Integrated combination of multiple colors as it is, color gestalt invariably troubles researchers as they seek to understand and analyze the complex constructions of affective factors. The author proposes a set of quantification methods for measuring color-affective factors of harmony, preference and structural composition. He also describes quantified models and interactive toolkits he built for both experimental purposes and user study. The author proposes a holistic method for understanding color combination that stands in contrast to conventional methods. Through this method, perception of color gestalt becomes computable and analyzable, inviting further research on interactive color computing and parametric design.

Color design generally involves interlacing colors into complex patterns, and both creating and analyzing color designs can be challenging. The term color gestalt, which refers to the integrity of multicolor design, generally hints at subtle interrelations of both color components and structural modes that determine how well the colors combine together [1].

Although there is clearly a conceptual relationship between color gestalt and Chevreul’s color principles of simultaneous contrast and harmony, the term gestalt as used here stems from gestalt psychology of cognition of the early years of the twentieth century [2]. Gestalt means that humans see objects with all of their elements taken together as a global construct, e.g. they see the overall interrelations between the figure in the foreground and the background, not only the individual component parts.

It is difficult to measure and analyze color gestalts because of the complicated interactions of their affective factors. For this reason, even though color researchers have studied affective factors for nearly two centuries, unquantified generalization still dominates their descriptions of color principles. Without quantifiable methods, one cannot reliably restore or reconstruct color gestalt by managing color combination rules. To this point, color research on computer platforms is largely infeasible, especially in regard to affective factors of multicolor relations. In general, there are three perplexing obstacles to current research on multicolor gestalt: interdisciplinary discrepancy (i.e. the differences between two given disciplines in terms of tools, approaches, etc.), the lack of a method for quantifying color combination and single-color focus (the tendency of researchers to take the colors as isolated objects when studying color affective factors in multicolor combinations).

- **Interdisciplinary discrepancy.** This discrepancy occurs when computers are brought into color research and application. Such a discrepancy is due to differences in the ways artists and computer engineers define and analyze color. Generally speaking, artists are accustomed to grasping and judging colors as a whole (color gestalt), while computer scientists tend to deduce parameterized relations from color appearances. Artists may describe a color gestalt using metaphorical expressions, such as “sparkling,” “vivid,” “elegant,” “gloomy” and so on. Computer scientists may intuitively weigh the individual factors that determine the overall color features. This discrepancy leads to obstacles for interchange between the instinctive synesthesia of artists and the programming languages used by computer engineers—computers cannot interpret the affective feeling of artists merely through synesthesia and metaphors. This discrepancy is a common problem for both artists and computer scientists in metaphorical-mathematical mapping.

- **Color standardization.** In color systems like Munsell’s, Ostwald’s, CIE, etc., colors are formatted as specific values of elements. The digitized element values allow color exchange between different systems. To some extent, color standardization implements color quantification and exchange in pigment mixing, color lighting and computer color simulation. This constitutes progress over previous conceptual systems, such as Goethe’s color wheel and
Runge’s color sphere; however, these systems do little to quantify color-affective factors and expression effects. Standardized color systems made progress in color digitalization but did nothing to further understanding and quantifying of color gestalt as integral expression.

- **Single-color focus.** In view of perceptual wholeness, color gestalt lies in the interactions of each component in sight. In contrast, traditional color researchers have usually taken colors as isolated objects, seldom perceiving color combinations as integral gestalts and leaving interrelations of color components untouched. Affective description and evaluation of color gestalt has remained a scarcely cultivated territory up to this point. Meanwhile, the concept of color in an art context is more likely to refer to multicolor combination than to single-color stimuli. Previous artistic investigations under gestalt theory have been unanimously based on multicolor compositions [3–5]. In short, isolated colors make no sense in an art context unless they are organized in certain interrelations that form an integral object.

For these reasons, color researchers should seek methods of affective factor quantification that can reconstruct and manipulate color gestalts. Each affective factor of color gestalt should be quantified and modeled for computing purposes. However, it is not enough to merely quantify individual affective factors; composing interrelations between each factor is also essential. Though it is complicated and challenging to do so, the integrity of different affective factors and the interrelations of each should be considered, too. Another matter is the diversity of individual observers. Although common sense exists in color perception, personal differences in response to color combinations can still be remarkable due to the observers’ personal instincts or cultural backgrounds. To avoid the interference of these subtle factors, researchers should make sure that each item under survey is confined in specific scope in order to isolate the affective factor from irrelevant subjects. The abstract organization of affective factors can then be restored and represented in a quantified data model.

