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Research Article

Generating Harmonious Colors through the Combination of n-Grams and K-means

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Abstract: Among the many approaches to studying color harmony tried so far, a relatively recent method is to leverage a large number of human-created and ranked color palettes, such as those hosted at colourlovers.com. Analysis of these large datasets could provide insights into the nature of color harmony but is usually overwhelming because of the sheer number of slightly differing colors. It is possible to quantize the colors in these color palettes to a manageable set of discrete colors without significantly affecting the harmony perception of the palette. Considering the quantized colors as words and the palettes as sentences, it is possible to form and compute the probabilities of n-Grams in the sentences. In this study, we create bigrams and trigrams from the corpus of highly ranked color palettes and use them to predict new color combinations. Respondents were asked to like or dislike the patterns colored with these color combinations. It was found that the new color combinations thus formed were almost as harmonious and pleasing as the originals.

Keywords: Color combination; Color harmony; Color quantization; Large datasets; n-Gram

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1. Introduction

1.1 Background

Color harmony is the aesthetically pleasing arrangement of colors within a composition [1]. It is a fundamental concept in design, art, and visual composition. Color harmony is important in different fields, such as graphic design, interior design, fashion, fine arts, etc. Currently, it is a multi-disciplinary study involving principles from physiology, psychology, and technology for creating visually impactful and engaging compositions.

Color and color arrangement have piqued the interest of scholars of all times since Aristotle, Sir Isaac Newton, Johann Wolfgang von Goethe, ME Chevreul, and Johannes Itten to name a few [2]. The 20th century saw continued development in the study of color harmony with new theories and technological advancements influencing the field. In the 21st century, the study of color harmony has continued to evolve, with researchers incorporating further technological advancements, cognitive science, and cultural studies [3].

Recently, there has been a rapid increase in the number of human-created harmonious color combinations. At sites like colourlovers.com, color.adobe.com, and coolors.co, users have created and ranked a large number of colors and color palettes. This study focuses on the data available at colourlovers.com, which provides an API [4] that gives access to the full range of data that it has collected since 2005. Currently, there are more than 10 million colors, 5 million color palettes, and 6 million colored patterns available for analysis of color aesthetics and color harmony.

1.2 The Problem

The analysis of large datasets of crowdsourced color palettes could lead to novel ways of creating harmonious color palettes. However, the problem with using large datasets of colors to study color harmony is that several recurrences of colors appear similar but are considered different by algorithms because their numerical values vary slightly [5]. This study aims to establish that it is possible to quantize the large dataset of colors to a limited set of colors without significantly affecting the user's preference with regard to color harmony. Once this is established, it should be possible to apply interdisciplinary approaches such as n-Grams [6] to create harmonious color combinations.

Burchett [7] states that color preference may vary by different attributes such as order, similarity, association, area, interaction, and configuration. The user may like or dislike a color or color palette based on these parameters, but the user's response should be the same for a palette consisting of slightly different colors.

1.3 Objective

The objective of this study is to perform quantization of color palettes using K-means clustering. By presenting the original color palette and quantized color palette in random order, the user is asked to like or dislike the color palette. Users who like the original color palette are expected also to like the quantized color palette. Users who dislike the original color palette will also dislike the quantized color palette. By doing this experiment, this study aims to establish that the perception of color harmony is not affected by minor changes in the individual colors, such as those introduced during color quantization.

Subsequently, this study computes the probabilities of all bigrams and trigrams from highly ranked color combinations and uses these to create new color combinations. By presenting patterns colored with these new color combinations, the respondents are asked to like or dislike the color palette. It is expected that the respondents will like the color palette thus created.

2. Preliminaries

2.1 Color Harmony

There is a long tradition of research into color harmony, and the majority of studies so far can be divided into two categories – those based on the orderly arrangement of colors and those based on the interrelationship between colors [8].

