Introduction to Image Processing

Ch 6. Color Image Processing

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Ch 6. Color Image Processing

6.1 Color Fundamentals

- Three basic quantities are used to describe the quality of a chromatic light (from about 400 to 700 nm) 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 achromatic notion of intensity of light

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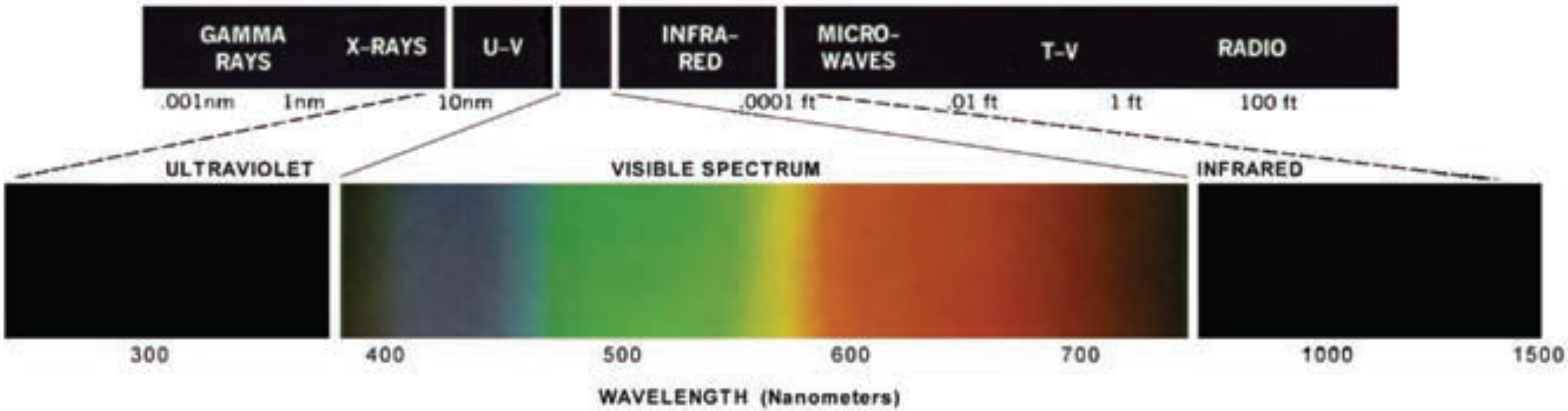
6.1 Color Fundamentals

- Chromatic light spans the electromagnetic spectrum from approximately 400 to 700 nm.
- Human color vision is achieved through 6 to 7 million cones in each eye.



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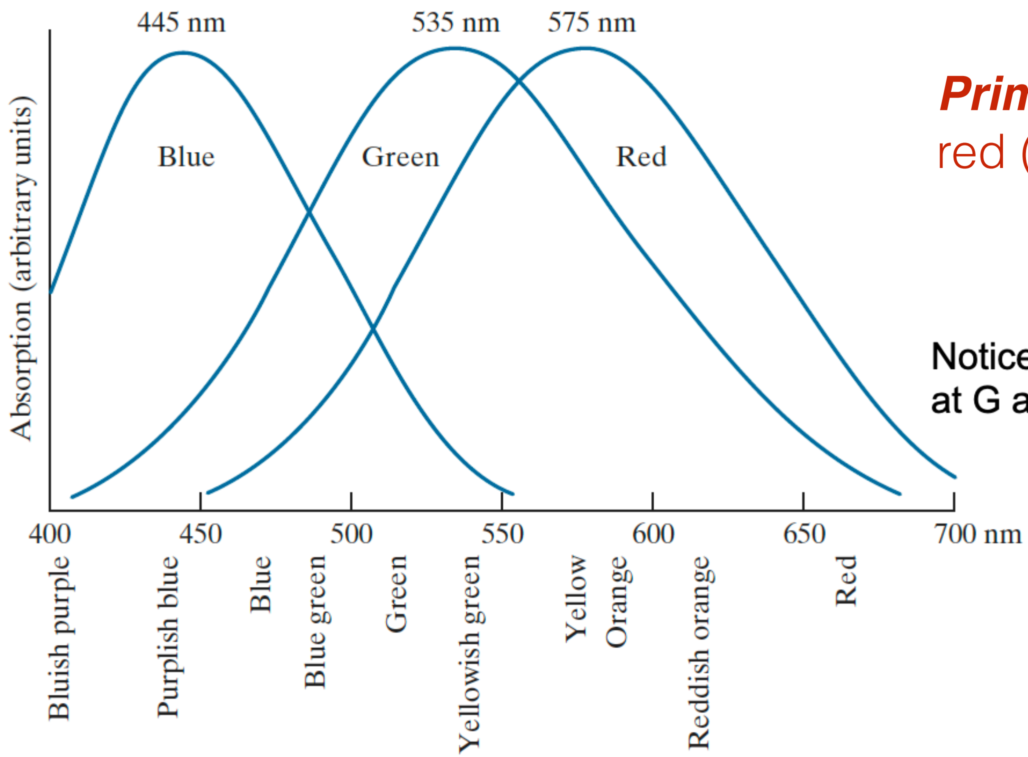
6.1 Color Fundamentals

- The human eye can be divided into three principal sensing categories:
  - 66% of these cones are sensitive to red light
  - 33% to green light
  - 2% to blue light (However, the blue cones are the most sensitive.)



absorption of light by the red, green, and blue cones in the eye determined experimentally

Primary colors:
red (R), green (G), and blue (B).

Notice that the curves centered at G and R are very close

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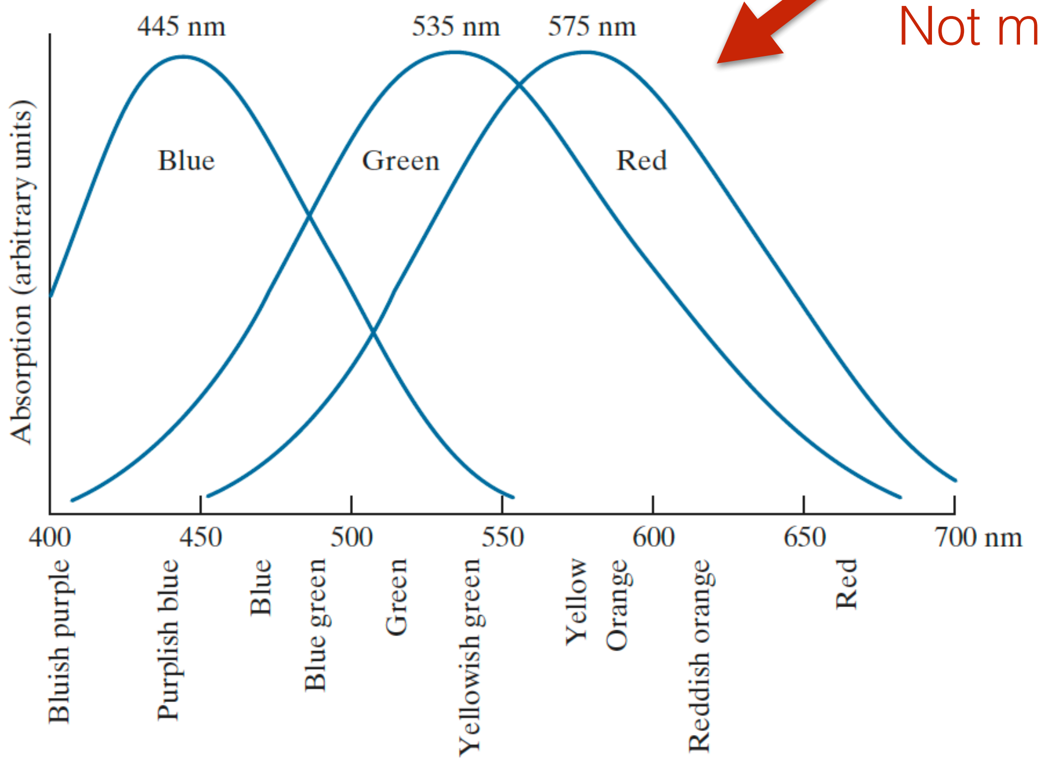
6.1 Color Fundamentals

- For the purpose of standardization, the CIE (Commission Internationale del'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.

Not match (Why?)



as the standards (1931) were developed before the experiments (1965)

absorption of light by the red, green, and blue cones in the eye determined experimentally

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6.1 Color Fundamentals

- **Wrong**: The linear combination of the three **primaries** (R, G, B) may produce all of the visible colors.

- This is true only if the centers of the three curves are shifted

  - This means that the wavelengths must change but then we have no longer the same primaries!

- The three curves are not a basis.

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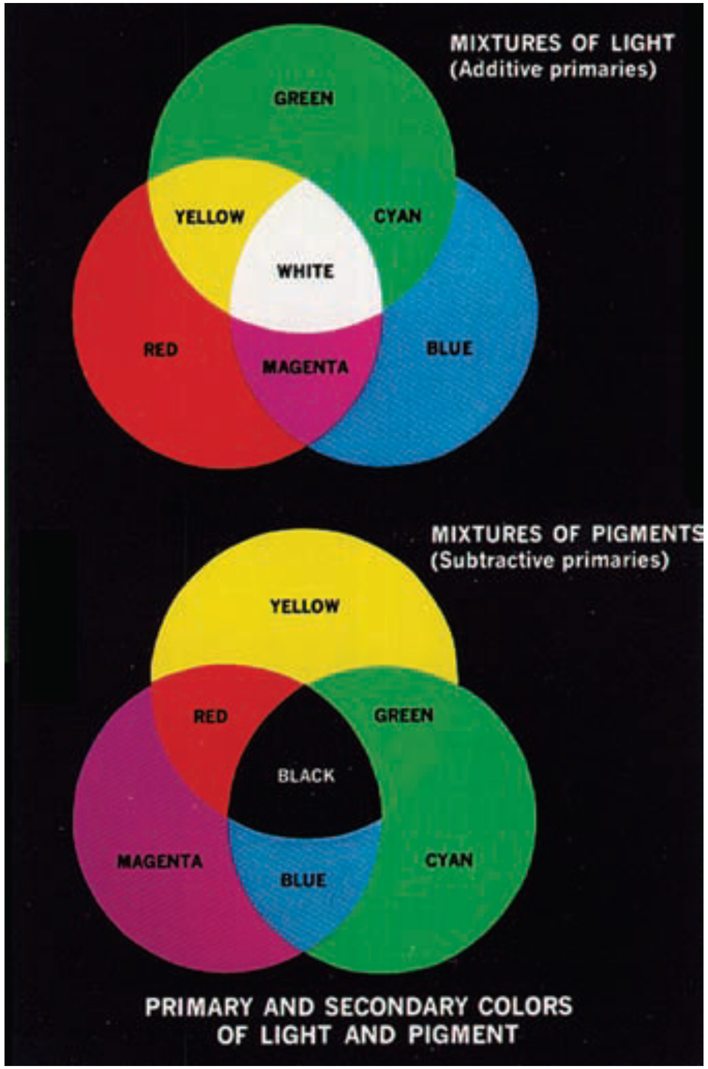
6.1 Color Fundamentals

- The primary colors can be added to produce the secondary colors.
- Mixing the three primaries produces white.
- Mixing a secondary with its opposite primary produces white (e.g. red+cyan).



