

COLOR ENCODING

GENEVIEVE EVINS

1. ABSTRACT

The ubiquitousness of color leads to a necessity for expression in all facets of life. With the evolution of expression into digital formats, there comes a need to translate over traditional mediums such as color. The concerns of a colorist are those of a software engineer- how does one best express the three aspects of color: hue, value, and saturation? When choosing a color for digital displays, the programmer must have the ability to create their desired color using only their general knowledge. In order to express color easily in code, it is necessary to create a standard that translates across platforms and is simple to conceptualize and understand. By this need for standardization, two identical systems were created to express color digitally: Hexadecimal and RGB.

2. TYPES OF COLOR SYSTEMS

There are two main systems by which we create color: additive and subtractive mixing. In order to utilize color mixing systems, we must understand the basis of human perception. To create colors, we stimulate the red, green, and blue cones in our vision to differing degrees. The three aspects of color that determine our perception are hue, value, and saturation. Hue refers to the appearance a color takes on in terms of the spectrum of light. In other words, hue is the base of a color on the rainbow; red, orange, green, blue, indigo, or violet. Value pertains to the lightness or darkness of a color, or rather how much white we add to a color. Finally, the saturation of color refers to its intensity. This is determined by the purity of a color, where low intensity is the result of combining complementary colors, which serve to dull a hue.

The most common method of mixing color is the additive system. Additive mixing uses the RGB, or red, green, and blue model to create combinations that form different colors. In this system, 'White' can be defined as a mixture of all visible colors. Inversely, we can define 'black' as the complete absence of color. Colors in this model can be de-saturated by adding in the complements directly. That is, if one wishes to de-saturate red, they would add green. RGB models are employed in digital displays via projections of light, as well as traditional pigment mixing for dyes and paints [3]. This method is most often the one taught in childhood when learning about color, and as a result is commonly understood.

Subtractive mixing uses the CMYK, or cyan, magenta, yellow, and key (black), model. Cyan, magenta, and yellow are chosen, since the colors are a complete absence of red, green, and blue, respectively. Using this model, the hues are combined to create a filter-like effect that removes a color, thus making new combinations. In this system, 'black' can be defined as a mixture of cyan, magenta, and yellow. Inversely, we can define 'white' as the complete absence of color. The method by which CMYK creates white is by simply not depositing color. Colors in this model are de-saturated by adding the key, or black, which in its construction is opposite to the natural RGB black which is an equal combination of red, green, and blue. The subtractive model is most often seen in printing, where a combination of small dots of color are used in order to force perception of a color, and subsequently an entire image [5].



FIGURE 1. Mixing with RGB Model [9]



FIGURE 2. Printing with CMYK Model [6]

3. THE AXIOM SYSTEMS OF COLOR

The subjectivity of color interpretation is widely known. In fact, it is a popular notion that no two people experience colors in the same exact ways. Thus, a need arrives for a system in which we can collectively agree on the composition and execution of a color. In order to interpret color effectively across mediums, it must lose some of that subjectivity and gain an axiom system that governs its expression. In other words, we must have a way to recreate colors precisely in an agreed upon fashion, where they can be identified not by name, but rather by composition. In particular, we seek to make color accessible by utilizing the simplest mixtures possible.

The additive RGB system is the simplest and most widely understood system by which we create color. The use of the subtractive CMYK color model can be far more complicated than useful for casual applications, as most who would utilize a standardized system would not have the background of color theory needed to understand the results of the CMYK model [5]. Additionally, cyan and magenta in particular are not thought of as 'natural' colors, and so their effects on other 'natural' colors can be difficult to predict for those who are not familiar with them already. In addition, the color spectrum for RGB is much larger than that of CMYK. That is, standardizing color using the additive model allows us to create far more colors than there would be if the subtractive model were

to be implemented. This limit of color comes from the use of the black key for de-saturation, by this the range of saturation is far smaller than a natural de-saturation used in additive color mixing, where complements are utilized [6]. Hence, the additive red, green and blue system is decidedly easier to understand, in addition to having a greater range of color. The two main ways we can encode color using the simpler additive model are using either the direct RGB or Hexadecimal (Hex) color systems. With one of these systems, we are enabled to create 16,777,216 distinct colors.

