Territories of Color: Towards a New Model of Simultaneous Color Contrast

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Abstract

Artists typically employ two-dimensional color diagrams and three-dimensional color solids to organize the three variables of color: hue, value, and intensity. Artists' color models typically assign each color a specific point-location within the coordinate system of the color-space. Yet, artists have understood for over a century the phenomenon of simultaneous color contrast, whereby a given color will change its appearance in response to its color context. The variable identity of a color due to simultaneous color contrast is at odds with the invariant point-locations of traditional artists' color models. The author proposes a "territorial" model of color in which a single color may occupy one of many possible points in color-space, while at the same time retaining the overall hue-value-intensity organization of traditional color solids. This territorial model of simultaneous color contrast offers artists a representation of colors that more closely matches the dynamic nature of color perception, and it provides artists with some predictive power in creating simultaneous color contrast illusions.

Introduction

The purpose of this paper is to identify the limitations of traditional artists' color models in representing the perceptual effects of color relativity and to offer a new model that can better account for them. While it will not be possible in the short space of this paper to provide a fully developed color model, the propositions below will offer not only an outline of the problems to be solved, but also specific solutions for many of those problems. Our concern is limited to artists' color models, which tend to be instrumental in nature, providing a map for locating and identifying specific colors to be used in mixing paints, inks, dyes, or other physical media. Artists' color models sometimes overlap with scientific color models, but are usually organized around the perceptual effects of colors rather than the physical causes. Moreover, most artists work with color as pigmented reflective surfaces resulting from subtractive color mixtures of yellow, cyan, and magenta more than they work with projected colored light resulting from additive mixtures of red, green, and blue. To be sure, there are many artists, especially in the last 50 years, who employ colored light as their primary medium, but color models employed by artists are nearly always based upon subtractive mixtures, and it is probably accurate to say that only a small minority of artists employ additive color models such as the CIE Chromaticity Diagram ([1], p. 16).

We should acknowledge at the outset that a paper whose subject is color is hampered by two limitations: (1) Words and diagrams can explain and describe color relationships, but they cannot substitute for the color perception itself. (2) A black and white printed edition of this paper is less than ideal when we are trying to grasp subtle and complex relationships of color. The reader is encouraged to see the electronic, color version of this paper and to consult the additional sources listed in the References section. It will be necessary in the next few paragraphs to establish some color terminology and definitions before we can delve into the main assertions of the paper.

Color Terminology and Color-Solid Models

In visual art, any given color is described as a unique combination of three variables: *value*, *hue*, and *intensity*. Value (or *brightness* or *luminosity*) identifies the degree of lightness and darkness of a color; for example, a pink rose is lighter in value than a red apple, which is lighter in value than a red wine. Hue is the quality of color by which we distinguish yellowness from redness from blueness, etc. Hue differences may be pronounced, such as in the hues of the rainbow, or they may be more subtle, such as the slightly warmer and cooler yellows of a daffodil, a lemon, and a canary. Intensity (or *saturation* or *chroma*) describes degrees of brilliance, from pure, spectral color to dull, earthy color. For example, "fire engine" red is more intense than "brick-red," which is more intense than the warm gray of sandstone. Value, hue, and intensity constitute the *dimensions* of color; every color possesses all three simultaneously, and so any color can be described in all three dimensions. For example, a "chestnut brown" horse would be more accurately described as middle-dark value, middle intensity, red-orange.

We shall employ the following terminology and diagrams to describe the variables of these color dimensions (see Figure 1). Value and intensity have high and low limits, and so are shown as linear scales (vertical bars), while hue is diagrammed not linearly but as circle of continuous change. While it would be possible to establish more detailed increments, we must be content in the limited space of this paper to employ five descriptors for value (*light, middle-light, middle-value, middle-dark, dark*) and intensity (*high, middle-high, middle-intensity, middle-low, low* or *neutral*; the last two terms we shall employ synonymously), and twelve descriptors for hue (*yellow*, *red*, and *blue* as primaries; *orange*, *violet*, and *green* as secondaries; and *yellow-green*, *yellow-orange*, *red-orange*, *red-violet*, *blue-violet*, and *blue-green* as tertiaries). For succinctness in this paper, we shall employ the abbreviations as seen in Figure 1.

