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Subject review

Theory of Colour Harmony and Its Application

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Abstract: The colour represents an essential element of visual and graphic communications. It plays an important role in the perception of visual design and it is significant for all participants in the process of planning, developing and promoting graphic products. Designers are interested in a psychological and presentational aspect of colours, while to the technologists the colour represents one of the most important quality attributes. The process of choosing colours that are harmonious, usable and efficient is complex. In addition, many designers have inadequate background knowledge of colour theory, which could help them with the selection of colours. As a result, designers usually spend a great deal of time and expend significant effort in choosing appropriate colour combinations. In this article, the importance of colour harmony and its application when extracting colours, rating and generating colour schemes is presented.

Keywords: colour extraction; colour harmony; colour harmony models; generating colour schemes

1 INTRODUCTION

The colour is a central component of visualisation in digital and conventional media. It plays an important role in the perception of visual design [1] and it is significant for all participants in the process of planning, developing and promoting graphic products. Colour properties affect the visual aesthetic value [1, 2] and therefore many designers consider colour as the most important component of the design. One of these colour properties is the colour harmony.

2 COLOUR HARMONY

Colours are said to be in harmony when their juxtaposition produces a satisfying unity or balance to the viewer [3]. In other words, colour harmony can be defined as a set of colours that produce a pleasing effect when seen together [4, 5]. Today it is well known that although many attributes have an influence on colour harmony, harmonious colours can often be represented as points in a colour system that are distributed evenly [5].

Throughout the history, many scientists, art theorists and practitioners tried to establish some basic rules of colour harmony. One of the first theories of colour harmony includes the following topics: colours with equal hue, but different chroma or lightness value; analogous colours and complementary colours. For interpretation of these relationships, different colour wheels could be used.

In the early 20th century, the work of Wilhelm Ostwald, Albert Munsell and Johannes Itten contributed to the understanding of colour harmony. All of them tried to define colour harmony as relationships between colours in colour solid or colour-order system [6].

Ostwald created a colour circle consisting of 24 hues arranged around an achromatic axis (in his circle opposite colours were red–green and blue–yellow). Ostwald proposed that colours are harmonious if they have the same amount of blackness/whiteness; the same chromaticity – distance from the centre; or equal hue content.

Albert Munsell developed a colour system, which is based upon the three rudimentary attributes of colour: value (lightness), chroma and hue. The Munsell colour system contains five basic hues: red, yellow, green, blue and purple. Munsell believed that colour harmony can be achieved if the colours are balanced around the achromatic axis, preferably around middle value [7]. This can be obtained by calculating the colour strength of a certain region or an image. Colour strength is defined as a product of colour lightness (value) and its chroma. Therefore, a region with a large area and low colour strength would be in balance with a small area that has a lower colour strength, as shown in Eq. (1).

$$A_1/A_2 = V_2C_2/V_1C_1 \quad (1)$$

In Eq. (1) marking A stands for an area, marking V stands for Munsell value and marking C stands for Munsell chroma. Munsell recognised that colours could be in harmony only when certain relationships between colours are formed in his formulated colour system:

- colours on the achromatic axis,
- colours with equal hue (H) and chroma (C),
- complementary colours with equal value (V) and chroma (C),
- sequence of colours, where the value (V) and chroma (C) is changed for one unit,
- colours with the same value (V) and chroma (C) - colours on an elliptical path.

Johannes Itten, one of the most important representatives of Bauhaus, suggested seven forms of colour contrasts: contrasts of value, hue, saturation, extension (size for different colours), warm/cool, complements and simultaneous contrast. Ittan claimed that these types of contrast are essential for all visual perception. Based on Goethe's findings that different hues are different in their intensities (I), Itten used his suggested values (yellow (I = 9), orange (I = 8), red (I = 6), green (I = 6), blue (I = 4) and violet (I = 3)) to get adequate area – the stronger colours should cover less area (e.g. orange : blue = 2 : 1). Itten was also concerned about simultaneous contrast, which is now well known phenomena in colour vision [8].

More recently, Holtzschue stated that any hues used together could be harmonious, as long as lightness and chroma are set accordingly:

- colours with variable lightness are in harmony as long as distances between them are sufficient and even,

- colours are in harmony only when they have an intermediate level of lightness – colours with the extreme value of hue are not pleasing) and
- colours with similar chroma and equal lightness tend to be harmonious [9].

