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Color Systems are Categories that Carry Meaning in Visualizations: A Conceptual Metaphor Theory Approach

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Abstract

Color is an ecologically organized, dynamic system. Each object inside the category (or domain) of color carries attributes, including image schemas. Image schemas are dynamic patterns, often connected to objects that emerge from embodied experiences; these are essential to the process of abstract conceptualization and reasoning. How image schemas manifest themselves is described in the section on the interaction of color, which focuses on the Bauhaus painter, Josef Albers.

The concept of color as a category is important; we categorize in order to construct thoughts. Even infants categorize; one cannot engage in intelligent thought and action without this capacity. Categories consist of entities that share similarities in varying degrees. The psychologist, Eleanor Rosch, approached and qualified color as a natural category. Berlin and Kay, started the Universalist, evolutionary view of color categorization in 1969, and anthropologists have added to this tradition ever since.

This paper shows examples of color mappings that can be described accurately and clearly using the language and thinking of conceptual metaphor theory. To this end I chose a particular path through the domain of color: Goethe, Runge, Wittgenstein and Westphal explored color separately from the optics of Newton. These authors opened the door to the semiotics of color, and it is this concept that I explore in relation to how color systems can be used more effectively in today's scientific visualizations.

Introduction

Germany, during the first twenty years of the nineteenth century, saw an explosion of color thinking: Goethe published *Zur Farbenlehre* in 1810 (*Color Theory*), Arthur Schopenhauer produced *Über das Sehn und die Farben* in 1816 (*On Vision and Colors*), and Philipp Otto Runge created his *Farbenkugel* (*Color Sphere*) in 1810.

Goethe, in the second volume of his color theory, was responding in a negative way to Isaac Newton's *Opticks* from one hundred years earlier, in 1704. He did not agree with the scientifically accepted "received knowledge" from Newton on the colors of the prismatic spectrum, or on refraction. He also wrote two short essays called *Contributions to Optics* on this subject [4]. The part of his treatise on color that is meaningful for this research is in the first volume, where Goethe's attention is applied to how color appears; these concepts are categories with dynamic relationships between the individual category members. Here is where I will focus—because of its usefulness in mapping information from other domains. This area of Goethe's research can be referred to as qualitative: "the dynamic observing subject itself became the locus of the research" [5, 6].

When Goethe first started thinking about color, he began to publish his findings in *Beiträge zur Optik* (the above mentioned *Contributions to Optics*) from 1791-92. These writings were then integrated into his great opus, *Color Theory,* in three volumes. Only the first part has been translated into English; it is entitled *Entwurf einer Farbenlehre* (*Color Theory Model*). This is the didactic section, which contains appropriate material for my discussion of semiotic color functions within categories.

During the middle of the twentieth century, Ludwig Wittgenstein undertook an analysis of Goethe's theory, interpreting it as a "phenomenological grammar of color," a philosophical analysis of color as a language. The book's title is *Bemerkungen über die Farben* (*Remarks on Colour*). The phrase *phenomenological grammar of color* is a multifaceted concept in philosophy that refers to the syntax and structure of meaning that is part of Wittgenstein's notion of "ordinary language"; therefore, this shows that he thinks of color as a language system [6]. At the end of the twentieth century, the philosopher Jonathon Westphal wrote *Colour: Some Philosophical Problems from Wittgenstein* [7]. I will interweave some of Westphal's comments and opinions as I write about Goethe's categorical analysis of color attributes, modes, and syntactical relationships between individual colors.

What is the role of a 'language' (often in a non-verbal, perceptual mode) within the realm of conceptual metaphor theory? The specific language forms the domain into which we map the source domain data. This process can also be thought of as a translation into a different language [8], one that is comprehensible to the human mind; a color system is such a language.

Runge developed a three-dimensional color-mapping sphere as a tool for artists. Although Runge's model was at first ignored, the twentieth-century artists and teachers Paul Klee (1879-1940) and Johannes Itten (1888-1967) discovered and taught Runge's system in the Bauhaus. Runge's sphere is the first color model that uses a three-dimensional spatial structure as a matrix for holding the individual colors in syntactical relationships to each other; colors that are more similar are closer to each other, and those that are dissimilar are far apart inside the color sphere space. Both Runge and Goethe are subjects of Wittgenstein's philosophical investigations of color [6].

Runge's Color Sphere: The Creation of a Scientific Model

On the top row there are two exterior views of the Color Sphere; the left shows the white "pole." The right image is the black "pole." The left image on the bottom row is a horizontal slice through the center of the sphere, while on the right, the slice is vertical cut from the white pole down to the black pole (showing the progressively smaller interior spheres, and a red section on the left, green on the right).

Figure 1: The Farbenkugel by Philipp Otto Runge [9]

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Runge's color wheel is a three-dimensional spherical body that brings together two color systems: chromatic (all hues, excluding black, white, and greys produced from mixing black and white in different proportions) and achromatic (the previously excluded black, white, and grays). His intention was to bring this color model to artists as an aid and inspiration in their paintings, although unfortunately, artists in his own time did not find it useful in their creative thinking. The color sphere used three primary colors: red, yellow, and blue, filling in the secondary and tertiary colors through mixtures of the original primary colors [9]. This is an example of how the ordering of a category's members can create a model in a space matrix.