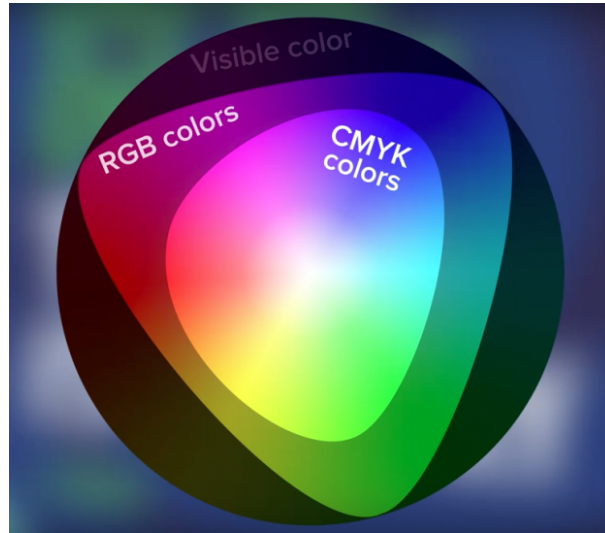


FIGURE 3. Range of color for additive RGB vs subtractive CMYK [7]

The RGB color system utilizes the decimal number system. Mixtures of colors are expressed as a triplet of values, the first representing a saturation of red, the second a saturation of green, and the third a saturation of blue. In this system, there are 255 levels of saturation for each of the three hues, with a value of 0 being a complete lack of that hue, and 255 a complete saturation. RGB, as a system of color encoding, is most commonly seen in digital displays such as projectors, cameras, and audio-video medias[8] [3]. The method by which we encode RGB is within a set of parenthesis, where each color saturation level is separated by a comma. The first value refers to red, the second green, the third blue. For example, an expression of white as defined in the additive process would be expressed in RGB as `rgb(255,255,255)`. Likewise, we can encode black as `rgb(0,0,0)`, purple as `rgb(128,0,128)`, and so on.

The Hex system is derived from the RGB system. It operates under a Hexadecimal system, where we count in the natural way beginning at 0, and ending at F. That is, we count decimal up to 9, then begin at A until F for a total of 16 values. In this system, 0 is a complete lack of that hue, and F a complete saturation. Hex codes begin with a # mark, and are followed by three pairs of values. The first pair of values correspond to red, the second to green, and the third to blue. So, an expression of white as defined in the additive process would be expressed in Hex as `#FFFFFF`, black as `#000000`, and purple as `#800080`. Hex is standard for colorists, digital artists, and HTML encoding [8]. Its initial derivation from the RGB system came from a need of further standardization; the Hex system is more consistent in terms of input. That is, we are guaranteed a Hex encoding will always contain six values following a hash mark, whereas in the RGB system, we could have a range from three to six values, with the number of characters expressing a single color saturation varying from one to two.

Because Hex is derived from RGB, we are able to convert relatively easily between the two encoding systems. For both systems, we count in the natural way. That is, beginning at 0. In converting RGB to Hex, we seek to express one value for each hue as the combination of two values. In order to do so, we follow a conversion from the decimal to the hexadecimal system [1]:

- (1) Take the first RGB term and divide by the base, 16, of Hex. This produces a whole number and a decimal value remainder.
- (2) Take the whole number value, and convert to the equivalent hexadecimal
- (3) Multiply the decimal remainder by 16, and convert to the equivalent hexadecimal.
- (4) Repeat this process for the subsequent two values.

decimal	hexadecimal	binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

FIGURE 4. The equivalencies of Decimal, Hexadecimal, and Binary counting [4]

To convert Hex to RGB, we seek to combine two hex digits into a single RGB value. In order to achieve this, we can follow a conversion from the hexadecimal to the decimal system [1]:

- (1) Convert the first value directly to decimal scale.
- (2) Multiply the decimal value result by 16, in order to scale back into the standard decimal scale. This result is called the partial value.
- (3) Multiply the decimal remainder by 16, and convert to the equivalent hexadecimal.
- (4) Take the second value in Hex, and convert directly to the decimal scale.
- (5) Sum the partial value with the previous result
- (6) Repeat this process for the subsequent two pairs

By the above methods, a programmer can easily convert any color encoded in one system to the other. This is particularly useful, as the preference tends to be up to the encoder or the program used. Notably, Hex is used in HTML encoding, and is easier on for humans to understand, since the scale is much smaller and the encoding is uniform [1]. Many object-oriented programming languages can accept both Hex and RGB inputs, so it is often a stylistic choice if performance is not considered. If the goal of a programmer is minimizing load time, however, Hex is preferred due to its simple conversion to binary, as illustrated in the figure above [1].

4. CONCLUSION

In order to express color in code, one does not need to be a colorist. Relationships between colors are established and discussed in terms of their proportions, and that is a quality that easily

translates to mathematics and computer science. The need to axiomatize color is a result of the human desire for consistency and efficiency, and few would have the patience to think of unique color combinations if not for the simple RGB systems discussed in this paper. By creating two axiom systems for color, not only has the programmer been given personal choice, but also freedom to create without restriction. Because of this, we are able to not only create, but view digital medias as if they were real, in color. The axiomatization and digitization of color systems goes so far as to come back around to becoming an artist's medium once again, with the heightened popularity of digital art in the last several years. There is no doubt that, like the development of the Hex system as a method of standardizing the standardization, there will emerge an even more efficient, perhaps with an even greater gamut, method of axiomatizing color in the future.

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