Visual Synthesizer Design:
Where modern art was headed

Fred Collopy
Case Western Reserve University

May 15, 2020

> The color-instrument of the future will not merely throw pretty squares, circles, coils, and volutes of colored light upon a screen, but will be able to record the artists' moods, desires and emotions along any visually formal aesthetic line. Only when such an instrument has been perfected can the modern artist's creative conceptions be properly expressed.
>
> Willard Huntington Wright, 1923

Abstract

With Romanticism and the rise of instrumental music, composers developed a language that allowed them to connect directly with human emotion, one in which an idea and its expression were one. Music's content is perceived entirely through its tonally moving forms (Herzog). All of the other arts, painting most of all, shared in an envy of music so that in 1888 the critic Walter Pater famously wrote: "all art constantly aspires to the condition of music."

Modernist art arose in part from this search for principles to function something like the *basso continuo* in music (Herzog). For many artists it was also driven by their search for a new visual aesthetic, something that had been in the air since Newton's *Optics* was published in the 17th century. By 1912, the poet and art critic Guillaume Apollinaire was predicting that modern art was about to become "an art that would be to painting…what music is to literature (p. 197)." And in his 1923 essay *The Future of Painting*, Wright argued that modern art was less about painting than about light and movement and more a performance art, like music.

Many modern artists wrote in specific terms about how painting and music inform and complement each other. In this paper, I describe how I used insights from painters such as Paul Klee, Leopold Survage, Georgia O'Keefe and Karl Gerstner as hypotheses to guide the design of a visual synthesizer. Kandinsky, for example, proposed that amplitude in music relates to thickness of line in painting: "The pressure of the hand upon the bow corresponds perfectly to the pressure of the hand upon the pencil (Kandinsky, p. 618)." I apply such hypotheses to creating visual interpretations of musical passages. The resulting clips play a role much like that of the pencil tests produced by animators while conceiving and developing a film.

Introduction

Synthesizer inventor Robert Moog was clear about the challenges of instrument design. "Music-making requires both the musician and the listener to function at the very limits of their perceptive and cognitive capabilities. Therefore a musical instrument has to be as effective as possible in translating the musician's gestures into the sonic contours that he is envisioning. When he performs, the musician feels his instrument respond as he hears the sounds that it produces. In terms of modern information theory, the musician-instrument system contains a multiplicity of complex feedback loops (Pinch and Trocco, p. vi)." This project engages a similar sensibility around the design of synthesizers for our eyes.

For over three centuries, designers have been conceiving instruments for the production of visual music, a dynamic abstract visual art that unfolds in time to move an audience as sonic music does.

This design inquiry is aimed at answering these questions: What will it take to produce an instrument that provides visual artists with the expressive power that a guitar, piano, violin or trap set provides to a musician? What more is required if those artists wish to engage in improvisational ways with musicians and with artists playing other visual instruments?

To answer these questions is to engage in practice-based research that has both an applied agenda and elements of use-inspired basic research (Dahl, p.76). As such, the project represents an exercise in performative research, "a third category of research method, equal to those of our currently recognized categories of quantitative and qualitative research (Boland & Lyytinen, p.249)." One important question for this type of action research is: How do we insure we are making progress in meeting the real goals of the research? By admitting diverse views from many artists and musicians, we expand the range of aesthetics that influence our judgments about what is desirable (Boland & Lyytinen, p.254); so the resulting instrument will have broad applicability in the way that the musical instruments identified above have. And by articulating the artists' insights as hypotheses, we facilitate addressing the evaluation challenges typically found in research of this kind (Dahl).

Design Issues

A considerable number of challenges face designers of visual synthesizers who hope to achieve the variety and expressiveness of musical instruments. The player of a visual instrument has to control about an order of magnitude more dimensions than the player of a sonic instrument. Where playing a musicical instrument can be thought of in terms of controlling melody, harmony, and rhythm, visual music must allow for control of color, form and motion. Each of the three visual dimensions is about as complex as all of the musical dimensions. For example, to express color, a player must control at least a tri-chromatic representation, such as hue, saturation and value, never mind texture, reflectance, simultaneous contrast, and other color moderators. Similarly to represent a form's movement requires controlling its rotation, translation, and scaling, each along two or three dimensions. And forms are essentially unlimited. David Bowie made the point poetically: "the eyes are a lot hungrier than the ears (Bowie)."