Studies based on the orderly arrangement of colors included those by Ostwald [9], Munsell [10], Itten [11], and Nemcsics [12], who suggested that colors could harmonize only when they were selected systematically from a hue circle or from a specific "path" within an ordered color space. On the other hand, studies based on the interrelationship of colors included those by Goethe [13], Chevreul [14], Moon and Spencer [15], Albers [16], and Chuang and Ou [17] proposed that colors could harmonize only when they were complementary or analogous (similar) in either hue, lightness, or chroma.

Itten [11] introduced a color wheel in which he described color harmony with an emphasis on hue. He referred to complementary colors as a two-color harmony. Itten also recognized the three-color harmony of hues that form an equilateral triangle, the four-color harmony of hues forming a square, the six-color harmony of a hexagon, etc. Artists and designers have widely adopted his schemes. Based on Itten's hue templates and extensive psychophysical research, Matsuda [18] introduced a set of 80 color schemes, defined by combining several types of hue and tone distributions. These schemes were used by Tokumaru et al. [19] for harmony evaluation and color design.

2.2 Color Compatibility from Large Datasets

Most color harmonization methods [20] and popular tools for creating harmonious color palettes, such as Color Schemer Studio, Colour Impact, and Kuler, are based on traditional color theory [21] extended by Matsuda and Tokumaru's hue templates [19]. Even the latest color harmony algorithms based on geometric approach [22], qualitative models [23], fuzzy logic [24], metaheuristic search [25], and CNNs [26] are based on some version of the hue templates.

In a study by O'Donovan et al. [27], the authors proposed an algorithm to extract harmonious color palettes from large datasets, specifically utilizing data from colourlovers.com. They analyzed over 200,000 color palettes from the site and used an optimization-based approach to generate a compatibility model for color palettes.

In addition, they investigated whether hue templates describe the themes that users create and whether the use of a template predicts better ratings. Their study suggests that designers do not create themes that match templates unless encouraged to do so by the interface. Contrary to popular belief, no evidence is found that hue templates (geometric rules in a color circle) can directly predict compatible colors [28], and preferences are not rotationally-invariant about the color wheel. In short, designers do not create themes that match templates unless encouraged to do so by the interface.

Their study thus scrutinizes the traditional approach of using hue templates for color harmony and opens up the search for newer methods of creating harmonious color schemes. It showcases the potential of using large datasets from online communities to study color harmony trends and preferences. In this paper, we propose a method to simplify the analysis of color harmony so that it is possible to find newer methods of understanding and creating color harmony from these large color datasets.

2.3 Text Prediction

n-Grams are used to predict a sequence of words in a sentence based on chained conditional probabilities. These probabilities are estimated by mining a collection of text known as a corpus. Language models are made up of such word sequence probabilities. In this language model [29], the probability of word w_2 occurring after word w_1 can be computed as in Equation 1.

$$P(w_2|w_1) = \frac{C(\text{'}w_1\, w_2\text{'})}{C(w_1)}, \tag{1}$$

This is the conditional probability of word w_2 following word w_1 computed as the ratio of the count of the bigram '$w_1\, w_2$' to the count of the unigram w_1. For trigram, the equation will be as in Equation 2.

$$P(w_3|\text{'}w_1\, w_2\text{'}) = \frac{C(\text{'}w_1\, w_2\, w_3\text{'})}{C(\text{'}w_1\, w_2\text{'})}, \tag{2}$$

Higher-order word sequence probabilities, such as 4-grams, can be created similarly. Using n-Grams, it is possible to construct new sentences [30]. This very simplistic approach, known as a Markov model, is usually applied to text prediction [31]. The process is programmatically described in [32]. This study uses this approach to create new color combinations using crowdsourced color combinations as a corpus for learning.

2.4 A Novel Interdisciplinary Approach

n-Grams have found uses in many fields, such as cryptography, machine translation, speech recognition, spelling correction, information extraction, and others. In this paper, we propose an interdisciplinary approach of using the text prediction algorithm to a quantized dictionary of colors and a corpus of quantized colors derived from crowdsourced color palettes such as those available at colourlovers.com to create new color combinations. To our knowledge, no previous studies have used this approach on large datasets of harmonious colors.

