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ColourVis: Exploring colour in digital images

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ABSTRACT

The colour palette of painters over history has been of interest to many, including: art historians, archaeologists, and art lovers. Colour usage in art changes from culture to culture and season to season and is often thought of as reflecting or inspiring mood and ambience. We present ColourVis: a visualisation that supports exploration of colour usage in digital images. In particular, we use as a case study European art over the last six centuries. Visualising this relatively unexplored area offers insights into such questions as: How blue was Picasso's blue period?; How do realist painters' colour choices compare to that of surrealist painters; or How has the usage of colours changed over time? Through ColourVis we offer an exploration and comparison tool for individual paintings, groups of paintings and trends in colour usage over time.

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1. Introduction

In ColourVis we explore the visualisation of colour as used in paintings and images. ColourVis graphically represents which colours and how much of each are used in single images and provides a graphical way to compare the colour usage of two or more paintings or images. Information about how colour has been used in paintings has been the focus of many scholarly studies [12], historical records [4], and literary criticisms [29]. Colour usage in paintings is an ongoing area of interest for art historians and archaeologists but depicting how colour usage has changed over time still remains a challenge. ColourVis aims to address this problem by graphically displaying trends and patterns in colour usage of paintings, artists, over time, over genres and across spectrums. Fig. 1

With ColourVis we can analyse any set of scanned images, such as paintings or advertisements, extracting the colour information from these images pixel by pixel. ColourVis presents this information for single images using our own custom histogram visualisations and, for exploration of trends in a series of images, colour information is visualised with a variation of a stacked line graph visualisation. We created both of these visualisations to give the viewer a sense of the colours and the amount of each of these colours, that make up either an image, or a series of images. ColourVis offers a new way to extend our understanding of colour

usage in images; for example, it can offer a unique perspective on a selection of historically relevant paintings.

2. Related work

Colour is a fascinating and diverse topic that has received attention from a wide variety of research areas including science, art, and history. Colour perception is a key attribute of human vision and a primary way in which people understand their world [13]. While both digital and non-digital colour representation have been previously explored in academic literature, colour and colour usage remain a fascinating topic in need of further exploration.

In the field of information visualisation, colour has historically been used as one of the primary visual variables through which difference in data can be distinguished and is considered as one of the fundamental building blocks of visualisations today [2]. One typical use of colour is in the labelling or categorising of information, as in legends for maps in order to facilitate the understanding of more complex visualisations [32,5]. When using colour to indicate or label changes in the data being visualised there are many perceptual factors to consider. These factors include: distinctness, unique hues, contrast with background, colour blindness, number, field size, and conventions [36]. While colour has an important role in information visualisation we see rich opportunities for new research into how the use of colour itself in digital images can be visualised and how colour information can be represented visually.

In order to explore colour usage over time we draw inspiration from existing research that focuses on visualising information

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Fig. 1. ColourVis representation of paintings by Vincent van Gogh.

chronologically, casual information visualisations, and artistic visualisation. Our prototype design was informed by works which present information using a stacking metaphor such as ThemeRiver [15], which visualises the changes in text data over time using the inspiration of a flowing river. Each current in the ‘river’ represents frequency of word or word phrase usage and is coloured distinctly. This depiction either narrows or widens indicating changing quantitative information about the dataset. Subsequently, the paper Stack Graphs by Byron and Wattenberg extended the ideas in ThemeRiver by exploring several variations stacked layered graphs and suggested that the implementation of complex layered graphs can be effective for displaying large amounts data in aesthetic manner to mass audiences [7].

ColourVis is designed with the analysis of images in mind but other researchers have explored how video data might be visualised over time and this too informed our design of ColourVis. The Last Clock project visualised video surveillance footage in public area capturing time and motion and then mapping seconds, minutes, hours using the metaphor of a clock face to show data variance over time [1]. The Video Traces Project, visualises video data in order to gain an understanding of activity of people captured on the video and supports rapid exploration of the history of a video stream [24]. Also, the Artifacts of the Presence Era visualisation make use of video as a data source but presents a stacked graph visualisation which uses the metaphor of sedimentary accumulation over time [35]. ColourVis can also be compared to parallel coordinates [17]. In parallel coordinates each data dimension is given an axis and the data values are then plotted on this axis. This has proved useful for multi-dimensional data since each dimension can be assigned its own axes. In ColourVis each image or group of images can be considered as an axis in parallel coordinates. However, the ColourVis data as shown on these axes represents percentage use of colour comparison purposes.

We also explored how tagged images have been visualised over time. The Flickr Flow visualisation project <http://hint.fm/projects/flickr/> was developed for Wired Magazine and calculates the relative proportions of different colours extracted from photographs taken in each month of a year. Flickr Flow then plots this colour data using a fluid and aesthetically pleasing radial representation. Wired magazine also presented a visualisation to extract “peak” colour from any image and then produce a bullseye pattern for each image analysed. This bullseye visualisation was presented by grouping many small visualisations in a grid layout on a single page for visual inspection while the Flickr Flow visualisation grouped the extracted image data into a single synthesised visualisation. ColourVis adopted the approach of synthesising many images into a single visualisation to allow for comparison of a large number of images without the need to compare many distinct but smaller visualisations.

2.1. The use and analysis of colour in science

Scientists have also long been interested in understanding colour. When depicting colour scientifically there are, generally, two types of

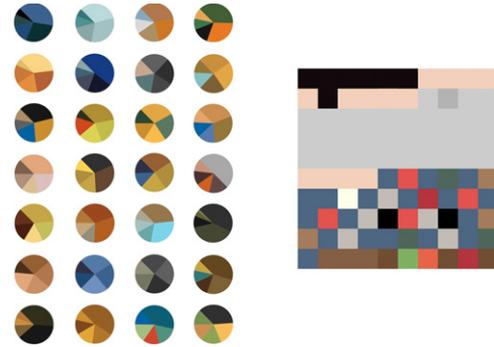


Fig. 2. Left: various pie charts representing a series of van Gogh’s paintings by Arthur Buxton. Right: a visualisation of the colours worn by Jacobo Zanella over a period of one day. Reprinted by permission of the artists.

colouring: true-colouring and false-colouring. An example of true-colouring is as follows: in an image of a blue ocean, the ocean appears to be the same colour as it would in the real world and, likewise, an image of a red brick of a house would appear to be the same red as it would in real life. False-colouring differs from true-colouring in that false-colour imagery alters the colour of the subject matter to appear as a different colour than it would normally appear to the human eye. One of the most iconic examples of false-colour imagery are images produced by astronomers using satellite technology, such as the Hubble Space Telescope. In false-colour satellite imagery, light spectra that are imperceptible to the human eye are altered in order to be perceived by humans in an understandable and visually appealing manner. Scientists also commonly observe trends in colour change and colour shifts in order to measure things such as the speed and distance of celestial objects, and for diagnosing medical conditions using medical imagery.

Scientific investigations of colour have also focused on using technologies, such as x-rays and other scanning technologies, to more closely examine the qualities and technical properties of pigments colours used in paintings [18]. Due to the historical significance of some paintings, analysing pigment from a painting in an unobtrusive and minimally impactful way has been a focus of research for many art historians. Examples of these types of investigations include the development of a minimally invasive process using x-ray fluorescence spectrometry to produce a gentle sampling technique in historical paintings and manuscripts [20] and viewing paint colours painted under other layers of painting in the works of Vincent van Gogh [10].

Archaeologists and historians have also examined exploring colour in paintings. Archaeological researchers are interested in things like the processes used to create certain colours used in historical paintings; for example, understanding how certain shades of blue and purple were created. Some of this curiosity stems from the elaborate or expensive process of creating certain pigments. Archaeologists have even attempted to replicate the historically correct methods of processing raw ingredients required to make rare pigments colours such as Royal Purple [23,22].

2.2. Colour visualisation in art

Most closely related to our work are Buxton's pie chart visualisations of Vincent van Gogh paintings that represent the colour usage in van Gogh's paintings [6]. In these visualisations, similar colours from van Gogh's paintings have been aggregated and are represented by a single colour in order to simplify the visualisation and make it more readable [6] (see Fig. 2). These pie chart visualisations represent various van Gogh paintings in five distinct colour regions or less. Rigau et al. also explored the evolution of the colour palette and composition of van Gogh's style [28] by introducing measures to better understand the changes in van Gogh's painting style over his career.

