Color Communication

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Contents

Abstract

The use of language to describe color is natural and intuitive and there seems to be some evidence that different languages refer to color in a consistent way. It is clear, nonetheless, that the reliance of language to communicate color is limited not least by the number of color names but also by the lack of precision that language affords. As an alternative to natural language, color-order systems have found widespread use; these usually consist of physical books of patches or swatches each of which carries a notation. Three representatives of such systems are referred to in this chapter: the Munsell system, the Pantone system, and the NCS system. Although physical-color order systems can be effective they are also limited by, for example, consisting of relatively few physical samples. The last couple of decades have seen increased use of numerical color communication and specification based upon the CIE system.

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List of Abbreviations

CIE	Commission Internationale de l'Eclairage
CMM	Color Matching Module
ICC	International Color Consortium
NCS	Natural Color System
PMS	Pantone Matching System

Introduction

A desire to communicate color is natural in the arts and in our everyday lives. However, in the last 50 years color communication has become essential as part of the design and specification of products in industrialized societies. The use of language to describe color is natural and intuitive and there seems to be some evidence that different languages refer to color in a consistent way. It is clear, nonetheless, that the reliance of language to communicate color is limited not least by the number of color names but also by the lack of precision that language affords. There is no clear answer to the question of how many different colors we can distinguish between; however, estimates range from three million to about ten million. It is clear that even if we use color names in a consistent and reliable way then there are limitations in the use of natural language for color communication. As an alternative to natural language, color-order systems have found widespread use; these usually consist of physical books of patches or swatches each of which carries a notation. Color-order systems are, however, themselves limited as tools for color communication. Numerical color communication is increasingly becoming the preferred method for color communication by professionals working in the field.

Color and Language

Previous research has proposed that in the English language black, white, red, green, yellow, blue, purple, orange, pink and gray are basic color terms or universal categories. The classic study in this area was conducted by Berlin and Kay who proposed that not only are there 11 basic color terms but that cultures evolve the use of these terms in way that is predictable and almost universal (Berlin and Kay 1969). As languages evolve, they acquire new basic color terms in a strict chronological sequence; if a basic color term is found in a language, then the colors of all earlier stages should also be present. The sequence is as follows:

- Stage I: Dark-cool and light-warm (this covers a larger set of colors than English “black” and “white”)
- Stage II: Red
- Stage III: Either green or yellow
- Stage IV: Both green and yellow

- Stage V: Blue
- Stage VI: Brown
- Stage VII: Purple, pink, orange, or gray

The Berlin and Kay study contested the Sapir-Whorf hypothesis; the idea that the varying cultural concepts and categories inherent in different languages affect the cognitive classification of the experienced world in such a way that speakers of different languages think and behave differently because of it. The study achieved widespread influence but has recently been criticized (Saunders 2000) and the notion of universality that has endured for the last 30 or so years is under attack from cultural relativists. Critics note that the language sample from which Berlin and Kay collected data was strongly biased in favor of written languages from industrialized societies. However, the Berlin and Kay study has not been refuted entirely and a current study underway at U.C. Berkeley and the University of Chicago is statistically testing comprehensive color-naming data, collected from 110 unwritten languages from non-industrialized societies, through the World Color Survey (http://www.icsi.berkeley.edu/wcs/. Last accessed 11 Aug 2010). More recently, there is evidence that possession of linguistic categories facilitates recognition and influences perceptual judgments (Roberson et al. 2000). There is therefore doubt about the universality of color perceptions and, more crucially, color naming. A further limitation in the use of natural language to communicate color is that the number of colors that we can differentiate between is extremely large. The number of colors that are discernable is difficult to quantify but is certainly measured in the millions. Judd and Wyszecki (1975) estimated that there were ten million discernable colors but a more recent estimate (Pointer and Attridge 1998) was more conservative and placed the number somewhere between two and three million.

Perceptual Color Attributes

Since the number of colors that can be observed is extremely large it is natural to consider systematic ways of organizing and describing colors that could lead to a more efficient and meaningful representation. One of the first people to arrange colors in a circle appears to have been Aron Sigfrid Forsius (1550–1637) although his work was not discovered until the twentieth century (Koenig 2003). Forsius's color circle included white and black. The first hue circle is credited to Newton who considered the spectral hues and presented them in a circular diagram along with the non-spectral hues (which Newton realized were required to complete the circle). *Hue* is that attribute of a visual sensation according to which an area appears to be similar to one of the perceived colors: red, yellow, green, and blue, or to a combination of two of them (Fairchild 2005a). Although hue is perhaps the most distinguishable attribute of a color, it is now established that color vision is based on three perceptual attributes: brightness, colorfulness, and hue (or correlates of three such attributes). *Brightness* is that attribute of visual sensation according to which an area appears to

