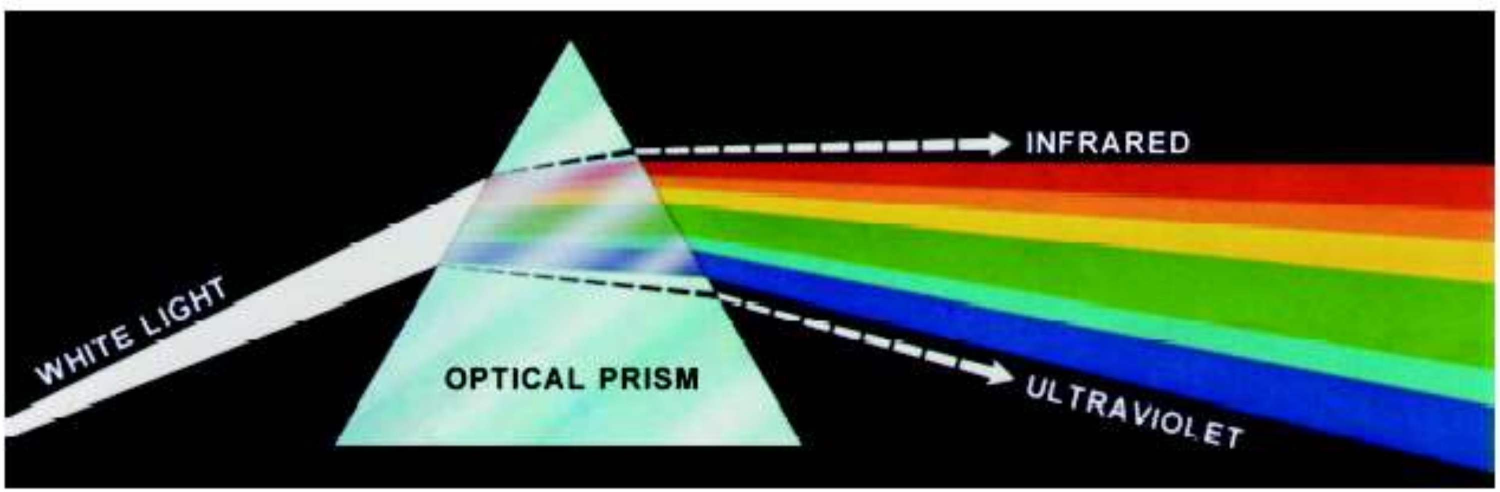
COLOR MODELING

Colour Fundamentals

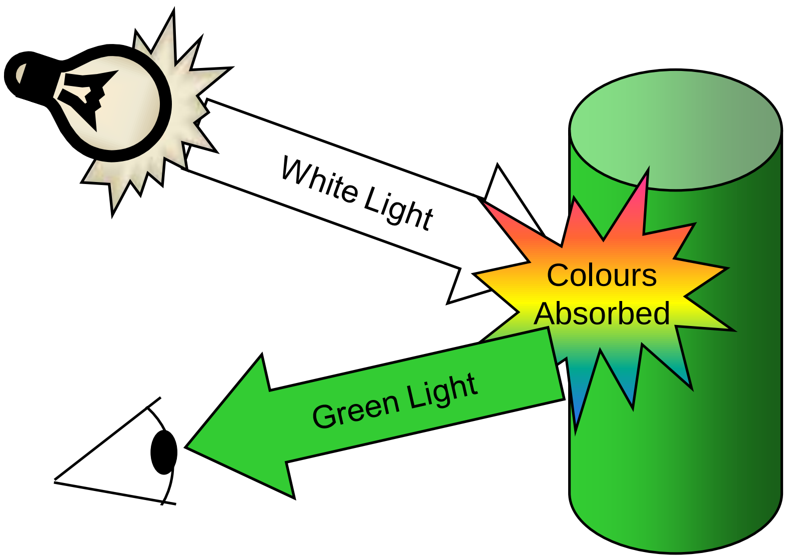
In 1666 Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging beam is split into a spectrum of colours



Colour Fundamentals (cont…)

The colours that humans and most animals perceive in an object are determined by the nature of the light reflected from the object

For example, green objects reflect light with wave lengths primarily in the range of 500 – 570 nm while absorbing most of the energy at other wavelengths

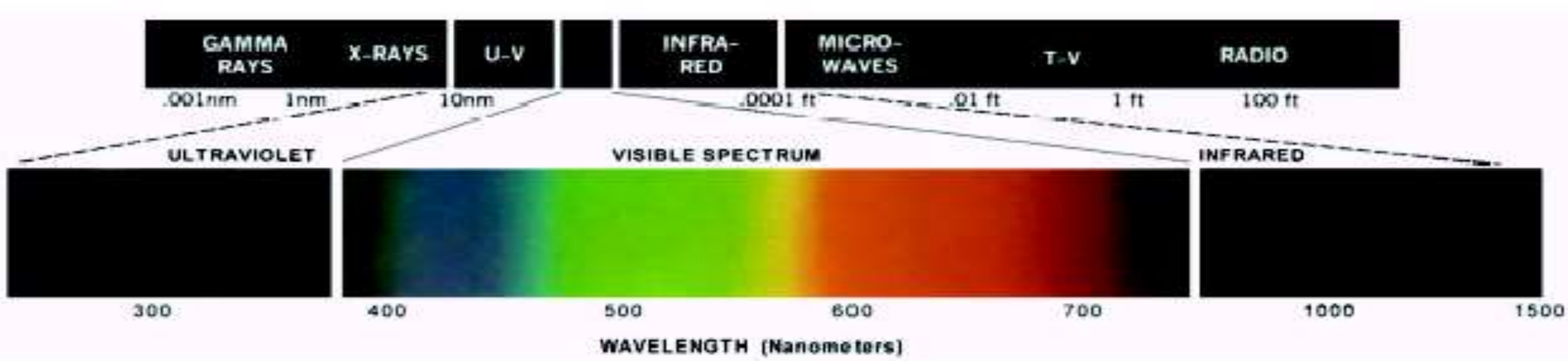


Colour Fundamentals (cont…)

-Colors : a narrow frequency band within the electromagnetic spectrum

-Chromatic light spans the electromagnetic spectrum from approximately 400 to 700 nm

Human colour vision is achieved through 6 to 7 million cones in each eye.



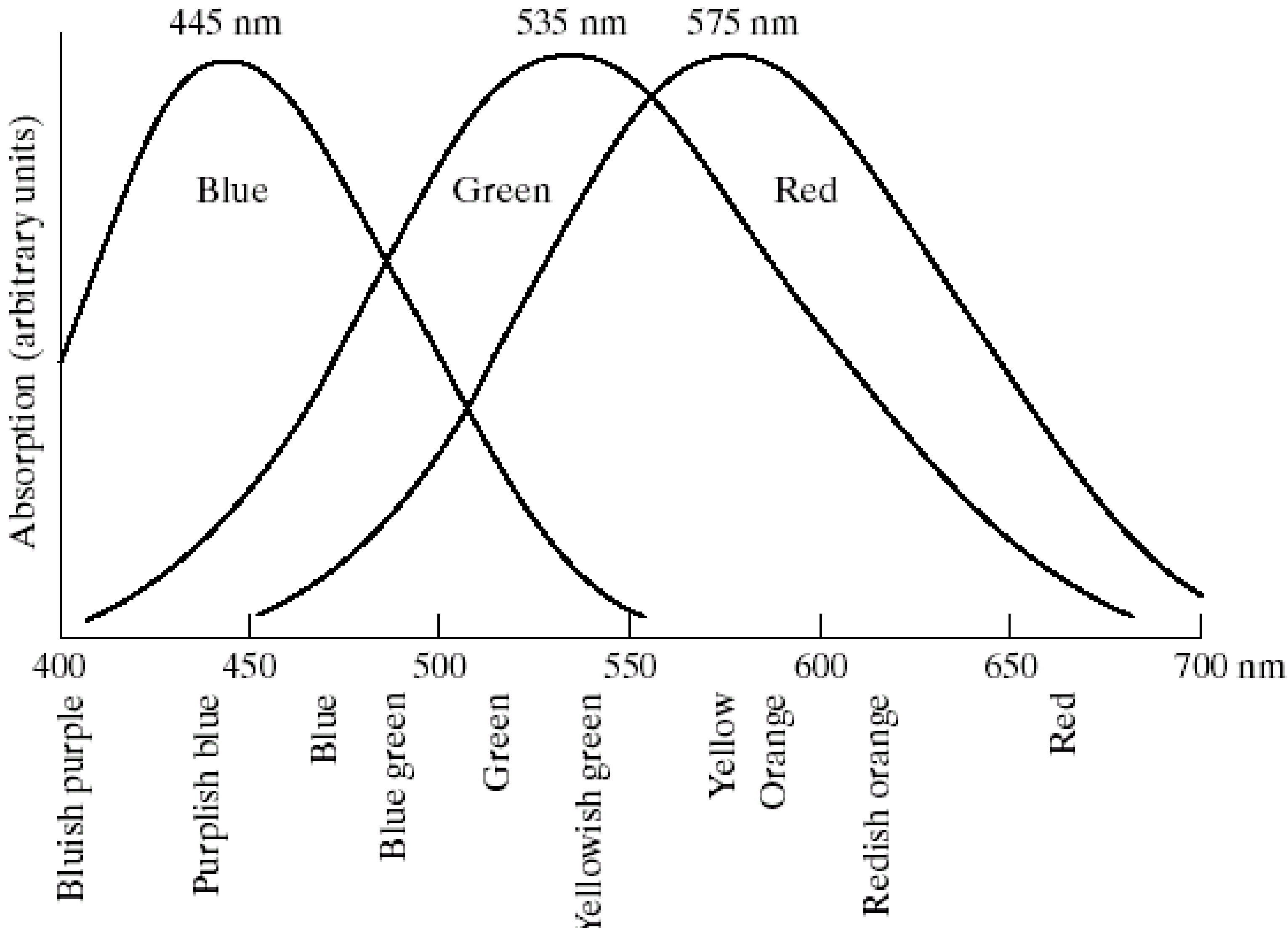
Colour Fundamentals (cont…)

Approximately 66% of these cones are sensitive to red light, 33% to green light and 6% to blue light.

