COLOR IMAGE PROCESSING

Color Fundamentals,

Color Models,

Pseudocolor Image Processing

MORPHOLOGICAL IMAGE PROCESSING

Basic Concepts,

Dilation and Erosion,

Opening and Closing,

Hit or miss transformation,

Sample applications

Color Image Processing

Very important field in Digital Image processing. It is motivated by 2 Factors Like

- We can identify objects in a color image
- Human Eye can detect 1000's of color shades

Color image processing divided into

- Full color processing
- Pseudo color processing

color processing

Full Color image processing

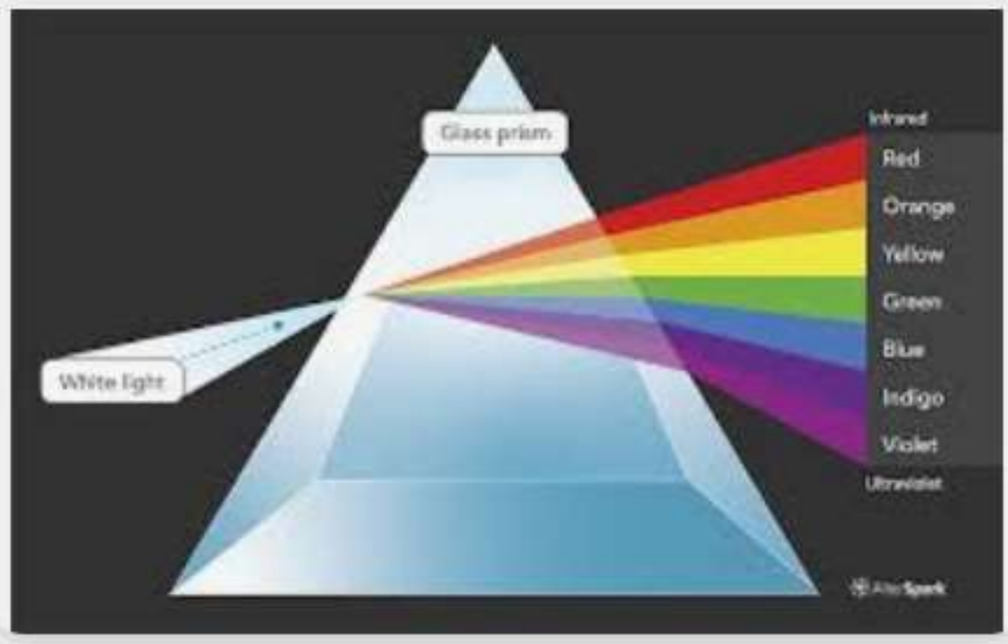
- Images are acquired using Full color sensors such as Color Cameras or Color scanner

Pseudo Color image processing

- Images are acquired using range of Intensities or 2 intensities sensors.
- Pseudo color image processing range of gray shades are assigned color codes for color processing

Color Fundamentals

Sir Issac Newton discovered that a white light when passed through a Transparent Pyramid will emit shades of colors ranging from Violet at one end to Red at other end.



This figure shows Color spectrum is divided into 6 Broad categories Like (ignore Indigo for now)

Violet
Blue
Green
Yellow
Orange
Red

Why Humans able to detect Colors?

A human eye or some animals which can detect an object in a color image is mainly due to the nature of light reflected from the Object.

Color Fundamentals

A body that reflects light that is balanced in all visible wavelengths is visible as WHITE to the observer.

A reflected Light in limited range of visible spectrum ➔ Some shades of Color

For Ex:

A green object which reflects the wavelength in the range 500-570nm, while absorbing most of the energy at other wavelengths. Hence the object is appear as Green.

Achromatic and Chromatic Light

Achromatic Light: A viewer can see on Black and White Television sets where they can perceive Gray shades is called Intensity or Gray Levels.

Attribute of this Light is: Intensity or Gray level

Chromatic Light:

The Light from Electro Magnetic spectrum approx from 400 – 700 nm.

Attributes: Radiance, Luminance, Brightness

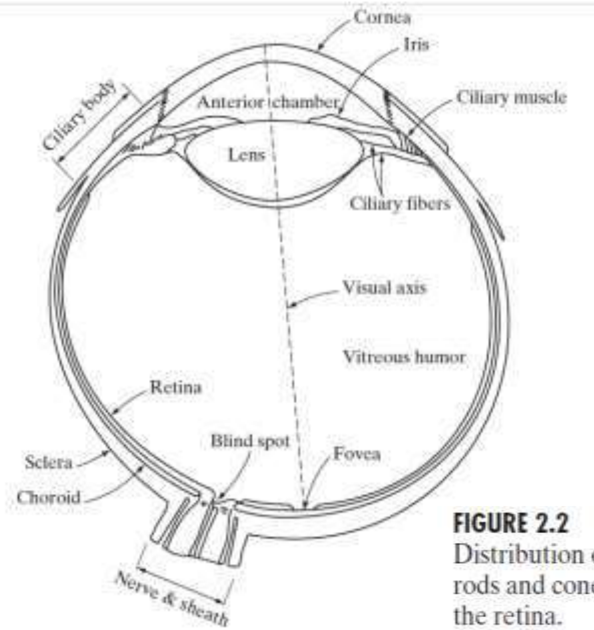
Chromatic Light Attributes

- **Radiance:** The Total amount of Energy that flows from the Light Source, and it is usually measured in Watts(W).
- **Luminance:** A Measure of amount of Energy Perceived from Light Source, measured in Lumen(lm)
- **Brightness:** Described as color sensation, Very difficult to Measure.

For Ex: A Light source emitted at Sun as source might be having very High Radiance but humans perceives very less due to Distance.

How Eyes perceives Color?

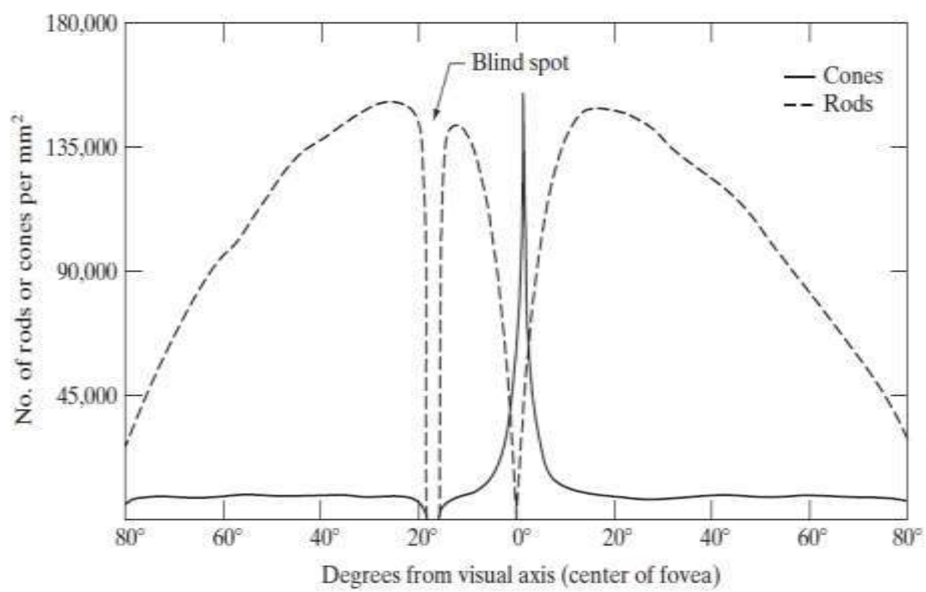
FIGURE 2.1 Simplified diagram of a cross section of the human eye.



Two Types of Perceptors in Eyes available:
Cones and Rods are present on **Retinal**,
Cones responsible for perception of Colors. The cones in each eye number between 6 and 7 million.

cones in the human eye can be divided into three principal sensing categories, corresponding roughly to red, green, and blue.

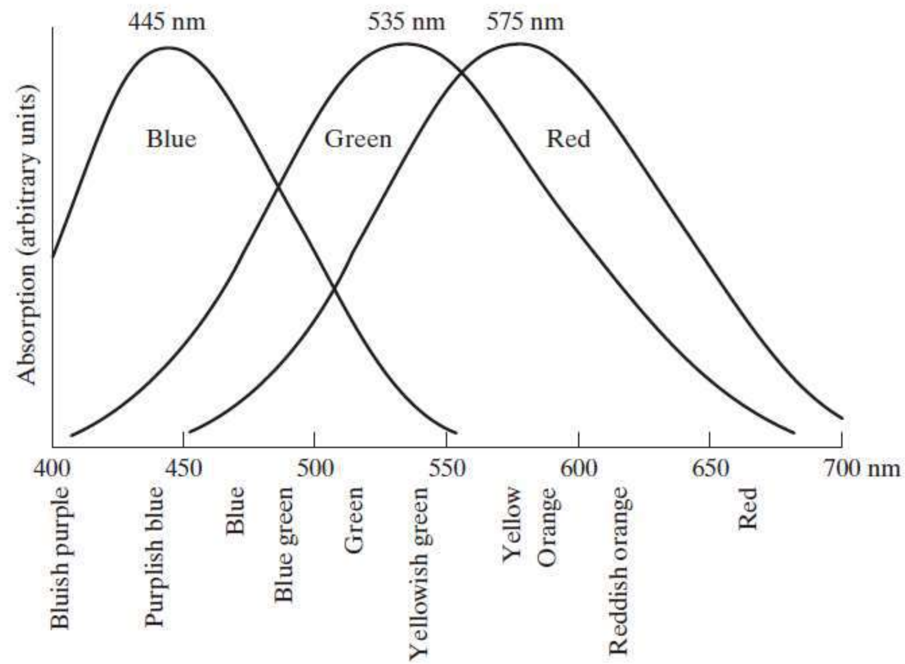
FIGURE 2.2 Distribution of rods and cones in the retina.



Approximately 65% of all cones are sensitive to red light, 33% are sensitive to green light, and only about 2% are sensitive to blue (but the blue cones are the most sensitive).

