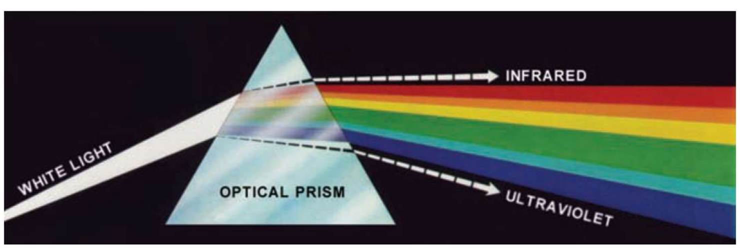
Chapter 7

Colour Images

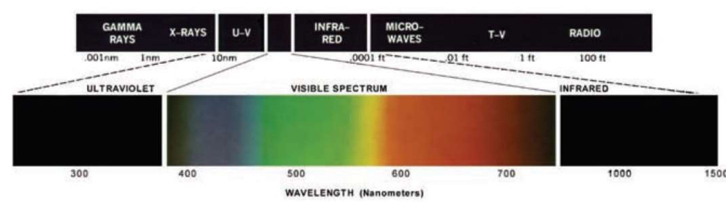
Introduction

- In 1666, Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging light is not white, but consists instead of a continuous spectrum of colors ranging from violet at one end to red at the other.

- The color spectrum may be divided into six broad regions: violet, blue, green, yellow, orange, and red.

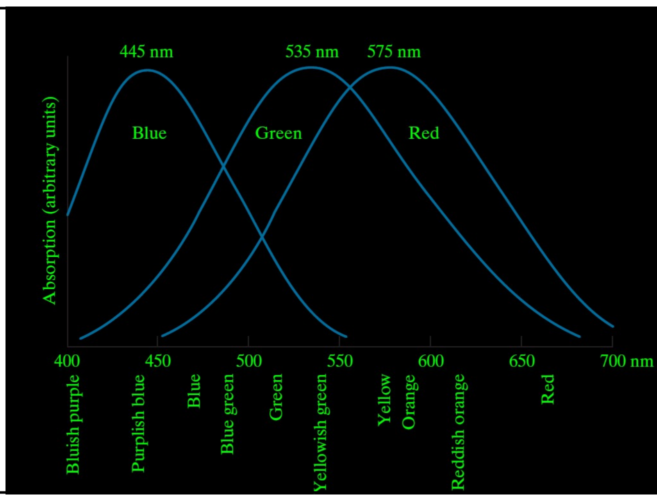


- When viewed in full color, no color in the spectrum ends abruptly; rather, each color blends smoothly into the next.

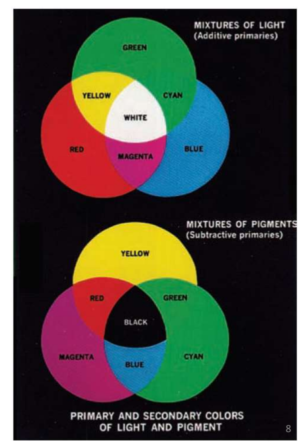


- The colors that humans and some other animals perceive in an object are determined by the nature of the light reflected from the object.
- Visible light is composed of a relatively narrow band of frequencies in the electromagnetic spectrum.
- A body that reflects light that is balanced in all visible wavelengths appears white to the observer.
- However, a body that favors reflectance in a limited range of the visible spectrum exhibits some shades of color.
- Green objects reflect light with wavelengths primarily in the 500 to 570 nm range, while absorbing most of the energy at other wavelengths.

- If a light is achromatic (void of color), its only attribute is its intensity, or amount.
- Chromatic light spans the electromagnetic spectrum from approximately 400 to 700 nm.
- The human eye sees colors as variable combinations of the so-called primary colors: red (R), green (G), and blue (B).
- The primary colors can be added together to produce the secondary colors of light—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.



- There is a difference between primary colors of light and the primary colors of pigments (colorants).
- The primary colors of pigments are magenta, cyan, and yellow, and the secondary colors are red, green, and blue.
- A proper combination of the three pigment primaries, or a secondary with its opposite primary, produces black.