Absorption curves for the different cones have been determined experimentally.

Strangely these do not match the CIE standards for red (700nm), green (546.1nm) and blue (435.8nm) light as the standards were developed before the experiments!

Colour Fundamentals (cont…)



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Colour Fundamentals (cont…)

3 basic qualities are used to describe the quality of a chromatic light source:

- **Radiance**: the total amount of energy that flows from the light source (measured in watts)
- **Luminance**: the amount of energy an observer *perceives* from the light source (measured in lumens)
  - Note we can have high radiance, but low luminance
- **Brightness**: a subjective (practically unmeasurable) notion that embodies the intensity of light

CIE Chromacity Diagram

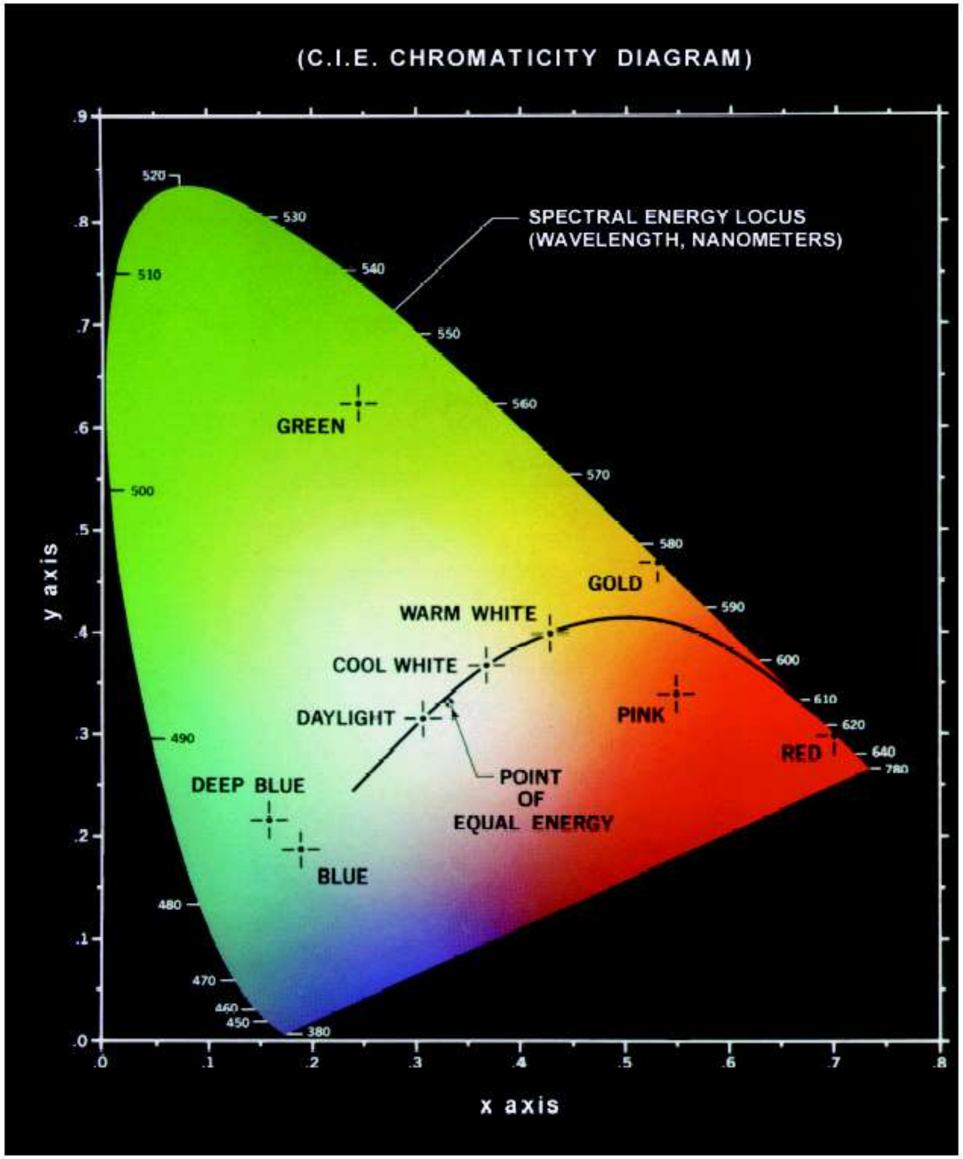
-Specifying colours systematically can be achieved using the CIE **chromacity diagram**

-On this diagram the x-axis represents the proportion of red and the y-axis represents the proportion of green used

-The proportion of blue used in a colour is calculated as:

$$z = 1 - (x + y)$$

CIE Chromacity Diagram (cont…)



CIE Chromacity Diagram (cont…)

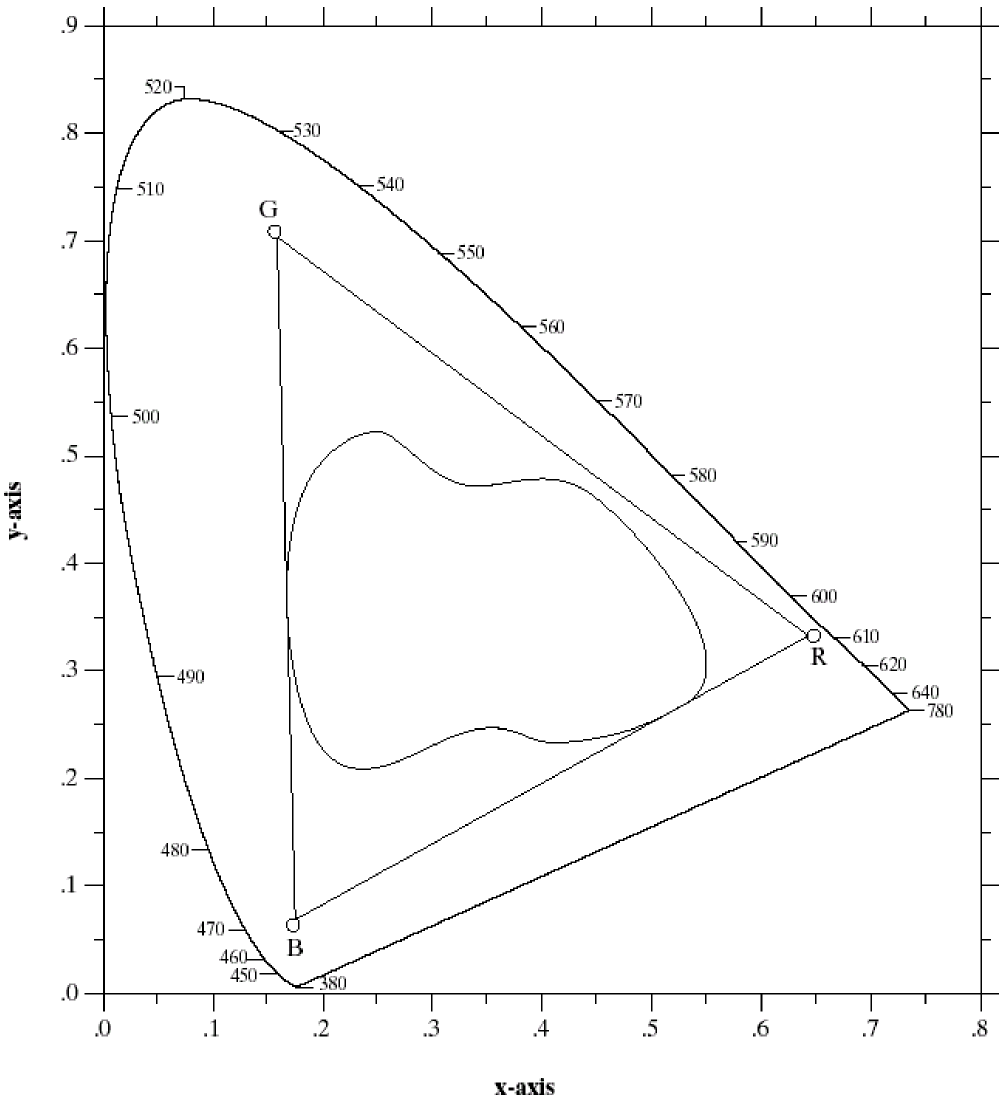
- Any colour located on the boundary of the chromacity chart is fully saturated

