Visual Exploration of Color Usage in Vincent van Gogh's Paintings

Xinyi Ding
Xi'an Jiaotong Liverpool University
China
xinyiding81615@163.com

Yejuan Xie
Xi'an Jiaotong Liverpool University
China
xieyejuan1029@163.com

Jielin Jing
Xi'an Jiaotong Liverpool University
China
tokxys@163.com

Fei Du
Xi'an Jiaotong Liverpool University
China
Fei.du21@student.xjtlu.edu.cn

Chengtao Ji*
Xi'an Jiaotong Liverpool University
China
Chengtao.Ji@xjtlu.edu.cn

ABSTRACT

This paper aims to explore the use of color and color harmony in Vincent van Gogh's paintings and present the results in the form of a web-based digital museum to provide an intuitive and immersive experience to the public audience. To achieve this goal, we tested four different color extraction algorithms and determined the *ext-colors* library to be the most effective method for extracting theme colors after interviewing ten random viewers. This study then conducted a visual analysis of the extracted colors, revealing that the predominant colors of van Gogh's paintings were yellow and green, followed by blue and red. We also identified the main types of color harmony used in van Gogh's paintings as monochromatic, analogous, and complementary harmony. The ultimate outcome of this research is a digital gallery that showcases the different periods of van Gogh's work via a timeline representation, highlighting the distinctive color schemes that were employed during each period. This presentation gives the exhibits a clear context and provides the viewer with a clear and vivid experience. Overall, the study's findings reveal insightful information about how color is employed in van Gogh's artwork and suggest a useful application which is in the form of a timeline representation that can be used to improve the audience's exposure to the art and cultural heritage.

CCS CONCEPTS

• **Applied computing** → **Arts and humanities**; • **Human-centered computing** → *Visual analytics.*

KEYWORDS

Vincent van Gogh, color extraction, color theory, color harmony, data visualization, timeline, digital museum

VINCI 2023, September 22–24, 2023, Guangzhou, China

ACM ISBN 979-8-4007-0751-3/23/09…$15.00
https://doi.org/10.1145/3615522.3615561

ACM Reference Format:
Xinyi Ding, Yejuan Xie, Jielin Jing, Fei Du, and Chengtao Ji*. 2023. Visual Exploration of Color Usage in Vincent van Gogh's Paintings. In *The 16th International Symposium on Visual Information Communication and Interaction (VINCI 2023), September 22–24, 2023, Guangzhou, China.* ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3615522.3615561

1 INTRODUCTION

The study of color is a vast and fascinating field that can influence people's emotions, behaviors, and attitudes, as well as reflect the emotional, psychological, and mental states of color users, especially art creators. The practical significance of color is undeniable, and Morris [10] even offers cases in industrial design to emphasize the importance of color. Color harmony, a more specific area of color usage, involves understanding how to use different colors to create a pleasing and balanced appearance. In art and design, color harmony can be used to create a sense of unity and harmony, while in marketing it can be used to create memorable and effective brand images.

Digital museums, on the other hand, represent a new and exciting frontier in the world of art and cultural heritage. With new technologies, museums are no longer confined to physical spaces and can now be accessed from anywhere in the world through digital platforms. Digitized collections and digital museum design offer visitors a different visual experience, which opens up new possibilities for the dissemination and preservation of art and cultural heritage, as well as new ways to engage with audiences.

However, some digital museums focus only on displaying digitized collections and related textual information, or on flashy visual effects, such as 3D effects, without effectively showing the characteristics of exhibits, the connections between exhibits, and the context of the era. To solve this problem, this paper proposes a timeline-based representation to effectively reflect the relationship between exhibits and the context of the exhibits. Collections from the same period can be displayed together to highlight commonalities, and items from different periods can be compared by adding the feature of double-selected time points to the timeline to illustrate the difference between the two periods. Attention must also be paid to the characteristics of the exhibits themselves, such as a painting's use of color, imagery, and emotional expression, to provide a more immersive experience for the viewer.

Vincent Willem van Gogh, one of the most influential artists in the history of modern art, is known for the vividness and emotional embodiment of color usage. His paintings have been the subject of numerous academic activities, art exhibitions, and museum collections, with the van Gogh Museum in Amsterdam, the Netherlands, being one of the most famous and extensive collections of van Gogh's artwork. The museum has also created a rich official online museum that contains a collection of van Gogh's works and also devotes a small amount of space to the story of van Gogh's paintings and variations in the use of color but it is still not very intuitive in terms of providing the user with a complete timeline van Gogh's painting.