Runge states that he does not include what I call *modal* issues in the sphere, such as transparency or opaqueness; the same colors appearing in different modes retain the specific characteristics of their color. All of the colors in Runge's model are opaque and smooth. He did this to keep the comparisons between colors clean and free of completing issues.

> A difference in material had to be disregarded entirely, and only the relation of the color impression as such considered, which could not happen with a conflicting difference in material [9].

He describes how he created his color sphere, beginning with an equilateral triangle marked with an R on one corner, Y on another, and then B.

> Completely free from any admixture— ...The three points *blue, yellow,* and *red* construe an equilateral triangle as the diagrammatical expression of the relation between these three pure natural forces [9].

Next, he defined the creation of the secondary colors: blue + yellow = green, red + yellow = orange, and red + blue = violet. These three colors were placed on the sides of the equilateral triangle. Each side of the triangle was then bisected and at the point of bisection was connected to the center of the other two sides inside the original triangle. The points of bisection attached the letters V, O, and Gr, and the combinations of one secondary with a primary color to either of its sides were placed between the secondary point and neighboring primary point. Runge had now created the content for a twelve-step color wheel that includes three primary colors, three secondary colors, and six tertiary colors: reddish-violet, bluish-violet, bluish-green, yellowish-green, yellowish-orange, and reddish-orange. No color has more than two primaries in its composition; the differences between them are results of different percentages of the two combined colors [9].

Runge determined that all chromatic colors "relate to *white* and *black* in a *general* sense (as a brightening and weakening, to black as a darkening or clouding), and that they are receptive to their influence" [9] . The one-third-size secondary color triangle, inside the bisection points of the primary triangle, was then enlarged to the same size as the primary triangle; together they form a six-pointed star. A perfect circle around the star points completed the geometric form. With the drawing of the two-dimensional circle, the tertiary colors can be placed between the primary and secondary color locations. This circle also shows the relationship of colors to their complementary colors, located directly across the circle (see the lower left circle in figure 1), because the chromatic color circle is based on three primary colors, expanded to twelve. (We will see later that when the circle is based on four primaries, colors are not directly opposite their complementary partners.) Runge's circle dissolves progressively into neutral gray at the center. When he says "neutral grey," Runge is referring to a gray created from achromatic white and black. I would change that model by having the progressive graying, as the circle rings move inward, be a product of ever increasing percentages of complementary colors from chromatic hues (as in figure 2). With insertion into the three-dimensional color sphere, the two-dimensional circle thickens to form a slab, so the outside ring of hues can be seen from the outside of the sphere. The layer occupies a "chunk" of space with volume in a three-dimensional model.

Now, Runge placed two small circles, one above and one below the center of the six-pointed star; the top point is pure white and the lower point is pure black. The white and black poles are the same distance from the center of the original circle as the radius of that circle. Therefore, all of the chromatic hues on the color-circle are equal distances from the white and black small circles, located on the north and south poles of the sphere. The thin cylinder that runs from the white circle to the black circle includes gradations of achromatic grey. As the horizontal sections get closer to the black or white poles, greater percentages of black or white are mixed with the chromatic hues. All of the basic elements of the sphere (primary, secondary, and tertiary colors) are equally distance from the white and black poles, and the center of the sphere; this means that they form a perfect sphere. Conceptually, the original twelve colors could be seen as an infinite number of gradations, so the possible number of colors accounted for in the sphere is also infinite. However, the low-resolution scale of twelve hues with black and white is a number that the human mind can work with. Runge said: "I do not doubt that the randomly divided twelve-fold surface can be easily thought of as a complete transition, on the basis of this scheme" [9].

Figure 1, which shows the color sphere, gives two views of the sphere cut in half. The first on the lower left shows the cut between the two poles, in the middle of the sphere; it is a view of complementary colors located directly opposite from each other. The other view shows that there are spheres within spheres, and it is cut from the white pole to the black pole. This structure accommodates white, black, and different shades of gray as additions to the original hues. Runge's spherical model resembles classic sets of Russian dolls that contain ever-smaller dolls. In this case there are five color spheres, with poles starting closer to the center of the sphere—and therefore an increasingly centered gray.

Runge wrote: "red and green, which through their union destroy each other in gray" [6]. The gray he is speaking of is a chromatic gray without a trace of black or white. In figure 2 one can see this pattern of colors with ever increasing percentages of their complementary color: the outer rings are 100% pure hue; second ring = 90% basic hue + 10% complementary color from the other side of the circle; third ring = 80% basic hue + 20% complementary color; fourth ring = 70% basic hue +30% complementary color; fifth ring = 80% basic hue + 20% complementary color; and last, the center ring consists of 50% + 50% of each color.