Besides in paintings, colour usage has an important impact in our everyday life and we constantly make colour-related choices. Artistically visualising these everyday choices regarding colour can lead to interesting insights about one's life. Artist Jacobo Zanella, for instance, has visualised the daily colour palette of the clothing he wore over the course of each day in 2010. In Zanella's work rectangles are used to depict not only which colours were worn but also, as shown by each rectangle's area, what quantity of each colour was worn (see Fig. 2) [38].

There also exist a large number of software tools designed to help designers and artists analyse, choose, compare, and generate colours based around themes and patterns. Examples include Adobe Software's Kuler, which is an online colour choosing application; they also include photo editing applications such as Photoshop™ or Gimp which can aid in the visualising of images by displaying histograms of the colours present in images.

Both academics and artists have explored colour usage and patterns in images and yet, to our knowledge, a system that allows for the visualisation of colour usage in a series of images chronologically ordered and also non-chronologically ordered images has yet to be undertaken. With ColourVis, we explore this area of visualising colour usage and changes in paintings and other images.

3. ColourVis information visualisation

ColourVis explores the pixel by pixel colour usage in images. In ColourVis we use the HSB (Hue, Saturation, Brightness) colour space. Our choice to use the HSB model is a result of our focus on producing a system that is informative to artists, scientists, designers, and casual observers alike. HSB provides a relatively natural method to think about a colour in terms of hue and saturation rather than needing to think in terms of additive or subtractive colour components. Additionally, the use of an HSB colour model allowed for smaller file sizes, as compared to CMYK (cyan, magenta, yellow, and black), which was useful in reducing the large amount of computation that occurs when processing a large number of images. Although the concept of the HSB colour system is well known, we reiterate the definitions here for the convenience of the reader since these factors are fundamental to ColourVis. Hue (H) is the colour range from red to violet; saturation (S) is the amount of hue present and ranges from full intensity to transparent; and brightness (B) is the degree of darkness or lightness of the particular colour.

To describe ColourVis we start by explaining how the colour usage in a single image is visualised. Then we will discuss how visual comparisons can be made with two or more images. To illustrate this discussion we use an image set of European paintings obtained from Freebase.com database [11]. In total this dataset contains approximately 1300 paintings by European painters created during the time period of 1475–2000 AD.

3.1. Visualising colour usage in one image

One way of visualising colour usage in an image is to measure the hue of each pixel and count how many pixels of a given hue were actually used. From this analysis, a hue usage histogram can be created. For the next series of images we will use the painting "Fishing in Spring, the Pont de Clichy" by Vincent van Gogh (see Fig. 3) as a sample image and discuss some colour visualisation possibilities. Fig. 4 shows a simple hue histogram for our sample painting. Note how even though this is an accurate representation of hues present this does not relate well to the actual colours in the painting, which combine hue with saturation and brightness. Taking this histogram and replacing the pure hue pixels with the actual pixel colours that are in the painting creates a much more compatible visual result (see Fig. 5). However, the variations of dark and light colours make the actual colour ranges hard to read. This histogram can be sorted according to saturation (see Fig. 6) or brightness (see Fig. 7). Both groupings help readability, but the gradient produced while sorting by brightness appears to be more readable. However, neither of these histograms leads to a completely simple gradation because variations in colour are caused by both saturation and brightness.

These histograms all indicate frequency distribution of colours in the van Gogh painting. Based upon the histograms' shape, they can indicate over-arching trends in colour usage such as symmetry or degree of skew of colour distribution. However, a simple question that might be of interest for further analysis, such as



Fig. 3. "Fishing in Spring, the Pont de Clichy" by Vincent van Gogh.



Fig. 4. Simple hue histogram of Fig. 3.

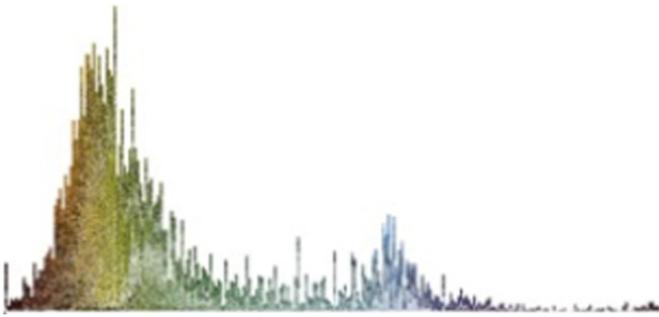


Fig. 5. Unsorted actual pixel colour hue histogram of Fig. 3.

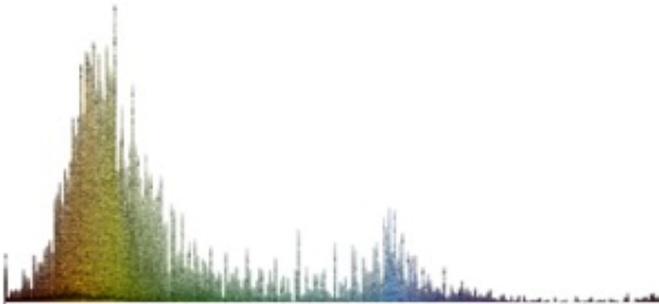


Fig. 6. Actual pixel colour hue histogram sorted by saturation of Fig. 3.

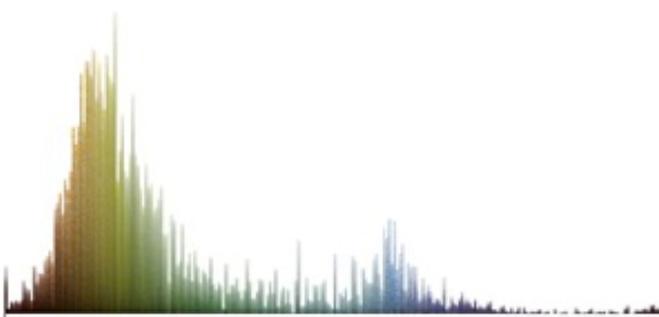


Fig. 7. Actual pixel colour hue histogram sorted by brightness of Fig. 3.

“Does this painting contain more blue than green?” cannot readily be answered and must be deduced by visually assessing the area of blue in the histogram and comparing it to the area of green in the histogram. It is well known that judging comparative size of areas of irregular shapes is a difficult task that is not often done successfully when trying to form judgments by eye [34,36]. If all the colours were grouped, according to how we are accustomed to recognising them, gathering the blues, greens, yellows, etc. together, the histogram could become a simple bar graph (see Fig. 8). However, exactly how to group them is a complex issue.

One possible solution for grouping colours is to use named colour spaces. Studies have been run asking people what name they would use for a set of colours [25,36]. There are some colours that were consistently named the same by most people. Post et al. [25] attempted to determine how participants named colours shown to them on CRT displays and found that only six colours were named by participants with high reliability: blue, green, yellow, orange, pink, purple. Research literature also suggests that the naming and banding of colours may be affected by the language and culture of participants [8,16,19,26,27]. Also, the named areas in the colour gamut are small with large areas in-between them where, for instance, some people would call a given colour blue and others would call it green.

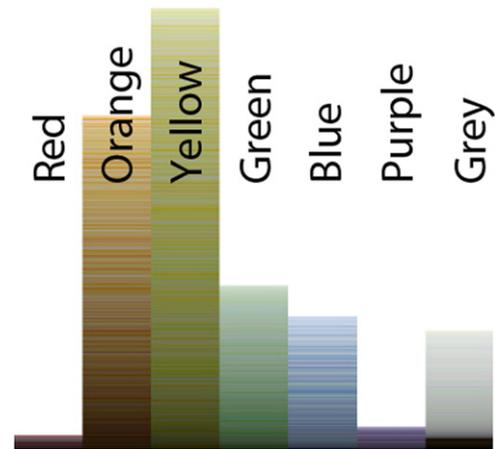


Fig. 8. Labeled linear banded histogram representations of Fig. 3.

