Essence of Image

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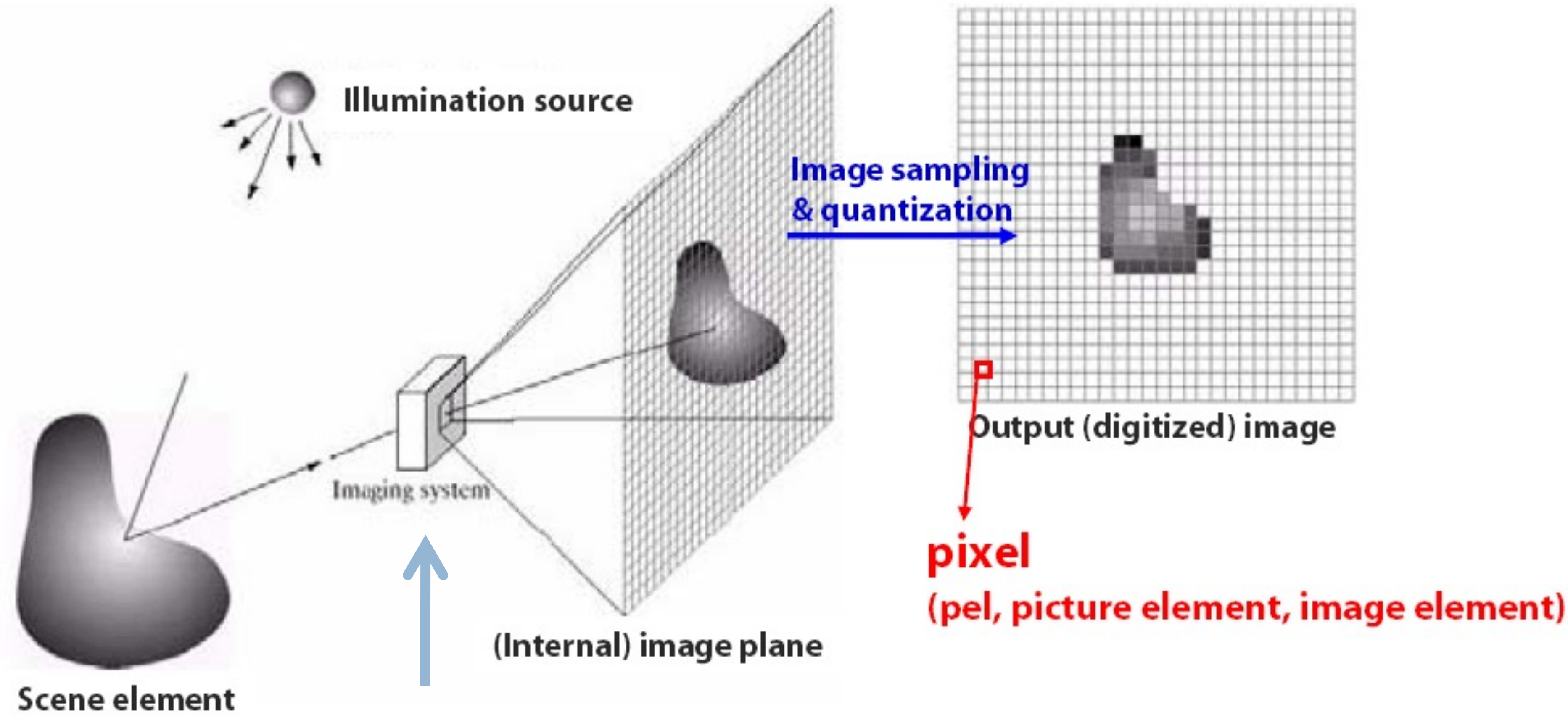
Chapters 2 and 6 of "Digital Image Processing" by R.C. Gonzalez and R.E. Woods, Prentice Hall, 2nd edition, 2001

Image Sensing and Acquisition



Collect the incoming energy and focus it onto an image plane.

