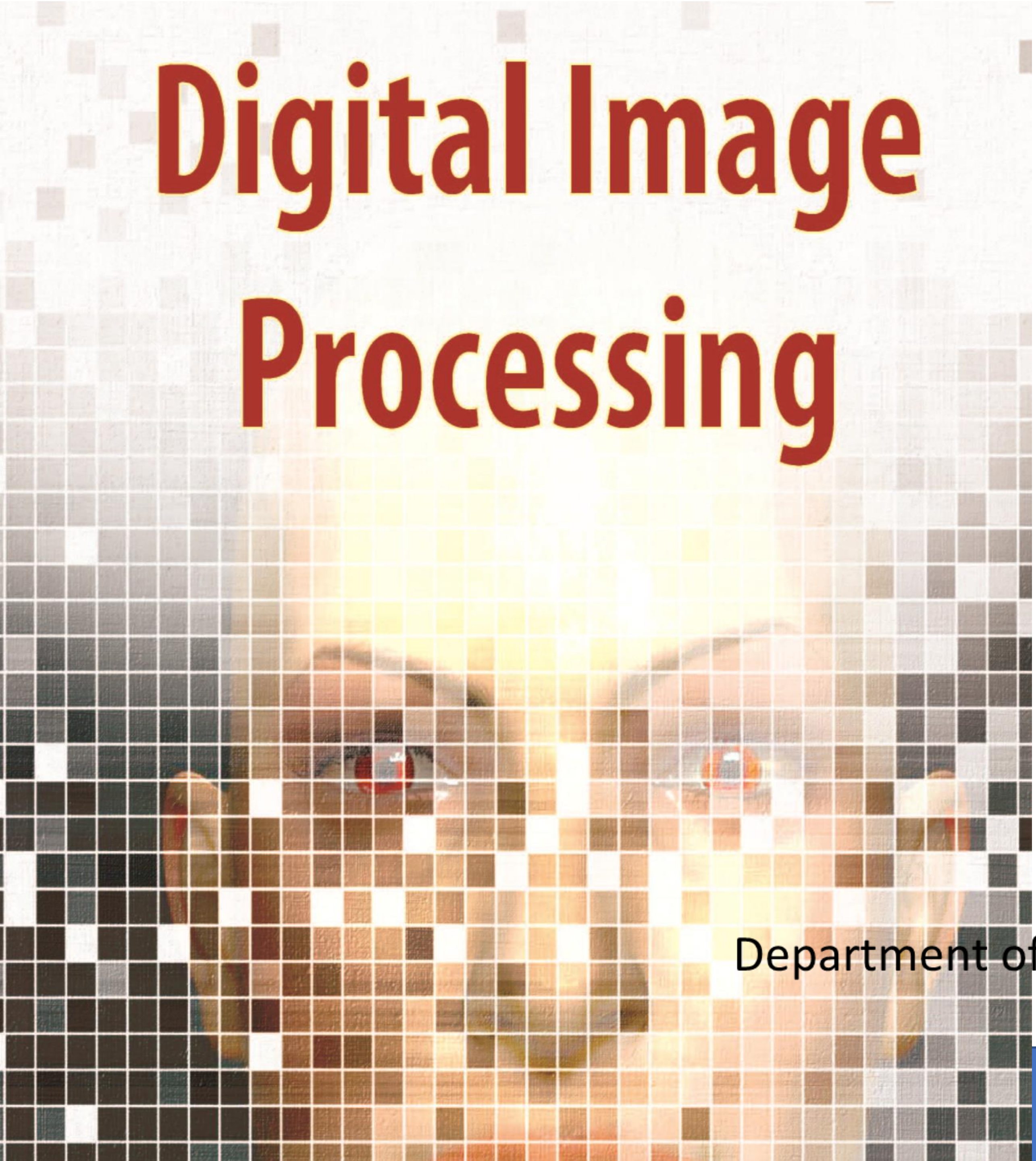


Colour Image Fundamentals and Processing Techniques

Prof. Sheli Sinha Chaudhuri
Department of Electronics and Telecommunication Engineering
Jadavpur University

Chapter 6

Colour Image Fundamentals and Processing Techniques

Contents

- Colour Fundamentals
- Colour Models
- Pseudocolour Image Processing
- Basics of Full-Colour Image Processing
- Colour Image Processing
- Image Smoothing and Image Sharpening
- Image Segmentation based on Colour
- Noise in Colour Images
- Colour Image Compression

Spectrum of White Light

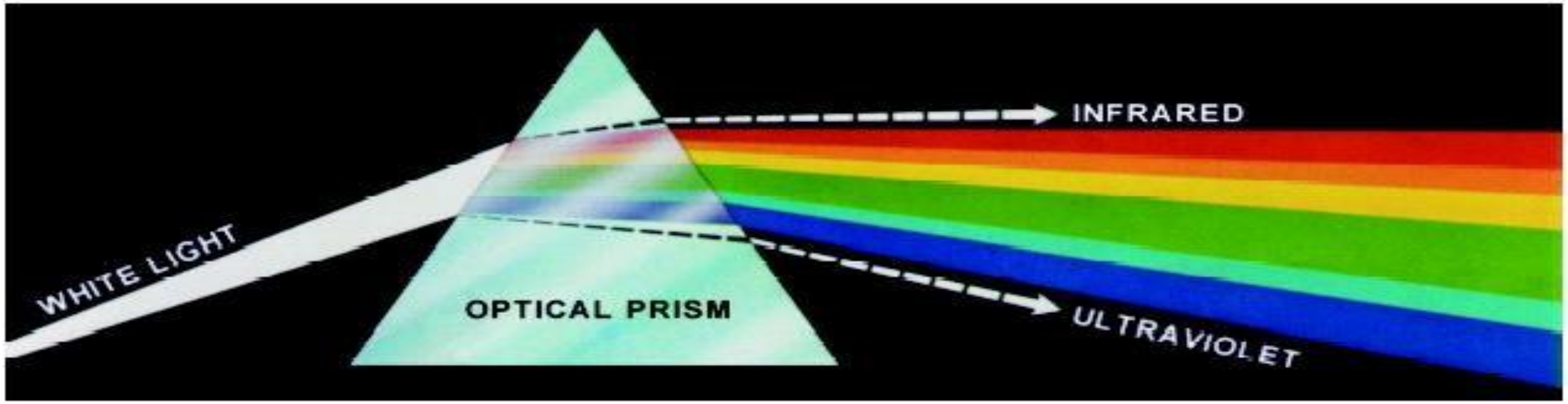
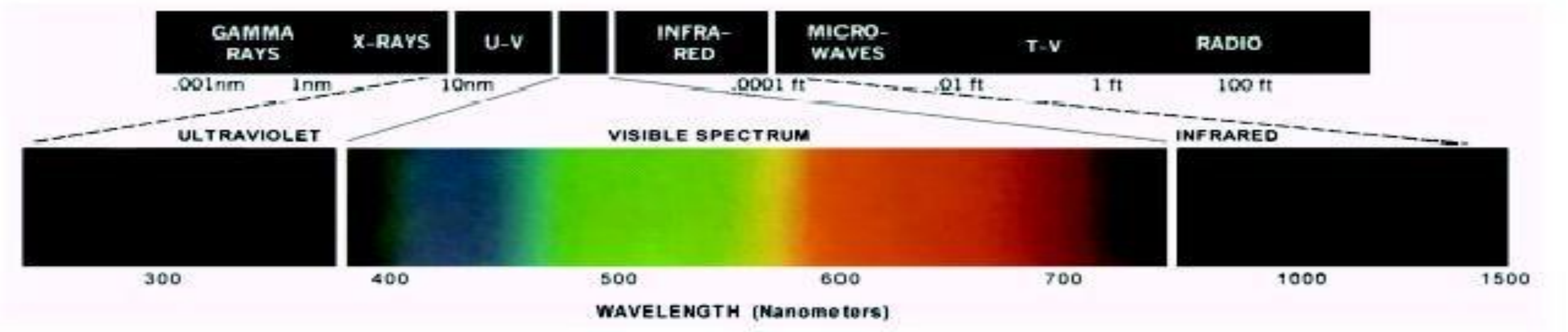


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

1666 Sir Isaac Newton, 24 year old, discovered white light spectrum.

Electromagnetic Spectrum



Visible light wavelength: from around 400 to 700 nm

1. For an achromatic (monochrome) light source,
there is only 1 attribute to describe the quality: intensity

2.For a chromatic light source, there are 3 attributes to describe the quality:
Radiance = total amount of energy flow from a light source (Watts) Luminance = amount of energy received by an observer (lumens) Brightness = intensity

Cross section illustration of the Human Eye

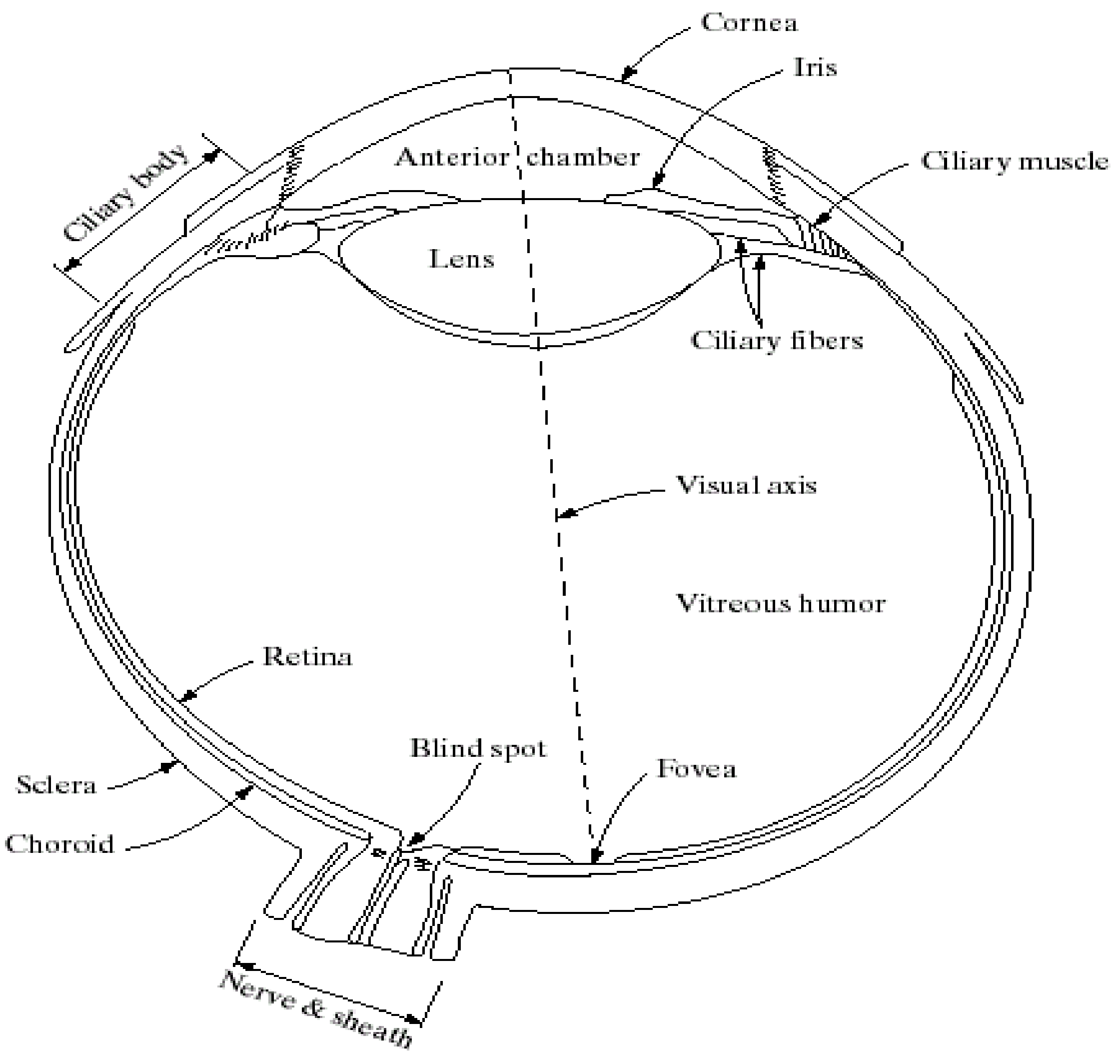


FIGURE 2.1 Simplified diagram of a cross section of the human eye.

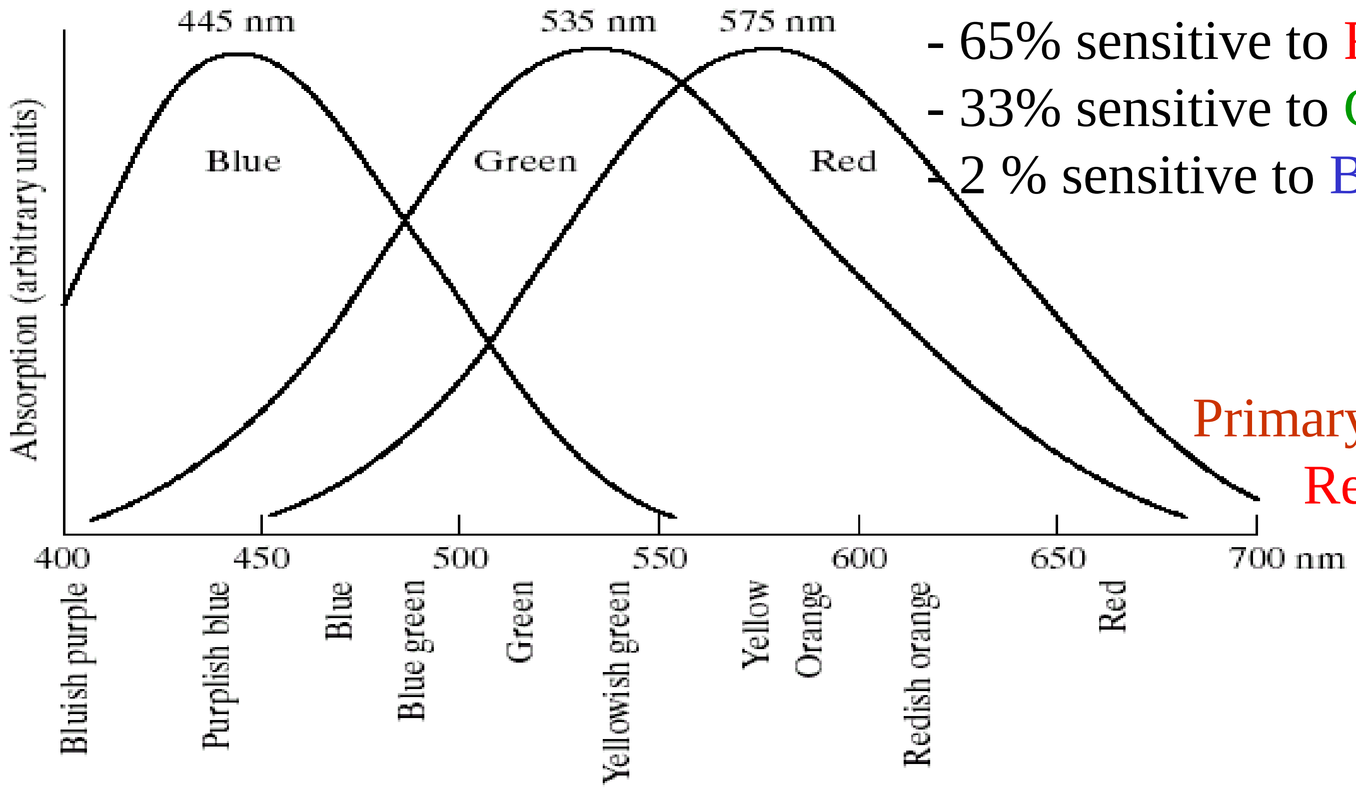
Types of Photoreceptors at Retina

- Rods
  - Long and thin
  - Large quantity (~ 100 million)
  - Provide *scotopic* vision (i.e., dim light vision or at low illumination)
  - Only extract luminance information and provide a general overall picture
- Cones
  - Short and thick, densely packed in fovea (center of retina)
  - Much fewer (~ 6.5 million) and less sensitive to light than rods
  - Provide *photopic* vision (i.e., bright light vision or at high illumination)
  - Help resolve fine details as each cone is connected to its own nerve end
  - Responsible for color vision

Our Interest
(well-lighted display)

Mesopic Vision is provided at intermediate illumination by both rod and cones

Sensitivity of Cones in the Human Eye



7millions cones in a human eye

- 65% sensitive to Red light
- 33% sensitive to Green light
- 2 % sensitive to Blue light

Primary colors: Defined CIE in 1931

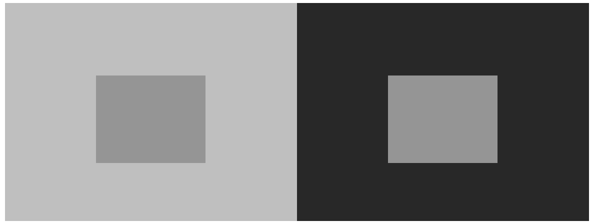
Red = 700 nm Green = 46.1nm

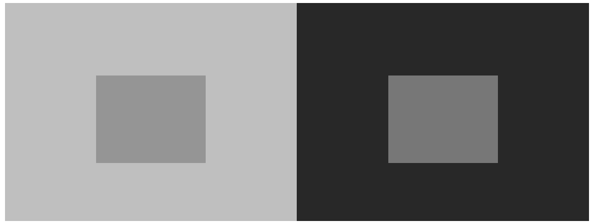
Blue = 435.8 nm

CIE = Commission Internationale de l'Eclairage (The International Commission on Illumination)

