

An Interactive Method for Generating Harmonious Color Schemes

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Abstract: We present an interactive visualization tool for generating color schemes that can be used by both professional artists and novice designers to improve their design efficiency. The method is developed on two color harmony principles of familial factors and rhythmic spans from conventional color theories. The interactive tool makes uses of these principles for users to interactively generate colors palettes containing harmonious combinations in the HSL (hue, saturation, and lightness) color space in as few steps as possible. A pilot study with 20 participants has shown that this tool provides efficient workflow, color-scheme harmony, and intuitive interaction, demonstrating the usefulness of the method. This work contributes to an artistic-theory driven harmonious color-scheme generation and to interactive user interfaces visualizing color relationships.

Key words: Color Harmony, Color Scheme, Familial Factors, Rhythmic Spans.

INTRODUCTION

Color is one of the most important yet difficult factors in visual design. One challenge is generating harmonious color schemes. Lacking practical methods and useful color tools, designers usually expend significant effort in making perceptually harmonious color combinations. Our purpose here is to devise a method to generate harmonious color schemes interactively in as few steps as possible (Figure 1).

Artists and designers usually create elaborate color patterns for their work in painting, textiles, craftworks, and photography. Traditionally, designers use simple tools to compose color combinations. Color index and color design theories provide many color schemes for visual designers' convenient reference¹ and guiding principles to make use of color motifs.² However, designers might not be color experts and most artists and professional designers often spend significant amounts of time composing useful color scheme. Professional training in color theory and skill in color use are often desirable.

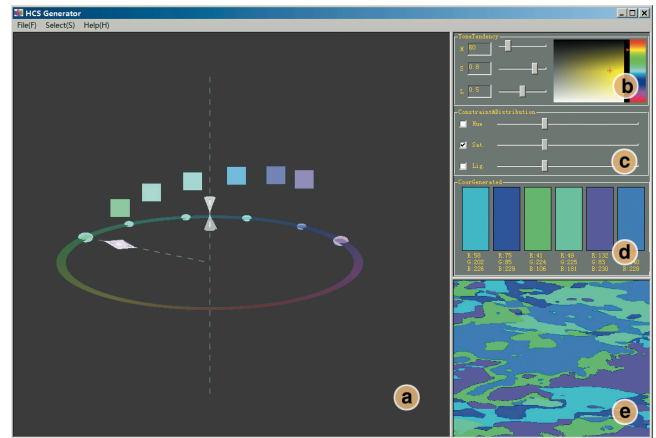


FIG 1. Our harmonic color generation toolkit user interface. (a) Color cylinder in the HSL color space, (b) tone tendency panel, (c) H, S, and L adjustment panel, (d), preview, and (e) an example color composition.

Our goal is to aid the design of the color schemes for novices; and the schemes are guaranteed to be harmonious arising from color harmony principles in art. Here designers are not required to have acquired color-mixing or harmony principles from color theories because such principles have been integrated in our harmonic color generation tool.

We start with the design guide of color combination choices based on two classical harmonious color principles.⁴⁻⁶ We then design a color composition user interface that supports a concise workflow to manipulate the overall color scheme for users to express their color design preferences. We have designed an interactive tool for color scheme generation that allows both novice and professional designers to attain variable combinational relationships based on users' harmonious compositional schemes. Various color adjustment methods are supported.

We have conducted a small-scale lab-based pilot experiment to evaluate the validity and features of our art-driven color harmony design method. The results demonstrate that both professionals and novices can easily compose harmonious color schemes with the method. Professional designers suggested that the tool also provided ease-of-use user interface for harmonic color design.

RELATED WORK

Color research has a history of hundreds of years. From Newton's explanation of the optical spectrum via dispersed light by a prism, Munsell's color space based on pigment and dye color, the CIE diagram for illuminative color, to the RGB color system, color theory has become more and more practical and easy to use in studio and digital media settings.^{2,3}

Several color theorists in particular have made contributions to color harmony principles. Itten inductively elaborated the principles of color contrast and harmony using musical chord metaphors to explain harmonious principles of chroma.⁴ Ostwald claimed that harmony equals order. In other words, it is the equal intervals of variables, e.g. gradations of grays, shadow series, isotones, isotints, etc, that make colors harmonious.^{5,6} Based on the Munsell color system, Moon and Spencer endorsed Birkhoff's aesthetic measure⁷ equation and refined it to measure color harmony.⁸ Burchett further refined color harmony attributes to eight categories: area, association, attitude, configuration, interaction, order, similarity, and tone.⁹ Of all these methods, it is Ostwald's theory that is the most computable and deducible in three-dimensional (3D) color space. Recently, Sanocki and Sulman also found that harmony increased the capacity of visual short-term memory.¹⁰ Our work has been motivated and is built on top of this line of research.

