Establishing a Tonic Space with Digital Color

Brian Evans

ABSTRACT

Since Isaac Newton, colorists have, with little success, looked for ways to associate the vibrations of light and color with the vibrations of music and sound. Although the idea of proportion has been mentioned in these efforts it has never been studied thoroughly. This paper proposes, through use of computers and digital raster graphics, a means of measuring the color balance of an image through proportions of red, green and blue intensities. With this method of measurement it is possible to apply several theories of color harmony and balance to computer-based abstract imagery. Through the computer we get specific control of the process. If, through this technique, a quantifiable means of creating concordant color relationships is possible, then it makes color available to the composer as material for the coherent structuring of time. As in tonal music, movement in time can be established by movement in and out of balanced, consonant areas. An area of balanced color relationships could be thought of as a tonic space, functioning like the tonic pitch or key in tonal music.

In the search for harmonious color many conflicting ideas have been offered. With a borrowing of the concept of harmony from music, some theorists sought to map concepts of Western tonal music directly to the color domain. Others dismissed the possibility of direct correlation as frivolous at best, being based on emotional considerations and inconsistent from one person to the next.

While there appears to be no scientific relationship between the percepts of color and sound vibrations, evidence indicates that a large percentage of people experience color when listening to music [Karowski and Adbert; Simpson, Quinn and Ausubel]. This color-hearing or synesthesia by itself does not seem of practical use to the artist, but it encourages continued exploration of color/music relationships.

Goethe, who in his theories doubted any direct relationship, said, "Color and sound do not admit of being compared together in any way, but both are referable to a higher formula" [Goethe]. Writers on color theory from Aristotle to Newton to today have theorized about a possible candidate for this 'higher formula' but followed their speculation with little study. I again suggest this idea, simple proportion, as being a basis for associating color with music.

John Whitney, with his work in abstract animation, has long understood the value of proportion as a basis for correlating visual and sonic materials [Whitney]. With progression through simple ratios he establishes temporal motion similar to harmonic motion in Western tonality. Consonance and dissonance occur from movement through points of resonance expressed as abstract or physical manifestations of whole number (Pythagorean) ratios. Although his work deals more with aspects of motion than pure color, his 'digital harmony' based on proportion has proved itself through the austere beauty of his pieces.

This paper does not pretend to offer final answers to questions of color harmony but will discuss a means of measuring color on a computer image. This measurement, expressed as a proportion of red, green and blue color values, allows us to study relationships that might lead to qualification of color spaces as concordant or dissonant.

With dissonance wanting to resolve itself into a point of balance or consonance, a hierarchy is established. Like a pendulum at the bottom of its swing, consonance becomes a point of attraction. This attraction is expressed in Western tonal music by the tonic note or key center. In color this could be considered a tonic space, a point of color balance that creates what colorists call a harmonious effect. Simple proportions as found in nature provide a point of departure in the search for tonic color spaces.

TONIC SPACE

In general, tonality in music concerns itself with the successive and simultaneous relationships of tones or pitches. As the description of a tonal system becomes more specific, a hierarchy is established with a central pitch or tone given the top position. This pitch is called the tonic. All other pitches in the system are described in relation to this tonic. They are seen as moving away from or towards the tonic pitch.

The 'common practice' period in Western music (roughly the eighteenth and nineteenth centuries) further specified this hierarchy, giving pitches, and especially chords, functions that establish motion or relaxation of motion up and down the hierarchical ladder. The tonic center was expanded to mean scales such as C major or E-flat minor—a collection of pitches commonly called the key of a piece. Chords moved the music through different scales, departing and moving back to an established tonic center or key.

Colorists trying to relate color to music often tried to map hues with particular pitches, chords or key centers as understood in the 'common practice' tonal system [Jones]. This approach was doomed to failure for several reasons, the primary one being that there is a tenuous physical basis for Western musical harmony: it is a Western invention, not a discovery. We hear consonance and dissonance just as we characterize music as happy or sad—through acculturation. These associations, in a state of flux, have been established over centuries. That definitions of harmonic concord and discord seem to change from generation to generation is good indication of a weak basis in physical truth.

There are a thousand years of cultural conditioning that dictate our responses to music. Over that thousand years a sophisticated musical environment has been established, and for Western ears all music is experienced within that environment. Consider the difficulty many Western listeners have with the music of other cultures such as Chinese opera or Javanese gamelan. Both exist far outside the Western musical tradition. Color experience has its own established

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environment and traditions. Trying to map our musical traditions directly into color, without the same culturally built associations in effect, has proven a futile endeavor.

