Color Image Processing

박 운 상

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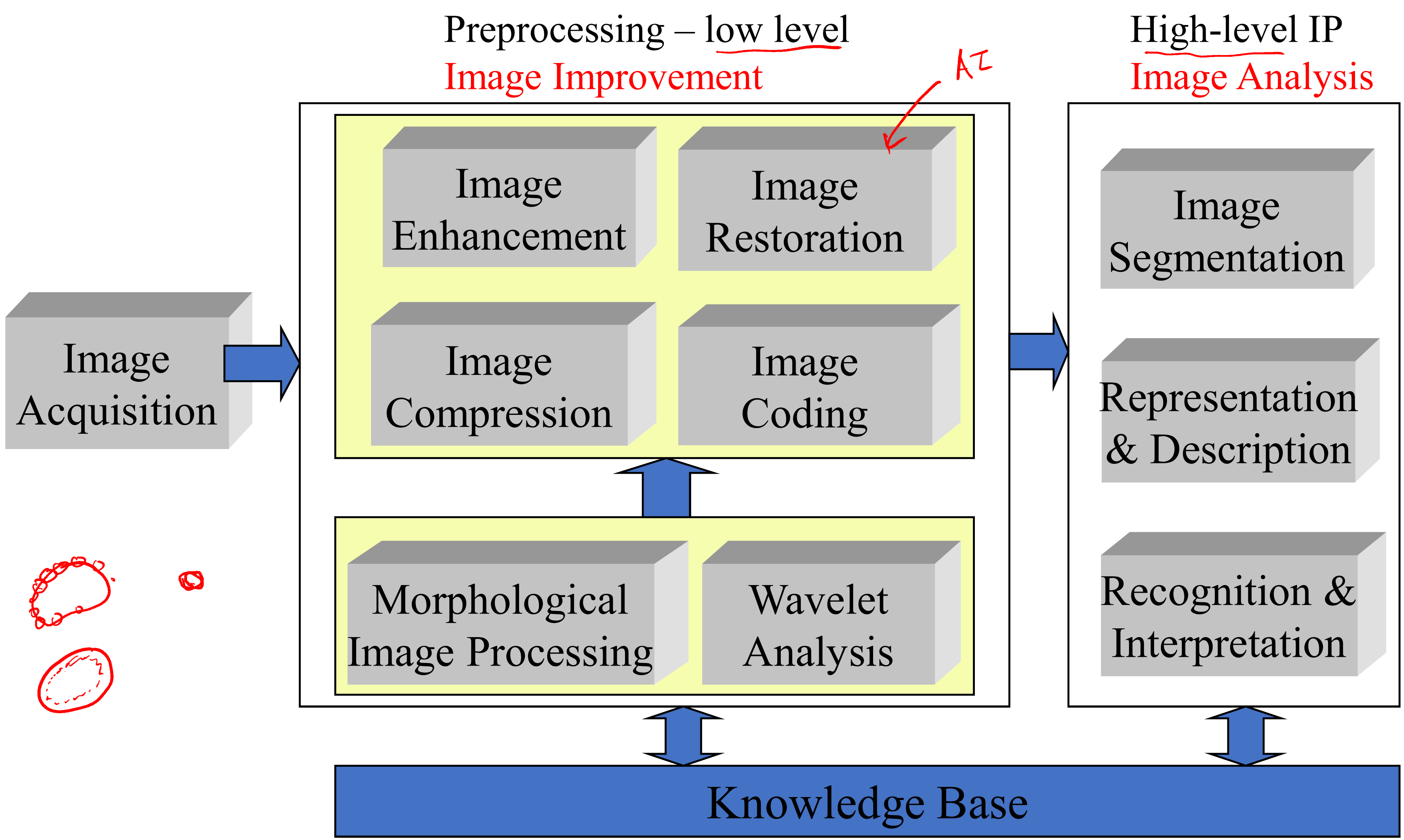
SOGANG UNIVERSITY

Image Processing

- Image improvement (enhancement)
  - Improving the visual appearance of images to a human viewer
- Image analysis
  - Preparing images for measurement of the featu res and structures present

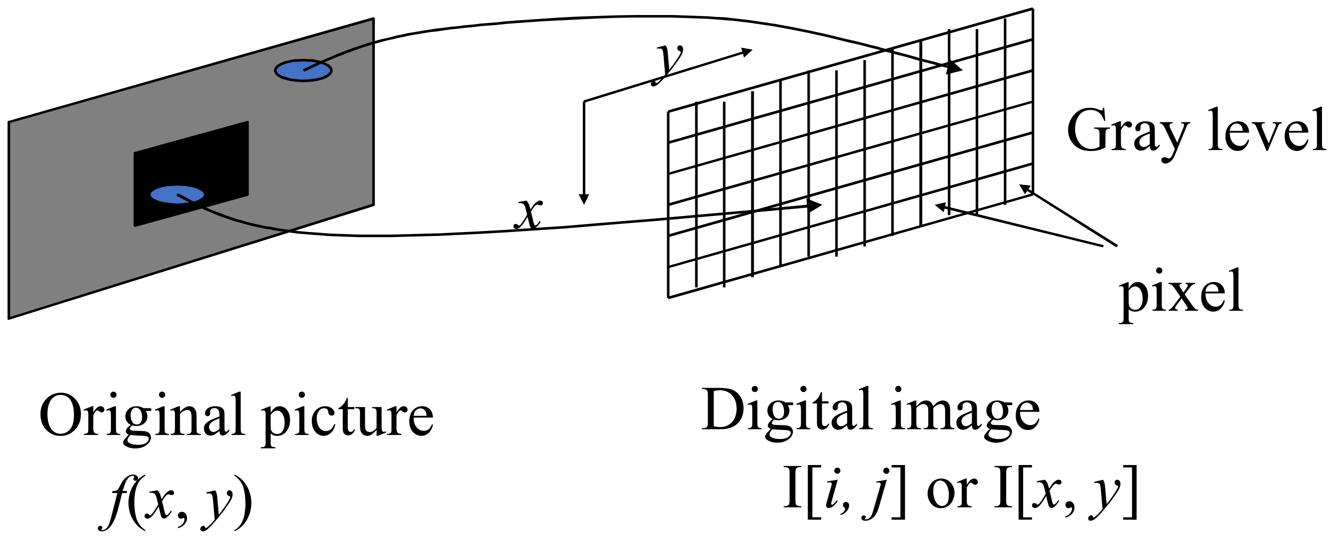
Image Processing



What is an image? – The bitmap representation

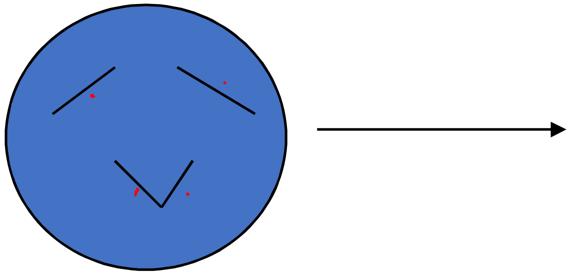
jpg · png. ·····

- Also called "raster or pixel maps" representation
- An image is broken up into a grid



What is an image? – The vector representation

- Object-oriented representation
- Does not show information of individual pixel, but information of an object (circle, line, square, etc.)

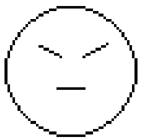


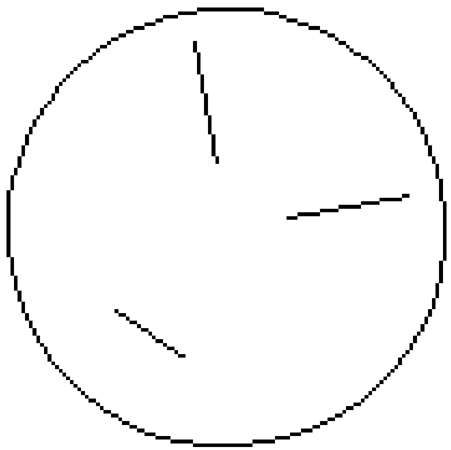
r x_0 y_0

Circle(100, 20, 20)
Line(xa1, ya1, xa2, ya2)
Line(xb1, yb1, xb2, yb2)
Line(xc1, yc1, xc2, yc2)
Line(xd1, yd1, xd2, yd2)

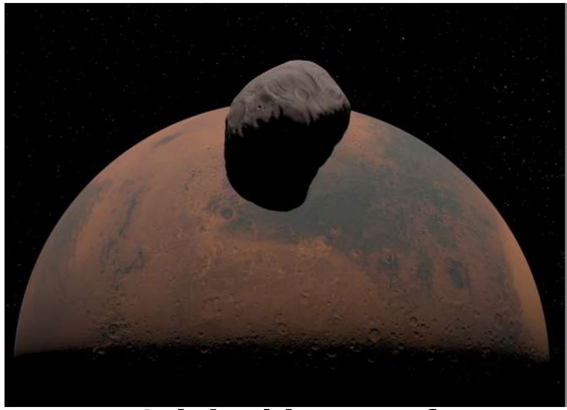
Comparison

- Bitmap
  - Can represent images with complex variations in colors, shades, shapes.
  - Larger image size
  - Fixed resolution
  - Easier to implement
- Vector
  - Can only represent simple line drawings (CAD), shapes, shadings, etc.
  - Efficient
  - Flexible
  - Difficult to implement

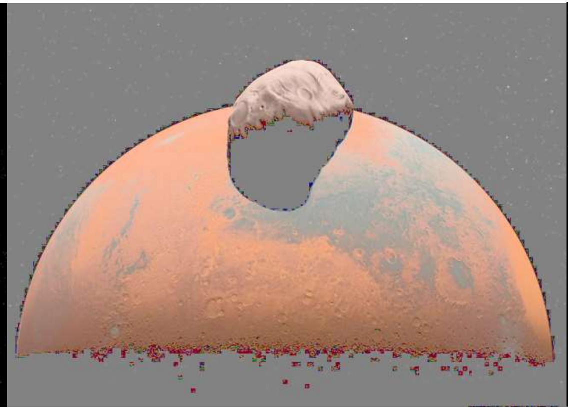




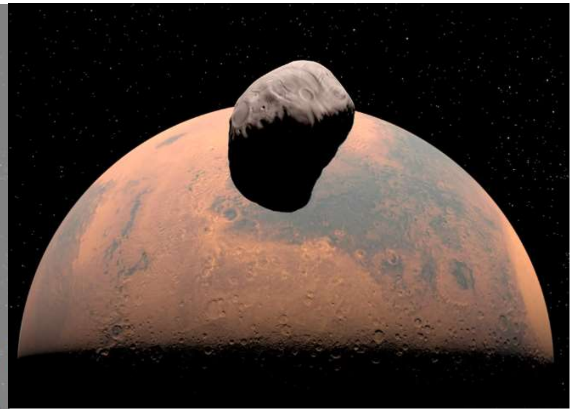
What is an image? – The bitmap representation



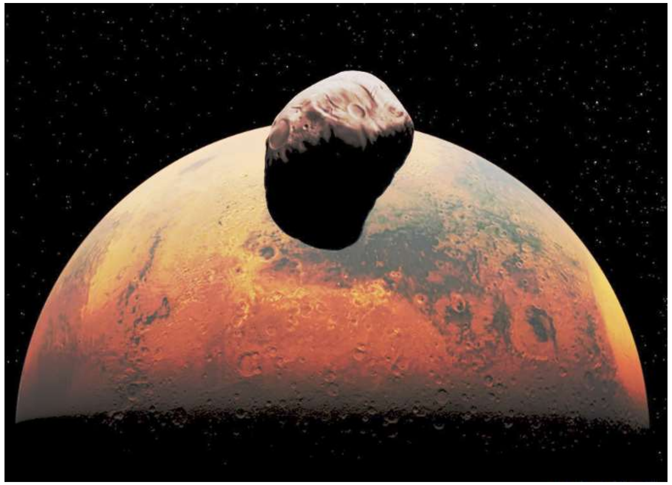
Original image of Mars and its moon
$APDG = 42.1$ $TEN = 12.1$



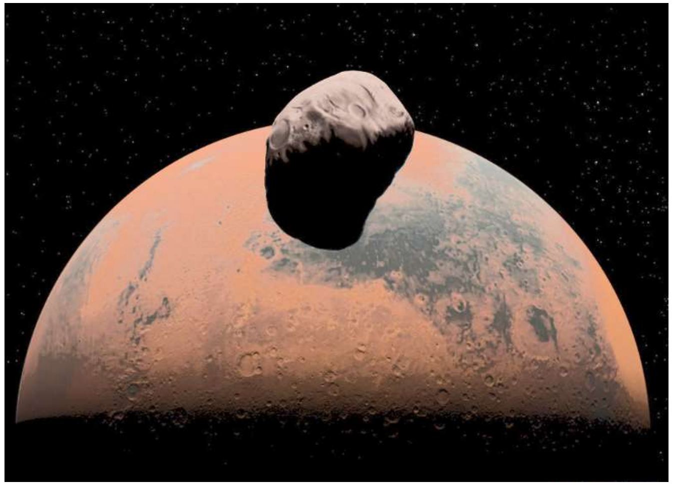
Histogram Equalization
$APDG = 28.4$ $TEN = 22.0$



Photoshop "Auto Contrast" result
$APDG = 72.9$ $TEN = 20.8$



GLG in RGB space
$APDG = 76.3$ $TEN = 27.0$



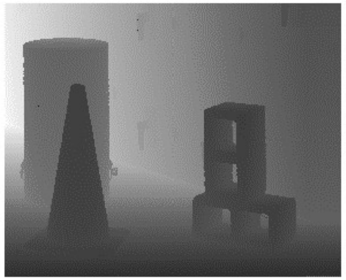
GLG in HSI space – better than Photoshop result
$APDG = 78.6$ $TEN = 26.6$

