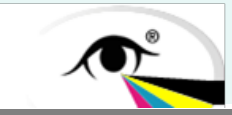
Correcting Displays for individual differences in color appearance

CAMILLA SIMONCELLI, FATEMEH CHARKHTAB BASIM, MICHAEL WEBSTER

DEPARTMENT OF PSYCHOLOGY, CENTER FOR INTEGRATIVE NEUROSCIENCE, UNIVERSITY OF NEVADA RENO (US)



ICC Experts' Day on Individual Colour Matching Functions

ICC Danny Rich Memorial Scholarship Fund 2024

Visual Perception Lab
University of Nevada Reno

Introduction

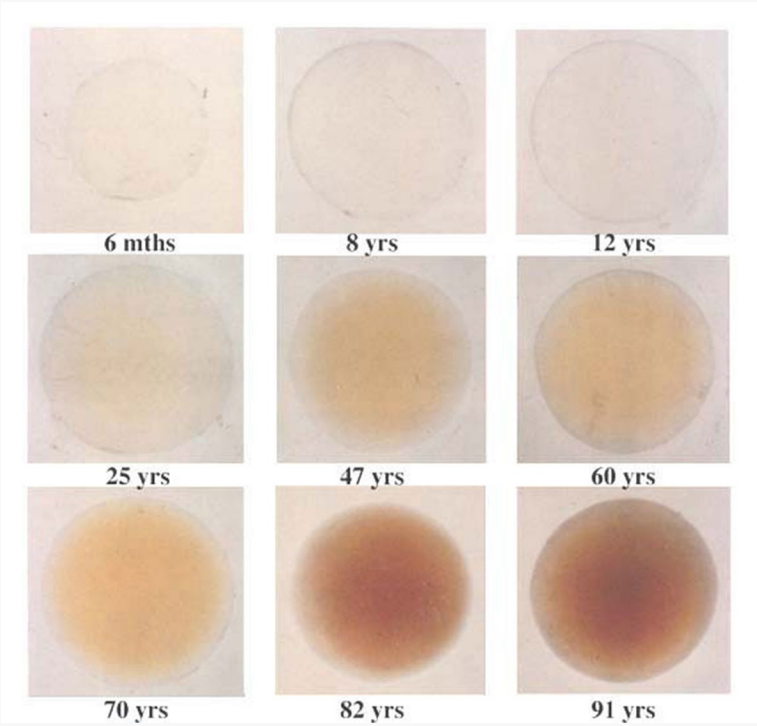
Individual differences in color vision can arise at many levels:

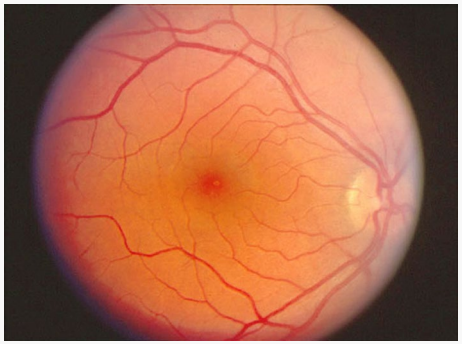
Differences in sensitivity (e.g. screening pigments and cone receptors)

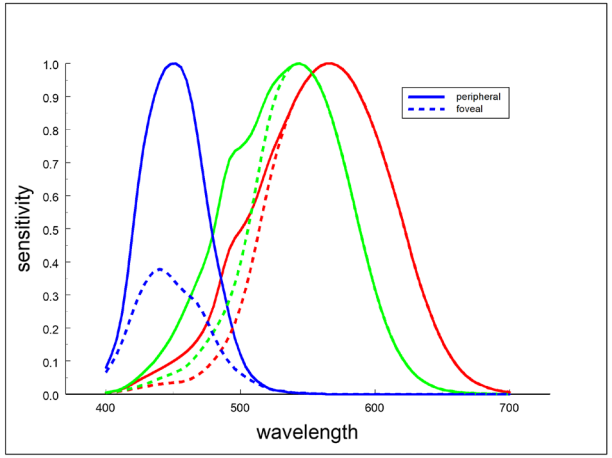
Differences in appearance (e.g. unique hues)

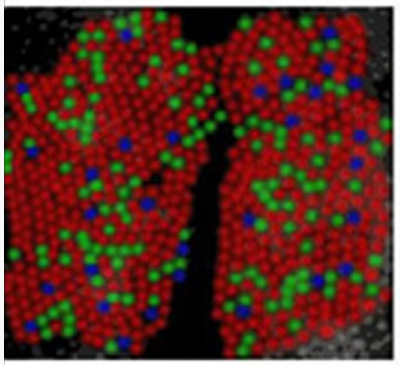
Differences in naming (e.g. color categories)