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6.1 Color Fundamentals

Important difference:

- Primary colors of light (RGB: red, green, blue)
- Primary colors of pigments/colorants (CMY: cyan, magenta and yellow)
  - A color that subtracts or absorbs a primary color of light and reflects the other two.
  - A proper combination of pigment primaries produces black.

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6.1 Color Fundamentals

Distinguishing one color from another:

- **Brightness (亮度):** the achromatic notion of intensity.
- **Hue (色調):** the dominant wavelength in a mixture of light waves (the dominant color perceived by an observer, e.g. when we call an object red or orange we refer to its hue).
- **Saturation (飽和度):** the amount of white light mixed with a hue. Pure colors are fully saturated. Pink (red+white) is less saturated.

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6.1 Color Fundamentals

- Hue and saturation taken together are called **chromaticity** (色度).

- Therefore, any color is characterized by its brightness and chromaticity.

- The amounts of red, green and blue needed to form a particular color are called *tristimulus* values and are denoted by X, Y, Z.

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6.1 Color Fundamentals

- A color is then specified by its *trichromatic coefficients:*

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

$$x + y + z = 1$$

- For any visible wavelength, the tristimulus values needed to produce that wavelength are obtained by curves or tables compiled by extensive experimentation.

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6.1 Color Fundamentals

CIE Chromaticity Diagram:

- Specifying colors systematically can be achieved using the CIE **chromaticity diagram.**

- On this diagram the x-axis represents the proportion of red and the y-axis represents the proportion of green used to produce a specific color.

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

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

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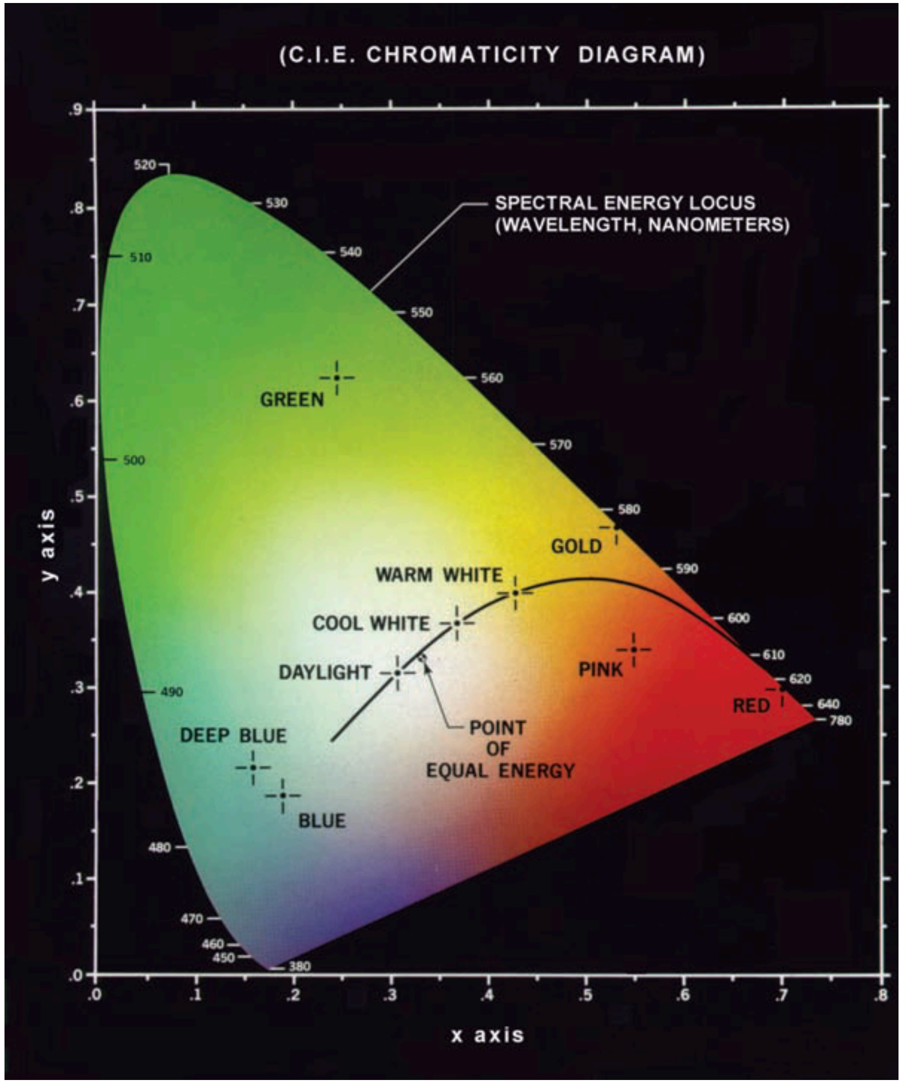
6.1 Color Fundamentals

CIE Chromaticity Diagram:

- Point marked “Green”
  – 62% green, 25% red and 13% blue.

- Point marked “Red”
  – 32% green, 67% red and 1% blue.

- The diagram is useful for color mixing



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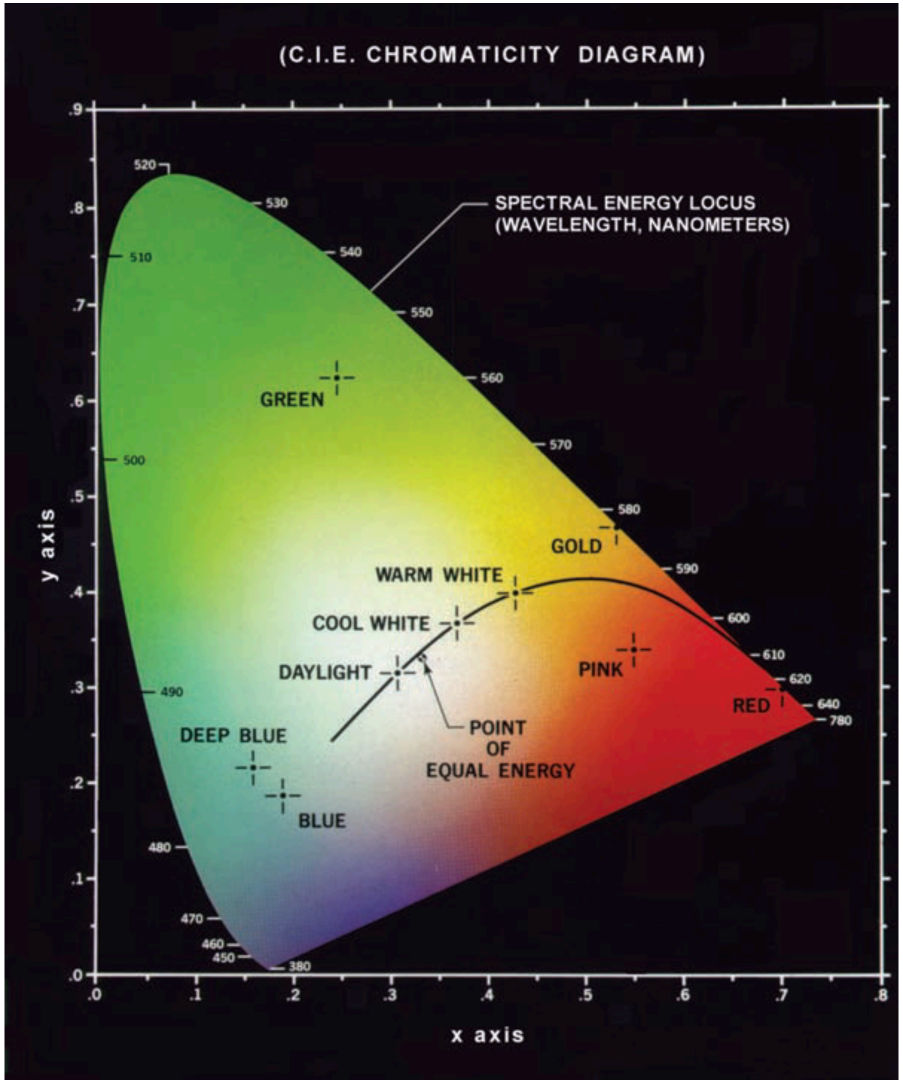
6.1 Color Fundamentals

CIE Chromaticity Diagram:

- Any color located on the boundary of the chromaticity chart is fully saturated (*Pure colors*).
- The point of equal energy (PEE) has equal amounts of red, green and blue.
  – It is the CIE standard for pure white.



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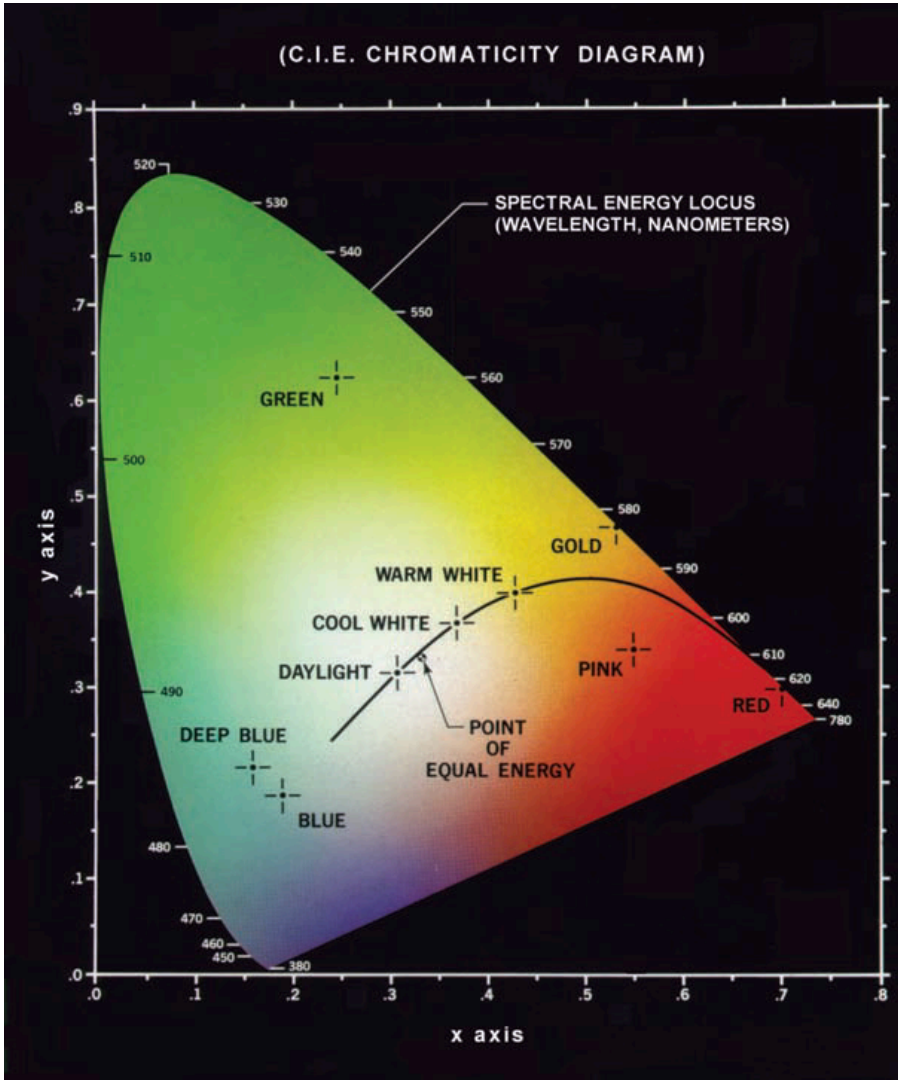
6.1 Color Fundamentals

CIE Chromaticity Diagram:

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

- A line drawn from the PEE to any point on the boundary defines all the shades of that particular color.

