Music composition usually structures materials in time-based relationships, through historically established grammars or, over the last century, often through grammars invented by the composer. These grammars allow control of the materials so that a composed piece will make formal sense in time. They offer a meaningful framework upon which a composer’s particular musical vision can be built.

As in music, the fundamental dimension of animation is time. The problems for the animator are the same ones a music composer faces—temporal coherence. But in using abstract visual materials, there is no centuries-old tradition the artist can turn to for guidance. Abstract visual composition (‘composition’ used here with respect to time rather than space) has two aspects that need to be considered, the graphic forms or shapes, and color.

A large body of theoretical work exists for static imagery. Extracting basic principles from the time-based art forms (theatre, poetry, music, dance, etc.) and applying them, along with fundamental ideas of color theory and graphic design, provides a starting point for a grammar and eventually a language of abstract visual composition.

Even in static imagery, use of color has proven to be an especially thorny issue and hence artists often make decisions based on personal whim. Some are so intimidated that they avoid the issue altogether, using only grayscale restricting their output to black pen plotters. The literature on color theory is often contradictory or confusing, caught in the struggle between the additive and subtractive color [2]. These phenomena allow us a percept of tension with color if there is no color.

The Neutral Color Domain

Starting with this premise we can build a hierarchy of color relationships and construct a simple, but effective, color grammar. Color is especially problematic, difficult to measure in all but the simplest applications; the literature of color theory and harmony is often confusing. To devise a syntax for structuring time with color, one can turn to the concepts of tension-release, of neutral, balanced and weighted color domains and of discrete computer raster images; they help to create and measure time-based color compositions. In parametrically defined color palettes, Color Study #7 (a computer-generated animated film) demonstrates the application of these ideas to a simple and effective compositional approach. Codifying this new common filmmaking practice, the author hopes to encourage others interested in aesthetically strengthened visual presentation to explore and develop time-based visual grammars.

The Balanced Color Domain

In the nineteenth century Chevreul defined the phenomena of successive contrast and simultaneous contrast for subtractive color [2]. These phenomena allow us a perceptual basis for the idea of a neutral gray color domain as being relaxed. In the case of successive contrast, staring at one of a pair of complementary colors will cause its complement to appear when one’s attention is moved to a neutral ground. For example, staring at red and then focusing on a

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ABSTRACT

To structure time with abstract visual materials requires a visual grammar of line, shape and color. Color is especially problematic, difficult to measure in all but the simplest applications; the literature of color theory and harmony is often confusing. To devise a syntax for structuring time with color, one can turn to the concepts of tension-release, of neutral, balanced and weighted color domains and of discrete computer raster images; they help to create and measure time-based color compositions. In parametrically defined color palettes, Color Study #7 (a computer-generated animated film) demonstrates the application of these ideas to a simple and effective compositional approach. Codifying this now common filmmaking practice, the author hopes to encourage others interested in aesthetically strengthened visual presentation to explore and develop time-based visual grammars.
neutral gray background will cause green to appear. Fatigue in the cones of the eye, caused by the imbalanced color domain of red alone, has caused a tension in the color percept.

In the case of simultaneous contrast, also based on the principle of color complements, prolonged observation of a color will cause its complement to appear in neighboring regions. For example, a light gray square surrounded by red will appear green. Here a lateral inhibition in the retina causes the complementary impression. Again we have a tension in the color percept.

These ideas indicate that the eye is always striving to balance the color environment, to create the relaxed state that exists when it is viewing an unperturbed gray. Expressing a similar premise nearly two centuries ago, Goethe stated in his treatise on color, "When the eye sees a colour, it is immediately excited, and it is its nature, spontaneously and of necessity, at once to produce another, which with the original colour comprehends the whole chromatic scale. A single colour excites, by a specific sensation, the tendency to universality.

To experience this completeness, to satisfy itself, the eye seeks for a colourless space next to every hue in order to produce the complemental hue upon it.

