# Color Scheme Search: A Statistics-Based IEC Method

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**Abstract:** This paper presents a statistics-based interactive evolutionary computation (IEC) method for color scheme search. Color schemes are utilized in an enormous range of items such as websites, clothing, advertising media, and housewares. However, people who do not have sufficient skill or knowledge of colors need to devote considerable time and effort to a creating color scheme. Currently, artists' color schemes are freely available from websites. However, obtaining an appropriate color scheme from a large data set is difficult for novice users. To overcome this problem, we rely on a statistics-based interactive genetic algorithm (IGA). Use of this IGA is expected to reduce computing costs compared with conventional IEC approaches and to take overall color scheme impressions into account. These contributions enable to realization of the *kansei*-based color search system in real time. In addition, we introduce four similarity search (SS) functions (hue, saturation, brightness, and color differences) to facilitate the convergence of a color scheme search. The combination of a statistics-based IGA and four SS functions allows users to easily and effectively find their desired color schemes. To investigate the performance of the proposed method, we conducted two experiments and confirmed that the implemented application allows users to obtain a desired color scheme in less than 48 s. In addition, we also confirmed that the proposed method can provide some favorable recolored illustrations in less than 52 s.

**Keywords:** Color Scheme Search, Interactive Evolutionary Computation, Statistics, Color Transfer.

## 1. INTRODUCTION

A color scheme is a significant element in most designs. Recently, some color websites, such as COLOURlovers[1] and Adobe® Kuler[2] have been available for general use. These websites allow

[1] COLOURlovers, http://www.colourlovers.com/ (accessed in January 2014)

users to share artists' color schemes and utilize them freely. However, finding their desired color schemes from a large dataset is difficult for novice users. Hence, people who do not have sufficient skills or knowledge of colors need to devote more time and effort to obtain their favorite color scheme.

In previous studies, an interactive evolutionary computation (IEC) has been applied to some color support systems for color scheme creation or color design. Existing IEC-based color schemes generating systems provide users with several suggested color schemes (Inoue et al., 2009; Tobitani et al., 2012). Other existing systems support color design for clothing, interior accessories, and products (Sugahara et al., 2008; Ito et al., 2009; Miki et al., 2011; Hsiao et al., 2013). An IEC-based approach gives users various color scheme candidates by changing color patterns; hence, users can find their favorites among all candidates. Furthermore, this method uses some human inputs; consequently, it is possible to gradually narrow the candidates based on user *kansei* (sensibility, preference, and aesthetic). Conventional IEC-based systems directly encode all color data in RGB, HSB, or L*a*b* color space; thereby, these approaches incur increasing computational costs with the number of target colors increases. In fact, most previous studies did not target more than three colors. Because of this limitation, a color scheme search method using the conventional IEC method typically does not handle more than three colors.

To overcome this limitation, we adopt an IEC method based on statistics. This new approach has two advantages. First, it decreases the computing cost compared to conventional IEC-based approaches because the proposed approach fixes the number of data; second, it maintains overall color scheme impressions. Previous studies have reported that people respond similarly to specific colors or color schemes (Kobayashi, 1992; Matsuda, 1995; Chijiiwa, 1999; Ou et al., 2004). The common responses or impressions are related to combinations of hue, saturation, and brightness. The statistics-based approach enables the overall impressions to be changed by using the statistics of a color scheme. In contrast, conventional IEC-based approaches do not consider the overall color scheme impressions. The proposed method enables users to find a desired color based on the user's *kansei*.

As mentioned previously, the features of the proposed method realize the *kansei*-based color search system in real time. In addition, this system introduces four similarity search (SS) functions based on hue, saturation, brightness, and color differences. Consequently, we expect that the combination of the proposed IEC method and four SS functions will enable users to find their desired color schemes based on their *kansei*.

## 2. RELATED WORK

Color is an effective graphic design element and can change the impressions of almost all advertising media. To fully utilize the effects of color, color harmony is significant because an appropriate combination of colors enables people to convey information efficiently and effectively. Moon & Spencer summarized a color harmony theory and quantified it as an aesthetic measure (Moon & Spencer, 1944a; 1944b; 1944c). Matsuda has created a color harmony model by summarizing some forms, schemes, and relationships in a practical color coordinate system developed by the *Japan Color Research Institute* (Matsuda, 1995). Previous studies were able to model or theorize color harmony. By referring to these outcomes, other studies have reported some color support methods for color transfer, color scheme creation, and other applications.