Nevertheless, putting aside cultural biases and emotional qualifications, it should be possible to consider the more general, abstracted case of a tonal system as a means by which dynamic time can be structured. This is done through creation and relaxation of tension, which is caused by movement away from and towards a tonic. This concept of tonality has been a part of Western music since its beginnings in plainchant with the *finales* of the church modes. It can also be found in the music of many non-Western cultures, as in the tonic drone of East Indian classical music.

Establishing this tonic area provides a basis for structuring time with sonic materials in music. If a similar tonic space can be defined in the domain of color, it should be possible to structure time with the materials of color. It should be possible to compose color-music. The work of color theorists over the past century or so indicates some possibilities for the creation of a balanced color space. With computer images and simple procedures for color measure, these possibilities can easily be explored.

METHOD OF MEASURE

Computer technology and raster graphics allow easy measurement of the color dimension. Raster images are made up of discrete pixels, with each pixel assigned red, green and blue (RGB) intensities and an address. If the graphic system uses a color look-up table, then each pixel holds a number associated with that table. The image becomes a digital paint-by-number canvas with the look-up table or color map containing the number-to-color palette. This paper concentrates on color map systems, as they are currently more prevalent and more affordable than the high color resolution RGB systems.

The measurement taken is that of proportions of the color primaries red, green and blue. In a color map this is done by summing all the values for each primary color. For a palette with 256 entries this can be expressed as

$$R = \sum_{i=0}^{255} r_i$$

$$G = \sum_{i=0}^{255} g_i$$

$$B = \sum_{i=0}^{255} b_i$$

For the graphs used in this report each value is normalized so that the maximum possible value for each primary is 100, with R, G and B expressing the percentage of the maximum that is actually present in the color map. A map with 256 entries using one byte each for the R, G and B intensities will have:

$$MAX = 256 * 28 = 65536$$

as the maximum possible intensity for each primary, giving

$$R = 100\ (R/MAX)$$

$$G = 100\ (G/MAX)$$

$$B = 100\ (B/MAX).$$

The color measurement for the map is then expressed as the proportion triplet R:G:B.

As most images do not contain equal amounts of all colors from a palette, the map proportions should be balanced against the color map index distribution of an image. This is accomplished by creating a histogram showing how many pixels are assigned to each index of the color map. Each element in the histogram array H_i contains the number of instances of color map index i on the image. Each element is normalized to a number between 0 and 1, with 1 being equal to the total image space and H_i equal to the percentage of the total.

The R:G:B triplet for a raster image with a 256-element color map is then calculated as

$$R = 100[(\sum_{i=0}^{255} r_i H_i)/MAX]$$

$$G = 100[(\sum_{i=0}^{255} g_i H_i)/MAX]$$

$$B = 100[(\sum_{i=0}^{255} b_i H_i)/MAX]$$

For a true RGB system the R:G:B triplet can be found directly by separately summing the values of each primary on all pixels. With n being the total number of pixels and allowing 8 bits each for R, G, and B values, the maximum possible intensity value for each primary is

$$MAX = 28n$$

Keeping the maximum normalized triplet value as 100 and i equal to a pixel number, the R component will then be

$$R = 100[(\sum_{i=0}^{n-1} r_i)/MAX]$$

G and B values of the triplet are calculated accordingly.

The R:G:B triplet gives a measure of the proportions of the color primaries that exist on a computer image. Many theories of color harmony suggest that an equality or simple proportion of the primary colors can create a balanced color space. From this perspective the R:G:B triplet should prove useful as a means of quantifying the harmonic color balance of a digital image.

TOWARDS DIGITAL COLOR CONCORD

For over a century colorists have been working on the idea of color harmony: the establishment of balanced and concordant color relationships. From the ideas of balance and concord we get the concept of tonic space. For many colorists the fundamental tonic space is simple neutral grey. This is substantiated by the visual phenomena of successive and simultaneous contrasts.

If one stares at a color for an extended period of time one will successively see the color's complement, that is, the color's opposite on the color wheel. (When a color and its complement are combined in the right proportions the resulting color in light will be white; in pigment it will be black.) If, for example, the eye is fixed on the color blue and then on a light grey background, the color sensation of yellow, blue's complement, will occur.

With simultaneous contrast, also based on the principle of color complements, one will see a color's complement in neighboring areas after prolonged observation. For example, a light grey square surrounded by blue will appear yellowish. This phenomenon works not only for hue but for brightness as well. A light square surrounded by dark will appear lighter than it actually is and conversely the dark area will seem darker. It seems as if the eye seeks to create a balance if balance is not there.

