UNIT V: Colour models and colour applications – properties of light – standard primaries and the chromaticity diagram – xyz colour model – CIE chromaticity diagram – RGB colour model – YIQ, CMY, HSV colour models, conversion between HSV and RGB models, HLS colour model, colour selection and applications.

TEXT BOOK

1. Donald Hearn and Pauline Baker, “Computer Graphics”, Prentice Hall of India, 2001.

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COLOR MODELS

Color Model is a method for explaining the properties or behavior of color within some particular context. No single color model can explain all aspects of color, so we make use of different models to help describe the different perceived characteristics of color.

15-1. PROPERTIES OF LIGHT

Light is a narrow frequency band within the electromagnetic system. Other frequency bands within this spectrum are called radio waves, micro waves, infrared waves and x-rays. The below figure shows the frequency ranges for some of the electromagnetic bands. Each frequency value within the visible band corresponds to a distinct color. **The electromagnetic spectrum is the range of frequencies (the spectrum) of electromagnetic radiation and their respective wavelengths and photon energies.**

Spectral colors range from the reds through orange and yellow at the low-frequency end to greens, blues and violet at the high end.

Since light is an electromagnetic wave, the various colors are described in terms of either the frequency for the wave length λ of the wave. The wavelength and frequency of the monochromatic wave is inversely proportional to each other, with the proportionality constants as the speed of light C where $C = \lambda f$.

- In this case, we say the perceived light has a dominant frequency (or dominant wavelength) at the red end of the spectrum. The dominant frequency is also called the hue, or simply the color of the light.
- One of these we call the brightness, which is the perceived intensity of the light. Intensity is the radiant energy emitted per unit time, per unit solid angle, and per unit projected area of the source. Radiant energy is related to the luminance of the source.
- The second perceived characteristic is the purity, or saturation, of the light. Purity describes how washed out or how "pure" the color of the light appears. Pale colors are described as less pure.

These three characteristics, dominant frequency, brightness, and purity are commonly used to describe the different properties we perceive in a source of light. The term chromaticity is used to refer collectively to the two properties describing color characteristics: purity and dominant frequency.

When we view light that has been formed by a combination of two or more sources, we see a resultant light with characteristics determined by the original sources. Two different-color light sources with suitably chosen intensities can be used to produce a range of other colors. If the two color sources combine to produce white light, they are referred to as **complementary colors**. Examples of complementary color pairs are red and cyan, green and magenta, and blue and yellow.

15.2. STANDARD PRIMARIES AND THE CHROMATICITY DIAGRAM

Since no finite set of color light sources can be combined to display all possible colors, three standard primaries were defined in 1931 by the International Commission on Illumination, referred to as the CIE (commission lnternationale de I'Eclairage). The three standard primaries are imaginary colors. They are defined mathematically with positive color-matching functions as in the below figure, that specify the amount of each primary needed to describe any spectral color. This provides an international standard definition for all colors, and the CIE primaries eliminate negative-value color matching and other problems associated with selecting a set of real primaries.

XYZ COLOR MODEL

The set of primaries is generally referred to as the XYZ or (X, Y, Z) color model where X, Y and Z represent vectors in a 3D, additive color space.

Any color $C\lambda$ is expressed as

$$C\lambda = X X + YY + ZZ$$

Where X, Y and Z designates the amounts of the standard primaries needed to match $C\lambda$.

It is convenient to normalize the amount in equation (1) against luminance (X + Y+ Z). Normalized amounts are calculated as,

$$x = X / (X+Y+Z), \quad y = Y / (X+Y+Z), \quad z = Z / (X+Y+Z) \quad \text{with } x + y + z = 1$$

Any color can be represented with just the x and y amounts. The parameters x and y are called the chromaticity values because they depend only on hue and purity.

CIE Chromaticity Diagram

When we plot the normalized amounts x and y for colors in the visible spectrum, we obtain the tongue-shaped curve shown in figure. This curve is called the CIE chromaticity diagram. Points along the curve are the "pure" colors in the electromagnetic spectrum, labeled according to wavelength in nanometers from the red end to the violet end of the spectrum.