These indeterminate spaces in-between named colours make for indistinct bins. We therefore choose to revert to painterly colour divisions: we categorised colours by the painterly primaries: red, yellow, and blue colours; and the painterly secondaries: orange, green, and purple. These six colour categories also contain red, green, blue (the three primary colours making up the trichromatic human colour vision [30]). Even then, the dividing line between these colours was a topic of much discussion.

In response to this potential for culture and lingual bias when representing the six colour categories we decided to provide configurable colour categories. ColourVis colour categories are configurable in category amount and hue. People can specify the number of colour categories and adjust the range of hues; both the start and stop point of any bin are settable. These customisations can be adjusted in a configuration file.

As a default, six colour categories seemed to be a reasonable number because a study has shown that five-colour target identification provided little difficulty for participants while seven-colour target identification has been found to be significantly more difficult for participants [14].

Note that the ColourVis actually consists of seven colour (see Fig. 8) categories with an additional grey scale category. While the pixels represented in the greyscale category do register as having hue, their saturation is so low that the hue is not perceived. If these were included in the colour categories they would show up as lines of black, white and grey. As with the simple histogram, these binned colour bar charts can be sorted by either brightness or saturation. The images in the rest of this paper are sorted by brightness.

From Fig. 8 one can see how van Gogh made more frequent use of lightly saturated colours in this particular painting. Notice how the binned colours support the comparison of the amount of blue colour (mostly the water and sky) to the green colour (representing foliage and the boats) in the painting. We are able to observe from the size of the banded histogram bars an approximation of how much of the natural scenery in the painting is in the orange range compared to green in colour.

3.2. Visualising and comparing two images

We extend ColourVis functionality to support colour usage comparisons across two or more images. While it is possible to do comparisons across images by generating the necessary set of histograms and then switching back and forth between histograms of individual images (see Fig. 9) this procedure increases the cognitive load on the observer [9]. ColourVis addresses this challenge through a specially tailored implementation of a stacked line graph that enables the comparison of colour usage in

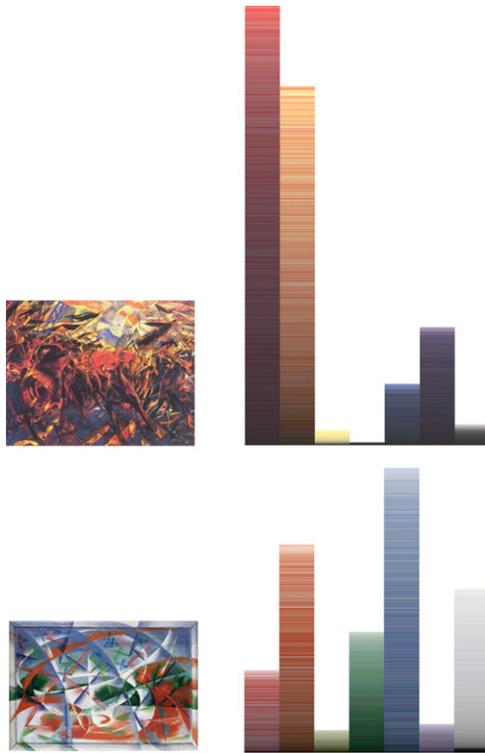


Fig. 9. Linear histograms representations of “The Funeral of the Anarchist Galli” by Carlo Carrà (top) and “Speed + Sound” by Giacomo Balla (bottom).

multiple images [7]. We note that there exist similarities between this approach and the technique of parallel coordinates, a visualisation technique used to plot individual data elements across many dimensions [17]. Our stacked line graph visualisation can therefore be thought of as a unique implementation of a stacked parallel coordinate visualisation.

To compare two or more paintings in ColourVis, we first stack our single painting bar graph, starting with red and moving through orange, yellow, green, blue and purple to end with the low saturation greys at the top. One could simply juxtapose these two (or more) stacked bar graphs. However, to emphasise changes and trends we draw quads between the respective colour bins to create a stacked line graph.

Fig. 10 shows a ColourVis stacked line graph for the same two paintings shown in Fig. 9. The same six colour categorisations are used. More specifically, we compare paintings from the Futurist time period using our stacked line graph implementation in Fig. 10. The outer vertical edges of Fig. 10 each represent a painting. The left column shows the colour usage in the painting “The Funeral of the Anarchist Galli” by Carlo Carrà and the right column shows the utilisation of colour in the painting “Speed + Sound” by Giacomo Balla. For each painting the colour bins of their linear histogram are stacked one on top of each other according to the hue range pattern. In a given colour bin the pixels are rendered using HSB as they are in the painting and are also sorted by brightness. This results in a stacked bar graph for one painting. Given two paintings, as in Fig. 10, the exact colours in each stacked bar differ. The hue colours are then blended between the left and the right image’s stacked bars using a linear interpolation between the colours on the left and right. In Fig. 10 we can observe the differences in the paintings by Carrà and Balla; in particular considering the different utilisations of the colours red, blue and green. The visualisation also shows that both paintings use a similar amount of yellow paint which would be difficult to observe by just visually comparing the paintings

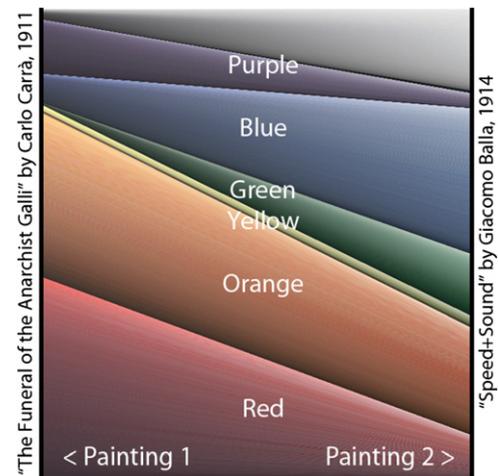


Fig. 10. Labeled stacked line graph representation of “Speed + Sound” by Giacomo Balla 1911 and “The Funeral of the Anarchist Galli” by Carlo Carrà 1914.

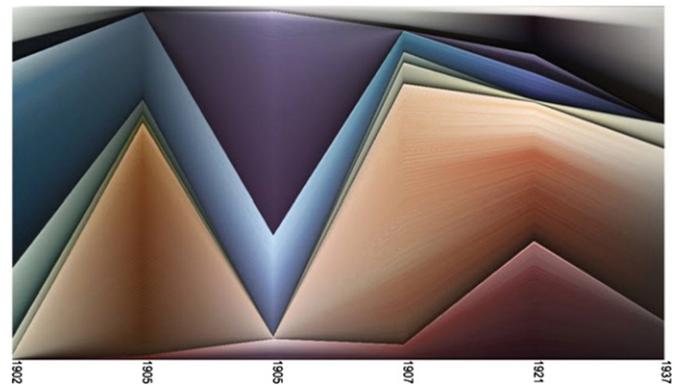


Fig. 11. Picasso paintings visualised using ColourVis. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

themselves or by analysing the ColourVis histograms created for these paintings (see Fig. 10).

3.3. Visualising and comparing collections of images

ColourVis stacked line graphs can be extended to compare entire series or collections of paintings to enable, for instance, comparisons between paintings across time periods, over the career of an artist, or across genres of paintings. Furthermore, ColourVis can combine groups of paintings into a singular vertical stacked bar graph, and by using this compiled group ColourVis can then create a stacked line graph to compare this combined grouping with other paintings or other groupings of paintings. Thus, entire collections of work can be compared with one another.

Fig. 11 presents six paintings by Picasso created from 1902–1937. Picasso is well known for his distinctive periods of painting, including his blue period (1901–1904) and his rose period (1904–1906) [31]. In Fig. 11 both the blue and rose period can be observed in Picasso’s work. His blue period consisted of paintings rendered in shades of blue and blue–green and this can be seen in large amount of blue and green colours used in 1902 painting in Fig. 11. By 1905 (see Fig. 11) we can see a decrease in Picasso’s use of blue and green colours in favour of a large amount of orange colouring and in this visualisations’ second painting from 1905 we see a large amount of purple/red/pink colours during his transition phase to the rose period.