Then there is the problem of aligning visual music with sonic music. There have been many proposals about how visual music should relate to sonic music, but none has seemed up to the demands represented by the extraordinary variety there is in music. There has been relatively little empirical exploration around which of the dimensions matter.

Color Scales

The earliest efforts to align visual and sonic music were through mappings of hues and pitches. This began in the 18th century with Newton's explorations of light and the visual music instrument it inspired, Louis Betrand Castel's *ocular harpsichord*. It has continued into the current century.

Three centuries of color scales

The most obvious observation to be made is that there is little consistency among the color scales proposed. Commenting on one such scale, the color theorist Patricia Sloane put it succinctly. "We should not need to be told that strong similarities rarely occur between systems created by human beings (say, music) and natural phenomena (say, color) (Sloane, p.314)."

Critical reviews have further argued about why direct mappings are unlikely to be satisfying. Jones concluded that there are significant differences between the nature of color and the nature of sound (Jones). The musical scale is divided into octaves with repeating qualities, where color has only a single spectrum. Where the ear can pick notes out of a chord, the eye is unable to distinguish various frequencies in a color-blend. And unlike the relationships among sound frequencies at various intervals, there are no such meaningful relationships between color sensations and light frequencies. Garner added that while a note produces harmonics, a color does not and that while notes in a musical chord occur together, hues in a color chord have to be placed separately. He concluded with the observation that notes are about time, while hues are about space (Garner).

Correspondences

Despite issues with the most obvious mapping, there is reason to hope that at some higher level, correspondences might trigger meaningful associations and responses. In his magnificent book *The Forms of Color*, the modern artist Karl Gerstner observed that each musical tone can be defined by three parameters: frequency (pitch), amplitude (volume) and overtones (tone color) and that each color can also be defined by three parameters: color tone (hue), lightness (value) and purity (saturation) (Gerstner). With that observation he initiated a search for correspondences in the work of modern painters and musicians. For a reason that will be discussed later, I have collapsed Gerstner's lightness and purity into a single dimension for which I continue to use his term 'purity'. I have expanded his model to include three additional musical dimensions (harmony, speed and melody) and two additional visual dimensions (form and motion).

This table shows the resulting model. The cells reference representative hypotheses derived from the literature. The entries are based on ideas in the writing of artists, musicians and cognitive scientists. Some

cells contain additional hypotheses that are not shown. Cells are empty where no hypotheses have yet been identified by this review. As discussed above, the hue to pitch hypothesis (in the upper left cell) seems already to have been disconfirmed.

Correspondences in sonic and visual music

	Hue	Purity	Form	Motion
Pitch	Hue to pitch	Purity to register	Size to pitch	
Amplitude		Purity to dynamics	Thickness to amplitude	
Timbre	Hue to timbre			
Harmony	Color chords	Purity to dissonance		
Speed			Shape to speed	Repose to rest
Melody				Path to pitch

Synesthesia, including chromethesia, where hearing a given note triggers the perception of a particular color, runs as a subtheme through the literature on correspondences. Its presence as a theme is in part due to the fact that "the initial emergence of abstract art coincides with a widespread interest in synesthesia from both a scientific and an artistic perspective [Betancort, p.60]." In much of the literature around visual music, color music and even abstract art, synesthesia carries the burden of supporting Romantic claims to a higher form of knowledge than is provided through science and empiricism. In the view of some of the artists included in this review, synesthesia constitutes evidence that there is an underlying reality that supersedes what is available to most of us, and that synesthetes have direct access to this deeper unity of the senses.

Having surveyed the history of synesthesia with a thoughtful eye, Dann lands on an introspective research program conducted by Wheeler and Cutsforth which suggested that the construction of meaning is kinesethic and that the difference for the synesthete is that meaning is only formed or recalled when the synesthetic cue is part of the experience. For them, "synesthesia *is* the act of perceiving, itself (Wheeler & Cutsforth, p.370)." In Dann's view "the religious sentiment that transformed the arcane perceptual style [of synesthetes] into a dream of expanded consciousness should have been tempered by Wheeler and Cutsforth's findings in the 1920's. (Dann, p.93)."

