Relationship between colour themes and perceived aesthetic quality in colour images: An exploratory study

Francesco Bianconi[1], Cinzia Buratti[1] and Giulia Pascoletti[1]

ADM2023 International Conference
Florence, Italy, 6–8 September 2023

[1]Department of Engineering, Università degli Studi di Perugia, Italy

Outline

Outline

Background and objectives

What makes an image beautiful? (1/2)

Beautiful?

Not so beautiful?

Image source: The Explainable Visual Aesthetics (EVA) Dataset

What makes an image beautiful? (2/2)

- **Semantics**
  - Content of the image (subject)
- **Composition**
  - Position and spatial relationship among objects in the scene
- **Quality**
  - Presence/absence of distortions, blur, noise, and/or other artifacts
- **Visual**
  - Light and colour

What is the role of colour in making an image beautiful?

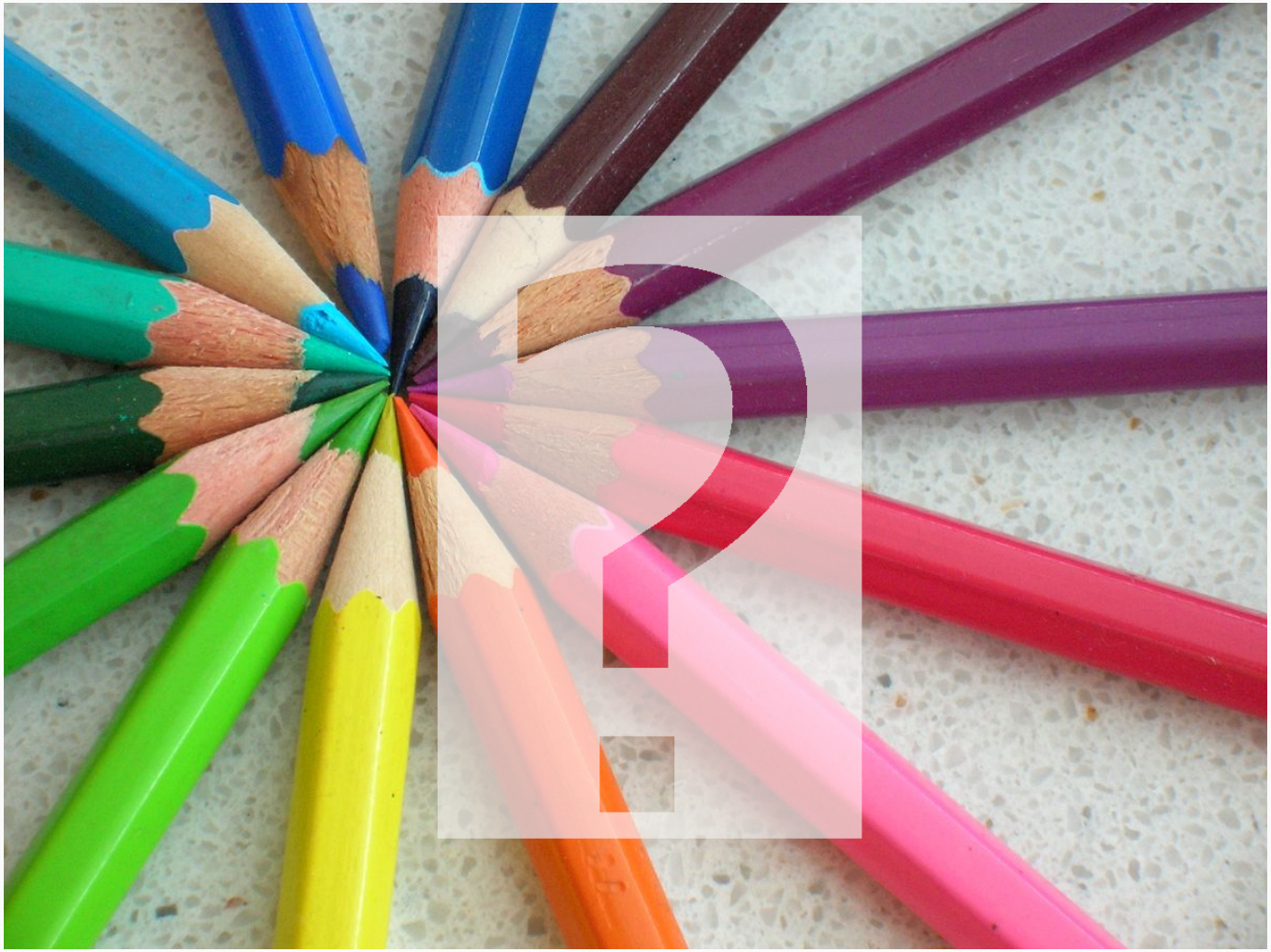


Image source: Wikimedia Commons (CC BY-SA 3.0, watermarked by the author.)

Objectives

To investigate potential relationship between:

- **Colour themes** (colour **palette**)

and

- Perceived aesthetic rating in colour images

Materials

The Explainable Visual Aesthetics (EVA) Dataset (1/3)

- 5,101 jpeg images of variable size
- Six categories: *animals*, *architectures and city scenes*, *human*, *natural and rural*, *still life* and *other*
- Manually-assigned aesthetic ratings (Likert scale) about:
  - Overall aesthetic quality (scale 1–10)
  - **Light and colour** (scale 1–4) $\leftarrow$ target variable
  - Composition and depth (scale 1–4)
  - Quality (scale 1–4)
  - Semantic (scale 1–4)
- Variable raters (number and /or identity) per image

The Explainable Visual Aesthetics (EVA) Dataset (2/3)

Overall score = 7.2
Light & colour = 3.2
Composition & depth = 3.2
Quality = 3.1
Semantic = 3.3

Overall score = 4.7