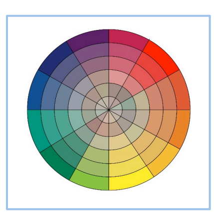

Figure 2: Twelve -step color wheel with complementary color percentages increasing towards the center. Jack Ox 2013.

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Goethe's Theory of Colors with Remarks by Wittgenstein and Westphal

Deep in the middle of *Theory of Colours,* Goethe completely and irretrievably removes his theory from Newton's optics:

> 725. The theory of colours, in particular, has suffered much, and its progress has been incalculably retarded by having been mixed up with optics generally, a science which cannot dispense with mathematics; whereas the theory of colours, in strictness, may be investigated quite independently of optics [4].

I agree with Goethe; optics can help explain how we see color, but it does not organize color units into categories that carry meaning. That is why I am focusing on the semiotics of color. What is the proper order of all the colors? How many patterns can we find that map to information informing visualizations?

Goethe fills in more about his approach when he compares the domain of color to the domain of music. He created an analogy between the two by mapping both to a landscape containing two rivers:

> 748. Colour and sound do not admit of being directly compared together in any way, but both are referable to a higher formula, both are derivable, although each for itself, from the higher law. They are like two rivers which have their source in one and the same mountain, but subsequently, pursue their way under totally different conditions in two totally different regions, so that throughout the whole course of both no two points can be compared. Both are general, elementary effects acting according to the general law of separation and tendency to union, of undulation and oscillation, yet acting thus in wholly different provinces, in different modes, or different elementary mediums, for different senses [4].

He is saying that although color and sound exist in different modes, in different contexts—they still retain structural similarities from their shared source. Goethe shows this by mapping the similarities and differences to a mountain landscape that contains two rivers. At the river sources, their starting points, they are very similar; but as each moves along a different path down the mountain, in different directions, which lead into different kinds of landscapes (with different qualities), each river develops in its own way as it responds to the changing environment. How do the different landscapes model the characteristics of two entities that began in the same source (the mountain)? Is the higher formula that he mentions an algorithm? This is a classic SOURCE-PATH-GOAL metaphor combined with a structure-mapping analogy. The rivers begin in the same source, but change independently as they choose different paths, arriving at the goal—the state of their existence in the present.

Wittgenstein considers the study of color to be a study of a specific language. This language includes both quantitative and qualitative information; both kinds of information contribute to the syntactical (grammatical) relationships between colors.

> 1. A language-game: Report whether a certain body is lighter or darker than another.– But now there's a related one: State the relationship between the lightness of certain shades of colour. (Compare with this: Determining the relationship between the lengths of two sticks – and the relationship between two numbers) – The form of the propositions in both language-games is the same: "X is lighter than Y". But in the first it is an external and the proposition is temporal, in the second it is an internal relation and the proposition is timeless [11].

This first comment in the *Theory of Colours* states that Goethe is interested in the quantifiable differences between colors, and therefore the meanings deduced from patterns of differences: this can be realized through hues showing their differences and then sliding into one another through gradations created from different proportions of each, or similar patterns of value changes. He says that people are able to see sequences of hue changes and can therefore understand them in a quantifiable way.

> 8. People might have the concept of intermediary colours or mixed colours even if they never produced colours by mixing (in whatever sense). Their language-games might only have to do with looking for or selecting already existing intermediary or blended colours [11].

Josef Albers later enlarged and specified this thinking; he studied under Johannes Itten at the Weimar Bauhaus, was a professor in the Dessau Bauhaus, later directed Black Mountain College, and was professor of design at Yale University. Albers developed and taught a class called *The Interaction of Color* [10]. However, Albers's vantage point was different from the preceding color theorists. In congruence with Goethe, he was not interested in the physics of color; nor was Albers interested in the kind of color ordering that we see in Runge, Munsell, or Newton:

> In order to use color effectively it is necessary to recognize that color deceives continually [10].

In the early twentieth century some philosophers took possession of Goethe's theory. Ludwig Wittgenstein continued the writing style of Goethe, using numbered thought fragments in *Remarks on Colour*, but let's begin with Jonathan Westphal's 118-page book that remarks on Wittgenstein's book. I will construct a conversation of what all three have written (Goethe, Wittgenstein, and Westphal).

Westphal begins his book with a summary of the six "puzzles propositions" Wittgenstein raised [7]:

i. Something can be transparent green or any other colour, but not transparent white;
ii. White is the lightest colour;
iii. Grey cannot be luminous;
iv. There cannot be a pure brown or brown light;
v. There is no blackish yellow;
vi. There can be a bluish green but not a reddish green

All concepts in this list seem to speak to the *appearance* of colors; however appearances can be relative to other colors and are therefore part of a syntactical relationship between two or more colors.

"Something can be transparent green or any other colour, but not transparent white."

Westphal thinks Wittgenstein is speaking of modes; "transparency" is a mode. Within the category color, there are various modes in which individual hues can appear: a shiny, reflective surface, or a flat, nonreflective one, transparent and semi-transparent, and the inverse, opaque. Through all of these possible appearances, the quality of the hue remains, even with the modifications brought by modal attributes [4].