[2] Adobe® Kuler, https://kuler.adobe.com/create/color-wheel/ (accessed in January 2014)

## 2.1. Color support methods

O'Donovan et al. and Lin et al. used a similar approach to investigate color compatibility or color impressions (O'Donovan et al., 2011; Lin et al., 2013). This approach uses large color datasets or data of user experiences. By analyzing these large datasets, O'Donovan et al. studied color compatibility theories and Lin et al. proposed two methods: a probabilistic factor graph model for coloring and a method for extracting color themes from images using a regression model. These methods allow users to utilize colors effectively. However, people also use an inharmonic color scheme intentionally to attract attention in advertising material. Therefore, our proposed method also considers inharmonic color schemes.

## 2.2. IEC-based color support methods

Inoue et al., Kinoshita et al. and Tobitani et al. have presented IEC-based color creation methods (Inoue et al., 2009; Kinoshita et al., 2006; Tobinatani et al., 2012). In particular, The method of Kinoshita et al. incorporated Moon and Spencer's color harmony equations. Sugahara et al., Ito et al., Miki et al., and Hsiao et al. have proposed colorization methods for Japanese kimonos (Japanese-style clothing), t-shirts, office space design, and product color design, respectively (Sugahara et al., 2008; Ito et al., 2009; Miki et al., 2011; Hsiao et al., 2013). The advantage of IEC is the incorporation of human evaluations into the results. Thus, IEC-based method makes it possible to obtain a desired result.

# 3. STATISTICS-BASED IEC METHOD FOR COLOR SCHEME SEARCH

Conventional IEC-based color support systems do not consider the characteristics of colors. Previous studies have introduced an objective function to adjust color scheme candidates based on color harmony theory (Kinoshita et al., 2006; Troiano et al., 2009; Tobitani et al., 2012). This is a good solution for the creation of harmonious color schemes; however, the use of the object function becomes a hindrance when obtaining a favorite color scheme. In addition, it is difficult for novice users to take color harmonics into consideration when generating a desired color scheme.

To overcome these issues, we utilize enormous color scheme dataset available from color websites. Consequently, the effective color scheme search method is required. This section describes our proposed statistics-based IEC method for color scheme search.

## 3.1. Statistics data of color scheme in IEC

Our proposed statistics-based IEC uses basic statistics: average values, standard deviations, or coefficient of variations in a color scheme. We focus on the overall color scheme impression. The impression is related to hue, saturation, and brightness. For example, when a user wants a warm color scheme, he/she will look for a reddish color scheme. We consider the statistics of overall impressions for color schemes. Human perception of colors is an important factor when choosing color schemes. Generally, HSV and HLS color models are utilized for hue, saturation, and brightness values. However, these models do not consider human perceptions. L*a*b* color space is a well-known perceptually-based color model. Color difference in L*a*b* indicates the Euclidean distance in the color space, and this distance corresponds to human perceptions. We uses L*c*h* values, which are represented in L*a*b* color space. L*c*h* means brightness, saturation, and hue values respectively. Note that $c^* = \sqrt{(a^*)^2 + (b^*)^2}$ and $h^* = \arctan(b^*/a^*)$, $L^*$ are calculated in L*a*b* color space. To consider human perception as much as possible, this study adopts the perceptually-based saturation $S = \sqrt{a^* + b^*}/\sqrt{a^* + b^* + L^*} \times 100\%$ reported by (Lübbe, 2010) instead of $c^*$. Therefore, we adopted the average values $L^*_{ave}$, $S_{ave}$, $h^*_{ave}$, the coefficient variations

**Table 1:** GA parameters and genetic operations

| Population size | Number of elites | Selection method |
|---|---|---|
| 9 | 2 | Roulette Selection<br>Elite Selection |
| **Crossover** | **Crossover rate** | **Mutation rate** |
| Uniform Crossover | 1.0 | 0.3 |