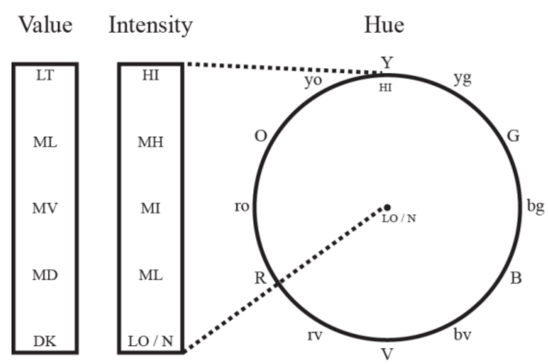

Figure 1: *The color-dimensions: value, intensity, and hue.*

Artists often employ three-dimensional models (sometimes referred to as *color-solids* or *color-spaces*) to differentiate and organize colors because the three color dimensions map conveniently onto the three spatial dimensions. Color theorists have proposed various color-solids, but spheres have been widely employed by artists because of the artist's convention of organizing hues in a color-circle, which wraps conveniently around the girth of a sphere. We shall use the sphere in referring to color-space and consider the color-circle diagram as a cross-section of the color-sphere. A color-sphere is probably best thought of as a globe, with an equator, poles, and an internal north-south axis. The traditional color-circle occupies the equator, with hues changing continuously eastward and westward around the sphere. Values change continuously north-to-south, from a LT north pole to a DK south pole. Intensities change perpendicularly to the central axis, gradually changing from HI colors on the surface to LO/N at the central axis inside the sphere. The interior color-space of the sphere is occupied by intermediate intensities. The central axis, connecting north and south poles in the interior, is a gray-scale. In a spherical color model, and others besides, it becomes possible to locate with a reasonable degree of accuracy any given color in the hue, value, and intensity coordinate system. Such models provide a practical means for artists to organize, classify, and communicate about a great variety of colors.

Simultaneous Color Contrast and Color Interaction

For well over a century, artists have been aware of an important phenomenon of color perception whereby a color changes its appearance when seen in juxtaposition with other colors. This effect, called *simultaneous color contrast* (we shall refer to it as *SCC*), had been observed by some scientists and artists prior to the 19th century, but it was Maurice Eugene Chevreul's 1839 book, *The Principles of Harmony and Contrast of Colours* that offered the first extended examination of the phenomenon. Chevreul (1786-1889), a scientist and Director of Paris' Gobelins tapestry works, became aware that some dyed colored threads changed markedly in their appearance after they were woven next to other colored threads. By the middle of the 20th century, with the publication of Josef Albers' monumental 1963 book and portfolio of prints, *Interaction of Color* [2], it became the norm for art students to learn how to produce SCC effects with colored papers and paints. It has become commonplace among artists to employ *color interaction* (Albers' term) and *simultaneous color contrast* synonymously, so we shall use the terms interchangeably here. In his teachings, Albers (1888-1976) established a standard arrangement for color interaction studies that we will use to demonstrate SCC (Figures 2a and 2b). This arrangement of squares defines roles and functions that will be important to our investigation. First, there are two roles for color in standard color interaction charts: *constituent color* occupies the smaller, surrounded squares and is the color that undergoes a change in appearance; *context color* occupies the larger, surrounding squares and is the color that causes the change in the appearance of the constituent color. Second, a color interaction chart shows one of two functions of SCC: the *divergent function* (Figure 2a) causes a single constituent color to appear as two different colors; the *convergent function* (Figure 2b) causes two different constituent colors to appear the same/similar.

