A definition of global hue contrast in artworks

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In the composition, analysis and evaluation of artworks, an understanding of colour is of high importance. Colour is commonly understood in terms of its perceptual components: hue, saturation and lightness. Of these, it is within the hue values of an artwork that many of their high-level aesthetic dimensions are found and it is through the global contrast of hue by which these dimensions are best expressed. However, there is currently no way to computationally define global hue contrast and it is this gap in knowledge that our work addresses. Here we quantify global hue contrast as two values: hue variety and hue antagonism. This definition was derived from Johannes Itten's work on colour contrast. Using our approach the hue contrast of a single image can be expressed as a single point in a plot. For this reason the approach is particularly suitable for the comparative analysis of groups of artworks, such as those by two or more artists or an artist at different times in their career. We describe two case studies both employing our proposed approach and the results agree with manual observations. We also include a user study the results of which further supports our proposed approach.

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Introduction

A 2D artwork such as a photograph, painting, movie or animation, is a special class of image, being the result of considerable visual organisation by an artist. Much of this organisation is in the selection and arrangement of its colour. Artists frequently comprehend colour through its hue, saturation and lightness components [2]. This they do for the intuitive and perceptual clarity of these values. Hue and saturation together make up the chromatic component of this model. Of colour and lightness, it is the former that is acknowledged to be the most significant in the impact of artworks (a common painter's saying is that lightness does all the work but colour gets all the glory). Saturation equates to the intensity component of colour, whilst hue is commonly described using discrete terms (red, blue, green, etc.) [1]. It is in the hue characteristics of a 2D artwork that many of the sophisticated aesthetic attributes lie [2-3]. However, these aesthetic attributes are currently only available to a 'manual' observation by someone with a trained eye. Such an observation will include a consideration of contrast, yet there currently exists no way to automatically compute the global contrast of hue. It is this gap in knowledge that our work addresses.

Work in similar areas

Much work has been done on the use of colour in art and design. This has tended to focus on the subject of colour harmony. Moretti and Lyons [4], and Neumann *et al.* [5] have developed tools to generate harmonious colour sets, which are sets of colour swatches selected for their harmonic accordance. Through an analysis of fashion and art, Matsuda developed a set of eight harmonic colour schemes [6] which represent how harmonious configurations of colour typically present within a colour wheel.

We understand the word harmony, as used in the context of colour and art, to broadly refer to 'good contrast'. Different to the preceding work, our aim is to define global hue contrast and on its own this does not cast any such 'judgment' on the quality of contrast in an artwork. We regard the evaluation of colour harmony to be a low-level addressal of the colour organisation in an artwork, providing detail specific to that artwork (e.g. 'this artwork employs an analogous harmony whereas that artwork employs a split complementary harmony'). Differently, our approach provides a general and therefore high-level definition of the hue organisation in an artwork wherein many artworks may be evaluated 'on a level playing field'.

Itten's colour contrast

The Victorian English art critic John Ruskin said: "...of course the character of everything is best manifested by Contrast" [7 p173]. Global contrast refers to an assessment of the entirety of a data set. Hence, the global contrast of the lightness values of a painting may be understood in terms of darkest, lightest and average values. Such an understanding can be expressed as a single number (e.g. using RMS or Michelson contrast definitions in the evaluation of lightness global contrast). This is different to a local contrast, which is a pair-wise and relative comparison (e.g. region A is darker than region B, yet lighter than region C) and which can be expressed as a ratio. The advantage of a definition of global contrast is that it may be used to compare many images with each other (for example: by expressing the global lightness values of many images, each one as a single point in a plot). Local contrast is not suitable for this purpose.

In the consideration of hue, saturation and lightness: those of lightness and saturation are typically calculated with reference to their intensity extremes i.e. their highest and lowest values [8]. Differently, hue is commonly represented as being arranged around a wheel [9], therefore determining its intensity extremes is like trying to find the head of the table at King Arthur's court. Conventional methods for global contrast evaluation are therefore inapplicable.