Bulat Galeyev, a prolific Russian visual music artist, had a more grounded view than the Romantics. "I start from the premise that synesthesia is a normal and common ability of intersensory association, a particular manifestation of imaginative thinking or (when it appears in verbal form) a double metaphor, in which the transfer of meaning inherent in metaphor is accompanied by the transition into another sensory modality (Galeyev, p.285)." He went on to illustrate how natural some synaesthetic associations are. "Among the most obvious and simplest examples of 'natural' (i.e. widely shared) synestheses is the 'pitch—size' association: A low pitch looks big, thick and opaque,

while a high pitch is small, thin and acute (children often describe pitches in this way). This association appears because in the physical world the pitch of a sounding object depends upon its size (a big object produces a low pitch and vice versa) (Galeyev, p.285)."

A contemporary clinical view of the phenomenon is that of neuroscientist Vilayanur Ramachandran who sees in the experiences of synesthetes true sensory rather than memory-based associations. In early experiments his team found that subjects with number-color synethesia identified shapes embedded in arrangements of numbers, more readily than control subjects. Such shapes pop out readily when shown using colored numbers. This led them to propose that synesthesia is the result of cross-wiring between adjacent brain maps (Ramaehandran & Hubbard, p.982). He has since theorized the possibility that principles on which both art and language are based might well have resulted from such genetically inherited cross-wiring. "The first words our ancestors evolved may not have been arbitrary—there's a non-arbitrary correspondence between visual object shape and sound 'shape' as represented in the superior temporal gyrus. The evidence for this is if you take two completely random nonsense shapes, one resembling an ink blot with undulating contours, and one resembling a shattered piece of glass with sharp corners, and ask 100 people, 'Which one of these represents the non-sense word Bouba and which represents the nonsense word Kiki,' 99% of them pick the amoeboid as Bouba and the jagged shape as Kiki. Presumably this is because the jagged edges synesthetically mimic the jagged sound of 'ki-ki' (Romano, p.16)"

Whatever the roots and meaning of synesthesia, for us the issue is whether its insights serve the artist's goal of "producing pleasing effects in the mind," to use a phrase from Ramachandran. It is interesting that "synesthesia is about eight times more common among artists, poets, novelists and other creative people than it is in the general population (Ramachandran, 4:20)."

The following sections each examine one of the visual dimensions. They describe ideas from literatures on music and art, treating them as hypotheses to be explored.

Hue

A bit more sophisticated than a simple hue to pitch mapping is Kandinsky's association of hues with the timbres of musical instruments. He saw in yellow, a loud trumpet blast; in orange, a church bell of medium pitch or a viola playing largo; in red, a tuba or powerful drumbeat; in purple, little bells or the singing tones of a violin; in violet, woodwinds; in light blue, a flute; in dark blue, a contrabass or bass organ; and in green, a quiet meditative violin. Other musicians and artists have made similar comparisons between music keys and colors. Beethoven called B minor the black key, Schubert likened E minor to a maiden robed in white, and Rimsky-Korsakoff and other Russian composers were said to agree that C major is sunlight (Jones, pp.100 ff).

A third way of relating hues to music is through the notion of harmony. Some combinations of colors appear, like some combinations of musical tones, consonant while others appear dissonant.

In 1921, the German chemist, painter and color theorist, Wilhelm Ostwald proposed a musical analogy for color that was based not on the scale itself but on the intervals. Having divided the color

wheel into 24 segments, the fundamental was made up of only the segment itself. The minor second is a shade composed of the slices immediately adjacent to it. The major second was comprised of the two adjacent to them, and so on until the octave consisted of only the complimentary color opposite the fundamental (Gerstner, pp.170-171).

Around the same time, students of the color theorist Ernest Perceval Tudor-Hart were working on ways of using his color wheel to produce harmony and dissonance. Stanton Macdonald-Wright and Morgan Russell were founders of an artistic movement known as Synchromism. In the 1910s they began writing about and experimenting with kinetic light machines that they created in their drive "to make painting an emotional art, such as music (South, pp.33-34)." Macdonald-Wright published a detailed description of a color scale that was particularly attentive to details of the intervals between hues. This attention to interval flowed from his belief that "The first requisite of color, as the first requisite of music, is that it be harmonious (Macdonald-Wright, p.2)."

