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TOWARDS A UNIVERSAL UNDERSTANDING OF COLOR HARMONY AND COLOR-EMOTION ASSOCIATIONS: FUZZY APPROACH

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  - Intensity and Saturation Analysis
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INTRODUCTION (1/2)

- The human brain naturally seeks visual harmony, especially as we encounter increasing digital content.

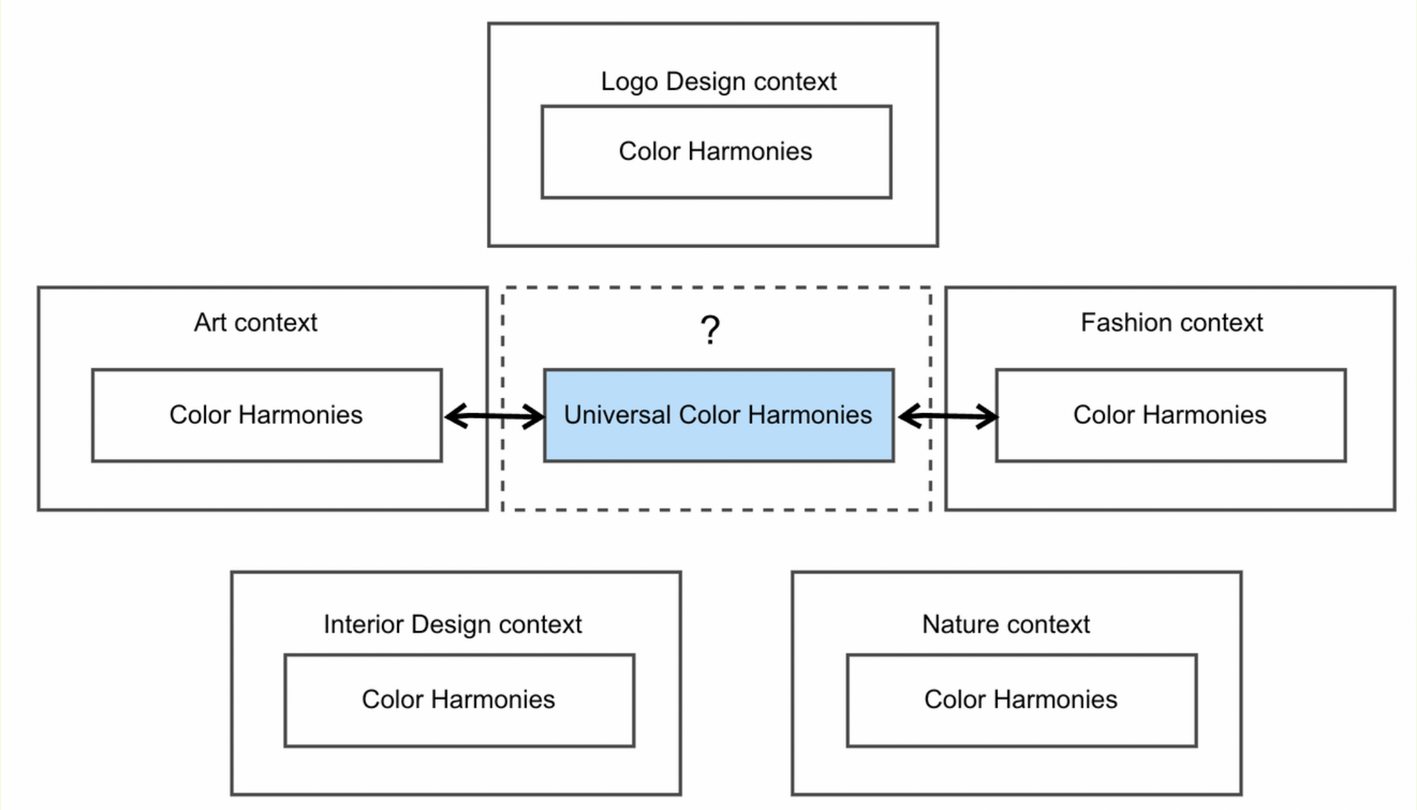
Color harmony is the art and science of creating color combinations, where colors work together in a balanced and aesthetically pleasing manner.

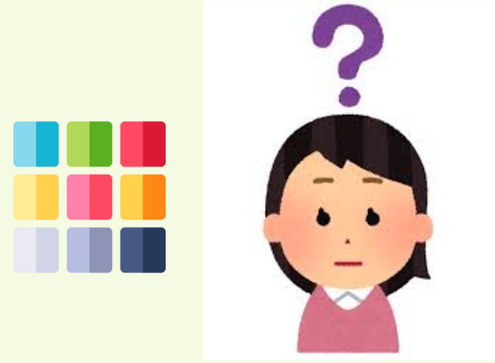
- It plays a pivotal role in various domains, from art and design to branding and nature.
- Aesthetic preferences vary across domains, and human perception is inherently subjective.
- Researchers have long examined image features for assessing aesthetic quality, but the question of context-dependent color aesthetics and harmony remains open.

INTRODUCTION (2/2)

HYPOTHESES

- ***Is color harmony universal or context-dependent?***
  - Whether color palettes accepted as harmonious in the context of fashion and art are also harmonious in the context of logo and interior design, nature, for example? If yes, to what extent?





we explore color harmony and address the question of its universality using:

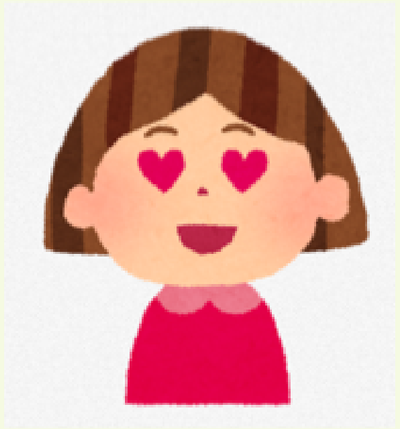
- a fuzzy-based color model
- 8-color palettes in five domains
- saturation and intensity alongside hue

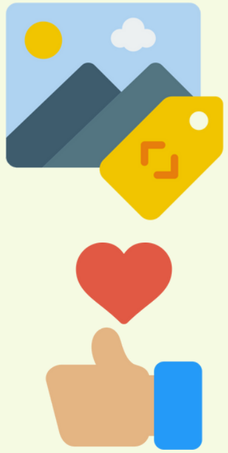
COLOR HARMONY (1/2)

RELATED WORK

Color harmony is the primary driver of aesthetic preference for color scheme. Color harmony universality remains an open question

Several researches have shown that color harmonies can be universal. Such combinations as monochromatic, complementary, analogous, etc. are widely used in art, fashion, and interior design. other hand, some studies show that it is highly context-specific.