The line joining the red and violet spectral points, called the purple line, is not part of the spectrum. Interior points represent all possible visible color combinations. Point C in the diagram corresponds to the white-light position. Actually, this point is plotted for a white-light source known as illuminant C, which is used as a standard approximation for "average" daylight.

Luminance values are not available in the chromaticity diagram because of normalization. Colors with different luminance but the same chromaticity map to the same point. The chromaticity diagram is useful for the following:

- Comparing color gamuts for different sets of primaries.

- Identifying complementary colors.
- Determining dominant wavelength and purity of a given color.

Color gamuts are represented on the chromaticity diagram as straight line segments or as polygons. All colors along the line joining points C_1 and C_2 in figure 15.8 can be obtained by mixing appropriate amounts of the colors C_1 and C_2. If a greater proportion of C_1 is used, the resultant color is closer to C_1 than to C_2. The color gamut for three points, such as C_3, C_4 and C_5 in figure 15-8, is a triangle with vertices at the three color positions.

Three primaries can only generate colors inside or on the bounding edges of the triangle. Thus, the chromaticity diagram helps us understand why no set of three primaries can be additively combined to generate all colors, since no triangle within the diagram can encompass all colors. Color gamuts for video monitors and hard-copy devices are conveniently compared on the chromaticity diagram.

Since the color gamut for two points is a straight line, complementary colors must be represented on the chromaticity diagram as two points situated on opposite sides of C and connected with a straight line. When we mix proper amounts of the two colors C_1 and C_2 in figure 15-9, we can obtain white light.

We can also use the interpretation of color gamut for two primaries to determine the dominant wavelength of a color. For color point C_1 in figure 15.10, we can draw a straight line from C through C_1 to intersect the spectral curve at point C_s. Color C_1 can then be represented as a combination of white light C and the spectral color C_s. Thus, the dominant wavelength of C_1 is C_s. This method for determining dominant wavelength will not work for color points that are between C and the purple line.

Drawing a line from C through point C_2 in Fig. 15-10 takes us to point C_p on the purple line, which is not in the visible spectrum. Point C_2 is referred to as a nonspectral color, and its dominant wavelength is taken as the compliment of C_p that lies on the spectral curve (point C_{sp}). Nonspectral colors are in the purple-magenta range and have spectral distributions with subtractive dominant wavelengths. They are generated by subtracting the spectral dominant wavelength (such as C_{sp}) from white light.

For any color point, such as C_1 in figure 15-10, we determine the purity as the relative distance of C_1 from C along the straight line joining C to C_s. If d_{c1} denotes the distance from C to C_1 and d_{cs} is the distance from C to C_s, we can calculate purity as the ratio d_{c1} / d_{cs}. Color C_1 in this figure is about 25 percent pure, since it is situated at about one-fourth the total distance from C to C_s. At position C_s, the color point would be 100 percent pure.

15.3 INTUITIVE COLOR CONCEPTS

An artist creates a color painting by mixing color pigments with white and black pigments to form the various shades, tints, and tones in the scene. Starting with the pigment for a "pure color" (or "pure hue"), the artist adds a black pigment to produce different shades of that color. The more black pigment, the darker the shade. Similarly, different tints of the color are obtained by adding a white pigment to the original color, making it lighter as more white is added. Tones of the color are produced by adding both black and white pigments.

To many, these color concepts are more intuitive than describing a color as a set of three numbers that give the relative proportions of the primary colors. It is generally much easier to think of making a color lighter by adding white and making a color darker by adding black. Therefore graphics packages providing color palettes to a user often employ two or more color models. One model provides an intuitive color interface for the user, and others describe the color components for the output devices.

15.4. RGB Color Model

The RGB color model is one of the most widely used color representation method in computer graphics. It uses a color coordinate system with three primary colors:

R(Red), G(Green), B(Blue)

Each primary color can take an intensity value ranging from 0(lowest) to 1(highest). Mixing these three primary colors at different intensity levels produces a variety of colors. The collection of all the colors obtained by such a linear combination of red, green and blue forms the cube shaped RGB color space.