As computers have become the primary design tool, many computer-based color design tools have been developed for designers' convenience.¹¹ Two major types of tools for composing color schemes are available on computers: color pickers and color scheme composers.

Color-picking tools are embedded in design software. The color picker in Photoshop permits picking colors from different color spaces. The color-picking tool embedded in CorelDRAW lets the user mix colors by visual experiments in color spaces, or simply pick standard colors such as 50% black, 100% red, and 100% white. With these color pickers, users still must mix colors one by one to compose color schemes and most tools do not guarantee that all colors are in harmony. Our design focuses on overall harmonious but individual colors.

Color scheme composers often provide fixed frameworks based on abstract hue relationships, allowing the users to select specific color palettes from set hues.¹² Its color-scheme generator provides prototypes based on conventional color harmony principles but lets users relax

the principles and choose colors without strict adherence to color-harmony rules. Thus, the quality of the scheme depends directly on the user's color skills.

The popular tool Color Wheel Pro enables users to choose fixed color-scheme frameworks from among different hue-relationship principles (monochromatic, analogous, complementary, split complementary, triadic, and tetradic).¹³ For a chosen hue framework, users can determine specific colors in their color scheme by adjusting the variables of saturation or brightness and picking the individual colors from system-provided palettes.

Professional editors such as Adobe Kuler allows the adjustment of different color modes on many good frameworks, such as HSV (hue, saturation, and value), RGB (red, green, and blue), CMYK (cyan, magenta, yellow and key), CIELAB (L*a*b*), and HEX (hexadecimal code of a color).¹⁴ While the users have the flexibility to adjust individual colors and the relationship of the whole scheme, it is more suitable to professional artists than novice designers. The interface is often so complex that users would have difficulty in understanding the color relationships. We thus simplify the interactive color editing for users to readily edit and examine color relationships.

Some tools support the generation of color schemes by analyzing photos that users can input images to form color schemes.^{14,15} New color schemes generated in this way give an impression similar to the original image, and their attributes depend on the features of the images, not on users' selection. While these color schemes tools have inspired us but they were limited to traditional color-harmony principles and to a few fixed hue frameworks, e.g., analogous, complementary, split complementary, triadic, and tetradic. Users must adjust lightness and saturation parameters for each color individually, a skilled and subjective process that may not yield harmonious color schemes. Our tool does not require this subjective process of color selection.

During the recent boom in computer-generated art and the needs for coloring complex datasets to aid visual discovery, color researchers have commonly focused on color management and image editing. Meanwhile, many issues and methods related to color combination and human-computer interaction (HCI) have been discussed. Scientists were able to map the colors to multivariate data to help reveal the data attributes.^{16,17} Meier et al. developed a set of interactive color palette tools that provide eight methods for color mixing: palette browser, image and composition tools, gradient mixer, dial-a-color tool, frequency visualizer, palette breeder, name IPT, and grouper.¹⁸

Yamazaki and Kondo introduced a method of editing color schemes in Kansei scales.¹⁹ Users can modify color schemes to creative images in subjective dimensions related to human perception, such as "warm to cool", "soft to hard", and "natural to artificial" to represent emotional feeling.²⁰ The color design system of Tokumaru et al. also takes into account harmony factors.²¹ Compared with

Shigenobu’s two-dimensional (2D) grid, the Tokumaru et al. system adopted a 3D space with an additional clear-gray axis for depth. It can locate input colors in emotion space for evaluation and thus can automatically generate colors that are in harmony with an input color. We have adopted the 3D grid design in our user interface while integrating new design principles.