-The point of equal energy has equal amounts of each colour and is the CIE standard for pure white

-Any straight line joining two points in the diagram defines all of the different colours that can be obtained by combining these two colours additively

This can be easily extended to three points

CIE Chromacity Diagram (cont…)



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

- This means the entire colour range cannot be displayed based on any three colours
- The triangle shows the typical colour gamut produced by RGB monitors
- The strange shape is the gamut achieved by high quality colour printers

Colour Models

- There are different ways to model colour

We will consider two very popular models used in colour image processing:

- RGB (**R**ed **G**reen **B**lue)
- HSI (**H**ue **S**aturation **I**ntensity)

RGB

In the RGB model each colour appears in its primary spectral components of red, green and blue

The model is based on a Cartesian coordinate system

- RGB values are at 3 corners
- Cyan magenta and yellow are at three other corners
- Black is at the origin
- White is the corner furthest from the origin
- Different colours are points on or inside the cube represented by RGB vectors

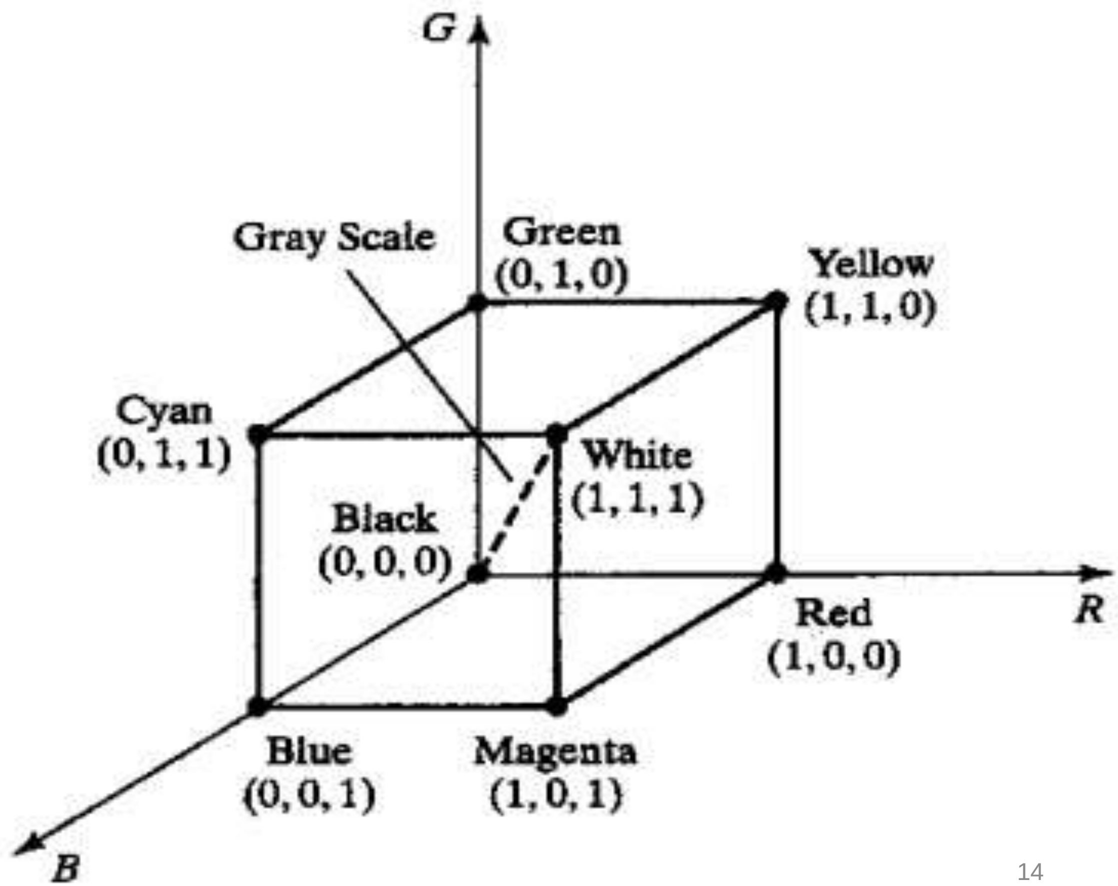
RGB (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

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

Color depth 24 bits
= 16777216 colors

RGB are natural choices for primaries as they can cover the largest part of the "horseshoe"



RGB (cont...)

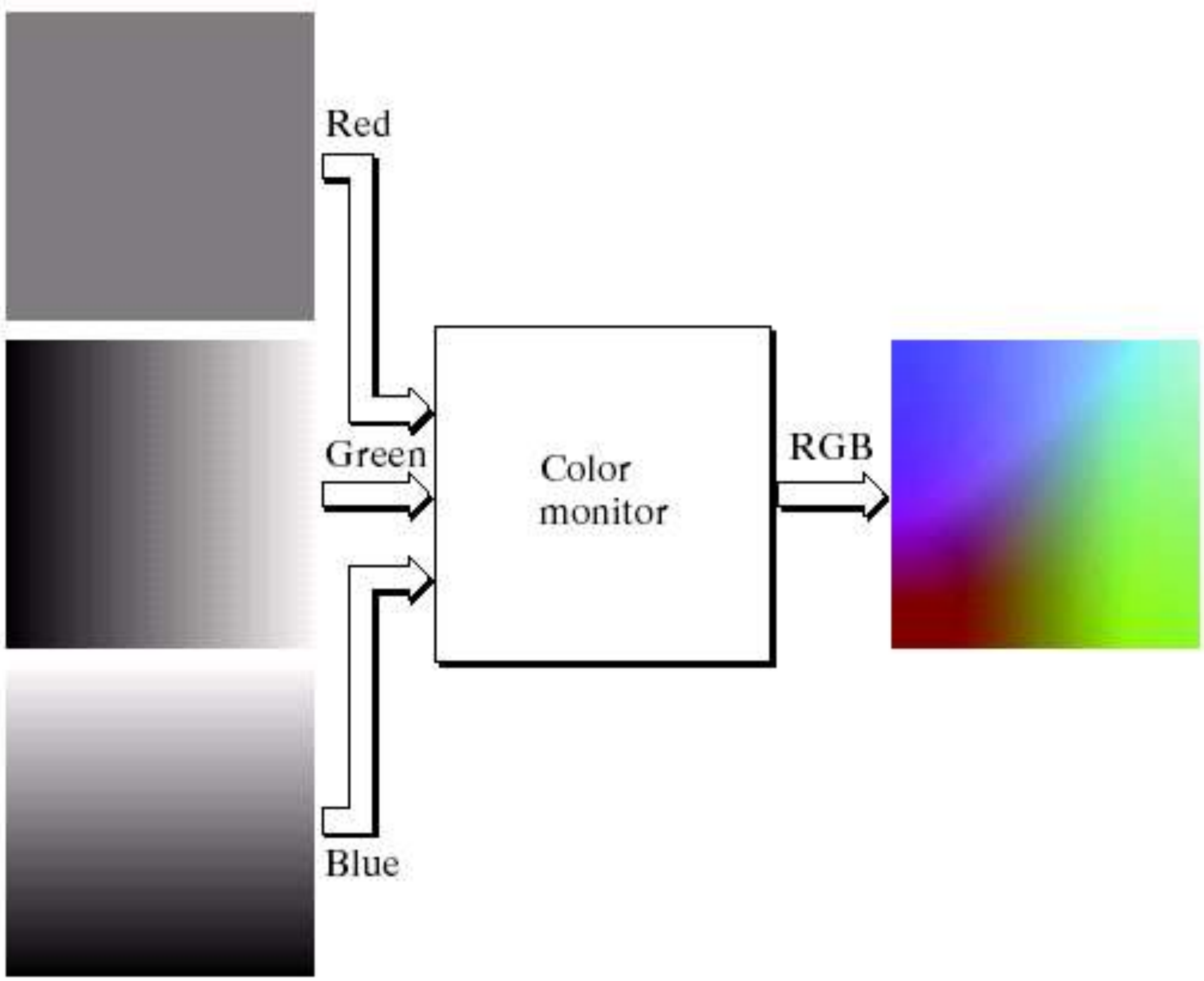
- Images represented in the RGB colour model consist of three component images – one for each primary colour

- When fed into a monitor these images are combined to create a composite colour image

- The number of bits used to represent each pixel is referred to as the colour depth

A 24-bit image is often referred to as a full-colour image as it allows $\left(2^8\right)^3$ = 16,777,216 colours

RGB (cont…)