Many other authors acknowledged the importance of lightness and chroma [10]. Furthermore, they have presented other factors that could influence colour harmony (e.g. rhythm, balance, proportion, scale etc.) [11]. In the following section, some of the basic studies about factors that influence colour harmony will be presented.

3 FACTORS THAT INFLUENCE COLOUR HARMONY

In recent decades, scientists and researchers have begun controlled studies of colour harmony [12-14]. While these studies are often contradictory, they all come to the conclusion that colour harmony can be established if colours have equal or similar chroma, the same hue or different lightness values.

Based on an extensive review of the leading theories of colour harmony, Westland et al. addressed the question if any fundamental laws of colour harmony exist. They concluded that colour harmony could not be predicted based on some general model or law, because colour harmony is greatly influenced by culture and trends, which change over time. In addition, colour harmony is application specific [6]. They also raised an interesting question: is particular colour combination pleasing because it is used properly within a specific design or artistic context or because of the special relationships between colours per se. Granville claims that selecting harmonious colours is a creative process that considers the design, fashions and mores of the times. Therefore fashion and personal preference are primary arbitrators of colour harmony [15]. Kuehni shares a similar perspective and argues that nurture and culture profoundly influence the perception of colour harmony [16].Wong also points out the importance of individual differences of taste, which is determined with sex, age, cultural backgrounds, education, etc., what is more, taste also changes from generation to generation [10].

Some studies also indicate that colour harmony is widely influenced by colour preference. Namcsics claimed that not only colour preference of a certain group of people can affect the perception of colour harmony, but can also change over time [17]. Although studies demonstrated that there is a strong relationship between colour preference and colour harmony, these two terms are dissociable. Clearly, harmony and preference increase as hue similarity between colours increases, however preference of a colour scheme is more affected on the preference of individual colour and sufficient lightness contrast between them [14]. Note that the majority of people prefer blue and purple, while dislike yellow hues [18-20]. Based on the analysis of popular colour schemes, O'Donovan et al. found that these single-colour preferences are not consistent with preferences for colour combinations. Although many schemes contained blue hues, they also observed greater density of colour schemes that contain warm hues (yellow, orange, red). They also noticed a more significant correlation between professional designers in comparison with average users, which might be due to the different focus when creating colour schemes – designers might also consider the usability aspect when rating colour schemes. Colours with warm hues around yellow and red were often adjacent, while cyan and yellow were frequently combined with many other hues. Interestingly, colour schemes rarely contained green and purple hues, when they did, they were usually combined with similar hues [21].

Burchett suggests essential attributes and terms that are related to colour harmony: association, area, attitude, configuration, similarity, order, interaction, and tone [5]. Among these, most frequently used term associated with colour harmony is order, which refers to points in a colour system that are evenly distributed.

Based on a large-scale experiment on colour harmony, which lasted fifty years and comprised ninety-five thousand participants, a comprehensive list of conditions and factors of colour harmony has been determined [17, 22-28].

Shen et al. argued that there are two types of colour harmony components – those that are speculative (e.g. colour mood, colour attraction, trends, similarity) and those that are operative (e.g. order, hue, area, entropy, power spectrum) [29]. However, most studies to date have only focused on operative ones. Westland et al. also recognised the need for investigating colour harmony from the perspective of art and design. They point out that colour harmony resulting from computational models, may not reflect the true preference of art and design practitioners since the models are missing their expressive ideas or responses to a design brief [6].

4 COLOUR HARMONY MODELS

In recent years, many colour harmony models that are based on the statistical analysis of user research results have been proposed. Papachristos et al. defined a model that predicts emotional and aesthetic values of the given colour scheme [30]. Based on an empirical study, Neumann et al. presented a set of methods and rules for the creation of harmonious colour combinations in the Colouroid colour system [31]. Recently, Ou et al. developed a computational model for predicting the colour harmony of two-colour combinations. The model suggests that the colour harmony of a pair of colours is proportional to the difference in their lightness values – the higher the difference in lightness, the more harmonious would colours be. In contrast, small differences in lightness would result in harmony reduction. Moreover, the model applies that higher lightness value of each component in a pair would lead to higher harmony. Regarding the hue of the component, the model suggests that blue is the most likely hue to create colour harmony, whereas red is the least likely one. A similar model for determining the colour harmony of two-colour and three-colour combinations was proposed by Szabo et al. The model is based on the CIECAM02 colour appearance model [13].