This paper tries to propose a solution to break through the limitations of existing online museums in terms of presenting the characteristics of exhibits and their temporal context. Here, we focus on a comprehensive analysis of all of van Gogh's paintings, with a particular interest in the colors used in the paintings, and works to create a virtual museum that exhibits in a timeline mode, allowing it to contextualize the exhibits and provide a more immersive and engaging experience for the viewer. Therefore, our contribution are as follows:

- Comparison of four color extraction methods to find the one that can accurately extract theme colors from a painting that best matches the human perception.
- Analysis of the use of colors in van Gogh's painting and revealing that the most used colors are yellow and green, followed by blue and red.
- Analysis of the use of color harmony in van Gogh's painting and found that monochromatic, analogous, and complementary color harmony are frequently employed by van Gogh as his preferred method of achieving harmonious compositions.
- A digital art gallery presents a selection of van Gogh's works in chronological order, showing viewers the transformation of van Gogh's use of color throughout his painting career.

2 LITERATURE REVIEW

The exploration of color in paintings is closely related to two subjects: Color Theme Extraction from digitized paintings and Color Harmony. This section, therefore, summarizes the relevant work in both of these areas.

2.1 Theme Color Extraction

Color extraction plays a crucial role in artwork analysis, and the precise extraction of the principal hues in a painting serves as the foundation for color exploration. Various methods have been proposed to extract color themes from an image that is a result of digitized paintings, such as clustering algorithms and histogram-based techniques. Typical clustering techniques for extracting representative colors from images include fuzzy C-Means and K-Means. On the other side, a different technique for identifying color themes is the image-based 3D color histogram.

2.1.1 Clustering Approaches. A common color quantization technique, which extracts representative colors in an image, is clustering algorithms such as K-Means [2, 8, 15, 16] and fuzzy C-Means [2, 8, 9]. The K-Means algorithm reduces the number of colors in an image to a defined value of K. However, it cannot identify the spatial arrangement of colors in an image, which results in important colors being erased and can differ significantly from the extracted colors by human perception. Parvaneh's RoyGBiv color extraction module [12] also relies on K-Means, which Vane [14] used to extract the colors of Cooper Hewitt's collection. The overall results were good, except that the colors of the background and the light and shadows on the objects would cause misleading in the resulting extracted colors. C-Means is extremely similar to K-Means and it optimizes the iterative process of K-Means and reduces the effect of outliers on the results, but still fails to overcome the drawbacks of K-Means.

2.1.2 Histogram-Based Approaches. Image-based 3D color histogram is another way to extract color themes. Delon et al. [6] represented colors in HSV (Hue, Saturation, Value) color space and extracted theme colors by calculating histogram peaks of hue, saturation, and value of the input image. However, the obtained color themes are often accompanied by the appearance of redundant colors since the extraction is done in tiers. Morse et al. [11] used a similar hierarchical histogram method and successfully extracted the theme colors, however, there was no comparative evaluation of the results they obtained with other methods. Ciocca et al. [2] evaluated nine image color theme extraction methods including those mentioned above, with the main method categories of supervised learning (e.g., logistic regression algorithms), unsupervised learning (e.g., K-Means algorithms), and commercial services. The evaluation modeled the perceptual differences between colors by using the Euclidean distance metric in the CIE-Lab color space and concluded that regression models trained on user-defined color themes performed best, while unsupervised clustering algorithms performed well. Lin and Hanrahan [8]. also used the LASSO regression model, a data-driven approach, which successfully simulated how humans extracted picture themes colors.

2.1.3 Others. In addition to the general color extraction algorithms mentioned above, there are also studies focusing on color theme extraction for color emotions. For example, Liu and Luo [9] proposed extracting emotional theme colors with a hierarchical structure. However, this scheme currently only performs simple theme color extraction for van Gogh's paintings without considering the emotions of the paintings. Due to the lack of human-extracted theme colors as sample data, the scheme of using the regression model is discarded, and the specific color extraction scheme will be specified in Section 4.2.

2.2 Color Harmony

In practice, it usually requires the discernment of classifying color harmony for the extracted theme colors. Therefore, throughout history, various scholars and experts have proposed their own classifications of color arrangements and color harmonies. In order to choose the most suitable color harmony theory, four frequently used color schemes with three dominating color harmony theories will be analyzed. The assessment will pay particular attention to the categorization of color harmony using the extracted theme colors. By synthesizing and evaluating the various perspectives of color theory, this study aims to contribute to the current understanding

of color harmony and its practical application in design, art, and related areas.

2.2.1 Color Wheels. Isaac Newton (1643-1727) made a key contribution to the early color theory by arranging the seven different spectral colors he identified into an incomplete circle, the hue wheel, also known as the geometric color model, which became the foundation for many of the subsequent color harmony theories [1, 17]. In contrast to Newton, Wolfgang Goethe (1749-1832) proposed that the opposing colors are arranged in a symmetrical way on the color wheel [1], for example, yellow is opposed to purple, and similarly, red to green and blue to orange. Analogous to Goethe's idea, Albert Munsell's (1858-1918) and Johannes Itten's (1888-1967) color wheels both show complementary colors, while at the same time blending the secondary colors formed by mixing two of the three primary colors, and the tertiary colors produced by mixing a secondary color with a primary color, on a single color wheel. In comparison with Newton's incomplete color wheel, and considering the small color gamut (only 6 colors) displayed by Goethe's color wheel, most of the color harmony models (further detail will be discussed in Section 2.2.4) are actually constructed based on Munsell's and Itten's color wheels, which are also used as a reference for the construction of the color wheel in the intermediate stage of this paper.