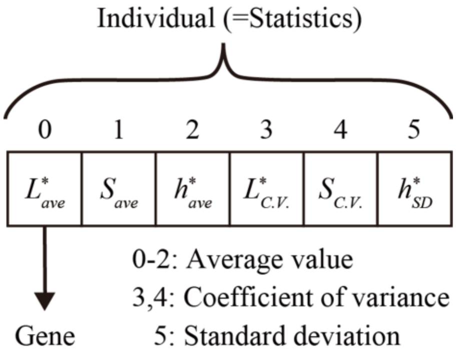



**Figure 1:** Configuration of an individual

$L^*_{C.V.}$, $S_{C.V.}$, and the standard deviation $h^*_{SD}$.

### 3.2. Interactive genetic algorithm for a color scheme search

In this study, we adopted an interactive genetic algorithm (IGA), which is a commonly used IEC method. Next, we describe the statistics-based IGA for color scheme search. The IGA processes are described in the following seven steps. GA parameters and the genetic operations are shown in Table 1.

STEP 1. Generate initial population

Statistics for an individual are provided in Figure 1. An initial population of IGA is strongly associated with IGA search performance. In this study, the search space is a dataset of color schemes; therefore, all generated individuals are color scheme data in the color scheme database (DB). The IGA used here utilizes probability distributions of each cluster to generate various candidates in the initial population. The process of generating the initial population is as follows.

The first process uses multidimensional scaling (MDS) for the color scheme DB. Then the color scheme DB is visualized as a 2D map.

The next process applies a k-means clustering technique to categorize the 2D map. Note that the number of neighboring clusters is set as $k = 9$ based on the dendrogram result. Figure 2 shows the results of k-means clustering. Each point is a color scheme in the DB. The coincident colored points have same cluster ID. Nine black points indicate the center of gravity of each cluster.

Final process assigns nine probability distributions on the basis of the Euclidean distances between each point and its center of gravity. The upper right portion of Figure2 shows the probability distribution of the brown cluster. The gradation colors show the probabilities. The reddish color denotes color schemes that have higher probabilities, and the bluish color denotes color schemes that have lower probabilities. A candidate is selected from the color scheme DB based on

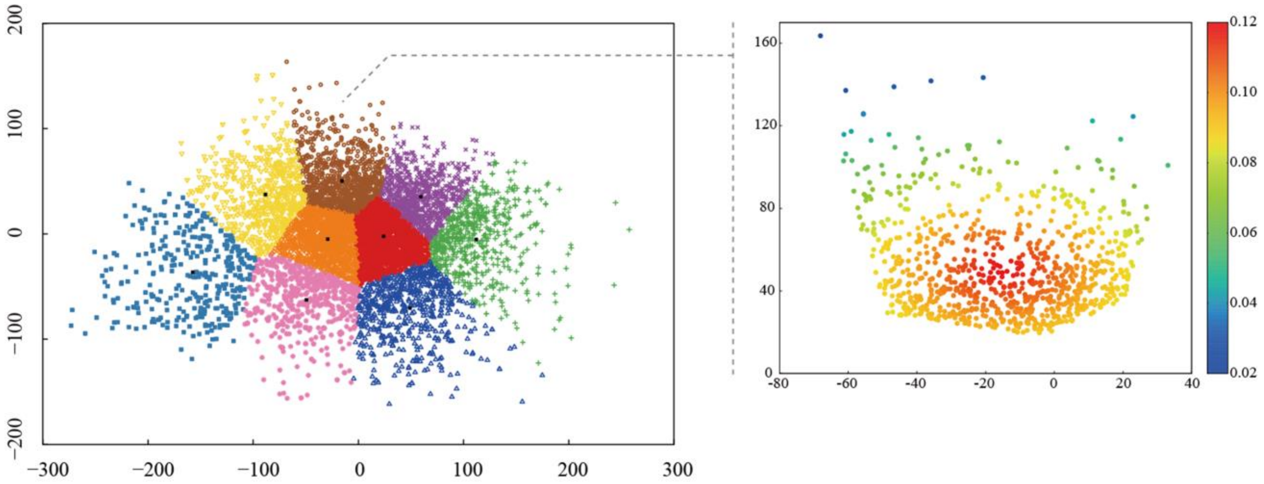



**Figure 2:** Result of k-means clustering and upper right portion is an example of a probability distribution

a probability distribution. Hence, nine candidates are stochastically chosen from the color scheme DB based on the probability distributions of each cluster as the initial population.