- By combining any three given colors we may obtain the colors enclosed in the triangle defined by the three initial colors.



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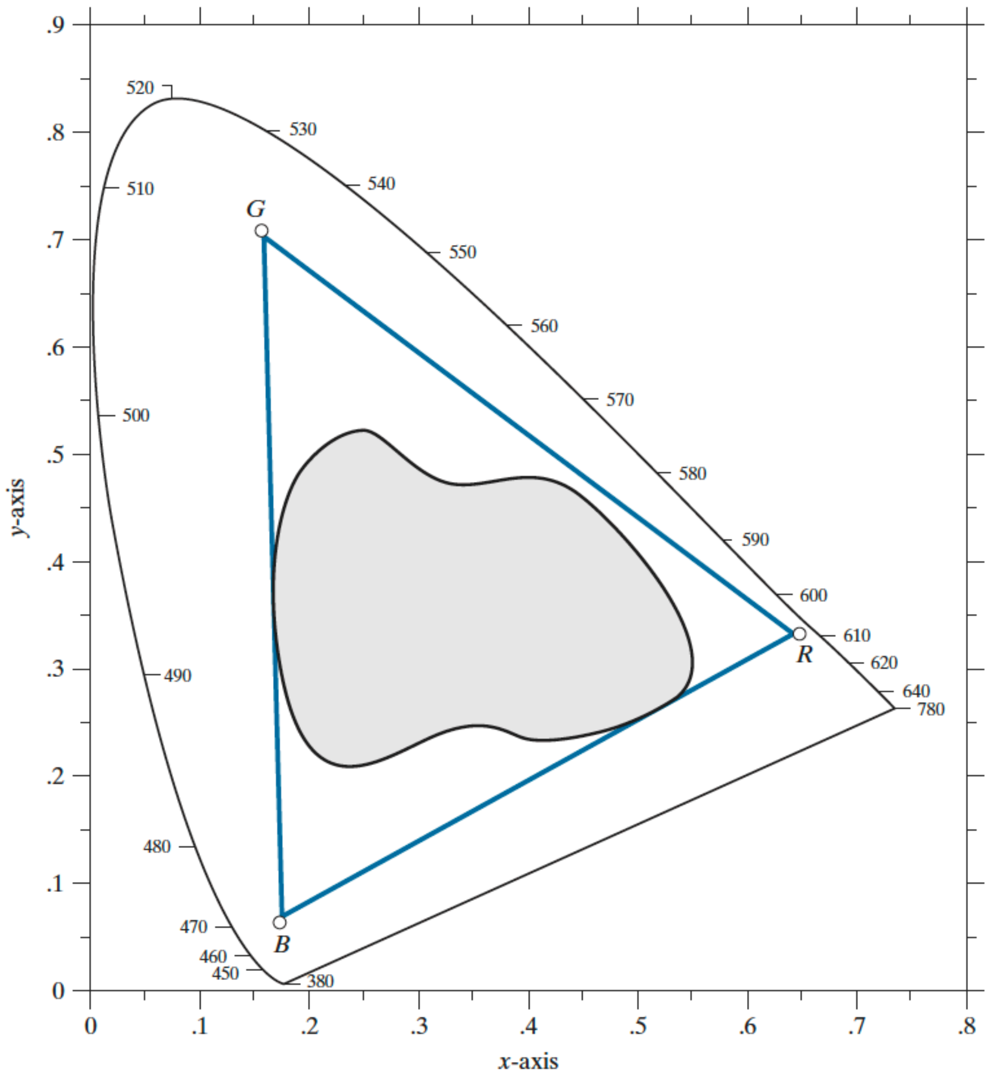
6.1 Color Fundamentals

CIE Chromaticity Diagram:

- A triangle with vertices at any three *fixed pure colors* cannot enclose the entire color region.



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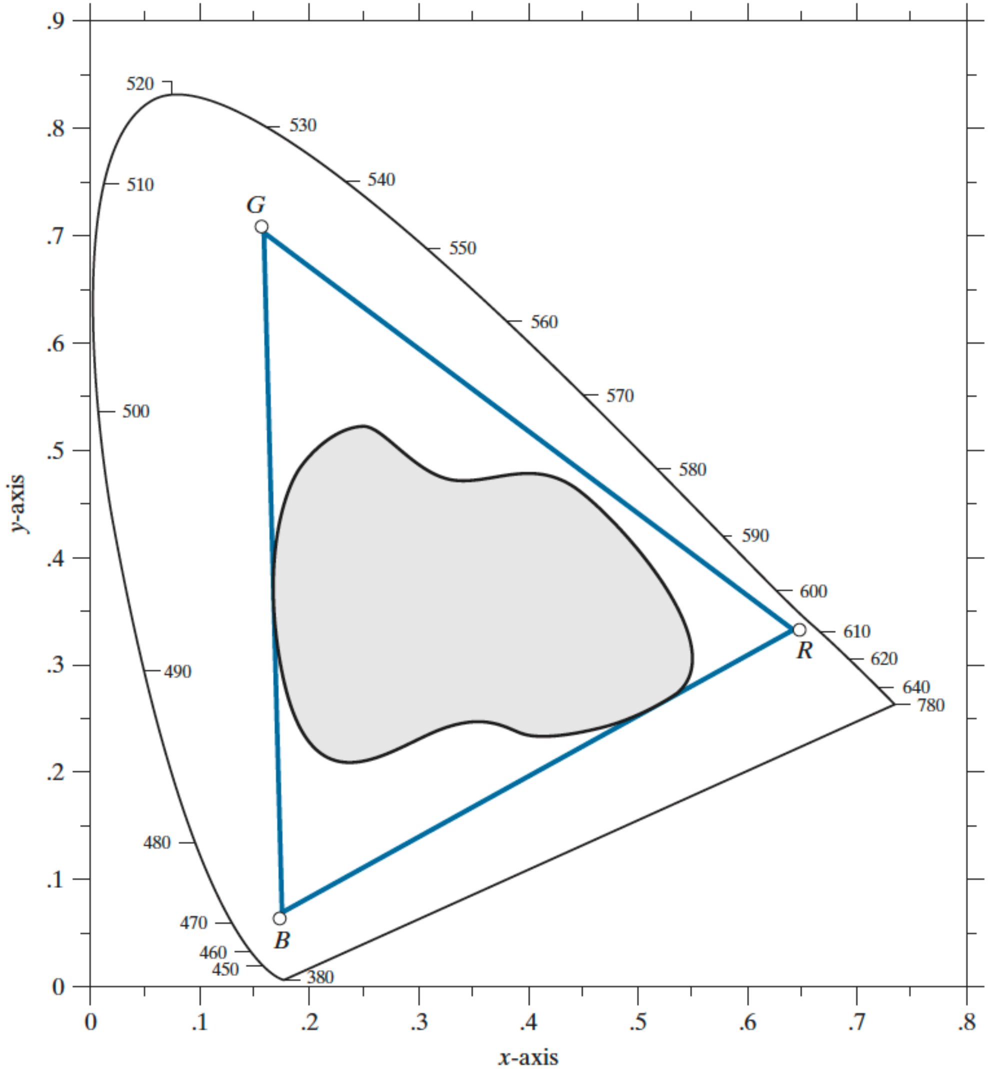
6.1 Color Fundamentals

CIE Chromaticity Diagram:

- The triangle shows the typical color gamut produced by RGB monitors.
- The entire color range cannot be displayed based on any three colors.
- The shaded region is the gamut achieved by high quality color printers.



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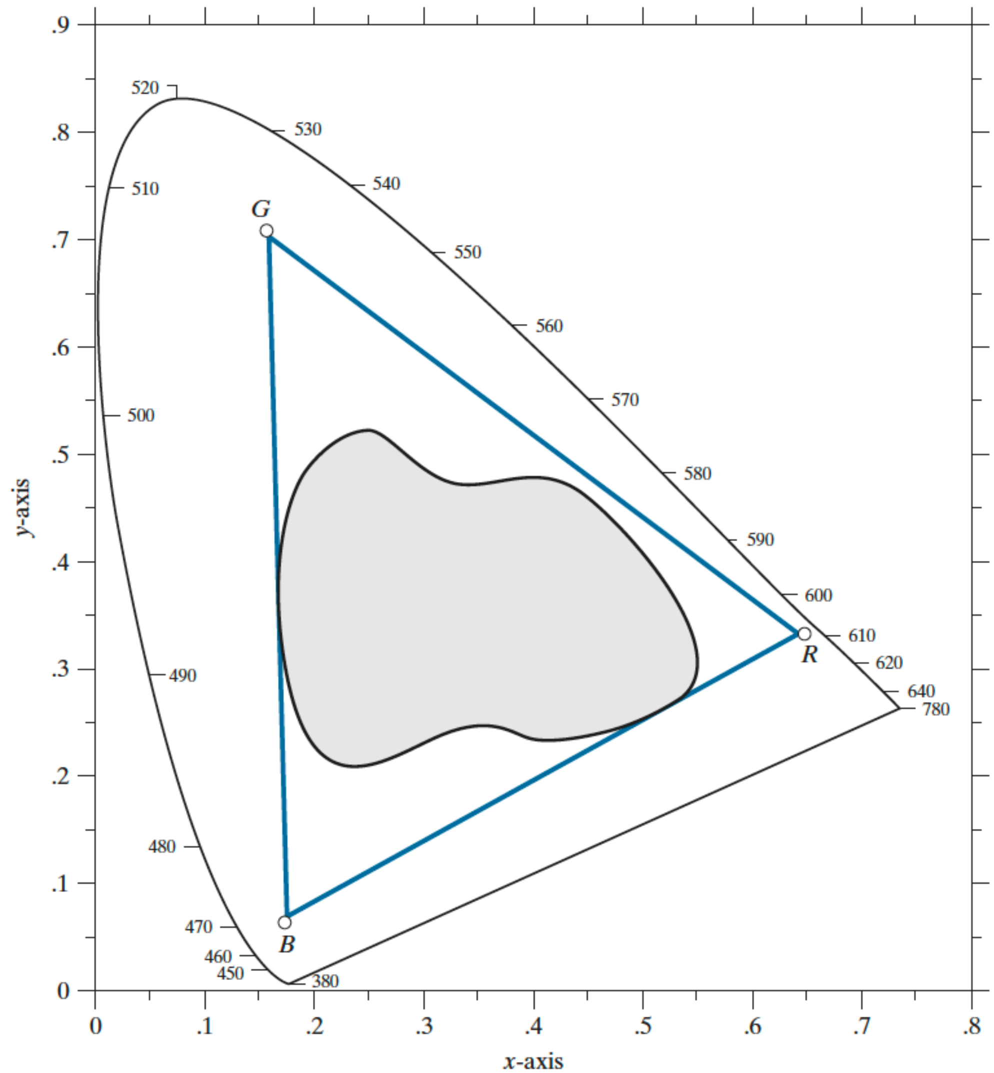
6.1 Color Fundamentals

CIE Chromaticity Diagram:

- The boundary of the printing gamut is irregular because printing is a combination of additive and subtractive color mixing.
- This is a more difficult process to control than that of displaying colors.
- While monitor is based on the addition of three highly controllable light primaries.