Obsorption of Light by Red, Blue, Green by Cones in Eye

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



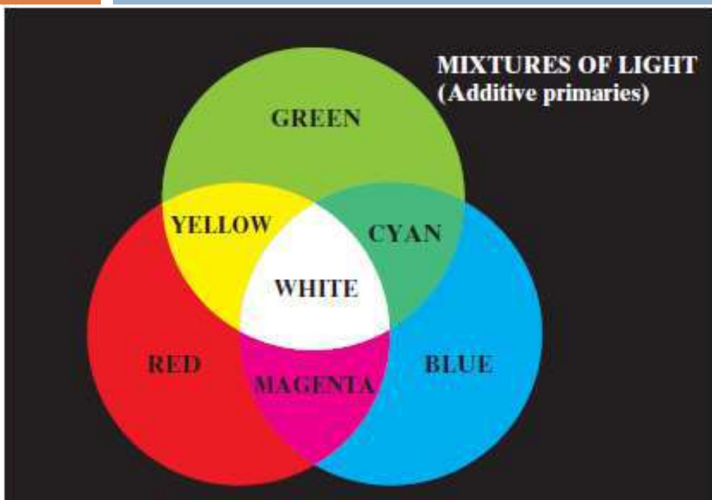
Due to these absorption characteristics of the human eye, colors are seen as variable combinations of the so-called *primary colors red (R), green (G), and blue (B).*

CIE (Commission Internationale de l'Eclairage—the International Commission on Illumination) designated in 1931 the following specific wavelength values to the three primary colors: blue = 435.8 nm, green = 546.1 nm, and red = 700 nm. in 1965.
But later they discovered other colors YELLOW, MAGENTA and CYAN can also be used as Primary colors. For now Primany colors refer to RED, BLUE, GREE colors otherwise stated.

Generating different colors?

- The primary colors can be added to produce the *secondary colors of light*—
- Example secondary magenta (red plus blue), cyan (green plus blue), and yellow (red plus green).
- Mixing the three primaries, or a secondary with its opposite primary color, in the right intensities produces white light. This result is shown in Fig. 6.4(a),
- which also illustrates the three primary colors and their combinations to produce the secondary colors.

Generating different colors?



a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Differentiating between the primary colors of light and the primary colors of pigments or colorants is important. In the latter, a primary color is defined as one that subtracts or absorbs a primary color of light and reflects or transmits the other two. Therefore, the primary colors of pigments are magenta, cyan, and yellow, and the secondary colors are red, green, and blue.
These colors are shown in Fig. 6.4(b).
A proper combination of the three pigment primaries, or a secondary with its opposite primary, produces black

TERMINOLOGIES

- Eyes: Retina, Cones and Rods
- Radiation
- Illumination
- Brightness
- Hue
- Saturation
- Primary Colors: R,G,B
- Secondary Colors: Primary colors added in right intensities to produce secondary colors
- Pure white:
- Pure Black:
- Pigments or colorants

Working of CRT, LCD Screens

- CRT: Screen is composed of a large array of triangular dot patterns of electron-sensitive phosphor. When Phosphor excited will radiate One of Primary color.
- CRT Produce RED Color: The intensity of the red-emitting phosphor dots is modulated by an electron gun inside the tube, which generates pulses corresponding to the "red energy" seen by the TV camera
- The green and blue phosphor dots in each triad are modulated in the same manner.
- The effect, viewed on the television receiver, is that the three primary colors from each phosphor triad are "added" together and received by the color-sensitive cones in the eye as a full-color image
- Video Perception: Thirty successive image changes per second in all three colors complete the illusion of a continuous image display on the screen

Working of LCD/Plasma Screens

- **LCD:** Require three subpixels (red, green, and blue) to generate a single color pixel.
- LCDs use properties of polarized light to block or pass light through the LCD screen and,
- An active matrix display technology, thin film transistors (TFTs) are used to provide the proper signals to address each pixel on the screen.
- Light filters are used to produce the three primary colors of light at each pixel triad location.
- **plasma units,**
- pixels are tiny gas cells coated with phosphor to produce one of the three primary colors.
- The individual cells are addressed in a manner analogous to LCDs.This individual pixel triad coordinate addressing capability is the foundation of digital displays.

Characteristics of Colors

- The characteristics generally used to distinguish one color from another are

brightness, hue, and saturation.

- ***Brightness***: The achromatic notion of intensity.
- **Hue:** is an attribute associated with the dominant wavelength in a mixture of light waves. Hue represents dominant color as perceived by an observer. Thus, when we call an object red, orange, or yellow, we are referring to its hue.
- **Saturation** refers to the relative purity or the amount of white light mixed with a hue. The pure spectrum colors are fully saturated. Colors such as pink (red and white) and lavender (violet and white) are less saturated, with the degree of saturation being inversely proportional to the amount of white light added.

Characteristics of Color

- ***Chromaticity***: Hue and saturation taken together.
- *A* color may be characterized by its brightness and chromaticity.
- Therefore the Color can be categorised as Chromaticity and Brightness
- The amount of RGB required to form any color is called the T*ristimulus. These values are denoted, X, Y, and Z, respectively. A color is then* specified by its *trichromatic coefficients, defined as*

$$x = \frac{X}{X + Y + Z} \tag{6.1-1}$$

$$y = \frac{Y}{X + Y + Z} \tag{6.1-2}$$

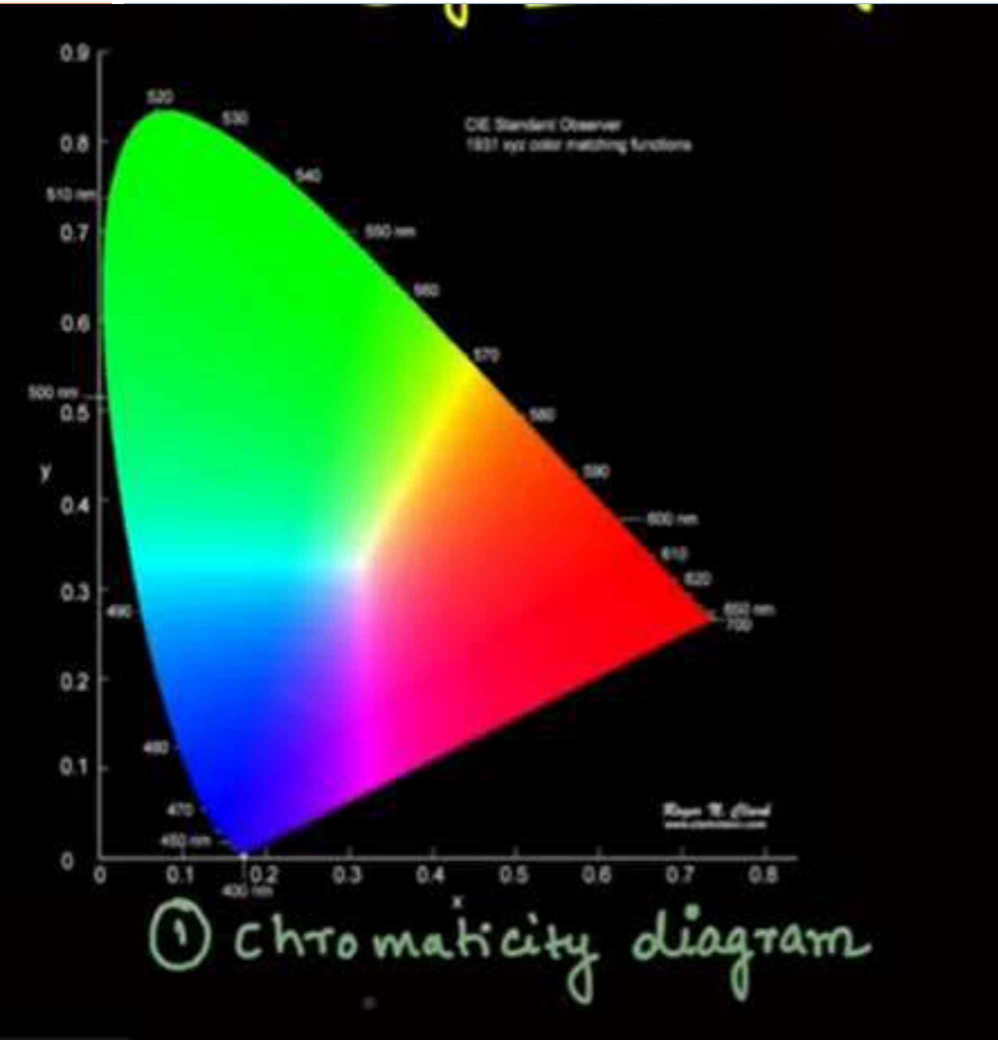
and

$$z = \frac{Z}{X + Y + Z} \tag{6.1-3}$$

It is noted from these equations that†

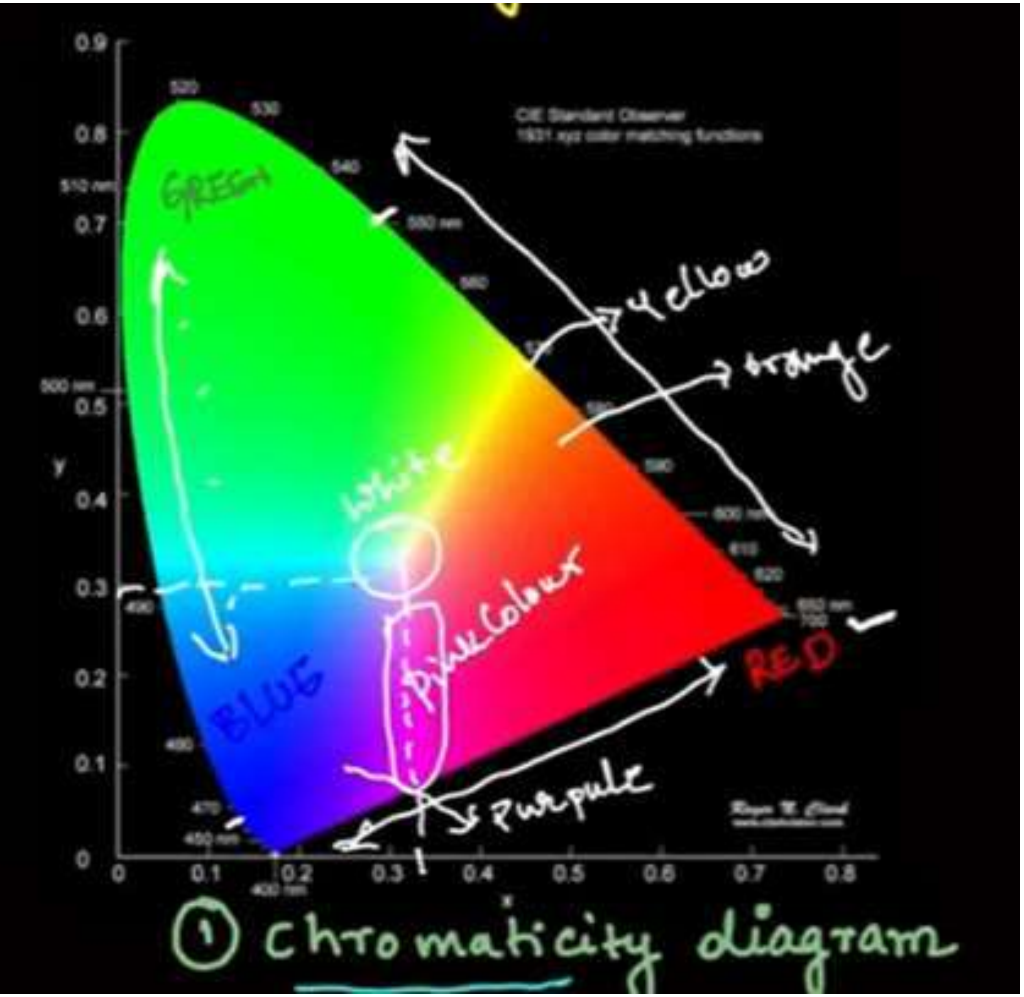
$$x + y + z = 1 \tag{6.1-4}$$

How to obtain Tristimulus values for a given color?



