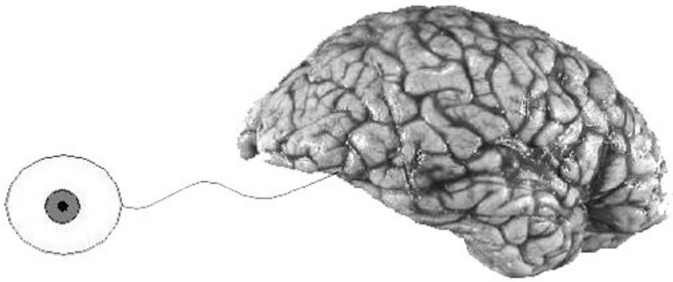
CHAPTER 1

VISUAL PERCEPTION AND IMAGE REPRESENTATION

Visual Perception

- The Human Visual System (HVS)
  - Vision is our most powerful sense
  - Enables us to gather information and learn through observation
  - Allows to interact with the environment without any physical contact
  - HVS consists of two primary components
    - The eye (receiving sensor)
    - The brain (processor)
      Both are connected by the optic nerve

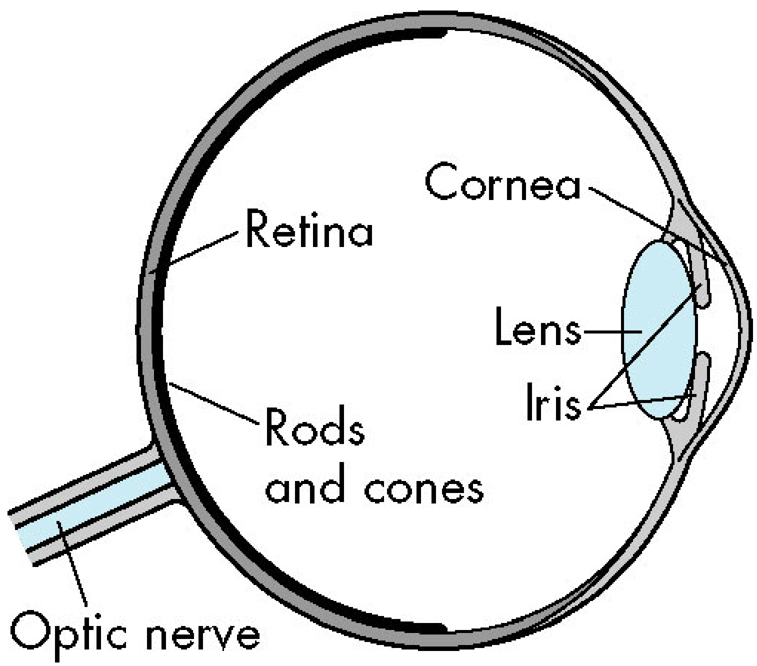


Visual Perception

How are images converted into information by the viewer?

- Understanding visual perception helps designing image processing algorithms.
- Image data represents physical quantities, e.g. chromaticity and luminance.
- Chromaticity: color quality of light defined by its wavelength.
- Luminance: amount of light

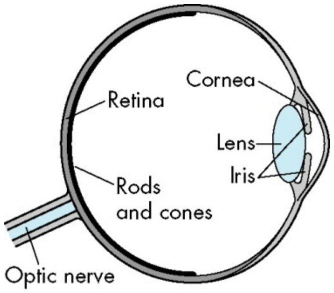
125 million rods
7 million cones



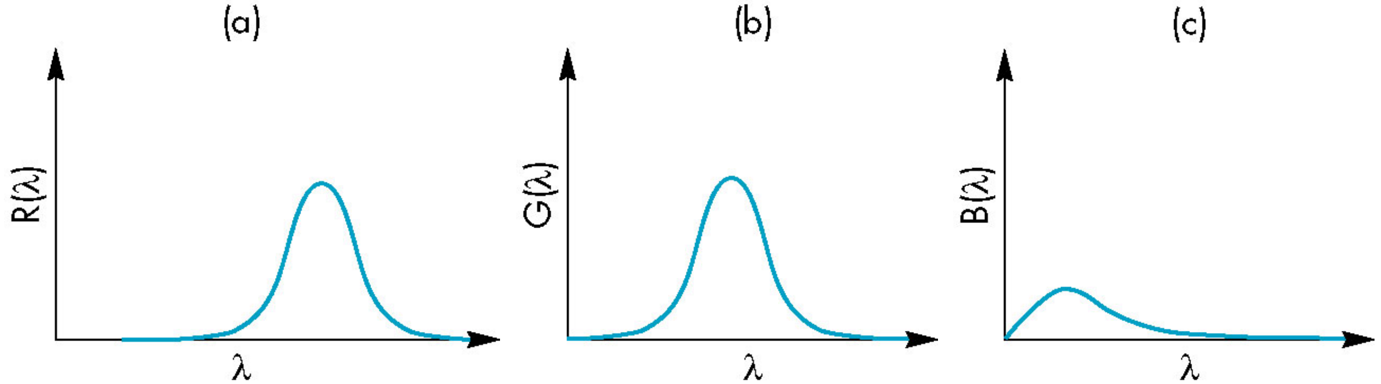
Cross section of working eyeball

Visual Perception

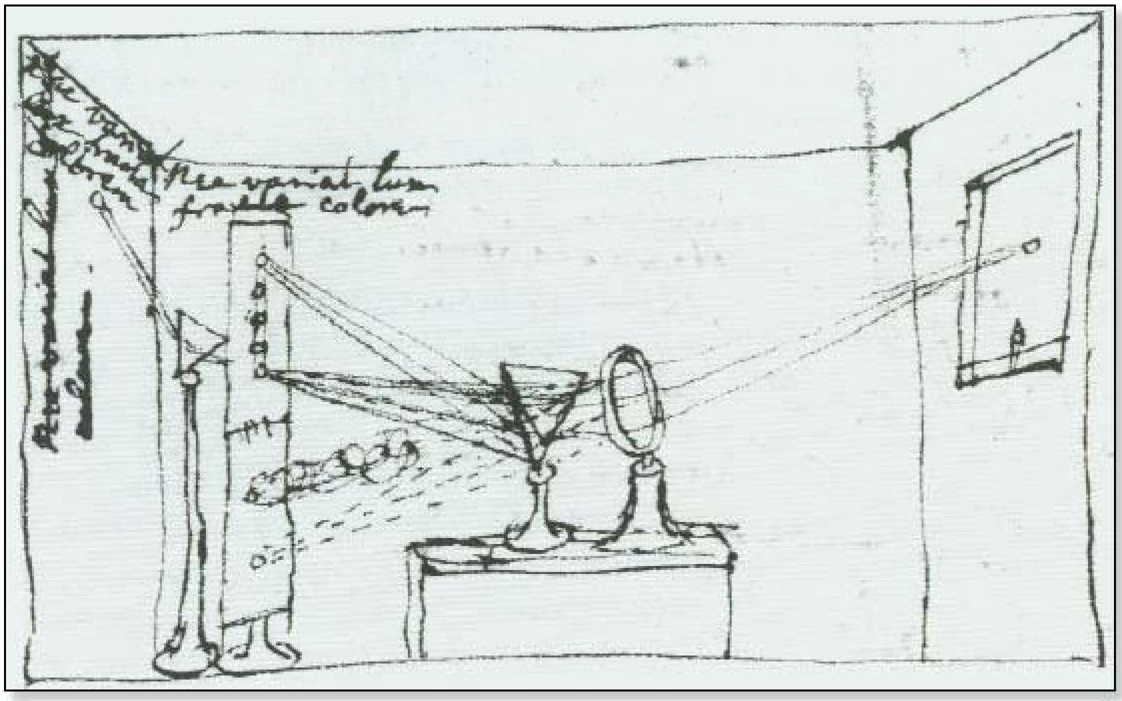
- Rods
  - Intensity only
  - Essentially night vision and peripheral vision only

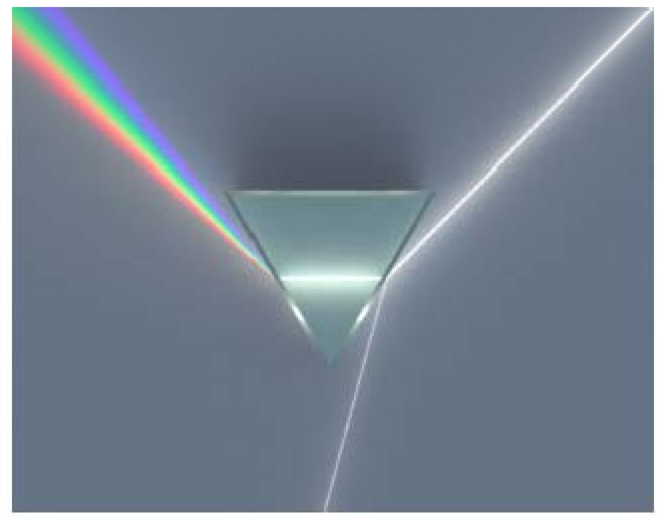


- Cones
  - Concentrated in the center of the retina in an area called the fovea.
  - Detect color and fine detail
  - Three types perceive different portions of the visible light spectrum