Luminance vs. Brightness

Same lum.
Different
brightness





Different lum.
Similar brightness

- Luminance (or intensity)
  - Independent of the luminance of surroundings

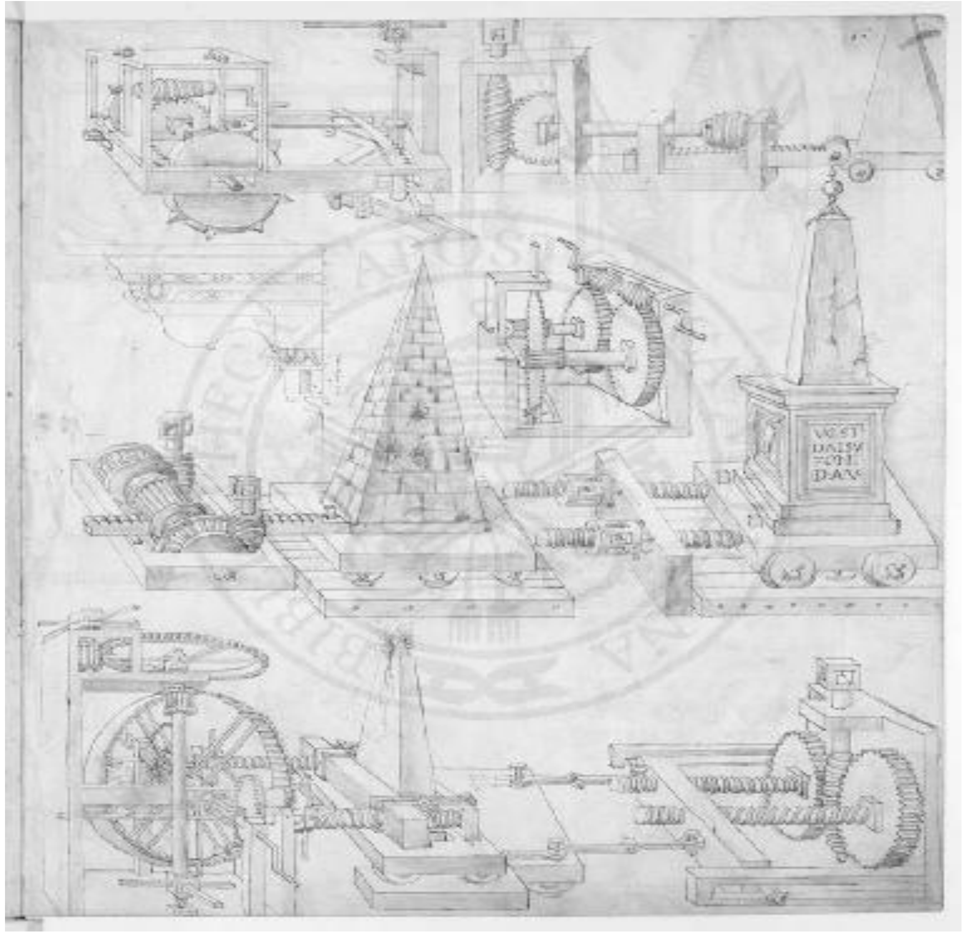
$$L(x,y) = \int_0^{inf} I(x,y,\lambda) V(\lambda) d\lambda$$

$I(x,y,\lambda)$ -- spatial light distribution
$V(\lambda)$ -- relative luminous efficiency func. of visual system ~ bell shape (different for scotopic vs. photopic vision;
highest for green wavelength, second for red, and least for blue)

- Brightness
  - Perceived luminance
  - Depends on surrounding luminance

Luminance vs. Brightness (cont'd)

- Example: visible digital watermark
  - How to make the watermark appear at the same graylevel all over the image?



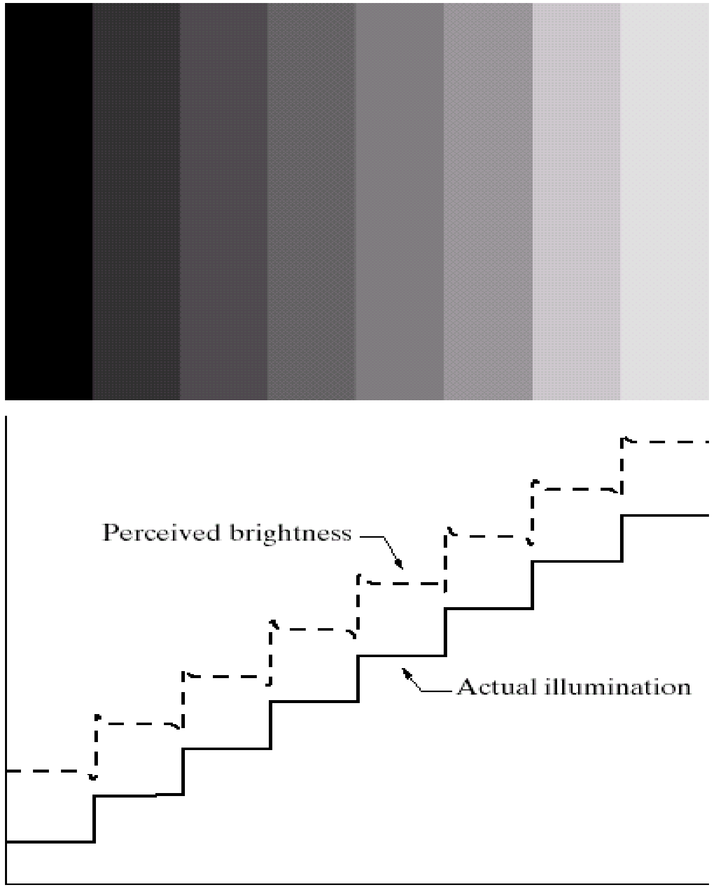
from IBM Watson web page "Vatican Digital Library"

Look into Simultaneous Contrast Phenomenon

- Human perception more sensitive to luminance contrast than absolute luminance
- Weber's Law: $| L_s – L_0 | / L_0 = \text{const}$
  - Luminance of an object (L_0) is set to be just noticeable from luminance of surround (L_s)
  - For just-noticeable luminance difference ΔL:

    $$\Delta L / L \approx d(\log L) \approx 0.02 \text{ (const)}$$

    - equal increments in log luminance are perceived as equally different
- Empirical luminance-to-contrast models
  - Assume $L \in [1, 100]$, and $c \in [0, 100]$
  - $c = 50 \log_{10} L$ (logarithmic law, widely used)
  - $c = 21.9 L^{1/3}$ (cubic root law)



a
b

FIGURE 2.7 (a) An example showing that perceived brightness is not a simple function of intensity. The relative vertical positions between the two profiles in (b) have no special significance; they were chosen for clarity.

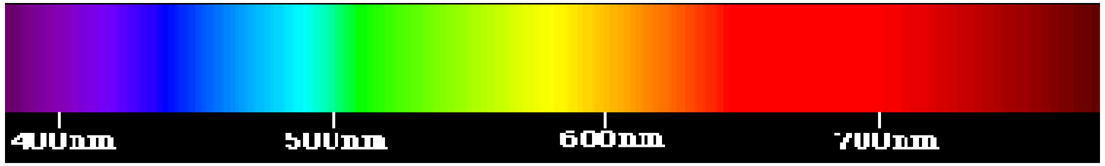
Figure is from slides at Gonzalez/ Woods DIP book website (Chapter 2)

- Visual system tends to undershoot or overshoot around the boundary of regions of different intensities

- Demonstrates the perceived brightness is not a simple function of light intensity

Color of Light

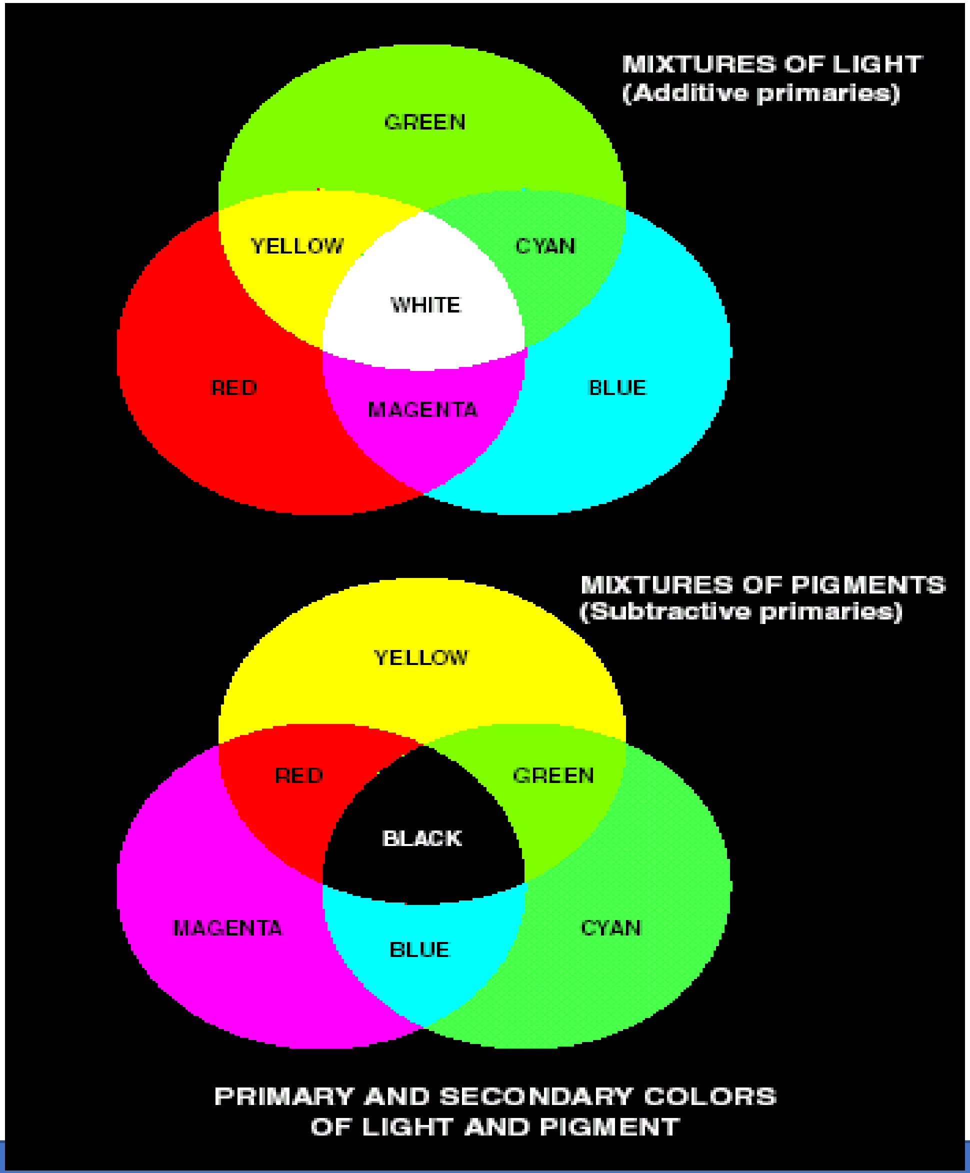
- Perceived color depends on spectral content (wavelength composition)
  - e.g., 700nm ~ red.
  - "spectral color"
    - A light with very narrow bandwidth



"Spectrum" from http://www.physics.sfasu.edu/astro/color.html

- A light with equal energy in all visible bands appears white

Primary and Secondary Colors



Additive primary colors: RGB used in the case of light sources such as colour monitors

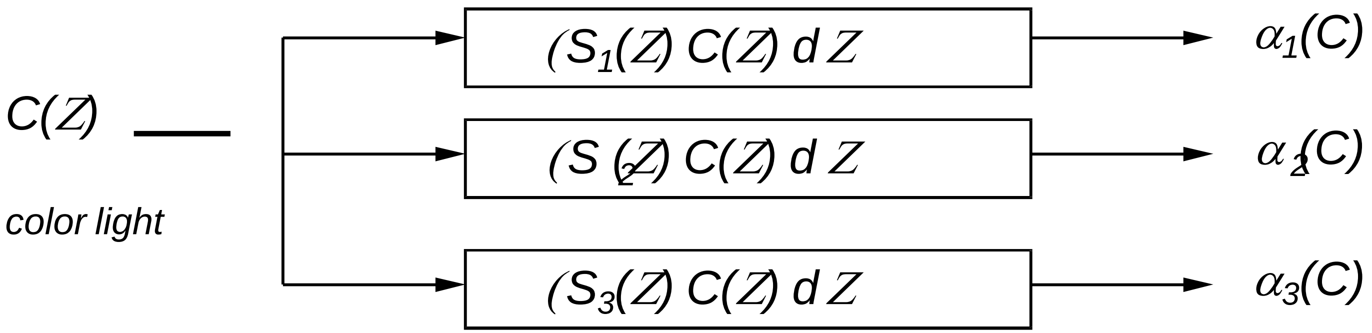
RGB add together to get white

Subtractive primary colors: CMY use in the case of pigments in printing devices

White subtracted by CMY to get Black

Representation by Three Primary Colors

- Any color can be reproduced by mixing an appropriate set of three primary colors (Thomas Young, 1802)
- Three types of cones in human retina
  - Absorption response $S_i(Z)$ has peaks around 450nm (blue), 550nm (green), 620nm (yellow-green)
  - Color sensation depends on the spectral response $\{\alpha_1(C), \alpha_2(C), \alpha_3(C)\}$ rather than the complete light spectrum $C(Z)$



Identically perceived colors if $\alpha_i(C_1) = \alpha_i(C_2)$

Example:Seeing Yellow Without Yellow

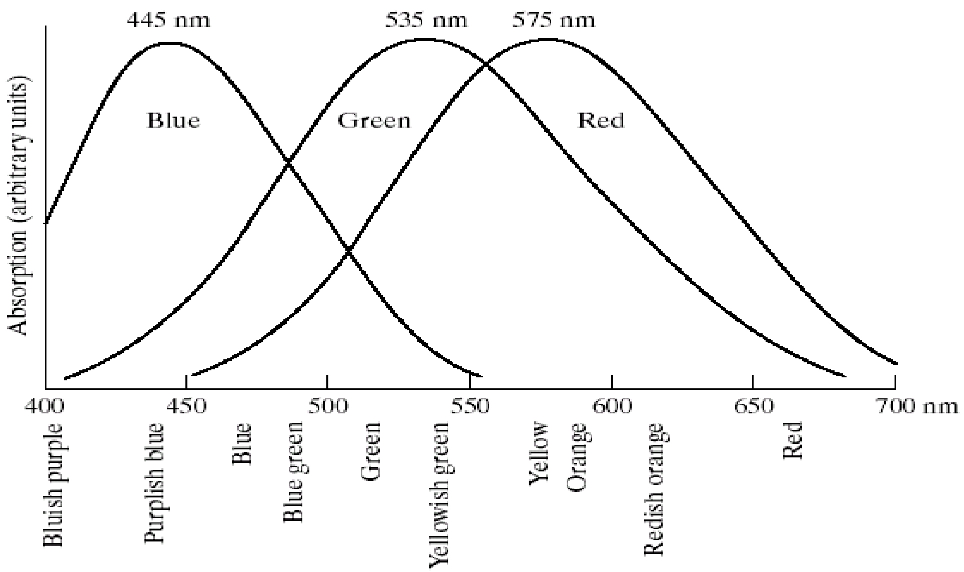
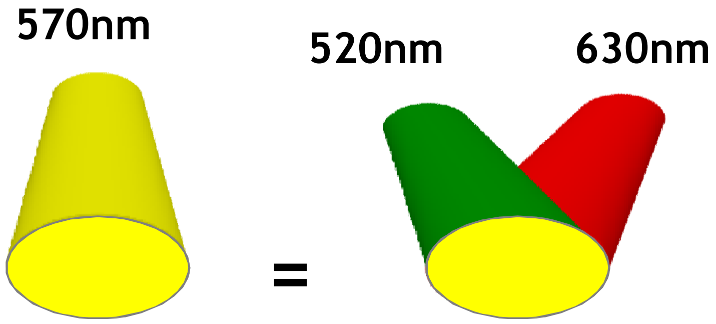


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.



<u>Green and red</u> light are mixed to obtain perception of <u>yellow</u>, without shining a single yellow photon

"Seeing Yellow" figure is from B.Liu ELE330 S'01 lecture notes @ Princeton; R/G/B cone response is from slides at Gonzalez/ Woods DIP book website

Color Matching and Reproduction

- Mixture of three primaries: $C = Sum(\int_k P_k(Z))$
- To match a given color C_1
  - adjust $\int_k$ such that $\alpha_i(C_1) = \alpha_i(C)$, $i = 1,2,3$.