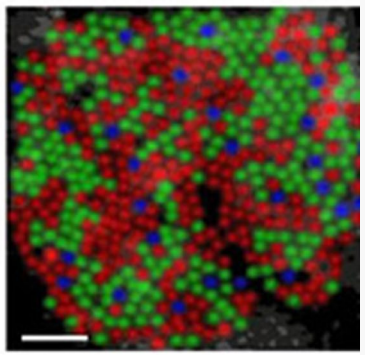
Introduction: physiological individual differences











Introduction: sensitivity differences

2 approaches for measuring and correcting for sensitivity differences

1. **Direct** – measure the individual's sensitivity or matches
   e.g. directly measure an observer's color matches

2. **Indirect** – measures underlying sources of variation to predict sensitivity

However, sensitivity differences don't predict appearance differences!

Corrections for color differences have mainly focused only on sensitivity

BUT some studies have looked at appearance (Shen and Fairchild 2024; Simoncelli and Webster, 2024).

Differences in color naming have not been addressed yet.

Thus, it is unclear how well these adjustments might correct for differences in color naming → **color categories' variation**.

The importance to address all levels

1. Little correlation between sensitivity and appearance
2. The relation between appearance and naming is not well established

Thus, corrections at one level will not mitigate differences at other levels, BUT...

Corrections at different levels may also serve different goals:

Sensitivity: to control for observer's metamerism

Appearance: to control for perceptual experience

Naming: to control for color communication and data visualization

Current Work

Measure and correct for differences in both appearance and naming

Questions:

1) Do focal colors vary independently of color categories?

2) How can we correct for both source of variations?

3) Does it really matter to correct for both?

What we measured:

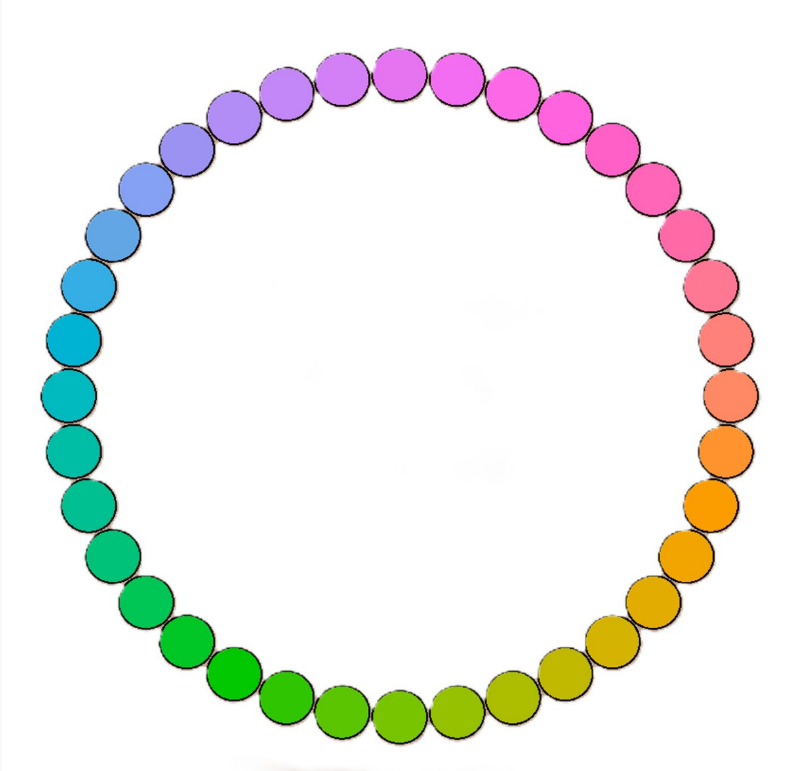
- Individual foci and category boundaries for 8 hues: red, green, blue, yellow, orange, purple, yellow-green, blue-green.

- Rendered images to align appearance or naming across observers based on their own foci or boundaries.

Stimuli:

Defined in the LvsM and SvsLM cone-opponent space (LvsM and SvsLM) on a uniform gray background (Lum = 20 cd/m²).