A Simple Image Formation Model

- Denote an image by a 2D function

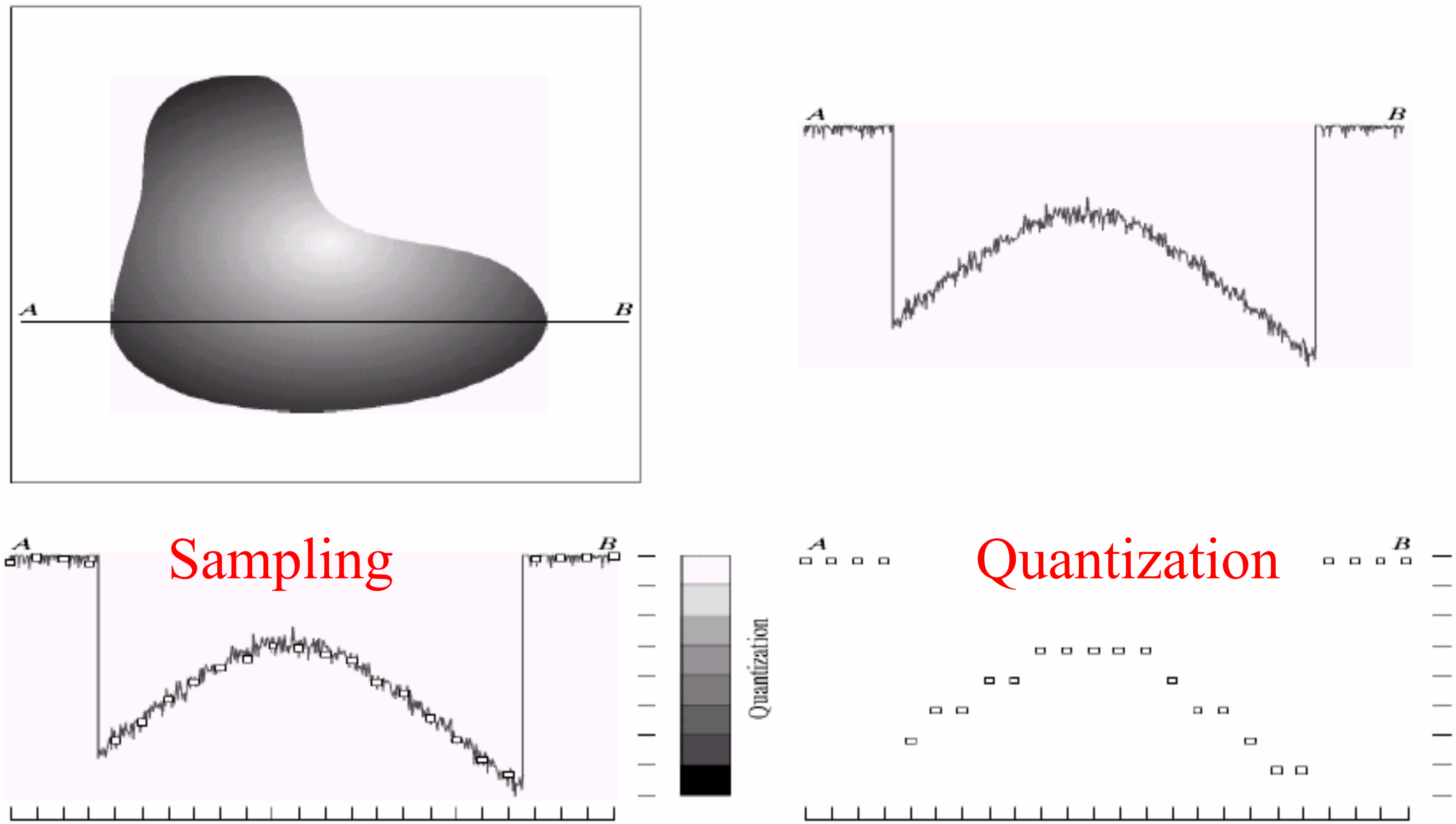
$$0 < f(x, y) < \infty$$

- Characterized by two components:

$$f(x, y) = i(x, y)r(x, y)$$

  - Illumination: $0 < i(x, y) < \infty$, determined by the illumination source
  - Reflectance: $0 < r(x, y) < 1$, determined by the characteristics of the imaged objects.

Image Sampling and Quantization

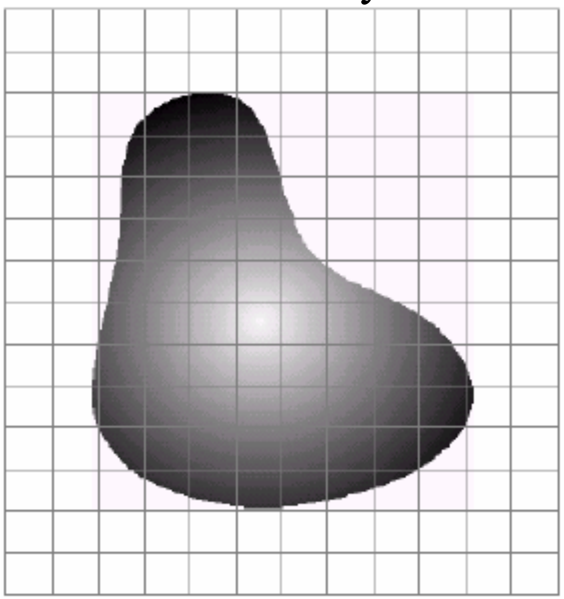


Digitizing the coordinate values

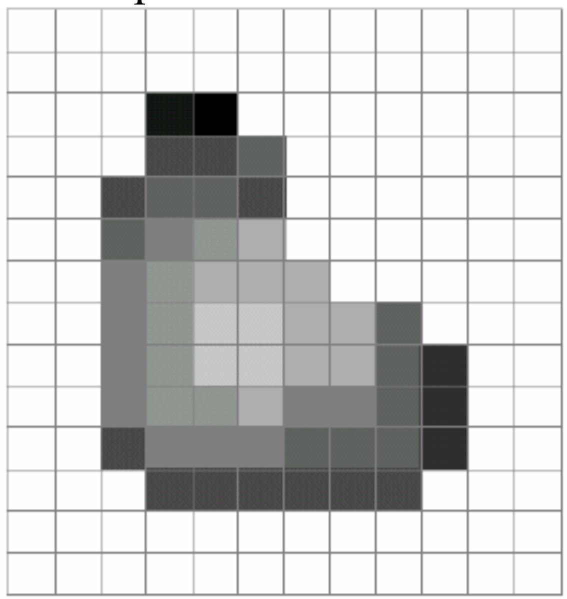
Digitizing the amplitude values

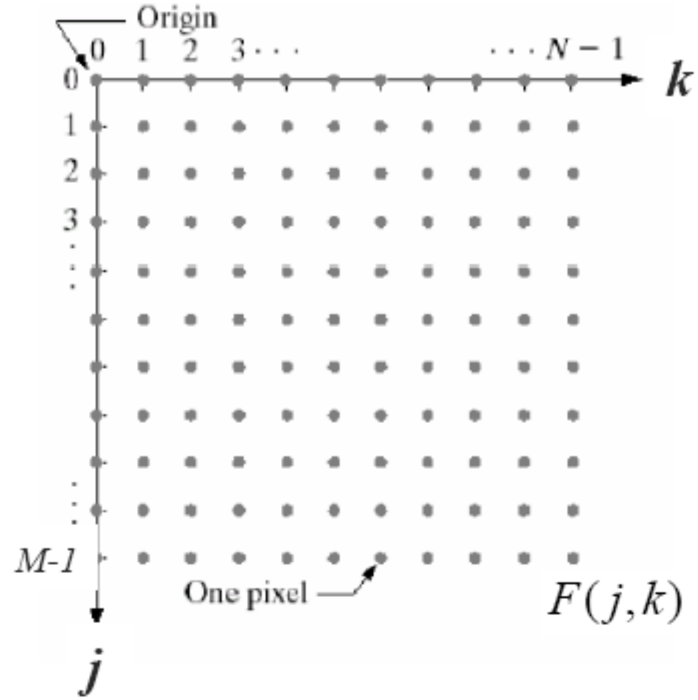
Image Sampling and Quantization

Continuous image projected onto a sensor array



Results of image sampling and quantization





$$A = \begin{bmatrix} a_{0,0} & a_{0,1} & \cdots & a_{0,N-1} \\ a_{1,0} & a_{1,1} & \cdots & a_{1,N-1} \\ \vdots & \vdots & \ddots & \vdots \\ a_{M-1,0} & a_{M-1,1} & \cdots & a_{M-1,N-1} \end{bmatrix}$$

$$F(j,k) = \begin{bmatrix} F(0,0) & F(0,1) & \cdots & F(0,N-1) \\ F(1,0) & F(1,1) & \cdots & F(1,N-1) \\ \vdots & \vdots & \ddots & \vdots \\ F(M-1,0) & F(M-1,1) & \cdots & F(M-1,N-1) \end{bmatrix}$$

Histogram

- The histogram of an image with gray level in the range [0, *L*-1] is a discrete function

$$h(r_k) = n_k$$

r_k is the kth gray level and n_k is the number of pixels in the image having gray level r_k