STEP 2. Replace all genes

General IGAs are used to generate fonts or musical content by combining parameters (genes). In this study, the IGA does not generate color schemes; it displays color scheme candidates. This method replaces each gene of an individual color scheme with each statistic of the color schemes in the DB. First, the fitness value is calculated by comparing an individual with each DB color scheme. Then, all genes of the individual are replaced with the set of statistics that has the maximum fitness value among the dataset in the DB. The fitness value $F$ is defined as follows:

$$F = 1.0 - \sum_i \omega_i A_i / \sum_i \omega_i,$$
$$A = \{\Delta L^*_{ave}, \Delta S_{ave}, \Delta h^*_{ave}, \Delta L^*_{C.V.}, \Delta S_{C.V.}, \Delta h^*_{SD}\} \tag{1}$$

Here $\omega$ is a weighting parameter and $A$ is a set of the difference values between the current selected color scheme and a DB color scheme with each statistic. In this study, all weighting parameters are set to $\omega = 0.2$ $(i = 1,2, \ldots ,6)$. In the future study, appropriate weighting parameters determined by user feedback will be investigated.

STEP 3. Display candidates

Nine candidate color schemes are displayed. These candidates are determined by each individual after the readout of the color schemes from the DB.

STEP 4. Evaluate candidates by user

A user evaluates the displayed candidates by choosing a candidate that is close to their desired color scheme. This method accelerates IGA search because the user performs an evaluation at each iteration (Kimura et al., 2008). If the user finds a desired color scheme, the process is terminated.

STEP 5. Select individuals

Here, the IGA uses Elite Selection and Roulette Selection as individual selection methods. In Elite Selection, the selected individual in STEP 4 (Elite *A*) and the individual with the maximum fitness (Elite *B*) become elites. In Roulette Selection, seven individuals are selected stochastically based on Eq. (2).

$$P_i = \frac{S_i}{\sum_{i=1}^{N} S_i} \qquad (2)$$

Here $s_i$ is the fitness value between Elite *A* and each individual $i$. $N$ is the number of all individuals excluding Elite *A*. This study sets $N$ = 8. Note that Elite *A* remains a selected individual each time.

STEP 6. Crossover

The IGA has adopted the uniform crossover technique. This technique exchanges the corresponding statistics. In this IGA, four pairs of individuals are selected from all individuals including the two elites. This process considers color compatibility on the basis of hue and tone (brightness and saturation) (Kobayashi, 1992; Matsuda, 1995; Cohen-Or et al., 2006; O'Donovan et al., 2011). Thus, for brightness and saturation, an average value and a coefficient of variation are paired. Two pairs exchange the statistics with each value. For hue, the average value and the standard deviation are exchanged individually. Note that the probability of exchange is 50% for each statistic item.

STEP 7. Mutation

The mutation process also considers color compatibility. This process has three replacement target patterns: statistics in brightness and saturation, statistics in hue, and all statistics. Note that the replacement target pattern is determined by a one-third probability. This mutation process randomly chooses a color scheme from the DB. Each statistic value of an individual is replaced with each corresponding statistic of the chosen color scheme. Note that the probability of running this process is determined by the mutation ratio.