The main concept of my method consists of classifying affective factors and constructing quantified models for each individual factor. I executed three research projects on aspects of, respectively, harmony principles, color preferences and composition factors. In the first project, I built a quantified model of harmony principles for harmony-acquiring and color-scheme generating. For preference quantification, I built a six-dimensional model of color preference traits to evaluate and reconstruct color combinations. In the project of composition factors modeling, I quantified the structural factors and their relations for structural assessment and composition rebuilding. Although there are other digitized color spaces such as CIE XYZ, CIE LAB, RGB cube and so on, I built my quantified models on HSL color space to make them more intuitive to artists, because artists are usually accustomed to the hue-saturation-lightness form.

### Modeling of Color Harmony Principles

Color harmony is pleasing affective or aesthetic content that is produced by colors when combined together [6]. Researchers after Goethe proposed many ways to generalize the principles of color harmony. Ostwald insisted that color harmony lies in ordered relations within elements, i.e. that the constitutive elements of harmonious colors are identical to chromatic spans, such as gradation, isotoncs, isoint and so on [7,8]. Itten proposed color harmony principles based on a series of graphic experiments, and he explained these principles using the metaphor of musical harmony [9]. Moon and Spencer divided the principles of harmony into categories of similarity, ambiguity, contrast and glare, in accordance with classical color harmony theory [10]. They also applied Birkhoff’s aesthetic measure $M = O / C$ (where $M$ stands for value of aesthetic measure; $O$ for order as identity, similarity, contrast and area balance; and $C$ stands for complexity as summation of color amount and pairs of colors with element difference) [11]. Pieters constructed a similar measure based on his own experimental results: $\text{Color Harmony} = S (+ \text{Change}) \times (\text{Hue Harmony} + \text{Lightness Harmony})$ [12]. Härder introduced a theoretical model for color harmony in which he divided harmony factors into three categories: color interval, color chord and color tuning [13].

However, all the aforementioned methods emerge from conceptual generalizations rather than computable measures. Moreover, many existing methods are confined to harmony principles of hue, leaving other element dimensions—say, saturation or lightness—unaddressed. Well-rounded harmony systems should be built on these all these factors together. Taking hue, saturation and lightness into consideration, I built an integral model of harmony principles by combining familial elements and rhythmic contrasts.

Lenclos proposed the concept of familial colors to refer to those colors with identical elements such as hue, saturation or lightness, because color combinations with corresponding elements tend to be harmonious [14]. In fact, Oswald had already proposed a similar idea, but his work emphasized the principles of contrasting elements, the opposite of familial elements [15]. According to familial color theory, one can set one or two of the three elements—i.e. hue, saturation or lightness—to be identical for all the colors to make a color combination harmonious. However, if all three elements are set in accordance with the familial rule, colors will become totally identical. Colors can only be distinct from one another if at least one element that fulfills the contrasts has different values. This leads to the other principle—rhythmic span for element contrast.

Rhythmic contrast refers to the element value contrast in repeated steps. Similar to the rhythm of music, rhythmic color contrast can be acquired by equal contrasts of element values. The idea of the color-rhythmic principle comes from Ostwald’s concept of color order [16]. According to Jacobson’s proposition, rhythm of color contrast can be acquired via equidistant color distribution in Ostwald’s color space. Conversely, unordered contrasts destroy rhythm and harmony, with some colors emphasized and others weakened. In accordance with the rhythmic principle, rhythmic span
determines the contrast of color combination (Fig. 1). The rhythmic structure of a color combination is constructed with identical spans of one or two element dimensions that do not follow the familial principle.

With familial and rhythmic principles combined, six styles of harmonious structure can be formed (Table 1). Those with only one element following the familial principle, and the other two elements in rhythmic contrast, tend to be more colorful and variable, while those with two elements following the familial principle, and only one in rhythmic contrast, tend to be purer and calmer. However, if all three elements follow the rhythmic contrast principle without familial dimension, harmony will be less likely, but the color combination may be more colorful and noisy. Following the two principles, harmonious color combinations can be constructed regardless of the diverse values of each component color.

I have built a color scheme generation toolkit of the model for user study (Fig. 2). With this toolkit, a user can generate harmonious color combinations by choosing and adjusting harmonious structure style in the GUI. The originality of the harmonious structures lies in global color interrelations and quantified element valuables. Hence, features of color combination can be quantified as global color relations rather than as the summation of individual colors. Further information and user study data for the project has also been published [17].