> 45. Opaqueness is not a *property* of the white colour. Any more than transparency is a property of the green [11].

And:

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> I 17. Runge says (in the letter that Goethe reproduced in his *Theory of Colours)*, there are transparent and opaque colours, White is an opaque colour.
>
> I 18. Can a transparent green glass have the same colour as a piece of opaque paper or not? If such a glass were depicted in a painting, the colours would not be transparent on the palette..... If we wanted to say the colour of the glass was also transparent in the painting, we would have to call the complex of colour patches which depict the glass its colour [11].

It is clear that hue and relative transparency are considered different attributes; hue refers to "green" in the example, and "transparent" is a very relative term with a location somewhere between two opposite qualities on the ends of a continuum that links transparency to opaqueness. In his next statement, #19, Wittgenstein points out that one can only *see* transparency when it is in front of something visually perceptible:

> The impression that the transparent medium makes is that something lies *behind* the medium If the visual image is thoroughly monochromatic it cannot be transparent [11].

The Merriam Webster dictionary defines transparent as: having the property of transmitting light without appreciable scattering so that bodies lying beyond are seen clearly. Wittgenstein compared *transparent* with *reflecting* (III 148) [11]. Both exist within the depth dimension of a visual image. Because white surfaces on the top layers deny access to marks on a lower layer, one can say that they block the depth of dimension necessary for perceiving the layers over the image as transparent [7].

Returning to the original puzzle: why is it not possible for white to be transparent? As Westphal points out [7]: Wittgenstein (section I; 39 and I; 40) which always functions as an opaque entity claims the answers to puzzles, such as the lack of a transparent white, belong to the "logic of color concepts," not "to the *physics* nor to the *psychology* of color." As noted before, Wittgenstein considered color from a linguistic point of view, in agreement with Goethe, foregoing the scientific terms Newton set forth in his *Opticks*. Wittgenstein refers to the structuring of elements within the domain of color—a hierarchical category within which individual colors exist.

When green is transparent, it is still green. Green survives transparency, whereas white does not. A transparent white is clear, which has no color by definition. Wittgenstein and Goethe understand that concept as connected to the grammar of colors, not the physics of color. The book *Remarks on Colour* is an interpretation of Goethe's theory as a phenomenological grammar of color—a philosophical analysis of the language of color and how a color appears next to other colors.

> I 39. I am not saying here (as the Gestalt psychologists do), that the *impression of white* comes about in such-and-such a way. Rather the question is precisely: what is the meaning of this expression, what is the logic of the concept? [11]

In the end, even though Westphal tried to solve the puzzle of white, he was left with a sense of disappointment because he did not find a direct answer from Wittgenstein to this puzzle, only the question [7]. Perhaps when considering color relationships as linguistic propositions that carry both qualitative and quantitative information within a language structure, where meaning is generated through connections and comparisons with other colors, it is possible to pose questions without answering them in just one way. As to the next mention of white in Westphal's list—"White is the lightest colour"—perhaps this is because when a white surface is in shadow, it no longer appears white; therefore, it is no longer white, and in fact, may be considered gray [4]. This is in contrast to a green in low light that will still retain some greenness. Westphal comments further on Wittgenstein's white puzzle: "White must be a surface color because it changes back to achromatic brightness when in other modes, such as transparent (clear)—where it is not considered white any more. In order for white to be perceived as white, it must reflect back a certain percentage of ambient light. Nothing ever looks whitish; there is no such thing as a white light" [7]. White must be the lightest color because it lightens hues with which it is mixed; and no other color lightens white.

"Grey cannot be luminous"

Here are the relevant passages in *Remarks on Color:*

> I 37. What we see as luminous we do not see as grey. But we can certainly see it as white.
>
> I 38. I could, then, see something now as weakly luminous, *now* as *grey* [11].

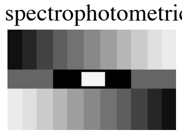
And later on in the same book:

> III 81. There is no such thing as luminous grey. Is that part of the concept of grey, or part of the psychology, i.e. the natural history, of grey?
> And isn't it odd that I don't know [12] ?

It appears that luminosity in gray changes the gray to white. This is interesting, because here the modal change transforms a gray to white, or vice versa, a distinctly different phenomenon from that which happens with chromatic hues. Achromatic gray is opaque because of the white that is mixed with the black. However, a chromatic gray (made by mixing complementary hues) can be transparent in that it contains no white or black in the mixture. According to Goethe, an achromatic gray surface is in between darkness (black) and brightness (white) [4].

> III 80. What makes grey a neutral colour? Is it something physiological or something logical?
> What makes bright colours bright? Is it a conceptual matter or a matter of cause and effect?
> Why don't we include black and white in the colour circle? Only because we have a feeling that it's wrong? [11]

Westphal gives a reason for the neutral quality of gray; the spectrophotometric curve (the quantitative measurement of the



reflections or transmission properties of a material as a function function of wavelength [13]) of a gray card shows a reflection of only 20% of any illuminating light. That is, no matter what illumination there is, the card will appear relatively dull or neutral. A gray area is a relatively dark area; gray participates in the *darkness* of black [7]. Because gray is considered a neutral color, gray scales are used to balance color in photography and computer monitors. This is known as white balance. A gray scale card is composed of achromatic grays ranging from pure black to pure white without a hint of color tint.