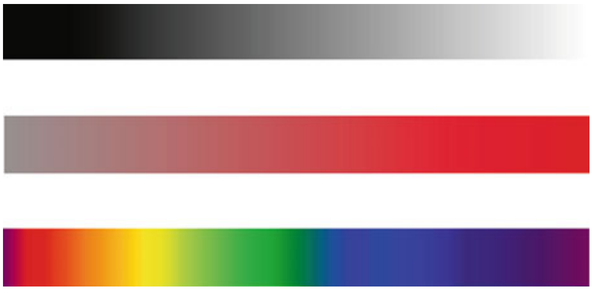

Fig. 1 The three attributes of color vision: lightness (*upper*), chroma (*middle*), and hue (*lower*)

emit more or less light whereas *colorfulness* is that attribute according to which the perceived color of an area appears to be more or less chromatic (Fairchild 2005a).

Relative color terms are frequently used. For example, lightness is a relative brightness (normalized for changes in illumination and viewing conditions) and chroma, saturation, and purity are all distinct from each other but describe various aspects of relative colorfulness. In this chapter a full explanation of these terms is not given but readers are directed to Fairchild (2005a) for authoritative definitions. In this chapter, the terms lightness, chroma and hue will be used in a general way to describe the three perceptual aspects of color perception. Figure 1 illustrates the three attributes.

The significance of these perceptual attributes is that it becomes possible to describe a color using three attributes in a semi-systematic way; thus, we might describe a light, saturated orange or a dark, desaturated blue. It also becomes possible to describe differences between two similar colors in a meaningful way; thus, we may say that one color is darker, stronger and bluer, for example, than another. This method of color communication avoids the use of arbitrary color names but is still limited as a method for precise and accurate color communication. However, a systematic understanding of color ontology led to the development of sophisticated tools for color communication such as the Munsell system.

The Munsell System

The idea of using a three-dimensional color solid to represent all colors was developed during the eighteenth and nineteenth centuries. For example, in 1810 Philipp Otto Runge developed a system based upon a sphere. However, although these systems became progressively more sophisticated, before Munsell none was based on any rigorous scientific understanding of human color vision. Prior to Munsell's contribution, the relationship between hue, lightness, and chroma was not well understood. Albert Munsell, an artist and educator, wanted to create a rational way to describe color that would use an alphanumeric notation instead of color names which he could use to teach his students about color. In 1905 he published *A Color Notation*, a description of his system with the first atlas being produced in 1907 (Kuehni 2003). In 1918, shortly before Munsell's death, the

Munsell Color Company was formed and the first *Munsell Book of Color* was published in 1929. An extensive series of experiments carried out by the Optical Society of America in the 1940s resulted in an improvement to the system known as the Munsell Renotations (Newhall et al. 1943).

Munsell was the first to separate lightness, chroma and hue into perceptually uniform and independent dimensions. The system consists of three independent dimensions which can be represented cylindrically as an irregular color solid: *hue*, measured by degrees around horizontal circles; *chroma*, measured radially outward from the neutral (gray) vertical axis; and *value*, measured vertically from 0 (black) to 10 (white). Munsell's value scale can be interpreted as a lightness scale. Munsell determined the spacing of colors along these dimensions by taking measurements of human visual responses.

Munsell based his hue notation on five principal hues: red, yellow, green, blue, and purple, along with five intermediate hues halfway between adjacent principal hues. Each of these ten steps is then broken into ten sub-steps, so that 100 hues are given integer values. Value, or lightness, varies vertically from black (value 0) at the bottom, to white (value 10) at the top. Neutral grays lie along the vertical axis between black and white. Chroma, measured radially from the center of each slice, represents the "purity" of a color (see Fig. 2). Note that there is no intrinsic upper limit to chroma. Different areas of the color space have different maximal chroma coordinates. For instance light yellow colors have considerably more potential chroma than light purples.

A color is fully specified in the Munsell system by listing the three numbers for hue, value, and chroma. For instance, a fairly saturated red of medium lightness would be R 5/10 with R indicating the hue, 5/10 indicating lightness and chroma respectively. The Munsell system is an example of a physical color-order system. By reference to the physical samples of color it is possible to provide reasonably accurate and precise color communication. The merits in the system are evident in the observation that the system is still in use today more than 100 years after it was

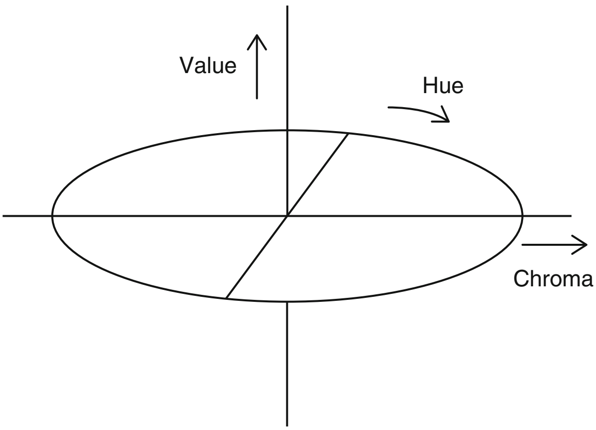

Fig. 2 The Munsell system arranged color in three dimensions. This idea remains in modern numerical color-communication tools such as CIELAB

developed. The current Munsell atlas is published in two parts, glossy (1,488 samples) and matt (1,277 samples) (McLaren 1987). However, as a method of communication the system is not without limitations. One problem of relying upon physical samples is that over time they may fade or become soiled. Perhaps more critically the system is limited to a couple of thousand color samples and invariably the color that one wishes to communicate lies somewhere between the colors of two adjacent samples in the system.