These tricks of the eye give credence to the concept of neutral grey as a physiological point of balance in color perception. The eye appears at rest when seeing grey, or more importantly when seeing a collection of colors that equal grey if combined. This idea of color harmony can be traced back to Goethe, who said, "The whole ingredients of the chromatic scale, seen in juxtaposition, produce an harmonious impression on the eye." This gives a good point of departure for building a tonic color space when using the R:G:B triplet.

Using the color measure on a digital image we can easily tell when there is a balance of primary color values. When the R:G:B values are all the same the combined color should be within the grey scale. A neutral gray should be found at half of full intensity, midway between white and black.

Fig. 1 shows a plot of red, green and blue values over a specific color map along with the map's actual color content. It also shows the R:G:B triplet values for the map alone and applied to the image shown in Color Plate A No. 2. The triplets are shown numerically and graphically. The histogram of color index distributions is shown in the Color Plate. (The sample image in the Color Plate is an abstract fractal-based graphic derived from Newton's method for finding roots of the equation $z^7 - 1$.)

The map in Fig. 1 has been adjusted so the R:G:B distribution on the image will be equal to half of full intensity—a normalized triplet of 50:50:50. This is done using the simple color measure summations. With the proportion triplet 1:1:1 and a method for quantizing the color measure of a specific image we have a basis for defining and exploring tonic color space.

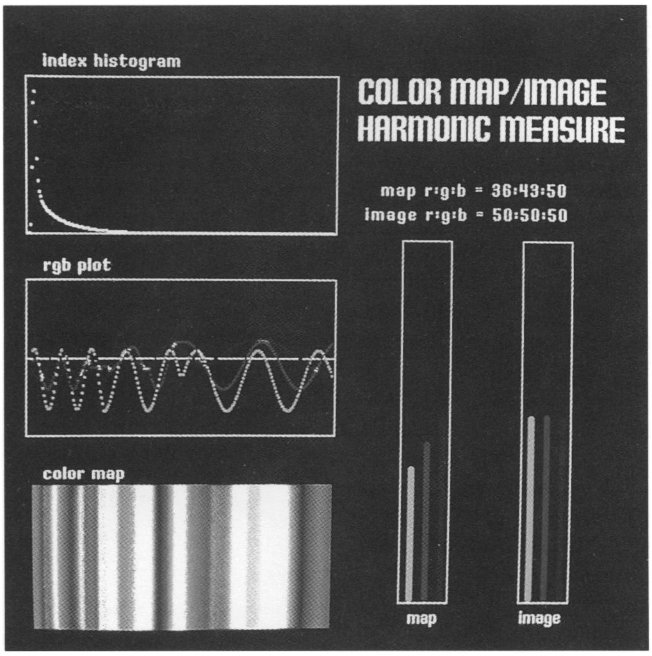

Fig. 1. Color measure of the fractal image in Color Plate A No. 2. All measurement components are shown including a plot of the color palette, a histogram of the distribution of color map indices over the Color Plate image, and the R:G:B triplet for the map and the image.

Reservations and Conclusions

It would be naive to suggest that setting a balance of color primaries on an image will guarantee a consonant color space. Theorists have found other dimensions of color to be important in the search for color harmony, and none of these are considered in the R:G:B triplet measure.

Shade and tint gain prominence in some theories [Birren, 1934, 1937]. Munsell introduced color measure through dimensions of hue, value and chroma [Munsell]. His ideas have been adopted in many areas including methods of specifying digital color [Smith]. Renner dismisses the idea of balanced primary intensities, looking to balance and contrast of the other dimensions to create his color 'accords' [Renner].

The use of the R:G:B triplet does provide a tool where a color palette can be fine tuned with respect to a number of the other color theories, many coming from the ideas of Goethe. Of perhaps more significance is the ease with which imbalanced color spaces can be defined and then, using the R:G:B measure, altered and neutralized. Interpolation through these spaces in time suggests a wealth of material for structuring time and color. This is one area where work is continuing.

Accepting the other dimensions traditionally used in the study of color harmony, development of transformation functions from one method of a color space measurement to another is also an area where work is continuing.

The early work done with the R:G:B triplet measure has, at the very least, been fruitful enough to encourage continuing. Animation of these color progressions should indicate the most promising directions for further study.

For someone working in the ivory tower of art and aesthetics, all these ideas are of course subservient to whim, taste and artistic vision. Fine art has never felt compelled to follow any laws and, we can only hope, never will. Still, the idea of proportion has always been a useful tool for the skilled craftsperson, something every good artist must be.

Newton wrote, "May not the harmony and discord of colors arise from the proportions of the vibrations propagated through the fibers of the optic nerve into the brain, as the harmony and discord of sounds arise from the proportions of the vibrations of the air?" With proportion measurable and controllable through computer graphics and the R:G:B triplet measure, music composers and other artists working with time have new materials and new tools for working with these materials.