In Figure 2a, the divergent color interaction demonstrates how a single MV Orange constituent color (labeled *2*; areas labeled with the same number are the same color mixture) appears darker at left on the LT context and lighter at right on the DK context. The smaller squares at the bottom center (also labeled *2*) are included in color interaction charts as "proof" that the two constituent colors are physically the same. In Figure 2b, the convergent color interaction demonstrates how two different values of Orange appear to be the same (or at least very similar). The left constituent color is in fact lighter (labeled *2*) and the right is darker (labeled *4*); the LT context causes its constituent to appear darker and the DK context causes its constituent to appear lighter. The effect is that the two constituents appear to converge in MV. Again, the proof occurrences appear at the bottom. Color interaction charts are usually more effective if the viewer temporarily hides the proof occurrences from sight. SCC illusions depend upon "means and extremes." The constituent color must be medial between the two context colors in at least one of the dimensions of color. In Figure 2a the MV constituent is a mean value between the LT context at left and the DK context at right. Human perception exaggerates the actual differences of value between constituent and context, and the constituent is "pushed" to appear darker at right and lighter at left. This principle of means and extremes applies not only to value but also to intensity and hue.

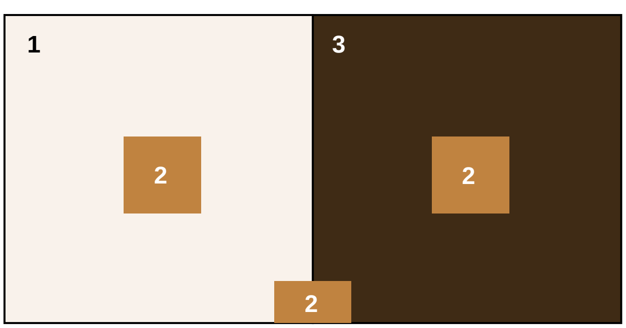

Figure 2a: *Standard color interaction chart, divergent function.*

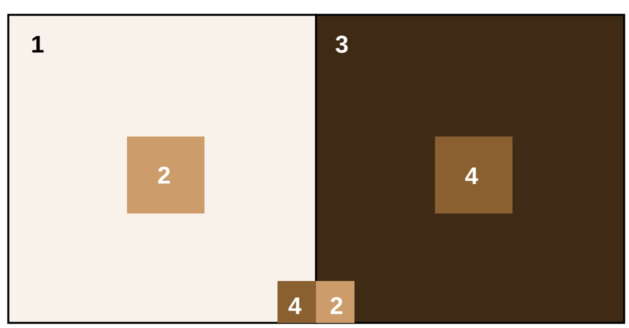

Figure 2b: *Standard color interaction chart, convergent function.*

For our discussions of SCC, we will need to distinguish between two aspects of color: *physical color* and *perceptual color*. It is of course true that all color is perceptual, existing only in the eye-brain system's conversion of light energy into perceptible form. However, we will assume physical color (the material surface that reflects light) to be invariant, and we will assume perceptual color (appearances resulting from the SCC effect) to be variant. We will also need to assume that perceptual color is invariant for different observers and under different lighting conditions; our emphasis here will be on discovering what is structurally constant in SCC and on developing a general model for SCC.

Simultaneous Color Contrast Territories

Traditional color-solids aspire to locate any visible color at a specific point in the system's color-space. Such a point-location implies that the identity of any given color is stable and static. Yet SCC tells us that a single physical color can assume a variety of perceptual identities—warmer or cooler in hue, lighter or darker in value, brighter or duller in intensity—when seen in varying color contexts. For artists, who must concern themselves with juxtapositions of colors, SCC is a critical concern. Traditional artists' color models, in their assumption of the invariance of colors, are inadequate to the task of modeling and predicting SCC appearances, or at least are too delimited in favoring physical color over perceptual color. If we wish to account for SCC and continue to employ traditional color-solid models, we must find a means of including perceptual color as well as physical color.