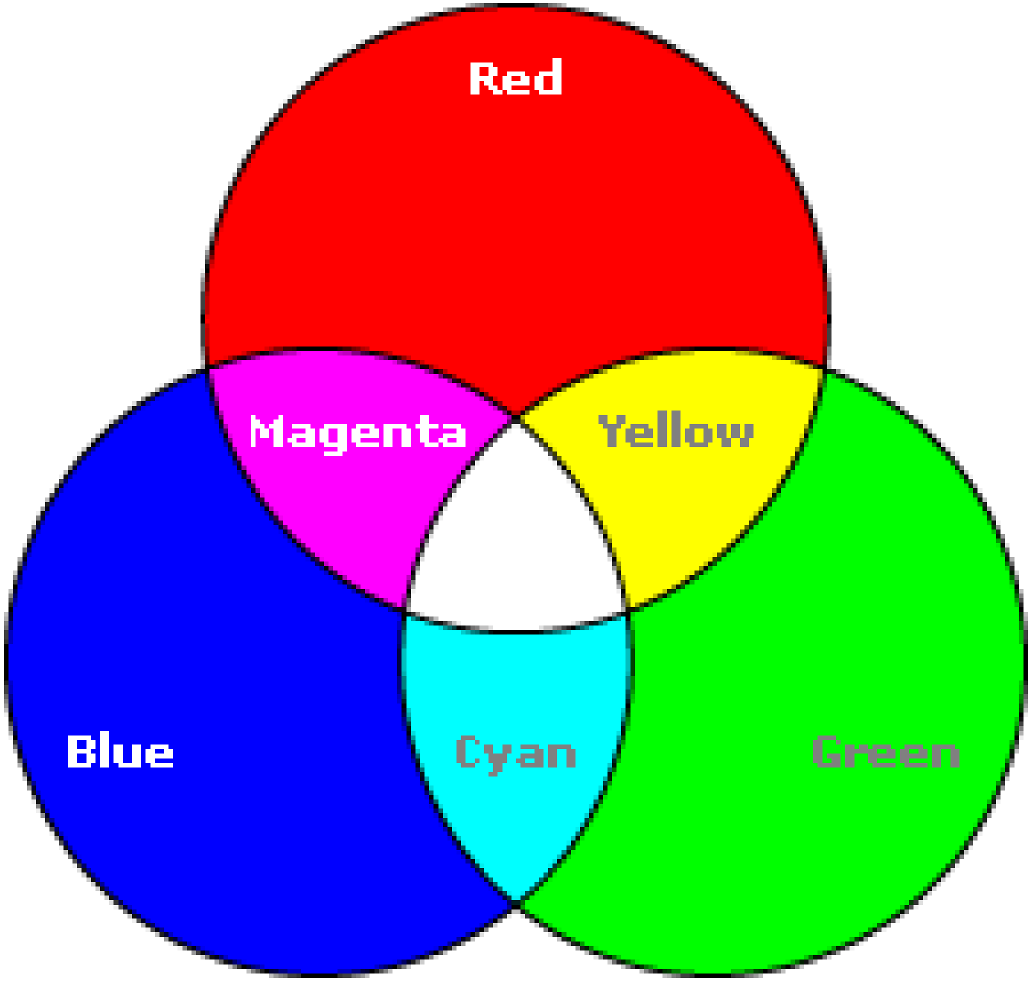


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

RGB Color Model

- Used in light emitting devices
  - Color CRT monitors
- Additive
  - Result = individual contributions of each primary color added together
  - $C = rR + gG + bB$, where $r, g, b \in [0, 1]$
  - $R = (1, 0, 0)$
  - $G = (0, 1, 0)$
  - $B = (0, 0, 1)$

RGB Color Model



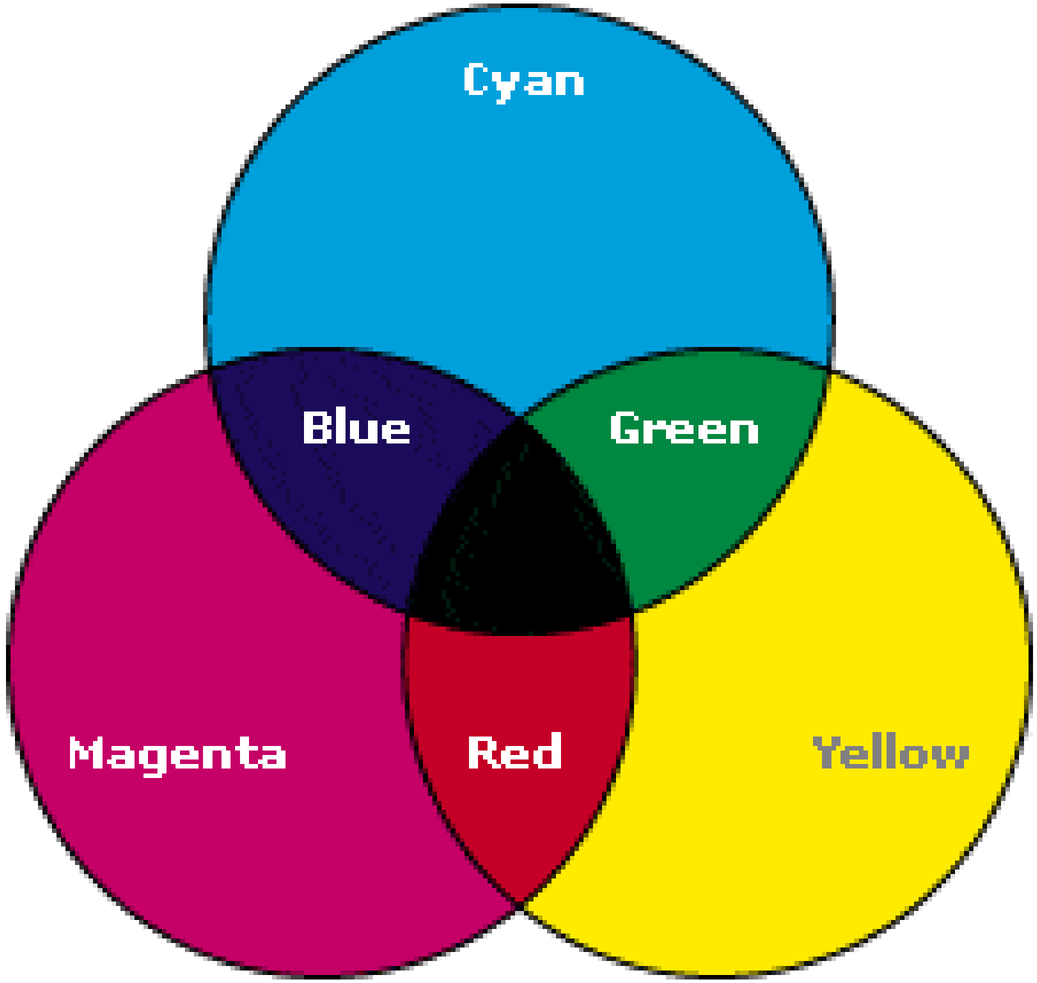
RGB Color Model

- Color Cube
  - $R + G = (1, 0, 0) + (0, 1, 0) = (1, 1, 0) = Y$
  - $R + B = (1, 0, 0) + (0, 0, 1) = (1, 0, 1) = M$
  - $B + G = (0, 0, 1) + (0, 1, 0) = (0, 1, 1) = C$
  - $R + G + B = (1, 1, 1) = W$
  - $1 – W = (0, 0, 0) = \text{BLK}$
  - Grays = (x, x, x), where $x \in (0, 1)$

CMY Color Model

- CMY: Complements of RGB
- Used in light absorbing devices
  - Hardcopy output devices
- Subtractive
  - Color specified by what is subtracted from white light
  - Cyan absorbs red, magenta absorbs green, and yellow absorbs blue

CMY Color Model

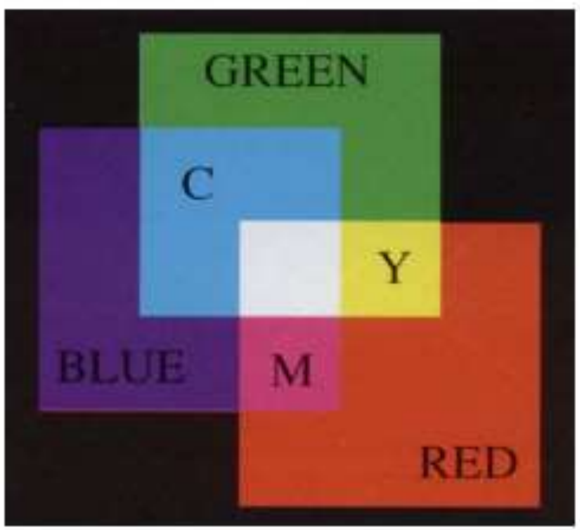


CMY Color Model

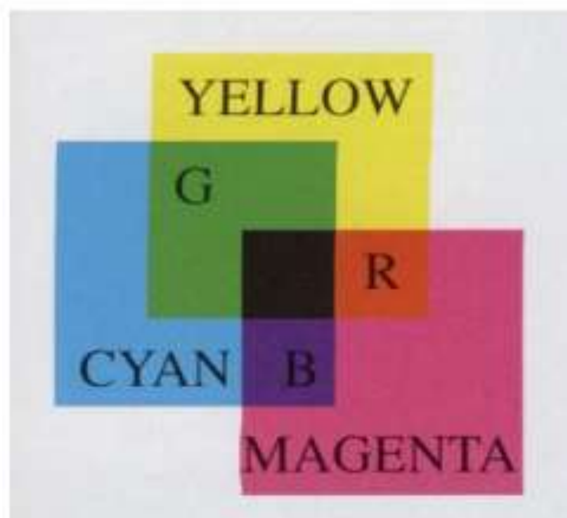
- $W = (0, 0, 0)$ $B = (1, 1, 1)$
- Conversion from RGB to CMY
- Conversion from CMY to RGB

RGB vs. CMY Color Model

- RGB and CMYK (Cyan, Magenta, Yellow and blacK) are **hardware-oriented** representations
- CMY is used in color photography and (with K) in most color printers



RGB is Additive



CMY is Subtractive

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

The HSI Colour Model

- RGB is useful for hardware implementations and is serendipitously related to the way in which the human visual system works.