As per [33], there are several algorithms for text prediction, such as prediction using frequencies, prediction using word probability tables, syntactic prediction using probability tables, syntactic prediction using grammar, and semantic prediction. Syntactic and semantic prediction are not applicable to color harmony, and frequency prediction would not yield the desired results. Hence, we chose the word probability table, i.e., the n-Gram method for text prediction in this study, to create harmonious color combinations.

The proposed approach builds on the additivity of color harmony [34], which stipulates that a three-color combination can be seen as a combination of three separate color pairs, each generating a harmonious/disharmonious feeling, and that the approach also applies to combinations generated by any number of colors.

3. Proposed Method

3.1. Data Acquisition

The top-ranked color palettes from colourlovers.com were acquired with a syntax such as the URL

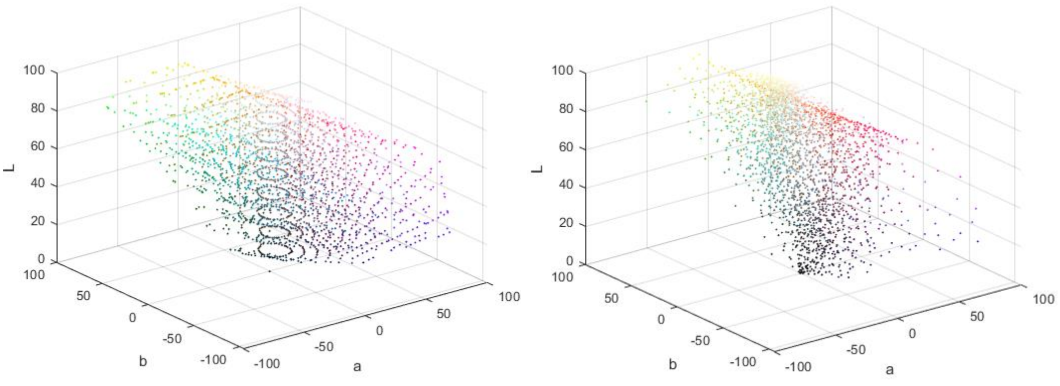
https://www.colourlovers.com/api/palettes/top?format=json&
showPaletteWidths=1&numResults=100&resultOffset=0.

The resultOffset can take values such as 100, 200, and so on up to 900, resulting in the top 1000 color palettes. Adding a hueOption parameter (with values of red, orange, yellow, green, aqua, blue, violet, and fuchsia) to the syntax provides access to 8000 more palettes, including the top 1000 palettes. A majority of color palettes in colourlovers.com have five colors. Out of the 8000 color palettes, 7152 had five colors. This study makes use of these 7152 color palettes.

3.2 Color Quantization

Color quantization is the process of mapping colors in a continuous color space to the closest color in a set of discrete colors. Color quantization is usually considered in the context of images where the number of distinct colors used in the image is reduced while maintaining visual quality [35]. In this study, we use color quantization in the context of color palettes. The colors in the color palettes downloaded from colourlovers.com can take on any value from continuous color space.

Several methods are available for color quantization, including the median cut algorithm, octree quantization, uniform quantization, and K-means clustering [36]. In an earlier study [37], the authors compared the effectiveness of uniform quantization to 2744 colors of the Munsell renotation data with K-means clustering to the same number of clusters (Figure 1). They found that the K-means method offered less quantization error. A user survey also showed that the likelihood that the respondent likes/dislikes the original image and responds similarly to the quantized palette was marginally better for palettes quantized to K-means clusters than the uniform clusters. Hence, this study uses the K-means clustering algorithm.



(a) (b)

Figure 1. Colors quantized to 2744 colors using (a) Munsell renotation data and (b) K-means cluster centroids

3.3 Color Distance Formula

The K-means clustering algorithm uses the CIE76 color distance formula in this study for performance reasons. While quantizing the continuous color space to discrete color space, the CIEDE2000 color distance formula [38] is used.