From Zhiyu Chen's preliminary proposal defense, January 2009

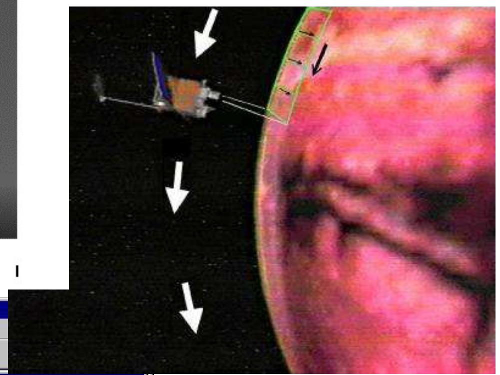
7

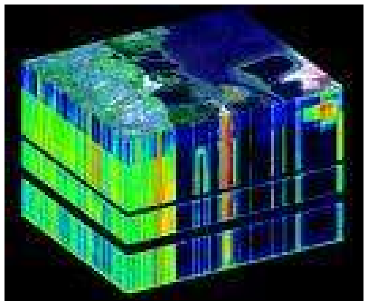
Image acquisition

- Video camera
- Infrared camera
- Range camera
- Line-scan camera
- Hyperspectral camera
- Omni-directional camera
- and more …



VIEW 1





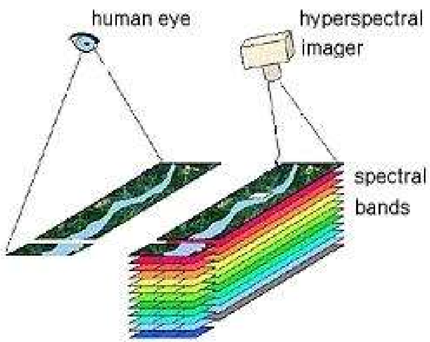
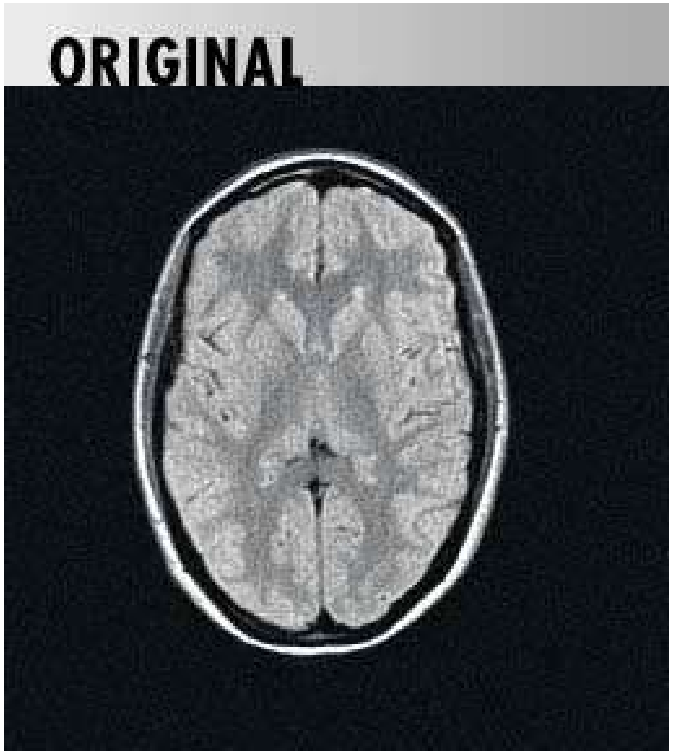
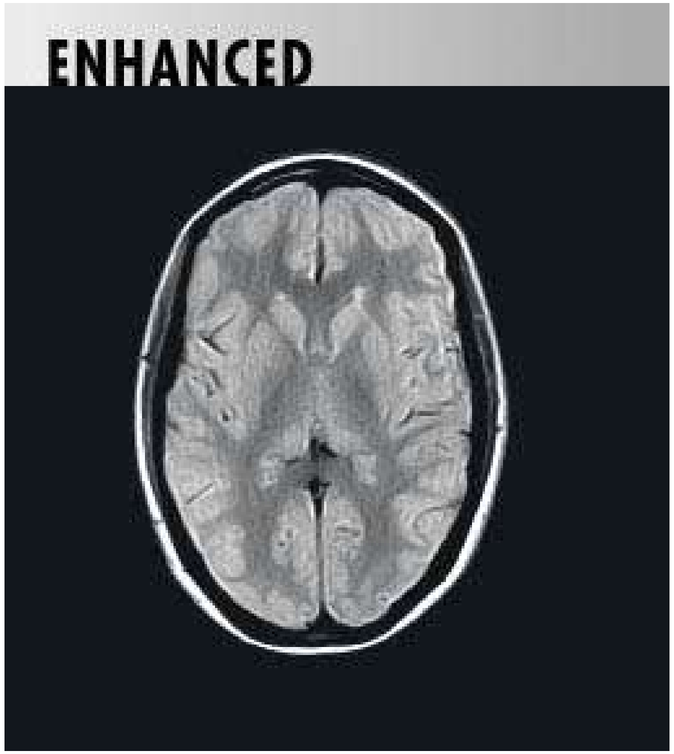


Image enhancement





Movie film restoration

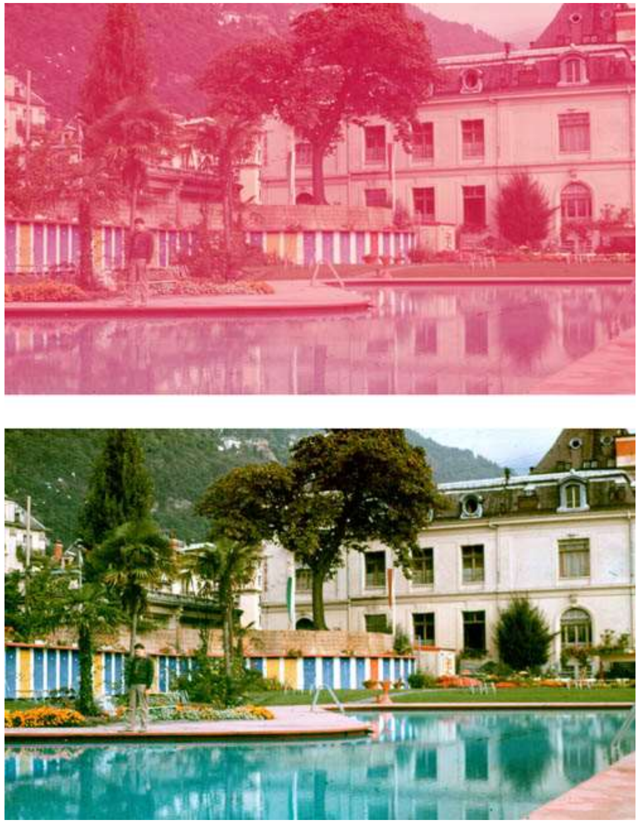


Image restoration

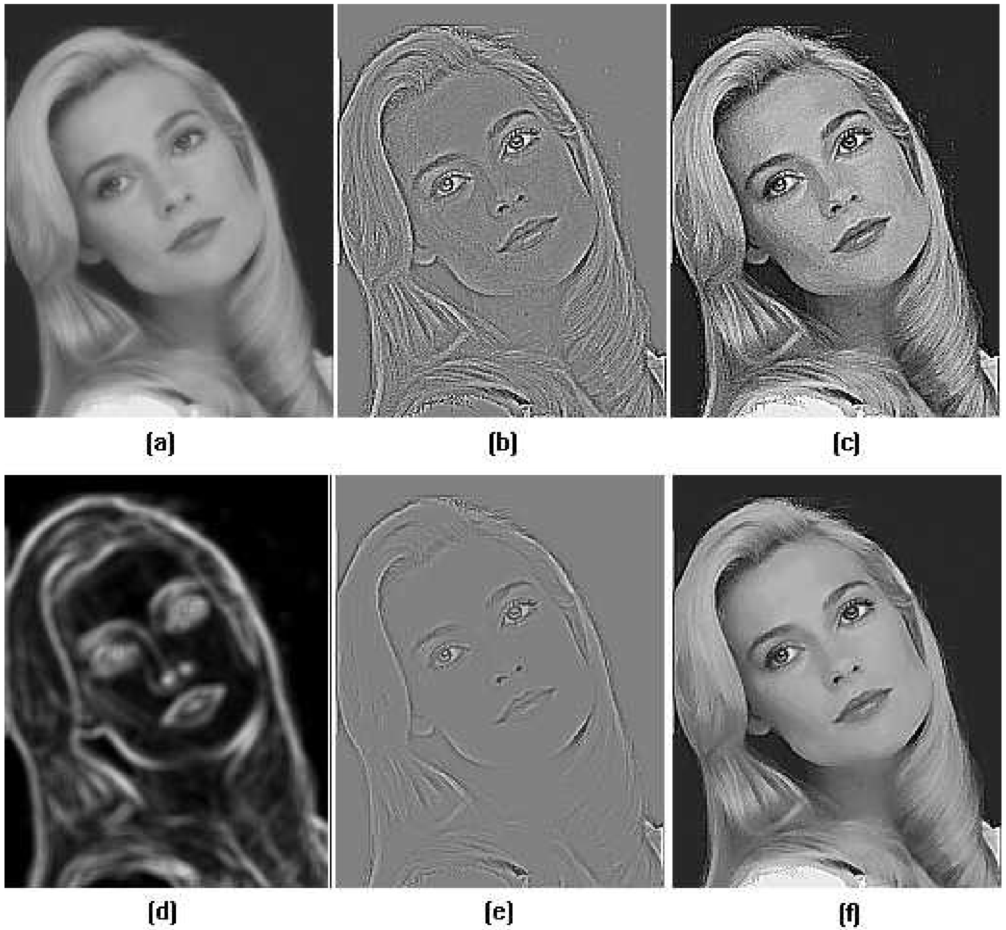
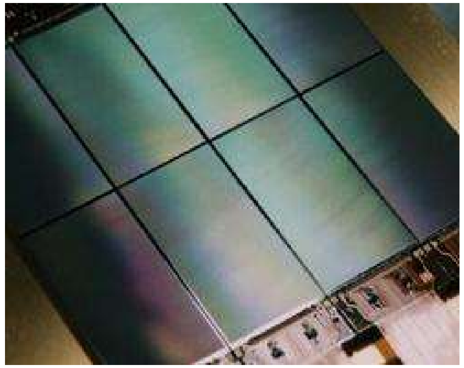
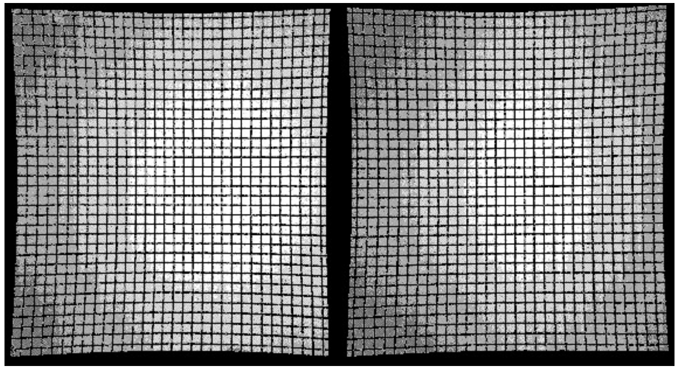
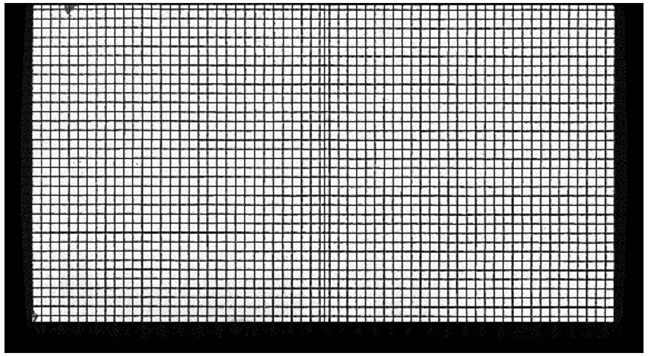


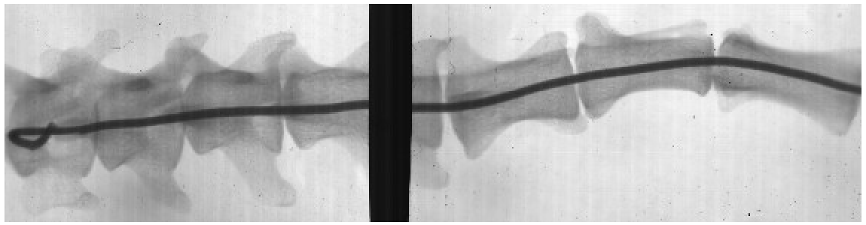
Image correction

- Geometric correction
- Radiometric correction









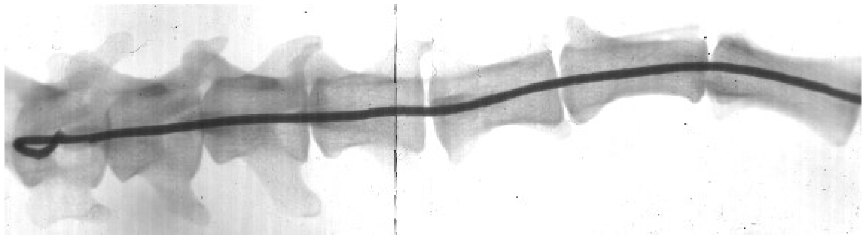
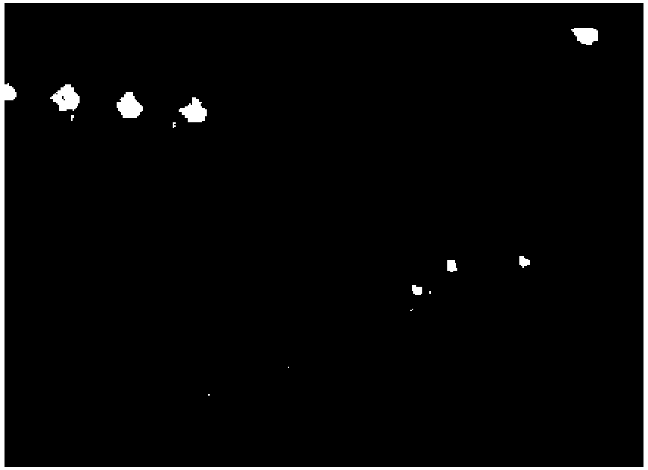


Image warping – geometric transformation

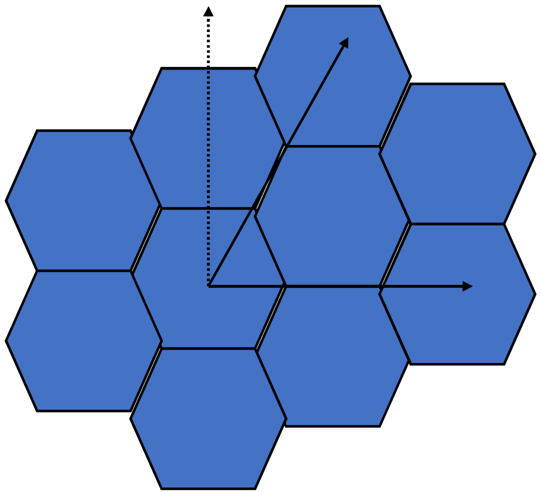
Image segmentation

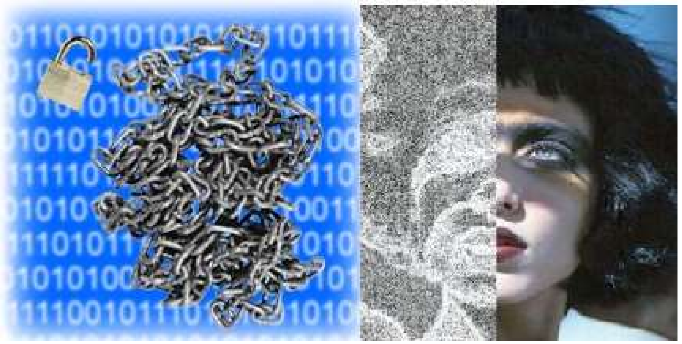


Fine Arts

Other processing

- Content-based image retrieval
- Human identification
- Multi-sensor data fusion
- Hexagonal pixel
- Steganography – concealing data into other data





How to address pixels of an image?

