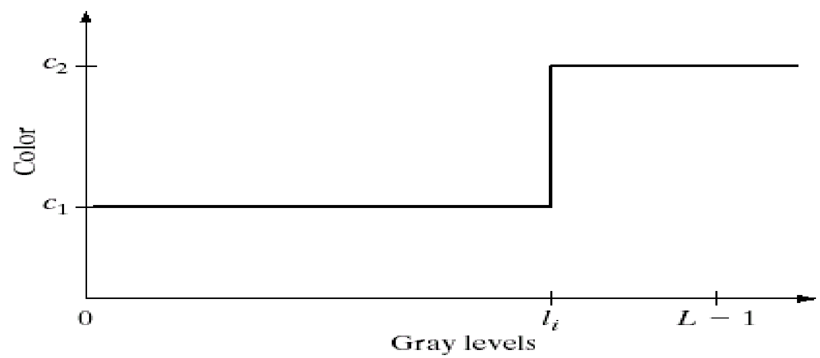




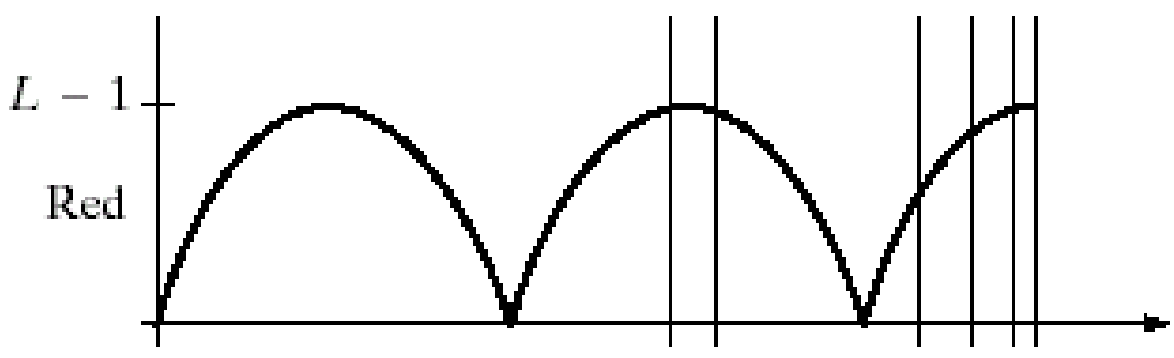


Gray level to color transformation

- Intensity slicing: piecewise linear transformation



- General rmation



Gray level to color transformation

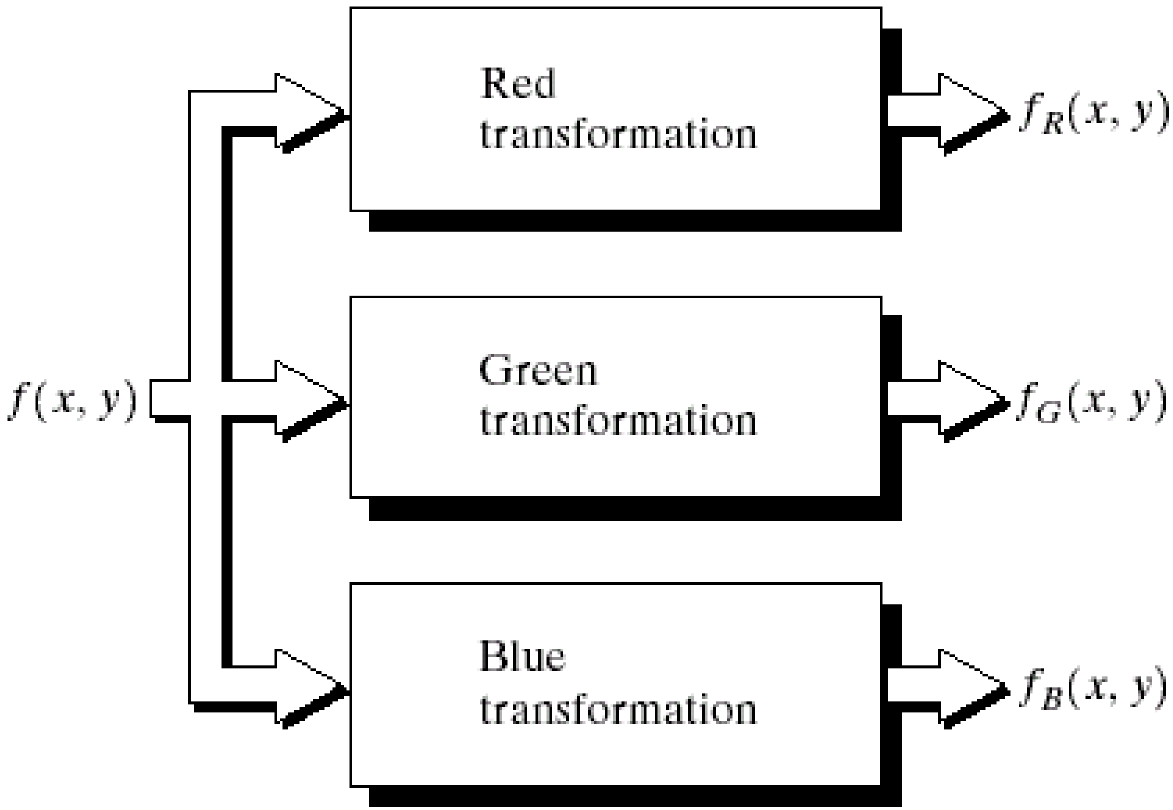
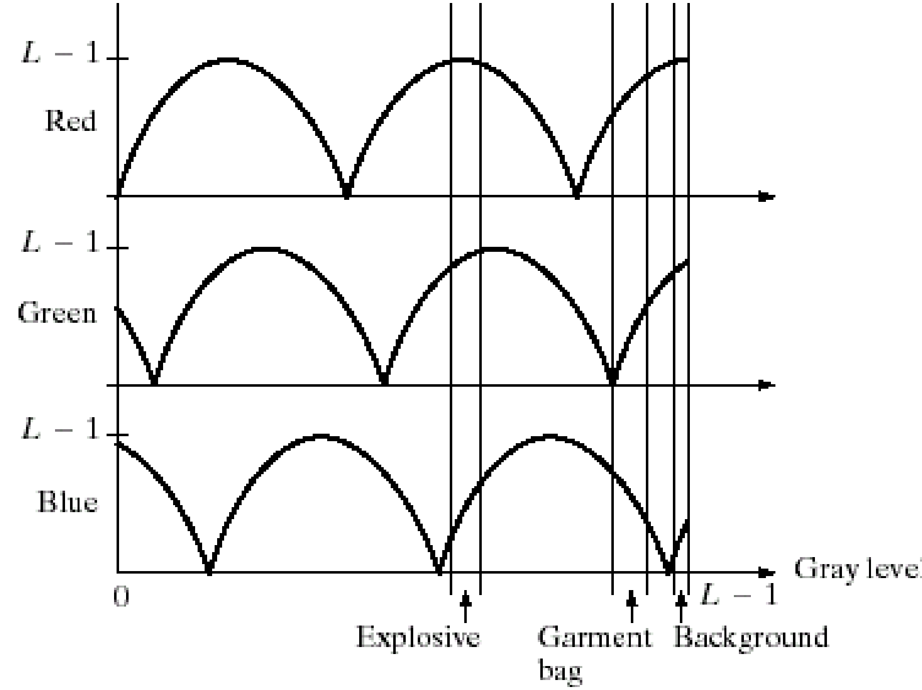
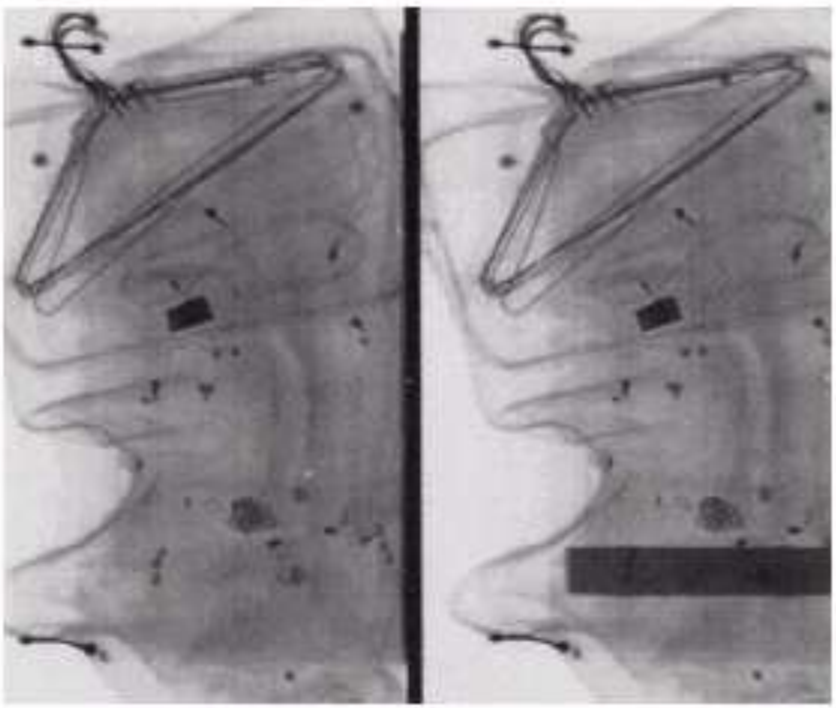