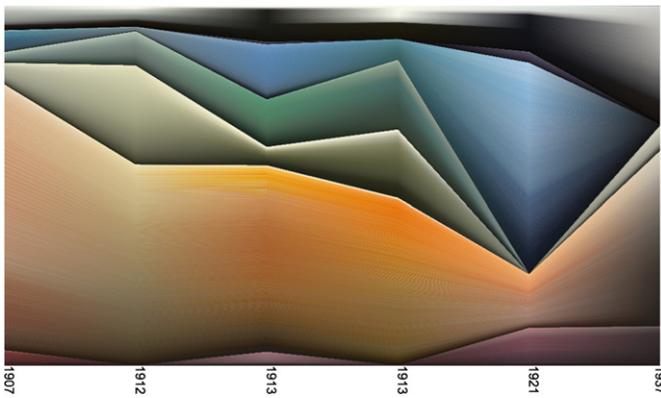


Fig. 12. Representation of 30 years of paintings from the cubism movement.



Fig. 13. ColourVis representation of Realism and Surrealism painting movements. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

We can also use ColourVis to observe entire genres, movements, or time periods in paintings (see Fig. 12). Further, ColourVis can be used to group collections of paintings into singular vertical points. In Fig. 13 paintings from realism (31 paintings) and surrealism (13 paintings) are compared in a normalised aggregated form. We see a decrease in the usage of red colours, a consistent use of greens and yellow, and an increase in oranges from the realism into the surrealism time period. We can also observe that purple colours were not as prevalent during these time periods. Understanding these changes in colour usage by visually examining hundreds of paintings from both time periods would be a large undertaking but by representing them in aggregated form using ColourVis these patterns become much more apparent.

In Fig. 14 we compare collected works of Rembrandt (34 paintings), van Gogh (56 paintings), and Picasso (7 paintings). Here we see Rembrandt's fondness of oranges and reds, Van Gogh's greater use of greens and yellows compared to the other two artists, and Picasso's noted choices of blues and purples. At a quick glance ColourVis allows for a viewer to gain a global understanding of colour usage of these three well know artists without having to manually compare their vast collected works. ColourVis allows for both a depth and breadth understanding of colour use across time, artists, and genres. ColourVis representations can be viewed along with the original paintings in order to gain a better understanding of the art, the artists' creation process, and larger views on art movements and trends across time.

3.4. Exploring image collections

Fig. 15 shows forty images from the German Expressionist period, ranging over the year 1901 to 1933. This series includes many artists such as Wassily Kandinsky, August Macke, Franz Marke, and Ernst Ludwig Kirchner. As mentioned in Section 3.3,

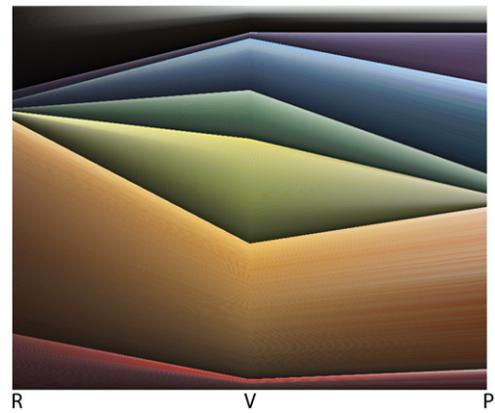


Fig. 14. Comparison of the Rembrandt Harmenzoon van Rijn/Vincent van Gogh/Pablo Picasso painting collections.

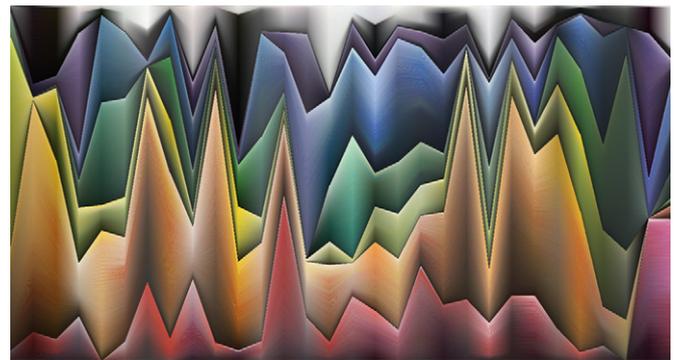


Fig. 15. Series of German expressionism paints visualised by ColourVis.

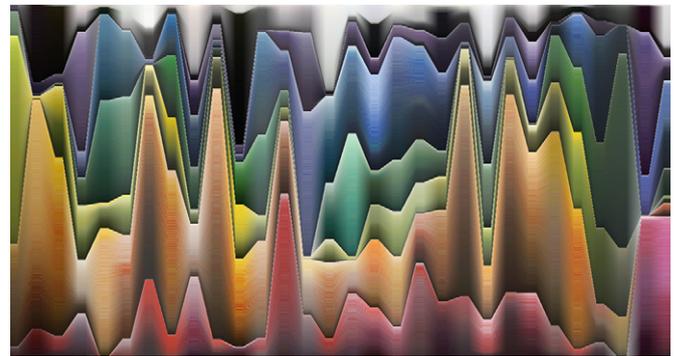


Fig. 16. German Expressionism series: depicted using a bar for each image in the series.

each image in ColourVis is represented using a single line of pixels, stacked on top of one another. Between two sets of pixels, a sloped region is created that contains the interpolation of these pixel values in a particular bin range. With the technique of interpolating between one set of pixels to another, the single width pixel representation for each painting or group of painting is perceptually quite narrow. This can lead to issues when trying to correctly deduce the colour values for a particular painting. To resolve this we use a bar, with adjustable width, for each of the painting or groups of paintings. This increases the visual impact for each grouping, emphasising the colours in use rather than the transitions between colours. We still keep the linear interpolation that visualises the change between one painting (or group) and the next. In Fig. 15 we show the original visualisation of the German Expressionist period. Fig. 16 shows the same set of paintings with

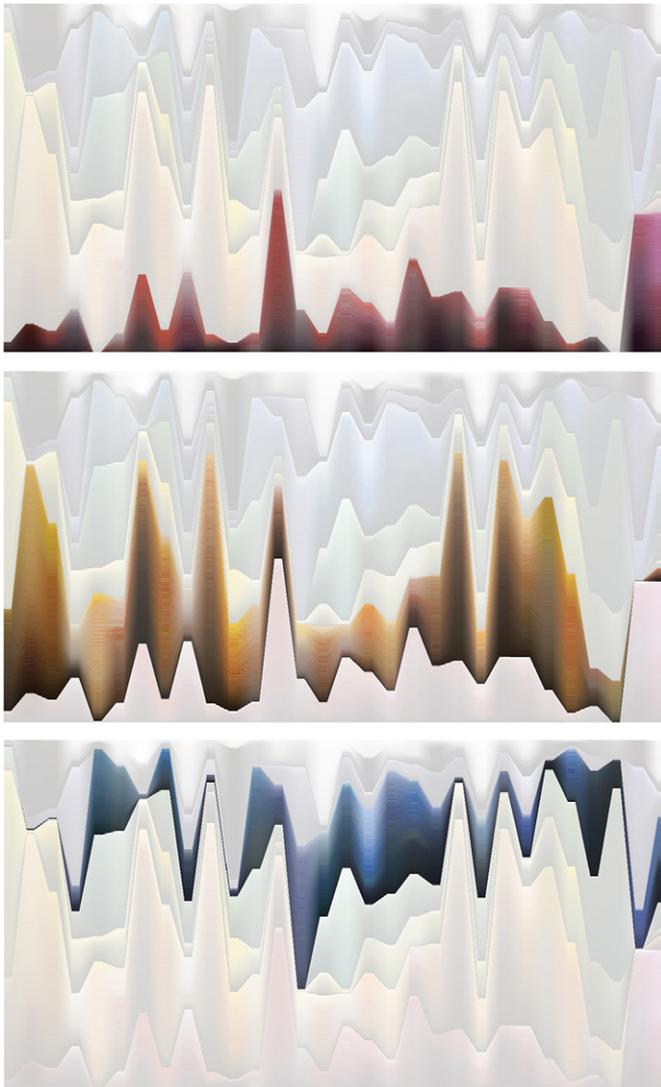


Fig. 17. Focusing ColourVis on one hue range. From top to bottom: red, orange and blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the addition of bars for each painting. Note how this brings more clarity to the colour values of each painting.