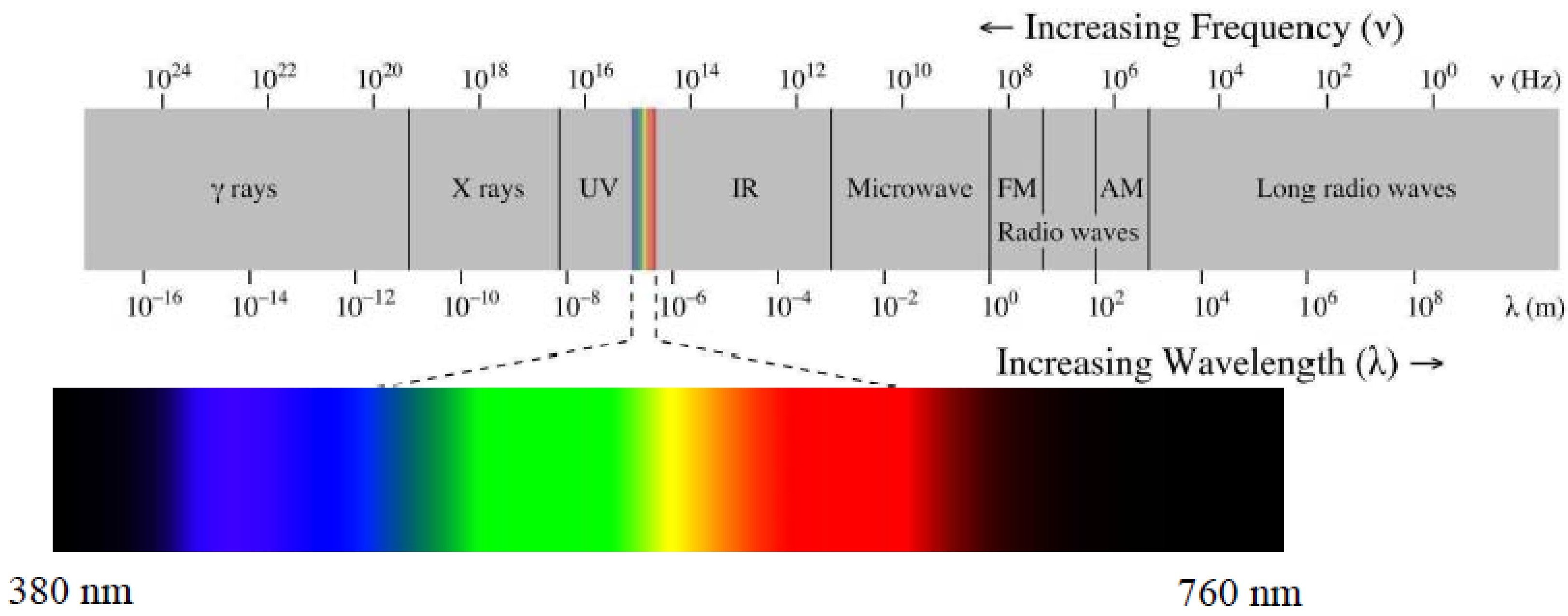


Newton's Prism Experiment - 1666

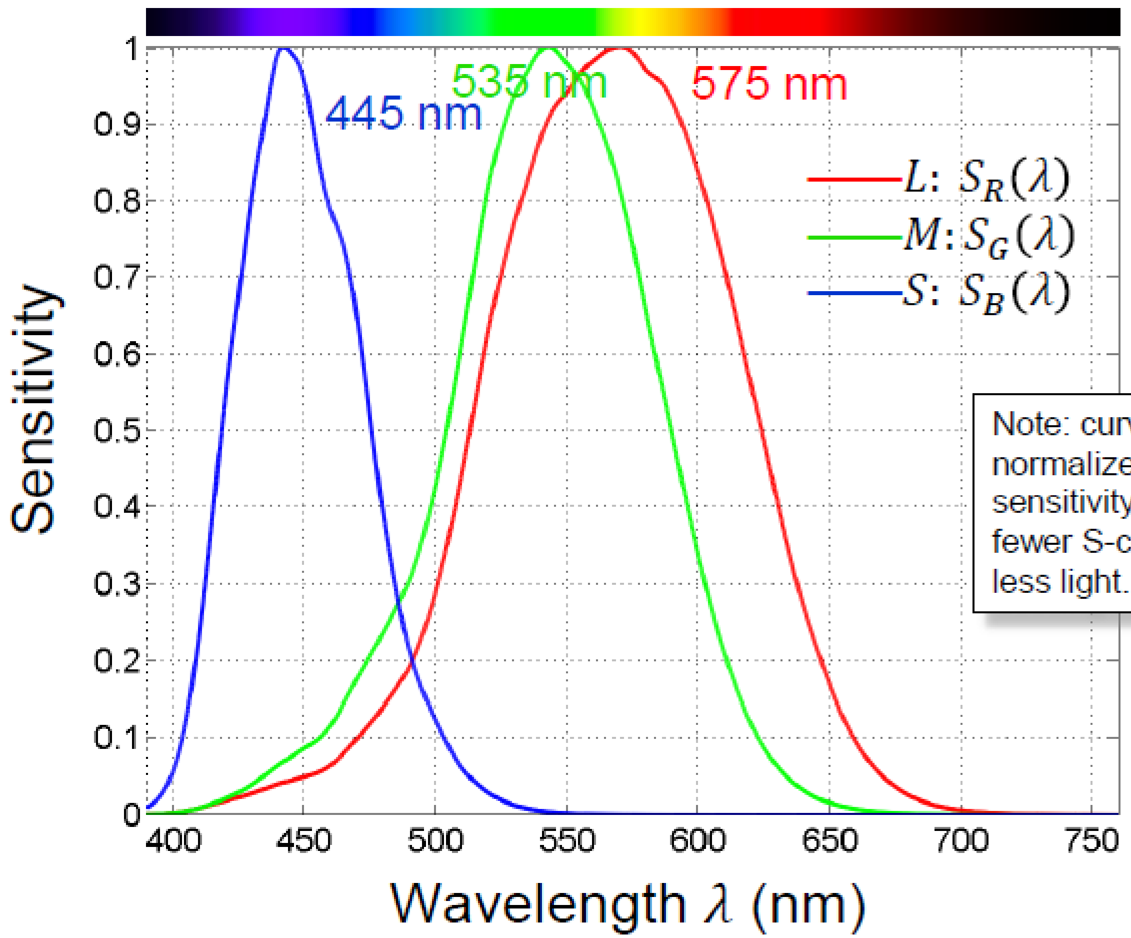




Color: visible range of the electromagnetic spectrum



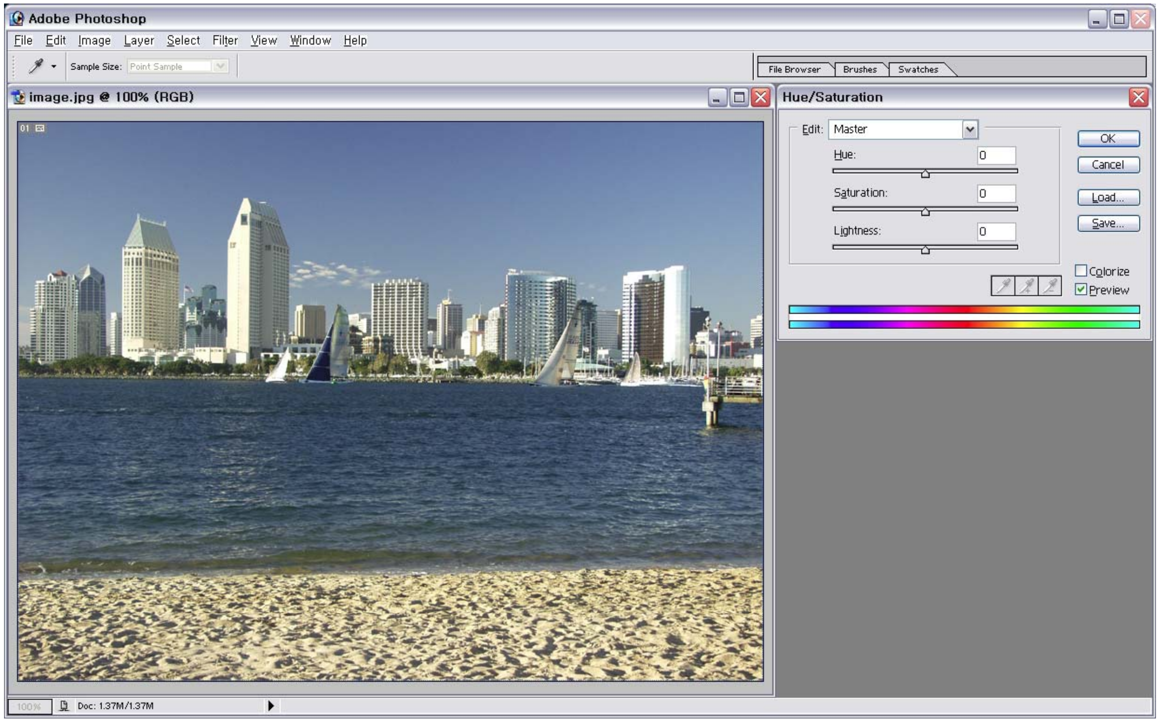
Absorption of light in the cones of the human retina



Note: curves are normalized. **Much** lower sensitivity to Blue, since fewer S-cones absorb less light.