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6.2 Color Models

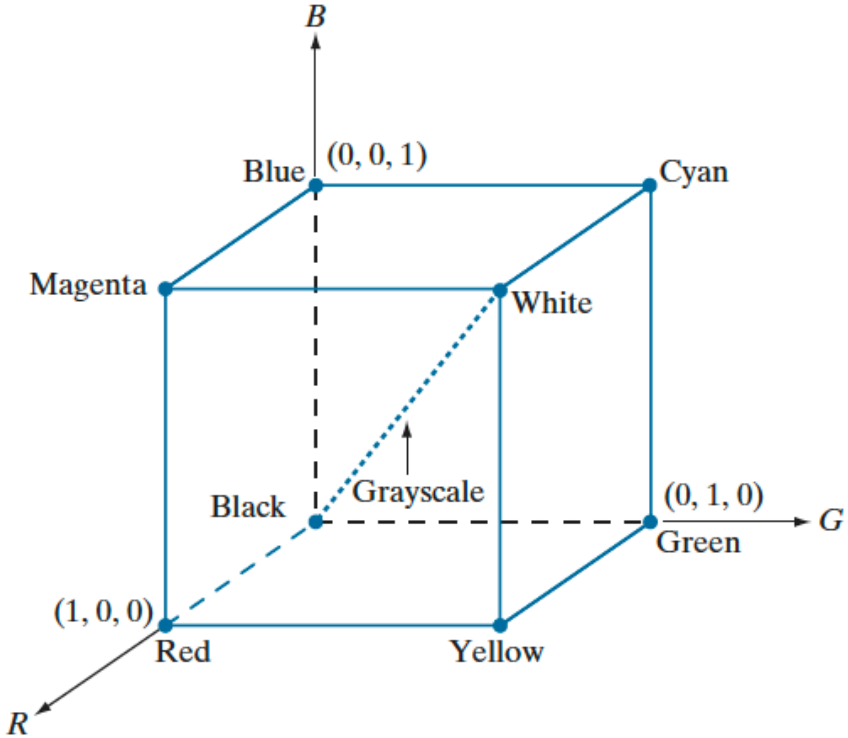
- The purpose of a color model (also called a color space or color system) is to facilitate the specification of colors in some standard way.

- Most color models in use today are oriented either toward hardware (such as for color monitors and printers) or toward applications

- Three very popular models used in color image processing:
  - **RGB** (**R**ed, **G**reen, **B**lue): for color monitors and a broad class of color video cameras.
  - **CMY** and **CMYK** (**C**yan, **M**agenta, **Y**ellow, blac**K**): for color printing.
  - **HSI** (**H**ue, **S**aturation, **I**ntensity): the way humans describe and interpret color. It decouples the color and gray-scale information and makes it suitable for many of the gray-scale techniques.

6.2 Color Models
- RGB Color Model

- 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 colors are points on or inside the cube represented by RGB vectors



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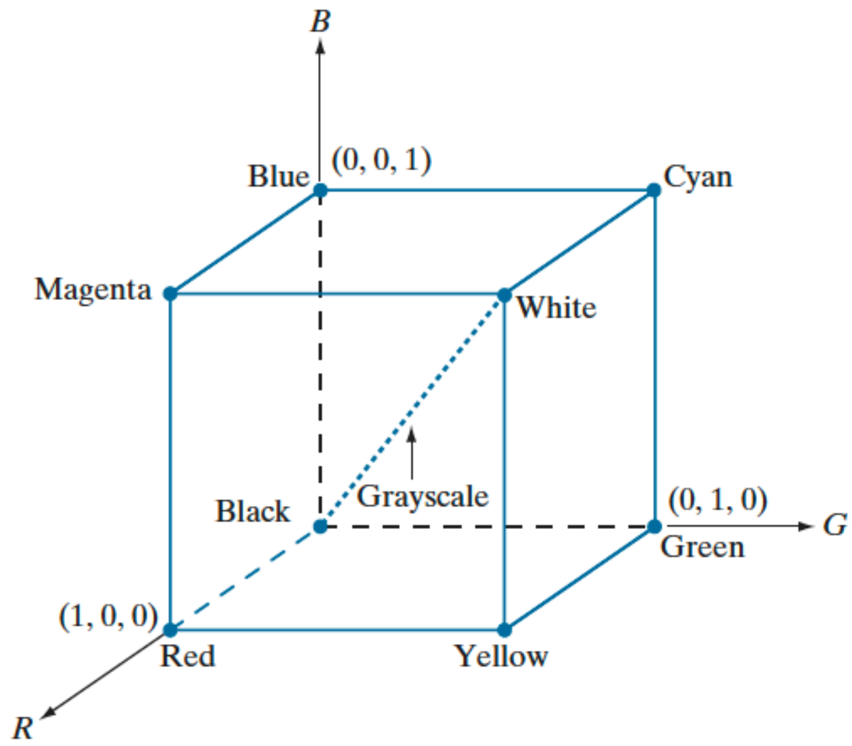
6.2 Color Models
- RGB Color Model

- Images represented in the RGB color model consist of three component images – one for each primary color
- When fed into a monitor these images are combined to create a composite color image
- The number of bits used to represent each pixel is referred to as the pixel depth
- A 24-bit image is often referred to as a full-color image as it allows $(2^8)^3$ = 16,777,216 colors



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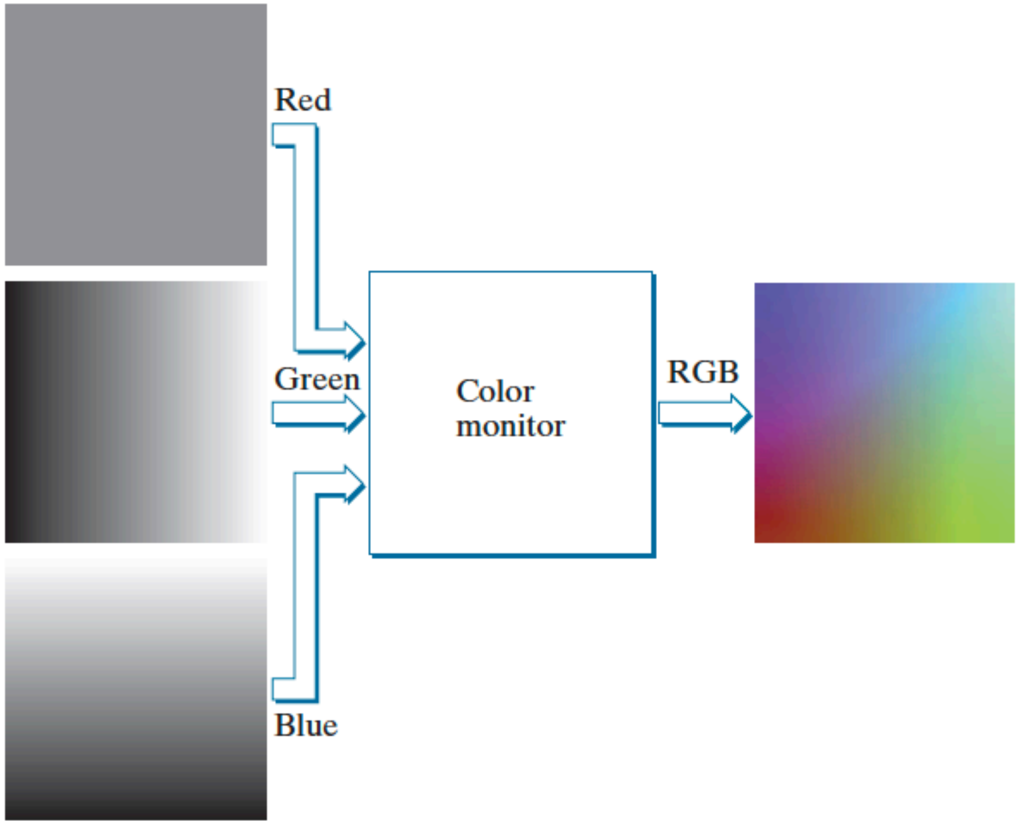
6.2 Color Models
- RGB Color Model

Generating a cross-section of the RGB color cube and its thee hidden planes

Example: cross-sectional color plane (127, G, B)



6.2 Color Models
- CMY and CMYK Color Models

- **RGB to CMY**:

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

- In practice, because C, M, and Y inks seldom are pure colors, combining these colors for printing black produces instead a muddy-looking brown.

- The black is added to produce true black, i.e **CMYK** color model for “four-color printing.”

6.2 Color Models
- CMY and CMYK Color Models

- **CMY to CMYK**:
  - If $K = 1$, $C = M = Y = 0$ for pure black
  - Otherwise, $K = \min(C, M, Y)$ $\quad C = (C - K)/(1 - K)$

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

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

- **CMYK to CMY**: $C = C * (1 - K) + K$

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

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

6.2 Color Models
- HSI Color 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 colors.

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

- RGB is great for color generation, but HSI is great for color description.