- Tristimulus values $T_k(C)$
  - $T_k(C) = \int_k / w_k$

    w_k – *the amount of* k^{th} *primary to match the reference white*
- Chromaticity $t_k = T_k / (T_1 + T_2 + T_3)$
  - $t_1 + t_2 + t_3 = 1$
  - *visualize* (t_1, t_2) *to obtain chromaticity diagram*

Color Characterization

Hue: Dominant color corresponding to a dominant wavelength of mixture light wave

Saturation: Relative purity or amount of white light mixed with a hue (inversely proportional to amount of white light added)

Brightness: Intensity

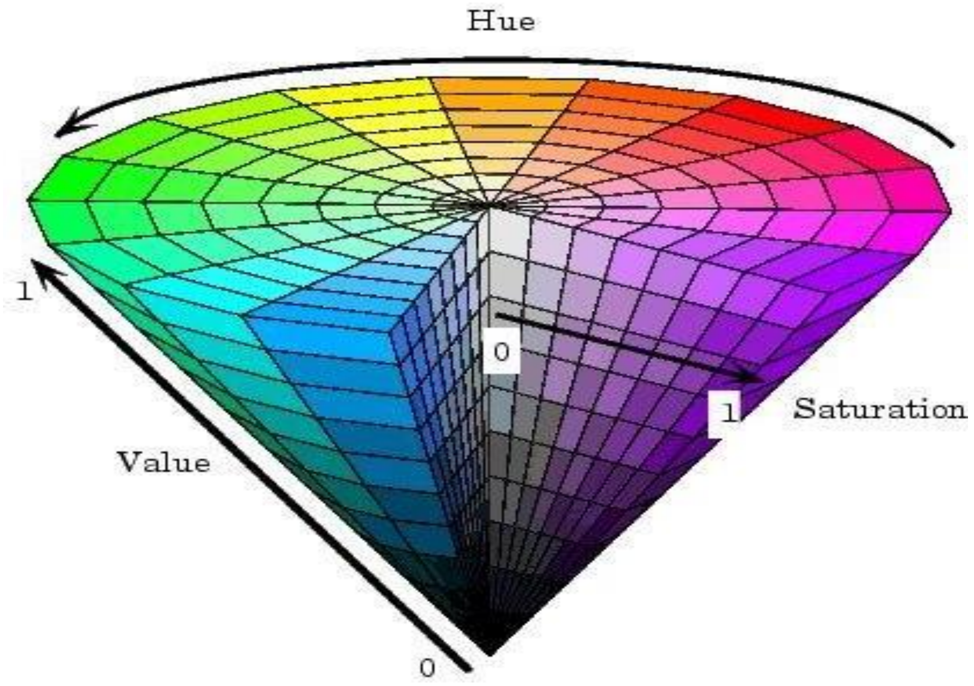
Hue Saturation } Chromaticity

amount of red (X), green (Y) and blue (Z) to form any particular color is called *tristimulus.*

Perceptual Attributes of Color

- Value of Brightness (perceived luminance)
- Chrominance
  - **Hue**
    - specify color tone (redness, greenness, etc.)
    - depend on peak wavelength
  - **Saturation**
    - describe how pure the color is
    - depend on the spread (bandwidth) of light spectrum
    - reflect how much white light is added

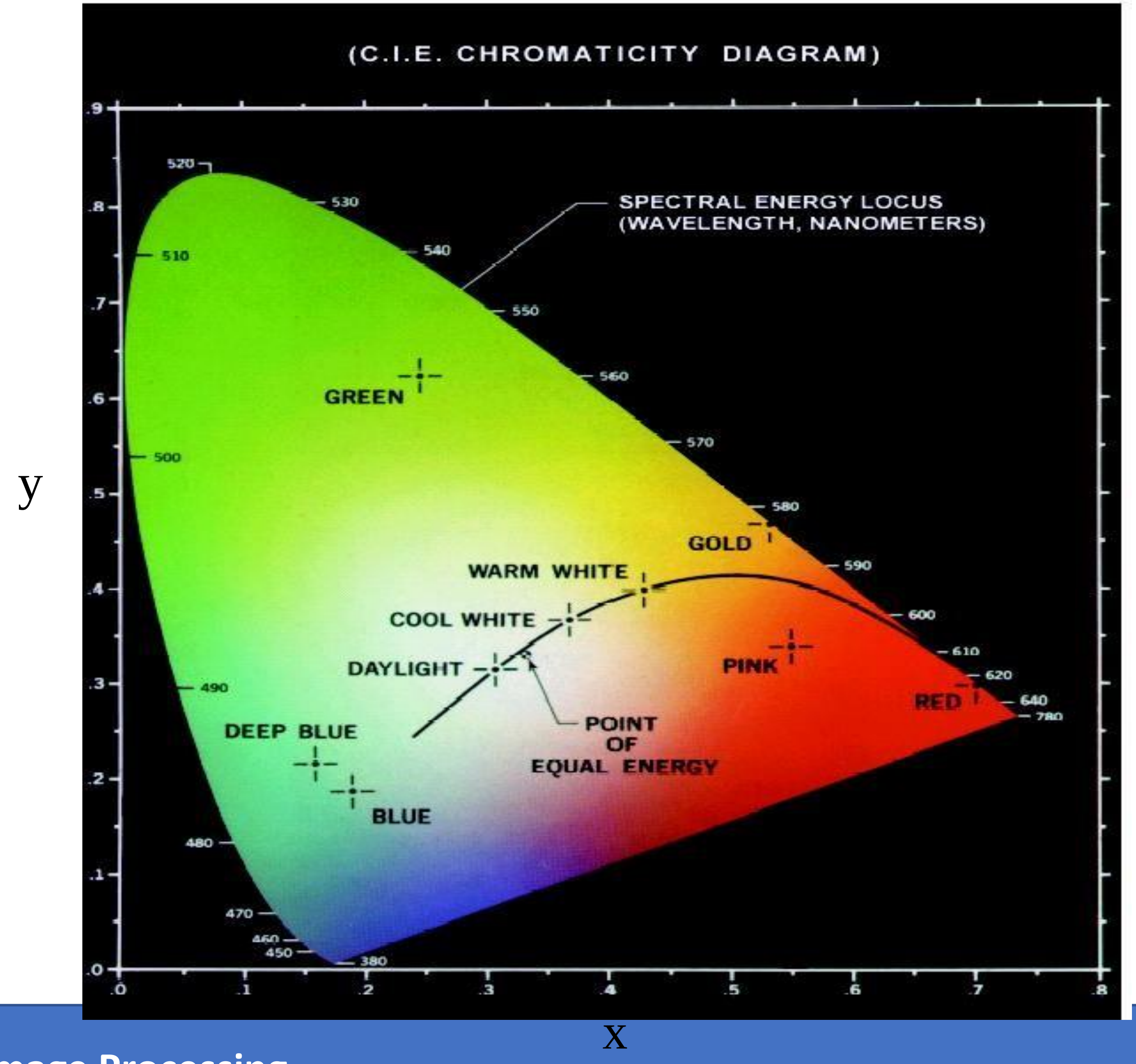
- RGB □ HSV Conversion ~ *nonlinear*



HSV circular cone is from online documentation of Matlab image processing toolbox

http://www.mathworks.com/access /helpdesk/help/toolbox/images/col or10.shtml

CIE Chromaticity Diagram



Trichromatic coefficients:

$$x = \frac{X}{X+Y+Z}$$

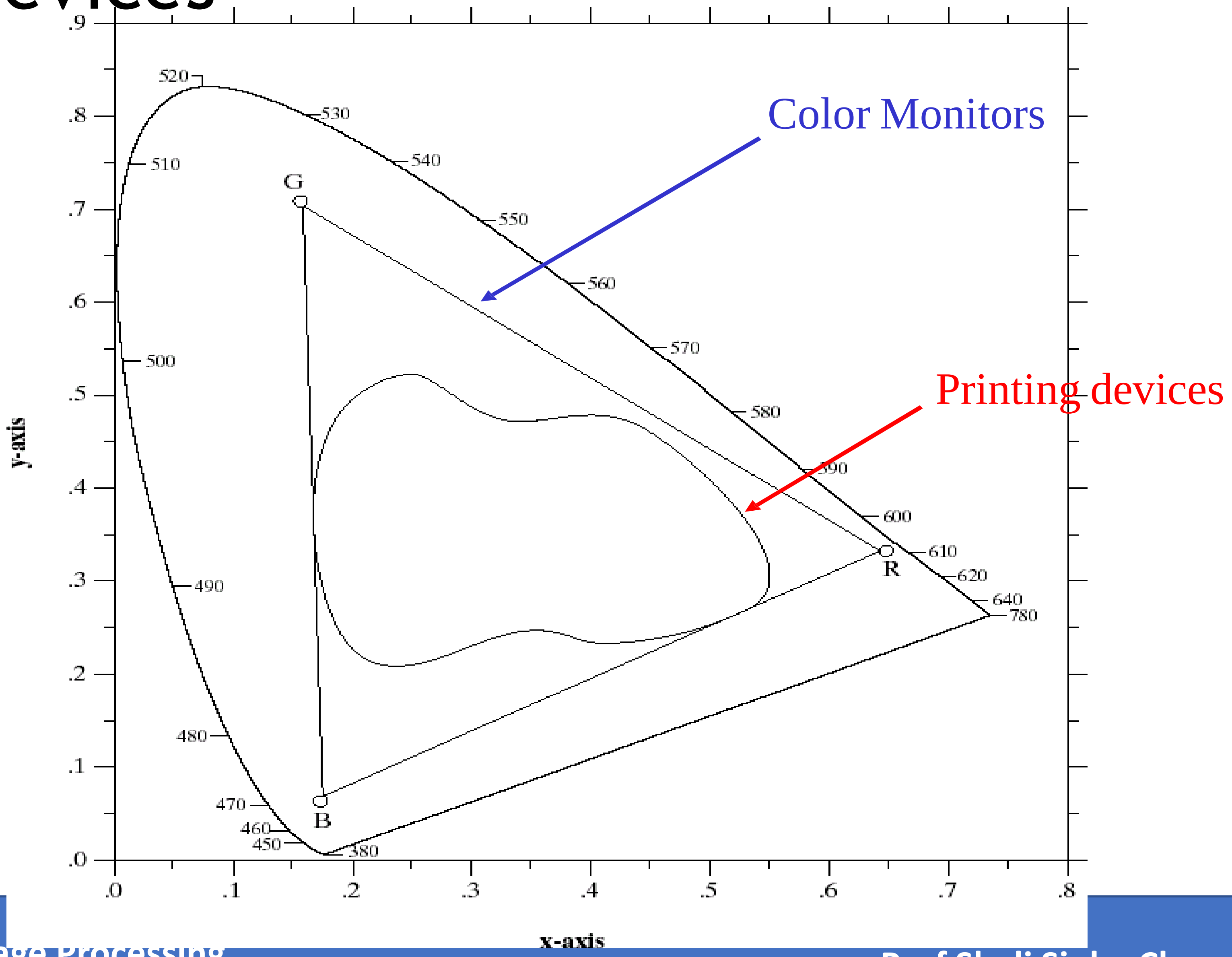
$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

Points on the boundary are fully saturated colors

Color Gamut of Color Monitors and Printing Devices

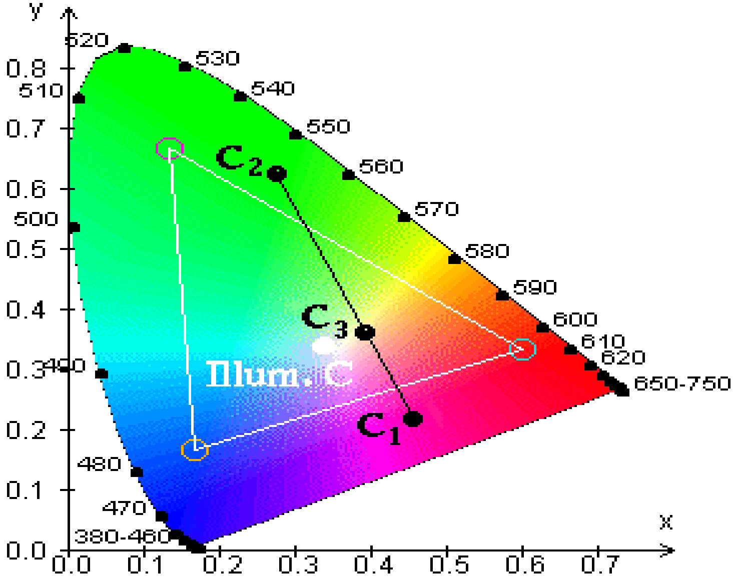


CIE Color Coordinates (cont'd)

- CIE XYZ system

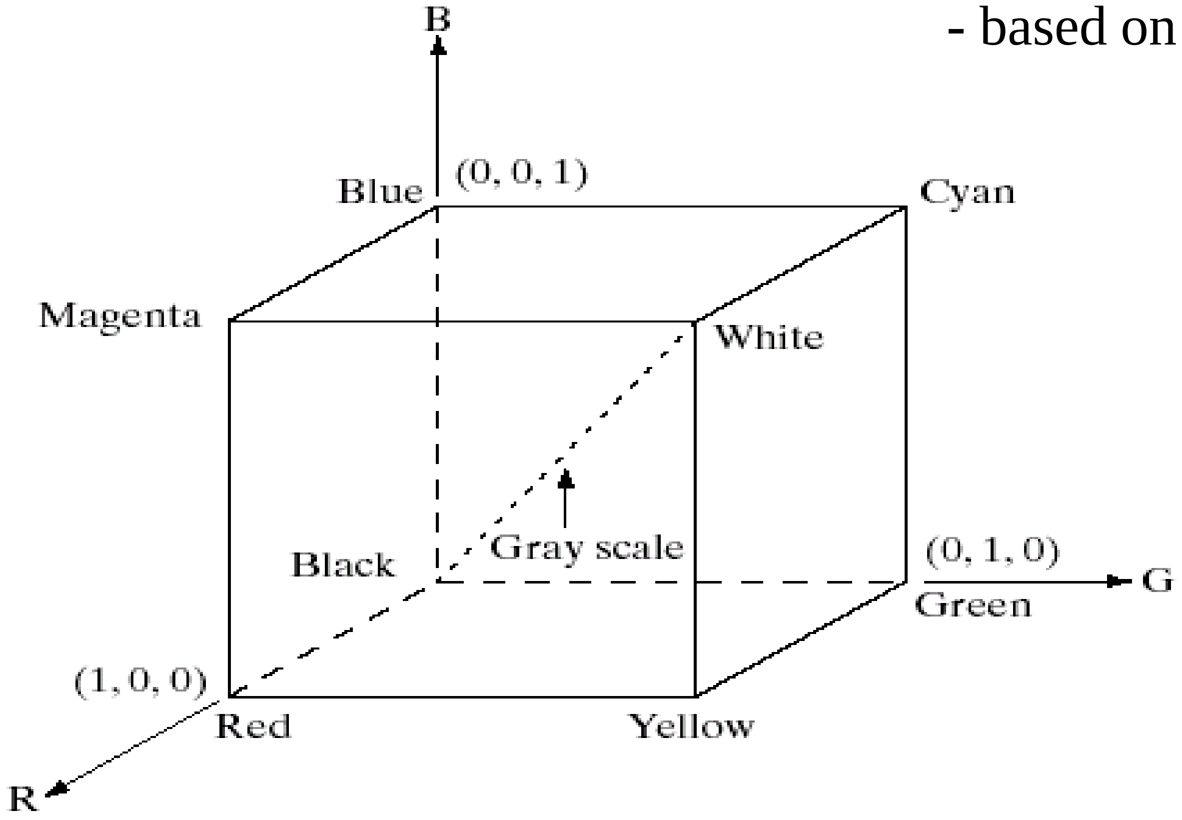
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.490 & 0.310 & 0.200 \\ 0.177 & 0.813 & 0.011 \\ 0.000 & 0.010 & 0.990 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

  - hypothetical primary sources to yield all-positive spectral tristimulus values
  - Y ~ luminance
- Color gamut of 3 primaries
  - Colors on line C1 and C2 can be produced by linear mixture of the two
  - Colors inside the triangle gamut can be reproduced by three primaries



RGB Color Model

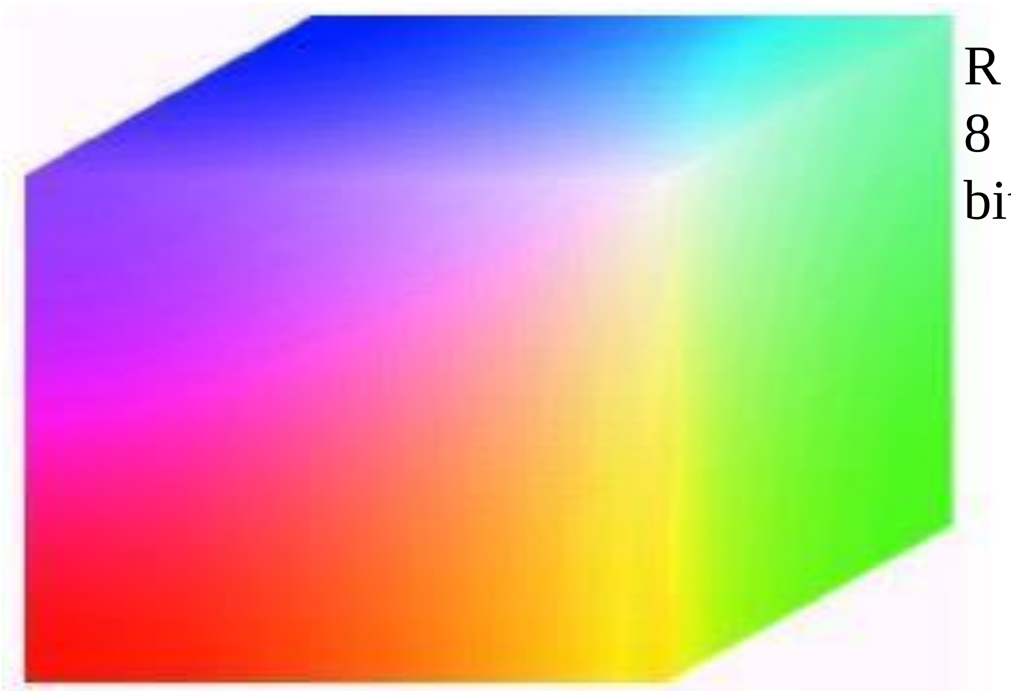
Purpose of color models: to facilitate the specification of colors in some standard