Runge wrote about this neutral quality of gray in a syntactical ordering of a group of colors; this can be found in the appendix attached to his writing on the color sphere:

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> 10. If we place three colors or colored rectangles beside each other, like blue, gray, and red, then gray is to be considered as a parenthetic clause, which connects and satisfies both its contrasts, blue and red, in that gray is the point to which all colors of the entire color circle have an equal relation. [9].

I think the reason everyone agrees on the neutrality of colors created from white and black is that they are in their own category; and this category does not include any chromatic colors. When achromatic colors are mixed with chromatic hues, they impart some of their modal attributes, such as opaqueness. The chromatic hues have their own category, and a third category is created when members of each are mixed together. Of course, I am speaking about pigment colors, not light, which follow a different set of rules. In any case, I think that these are reasons why black and white are not included in the chromatic color wheel.

"There can be a bluish green but not a reddish green"

Multiple entries in *Remarks on Colour* refer to a "greenish-red." There is also a translator's note: "Wittgenstein wrote 'greenish' here but presumably meant 'bluish'" [11]. I believe that the translator was thinking of the *Opponent Color Theory* Ewald Hering devised at the end of the nineteenth century, which was later recognized as being based on perception and was favored by psychologists; in this system opposite colors are organized by the red and green sensors in one cone set of the eye, and yellow and blue in the other. (I will describe a color system based on these four hues plus white and black later: the Swedish Natural Color System.) But I am quite sure that Wittgenstein meant reddish-green, and I can show why it is a logical choice. In fact, figure 2 shows complementary color mixtures, especially toward the center of the color wheel.

I know from my own history of mixing complex, transparent color glazes that mapped the harmonic qualities of specific musical instances how important these graduated complementary color mixtures are; they have a great potential for carrying specific kinds of information. I developed a visualization system that combines layers of transparent, complementary colors in the encoding and mapping process of changing dissonance and consonance values in the musical source domain. In figure 4, one can see on the left side a gray-green; immediately to the right of that gray-green section is a color that leans more to red; however, they are both constructed out of the same red and green, but in different proportions. In the box below figure 4 is a description of how the transparent colors that are layered over opaque architectural and landscape images are calculated and what information they transfer from the music.

Figure 3: Jack Ox : Third theme from the first movement of Anton Bruckner's Eighth Symphony: visualization by Jack Ox © 1983 [14, 15]

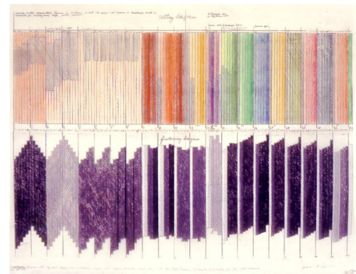

Figure 4: The diagram above shows the transparent glaze colors that are seen in Figure 3. The diagram on the bottom maps six levels of black to four graduated greys and white; these greys signify the percentage of complementary color that forms the final transparent color. Jack Ox, 1983.

Figure 4 blend the information given in the top sector with the information in the bottom sector and the result is what appears as a transparent overlay in the figure 4 painting that depicts the third theme in the first movement of Anton Bruckner's Eighth Symphony.

> I 10. Someone who is familiar with reddish-green should be in a position to produce a colour series which starts with red and ends with green and which perhaps even for us constitutes a continuous transition between the two...[11]

Wittgenstein's instructions (I 10.) are helpful for finding and learning about different proportions of red to green, orange to blue, violet to yellow, and so on. Complementary colors are opposites in temperature; one always comes from the *cool* side of the color wheel while the other is a *warm* color. A true reddish-green is neither reddish nor greenish because the combination of true complementary colors, opposites in temperature, is neither, but instead is a chromatic grey.

Arthur Danto's forward to C. L. Hardin's book *COLOR for Philosophers* [16] led me to the 1983 article "On Seeing Reddish Green and Yellowish Blue" [17] in *Science* magazine. The following is the abstract of that article:

> Four color names-red, yellow, green, and blue-can be used singly or combined in pairs to describe all other colors. Orange, for example, can be described as a reddish yellow, cyan as a bluish green, and purple as a reddish blue. Some dyadic color names (such as reddish green and bluish yellow) describe colors that are not normally realizable. By stabilizing the retinal image of the boundary between a pair of red and green stripes (or a pair of stripes) but not their outer edges, however, the entire region can be perceived simultaneously as both red and green (or yellow and blue) [17].

Red and green are encoded in the same opponent-processing channel in our visual system; that is, an electrical signal for red in this channel will diminish the signal for green. The same is true for yellow and blue, as they share the same channel. Human subjects looked at a series of small islands of one color against a background of the other color, or a field of color that has an outward appearance of unity but is composed of tiny elements from both, but they perceived this region as simultaneously red and green. The experiment had a vertical strip of red on one side and green on the other. In the middle of the region where the two came together was an array of small units of each. One often sees color mix this way in textiles, with contrasting warp and weft.