## 4. COLOR SCHEME SEARCH APPLICATION

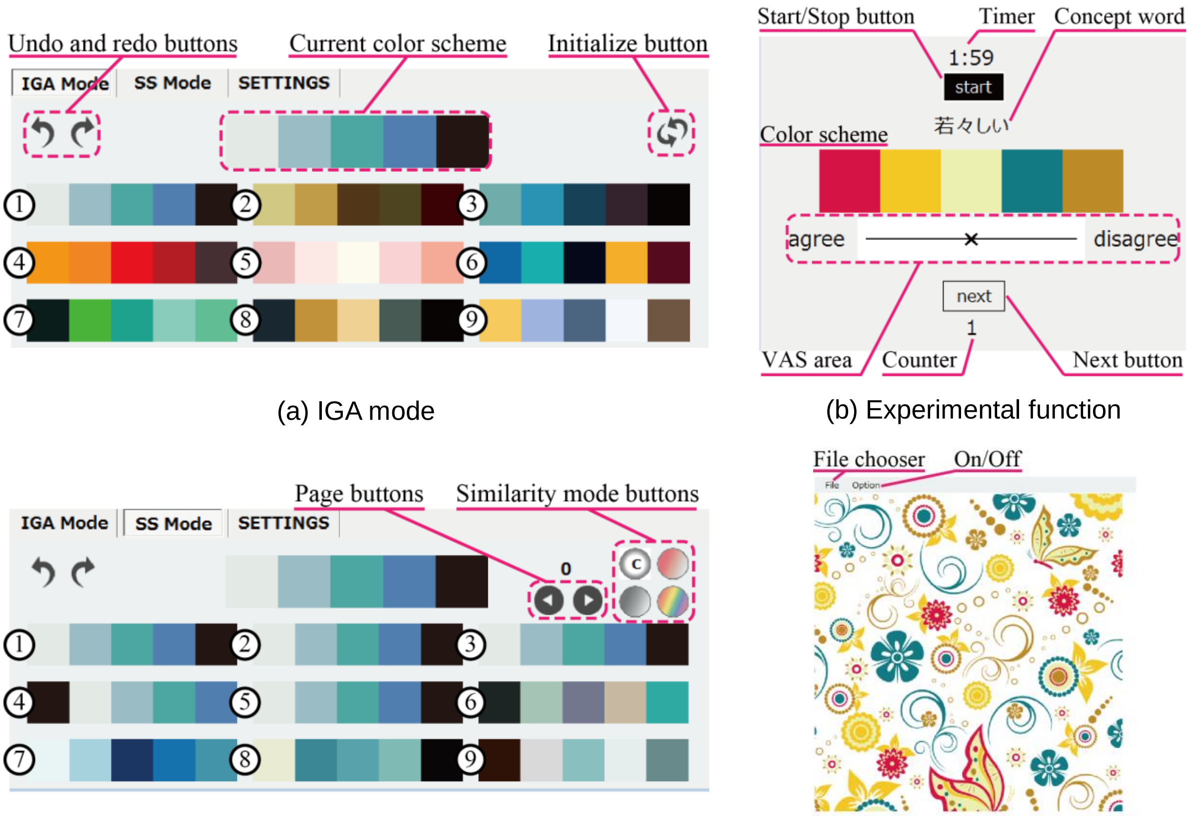
A color design support application has been implemented by using the proposed method. Furthermore, this application incorporates four SS functions. The combination of the proposed method and the four SS functions improve the search performance. This section describes the application and the details of the four SS functions. In addition, this application has a color transfer function. This section also illustrates the process flow. Figure 3 shows screenshots of each function in the implemented application.

### 4.1. IGA mode: the color scheme search function

Figure 3 shows a screenshot of the color scheme search function, named IGA mode. The IGA mode applies the proposed statistics-based IGA. The statistics-based IGA enables searching of a color scheme based on an impression of overall color scheme. Thus, the various color scheme candidates can be displayed. Normally, users use this mode to search for various types of color schemes as a global search. This system consists of undo and redo buttons, the display area for each color scheme, and an initialize button. This mode simultaneously shows 10 color schemes. The biggest color scheme shown in Figure 3(a) indicates the currently selected candidate. The other color schemes are the selectable candidates. This system displays various color scheme candidates based on user evaluation, and the displayed candidates are gradually narrowed with each iteration of the user selection operation. The evaluation is performed by clicking on a favorite color scheme. When the user chooses a candidate, the system presents other candidates.