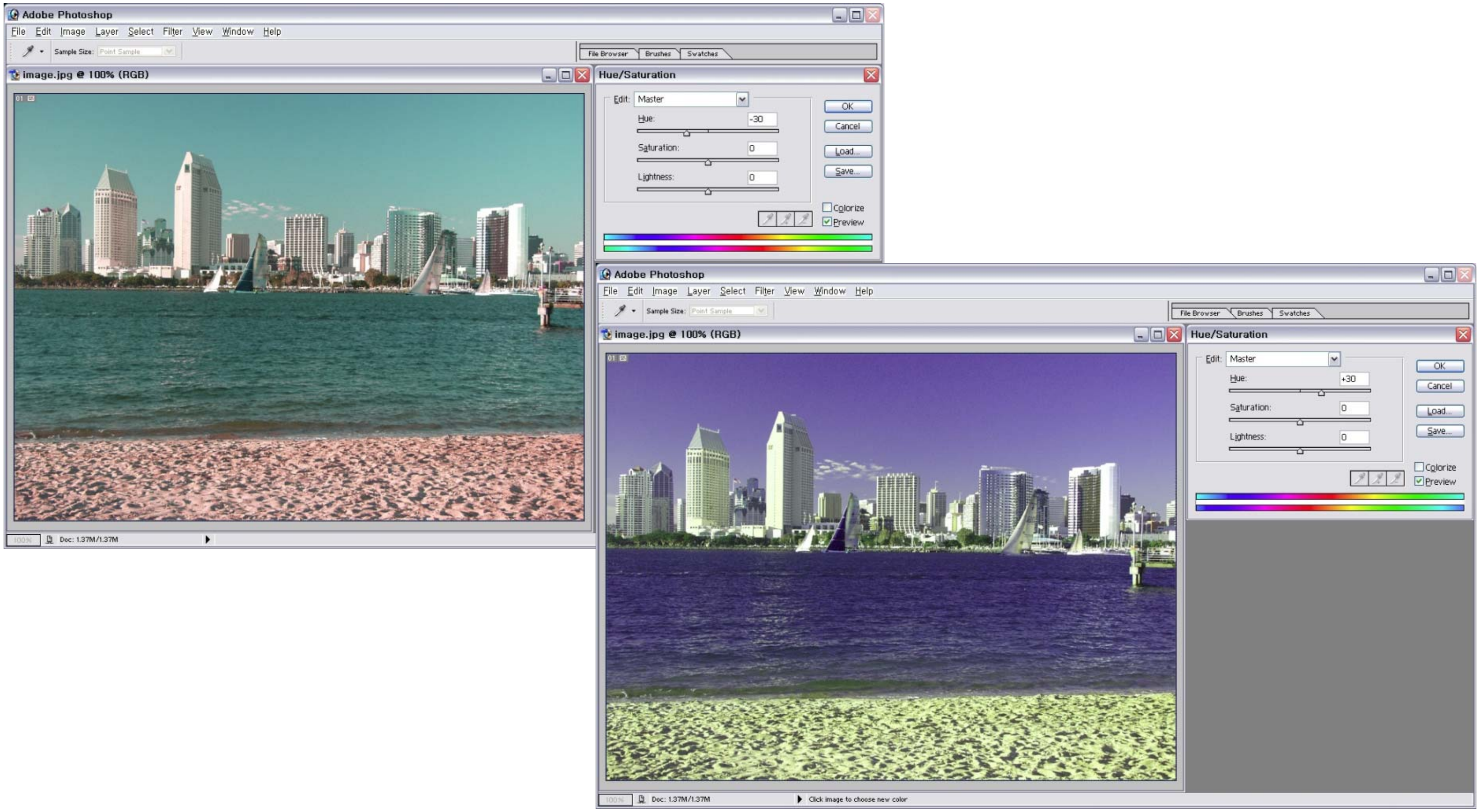
Visual Perception

- Three variables for color image perception:
  - Hue
  - Saturation
  - Lightness