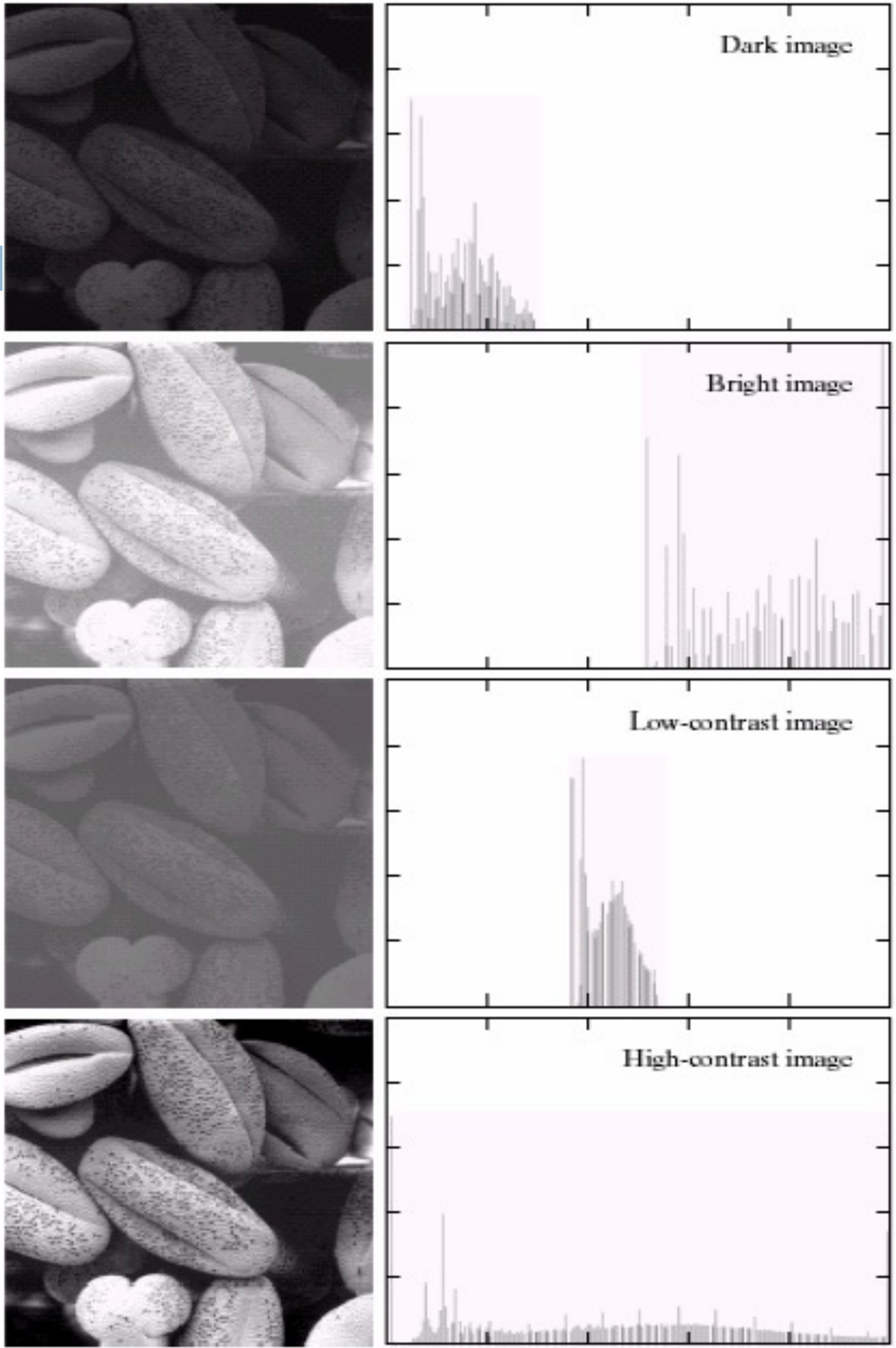
- Normalized histogram

$$p(r_k) = n_k/n$$

n is the total number of pixels in the image

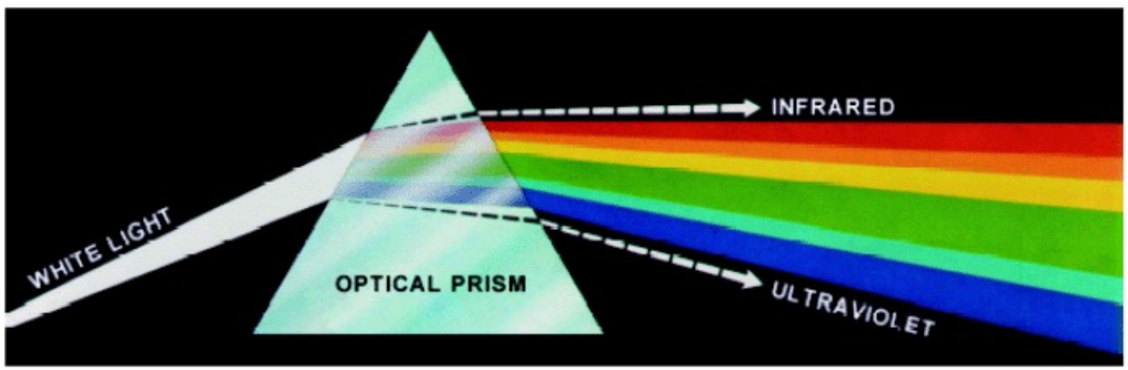
Histogram

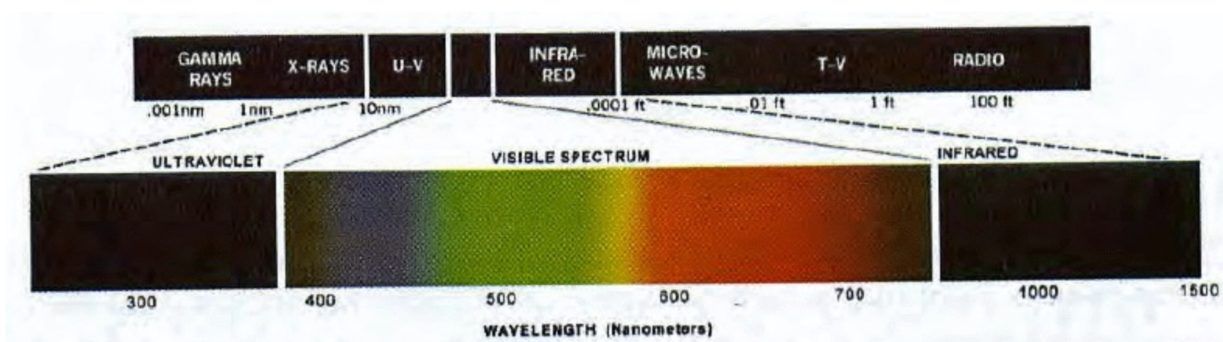
- Useful image statistics
- Image processing applications
  - Image enhancement
  - Image compression
  - Image segmentation