RGB color models:

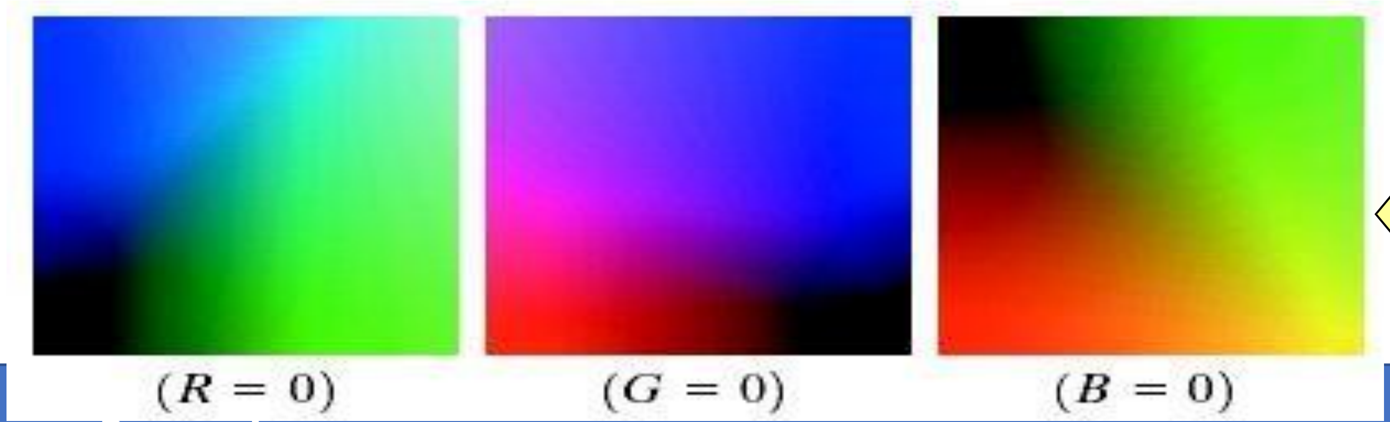
- based on cartesian coordinate system

RGB Color Cube



R = 8 bits G = 8 bits B = 8 bits

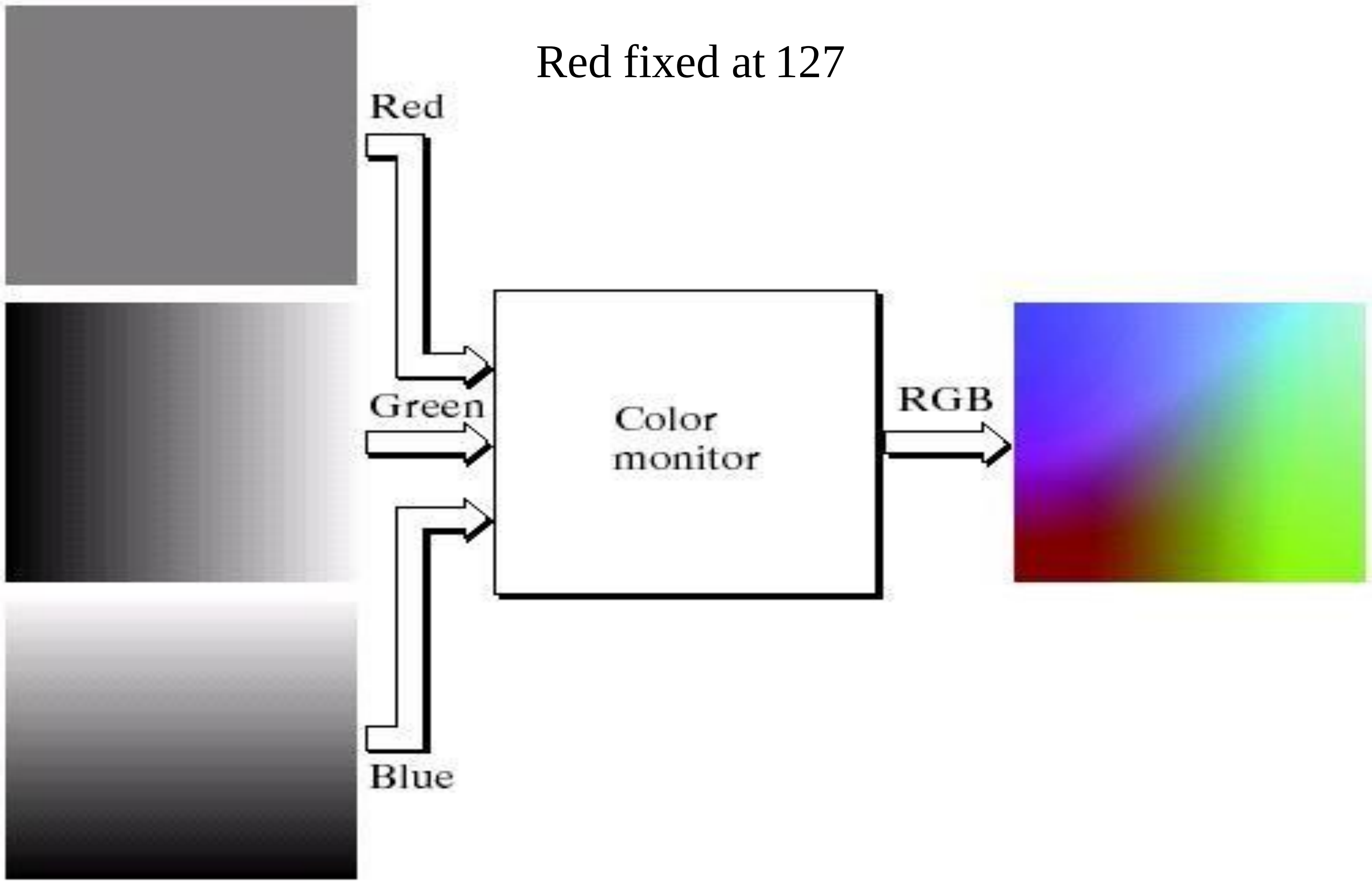
Color depth 24 bits = 16777216 colors



Hidden faces of the cube

RGB Color Model

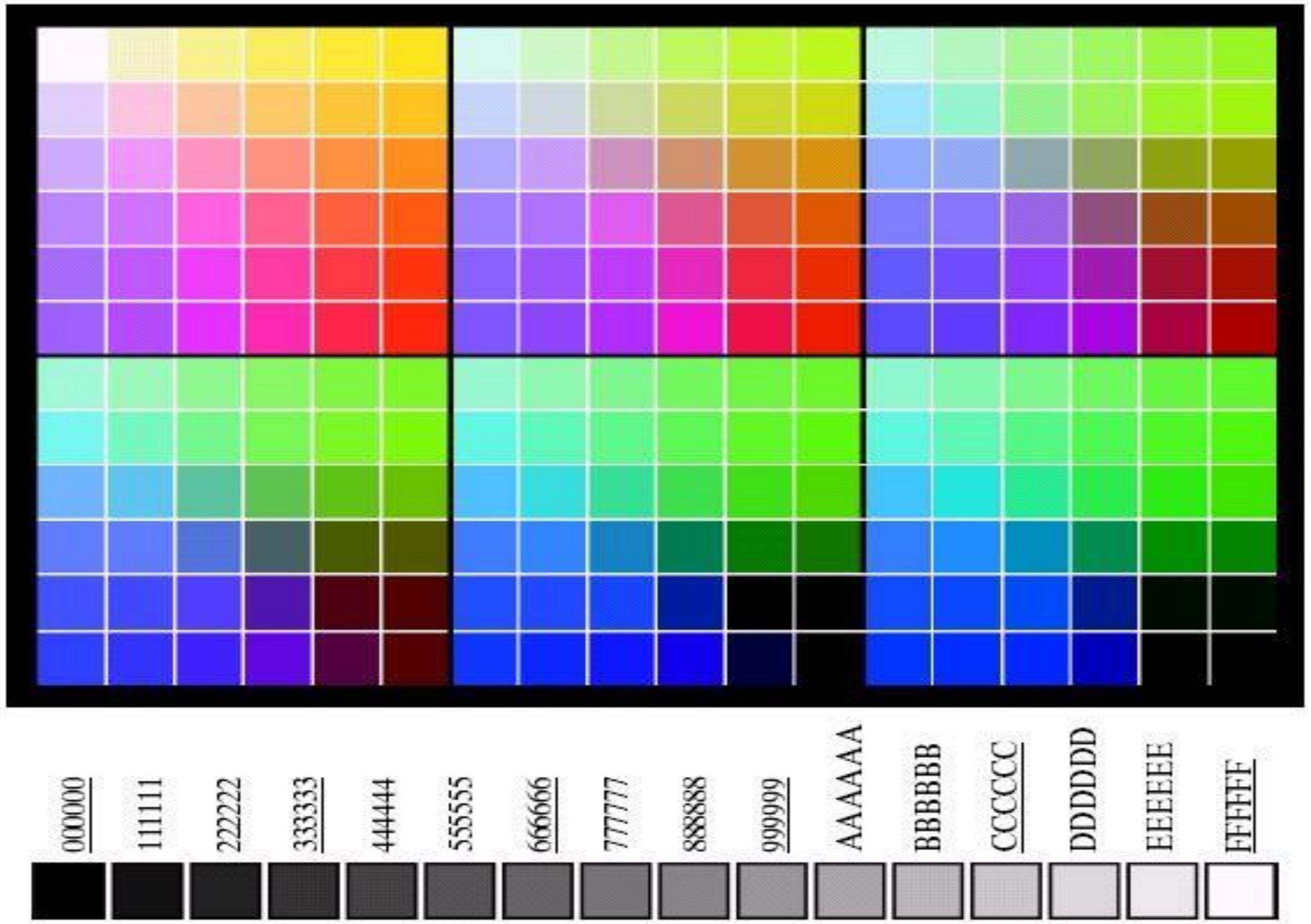
Red fixed at 127



Safe RGB Colors

Safe RGB colors: a subset of RGB colors.

There are 216 colors common in most operating systems.



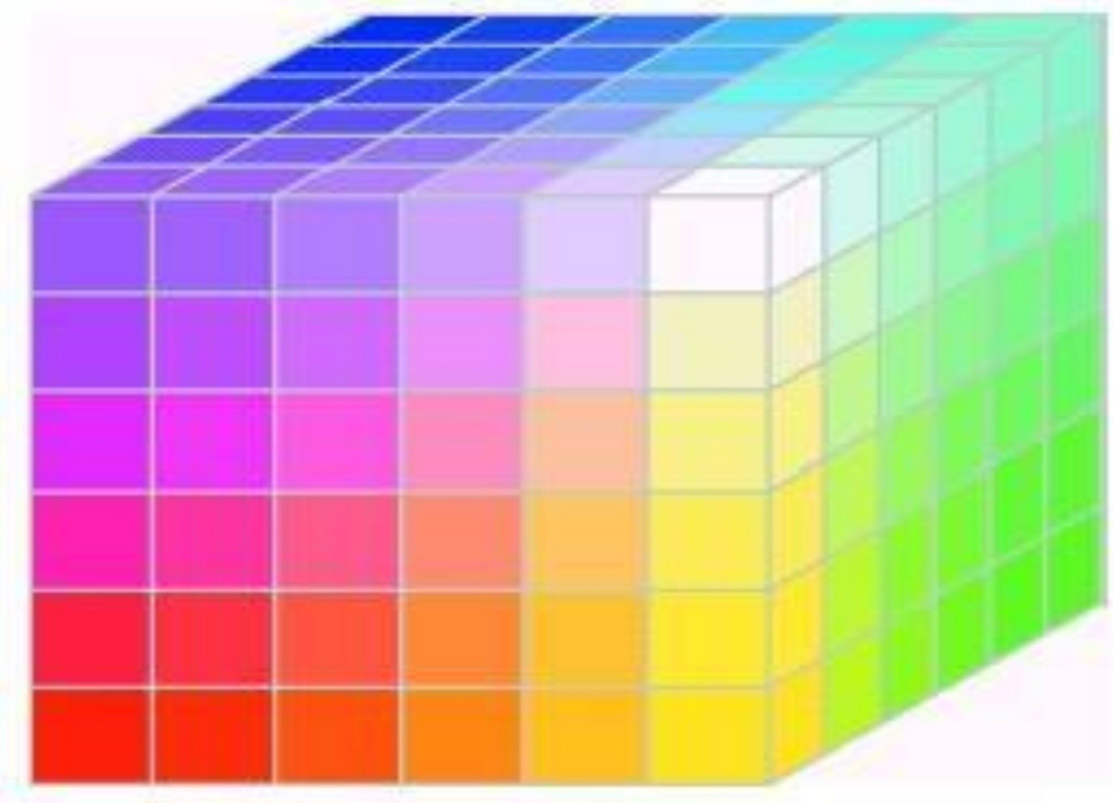
a
b

FIGURE 6.10
(a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

RGB Safe-color Cube

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.



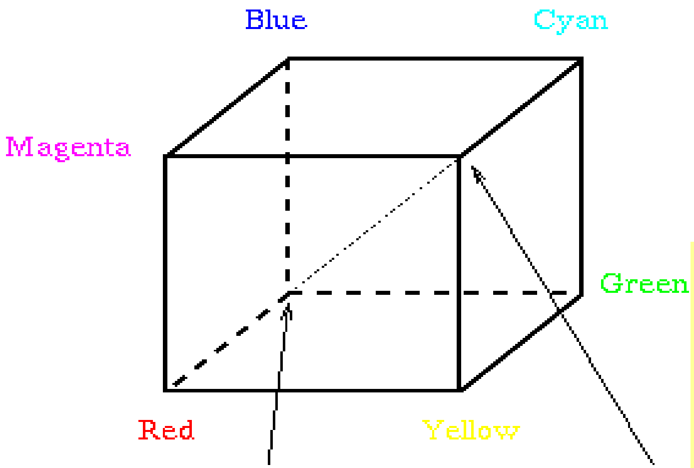
The RGB Cube is divided into 6 intervals on each axis to achieve the total $6^3 = 216$ common colors.

However, for 8 bit color representation, there are the total 256 colors. Therefore, the remaining 40 colors are left to OS.