3.4 K-means Clustering

The K-means algorithm is one of the most widely used methods for data clustering. Colors in continuous CIELAB space can be represented as a data set $X = \{x_1, \dots, x_n\} \in \mathbb{R}^3$. K-means clustering partitions X into K exhaustive and mutually exclusive clusters $S = \{S_1, \dots, S_K\}$ minimizing the sum of squared errors $SSE = \sum_{k=1}^{K} \sum_{x_i \in x_k} \|x_i - c_k\|^2$ where $\|\ \ \|$

denotes the Euclidean (L_2) norm and c_k is the centroid of the cluster S_K calculated as the average of points that belong to this cluster [39].

In this study, 7152 palettes with five colors each were considered, so N = 7152×5 = 35760. K is taken to be 2744 to match the author's earlier work [37], comparing with the quantization to Munsell renotation data. The algorithm starts with K arbitrary centers chosen uniformly at random from the data points. Each point is assigned to the nearest center, and each center is recalculated as the mean of all points assigned to it.

3.5 n-Grams

Text mining, bigrams, trigrams, and n-Grams are usually used in the context of natural language processing and text prediction algorithms. Here, we use n-Grams in the context of color combinations. Each quantized palette with five colors would be a sentence composed of words from a dictionary of 2744 words. A palette of 5 colors has 120 permutations (Figure 2), so 7152 palettes would result in a corpus of 7152×120 = 858240 sentences.

The bigram table would be a 2744 by 2744 unigrams table of probabilities of two colors appearing together, resulting in 7529536 bigrams. Similarly, the trigram table would be a table of 7529536 bigrams by 2744 unigrams table of probabilities. We could go on for higher order combinations, but in the naïve approach used in this study, the computational requirements would grow exponentially. It is possible to optimize the computational and storage requirements [40], but the optimization is not essential for this study as bigrams and trigrams are sufficient to demonstrate the possibility of creating new color combinations using the n-Gram approach. Hence, in this study, we limit to the use of bigrams and trigrams (Figure 3).

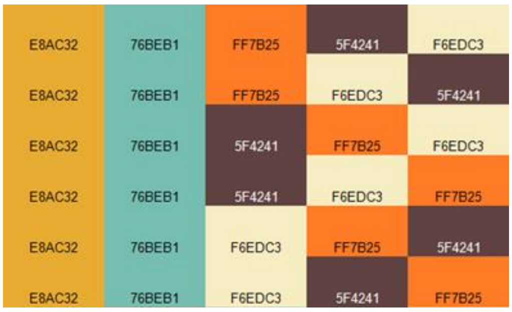


Figure 2. A portion of 120 possible permutations of 5 colors.

Figure 3. Some bigrams (left) and trigrams (right) from highly ranked color palettes.

3.6 The Proposed System

The proposed system is depicted in Figure 4. First, high-ranking colors are downloaded from colourlovers.com. Color palettes not having five colors are discarded. K-means clusters are computed from the remaining colors. All the color palettes are quantized to these clusters. The quantized palettes are then permuted to get all possible color combinations.

All unigrams are listed from these color combinations. A sparse table lists the probabilities of each unigram appearing after every other. This is the table of bigram probabilities. Another sparse table lists the probabilities of each unigram appearing after every other possible bigram. This is the table of trigram probabilities.

The bigram and trigram tables are used separately to create color combinations. This method can create a harmonious color combination without any user input, by randomly selecting the first color. Alternatively, the user can specify a target color [41], and the system will select the remaining colors based on the probability tables. The resulting color combinations are then used to color patterns, which are then presented to the user for evaluation.