Color Fundamentals

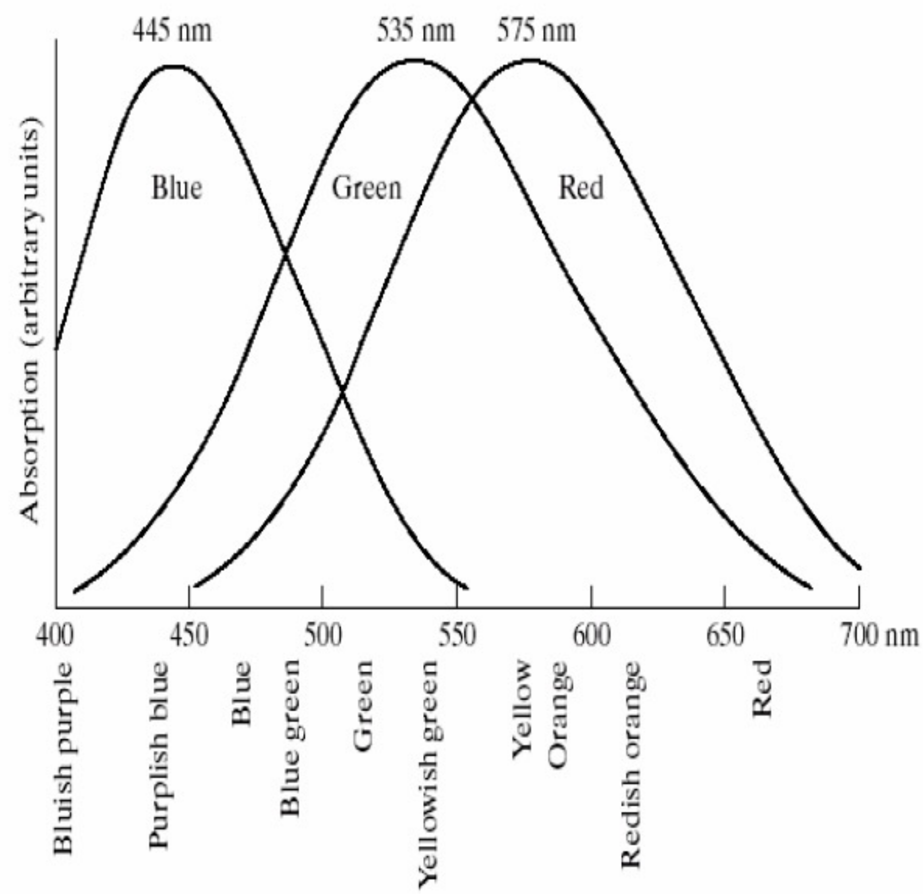
- Color spectrum: violet, blue, green, yellow, orange & red
- Each color in the spectrum blends smoothly into the next
- The color perceived in an object are determined by the nature of the light reflected from the object





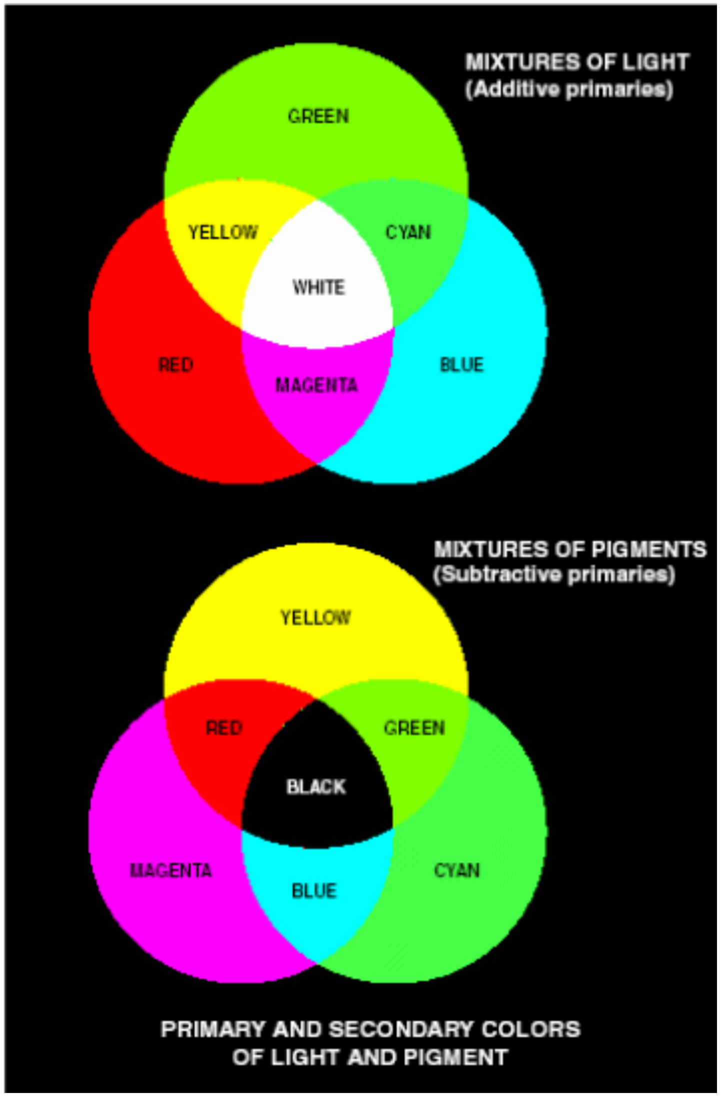
Color Fundamentals

- Cones can be divided into three principal sensing categories
- Due to the absorption of the human eyes, colors are seen as variable of three primary colors (red, green, blue)
- Approximately 65% of all cones are sensitive to red light, 33% to green light, 2% to blue light.



Color Fundamentals

- Secondary colors of light
  - Magenta (R + B)
  - Cyan (G + B)
  - Yellow (R + G)
- The primary color of pigments subtract a primary color of light and reflects the other two.



Color Fundamentals

- Brightness
  - Embodies the chromatic notion of intensity
- Hue
  - Attribute associated with the dominant wavelength in a mixture of light waves
  - Dominant color as perceived by an observer
- Saturation
  - The relative purity of the amount of white light mixed with a hue
  - Less saturated: e.g. pink (red+white), lavender (violet+white)
- Hue and saturation taken together as called chromaticity.