At least since Goethe, color theorists have argued that there is something harmonious about complimentary hues, colors that are related through the experience of the after image. The artist Gyorgy Keypes referred to this universal color harmony as "a conformity to the law of the human organism, an equilibrium in visual experience (Kepes, p.35)."

As important as harmony is in both music and painting, dissonance is what often moves things along. Macdonald-Wright was specific about how dissonance could be achieved. "If a harsh clash is desired use red-orange and blue-green. For a clash less harsh use orange and blue. All sets of complementarities follow in the order of their harshness: yellow-orange and blue-violet; yellow-green and red-violet; green and red; and softest of all opposites, yellow and violet (Macdonald-Wright, p.23)." Bainbridge Bishop made similar suggestions (Bishop, pp.10-12).

Brian Evans, starting with a focus on the idea of tension-release, a recurring aspect of time-based art forms, created a hierarchy of color relationships with three domains. The neutral domain is comprised of the grayscale, the absence of color. The balanced domain is one where the sum of the colors in an image equals grey. The weighted domain is one where one hue is dominant. It is the most unsettled or dissonant domain (Evans).

Hypotheses related to the use of hues are:

H1. Hue to timbre: A hue can reflect the timbre of a particular musical instrument.

H2. Color chords: Color chords can achieve visual consonances and dissonances that interact with musical ones.

Purity (value and saturation)

Value represents the relative lightness or darkness of a color. One can think of it as the inverse of the amount of black that is mixed into a pure hue so that as the value decreases, the color becomes more muted, dusty, grey, ultimately reducing to black. Saturation refers to the intensity of the color. It can be thought of as the inverse of the amount of white mixed into a pure hue. As the saturation reduces,

the hue transforms into a lighter version of itself, so that red, for example, becomes pink and ultimately white.

Modern artists' writing about color, particularly related to music, has little discussion of how pure hues are altered, only that they are. For that reason, I have chosen to express these as a single construct, purity. You can think of it as the amount of grey mixed into the color.

Purity heightens or moderates many of the effects associated with hue combinations. Macdonald-Wright found, for example, that the dissonance created by using complementary pairs of hues is reduced if their purity is (Macdonald-Wright, pp.23-24). The painter I. J. Belmont considered black, an extreme where hues become indistinguishable, dissonant when combined with other colors (Belmont, p.119).

Vincent Van Gogh, like other artists of his time, saw that painting was undergoing a transformation in which the qualities of color were playing an ever more important role. And he felt that the new role of color was making painting more like music and less like sculpture. The German art historian Kurt Badt distilled a color theory from Van Gogh's pictures and letters that provides important analogies to music. Gerstner quotes Badt in translation: "We are used to seeing the dark colored as the deep-toned, the light as the high. And dark and light colors do actually have effects which are comparable to low and high musical tones. Dark colors are sonorous, powerful, mighty like deep tones. But light colors, like those of the Impressionists, act, when they alone make up a whole work, with the magic of high voices: floating, light, youthful, carefree, and probably cool too (Gerstner, p.173)."

Karl Gerstner hypothesized a correspondence between lightness and purity in color and amplitude in music. "Pure florescent colors are loud. Muted, that is broken colors with a high proportion of black and white, are soft (Gerstner, p.173)."

Recognizing that music contains both big changes (such as a change in key) and small changes (such as where in a phrase an emphasis is placed), the composer Scriabin looked to changes in hue and changes in purity as playing analogous roles in color. "Scriabin held that each mode corresponded to a particular shade of colour, and each modulation to a nuance of this shade. Changes from the major into the minor could therefore be underlined by strong contrasts, on a visual as well as a chromatic level (Popper, p.157)."

Hypotheses that address changes in the purity of colors are:

H3. Purity to register: Darker colors reflect full, deep, rich voices or passages, while lighter colors echo higher and lighter voices and passages.