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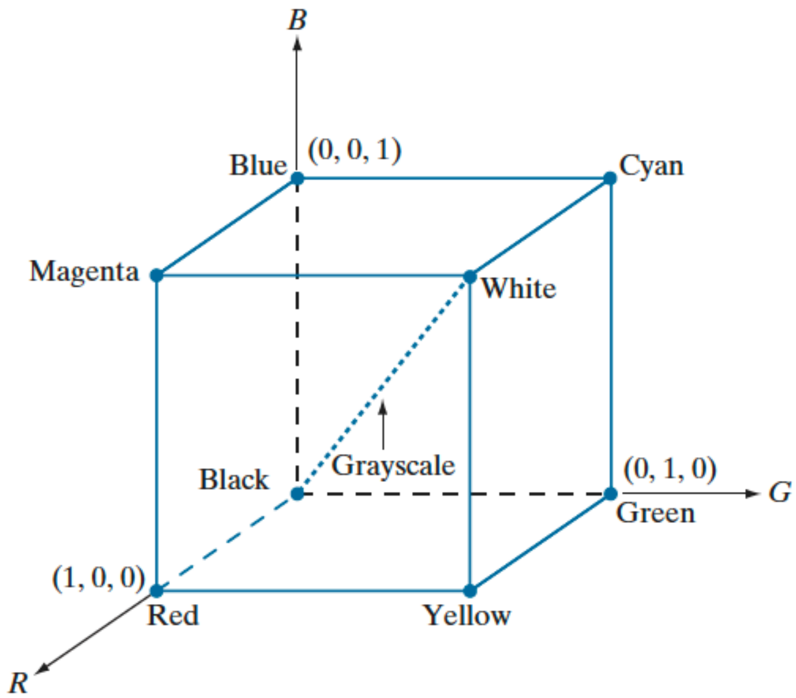
6.2 Color Models
- HSI Color Model

Relationship between RGB and HSI model: (Intensity)

- Intensity can be extracted from RGB images.
- However, human perception of color does not refer to percentages of RGB.
- Remember the diagonal on the RGB color 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 .



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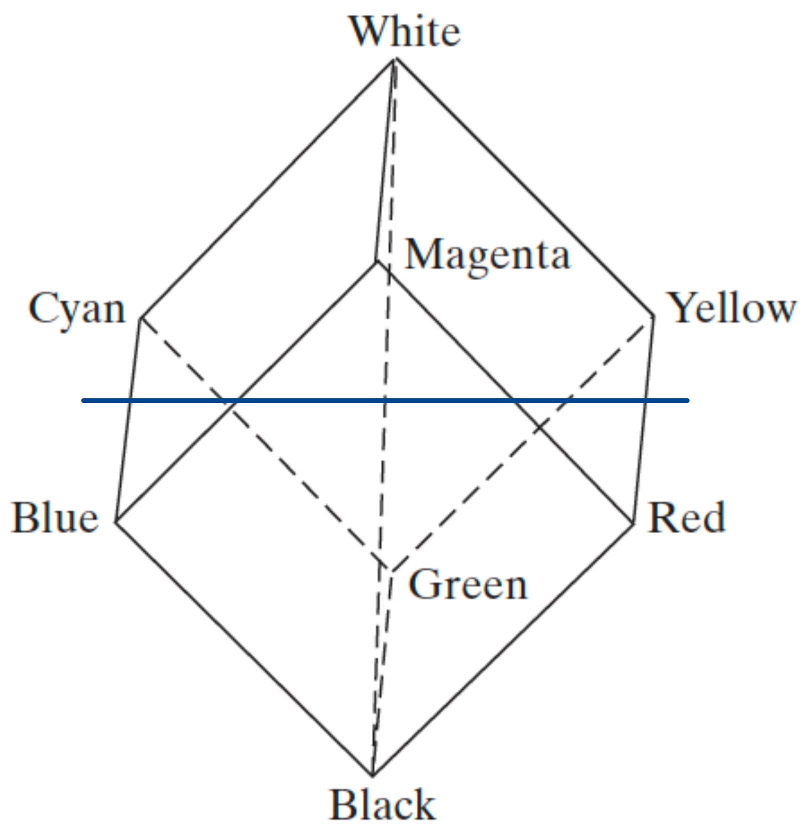
6.2 Color Models
- HSI Color Model

Relationship between RGB and HSI model: (Intensity)

- The intensity component of any color can be determined by passing a plane perpendicular to the intenisty axis and containing the color point

- The intersection of the plane with the intensity axis gives us the intensity component of the color .



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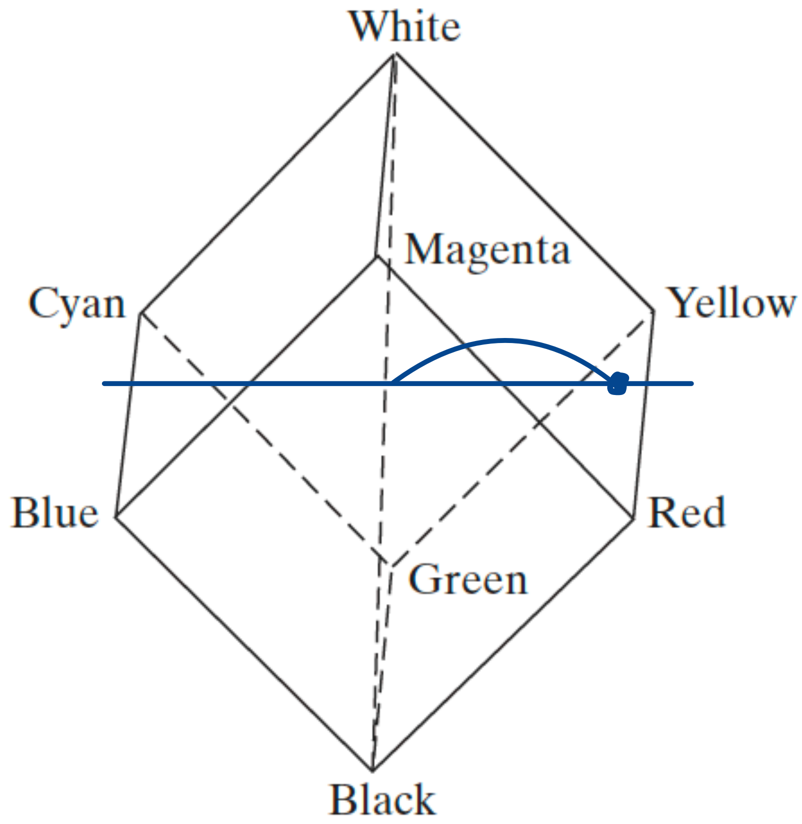
6.2 Color Models
- HSI Color Model

Relationship between RGB and HSI model: (Saturation)

- The saturation of a color (percentage of white missing from the color) increases as a function of distance from the intensity axis.



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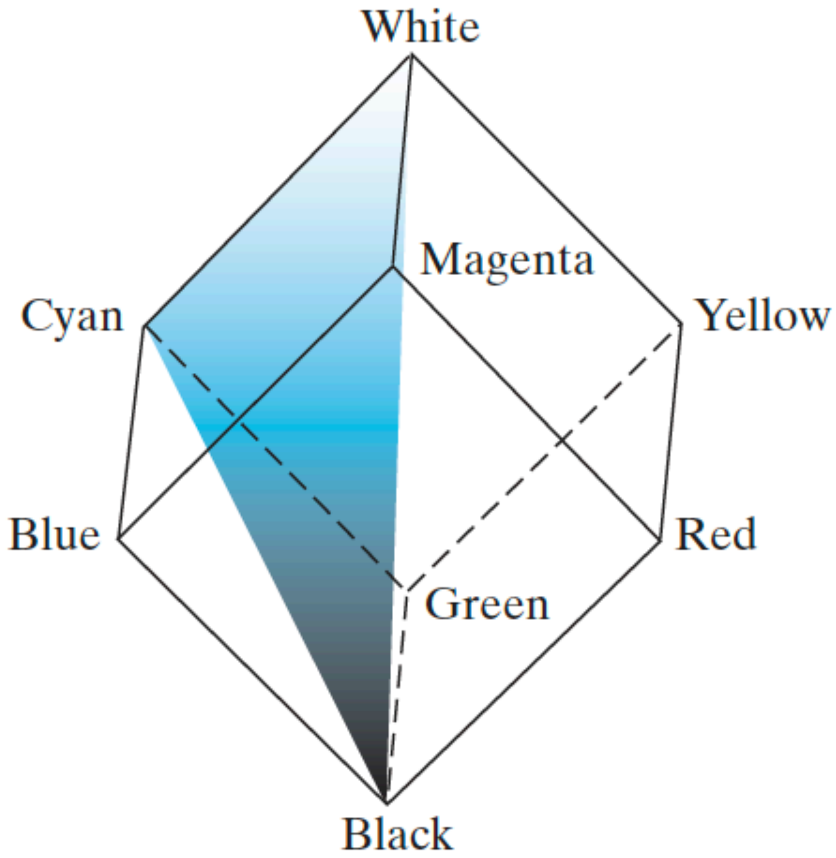
6.2 Color Models
- HSI Color Model

Relationship between RGB and HSI model: (Hue)

- In a similar way we can extract the hue from the RGB color 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 color.



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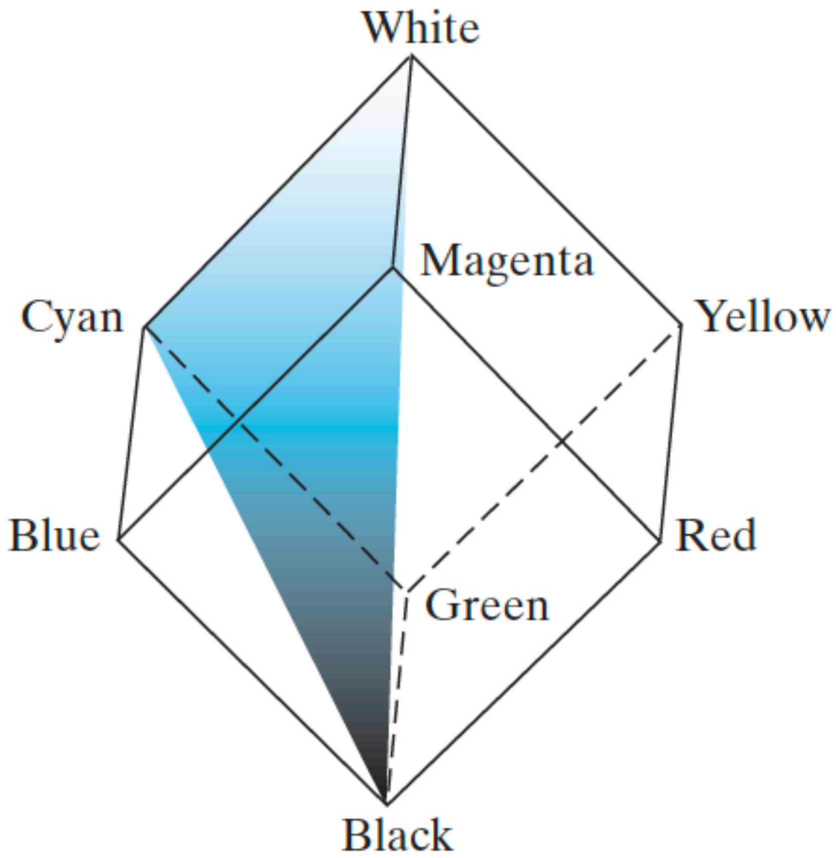
6.2 Color Models
- HSI Color Model

- By rotating the shaded plane around the intensity axis we obtain different hues.