Specifying Colors

- The amounts of red, green, and blue needed to form any particular color are called the tristimulus values and are denoted X, Y, Z, respectively.
- A color is then specified by its trichromatic coefficients, defined as

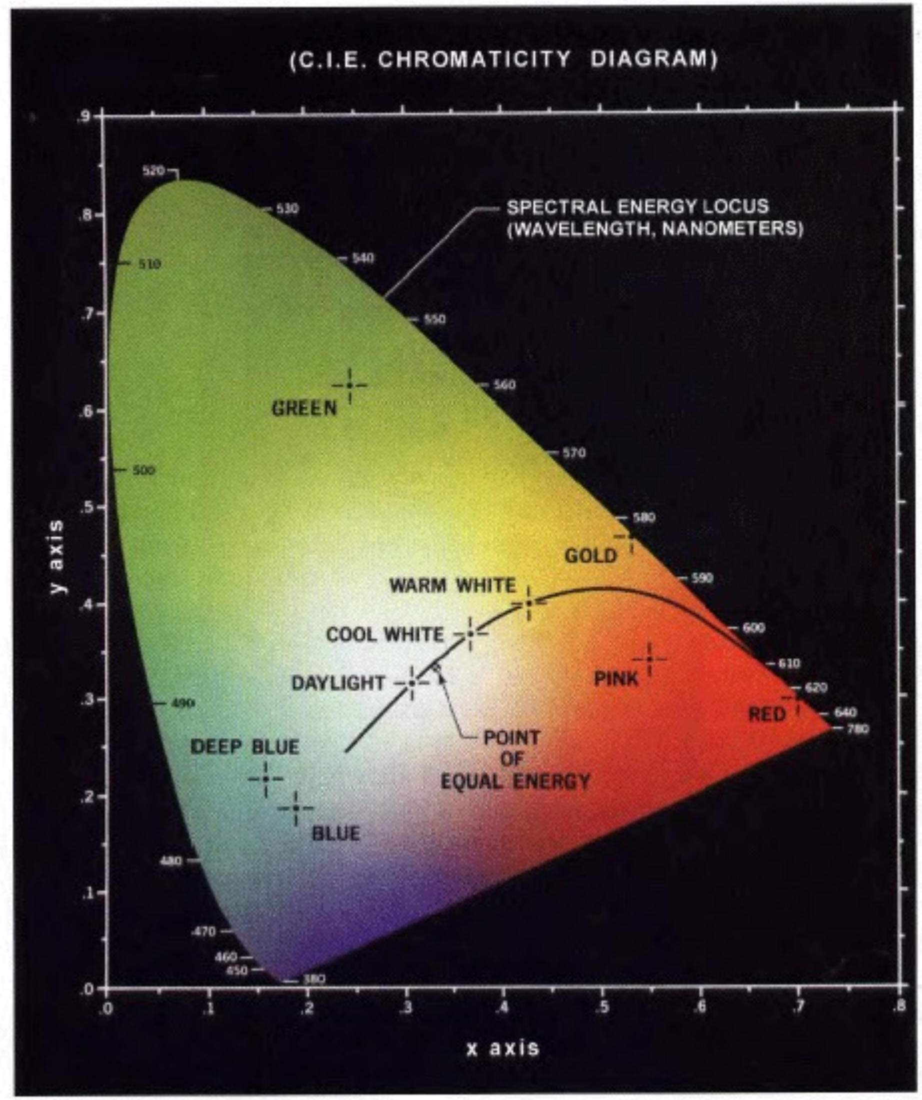
$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

- Using CIE chromaticity diagram, which shows color composition as a function of x (red) and y(green)

Specifying Colors

- The point marked green has approximately 63% green and 25% red content. The composition of blue is approximately 13%.

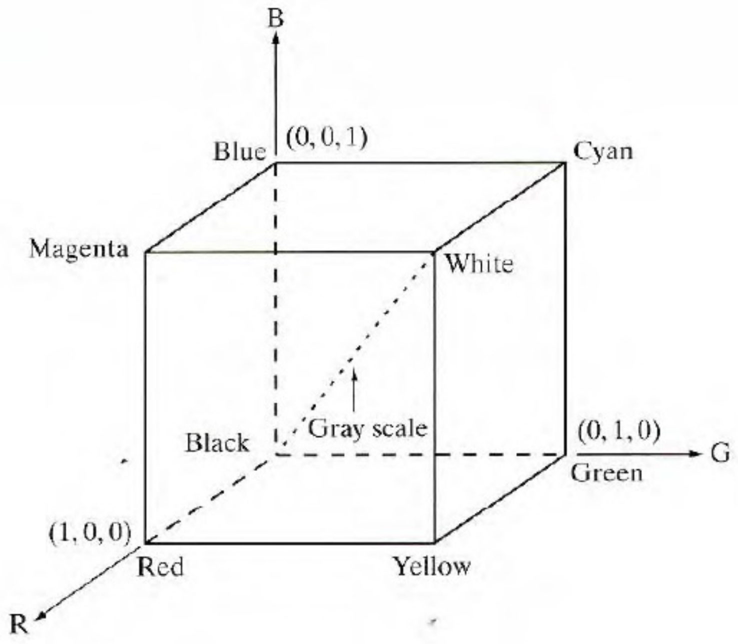


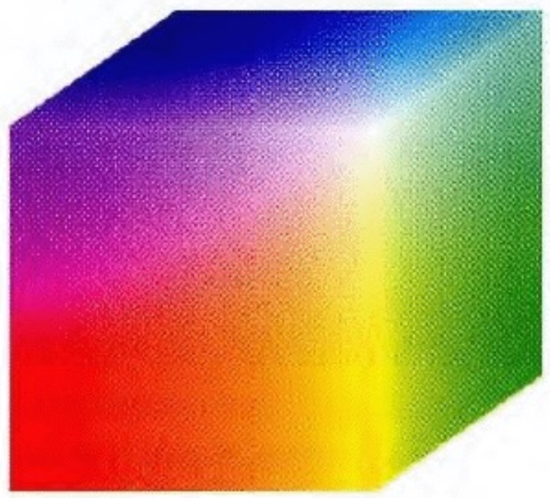
Color Models (Color Spaces)

- A color model is a specification of a coordinate system and a subspace within that system where each color is represented by a single point.
- Hardware-oriented & application-oriented
  - RGB – color monitor, color video cameras
  - CMY (cyan, magenta, yellow) – color printing
  - CMYK (cyan, magenta, yellow, black) – color printing
  - HSI (hue, saturation, intensity) – closely matching with human perception