H4. Purity to dissonance: Reductions in purity can moderate dissonant hue combinations.

H5. Purity to dynamics: Changes in purity can emphasize and reflect changes of amplitude in the music.

H6. Purity as secondary change: Large musical changes (such as key changes) can be reflected by changes in hue, while smaller changes can be reflected by changes in purity.

Form

Form has, as much as color, been the subject matter of abstract painters. And in form too, they have sought out correspondences with musical ideas. Gyorgy Kepes observed that most of us would feel that a high pitch indicates smallness while a lower pitch indicates a larger size (Kepes, p.167).

In his examination of points and lines, Kandinsky added orientation as a feature of shape. While a horizontal line associates with a steady frequency, a line that is rising does so with a pitch that is getting higher and one that is sinking, a pitch that is descending (Kandinky).

Still more interesting is Kandinsky's association of the line's character with amplitude in music. As he poetically put it, "the pressure of the hand upon the bow corresponds perfectly to the pressure of the hand upon the pencil (Kandinsky, pp.618)." The form's thickness, its sharpness and even its purity of color are changed as the amplitude varies.

Lawrence Marks, who has written a defining work on the subject of synesthesia, noted that because music is such a complex art form, it is not surprising that "when synesthetes listen to music, their visual responses--color, form, movement—may shift, surge, and ebb according to musical key, to musical pattern, to musical progression. But here too results are divergent, with little specific agreement on the images reported by different individuals." But there are notable exceptions. He cited a 1938 study that found a systematic relationship between the shapes of synesthetic visual forms and musical tempos. "The faster the music, the shaper and more angular the visual image." This result is complemented by a 1944 study in which composers wrote music based on several themes presented to them as line drawings. "The angular and irregular drawings yielded louder sounds, faster tempos, and syncopated rhythms (Marks, p .93)."

Hypotheses related to form are:

H7. Size to pitch: Size can reflect the frequency of sounds, with small objects representing higher pitches and larger ones representing lower.

H8. Orientation to pitch change: The orientation of lines can reflect pitch changes in music with horizontal lines representing no change, while ascending and descending lines suggest movement to higher and lower pitches respectively.

H9. Thickness to amplitude: The thickness and darkness of lines can reflect amplitude in the music, with louder music calling for thicker lines.

H10. Shape to amplitude: Angular and irregular forms can reflect greater amplitudes.

H11. Shape to speed: The shapes of objects can pick up on the speed or rhythmic structure of music, with sharper and more angular forms reflecting faster tempos and complex rhythms.

Motion

Rhythm plays an important role in both sonic and visual music as it does in much else of life. "Woodworking, hammering, swimming, rowing, walking, running, dancing are familiar activities in which the metre makes work easier and at the same time endows it with the feeling of pleasure. The proportion of action and repose—that is, the rhythm—depends upon the nature of the work (Kepes, p.53)."

Unlike the Romantics, Paul Klee thought of rhythm as the basis for analogies of painting with music. He considered rhythm the inner being of music (Duchting, p.13). In his *Fugue in Red*, for example, the temporal is shown in the way that the mass of the forms grows out of the black background, becoming more brilliant with each layer, until finally they are quite bright (Duchting, p.28). Described in that way, the painting reads as a demonstration of H6; but for Klee, that is but a special case of a more general principle that draws art toward the domain of music. In his lecture notes he distinguished the individual component of a composition from the dividual components. The former is a large, rhythmically independent, unrepeatable unit of composition, where the latter, which he also called structural components, are smaller repetitions of similar structure and hence divisible (Duchting, p.35). The pursuit of such rhythm can be seen in Klee's use of color, form and composition. So guidance drawn from it represents a hypothesis that touches many cells of our framework and points to structuring works at a higher level than most of what I have been exploring in this paper.

Gyorgy Kepes noted that painters in many periods had devised ways of showing motion, which could be "emphasized by dynamic outlines, by a vehement interplay of vigorous contrast of light and dark and by extreme contrast of colors (Kepes, p.173)." Rhythm was generally achieved through subdivision of the space but "the invention of the motion picture opened the way to hitherto undreamed scope and flexibility of rhythmic organization (Kepes, p.58)."