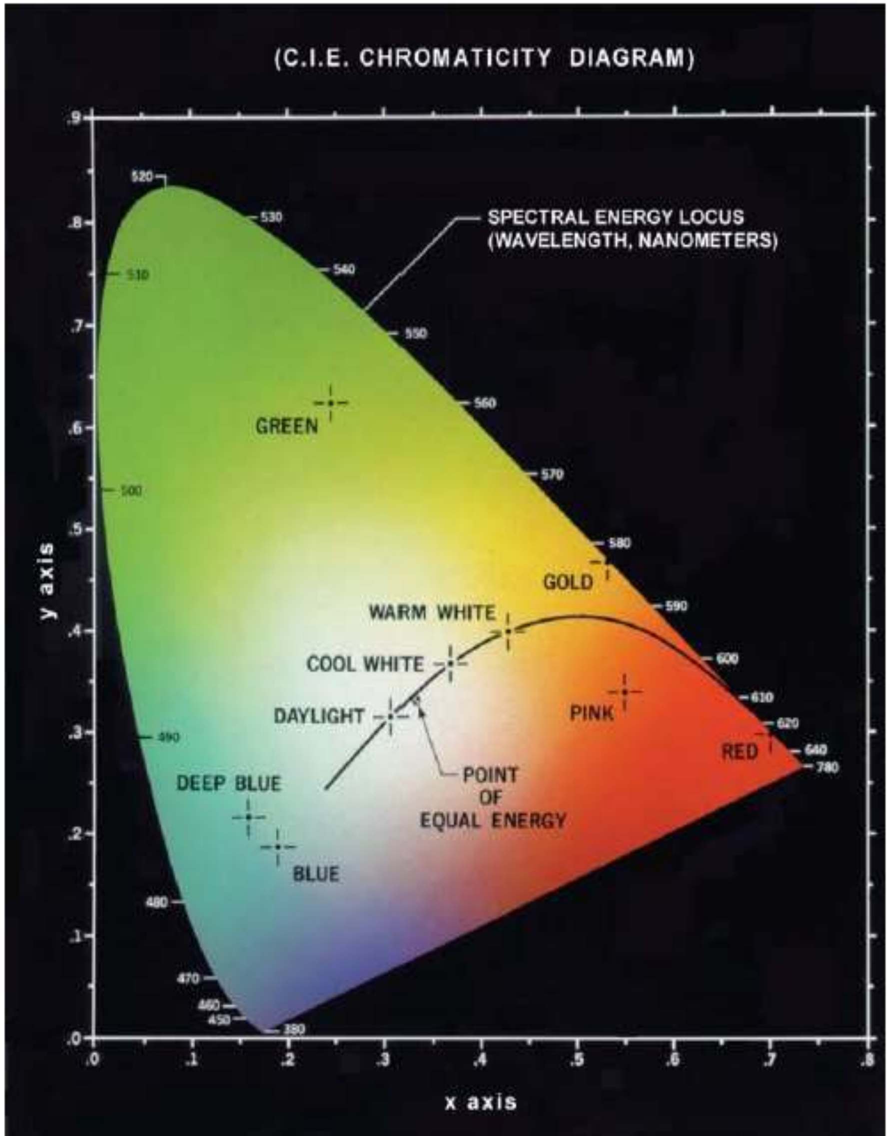
- The chromatic dig has RED, GREEN and BLUE and shades when travel from one color to another.
- Each color has particular standard wavelength Red=700nm, Green 546.9 nm, Blue = 438.8nm
- Observe the co-ordinates of these colors has different shades of Color. For example observe between Red and Green we have Yellow and Orange and other Lighter shades of Red,
- Between Red and Blue we have Purple and other lighter shades
- Between Green and BLue is different shades of colors.
- Chromatic diagram is useful in mixing colors to produce different shades of color.
- Centre: WHITE Color.

How to obtain Tristimulus values for a given color?



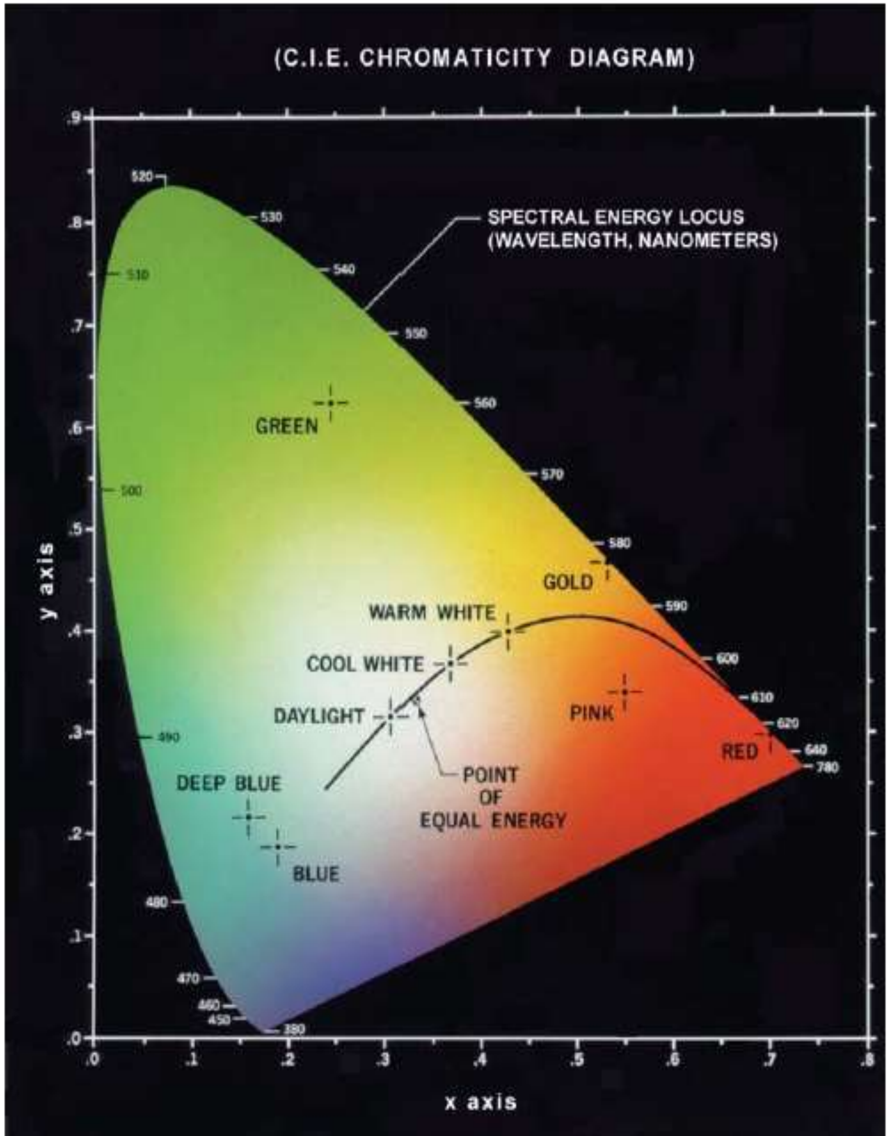
- If you want to produce White color
- x= 0.31, y=0.32 we get white color.

How to obtain Tristimulus values for a given color?



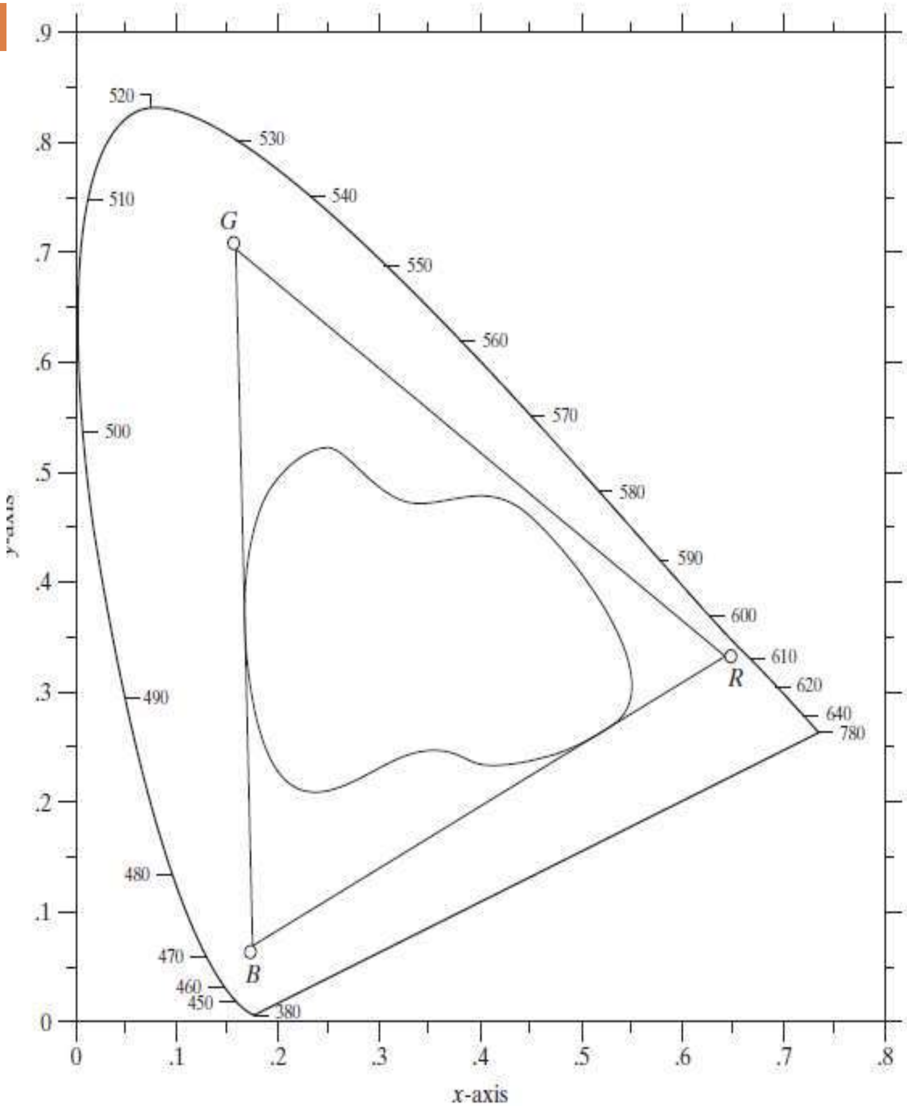
- For specifying colors is to use the CIE *chromaticity diagram* which shows color composition as a function of *x (red) and y* (green). For any value of *x and y, the corresponding value of z (blue) is obtained* from z = 1 - (x + y).
- The point marked green in Fig. 6.5, for example, has approximately 62% green and 25% red content. From Eq. (6.1-4), the composition of blue is approximately 13%.
- The chromaticity diagram is useful for color mixing because a straight-line segment joining any two points in the diagram defines all the different color variations that can be obtained by combining these two colors additively
- A straight line drawn from the red to the green points shown in Fig. If there is more red light than green light, the exact point representing the new color will be on the line segment, but it will be closer to the red point than to the green point.

