Digital analysis of Van Gogh's complementary colours

Igor Berezhnoy Eric Postma Jaap van den Herik

IKAT/Computer Science, Maastricht University

Abstract

Traditionally, the analysis of visual arts is performed by human art experts only. The availability of advanced artificial intelligence techniques makes it possible to support art experts in their judgement of visual art. In this paper image-analysis techniques are applied to measure the complementary colours in the oeuvre of Vincent van Gogh. It is commonly acknowledged that, especially in his French period, Van Gogh started employed complementary colours to emphasize contours of objects or parts of scenes. We propose a method to measure complementary-colour usage in a painting by combing an opponent-colour space representation with Gabor filtering. Using this method, the analysis of a dataset of 617 digitised oil-on-canvas paintings confirms art-expert's knowledge about the global pattern of complementary-colour usage in Van Gogh's paintings. In addition, it provides an objective and quantifiable way to support the analysis of colours in individual paintings. Our results show that art experts can be supported by artificial-intelligence techniques.

1. Introduction

Attempting to mimic and amplify the perceptual impact of natural scenes, Vincent van Gogh used complementary colours as a means to emphasize contours and to enhance the vividness of natural colours (Hulsker, 1996). Whereas early in his artistic career, he refrained from using bright colours, in his later career, while residing in Paris and the South of France, Van Gogh made abundant use of bright and complementary colours (Maffei & Fiorentini, 1999). In analysing paintings of Van Gogh, art experts are particularly interested in the usage of colour. AI techniques may aid the art expert in quantifying the distribution of colours in Van Gogh's oeuvre. Moreover, these techniques may be used by art experts to test hypotheses on the development of Van Gogh as an artist. To investigate the viability of applying AI techniques to support the study of paintings, we focus on the digital analysis of colours in Van Gogh's work. More specifically, we perform a digital analysis of Van Gogh's oil-on-canvas paintings in an attempt to quantify and detect the transition in his usage of complementary colours.

The outline of the remainder of the paper is as follows. Section 2 is a concise introduction to colour and colour perception. Section 3 presents our method to analyse complementary colours in digital reproductions of paintings. In section 4 we present the results of applying the method to a large part of Van Gogh's oeuvre. In section 5 we discuss our approach. Finally, section 6 draws conclusions and points at future work.

2. The perception of complementary colours

Colour is a mental construct (see, e.g., Mollon, 1990). Therefore, when digitally analysing colour, the brain mechanisms responsible for generating a colour experience have to be taken into account (insofar as possible). Our analysis of Van Gogh's paintings is guided by neuroscientific knowledge about how the human visual system processes chromatic signals. Given the importance of complementary colours in Van Gogh's work and in the present study, we discuss the psychological and biological basis of complementary-colour perception.

By definition, complementary colours produce white light when added together as lights[1]. The human visual system processes chromatic signals using three types of retinal cone photoreceptors. The neural transformation of the signals yields an opponent-colour representation in which chromatic information is expressed in three channels: a red-green channel, a yellow-blue channel, and a black-white (luminance) channel (Wandell, 1995; Zeki, 1999). Recent evidence suggests that these opponent channels arise naturally from the chromatic statistics of natural images (Lee, Wachtler, & Sejnowski, 2002). It is generally believed that the perception of complementary colours is related to the existence of opponent channels (Wandell, 1995).

The processing of colours in the human visual system proceeds through a two-channel system consisting of a red-green channel and a yellow-blue channel. The pairs of colours associated with a channel are called opponent colours because a colour is never perceived as a combination of the two colours (e.g., a colour is never perceived as being "red-green") and because prolonged perception of one colour induces an after-effect of the opponent colour (prolonged stimulation with red induces the perception of green; De Valois and De Valois, 2000). Biological studies have revealed individual neurons in the visual system to respond to opponent colours.

The biological plausibility of opponent channels as the basis for the perception of complementary colours leads us to employ an opponent colour space representation for our analysis in the next section.

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[1] This definition applies for additive color mixing only.