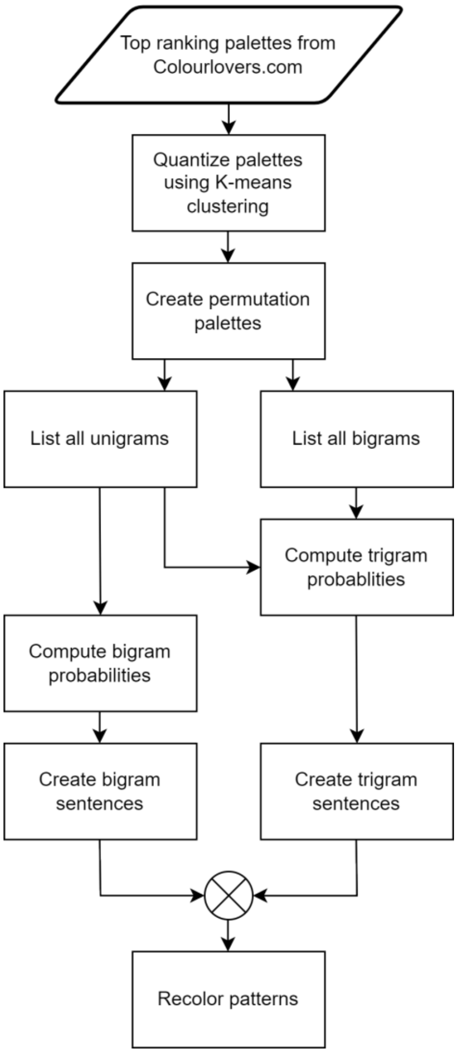


Figure 4. The proposed system.

3.7 Hue Templates

The traditional method of creating harmonious color combinations is using hue templates. In this study, we use traditional hue templates [19] to create color combinations for comparison purposes. As described in the paper, we used the traditional way to create color combinations of the i-type, V-type, L-type, I-type, T-type, Y-type, and X-type templates.

3.8 User Validation

A set of 24 patterns with five colors each were selected. For this study, we chose patterns with a fixed number of colors, such as those used in carpet or textile weaving. Photographic images with a large number of colors were out of the scope of this study.

Each pattern was colored with a random palette, a version of the palette quantized to 2744 K-means clusters, new color combinations created using bigrams and trigrams, and color combinations created with traditional hue templates. Since we are creating the n-Grams from permutations of the color patterns, patterns colored with the permutations of the original color palette were also included. An app was developed to present 300 such images in random order interspersed with 200 other colored versions of the same 24 patterns to 20 respondents.

The respondents were asked to like or dislike the colored patterns. Screenshots from the app used for the survey are shown in Figure 5. To check the consistency of the responses, 50 check images were also introduced. The check images were the same as the original images. If the responses for check images differed from those for the original image in 75% of the cases, the respondent's response was discarded.

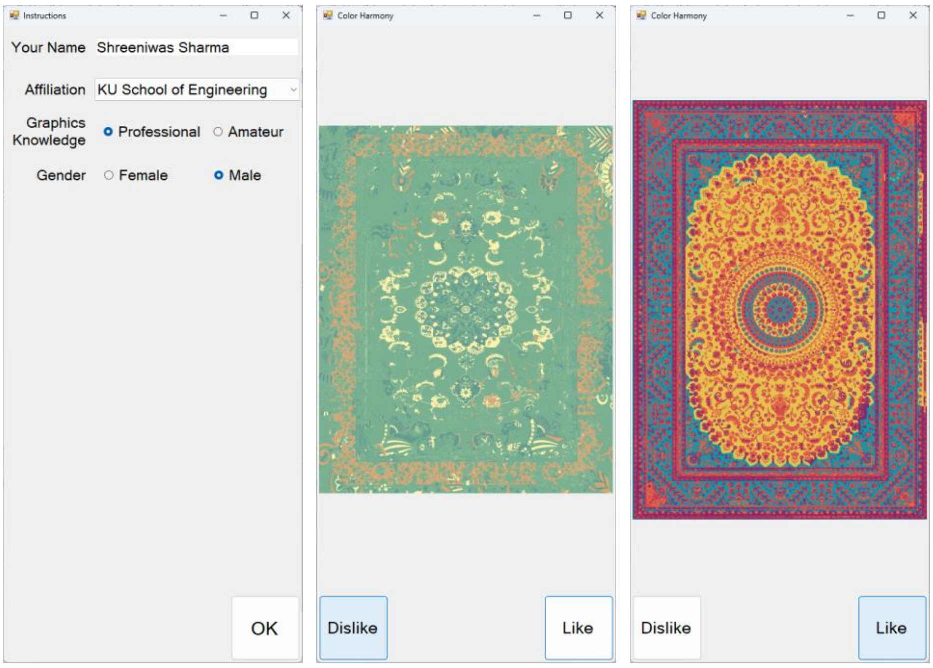


Figure 5. Screenshots from the user survey app.

