COLOR SPECIFICATION AND CARTOGRAPHY: A COMPARISON OF THE MUNSELL COLOR SYSTEM AND THE HLS SYSTEM

by

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ABSTRACT: Progress in the development of color CRT's and color graphic hard-copy devices offers a new tool for the thematic mapper. From a cartographic perspective, the technology for displaying and producing color maps has advanced without concern for cartographic principles and conventions in the employment of color. Since it is necessary to incorporate good cartographic design in the development of software, this paper will offer suggestions to achieve such a union. Attention is focused on a comparison of the Munsell Color System and the HLS System, and recommendations for future topics of research are discussed.

INTRODUCTION

Geographers are concerned with the spatial characteristics and relationships of physical and cultural phenomena, and historically, maps have been a valuable tool in their studies. Maps have enabled the geographer to express ideas, places, and interrelationships that are not readily apparent by any other means. This has added to the geographic understanding of viewers other than geographers.

The map is a powerful medium of geographic expression and visual communication. One map design element, color, is especially valuable and, if used carefully, can enhance communication. Originally, color was painstakingly applied by hand. The first published work which offered guidance to the early map colorer was a treatise by John Smith (1769). Smith devotes a chapter to the discussion of the employment of color on maps. He provides a detailed description of the mixing of pigments, as well as suggesting appropriate colors to be used to enhance different mapped features. For example, Smith states:

> . . . if there be any woods, dab every tree with the point of a very fine pencil dipped in grass-green (Smith 1769, p. 104).
>
> . . . color the sea-shore, and all lakes or water, if there be any, with thin indigo (Smith, 1769, p. 106).

The use of blue for water and green for vegetation has evolved into a connotative convention.

Since the time of Smith's treatise, advancements in technology, industry, color science and color theory have profoundly influenced the employment of color on maps. As more colors became available, and researchers began to study the physical and psychological aspects of color, it became increasingly necessary to develop a logical method of ordering and specifying color to improve color communication. One system, the Munsell Color System, which is based on the principles of color perception, is widely employed by cartographers.

A recent technological contribution to color mapping has come from the computer industry. Progress in computer technology, especially in the development of color CRT's and color graphics hard-copy devices, offers a new tool for the thematic mapper. However, from a cartographic perspective, the technology for displaying and producing color maps has advanced without concern for many of the cartographic principles and conventions that have developed which encourage the wise employment of color on maps.

With the advent of the computer, a wide variety of colors can be obtained by a mere push of a button. The ease in which we can access colors selected from a palette of thousands, combined with the probability that "by 1986, 85% of all graphic terminals will be color units" (Cramer, 1983, p. 29), expands the responsibility of both the computer industry and the cartographer. The color graphic terminal gives the average person, who may not be aware of the design principles which guide the cartographer in the selection of color, the ability to create color maps. This could lead to the production of color maps that do not portray geographical data in a meaningful manner, and which are misleading or confusing to the map viewer. To alleviate this problem, it is necessary to incorporate good cartographic design in the development of software.

It is as unreasonable to expect the software designer to become an expert in color principles and conventions, as they are applied in mapping, as it is to expect the cartographer to become an expert in the intricacies of software design. Therefore, it is important to establish a system of communication between the computer industry and cartographers. An effective method of color communication that is used by industry, designers, artists, psychologists and cartographers is through color-ordering systems.

Wyszecki and Stiles (1982, pp. 506-507) suggest that all color-order systems can be divided into three broad categories: those based primarily on the additive mixtures of color stimuli; those based on the principles of colorant mixtures; and those based on the principles of color perception, commonly referred to as color-appearance systems. As mentioned earlier, the Munsell Color System is a color-appearance system. The HLS System, used in computers, is also a color-appearance system and is conceptually similar to the Munsell System.

The focus of this paper will be on a comparison of the Munsell Color System and the HLS System, used by Tektronix. To comprehend the significance of this comparison, an understanding of the complexity of color and its employment in cartography is necessary. Therefore, this paper will provide a brief description of the physical, physiological, and psychological phenomena which influence our perception of color. Also, the three psychological dimensions of color: hue, value, and chroma, are defined. All of these topics are described and defined with a cartographic bias.

COLOR PERCEPTION

Our perception of color is a result of a combination of complex interrelated processes. Chamberlin and Chamberlin (1980, pp. 1-9) conveniently break down the way we perceive color into four stages: the light source, the colored object, the eye, and the brain. Since it is well beyond the scope of this paper to provide an in-depth examination of these stages, they are only briefly mentioned and discussed in a cartographic context.

The Light Source

Physically, visible light is the segment of the electromagnetic spectrum having wavelengths ranging from about 380nm to 750nm (Billmeyer and Saltzman, 1966, p. 4). A combination of all the wavelengths of visible light produces the sensation of white light. When white light is passed through a prism, it is divided into individual wavelengths known as the spectral hues. The spectral progression of hues from the shortest wavelength to the longest wavelength is: violet, blue, green, yellow, orange, and red. This spectral order is important because a partial spectral progression is often used in cartographic design to portray classes of data that are related.

The Object

The physical characteristics of the colored surface also affect the way we perceive color. Surfaces can either transmit, absorb, or reflect light (Billmeyer and Saltzman, 1966, pp. 8-11). Thus, a surface must be illuminated before we can perceive color. Also, the perceived color of a surface will depend on its ability to absorb and to reflect visible light (Chamberlin and Chamberlin, 1980, p. 3).

The Eye

Physiologically, our ability to perceive color is a function of light receptors in the retina of the eye, called cones (Verity, 1980, p. 84). Physiological phenomena, such as color blindness, visual acuity, and simultaneous contrast, are considered by the cartographer when selecting colors to be employed on maps.

