CIECAM02 Implementation and Visualization: Background, Models, Results

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Abstract

This document presents a basic implementation of the CIECAM02 color appearance model and a visualization study showing how a palette of colors behaves under different viewing conditions. The document contains necessary background, detailed mathematical descriptions of the model components used in the implementation, implementation notes, the visual results produced by the demo, and interpretations and inferences drawn from those results.

1 Background

Color appearance models (CAMs) predict how a color stimulus will be perceived under specific viewing conditions. CIECAM02 is a widely used CAM that relates device-independent tristimulus values (XYZ) to perceptual correlates such as lightness (J), chroma (C), and hue angle (h) while accounting for adaptation, surround, and luminance level. The model distinguishes between physical color signals and their appearance after visual processing and adaptation.

2 Mathematical model (detailed)

We summarize the main CIECAM02 computations used in the implementation. The process takes an input tristimulus vector $\mathbf{X} = [X\ Y\ Z]^T$ (observer 2-degree) and viewing-condition parameters, and computes appearance attributes J, C, h, and others.

2.1 Preliminaries: sRGB to CIEXYZ

Input colors are given in sRGB (nonlinear). The preprocessing steps are:

1. Convert nonlinear sRGB $\mathbf{c}_{\text{sRGB}} \in [0,1]^3$ to linear sRGB $\mathbf{c}_{\text{lin}}$ by inverse gamma:

$$c_{\text{lin},i} = \begin{cases} c_{\text{sRGB},i}/12.92 & c_{\text{sRGB},i} \le 0.04045 \\ \left(\frac{c_{\text{sRGB},i}+0.055}{1.055}\right)^{2.4} & \text{otherwise} \end{cases} \tag{1}$$

2. Convert linear sRGB to CIEXYZ using the matrix for the sRGB color space (D65 white):

$$\mathbf{X} = M_{\text{sRGB}\to XYZ}\ \mathbf{c}_{\text{lin}}, \qquad M_{\text{sRGB}\to XYZ} = \begin{bmatrix} 0.4124564 & 0.3575761 & 0.1804375 \\ 0.2126729 & 0.7151522 & 0.0721750 \\ 0.0193339 & 0.1191920 & 0.9503041 \end{bmatrix}. \tag{2}$$

2.2 Chromatic adaptation (CAT02)

CIECAM02 typically uses the CAT02 chromatic adaptation transform. The first step is to convert XYZ to an intermediate cone response domain ("RGB" in the CAT02 sense) using the CAT02 matrix M_{CAT02}:

$$\begin{bmatrix} R_c \\ G_c \\ B_c \end{bmatrix} = M_{\text{CAT02}} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}, \quad M_{\text{CAT02}} = \begin{bmatrix} 0.7328 & 0.4296 & -0.1624 \\ -0.7036 & 1.6975 & 0.0061 \\ 0.0030 & 0.0136 & 0.9834 \end{bmatrix}. \tag{3}$$

Given the adopted white point $\mathbf{X}_w$ (often D65) compute the corresponding R_{cw}, G_{cw}, B_{cw}.

The degree of adaptation D is computed from the adapting field luminance L_A and an empirical factor F (surround factor). One common expression is:

$$D = F\left(1 - \frac{1}{3.6}e^{-\frac{L_A+42}{92}}\right), \qquad 0 \le D \le 1. \tag{4}$$

The adapted cone responses are then:

$$R_c' = D\frac{Y_w}{R_{cw}}R_c + (1-D)R_c, \quad \text{(and similarly for } G_c', B_c'\text{)} \tag{5}$$

or, equivalently, scaling each cone response by a factor derived from reference white and D.

2.3 Nonlinear response and achromatic response

To approximate the nonlinear response of the visual system, CIECAM02 applies an elementwise nonlinearity to the adapted cone responses:

$$R_a = \operatorname{sign}(R'_c)\,\frac{400(\,F_L R'_c/100\,)^{0.42}}{27.13 + (\,F_L R'_c/100\,)^{0.42}}, \tag{6}$$

where F_L is a luminance-level adaptation factor computed from the adapting luminance L_A and the surround. The same formula applies to G_a and B_a.

The achromatic response A is a weighted sum of these nonlinear responses:

$$A = 2R_a + G_a + \frac{1}{20}B_a - 0.305. \tag{7}$$

2.4 Computing correlates J, C, h

The lightness correlate J is computed relative to the achromatic response of the white point A_w:

$$J = 100\left(\frac{A}{A_w}\right)^{cz}, \quad z = 1.48 + \sqrt{\frac{L_A}{10}}, \tag{8}$$

with c the surround-specific exponent. Chroma C and colorfulness M are computed from opponent coordinates and a post-adaptation multiplicative factor; the hue angle h is computed from opponent components a and b (derived from R_a, G_a, B_a).

For completeness, the hue angle is obtained via:

$$h = \operatorname{atan2}(b_H, a_H) \quad \text{(converted to degrees, } 0 \le h < 360\text{)}, \tag{9}$$

where a_H, b_H are linear combinations of R_a, G_a, B_a defined in the standard. The full standard contains additional steps to compute the hue composition and eccentricity constants used to compute C and M.

3 Implementation details

The demo implementation follows the above pipeline at a level of fidelity sufficient for visualization. Practical notes:

- sRGB inputs are linearized and converted to XYZ using the matrix presented above.

- For chromatic adaptation we used the CAT02 matrix and a standard D65 whitepoint scaled to $Y_w = 100$.
- Surround/adaptation parameters were set to three representative conditions: "Average" ($L_A = 64$ cd/m^2), "Dim" ($L_A = 20$), and "Dark" ($L_A = 5$), with corresponding surround parameters (F, c, N_c) chosen to illustrate typical model behavior.
- Where a full reference implementation (the `colour-science` package) is available the demo can call direct library functions; otherwise a careful approximate implementation of the main equations was used.

All code was written in Python and uses `numpy` and `matplotlib` for data processing and plotting. If available, the `colour` package (`colour-science`) is used for validated conversions.

4 Results

The demo produced a color palette and computed the CIECAM02 correlates (J, C, h) for each palette color under the three viewing conditions. Visual outputs were saved.

4.1 Qualitative observations

- Lightness J systematically decreases for darker viewing conditions: the same physical stimulus is predicted to appear less light under lower adapting luminance L_A.
- Chroma C values typically show a modest decrease for darker conditions, reflecting reduced perceived colorfulness at low luminance.
- Hue h is generally stable under chromatic adaptation when the CAT02 transform and appropriate degree-of-adaptation D are applied, but minor shifts can appear for extreme surrounds.

5 Inference and discussion

The implemented pipeline demonstrates core capabilities of CIECAM02: accounting for luminance-level adaptation and surround effects in predictions of lightness and chroma. The demo is suitable for pedagogical visualization and quick comparisons between conditions, but careful colorimetric experiments would require:

- Using measured spectral data (rather than device sRGB) when high accuracy is required.
- Ensuring correct definitions of viewing conditions (adapting field size, black/white surround) and calibration of display luminance.
- Validating the implementation against a reference implementation such as the official `colour-science` CIECAM02 routines and published test cases.

6 Conclusion

This basic implementation offers a compact, reproducible demonstration of CIECAM02 predictions and behavior for a synthetic palette under three viewing conditions. It is a useful starting point for education, visualization, and integration into larger color-management or image-processing pipelines.

References

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