The corner of RGB color cube that is at the origin of the coordinate system corresponds to black, whereas the corner of the cube that is diagonally opposite to the origin represents white. The diagonal line connecting black and white corresponds to all the gray colors between black and white, which is also known as gray axis.

We can represent this model with the unit cube defined on R, G, and B axes, as shown in figure 15-11. The origin represents black, and the vertex with coordinates (1, 1, l) is white. Vertices of the cube on the axes represent the primary colors, and the remaining vertices represent the complementary color for each of the primary colors.

As with the XYZ color system, the RGB color scheme is an additive model. Intensities of the primary colors are added to produce other colors. Each color point within the bounds of the cube can be represented as the triple (R, G, B), where values for R, G, and B are assigned in the range from 0 to 1.

C_λ is expressed in RGB components as

$$C_\lambda = R\mathbf{R} + G\mathbf{G} + B\mathbf{B} \tag{15-5}$$

The magenta vertex is obtained by adding red and blue to produce the triple (1, 0, l) and white at (1, l, 1) is the sum of the red, green and blue vertices. Shades of gray are represented along the main diagonal of the cube from the origin (black) to the white vertex.

15.5. YIQ Color Model

Whereas an RGB monitor requires separate signals for the red, green, and blue components of an image, a television monitor uses a single composite signal. The **National Television System**

Committee (NTSC) color model for forming the composite video signal is the YIQ model, which is based on concepts in the CIE XYZ model.

In the MQ color model, parameter Y is the same as in the XYZ model. Luminance (brightness) information is contained in the Y parameter, while chromaticity information (hue and purity) is incorporated into the 1 and Q parameters. A combination of red, green, and blue intensities are chosen for the Y parameter to yield the standard luminosity curve. Since Y contains the luminance information, black-and-white television monitors use only the Y signal.

The largest bandwidth in the NTSC video signal (about 4 MHz) is assigned to the Y information. Parameter I contains orange-cyan hue information that provides the flesh-tone shading, and occupies a bandwidth of approximately 1.5 MHz. Parameter Q carries green-magenta hue information in a bandwidth of about 0.6 MHz.

An RGB signal can be converted to a television signal using an NTSC encoder, which converts RGB values to YIQ values, then modulates and superimposes the I and Q information on the Y signal.
The conversion from RGB values to YIQ values is accomplished with the transformation

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.528 & 0.311 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad (15\text{-}6)$$

This transformation is based on the NTSC standard RGB phosphor, whose chromaticity coordinates were given in the preceding section. The larger proportions of red and green assigned to parameter Y indicate the relative importance of these hues in determining brightness, compared to blue.

An NTSC video signal can be converted to an RGB signal sing an NTSC decoder, which separates the video signal into the YlQ components, then converts to RGB values. We convert from YIQ space to RGB space with the inverse matrix transformation from Eq. 15-6:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.000 & 0.956 & 0.620 \\ 1.000 & -0.272 & -0.647 \\ 1.000 & -1.108 & 1.705 \end{bmatrix} \cdot \begin{bmatrix} Y \\ I \\ Q \end{bmatrix} \qquad (15\text{-}7)$$

15.6. CMY Color Model

A color model defined with the primary colors cyan, magenta, and yellow (CMY) is useful for describing color output to hard copy devices.

It is a subtractive color model (i.e.,) cyan can be formed by adding green and blue light. When white light is reflected from cyan-colored ink, the reflected light must have no red component. i.e., red light is absorbed or subtracted by the link.

Magenta ink subtracts the green component from incident light and yellow subtracts the blue component.