These mixtures vary in qualities because each of the primary chromatic colors has a natural value at full saturation. In fact, each pair of complementary colors differs from the others in the amount of distance between them; red and green are fairly equal values

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(light and dark), orange is lighter than blue, and yellow is lighter than violet. Wittgenstein addresses this issue:

III 3. Here we have a sort of mathematics of colour.

III 4. But pure yellow too is lighter than pure, saturated red, or blue. And is this proposition a matter of experience? — I don't know, for example, whether red (i.e. pure red) is lighter or darker than blue; to be able to say, I would have to see them. And yet, if I had seen them, I would know the answer once and for all, like the result of an arithmetical calculation [11].

Where do we draw the line here between logic and experience?

The Polarity of Colors

696. Considered in a general point of view, colour is determined towards one of two sides. It thus presents a contrast which we call a polarity, and which we may fitly designate by the expressions *plus* and *minus* [4]

This bifurcation is easy to understand if one considers that one-half of the twelve-step color wheel consists of *warm* colors and the other side of distinctly *cool* colors. How do we know this? Why does this feel natural and instinctive? Goethe was exploring the binary nature of color as a "polarity" of two values (quantities) with the shades in between.

Goethe addressed the reddish-green issue, which is really about the combination of opposite, or complementary, colors:

697. If these specific, contrasted principles are combined, the respective qualities do not therefore destroy each other; for if in this intermixture the ingredients are so perfectly balanced that neither is to be distinctly recognized, the union again acquires a specific character; it appears as a quality by itself in which we no longer think of combination. The union we call green [11].

He appears to be speaking about the opposite temperatures of warm and cool that we find on the color wheel. Under the subtitle *"JUNCTON OF THE TWO AUGMENTED EXTREMES"* Goethe wrote:

702. As the extremes of the simple contrast produce a beautiful and agreeable appearance by their union, so the deepened extremes on being united, will present a still more fascinating colour; indeed, it might naturally be expected that we should here find the acme of the whole phenomenon [11].

When one combines the quality *warm* with the quality *cool*, the result is a temperature quality located between the two contributors; there is no wiping out or destruction of either that occurs, but instead, the formation of something new. The same can be said of another sort of polarity: complementary colors, or colors located directly across from each other on a color wheel that has an even number of six or more pie sections (figure 1) with a base number of three primary colors. The Swedish Natural Colour System has four primary colors as a base; in this system there is no complementary color relationship located across the wheel.

I created a visualization of Kurt Schwitters's *Ursonate* [18, 19] in the 1990s and made a color chart (figure 5) that maps the International Phonetic Alphabet (IPA) vowel chart to a metaphorically ordered color chart; for instance, lighter colors are in higher positions than darker colors. This is consistent with the image schema that has a basis in gravity, UP➔HIGHER/DOWN➔ LOWER, and HIGHER➔LIGHTER/LOWER➔DARKER. The chart also reflects the polarity needed for phonetics; unrounded vowels are represented by colors from the warm side of the color wheel and cool colors are represented by vowels made with rounded lips (thereby lengthening the vocal chamber for a lower resonance). The IPA vowel chart maps the locations of vowel production in the vocal tract (front, middle, or back) and the tongue height needed for production of each vowel sound.

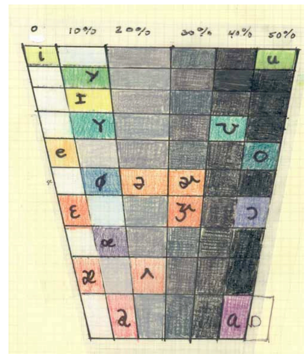

Figure 5: Color chart reflecting the sixteen German vowel sounds placed in a spatial representation of the vocal tract [19, 21, 22].

Spatial Metaphors for Color Systems

I 66. Can't we imagine certain people having a different geometry of colour than we do?' That, of course, means: Can't we imagine people having colour concepts other than ours? And that in turn means: Can't we imagine people who do *not* have our colour concepts but who have concepts which are related to ours in such a way that we would also call them "colour concepts" [11]?

Westphal interprets this passage from Wittgenstein as a reference to geometries of color space. That is the metaphor he uses to describe how different people might have different color concepts from ours, and these are known through a mapping to some geometrical form. He asks: "Is it more than a metaphor?" Perhaps this is an example of thinking about color as a large, complex, dynamic system.

What is wanted is a fuller understanding of what the colour circle or hue circuit *is*, which would consist of an explanation of its origin or basis, just as with the periodic table. Is there a theory which would generate the arrangement of all the colours in an order, of which the hue circuit would be a cross section [7].

Interaction of Colors

There is no consensus in philosophy or psychology on the syntax of colors; however, most recognize that structured color patterns reflect the categorical ordering of relations between them. For Aristotle, one of the earliest color thinkers, an important and interesting ordering relation was the darker/lighter conversation. For mid-twentieth-century philosophers (and scientists using visualizations such as fMRIs into the twenty-first century), the Newtonian color spectrum (chromatic hues) dominates, as seen in the refracted light of a prism [21].