How to obtain Tristimulus values for a given color?



- Extension of this procedure to three colors is straightforward.To determine
- the range of colors that can be obtained from any three given colors in the chromaticity diagram, we simply draw connecting lines to each of the three olor points. The result is a triangle, and any color on the boundary or inside the triangle can be produced by various combinations of the three initial colors.
- A triangle with vertices at any three *fixed colors cannot enclose the entire* color region in Fig.
- This observation supports graphically the remark made earlier that not all colors can be obtained with three single, fixed primaries

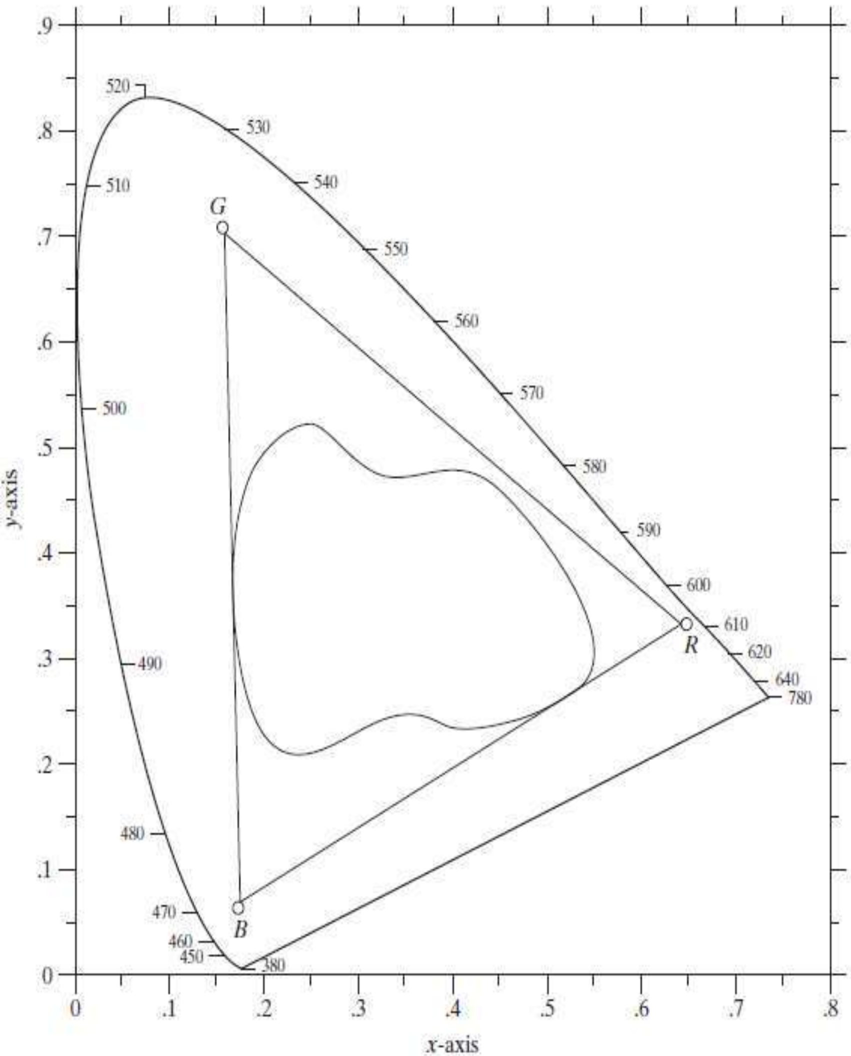
How to obtain Tristimulus values for a given color?



- The triangle in Figure 6.6 shows a typical range of colors (called the *color gamut*) *produced by RGB monitors.The irregular region inside the triangle* is representative of the color gamut of today's high-quality color printing devices.
- The boundary of the color printing gamut is irregular because color printing is a combination of additive and subtractive color mixing, a process that is much more difficult to control than that of displaying colors on a monitor, which is based on the addition of three highly controllable light primaries.

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

Color Mixing with help of Chromaticity Figure (Tristimulus)



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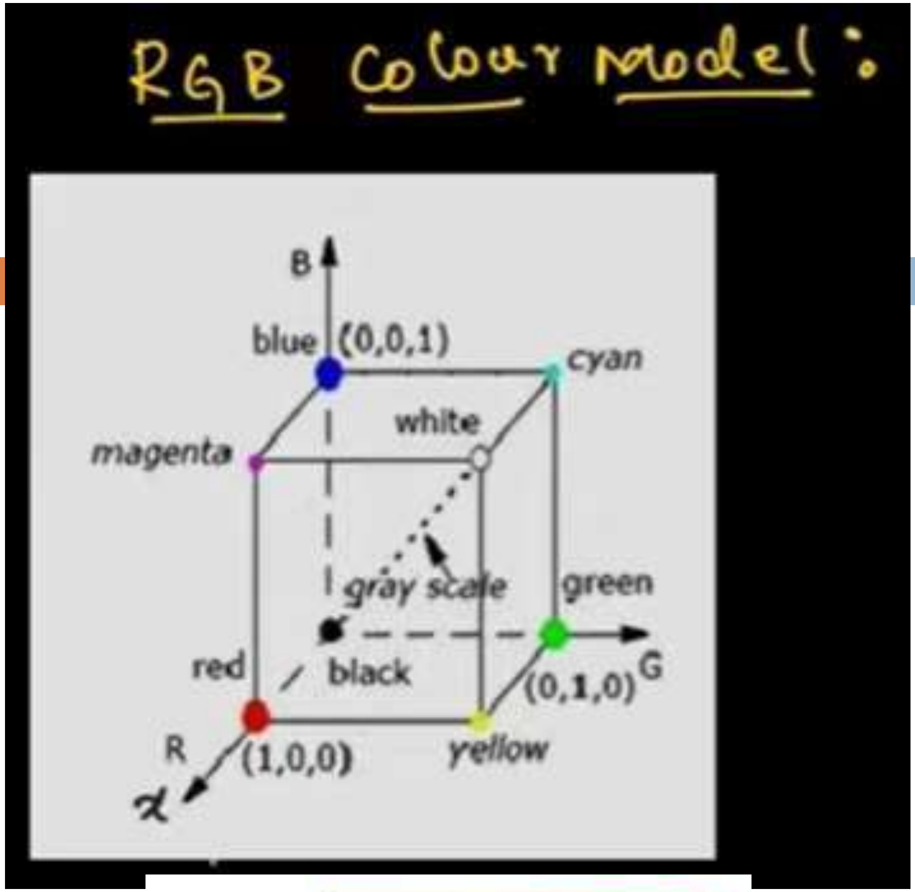
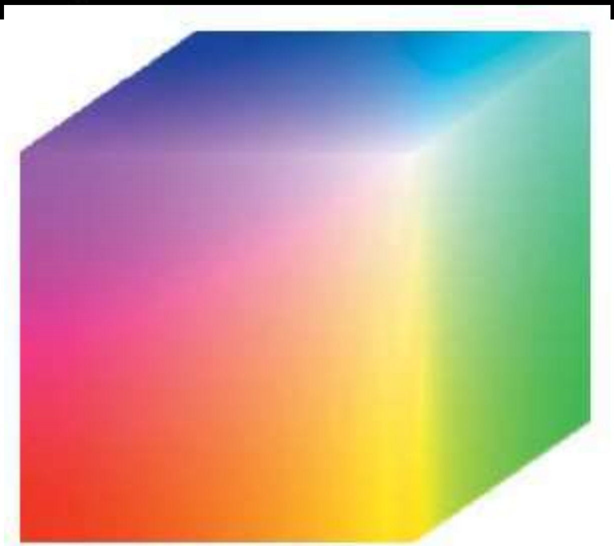
COLOR Models Introduction

- Also known and Color space or Color System.
- Provides specifications in standard Form
- Specification of Cardinal system or subspace, where each color is represented by a Single Point.
- Each color model is used or oriented towards hardware or applications where color manipulations are goal.
- hardware ex: Color Monitor or Printer
- Software: Color manipualation apps
- Digital Image processing: USe different hardware processing
- Various Color models:
- RGB: RED, GREEN, BLUE
- CMY/CMYK: CYAN MAGENTA YELLO/ CYAN MAGENTA YELLOW BLACK
- HSI: HUE, SATURATION AND INTENSITY.

RGBColor models

- RGB: Digi Cameras
- CMY/CMYK: Color printers
- HSI: Where most humans describe and interpret colors. This model decouples the color and Grey scale information in an Image, which makes useful for Gray scale applications.





RGB Color Models

- Each color is aligned to each axis.
- Cartesian 3-D Co-ordinate system

•Consider (x,y,z) points equivalent to (RED, GREEN, BLUE)

•RED: - (1,0,0)

•GREEN: (0,1,0)

•BLUE: - (0,0,1)

•Magenta (1,0,1): Equal distance from Blue and Red, but ZERO distance from Green axis.