In the German Expressionist period, a wide range of hues can be seen, with fairly large variation within each hue range. ColourVis supports the option of choosing a particular hue for a focus. For example, if one is interested in how much red is used in the expressionist period, the band of red hues can be selected. ColourVis isolates a particular hue range by fading out other hues. Fig. 17 shows three examples of colours in focus, specifically the isolation of red, orange, and blue, respectively, applied to the ColourVis of German Expressionist paintings in Fig. 16.

The ColourVis visualisations shown in all of the previous examples have the band of red hues at the base. Therefore, it is easy to make a direct comparison between the relative amount of reds in each painting. Since all other hues are stacked one on top of the other, none except the base red hues have a consistent base line. This varying baseline can lead to difficulty in direct comparison.

To address this, we provide the ability to move the baseline, changing which hue has a flat baseline for the visualisation. This technique is shown in Figs. 18 and 19. These images place the straight baseline under orange hues (Fig. 18) and green hues (Fig. 19), respectively. This enables viewer choice of baseline

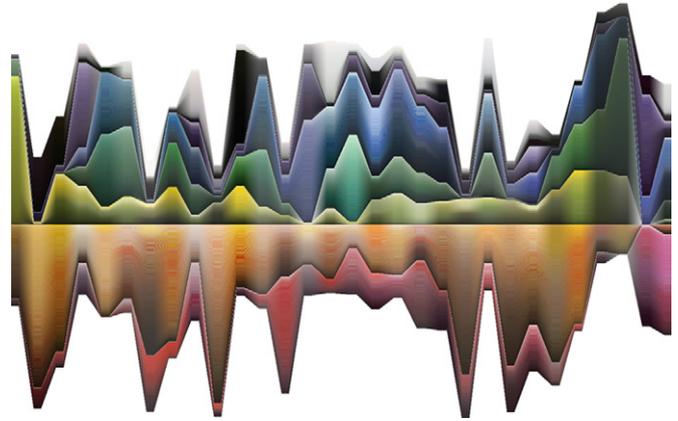


Fig. 18. German expressionism with a baseline of yellow. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

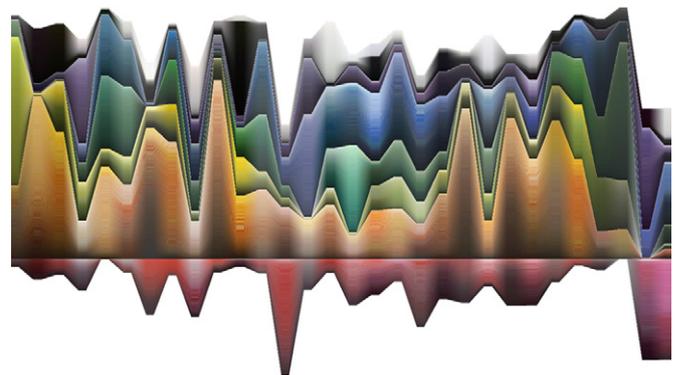


Fig. 19. German expressionism with a baseline of orange. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

positioning and provides a relative ease of comparison for any chosen hue. Note that in moving the baseline, the hue bands below are not removed but are reflected downwards to still provide full context.

Alternatively, the paintings can be re-ordered to provide the option of sorting by different aspects of the data such as time, tags, and hue. This technique is shown for the hues red, orange and blue in Fig. 20.

4. Applications of ColourVis

4.1. Sunrises and sunsets

One of the things we wanted to do in ColourVis was to allow it to be applied to a series of images, not just paintings. We enable the ability to do this by taking Flickr API search results and using them in ColourVis. With this ability we can search by parameters such as time period, image tags, titles, and generate visualisations based on these search results.

From Flickr we gathered two data sets, both with 50 images each, that were tagged as being either of a sunset (Fig. 21) or a sunrise (Fig. 22). All of these images were taken in Vancouver, Canada. In both Figs. 21 and 22 the images have been sorted by the red hue. While commonly we think of both sunsets and sunrises containing considerable warm colours such as red and orange, in this data set, an interesting phenomenon can be observed: the amount of red hues in images of sunsets is much more prominent than the reds in sunrises.

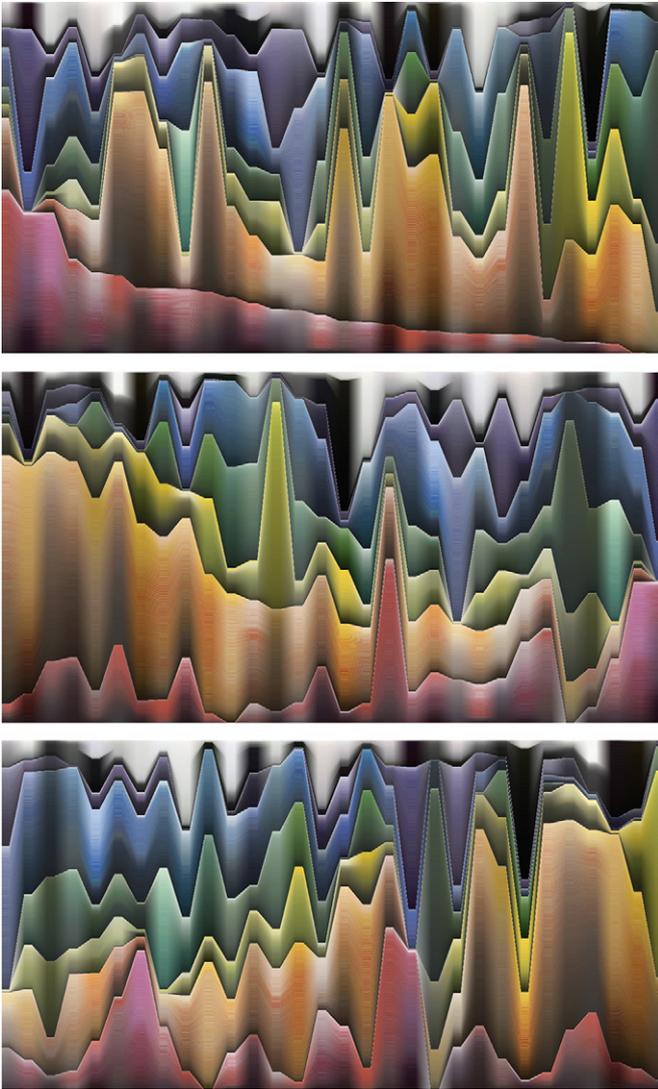


Fig. 20. Sorting paintings by colour usage. From top to bottom: red, orange, and blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

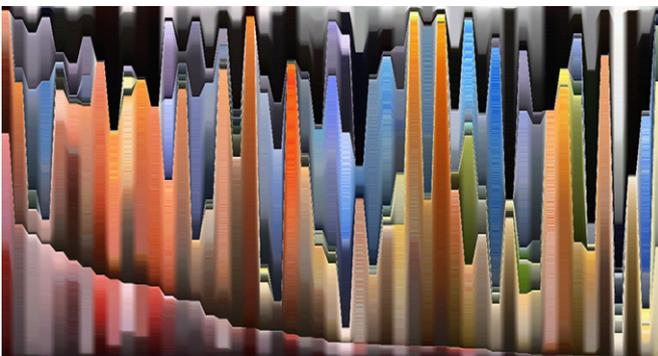


Fig. 21. Vancouver sunsets sorted by red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4.2. Characterising images as warm and cool

Often when colours are being discussed colours in the red, orange, yellow range are referred to as warm and colours in the blue, green range are referred to as cool. Using images from Flickr we gather images tagged as cold, cool, warm and hot. Using the

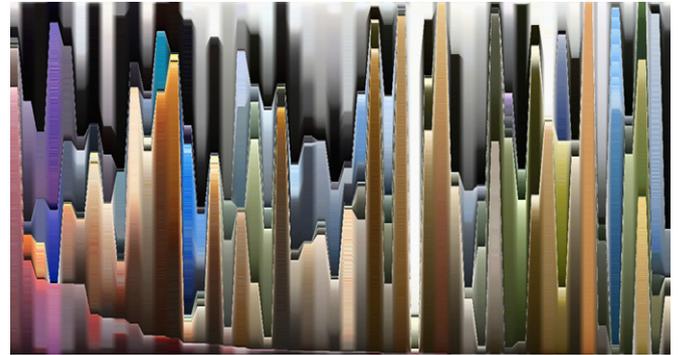


Fig. 22. Vancouver sunrises sorted by red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



Fig. 23. Images tagged for temperature: cold, cool, warm and hot tagged images.

first 100 images in each category the image in Fig. 23 was created. Note how for the groupings cold, cool and warm the colours are approximately what might be expected. That is, the colours in the blue and green range tend to be more common in the images tagged cold and less common in the images tagged warm. However, the grouping under hot seems to be counter intuitive. Perhaps this is because the word hot has many uses.