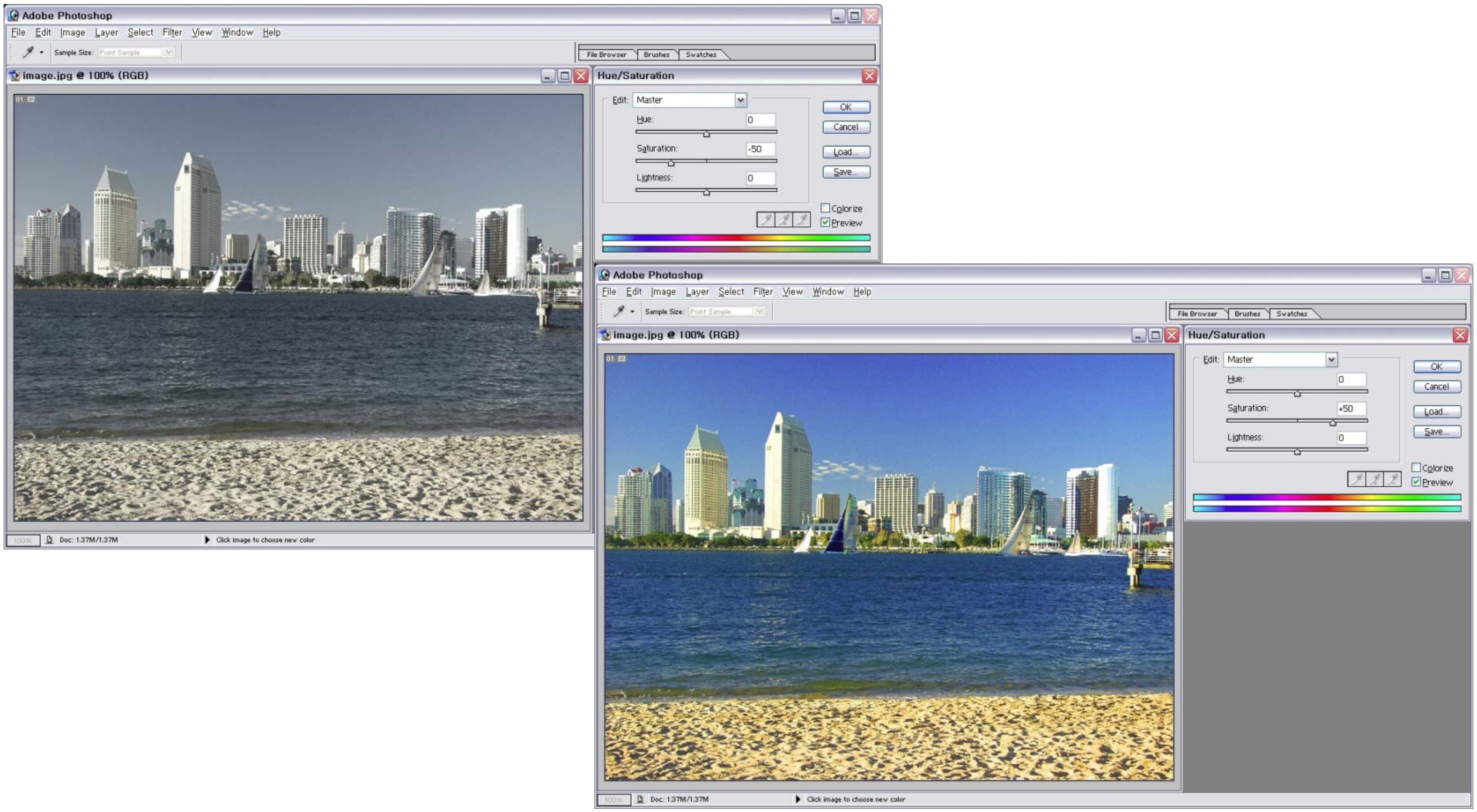
Visual Perception

- Hue



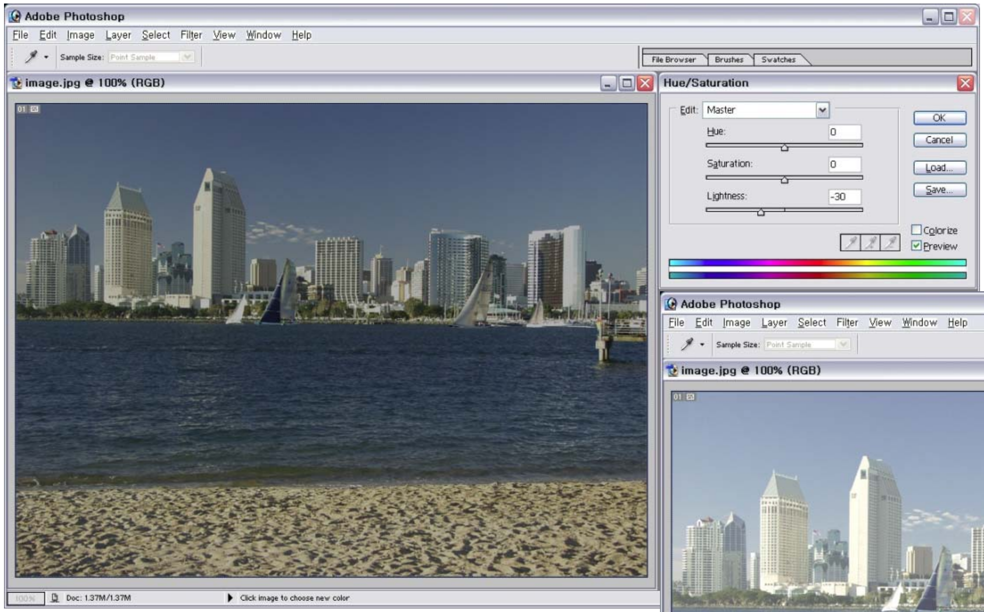
Visual Perception

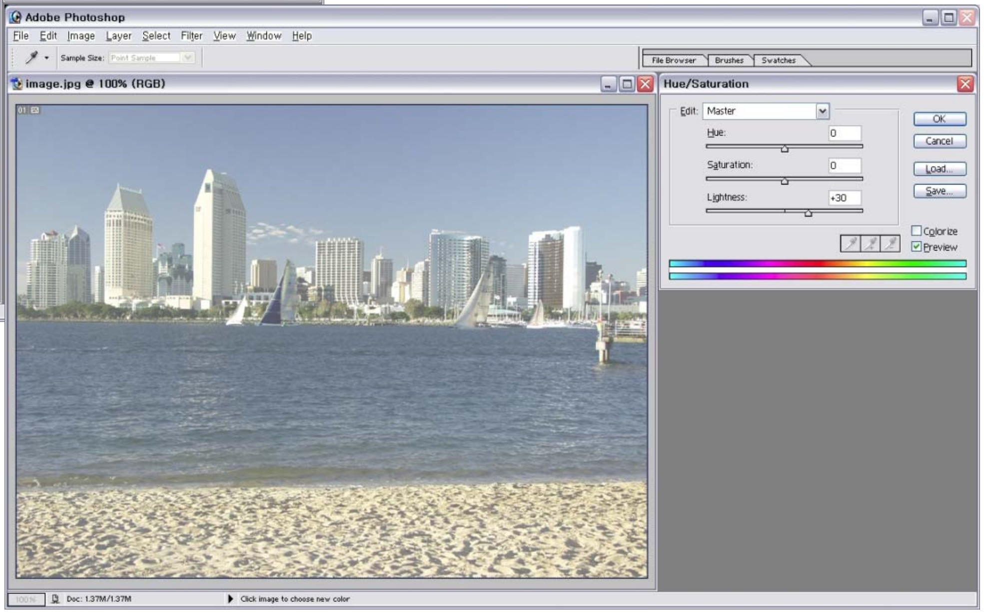
- Saturation



Visual Perception

- Lightness



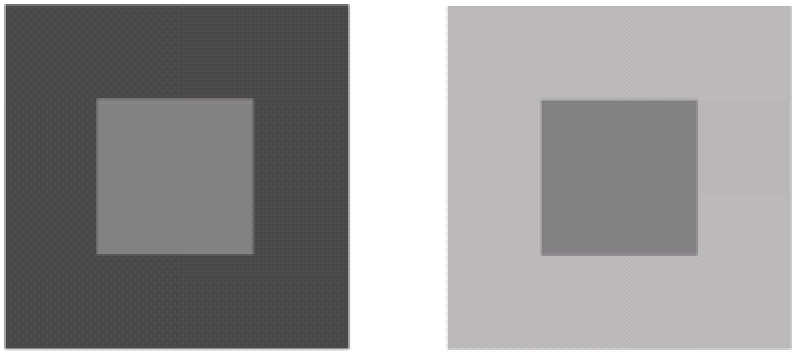


Visual Perception

- Contrast
  The range from the darkest regions of the image to the light regions.

$$contrast = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

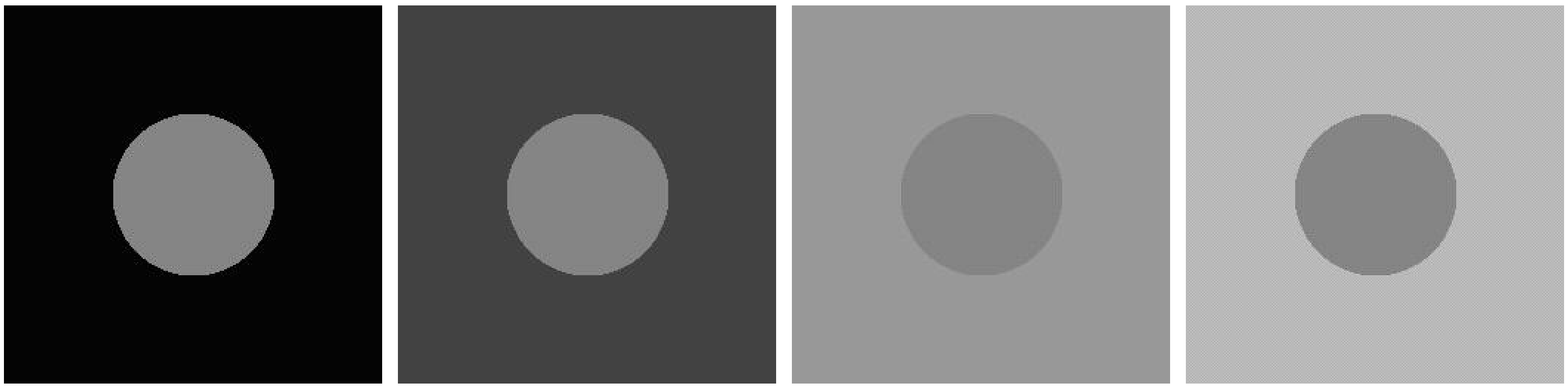
I_{max} , I_{min} : maximum, minimum intensities of a region or image



Visual Perception

- Simultaneous Contrast

  A phenomenon of the human visual system that causes perceived brightness to be dependent not only on the brightness levels, but also on brightness levels of the adjacent areas



Circle = 127, background =0 | Circle = 127, background =64 | Circle = 127, background =150 | Circle = 127, background =180

All the inner circles have the same intensity, but they appear progressively darker as the background becomes lighter.

Visual Perception

- The Mach Band Effect

  The response of our visual system to an abrupt change in luminance tends to emphasize the edge.

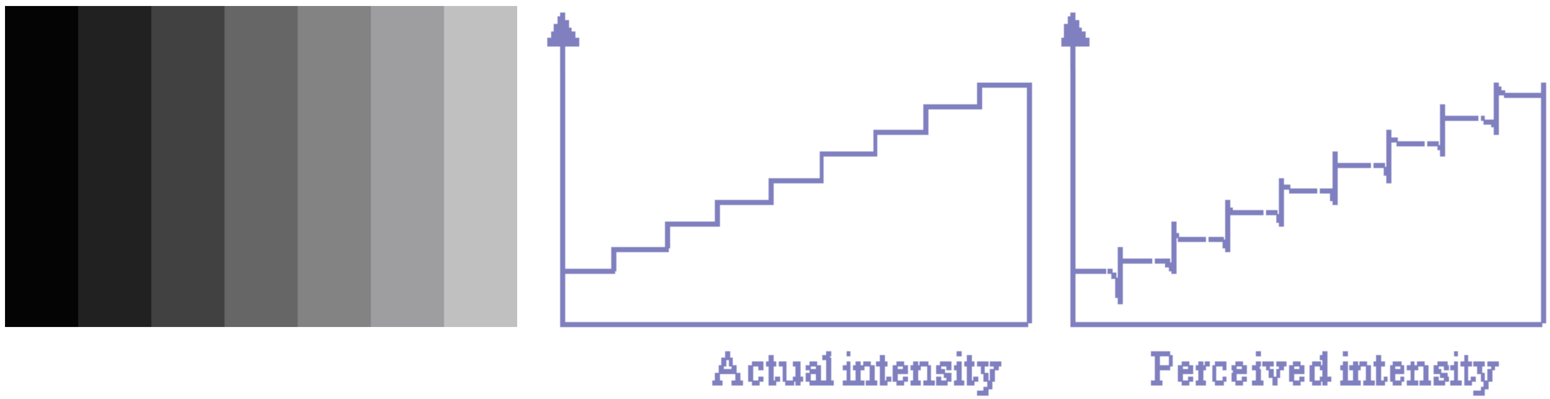


Image Formation

- Light source (λ: wavelength of the source)
  - E(x,y,z,λ): incident light on a point (x,y,z)
- Each point of the scene has a reflectivity function
  - r(x,y,z,λ): reflectivity function
- Light reflects from a point and the reflected light is captured by an imaging device
  - C(x,y,z,λ)=E(x,y,z,λ)*r(x,y,z,λ): reflected light