COLOR HARMONY (2/2)

RELATED WORK

- Several approaches were proposed to perform color image harmony assessment, including:
  - Deep learning, CNN, Matsuda’s color coordination
  - Using features like hue count, global edge, contrast, and brightness levels
  - A selection of colors from a color wheel was suggested by Goethe, Itten .
  - Examining the relations between colors by Moon and Spencer, Chevreul.
- Research on **color harmony** has a long history, but uncertainty mechanisms of color harmonies are still controversial and challenging. Color harmony universality is no less controversial.
- **Color harmony's specificity varies based on the field of application, viewer's condition, and subjective judgments. Some studies, though, discovered universal color combinations that elicit similar human responses across various contexts.**

So, further research is required in order to resolve these contradictions

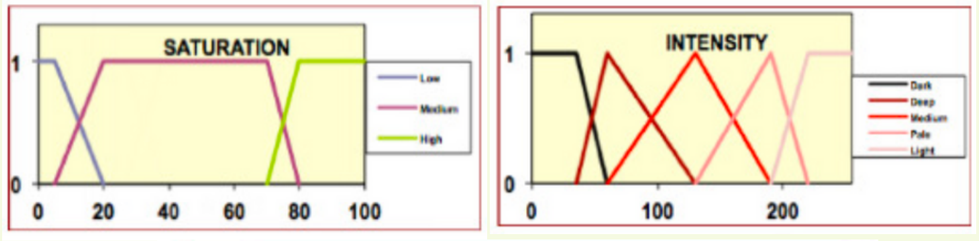
METHODS (1/6)

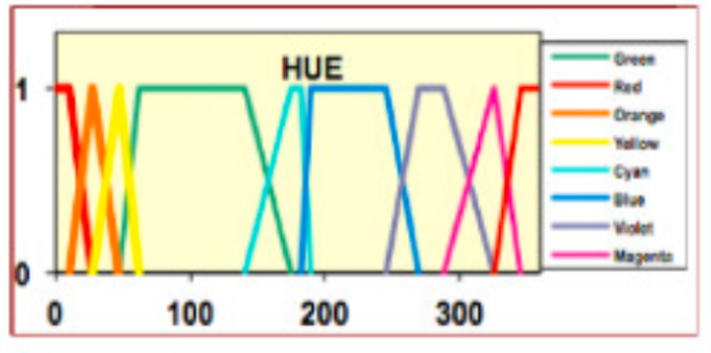
RESEARCH BACKGROUND

- We introduced a novel fuzzy perceptual color model (FHSI) in our previous works. It can be used to address the uncertainty associated with images and model high-level aesthetic judgments.

- We also provided objective measures for finding the image / palette similarity to match human evaluation

3	Any	Low	Medium	23	Orange	High	Deep	61	Blue	Medium	Dark	
4	Any	Low	Pale	24	Orange	High	Medium	62	Blue	Medium	Deep	
5	Red	Low	Light	25	Orange	High	Pale	63	Blue	Medium	Medium	
6	Red	Medium	Dark	26	Orange	High	Light	64	Blue	Medium	Pale	
7	Red	Medium	Deep	27	Yellow	Low	Light	65	Blue	Medium	Light	
8	Red	Medium	Medium	28	Yellow	Medium	Dark	66	Blue	High	Dark	
9	Red	Medium	Pale	29	Yellow	Medium	Deep	67	Blue	High	Deep	
10	Red	Medium	Light	30	Yellow	Medium	Medium	68	Blue	High	Medium	
11	Red	High	Dark	31	Yellow	Medium	Pale	69	Blue	High	Pale	
12	Red	High	Deep	32	Yellow	Medium	Light	70	Blue	High	Light	
13	Red	High	Medium	33	Yellow	High	Dark	71	Violet	Low	Light	
14	Red	High	Pale	34	Yellow	High	Deep	72	Violet	Medium	Dark	
15	Red	High	Light	35	Yellow	High	Medium	73	Violet	Medium	Deep	
16	Orange	Low	Light	36	Yellow	High	Pale	74	Violet	Medium	Medium	
17	Orange	Medium	Dark	37	Yellow	High	Light	75	Violet	Medium	Pale	

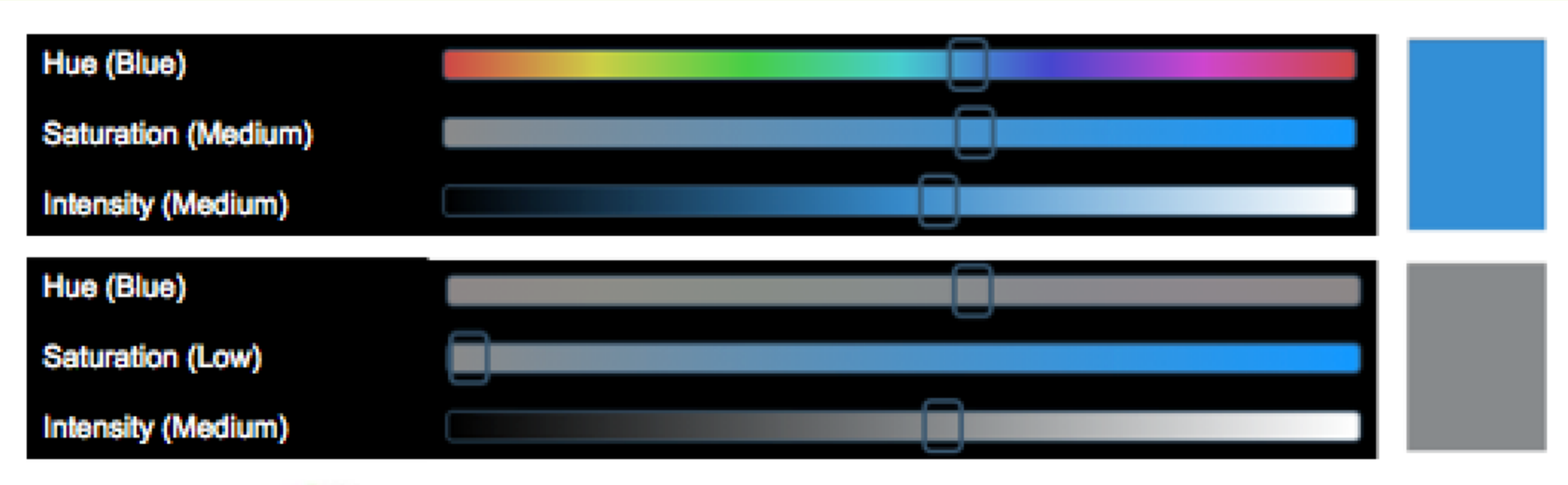




Fuzzy variable	Term set	Domain
Hue	T = { Red, Orange, Yellow, Green, Cyan, Blue, Violet, Magenta }	X = [0, 360]
Saturation	T = { Low, Medium, High }	X = [0, 100]
Intensity	T = { Dark, Deep, Medium, Pale, Light }	X = [0, 255]

Description of fuzzy attributes of the fuzzy color space we proposed in earlier work

FUZZY COLOR MODELLING



id	hue	saturation	intensity	description
1	Any	Low	Dark	
2	Any	Low	Deep	
3	Any	Low	Medium	
4	Any	Low	Pale	
5	Any	Low	Light	

Saturation serves as a weighting factor for the intensity and hue.