4.3. Seasons of the year

Results which, upon initial exception, seem unexpected, can be explained rationally upon closer examination. For instance, in Fig. 24 the fact the images tagged as winter show more reds and oranges than any of the other seasons seems surprising. However, it appears the many images so tagged actually taken in the winter up during trips to warm places, such as “winter in the Bahamas.”

4.4. Colour tags

We wanted to explore if images tagged with colour keywords would show clear differences in colour composition. We explored this idea by searching for images tagged “red” and “pink” on Flickr.

Interestingly in Figs. 25 and 26 we can see that many images tagged by colour names on Flickr do not contain any or only very small amounts of the colour they have potentially been tagged for.

We might also expect to see a large amount of pure red in images tagged “red” and large amounts of pinks, light purples, and light oranges in images tagged “pink” but instead in Fig. 27 we find similar amounts of colour distribution across these two sets of tagged images.



Fig. 24. Seasons of the year. From left to right: fall, winter, spring and summer. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

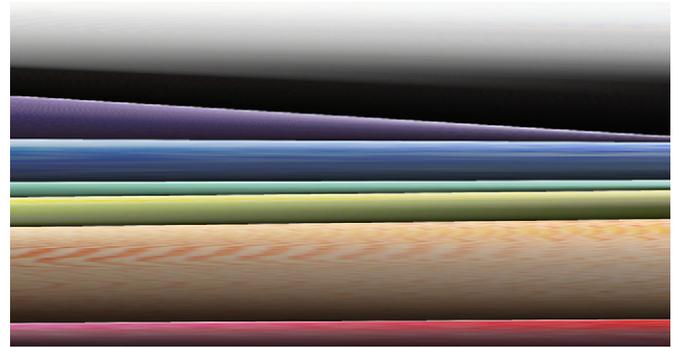


Fig. 28. Images tagged as “love” (left) and “hate” (right).

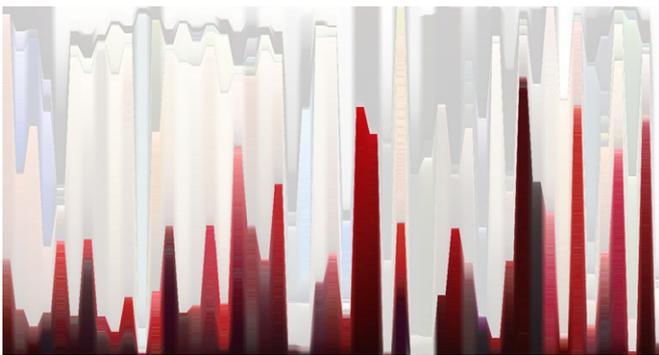


Fig. 25. Images tagged as “red”. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

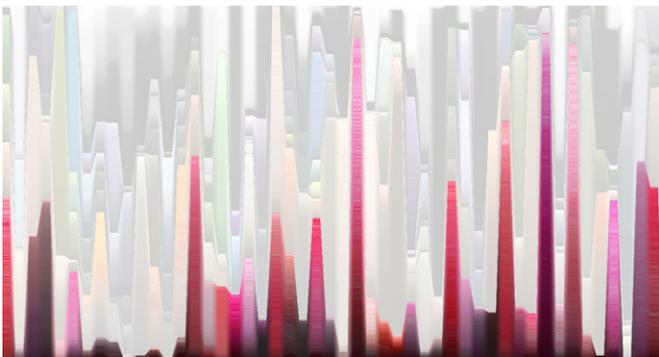


Fig. 26. Images tagged as “pink”. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

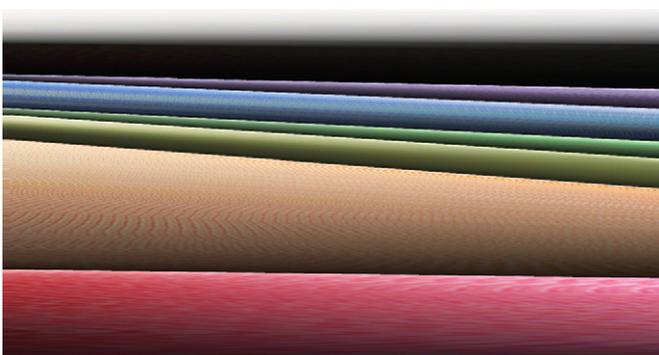


Fig. 27. Images tagged as “red” (left) and as “pink” (right). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4.5. What colour is an emotion? ColourVis for abstract ideas

ColourVis can also be used to explore more abstract ideas and language by using tagged words such as emotions, concepts, and places. We explore the outcome of comparing images tagged on Flickr as “love” and “hate” in order to see this outcome.

In Fig. 28 we can see a much greater amount of dark blacks represented in the “hate” images on the right hand side as compared to the images tagged “love” on the left. This greater amount of blacks in images tagged “hate” may be said to be an expected outcome. However, far less purple is seen in the images tagged “hate” than in the images tagged “love”. Interesting or unexpected results such as this may reveal interesting avenues for further exploration.

4.6. Applying ColourVis to magazine covers

In the following example we have applied ColourVis to present the “People” and the “New Yorker” magazine covers from the period of April 2010 to March 2011. To view these magazine covers please visit: (a) People Magazine: <http://www.people.com/people/archive/> (b) New Yorker Magazine: <http://www.newyorker.com/magazine/covers/2010>.

In Fig. 29 we can observe the prominent use of bright primary colours (reds and blues) used in the “People” magazine cover images contrasted with the more muted tonal colours used in the “New Yorker” magazine cover images. Also visible from the stacked line graph representation are the bright yellow subtitles employed by “People” magazine covers. In contrast, the “New Yorker” magazine does not use consistently bright colour titles in their cover images but alternates between black and white titles. We can observe relative consistency in the colour choices for “People” magazine cover images, while the colour choices of the “New Yorker” magazine fluctuate more frequently. We can also clearly see the fluctuation of bright blue and bright pink colours used on the covers of “People” magazine; and we can see a trend forming, from July to March, where months of high pink usage result in lower levels of blue usage and vice versa.

An aggregation of the April 2010–March 2011 covers of “People” and the “New Yorker” magazine (see Fig. 30) reveals that “People” magazine uses a larger amount of blue and red colour in their covers than the “New Yorker” magazine. In contrast, the “New Yorker” magazine covers show more green colours than the “People” magazine covers. The visualisation also reveals that the six colour categories are more evenly distributed in covers of the “New Yorker” magazine than in the “People” magazine covers.