36 Hue angles were varied at a fixed chromatic contrast (80 cd/m²).



Methodology

Participants:

N=18 English-speaking, color-normal observers

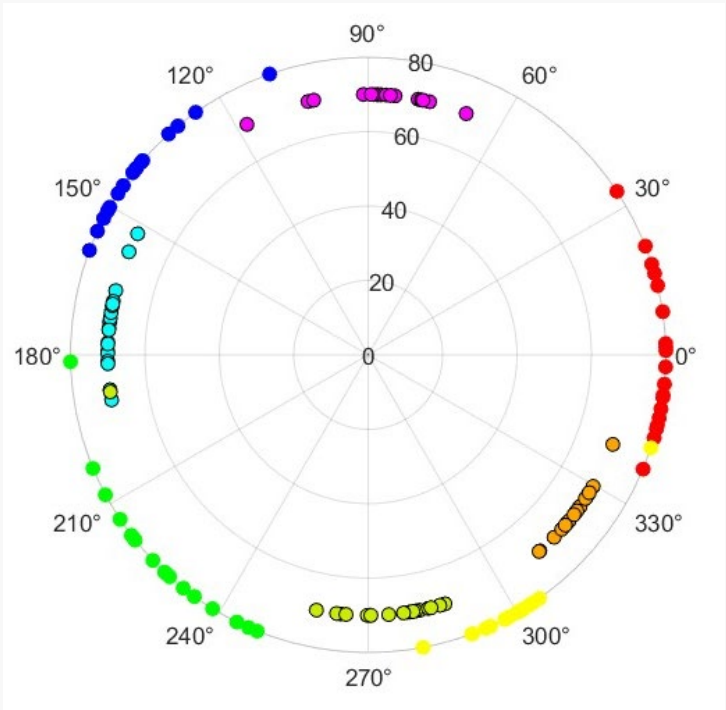
Tasks:

1. Focal Task: Choose the "best" example of the color term.
2. Naming Task: choose all hues labeled by the color term.

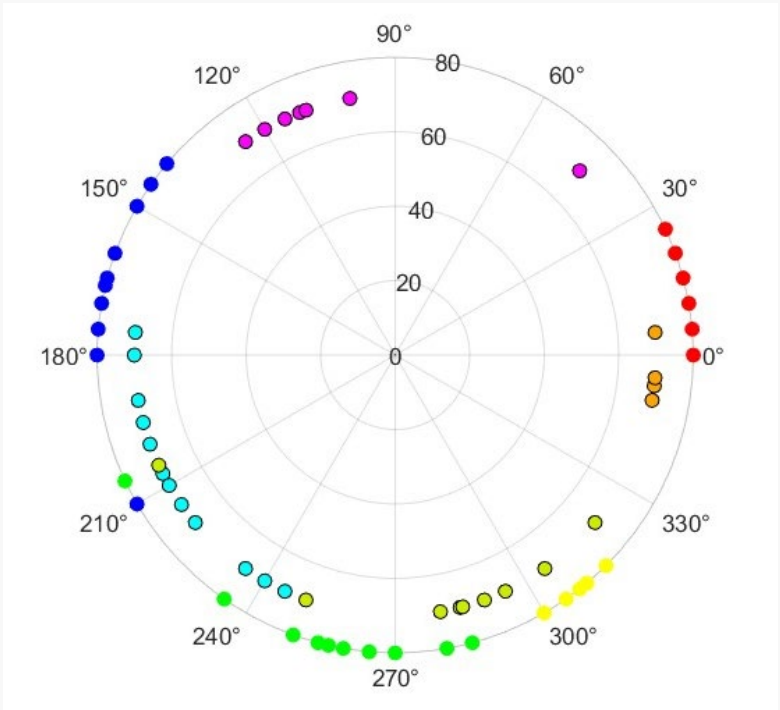
For foci, observers continuously varied the hue. For naming, they labeled 36 equally spaced angles in the space with the same 8 color terms.

Results:
Focal Colors vs. Color Categories

Individual Focal Choices
for each of the 8 hues.