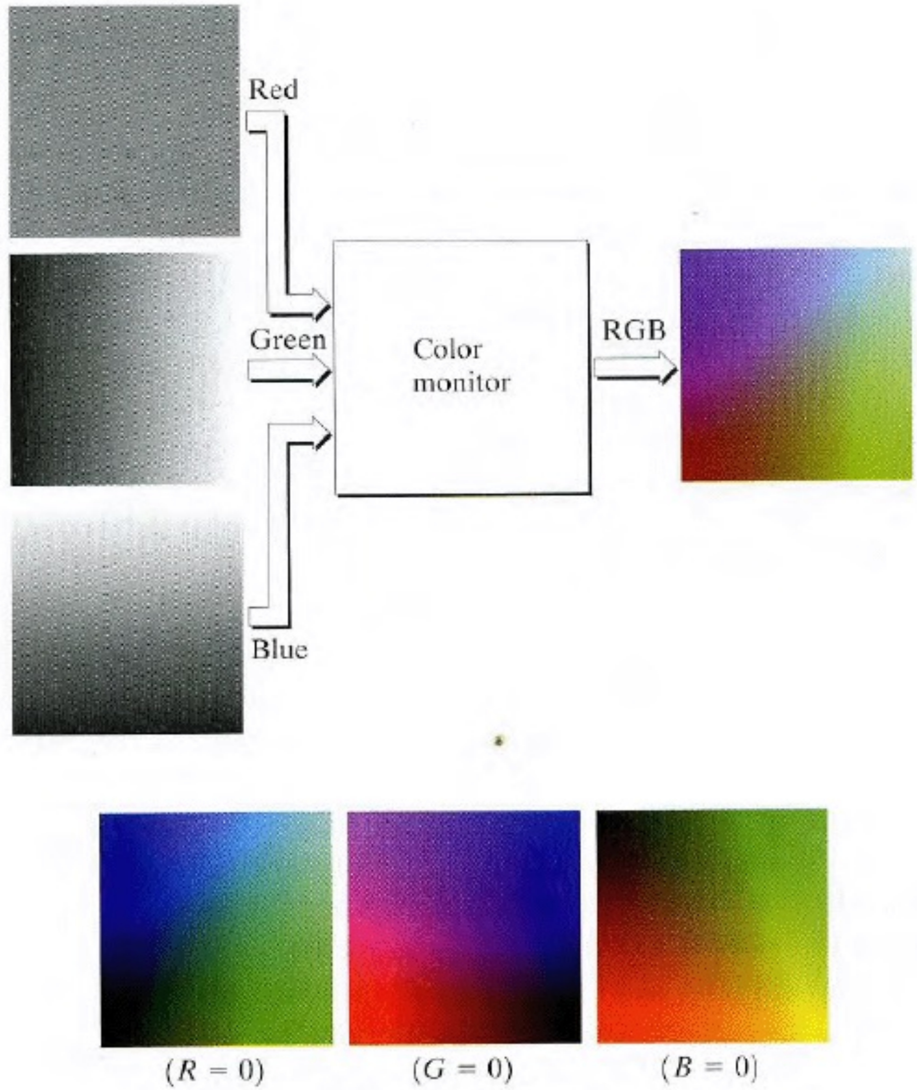
The RGB Color Model

- Based on Cartesian coordinate system
- Different colors are points on or inside the cube
- Full color image: 8 bits for each component, total 24 bits





The RGB Color Model



a
b

FIGURE 6.9 (a) Generating the RGB image of the cross-sectional color plane $(127, G, B)$. (b) The three hidden surface planes in the color cube of Fig. 6.8.

The CMY and CMYK Color Models

- When a surface coated with cyan pigment is illuminated with white light, no red light is reflected from the surface.
  - Cyan subtracts red light
- Most devices that deposit colored pigments on paper require CMY data input or perform RGB to CMY conversion.
- Equal amounts of CMY pigments should produce black.

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

The HSI Color Model

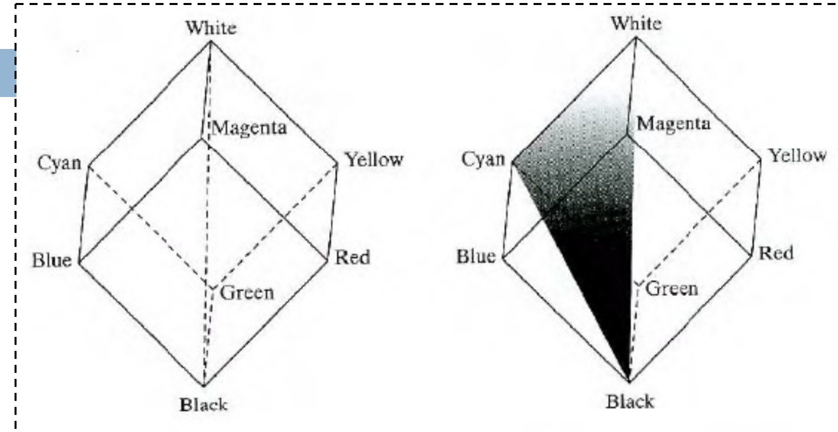
- RGB/CMY color systems are suited for hardware implementations.
- RGB system matches nicely with the fact that the human eye is strongly perceptive to red, green, and blue primaries.
- But RGB and CMY are not well suited for *describing* colors for human interpretation.

The HSI Color Model

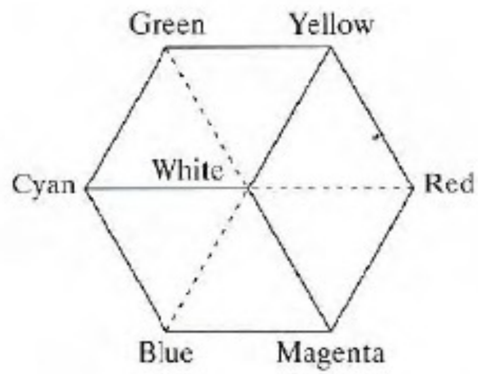
- We describe a color object by its hue, saturation, and brightness.
  - Hue: color attribute that describes a pure color
  - Saturation: degree of pure color diluted by white light
  - Brightness: measured by intensity
- HSI color model decouples the intensity component from the color-carrying information

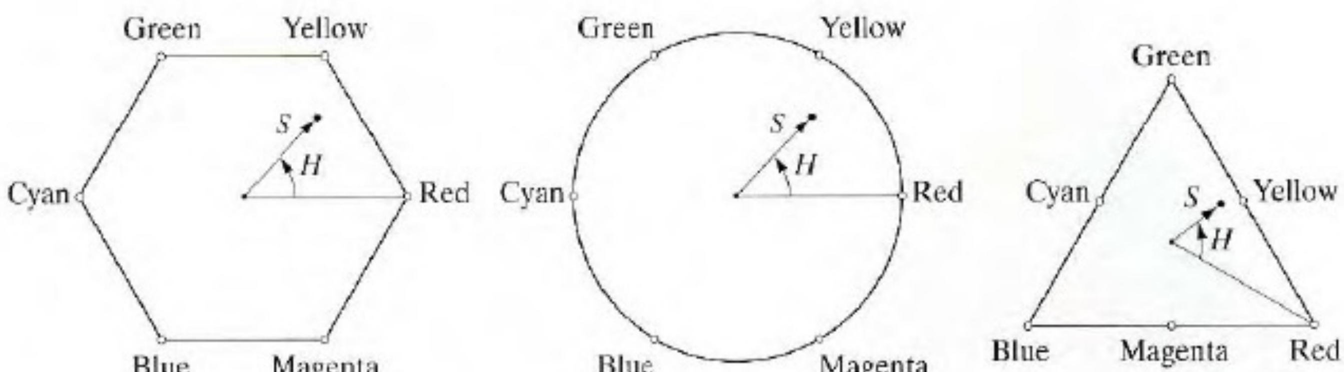
The HSI Color Model

- Take the RGB cube, stand on the black vertex, with the white vertex above it.