In addressing this gap in knowledge, we referenced the work of the Swiss art critic, teacher and theorist, Johannes Itten (1888 – 1967). In his seminal book 'The Art of Color' [10] he describes seven colour contrasts of which three are global and hue specific, namely:

1. *The contrast of hue*. This refers to the amount of perceptually different hue values in an artwork.
2. *The contrast of warm and cool*. Perversely, this has two readings: warm and cool as a relative (as in the warm yellow of a sunflower versus the cold yellow of a lemon) and warm and cool as an absolute. The latter assumes that the RYB hue wheel be bifurcated along an axis with yellow to red-violet being warm and all other values being cool.

3. *The contrast of complements*. This describes the contrast of values located on opposite sides of the RYB hue wheel.

Itten describes other contrasts, which indirectly involve hue: simultaneous contrast and the contrast of extension. These are both local contrasts, and therefore not of relevance to this enquiry.

Defining contrast

Itten's contrast of warm and cool is, in its relative form, a measure of local contrast and therefore can therefore be dismissed. Itten's contrast of complements may be considered as a class of the absolute form of temperature contrast as there is no complementary contrast that is not also an absolute warm / cool contrast. We may therefore generalise Itten's hue contrasts using two values: one referring to the amount of perceptually different hue values and the other referring to values on opposite sides of the Red, Yellow and Blue (RYB) hue wheel. These we term respectively hue variety and hue antagonism.

To quantify these values we utilise two different hue wheels for the different manner in which they present hue.

The distinguishing feature of a hue wheel is the particular complementary pair that it presents. A complementary pair exhibits two properties: the first is that when mixed together the two colours of a complementary pair produce an achromatic result. This mixing may take two forms: mixing subtractively (e.g. two colours being mixed together as pigments to produce a neutral) or mixing additively (such as in Maxwell's discs). The second property is that each hue finds in its complementary the maximum possible visual difference. This quality is strongest in the complimentary pairs found within the RYB hue wheel that was first described by Johann Goethe in 1840 [11]. It is experimentally difficult to demonstrate the property of maximum possible difference. In colour theory perceptual difference is usually measured in steps of equal perceptual magnitude (as in the Munsell system). As far as we know, there has been no modern systematic examination of this phenomenon. However, of note is the fact that Kuler (Adobe's online colour picker which is designed to select complementary pairs and other so called harmonious sets) and other similar services (e.g. colorschemedesigner.com) employ the RYB colour wheel. Additionally, the support for this among artists has a long history. In his book 'The Art of Painting', Leonardo Da Vinci describes the colour pairs blue / orange and red / green as being opposite (retto contrario, literally 'exactly opposite'). Most artist and designers accept these 'strongest possible visual contrast' RYB complimentary pairs as 'de facto'.

The other distinguishing feature of hue wheels is the manner in which the hue values are spatially arranged around the wheel. Though the order of hue terms is the same in all hue wheels, their spatial distribution is different. For example, there is a larger 'pie slice' of green in the RGB hue wheel that in the RYB hue wheel. The Munsell wheel, invented by the artist Albert Munsell in 1915 [12], is perceptually uniform. This means that there are as many perceptually different hue values in any pie-slice of the wheel as there are in a pie-slice of the same degree of spread in any other part of the wheel.

Our approach

Our approach is as follows. Firstly: grey, black and white (i.e. de-saturated) regions have no perceptual hue. To eliminate the influence of such values, pixels with a saturation less than an absolute threshold rate are ignored leaving only those with a perceptually apparent hue. Following this we utilise the different properties of the Munsell and RYB hue wheels to define hue variety and hue antagonism. The process is outlined below and full technical details can be found in the supplementary material.