2.2.2 Munsell's Perceptual Harmonies. Munsell first proposed a color notation system in 1905, which is known as the Munsell Color System, and the system consists of three components: value (V), hue (H), and chroma (C). Based on this system, he proposed to express the color intensity as the product of the Munsell value, and the Chroma value and concluded that the balance of a color area needs to be such that the area of that area is inversely proportional to the color intensity, which means that the color area with high color intensity should be small, and vice versa.

2.2.3 Itten's Harmony. According to Itten, all complementary pairs of colors, three-color combinations in which the colors form equilateral or isosceles triangles in a color wheel, and all four-color combinations that form squares or rectangles are harmonious in a color wheel, can be seen as color harmony.

2.2.4 Three Prevalent Harmony Schemes [14, 17].

- `Monochromatic Color Scheme`: This scheme involves selecting colors that have the same or similar hue, resulting in a harmonious color palette with a single dominant color.
- `Complementary Color Scheme`: This scheme refers to the use of colors that are opposite to each other on a color wheel. This creates a high contrast and dynamic effect in the color scheme.
- `Analogous Color Scheme`: This scheme involves selecting colors that are adjacent to each other on the color wheel, creating a color palette with a harmonious and cohesive feel due to their similarity in hue.

Figure 1 illustrates the five schemes mentioned above. Munsell's harmony theory is too abstract to intuitively understand the harmonious relationship between colors, therefore, instead of choosing Munsell's harmony theory in this paper, Itten's ideas and commonly used harmony types were synthesized and used as a reference standard in order to visually derive the color harmony types from the palette.

Figure 1: Color wheels corresponding to five common harmony schemes

3 DATA COLLECTION AND TASKS

3.1 Dataset

The data for this study was sourced from Wikiart[18], which provided 1931 high-resolution images along with their associated metadata. The metadata includes details such as the name, year, genre, and type of each painting. To facilitate the subsequent color analysis, the paintings were manually categorized into two groups: color paintings (878 in total) and black-and-white paintings (1053 in total).

3.2 Tasks

To effectively explore the color and color harmony in van Gogh's painting, we compiled the following tasks:

T1: Exploring Dominant Color Themes in van Gogh's Paintings: This task aims to create visualizations that showcase the dominant color themes used in Vincent van Gogh's artworks, illustrating his color preferences and how they evolved over time. By analyzing his paintings, the visualization provides insights into his artistic style and emotional expression through color.

T2: Exploring Color Harmony in Artworks: This task focuses on creating visualizations that highlight the application of different types of color harmony in artworks. By analyzing the color relationships within the artworks, the visualization showcases how complementary, monochromatic, analogous, triad, and tetrad harmonies are employed, contributing to aesthetic appeal and visual coherence.

4 SYSTEM WORKFLOW

The focus of this study is a comprehensive analysis of the characteristics and changes over time in the use of color in van Gogh's paintings. In order to accomplish these tasks, the dataset was first processed, e.g., image sampling, extracted palette color for each image and matched the corresponding color harmony type.

4.1 Data Sampling

To achieve a more accurate approximation of the subject colors chosen by humans, it is essential to test and compare color extraction algorithms. Considering the computational demands of extracting five colors for each of the 876 paintings and repeating this process four times, we narrowed our analysis to a subset of the colored paintings. To ensure a balanced and representative sample that encompasses van Gogh's entire artistic career, we employed a stratified sampling method based on the year of the painting. Consequently, 100 paintings were randomly selected for color extraction and the specific number of paintings for each year can be found in Table 1. By adopting this approach, we significantly improved the validity, generalizability, and scientific rigor of the algorithm selection process.

Table 1: Stratified Sampling

Year/Total	Color Works	Sample Size	Year/Total	Color Works	Sample Size
1881	20	2	1886	85	10
1882	47	5	1887	133	15
1883	26	3	1888	170	19
1884	41	5	1889	143	16
1885	97	11	1890	114	13
Total	876	100			

4.2 Theme Color Generation

To generate theme color data for each selected picture, the trials will be carried out by putting some of the methods to the test and optimizing them. The major algorithms examined and the relevant variables are described in the sections that follow.

Median-Cut: The Cyrain-provided [3] source code for extracting theme colors using the median-cut was put to the test. The theme colors can be obtained by inputting the image and the number of target colors.