3. The Analysis of Complementary Colours

The analysis of complementary colours is performed on digitised reproductions of (almost) all oil-on-canvas paintings of Van Gogh. This section discusses the data set, the transformation of the data, and the method of analysis.

3.1. The data set

The analysis of colours from paintings is hampered by two problems. First, the physical appearance of colours on a painting depends on factors such as ageing and the intensity and spectral composition of the light source. Second, the appearance of colours in a digital reproduction of a painting depends on the characteristics of the photosensitive film or CCD element in the camera and on the specific effects of subsequent processes. In general, each operation (capture, reproduction, scanning) introduces artefacts that may introduce a bias in the analysis. Figure 1 illustrates the deviation in colours caused by scanning the same printed reproduction of a painting with two different scanners (a HP ScanJet 5370c and a Microtek ScanMaker 9800XL).

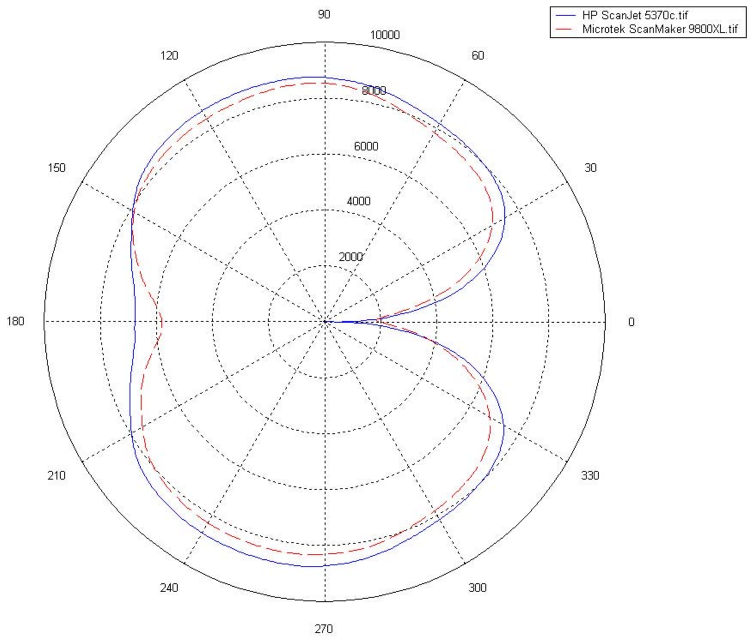


Figure 1. A polar plot of two hue histograms from the same printed image scanned by two different scanners. The angle represents the hue value (the entire circle represents the colour wheel), the amplitude the number of pixels with that hue value.

The figure shows the hue histograms of both scanned reproductions as polar plots. The angle corresponds to the hue value of the HSI-coded image and the amplitude indicates the number of pixels with that hue value. Although both histograms are fairly similar, clear deviations are visible. These deviations are caused by differences in the scanning processes associated with the two scanners.

Because of the unreliability of digital colour reproduction, great care has to be taken in the selection of the data set and in the interpretation of the results of their analysis. Anticipating our study of colour-calibrated digital reproductions of Van Gogh's paintings, in the present study we assume that the opponency is relatively insensitive to the disturbing factors. We believe that this assumption is warranted because a preliminary analysis of the hue histograms (based on those hue values with more than 25% intensity and saturation only) revealed a fairly consistent distribution of colours over the entire data set.

The data set consists of 617 reproductions of (almost) all oil-on-canvas paintings made by Van Gogh. All images are stored in compressed jpg format. The dimensions of the images vary with the dimensions of the paintings. However, the dimensions in pixels do not reflect the true dimensions of the paintings in a consistent way. Therefore, in our analysis scale is largely ignored by averaging over a range of scales. The average resolution of the images in the data set is about 500^2 pixels.