An ideal solution would be to retain the basic organization of a hue-value-intensity coordinate system for physical color (reflective surfaces) yet at the same time permit movement within that coordinate system for perceptual color (SCC effects). A single physical color, then, could move among a cluster of points, where all of the points of the cluster correspond to all of the possible perceptual appearances of that constituent as modified by context colors. This cluster of points can be considered to define a "territory" within which a constituent color could be found. This territory is a volume within the larger color-solid or an area within the larger two-dimensional color-circle diagram. We will designate that volume/area as a color's *Simultaneous Color Contrast Territory* (*SCC Territory*). In what follows, we will see the two-dimensional SCC Territories for each color dimension (value, intensity, and hue) and for each color interaction type (divergent and convergent). These individual diagrams will be understood as cross-sections of three-dimensional SCC Territories within the larger color-space.

Perhaps the most difficult task at this stage is to quantify precisely the degree to which a constituent color is affected by its context color, and to apply this quantification with confidence across all colors. Indeed, current literature recognizes this limitation: "…Objects may change their appearance within a wide range depending on the local surround, according to processes that are not yet understood….Mathematical models to predict these effects remain comparatively crude, with reasonable results only for limited conditions" ([1], p. 5). In the face of this problem, we will conjecture only a general estimate and keep the quantitative discussion brief, in favor of understanding through diagrams how SCC Territories are shaped and how they interact. Nevertheless, the quantitative estimates put forward here are not mere guesses, but instead are informed by the author's over 25 years of practical experience in creating many hundreds of color interactions in paint, collage, and digital prints. Based upon that experience, the constituent color is "pushed" approximately 20% in the direction opposite of the context color. For example, Figure 3a is a diagram for the SCC color shifts of Figure 2a. The physical constituent (MV Orange) is the solid circle at the center of the value continuum; the perceptual colors (the appearances of lighter and darker Oranges) are the hollow circles, each of which is approximately 20% of the distance from the physical constituent to the physical context, *but in the opposite direction of the context that caused the shift*. In other words, the upper hollow circle is caused by the lower context color, and the lower hollow circle is caused by the upper context color. Figure 3b is a diagram for the SCC color shifts of Figure 2b. Each of the two physical constituent colors (solid circles) is shifted approximately 20% in opposite directions (towards each other), converging in the center perceptual color (hollow circle). We now have a link between the color interaction charts and SCC Territories: in both diagrams, the perceptual constituent colors (hollow circles) define the limits of each constituent color's SCC Territory. These territories are circumscribed in Figures 3a and 3b by dashed or solid lines. Further, an important corollary emerges from Figure 3b: Since convergence of the two constituents occurs in the overlap region of the two adjacent SCC Territories, we might infer that this is generalizable to any overlapping SCC Territories throughout the color-space. This would offer the artist a new, predictive model for finding convergent color pairs, currently more a matter of trial and error discovery than planning for most artists.