In his 1987 search for a visual aesthetic informed by music, Tom Dewitt (now Ditto) noted that persistence of vision closely matches where discrete sound events become continuous tones at about 20 cycles per second. "The film medium invites artists to become visual musicians, dividing up time according to a sense of change. Hence, one aesthetic that music can teach visual artists is that of tempo [DeWitt, p.118]." Though DeWitt specifically references tempo (the speed at which the music is played), his observation seems relevant to rhythm (the mix of sound and silence) as well.

It would be a pity to leave the hunt for correspondences without touching on an element of music that is taken by so many to be its very essence, the melody. Here's how jazz guitarist Pat Metheny speaks about melody: "What melody represents to me is actually what's happening in between the notes. It's the way its all connected. People use a word like swing or flow. It's the glue that connects ideas and the way you express time in a narrative way is the thing that makes it accessible (Metheny, video at approximately 1:22:00)." And these are not entirely new ideas. Music theorists were writing similar things in the middle of the 20th century. So when writing about the organization of space in the plastic arts (painting, sculpture) in 1944, Kepes turned to the concept of melody to explain the role played by paths (of color, form, focus of the eye, etc.): "The function of the kinetic linear path in plastic organization may be compared with the function of melody in musical composition (Kepes, p.59)." This invites application in the other direction. By attending to the paths along which the eye of the viewer is moved in a piece of visual music, it is possible to engage in a dialogue with the melody line of the sonic music being played. This is used to great effect, for example, by Stephen Malinowski's *Music Animation Machine*.

Hypotheses related to motion are:

H12. Repose to rest: The proportions of action and repose in the visuals can reflect that in the music.

H13. Path to pitch: The focus of the eye within the visual space and other paths can be orchestrated to complement the movement of the melody in the music.

H14. Individual and structural: Large, singular components of the visuals and smaller, repeating structural components can reflect like aspects of the music.

Prior Tests

A few of the hypotheses I have identified in the writing of artists have been explored in prior visual music research.

Among the most successful pieces of visual music yet created is Oscar Fischinger's *Motion Painting 1* (1947). Brian Evans gives a nice description of the ways in which that piece makes use of purity as secondary change [H6], using hue changes to emphasize large developments while using changes in purity structurally. "In the first section especially, the movement of color is important as it builds large phrases…[As the painting develops] larger structures are perceived as repetition and contrast of hue choices. Tension resolves as high saturation, and bright colors give way to darker colors and lower saturations (Evans, pp.18-19)."

In an article describing the use of Max/MSP/Jitter to create visual music, Jones and Nevile discuss three correspondences they explored (Jones & Nevile). One was the size to pitch relationship that we've seen from Kepes [H7]. Another was the purity to dynamics relationship proposed by Gerstner [H5]. The third was to have shape correspond to timbre, much as Marks reported it does to speed [H11]. They hypothesized that some timbres would be spikier while others were rounder. How the timbre parameter was determined was not described, nor was how they evaluated the results produced by these mappings.

Katherine Lubar compared color intervals and musical intervals (Lubar). Her aim was to learn whether intervals that are harmonious or discordant in music have similar effects when used to define color chords [H2]. She identified some issues with constructing intervals, such as that on the color wheel, intervals can move in either direction and that larger intervals lead to inversions of their musical counterparts unless some adjustment is made (she suggested a change in value). Still, there is much of interest in her careful parsing of how specific aspects of each color interval contributes to a sense of consonance or dissonance.

DeWitt reported that while he could not identify a universal color aesthetic, there seemed to be particular potential at the threshold between monochrome and color. This would amount to a test of the extreme case of the purity to register [H3], purity to dissonance [H4] and purity to dynamics [H5] hypotheses. "I found this transition to trigger a psychological release with emotional connotations" he reported. "Perhaps because the monochrome retinal neurons, called rods, are more sensitive to light than the color-sensitive cones are, the transition from black and white to color can produce the sensation of awakening…The reverse transition from color to black and white leaves a feeling of release into twilight (DeWitt, p.116)."