4.7. Applying ColourVis to graffiti

We also wanted to explore if ColourVis could be used to explore additional media streams. In Fig. 31 we represent a

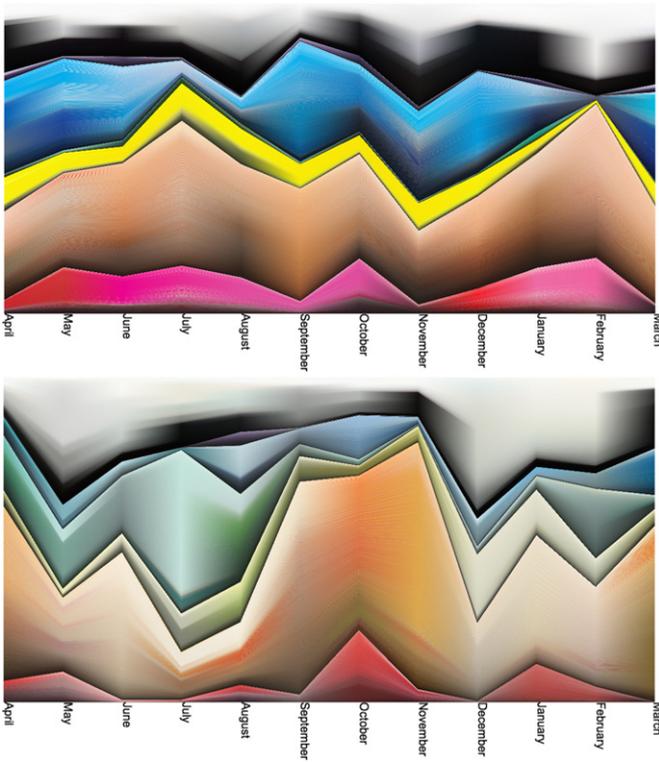


Fig. 29. ColourVis representation of “People” (top) and “New Yorker” (bottom) magazine covers from April 2010 to March 2011. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



Fig. 30. ColourVis overview representation of “People” (left) and “New Yorker” (right) magazine covers from April 2010 – March 2011.

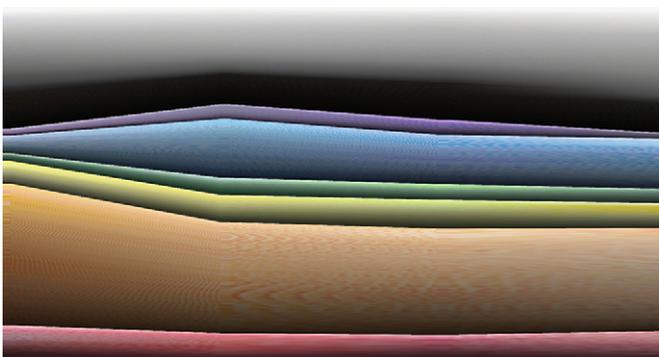


Fig. 31. ColourVis overview representation of photos tagged “graffiti” from different geographic areas. From left to right: Chicago, New York, Los Angeles, Lisbon. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

collection of images tagged as “graffiti” from different geographical locations. Using ColourVis we then attempt to observe trends or differences between graffiti from different cities. In Fig. 31 we observe that the city of Chicago (furthest left) is represented with more oranges and blacks than the other cities in our sample set. New York (second from the left) however, contains more blue than the other cities analysed in Fig. 31. The reasons for these differences provide potential for further investigation which may not have been at first apparent without the use of the image generated by ColourVis.

5. Broadening applications of ColourVis

5.1. Aurora borealis

While the motivation for this work was to explore art and design colour palettes, it can also be applied to image data. Fig. 32 shows ColourVis applied to a series of false coloured images of the aurora borealis taken from 6:30 to 6:59 on February the 16th, 1996. These images and considerable information about the aurora borealis can be found at <http://aurora.phys.ucalgary.ca/cgi-bin/browser1a.pl?year=1996&month=02&day=16>.

5.2. Video sequences

While to this point we have discussed applying ColourVis to images and series of images, it can also be used with videos and films. Here we apply ColourVis to the final series of shots in the film Shawshank Redemption (1994) (see Fig. 33). The clip length

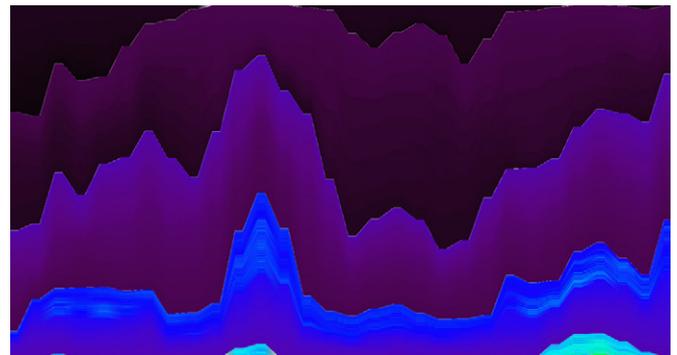


Fig. 32. ColourVis applied to a series of false-colour images of the aurora borealis.

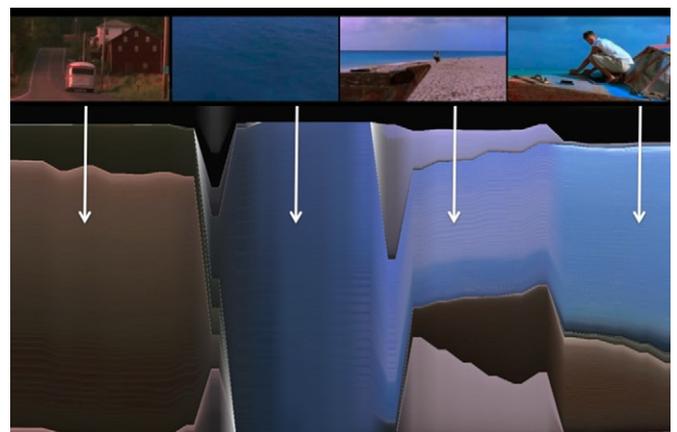


Fig. 33. ColourVis applied to a short video clip from the film Shawshank Redemption. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

is only 25 s, but contains four distinct transitions. This short video clip depicts the end of the movie *Shawshank Redemption* in which “Red”, played by Morgan Freeman, violates his parole and heads south towards Mexico in hopes of finding his good friend and the protagonist of the film *Andy Dufresne*, played by Tim Robbins. The following scenes are depicted in the video and visualised in Fig. 33:

- Scene 1: Red travels by bus down a plain looking country road.
- Scene 2: Scene one fades to a shot of the ocean as the camera movies rapidly over the water.
- Scene 3: We then transition to a scene of Red walking down an off-white sandy beach with a clear blue sky above him and the darker blue ocean to his right occupying half of the shot.
- Scene 4: We transition to a shot of Andy crouched down on his boat, scraping old paint off the hull, and then the camera turns to see his friend Red walking towards him.

In order to analyse this short video clip using ColourVis the one frame for every second of video was extracted and then this sequence of captured still images was entered into ColourVis. The large amount of black in the representation of the still images is due to the thin black bars above and below the video footage used in this analysis. The visualisation of this video clip allows the viewer to clearly see the transitions in the scenery and shots that compose this short video clip.

6. Discussion on using ColourVis

The data that ColourVis is based on is all the pixels of a painting, image, or set of paintings or images. As these sets approach tens or hundreds of images, these pixel count data sets can become huge. In visualising all these pixels, ColourVis, like many other visualisation approaches, performs common visualisation functions like providing overviews, summarising the data, displaying the visualised data in a manner that invites comparison and reveals trends. We have illustrated many possible applications of ColourVis ranging from studying how human applied tags of emotion words, and colour names relate to the actual colours present in the images, to showing trends in colour usage in different aspects of the media ranging from print to video.

In addition, ColourVis parameters can be changed from the current settings that examine seven prominent named colour ranges, to focusing on specific colour ranges that are related to specific interests. For example, as possible future work, one could consider fine tuning the ColourVis colour ranges to the required skin tones to aid in diagnosis of specific skin disorders, exploring the potential for detecting subtle changes in colour using the ColourVis system. An example use case of this functionality could include measuring the slight variations in skin colour of a small patch of skin in order to indirectly measure heart rate [33]. In order to explore this type of subtle variation further, ColourVis functionality would need to be extended to allow for a greater level of granularity and control in the colour grouping system employed.

Further, ColourVis could potentially be extended in order to ascertain if an image has been retouched or edited in post-production. If ColourVis was extended in order to allow the selection and comparison of small subregions of an image, the colour composition of these subareas could then be directly compared. Retouched regions of images might reveal impossibly similar colour usage patterns which may imply the areas have been retouched using post-production image colour cloning tools. This indication of retouching could then be further explored with other tools and methods to confirm or deny this possible warning sign.