Some application-specific tools are designed for various applications. Nack, Manniesing, and Hardman provided a constraints-driven use-centric design method of creating harmonious and legible color schemes for automatically generated multimedia presentations that keeps a balance between function, form, and neutral.²² Moretti designed and implemented a system for auto-generating color schemes for graphical user interfaces (GUIs) that has three stages: specifying color constraints, defining color relationships to constitute an abstract color scheme, and actualizing the abstract color scheme into a real color scheme.²³

Moretti, Lyons, and Mrsland created a 3D mathematical tool to generate harmonious color schemes for coloring computer interfaces and websites.^{25, 26} It allows the user to choose among several color schemes, and then alter the overall hue orientation of the color scheme, to change the light-dark balance and to manipulate the overall lightness and saturation of the scheme. The architecture uses interchangeable models of color harmony, from which the designer can select the type of color scheme to be used from the complementary, split complementary, elliptical, monochromatic, and analogous color schemes. The black-white, hue, and saturation axes can be explored on a rigid grid in a three-dimensional color space.

Wang et al. distributed a color harmony system based on the L*a*b* color space.²⁶ They built a matrix of hundreds of colors in the L*a*b* color space, and put the geometric hue frameworks of harmony principles into the matrix to map the nodes for particular colors. These geometric frameworks of harmony principles are limited to slices of uniform lightness and saturation.

DESIGN PRINCIPLES

Our automatic color-scheme generation method is based on conventional harmony principles consisting of *familial factors* and *rhythmic spans* that guarantee holistic harmony of the color schemes generated. We have constructed harmonic colors in the hue, saturation, and lightness (HSL) color space. Using this method, users can easily compose harmonious color schemes interactively and focus on relationships between colors and their own color preferences, without needing to consider aesthetic aspects and the details of individual colors. An interface is provided to present overall color relationships in the schemes via which users can dial buttons to fit their preference directly onto the pattern they input for coloring.

Familial Factors

The term *familial factor*, defined by Lenclos, refers to the sharing of attributes among colors, which explained that it is easier to achieve harmonious sense of color in color schemes that are built up from colors having identical components.²⁷ This theory suggests that when we use (HSL) color space, we can achieve harmonic colors by having the same or similar values in at least one of the dimensions of H, S, or L.

Using the familial factors theory, we choose color schemes relying on colors with consistent HSL components. We fix one dimension of H, S or L in the color space of all colors in the color scheme and then vary at least one of the other two dimensions so as to produce a scheme that is not all in one color. For example, if all the colors in a color scheme have the same lightness, the requirement for diversity is handled by variation in hue, saturation, or both. Theoretically, every scheme should embody familial factors and contrast attributes on one or two dimensions.

Rhythm Span

Rhythm is a property of repeated distances in the color space. Our design of the rhythm follows Ostwald’s “order” principles on his color solid.⁵ For example, rhythm needs to be formed on orderly variables that are equidistant along one of the color space dimensions. In contrast, irregular color contrasts in a scheme emphasize some of the colors and unduly obscure others, as breaking up a rhythm inevitably destroys a piece’s unity and harmony.

We have adopted a rhythmic contrast principle for the color variables H, S, and L in which every color fits into a uniform rhythm. Regular distributions of H, S, or L are designed to create a rhythmic structure in a color scheme. Figures 2-4 present rhythmic principles for the three dimensions. To create rhythm in color scheme, there must be at least three colors, since otherwise there are no repeated distances to define the rhythm.

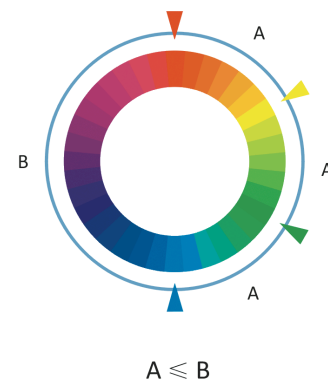


FIG 2. **Rhythmic principle for hue.** The distribution of the hues is uniform between adjacent hues in the selected hue space of A.