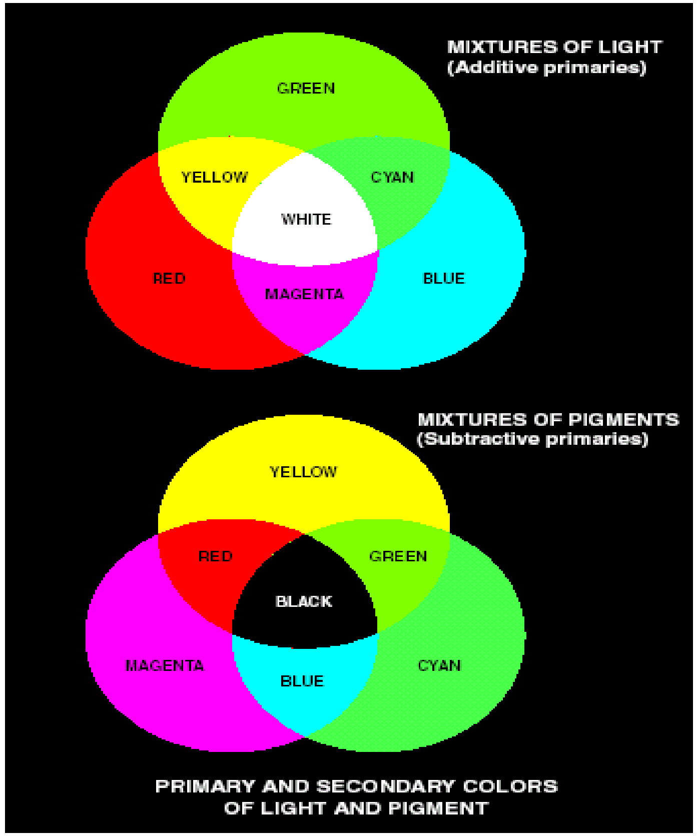
CMY and CMYK Color Models

- Primary colors for pigment
  - Defined as one that subtracts/absorbs a primary color of light & reflects the other two
- CMY – Cyan, Magenta, Yellow
  - Complementary to RGB
  - Proper mix of them produces black

C=Cyan M = Magenta
Y = Yellow K = Black



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



HSI Color Model

RGB, CMY models are not good for human interpreting

HSI Color model:

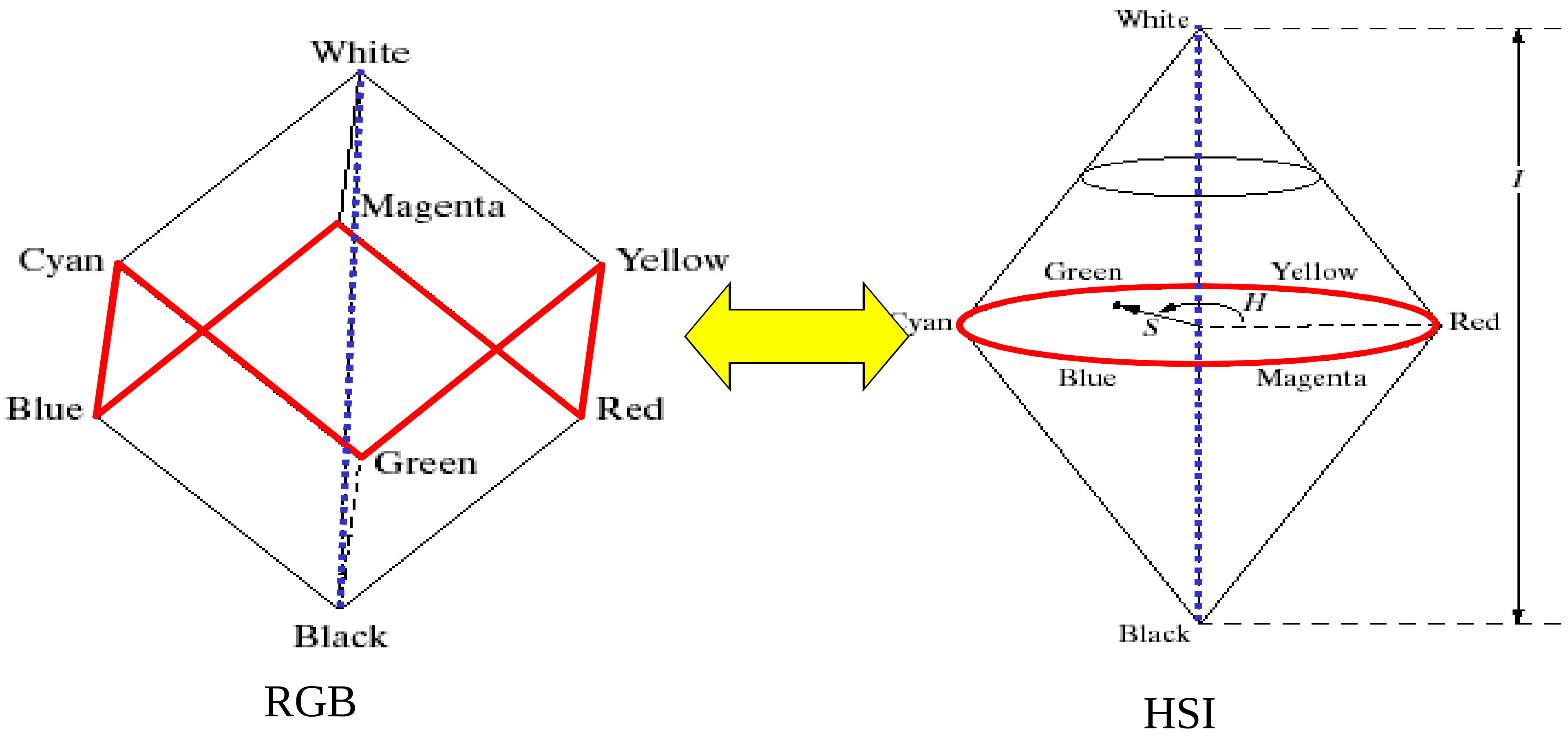
Hue: Dominant color

Saturation: Relative purity (inversely proportional to amount of white light added)

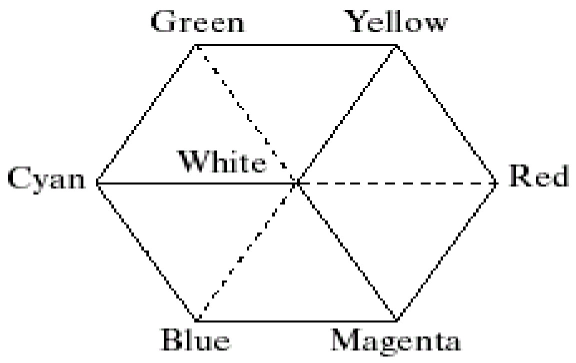
Intensity: Brightness

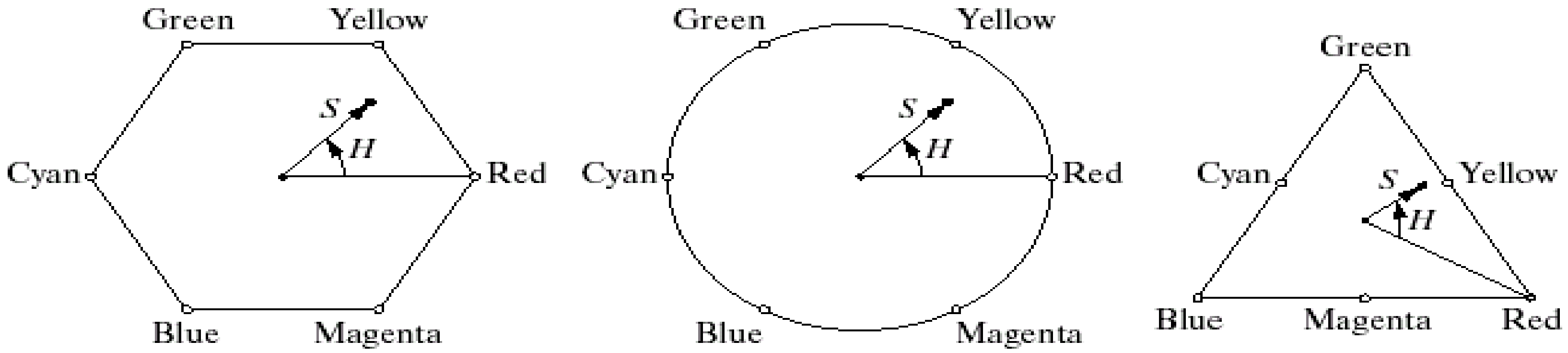
Hue and Saturation: Color carrying information

Relationship Between RGB and HSI Color Models



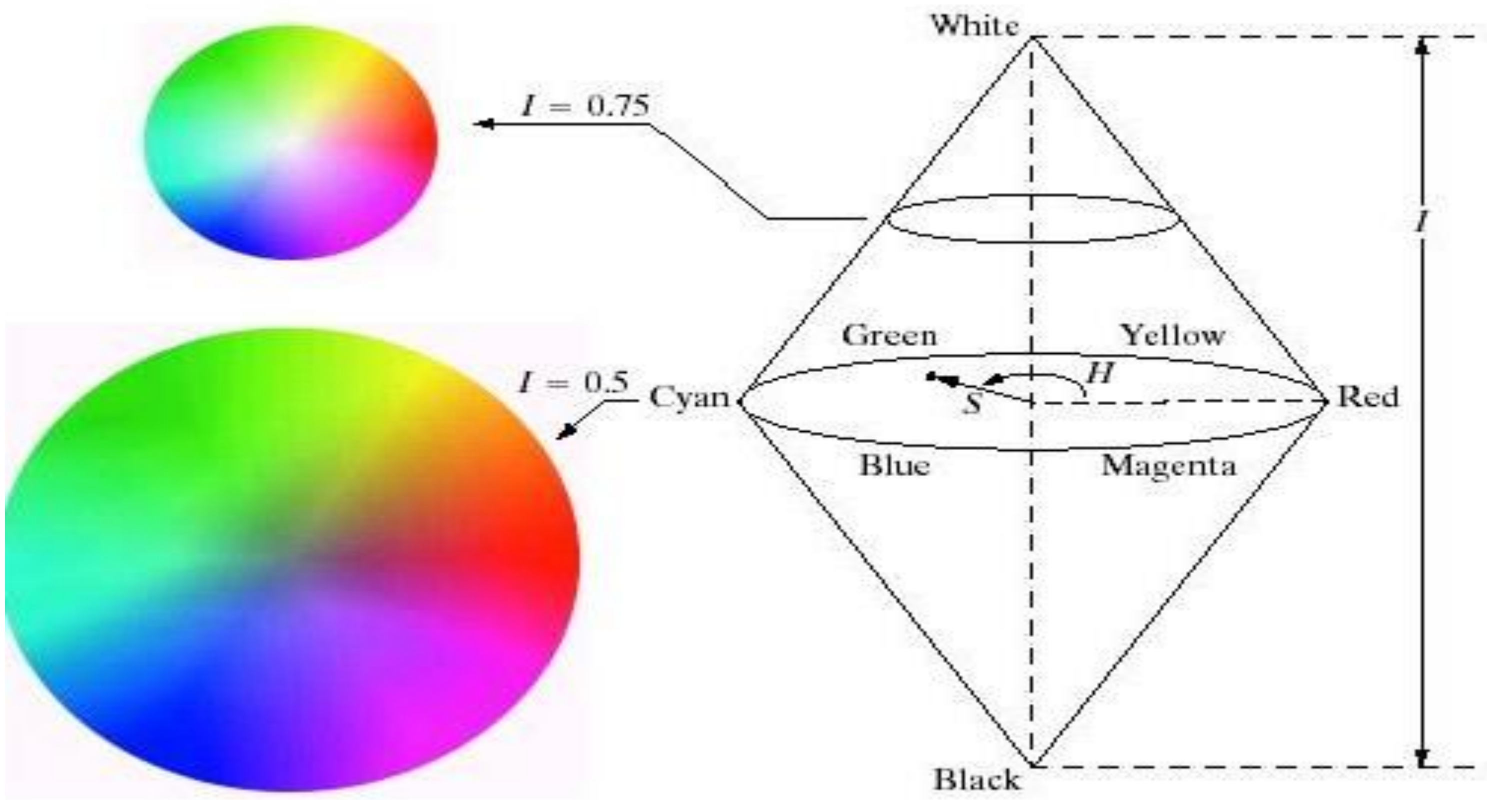
Hue and Saturation on Color Planes

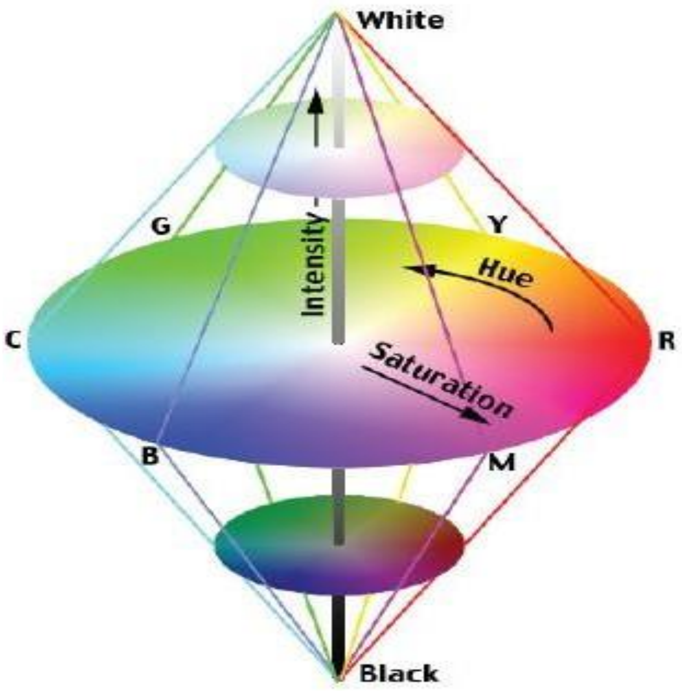




1. A dot is the plane is an arbitrary color
2. Hue is an angle from a red axis.
3. Saturation is a distance to the point.

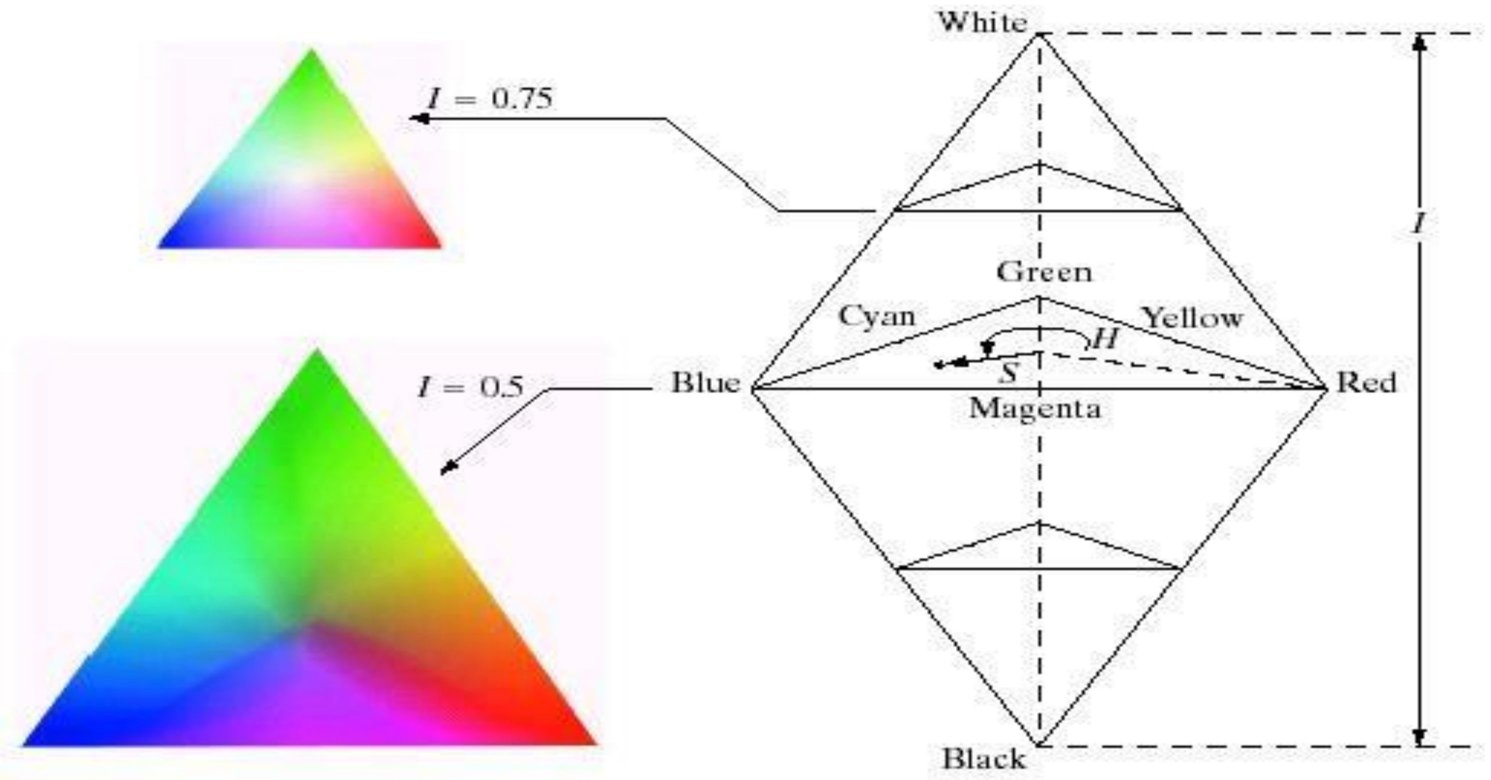
HSI Color Model (cont.)





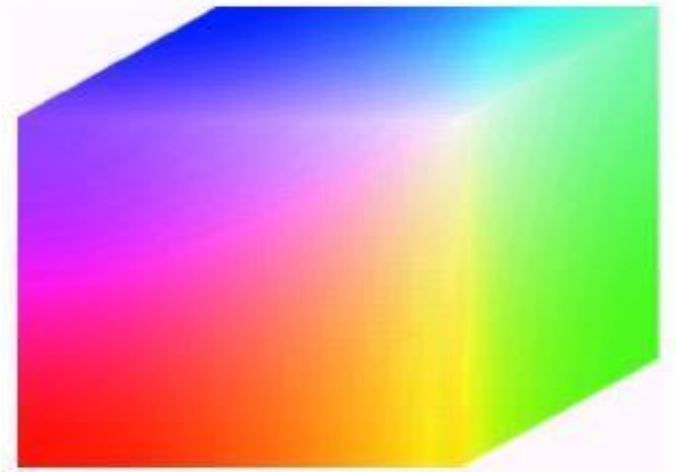
Intensity is given by a position on the vertical axis.