- C language

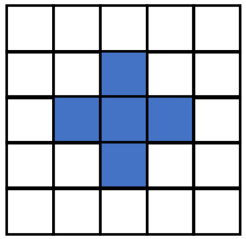
```
int i, j, k;
int nr,   // number of rows
    nc,   // number of columns
    nchan;// number of channels

nr = 128; nc = 128; nchan = 3;
for (i=0; i<nr; i++) {
  for (j=0; j<nc; j++) {
    for (k=0; k<nchan; j++) {
      do the processing on (i,j,k);
      ………
    }
  }
}
```

- Neighbors of a pixel

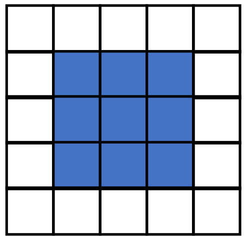
j (column)

i (row)

(i-1, j-1)	(i-1, j)	(i-1, j+1)
(i, j-1)	(i, j)	(i, j+1)
(i+1, j-1)	(i+1, j)	(i+1, j+1)



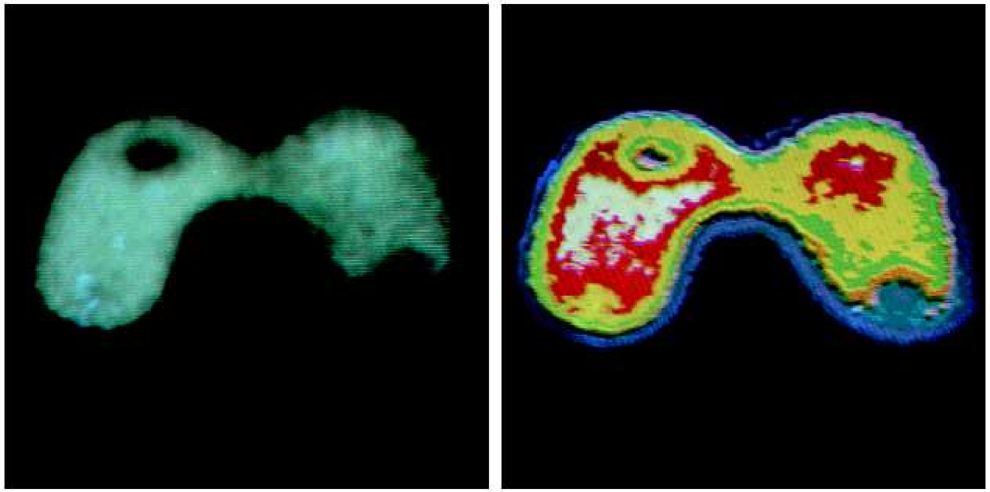
4-neighborhood



8-neighborhood

Why use color in image processing?

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



Two category of color image processing

- Full color processing
  - Images are acquired from full-color sensor or equipment
- Pseudo-color processing
  - In the past decade, color sensors and processing hardware were limited
  - Colors are assigned to a range of monochrome intensities

Color fundamentals

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

Color fundamentals

- 1666, Isaac Newton

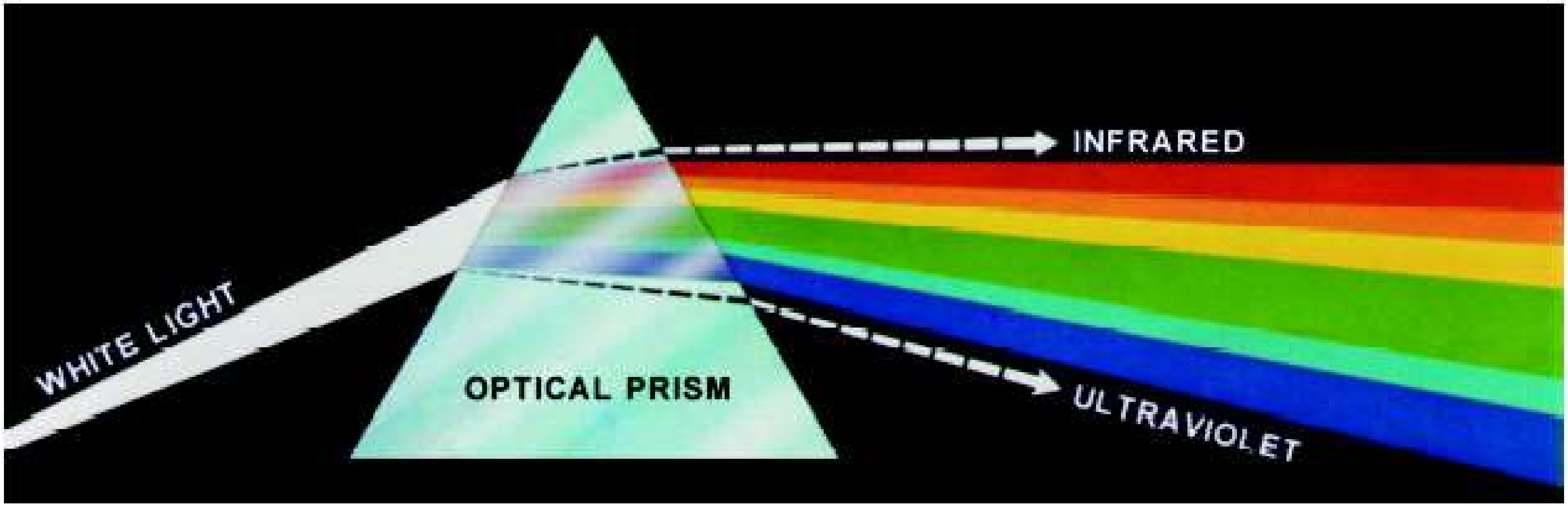


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Visible light

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

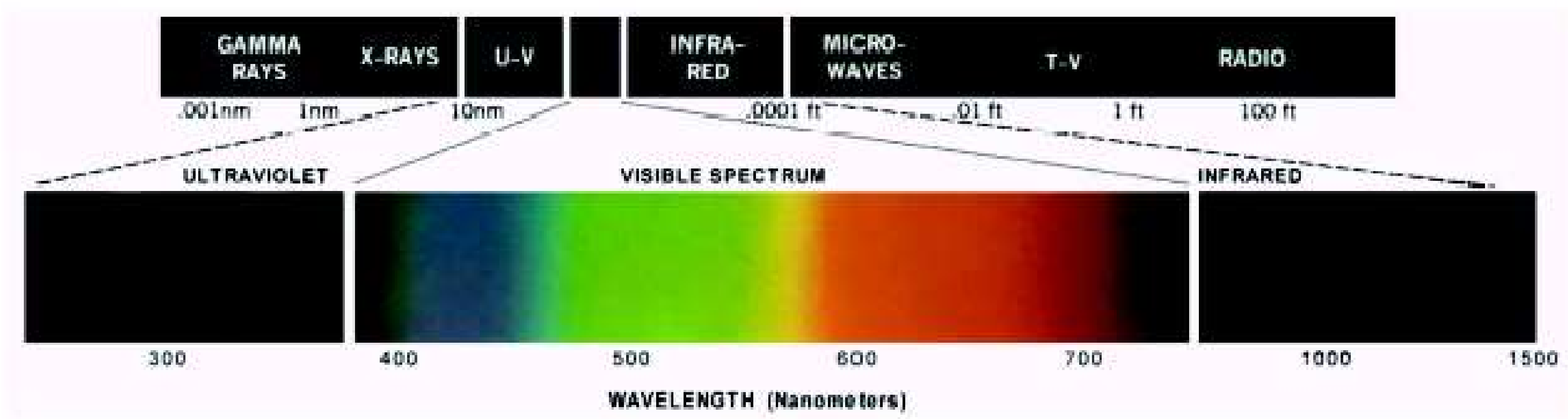
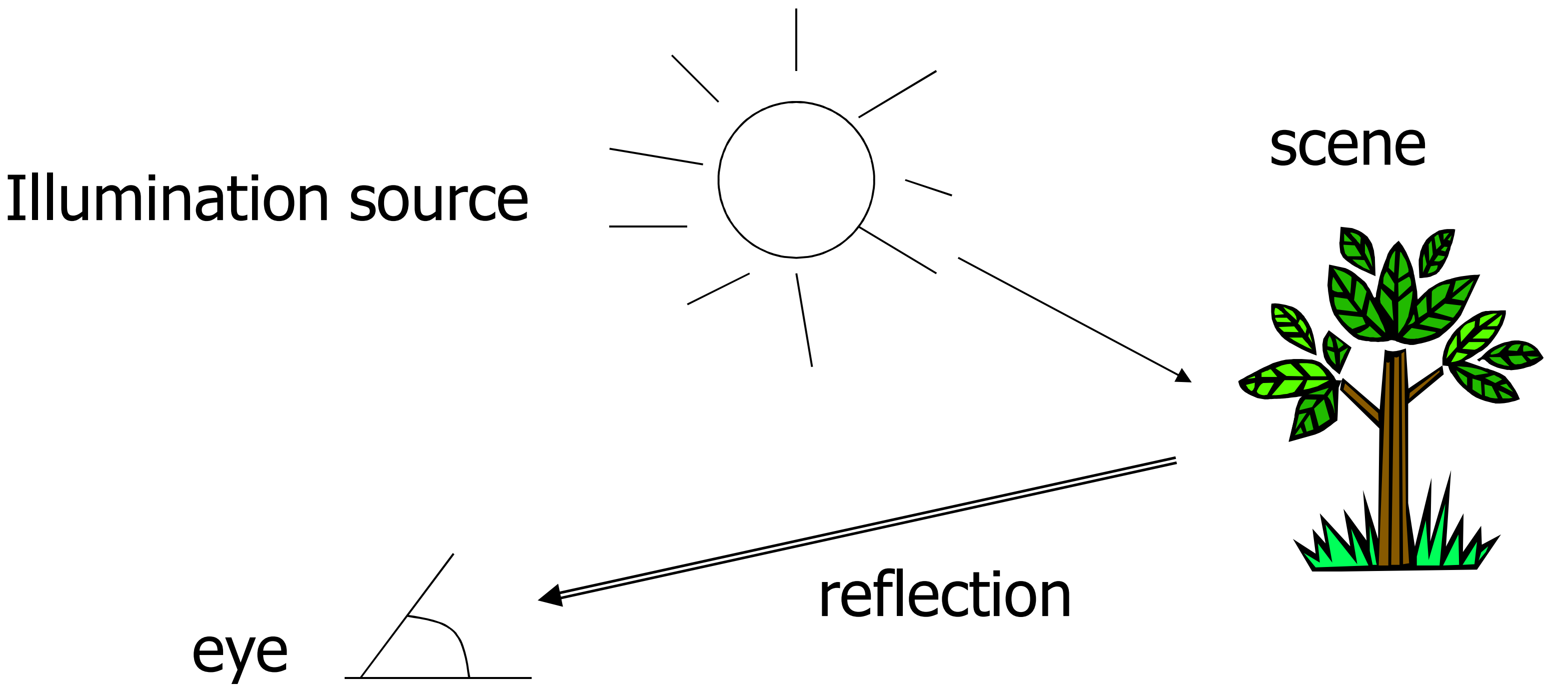