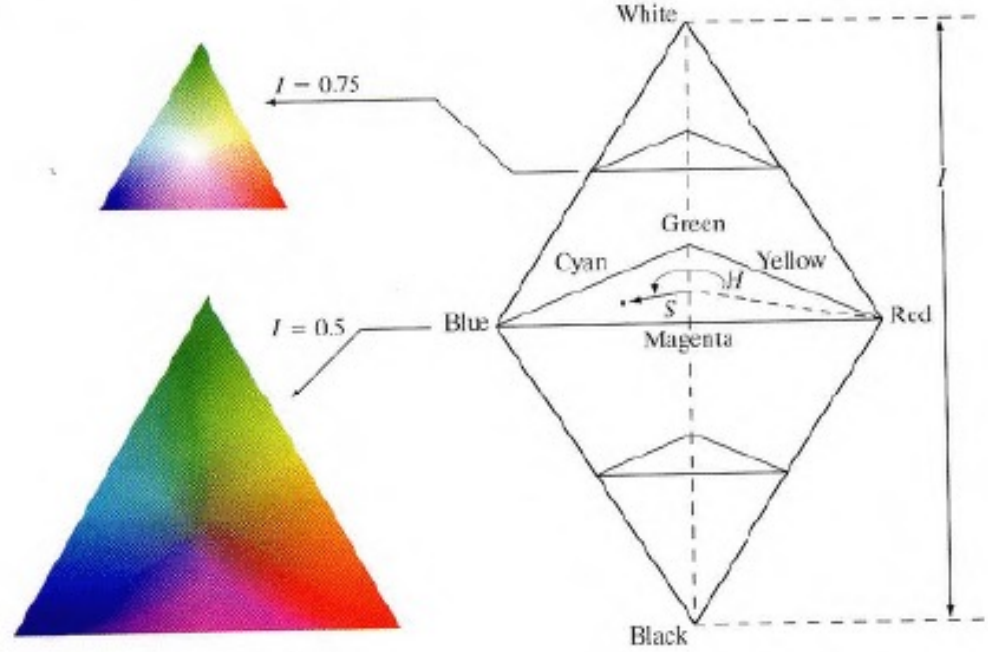
The intensity (gray scale) is along the line joining these two vertices.

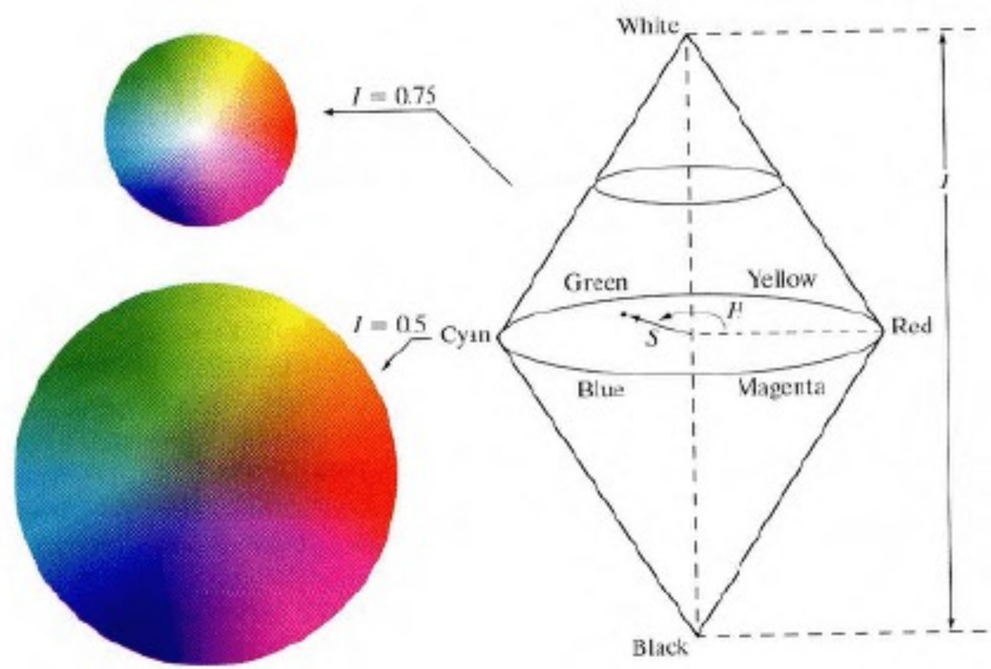




HSI

- HSI is also known as HSL, HLS
- HSV color space





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

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases} \qquad (6.2\text{-}2)$$

with

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

The saturation component is given by

$$S = 1 - \frac{3}{(R + G + B)}[\min(R, G, B)]. \qquad (6.2\text{-}3)$$

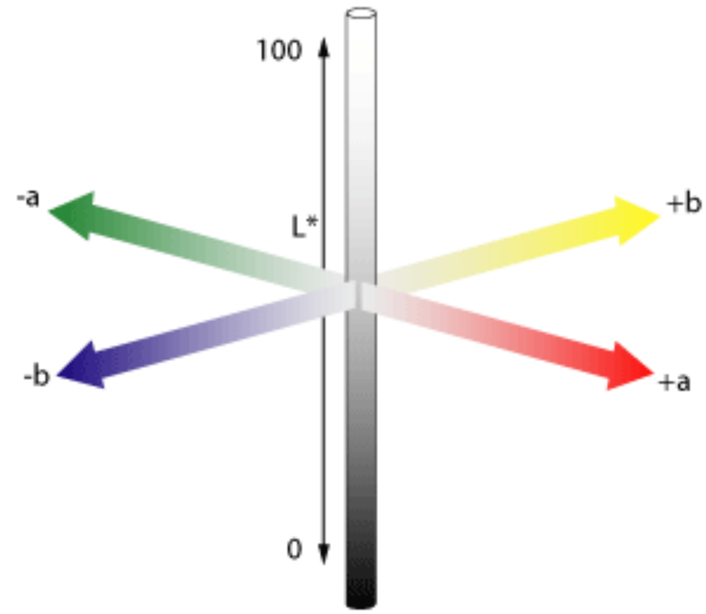
Finally, the intensity component is given by

$$I = \frac{1}{3}(R + G + B). \qquad (6.2\text{-}4)$$

RGB values have been normalized to the range [0,1]
The angle θ is measured with respect to the red axis of the HSI space.