3.2. Data transformation

The rgb-coded images contained in the data set are transformed into opponent-colour format. For this purpose we use the opponent-colour space representation proposed by Wandell (Wandell, 1995) in which rgb vectors are transformed as follows.

$$\begin{pmatrix} O_{lum} \\ O_{rg} \\ O_{yb} \end{pmatrix} = \begin{pmatrix} 0.2814 & 0.6938 & 0.0638 \\ -0.0971 & 0.1458 & -0.0250 \\ -0.0930 & -0.2529 & 0.4665 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad (1)$$

In this equation, R,G, and B represent the normalized rgb values, and O_{lum} represents the luminance (black-white) value and O_{rg} and O_{yb} the red-green and yellow-blue values, respectively. Applying the transformation (1) to the entire image yields our artificial analogues of the human opponent channels, one luminance channel and two chrominance channels.

3.3. Opponent-colour Analysis

Application of the opponent-colour transform yields three images (one for the luminance channel and one for each chrominance channel). Since our analysis focusses on opponent-colour transitions, the two chromatic-channel images are convolved with odd and even Gabor filters in four orientations (horizontal, vertical and along both diagonals) and at four scales. For the four scales, the support for the Gabor filters measured 8^2, 16^2, 32^2, and 64^2 pixels. The opponency for each channel is defined as the total energy averaged over the orientations and scales and divided by the number of pixels in the image. The opponency value for a painting equals the summed opponencies of the red-green and blue-yellow channels.

4. Results

The overall results of the analysis are shown in figure 2. This graph displays the opponency values of the paintings as a function of the Jan Hulsker (JH) numbers which reflect the chronological order of creation dates quite reliably (Hulsker, 1996). The dots represent the opponency values, the solid curve is a smoothed function of the average.

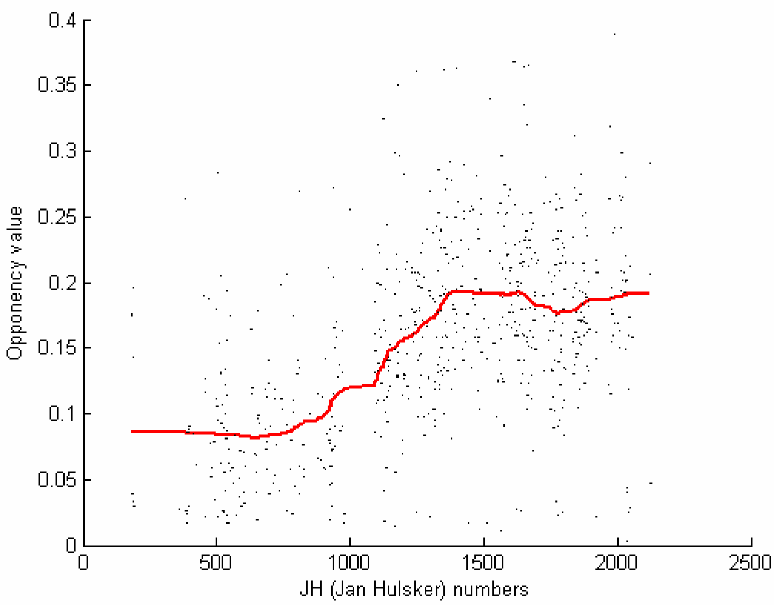


Figure 2. Opponency values of the paintings as a function of the JH (Jan Hulsker) numbers. The dots represent the opponency values, the solid line a smoothed approximation of the average opponency.

A clear transition in opponency is observed between JH numbers 1000 and 1500. The transition agrees well with the increased usage of complementary colours by Van Gogh (Maffei & Fiorentini, 1999)..