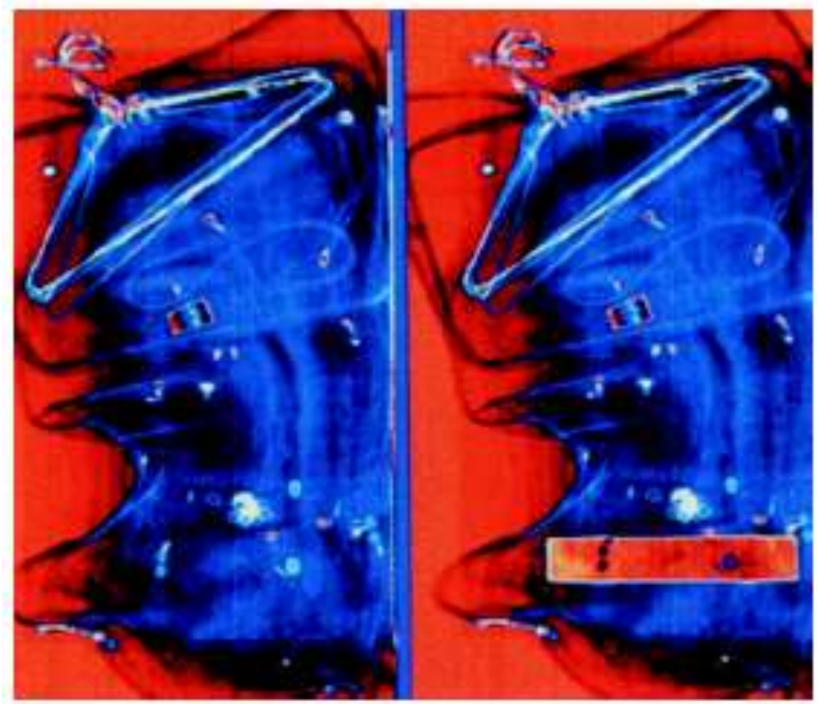
FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