Approximately 8.5 percent of males and 0.5 of females suffer from some form of color blindness (Marcus, 1982, p. 78). Of the different forms of color blindness, the most common form of color vision deficiency is an inability to distinguish between red and green (Kaufman, 1975, p. 275). Therefore, the employment of reds and greens on a map should be used with discretion.

When viewing a color map, a single color is perceived by the reader in relation to the colors surrounding it, not in isolation. This circumstance is important to the cartographer as it relates to the physiologically-based phenomena of visual acuity and simultaneous contrast, both of which affect the legibility of the map.

Simply stated, visual acuity affects the ability of the eye to resolve detail. For example, it is easier for the eye to distinguish black symbols on a white background than yellow symbols on the same white background. Our ability to perceive color is also influenced by the phenomenon of simultaneous contrast. When two colors are adjacent, or one color surrounds another, the perceived color of one is affected by the color next to it (Committee of Colorimetry, 1953, p. 155). This phenomenon is of concern to the cartographer because the map reader may have difficulty recognizing a color if it is surrounded by two totally different colors. For example, a violet is surrounded by yellow in one portion of the map and surrounded by blue in another portion of the map. Due to the phenomenon of simultaneous contrast, the two violets may appear to be different colors.

The Brain

Before color perception can actually occur, a set of electrical impulses or messages must be sent to the brain (Chamberlin and Chamberlin, 1980, p. 8). However, the cartographer is concerned with our psychological responses to color rather than the physiology of the brain. Usually the cartographer's selection of colors is based on the reader's connotations or associations of color with reality. Blue is often associated with wetness and, therefore, is used to portray water bodies or class intervals on precipitation maps. The hue red is associated with warmth and is often employed on maps of regional temperature.

In order to clarify the reader's understanding, some of the physical, physiological and psychological processes of color perception have been discussed separately. However, it is important to realize that all of these processes are interdependent. In other words, color cannot be perceived without a source of illumination, a surface to be illuminated, a receptor of the reflected light, and our consciousness. Finally, the purpose of this very brief discussion is meant to sharpen the awareness of the potential mapmaker regarding the complexity of the employment of color in cartography, and not to provide a comprehensive dialogue on color perception.

COLOR DESCRIPTION

Perceived color can be described by the psychological dimensions of hue, value, and chroma. For the purposes of this paper, these dimensions are defined and their application in cartographic design is briefly discussed. Unless otherwise noted, the cartographic principles of the employment of hue, value and chroma have been gleaned from Robinson et al. (1978, pp. 310-314).

Hue

Hue is the perceptual attribute of color that is related to the physical phenomena of wavelengths. An infinite number of colors can be produced by the combination of different wavelengths. However, the eye can distinguish only about 200 different hues (Evans, 1948, p. 118). Most people are referring to hue when they describe the color of an object.

There are many ways that hues can be ordered and described. One method of ordering hues, according to their spectral progression, has already been mentioned; and its cartographic applications have also been noted. Color can be described in terms of primary hues which, when combined, form all other hues. Of special interest to this study are the additive (red, green, blue) and subtractive (cyan, magenta, yellow) primaries. The fundamental difference between these two types of primaries is that additive primaries refer to the source of illumination and subtractive primaries refer to the light reflected from a surface (Simon, 1980, p. 21). This distinction is important, because the perceived colors on a printed map are a combination of the subtractive primary hues, while the colors displayed on a computer terminal are a combination of the primary hues.

An aspect of hues that deserves mention is that red, yellow, green, and blue are not perceived as mixtures (Agoston, 1979, p. 10). In cartography, these perceptually unique hues are used to symbolize distinctly different phenomena. Apparent mixtures of hues, such as reddish yellows and oranges, are used to portray phenomena that have common attributes.

Value

Value is the perceived lightness or darkness of a color and cannot be instrumentally measured (Marcus, 1980, p. 80). For example, yellow is perceived as a "lighter" color than navy blue. Cartographers employ variations in value to portray quantitative differences of phenomena: the darker symbolizes more and the lighter symbolizes less. The employment of variations of value must be exercised with care because the perceived value of a color is affected by its surroundings.

Chroma

Chroma refers to the purity or saturation of a color and reflects the amount of gray a color contains. A color becomes more saturated or higher in chroma as it moves away from the gray scale. Chroma progressions are often employed in cartography to depict changes in quantitative data: the higher the chroma level, the greater the amount of the variable being mapped. Chroma is perhaps the most complicated of the three perceptual dimensions of color and will be discussed in more detail later.

Hopefully, this brief overview concerning the properties of color perception and the three perceptual dimensions of color will enable the reader to better understand the following discussion of two color systems. Attention is now focused on a description and comparison of the Munsell Color System and the HLS (hue, lightness, saturation) System.

THE MUNSELL COLOR SYSTEM

The Munsell Color System identifies color in terms of hue, value and chroma (Munsell, 1907). Munsell's system, originally published in 1905, revolutionized color order and color description. To appreciate Albert H. Munsell's contribution to the art and science of color order, it is helpful to examine the development and purposes of his idea before addressing the specifics of his color system.

The Author and the Development of an Idea

As part of the description of the Munsell Color System, it is appropriate to pay tribute to its author. In the forward to Cleland's (1921) description of Munsell's color system, Munsell's son provides a brief biographical sketch of his father. The following discussion is a summary of this sketch, highlighting events related to the development of the Munsell Color System.

Albert H. Munsell, considered America's greatest colorist, was fundamentally an artist. He studied art at the Boston Normal Arts School and, upon graduating, won a fellowship for foreign study. When he returned to the United States three years later, he was appointed lecturer in artistic anatomy and color composition at the Boston Normal Arts School. He held this position for twenty-five years.