Light & colour = 2.8
Composition & depth = 3.0
Quality = 3.0
Semantic = 2.2

Image source: The Explainable Visual Aesthetics (EVA) Dataset

The Explainable Visual Aesthetics (EVA) Dataset (3/3)

Data cleaning:

- We retained only the true-colour 24-bit RGB images $\rightarrow$ total of 4,647 images after cleaning

We assumed that all the images were encoded in the **sRGB** colour space.

Methods

Main steps

1. Extraction of the colour theme
2. Characterisation of the colour theme by hand-crafted features
3. Correlation analysis with manually-assigned visual scores

Colour theme or palette (1/2)

Set of ‘most representative’ colours in an image

Image source: The Explainable Visual Aesthetics (EVA) Dataset (palettes added by the authors).

Colour theme or palette (2/2)

More formally:

- A set of m colours $\mathcal{P} = \{\mathbf{c}_1, \ldots, \mathbf{c}_i, \ldots, \mathbf{c}_m\}$, $\mathbf{c}_i = \{c_{i1}, \ldots, c_{ij}, \ldots, c_{ir}\}$

Where:

- $c_{ij} \rightarrow j$-th component of the $\mathbf{c}_i$ colour in an r-dimensional colour space – e.g. red, green and blue for RGB images
- $m \rightarrow$ dimension of the palette

Furthermore:

- $p_i \rightarrow$ probability of occurrence (strength) of the i-th colour of the palette in the image

Colour theme extraction

- k-means clustering
  - L_2 distance in the RGB space
  - seeds sampled uniformly along the RGB cube diagonal from black $(0, 0, 0)$ to white $(N - 1, N - 1, N - 1)$
- $k \triangleq m = 5$ (based on Ciocca *et al.*[1])

[1] G. Ciocca, P. Napoletano, and R. Schettini. **"Evaluation of Automatic Image Color Theme Extraction Methods".** In: *Proceedings of the International Workshop on Computational Color Imaging CCIW 2019*. Lecture Notes in Computer Science 11418. Chiba, Japan: Springer, Mar. 2019, pp. 165–179.