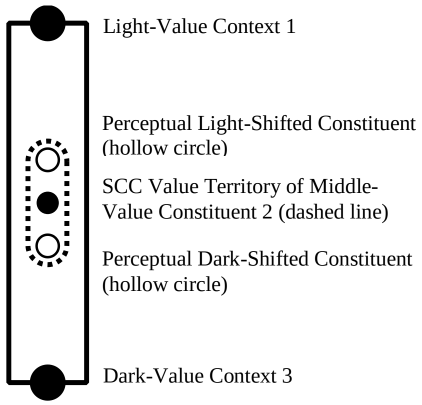

Figure 3a: *SCC Value Territory for the Constituent in Figure 2a.*

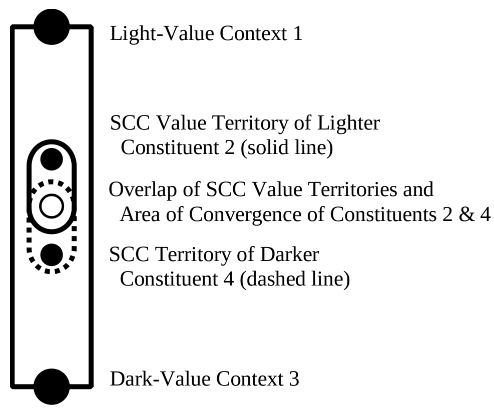

Figure 3b: *SCC Value Territories for the Constituents in Figure 2b.*

The second pair of color interaction charts (Figures 4a and 4b) demonstrates SCC in the dimension of intensity. In the divergent chart (Figure 4a), the MI Orange constituent at left appears less intense on the HI Orange context, and the MI Orange constituent at right appears more intense on the LO Orange/N context. Since we assume the "20% rule" for intensity as well as for value, the diagram of the SCC Territory (Figure 5a) is identical to the value diagram, except that it is in the dimension of intensity. In the convergent color interaction chart (Figure 4b), the more intense Orange constituent at left appears to be lower intensity on the HI Orange context, while the less intense Orange constituent at right appears to be higher intensity on the LO Orange/N context. The two different constituents converge, by SCC, in a MI Orange appearance. The diagram (Figure 5b) for this convergent interaction (again, identical in form to the convergent value diagram) shows each constituent's SCC Territory (solid-line for the higher intensity constituent; dashed-line for the lower intensity constituent). The region of overlap marks the possibility for both constituents to assume the same appearance—the region of convergence.