Munsell's interest in color began while he was a student, and by 1898 he was spending most of his spare time experimenting with the physical bases of pigment color. In 1898, Munsell created the Color Sphere (Figure 1), a three-dimensional solid which demonstrates the

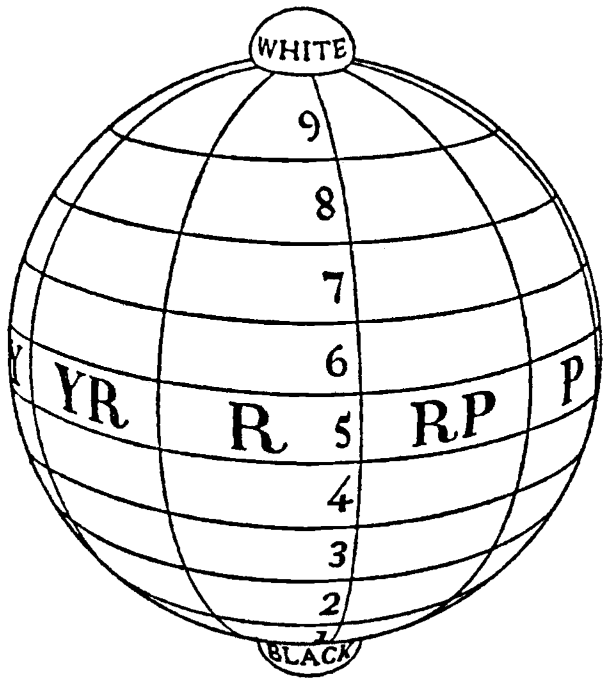

Figure 1. The Munsell Color Sphere.

relationship between hue, value, and chroma. Three years later, Munsell patented a photometer, an instrument used to measure the intensity of light. Specifically, Munsell used the photometer to compare the relative intensities of the light emitted from various colored surfaces. Munsell's intense study of color culminated in the unfolding of his system of color notation.

One of Munsell's purposes in developing his color notation system was to provide an accurate method of color expression. Prior to the development of his system, color was described in terms of natural objects such as: pea green, lemon yellow, rose pink, plum, sky blue, etc. Some of the inherent problems of this form of color communication are illustrated in a letter by Stevenson, the famous author:

> . . . well, I'll be hanged if I can describe this red. It's not Turkish, and it's not Roman, and it's not Indian; but it seems to partake of the last two, and yet it can't be either of them, because it ought to be able to go with vermilion. Ah, what a tangled web we weave! Anyway . . . send me some — many — patterns of the exact shade (Stevenson, 1902).

Munsell considered this method of color description not only inaccurate and subject to the various connotations of different people, but "incongrous" and "bizarre" (Munsell, 1907, p. 10). He suggested that describing color in this manner was comparable to describing musical tones in terms of the cries of animals:

> Can we imagine musical tones called lark, canary, cockatoo, crow, cat, dog, or mouse, because they bear some distant resemblance to the cries of those animals (Munsell, 1907, p. 10)?

Munsell continues his comparison by noting that the ability to define color should be as well developed as the ability in music to define sound:

> Music is equipped with a system by which it defines each sound in terms of pitch, intensity, and duration, without dragging in loose illusions to the endlessly varying sounds of nature. So should color be supplied with an appropriate system, based on the hue, value, and chroma of our sensations, and not attempting to describe them by indefinite and varying colors of natural objects (Munsell, 1907, p. 10).

Thus, it is obvious that Munsell intended to design an orderly and accurate method of color description. Another important purpose of the development of his color notation system was to provide an aid to teaching color by making the recording of color easier and more convenient (Nickerson, 1976b, p. 69). Munsell also incorporated his theories and principles of color harmony and balance into his color system (Cleland, 1921). Time and space will not allow a broader and deeper analysis of Albert H. Munsell and the development of his color notation system. However, the author is confident that the reader will recognize Munsell's brilliant contributions to the world of color in the following discussion of hue, value, chroma, and the color solid. Finally, it is fitting to conclude this section with Munsell's opinion of his color notation system:

> Color anarchy is replaced by systematic color description (Munsell, 1907, p. 76).

As previously mentioned, the Munsell system identifies color in terms of hue, value, and chroma. Each dimension is divided into a series of perceptually equal steps that are assigned a specific code. Consequently, a color is actually described by the combination of a hue, value, and chroma code, in that order. First, for the purpose of clarity, each dimension will be addressed separately. Subsequently, the three-dimensional relationship between hue, value, and chroma, visually illustrated by the color solid, will be discussed.

The definitions of hue, value, and chroma appearing at the head of their respective sections, are taken from the glossary included in the second edition of A Color Notation, published in 1907. Their inclusion reflects this author's preference for primary sources of information. The author apologizes to those readers who find this inclusion unduly repetitive.

Hue

> HUE -- Specifically and technically, distinctive quality of coloring in an object or on a surface; the respect in which red, yellow, green, blue, etc., differ one from another; that in which colors of equal luminosity and CHROMA may differ (Munsell, 1907, p. 109).

The Munsell hues are arranged in the form of a circle, and their placement around the circle corresponds with the spectral order of visible light (Cleland, 1921, p. 6). Munsell describes the hues included in his circle as either simple or intermediate (Birren, 1969, p.18). The notation for the simple hues, i.e., red, yellow, green, blue, and purple, is R, Y, G, B, and P, respectively. The intermediate hues (yellow-red, green-yellow, blue-green, purple-blue, and red-purple) are written as YR, GY, BG, PB, and RP, respectively.

As illustrated in Figure 2, the simple and compound hues equally divide the hue circle into ten segments. These are then divided into ten steps, numbered one through ten, so that the simple and intermediate hues are always marked by the number five (Overheim and Wagner, 1982, p. 79). Thus, the Munsell system of notation provides an alphanumeric code for each one of the one hundred hues -- for example: 5R, 10BG, 7P. Although less descriptive, the hues can also be written strictly numerically, from 1 to 100 (Robinson et al., 1978, p. 307). Finally, it is important to note that each one of the equally-spaced Munsell hues are perceptually unique.