### 4.2. SS mode: four similarity search functions

Figure 3(c) presents a screenshot of the SS mode. The SS mode has four different SS functions. One function is based on the color difference in L*a*b* color space. This similarity is a minimum




(a) IGA mode

(b) Experimental function

(c) SS mode

(d) Color transfer function

**Figure 3:** Screenshot of the color design support application

value among a set of the sum of values of color differences for every color scheme and each DB color scheme. This SS function shows results in ascending order. The other functions are based on hue, saturation, and brightness. These SS functions also shows results in ascending order, respectively. In addition, we set two constraint parameters $\varphi^A$ and $\varphi^B$to preserve overall color impression. $\varphi^A$ is relative to the average values of hue, saturation, and brightness ($L^*_{ave}$, $h^*_{ave}$, and $S_{ave}$), $\varphi^B$ is relative to the coefficient variations of saturation and brightness, and the standard deviation of hue ($L^*_{C.V.}$, $S_{C.V.}$, and $h^*_{SD}$). For example, in the case of brightness, the SS function candidates fulfill the following condition; the SS function candidates fulfill the following condition; $|\Delta h^*_{ave}|^2/|\varphi_1^A|^2 + |\Delta S_{ave}|^2/|\varphi_2^A|^2 \leq 1 \cap |\Delta h^*_{SD}|^2/|\varphi^B|^2 + |\Delta S_{C.V.}|^2/|\varphi^B|^2 \leq 1$. The same constraint is employed for hue and saturation. Note that $\varphi_1^A$ is set for hue and $\varphi_2^A$ is set for saturation and brightness. We set these parameters as $\varphi_1^A = 18$, $\varphi_2^A = 5$, and $\varphi^B = 0.1$.

### 4.3. Color transfer function

This application has a color transfer function that changes the color pattern of a scalable vector graphics (SVG) image. SVG images do not deteriorate by color transfer processing and can be rendered most web browsers. The color scheme search function targets five colors. However, some SVG images are composed of more than five colors. Thus, a color reduction process is required for color transfer processing. The color reduction process continues to merge a pair of colors with the smallest color difference until the number of colors becomes five. This process is based on a process presented in (Kondo et al., 2000) shows a screenshot of this function. The color reduction process applies the specified SVG image. When the user chooses a color scheme using the color scheme search function, this color transfer function changes the color pattern of a SVG image based on the chosen color scheme. Each color assignment is determined by the color difference of

CIEDE2000. The function computes the sum of color differences for all assignment patterns, and the assignment pattern with minimum value is applied.

## 5. EXPERIMENTAL EVALUATION

The proposed color search method can search a desired color scheme without the user having any knowledge or skills regarding colors. We considered that setting a user's desired color scheme is difficult for novice users because the desired color scheme is often unclear in the user's mind. Furthermore, the user may frequently change the desired color scheme during the color scheme search. Therefore, it is impossible to evaluate whether the user can actually obtain a desired color scheme. Section 1 described some common impressions that people characteristically have of specific colors and color schemes. We conducted an experiment that focused on this characteristic. In addition, we also conducted an experiment using the color transfer function. The goal of the second experiment was to investigate the effectiveness of the practical use of the proposed method.