HSI Color Model

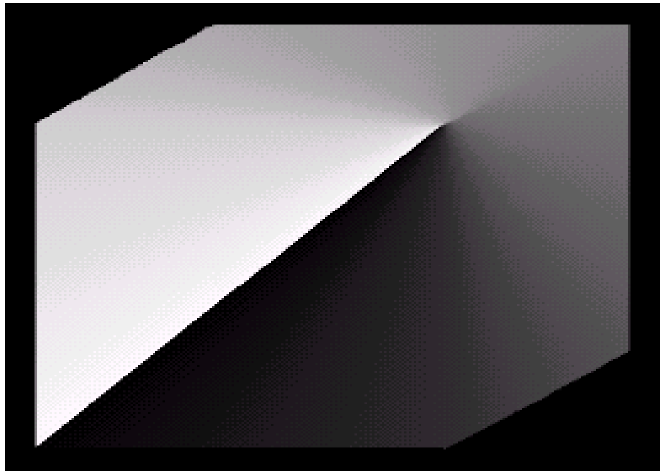


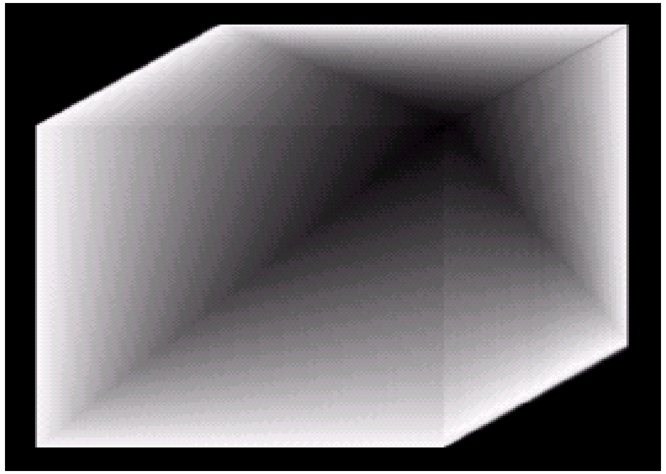
Intensity is given by a position on the vertical axis.

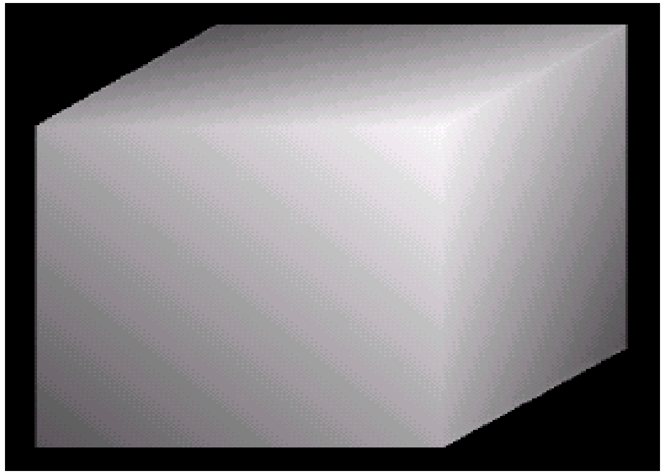
Example: HSI Components of RGB Cube



RGB Cube







Hue

Saturation

Converting Colors from RGB to HSI

$$H = \begin{cases} \gamma & \text{if } B \le G \\ 360 - \gamma & \text{if } B > G \end{cases}$$

$$\Upsilon = \quad cos^{-1}[\{1/2\ \{(R-G)+(R-B)\}\}/\{[(R-G)]\hat{}2+(R-B)(G-B)\}\quad ^{1/2}]$$

$$S = 1 - \frac{3}{R+G+B}$$

$$I = \frac{1}{}(R+G+B)\ \ 3$$

Converting Colors from HSI to RGB

RG sector: $0 \le H < 120$

$$R = I\left[1 + \frac{S\cos H}{\cos(60^{o} - H)}\right]$$

$$B = I(1-S)$$

$$G = 1-(R+B)$$

GB sector: $120 \le H < 240$

$$H = H - 120$$

$$R = I(1-S)$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60^{o} - H)}\right]$$

$$B = 1-(R+G)$$

BR sector: $240 \le H \le 360$

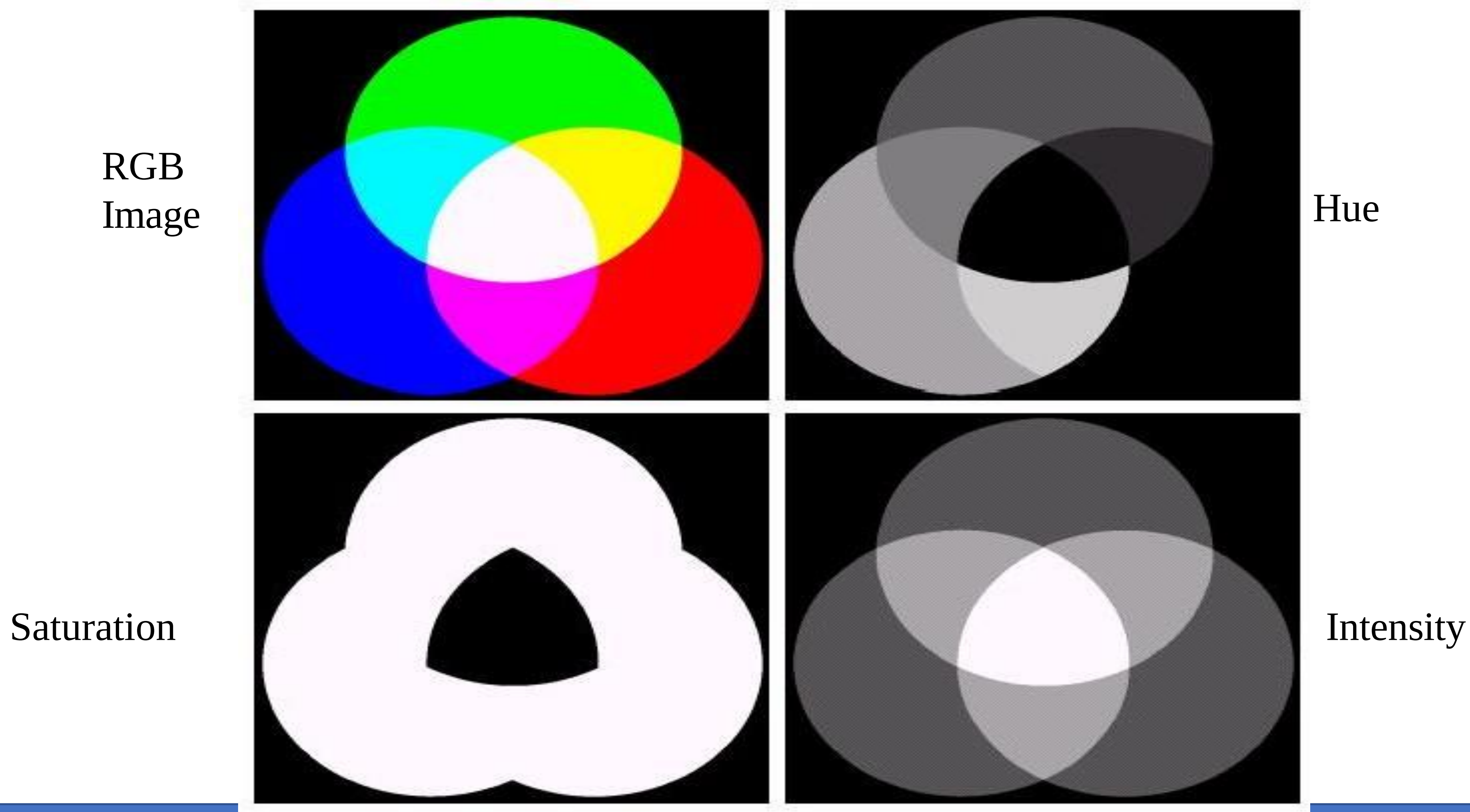
$$H = H - 240$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^{o} - H)}\right]$$

$$G = I(1-S)$$

$$R = 1-(G+B)$$

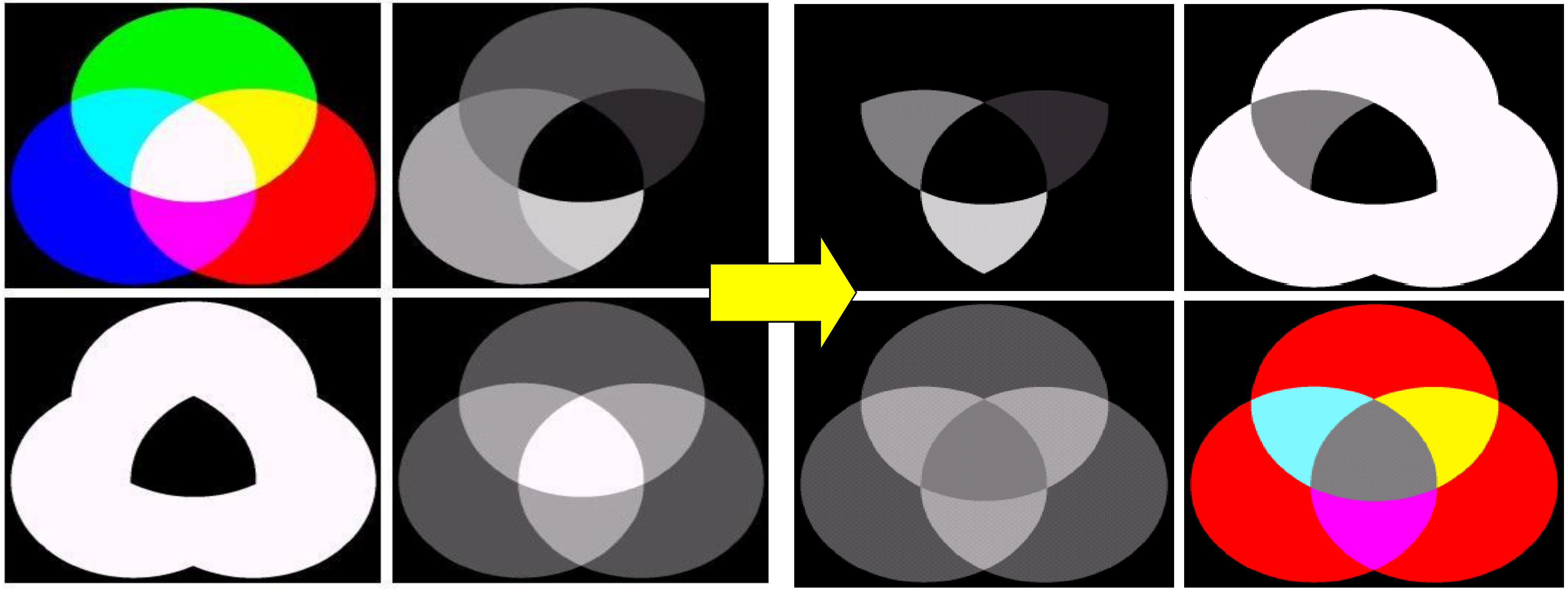
Example: HSI Components of RGB Colors



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Example: Manipulating HSI Components

RGB Image | Hue | Hue | Saturation



Saturation | Intensity | Intensity | RGB Image

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Color Coordinates Used in TV Transmission

- Facilitate sending color video via 6MHz mono TV channel
- YIQ for NTSC (National Television Systems Committee) transmission system
  - Use receiver primary system (R_N, G_N, B_N) as TV receivers standard
  - Transmission system use (Y, I, Q) color coordinate
    - Y ~ luminance, I & Q ~ chrominance
    - I & Q are transmitted in through orthogonal carriers at the same freq.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R_N \\ G_N \\ B_N \end{bmatrix}.$$

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \begin{bmatrix} R_P \\ G_P \\ B_P \end{bmatrix}.$$

- YUV (YCbCr) for PAL and digital video
  - Y ~ luminance, Cb and Cr ~ chrominance

Color Coordinates

- RGB of CIE
- XYZ of CIE
- RGB of NTSC
- YIQ of NTSC
- YUV (YCbCr)
- CMY

Examples

Examples

A colour image

Red component

Green component

Blue component

RGB

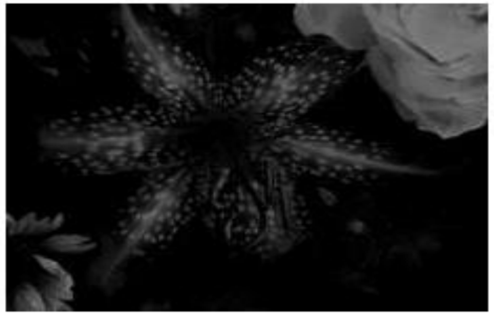
Hue

Saturation

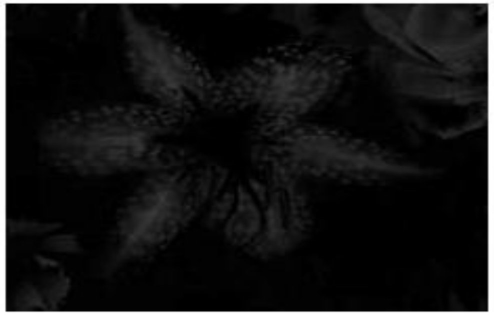
Value

HSV

Y



I



Q

YIQ

Summary

- Monochrome human vision
  - visual properties: luminance vs. brightness, etc.
  - image fidelity criteria
- Color
  - Color representations and three primary colors
  - Color coordinates

Color Image Processing

There are 2 types of color image processes

1. Pseudocolor image process: Assigning colors to gray values based on a specific criterion. Gray scale images to be processed may be a single image or multiple images such as multispectral images

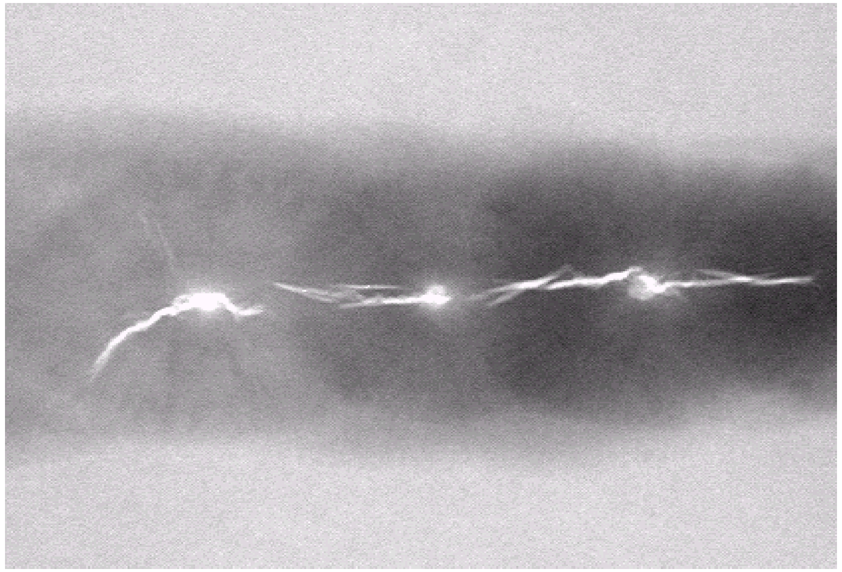
2. Full color image process: The process to manipulate real color images such as color photographs.

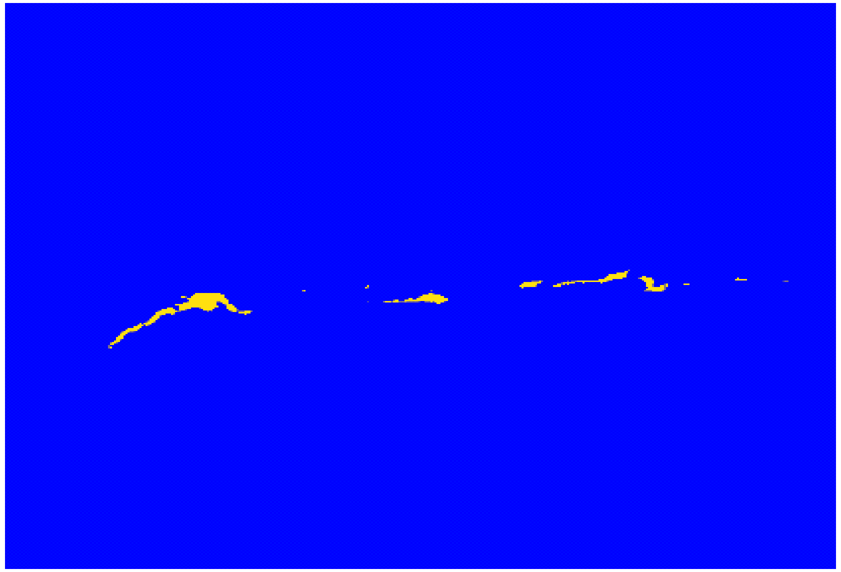
Pseudocolor Image Processing

Pseudo color = false color : In some case there is no “color” concept for a gray scale image but we can assign “false” colors to an image.

Why we need to assign colors to gray scale image?

Answer: Human can distinguish different colors better than different shades of gray.