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Color fundamentals

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

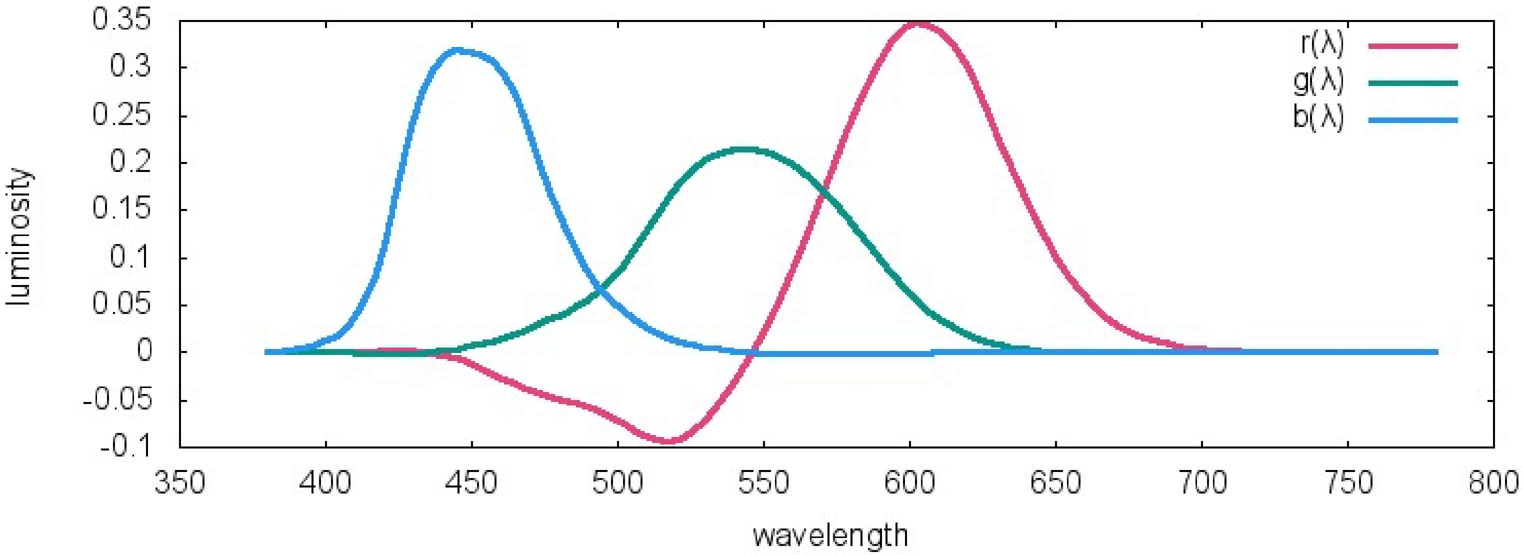


Color fundamentals

- 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
  - Far infrared light: high radiance, but 0 luminance
  - Brightness: subjective descriptor that is hard to measure, similar to the achromatic notion of intensity

Color fundamentals

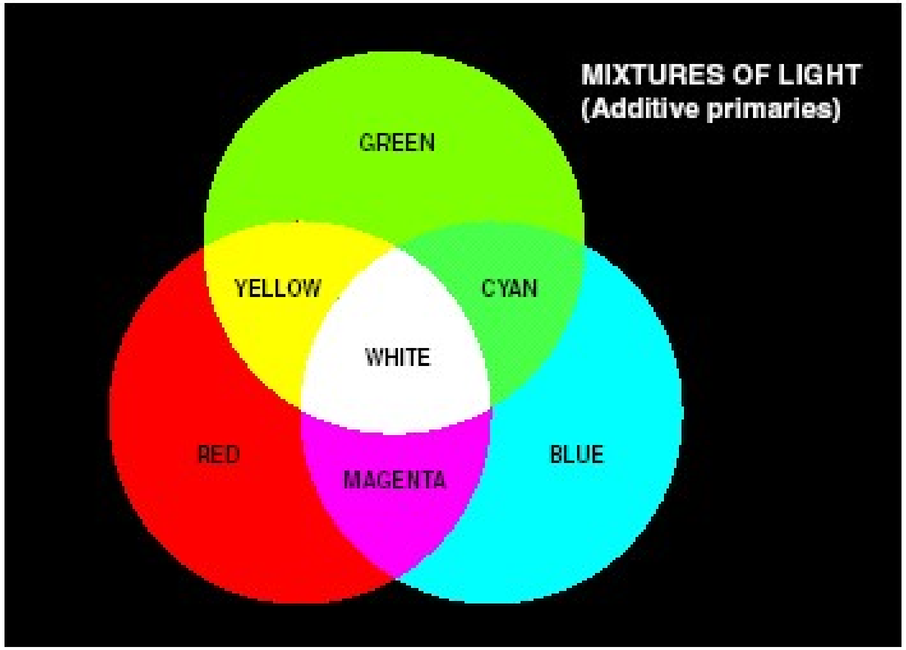
- 6~7M cones are the sensors in the eye
- 3 principal sensing categories in eyes
- Red light 65%, green light 33%, and blue light 2%

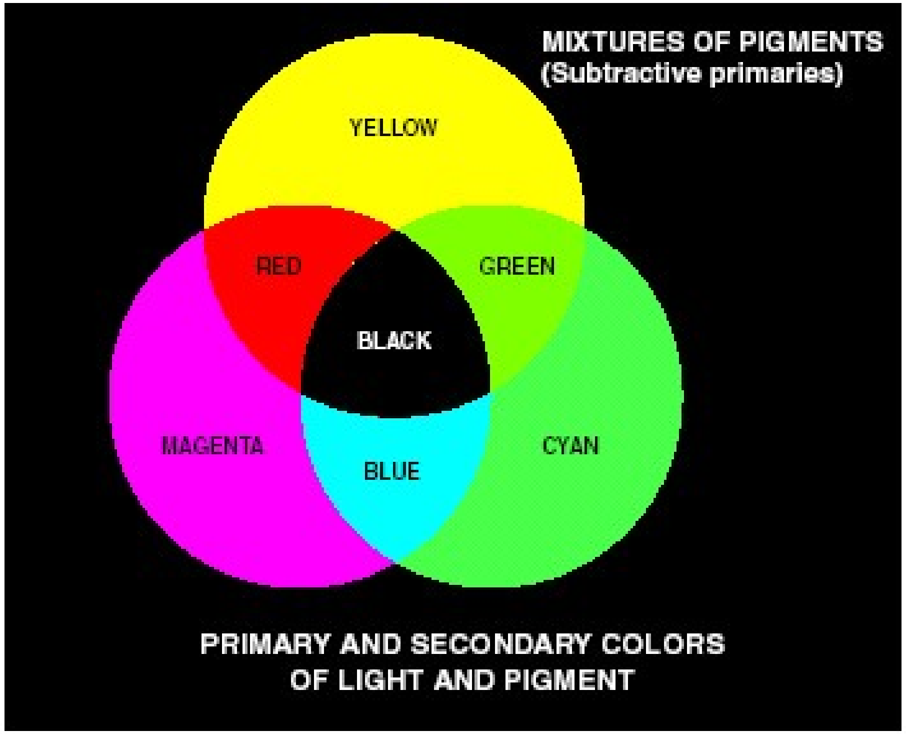


RGB Color Matching Functions (1931)

Color fundamentals

- 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





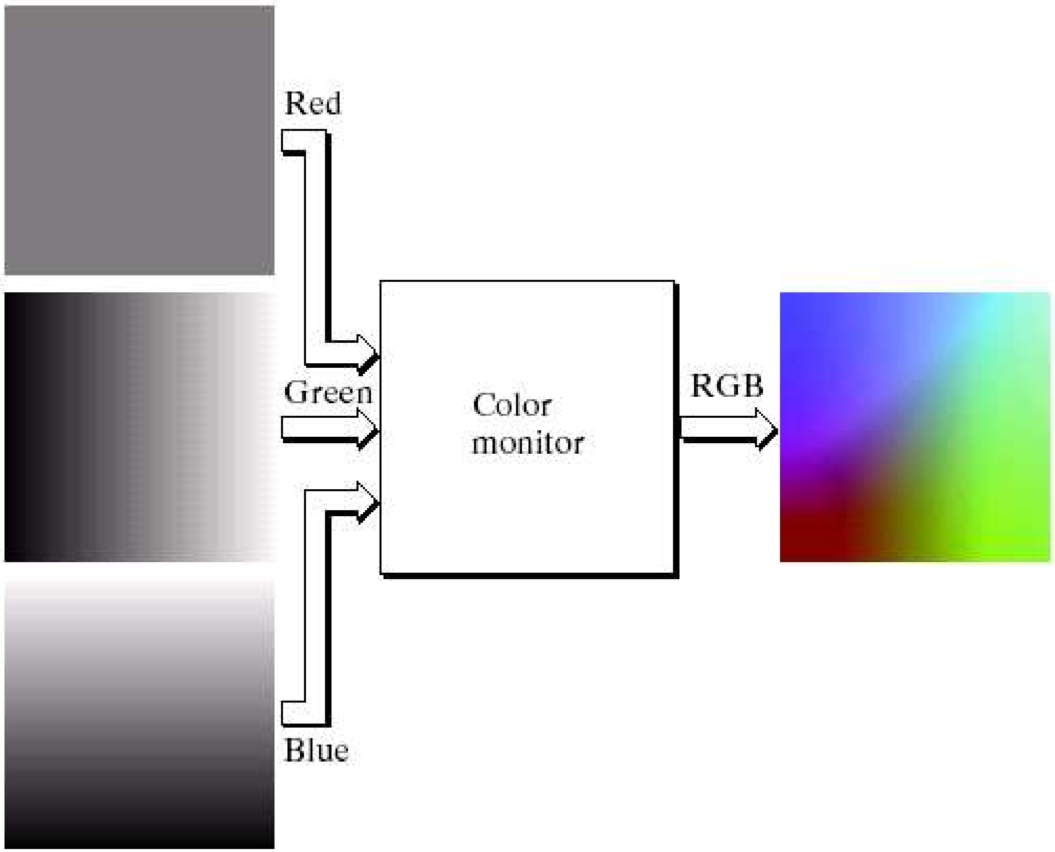
Color fundamentals

- 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

Color fundamentals

- Color TV



CIE XYZ model

- RGB -> CIE XYZ model

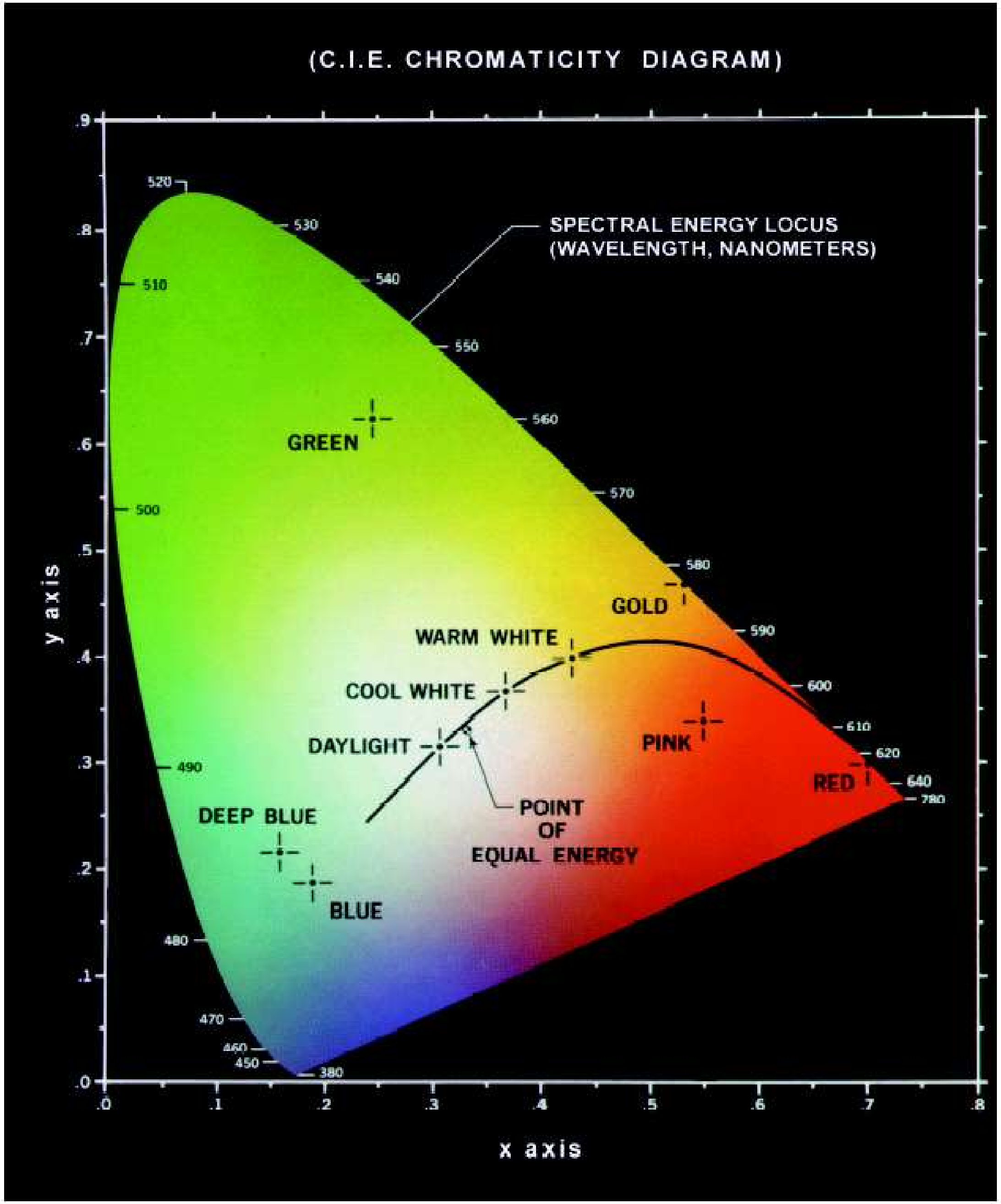
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.431 & 0.342 & 0.178 \\ 0.222 & 0.707 & 0.071 \\ 0.020 & 0.130 & 0.939 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Normalized tri-stimulus 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