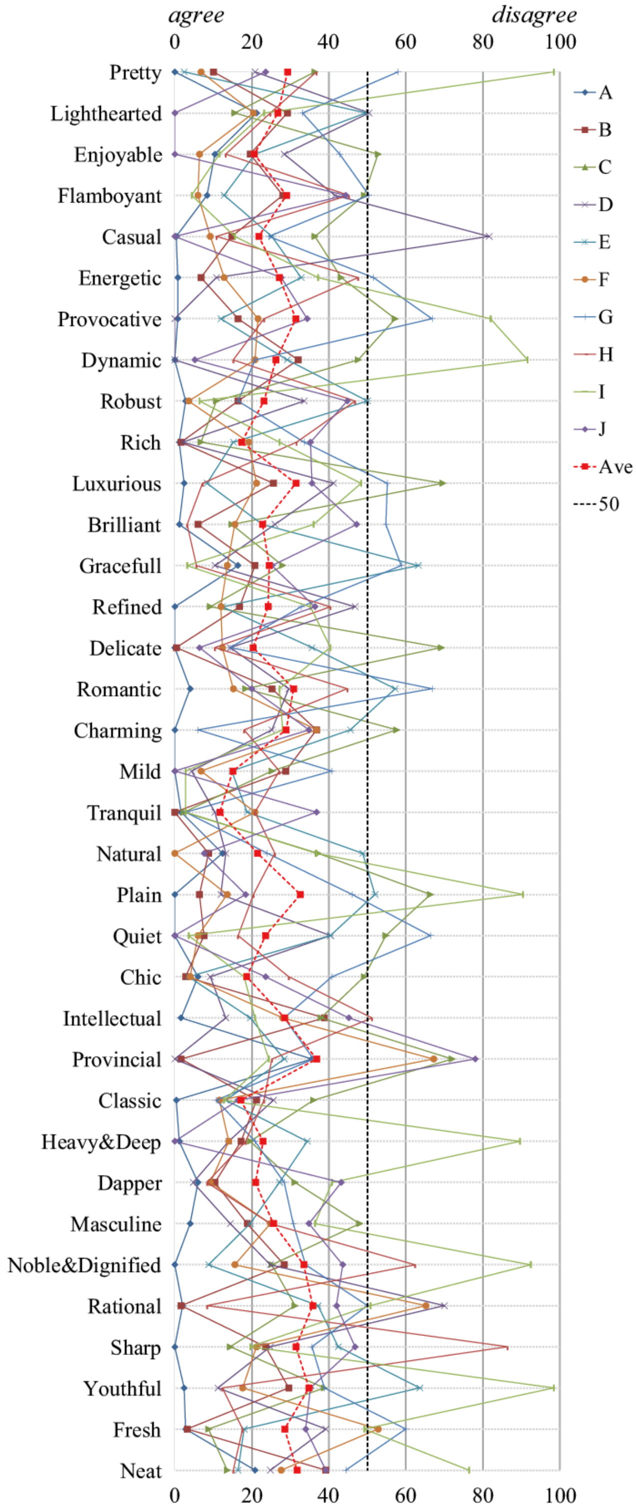
### 5.1. Details of the two experiments

The task of first experiment was to find a suitable color scheme for some concept words. Figure 3(b) shows the experimental function. This function has a start and stop button, a timer, a display area for a concept word, a display area for the selected color scheme, a visual analog scale (VAS) area (an evaluation area), a counter, and a next button. First, the participant searched for a suitable color scheme for the displayed concept word using the color scheme search system. If the participant found the best color scheme or exceeded the time limit, the experiment was terminated. The evaluation method adopted a VAS (Cox & Davison, 2005). The evaluation item of this experiment was “agree-disagree” scale. Thus, the participants were required to evaluate whether the color scheme gave the same impression as the concept word. The evaluation range of the VAS was from 0 to 250.

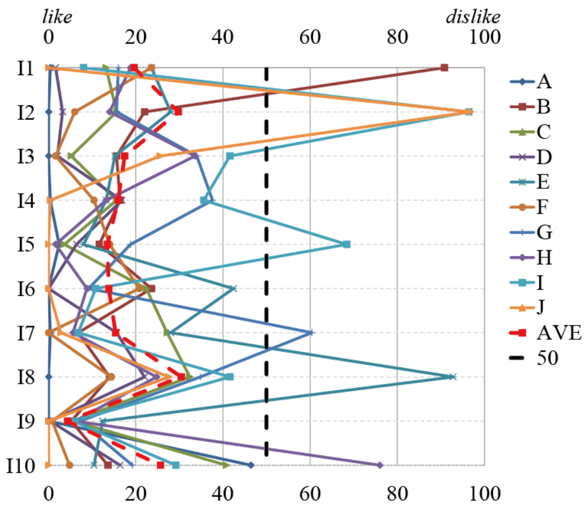
The task of the second experiment was to determine the preferred color pattern for some SVG images. The participants could change the color pattern of each SVG image using the proposed color scheme search method. If the participant found the best color scheme or exceeded the time limit, the experiment was terminated. The participant evaluated the recolored SVG images using the VAS with a “like-dislike” scale. The SVG images were displayed sequentially, as is shown in Figure 3(d). The size of the display area was fixed at 500×500 pixels, and each SVG was scaled to fit in the entire display area.