Value

> VALUE -- In painting and the allied arts, relation of one object, part, or atmospheric plane of a picture to the others, with reference to light and shade, the idea of HUE being abstracted (Munsell, 1907, p. 112).

Munsell later defined value simply as "The quality by which we distinguish a light color from a dark one"; and, to determine the

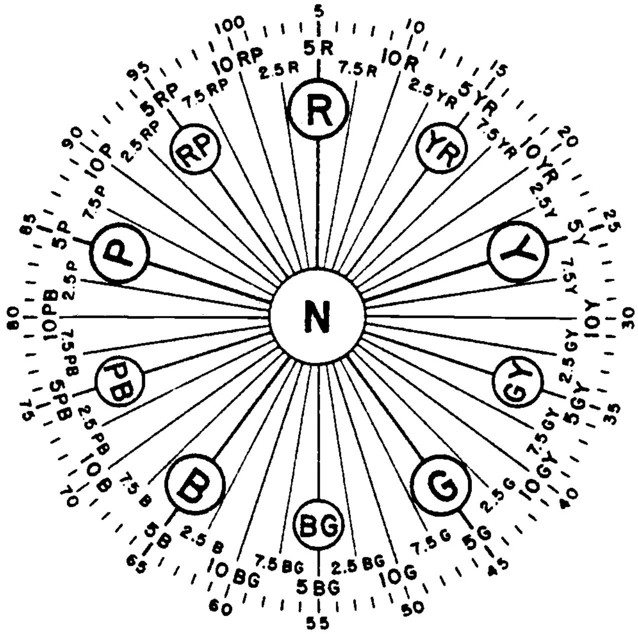

Figure 2. The Munsell hue circle.

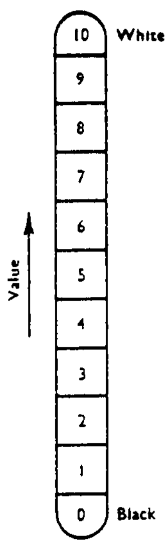

Figure 3. The Munsell value scale.

lightness or darkness of a color, he developed a value scale (Cleland, 1921, p. 7). The value scale is composed of white, nine equal steps of gray, and black. The steps are numbered 0 to 10, with 0 representing black and 10 representing white. However, for practical purposes, only steps 1 through 9 are used, with 1 denoting the darkest gray (which is one perceptual step above black) and 9 denoting the lightest gray (one perceptual step below white) (Figure 3). Thus, the lower numbers on the scale represent darker values, and the higher numbers represent lighter values. For example, a color that is commonly referred to as "sky blue" is high in value and considered a light color; "navy blue," on the other hand, is low in value and, therefore, considered a darker color. In Munsell notation, a color's value is expressed by a number above a line which indicates its step on the value scale. For instance, 8/ denotes the value of sky blue, and 2/ denotes the value of navy blue. A significant aspect of the Munsell value scale is that each step is perceptually equidistant.

Chroma

> CHROMA -- The degree of departure of a color sensation from that of white or gray; the intensity of distinctive hue; color intensity (Munsell, 1907, p. 107).

The third dimension of color included in Munsell's specification system is chroma. As previously discussed, chroma is the perceived amount of grayness in a color and is commonly referred to as saturation, purity, or intensity. The chroma of a constant hue and constant value is measured radially from the value scale (Munsell, 1929, p. 9). The chroma scale begins with 0 at neutral gray and moves to higher-numbered values, becoming more saturated as the distance from the value scale increases. Each step of the chroma scale is perceptually equally spaced.

The chroma of a color differs depending on its hue and value. For instance, Munsell observed that "colors differ by nature in their chroma strength, some being much more powerful than others" (Birren, 1969, p. 25). In other words, at the same step on the value scale, a fully-saturated red requires more chroma steps to reach neutral gray than a fully-saturated blue-green (Figure 4). Differences in value also affect chroma, and Munsell noted that "All colors do not reach their maximum chroma strength at the same level of value," (Birren, 1969, p. 25). Munsell illustrated this point by comparing yellow and purple-blue. Yellow is considered a light color and reaches its highest chroma level at value step 7; whereas, purple-blue, considered a dark color and, therefore, low on the value scale, becomes fully saturated at value step 4 (Figure 5).

In order to complete this discussion of chroma, a description of its Munsell notation is necessary. Simply, the number for the chroma step is written below the line that separates value and chroma. For example, the chroma level of sky blue is written as /4 and the chroma level for navy blue is written as /9.

Now that each dimension of the Munsell system of color specification has been discussed, it is possible to complete the formula for sky blue and navy blue. The notation for sky blue is 5B 2/4,

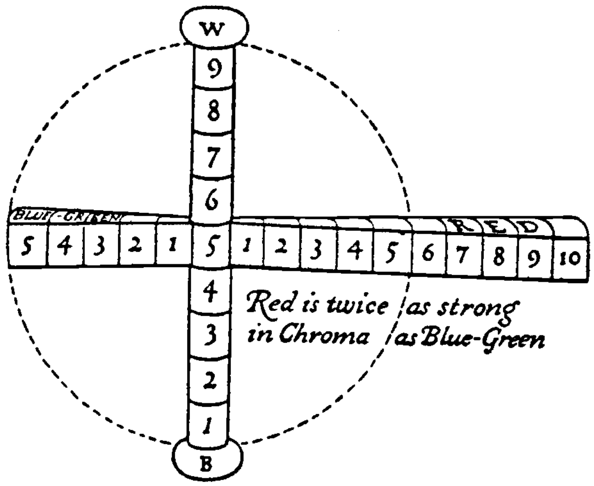

Figure 4. Chroma as affected by hue.