4. Results and Discussion

From 35760 colors of the 7152 palettes, 2744 K-means clusters were computed, and the colors from the palettes were quantized to the centroids of these clusters. Figure 6 shows the effect of quantization visually. The effect of the color quantization is visible when the individual colors are examined side by side. However, color harmony is the effect of considering all the colors as a whole, and in that case, the aesthetic response for the original and the quantized color swatches is not that significant.

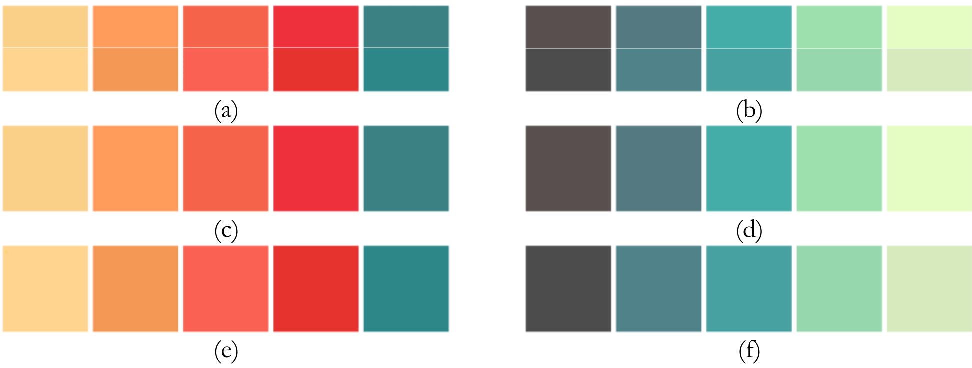


Figure 6. Two example color palettes with versions quantized to K-means clusters with average ∂E=1.22 (left) and with average ∂E=2.17 (right). The individual color differences are perceptible in (**a**) and (**b**). In (**c**) original and (**e**) quantized, as well as (**d**) original and (**f**) quantized, the perception of color harmony remains unaltered.

The original and quantized color palettes were applied to a pattern randomly selected from the set of 24 patterns. A permutation of the palette was also applied to the pattern to verify that the order of the colors in the palette did not significantly affect the harmony perception of the colors in the selected patterns. The bigram and trigram algorithms were used to create new palettes which were also applied to the selected pattern. To compare with traditional methods of creating color harmony, a palette was also created from one of the conventional hue templates and this was also applied to the selected pattern. Example sets of images used in the survey are shown in Figure 7. The set of these six images, randomly interspersed with other colored images and check images were presented to the user.

A total of 32 respondents participated in the user survey. The study group consisted of 17 males and 15 females. It included a mix of graphic designers, engineers, students from the Kathmandu University School of Art and students from the Kathmandu University School of Engineering. Users were requested not to participate in the survey if they had known color vision deficiencies.