1. To calculate the hue variety, the hue is mapped as a circular histogram within a Munsell hue wheel. We consider the wheel as a collection of 360 degrees of hue difference. Hue variety is calculated as being the total number of those degrees of hue difference that lie within the spread of the histogram. The perceptually uniform nature of the Munsell wheel means that this figure is a reliable indicator of the amount of perceptually different hue values within the artwork. This process is visually summarised in Figure 1 where the hue variety may be understood as the sum of the grey areas as expressed against a possible maximum of 360. For computational details of this process, please refer to the supplementary material section.

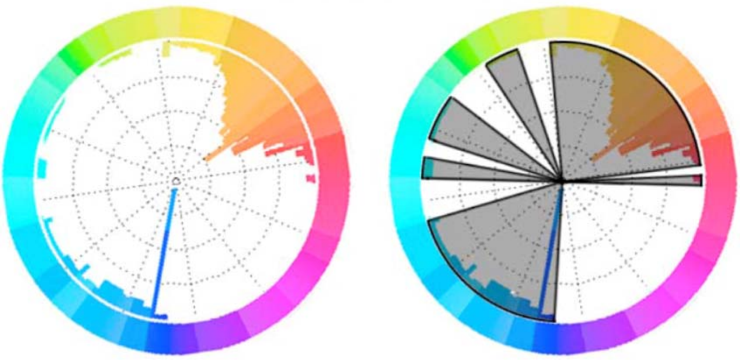

Figure 1: A set of hue values expressed as a circular histogram within a Munsell hue wheel (left). Hue variety is defined as the sum of the spread angles (the shaded grey regions in the figure on the right).

2. To calculate the hue antagonism the hue is mapped as a circular histogram within the RYB hue wheel. We consider the wheel as a collection of 360 degrees of hue difference. The wheel is bisected at any axis and the hue of the half-histogram on one side of the wheel is examined to determine if there is a corresponding hue in the half-histogram on the other side of the wheel. As the RYB hue wheel presents hue in its artistic antagonistic pairing, this value is therefore an indicator of the amount of hue antagonism within the artwork. This process is visually summarised in Figure 2 where the dark grey regions represent hue within the histogram that is in an antagonistic relationship to hue within the half of the histogram on the opposite side of the wheel. For computational details of this process, please refer to the supplementary material section.

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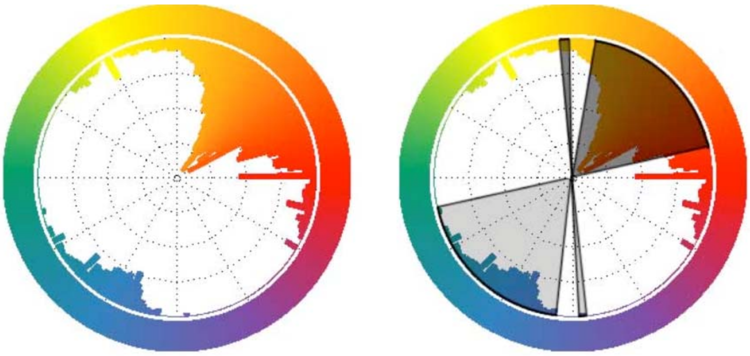

Figure 2: Hue values expressed as circular histogram around an RYB hue wheel (left). The hue values in dark grey are in an antagonistic relationship to the values in light grey (right). The hue antagonism is calculated as the angle of spread of this antagonism in ratio to 180.

3. The hue variety and hue antagonism can be visualised in a plot with the former expressed on the x-axis and the latter on the y-axis.

As each artwork returns a single point on the global hue contrast plot, the hue characteristics of many artworks may be evaluated easily. This is particularly useful in the comparison of large groups of stylistically consistent images such as work by different artists, or by artists at different times in their careers.