Colour theme features

We characterised the colour themes by 21 hand-crafted features:

- **Average contrast ratio** (1 feature)
- **Colour harmony** (3 features)
- **Correlated colour temperature** (5 features)
- **Entropy** (1 feature)
- **Intensity** (5 features)
- **Saturation** (5 features)
- **Munsell's perceptual harmony** (1 feature)

Average contrast ratio

Average contrast ratio $\mathrm{CR}_{i,j}$ over each pair of colours in the palette (as defined by W3C recommendations).

$$\mathrm{CR}_{i,j} = \frac{L_l + 0.05}{L_d + 0.05} \tag{1}$$

where:

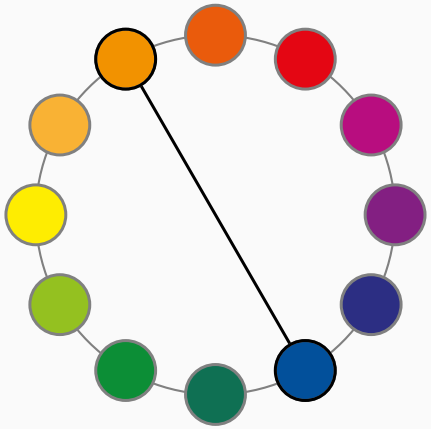
$$L = 0.2126R + 0.7152G + 0.0722B \tag{2}$$

and L_l, L_d indicate the lighter and darker colour of the pair.

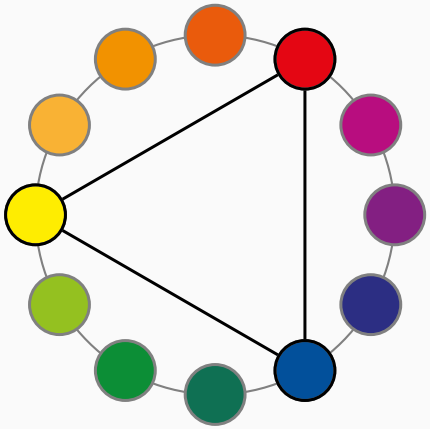
No. of features: **1**

Colour harmony (1/1)

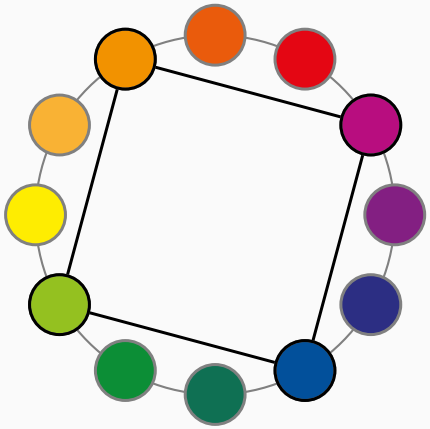
Related to the colour distribution along the hue circle. Maximum when the hue values are equally-spaced.



Complementary ($n = 2$)



Triadic ($n = 3$)



Quadratic ($n = 4$)

Ratio between the area of the n-agon inscribed in the hue circle and the area of a regular n-agon (see paper for formulas).

No. of features: **3** (complementary, triadic and quadratic)

Correlated colour temperature

- **Colour temperature** (CT): colour of the light emitted by an incandescent black body when heated to that temperature
- **Correlated Colour Temperature** (CCT): generalisation of CT when the emitted light does not follow Planck's black body locus

1000 K ← Warm colours Cool colours → 12000 K

No. of features: **5** (one for each colour in the palette)

Entropy

Entropy (E) of the probability distribution of each colour in the palette

It is maximum when all the colours appear with the same frequency in the input image

$$\mathrm{E} = \frac{-1}{\log_2(m)} \sum_{i=1}^{m} p_i \log_2(p_i)$$

where p_i is the probability of the i-th colour of the palette in the input image.