Applica



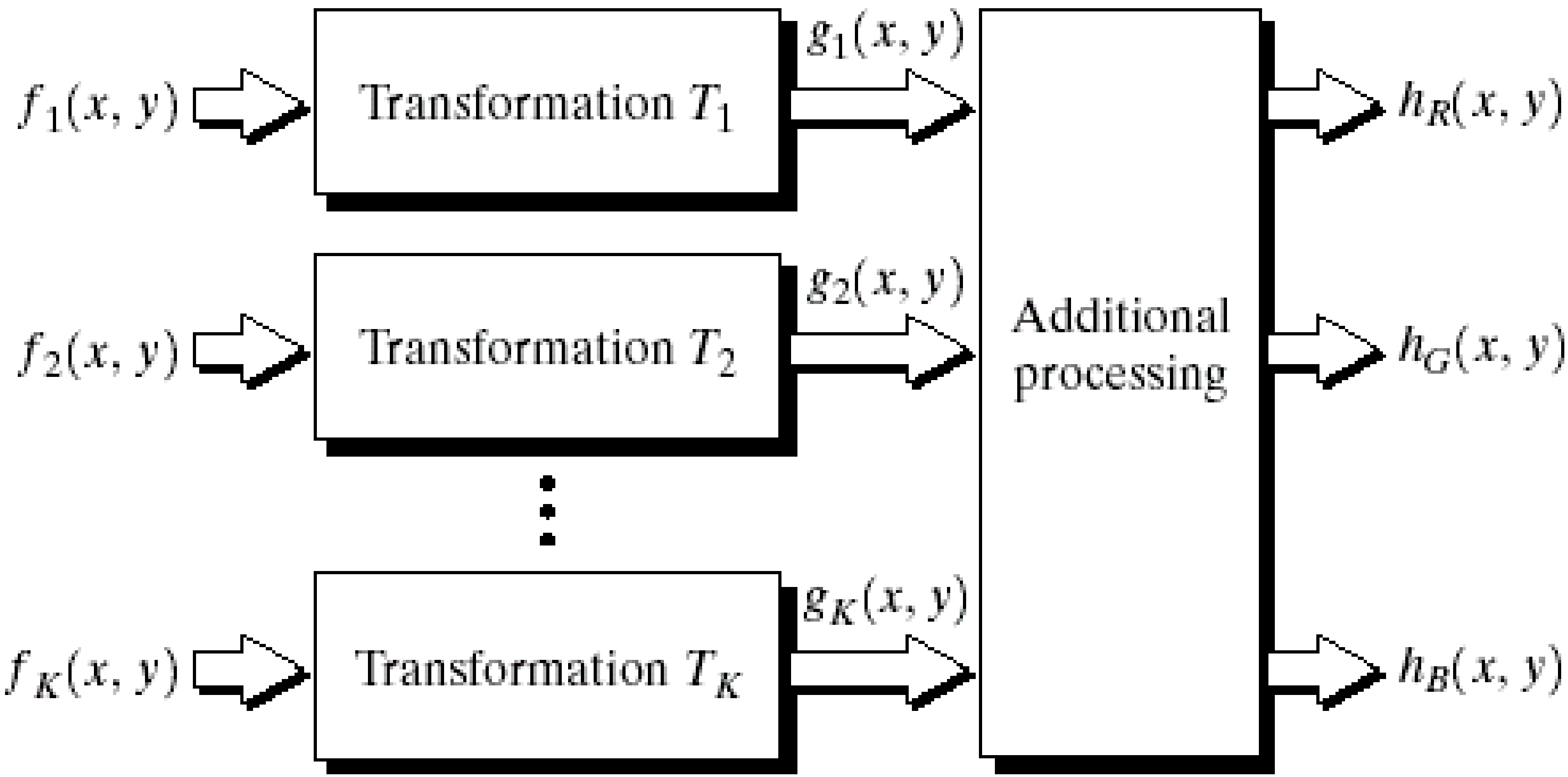
L − 1
Red
L − 1
Green
L − 1
Blue
Gray level
0
L − 1
Explosive
Garment bag
Background





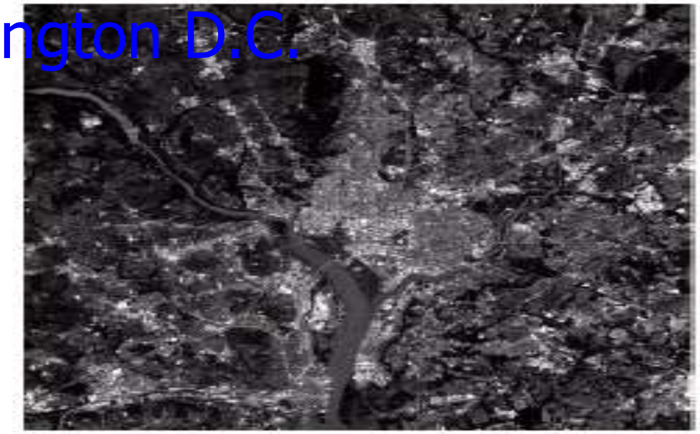
Combine several monochrome images

Example: multi-spectral images



Washington D.C.

R

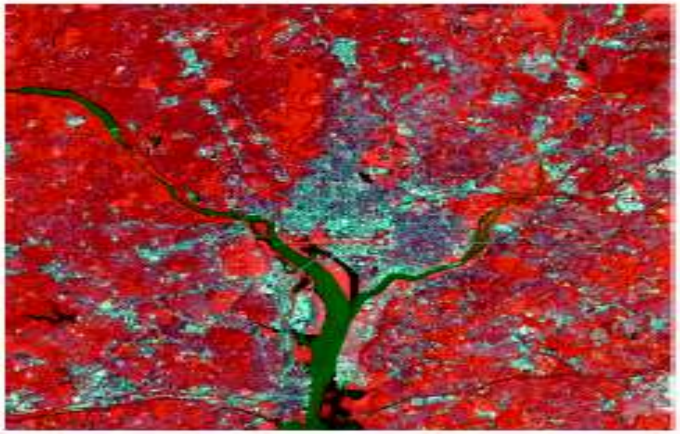


G

B

Near Infrared (sensitive to biomass)

