NOTICE: This document details the equations of the CIECAM97s model agreed upon by CIE TC1-34 at its May, 1997 meeting in Kyoto Japan. This document is an excerpt of work that has been prepared for course notes and an upcoming book on color appearance models. The CIECAM97s model has not yet been formally approved or published by the CIE. In the process of preparing, balloting, and publication of an official CIE report on this model it is possible that minor changes might be made, particularly in notation. These equations are provided for interested parties who want to begin testing the CIECAM97s model and do not represent an official publication of the CIE or TC1-34. Updates from the originally posted version have been made based on committee input (7/15/97)

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A.4 The CIE TC1-34 Model, CIECAM97s

Some slight, but important, revisions were made to the Bradford-Hunt 96S model to derive the model agreed upon by TC1-34 to become the CIECAM97s model (*i.e.*, the simple version of the CIE 1997 Interim Color Appearance Model). These include a reformulation of the surround compensation to use power functions in order to avoid predictions of corresponding colors with negative CIE tristimulus values and a clear definition of the adaptation level factor, D. It is important to note that the formulation of CIECAM97s builds upon the work of many researchers in the field of color appearance. This was a key issue in TC1-34's establishment of this model as the best of what is currently available. Various aspects of the model can be traced to work of (in alphabetical order) Bartleson, Breneman, Fairchild, Estevez, Hunt, Lam, Luo, Nayatani, Rigg, Seim, and Valberg among others. The comprehensive model, CIECAM97c, will be derived from the simple model, CIECAM97s, by adding features in a process similar to that used to derive the Bradford-Hunt 96C model from the 96S version.

A.4.1 Input Data

The input data to the model are the luminance of the adapting field (normally taken to be 20% of the luminance of white in the adapting field), L_A, the tristimulus values of the sample in the source conditions, XYZ, the tristimulus values of the source white in the source conditions, $X_wY_wZ_w$, the relative luminance of the source background in the source conditions, Y_b. Additionaly, the constants c, for the impact of suround, N_c, a chromatic induction factor, F_{LL}, a lightness contrast factor, and F, a factor for degree of adaptation, must be selected according to the following guidelines.

Viewing Condition	c	N_c	F_{LL}	F
Average Surround, Samples Subtending> 4°	0.69	1.0	0.0	1.0
Average Surround	0.69	1.0	1.0	1.0
Dim Surround	0.59	1.1	1.0	0.9
Dark Surround	0.525	0.8	1.0	0.9
Cut-Sheet Transparencies	0.41	0.8	1.0	0.9

A.4.2 Chromatic Adaptation

An initial chromatic adaptation transform is used to go from the source viewing conditions to the equal-energy-illuminant reference viewing conditions (although tristimulus values need never be expressed in the reference conditions). First, tristimulus values for both the sample and white are normalized and transformed to spectrally-sharpened cone responses using the transformation given in Eqs. A-39 and A-40.

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \mathbf{M}_B \begin{bmatrix} X/Y \\ Y/Y \\ Z/Y \end{bmatrix} \quad \text{(A-39)}$$

$$\mathbf{M}_B = \begin{bmatrix} 0.8951 & 0.2664 & -0.1614 \\ -0.7502 & 1.7135 & 0.0367 \\ 0.0389 & -0.0685 & 1.0296 \end{bmatrix} \quad \text{(A-40)}$$

The chromatic-adaptation transform is a modified von Kries transformation (performed on a type of chromaticity coordinates) with an exponential nonlinearity added to the short-wavelength sensitive channel as given in Eqs. A-3 through A-6. In addition, the variable D is used to specify the degree of adaptation. D is set to 1.0 for complete adaptation or discounting the illuminant. D is set to 0.0 for no adaptation. D takes on intermediate values for various degrees of incomplete chromatic adaptation. Equation A-45 allows calculation of D for various luminance levels and surround conditions.

$$R_c = \left[D\left(1.0/R_w\right) + 1 - D\right]R \quad \text{(A-41)}$$

$$G_c = \left[D\left(1.0/G_w\right) + 1 - D\right]G \quad \text{(A-42)}$$

$$B_c = \left[D\left(1.0/B_w^p\right) + 1 - D\right]\left|B\right|^p \quad \text{(A-43)}$$

$$p = \left(B_w / 1.0\right)^{0.0834} \quad \text{(A-44)}$$

$$D = F - F\Big/\left[1 + 2\left(L_A^{1/4}\right) + \left(L_A^2\right)\Big/300\right] \quad \text{(A-45)}$$

If B happens to be negative, then B_c is also set to be negative. Similar transformations are also made for the source white since they are required in later calculations. Various factors must be calculated prior to further calculations as shown in Eqs. A-46 and A-49. These include a background induction factor, n, the background and chromatic brightness induction factors, N_{bb} and N_{cb}, and the base exponential nonlinearity, z.

$$k = 1/(5L_A + 1) \tag{A-46}$$

$$F_L = 0.2k^4(5L_A) + 0.1(1 - k^4)^2(5L_A)^{1/3} \tag{A-47}$$

$$n = Y_b / Y_w \tag{A-48}$$

$$N_{bb} = N_{cb} = 0.725(1/n)^{0.2} \tag{A-49}$$

$$z = 1 + F_{LL} n^{1/2} \tag{A-50}$$

The post-adaptation signals for both the sample and the source white are then transformed from the sharpened cone responses to the Hunt-Pointer-Estevez cone responses as shown in Eqs. A-51 and A-52 prior to application of a nonlinear response compression.