In both experiments, the time limit was 2 min. Ten male graduate students in 20s participated in the experiment. The experimental equipment included the LCD monitors (FlexScan M1950-R, Size: 19 inch, Resolution: 1280×1024) and PCs (Intel Core i7 2.3GHz, 8GB RAM). In some cases, different equipment of equal performances was used. The color of the LCD monitor was adjusted by using the following values: color temperature, 6500K; contrast, 50; brightness, 30. The distance between each participant and the LCD monitor ranged from 40 to 50 cm. All participants performed this experiment in the same room. The first experiment used 35 concept words described by (Kobayashi, 1995). The second experiment used 10 vector images selected from a website[3]. The DB was constructed by using 7850 color schemes from COLOURLovers.

[3] ALL-free-download.com, http://all-free-download.com/ (accessed in January 2014)




(a) Results of the first experiment




(b) Results of the second experiment

(c) Selected color schemes for “Tranquil”


(d) Recolored images for “I9”

**Figure 4:** Experimental results

### 5.2. Experimental results

We recorded all evaluation items and operation times for both experiments. Figure 4 show the results of the first and second experiment.

In both results, the letters are the participants ID. The red dashed line indicates the average values of the experimental results. The black dashed line indicates the center value. Note that all


(a) Example A (ID: I1, I2)


(b) Example B (ID: I9, I10)

**Figure 5:** Examples of recolored images

evaluation values are normalized in the range [0, 100]. In the first experiment, 0 indicates "agree" and 100 indicates "disagree." The results are shown for each concept word. In the second experiment, 0 indicates "like" and 100 indicates "dislike." IDs, such as "I1," indicate each illustration (examples are shown in Figures 5 and 6). The average time for the first experiment was 47.30 s. The average time for the second experiment was 51.97 s.

In the first experiment, all average values indicate "agree." The results for the concept word "Tranquil" strongly indicate an "agree" response. Figure 4(c) shows examples of the selected color schemes for "Tranquil." These examples have two features. Some color schemes consist of (1) similar tone (saturation and brightness) patterns and (2) similar hue patterns. The results indicate that the statistics-based approach works effectively.

This result indicates that the proposed method allowed users to obtain a desired color scheme based on concept words. Furthermore, the average operation time was 47.30 s. In the experiment discussed by (Inoue et al., 2009), which targeted three colors, the average operation time was approximately 1.5 min. However, the proposed method targeted five colors, and the operation time was less than that of the existing method proposed by (Inoue et al., 2009).

In the second experiment, all average values indicate "like" responses. The results for "I9" strongly indicate "like" responses. Figure 4(d) shows examples of recolored images for "I9." The common feature is that the silhouette regions (castle and bats) are darker colors. We suppose that the castle and the bats in the image gave the specific meaning as "silhouette," thereby the participants fixed a darker color. From this assumption, the participants would focus on the other four colors in their color choice. Consequently, the participants could determine a favorite color pattern more easily and efficiently.

The operation time was only 3 s slower than the first experimental result. The participants could obtain a favorable colored illustration using the color scheme search. Therefore, we assume that the proposed method has an acceptable level of practical usability. Figures 5 and 6 show some


**Figure 6:** Examples of recolored illustrations (ID: I3 -I8)

examples of the recolored illustrations. Note that the ID numbers corresponding to Figure 4(b).

## 6. CONCLUSION

This study aims to find a desired color scheme without any requiring the user to have special skills or knowledge regarding colors. To achieve this goal, we proposed a color scheme search method using a statistics-based IEC method. The proposed statistics-based IEC method considers overall color scheme impressions. The proposed method provides the suggestions for various types of color scheme candidates and gradually narrows the candidates based on user evaluations. A color support application was implemented for experimental evaluations. This application introduced four SS functions and a color transfer function. To investigate the effectiveness of the proposed method, two experiments were conducted.

The experimental results confirm that the implemented application allows users to obtain a desired color scheme in less than 48 s. Relative to operation time, the proposed method is superior to the existing method proposed by Inoue et al. In addition, the results of the second experiment indicate that the proposed method enables users to obtain some favorable recolored illustrations in less than 52 s. Therefore, we consider that the proposed color support method is valid for practical use. In future, we will improve the proposed method by including the ability to respond to gradational color combinations and texture combinations.

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