K-Means: The first implementation of K-Means, again, uses Cyrain's [5] source code of using k-means from Python package *sklearn* to extract the theme colors. The second implementation of K-Means uses k-means from the OpenCV library to extract colors with reference to Alberto's code.

Python extcolors library: The last approach to test is to use a ready-made Python *extcolors* library for extracting colors. It has the advantage of being able to adjust the tolerance to zoom in on colors that stand out in small color blocks and are not picked up by the clustering algorithm but are obvious to the human eye.

4.2.1 Yearly Theme Color. To extract the Theme colors for each year, we first extract the five theme colors for each painting. Then, to evenly calculate the theme color for each year, we calculate the average theme colors for each order over the year. This way can avoid color cross-diminishing which was caused by the various size of paintings and the use of background colors in different paintings.

4.3 Color Standardization and Color Harmony

Color information is esoteric and challenging to comprehend; for instance, it is difficult for humans to distinguish a color from its RGB or HEX values. Instead, people are more used to either the color itself or the terminology used to describe it.

Therefore, it is crucial to have a consistent color standard before any color analysis is performed, as there are approximately 10 million hues that can be distinguished by the human eye. In this study, the extracted colors will be compared with 986 specified standard colors, and the extracted color will be assigned to the standard color which is closest to the extracted color. These 986 standard colors refer to a comprehensive list available on the Color-Hex website[4]. Additionally, the extracted color will be visualized by word cloud since the word cloud is a widely used data visualization technique that can effectively display the frequency of words or themes in a dataset.

In addition to an overall analysis of all the colors, this study also conducted a visual analysis of the harmony of colors used for each piece. To be specific, the color palette is used for this purpose and it is divided into twelve equal parts, and the extracted colors are then placed in the corresponding color positions of the palette according to the hue. If there exists some of the extracted colors belong to the same hue, they will be distributed in the order of saturation from the lowest to the highest in the sector from the inside to the outside.

Afterward, to effectively document all color harmony types present in the work, a simple algorithm was devised to calculate these types based on the resulting color palette. The algorithm primarily focuses on determining the relationships between colors by comparing their positions within the palette. These positional comparisons classify the colors as relative, adjacent, or identical, corresponding to complementary harmony, similar harmony, and monochromatic harmony, respectively. Furthermore, the algorithm identifies more complex three-color harmony based on specific triangular positions, while four-color harmony require two sets of colors to be positioned opposite each other within the palette.

4.4 Timeline representation

A web-based exploration system was developed to meet the two tasks presented in Section 3.2 in an interactive way. The main focus of this system is to present the results of the color study, as well as an overview of van Gogh's entire painting oeuvre. The interface of this system is shown in Figure 2, and divided into four main components:

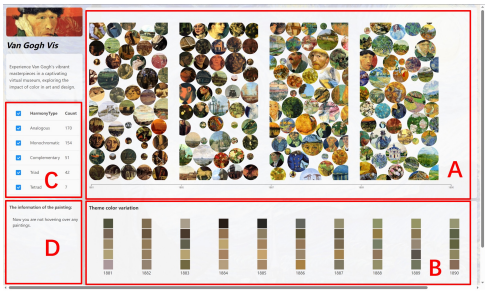

Figure 2: Main interface of the timeline representation.

- **Paintings over four time periods:** The main window displays a selection of paintings for the four periods depicted in the timeline (Figure 2(A)).
- **Yearly Theme color:** The yearly theme colors extracted by the Python extcolors library are depicted at the middle bottom (Figure 2(B)).
- **Color Harmony Filtering:** A list of checkboxes to filter the paintings displayed in the main window by their color harmony. Each color harmony type is shown along with the number of times it was used in a total of 200 works (Figure 2(C)).
- **Painting Information:** The painting information is displayed when the mouse hovers over a piece of artwork (Figure 2(D)).

4.4.1 Interactivity.

(1) **Hovering over a painting:** When the mouse hovers over any painting, a colorful infographic of the work is displayed. The infobox includes the name of the work, the year it was

created, and the type of harmony used, shown in the lower left corner.

(2) **Clicking over a time period:** Clicking on any time interval at the bottom of the timeline representation, all paintings in that period will display in a new window, allowing for a closer examination. Clicking on the back button on the top left from the new window, it will return to the main interface.

(3) **Color Harmony Filtering:** Users can make single or multiple selections to filter the paintings based on the desired color harmony types they want to view. This feature enables users to focus on specific color schemes and explore artworks that exhibit those harmonies.

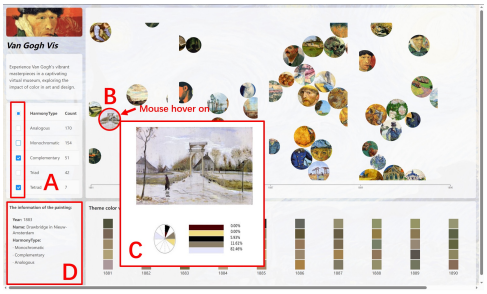

Figure 3: Hovering over a specific painting: (A) Selected color harmony types; (B) Selected painting; (C) Enlarged version of the selected painting with the color wheel and theme colors ; (D) Meta-information about the selected painting.