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Selected Reading

Albers, J., *Interaction of Color* (New Haven, CT: Yale University Press, 1963).

Arnheim, R., *Art and Visual Perception* (Los Angeles: University of California Press, 1974).

Birren, F., *Color Dimensions* (Chicago: The Crimson Press, 1934).

Birren, F., *Functional Color* (New York: The Crimson Press, 1937).

Cox, D.J., "Interactive Computer-Assisted RGB Editor (ICARE)", *Proceedings of the Seventh Annual Symposium on Small Computers and the Arts* (Philadelphia, PA: SCAN, 1987).

De Grandis, L., *Theory and Use of Color* (New York: Harry N. Abrams, Inc., 1984).

Goethe, J.W. v., *Zur Farbenlehre* (1810). In English: *Theory of Colors* (Cambridge, MA: MIT Press, 1963).

Itten, J., *The Elements of Color* (New York: Van Nostrand Reinhold, 1970).

Jones, T.D., *The Art of Light and Color* (New York: Van Nostrand Reinhold, 1972).

Karowski, T.F. and H.S. Adbert, "Color Music", *Psychological Monographs* **50**, No. 2 (Columbus, OH: Ohio State University, 1938).

Kueppers, H., *The Basic Law of Color Theory* (Woodbury, NY: Barrons, 1980).

Land, E.H., "The Retinex Theory of Color Vision", *Scientific American* **237**, No. 6., 108–128 (1977).

Munsell, A.H., *A Color Notation* (Baltimore, MD: Munsell Color Company, Inc., 1946).

Newton, I., *New Theory About Light and Colors* (Munich: W. Fritach, 1967).

Renner, P., *Color: Order and Harmony* (New York: Reinhold Publishing Corp., 1964).

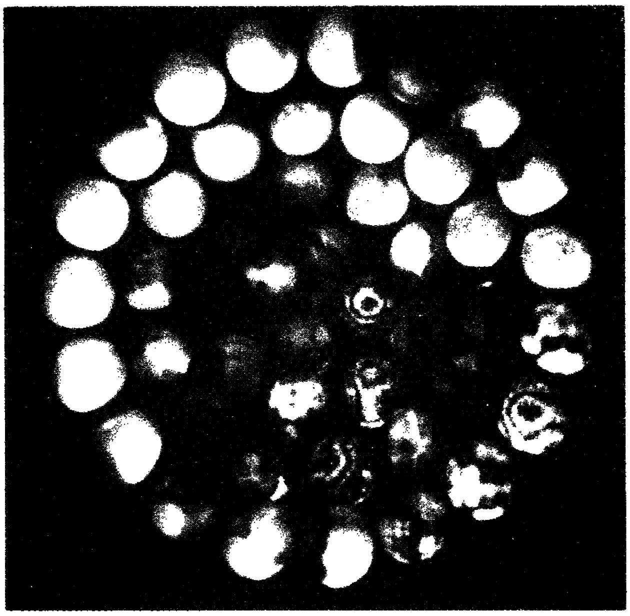
Salter, L., "Tonality", in *The New Grove Dictionary of Music and Musicians*, Vol. 19, Stanley Sadie, ed. (London: Macmillan Publishers, 1980).

Simpson, R.H., M. Quinn and D.P. Ausubel, "Synesthesia in Children: Association of Colors with Pure Tone Frequencies", *The Journal of Genetic Psychology* **89** (1956) pp. 95–103.

Smith, A.R., "Color Gamut Transform Pairs", *Computer Graphics* **12**, No. 3 (1978).

Truckenbrod, J., "Effective Use of Color in Computer Graphics", *Computer Graphics* **15**, No. 3 (1981).

Whitney, John, *Digital Harmony: On the Complementarity of Music and Visual Art* (New York: McGraw, 1980).



Color Plate A

No. 1. Top. Joan Truckenbrod, *Time Knit*, digital photograph, 24 × 26 in, 1988.

No. 2. Bottom left. Brian Evans, fractal image created using Newton's method for finding roots of the equation $f(z) = z^7 - 1$. The RGB triplet measure for this image is 1:1:1 with total intensity at half of full.

No. 3. Bottom right. Richard Wright, *Parameter Space*, software: artist's software in 'C'; hardware: VAX 11/785, Gems Framestore, Dunn Film Recorder; format: 35-mm slide of computer-generated image. 1987. A fractal sine function was used to solid texture map a conical arrangement of spheres. Computer algorithms can take arbitrary sets of data and fuse them together to create an object that possesses the quality of tangible reality.