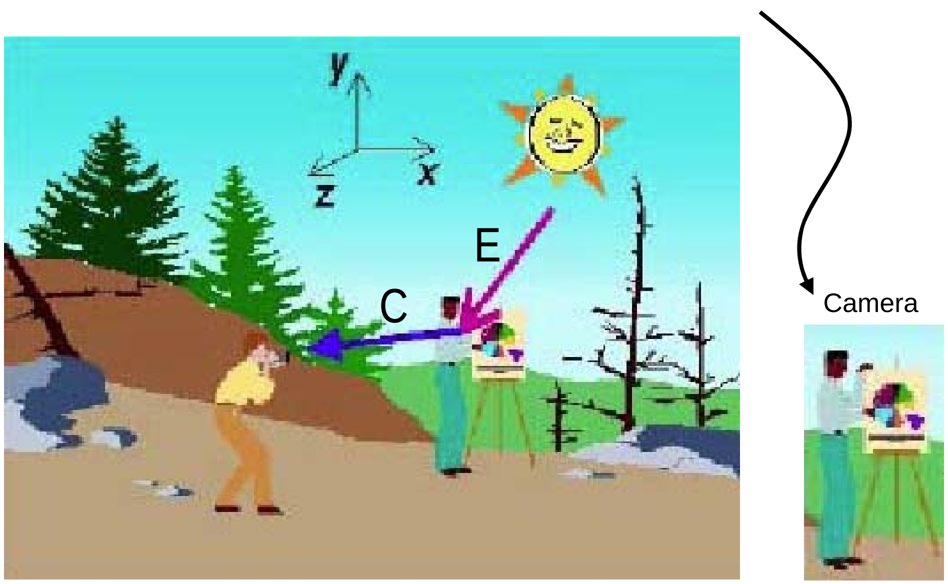
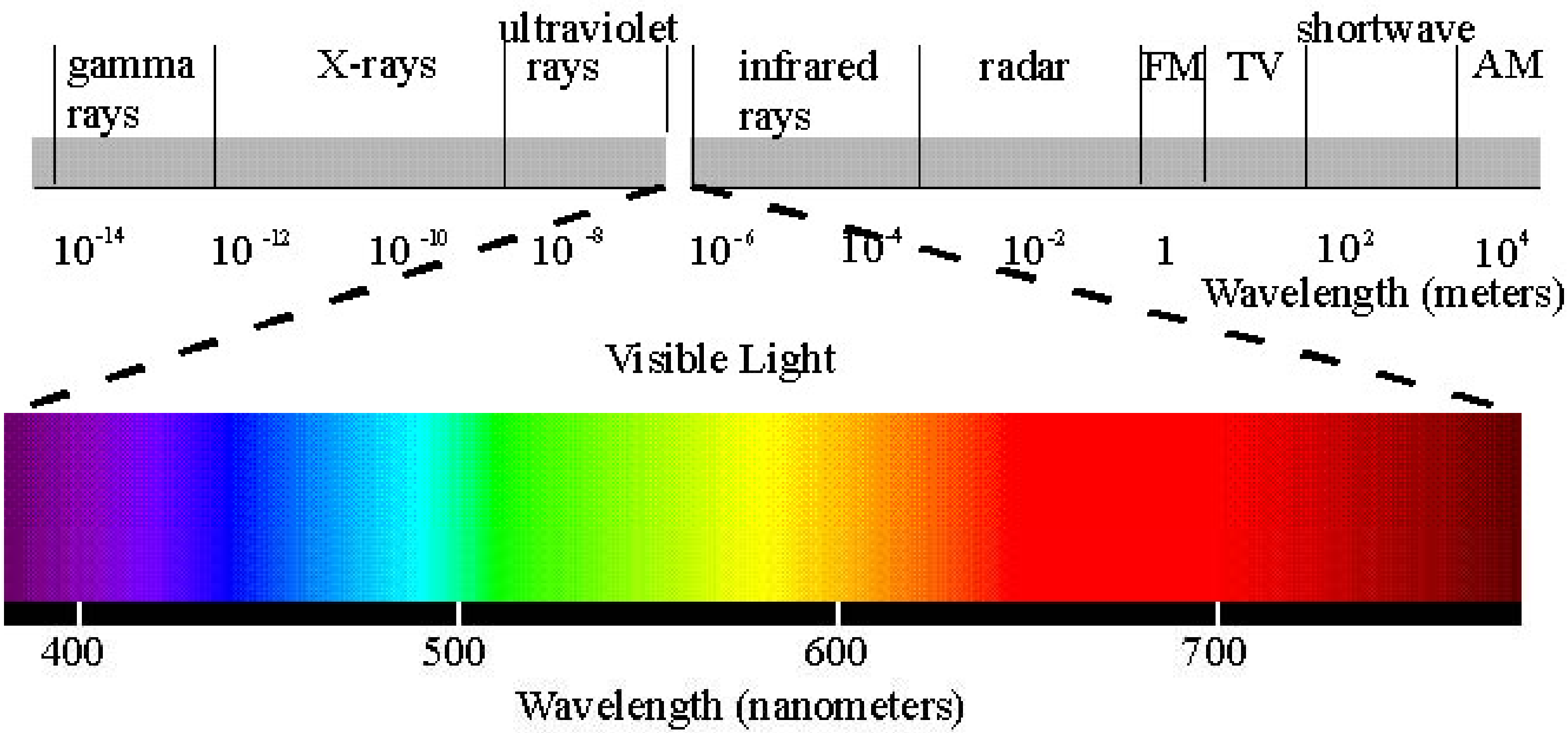


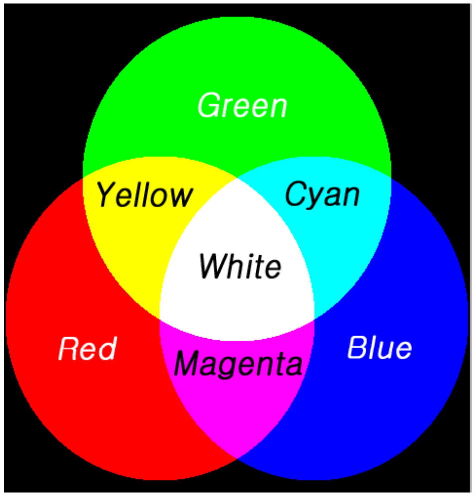
Image Formation

- Visible light is a form of ElectroMagnetic (EM) radiation, with λ at 350nm to 750nm.



Two Types of Light Source

- Primary Light
  - Emits the EM wave (sun, light bulb, etc.)
  - Folllows the <u>additive law</u>
  - Primary colors: Red/Green/Blue



- Secondary Light
  - Reflects an incident light (dye, object, etc.)
  - Follows the <u>subtractive law</u>
  - Primary colors: Cyan/Magenta/Yellow

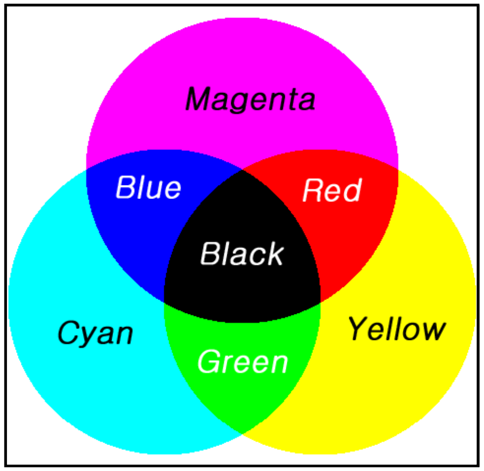
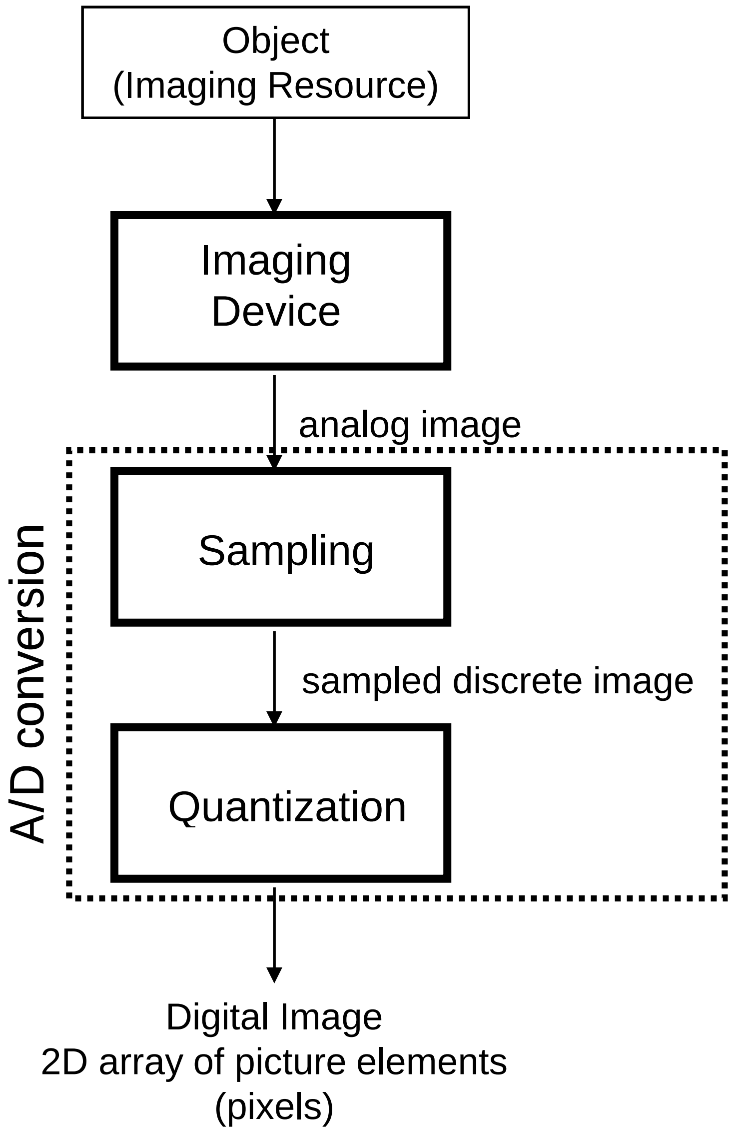
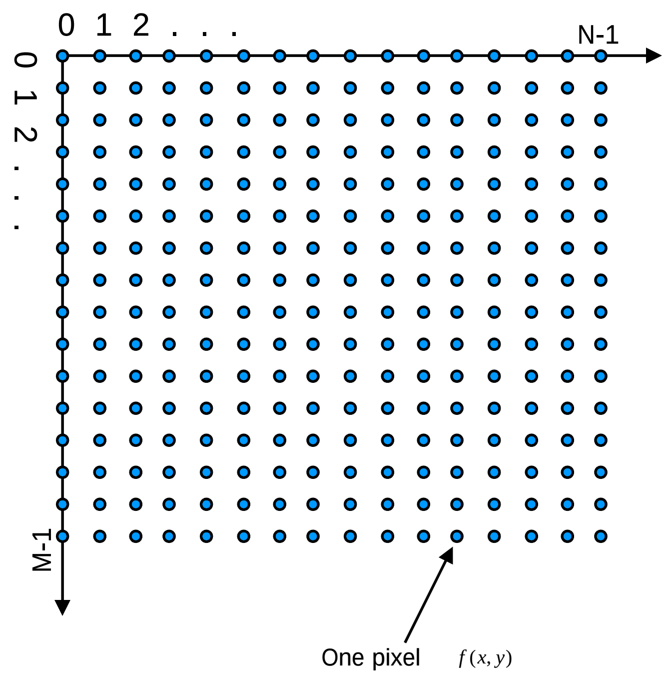