**QUANTIFICATION OF PREFERENTIAL TRAITS**

Color preference is a kind of affective bias both for individual colors and for color combinations. However, existing research focuses mainly on individual color preferences; it seldom focuses on preferences for multicolor combinations. This may be due to the difficulties inherent in analyzing the complex constructions of color combinations with multidimensional interrelation of elements. Nevertheless, there are still some contributions in the research related to multicolor combination. Chuang studied preference in two-color combinations and discovered that, in the preferred combinations, both components of color pairs were dominant, because people tended to favor those pairs composed of preferred colors [18]. Palmer and Griscom found that correlations between preference and harmony are reliably positive [19]. Schloss surveyed different opinions on preference, harmony and similarity, and found remarkable effect of element relations on two-color preference [20]. Ou et al. surveyed perception influence on multicolor combinations, such as gender, culture and other affective factors [21].

When it comes to preference research, it is crucial to begin by classifying the viewer subjects. It is meaningless to talk about color preference without considering viewers’ perception traits. However, few research projects have focused on individual preference, let alone further research in specific cases of various subjects. The reason may lie in two aspects: (1) although preferences of viewers may be significantly different without obvious common traits, data from a large group of homogeneous subjects are essential for some purposes; and (2) individual data may be less important to engineers, and people can seldom objectively describe their

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H₁, S₁ and L₁ represent hue, saturation and lightness elements in rhythmic contrast; H₂, S₂ and L₂ represent the uniform elements that follow the familial principle. (© Guosheng Hu)
own preferential traits, so that researchers in that field pay less attention to individual subjects.

I recognized that it was necessary to find a feasible method for measuring personal preference traits of color combination so that color preference could be considered on a personal level. For this purpose, I designed a quantified model for measuring combinative color features of personal preference. This model allows preferential color features to be determined and preferential color combinations to be reconstructed. Preferential color combination lies in acquiring personal preference parameters via the quantified preferential measure.

The preferential measure consists of the color distribution parameters in the HSL color space: the locations of the colors and the covered spans of the colors. While the colors themselves are determined by their own elements (hue, saturation and lightness), location parameters define the global color tendencies of the color combination, and span parameters determine the overall contrasts in each element dimension. For example, the higher the saturation span value is, the more intense the saturation contrast of a color combination will be. Every color combination can be represented as value codes of the six-dimensional parameters shown in Fig. 3. Preferential color combinations then can be constructed based on the personal values of these parameters. That is what I mean by "the quantified model for preferential traits"—the model measures the specific viewer's preferential traits in parameter values. I built an interactive system on the model to access personal data about color preferences and to generate preferential color combinations in reverse [22].

The preferential quantification method translates color combination characteristics into certain structural color relations rather than a totality of individual component colors. It can precisely measure out features of color combination regardless of number of colors and individual color values. In other words, color combination effects will be similar no matter how many colors the color combinations have and no matter what colors they are, if the color combinations possess identical structural parameters (Color Plate C, top). This method demonstrates a new way of understanding and analyzing multicolor combinations. The quantified preference model can be applied to color preference analysis, as well as to color research and application.

**MODELING OF COMPOSITION FACTORS**

Assuming a set group of component colors, composition is also an influential factor for color gestalt appearance. Research on color composition stems mainly from the studies of De Stijl artists in the early 1900s, such as Mondrian's painting experiments on composition of plastic units and colors [23]. At that time, color composition research witnessed great progress through intensive experiments and analysis at the Bauhaus. Color composition theories appear abundantly in the works and classes of teachers like Kandinsky, Klee and Itten [24]. Itten insisted that composition units—such as shape, area and block—have a significant influence on color presentation. Albers took a similar approach and made substantial progress in visual experiments [25]. He explored the interaction between color and composition through experimental painting and exposed the delicate compositional influence on pattern and color. These studies of color composition theoretically originated from gestalt psychology. Much of the explorations of the De Stijl artists, the Bauhaus school and Arnheim can be traced back to the experiments of Wertheimer and Rubin, who emphasized the wholeness of formative arts and the interrelation of plastic units [26,27].

However, these studies only revealed the influence of composition factors but are not adequate to describe that influence in quantifiable terms. Another problem was that these studies usually focused on area proportions while color gestalt is also influenced by other factors, such as position, shape and the interrelations of these factors.

In a survey of the structural factors, three factors—the area, distribution and patch amount of each component color—along with their interrelations, stood out prominently (Color Plate C, bottom). By borrowing ideas from Kansei engineering and affective computing domains, I was able to build a computable composition model accounting for these factors. Structural interrelations can be represented as quantified parameters via the model. Composition features and characteristics of each component color can also be evaluated.