Johannes Itten published and taught about his own color-harmony system; that is, color groups that provide a "chordal harmony" that is analogous to music [22]. His process includes an interesting way to connect colors: the mapping of different two-dimensional geometric shapes over a color wheel. In fact, the shapes operate like algorithms; however, the chosen colors may not actually provide each viewer with a superlative feeling of a well-endowed chord. Itten admits that when teaching a class in 1928, evidence accumulated that showed each person has their own subjective sense of *timbre* (literally meaning *color* in French and usually referring to the color of sound) [22]. Itten mapped a

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square, a rectangle, an equilateral triangle, and an isosceles triangle over a twelve-step color circle to create chords. The colors the points of these geometric shapes touch create the chord:

> We can make the general statement that all complementary pairs, all triads whose colors form equilateral or isosceles triangles in the twelve-member color circle, and all tetrads forming squares or rectangles, are harmonious [22].

Here is a completely different viewpoint from Josef Albers:

> What interests me...is how colors change one another..[it is] terribly exciting...opaque colors appear transparent only as a result of the way they are combined...light [colors], heavy and the other way round, shiny [colors] matt etc... [23] Quoted from: Josef Albers to Franz Perdekam, September 1947. Feja Family Collection, Recklinghausen, Germany.
>
> In order to use color effectively it is necessary to recognize that color deceives continually. To this end, the beginning is not a study of color systems [10].

Certainly, Albers created his own system; it was based on perceived interactions between colors, which can be dynamically ordered. What he accomplished is an amazing contribution to the syntax of color. He had a dedication to the notion of relative, rather than absolute relationships, where context plays a central role. For Albers, there were no absolute 'focal' colors as established by anthropologists [1, 2]; no true red, yellow, or blue exists. Colors stand in relationships to other colors; they are very relative in their effects, changing when put next to other hues.

> Our concern is the interaction of color; that is, seeing what happens between colors.
>
> Colors present themselves in continuous flux, constantly related to changing neighbors and changing conditions [10]."

Although Josef Albers may have thought he was not creating another color system, his is one of the most flexible and creative systems for carrying meaning in the history of color.

He began his famous class on the interaction of color with the haptic experiment of dipping one's hands into three different containers of water: cold in the left container, hot water in the container on the right, and warm water in a container located between the other two. Here he represented for students the notion of relative values, writing on the blackboard: "Color is the most relative medium in art" [10]. In his class, he set up a laboratory environment with experiments on how color appears when integrated with different colors, without any attention to subjective expressions. With his water experiment he also used a spatial metaphor to underline the meaning; the containers sit on an imaginary line in the order of warming in one direction and cooling in the other. This is an image schema. This first haptic experiment is also multimodal in that the notions of temperature felt through the hands are also frequently used in differentiations in color.

Timbre: Mapping from the Domain of Color to the Domain of Music

Albers taught us to think about how to use color syntactically in visualization systems; this thinking can be extended to sound and sonifications when one maps the principles discovered with visual-color to sound-color, or *timbre*. Music composers have historically made use of this practice, especially in the twentieth-century genre of *timbre-based* music. One way to describe this phenomenon is to reduce an orchestrated composition to a piano score; if the musical structure and meaning disappear, it is then timbre based. The timbre, or specific sounds of a blended instrumentation, creates the meaning and character of this kind of music.

During the late 1990s I collaborated with a composer who not only developed a rich timbre vocabulary for full orchestra with an extended percussion section, but also used sung vowel sounds as a timbre element. We defined and described the myriad timbre-sounds instruments in the orchestra made, and I created a complete set of colors based on these highly specific sounds.

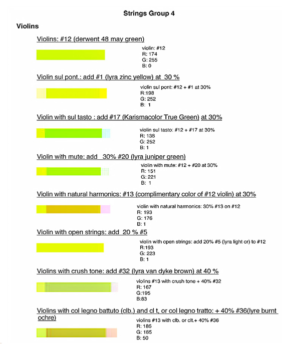

Figure 6: On right—Timbre colors and RGB notations for different ways to play the violin.

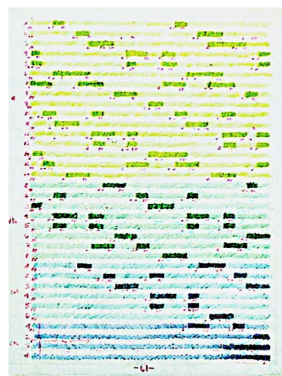

Figure 7: On the Left—A look at how the glazes would look in the visualization of a score containing violins, violas, cellos, and double basses created by Ox in 1998.