Image Representation





Grayscale Images

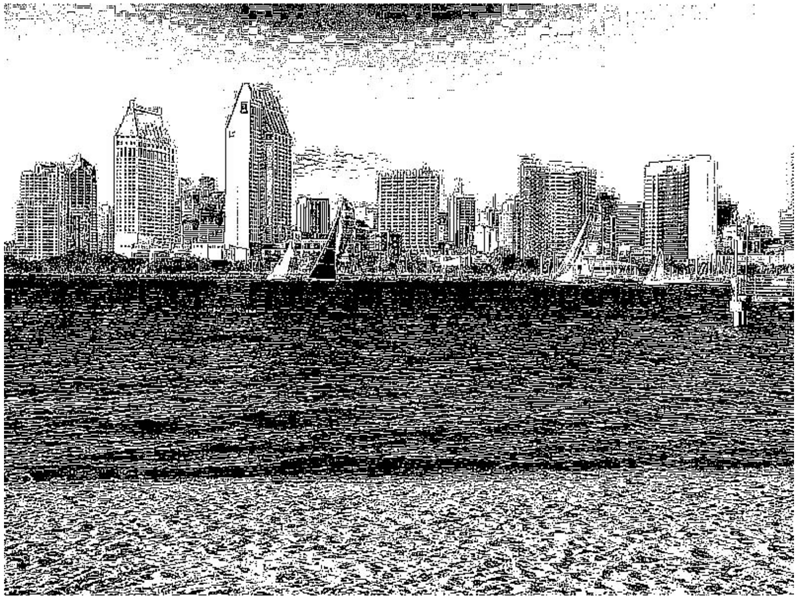
- The intensity value of each pixel is 0 ~ 255.
- Matrix representation of 2-D image:

The Lena Picture

$$F = \begin{bmatrix} 142 & 139 & \cdots & 192 & 213 \\ 146 & 137 & \cdots & 187 & 205 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 94 & 93 & \cdots & 84 & 89 \\ 87 & 89 & \cdots & 79 & 82 \end{bmatrix}$$

Binary vs. Grayscale Images

- Binary images use only 2 levels (0 or 1)
- Grayscale images use 256 (=2^8) gray levels (0 to 255)



Binary Image

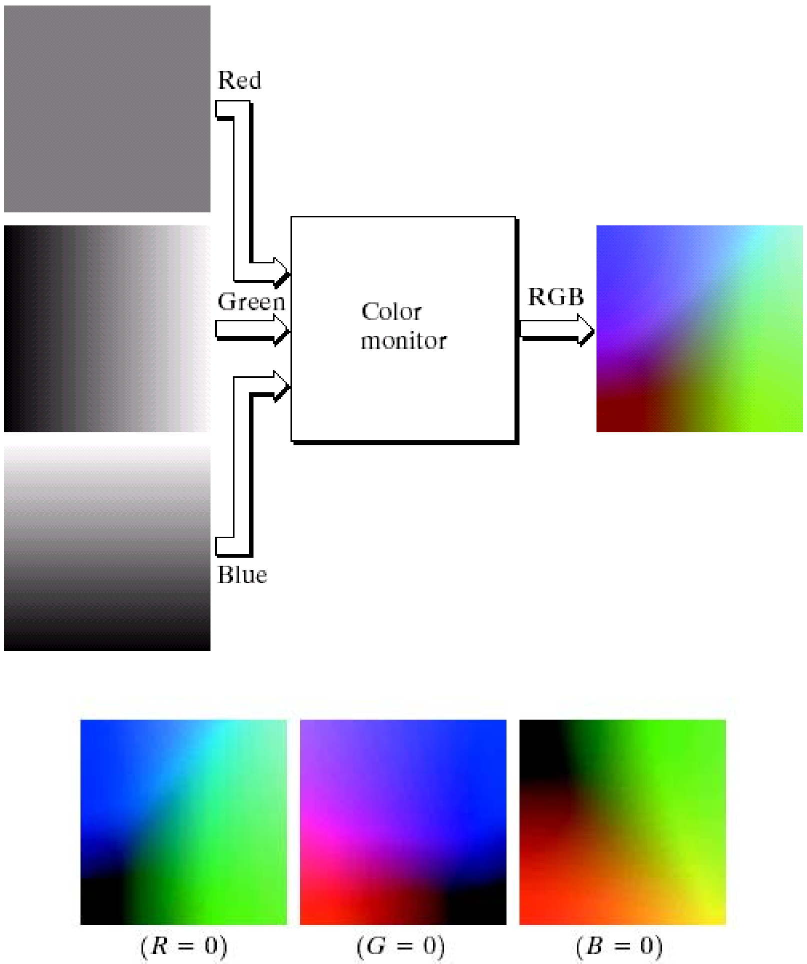
Grayscale Image

Color Images

- Generating RGB Images

a
b

(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.



Color Images

a b
c d

(a) RGB image.
(b) Red component image.
(c) Green component.
(d) Blue component.

Color Representation

- Different image processing systems use different color models for different reasons.

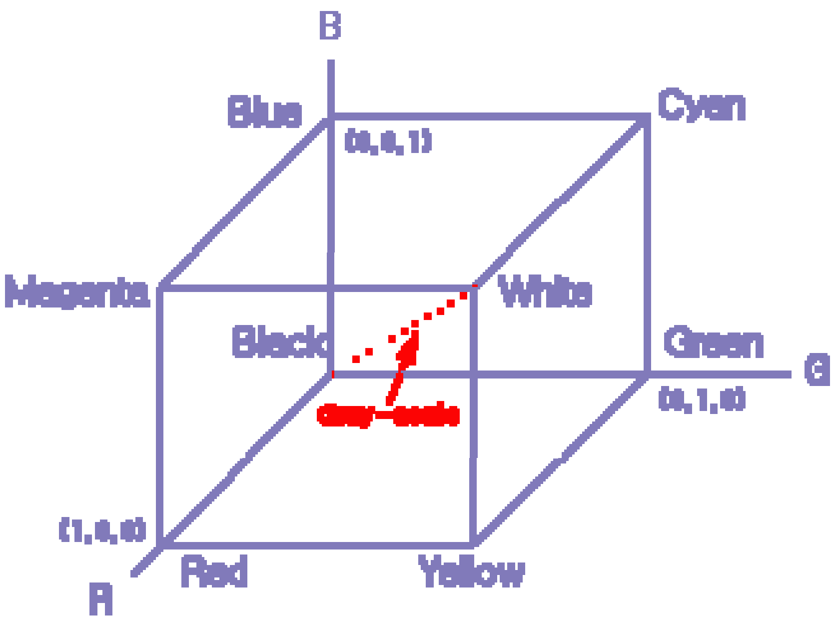
- Human perception of color is a function of the response of three types of cones.

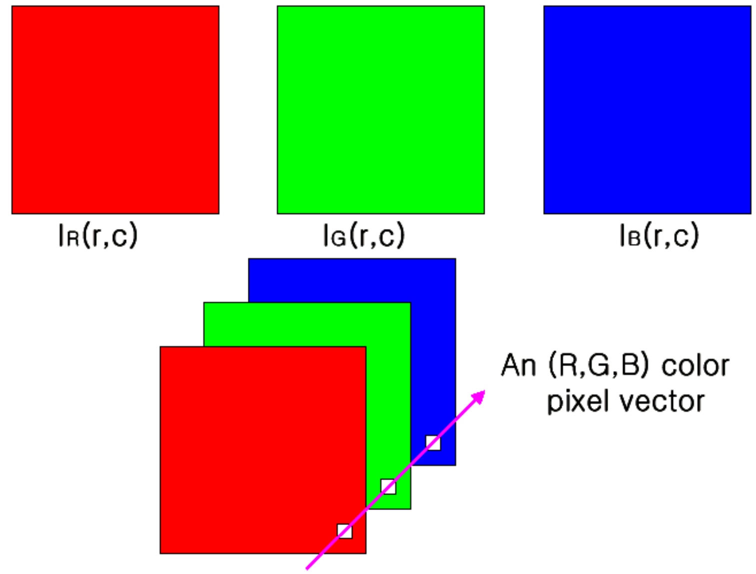
- Color systems are based on three numbers (tristimulus values).