- **Conclusion**:
  - The HSI values can be obtained from the RGB values.
  - We have to work the geometric formulas.

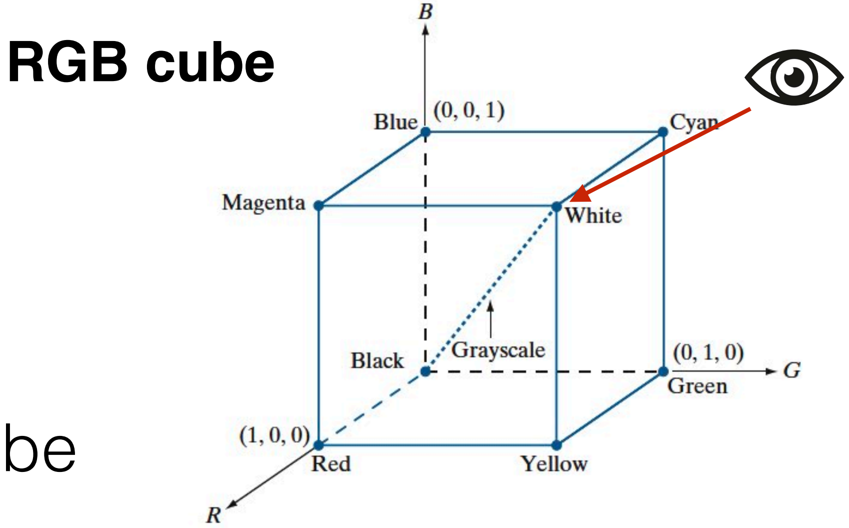


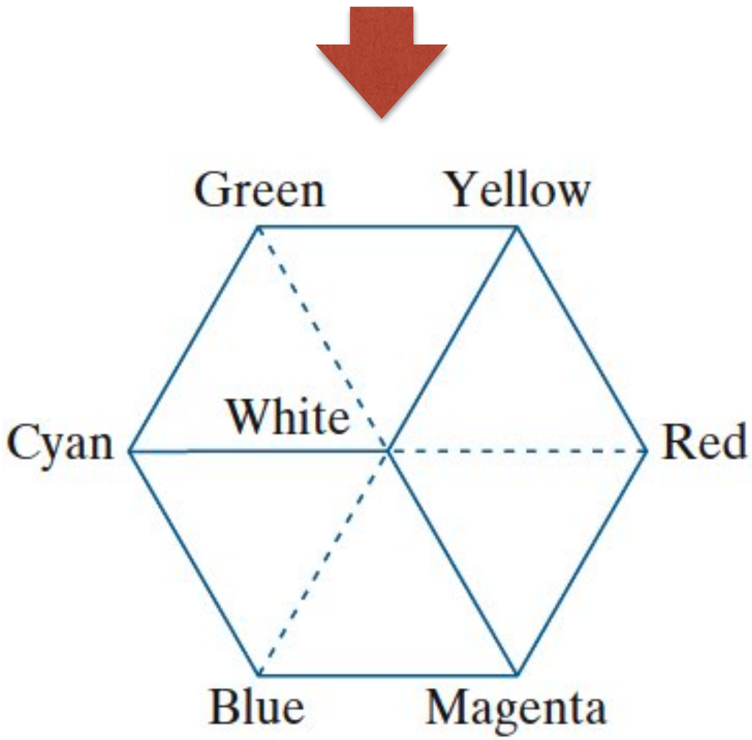
6.2 Color Models - HSI Color Model

- If we look straight down at the RGB cube

- We would see a hexagonal shape with each primary color separated by 120° and secondary colors at 60° from the primaries.

- The HSI model is composed of a vertical intensity axis and the locus of color points that lie on planes perpendicular to that axis.





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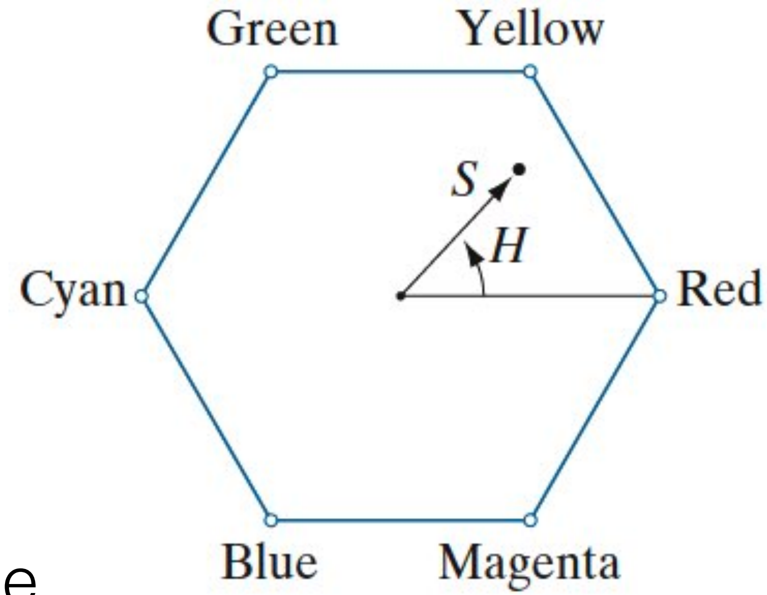
6.2 Color Models
- HSI Color Model



- Hexagonal shape at an arbitrary color 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 intensity axis this hexagonal plane sits (not apparent from this diagram)

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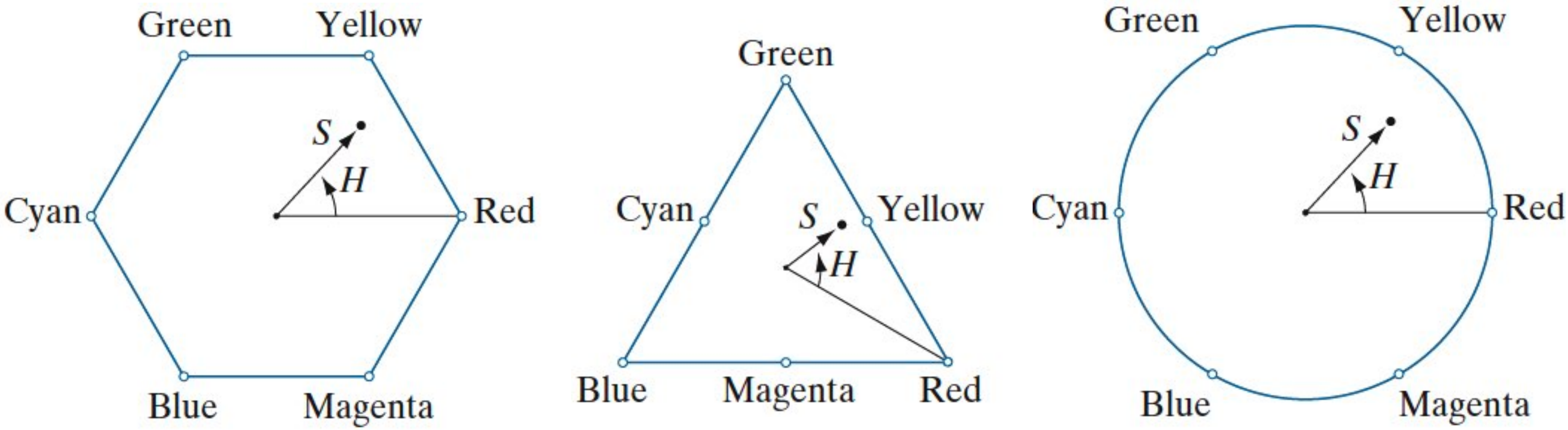
6.2 Color Models
- HSI Color Model

- As 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.