R+G+B



near-infrared+G+B

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Color pixel

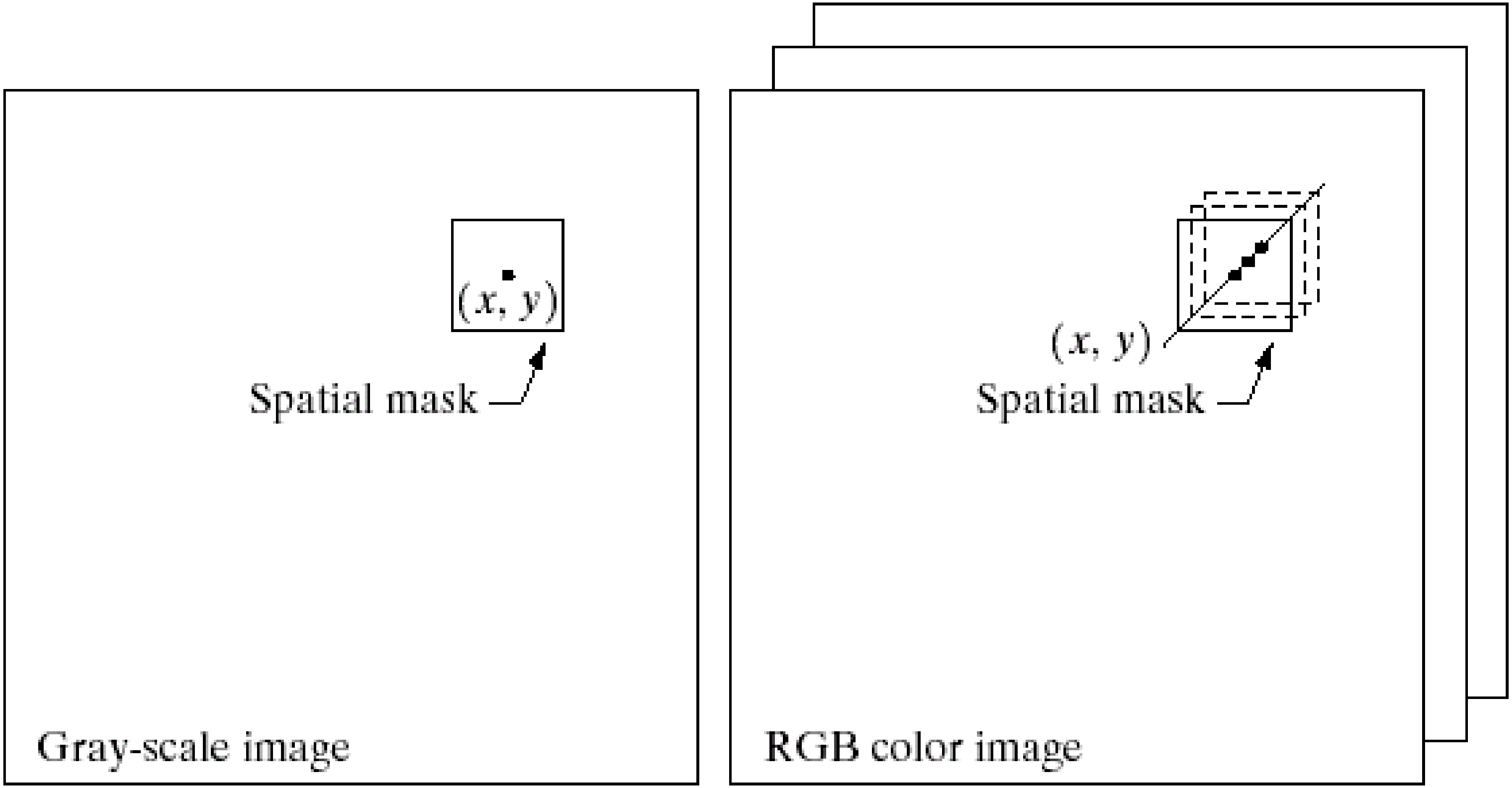
- A pixel at (x,y) is a vector in the color space
  - RGB color space

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

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

Outline

- Color fundamentals
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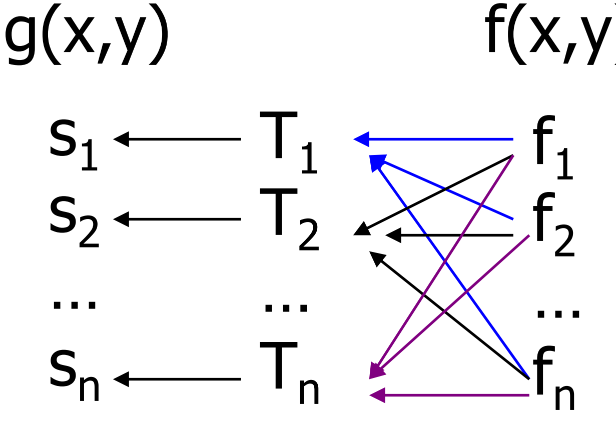
Color transformation