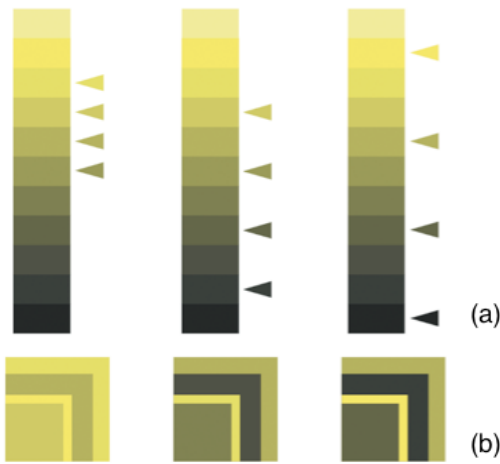


FIG 3. **Rhythmic principle for saturation.** (a) Some examples of the uniform steps on saturation contrast. (b) The square images of the effects by each of the three constructions in (a). The wider the total span, the stronger the contrast for saturation.

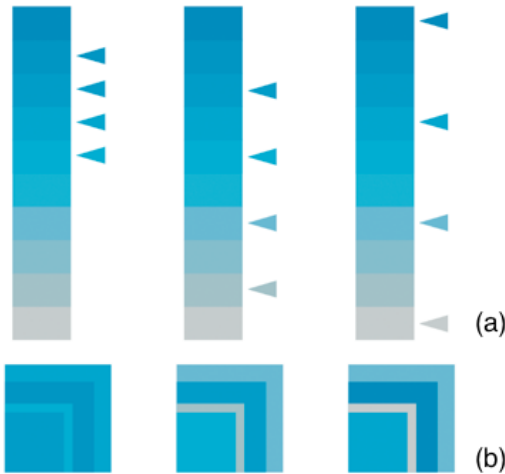


FIG 4. **Rhythmic principle for lightness.** (a) Some examples of the uniform steps on lightness contrast. (b) The square images of the effects by each of the three constructions in (a). The wider the total span, the stronger the contrast for saturation.

Because of the adaption of the two design principles of *familial factors* and *rhythm span*, we can easily achieve a unified modeling of hues that is considered to be harmonic by adjusting the rhythmic structure. Hues can be achieved by setting the number of colors and adjusting the distribution spans²⁸ as shown in Figure 5 using four classic settings of monochromatic, analogous, triadic complementary, and tetradic complementary colors. Monochromatic principle can be represented with identical hues; analogous principle spans lower than 90°, and complementary principles make use of the full span.

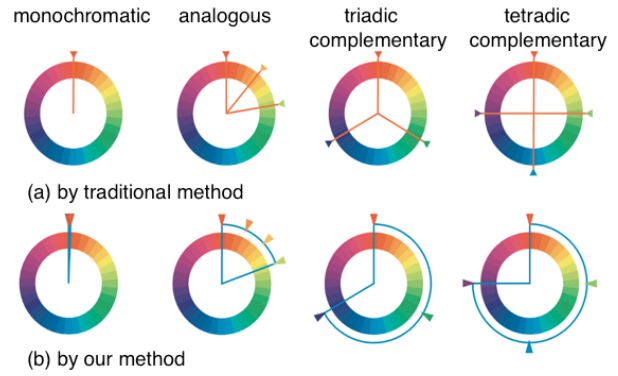


FIG 5. Our rhythmic principles of hues can be used to reconstruct the traditional harmony scales.

Design Considerations

Table 1 subdivides our two principles into six categories to demonstrate the detailed design considerations. In general, color schemes conforming to a uniform principle in one dimension are more diverse and colorful than those that are uniform in two or more color dimensions. On the other hand, those having a uniform principle in two axes are more unified and calm. Schemes with no uniform variable are not included in our method as they cannot be guaranteed to be harmonious.

One-uniform component	Two-uniform component
H_U, S, L	H, S_U, L_U
H, S_U, L	H_U, S, L_U
H, S, L_U	H_U, S_U, L

Table 1. Six settings with either one- or two-uniform component. H, S, and L represent hue, saturation, and lightness in rhythmic contrast; the footnote 'U' represents a uniform component.

HARMONIC COLOR GENERATOR TOOL

Our interactive color scheme generator toolkit allows users to manipulate the design principles (Figure 1). We have designed the HSL color cylinder for use in interaction (Figure 1(a)). The interactive model shows the HSL color cylinder similar to the Munsell color space familiar to artists and designers. This 3D cylindrical display shows the selected colors in the HSL color space and a widget user interface controls the tone tendency (Figure 1(b)) and HSL constraints for constructing color relationships using our two design theories (Figure 1(c)). The resulting colors (Figure 1(d)) and color pattern (Figure 1(e)) is also shown on the screen.