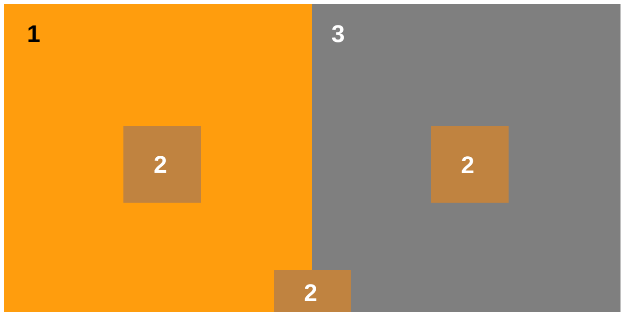

Figure 4a: *Divergent intensity interaction.*

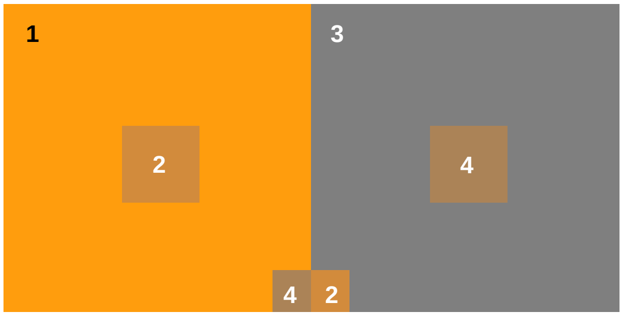

Figure 4b: *Convergent intensity interaction.*

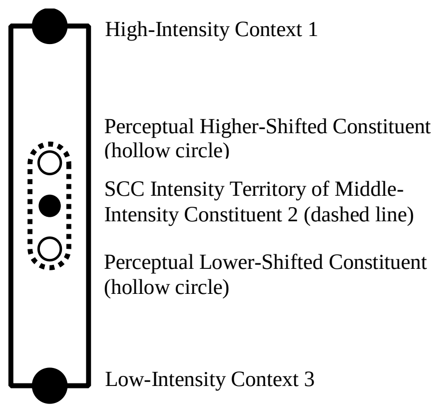

Figure 5a: *SCC Intensity Territory for the Constituent in in Figure 4a.*

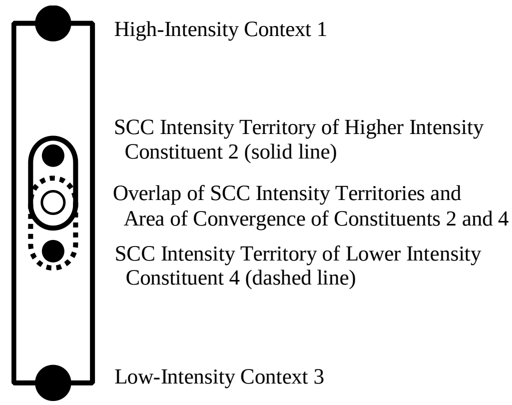

Figure 5b: *SCC Intensity Territories for the Constituents in Figures 4b.*

In the third set of color interactions, constituents are changed in the dimension of hue. In the divergent chart (Figure 6a), an Orange constituent appears redder in hue on the Yellow context at left, and the Orange constituent appears yellower in hue on the Red context at right. In the convergent chart (Figure 6b), the yellowish Orange constituent appears slightly redder on the Yellow context at left, and the reddish Orange constituent appears slightly yellower on the Red context at right. Each context "pushes" its constituent towards the other, and the constituents appear by SCC to converge in Orange. As in previous convergent charts, the physical color difference between the constituents may be seen in the proof occurrences at bottom center, and temporarily hiding those proof occurrences from view tends to enhance the perception of the context-constituent interactions. To diagram the SCC Territories of the constituents in Figures 6a and 6b, we must shift our attention to the color-circle, since hues change in arcs around the circle. In the SCC Territory diagram (Figure 7a) for the divergent chart (Figure 6a), the Orange constituent can be seen to occupy a territory warmer (redder) and cooler (yellower) than its physical color position. The physical constituent color (solid circle in the center of the arc) assumes two perceptual identities (hollow circles), which define the extent of the SCC Hue Territory. The diagram of convergent SCC Territories (Figure 7b) derived from the convergent hue chart (Figure 6b) shows two distinct territories for the cooler (solid line) and warmer (dashed line) constituents, overlapping in the region of convergence (Orange).

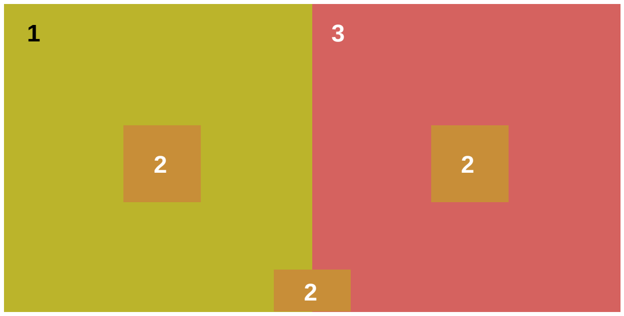

Figure 6a: *Divergent hue interaction.*

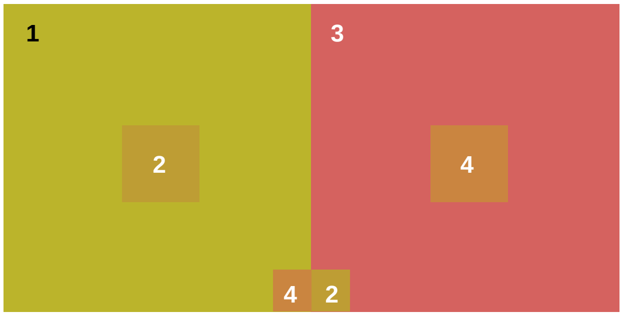

Figure 6b: *Convergent hue interaction.*

Since color-circles contain both hue transitions (arc-wise) and intensity transitions (radially), we can combine those territories in a single diagram. The previous diagrams of divergent SCC Territories for MI Orange (Figures 5a and 7a) have been overlapped in Figure 8a. The previous diagrams for convergent SCC Territories for higher and lower intensity Oranges, and for warmer and cooler Oranges (Figures 5b