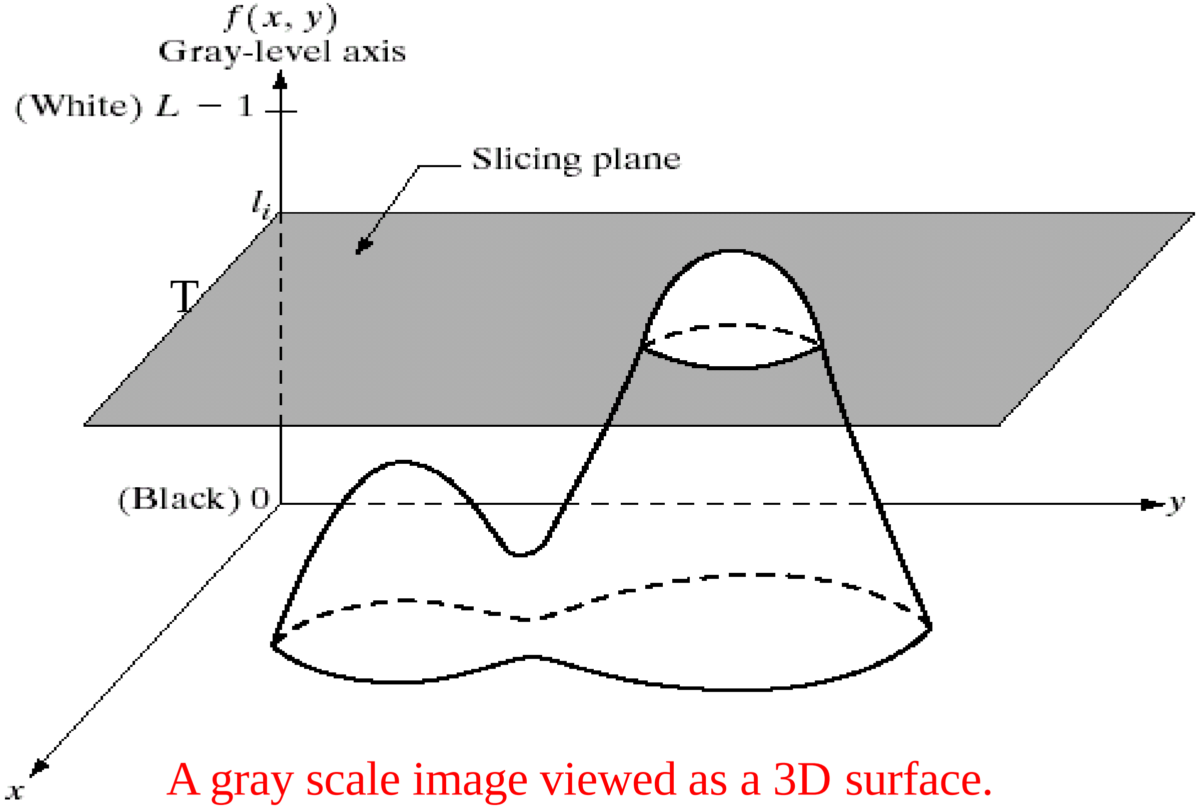
(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Intensity Slicing or Density Slicing

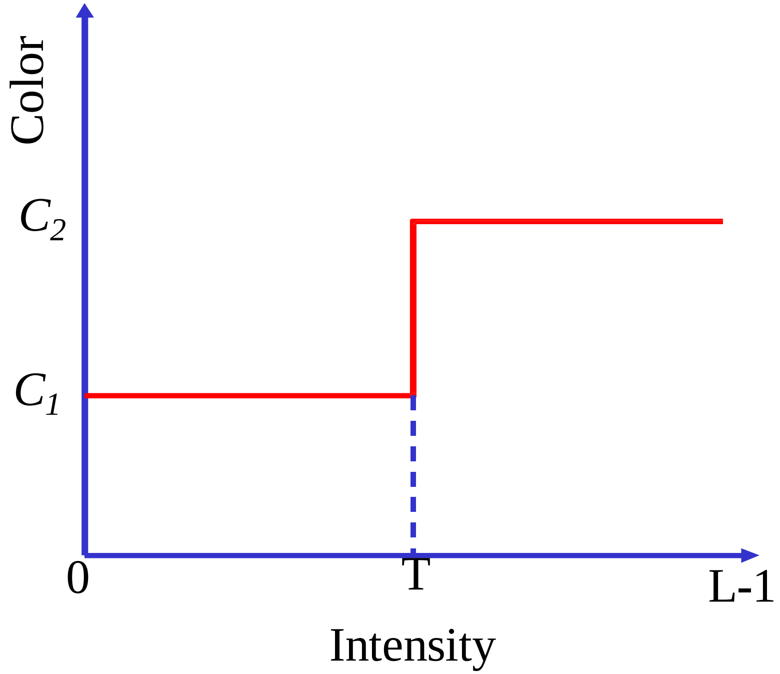
Formula:

$$g(x,y) = \begin{cases} C_1 & \text{if } f(x,y) \le T \\ C_2 & \text{if } f(x,y) > T \end{cases}$$

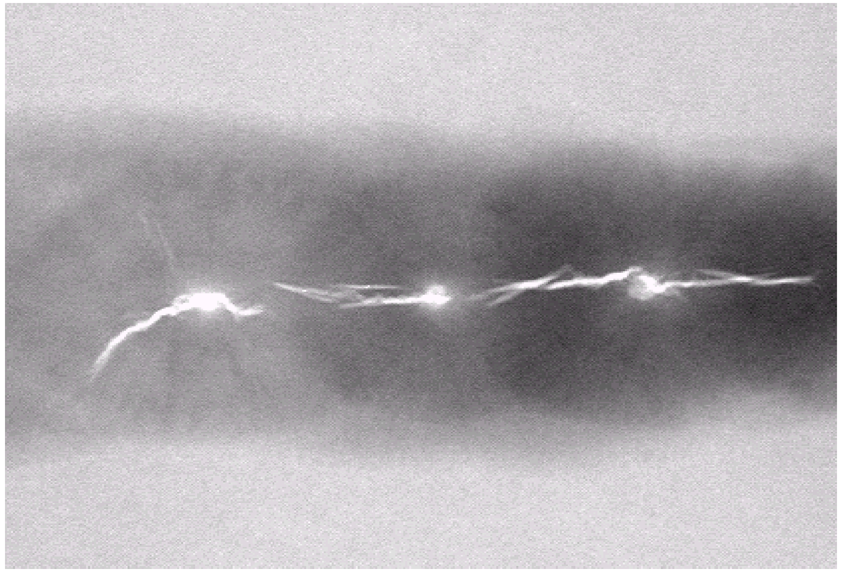
C_1 = Color No. 1
C_2 = Color No. 2



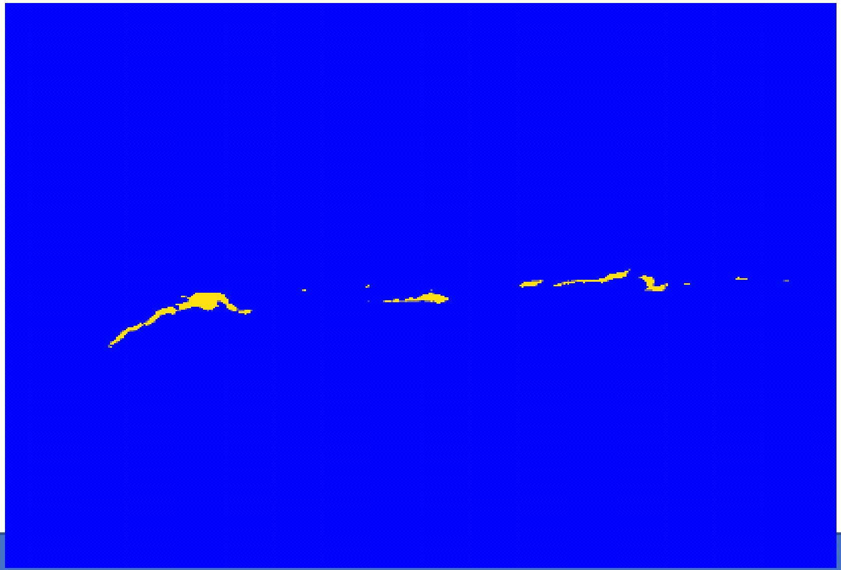
A gray scale image viewed as a 3D surface.



Intensity Slicing Example



An X-ray image of a weld with cracks



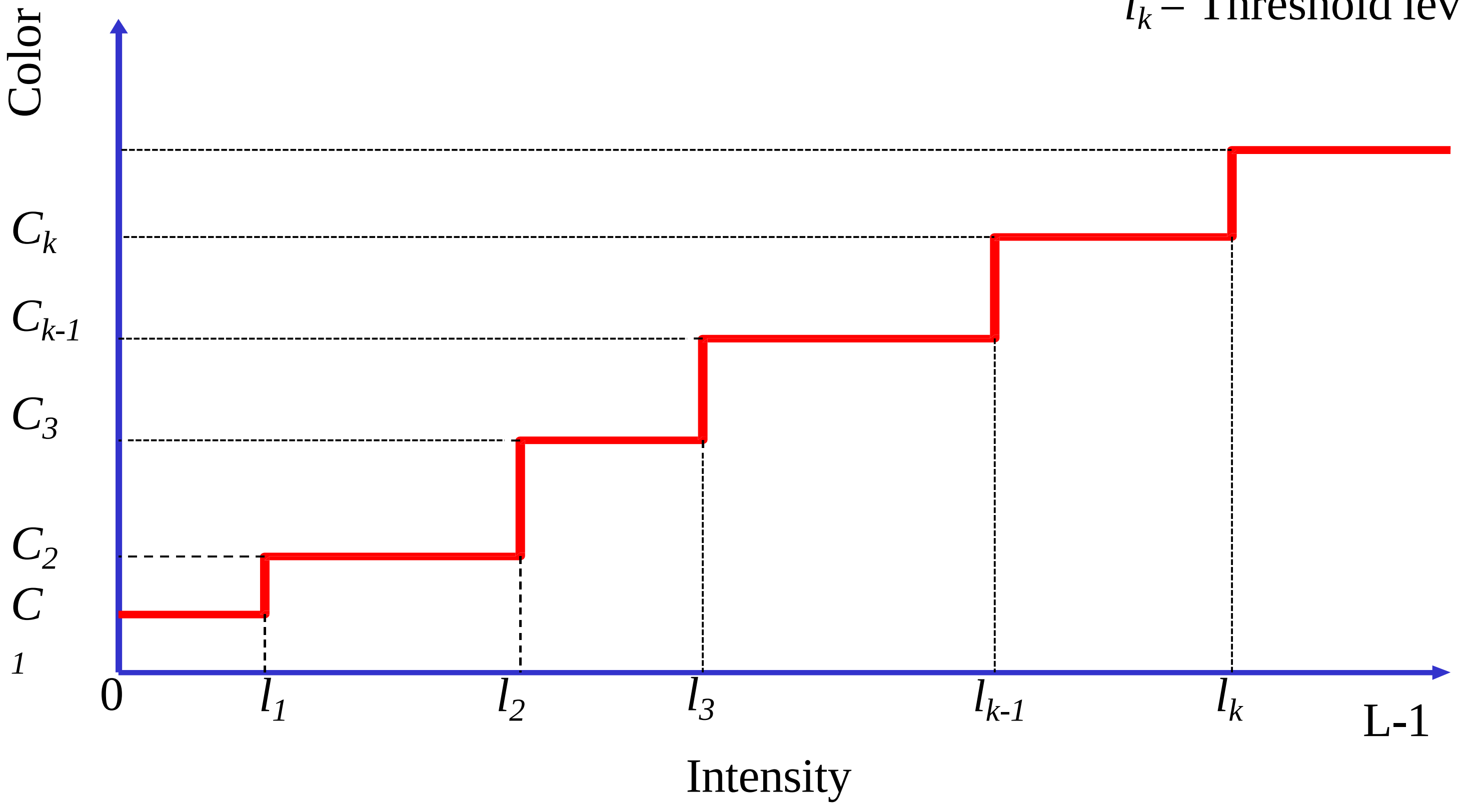
After assigning a yellow color to pixels with value 255 and a blue color to all other pixels.

Multi Level Intensity Slicing

$$g(x, y) = C_k \qquad \text{for } l_{k-1} < f(x, y) \le l_k$$

grey level:	0–63	64–127	128–191	192–255
colour:	blue	magenta	green	red

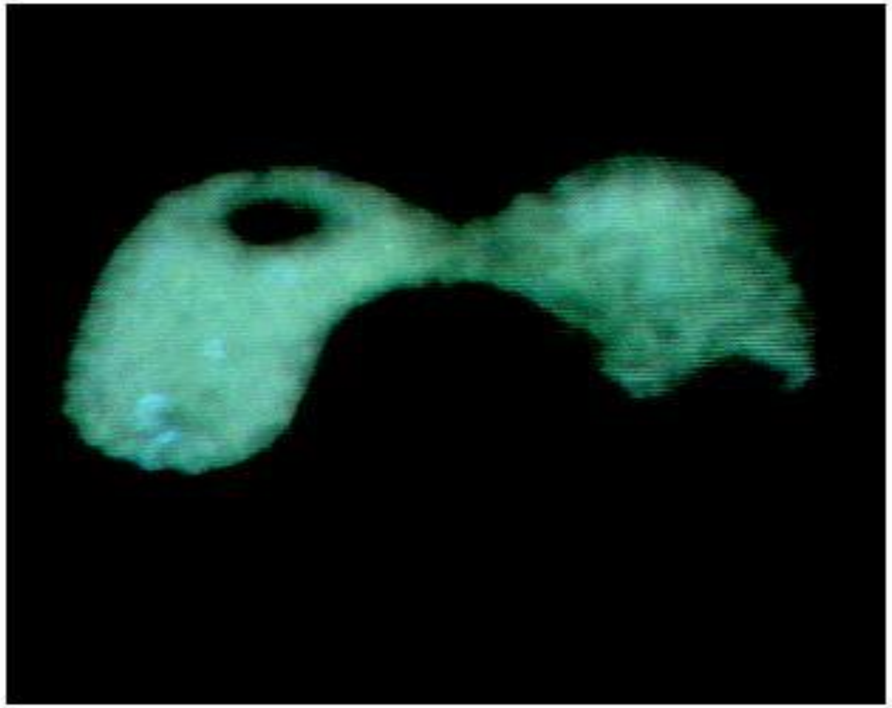
C_k = Color No. k
l_k = Threshold level k



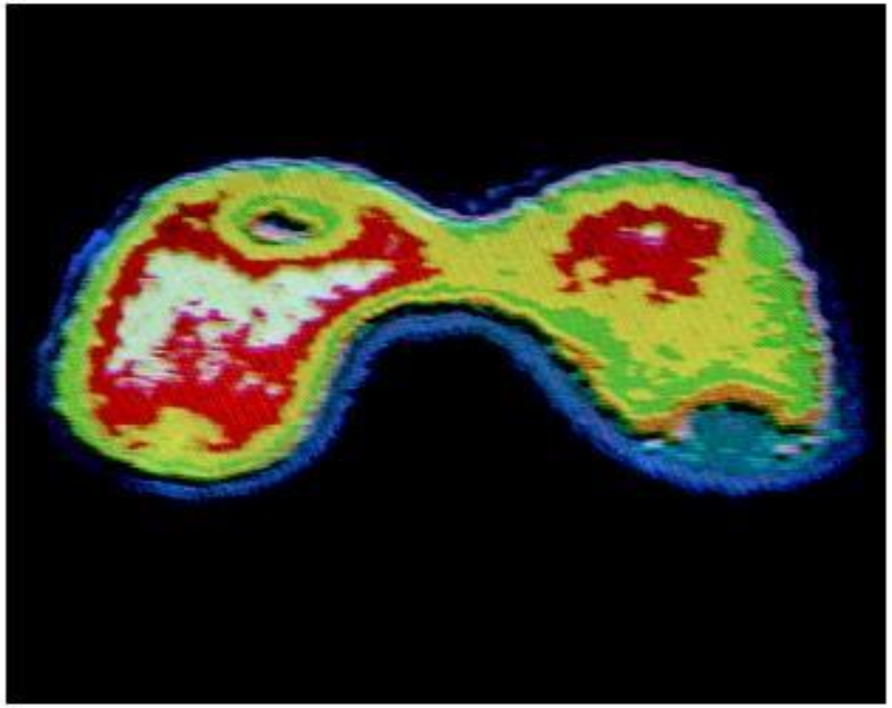
Multi Level Intensity Slicing Example

$$g(x,y) = C_k \qquad \text{for } l_{k-1} < f(x,y) \le l_k$$

C_k = Color No. k
l_k = Threshold level k

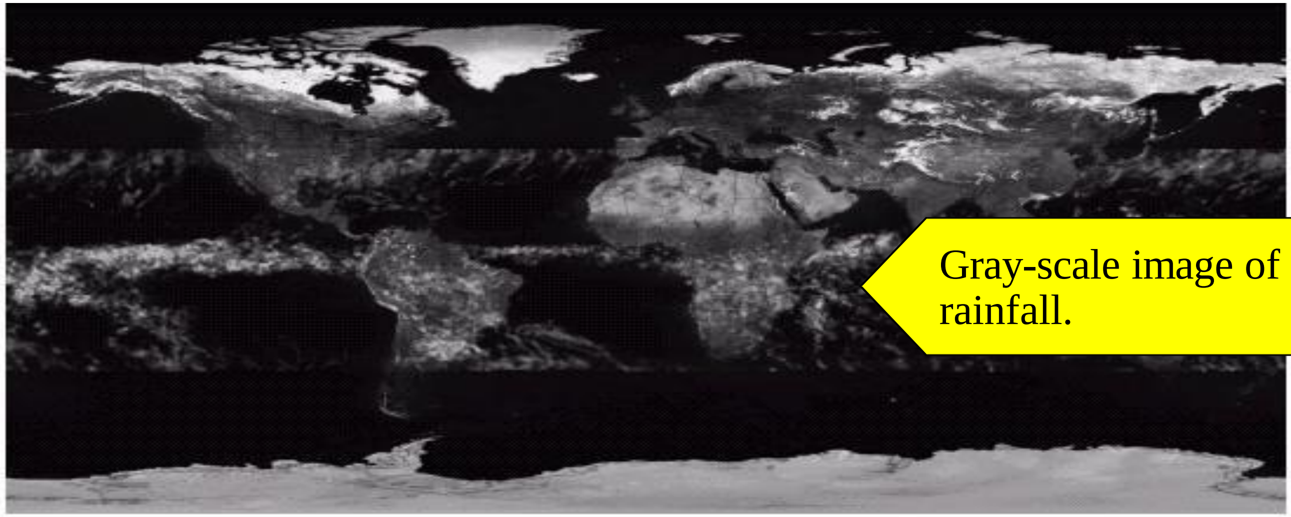


An X-ray image of the Picker Thyroid Phantom.