To control the familial factor, at least one dimension of the three parameters in the HSL color space must be kept constant and the user can alter the color variables in only one or two other dimensions. The Constraints Distribution part of the control (Figure 1(c)) has three slider bars to set the maximum span of hue, saturation, or lightness; these parameters can be set to be uniform by clicking the corresponding check-boxes.

Our interface also supports image import for coloring and saves the resulting new images generated by the system. Additionally, the user can set its average tendency using the Tone Tendency column GUI (Figure 1(b)). This feature is especially helpful to those who know the color effects they like to achieve. The system refreshes the image preview window (Figure 1(e)) instantly when the user changes the color design space. The tool also allows users to exchange colors among different areas on the preview pattern. Users can test and evaluate a color scheme by changing the juxtapositions from the preview panel (Figure 1(d)).

Figure 6 shows some of the harmonious color schemes constructed by our users by manipulating color relationships using our toolkit.

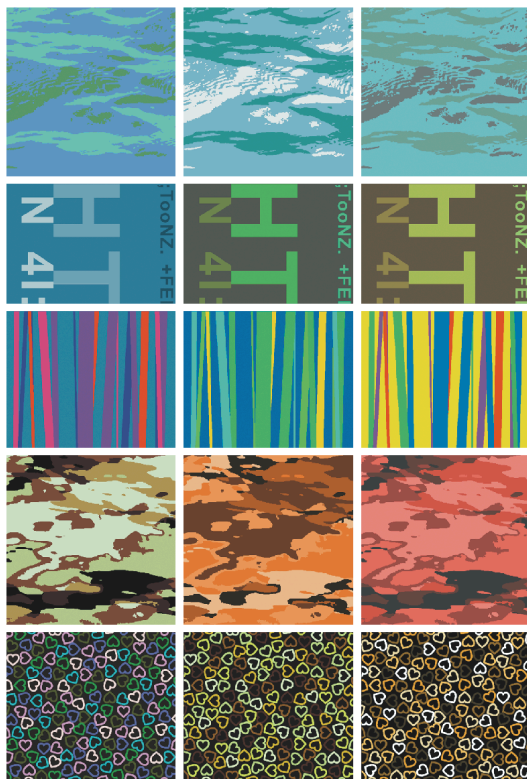


FIG 6. Some patterns constructed by participants using our toolkit.

EVALUATION

We conducted an informal, small-scale pilot experiment to test the usefulness of familial factors and rhythmic spans

and to see whether color schemes generated by the tool are aesthetically suitable or harmonious. If novice users can compose harmonious color schemes as easily as professional designers do, then our method would be useful. We thus recruited novice and expert participants with and without formal training in art or color design accordingly.

Participants

Twenty participants volunteered for the study, 10 in each group, of ages from 18 to 41 years. The 10 novices included a librarian, a law student, a secretary, three engineers, and four computer engineering students; the expert group had an interaction designer, two artists, three fashion designers, an art teacher, and three art students. Each of the 10 participant groups had five females and five males. We balanced gender because gender differences were common in color cognition. The participants were asked to state that they were not color-blind.

Evaluation tasks, procedure, and metrics

Participants were asked to compose 10 new color schemes from one pattern chosen from a pre-designed set of 10 patterns (Figure 7). These pre-defined 10 patterns had a different numbers of colors ranged from three to seven to form five categories – two patterns (A and B) from each of the five categories. Considering the influence of composition on color effect, these patterns were also designed in different styles such as latticed, symmetrical, character-based, wavy, and geometric.