- If **(S is high)** H is more important
- If **(S islow)** I is more important

So, we use *Pertinence*values to each of the color channels

METHODS (2/6)

RESEARCH BACKGROUND

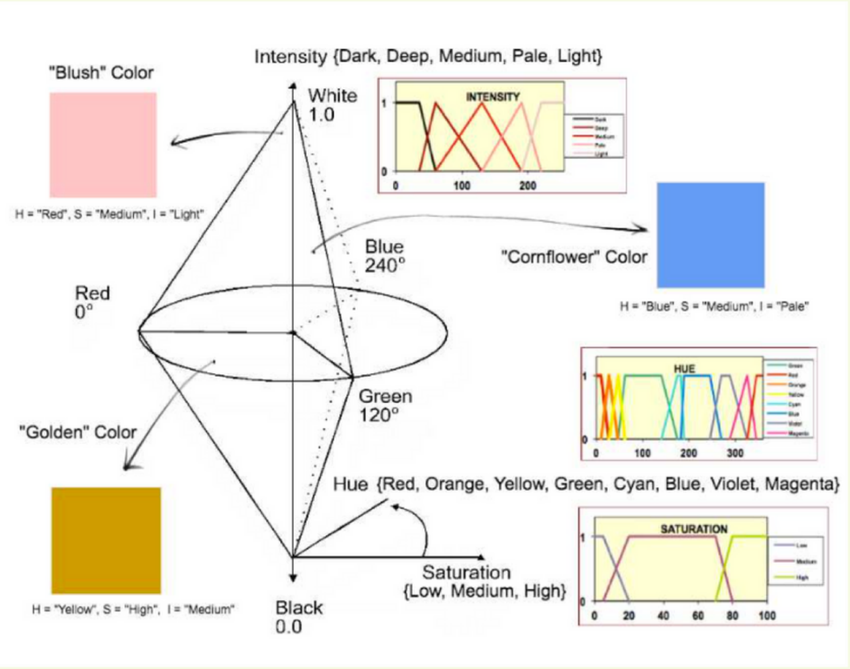
Definition 1 ***FHSI (fuzzy HSI) color*** *C is a linguistic label whose semantic is represented in HSI color space by a normalized fuzzy subset of* $D_H \times D_S \times D_I$.

Definition 2 ***FHSI (fuzzy HSI) color space*** *is a set of fuzzy colors that define a partition of* $D_H \times D_S \times D_I$.

Definition 3 ***FHSI (fuzzy HSI) color palette*** *is a combination of several fuzzy colors.*

In a fuzzy color palette, each color is not crisp (point), but a fuzzy color (region).

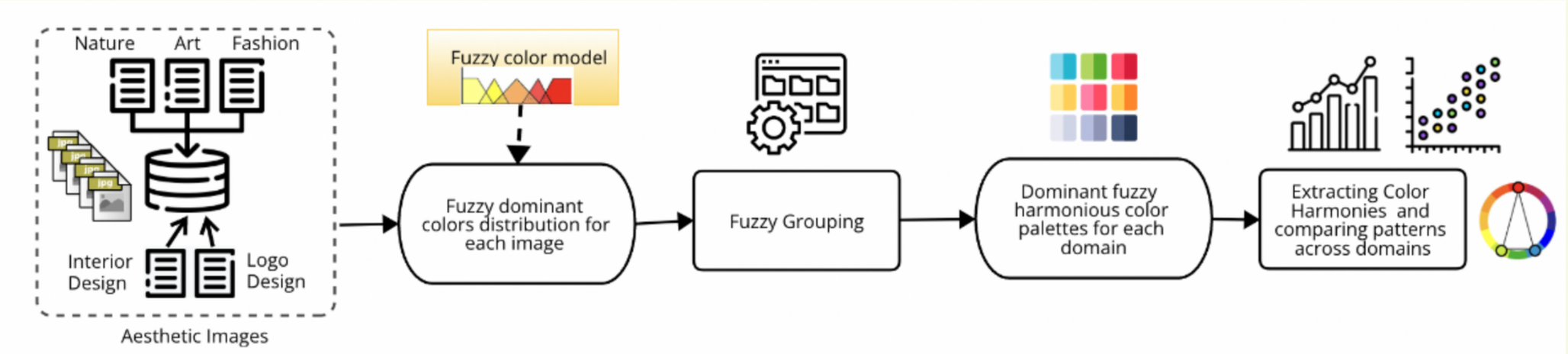
Example : **Blush color.** We take crisp inputs and transform them into fuzzy sets. Blush: R=241, G=171, B=185, convert it into HSI (H = 349, S = 14%, I = 78%), then to the FHSI model (H = Red, S = Medium, I = Light).



FHSI Color Space. Hue, Saturation, and Intensity attributes are represented as fuzzy sets.

Hue, in this case, is partially 'Red' and 'Magenta', while Saturation is partially 'Low' and partially 'Medium'.

METHODS (3/6)
PROPOSED APPROACH



Proposed fuzzy approach for color harmony universality estimation

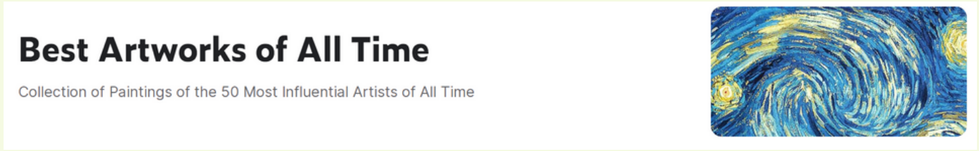
1. We **collect a dataset** comprising **aesthetically appealing images** from five distinct domains.
2. Then, we **extract fuzzy dominant colors** in each image and group the images, forming fuzzy color palettes for each domain.
3. Finally, we **extract color harmony patterns** and compare them.

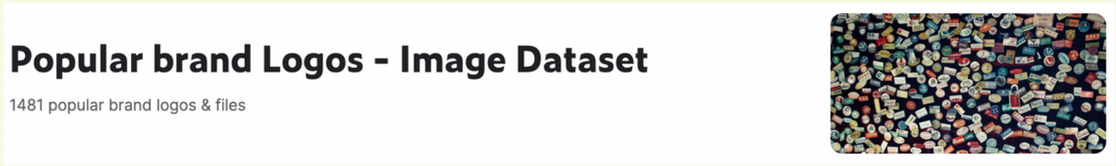
METHODS (4/6)

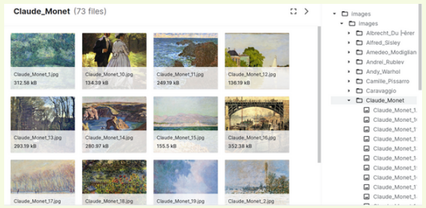
DATA COLLECTION

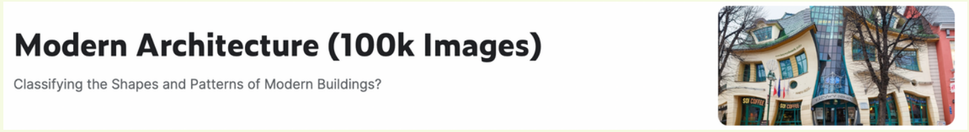
We used images linked to a high level of aesthetic pleasantness.