- Color image is characterized by, brightness, Hue and Saturation.
- **Brightness** is similar to intensity of graylevel image.
- **Hue** is an attribute associated with the dominant wavelength in a mixture of light waves. It is 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

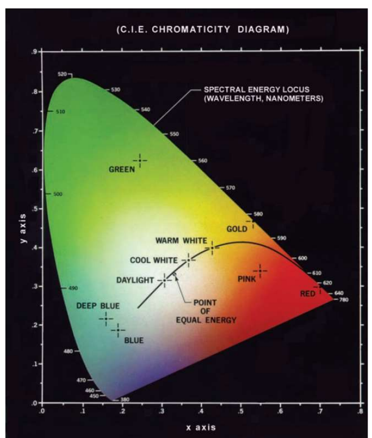
- The amounts of red, green, and blue needed to form any particular color are called the tristimulus values.
- Tristimulus values are denoted, X, Y, and Z, respectively.
- A color is then specified by its trichromatic coefficients, defined as

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

- We see from these equations that

$$x + y + z = 1$$

- CIE chromaticity diagram 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 has 62% green and 25% red content.
- So the composition of blue is approximately 13%.



Color Models

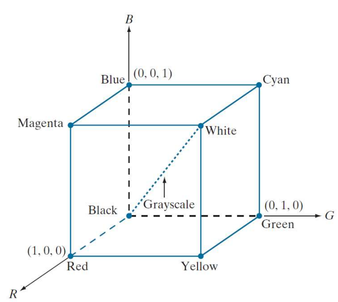
- The purpose of a color model is to represent colors in some standard way.
- A color model is based on
  (1) a coordinate system, and
  (2) a subspace within that system, such that each color in the model is represented by a single point contained in that subspace.
- Most color models in use today are oriented either toward hardware (such as for color monitors and printers) or toward applications.

- The hardware-oriented models most commonly used in practice are the RGB (red, green, blue) model
- It is used in for color monitors and a broad class of color video cameras.
- The CMY (cyan, magenta, yellow) and CMYK (cyan, magenta, yellow, black) models are used for color printing.
- The HSI (hue, saturation, intensity) model corresponds closely with the way humans describe and interpret color.
- The HSI model has the advantage that it decouples the color and gray-scale information in an image, making it suitable for many of the gray-scale techniques we have learned.

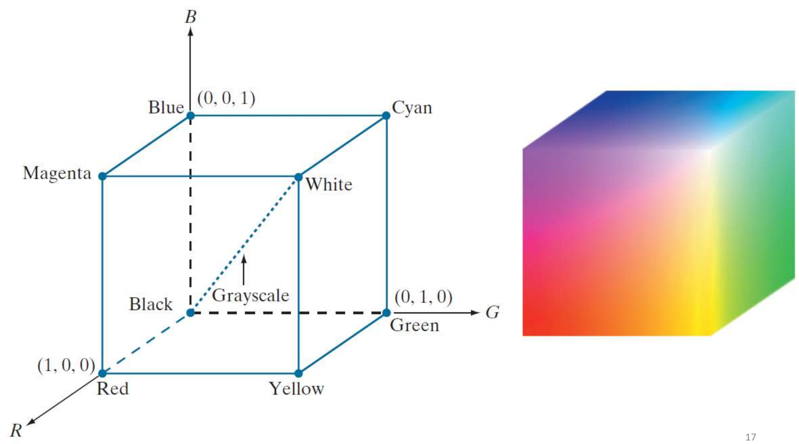
The RGB Color Model

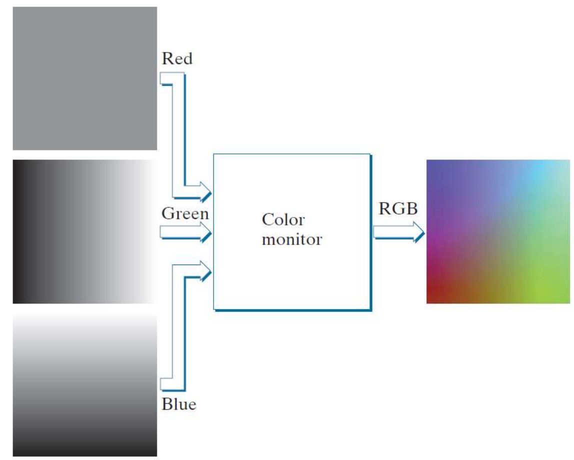
- Images represented in the RGB color model consist of three component images, one for each primary color. When fed into an RGB monitor, these three images combine on the screen to produce a composite color image.
- The number of bits used to represent each pixel in RGB space is called the **pixel depth**.