Other Color-Order Systems

The Munsell system was important for the influence that it had upon ideas about color spaces and representations (Kuehni 2003). Although the Munsell system is still in use today, other color-order systems have been developed and have found widespread use. The Pantone system is particularly popular in the graphic arts and printing industries. Pantone Guides consist of a large number of cardboard sheets, printed on one side with a series of related color swatches and then bound into a small flipbook. For instance, a particular sheet might contain a number of yellows varying in luminance from light to dark. There are several Pantone systems; the Pantone solid color system, for example, consists of over 1,100 unique, numbered colors (e.g., Pantone 198). The Pantone samples, unlike those of the Munsell system, are not organized in a way that is consistent with the human visual system nor spaced uniformly with respect to perception. However, Pantone systems have found widespread use because their use can assist printers to match colors (Pantone samples typically include information about which inks can be used to match that color). The Pantone Matching System (PMS), for example, provides information on how a printer should obtain the solid colors and there are also guides that provide the closest process color (CMYK) equivalent.

Another color-order system that has been successful is the Natural Color System (NCS) (Hesselgren 2007). The NCS system is perhaps more like the Munsell system than the Pantone system. The color samples are logically arranged in a three-dimensional space. However, there are some important differences between Munsell and NCS. For example, the Munsell system is based upon five primary hues whereas the NCS system is based upon four hues. In fact, the NCS system is based upon three pairs of elementary color percepts: white-black, red-green, and yellow-blue. NCS colors are defined by the amount of blackness, chromaticness, and a percentage value between two hues, red, yellow, green or blue. For example, the NCS color NCS 0580-Y10R refers to a color with 5 % darkness, 80 % saturation, and whose hue is 90 % yellow and 10 % red.

Numerical Color Communication

That color-order systems such as Pantone and Munsell contain relatively few samples is problematic for modern color communication. Physical color-order systems are also subject to the limitation that even if they are manufactured to a very close tolerance the samples inevitably fade over time or change in color because they become soiled. The use of color-order systems also requires so-called normal color vision, whereas approximately 5 % of the population is estimated to suffer from some type of color-vision defect. The Commission Internationale de l'Eclairage (CIE) developed a system for the specification of color stimuli that was recommended for widespread use in 1931 (Publication CIE No. 15.2 1986). This system allows measurements of spectral reflectance factors of spectral radiance to be converted to CIE XYZ tristimulus values or, in turn, to other (more uniform) color spaces such as CIE (1976) $L^*a^*b^*$ or CIELAB. The CIE system is described in more detail in chapters "▶ The CIE System" and "▶ Uniform Color Spaces." The second half of the twentieth century saw color measurement using the CIE system become ubiquitous in many industries including textiles, paints, and plastics.

The advent of affordable color-imaging devices in the last couple of decades, however, has led to an explosion in digital color communication. Color management is a process that aims to allow color to be transferred across various technologies (printers, cameras, displays etc.) without loss of fidelity. Color management systems are now embedded as part of most popular operating systems that make use of imaging device profiles that allow a device's color space to be transformed into a standard device-independent color space. Several device-independent color spaces are used including the CIE system but also sRGB (a standard RGB color space) (Stokes and Anderson 1996). The International Color Consortium (ICC) is an industry consortium which has defined an open standard for a Color Matching Module (CMM) at the operating system level, and color profiles for the devices and working *space* (the color space the user edits in).

Summary

There are numerous ways to specify and communicate color. The use of language is natural and intuitive but lacks precision for all but crude descriptions of color. The use of reference to physical samples (arranged in a color-order system) has become widespread. The Munsell system was revolutionary in its approach and is still in use today but other systems (such as Pantone and NCS) have developed specialist appeal and offer advantages for certain applications. The main advantage of a color-order system is that it is easy to use. However, the number of different colors that we would like to communicate is certainly in the millions and yet even the largest color-order systems contain only a few thousand samples. Arguably, the notation systems of some of these color-order systems allow colors that are between colors in the systems to be notated but with some loss of precision. There is also the argument that to use a color-order system effectively one should possess normal color vision. For this reason, and others, numerical color specification is widely used in industry and is based upon a system for specifying color that was introduced in 1931.

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