While ColourVis has been developed through an extensive iterative process often involving design charettes [37] and critiques [3], it has not yet been formally evaluated. Common possible evaluation scenarios [21] such as evaluating visual data analysis and reasoning; evaluating communication through the visualisation; and evaluating user performance require establishment of a particular usage scenario with established tasks and analysis goals. However, at this point in time ColourVis is a new visualisation that could be applied to a wide variety of possible scenarios. As such an initial evaluation approach such as evaluating environments and work practices might be most appropriate. With this type of approach we could build a better understanding of the possible usage practices, tasks and goals. In fact, preliminary work discussions with artists who focus on colour usage in their own work is leading us in this direction.

7. Conclusions

ColourVis visually supports the exploration of colour usage in individual or multiple digital images through the use of histograms, bar charts, a custom version of stacked line graphs, hue isolation, and through different methods of sorting. Using ColourVis particular trends over time or by artists can be made visible. With ColourVis we contribute:

- the design and exploration of customisable banded histogram used to represent colour,
- the design and exploration of a customisable stacked line graph visualisation,
- the ability to manipulate different aspects of a customisable stacked line graph,
- a colour abstraction that supports the comparison of two or more paintings,
- a novel way to track the change of painter's colour usage over a career and/or painting genre or across time.
- a way to visualise a series of images using multiple parameters.

ColourVis has the potential to further promote discussions around colour usage in images by visually representing trends and patterns in the colour usage of images, paintings, artists, and over time/genre spectrums not previously understood or explored.

ColourVis is a first step towards examining colour usage in images. There is considerable opportunity for further exploration into additional scenarios where the analysis of colour is important and into how experts in different fields such as art history, design, or advertisement would experience the opportunity to make use of such tools.

This project has brought to light some of the challenges of depicting colours with named colour space and how these colour values range using the hue colour spectrum. ColourVis offers a customisable solution to alleviate issues related to labelling colour which could be adopted and extended by future systems.

Other future work may include exploring other data sets using this application, enabling direct manipulation of parameters inside the visualisation for customisation purposes, and moving the application to the web so that it can be accessed by the public more easily.

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References

- [1] Angesleva J, Cooper R. Last clock. *Comput Graph Appl*, IEEE 2005;25(1):20–3.
- [2] Bertin J. *Semiology of graphics: diagrams, networks, maps*.
- [3] Buxton B, Greenberg S, Carpendale S. *Sketching user experiences: the workbook*. Elsevier Science & Technology; 2012.
- [4] Birren F. *History of color in painting*. John Wiley & Sons; 1965.
- [5] Brewer C. Color use guidelines for mapping and visualization. *Vis Modern Cartography* 1994;2:123–48.
- [6] Buxton A. Van gogh visualisation, November 2010. <<http://arthurbuxton.blogspot.com/2010/11/van-gogh-visualisation.html>> (Retrieved 2011-04-26).
- [7] Byron L, Wattenberg M. Stacked graphs—geometry and aesthetics. *IEEE Transactions on Visualization and Computer Graphics* 2008:1245–52.
- [8] Conklin H. Hanunoo color categories. *Southwestern J Anthropol* 1955:339–44.
- [9] Chandler P, Sweller J. Cognitive load theory and the format of instruction. *Cogn Instr* 1991;8(4):293–332.
- [10] Dik J, Janssens K, Van Der Snickt G, van der Loeff L, Rickers K, Cotte M. Visualization of a lost painting by Vincent van Gogh using synchrotron radiation based X-ray fluorescence elemental mapping. *Analytical Chemistry* 2008;80(16):6436–42.
- [11] Freebase.com: Freebase, April 2010. <<http://www.freebase.com/>> (Retrieved 2011-04-27).
- [12] Gage J. Color in western art: an issue? *The Art Bulletin* 1990;72(4):518–41.
- [13] Gregory R. *Eye and brain: the psychology of seeing*. McGraw-Hill; 1973.
- [14] Healey C. Choosing effective colours for data visualization. In: *Visualization'96. Proceedings*. IEEE; 1996. p. 263–70.
- [15] Havre S, Hetzler E, Whitney P, Nowell L. Themeriver: visualizing thematic changes in large document collections. *IEEE Transact Visual Comput Graph* 2002;9–20.
- [16] Heider E, Olivier D. The structure of the color space in naming and memory for two languages* 1. *Cogn Psychol* 1972;3(2):337–54.
- [17] Inselberg A, Dimsdale B. Parallel coordinates: a tool for visualizing multi-dimensional geometry. In: *Proceedings of the 1st conference on visualization'90*. IEEE Computer Society Press; 1990. p. 361–78.
- [18] Krug K, Dik J, Den Leeuw M, Whitson A, Tortora J, Coan P, et al. Visualization of pigment distributions in paintings using synchrotron k-edge imaging. *Appl Phys A: Mater Sci Processing* 2006;83(2):247–51.
- [19] Kay P, Regier T. Resolving the question of color naming universals. *Proc Natl Acad Sci U S A* 2003;100(15):9085.
- [20] Klockenkamper R, von Bohlen A, Moens L. Analysis of pigments and inks on oil paintings and historical manuscripts using total reflection x-ray fluorescence spectrometry. *X-Ray Spectrom* 2000;29:119–29.
- [21] Lam H, Bertini E, Isenberg P, Plaisant C, Carpendale S. Empirical studies in information visualization: seven scenarios. *IEEE Transact Vis Comput Graph* 99 PrePrints; 2011.
- [22] Michel R, McGovern P. The chemical processing of Royal Purple dye: ancient descriptions as elucidated by modern science. *Archeomaterials* 1987;1(2):135–43.
- [23] McGovern P, Michel R. Royal purple dye: the chemical reconstruction of the ancient mediterranean industry. *Acc Chem Res* 1990;23(5):152–8.
- [24] Nunes M, Greenberg S, Carpendale S, Gutwin C. What did I miss? Visualizing the past through video traces ECSCW 2007;2007:1–20.
- [25] Post D, Calhoun C. An evaluation of methods for producing desired colors on CRT monitors. *Color Res Appl* 1989;14(4):172–86.
- [26] Roberson D, Davies I, Davidoff J. Color categories are not universal: replications and new evidence from a stone-age culture. *J Exp Psychol: General* 2000;129(3):369.
- [27] Roberson D, Davidoff J, Davies I, Shapiro L. Color categories: Evidence for the cultural relativity hypothesis. *Cogn Psychol* 2005;50(4):378–411.
- [28] Rigau J, Feixas M, Sbert M, Wallraven C. Toward auvers period: evolution of van gogh's style. The Eurographics Association, *Computational Aesthetics in Graphics, Visualization, and Imaging*; 2010.
- [29] Riley C. *Color codes: modern theories of color in philosophy, painting and architecture, literature, music, and psychology*. Univ Pr of New England; 1996.
- [30] Roorda A, Williams D. The arrangement of the three cone classes in the living human eye. *Acoust Soc Am* 1988;83:1102–16.
- [31] Stein G. *Picasso*. Dover Publications; 1984.
- [32] Stone M. *A field guide to digital color*. AK Peters, Ltd.; 2003.
- [33] Takano C, Ohta Y. Heart rate measurement based on a time-lapse image. *Med Eng Phys* 2007;29(8):853–7.
- [34] Tufte E. Envisioning information. *Optom Vis Sci* 1991;68(4):322.
- [35] Viegas F, Perry E, Howe E, Donath J. Artifacts of the presence era: using information visualization to create an evocative souvenir. In: *IEEE Symposium on Information Visualization, INFOVIS 2004*. IEEE; 2004. p. 105–11.
- [36] Ware C. *Information visualization: perception for design*. Morgan Kaufmann; 2004.
- [37] Wikipedia: Charrette — wikipedia, the free encyclopedia, 2011. [Online; accessed 18-January-2012].
- [38] Zanella J. My daily color palette 2010, December 2010. <<http://www.flickr.com/photos/jaco/sets/72157623126461021/>> (Retrieved 2011-04-27).