-However, RGB is not a particularly intuitive way in which to describe colours.

-Rather when people describe colours they tend to use **hue**, **saturation** and **brightness.**

RGB is great for colour generation, but HSI is great for colour description.

The HSI Colour Model (cont…)

The HSI model uses three measures to describe colours:

- **Hue**: A colour attribute that describes a pure colour (pure yellow, orange or red)
- **Saturation**: Gives a measure of how much a pure colour is diluted with white light
- **Intensity**: Brightness is nearly impossible to measure because it is so subjective. Instead we use intensity. Intensity is the same achromatic notion that we have seen in grey level images

Intuitive Color Concepts

- Terminology

Perceptual Term	Colorimetry	Comments
hue	dominated wavelength	to distinguish colors
saturation	excitation purity	e.g., red and pink
Lightness (reflecting objects)	luminance	
Brightness (self-luminous objects)	luminance	e.g., Sun, CRT

The HSI Colour Model (cont…)

Hue (red, green, yellow, blue ...)
Saturation (pink, bright red, ...)
Lightness (black, grey, white ....)

The HSI Colour Model (cont…)

- HSI decouples intensity from color information
  - allow algorithms that developed for black and white or grey scale images can also be used here HSI

HSI, Intensity & RGB

-Intensity can be extracted from RGB images which is not surprising if we stop to think about it.

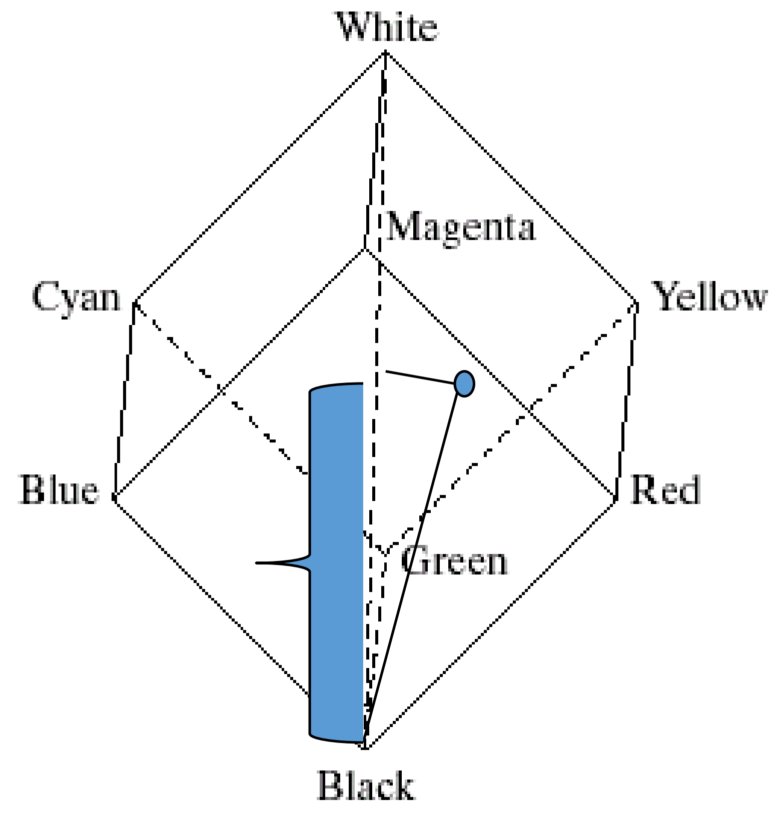
-Remember the diagonal on the RGB colour cube that we saw previously ran from black to white.

-Now consider if we stand this cube on the black vertex and position the white vertex directly above it

HSI, Intensity & RGB (cont…)

Now the intensity component of any colour can be determined by passing a plane *perpendicular* to the intensity axis and containing the colour point

The intersection of the plane with the intensity axis gives us component of the colour

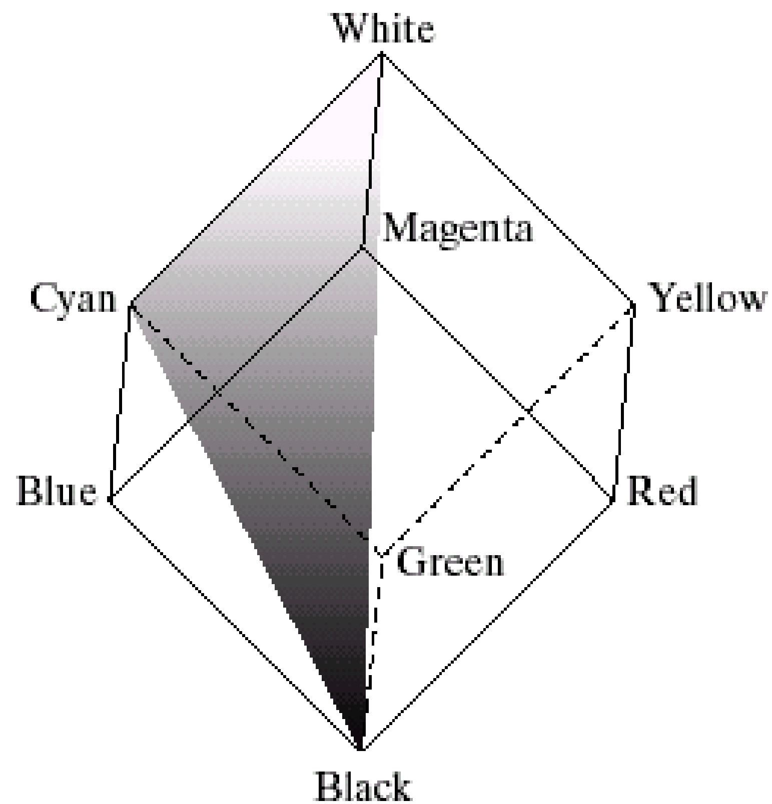


HSI, Hue & RGB

In a similar way we can extract the hue from the RGB colour cube

Consider a plane defined by the three points cyan, black and white

All points contained in this plane must have the same hue (cyan) as black and white cannot contribute hue information to a colour

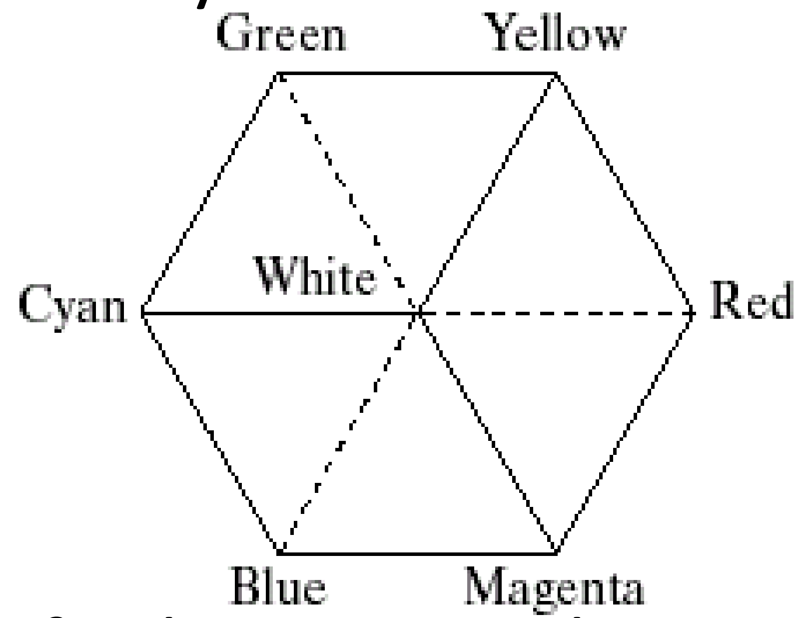


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

The HSI Colour Model

Consider if we look straight down at the RGB cube as it was arranged previously

We would see a hexagonal shape with each primary colour separated by 120° and secondary colours at 60° from the primaries