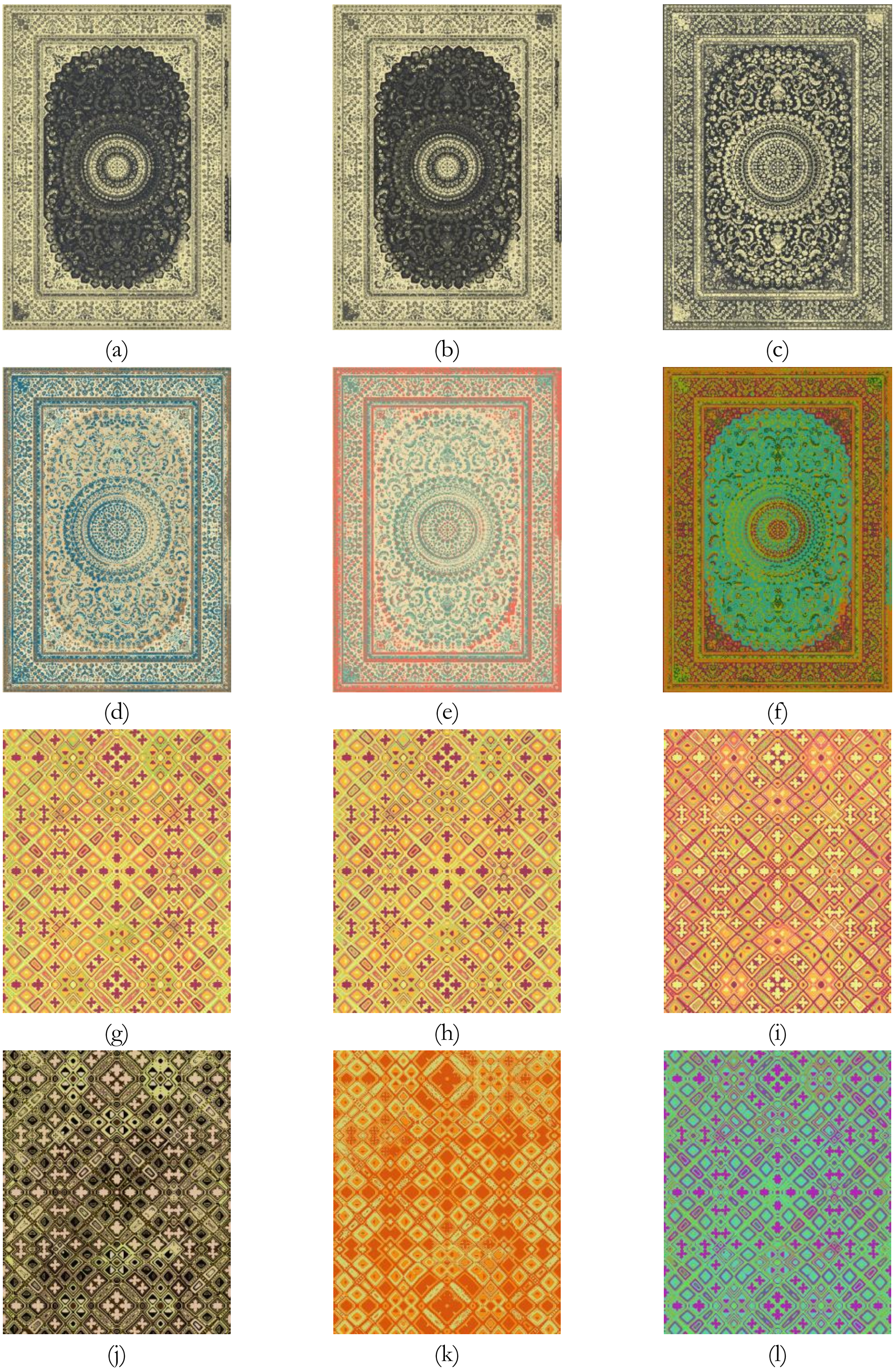


Figure 7. Two example sets of results (**a**, **g**) Original and check image (**b**, **h**) Image with quantized colors (**c**, **i**) Permutation of original image colors (**d**, **j**) New color combination produced using bigram (**e**, **k**) New color combination produced using trigrams (**f**, **l**) New color combination produced using hue templates

The results of 6 respondents were discarded because the consistency of responses among original and check (repeating the original) images were not the same in more than 75% of the cases. This method thus includes only the respondents who consciously liked or disliked the presented images. The responses of the remaining 26 participants are summarized in Table 1.

Table 1. The likelihood that the respondent likes/dislikes the original image and gives the same response for the quantized palette

Palette	Likelihood
Check palette (same as original palette)	83.6%
Palette quantized to K-means clusters	81.6%

It follows that in 97.6% of the cases where a respondent would like/dislike the original image, the user would also give the same response for the quantized image. This implies that quantizing colors to K-means clusters of the colors does not significantly affect the perception of harmony of a color palette. This simplifies further studies on color harmony as we now have to deal with a set of limited colors rather than an infinitely large set of slightly different yet perceptually the same colors. This study uses this simplification to apply an n-Gram approach to create new color combinations, which would otherwise be challenging.