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

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

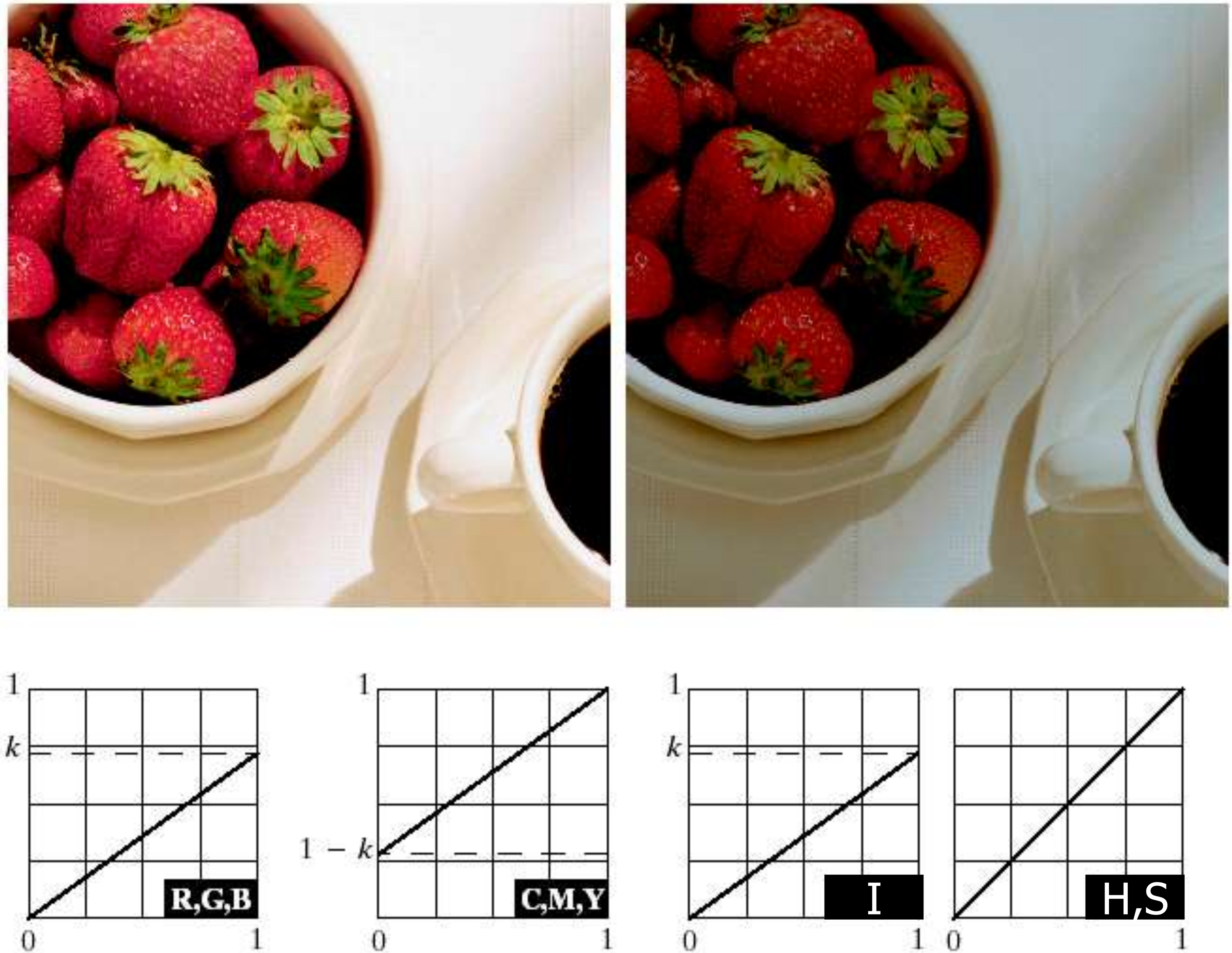


Use which color model in color transformation?

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

Example: modify intensity of a color image

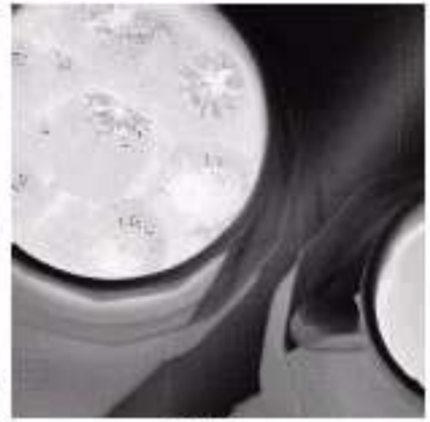
- **Example:** $g(x,y)=k\,f(x,y)$, $0<k<1$
- HSI color space
  - Intensity: $s_3 = k\, r_3$
  - Note: transform to HSI requires complex operations
- RGB color space
  - For each R,G,B component: $s_i = k\, r_i$
- CMY color space
  - For each C,M,Y component:
  - $s_i = k\, r_i + (1-k)$