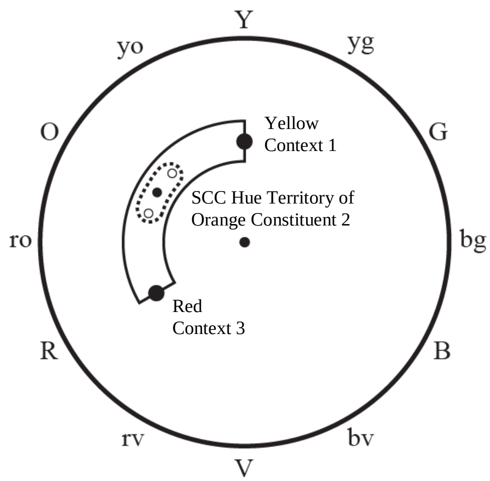

Figure 7a: *SCC Hue Territory for the Constituent in Figure 7a.*

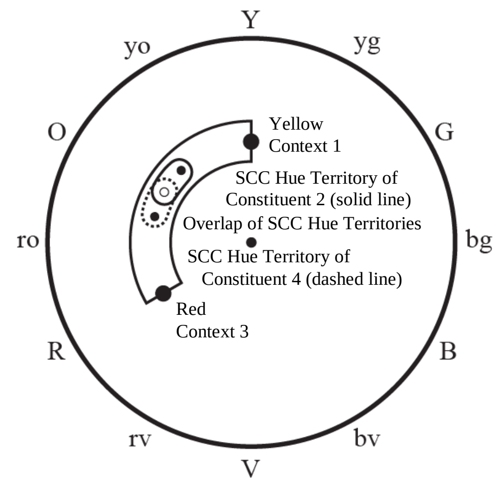

Figure 7b: *SCC Hue Territories for the Constituents in Figures 7b.*

and 7b) have been overlapped in Figure 8b. However, since we are working with two different colors of Orange, in Figure 8b we have diagrammed the intensity territories for each, yielding two distinct intensity-hue overlaps—this will be important for the next and final SCC Territory diagrams. Finally, we simplify and combine the intensity-hue territories for both the divergent and the convergent color interactions into two-dimensional shapes, generalized here as "rounded squares" (Figures 9a and 9b). Not diagrammed, but important to completing a three-dimensional model, would be the inclusion of the third dimension—value. The SCC Value Territory would be, generally, a cylindrical volume perpendicular to the page, extending above and below each central constituent color (the solid circles at the centers of each territory). Since we are generalizing the two-dimensional territories as rounded squares, we can imagine the addition of the value dimension as creating a "rounded octahedron" in three-dimensional color-space. In the divergent case, a single rounded octahedron; in the convergent case, two rounded octahedra, interpenetrating at a vertex. While these are unlikely to be the precise shapes of the SCC Territories—perhaps they are spherical or entirely asymmetrical—we have derived our shapes from observing and estimating the color effects in the color interaction charts, and we have built these shapes from a step-by-step process of "mapping" the perceptual effects of each color dimension.

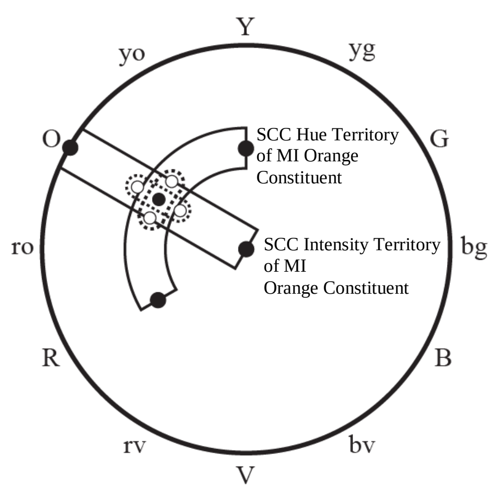

Figure 8a: *Overlapped SCC Intensity & Hue Territories for Constituent in Figures 5a & 7a.*