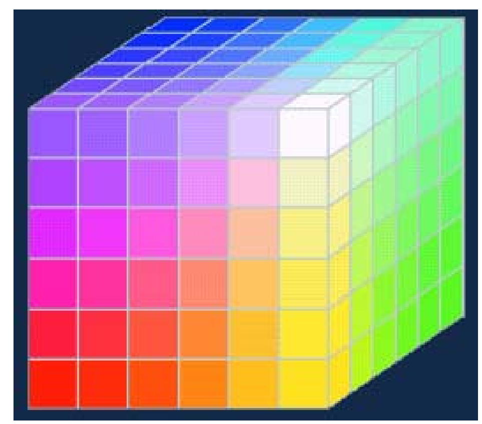
- Color Models
  - RGB: CRT monitors and most computer graphics systems
  - CMY: color picture publishing industry
  - HSI: systems requiring manipulations of Hue/Saturation/Intensity separately
  - YC_bC_r: systems needed to separate the luminance from the color information

Color Representation

- RGB Model



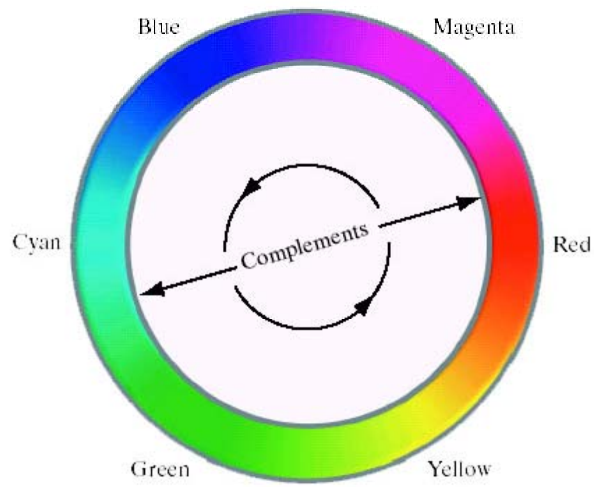




- RGB to Grayscale Conversion
  - NTSC standard: 0.299R + 0.587G + 0.114B
  - Simple average: 0.333R + 0.333G + 0.333B

Color Representation

- CMY Model
  - Consists of cyan, magenta, and yellow.
  - Cyan, magenta, and yellow are the complements of red, green, and blue, respectively.
  - To go from RGB to CMY, subtract the complement from white:
    - C=1.0-R (R=1.0-C) (in a 24-bit color system, C=255-R)
    - M=1.0-G (G=1.0-M)
    - Y=1.0-B (B=1.0-Y)



- CMYK Model
  - Black (K) is added in the printing process : CMYK=CMY+K
  - Pure black provides greater contrast.
  - CMY to CMYK conversion:
    - K=min(C,M,Y)
    - C=C-K
    - M=M-K
    - Y=Y-K

Color Representation

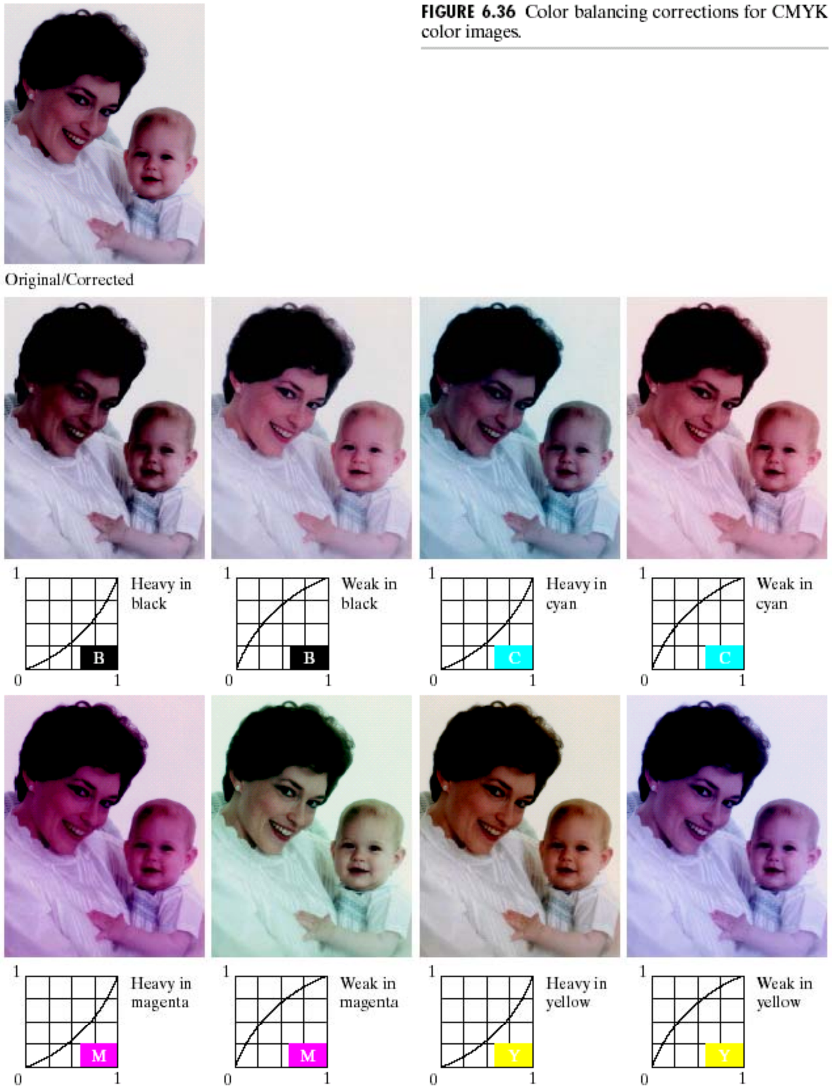
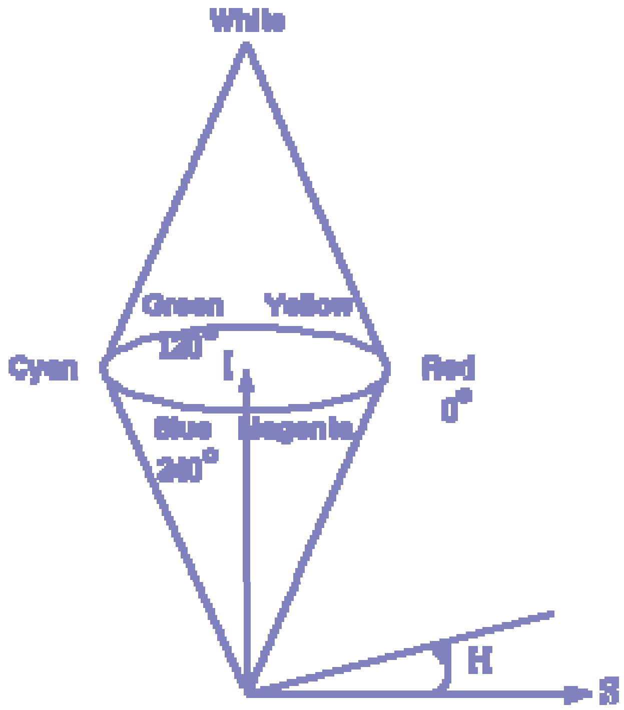


FIGURE 6.36 Color balancing corrections for CMYK color images.