- 1276 artworks from the '*Best Artworks of All Time*' dataset
- 1204 pictures of '*Dataset of natural landscapes*'
- a dataset of '*Modern Architecture*' (1250 images)
- '*Popular Brand Logos*' image dataset (1250 images)
- Fashion looks (10 000 images)



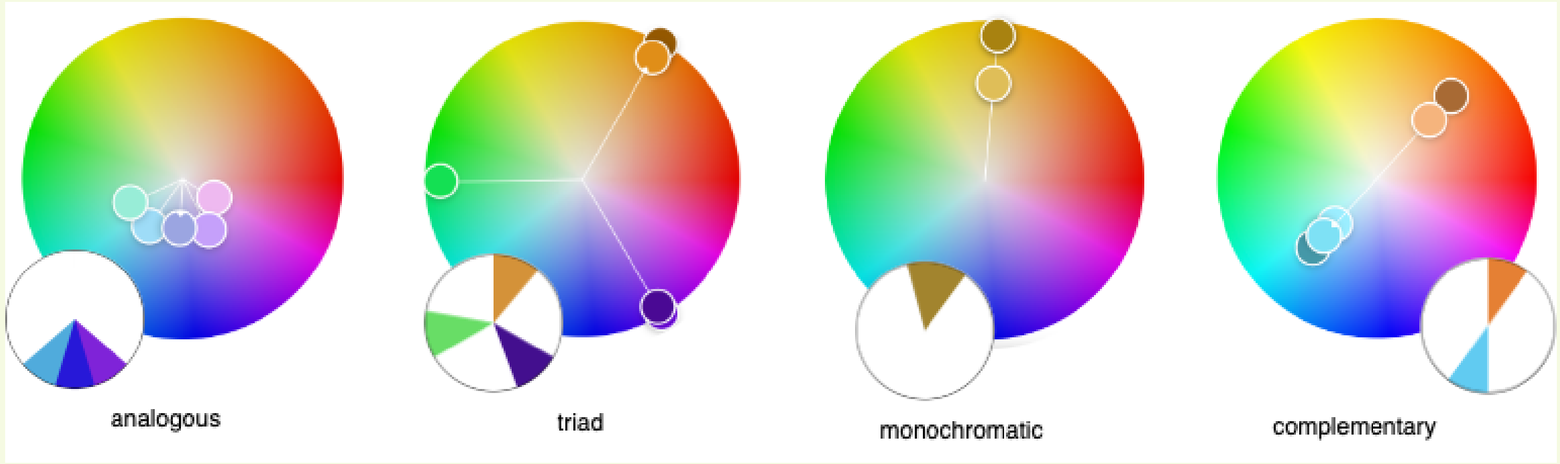






METHODS (5/6)

COLOR WHEEL



- Johannes Itten proposed a **color wheel** and described rules for constructing harmonious color combinations:
  - e.g., a **monochromatic** color scheme means selecting one hue and its darker or lighter variations.
  - Diametrically opposed colors are called **complementary** and produce the high contrast
- Balancing saturation and lightness is vital for color harmony, especially with more colors.
- Our experiment explores *Monochromatic, Complementary, Split Complementary, Triad, Square, Rectangular, Analogous* harmonies.

METHODS (6/6)

FUZZY PALETTES EXTRACTION

- Harmonious fuzzy color palettes were generated from the dataset by grouping images with similar color schemes
- We used the fuzzy color model with formulas for color difference and palette similarity (Shamoi et al., 2020)

Data: dataset of images $M_1, \ldots, M_n$ in some domain D
Result: list of fuzzy dominant color palettes $P_1, \ldots, P_k$ in D
$FuzzyPalettes \leftarrow$ an empty list;
while *not at end of dataset* **do**
  read current image M_i;
  $FP_i \leftarrow$ FindFuzzyDomColors (M_i);
  $Dp_{avg} \leftarrow$ FindAvgPercDif (M_i);
  ... /* the perceptual difference Dp_{avg} is found between FP_i and members of each fetched harmonious group. See Algorithm 1 in [3]. */
  if *minimal* $Dp_{avg} \geq diffThreshold$ **then**
    form a new Palette and add M_i to it. Add Palette to $FuzzyPalettes$
  else
    add M_i to a palette in $FuzzyPalettes$ with which M_i has minimal Dp_{avg}.
  end
end
return $FuzzyPalettes$;

Algorithm 1: Extracting fuzzy dominant palettes

Algorithm 1 identifies dominant fuzzy color palettes P1, ..., Pk within a domain D, employing a method for assessing image similarity using FHSI, as defined in M1 and M2

(a) Logo design

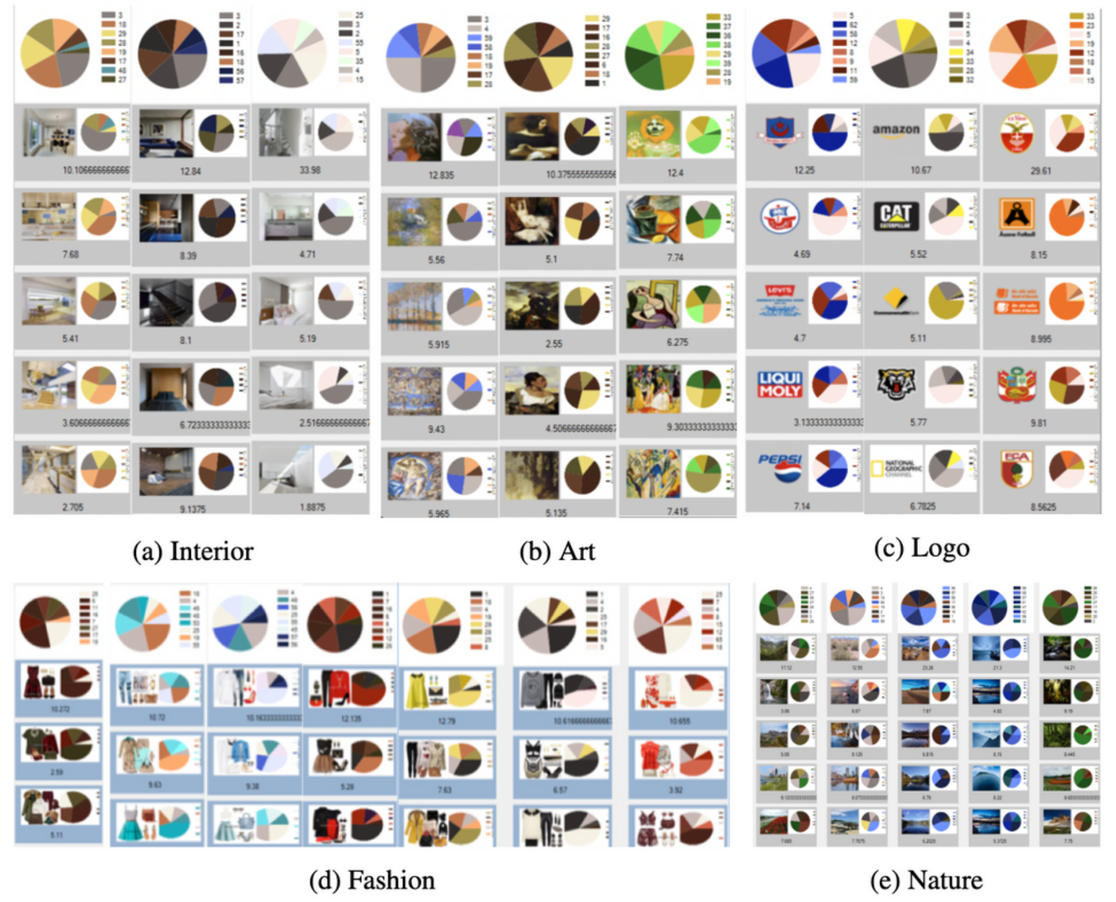
(b) Interior design

Examples of extracted fuzzy color palettes

EXPERIMENTAL RESULTS (1/4)