Evans' *Color Study #7* followed an arch moving from a neutral color domain through a weighted one to a balanced one to climax in another weighted one, and then mirrored the sequence. His color

plate 4, in particular, suggests that the piece does successfully represent the arch structure with its move to and from a climax, thereby making use of color chords [H2] as he intended. Evans concluded that the piece demonstrates that "it is possible to create coherent compositions with a formal foundation similar to that found in traditional Western music practice (Evans, p.46)."

Use of the Hypotheses

Most of the hypotheses can be used either to reinforce a musical idea or contrapuntally. Their formulation should not be taken to support the idea that the sonic music always leads the visual music. Indeed, the point of creating a visual music instrument suited to improvisation is to allow for an ongoing conversation between the sonic and the visual.

As part of the process of designing the Imager visual synthesizer, I use visual clips as a way to test the hypotheses I have drawn from the artists. The clips play a role in our design process much like that of the pencil tests produced by animators while conceiving and developing a film. Creating them pushes Imager's design to accommodate a wide variety of aesthetics and to make moving from one musical or visual idea to another more fluid. Illustrations are provided at: https://rhythmiclight.com/videos.

Hypotheses H1 through H14 are about some of the kinds of performance interactions that a visual synthesizer should support. They serve as a foundation for developing synthesizer design hypotheses. A few examples follow. These can more properly be seen as hypotheses if you add conditional logic around them such as, "Imager will be more playable, valuable, flexible, etc. if…". Because they drive a design process rather than a research study, I tend to formulate them more normatively.

Here are examples of instrument design hypotheses:

H15. For improvisation, provide ready access to, and control of, arrangements of hues that constitute color chords of various types (adjacent, complementary, triadic, dissonant, etc.).

H16. To reduce cognitive load, replace the traditional saturation and value constructs with a simpler purity construct.

H17. To provide for Klee's dividual (repeating) components allow reuse with modification of structural components.

H18. To facilitate DeWitt's and Evans' uses of monochrome, provide a separate grey scale ribbon.

H19. To support complex visual rhythms, allow note durations to affect pen thickness, purity, size and other features of objects when they are created.

Such hypotheses or guidelines can then be incorporated into design briefs. The challenges and benefits of providing each capability can be estimated. And ultimately the resulting mechanism's utility and efficacy can be assessed.

Conclusion

The framework and hypotheses presented are an effort to organize the insights of artists and musicians about the relationships of painting and music. The reason for doing so is to clarify and prioritize design

specifications for the Imager visual synthesizer. Treating these principles as hypotheses about the resulting works of art has enabled us to conceive of fresh designs that can be prototyped and understood through interacting with a variety of musical styles. Given the range and depth of talent that has been tackling this problem and writing about the topic over several centuries, visual music instrument design represents an ideal domain for a hypothesis-based approach. Ultimately the goal of our design is to enable artists to express as wide a range of human emotion as musicians do.

Ackkowledgements
Thanks to Michael Betancourt, Andy Collopy, Peter Collopy, Tom Ditto, Martin Keary, Katherine Lubar, Stephen Malinowski, and Youngjin Yoo for comments on earlier drafts of this paper.

References

Apollinaire, Guillaume, "On the Subject in Modern Painting," 1912 in *Apollinaire On Art*, L. C. Breunig [ed], 1960, 197-198.

Belmont, I.J., *The Modern Dilemma in Art: Reflections of a Color-Music Painter*, New York: Harbinger House. 1944.

Betancort, Michael, "A taxonomy of abstract form using studies of synethesia and hallucinations," *Leonardo*. 40.1 (2007), 59-65.

Bishop, Bainbridge, *A Souvenir of the Color Organ*. New Russia, NY. 1893.

Boland, Richard J., Jr. and Kalle Lyytinen, "The limits of language in doing systems design," *European Journal of Information Systems*. 26 (2017), 248-259.

Bowie, David. *Black Tie, White Noise* (video), 1993.

Dahl, Luke, "Designing new musical interfaces as research: What's the problem?" *Interfaces*, 49.1 (2016), 76-77.

Dann, Kevin T., *Bright Colors Falsely Seen: Synaesthesia and the Search for Transcendental Knowledge*. New Haven: Yale University Press. 1998.

DeWitt, Tom, "Visual music: Searching for an aesthtic," *Leonardo*, 20 (1987), 115-122.