CIE XYZ model



CIE XYZ model

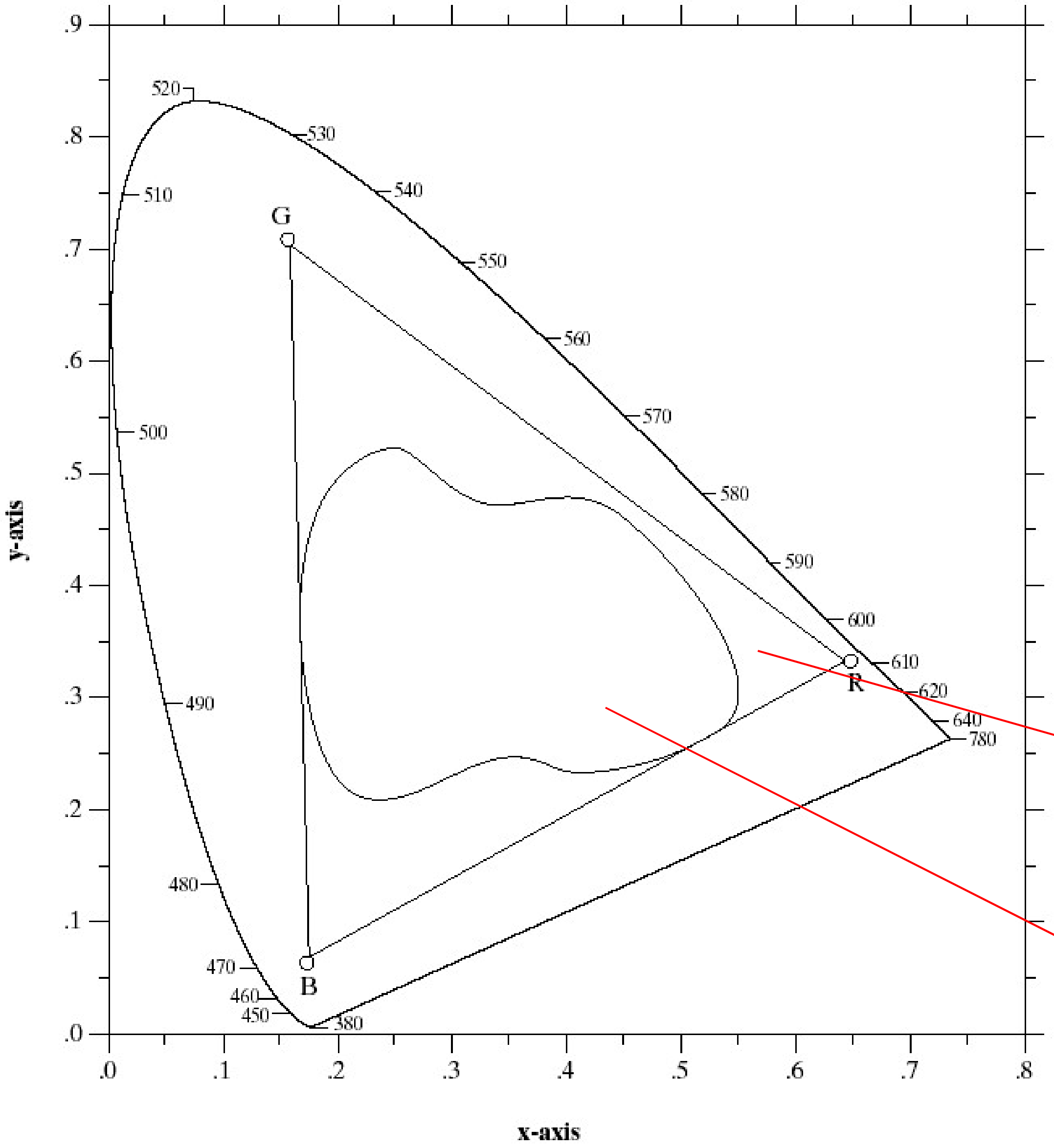


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

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

Color models

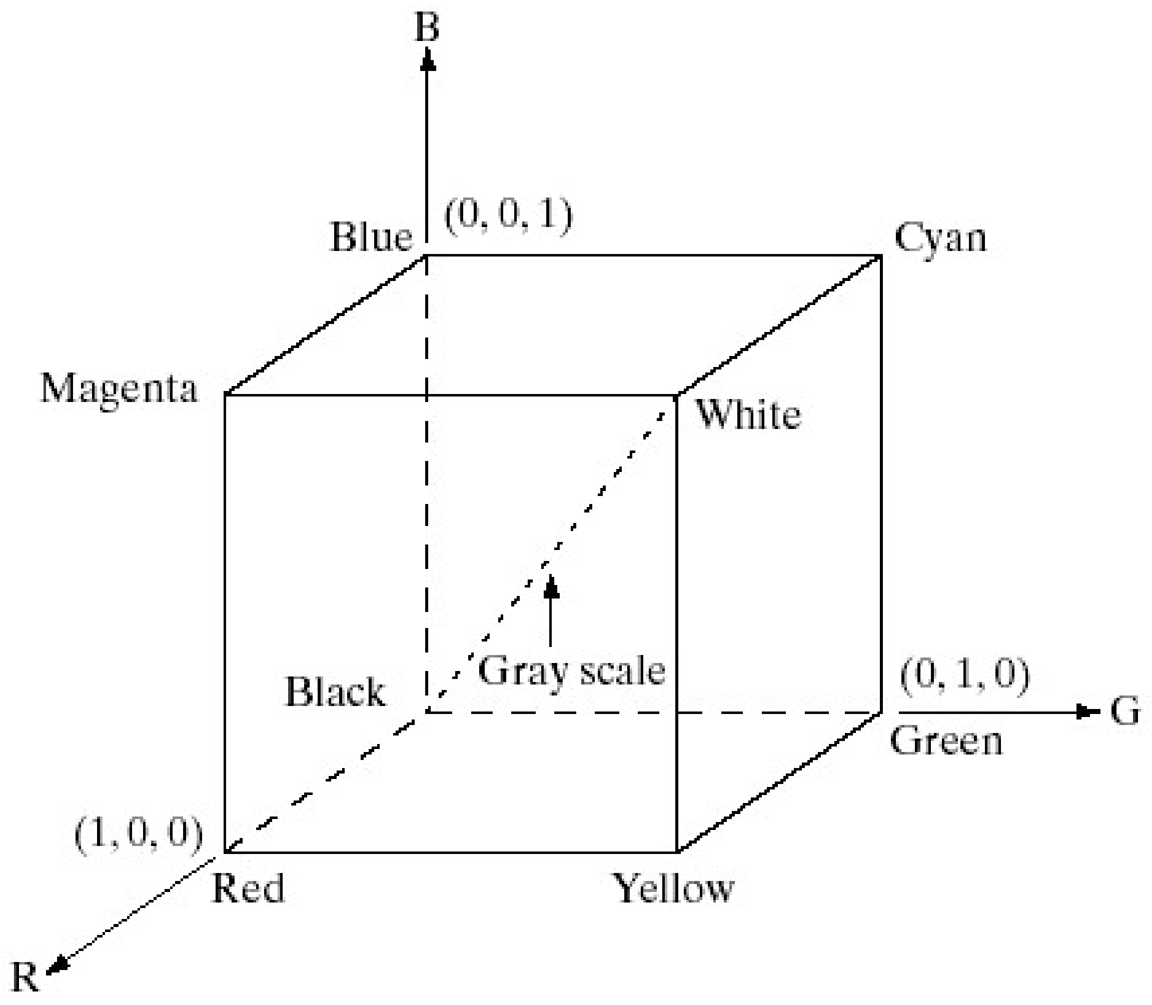
- Color model, color space, color system
  - Specify colors in a standard way
  - A coordinate system that each color is represented by a single point

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

Suitable for hardware or applications

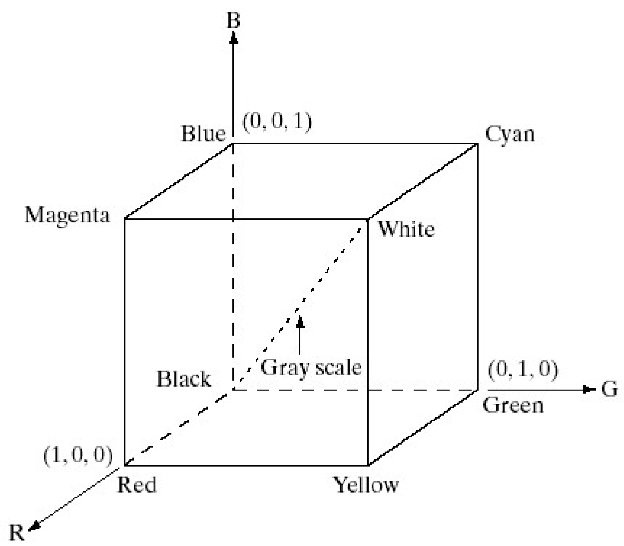
- match the human description

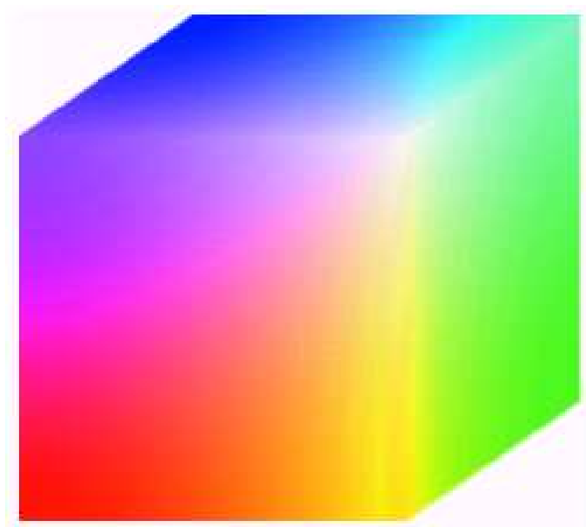
RGB color model



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)





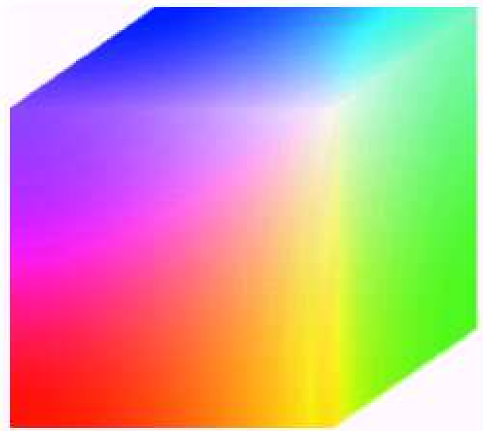
Safe RGB colors

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

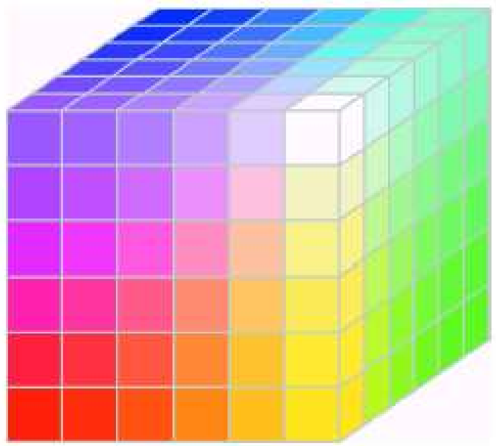
$(6)^3 = 216$

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.



Full color cube

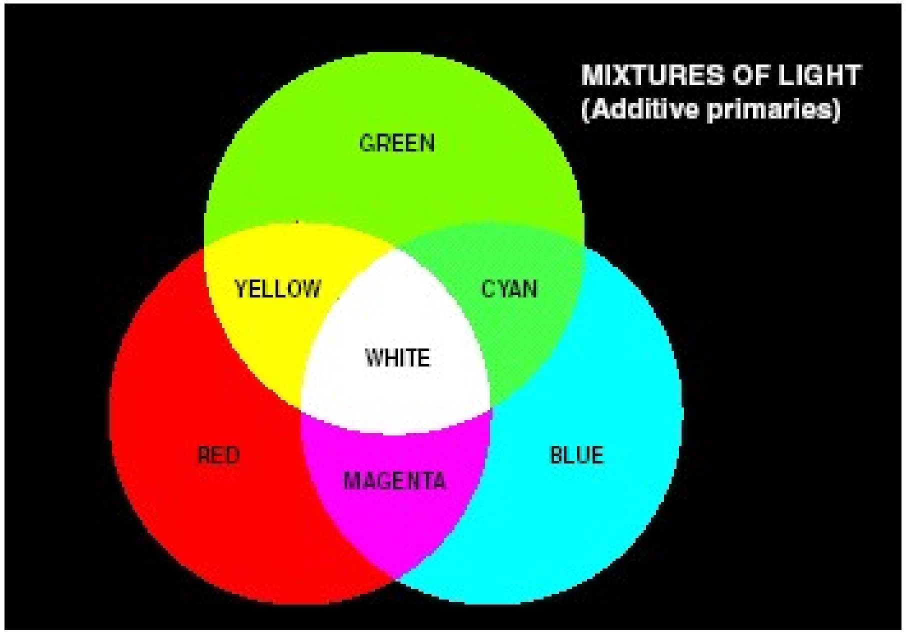


Safe color cube

CMY model (+Black = CMYK)