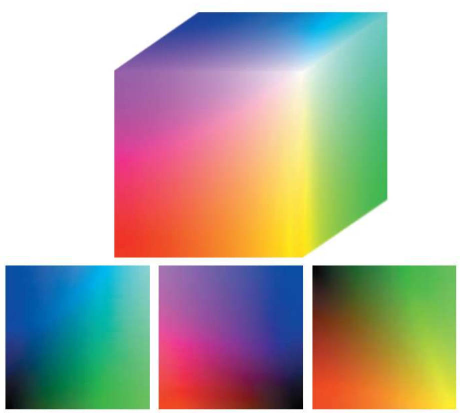
- This model is based on a Cartesian coordinate system.
- The color of interest is the cube in which RGB primary values are at three corners.
- The secondary colors cyan, magenta, and yellow are at three other corners.
- Black is at the origin.
- White is at the corner farthest from the origin.



- In this model, the grayscale (points of equal RGB values) extends from black to white along the line joining these two points.
- The different colors in this model are points on or inside the cube, and are defined by vectors extending from the origin.
- All color values have been normalized so the cube is the unit cube.
- All values of R, G, and B in this representation are assumed to be in the range [0, 1].







$(R = 0)$ $(G = 0)$ $(B = 0)$

- Consider an RGB image in which each of the red, green, and blue images is an 8-bit image.
- Under these conditions, each RGB color pixel has a depth of 24 bits.
- The term full-color image is used often to denote a 24-bit RGB color image.
- The total number of possible colors in a 24-bit RGB image is $(2^8)^3 = 16,777,216$.

The CMY And CMYK Color Models

- Cyan, magenta, and yellow are the secondary colors of light.
- They are the primary colors of pigments.
- When a surface coated with cyan pigment is illuminated with white light, no red light is reflected from the surface.
- Cyan subtracts red light from reflected white light.
- It is composed of equal amounts of green, and blue light.

- Most devices that deposit colored pigments on paper, such as color printers and copiers, require CMY data input.
- Otherwise they perform an RGB to CMY conversion internally.
- This conversion is performed using the simple operation.

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

- Here, all RGB color values have been normalized to the range $[0, 1]$.

- Light reflected from a surface coated with pure cyan does not contain red because $C = 1 - R$.
- Pure magenta does not reflect green.
- Pure yellow does not reflect blue.
- Similarly, RGB values can be obtained easily from a set of CMY values by subtracting the individual CMY values from 1.
- Equal amounts of the pigment primaries, cyan, magenta, and yellow, produces black.
- If we add black in CMY, we get CMYK model, k stands for black.

- The conversion from CMY to CMYK begins by letting

$$K = \min(C, M, Y)$$

- If $K = 1$, then we have pure black, with no color contributions, from which it follows that

$$C = 0$$

$$M = 0$$

$$Y = 0$$

- For the values of K except 1,

$$C = (C - K)/(1 - K)$$

$$M = (M - K)/(1 - K)$$

$$Y = (Y - K)/(1 - K)$$

- Here all values are assumed to be in the range $[0, 1]$.
- The conversions from CMYK back to CMY are

$$C = C * (1 - K) + K$$

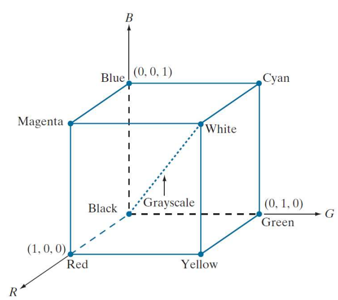
$$M = M * (1 - K) + K$$

$$Y = Y * (1 - Y) + K$$

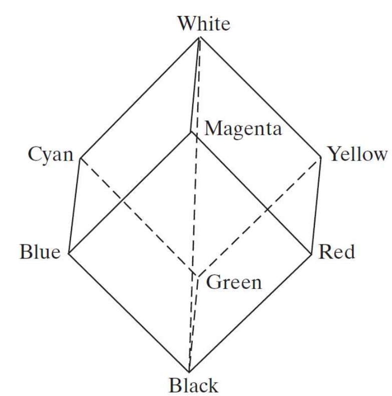
HSI (Hue, Saturation, Intensity) Color Model

- When humans view a color object, we describe it by its hue, saturation, and brightness.
- Hue is a color attribute that describes a pure color (pure yellow, orange, or red).
- Saturation gives a measure of the degree to which a pure color is diluted by white light.
- Brightness is similar to intensity of gray-level image.
- HSI model is a useful tool for developing image processing algorithms based on color descriptions that are natural and intuitive to humans.