RETRIEVED PALETTES

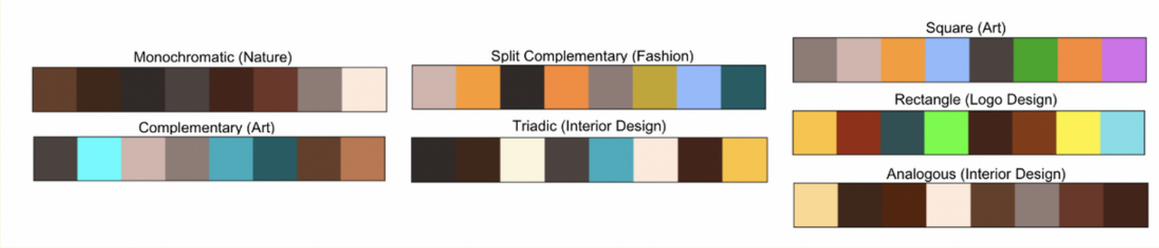
Examples of fuzzy dominant palettes and representative images extracted from considered domains



We processed datasets with **Algorithm 1** to obtain fuzzy color palettes for each context.

For example, in the Art domain, we found 46 groups of similar palettes.

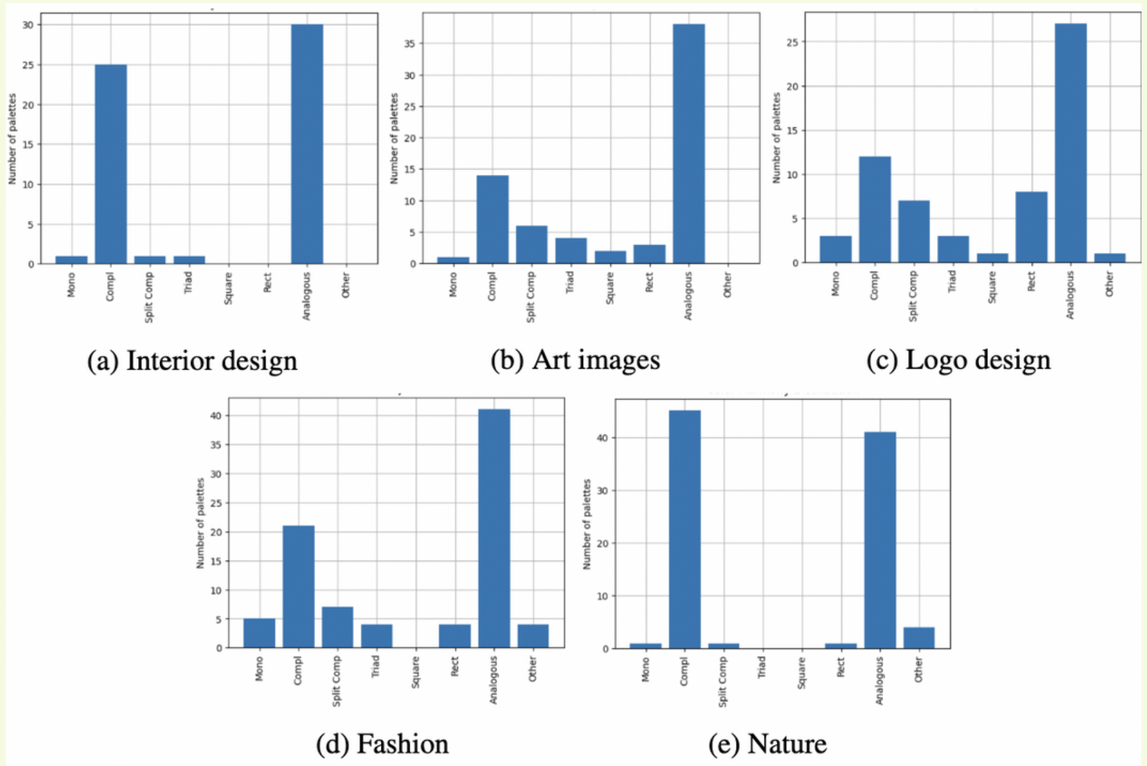
Examples of color palettes associated with certain harmonies



EXPERIMENTAL RESULTS (2/4)

WHEEL HARMONIES

Distribution of Color Harmonies among considered domains



(a) Interior design (b) Art images (c) Logo design

(d) Fashion (e) Nature

- We identified colors on the RGB wheel, examined tertiary hues (12-split), and computed harmonies.
- **Most schemes adhered to color wheel relationships**, but some fell into the ’Other’ category, deviating from these norms.
- Some rules like **’Triad,’ ’Square,’** and **’Rectangle’** were less frequent, while **’Analogous’** and **’Complementary’** harmonies prevailed in all domains.

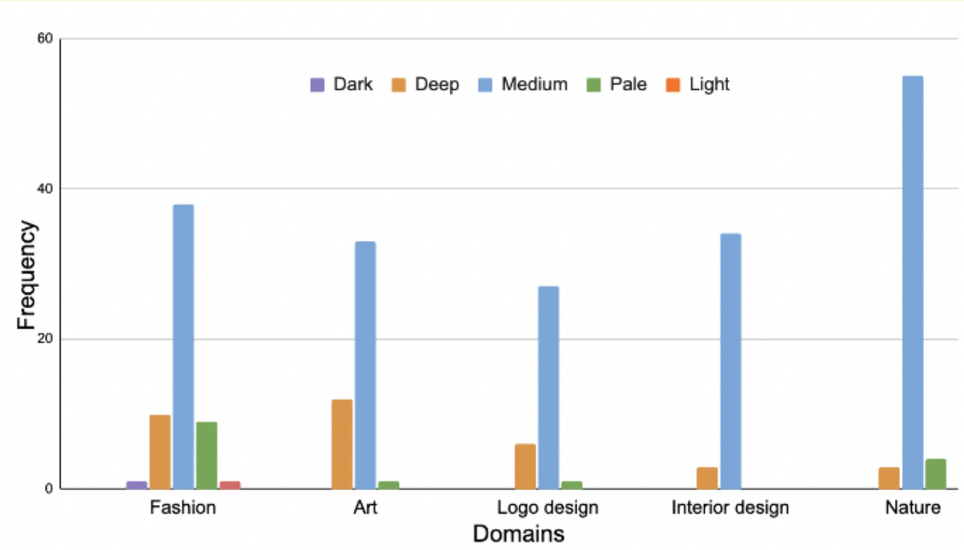
Summary of harmonious dominant fuzzy palettes from considered domain

Context	#Palettes	Top harmony	Other, %	Mean I	Mean S	Top Fuzzy Colors
Fashion	59	Analogous	6.8	0.50	0.40	
Nature	62	Complimentary	6.5	0.53	0.46	
Logo Design	34	Analogous	2.9	0.49	0.48	
Interior Design	37	Analogous	0	0.47	0.36	
Art Images	46	Analogous	0	0.46	0.40	