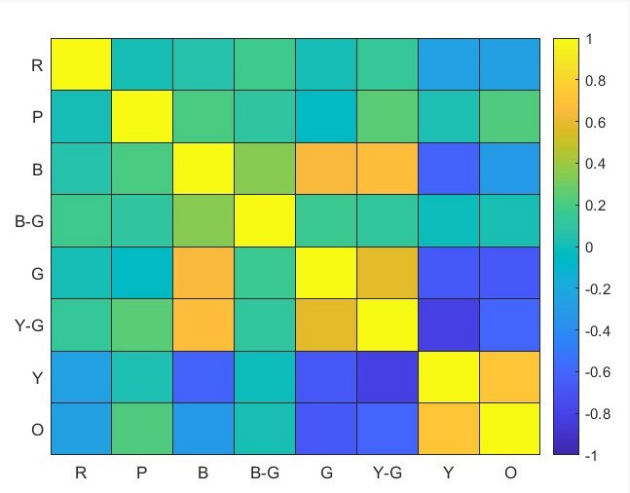


Individual Category Boundaries
for each of 8 hues

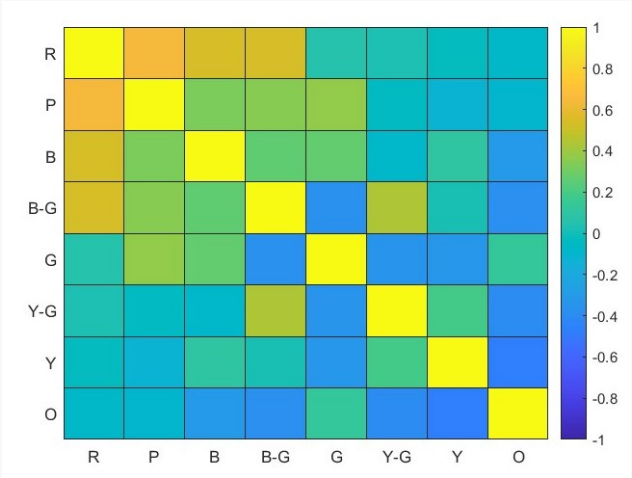


Results: correlations

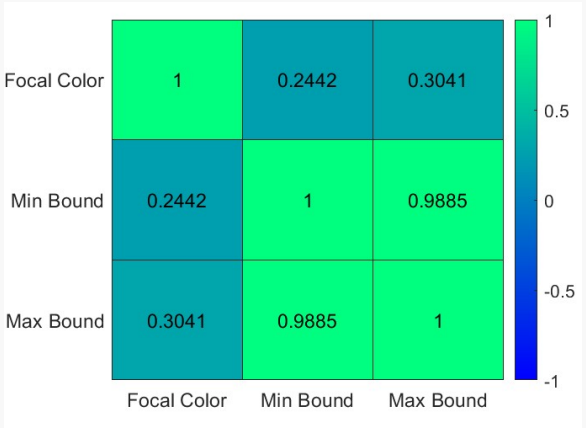
- High variability in individual foci and category boundaries across observers
- Weak correlations between foci across observers
- Weak correlations between boundaries across observers
- Weak correlations between foci and corresponding boundaries



Correlation in focal angles



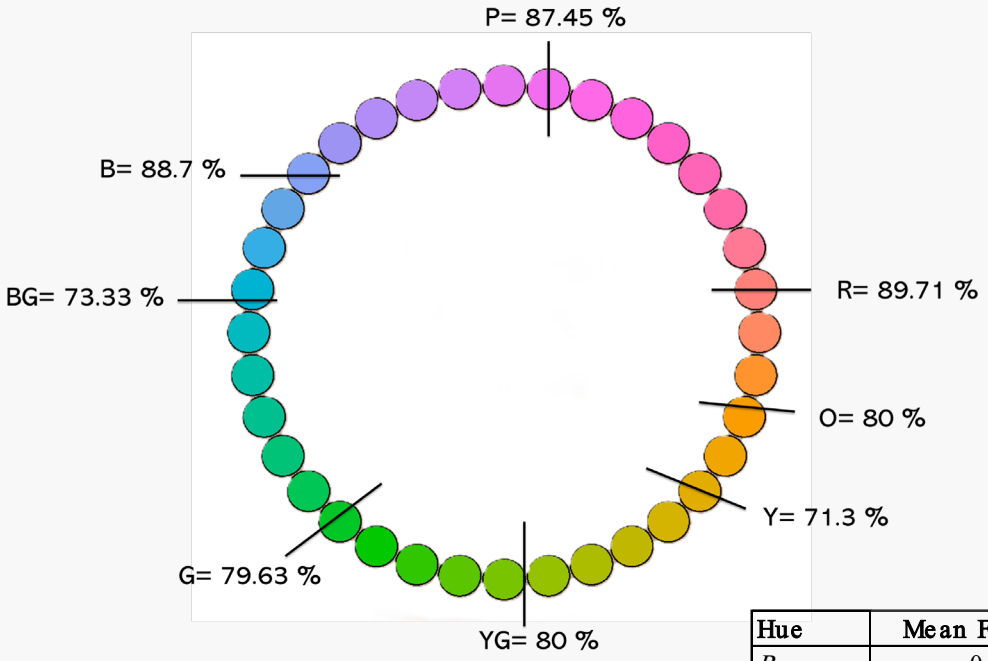
Correlation in boundaries midpoints



Correlation foci vs adjacent boundaries

Results:

Most hues were labeled with high concordance: 83.16% (avg)



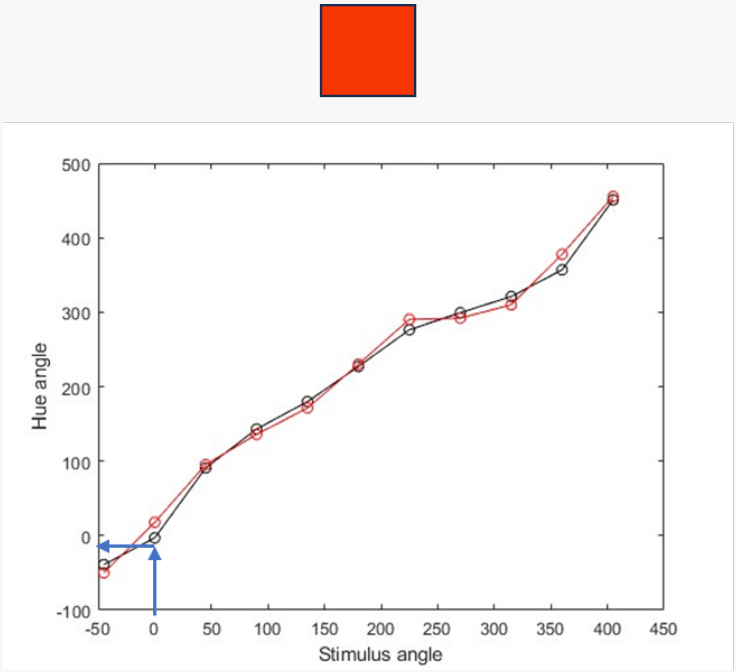
Variability is similar in the focal color and boundary angles

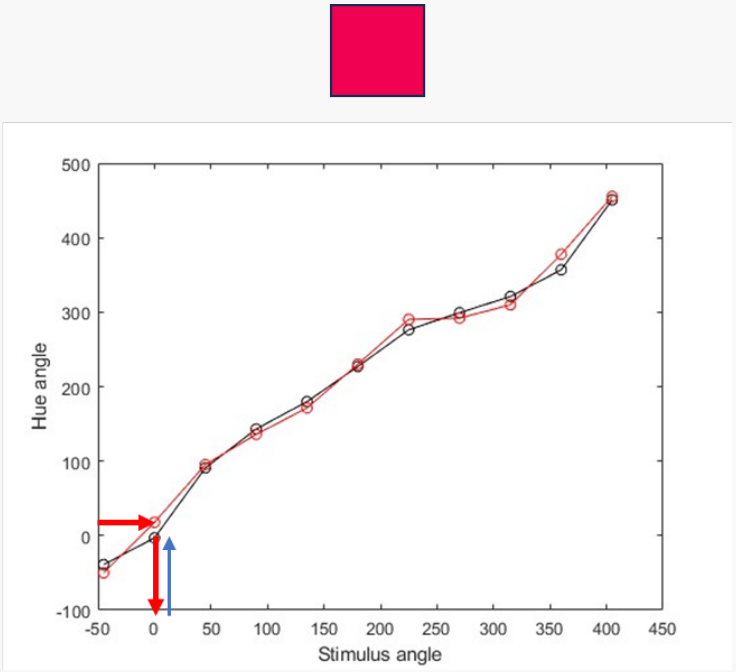
Hue	Mean Focal Color (SD)	Mean Boundary 1 (SD)	Mean Boundary 2 (SD)
R	0.02 (15.31)	350 (7.69)	360 (2.18)
G	223.85 (16.62)	191.67 (20.07)	268.33 (10.98)
B	141.95 (12.03)	116.11 (6.98)	173.89 (25.24)
Y	300.05 (12.01)	288.33 (5.14)	309.44 (2.36)
O	322.68 (6.89)	307.22 (7.52)	342.22 (6.47)
P	86.67 (11.68)	40.56 (14.74)	116.11 (6.98)
YG	270.66 (22.28)	244.44 (30.72)	294.44 (16.88)
BG	173.7 (9.65)	161.67 (15.05)	210.56 (28.38)