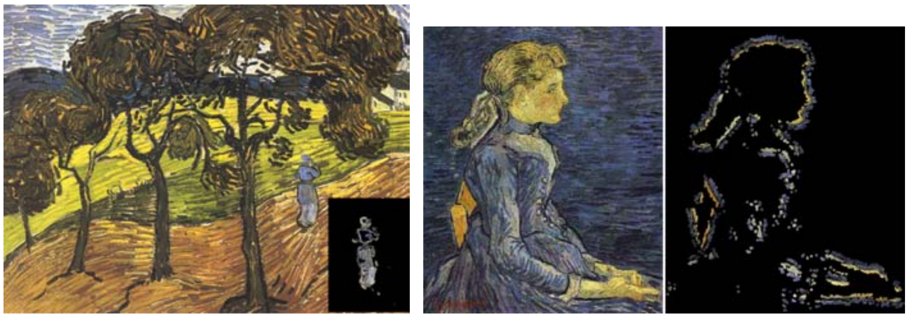
To further elucidate the development of opponency in Van Gogh's career, we examine the opponency values averaged over six consecutive periods in his life. These periods correspond to Van Gogh's stays in cities and villages in the Netherlands, Belgium, and France. The periods are designated as "Earliest Paintings" (ranging from 1881 to about 1883), "Nuenen /Antwerpen" (1883 to 1886), Paris (1886-1888), Arles (1888-1889), Saint-Rémy (1889-1890), and Auers-sur-Oise (1890). Table 1 lists the average opponencies for these six periods along with the number of oil-on-canvas paintings analysed and the standard deviations. As these results clearly show, the opponency increases with the period starting at a very small value during the "Earliest Paintings" period rising to twice the value while moving to "Paris" and remaining at that value throughout the remaining French periods.

Period	**JH numbers**	**Number of paintings**	**Avarage Opponency**	**Standart deviation**
Earliest Paintings (1881-83)	81 – 421	18	0.088	0.073
Nuenen /Antwerpen (1883-86)	450 - 1192	202	0.113	0.065
Paris (1886-88)	1235 - 1356	76	0.172	0.061
Arles (1888-89)	1360 - 1686	165	0.193	0.066
Saint-Rémy (1889-90)	1693 - 1982	130	0.178	0.056
Auers-sur-Oise (1890)	2010 - 2123	26	0.176	0.085

Table 1. Average opponencies for six periods during Van Gogh's career.

5. General discussion

The global pattern of our results confirms the generally acknowledged transition in complementary-colour usage by Van Gogh. As stated in the introduction, Van Gogh used complementary colours to enhance or emphasize the contours of objects in his paintings. To verify if large opponency values detected by our analysis corresprond to such enhanced contours, we projected regions with opponency values exceeding a threshold onto the original painting. The threshold was determined manually in an attempt to reveal contours of objects. Figures 3a and 3b show two typical examples of paintings with a high opponency value that where thresholded to reveal contours. Evidently, the largest opponency values correspond to the contours of a person in both paintings (inset of figure 3a and the right image in figure 3b).



(a) (b)

Figure 4. (a) The painting "Landschap met bomen en vrouwelijke figuur" Saint-Rémy, 1889, (JH 1848). The inset displays the image obtained by thresholding opponency. The contours of the female figure are clearly visible. (b) The painting "Portrait of Adeline Ravoux" Auvers-sur-Oise, 1890, (JH 2035). The original painting is shown on the left, the opponency-thresholded image on the right.

Despite these encouraging results, the validity of our analysis depends critically on two factors: (1) the biological plausibility of our opponent-space representation and Gabor filtering, and (2) the quality of the data set. We are confident that our analysis is biologically plausible although further improvements may be obtained by deriving the opponent-colour space and Gabor filters automatically from the images using statistical techniques based on independent component analysis and principal component analysis (Lee, Wachtler, & Sejnowski, 2002). However, we do have some doubts about the quality of the data set since we cannot match the colours in a straightforward way to a golden standard. Therefore, in our future work we intend to replicate our findings with a colour-calibrated set of images.

6. Conclusion and future work

Our analysis of the usage of complementary colours by Van Gogh is limited by the quality of the digitial reproductions. However, since the projections of the detected complementary-colour contours correspond to the contours of objects in the painting, we are confident that our analysis is fairly reliable. We conclude that AI techniques allow the objective detection and quantification of visual features in paintings. We foresee an increasing use of AI techniques in the domain of visual arts to support art experts in their analysis and of paintings. In our future work we expand our investigations covering the colour, texture, shape, and composition of Van Gogh's paintings using a calibrated data set.

Acknowledgement

This research is carried out within the Netherlands Organization for Scientific Research (NWO) Token 2000 project Authentic (grant 634.000.015).

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