If again, the entire scale is presented to the eye externally, the impression is gladdening, since the result of its own operation is presented to it in reality. We turn our attention therefore, in the first place to this harmonious juxtaposition [3].

More recently Rudolf Arnheim sums up what many color theorists discuss in their attempts to define and codify color harmony.

These three fundamental primaries [he is speaking of the subtractive primaries—red, yellow and blue] behave like the three legs of a stool. All three are needed to create complete support and balance. When only two are given they demand the third. The tension aroused by incompleteness of the triplet subsides as soon as the gap is filled.

This particular structural combination of mutual exclusion and attraction is the basis for all color organization—much as the particular structure of the diatonic scale is the basis of traditional Western music [4].

From all this we can define the second level in our hierarchy as a balanced color domain. A color domain is in balance if the sum of the colors in an image will neutralize each other so as to equal gray.

**The Weighted Color Domain**

The remaining color juxtaposition is the domain where one hue is dominant. This weighted color domain will be the most dynamic, the most unsettled, and, in an abstract sense, the most dissonant. To say a color domain is dissonant or inharmonious is not to say it is bad. As a matter of fact, in music the most beautiful and interesting sounds may be those with kinetic energy, those that create tension. The same is true for visual imagery. (In music, harmony deals with all pitch relationships, not just those that are consonant; unfortunately, when color harmony is discussed a qualitative aspect usually is attached to the label. This paper considers color harmony to include the set of all color relationships, in the hope of finding some guiding principles for structuring those relationships as they unfold in time.)

Similar to the consonance-dissonance premise nearly two centuries ago, Goethe stated in his treatise on color,
structure in music is the three-level hierarchy of color relationships that we have now defined. We can apply these to abstract visual composition: tension moves to resolution from weighted to balanced to neutral color domains.

**COLOR MEASURE**

What is of importance in applying these ideas of color theory is not the specific colors used but rather the relationships of the colors. A simple way to measure color relationships of a raster image to determine the quality and syntactic function of its color domain is to make separate summations of all red, green and blue (r, g, and b) intensities in the image and to normalize them between 0.0 and 1.0 [5]. The simple formulae

1. \[ h_{\text{sum}} = \left( \sum h \right) / \text{MAX} \]
2. \[ g_{\text{sum}} = \left( \sum g \right) / \text{MAX} \]
3. \[ b_{\text{sum}} = \left( \sum b \right) / \text{MAX} \]

with \( h, g, b \) being the total number of pixels in the image and \( \text{MAX} \) being the maximum possible summation intensity for each color. Assuming 8 bits for each color, \( \text{MAX} = 2^8 \). The summation triplets for red, green and blue values is denoted \( \Sigma rgb \). A totally white image, for example, would have a summation of

\[ \Sigma rgb = \left( \text{hsum}, \text{gsum}, \text{bsum} \right) = \left( 1.0, 1.0, 1.0 \right) \]

The quality or syntactic function of the color domain described by \( \Sigma rgb \) is then determined. If the components are equal, the image is either neutral or balanced. If the image is seen to be all one in the grayscale it is neutral; otherwise it is a balanced color domain. If the components are not equal, the image is weighted.

Using simple transformations we can also create an \( \Sigma hsv \) summation triplet for the image [6]. The hue (h) will tell the fauvist hue in a weighted color domain by in circular fashion, with red = 0, green = 0.333, blue = 0.666 and red = 1.0). The value (v) tells the maximum intensity of the image (0-1), and the saturation (s) tells us how balanced (s=0) or weighted (s=1) the color is domain is. If for example

\[ \Sigma hsv = \left( 0.666, 0.295, 0.492 \right) \]

for a summation triplet indicates a color domain with a weighting in blue. The saturation level is low, which would indicate a gray-blue weighting, a low-saturation blue. With an intensity value near 0.492, we can also expect the image to be relatively bright.

It is important to reiterate that the summation triplets \( \Sigma rgb \) and \( \Sigma hsv \) tell us little about the actual color values in the image but give more general information about the color domain of the image. To understand this clearly, we can pick for analysis two color keyframes from the animation Color Study #7 (see Color Plates 1a and 2a).