No. of features: **1**

Intensity

The **intensity** of each colour in the palette defined as the level of the *I* channel in the HSI colour space:

$$\mathsf{I} = \frac{R + G + B}{3}$$

Increasing intensity $\rightarrow$

No. of features: **5** (one for each colour in the palette)

Saturation

The **saturation** of each colour in the palette defined as the level of the S channel in the HSI colour space:

$$S = 1 - 3\frac{\min(R, G, B)}{R + G + B} \tag{3}$$

Increasing saturation $\rightarrow$

No. of features: **5** (one for each colour in the palette)

Munsell's perceptual harmony

An adaptation of Munsell's criterion of harmony as generalised by Moon & Spencer[2]:

$$\mathrm{MPH} = \sum_{i=1}^{m} \gamma_i v_i p_i \tag{4}$$

where γ_i, v_i respectively indicate the *chroma* and *value* as defined in Munsell's colour system.

No. of features: **1**

[2]P. Moon and D. E. Spencer. **"Geometric formulation of classical color harmony".** In: *Journal of the Optical Society of America* 34 (1944), pp. 46–50.

Correlation analysis

- Investigated correlations between:
  - The 21 features extracted from the image colour themes
  - Manually assigned score about **light and colour** (*visual*)
- Spearman's rank-correlation coefficient (ρ)
- Values considered significant at $\alpha = 0.05$
- Bonferroni's correction for multiple tests

Implementation, execution & reproducible research

- **Implementation**:
  - Python 3.10.4
- **Hardware and OS**:
  - Asus ProArt Laptop PC
  - CPU: Intel® Core™ i7-9750H @ 2.60GHz
  - RAM: 36 Gb
  - Windows 10 Pro 64-bit

Results and discussion

Significant features

Feature	Spearman's ρ	p-Value
Avg. contrast ratio	-0.09	< 0.001
Corr. col. temperature ($\mathbf{c}_2$)	-0.09	< 0.001
Corr. col. temperature ($\mathbf{c}_3$)	-0.12	< 0.001
Corr. col. temperature ($\mathbf{c}_4$)	-0.15	< 0.001
Corr. col. temperature ($\mathbf{c}_5$)	-0.09	< 0.001
Triadic colour harmony	0.13	< 0.001
Quadratic colour harmony	0.13	< 0.001
Saturation ($\mathbf{c}_1$)	0.20	< 0.001
Saturation ($\mathbf{c}_2$)	0.21	< 0.001
Saturation ($\mathbf{c}_3$)	0.24	< 0.001
Saturation ($\mathbf{c}_4$)	0.22	< 0.001
Saturation ($\mathbf{c}_5$)	0.19	< 0.001

Discussion (1/2)

- Twelve of the 21 features significantly correlated with manually assigned visual score in terms of light and colour
- The correlation strength was at best weak ($|\rho| \leq 0.24$)

Discussion (2/2)

- Positive correlation ($0.19 \leq \rho \leq 0.24$) between **saturation** and visual score
  - $\rightarrow$ Suggests preference for **sharp**, **vivid** colours
- Positive correlation ($\rho = 0.13$) between **triadic** and **quadratic colour harmony** and visual score
  - $\rightarrow$ Suggests preference for **harmonic** colour schemes
- Negative correlation (-0.14 $\leq \rho \leq$ -0.09) between correlated col. temp. and visual score
  - $\rightarrow$ Indicates preference for **warm** colours

Conclusions and future work

Conclusions

- Explored correlations between colour themes – the most significant colours in an image – and manually-assigned aesthetic score (light and colour)
- Characterised colour themes through a set of 21 hand-designed features
- Twelve features showed significant association with image aesthetics...
- ... but the overall correlation strength was rather weak

Limitations and future work (1/2)

Preliminary study; a number of limitations apply:

- Colour theme extraction based on simple k-means clustering; other methods could be considered
- Analysis based on average scores; inter-observer variability not investigated
- Effects of gender, ethnicity and/or cultural background not assessed

All the above is interesting subject for future studies

Limitations and future work (2/2)

Other directions for future work:

- Investigate other classes of features (e.g. based on Deep Learning)
- Validate the results on other datasets

Thank you for your attention!

Any questions?