The Swedish Natural Color System

The Natural Colour System is a commercial product of a group of Swedish researchers who began working together in the 1930s. The scientists, architects, psychologists, and designers who were brought together in order to explore how to use color as a communication system based their work on Ewald Hering's 1874 treatise, *Das natürliche System der Farbempfindungen* (The Natural Color System). In 1974 the researchers published the NCS, as in the Natural Colour System, thereby establishing the Swedish National Standard of color. Eventually, working with the Swedish paint industry, they created a scientific notation system of color, along with corresponding color samples, as part of the system. Their objective was to create a systematic color tool based on human perception and experience of color. The first NCS Atlas was launched fifteen years later [24].

> Beginning with the elementary colours, it is possible to construct a three-dimensional descriptive model called NCS Colour Space,

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which includes the whole colour world and makes it possible to describe any conceivable colour percept [24].

This claim is not completely fulfilled. In the NCS system there are six primary colors: red, green, yellow, blue, black, and white. The shape of the color model consists of two umbrellas joined at the middle: The circle that forms the very center of the shape consists of chromatic colors only, excluding black and white from the mixtures, although the highest level of *chromaticness* (corresponding to the hue and saturation of a color) is only 80%; these are yellow, orange, and red. As the hues become cooler, the chromaticness goes down to the 60% or 70% range. Each place on the color wheel has a triangle that lies with its point on the outside of the model and base side against the center pole. The available color swatches differ from triangle to triangle.

In figure 9, I have placed next to each other the NCS chromatic hue circle and my complementary color wheel introduced earlier during the description of Runge's color sphere. Both of the wheels' colors are unadulterated by any additions of black or white.

These two color wheels side by side show how one small beginning detail leads to two very different systems, which is the base number of primary colors. Runge's wheel and mine are based on the number three, with three primary colors: red, yellow, and blue. The NCS wheel is based on the number four because there are four chromatic primary colors: red, yellow, blue, and green, with forty different hues in the color model. The twelve-step wheel on the right originates with Runge's layering of equilateral triangles to find and place twelve units within the circle; Goethe also found this arrangement to be a *natural order*. [4]

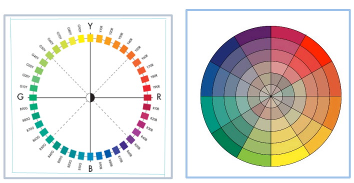

Figure 9: NCS chromatic hue circle on left On the right, the Ox chromatic hue circle mixed with progressively greater percentages of their complementary colors that are located directly across the wheel.

If one looks closely at the two circles in figure 9 and notes which color is located directly across the wheel, one can see that the two wheels are not synchronous. Both wheels have green and red directly across, but the wheel on the left has yellow opposite to blue, and the wheel on the right has yellow opposite to violet; there is a difference between orange opposite to blue-green on the left and opposite to blue on the right. The wheel on the right, because of its original base unit of three primaries, has opposition in the complementary colors (described in terms of relative warmth or coolness of the hue); each color supplies the opposite of what its complement supplies.

In the NCS system of four primary colors, complementary colors cannot be identified as the hue directly across on the wheel. The NCS wheel uses what is called *opponent colour theory*, originally devised by Hering in the late nineteenth century. In this system red is opposite to green, blue to yellow, and black is in opposition to white. But opposition means something very different than opposition in discussion of complementary colors. Here opposition is taken from the human optical system. NCS is based on the belief that color signals are transmitted to the brain analogously to opponent colour theory. There is another color theory from the nineteenth century called the *trichromatic theory*, by Thomas Young and Hermann von Helmholtz; they assumed that there are three types of cone-shaped light receptors in the retina: red, green, and blue [25]. This is the basis for Goethe's theory and the Runge Color-Sphere. Goethe and Runge use a twelve-step color wheel that is a multiplication of three (4 x 3); NSC's color wheel, from opposition theory, has four chromatic primary colors and forty hues around the wheel, or a multiplication of four (10 x 4).

The twelve-step wheel based on three primaries has the property of placing each color directly across from the color with an opposite temperature (the warm and cool sides of the color wheel), known as a complementary color. This is the result of laying equilateral triangles over one another, which are base three. The twelve-step color wheel is certainly friendly to concepts in Western music, such as the twelve notes in a scale, or the circle of fifths. I have found this structural crossover between music and color extremely useful in building analogies between sonic and visual representation.

The purpose of the NSC model is to provide a system for picking out color schemes for architecture and product design with a need to view choices of formulated colors.

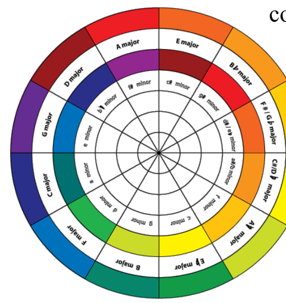

Figure 7: The Color/Harmony Wheel I developed for Anton Bruckner's Eighth Symphony visualizations 1983-91. The major keys are on the outer ring, and the minor keys are three steps behind the major keys.

In Conclusion

Why have so many scientific visualizations deferred to Newton's prism color scale in order to differentiate between entities? Color systems have potential capabilities to express dynamically changing data, and these color mappings can be described through the language of conceptual metaphor theory. Approaching color as a semiotic system opens up a valuable tool for visualization.

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