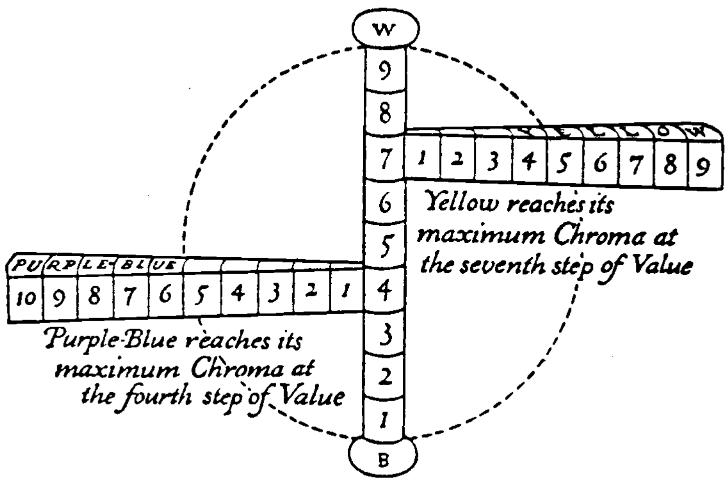

Figure 5. Chroma as affected by value.

and navy blue is written as 5B 8/9.

The Munsell Color Solid

Up to this point hue, value, and chroma have been discussed independently. This section will focus on their relationship in color, illustrated by the three-dimensional color solid.

Munsell used a sphere to aid in the visualization of the relationship between hue, value, and chroma (Munsell, 1929, p. 11). The axis of the sphere represents the value scale, with white capping the north pole and black capping the south pole. The hues are equally spaced around the equator, and the chroma steps radiate perpendicularly from the value axis. The colors north of the equator get progressively lighter as they approach white, and the colors south of the equator get progressively darker as they approach black. Also, as we move from the equator towards the value axis, the colors appear progressively grayer. The three-dimensional relationship between hue, value, and chroma in color space is illustrated in Figure 6. However, as discussed in the chroma section of this paper, the properties of a given hue and value affect the number of chroma steps required for a color to reach full saturation. Therefore, Munsell's color solid is not a symmetrical sphere but has an irregular shape (Figure 7).

Present Use of the Munsell System

The color system originally published by Munsell in 1905 has subsequently been revised and improved (Nickerson, 1976a). Presently, Munsell colors physically exist in the form of color "chips"

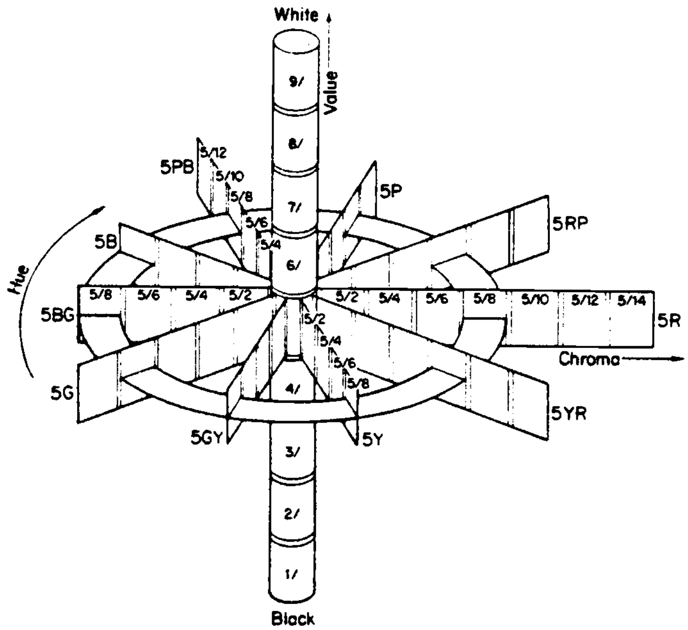

Figure 6. Munsell hue, value, and chroma scales in color space.

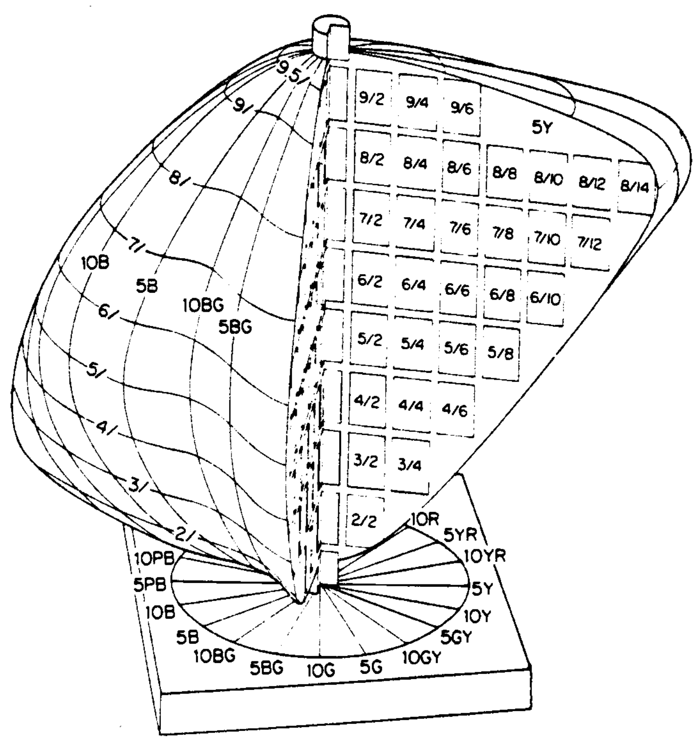

Figure 7. The irregular three-dimensional shape of the Munsell color solid with a cutaway to show constant hue 5Y.

which have been assigned a Munsell notation. To determine the Munsell specification for a sample of an unknown color, it is visually compared with the color chips. A sample of color chips is displayed in a color solid called the Munsell Color Tree (Figure 8). It is interesting to compare Figure 8 with an artist's drawing of the Color Tree (Figure 9).