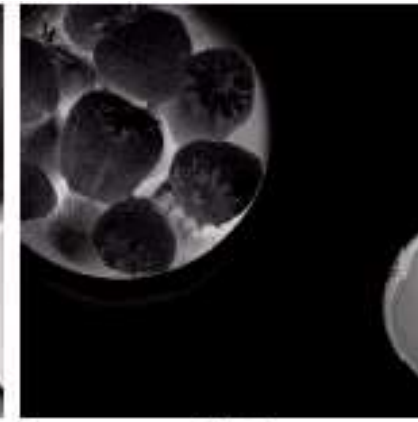


1
k
0
1
R,G,B
1
1 − k
0
1
C,M,Y
1
k
0
1
I
0
1
H,S


Cyan


Magenta


Yellow

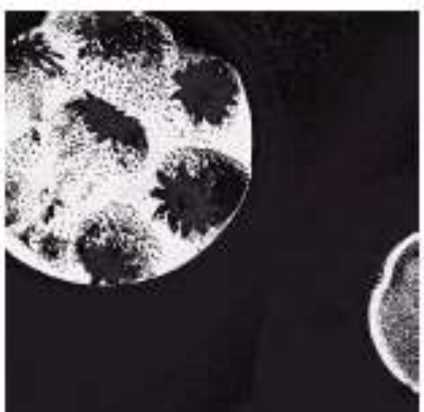

Black


Red


Green


Blue

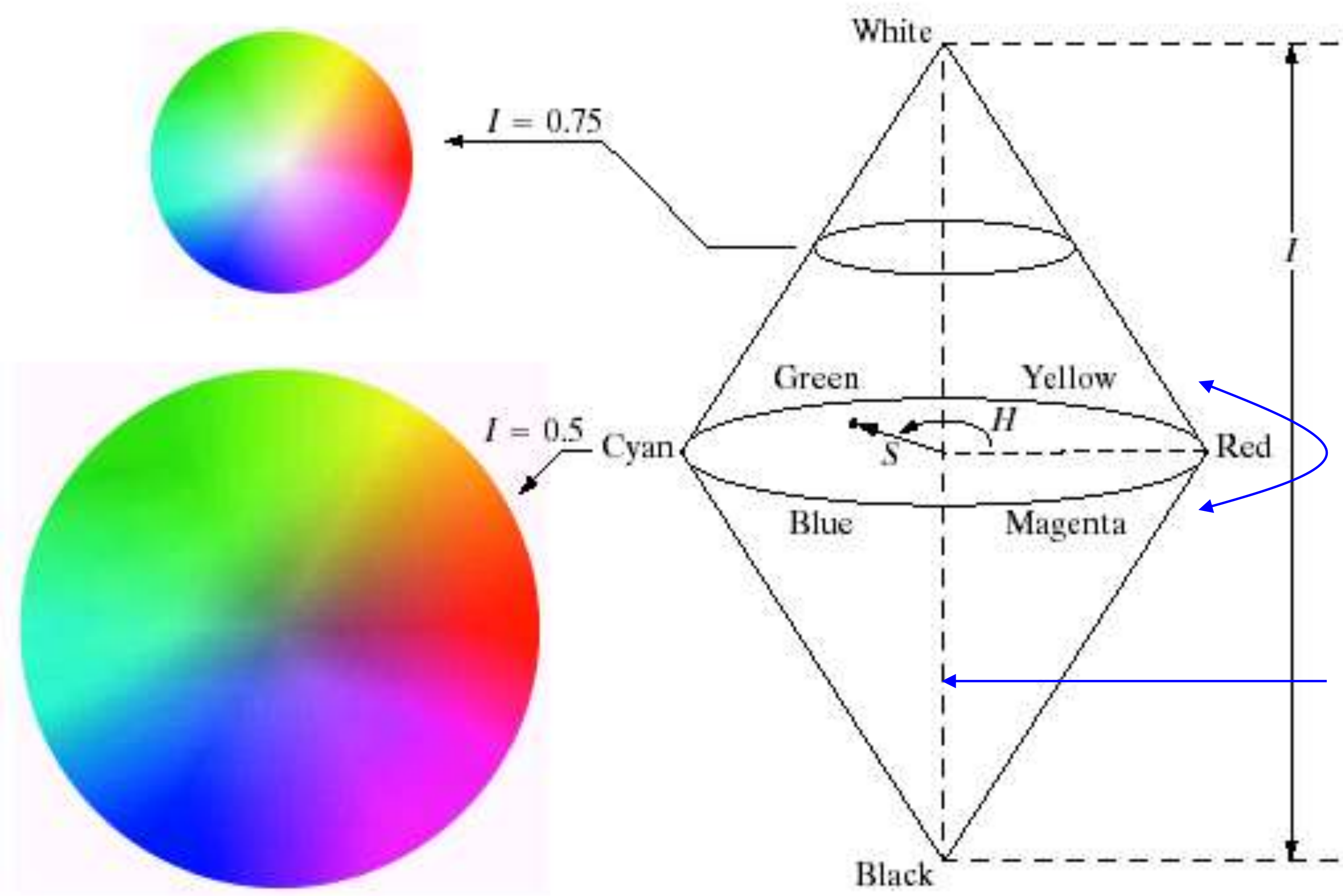

Full color


Hue


Saturation


Intensity

Problem of using Hue component

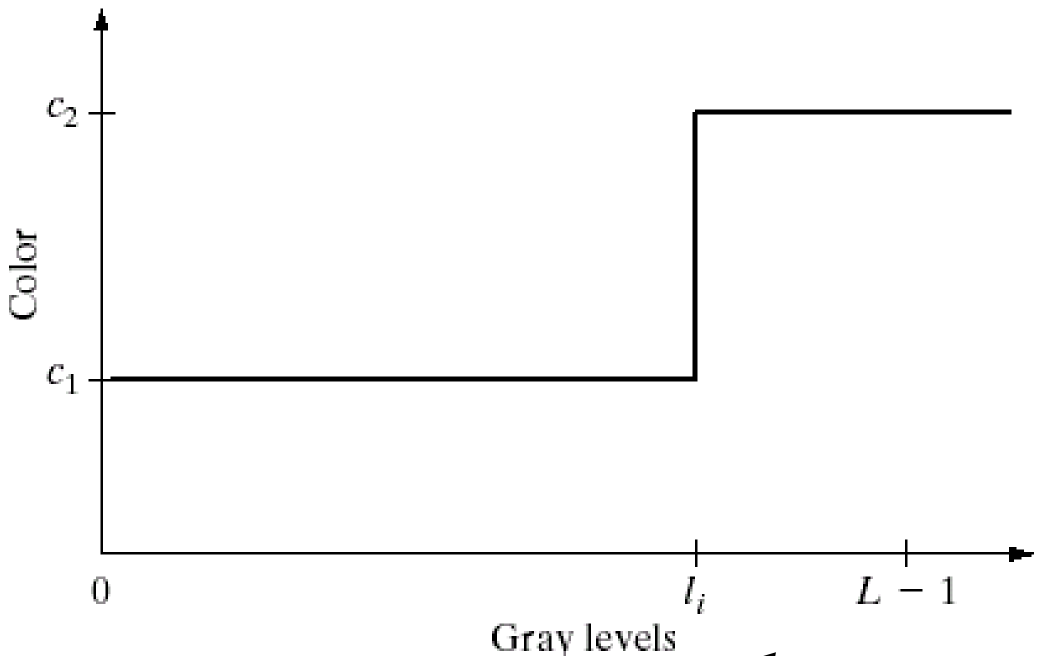


dis-continuous

Un-defined over gray axis

Implementation of color slicing

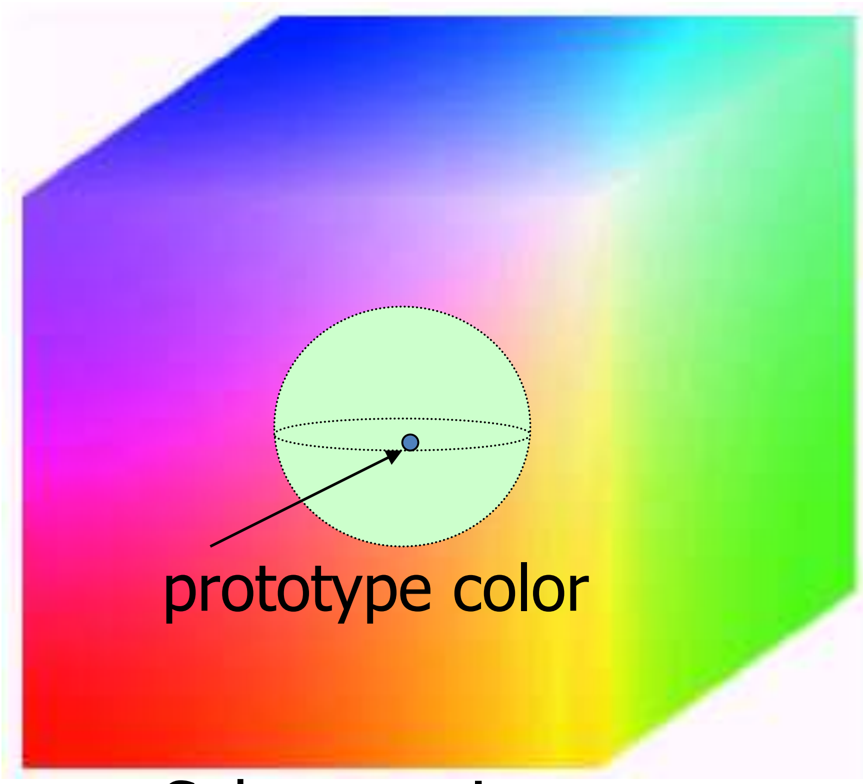
- Recall the pseudo-color intensity slicing