Color Plate 1a is frame 2400 from the study. It is an example of a balanced color domain. The \( rgb \) and \( hsv \) summation triplets for the images are

\[ \Sigma rgb = \left( 0.355, 0.335, 0.362 \right) \]
\[ \Sigma hsv = \left( 0.790, 0.0746, 0.362 \right) \]

We can tell from both triplets that the image is balanced. The \( rgb \) components are nearly equal, and the saturation level is near zero. If there is a weighting at all, it is in the violet range, but the overall effect should be minimal as the \( rgb \) summation intensities balance one another.

To further illustrate this balance, we can redistribute the pixels from frame 2400 in random order within the raster. If the image is truly balanced, the overall impression when seen from a slight distance should still be gray. The pixels should mix together like the dots of a Seurat painting. This image can be seen in Color Plate 1b. It has a neutral quality with perhaps a slight tinge of violet as indicated in \( \Sigma hsv \).

Color Plate 2a, frame 3000 from the study, has the following summation triplets:

\[ \Sigma rgb = \left( 0.347, 0.348, 0.492 \right) \]
\[ \Sigma hsv = \left( 0.665, 0.295, 0.492 \right) \]

Here we have a domain weighted in blue with low saturation. Redistributing the pixels gives us an image with a definite blue weighting, but not highly saturate, as seen in Color Plate 2b.

**PARAMETRICALLY DEFINED COLOR PALETTES**

Now that we have defined a basic color syntax, how can it be compositionally applied? An early problem encountered is how to move from one color domain to another. One solution is to use color maps for key images and to interpolate from one keyframe map to the other.

In its simplest form this solution is not satisfactory, as interpolating through the \( rgb \) values from one map to the next can often wash out all detail in an image. For example, in Table 1, linear interpolation from a start color to an end color has a pure gray as the midpoint color. Setting up keyframe color palettes to avoid these relationships would require heavy constraints and make the task overly difficult and needlessly limiting.

A simple and effective method is to define the keyframe color maps parametrically and then to interpolate through the parameters rather than through the actual color values. The ICARE color map editor designed by graphic artist Donna Cox will allow this parametric definition [7]. With ICARE, the \( rgb \) entries in a color map are derived from periodic functions. Parameters of amplitude, frequency, phase and offset are plugged into a sine function that calculates the \( rgb \) array elements for the color map. In Color Study #7 this approach was applied to an \( hsv \) rather than an \( rgb \) color space and then transformed into the \( rgb \) map entries.

Table 2 shows the parameters defining the color palette for frame 1800 (Color Plate 3) of the study.

Figure 1 shows graphically the \( hsv \) components for each entry of the 1.024-
A COMPOSITIONAL APPROACH

Color Study #7 illustrates one method of applying these ideas to temporal color composition. An analysis of the compositional approach used with respect to the evolving color relationships in the study reveals an underlying arch form (Fig. 2). The arch form is a common musical architecture in which the focus or perhaps climax of the piece occurs in the middle. The closing half works its way to the end as a loosely mirrored unraveling of the first half.

We accomplish this analysis of the study by dividing its 3,600 frames into six equal sections of 600 frames each, using seven keyframe color palettes. A storyboard of the entire composition can be seen in Color Plate 4 with the animation progressing from upper left to lower right. The study begins and ends in a neutral color domain. The peak of the study is at frame 1860 (Plate 3) which has the maximum hue weighting. The study progresses to the climax point at keyframe 4 with a yellow-gold weighting (Plate 3). Again we return to the balanced domain we analyzed earlier (Plates 1a and 1b), and then on to another weighted relationship, also analyzed earlier (Plates 2a and 2b). The blue weighting resolves itself to the neutral keyframe 7 palette, ending the composition (corresponding with the image in the lower right of Color Plate 4).