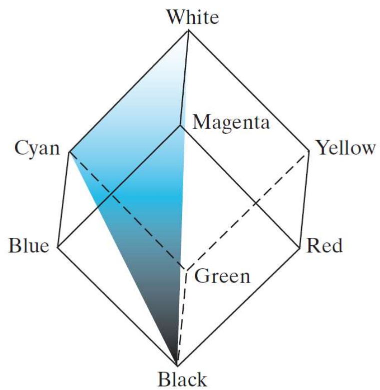
- We can to extract intensity from an RGB image.
- The intensity (gray) axis is along the line joining black vertex $(0, 0, 0)$ and white vertex $(1, 1, 1)$ of a color cube.
- From this we can find intensity of color.
- The intersection of the plane with the intensity axis would give us a point with intensity value in the range $[0, 1]$.



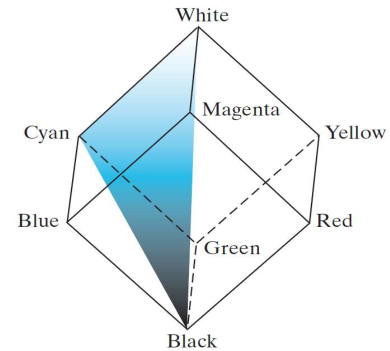
- The saturation (purity) of a color increases as a distance of color from the intensity axis increases.
- The saturation on the intensity axis is zero because all points along this axis are gray.



- Hue can be determined from an RGB value also.
- Consider a plane defined by three points (black, white, and cyan).
- Black and white points are contained in the plane.
- The intensity axis is also contained in the plane.

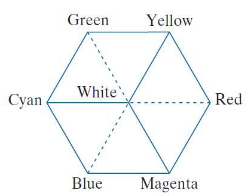


- All points contained in the plane segment defined by the intensity axis and the boundaries of the cube have the same hue (cyan in this case).
- By rotating the shaded plane about the vertical intensity axis, we would obtain different hues.

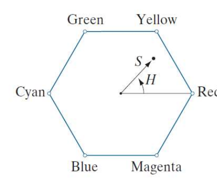


- The hue, saturation, and intensity values required to form the HSI space can be obtained from the RGB color cube.

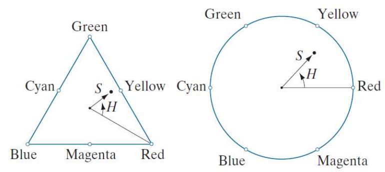
- HSI space is represented by a vertical intensity axis, and the locus of color points that lie on planes perpendicular to that axis.
- As the planes move up and down the intensity axis, the boundaries defined by the intersection of each plane with the faces of the cube have either a triangular or a hexagonal shape.
- This can be visualized much more readily by looking at the cube straight down its grayscale axis.



- The primary colors are separated by 120°.
- The secondary colors are 60° from the primaries, which means that the angle between secondaries is 120° also.
- The hue of the point is determined by an angle from the red axis.
- Red axis means 0 hue, and the hue increases counterclockwise from there.



- The saturation (distance from the vertical axis) is the length of the vector from the origin to the point.
- The origin is defined by the intersection of the color plane with the vertical intensity axis.
- Usually HIS planes are defined in terms of a triangle, or even a circle.