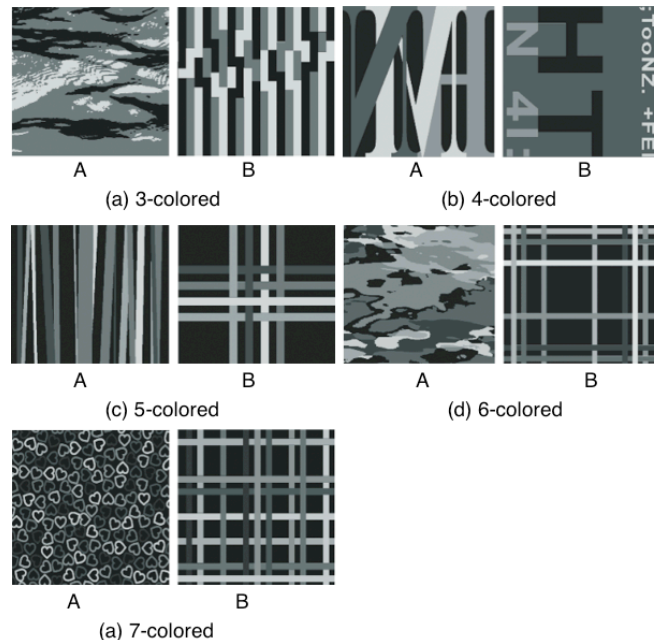


FIG 7. The ten patterns pre-designed for the experiment.

The participants were trained on some design principles and their uses in composing some color schemes. They were given several practice tasks and then asked to choose one of the patterns available and use it to build 10 aesthetically

pleasing color schemes. Calling for aid was allowed during the process only when they had problems using the user interface.

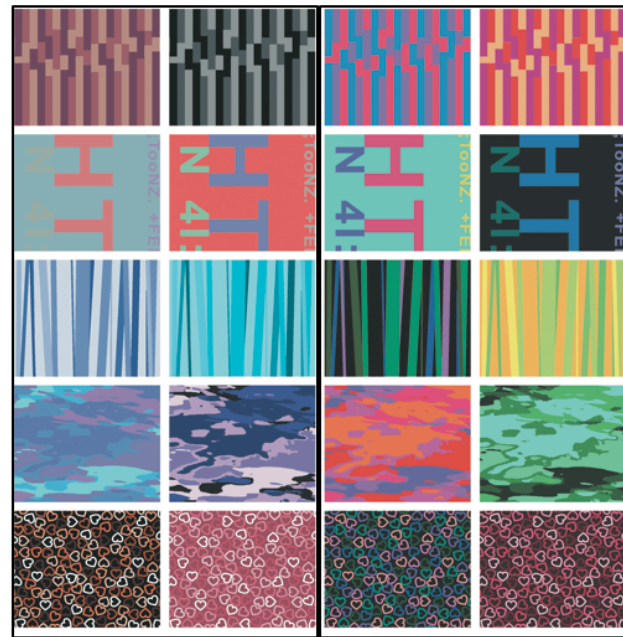
The test took 10 to 30 minutes to complete. The pattern design results in these two groups were compared and evaluated by 14 professional designers and artists (7 female and 7 male) to compare the aesthetic impression. There was no overlap between the participants and the evaluators. These evaluators were asked to choose the aesthetically harmonious color schemes from the experimental results. If our approach to color scheme generation is valid, then the number of images chosen from those generated by novices should be approximately equal to that chosen from the images generated by professionals. The evaluators did not know that the data they were evaluating belonged to two categories and the experimental images were randomly ordered. Each evaluator was asked to choose the 20 most aesthetically pleasing colored images from the 200 images.

Experimental Results and Discussion

Two hundred colored images were generated by the 20 participants. Figure 8 shows some of the composition results designed by professionals and novices. In general, feedback from the evaluators supported the contention that all the color schemes generated with the tool were holistically harmonious. Evaluators also commented that most of the images were beautiful, especially when browsed in full-screen view. Novices felt that they could compose harmonious colors even after a brief training in color-space concepts and the use of the tool. These comments showed that our design principles functioned as we intended.

From the 20 out of the 200 images that the 14 evaluators chose, it appeared that professional designers did slightly better than novices overall, where 151 and 129 pieces chosen from these two categories accordingly (Figure 9). The results were significant in the three-colored design scheme (13 from novices and 21 from professionals).