Results and interpretations

To demonstrate our approach we present here the results from computing the hue contrast of 2 pairs of sets using our proposed method. Each pair of sets was composed of two stylistically coherent groups and chosen for the fact that the most significant differences between them were commonly believed to be in their hue contrast. The 2 pairs of sets were: Pablo Picasso's (1881 – 1973) Blue Period paintings with Picasso's Rose period painting [13] (each set consisting of 74 paintings) and Pixar's 'Finding Nemo' [14] (consisting of 144,513 frames) with DreamWorks's 'Shark's Tale' [15] (consisting of 129,020 frames). In the case of the painting pair of sets, we used as source material the highest quality digital reproductions available online. The frames used in the animation pair of sets were taken directly from the DVD of these movies, which were rendered as image sequences at maximum quality and size. The results are here presented together with a selection of our interpretations.

Firstly it can be observed that the painting pair of sets (Figure 3) present clearly different characteristics through their hue contrasts computed using our approach. Generally, it can be observed of the Rose Period paintings that:

- They are more inclined than the Blue Period paintings to be monochrome (as evidenced by the massing of points at the bottom of the plot).
- Unlike the Blue Period paintings, they never exhibit full hue variety (as evidenced by the dearth of points in the top right hand corner of the plot).
- They have significantly more hue antagonism than the Blue Period paintings (as evidenced by the slight massing of the points towards the left of the plot).

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In both the Blue Period and Rose Period sets, there are gaps midway in the plots (regions A and B). These are at different locations in the two sets, yet are clear in both and are most clearly evidenced in the antagonism histogram bar. These are signs that the artist had actively favored either configurations of low or high hue antagonism, broadly corresponding to a perceptual 'likeness' and 'oppositeness' of hue values. This goes some way to evidencing Rudolph Arnhem's observation that for a painter: '…a configuration of colours will strive either toward contrast or toward assimilation' [16].

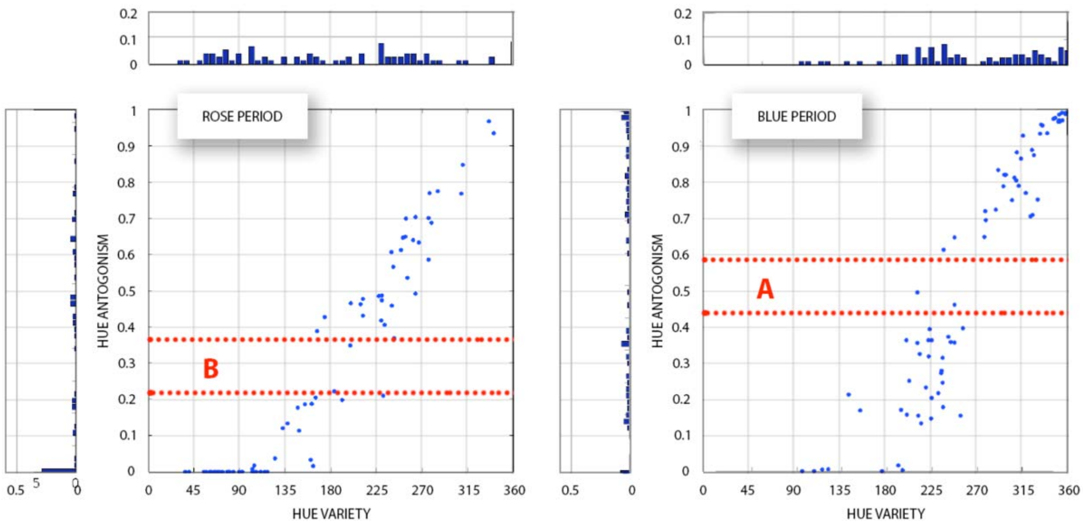

Figure 3: Global hue contrast results of Picasso's Rose Period (left) and Picasso's Blue Period (right).