For the purpose of quantification, I designed three linear scales for measuring the structural factors. Colors of larger area usually play predominant roles in images, while the smaller areas of color appear less significant. Area proportion of colors also has influence on figure-ground relationship. To quantify the proportion in scale value, I set the total area of an image to 1, so the range of area proportion...
for any given color is between 0 and 1. Color distribution plays an important role in color emphasis and figure-ground relationship. A centralized color is usually emphasized as the primary figure or dominant part, while a dispersive color usually fades into the background texture by cross-juxtaposing with other colors. To quantify the distribution of a color component, I set the distribution parameter between 0 and 1, using the distribution value 1 for a color that is absolutely dispersive and 0 for a color that is concentrated in a single area. To measure the distribution value of certain colors, I conducted a user study to help me build the algorithm. A color can be laid in a continuous area enclosed by other colors or it can be segmented into separate patches. This determines whether the shape of a color is a continuous shape or decentralized fragments. A lesser patch amount means the color is emphasized as a solid figure, while a greater patch amount means the color is interwoven with other colors. The patch amount of a color depends on the image configuration itself. Finally, I count each continuous area of color to get the total number of patches.

Taking all three scales into consideration, each color of an image has certain parameter values, respectively, on the axis of area, patch amount and distribution. The character of each color is codetermined by these structural parameters. When the comprehensive model is built at the conjunction of the three axes, the structural interrelations of the colors can be visualized, because every point in this coordinate space embodies a certain set of parameters. Figure 4 is the coordinate cube built on the three dimensions of the compositional factors. Composition features of both integral color image and each color can be visualized and analyzed in this coordinate space. The overall structural features can also be estimated according to the distribution of representative points in it. To test the coordinate model, I designed a visualization toolkit to evaluate color images (Fig. 5).

Although it involves only three structural factors, the affective evaluating cube presents a new method for understanding and analyzing the composition of color gestalt. The quantified structural model can also make color composition more legible and analyzable. In the field of application, this model can be applied to color gestalt assessment, automatic pattern design, data mining for structural features and so on. Further technical details are available elsewhere [28].

**DISCUSSION**

My interest in affective quantification of color focuses on the interrelations of the colors and the integrity of the color combination, namely color gestalt, so that my method of color affective quantification is to evaluate the combinative color relations but not to measure certain values for individual colors. The affective feature of each color combination can be measured as certain parameter values in these models. Effects of color combination can be evaluated relatively within the affective models. These models and methods can be adopted in color computing and computer-aided design. And as the data structure of color gestalt is embodied, these models will benefit color data analysis in artificial intelligence systems. Considering interrelations of component colors, these models can also help further research on color gestalt.

The three models of affective quantification were built separately on harmony, preference and composition factors. They take multicolor gestalt as an integral object by modeling the affective factors rather than defining each component color, as conventional methods do. These affective factors and their interrelations respectively affect color appearance, but that does not mean that color affect lies only in the three...
categories of factors. This article aims to introduce a quantification method for color appearance study and to inspire new methods for color gestalt research (Fig. 6).

For technical purposes, color affective factors are classified into individual items and then intensively surveyed one by one. However, it is still difficult to restore the complicated color gestalts through isolated models of affective dimensions. A more practicable way to conduct color gestalt study would be to build a synthesized model based on more rounded achievement of color affective quantification. Thus, I plan to undertake further studies in two directions: analyzing and quantifying more affective factors and constructing an integral computing model of synthesized affective factors.

Fig. 6. Echoes Talking. A generative work with the methods of harmony modeling and preferential traits measuring involved, 2015. (© Guosheng Hu)

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COLOR PLATE C: AFFECTIVE QUANTIFICATION OF COLOR GESTALT: MODELING OF AFFECTIVE FACTORS FOR COMBINATIVE COLOR DESIGN

Top: Comparison of color combinations with identical preference parameters. Color combination of preferential traits can be restored via the structural measure of the six-dimensional model, regardless of the individual component colors. The left image has three colors, while the right one has five. All the colors of the two images are different. But the two images have similar color effects for the structural parameters they share. (© Guosheng Hu) Bottom: Comparison of compositional factors. Color gestalt is not only determined by colors themselves but is also significantly influenced by the composition they interweave. The images above of one color scheme are obviously different in proportion of area covered, distribution and patch amount of each component color. The three factors characterize the overall color effects. (© Guosheng Hu) [See article in this issue by Guosheng Hu.]