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

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

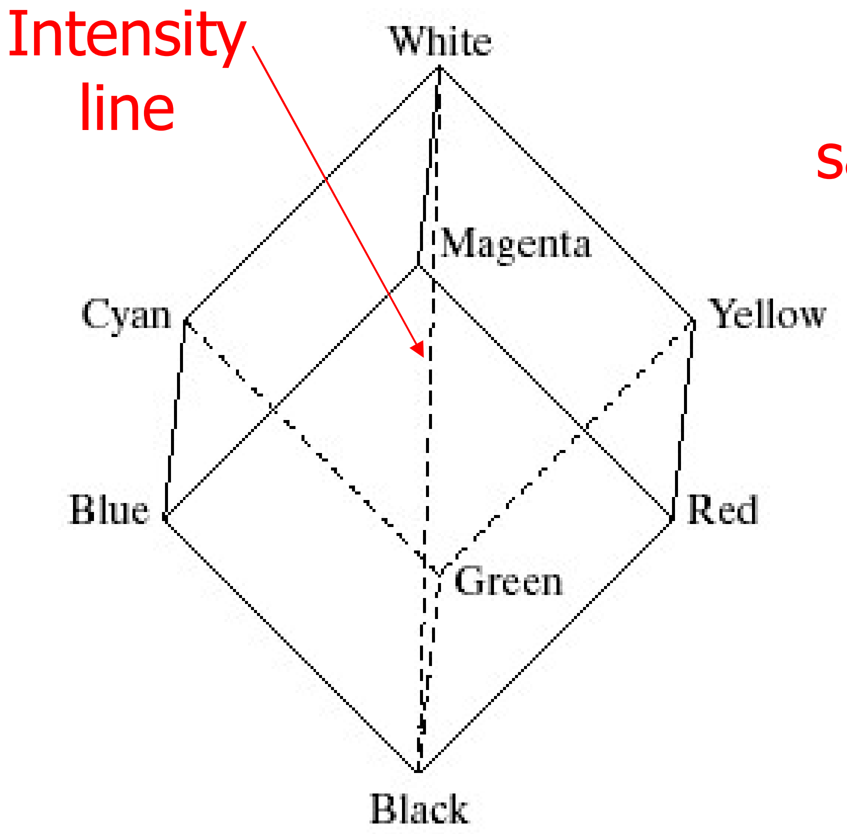


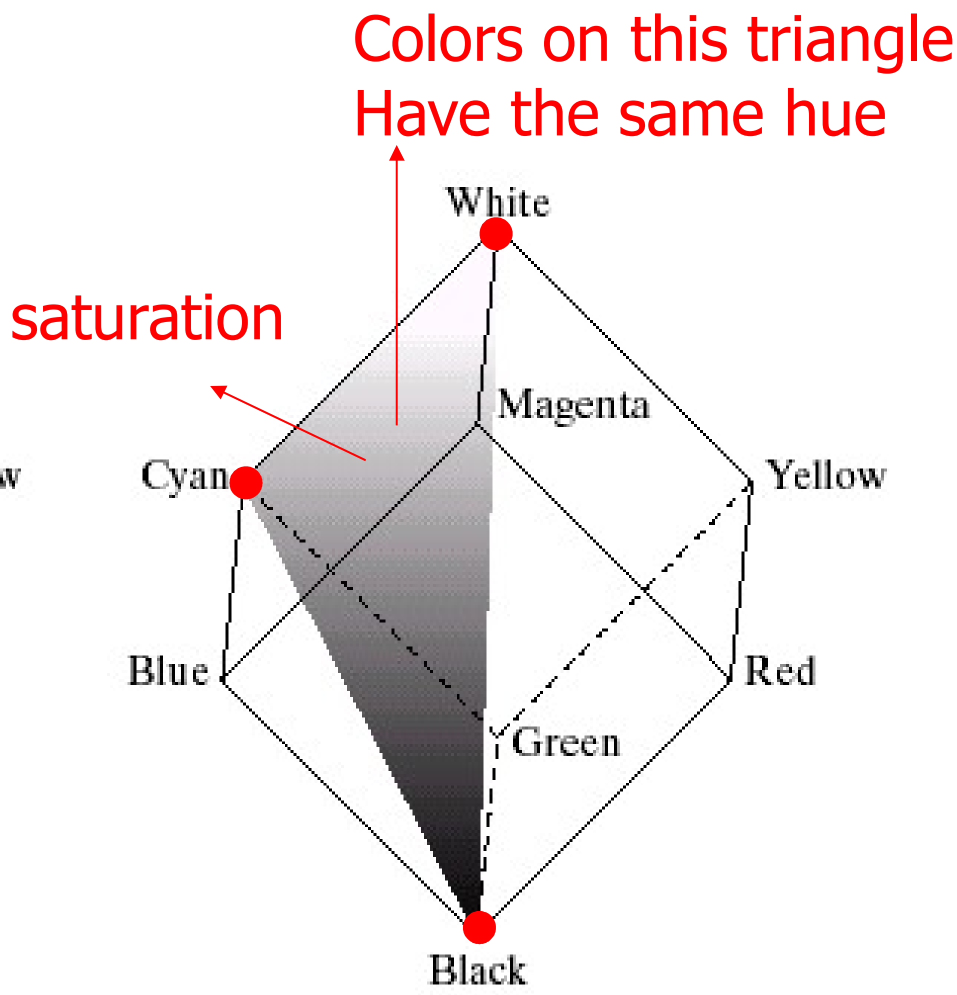
HSI color model

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

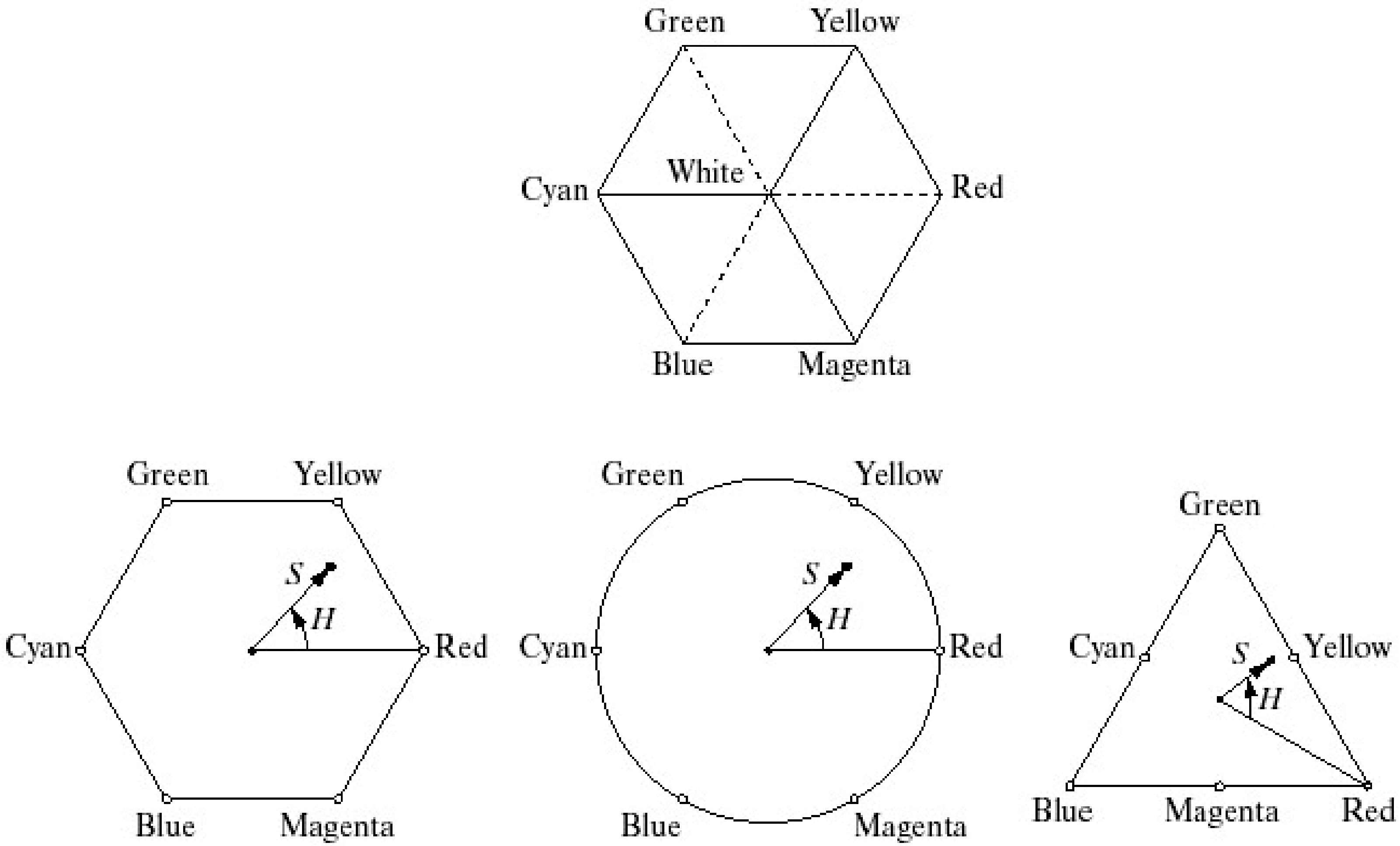
HSI color model

- RGB -> HSI model





HSI color model



HSI color model

RGB to HSV

Map R, G, B value range to 0~1

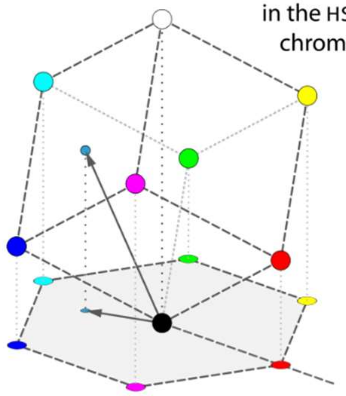
R '= *R* / 255
G '= *G* / 255
B '= *B* / 255

Cmax = max(*R* ', *G* ', *B* ')
Cmin = min(*R* ', *G* ', *B* ')
Δ = *Cmax* - *Cmin*

$$H = \begin{cases} 0^\circ & \Delta = 0 \\ 60^\circ \times \left(\frac{G'-B'}{\Delta} mod6\right) & , C_{max} = R' \\ 60^\circ \times \left(\frac{B'-R'}{\Delta} + 2\right) & , C_{max} = G' \\ 60^\circ \times \left(\frac{R'-G'}{\Delta} + 4\right) & , C_{max} = B' \end{cases}$$

$$S = \begin{cases} 0 & , C_{max} = 0 \\ \frac{\Delta}{C_{max}} & , C_{max} \neq 0 \end{cases}$$

V = *Cmax*

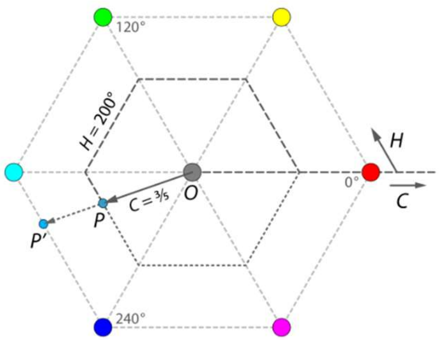


$$R = \frac{1}{5}, G = \frac{3}{5}, B = \frac{4}{5}$$

$$\Delta = Cmax - Cmin = \frac{4}{5} - \frac{1}{5} = 0.6$$

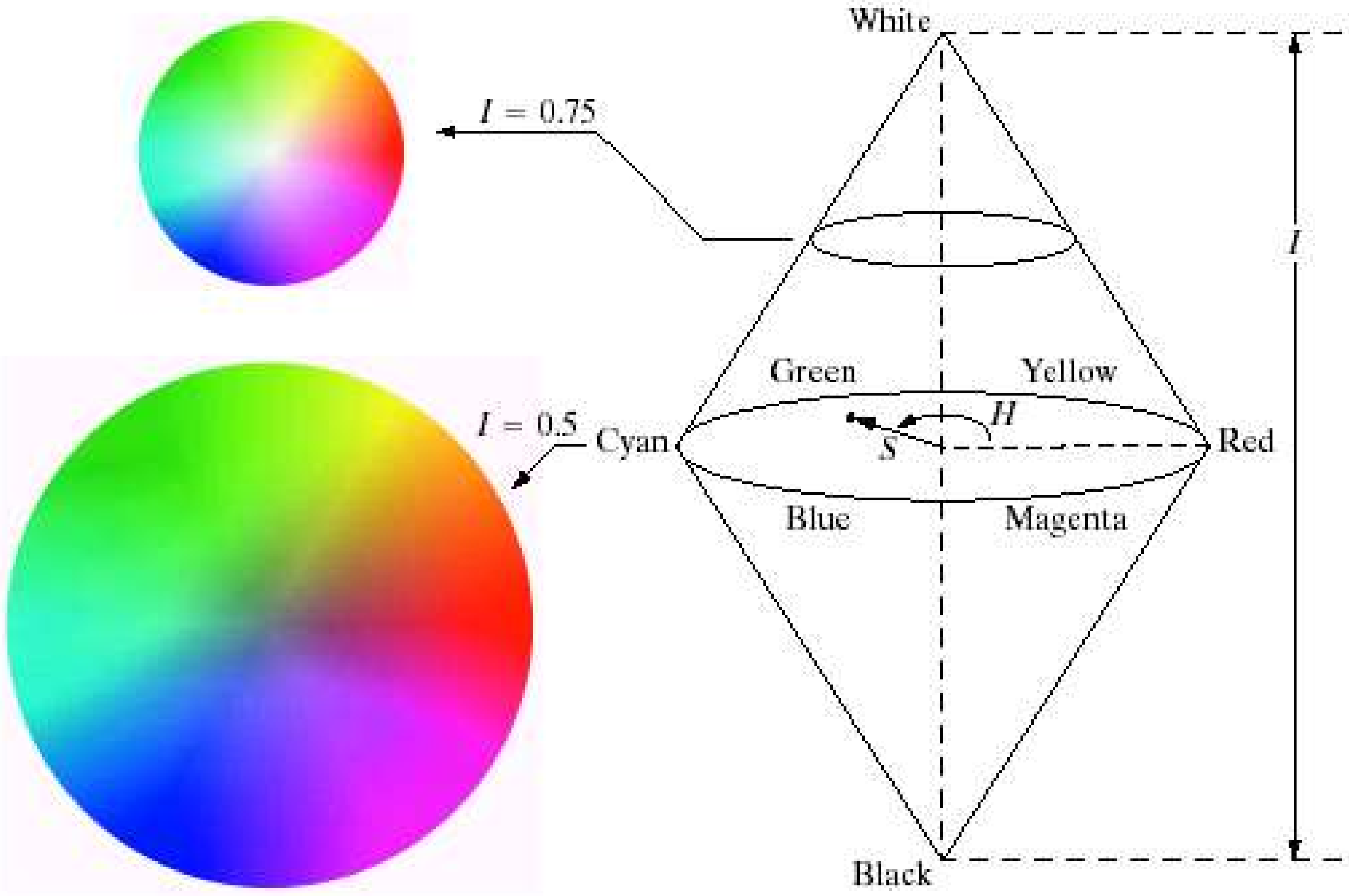
$$H = 60^\circ \times \left(4 + \frac{R-G}{\Delta}\right) = 60^\circ \times \left(4 + \frac{2}{3}\right)$$