The Munsell color system is used by industry and government, and has gained wide acceptance in the United States, Japan, and England (Agoston, 1979, p. 85). The Munsell system has also formed the basis for a standardized system of color names (ISCC-NBS, 1976). In addition, the Munsell color system is employed in the matching of soil colors and to color-code wires in electronics (Robinson et al., 1978, p. 306). The Munsell system replaces loosely stated color terms with a definite color code. The system also has built-in flexibility, and new colors that are developed can easily be added.

THE HLS SYSTEM

The HLS (hue, lightness, saturation) system is one of several color specification systems used in computer graphics. As was mentioned at the beginning of this paper, it is conceptually similar to the Munsell system. The HLS system is based on the perceptual attributes of color: hue, lightness (Munsell value), and saturation (Munsell chroma), not on how color is generated. Thus, this system is people-oriented rather than hardware-oriented. The HLS system of color specification was originally adopted by

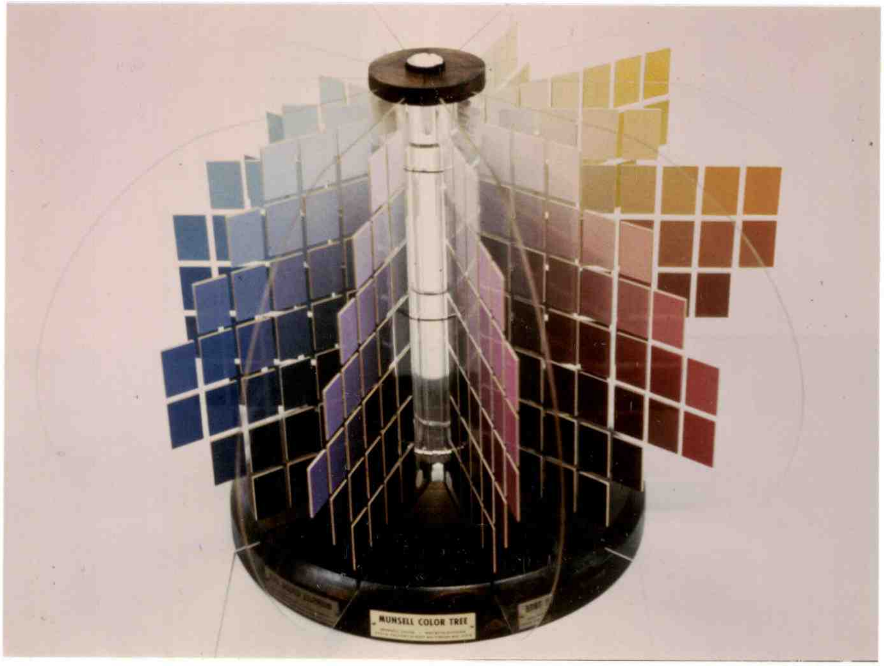

Figure 8.
The Munsell
Color Tree.

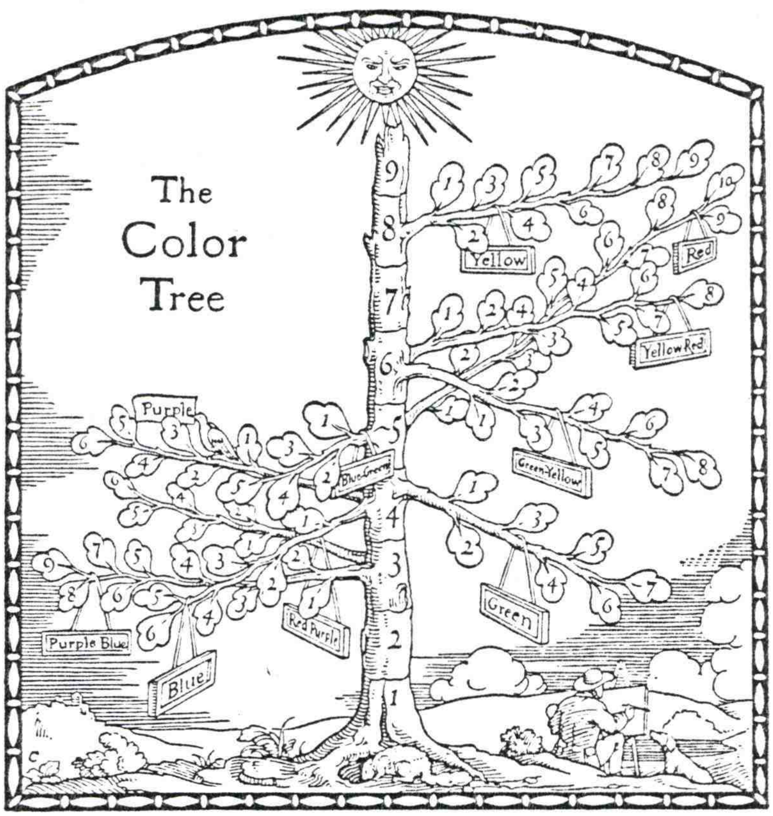

Figure 9.
Artist's drawing
of the Munsell
Color Tree.

Tektronix for their 4027 color graphics terminal (Tekscope, 1978). Their decision was based on the belief that this system would be easy for users to learn and that it facilitated interactivity.

Before discussing the HLS system of color specification, it is necessary to briefly examine how color is produced on a color computer terminal. The face of the computer terminal is composed of tiny dots of three kinds of phosphors (Murch, 1983, p. 19). When these phosphors are stimulated by electron beams, one type of phosphor will emit red light, one will emit green light, and one will emit blue light. Thus, the colors displayed on the graphics terminal are produced according to the principles of additive color mixture. Also, the intensity of the electron beam determines the brightness of the phosphors.