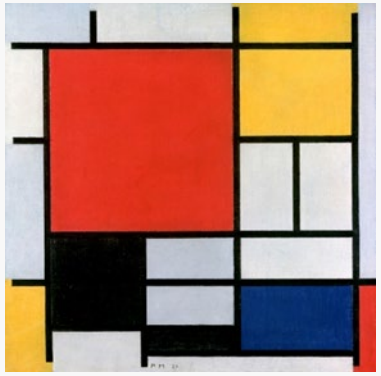
Images' correction comparison

Examples of images corrected for differences in appearance vs naming

Images were adjusted based on interpolating the focal or boundary values so that appearance or naming should be consistent across observers (Simoncelli and Webster 2024).

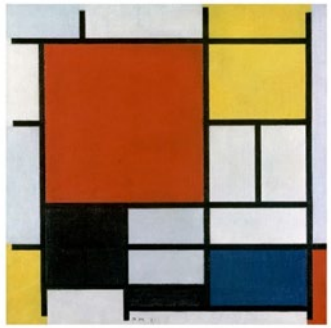




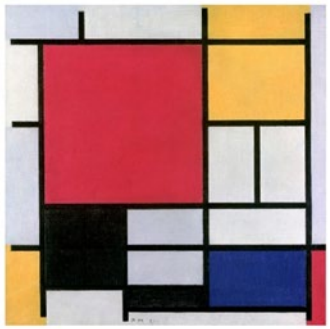


Reference Image

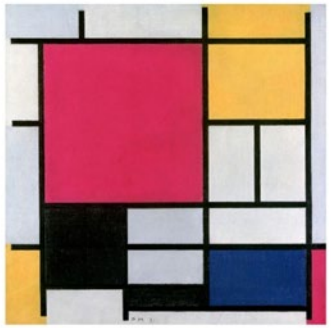
Focal Colors' correction



Obs 1



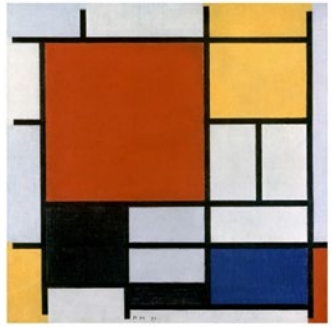
Obs 2



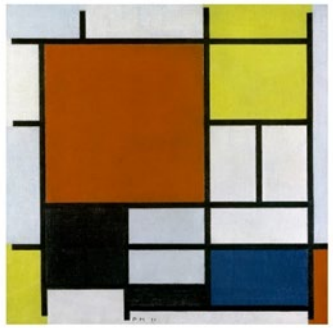
Obs 3

Color Categories' correction