•CYAN (0,1,1): Equal distance from Blue and Green but ZERO distance form RED axis

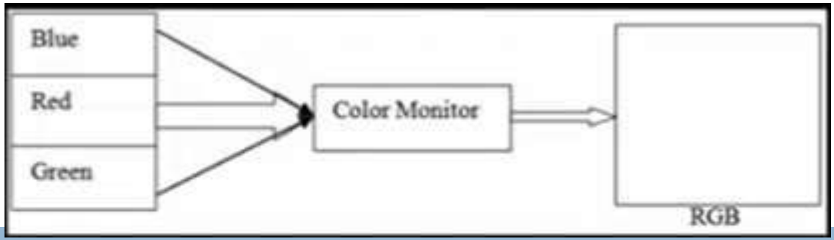
•YELLOW (1,1,0): ???

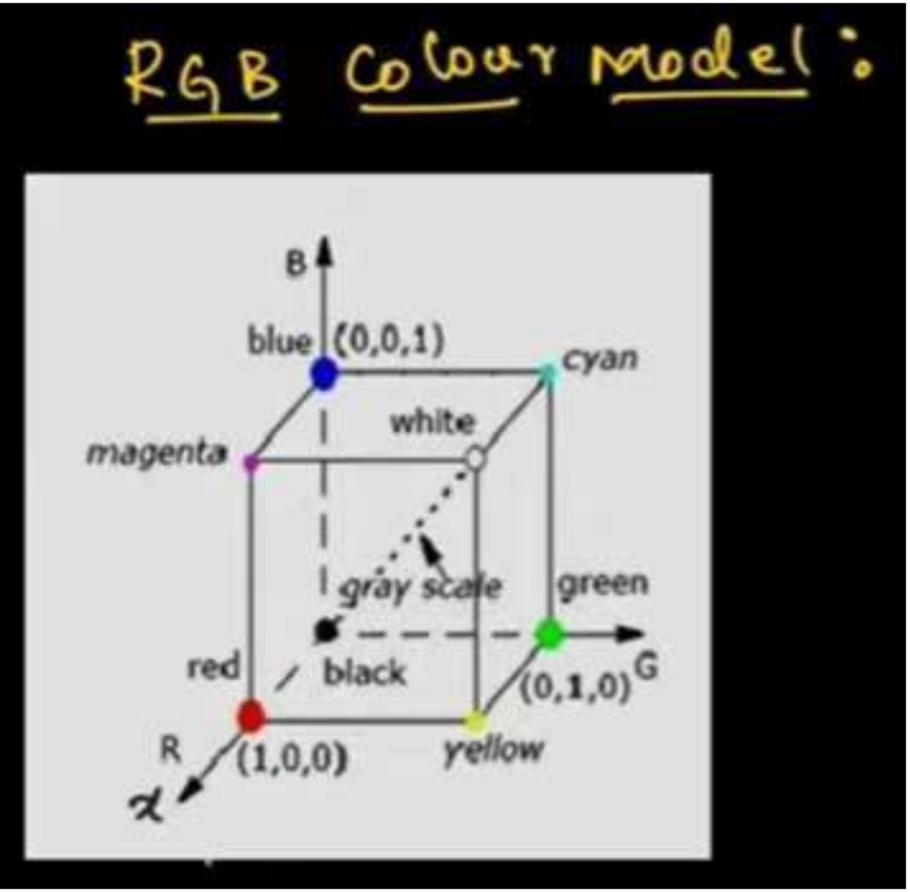
•WHITE (1,1,1): Equal distance from all 3-Axes

•BLACK (0,0,0): ZERO distance from all 3 – Axes.

•The Region between Black and WHITE: Gray scale

RGB Color Models





RGB is ADDITIVE COLOR MODEL

The Image representation in RGB model has each component. These component image are fed to the Color Monitor. These three images are combined on Phosphrous on monitor to produce a color combination image.

Each color in the RGB Model is represented by 8 Bit.

Red: 8bits (0..255)

Green: 8 Bits (0..255)

Blue: 8 Bits (0..255)

Number of Bits used to used to represent each pixel in an image in RGB color space is called PIXEL DEPTH = (8+8+8=24bits)

24 Bits image: Full color Images

Total number of colors possible = 2^{24} = 16777216 color combinations possible to display in RGB color model.

CMY/CMYK(Black) Color model

Subtractive Color Model:

Inorder to get Secondary colors we subtract Primary color from WHITE (value 1)

CYAN: WHITE-RED (subtrace Red from White)

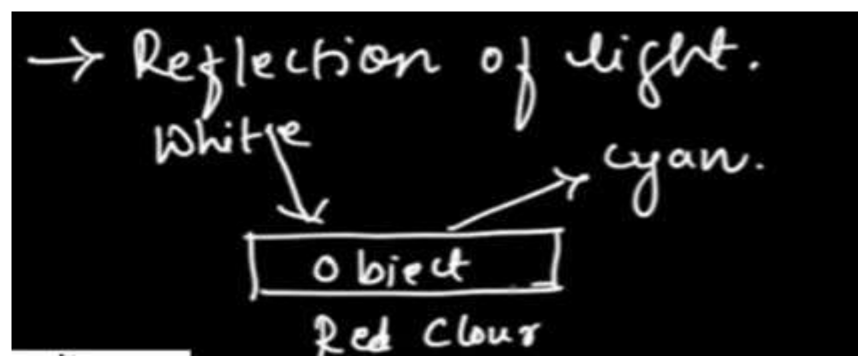
Magenta : WHITE-GREEN (subtrace Green from White)

YELLOW: WHITE –BLUE (subtrace Blue from White)

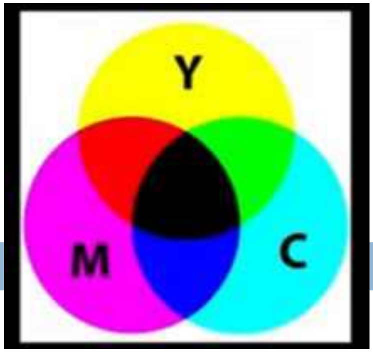
Figure also shows this in Matrix Form, where White represented by 1.

These are obtained by Reflection of Light incident on an Object.

Let us consider an Object which obsorbs Red color then it reflect CYAN color. So the above Mathematical equation repsents the idea of Subtracting RED from WHITE color.

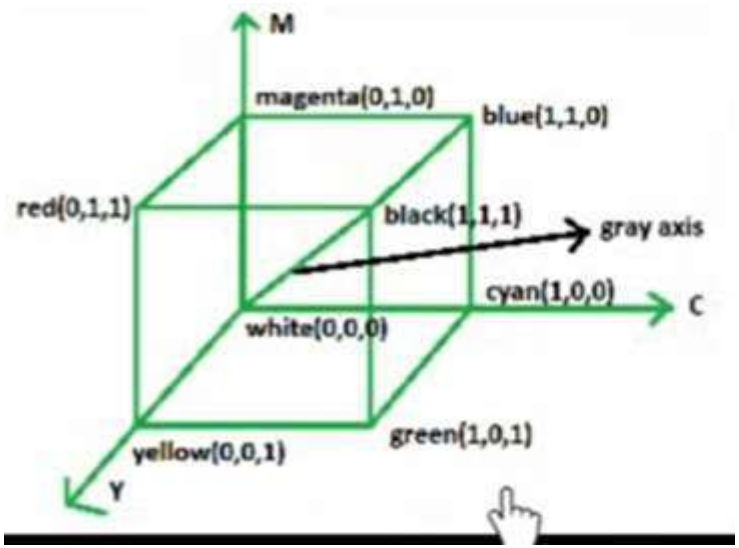


CMY/CMYK Color Model



- RED color = Subtract CYAN from White.
- BLUE color = Subtrace Yellow from WHite
- Green color = Subtract Magenta from White
- If you want BLACK: CYAN+Yellow+Magenta

- Color Cube having 3-D co-ordinates.
- Origin: White (0,0,0),
- X-Axis: Cyan (1,0,0)
- Y-Axis: Magenta (0,1,0)
- Z-Axis: Yellow (0,0,1)
- BLUE (1,1,0)
- Green (1,0,1)
- RED (0,1,1)
- If you add all colors you get: BLACK: (1,1,1)
- If no color then it is represented as WHITE (0,0,0)



- Applications: Color priting

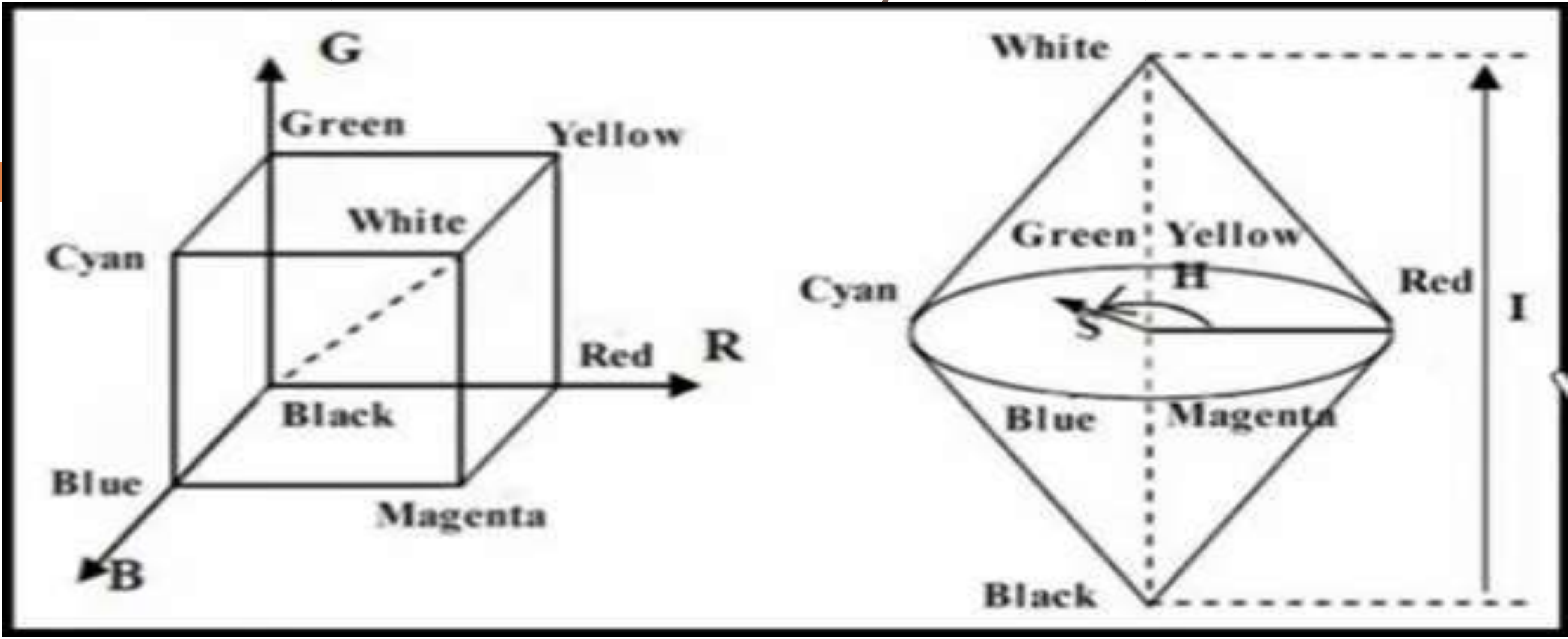
HSI Color model (HUE, Saturation and Intensity color Model)

- Depends on Human Perception: When Humans sees color describes by its saturation and Brightness. Here Human Eye decouples Intensity information from Color object.
- HUE: Describes Pure Color component

Ex: Red, Yello, Orange

- Saturation: Describes How much a pure color is diluted by mixing White color.
- Intensity: a Chromatic notation of Brightness of Black and White Range.