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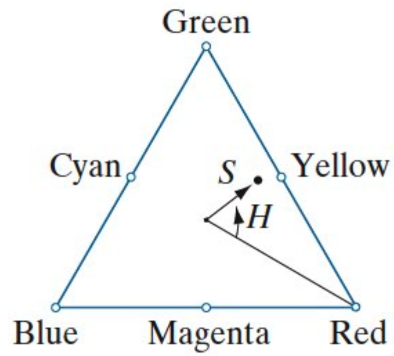
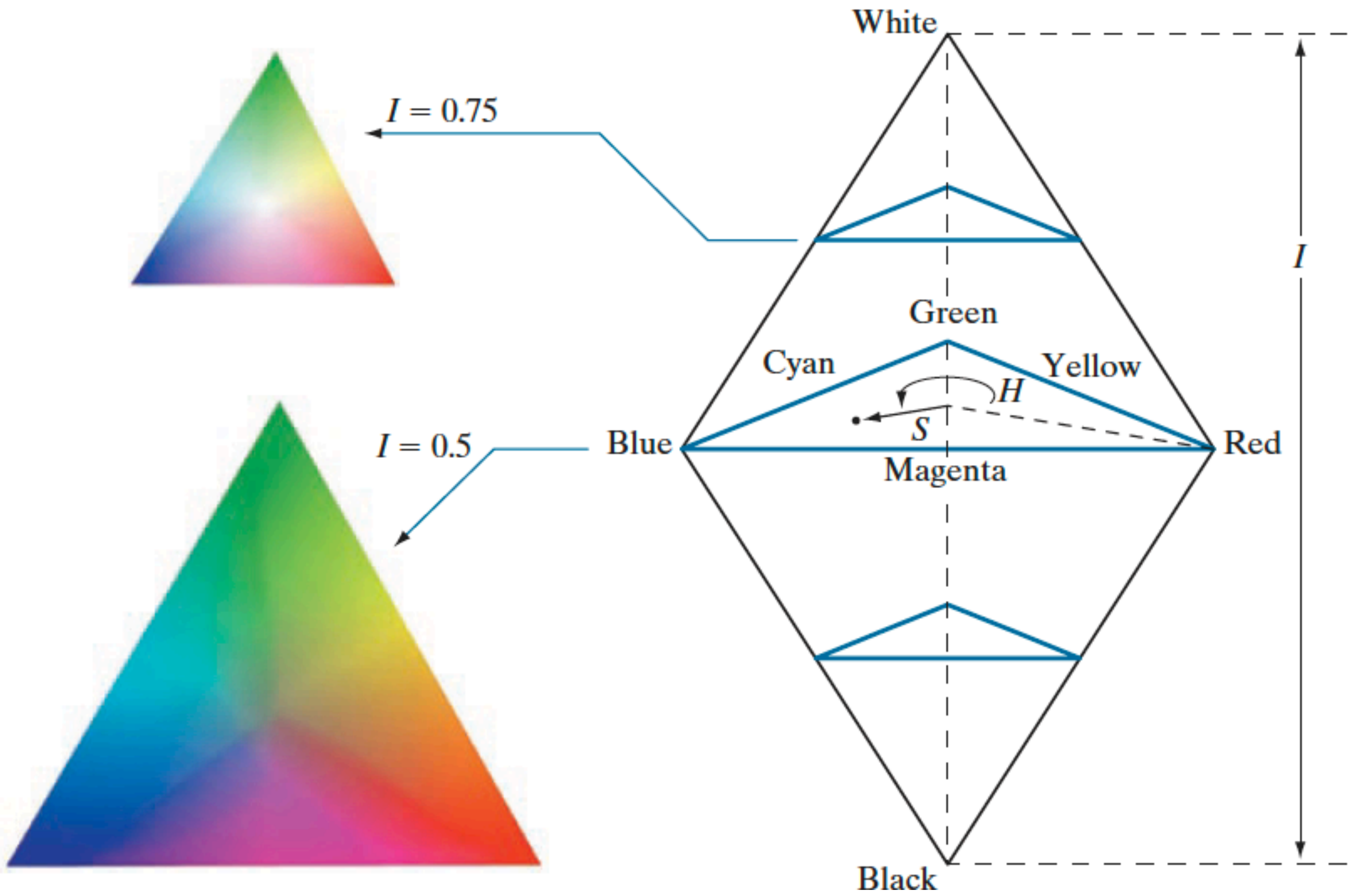
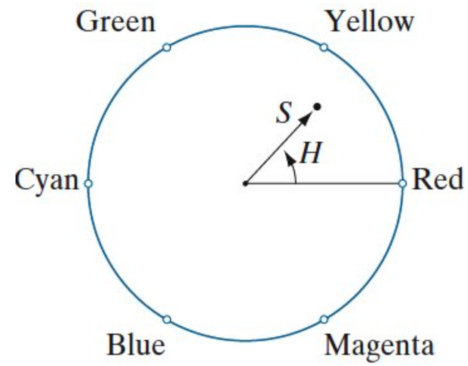
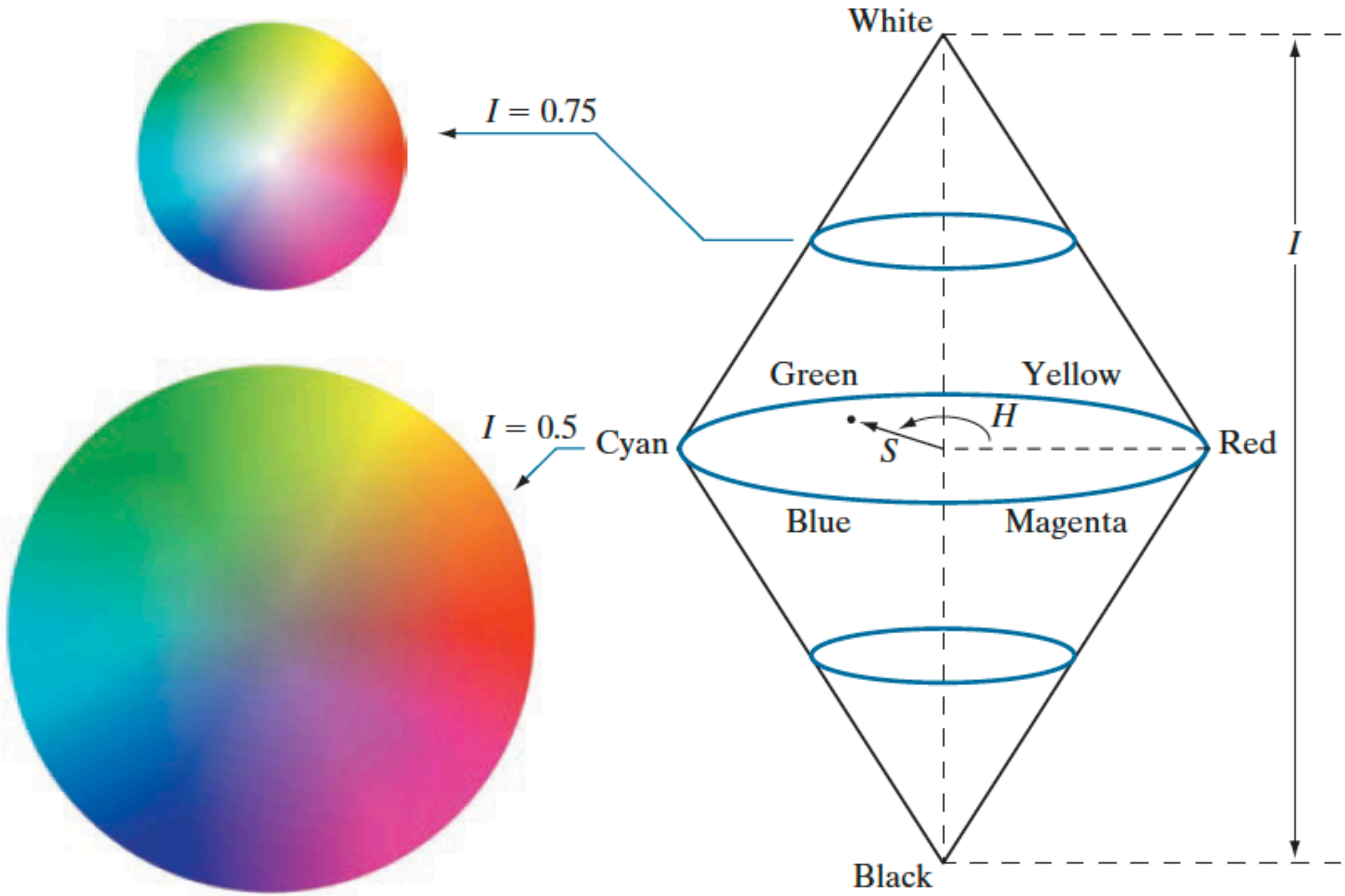
6.2 Color Models
- HSI Color Model





6.2 Color Models
- HSI Color Model





6.2 Color Models
- HSI Color Model

- **RGB to HSI**:

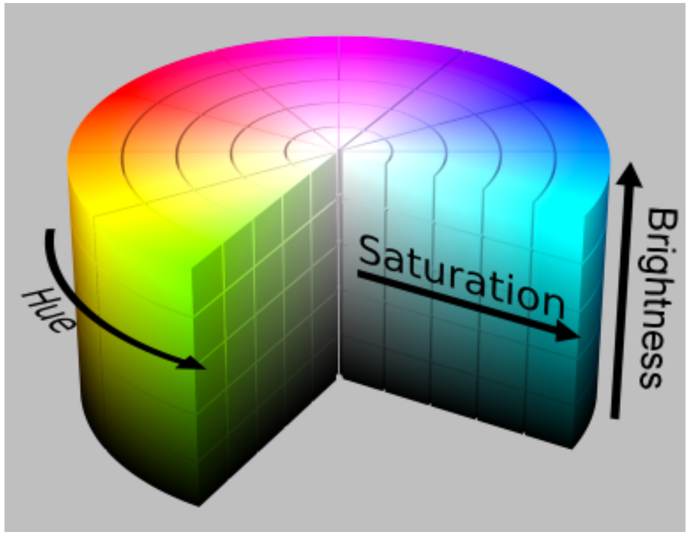
$$H = \begin{cases} \theta & \text{if } B \le G \\ 360 - \theta & \text{if } B > G \end{cases}$$

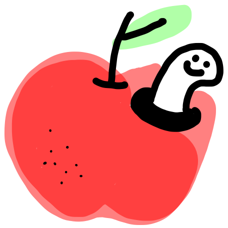
$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\left[(R-G)^2+(R-B)(G-B)\right]^{1/2}} \right\}$$

不會考算

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

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





6.2 Color Models
- HSI Color Model

- **HSI to RGB**:
  - RG sector (0 <= H < 120°)

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

  - GB sector (120° <= H < 240°) $\boxed{H = H - 120^\circ}$

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

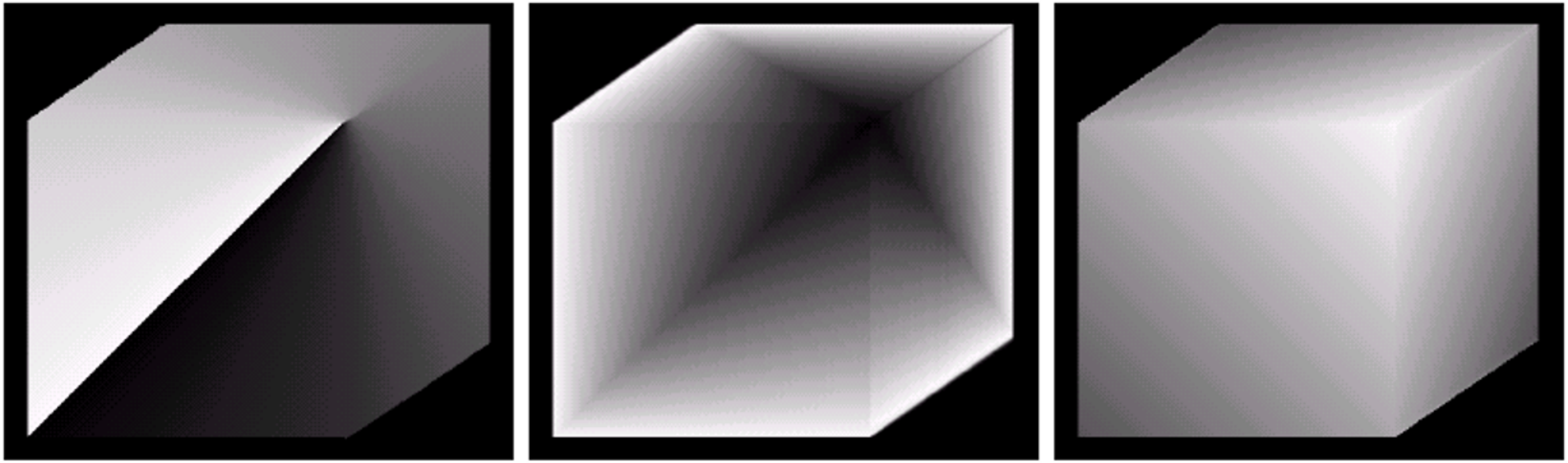
  - BR sector (240° <= H <= 360°) $\boxed{H = H - 240^\circ}$