Obs 1



Obs 2



Obs 3

Reference Image

Focal Colors' correction

Obs 1

Obs 2

Obs 3

Color Categories' correction

Obs 1

Obs 2

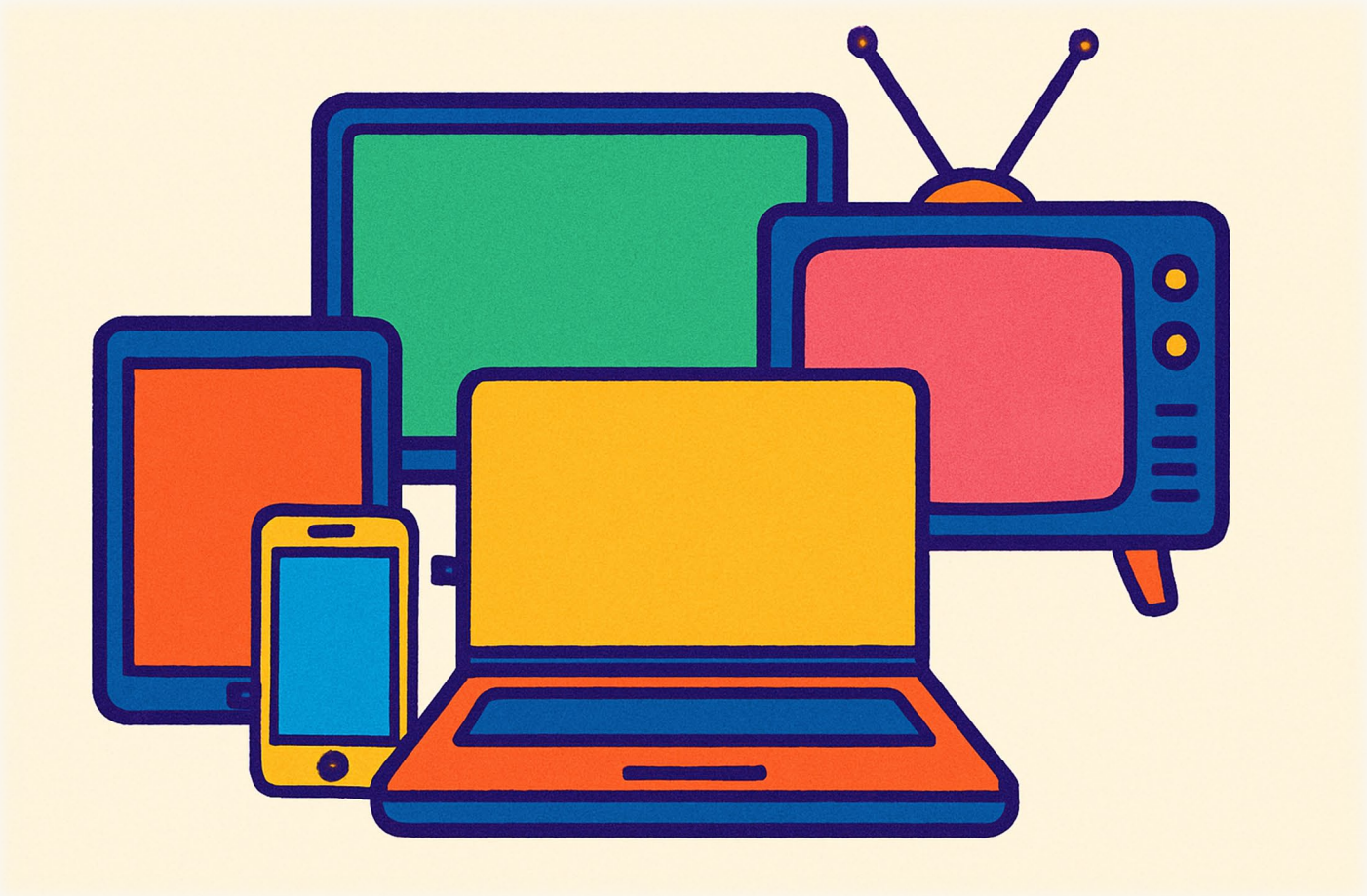
Obs 3

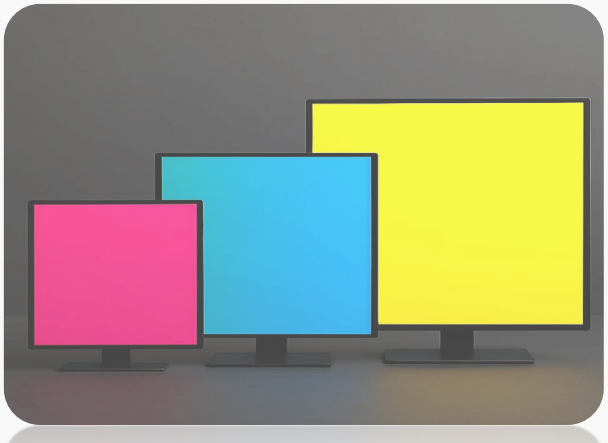
Implementing corrections in the color management pipeline

Shen and Fairchild's work (2024) : unique hues can be used to adjust the coordinates in CIECAM16.

We are designing a similar algorithm that could be applied for finer sampling of color (e.g. both unique and binary hues) or for color categories, or for both the levels.

Can we implement these measurements in any kind of device?