However, aforementioned models are based on experimental data of a small number of participants and only support two or three colour combinations, which narrow their capacity for generalisation. To create a model that would be useful for general purpose and could also reflect current trends, O'Donovan et al. studied colour harmony using large datasets of colour schemes and their corresponding ratings – 327,381 human ratings of 22,376 colour schemes [21]. Datasets were collected from the popular websites for creating colour schemes, such as Adobe Color CC and COLOURLovers, and using Amazon Mechanical Turk (MTurk) crowd sourcing platform. Based on an analysis of collected datasets O'Donovan et al. came to the following observations:

- User-created colour schemes are not random, but form clusters in the space of 5 colours. Colour schemes consisting of colours that are farther from the centre of a cluster would probably be rated worse.
- Colour preference strongly influences the creation of the colour scheme – colour schemes consisting of warm and cyan, are preferred.
- No evidence is found that hue templates (geometric rules in a colour circle) can directly predict compatible colours.
- Users generally prefer themes, which are neither too simple (i.e. monochromatic), nor too complicated (more than 2-3 different hues).
- As suggested by many scholars, lightness plays an essential part in colour harmony; colour schemes with many dark colours were poorly rated, while gradients from light-to-dark or vice-versa were rated higher.
- Colour schemes should not consist of too similar colours in order to be harmonious.

Based on the collected data they constructed a new colour harmony model, which is trained using a machine-learning algorithm. Not only that the model can predict ratings, but it can also examine features of colour scheme and define the most important ones for colour harmony. The model uses more than 300 features, which are defined in different colour spaces [21]. Because they used colour themes without context, the model can only be used for general purpose and may not yield a good result in some specific context.

Kitta and Miyata eliminated limitation of the previous model, which can only rate colour schemes with a limit number of colours. They proposed a machine-learning model that takes into account the different features of a colour scheme components and it is capable of evaluating and generating colour schemes of a different number of colours. This can be useful for a wide range of applications, such as compatible colour suggestion, 2D pattern colouring, and other fields of colour design [32].

5 HUE TEMPLATES AS COLOUR HARMONY MODELS

Hue templates can be defined as fixed sets of rotations around the colour wheel, which produce compatible colours [21]. There are six basic hue templates (Fig. 1):

- Monochromatic harmony: colours with similar or equal hue,
- Complementary harmony: colours lying opposite each other on the colour wheel,
- Analogous harmony: colours with similar hues, lying next to each other on the colour wheel,
- Triadic harmony: three colours that have separated hues by about 120 degrees on the colour wheel,
- Split-complementary harmony: includes three colours, with two being either side of the complement of the third on the colour wheel,
- Tetradic harmony: double complementary scheme, two complementary pairs lying opposite each other on the colour wheel [6].

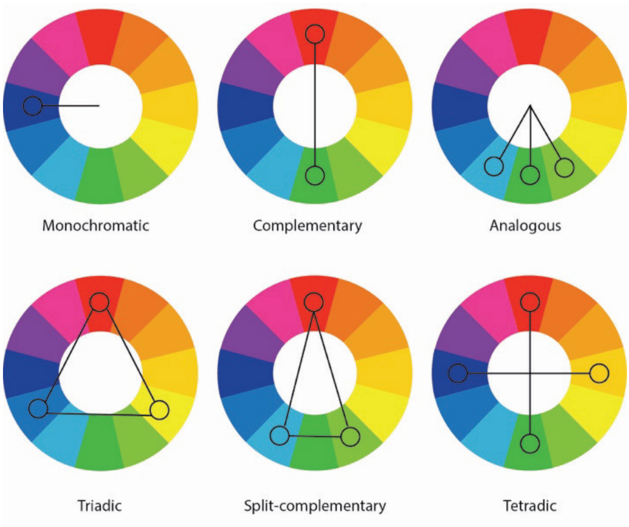

Figure 1 Six basic hue templates

In order to make the above schemes harmonious, the lightness, saturation and extension (area of coverage) of the colours need to be adjusted to equalise their visual strength.