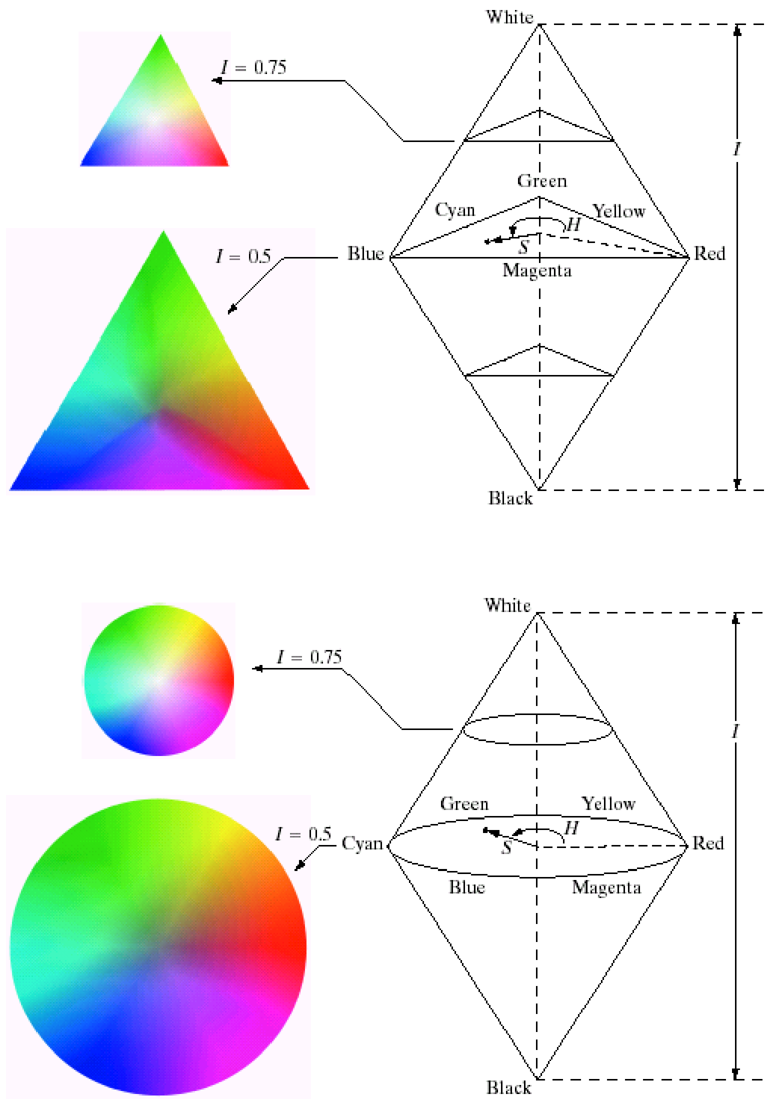
Color Representation

- HSI Mode
- (Hue), (Saturation), (Intensity)



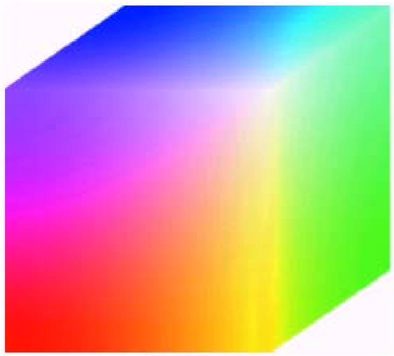
Color Representation

- HSI Model (continued)
  - To produce a color, simply adjust the hue. (angle H)
  - To make it deeper or shallower, adjust the saturation. (radius S)
  - To make it darker or lighter, adjust the intensity. (vertical axis I)

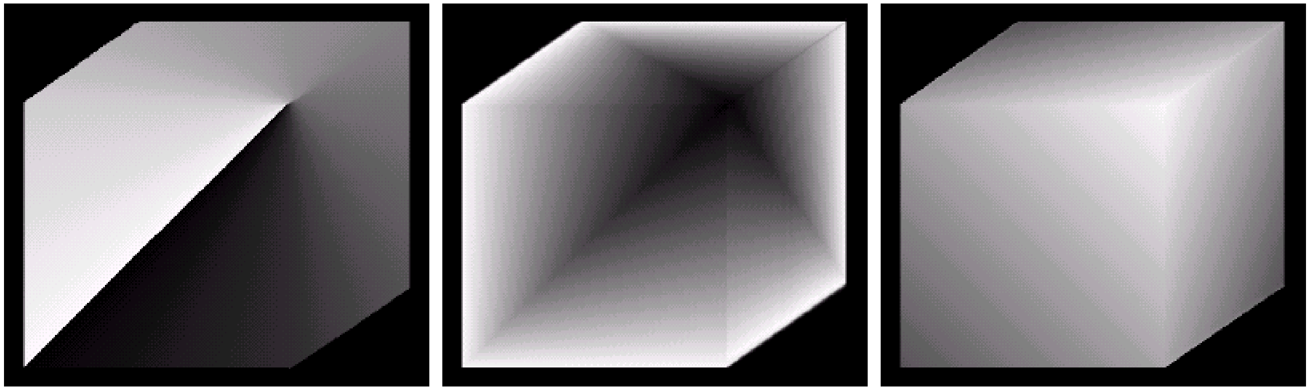


Color Representation

- RGB vs. HSI



RGB 24-bit color cube.

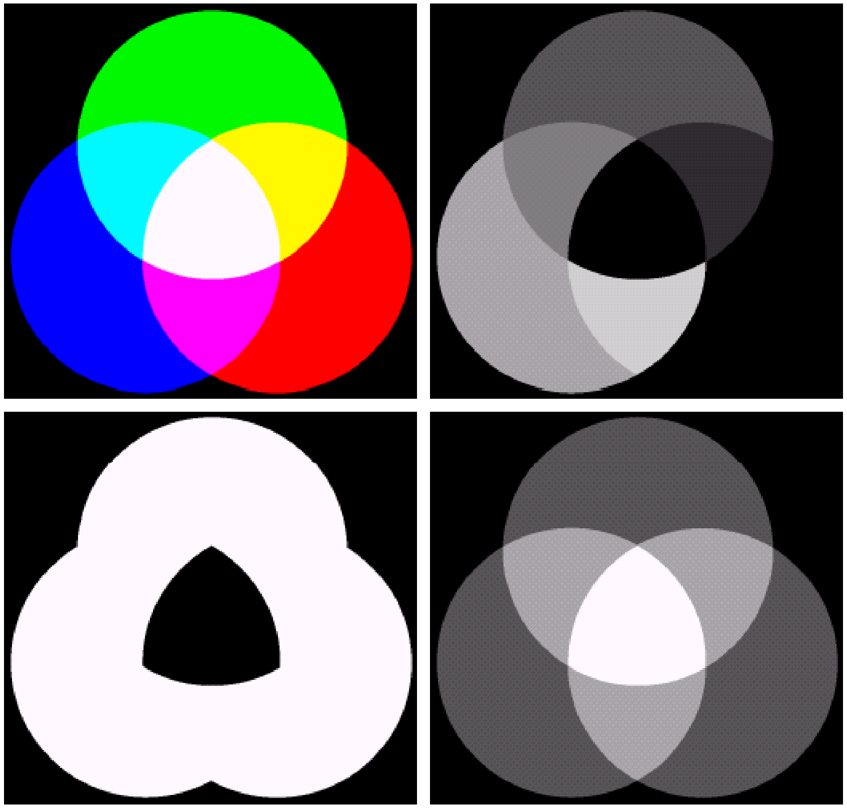


a b c

HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

Color Representation

- RGB vs. HSI

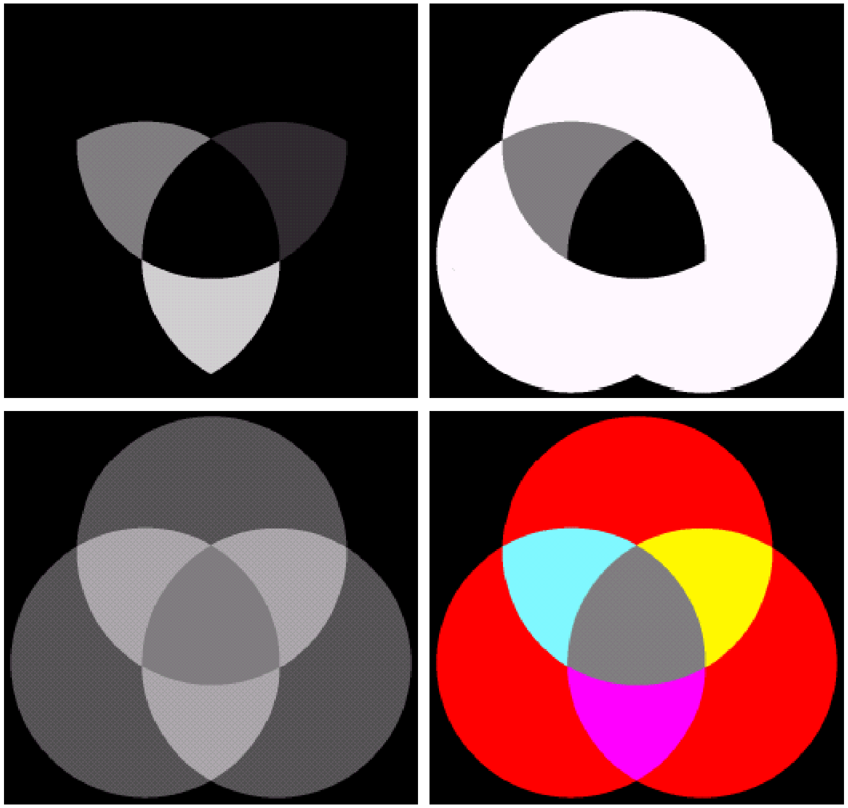


a b
c d

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

Color Representation

- RGB vs. HSI



a b
c d

(a)–(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)

Color Representation

a b c

HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.

Color Representation

- YC_bC_r Mode
  - Another color space that separates the luminance from the color information.
  - The luminance is encoded in Y and the blueness and redness encoded in C_bC_r.

  - Conversion from RGB to YCbCr:

    Y = 0.29900R + 0.58700G + 0.11400B
    Cb = -0.16874R - 0.33126G + 0.50000B
    Cr = 0.50000R - 0.41869G - 0.08131B

  - Conversion from YCbCr to RGB:

    R = 1.00000Y + 1.40200Cr
    G = 1.00000Y - 0.34414Cb - 0.71414Cr
    B = 1.00000Y + 1.77200Cb

Color Representation

A full-color image and its various color-space components.