$$= 200^\circ$$



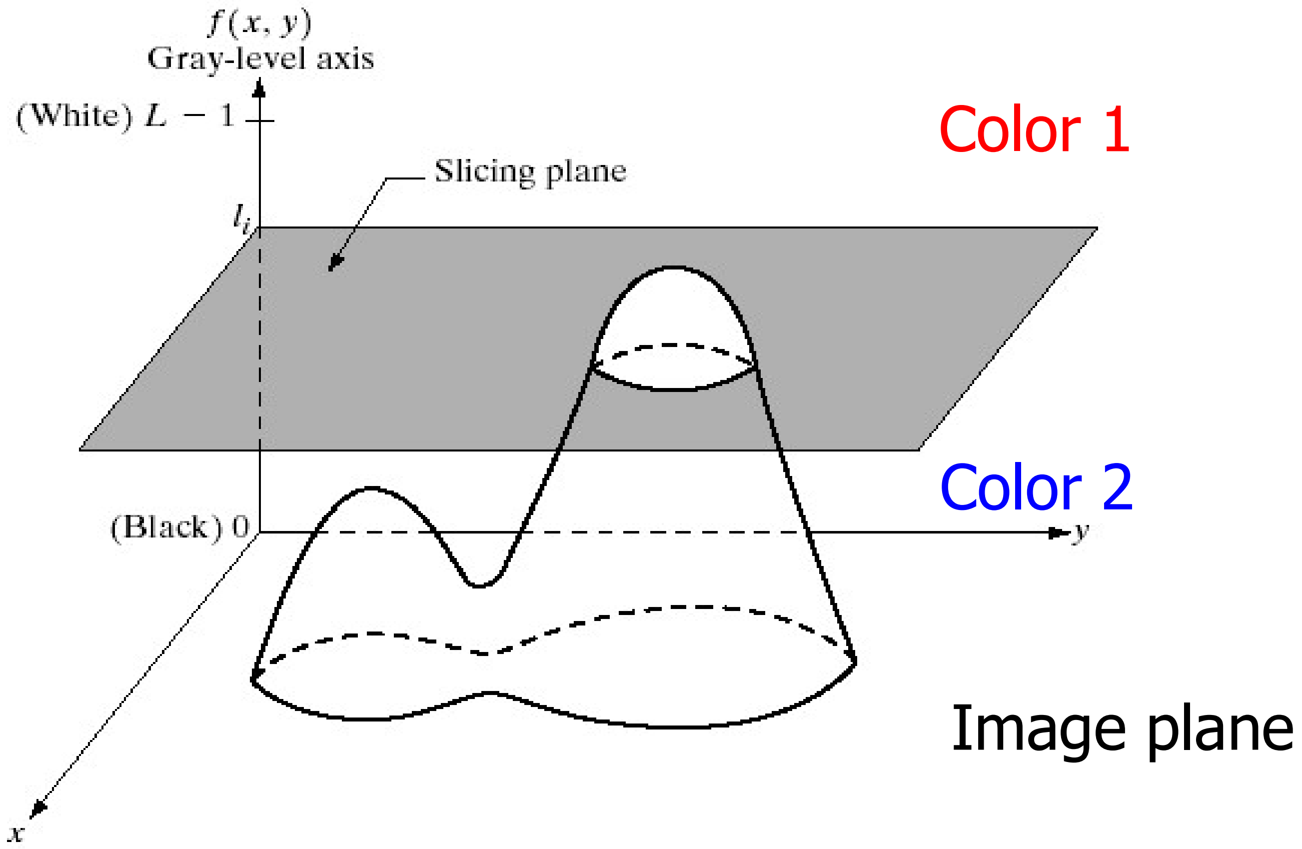
color	Color name	Hexadecimal	(R, G, B)	(H, S, V)
	Black	# 000000	(0,0,0)	(0 °, 0 %, 0 %)
	White	#FFFFFF	(255,255,255)	(0 °, 0 %, 100 %)
	Red	# FF0000	(255,0,0)	(0 °, 100 %, 100 %)
	Lime	# 00FF00	(0,255,0)	(120 °, 100 %, 100 %)
	Blue	# 0000FF	(0,0,255)	(240 °, 100 %, 100 %)
	Yellow	# FFFF00	(255,255,0)	(60 °, 100 %, 100 %)
	Turquoise (청록색)	# 00FFFF	(0,255,255)	(180 °, 100 %, 100 %)
	Magenta	# FF00FF	(255,0,255)	(300 °, 100 %, 100 %)
	Silver	#BFBFBF	(191,191,191)	(0 °, 0 %, 75 %)
	Gray	# 808080	(128,128,128)	(0 °, 0 %, 50 %)
	Maroon (적갈색)	# 800000	(128,0,0)	(0 °, 100 %, 50 %)
	Olive	# 808000	(128,128,0)	(60 °, 100 %, 50 %)
	Green	# 008000	(0,128,0)	(120 °, 100 %, 50 %)
	Violet	# 800080	(128,0,128)	(300 °, 100 %, 50 %)
	Teal (물오리)	# 008080	(0,128,128)	(180 °, 100 %, 50 %)
	Navy	# 000080	(0,0,128)	(240 °, 100 %, 50 %)