Research for two and three colour combinations [12, 13] has indicated that complementary and triadic hue templates are not likely to be harmonious. However, these conclusions are based on experimental data of a small number of participants. O'Donovan et al. suggested that designers would rarely create a colour scheme based on hue template unless the interface provides the option to do so [21]. They also pointed out that hue template alone is not sufficient to establish colour harmony, e.g. green's complement is purple, however, their data suggest users prefer to pair green with blue or yellow instead. Results also showed that the colour schemes based on analogous, monochromatic and complementary hue templates are preferable. Interestingly, on websites that enable the creation of colour schemes (e.g. Adobe Color, COLOURLovers), schemes, which are close to hue templates, have even slightly lower scores. They hypothesised this due to the fact that more inexperienced users create these schemes, or the community penalises schemes close to the interface defaults. However, crowd sourcing results, which had no interface biases, also show little evidence that colour harmony is contingent on hue templates distance. Colour schemes with 2–3 hues were rated higher; while colour schemes created using templates provided by the interface were rated lower.

6 APPLICATION OF COLOUR HARMONY THEORY
6.1 Image Colour Extraction

Extracting colours from images is useful in many fields and has several applicative values. It can be used to obtain a certain number of predominant colours of the image and to harmoniously adapt them to the environment, for example, image colours could be adapted according to colours of a user interface, or vice versa. The challenge of colour image representation, using a colour palette construction, can be considered as an unsupervised (calculated by software) classification of the three-dimensional colour space. For that purpose, several techniques and method have been proposed. One of the most popular and efficient methods for extracting a set of representative colours from an image is general clustering, such as k-means [33] and fuzzy c-means [34].

Method k-means is defined as a hard clustering that includes a family of algorithms where each sample in a dataset is assigned to exactly one cluster. Superficially, it can be described as a method of grouping and classification of a certain type of information. Since it does not consider spatial information of the colours in an image, it can overlook important and prominent colours. Fuzzy c-means clustering that is similar to k-means is defined as soft clustering that assigns a sample to one or more clusters. Lin and Hanrahan found out that people usually select colours that are different from the colours extracted with popular clustering methods, such as k-means and c-means. Also, people will more likely choose diverse colours and concentrate on colours in salient regions of the image. They presented a regression model for extracting colour schemes from images. Similar to O'Donovan et al., the model is trained on user-generated colour schemes [35]. Delon et al. argue that people usually select colours from distinctive regions of the image and that these regions can be used to determine the set of a minimal number of colours, needed to describe an image. They developed an algorithm that finds peaks of one-dimensional histograms of hue, saturation and lightness component of the image colours, which according to their opinion, correspond well to spatial regions. These colours can be further used as initial seeds for the aforementioned clustering methods [36]. A similar approach was used by Morse et al. who presented a method for colour image extraction based on the histogram analysis that also allows a user to specify a maximum number of extracted colours and a minimum distance between them. The method takes into account the importance of hue component of the colours and also their local spatial coherency to get their overall visual impact [37]. Zhang et al. investigated which colour difference formula is the most efficient to be used in image colour extraction algorithms. Based on theoretical analysis and experimental data, they came to the conclusion that CIE94 colour difference formula is most efficient at grouping colours with common clustering algorithms [38]. Different from the aforementioned algorithms, which only consider colour information, Liu and Luo presented a method that takes into account users' emotion and feeling about the image [39].

Some web tools are used as colour scheme generators and provide an option for extracting colours from the image. ColorExplorer and Spectrum can extract a different number of colours from the image, while Adobe Color CC and Coolors can extract only five colours at once. Adobe Color CC and ColourExplorer offer additional settings for extracting colours from the image. Adobe Color CC provides five different colour modes (colourful, bright, muted, deep and dark), whereas with ColourExplorer the level of colour analysis refinement can be determined by the user. With Adobe Color CC and Coolors colours can also be manually selected from the image and Spectrum provides an option for selecting the analysed area on the image [40].