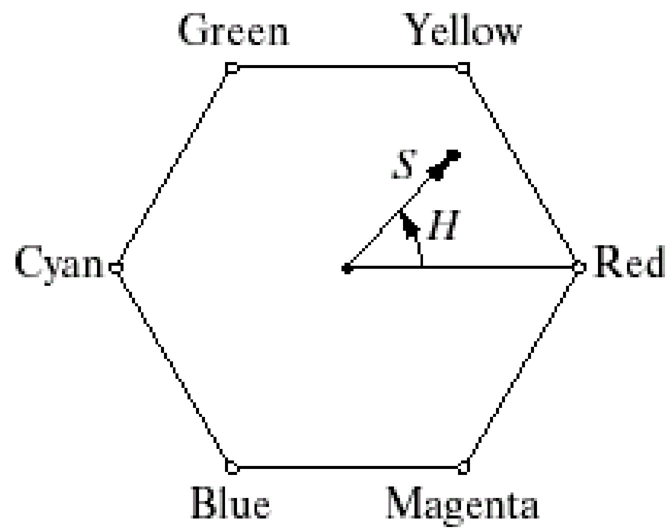


So the HSI model is composed of a vertical intensity axis and the locus of colour points that lie on planes perpendicular to that axis

The HSI Colour Model (cont…)

To the right we see a hexagonal shape and an arbitrary colour point

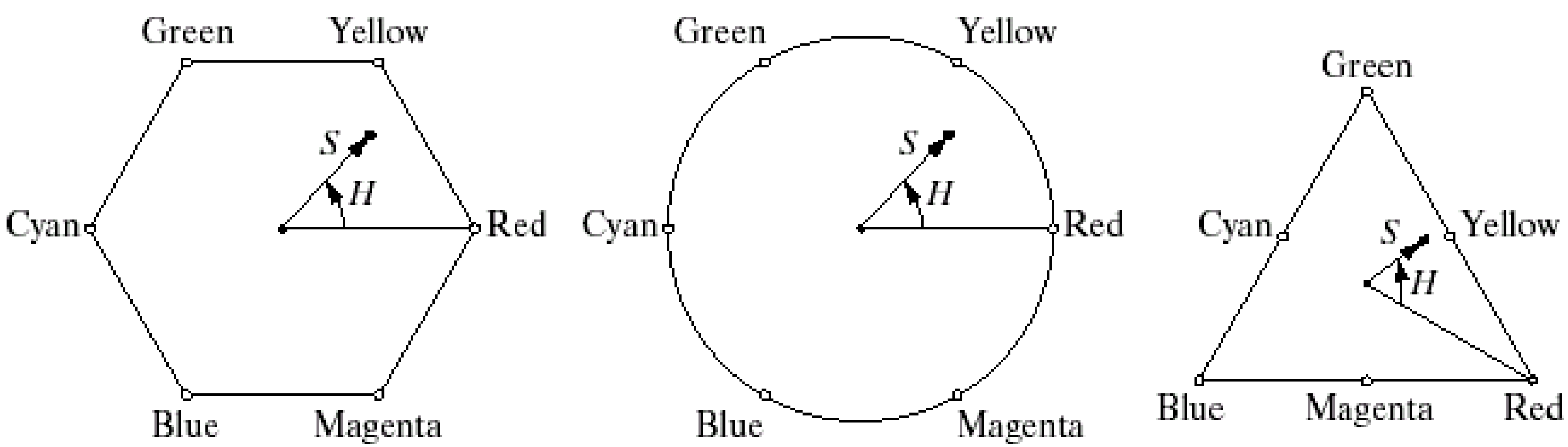
- The hue is determined by an angle from a reference point, usually red
- The saturation is the distance from the origin to the point
- The intensity is determined by how far up the vertical intenisty axis this hexagonal plane sits (not apparent from this diagram



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

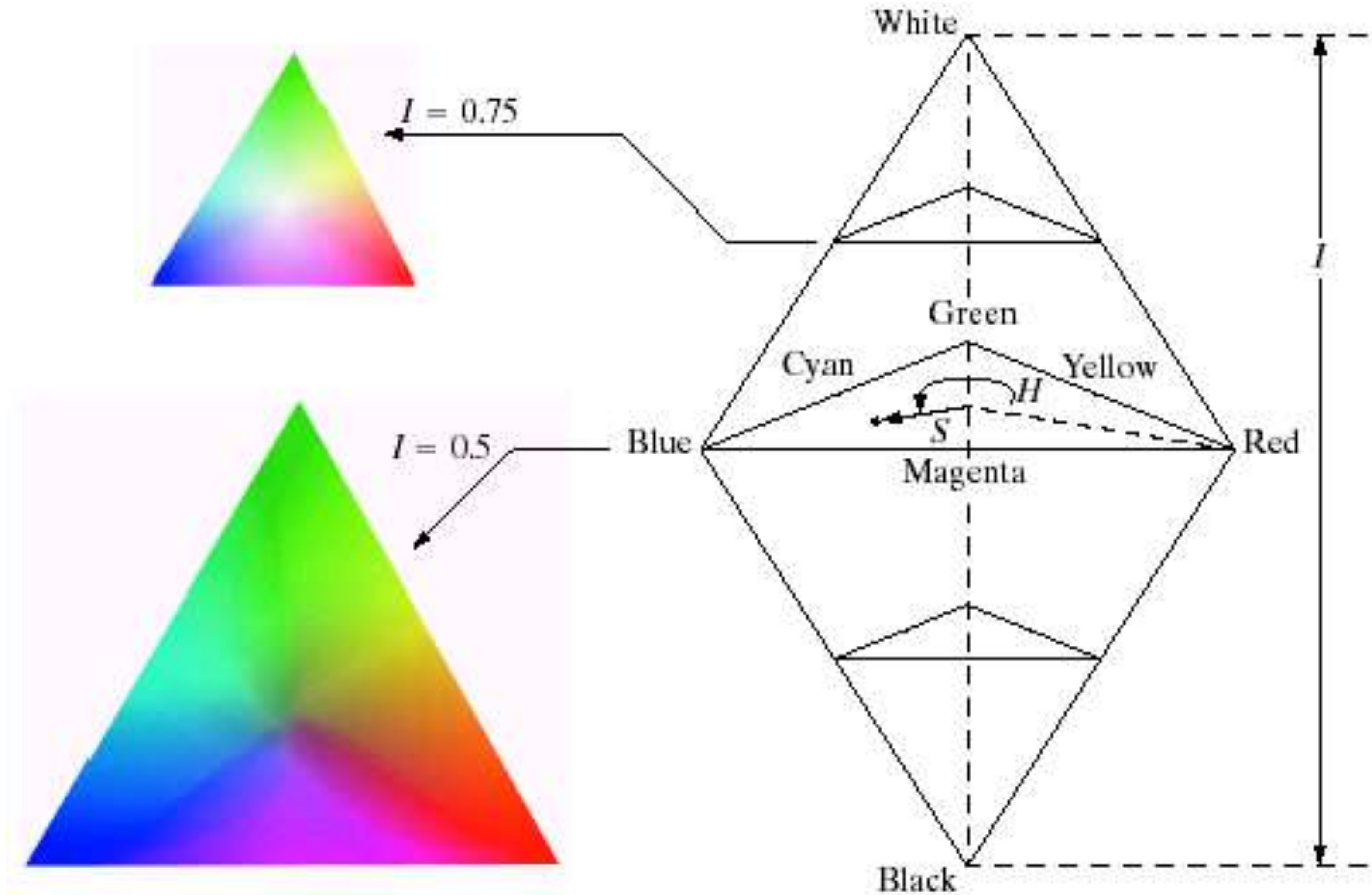
The HSI Colour Model (cont…)

Because the only important things are the angle and the length of the saturation vector this plane is also often represented as a circle or a triangle