Figure 3 demonstrates the filter function by selecting the Complementary and Tetrad harmony types. It is noticeable that there are fewer paintings displayed compared to the main window shown in Figure 2, where all harmony types were selected. Additionally, Figure 3 showcases the hovering effect, where hovering over the painting of the bridge triggers the display of a color infographic, and the painting information is shown at the bottom left of the system.

Figure 4: Timeline extension function.

Figure 4 demonstrates the selection of a specific time period. The chosen time period, 1881–1885, is extended to encompass the entire timeframe and provide a clearer view of each picture. Additionally, it is obvious that each painting is composed of circles of varying sizes, which corresponds to the number of color harmony types that the painting utilized; the more harmony types employed, the greater size it is.

5 RESULTS AND DISCUSSION

5.1 Comparison of Theme Color Extraction Algorithms

This subsection focuses on presenting the results of the experimental test algorithms.

The illustration chosen to exhibit the algorithm's effectiveness is van Gogh's "Blossoming Almond Branch in a Glass with a Book," and Figure 5 displays the visualization of theme colors. The name of the method used to extract the color from the painting is shown in the text above each palette, and the numbers "5" or "10" at the end of the text indicate how many colors were extracted. It's important to note that the tolerance of similar colors is represented by the "tol" at the end of the text of the color palette titled "extcolors", and its value may be changed to produce various effects here.

It might be noticed that the color palette of "*extcolors*_5, tol=40" has only four colors, which is actually because there is another color that is white, so it is not obvious on the color wheel.

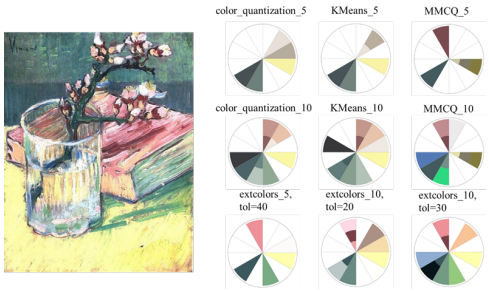

Figure 5: Example of a picture with the theme colors extracted using different methods.

It can be seen that the five colors extracted using the *extcolors* library are the most effective reflect the painting's color and best match human perception. While the colors recovered using the median cut approach were darker, the findings of the other two K-Means methods were comparable.

To evaluate the effectiveness of the extraction algorithms, ten individuals were randomly interviewed to gather their perceptions on the results of these methods. The interviewees consisted of five males and five females, including eight undergraduate college students and two employee one of which is working in the battery field while the other is a bank clerk. The average age of the participants was 25.1 years, and all are Chinese. Among the respondents, 80% expressed that the colors extracted from the *extcolors* library provided the most accurate representation of the painting subjects. However, two individuals preferred the median-cut method, as they believed it produced better results. Based on these findings, the *extcolors* library was ultimately chosen for the extraction of theme colors.

5.2 Theme Color Extraction and Analysis

5.2.1 General Results. We extract five primary colors for each artwork by the *extcolors* library and the information for each of the five extracted colors is presented in Table 2.

On the basis of all the colors extracted, a general statistical analysis was conducted by eliminating some of the dominant black and dark colors, and a word cloud was generated to visualize the overall color usage of all of van Gogh's artworks. The colors and color

Table 2: Information of extracted colors for a painting

Painting ID	Color	RGB	Proportion	Hex	Hue	Saturation	Lightness
206994	color1	(237, 215, 54)	55.147%	#E4D00A	54.5	-0.92	119
206994	color2	(8, 8, 8)	16.805%	#080808	0	0	8
206994	color3	(71, 141, 78)	15.478%	#4D8C57	129.52	-0.29	108.5
206994	color4	(32, 68, 126)	5.876%	#104E8B	209.76	-0.8	77.5
206994	color5	(176, 178, 157)	4.282%	#A9BA9D	95.17	-0.09	171.5

names of the text in the word cloud are the 986 standard colors summarized by Color-Hex[4]. By looking at this word cloud, it can be seen that the most frequently used colors in van Gogh's paintings are yellow and green, including some brown colors and a few blue-violet and red colors. To make the word cloud more interesting and to fit the theme of this study, the van Gogh sunflower with the background removed was used as a mask for the word cloud (see Figure 6, right).

Figure 6: Word Cloud of Color Usage (left) Sunflower without Background (right)

A visualization of the color wheel and the percentage of each major color in a painting was generated as an image, which means that a total of 878 color information maps were generated for this project. This color infographic can give an overview of the color information and relationships of a painting. To be explicit, in a color wheel information image, the original painting, the color wheel, and the scale bar are included. For the example painting given in Table 2, its color wheel information image is shown in Figure 7.