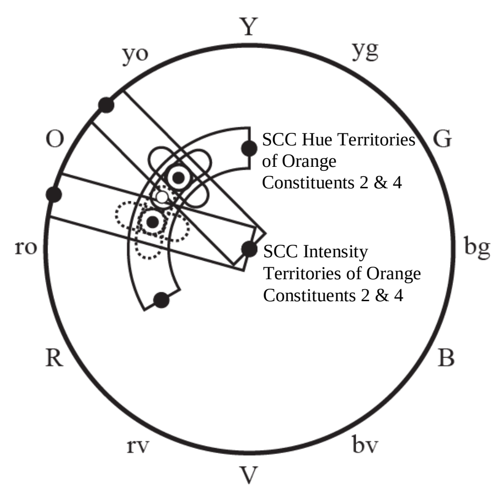

Figure 8b: *Overlapped SCC Intensity & Hue Territories for Constituents in Figures 5b & 7b.*

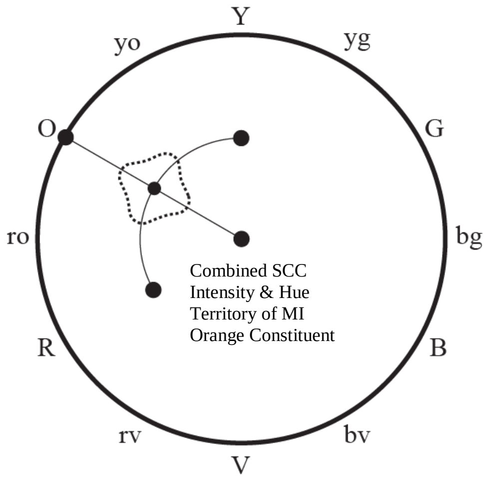

Figure 9a: *Combined SCC Intensity-Hue Territories for Constituent in Figures 5a & 7a.*

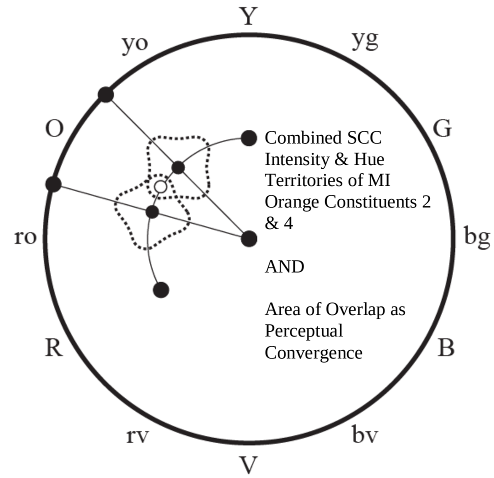

Figure 9b: *Combined SCC Intensity-Hue Territories for Constituents in Figures 5b & 7b.*

Conclusion

The most significant challenges for this SCC Territorial Color Model probably lie in determining the precise shapes and sizes of the many territories in color-space. American artist and color theorist Albert Munsell (1858-1918) overcame a similar challenge in developing his Munsell Color System, which resulted in a remarkably enduring model still used in art, industry, and the physical sciences today ([1], pp. 114-5). Munsell's "Color Tree" is similar to a traditional color-sphere in its basic organization, but it differs in one important respect: the three-dimensional shape is asymmetrical. Munsell recognized that human vision sees different ranges of intensity and value for different hues, so he carefully measured the perceptually equal color steps of each hue and permitted those different ranges to determine the shape of the color-solid. The result was not a sphere but an asymmetrical form—the "Color Tree." It may be that each SCC Territory also is distinct in size and shape and will result in an overall asymmetrical volume occupied by asymmetrical territories. In determining these territories, vision research and scientific color models could contribute much to an artist's SCC color model. The CIE L*a*b* perceptually uniform color space ([1], pp. 15-17, 152-170) might offer an important bridge between objective color measurements and perceptual SCC territories, and certainly studies in metamerism and color constancy ([1], pp. 4-6) overlap with SCC perceptions. Yet even in its current general state, this SCC Territorial Color Model provides artists with a means for visualizing the variable nature of color interactions. Color perception is always more complex than color models, but perhaps this SCC Territorial Color Model may shed new light on important aspects of color not accounted for in traditional artists' color models.

References

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