In the two animation sets (Figure 4) a large number of frames constitute the animations and this means that there was much colocation of data. Regions of dense colocation signifies heavy use of the corresponding global hue contrast values:

- In both sets there is heavy collocation at the top corner of the plot indicating that the artists had employed full hue variety. However, it is clear that 'Shark Tale' employs this strategy more than 'Finding Nemo'. This tendency is carried through into the lower-upper regions, indicating a favoring of configurations featuring high hue variety. High hue variety broadly corresponds to one reading of the word 'colourful' (the other being high saturation).
- On the opposite side of the scale, the yellow bands at the bottom of the plots indicate that both animations feature heavy use of monochrome arrangements; however 'Finding Nemo' exhibits this more than 'Shark Tale'.
- Within the bottom left corners of the plot, the 'Shark Tale' results are more thinly populated than those of 'Finding Nemo'. Frames within this region do not have many distinct hue values, yet those hue values that were employed are in full or high antagonism. The reason for this difference becomes clear when we consider that the colour of the two main protagonists in 'Finding Nemo' is orange who are frequently pictured against a plain blue sea (in the RYB hue wheel blue and orange are an antagonistic pair).
- In both plots, there are yellow 'rivers' that show a slight vertical tendency. This indicates a propensity by the animators to favour a low hue opposition in their hue configurations.

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- Aside from these differences, both animations present nearly all-possible combinations of variety and antagonism, but it can be generally observed that the distribution of differences is far more even-form in ‘Finding Nemo’.

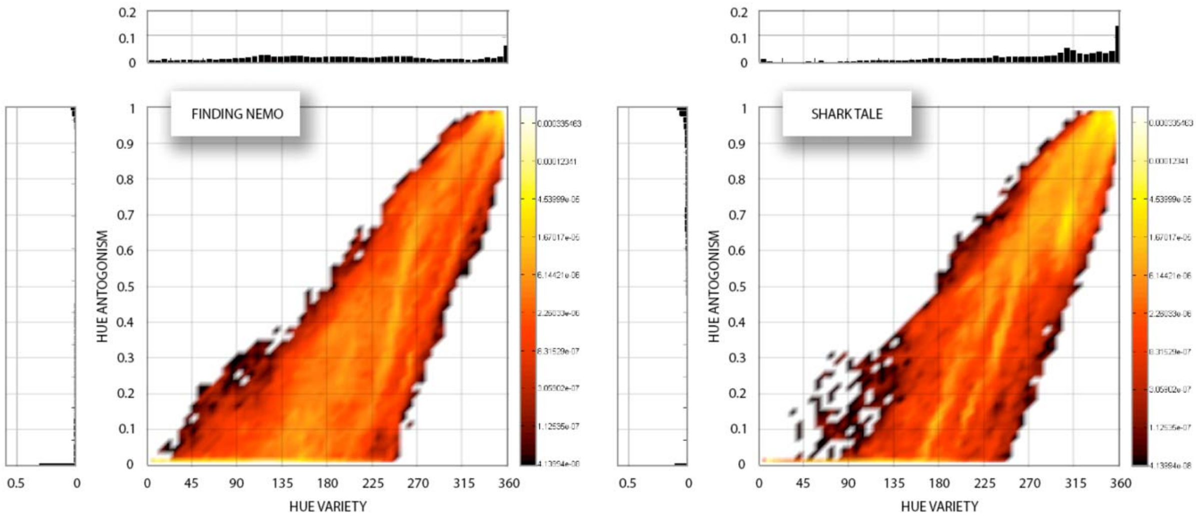

Figure 4: Global hue contrast results of ‘Finding Nemo’ by Pixar studios (left) and ‘Shark Tale’ by DreamWorks studios (right).

Evaluation through a user study

To test our approach, a user study was performed. From one of the image set results, two images were selected for the proximity of their plotted global hue contrast values. These two images we term the ‘match pair’. A third image was selected, the global hue contrast result of which was not so far away from the match pair as to be evidently different, nor so close as to be confused with the pair. Thirty of such image sets were presented to 61 undergraduate art students.

The format of their study was as follows: for each image set, one of the match pairs was presented to the students as a ‘master’ reference image. The students were told to select one from the remaining two images for its similarity to the master image of its high-level hue organisation. They were told to ignore differences in lightness, saturation, content and composition. To prepare them, they were shown four examples of match pairs. They were told nothing of the basis on which our principle operates (variety and antagonism).