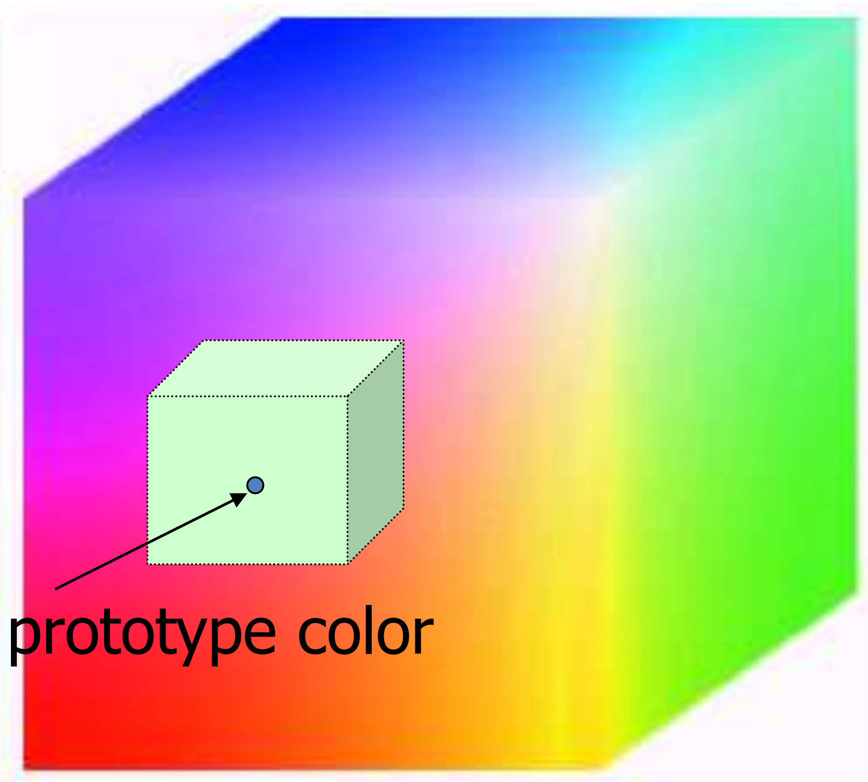
1-D intensity

Implementation of color slicing

- How to take a region of colors of interest?