We have observed that expert evaluators often unconsciously chose some patterns more than the others. For example, the evaluators had preferences for specific patterns in the five-colored schemes: *five-colored A* and *five-colored B* showed distinct differences, with a ratio of 34 (17 from novices, 17 from professionals) to 20 (nine from novices, 11 from professionals), even though there were equal numbers of patterns in these two groups. When asked about this result, evaluators replied that pattern itself also influenced color effect. Participants preferred the abstracts five-colored A patterns.



(a) by professional

(b) by novice

FIG 8. Some patterns generated by participants.

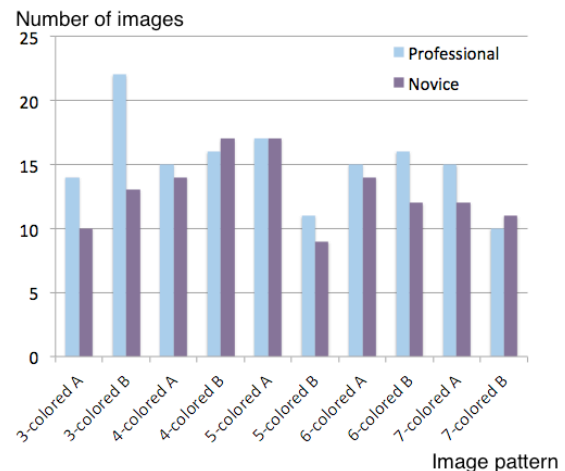


FIG 9. Summary experimental results of the number of images chosen by evaluators. The horizontal axis represents patterns in FIG 7.

Some expert evaluators commented that most juxtapositions of colors were represented in harmonic ways and providing the preview (Figure 1(d)) was good for optimizing the juxtapositions to provide visually pleasing harmonic color patterns (Figure 1(e)). However, they also discovered some ill-suited compositions, such as that in Figure 10. Experts preferred to use white background in Figure 10(b) instead and exchanged that color with the original background color in Figure 10(a). They suggested that the tool should allow changes in color area juxtaposition after the color scheme has been composed. This is because the color effect

of an image is influenced not only by color scheme but also by color juxtaposition and pattern.

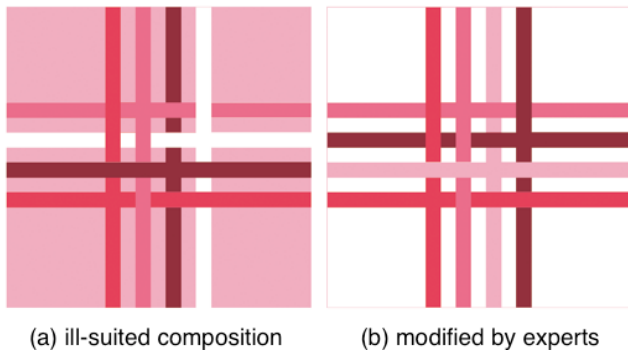


FIG 10. A color scheme created was ill composed in (a) compared to the new composition in (b) despite they had the same color scheme.

DISCUSSION

Our method focuses on the relationships in especially harmonic color generations, rather than on the variables of each color that other methods consider. Because of its overall working style, our tool prevents users from creating mismatched color styles. Users can modify one or two of the colors to create more harmonic colors without constraining other dimensions. This feature may limit professionals, but it frees novices to proceed in accordance with harmonious principles of color composition. Professionals commonly required more freedom to adjust colors one by one, since they had their own opinions about color usage. In contrast, many novices requested that built-in schemes be available because they were unaccustomed to the attribute relationships represented in the HSL color space. Therefore, our tool is more suitable for novices wanting to design good colors from scratch and for professionals wanting to test harmonic patterns once they had a design in mind.

It will be interesting to integrate more rules into our design, since some conventional color schemes follow semiological rules in addition to aesthetic ones. Two-color color schemes are determined only by contrast with freer color relationships over the harmony principles, so that they are not covered by this method. It will also be interesting to further test the mapping of the colors to some scientific data¹⁶ or digital media²⁹ or to compare the results to those mathematics-based approaches for specific applications.³⁰

CONCLUSION

This paper introduces a simple method of composing harmonious color schemes in accordance with two principles, familial factors and rhythmic spans, and discusses an interactive color-scheme generator tool developed on the basis of these principles. Owing to the

straightforward procedure and minimal interactive apparatus, this method lets users develop harmonious color schemes in a few easy steps.

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