HLS Color Specification System

The HLS system specifies color in terms of hue, lightness, and saturation coordinates. Since the definitions for hue, lightness, and saturation correspond to the definitions already provided for hue, value, and chroma, respectively, only a brief summary of these perceptual dimensions is required. Hue is the attribute that is associated with a color's name, such as: blue, green, or yellow. Lightness describes whether the color is light or dark, and saturation expresses the degree to which the color differs from gray.

The conceptual relationship between hue, lightness, and saturation can be visualized in the form of a double-cone (Figure 10). This diagram will be used to illustrate the discussion of the HLS method of color specification. The hues are arranged in a circle

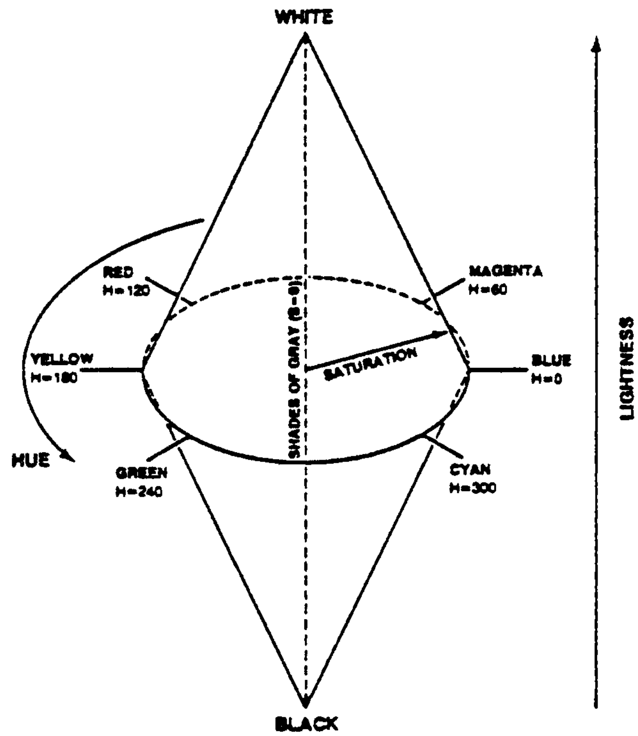

Figure 10. HLS color solid.

surrounding the mid-point of the vertical axis (Murch, 1983, p. 35). The hue coordinate is specified in terms of degrees around the circle. Beginning with blue at 0 degrees and moving counterclockwise, magenta, red, yellow, green, and cyan are specified as 60, 120, 180, 240, and 300 degrees, respectively. The complement of any hue is located 180 degrees around the circle. The lightness scale forms the vertical axis of the double-cone and is specified in percentages from 0 percent, which is black, to 100 percent, which is white. Saturation is the radial distance from the lightness axis to the surface of the cone and is also measured in percentages from 0 to 100 percent. The saturation coordinate is expressed as the maximum saturation that is possible at a given lightness level. The most fully saturated colors are obtained at the 50 percent lightness level. The HLS specification for sky blue would likely be 0, 67, 100 and for navy blue 0, 33, 100.

COMPARISON OF TWO SYSTEMS

It is a difficult task to compare two color systems which specify color produced by two different mediums. The Munsell system specifies pigment color and the HLS system specifies color that is produced by light. However, it is necessary to make this comparison because the product, color, is an important communication tool; and wise employment of color is essential in good map design. Superficially, there appear to be similarities between the Munsell system of color specification and the HLS system. However, beneath the surface one finds significant differences.

Conceptually, the HLS system of color specification and the Munsell system are similar. Both systems are based on color-appearance and, therefore, define color in terms of its three perceptual attributes: hue, lightness (Munsell value), and saturation (Munsell chroma). The three-dimensional color solid illustrates the relationship between the perceptual attributes of color; and, when the Munsell solid and the HLS solid are placed side-by-side, certain similarities are obvious (Figure 11). In both solids, the hues are arranged in a spectral order around a circle which surrounds a vertical axis. The vertical axis represents the lightness (Munsell value) scale, and on the axes the white north pole and the black south pole are separated by a progression of gray tones. In both