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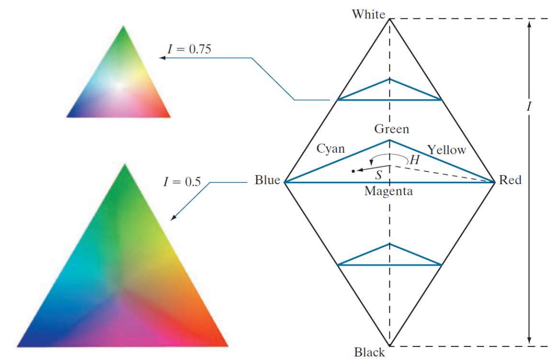
HSI model based on color triangles



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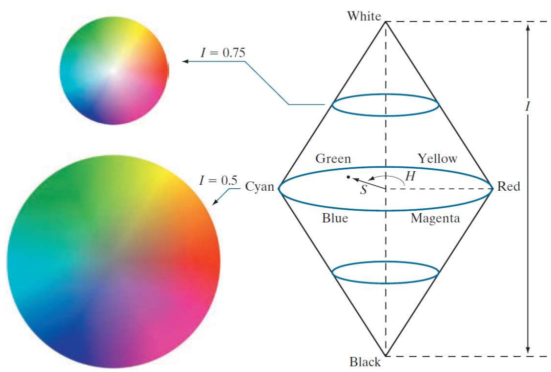
HSI model based on color circles



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Converting Colors from RGB to HSI

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

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

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

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The saturation component is given by

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

Finally, the intensity component is obtained from the equation

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

Converting Colors from HSI to RGB

- Given values of HSI in the interval [0, 1], we now want to find the corresponding RGB values in the same range.
- The applicable equations depend on the values of H.
- There are three sectors of interest, corresponding to the 120° intervals in the separation of primaries.
- We begin by multiplying H by 360°, which returns the hue to its original range of [0°,360°].

RG sector $(0° \le H < 120°)$: When H is in this sector, the RGB components are given by the equations

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

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

and

$$G = 3I - (R+B)$$

GB sector $(120° \le H < 240°)$: If the given value of H is in this sector, we first subtract 120° from it:

$$H = H - 120°$$

Then, the RGB components are

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

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

and

$$B = 3I - (R+G)$$

BR sector $(240° \le H \le 360°)$: Finally, if H is in this range, we subtract $240°$ from it:

$$H = H - 240°$$

Then, the RGB components are

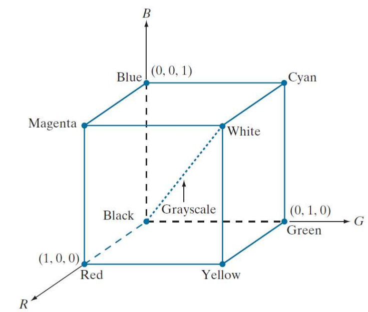
$$G = I(1 - S)$$

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

and

$$R = 3I - (G + B)$$

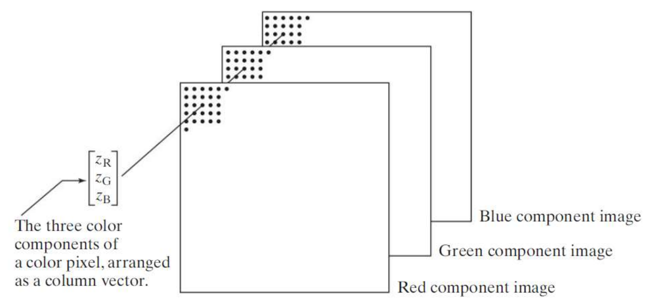
RGB colour cube



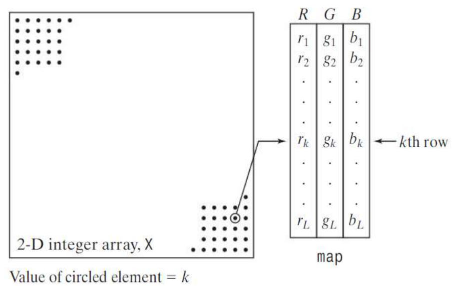
RGB values of primary and secondary colours

Long name	Short name	RGB values
Black	k	[0 0 0]
Blue	b	[0 0 1]
Green	g	[0 1 0]
Cyan	c	[0 1 1]
Red	r	[1 0 0]
Magenta	m	[1 0 1]
Yellow	y	[1 1 0]
White	w	[1 1 1]

How colour images are stored digitally?



Each pixel has 3 values R, G and B



- We can easily convert any coloured image in grayscale image and then apply all the techniques that we have learned.

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