To visually evaluate the hue values of an image in exclusion to all other values is something that even a trained artist would have trouble with, let alone an undergraduate art student. The test was therefore a tough one for our procedure. Despite this, the results show that there is significant correspondence between the students’ pairing choices and the pairs derived from our approach.

Figure 5 shows a box plot depicting the distribution of successful pairings out of the total 30 candidate image sets. Should the pairing have been entirely random, a median of around 15 would have resulted, with a wide spread of values either side (i.e. a large interquartile range). Instead we see a median of 20 with a small interquartile range. Tellingly, only one student scored less than 15.

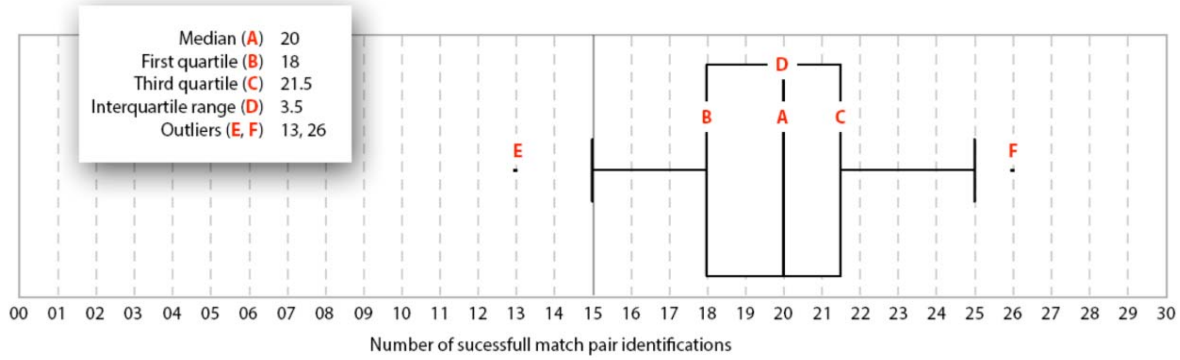

Figure 5: A box plot showing the number of successful pair match identifications per student.

Limitations of our approach and possible future work

Our approach is a high-level one, generalising the hue organisation of an artwork. However, the aesthetic value of an artwork may also be dependent on many low-level aesthetic attributes such as particular colour schemes. Though our approach can sometimes generalise the effect of such schemes (e.g. the complementary colour scheme constitutes a high hue antagonism), there are some schemes to which our approach is blind. An example of such a scheme is the single split complementary. An example of such a case is where hue_{180} is opposed to the forked pairs: hue_{20} and hue_{340}. Our approach would not detect any antagonism in such a configuration. Significantly, clear examples of such configurations, whilst being common in 'flat' design (web design, fashion etc.) are almost unheard of in painting, where such forked pairs are more likely to be joined by mediating values. This indicates that our approach might be more suitable to the analyses of painting, photographs, films and animations and less suitable for flat designs. Addressing this issue could be suitable territory for further work.

Additionally, our approach does not take into account the area of a region of hue. Taking his cue from Goethe, Itten [10 p59] says that yellow is three times as strong as its complementary violet, so should occupy one third as much area in order to achieve 'balance'. Though Itten describes this phenomenon entirely in terms of being a local contrast, it is nonetheless clear that it constitutes a dimension in the lower-level global contrast of an image and is therefore possibly fruitful area for future work.

Conclusions

These results and their interpretations demonstrate the usefulness of our approach in the aesthetic evaluation of global hue contrast in artworks. It surprised us how much could be read from these plots and how much light that they cast on our subject artworks. The amount of information we garnered from our data we have barely touched on in these pages, and there remains much work to be done on interpreting these results and those of other datasets. We envisage that as well as its application as a tool by which an aesthetic evaluation of hue in artworks may be made; our approach could also be used as a means by which a search by similarity of hue contrast may be made upon a group of images.

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