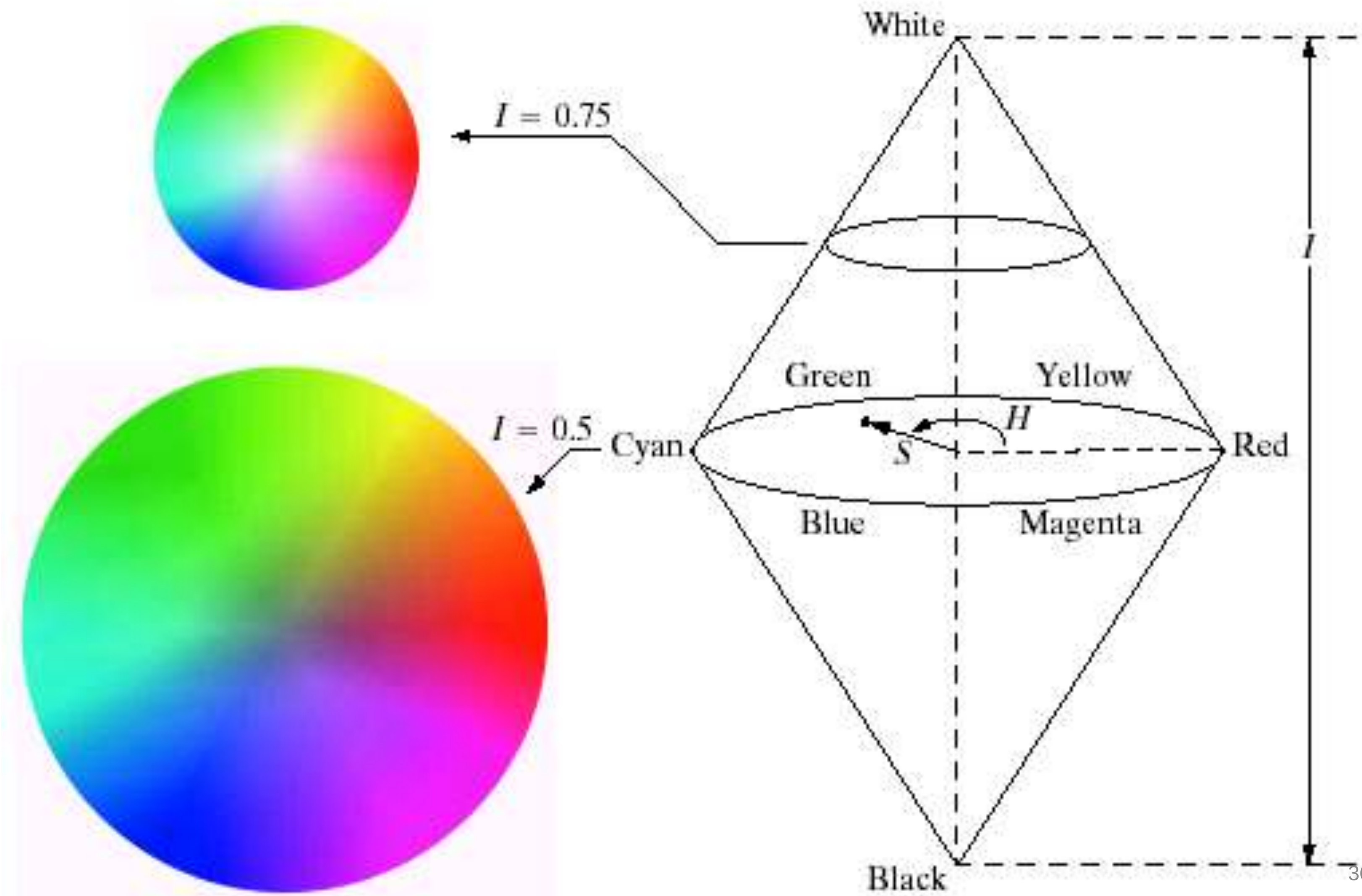
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

HSI Model Examples



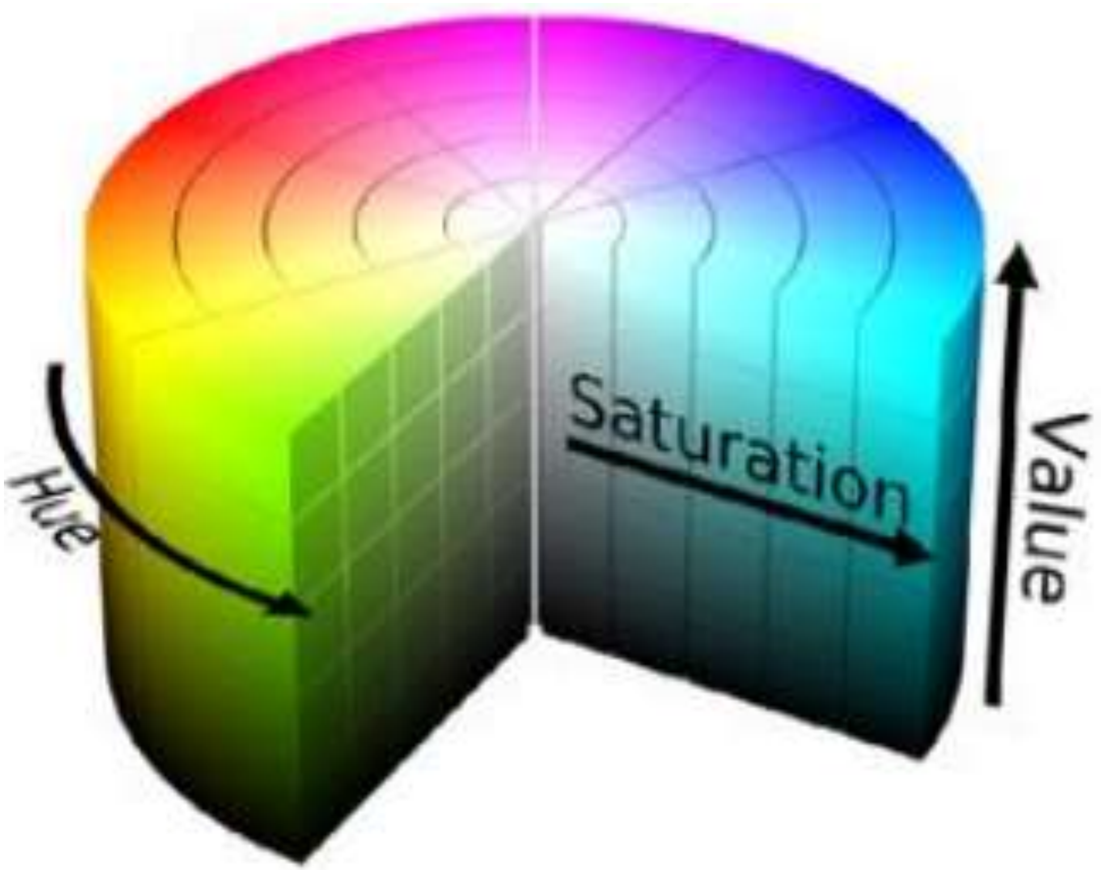
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

HSI Model Examples



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

HSI Model Examples



Converting From RGB To HSI

Given a colour as R, G, and B its H, S, and I values are calculated as follows:

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

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

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

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

Converting From HSI To RGB

Given a colour as H, S, and I it's R, G, and B values are calculated as follows:

- RG sector ($0 <= H < 120°$)

$$R = I\left[1 + \frac{S\cos H}{\cos(60 - H)}\right] \qquad G = 3I - (R + B) \qquad B = I(1 - S)$$

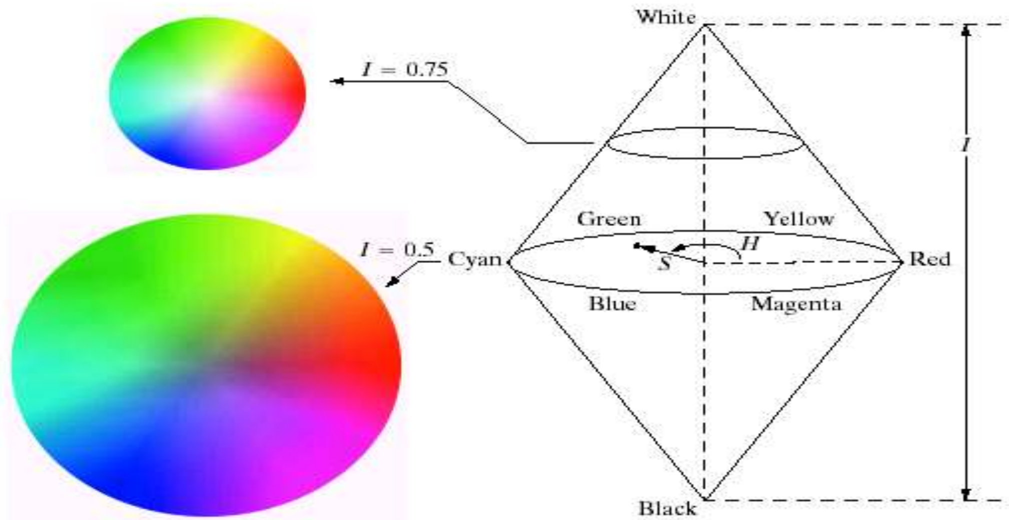
- GB sector ($120° <= H < 240°$)

$$R = I(1 - S) \qquad G = I\left[1 + \frac{S\cos(H - 120)}{\cos(H - 60)}\right] \qquad B = 3I - (R + G)$$

Converting From HSI To RGB (cont…)

- BR sector ($240° <= H <= 360°$)

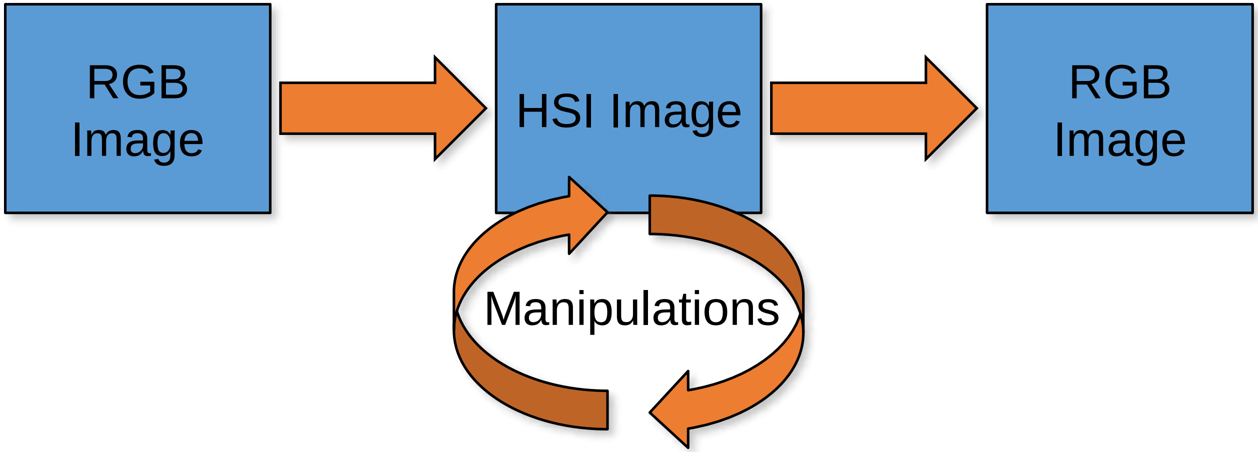
$$R = 3I - (G + B) \quad G = I(1 - S) \quad B = I\left[1 + \frac{S\cos(H - 240)}{\cos(H - 180)}\right]$$