In Fig. 4 we can also follow the arch form, using \( I.\text{rgb} \) components. The actual image intensity, or value \((I)\), peaks at the midpoint, keyframe 4. The saturation summations agree with the \( I.\text{rgb} \) components: low saturation values indicate neutral or balanced domains. The hue component indicates overall hue weighting for saturated domains, keyframe 4 shows a hue value of 0.094 or yellow-gold (see Fig. 5).

UNRESOLVED ISSUES

Color is only one aspect of a visual composition, and color domains are one small part of a complete color grammar. Although we have established a syntax for moving through color relationships we have not dealt with the connotative aspects of particular hues. What might be considered the semantic side of a color grammar.

Other issues remain: questions of shape and form; the distribution of different hues and values over the image; questions of temporal design; and the evolution of abstract shapes in time. A complete time-based visual grammar has many facets, all of which must eventually be considered in abstract visual composition. These questions are, of course, more than can be covered in a short paper, but they suggest many directions for further study.

The imagery for Color Study #7 is a visualization of a simple mathematical process. Each frame is a two-dimensional grid of 10-bit numbers, which are assigned color from a 1,024-element color map. Although the procedure for creating the animation frames is beyond the scope of this paper, it uses a simple design principle that is worth noting. The piece is set up with a start frame and an end frame defined. All frames in between are calculated as interpolations revealing a single gestural phrase. A simple motion of relaxation-release is created by moving from and to points of dynamic symmetry [8], from one point of visual balance in spatial composition to another.

As temporal color relationships are of primary importance in the study, elements of motion and shape were minimized, using either simple shapes or a single gesture. Theories of tension-release in pure design already exist and provide a good point of departure for further work in the non-color design aspects of a time-based visual grammar [9]. Combined with this color research, they begin to establish a language for abstract visual composition.

FINAL REMARKS

Color Study #7 illustrates rigorous control of color relationships over time. It shows that it is possible to create coherent compositions with a formal foundation similar to that found in traditional Western music practice.

The idea of a neutral-weighted dynamic with respect to color is not a new one. Hence this work serves not only as theoretical invention but rather as codification of a practice in filmmaking that dates back at least 50 years. In 1939, MGM's The Wizard of Oz was divided into three sections. The opening and closing, set in the stables of "home", were in neutral black and white. The action of the story in the land of Oz was in color.

Today's music videos make extensive use of the interplay of neutral (black and white) and weighted domains. An hour's worth of viewing demonstrates that, though filmmakers may not follow a rigorous theory, they instinctively understand the kinetic potential of structuring time with color.

The work discussed here is but a start toward a design language for abstract visual composition. Over the last century experimental animation has made only a small mark on the artistic landscape [10]. Many of the problems these filmmakers faced have been alleviated with the advent of computer technology. Obstacles of expense, equipment access and time expenditure all have
been minimized. As interest in technology for technology's sake wanes (as the technology becomes more readily available), the focus will return to its creative use. The body of work and working vocabulary and grammar is theory will grow.

There is of course no one solution for each aesthetic problem to be encountered. It is doubtful that artists will even agree on what the problem is. This research offers one approach to the problem of color.

Although this paper has focused on the technical elements of a process, it must be remembered that the details of craft are important to the artist but must be remembered that the details of the technical elements of a process, it should be invisible and seamless to the audience. As in analyzing a music composition, we can graph, chart and quantify the elements of a piece and lose sight of the work as a piece of music. We are, after all, dealing with art. While we accept the discipline and responsibility of the craft, we must be cautious of intellectualizing what we do, and of leaving the work cold and sterile.

Finding that balance is a challenge all artists face. John Whitney says, "Art, unlike science, is proven by art alone" [11]. As we each find our own way, and as we discover and share new techniques, the work eventually will speak for itself, with time as the final arbiter.

Table 1. Start, midpoint and endpoint of the color map, which defines color as 1 byte (0–255) each of red, green and blue.

<table>
<thead>
<tr>
<th>start</th>
<th>mid</th>
<th>end</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td>160</td>
<td>120</td>
</tr>
<tr>
<td>green</td>
<td>200</td>
<td>120</td>
</tr>
<tr>
<td>blue</td>
<td>20</td>
<td>120</td>
</tr>
</tbody>
</table>

Table 2. Sine function parameters of frame 1800, color map (hsv space).