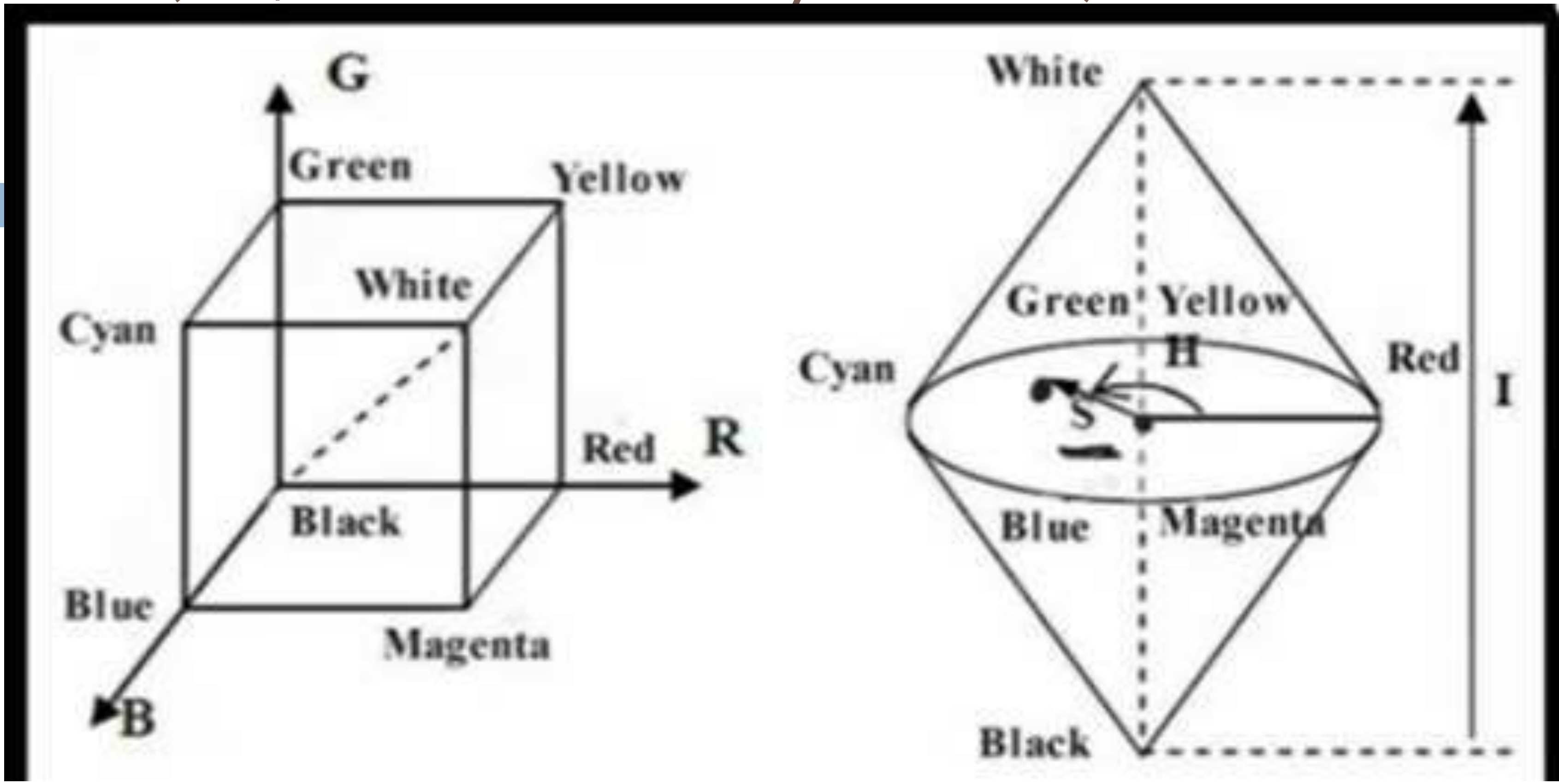
HSI Color model (HUE, Saturation and Intensity color Model)



- Let us place Black at bottom and White at the Top. So this Axis between Black and White is known as Intensity axis, represented as I.
- Saturation at Intensity axis is 0.
- In HSI cube HUE is always measured from RED. You can see
- From RED the Green is at 120^0

From Green the BLUE is at 120^0.
RED is at 120^0 from BLUE.
From RED 60^0 at YELLOW.
From YELLOW 60^0 at GREEN.
From GREEN 60^0 at CYAN.
From CYAN 60^0 at BLUE.
From BLUE 60^0 at MAGENTA

HSI Color model (HUE, Saturation and Intensity color Model)



- Let us consider a Point in HSI CUbe
- The distance from Intensity axis to the point is called Saturation.

HSI color model

Given an image in RGB color format, the *H component of each RGB pixel is* obtained using the equation

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

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

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

, the intensity component is given by

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

Converting RGB to HSI

Converting Colour from RGB to HSI:

1. Read a RGB image
2. Represent the RGB image in the Range [0,1]
3. Find HSI Components

$$\boxed{H = \begin{cases} \theta & \text{if } B <= G \\ 360 - \theta & \text{if } B > G \end{cases}}$$

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

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

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

Ex:- Convert RGB (29, 104, 215) to HSI

$R_{nor} = 29/255 = 0.113$

$G_{nor} = 104/255 = 0.407$

$B_{nor} = 215/255 = 0.843$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(0.113-0.407)+(0.113-0.843)]}{[(0.113-0.407)^2 + (0.113-0.843)(0.407-0.843)]^{1/2}} \right\}$$

$\boxed{\theta = 143.6^\circ}$ $\quad H = 360^\circ - 143.6^\circ \Rightarrow \boxed{H = 216.4^\circ}$

$$S = 1 - \frac{3}{(0.113+0.407+0.843)} \times (0.113) \Rightarrow \boxed{S = 0.752}$$

$$I = \frac{1}{3}(0.113 + 0.407 + 0.843)$$

$I = 0.45$

Convert from HSI to RGB

Converting colour from HSI to RGB:

→ the values of HSI in the Interval $[0,1]$

→ Find the Corresponding RGB Values in the Same range.

1) RG Sector $(0^\circ \le H \le 120^\circ)$

$$\boxed{B = I(1-S)}$$

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

& $\boxed{G = 3I - (R+B)}$

2) GB Sector $(120^\circ \le H \le 240^\circ)$

$$H = H - 120^\circ$$

$$\boxed{R = I(1-S)}$$

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

$$\boxed{B = 3I - (R+G)}$$

3) BR Sector $(240^\circ \le H \le 360^\circ)$

$H = H - 240^\circ$ $\boxed{G = I(1-S)}$

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

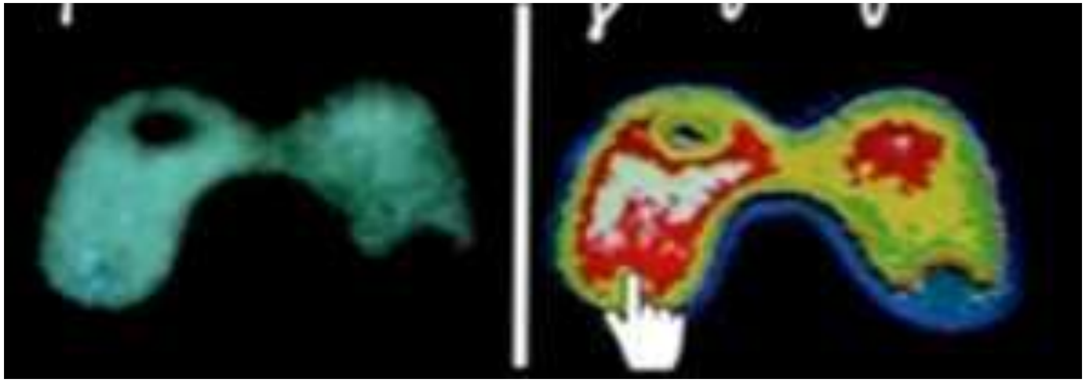
$$\boxed{R = 3I - (G+B)}$$

If the HSI values are in the Range [0,1] then correpsonding RGB values should be in the same Range. To find the values of RGB we use HSI. There are 3 Sectors correponding to 120^0 each. In each sector we find value of H, we find RGB values. All 3 sectors has same formula but the forumal for finding RGB are cyclically used.

Pseudo color image processing

- Full color image processing
- Pseudocolor image processing
- Pseudo color means a False color. We are assignving values to Gray values based on specific criteria. For Human visualization and interpretation of Gray scal images.

Pseudo color image processing



Here in the Image in the left using Pseudo color image processing by assigning specifi color values to the gray scale image for easy interpreation and visualization.