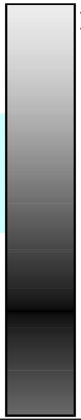
After density slicing into 8 colors

Color Coding Example



Gray-scale image of average monthly rainfall.

Gray Scale

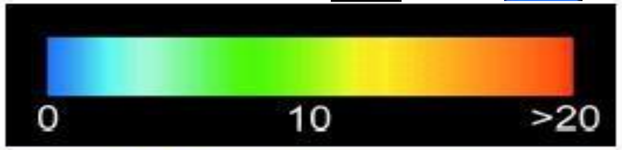


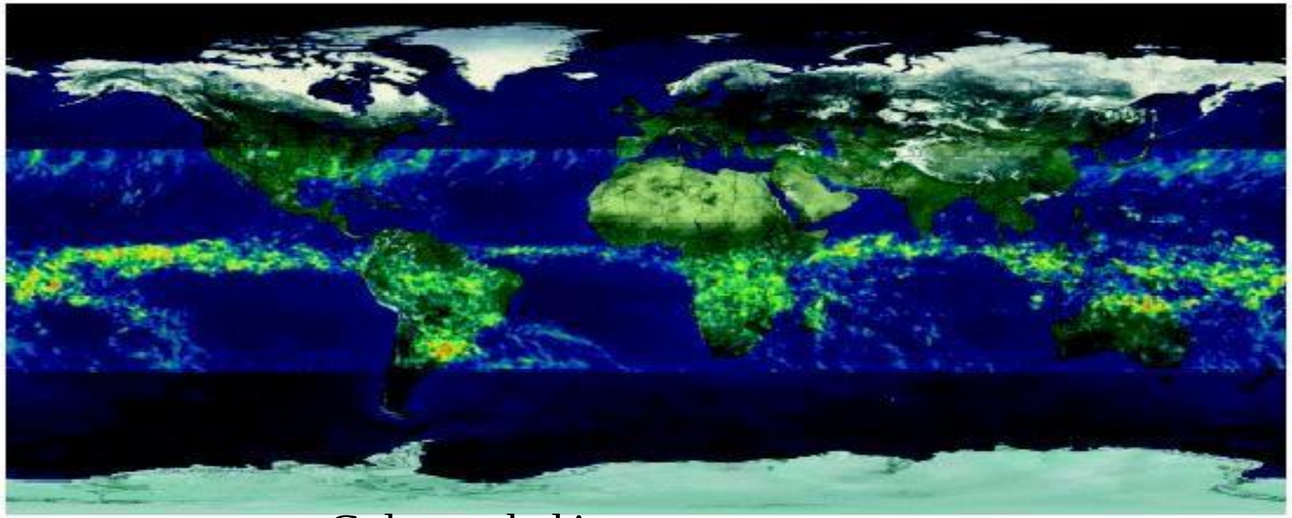
>20

10

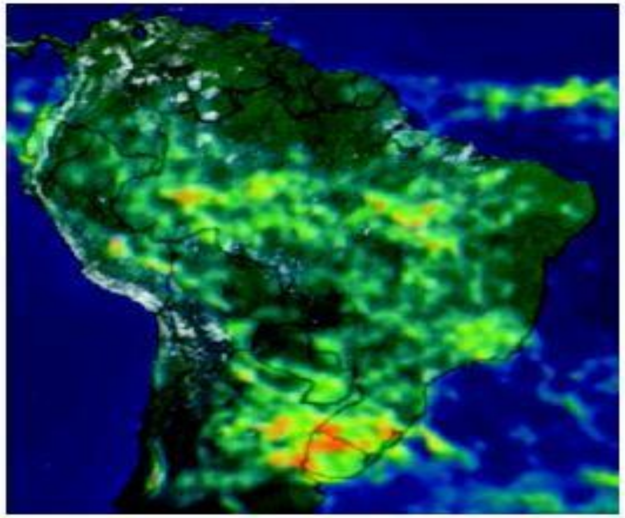
0

Color map





Color coded image

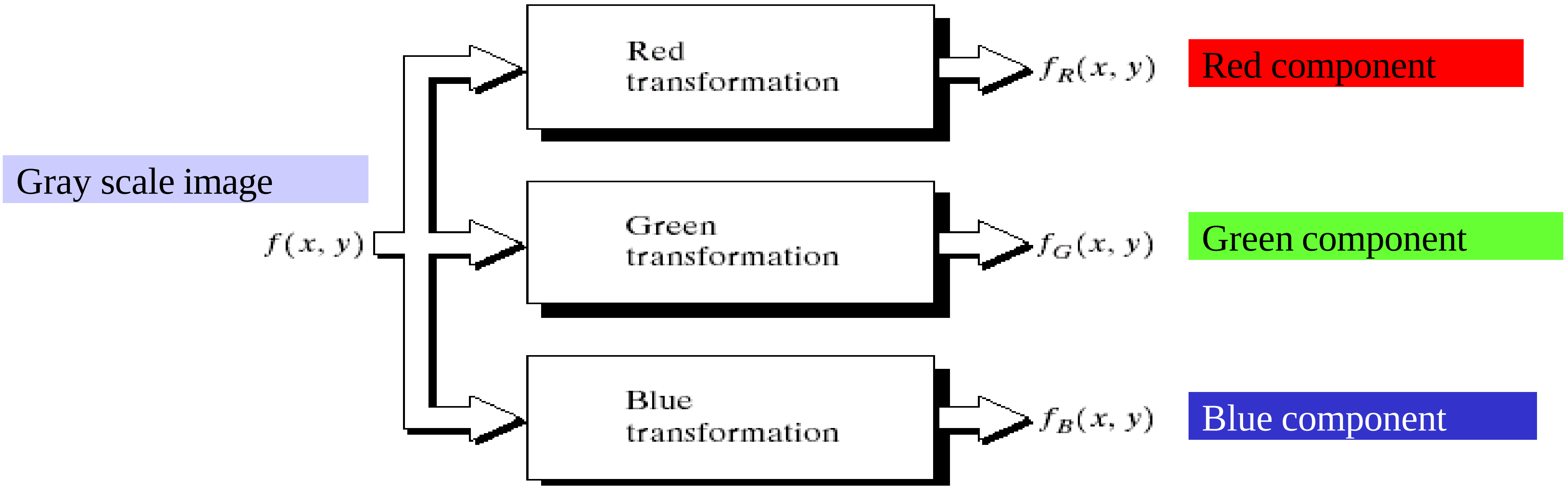


South America region

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

Gray Level to Color Transformation

Assigning colors to gray levels based on specific mapping functions

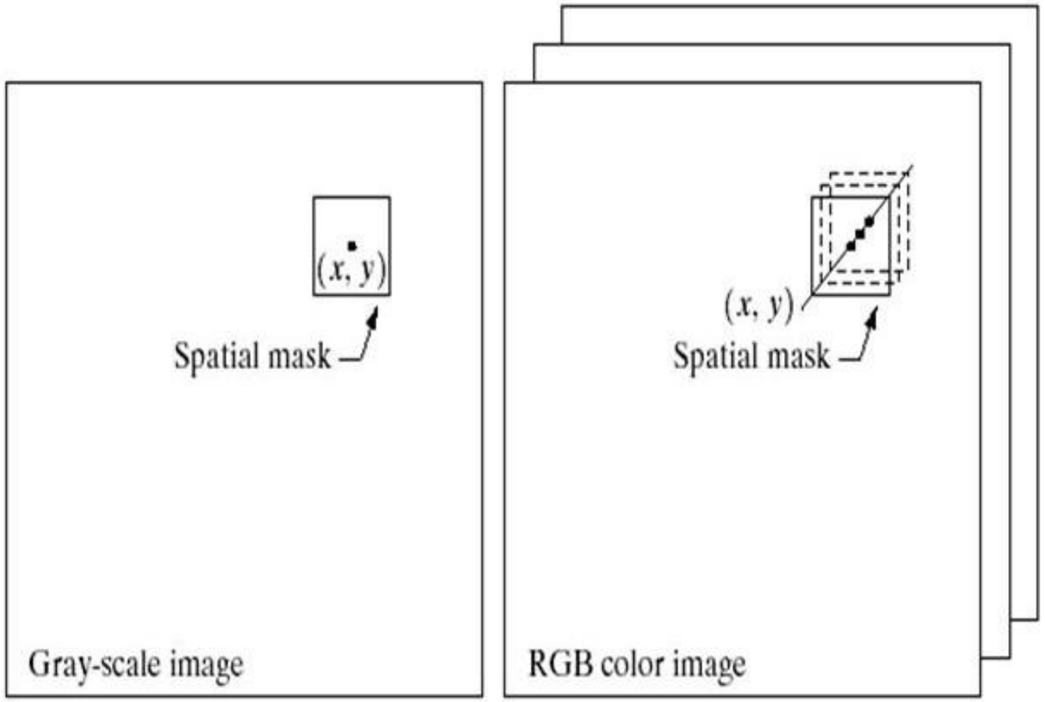


Therefore 3 independent transformations on the intensity of any input pixel is performed.
Then the 3 results are fed separately into the red, green and blue channels of a colour monitor
This produces a composite image whose colour content is modulated by the nature of the transformation functions.
They are not functions of position.

Colour Transformation

a b

FIGURE 6.29 Spatial masks for gray-scale and RGB color images.



Colour Transformation

- Color transformation can be represented by the expression ::

$$g(x,y)=T[f(x,y)]$$

$f(x,y)$: input image
$g(x,y)$: processed (output) image
$T[*]$: an operator on f defined over neighborhood of (x,y).

The pixel values here are triplets or quartets (i.e group of 3 or 4 values)

Colour Transformation

- $S_i = T_i(r_1, r_2, \ldots, r_n)$ $i = 1, 2, 3, \ldots, n$

  ri and Si are variables denoting the color components of f(x,y) and g(x,y) at any point (x,y).

  n is the no of color components

  {T1,T2,.....,Tn} is a set of transformation or color mapping functions.

- Note that n transformations combine to produce a single transformation T

Colour Transformation

- The color space chosen determine the value of n.
- If RGB color space is selected then n=3 & r1,r2,r3 denotes the red, blue and green components of the image.
- If CMYK color space is selected then n=4 & r1,r2,r3,r4 denotes the cyan, hue, magenta and black components of the image.
- Suppose we want to modify the intensity of the given image using $g(x,y)=k*f(x,y)$ where $0<k<1$

Full color

Colour Transformation

- In HSI color space this can be done with the simple transformation
  $s3=k*r3$
  where $s1=r1$ and $s2=r2$
  Only intensity component r3 is modified.

- In RGB color space 3 components must be transformed:
  $si=k*ri \qquad i=1,2,3.$

- Using k=0.7 the intensity of an image is decreased by 30%

Colour Transformation

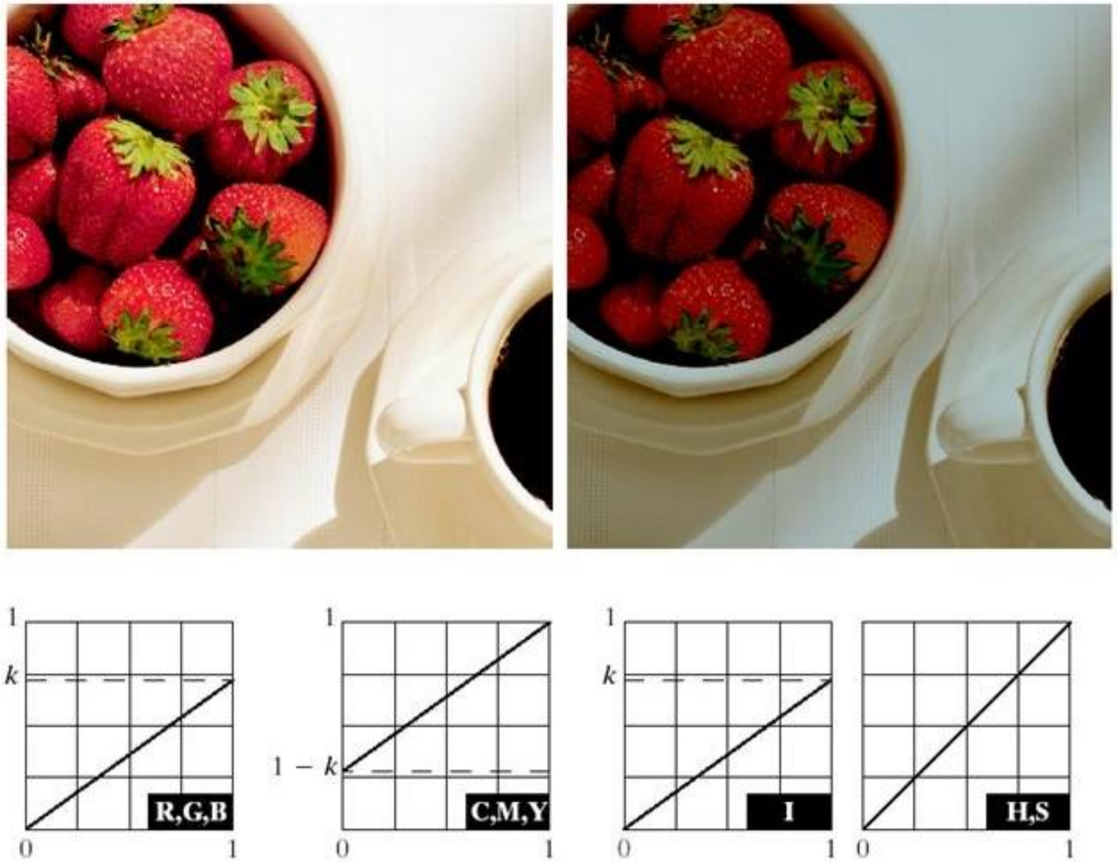


FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

Colour Complements

- The hues opposite to one another on the Color Circle are call Complements.

- Color Complement transformation is equivalent to image negati in Grayscale images

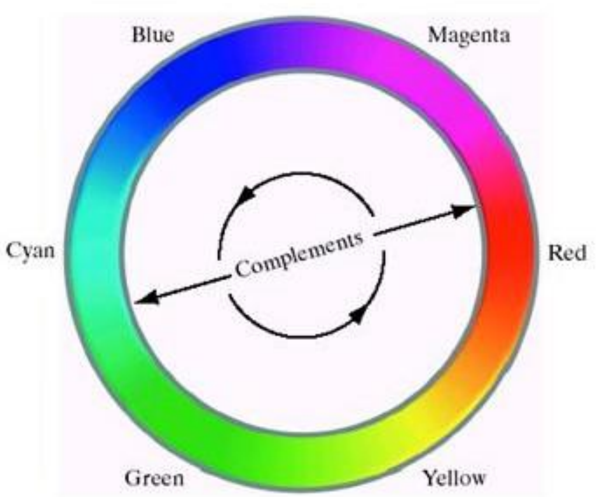


FIGURE 6.32 Complements on the color circle.

Colour Complements

Colour Slicing

•Highlighting a specific range of colors in an image is useful for separating objects from their surroundings.

•Display the colors of interest so that they are distinguished from background.

•One way to slice a color image is to map the color outside some range of interest to a non prominent neutral color.

Full color

Colour Image Smoothing

$$\bar{C}(x,y) = \begin{bmatrix} \frac{1}{k} \sum_{(x,y) \in S_{xy}} R(x,y) \\ \frac{1}{k} \sum_{(x,y) \in S_{xy}} G(x,y) \\ \frac{1}{k} \sum_{(x,y) \in S_{xy}} B(x,y) \end{bmatrix}$$

- We recognize the components of this vector as the scalar images that would be obtained by independently smoothing each plane of the starting RGB image using conventional gray scale neighborhood processing.

- Thus we conclude that smoothing by neighborhood averaging can be carried out on a per color plane basis.

Colour Image Smoothing

a b
c d

FIGURE 6.38
(a) RGB image.
(b) Red component image
(c) Green component.
(d) Blue component.

Colour Image Smoothing

a b c

FIGURE 6.40 Image smoothing with a 5 × 5 averaging mask. (a) Result of processing each RGB componen image. (b) Result of processing the intensity component of the HSI image and converting to RGB. (c) Dif ference between the two results.

Colour Image Smoothing

- Color images can be smoothed in the same way as gray scale images, the difference is that instead of scalar gray level values we must deal with component vectors of the following form:

$$C(x,y) = \begin{bmatrix} C_R(x,y) \\ C_G(x,y) \\ C_B(x,y) \end{bmatrix} = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

- The average of the RGB component vector in this neighborhood is:

$$\bar{C}(x,y) = \frac{1}{k} \sum_{(x,y) E\, S_{xy}} C(x,y)$$

Colour Image Sharpening

a b c

FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Resul processing the intensity component and converting to RGB. (c) Difference between the two results.

Chapter 6

END OF LECTURE