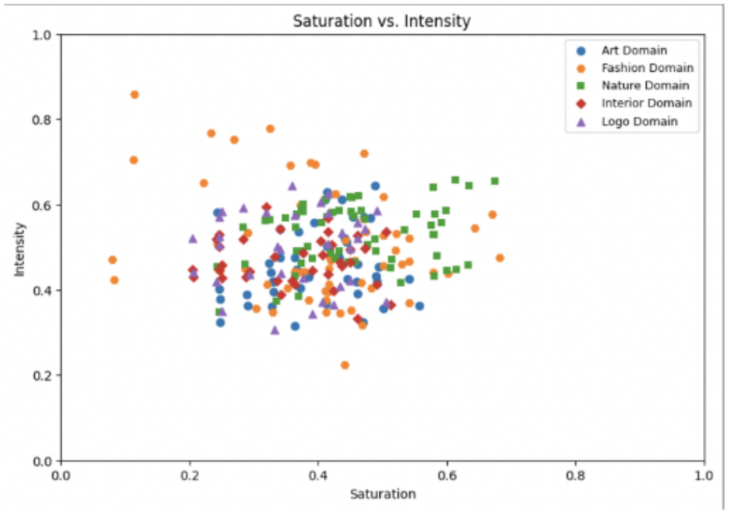
EXPERIMENTAL RESULTS (3/4)

INTENSITY AND SATURATION ANALYSIS

- According to the results, **color harmony** based on the color wheel **relates to specific I and S levels.**
- Even when following color wheel relationships like ’Triadic,’ variations in S and I impact harmony. In the majority of harmonious schemes, there is a dominance of **’medium’ S and I levels.**



(a) Distibution of fuzzy intensities across domains



(b) Trends in *Intensity* and *Saturation*

Results suggest that while color harmony is largely universal, some context influence remains

Distribution of intensities.
Fuzzy partition
Dark, Deep, Medium, Pale, Light

EXPERIMENTAL RESULTS (4/4)

WHY THESE RESULTS ARE USEFUL?

- The future phase will formalize these patterns as fuzzy rules for **predicting image harmony.**
- evaluate **’Color Harmony’** using three fuzzy variables: **Color Wheel Correspondence** (C), **Saturation** (S), and **Intensity** (I), each with terms like *'low,' 'medium,'* and *'high.'*
- We then apply fuzzy rules connecting these variables to **’Color Harmony.’**
  - e.g., ***"IF (C is 'high') AND (S is 'medium') AND (I is 'medium'), THEN Color Harmony is 'very High."***
- This process concludes with defuzzification, yielding the crisp harmony value.

COLOR-EMOTION ASSOCIATIONS

FUZZY APPROACH

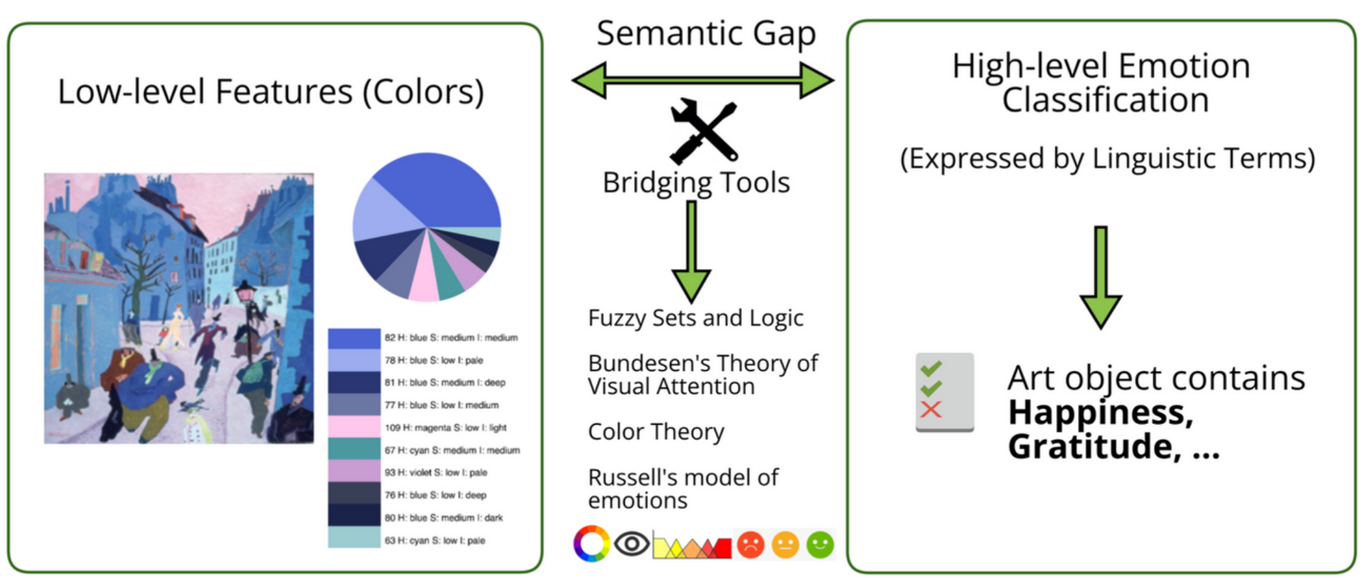
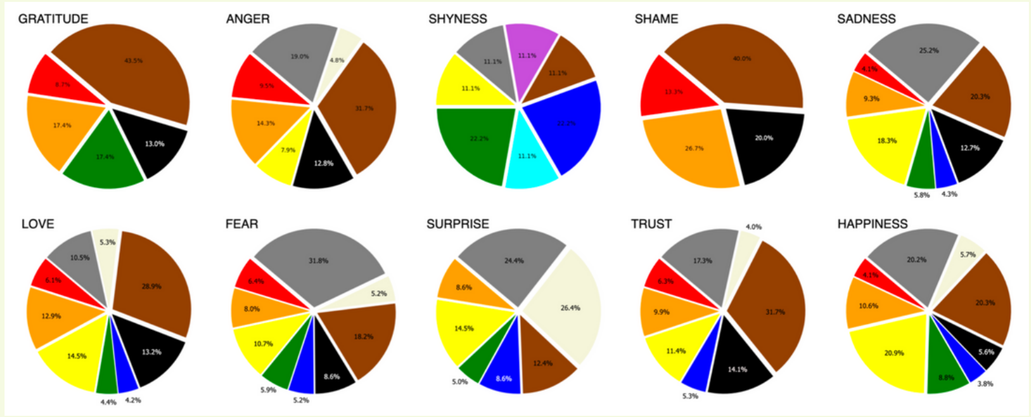
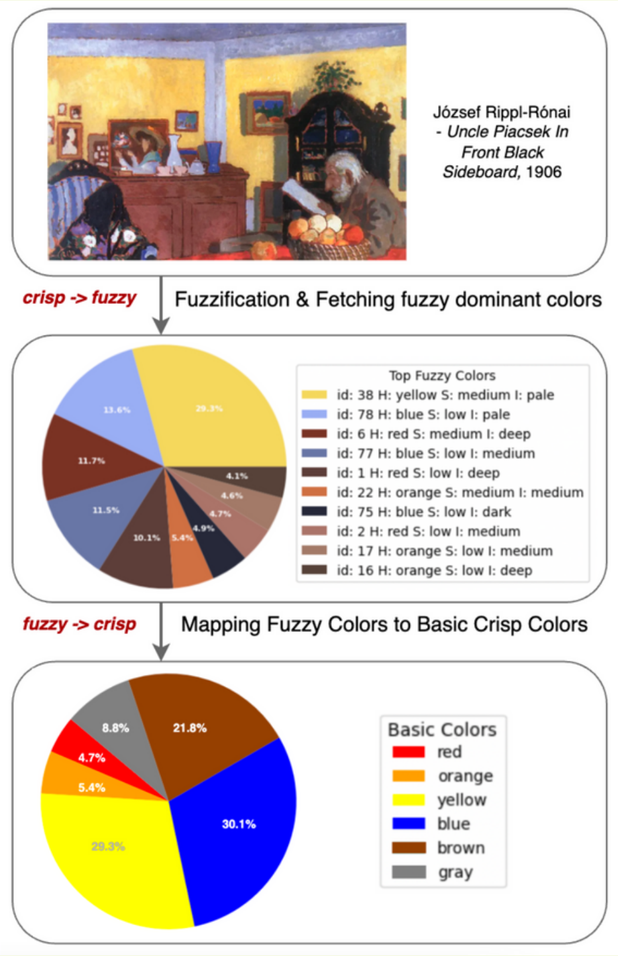