The LAB (CIELAB) Color Models

- CIELAB ($L^*a^*b^*$) color space
  - L^*: lightness dimension
  - a^*,b^*: two chromatic dimensions that are roughly red-green and blue-yellow.
  - $L^*a^*b^*$ color is designed to approximate human vision



http://en.wikipedia.org/wiki/Lab_color_space
http://coatings.specialchem.com.cn/tc/color/index.aspx?id=cielab

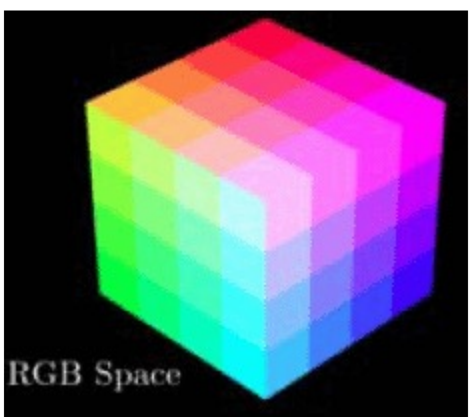
Other Color Models

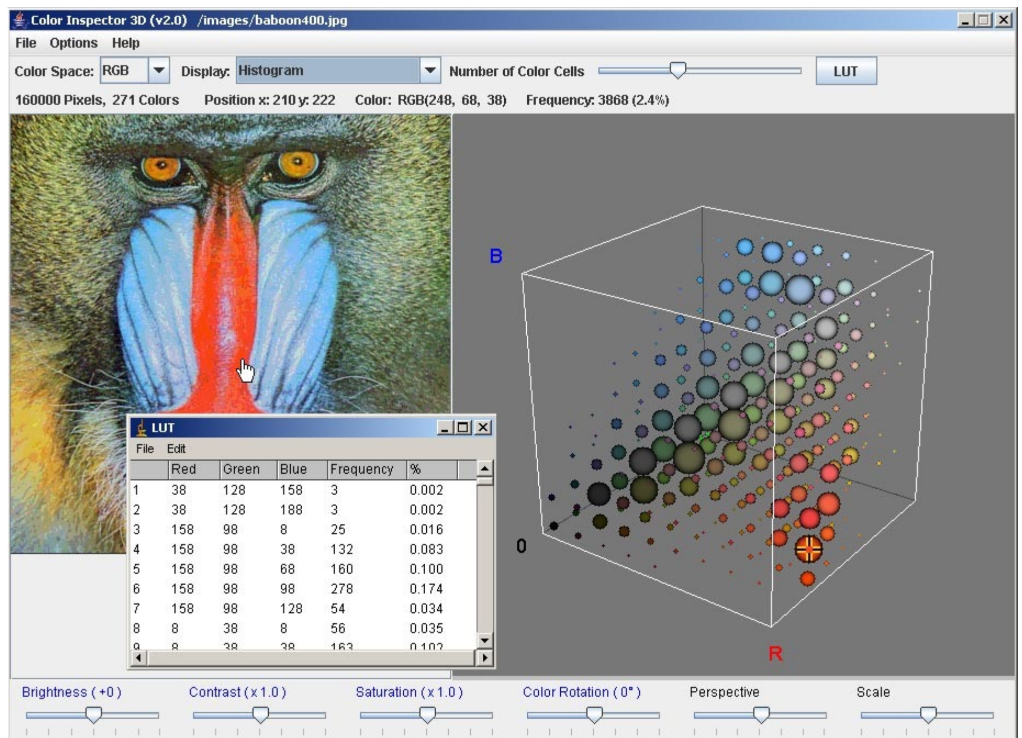
- YUV, YIQ, YCbCr color spaces
  - YCbCr is widely used in video/image compression schemes such as MPEG and JPEG
- Please refer to
  - http://en.wikipedia.org/wiki/Color_space

Color Histogram

- A representation of the distribution of colors in an image.
- Discretize colors into a number of bins, and counting the number of pixels with colors in each bin.

		red			
		0-63	64-127	128-191	192-255
blue	0-63	43	78	18	0
	64-127	45	67	33	2
	128-191	127	58	25	8
	192-255	140	47	47	13





http://rsb.info.nih.gov/ij/plugins/color-inspector.html

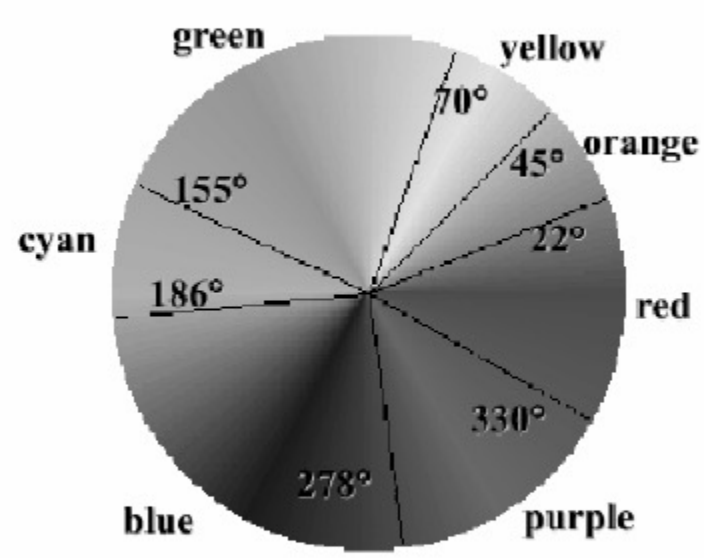
Nonuniform Quantization

- An example in HLS (HSI) space
  - Considering human perception

NUMBER OF QUANTIZATION LEVELS FOR EACH COMPONENT IN THE THREE SUBREGIONS

Regions / # of colors	*Achromatic*			*Low chromatic*			*High Chromatic*		
	H	*L*	*S*	*H*	*L*	*S*	*H*	*L*	*S*
32	1	4	1	7	3	1	7	1	1

Lee, et al. "Spatial color descriptor for image retrieval and Video summarization", IEEE Trans. on Multimedia, 2003.



Characteristics of Histogram

- The color histogram of an image represents the global statistics (color distribution) of pixels' colors
- Histogram is one of the most useful feature to describe images or be the basis for similarity measure

Histogram-based Difference

- Bin-wise histogram difference between Image I_1 and I_2

$$D_j(I_1, I_2) = \sum_{i=1}^{B} |H_j^1(i) - H_j^2(i)|$$

$$D(I_1, I_2) = w_1 D_1 + w_2 D_2 + w_3 D_3$$

Short Introduction to Image Features

- Color features
  - Color histogram
  - Color moments
  - Color coherence vectors (CCV)
  - Color correlogram

Ma, et al. “Benchmarking image features content-based image retrieval”, Record of the 32nd Asilomar Conf. on Signals, Systems & Computers, vol 1., 1998.

Short Introduction to Image Features

- Texture features
  - Tamura features (coarseness, directionality, contrast)
  - Multi-resolution simultaneous auto-regressive model
  - Canny edge histogram
  - Gabor texture feature
  - Pyramid-structured wavelet transform (PWT) feature
  - Tree-structured transform (TWT) feature

Ma, et al. “Benchmarking image features content-based image retrieval”, Record of the 32nd Asilomar Conf. on Signals, Systems & Computers, vol 1., 1998.