6.2 Tools for Choosing Colours and Generating Colour Schemes

Choosing colour combinations that are harmonious, usable and attractive to a specific target group is not a simple task. Furthermore, many designers do not have sufficient background knowledge about colours and art theory, which could help them with the selection of colours. This leads to a great deal of time that designers usually spend choosing appropriate colour combinations.

One of the solutions are books which contain lists of colour schemes and provide background information for choosing harmonious colours and are mostly intended for interior designers and artists [41-43]. They are also so-called colour indexes, which graphic designers usually use for guiding principles and reference or inspiration [44, 45].

With the digitalisation process in the last decades, most designer's work today is done on the computer, using different applications. Colours are usually selected by specifying their numeric values or with the colour-picking tool, which is a fundamental part of every operating system or graphic design software. Another common way of defining colours is by selecting them from popular libraries, such as Pantone or Toyo.

In recent years plenty of tools were developed to help designers selecting harmonious or preference colours. So-called colour scheme composers or generators are built for different platforms and have different functionality and supported features. Weingerl et al. have published a systematic and comprehensive review of the ten most popular solutions for generating colour schemes. Based on the analysis of supported colour spaces and export options, they came to the conclusion that most of the tools are primarily intended for web developers and designers. More than half of the analysed tools provide an option for generating a colour scheme based on specified base colour and selected colour harmony rule. Few tools can also be used for generating colour schemes with spot or process colours, but none of them supports colour management option or specifies which colour space is used for interpreting these values [40].

In addition to the above-mentioned tools, there are also few tools for generating colour schemes, which were presented by the scientific community. Gramazio et al. developed a web-based tool for creating discriminable and aesthetically preferable colour schemes. Colours are iteratively and semi-random selected from the CIELAB colour space until discriminable and preference user-defined criteria are met (perceptual distance, name difference, name uniqueness, and pair preference) [46]. Hu et al. developed an interactive visualisation tool for creating harmonious colour schemes [47]. The colours are selected based on two harmony principles (familial factors and rhythmic spans) and can be changed interactively. In addition, they also developed a tool for generating colour schemes that are based on user's preference [48]. Both tools were designed to help professional artists and novice designers to improve their design efficiency. On the basis of psychophysical studies of semantic associations of colours and colour harmony, Ou and Cui presented a colour design tool to provide assistance and support not only for unskilled users but also for designers [49].

Understanding of colour harmony and its influence on an aesthetic value have also contributed to the development of many practical tools and applications for image or interface recolouring [50-53]. One of the most cited works is done by Cohen-Or et al., who presented a method that enhances the colour harmony of the image, while remaining faithful, as much as possible, to the original image. This harmonisation method optimises the histogram of hues in an image to lie within the closest hue templates [51]. Lalonde and Efros used colour harmony or compatibility to evaluate image realism for realistic recolouring and compositing [52]. Wang et al. suggested a data-driven method for enhancing the desired colour theme in an image. This method considers a desired colour theme, texture-colour relationships as well as automatic or user-specified colour constraints in order to enhance or optimise the input image [53].

Gu and Lue proposed a data-driven design framework for automatic web page colouring, which takes into account three fundamental design objectives: proper visual contrasts, multi-colour compatibility and semantic associations [54].

There are also some tools available, which are not directly connected with defining harmonious colours but can help facilitate the selection of colours and teach concepts about colour theory and colour appearance [55-58]. Lynch et al. presented a visualisation method for analysing and exploring colour usage in digital images. ColourVis visualises in a user-friendly manner which colours are presented in the image and how they are distributed across the image. In addition, it can also analyse multiple images at the same time and therefore determine correlations and trends in images [59].

7 CONCLUSION

Nowadays, visual communication is one of the key components of digital marketing. When promoting products on the web, maximum deviation from the average and also a need for greater recognition of the product is desirable. Colour is one of the critical elements of visual communications that can attract a user or customer. Knowledge of colour harmony theories and its use can help us in creating and designing of websites for the target group of users. That is important for textile designers that represent their products on the web, graphic designers that create and design the websites and also for everyone that is involved in visual communications.

This paper presents a colour harmony and its application value. The years of the development of colour theories have finally chosen a path to practical use, e.g. it enables the creation of high-quality content on the web, greater visibility and better advertising of products.

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