Fig. 1: Bridging the semantic gap between low-level features in art objects and high-level semantic concepts of emotions. Lyonel Feininger "Carnival in Arcueil" painting.

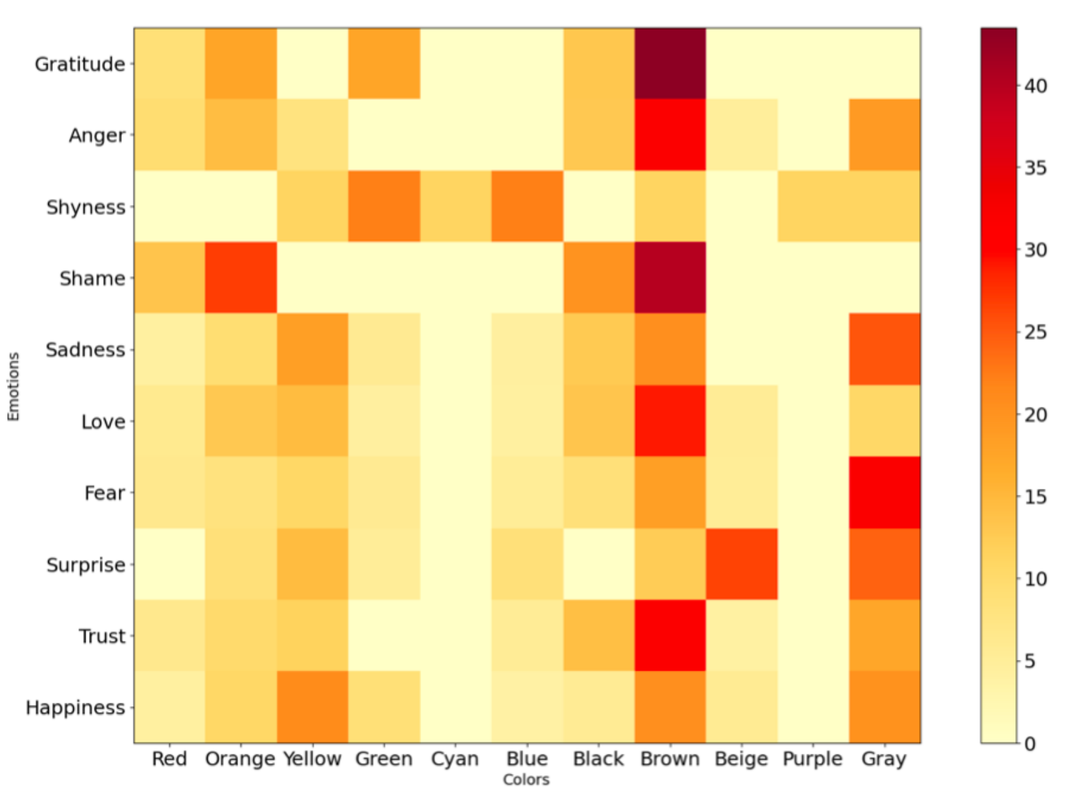




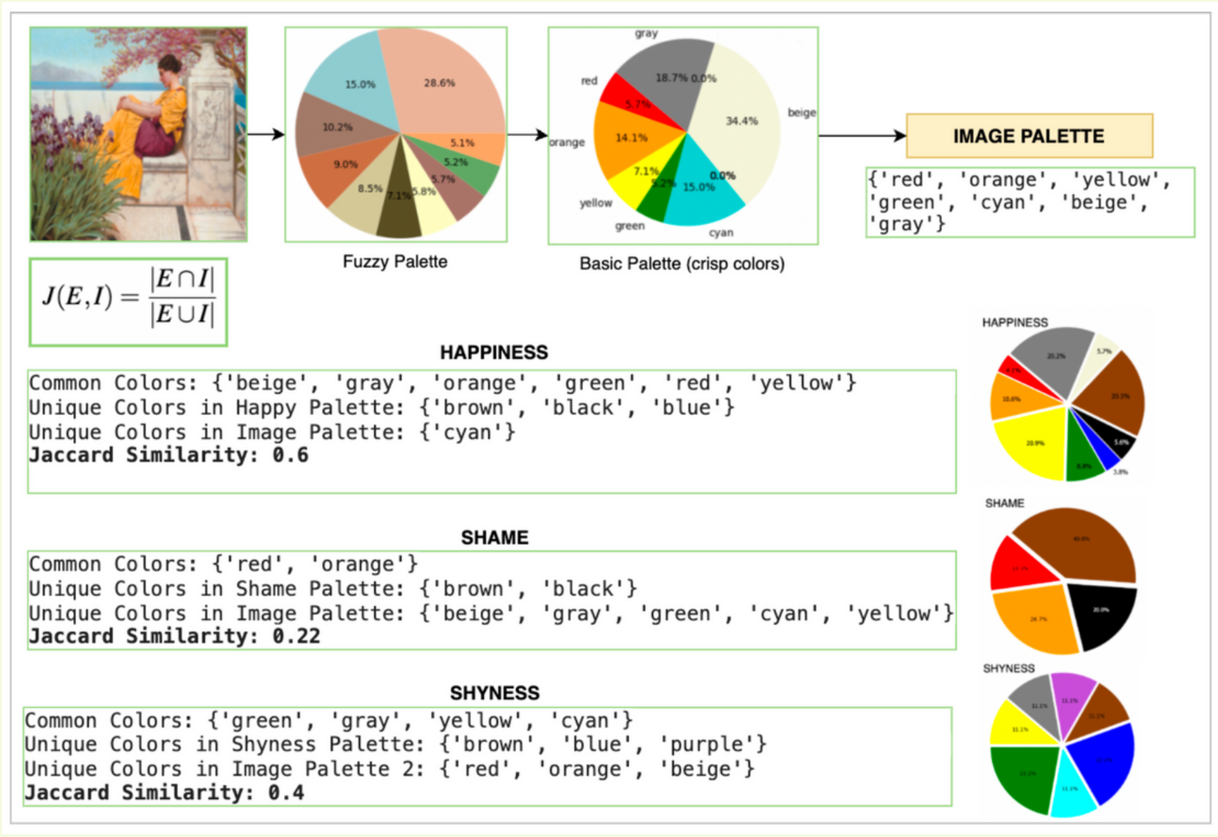
Extracting the fuzzy dominant colors from art images and mapping them to basic crisp colors.