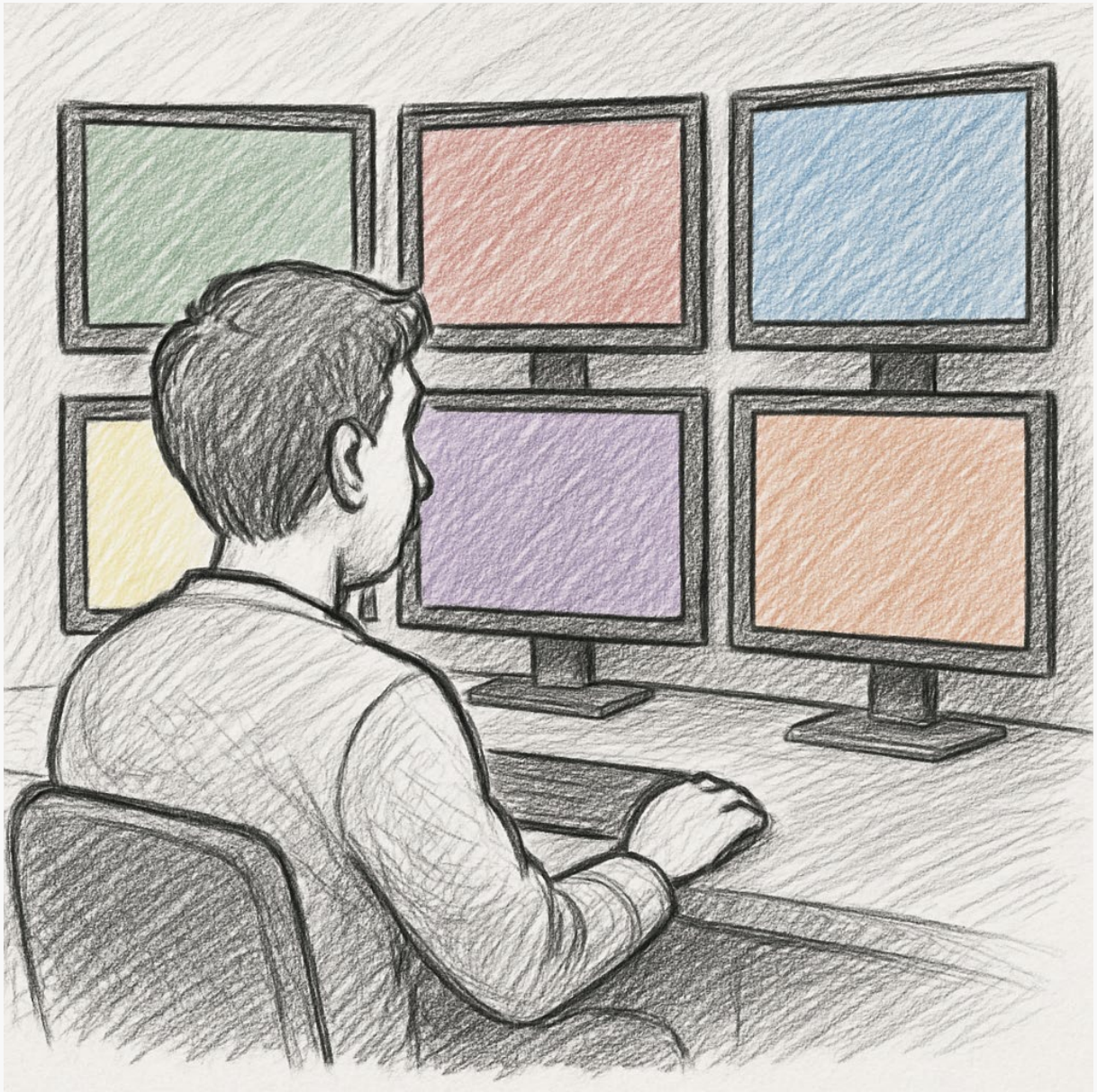




Compared to sensitivity corrections, differences in appearance or categories are simple to measure on any device and require no special equipment.

How?

Simply measuring focal colors and the corresponding categories for individual calibration, for the device of interest.



Key Findings

1) Variability exists across both focal colors and category boundaries

2) Focal angles and naming boundaries are largely uncorrelated

3) Thus, appearance-based corrections (foci) do not improve consistency in color naming across observers

4) Corrections for perceptual differences alone may not suffice → need to consider a 'third-level' profiling: categories, beyond sensitivity and appearance.

Ongoing Work

- Model predictors of categorical naming differences and hue foci differences.

- Create a unified algorithm for correcting images for both hue foci and color boundaries' differences.

- Broaden research across diverse populations and languages to verify the % of variation.

- Empirical validation of the approach (*data analysis in progress*): the error rate across observers after correction should be near 0.

Future Work

1. Examine how many measurements are necessary for a given level of correction

2. Determine how well the measurements and corrections generalize to other colors (i.e. differences in saturation or lightness, or simple vs. complex scenes).

3. Assessments of tasks affected by the corrections (e.g. color communication)

4. Implement the task in devices for correcting colors in displays, based on ICC profiles.

Contact: camilla.simoncelli@gmail.com

Thank you for your attention
And your support!

Questions?

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Visual Perception Lab
University of Nevada Reno