Duchting, Hajo, *Paul Klee: Painting Music*. Munich: Prestel-Verlag. 1997.

Evans, Brian, "Temporal coherence with digital color," *Leonardo*. Digital Image–Digital Cinema Supplemental Issue (1990), 43-49.

Evans, Brian, "Foundations of a visual music," *Computer Music Journal*, 29.4 (Winter 2005), 11-24.

Galeyev, B. M. , "The nature and functions of synesthesia in music," *Leonardo*, 40.3 (2007), 285-288.

Garner, W., "The relationship between colour and music," *Leonardo*, 11 (1978), 325-326.

Gerstner, Karl, *The Forms of Color: The Interaction of Visual Elements*, Cambridge, MA: MIT Press, 1986.

Herzog, Patricia, "The condition to which all art aspires: Reflections on Pater on music*," British Journal of Aesthetics*, 36 (1996), 122-134.

Jones, Randy and Ben Nevile, "Creating visual music in Jitter: Approaches and techniques," *Computer Music Journal*, 29 (2005), 55-70.

Jones, Tom Douglas, *The Art of Light and Color*, New York: Van Nostrand Reinhold, 1972.

Kandinsky, Wassily. "Point and line to plane," 1926 in NY: *Kandinsky: Complete Writings On Art*, K. C. Lindsay and P. Vergo [eds], NY: Da Capo Press 1994, 524-699.

Kepes, Gyorgy, "T*he Language of Vision*," Chicago: Paul Theobald, 1944.

Lubar, Katherine, "Color intervals: Applying concepts of musical consonance and dissonance to color," *Leonardo*, 37 (2004), 127-132.

Macdonald-Wright, Stanton, *A Treatise on Color*, 1924.

Marks, Lawrence E. *The Unity of Senses: Interrelations Among the Modalitie*s. NY: Academic Press. 1978.

Pater, Walter, "The school of Giorgione," *Fortnightly Review*, 1888.

Metheny, Pat, "Music and the brain" Neuroscience 2019, 2018.

Pinch, Trevor and Frank Trocco. *Analog Days: The Invention and Impact of the Moog Synthesizer*. Cambridge, MA: Harvard University Press, 2002.

Popper, Frank. *Origins and Development of Kinetic Art*. NY: New York Graphic Society. 1968.

Ramachandran, V. S. and E. M. Hubbard, "Psychophysical investigations into the neural basis of synaesthesia," *Proceedings of the Royal Society B Biological Sciences*, 2001, 979-983.

Ramachandran, Vilayanur, *3 clues to understanding your br*ain, TED 2007.

Romano, C. Justin, "The mind's eye—Neuroscience, synesthesia, and art," *NeuroPsychiatry Review*, 3.6 (July 2002). 1, 15-18.

Sloane, Patricia. *The Visual Nature of Color*. NY: Design Press. 1989.

South, Will. *Color, Myth and Music: Stanton Macdonald-Wright and Synchromism*, Raleigh, NC: North Carolina Museum of Art, 2001.

Wheeler, R. H. and T. D. Cutsforth, "Synaesthesia and meaning," *American Journal of Psychology*. 33 (1922), 361-384.

Wright, Willard Huntington, *The Future of Painting*, New York: B. W. Huebsch, Inc., 1923.

Author's biography

Fred Collopy is an Emeritus Professor of Design and Innovation at Case Western Reserve University. He received his PhD in Decision Sciences from the University of Pennsylvania in 1990. He has created numerous computer-based instruments, including the *Imager visual synthesizer*, an instrument for playing abstract visuals musically. He has written and spoken extensively on visual music, including in *Leonardo*, *Glimpse*, and the *Journal of Visual Programming Languages* and at numerous conferences, including Seeing Sound 2006, Sonic Light 2003, SIGGRAPH 2000, IEEE Symposium on Visual Languages 1999, and ISEA 1998. In 2000 he produced the visual CD, *Unauthorized Duets*. His web site at RhythmicLight.com has been a reference in the field since he established it in 1998. He has been a visiting scientist at IBM's Thomas J. Watson Research Center and at Cornell University's Human Computer Interaction Lab.