<table>
<thead>
<tr>
<th>amplitude</th>
<th>frequency</th>
<th>offset</th>
<th>phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>[0–1]</td>
<td>5.0</td>
<td>[0–1]</td>
<td>(radians)</td>
</tr>
<tr>
<td>0.012</td>
<td>6.0</td>
<td>0.094</td>
<td>0.0</td>
</tr>
<tr>
<td>0.039</td>
<td>2.0</td>
<td>0.273</td>
<td>0.0</td>
</tr>
<tr>
<td>0.273</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. rgb components for keyframe palette color domains.

<table>
<thead>
<tr>
<th>keyframes</th>
<th>red</th>
<th>green</th>
<th>blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.361</td>
<td>0.363</td>
<td>0.352</td>
</tr>
<tr>
<td>2</td>
<td>0.547</td>
<td>0.352</td>
<td>0.204</td>
</tr>
<tr>
<td>3</td>
<td>0.318</td>
<td>0.306</td>
<td>0.320</td>
</tr>
<tr>
<td>4</td>
<td>0.659</td>
<td>0.386</td>
<td>0.034</td>
</tr>
<tr>
<td>5</td>
<td>0.355</td>
<td>0.335</td>
<td>0.362</td>
</tr>
<tr>
<td>6</td>
<td>0.347</td>
<td>0.348</td>
<td>0.492</td>
</tr>
<tr>
<td>7</td>
<td>0.354</td>
<td>0.349</td>
<td>0.373</td>
</tr>
</tbody>
</table>

Table 4. hsv components for keyframe palette color domains.

<table>
<thead>
<tr>
<th>keyframes</th>
<th>hue</th>
<th>saturation</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.197</td>
<td>0.030</td>
<td>0.363</td>
</tr>
<tr>
<td>2</td>
<td>0.072</td>
<td>0.627</td>
<td>0.547</td>
</tr>
<tr>
<td>3</td>
<td>0.810</td>
<td>0.044</td>
<td>0.320</td>
</tr>
<tr>
<td>4</td>
<td>0.094</td>
<td>0.948</td>
<td>0.659</td>
</tr>
<tr>
<td>5</td>
<td>0.790</td>
<td>0.075</td>
<td>0.362</td>
</tr>
<tr>
<td>6</td>
<td>0.665</td>
<td>0.295</td>
<td>0.492</td>
</tr>
<tr>
<td>7</td>
<td>0.701</td>
<td>0.064</td>
<td>0.373</td>
</tr>
</tbody>
</table>


10. Rustess and Starr [9].

11. Whitney [9].

Acknowledgments

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General Bibliography


Evans, B., *Color Study #7* (videotape distributed by University of Illinois Film Center, Champaign).


Color Plate 1a. (left) Frame 2400 of Color Study #7 (keyframe color palette 5), an example of a balanced color domain in which rgb summation intensities balance one another.

Color Plate 1b. (left) Random redistribution of pixels in frame 2400 (see Color Plate 1a), demonstrating a neutral quality due to the balanced color components.

Color Plate 2a. (right) Frame 3000 of Color Study #7 (keyframe color palette 6), a domain weighted in blue with low saturation.

Color Plate 2b. (right) Random redistribution of pixels in frame 3000 (see Color Plate 2a), demonstrating a weighting in low-saturate blue.
Color Plate 3. (top) Frame 1800 of Color Study #7 (keyframe color palette 4), climax of the composition, with a high-saturate yellow-gold weighting.

Color Plate 4. (bottom) Representative frames from the entire composition of Color Study #7, beginning, at the upper left, in the neutral color domain, passing through a colored domain (orange), then a balanced domain (row 2, image 2) and to the peak with maximum weighting (yellow-gold); the study resolves at the lower right in the neutral domain after passing through another weighted domain (blue).