The probabilities of all possible bigrams and trigrams of colors were computed using the quantized color palettes and their permutation palettes. From one palette of 5 colors, we get four bigrams and three trigrams. Since each palette has 120 permutations, we get 480 bigrams and 360 trigrams from one palette, resulting in a total of 3.4 million bigrams and 2.5 million trigram occurrences. Due to the quantization, some of these bigrams and trigrams will occur repeatedly. It was found that there were 143091 unique bigrams and 699944 unique trigrams. The probabilities of one color appearing after a unigram or bigram of colors were calculated from these repeated occurrences. New color combinations were created using these bigram and trigram probabilities.

When the color combinations created by the n-Gram approach were presented to the user, their responses were as in Table 2.

Table 2. The likelihood that the respondent likes a pattern

Pattern colored with	Likelihood
Colourlovers.com palette	49.8%
Permutation of the original palette	48.9%
Bigram color combinations	46.2%
Trigram color combinations	46.2%
Traditional hue templates	29.6%

From the results, it was found that the preference of permutations of the original palette (48.9%) was comparable with the preference of the original palette (49.8%), hence justifying the use of permutations of the original color palette to form the corpus. Further, we can infer that the algorithmically created color combinations using the bigram and trigram approach are 92.8% as likely to be preferred as human created high ranking palettes. This is a significant improvement compared to the traditional hue template approach, where the relative success rate is less than 60% (Figure 8).

Thus, once the seemingly large number of colors in crowdsourced color palettes is reduced to a manageable set of quantized colors, it becomes easier to understand color harmony and apply interdisciplinary algorithms to create new color combinations. We created new color combinations using the n-Gram approach and demonstrated that such algorithmically created color combinations perform quite well compared to human created high-ranking color combinations. It was also found that the approach created significantly better color combinations than the traditional hue template method.

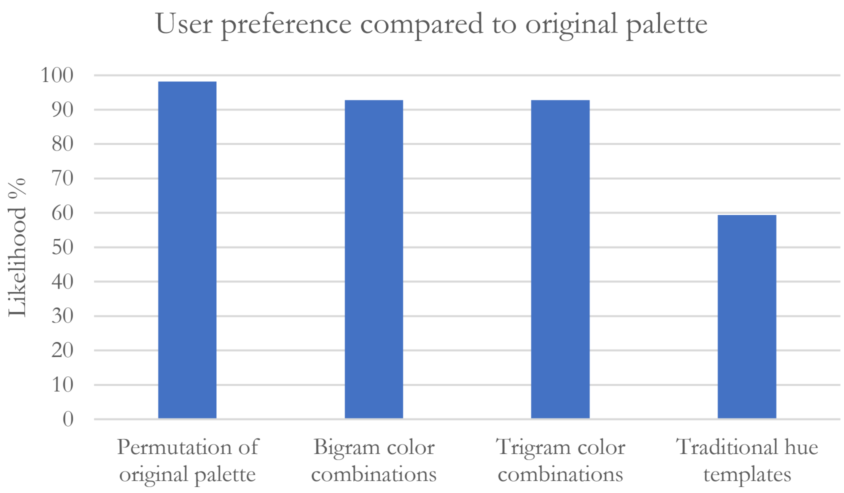


Figure 8. The likelihood that the user likes a palette relative to the likelihood that the user likes the original palette.

5. Conclusion

The subject of color quantization of images has been well studied, but the quantization of harmonious color palettes has not been studied so much. This study applied some of the color quantization methods to crowdsourced color palettes. It demonstrated that the quantization of colors of a palette does not significantly affect the harmony perception of the color palette. This leads to the simplification of analytical studies on color harmony. A simple n-Gram language model used in text prediction created harmonious color combinations that performed comparably well as human-created palettes.

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