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

6.2 Color Models
- HSI Color Model

RGB color cube

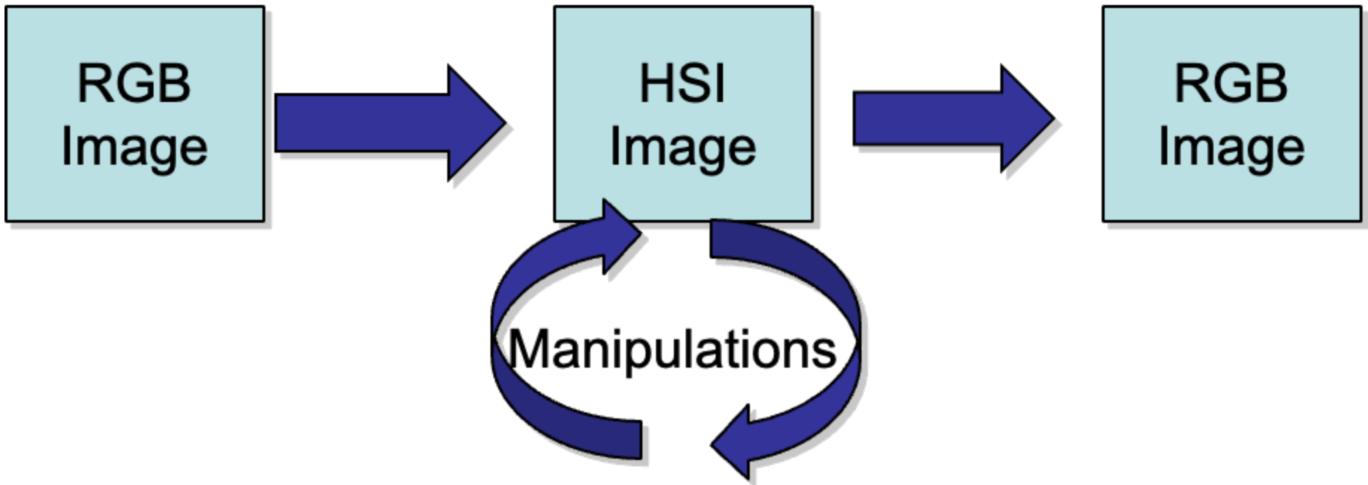
corresponding HSI components



Hue Saturation Intensity

6.2 Color Models
- Manipulating HSI Component Images

- **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



Allow Independent Control over H, S, I

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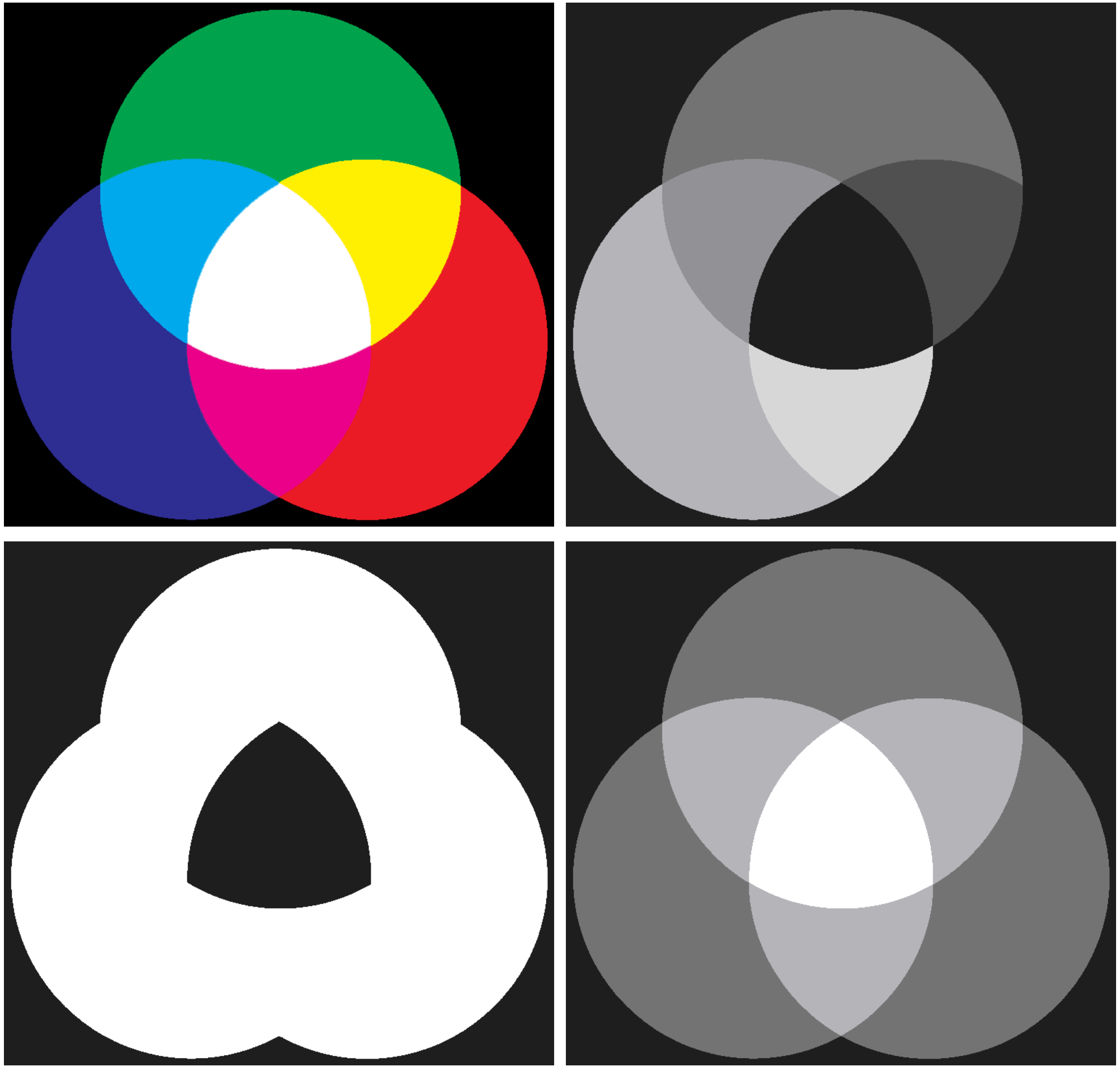
6.2 Color Models
- Manipulating HSI Component Images

RGB image

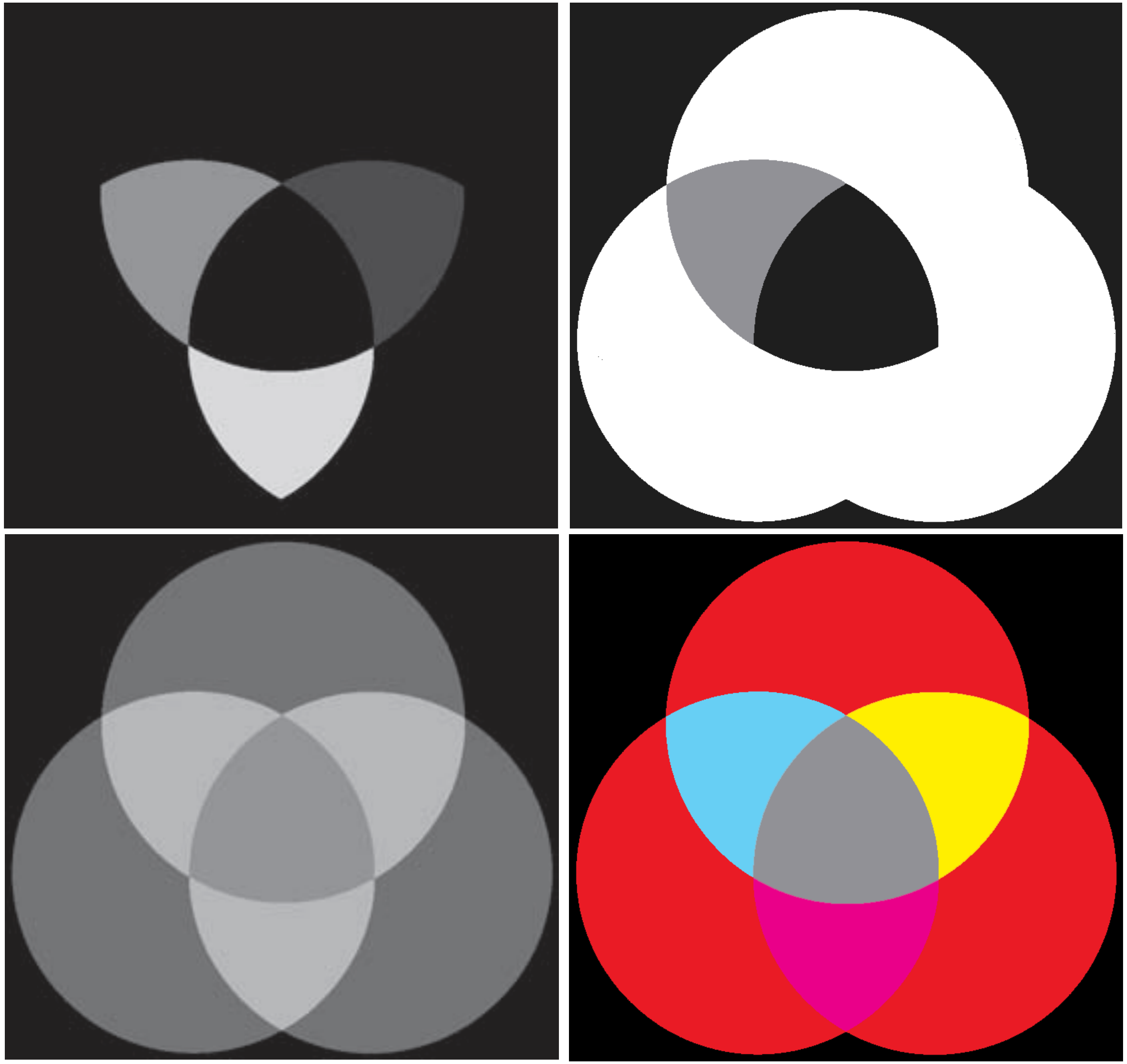
Hue



Saturation

Intensity

6.2 Color Models
- Manipulating HSI Component Images



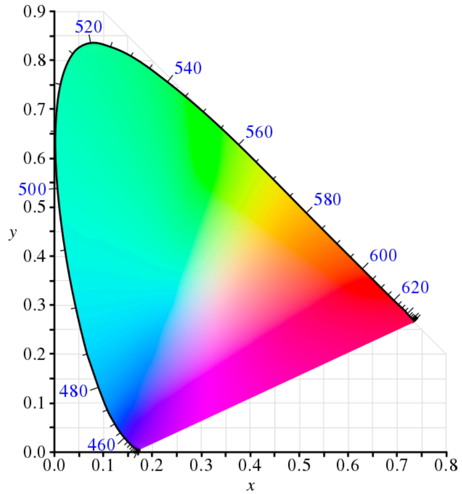
Modified Hue

Modified Saturation

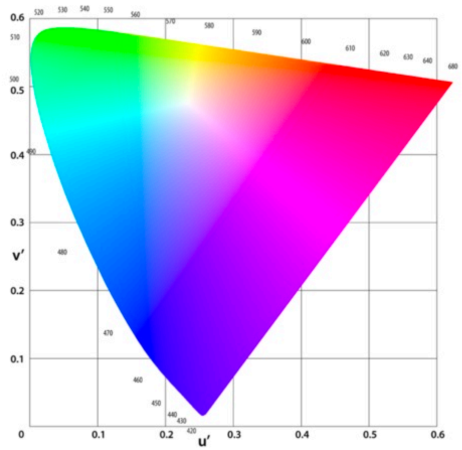
Modified Intensity

Resulting RGB image

6.2 Color Models
- Other Color Models



- CIE XYZ (1931)



- CIE LUV (1976)

- CIE LAB (1976)