COLOR–EMOTION ASSOCIATIONS

FUZZY APPROACH



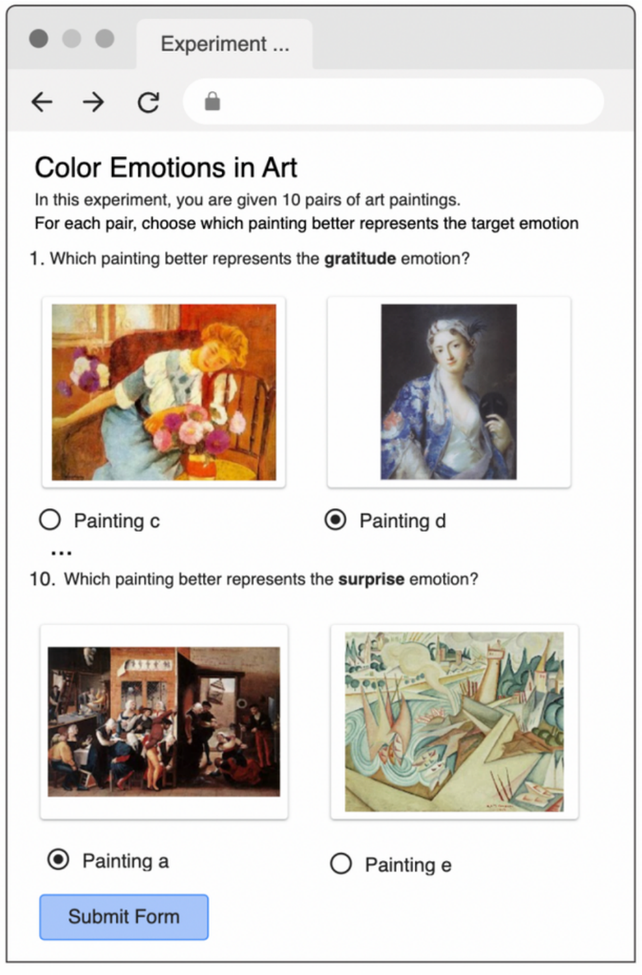
Heatmap of color-emotion association



Examples of Jaccard similarity calculation using happy, shy, and shameful emotion palettes and the J.W. Godward painting - Under the Blossom that Hangs on the Bough, 1917.

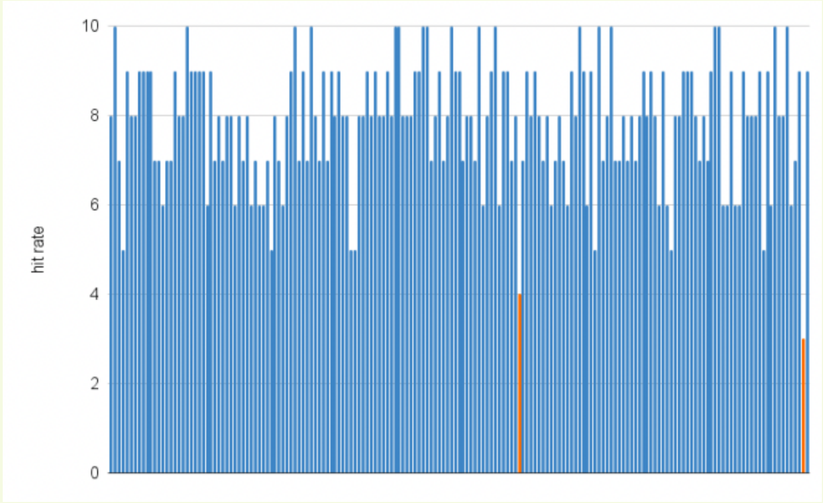
COLOR–EMOTION ASSOCIATIONS

FUZZY APPROACH



2AFC Experiment on perceptual emotion categorization of art paintings.

- We conducted a 2AFC experiment involving human subjects to evaluate the proposed method.
- The average hit rate 0.77 indicates a significant correlation between the method's predictions and human perception.



Survey participants hit rates distribution. Outliers are marked with orange color. Their responses were excluded from the analysis.

2AFC EXPERIMENT RESULTS

	Anger	Shyness	Happiness	Sadness	Gratitude	Shame	Fear	Trust	Love	Surprise
# hit rates	165	163	148	97	146	146	156	81	166	70
hit rate, %	0,95	0,94	0,86	0,56	0,84	0,84	0,9	0,47	0,96	0,4
Difference in Emotion Predictions	0,76	0,37	0,05	0,13	0,2	0,38	0,37	0,12	0,05	0,27

DISCUSSION

- Our experiments affirm the prevalence of analogous and complementary pairs for harmony [1], with a preference for mid-range S and I values.
- Our results align with Granger's emphasis on **consistent S and I levels** for harmony[2].
  - S and I cluster around mid-ranges across five domains, confirming their consistency.
- **Harmony and Color Wheels:**
  - Our study supports the idea that color harmony often relates to color wheel schemes, as discussed by Itten, Munsell, and Ostwald [3].
- **Universal vs. Contextual:**
  - Our findings highlight the universal nature of color harmony while acknowledging its sensitivity to context, in line with [4],[5].

[1] Briggs D, Westland S. In: Itten, Johannes; 2014. p. 1-3.
[2] Granger GW. An Experimental Study of Colour Harmony, The Journal of General Psychology. General Psychology. 1955;52:1:21 -35
[3] Schloss K, Palmer S. Aesthetic response to color combinations: Preference, harmony, and similarity. Attention, perception & psychop-s. 2011
[4]Ou LC, Luo MR, Cui G. A Colour Design Tool Based on Empirical Studies. Und Des Res Society Conf. 2009:175
[5] Markovic S. Object Domains and the Experience of Beauty. Art and Perception. 2014;2(1-2):140-19.

CONCLUSION (1/2)

- We explored the context dependency of color harmony using a fuzzy approach.
- **Analysis of Color Harmony in 5 contexts:**
  - importance of color wheel principles, saturation, and intensity.
  - Most harmonious schemes follow 'Analogous' and 'Complementary' color wheel rules, balancing medium saturation and intensity.
- These results are useful for fields like e-commerce, marketing, interior, and web design, e.g., they can improve web search and recommendation systems

- **The results show that color harmonies are universal to large degree within investigated contexts**

CONCLUSION (2/2)

LIMITATIONS AND FUTURE WORK

- The study has **limitations**:
  - with datasets potentially not fully representative of real-world diversity.
  - Expanding dataset variety and size can enhance generalizability.

- **Future Work:**
  - we plan to introduce a fuzzy inference system using rules based on color wheel correspondence, saturation, and intensity.
  - incorporate user evaluations to gain deeper insights into color harmony.

THANK YOU FOR YOUR KIND ATTENTION !

Contact me if you have further questions:

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