Two methods to do:

1. Intensity slicing
2. Gray level to color transformations.

Pseudo color image processing: Intensity Slicing

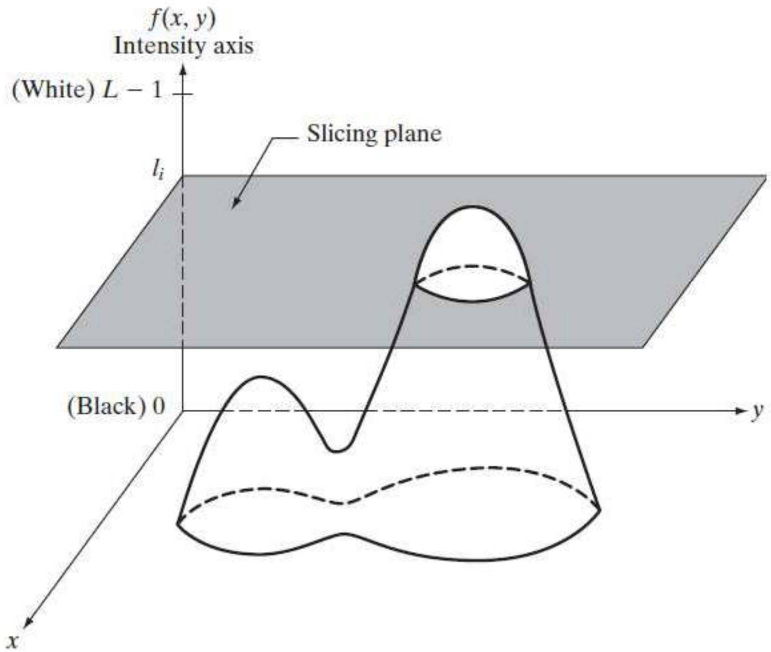
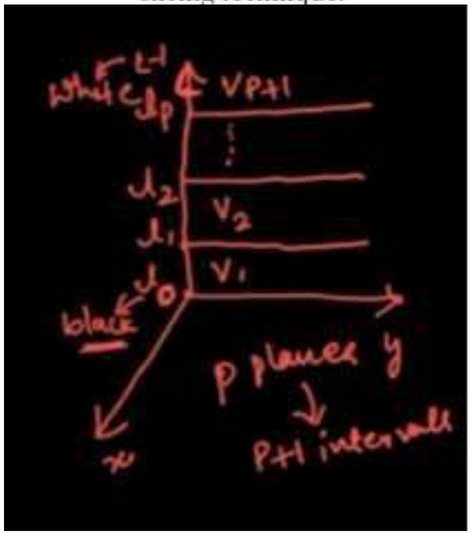


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.



In Intensity slicing an Image is considered as 3-D function and it is plotted using spatial co-ordinates to the Intensities as shown in the Figure.

x-axis and Y-axis are co-ordinates and Z-axis as intensity. At origin Black.

Let us consider a plane at certain level, this is slicing the intensity at one level of Intensity. Upper section of plane assign one color and lower section assign another color. Such planes can be assumed to assign different colors to the different intesity planes.

In general Intensity slicing is summarized as:

Let [0, L-1] represent Gray scale values. Black = 0, white = L-1

Let L_0 represent black (f(x,y)=0) and L_{n-1} as white (f(x,y)=L-1) .

Plane P represented perpendicular to Intensity Axis. Consider n Planes at each Gray scale, L_1, L_2, L_3 … L_{l-1}

Assume total plaens 0<P<n-1 then n planes partitions the gray scale using n-1 planes which creates n+1 intervals names V_1, V_2 …. V_{n+1}

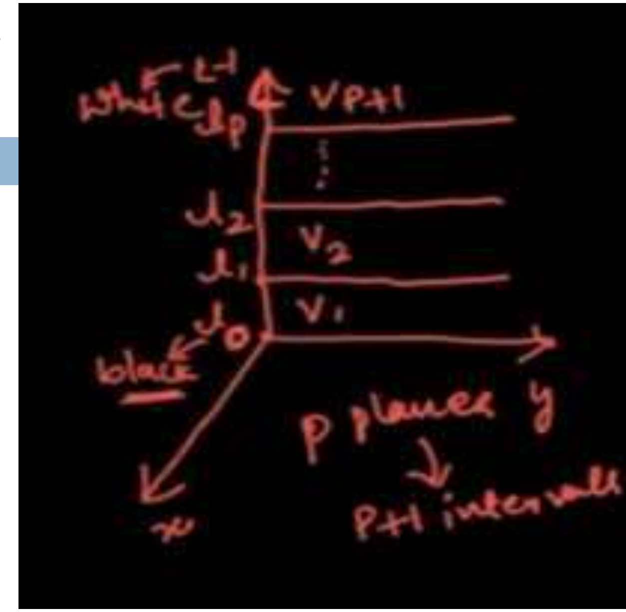
Pseudo color image processing: Intensity Slicing

To assign different colors to the intervals we can use this formula

$f(x,y) = c_k$ if $f(x,y) \in V_k$

Where c_k color is associated with the K^{th} intensity level.

V_k defined by the partitioning plane at l=k-1 and l=k.



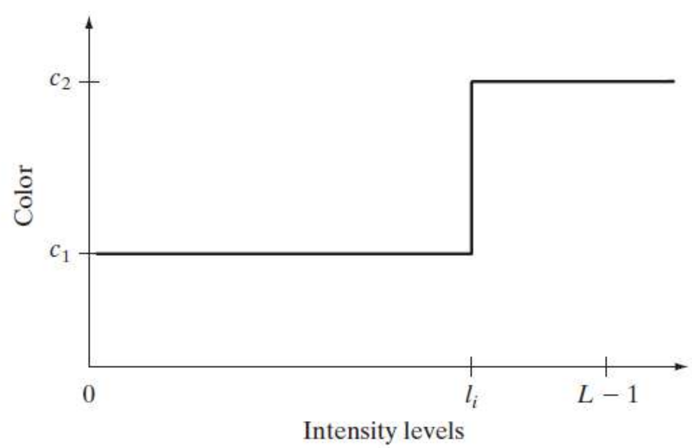
Color assignment:

If the Intensity of the image belong to the V1 assign one color C1

If the Intensity of the image belong to the V2 assign one color C2 and so on.

REMEMBER:

The above formula, Intensity is assigne a color if it belong to a partition.

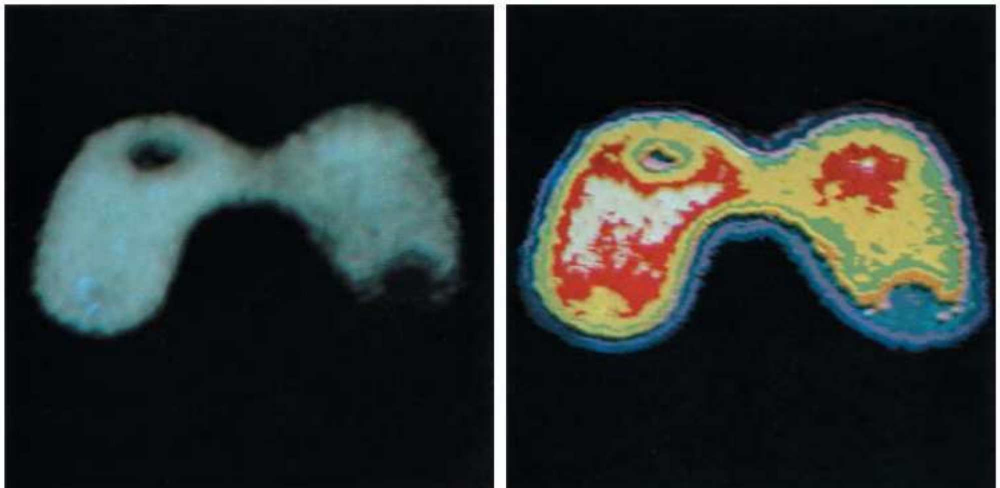


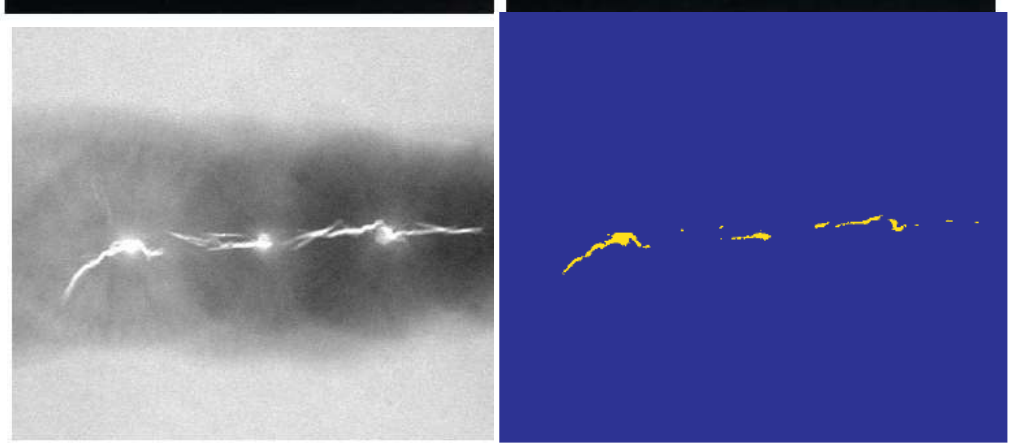
Alternatively you can assign color as shown next Graph, X-Axis Intensity levels, Y-Axis Color code. You can chose Color values for a One range of Gray scale. and Another color values to another Range of Gray scale.

Pseudo color image processing: Intensity Slicing : Example

a b

FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)





We are taking an Example image a Radiation Test pattern, For this image we are assigning 8 different colors for range of Gray scales and the Output image is see on Right.

An X-ray image we are assigning 2 Color regions.