Manipulating Images In The HSI Model

In order to manipulate an image under the HSI model we:

- First convert it from RGB to HSI
- Perform our manipulations under HSI
- Finally convert the image back from HSI to RGB



Types of Color Processing

1. Full color processing. Images are quarried by color camera

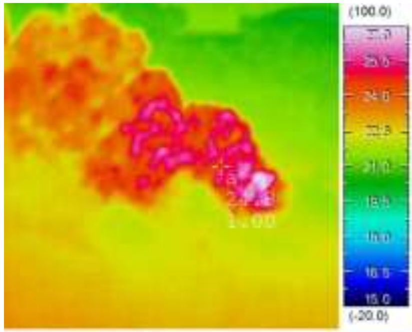
2. Pseudocolour (also called false colour) image processing consists of assigning colours to grey values based on a specific criterion

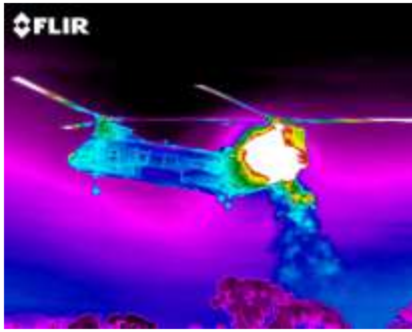
Pseudocolour Image Processing

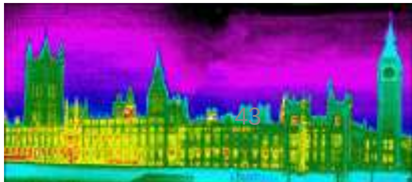
Pseudocolour (also called false colour) image processing consists of assigning colours to grey values based on a specific criterion

The principle use of pseudocolour image processing is for human visualisation

- Humans can discern between thousands of colour shades and intensities, compared to only about two dozen or so shades of grey







Pseudo Colour Image Processing – Intensity Slicing

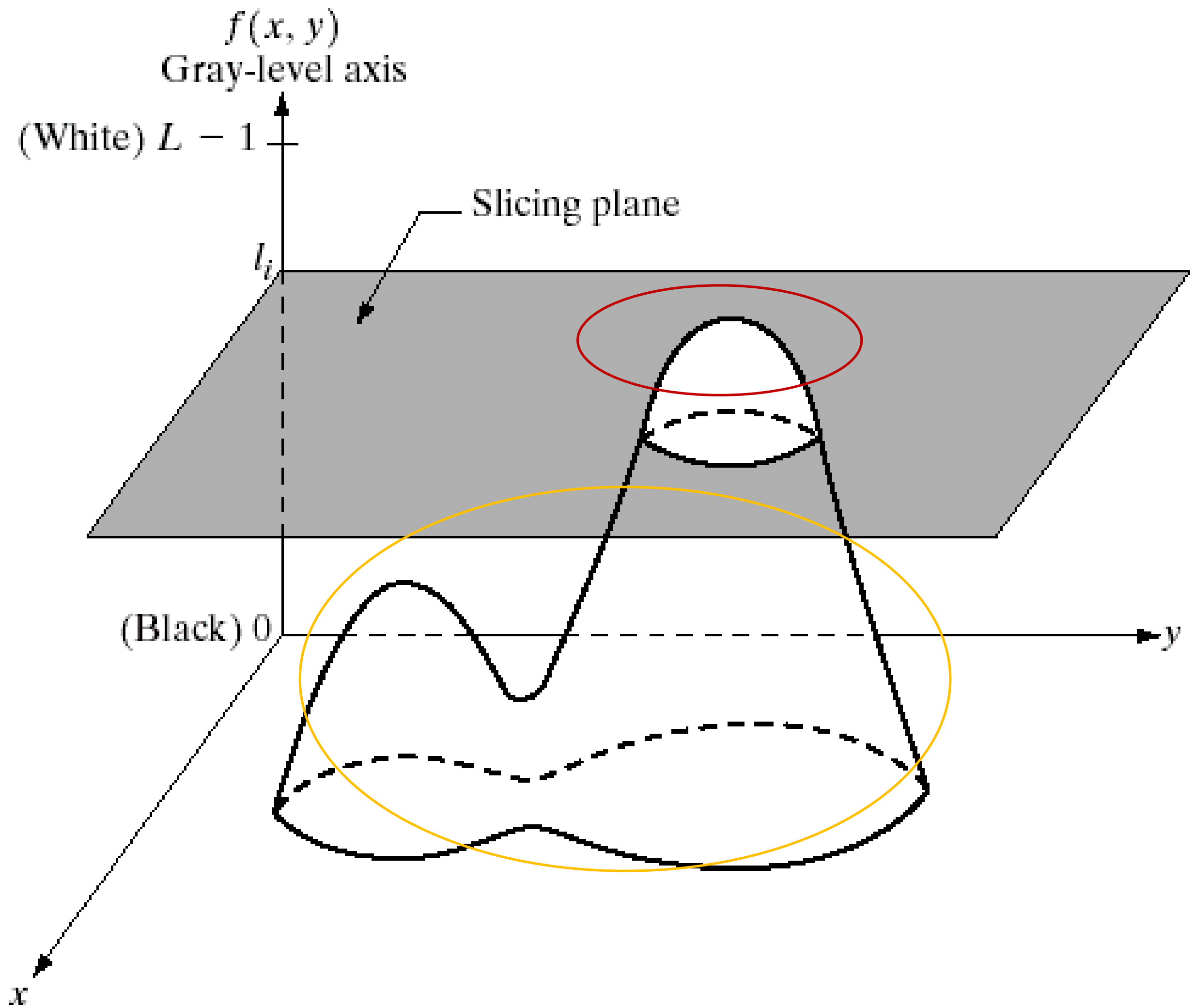
Intensity slicing and colour coding is one of the simplest kinds of pseudocolour image processing

First we consider an image as a 3D function mapping spatial coordinates to intensities (that we can consider heights)

Now consider placing planes at certain levels parallel to the coordinate plane

If a value is one side of such a plane it is rendered in one colour, and a different colour if on the other side

Pseudocolour Image Processing – Intensity Slicing (cont…)



Pseudocolour Image Processing – Intensity Slicing (cont…)

In general intensity slicing can be summarized as:

- Let $[0, L-1]$ represent the grey scale
- Let l_0 represent black $[f(x, y) = 0]$ and let l_{L-1} represent white $[f(x, y) = L-1]$
- Suppose P planes perpendicular to the intensity axis are defined at levels $l_1, l_2, \ldots, l_p$
- Assuming that $0 < P < L-1$ then the P planes partition the grey scale into $P + 1$ intervals $V_1, V_2, \ldots, V_{P+1}$

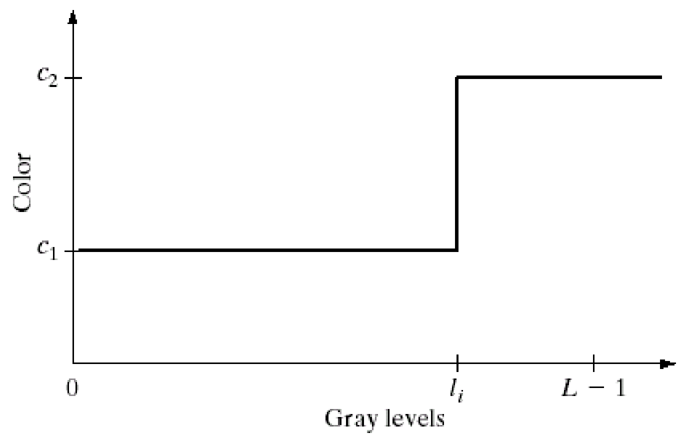
Pseudocolour Image Processing – Intensity Slicing (cont…)

- Grey level colour assignments can then be made according to the relation:

$$f(x,y) = c_k \qquad \text{if } f(x,y) \in V_k$$

- where ck is the colour associated with the k^{th} intensity level V_k defined by the partitioning planes at $l = k - 1$ and $l = k$

RGB -> HSI -> RGB (cont…)



RGB -> HSI -> RGB (cont…)