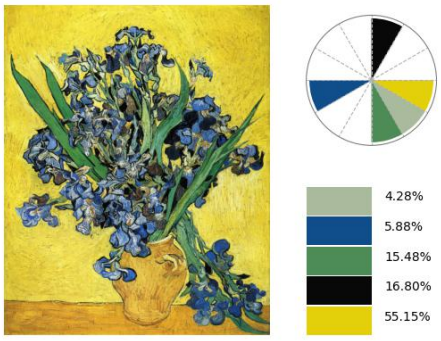

Figure 7: Color infographic for a painting

5.2.2 *Special Cases.*

Case One: Theme color with 0 proportion. As a matter of fact, by looking through the entire color data file, it is easy to notice that several of the theme colors are not very relevant to the artwork, with "Proportion" values being near 0 or exactly 0. The reason for this is that by using the *extcolors* library to extract theme colors, the parameter of "tolerance" must be set, which has a significant impact on the proportion of the final extracted color. More colors will be assigned to the same cluster center color when the value of "tolerance" is higher. Consequently, a high tolerance may decrease the amount of colors that may be extracted, to be specific, if the tolerance is too high, only 3 or 4 colors may be extracted, or even less. In our experience, the "tolerance" value was set at 30, which is a reasonable amount that enables most paintings to be effectively extracted their five primary colors. For a few paintings, less than 5 topic colors can be retrieved with a tolerance of 30, hence in this situation, the tolerance value needs to be decreased. For this case, the tolerance value is iteratively subtracted by 10, followed by another round of extraction, and so on until 5 colors are obtained. With this optimization, all of the paintings are able to extract the five main colors; however, some of the colors are only extracted to a percentage of 0.01% or lower, which can be roughly equivalent to 0 when the percentage is retained with two decimal places. Figure 8 depicts a typical case with the aforementioned situation. The sheer similarity of the colors employed in the painting may be the cause of this phenomenon, as seen in Figure 8, where the painting "A Field of Yellow Flowers" appears to be made up mostly of yellows of various lightnesses or chromas.

Figure 8: A Field of Yellow Flowers

Case Two: Non-Extracted Distinguishable Colors. Although most of the colors are well-extracted, there are a few paintings with discernible colors that have not been extracted. In other words, the extracted colors may not fully satisfy human perception. It is easy to recognize that pink is the primary hue in Figure 9. However, as the result shown in Figure 9, no pink hue is recognized by the extraction algorithm. This issue is difficult to resolve given that the algorithm works well for most paintings indeed. To get a more suitable outcome, a possible solution is to manually adjust the tolerance values multiple times. Nevertheless, this approach is time-consuming and repetitive. Thus, we do not perform further processes since they do not have a significant impact on the overall analysis.

Case Three: The main colors extracted is not easily noticeable. In contrast to the second case, other case is that colors that are not easily perceived and noticed by human beings are extracted by the algorithm. However, after a closer inspection of the painting, the color can be found to be present, which means that its extraction is reasonable, even if it is incomprehensible at first glance. Figure 10 is an exemplary example of this phenomenon, showing the color wheel of the painting "Blooming Acacia Branches". It is noteworthy that the orange-brown color with a scale of 0% is one of the thematic colors of this painting. However, the real presence of the orange-brown color may only be noticed when focusing on the upper right and lower left corners.

Figure 9: The Almond Tree in Blossom

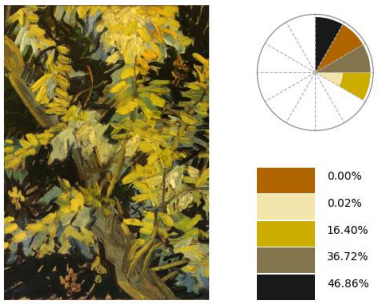

Figure 10: Blossoming Acacia Branches

5.3 Color Harmony Analysis

The created color wheel generated in section 5.2 can be used to determine the type of color harmony. The harmony types of each painting are shown in Table 3. Each painting typically includes one or more harmony types, but there are some paintings has no color harmony types. The last line of this table indicates that van Gogh's paintings predominantly exhibit analogous and monochromatic color harmonies, with 743 and 702 occurrences respectively. The tetradic color harmony is the least utilized, with only 20 instances observed. However, despite their relative infrequency, complementary and triadic color harmonies still appear frequently in van Gogh's paintings, with 226 and 181 occurrences respectively.