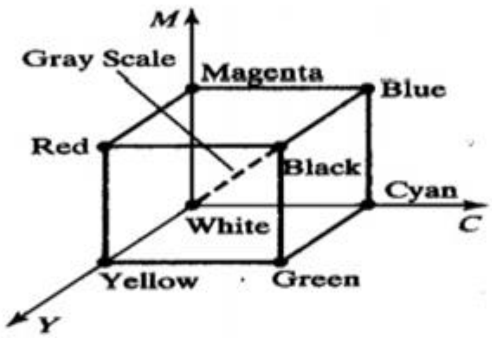

Fig: The CMY color model defining colors with a subtractive process inside a unit cube

In CMY model, point (1,1,1) represents black because all components of the incident light are subtracted. The origin represents white light. Equal amounts of each of the primary colors produce grays along the main diagonal of the cube. A combination of cyan and magenta ink produces blue light because the red and green components of the incident light are absorbed. Other color combinations are obtained by a similar subtractive process.

The printing process often used with the CMY model generates a color point with a collection of four ink dots. One dot is used for each of the primary colors (cyan, magenta and yellow) and one dot is black. A black dot is included because the combination of cyan, magenta, and yellow inks typically produce dark gray instead of black. Some plotters produce different color combinations by spraying the ink for the three primary colors over each other and allowing them to mix before they dry.

We can express the conversion from an RGB representation to a CMY representation with the matrix transformation

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

where the white is represented in the RGB system iis the unit column vector. Similarly, we convert from a CMY color representation to an RGB representation with the matrix transformation.

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

where black is represented in the CMY system as the unit column vector**.**

15.7. HSV Color Model

HSV (Hue, Saturation and Value) defines a type of color space. It is similar to the modern RGB and CMYK models. The HSV color space has three components: hue, saturation and value. ‘Value’ is sometimes substituted with ‘brightness’ and then it is known as HSB. The HSV model was created by Alvy Ray Smith in 1978. HSV is also known as the hex-cone color model.

Hue
In HSV, hue represents color. In this model, hue is an angle from 0 degrees to 360 degrees.
Saturation
Saturation indicates the range of grey in the color space. It ranges from 0 to 100%. Sometimes the value is calculated from 0 to 1. When the value is '0,' the color is grey and when the value is '1,' the color is a primary color. A faded color is due to a lower saturation level, which means the color contains more grey.
Value
Value is the brightness of the color and varies with color saturation. It ranges from 0 to 100%. When the value is '0' the color space will be totally black. With the increase in the value, the color space brightness up and shows various colors.

Applications of HSV
The HSV color space is widely used to generate high quality computer graphics. In simple terms, it is used to select various different colors needed for a particular picture. An HSV color wheel is used to select the desired color. A user can select the particular color needed for the picture from the color wheel. It gives the color according to human perception.

Advantages of HSV
The HSV color space is quite similar to the way in which humans perceive color. The other models, except for HSL, define color in relation to the primary colors. The colors used in HSV can be clearly defined by human perception, which is not always the case with RGB or CMYK.

15.8. CONVERSION BETWEEN HSV AND RGB MODELS

Given RGB color range, our task is to convert RGB color to HSV color.
RGB Color Model:
The RGB color model is an additive color model in which red, green and blue light are added together in various ways to reproduce a broad array of colors. The name of the model comes from the initials of the three additive primary colors, red, green, and blue.

HSV Color Model:
HSV – (hue, saturation, value), also known as HSB (hue, saturation, brightness), is often used by artists because it is often more natural to think about a color in terms of hue and saturation than in terms of additive or subtractive color components. HSV is a transformation of an RGB color space, and its components and colorimetry are relative to the RGB color space from which it was derived.

15.9. HLS Color Model

HLS color model A color model that defines colors by the three parameters hue (H), lightness (L), and saturation (S). It was introduced by Tektronix Inc. Hue lies on a circle, saturation increases from center to edge of this circle, lightness goes from black to white. This model uses the same hue plane as the HSV model, but it replaces value (V) by an extended lightness axis so that the maximum color gamut is at L=0.5 and decreases in each direction towards white (L=1) and black (L=0). The HLS color model is represented by a double hexagonal cone, with white at the top apex and black at the bottom.