Pseudo color image processing: Intensity Slicing : Example

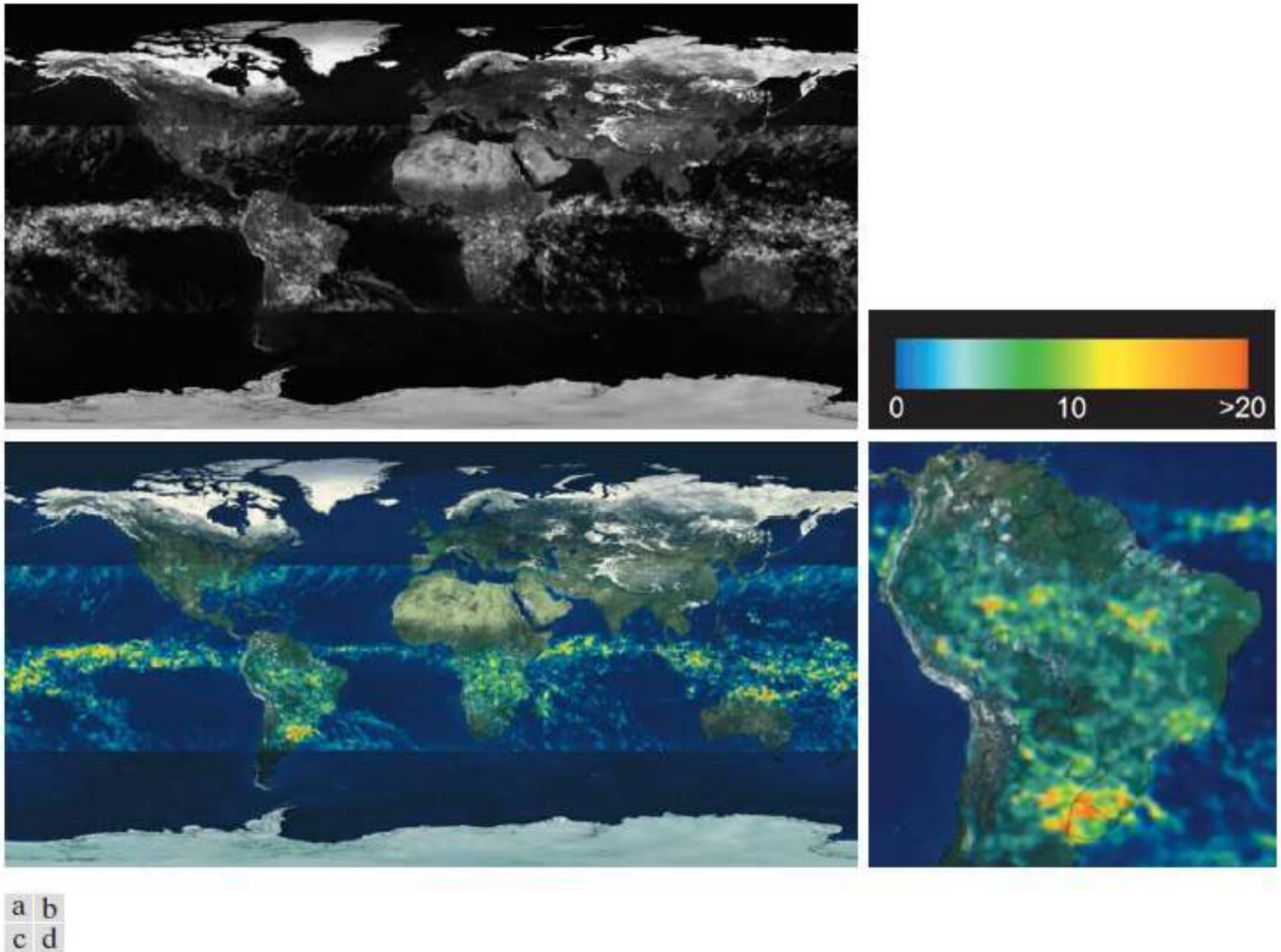
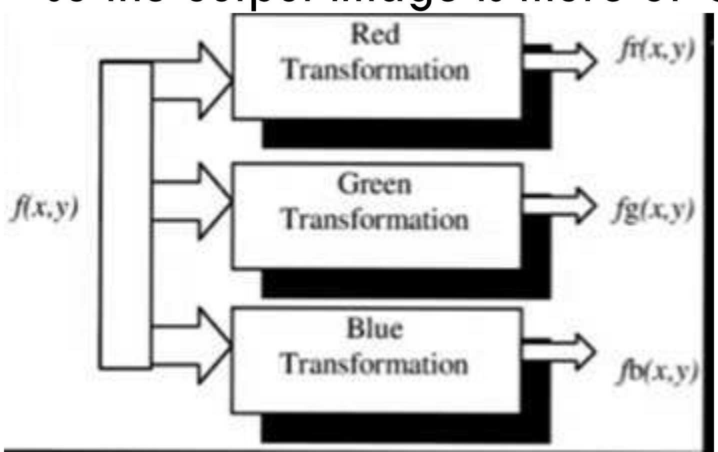


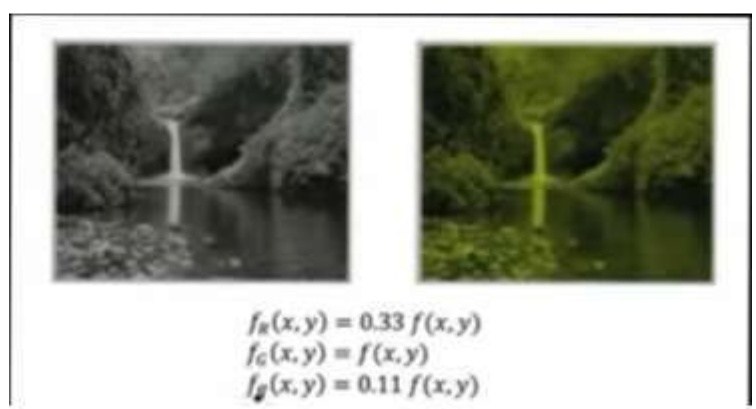
FIGURE 6.22 (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South American region. (Courtesy of NASA.)

- We can use Multiple color assignment in the image showing the Average monthly Rainfall.
- Assigning colors to specify the amount of Rainfall gives more appealing visualization and Easy interpretation.

Gray level to Color Transformations

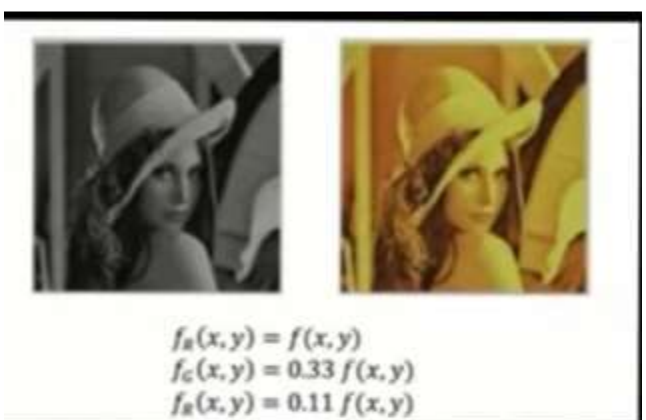
- This block diagrma shows Gray level to Color Transformations. This gray scale imge is pass thr 3 Transformations which are Red Transfm, Green Trfm, Blue Trfm to get Red Plane, Green Plane and Blue Plane, If we combine all three planes we get our Pseudocolor image.
- The Gray scale Image below converted or Tranformed into a Psuedocolor image. The Red Plane is obtained using the Formula
- $f_r(x,y) = 0.33\ f(x,y)$ RED Plane is obtained by multiplying 0.33 with gray scale
- $f_g(x,y) = f(x,y)$
- $f_b(x,y) = 0.11\ f(x,y)$
- Observe, Green Plane is considered as a major contributor of Gray scale mapping so the output image is more of Green shade in nature.





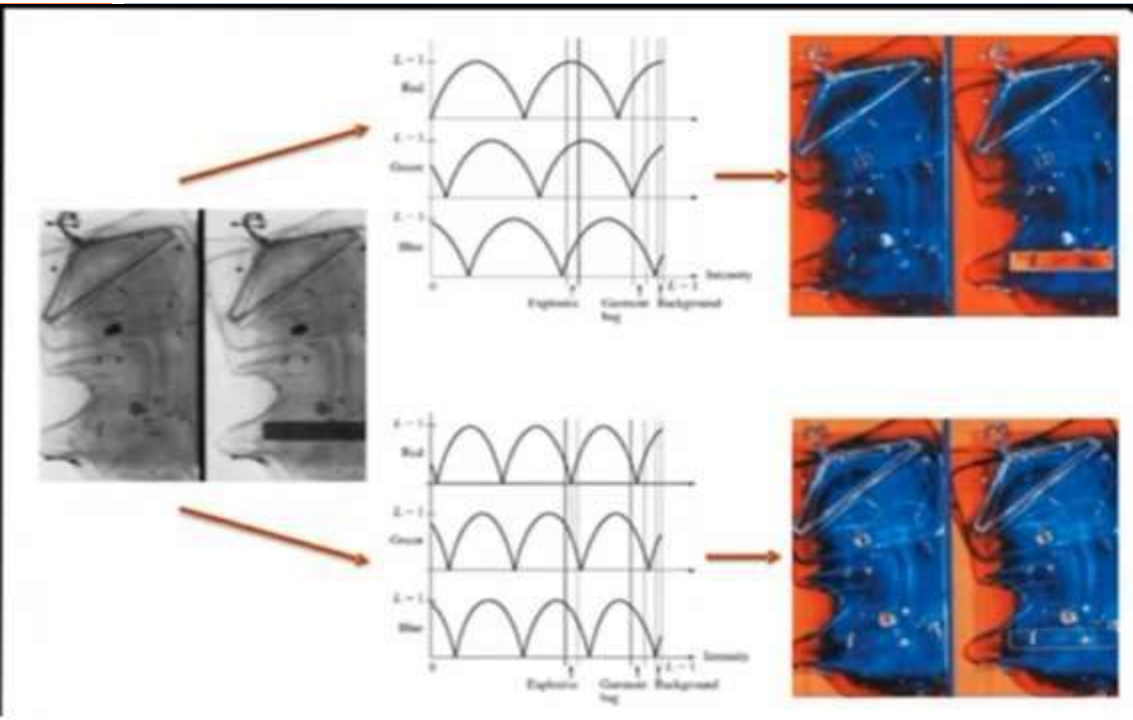
Gray level to Color Transformations

- Let us consider another example
- $f_r(x,y) = f(x,y)$
- $f_g(x,y) = 0.33 * f(x,y)$
- $f_b(x,y) = 0.11\ f(x,y)$
- Observe, Red Plane is considered as a major contributor of Gray scale mapping so the output image is more of Red shade in nature.



Gray level to Color Transformations (Let us consider another example of x-Ray machine in the Airport to identify explosives in the carry bags.)

On the Left side of Figure has 2 images one with Garment and another having Garment with an Explosive packed in the bag. The Rectangular object is an Exposive that should be identified. To identify we considering 3 Transformations Red, Green and Blue using Sinusoidal wave forms Which is similar to the Full Wave Rectified Output. If you observe the Wave forms of R,G,B their Phases are shifted (i.e each wave form is not starting from same point in the Graph)



Garment: To identify the Garmet the Band has Blue has more contribution than other Two colors.: Garments looks Blue Shades
Background: Again Red has more contribution. So it looks RED shades
To identify the explosive this is the coding is done like Red is given more priority compared to others, so the Explosive is seen as RED color shade

WHy these Color sinusoids are phase shifted? To prevent the combination of 3 waves to form a Gray image. (Look at the Sinusoidal rectified waves, where Explosive is marked in the RED band has more contribution compared to other colors. Explosive looks RED shade