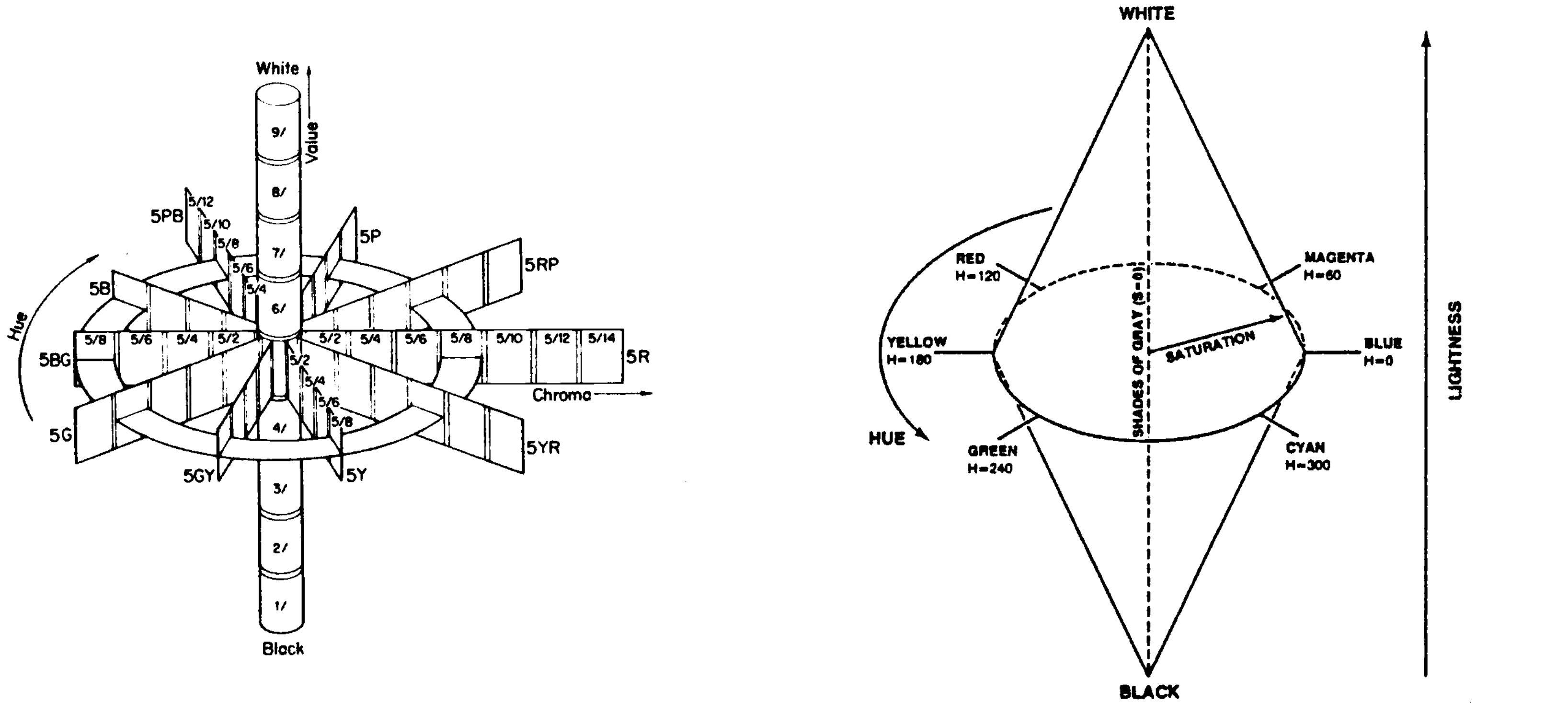

Figure 11. Comparison of Munsell solid and HLS solid.

solids, saturation (Munsell chroma) is illustrated as emanating radially from the lightness (value) axis. Thus, superficially these two models are similar. However, the similarities are deceiving. Although the models conceptualize the relationship between hue, lightness (Munsell value), and saturation (Munsell chroma) in the same fashion, in a perceptual context — and in their theoretical development — the systems are different.

The most significant difference between the Munsell system and the HLS system is related to our perception of the colors specified in each system. Although both systems specify color in <u>terms</u> of perceptual dimensions, the colors produced in the HLS system are <u>not always</u> perceptually different; whereas all Munsell colors are perceptually different. This difference is best understood by examining the dimensions of hue, lightness (Munsell value), and saturation, as specified in both systems.

In the Munsell system of color specification, each dimension is divided into equal perceptual steps. Each hue included in the Munsell hue circle is perceptually linked to the hue next to it, and each hue is one perceptual step from the adjacent hue. Also, the Munsell value scale is composed of gray tones that have been determined to be perceptually equidistant. Finally, the chroma levels of a given hue at a given value are also divided into equal perceptual steps. Thus, all Munsell colors are perceptually unique, as determined by group testing.

The HLS system does not divide the three dimensions of color neatly into perceptually equal steps. Hues are expressed in terms of degrees around a circle, and the hue located at 320 degrees is not necessarily perceptually different from the hue at 330 degrees. Also, lightness and saturation are ranked in percentages along a continuum ranging from 0 to 100 percent (Murch, 1983, p. 35). It is unlikely that a lightness level of 30 percent is perceptually different from 35 percent, or that 40 percent saturation is perceptually different from 45 percent saturation. Thus, although two colors may have different numerical specifications in the HLS system, they may in fact be perceived as identical colors.

In terms of the practical application of the Munsell system and the HLS system in a cartographic context, the differences between the two systems are significant. For example, cartographers often employ value and chroma progressions to portray classes of quantitative data, and it is important that each class appear distinct so as not to confuse the map viewer. Since the Munsell system is based on equal perceptual differences, it is convenient for the cartographer to use. It appears possible to obtain perceptually spaced value and chroma progressions with the HLS system, but the user would have to decide on a value or chroma progression by trial and error.

CONCLUSION

The purpose of this paper was not to provide a definitive statement of the employment of color in cartography or a complete analysis of the Munsell color system and the HLS system. Rather, its purpose was to bring to the forefront the complex nature of color and the problems that can arise if color is not employed with knowledge and care. The importance of a systematic method of color specification based on perceptual differences in color has been stressed.

The employment of color in cartography is very complex. The Munsell system of color specification offers a method to reduce the complexity of color selection. The HLS system, on the other hand, has future possibilities but, at present, the selection of color is subject to the user's knowledge of color principles and, therefore, may often result in undesirable color combinations.

While the field of computer graphics is characterized by rapid change and innovation, workers in that area should not ignore the contributions made by cartographers and other color researchers concerning cartographic principles and conventions in the employment of color. At this early stage in the development of software designed for color mapping, it is important that a comprehensive set of guidelines incorporating cartographic principles and conventions be established for the computer programmer. The first step in the development of these guidelines would be to assign Munsell notation to the colors displayed on the computer screen. From this point, standardized hue, value, and chroma progressions could be developed for different types of maps. For example, a set of blue chroma progressions could be established for employment on precipitation maps. In general, these types of maps should not employ more than seven classes, and five is preferred. The computer has the ability to vastly expand the design possibilities for the cartographer and others; however, we should proceed with caution and utilize color with the best possible methods that increase its effectiveness as a communication tool.

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