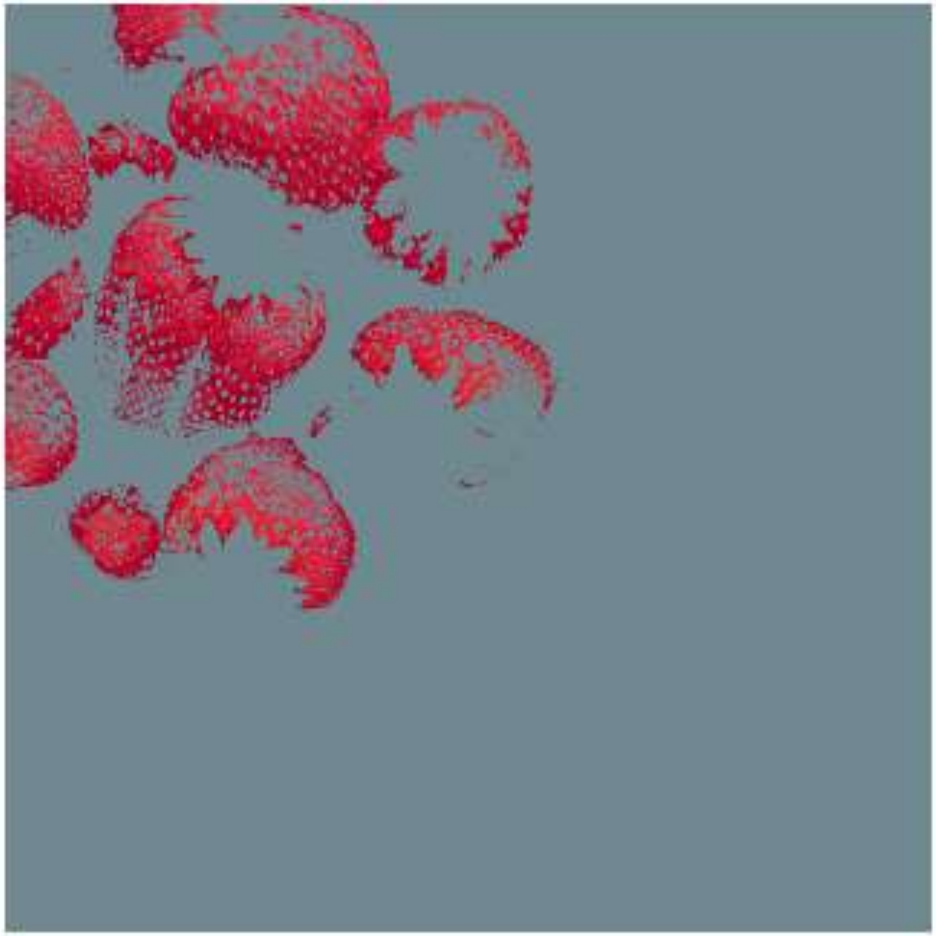
Sphere region



Cube region

Application

Full color



cube

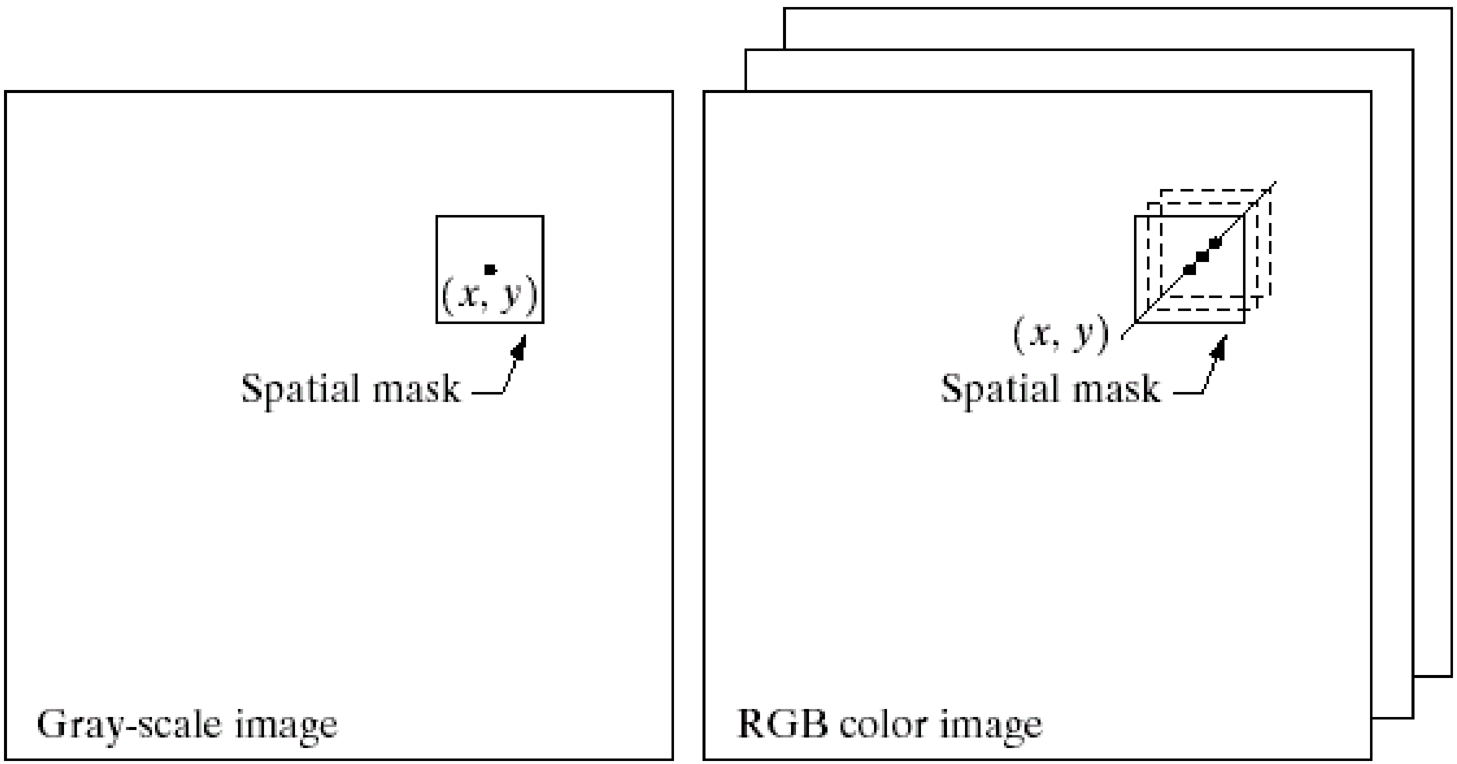
sphere

Outline

- Color fundamentals
- Color models
- Pseudo-color image processing
- Basics of full-color image processing
- Color transformations
- Smoothing and sharpening

Color image smoothing

- Neighborhood processing



Color image smoothing: averaging mask

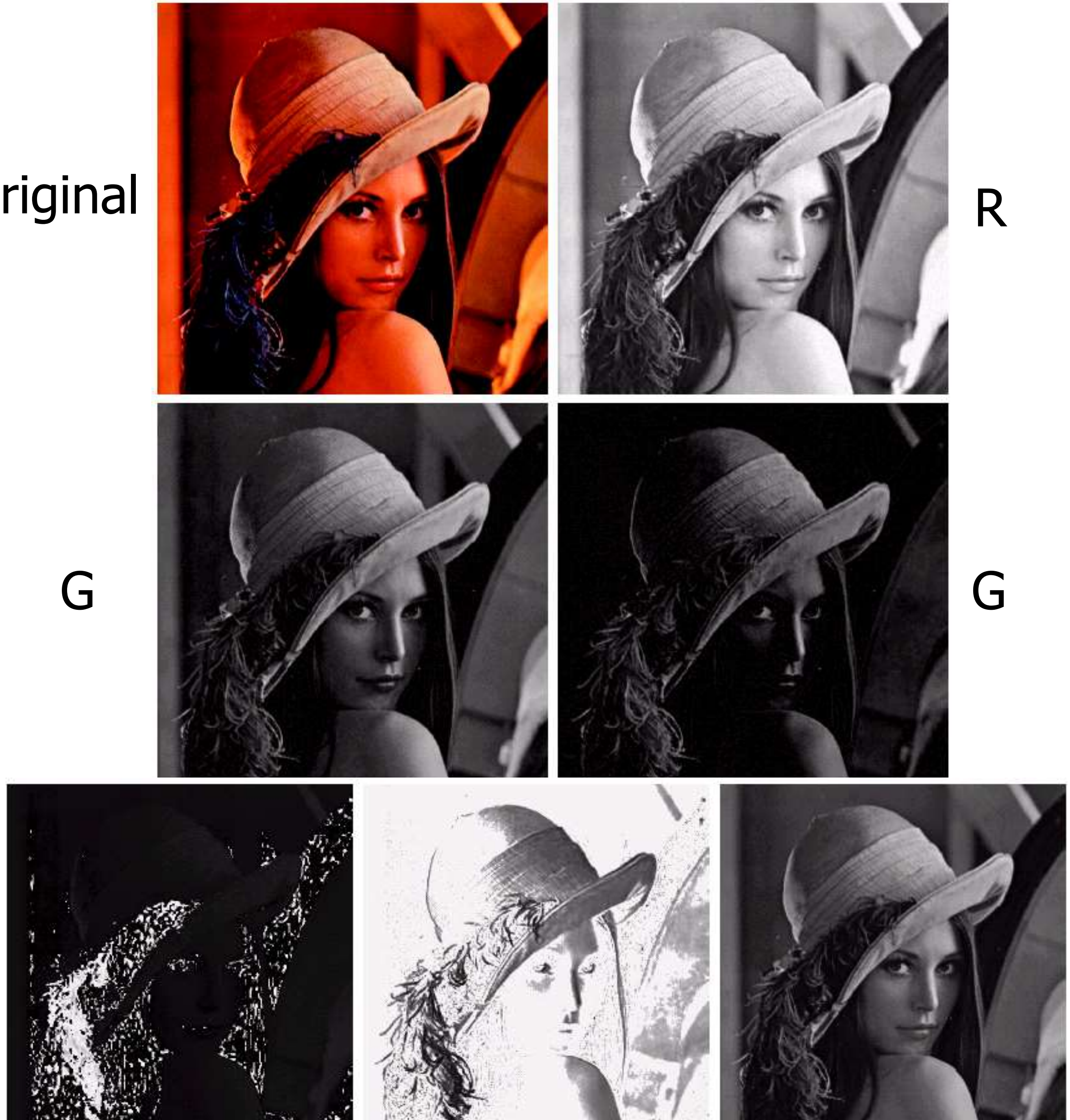
$$\bar{\mathbf{c}}(x,y) = \frac{1}{K} \sum_{(x,y)\in S_{xy}} \mathbf{c}(x,y)$$

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 G

H S I

Example: 5x5 smoothing mask

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.