Table 3: Information of extracted colors for a painting

Painting ID	Monochromatic	Complementary	Analogous	Triad	Tetrad
205883	FALSE	TRUE	TRUE	TRUE	TRUE
206198	TRUE	FALSE	FALSE	FALSE	FALSE
206953	TRUE	FALSE	TRUE	FALSE	FALSE
206981	FALSE	FALSE	TRUE	FALSE	FALSE
205662	TRUE	FALSE	TRUE	FALSE	FALSE
...	...	...	...	...	...
Sum of True	702 (37.5%)	226 (12.1%)	743 (39.7%)	181 (9.7%)	20 (1.0%)

Figure 11 is an example diagram of color harmony. Specifically, the upper left disc represents similar colors, meaning they have close values of hues, and the red sector area and the green sector area represent two parts of the analogous harmony, respectively; the lower left figure shows the complementary color harmony, from the color disc, the two color blocks that are on the diagonal form a contrasting harmony, and the red area and the yellow area in the figure are two parts of the contrasting color harmony, respectively; the upper right figure shows the four color harmonies that form a rectangle. In general, two groups of contrasting harmony then can form a four-color harmony; the lower right figure represents the formation of a triangle of three-color harmony, that is, three yellow sectors circled by three colors, can form a three-color harmony.

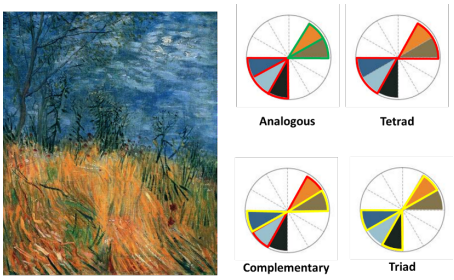

Figure 11: Different Harmony Type of Painting 205883

In contrast to one painting that has multiple color harmony, Figure 12 shows a painting with all its theme colors in the same sector of the color palette, that is, it has only one harmony type: " Monochromatic color harmony".

Figure 12: Painting 206198

6 CONCLUSION

The significance of color and color harmony in art, design, and marketing has long been acknowledged. The emergence of digital technology has brought about a heightened complexity and relevance of color in contemporary society. Digital museums have revolutionized the way people engage with art and culture, presenting an unprecedented opportunity for research related to color. Computer techniques of color extraction have emerged as valuable tools in this area. Furthermore, the enduring relevance of color theories and insights from prominent figures such as Munsell and Itten provides a strong theoretical foundation for color analysis across various fields. This study focuses on van Gogh's color paintings throughout his lifetime, delving into his use of color and color harmony to construct a digital museum based on a timeline of his works. This approach highlights the correlation between changes in color usage over time, providing viewers with an intuitive experience and perception of the paintings.

This study initially assessed four color extraction algorithms to determine which one can accurately depict subject colors in paintings. The *extcolors* library yielded results that were more closely aligned with human perception compared to the other evaluated algorithms. These alternative algorithms failed to adequately reflect the theme colors of the paintings and often resulted in darker, less

satisfactory colors. Overall, the *extcolors* library proved to be the most reliable algorithm for color extraction in this study.

The present study delved into van Gogh's artistic oeuvre by investigating his color usage over his entire career. The analysis involved examining the extracted colors as a whole, visualizing the color wheel independently, and quantifying the frequency of each color harmony type. The findings indicate that van Gogh's paintings predominantly feature shades of yellow and green, with blue and red being the other major colors. Additionally, the study reveals that monochromatic and analogous color harmonies were the most frequently employed in van Gogh's works, followed by complementary and triadic harmonies, whereas tetrachromatic harmonies were the least utilized.

Additionally, a digital art gallery was erected to showcase selected van Gogh's paintings in chronological order. Regrettably, due to time constraints, both the timeline and digital museum design were kept rudimentary, featuring only 200 paintings with limited functionality; interactive capabilities were restricted solely to color wheel infographics.

In conclusion, this study assessed four color extraction algorithms to determine the most accurate representation of the subject's colors in a painting, with the *extcolors* library proving to be the most reliable. Furthermore, van Gogh's use of color throughout his career was examined and revealed a preference for yellow and green hues, while blue and red were also prominent. Monochromatic, analogous, and complementary color palettes were frequently employed by van Gogh as his preferred method of achieving harmonious compositions. A digital art gallery based on these findings presents a selection of van Gogh's works in chronological order, showing viewers the transformation of van Gogh's use of color throughout his painting career in the simplest of designs.

7 FUTURE WORK

Despite achieving satisfactory results, this study has some limitations that must be acknowledged. One of the primary limitations is the narrow focus on analyzing the paintings themselves without consideration of the social, cultural, and historical context surrounding van Gogh's works. As a result, conclusions regarding the changes in color usage over time may lack the necessary factual support. Therefore, future studies on painting-based artworks should consider incorporating an analysis of color changes within their socio-cultural and historical contexts to provide a more comprehensive understanding of the artist's color choices.