HSI color model

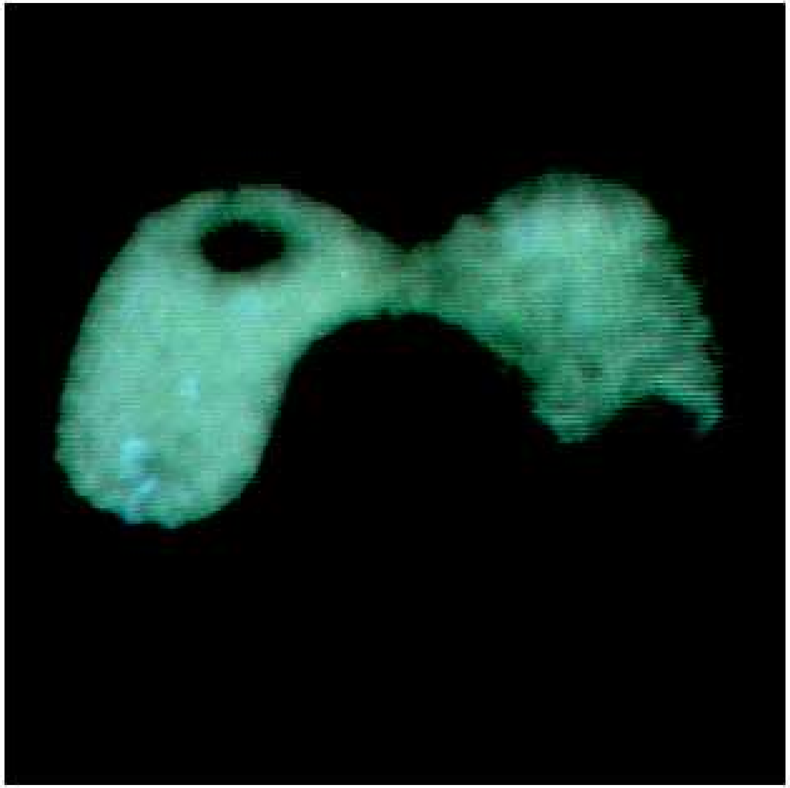


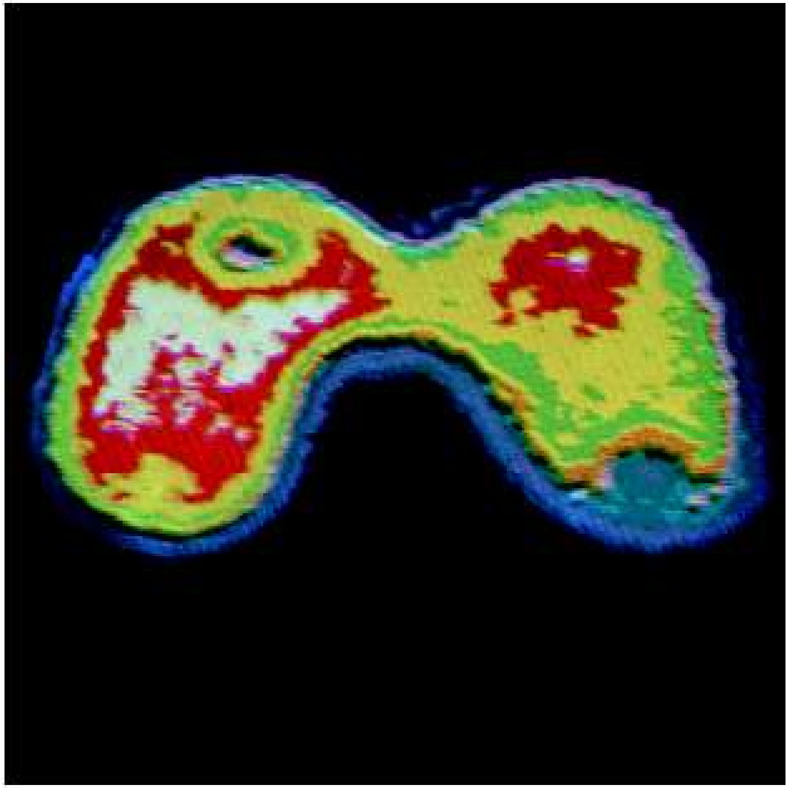
Intensity slicing

- 3-D view of intensity image



Intensity slicing

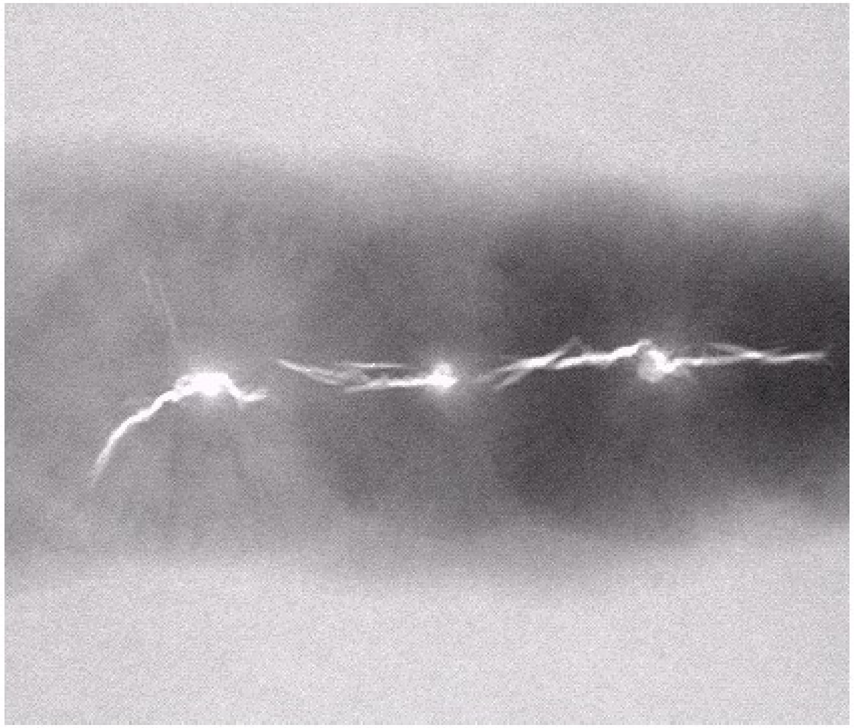




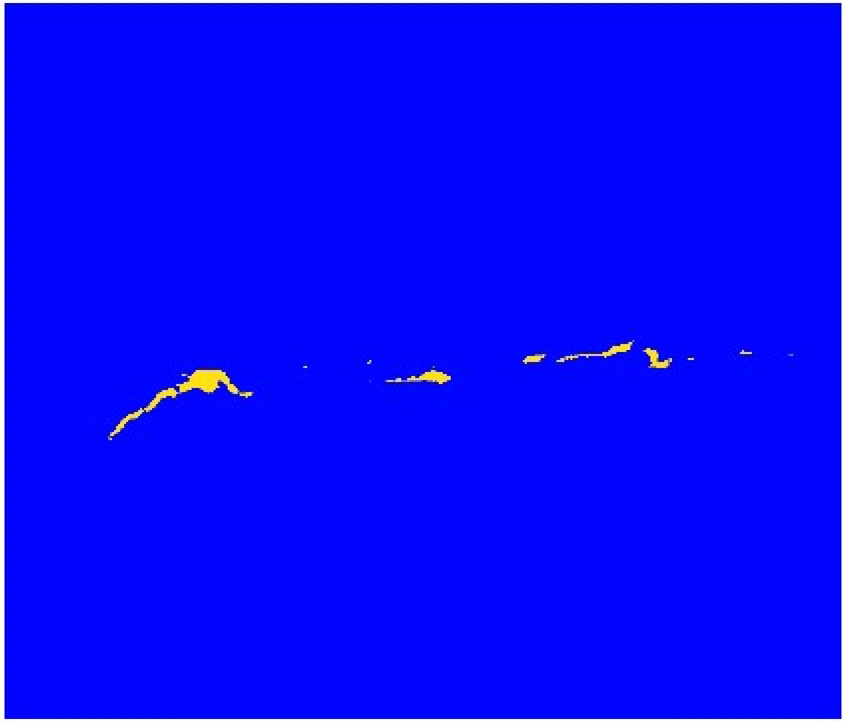
Radiation test pattern

8 color regions

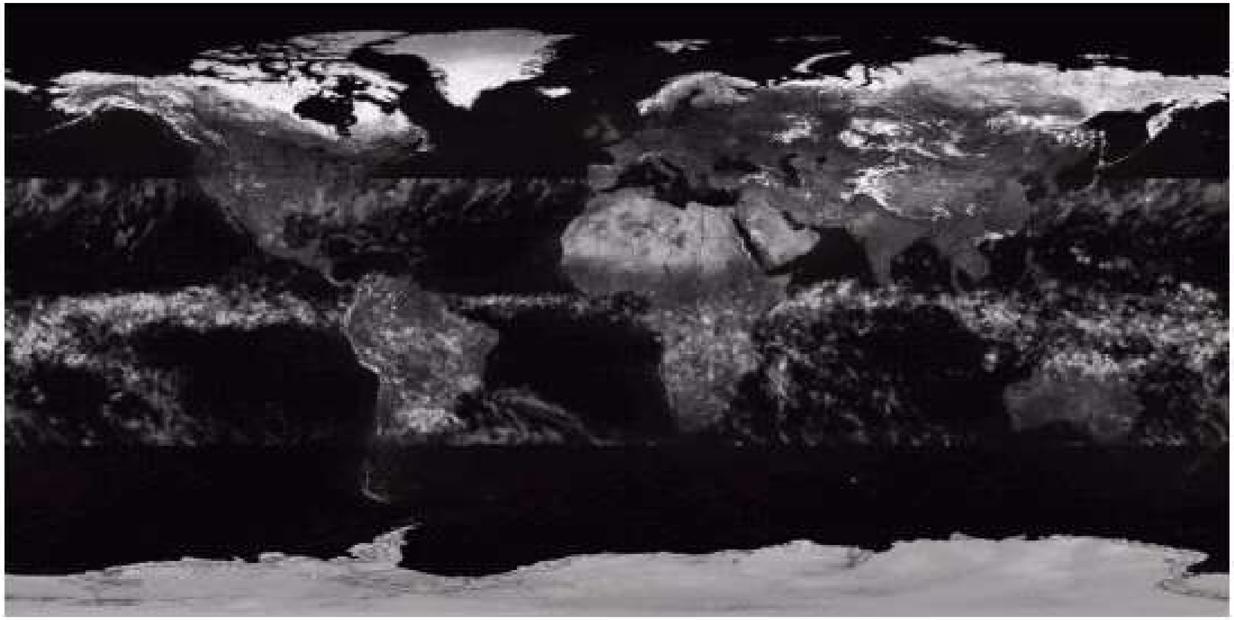
Intensity slicing



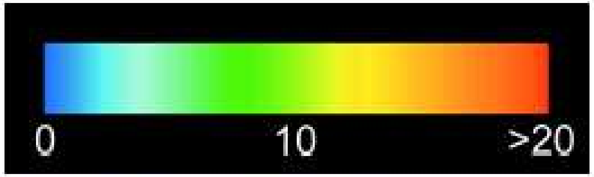
X-ray image of a weld

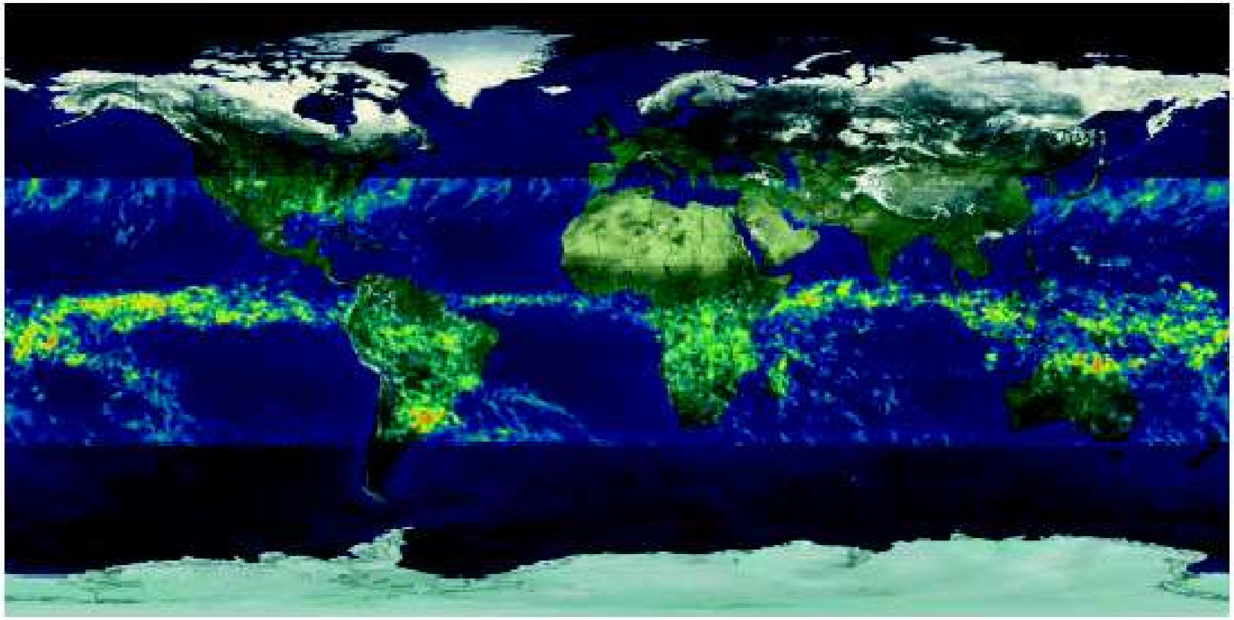


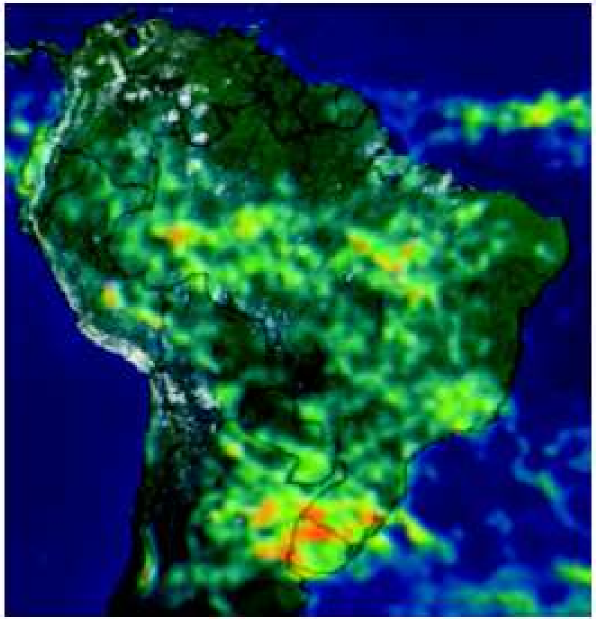
Intensity slicing



Rainfall statistics

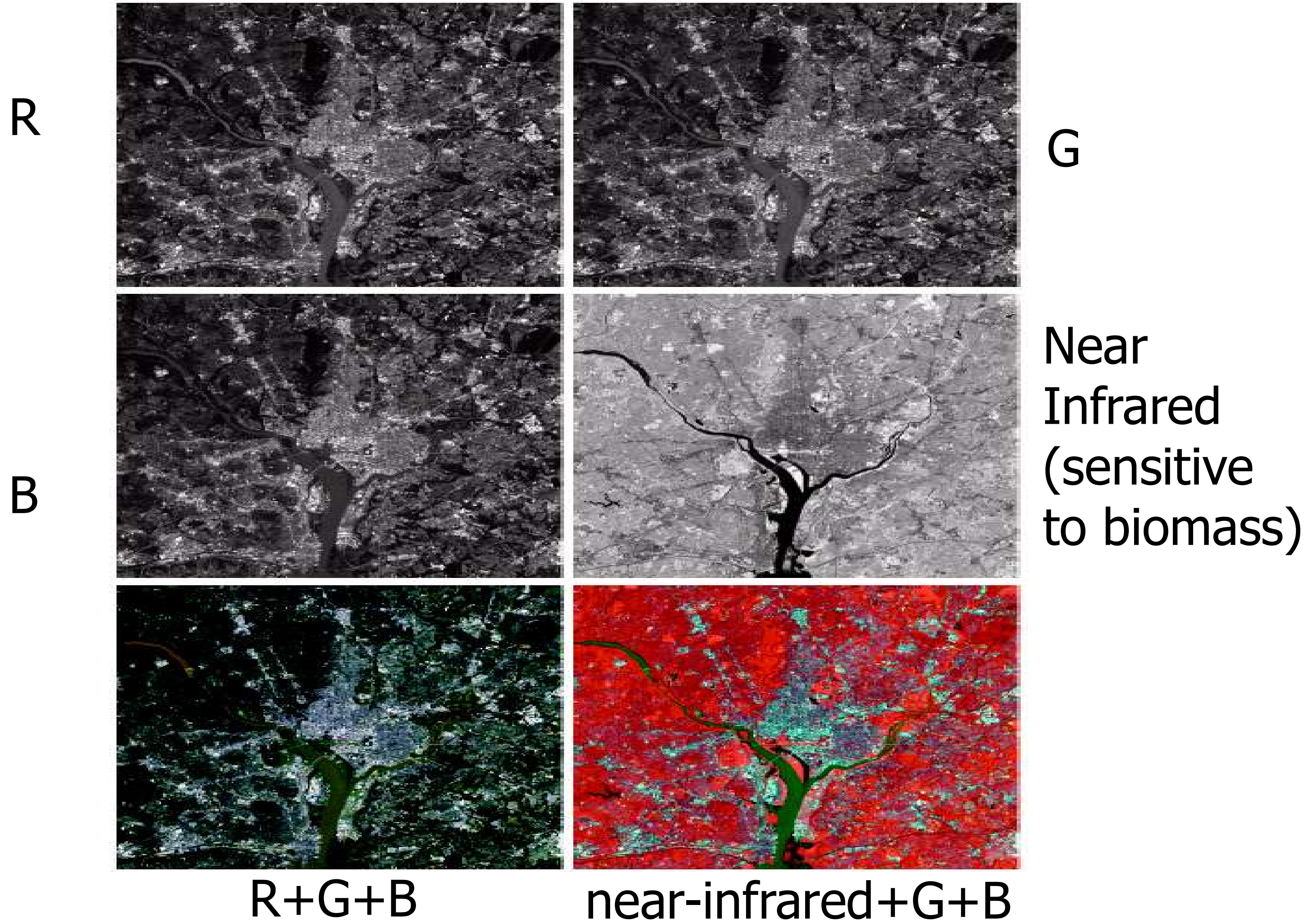






Combine several monochrome images

- Example: multi-spectral images



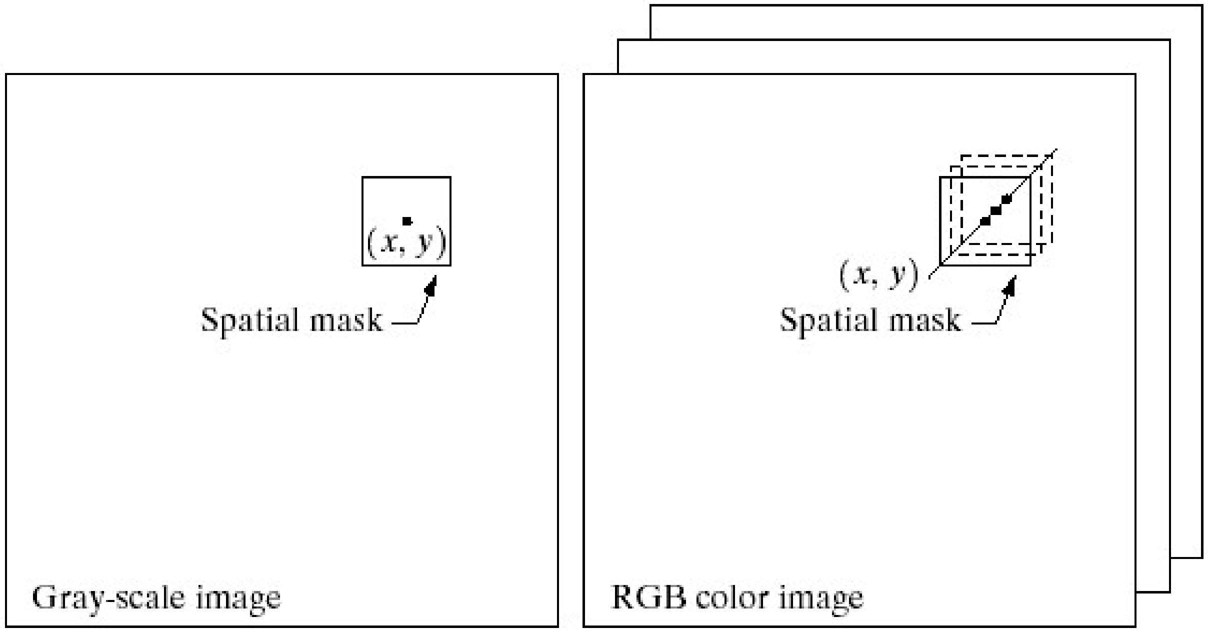
Color pixel

- 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)



How to deal with color vector?

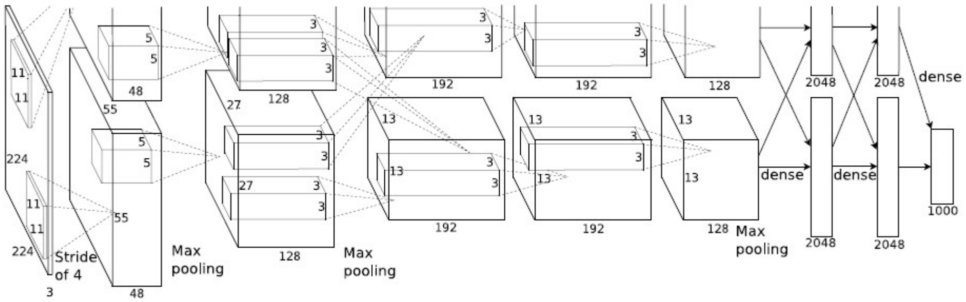
- Per-color-component processing
  - Process each color component
- Vector-based processing
  - Process the color vector of each pixel
- When can the above methods be equivalent?
  - Process can be applied to both scalars and vectors
  - Operation on each component of a vector must be independent of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

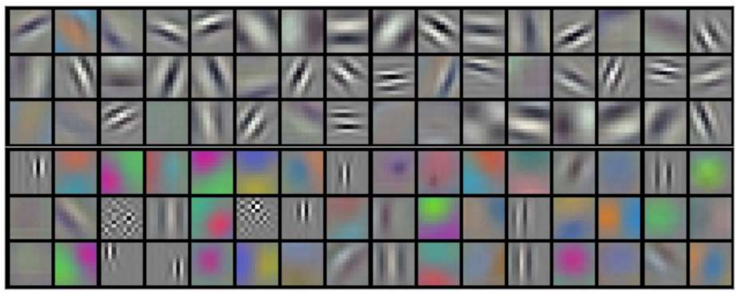
Color models and Image Processing

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

Color models and Image Processing

- Image processing techniques typically used gray scale images
- Deep learning utilizes colors better





kernels