In addition, several elements such as classification and search capabilities that were intended for the development of the digital museum were not completed. The lack of these functions significantly hampers the user's interactive experience with the exhibited works. To overcome this limitation, future work can solve these problems. Additionally, researchers can also explore new techniques and technologies that may offer more effective and efficient ways to analyze and present color usage in the artwork.

For the future, the project will focus on analyzing the use of color in the broader context of van Gogh's life, including the influence of Impressionism and Post-Impressionism during his time in Paris, his fascination with Japanese art elements, and the impact of his living situation in Arles. This analysis will provide a more comprehensive understanding of van Gogh's color choices and how they reflect his artistic development over time.

The research conducted by Hochman and Manovich in 2013 [7], which analyzed the visual characteristics of images, particularly focusing on tone and color, aligns with the central theme of this paper. Thereafter, in 2015, Tifentale and Manovich [13] proposed a study exploring the connection between photographs and their predecessors in various historical contexts, emphasizing differences in composition, content, and other aspects. This notion of investigating the relationship between images and their historical predecessors serves as a valuable reference point. Building upon this idea, future studies on van Gogh's paintings will aim to explore the interplay between content, color usage, and historical context. This approach will further enrich the analysis and understanding of van Gogh's artworks.

In addition, the digital art gallery will keep developing, and several additional features will be implemented. These include filtering, searching, and information display functions that will enhance the user's experience by providing more in-depth knowledge of the paintings.

REFERENCES

[1] Christel Chamaret. 2016. *Color harmony: experimental and computational modeling*. Ph. D. Dissertation. Université Rennes 1.

[2] Gianluigi Ciocca, Paolo Napoletano, and Raimondo Schettini. 2019. Evaluation of automatic image color theme extraction methods. In *Computational Color Imaging: 7th International Workshop, CCIW 2019, Chiba, Japan, March 27-29, 2019, Proceedings 7*. Springer, 165–179.

[3] Daniel Cohen-Or, Olga Sorkine, Ran Gal, Tommer Leyvand, and Ying-Qing Xu. 2006. Color harmonization. In *ACM SIGGRAPH 2006 Papers*. 624–630.

[4] Color-hex. 2010. *Color Names*. Retrieved May 28, 2023 from https://www.color-hex.com/color-names.html

[5] Cybrain. 2015. *Extract Color Themes from Images*. Retrieved May 28, 2023 from https://github.com/rainyear/ImageColorTheme

[6] Julie Delon, Agnes Desolneux, Jose Luis Lisani, and Ana Belen Petro. 2005. Automatic color palette. In *IEEE international conference on image processing 2005*, Vol. 2. IEEE, II–706.

[7] Nadav Hochman and Lev Manovich. 2013. Zooming into an Instagram City: Reading the local through social media. *First Monday* 18 (2013).

[8] Sharon Lin and Pat Hanrahan. 2013. Modeling how people extract color themes from images. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 3101–3110.

[9] Shiguang Liu and Huarong Luo. 2016. Hierarchical emotional color theme extraction. *Color Research & Application* 41, 5 (2016), 513–522.

[10] Jason A Morris. 2006. The Purpose and Power of Color in Industrial Design: Encouraging the Meaningful Use of Color in Design Education. *Washington DC, Estados Unidos: Western Washington University and Industrial Designers Society of America* (2006). http://www.idsa.org/sites/default/files/nec06_morris_jason.pdf

[11] Bryan S Morse, Daniel Thornton, Qing Xia, and John Uibel. 2007. Image-based color schemes. In *2007 IEEE International Conference on Image Processing*, Vol. 3. IEEE, III–497.

[12] Giv Parvaneh. 2018. *RoyGBiv*. Retrieved May 28, 2023 from https://github.com/givp/RoyGBiv

[13] Alise Tifentale and Lev Manovich. 2015. Selfiecity: Exploring photography and self-fashioning in social media. In *Postdigital aesthetics: Art, computation and design*. Springer, 109–122.

[14] Olivia Vane. 2020. *Timeline design for visualising cultural heritage data*. Royal College of Art (United Kingdom).

[15] Alberto Fernández Villán. 2019. *Mastering OpenCV 4 with Python: a practical guide covering topics from image processing, augmented reality to deep learning with OpenCV 4 and Python 3.7*. Packt Publishing Ltd.

[16] Arthur Robert Weeks and G Eric Hague. 1997. Color segmentation in the hsi color space using the k-means algorithm. In *Nonlinear image processing VIII*, Vol. 3026. SPIE, 143–154.

[17] Stephen Westland, Kevin Laycock, Vien Cheung, Phil Henry, and Forough Mahyar. 2007. Colour harmony. *Colour: Design & Creativity* 1, 1 (2007), 1–15.

[18] WikiArt. 2021. *Vincent van Gogh: List of works*. Retrieved May 28, 2023 from https://www.wikiart.org/en/vincent-van-gogh/all-works/text-list