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \mathbf{M}_H \mathbf{M}_B^{-1} \begin{bmatrix} R_c Y \\ G_c Y \\ B_c Y \end{bmatrix} \tag{A-51}$$

$$\mathbf{M}_H = \begin{bmatrix} 0.38971 & 0.68898 & -0.07868 \\ -0.22981 & 1.18340 & 0.04641 \\ 0.00 & 0.00 & 1.00 \end{bmatrix} \tag{A-52}$$

The post-adaptation cone responses (for both the sample and the white) are then calculated using Eqs. A-53 through A-55.

$$R'_a = \frac{40(F_L R'/100)^{0.73}}{\left[(F_L R'/100)^{0.73} + 2\right]} + 1 \tag{A-53}$$

$$G'_a = \frac{40(F_L G'/100)^{0.73}}{\left[(F_L G'/100)^{0.73} + 2\right]} + 1 \tag{A-54}$$

$$B'_a = \frac{40(F_L B'/100)^{0.73}}{\left[(F_L B'/100)^{0.73} + 2\right]} + 1 \tag{A-55}$$

A.4.3. Appearance Correlates

Preliminary red-green and yellow-blue opponent dimensions are calculated using Eqs. A-56 and A-57.

$$a = R'_a - 12G'_a / 11 + B'_a / 11 \quad \text{(A-56)}$$

$$b = (1/9)(R'_a + G'_a - 2B'_a) \quad \text{(A-57)}$$

The hue angle, h, is then calculated from a’ and b’ using Eq. A-58.

$$h = \tan^{-1}(b/a) \quad \text{(A-58)}$$

Hue quadrature, H, and eccentricity factors, e, are calculated from the following unique hue data in the usual way (linear interpolation):

Red: h = 20.14, e = 0.8, H = 0 or 400,

Yellow: h = 90.00, e = 0.7, H = 100,

Green: h = 164.25, e = 1.0, H = 200,

Blue: h = 237.53, e = 1.2. H = 300

Equations A-59 and A-60 illustrate calculation of e and H for arbitrary hue angles where the quantities subscripted 1 and 2 refer to the unique hues with hue angles just below and just above the hue angle of interest.

$$e = e_1 + (e_2 - e_1)(h - h_1)/(h_2 - h_1) \quad \text{(A-59)}$$

$$H = H_1 + \frac{100(h - h_1)/e_1}{(h - h_1)/e_1 + (h_2 - h)/e_2} \quad \text{(A-60)}$$

The achromatic response is calculated as shown in Eq. A-61 for both the sample and the white.

$$A = \left[2R'_a + G'_a + (1/20)B'_a - 2.05\right]N_{bb} \qquad \text{(A-61)}$$

Lightness, J, is calculated from the achromatic signals of the sample and white using Eq. A-62.

$$J = 100\left(A / A_w\right)^{cz} \qquad \text{(A-62)}$$

Brightness, Q, is calculated from lightness and the achromatic for the white using Eq. A-63.

$$Q = \left(1.24 / c\right)\left(J / 100\right)^{0.67}\left(A_w + 3\right)^{0.9} \qquad \text{(A-63)}$$

Finally, saturation, s; chroma, C; and colorfulness, M; are calculated using Eqs. A-64 through A-66, respectively.

$$s = \frac{50\left(a^2 + b^2\right)^{1/2} 100e(10/13)N_c N_{cb}}{R'_a + G'_a + (21/20)B'_a} \qquad \text{(A-64)}$$

$$C = 2.44s^{0.69}\left(J/100\right)^{0.67n}\left(1.64 - 0.29^n\right) \qquad \text{(A-65)}$$

$$M = CF_L^{0.15} \qquad \text{(A-66)}$$

A.4.4. Inverse Model

The CIECAM97s Model can be analytically inverted. Beginning with lightness, J; chroma, C; and hue angle, h; the process is as follows:

1. From J obtain A.
2. From h obtain e.
3. Calculate s using C and J.
4. Calculate a and b using s, h, and e.
5. Calculate R'_a, G'_a, and B'_a from A, a, and b.
6. Calculate R', G', and B' from R'_a, G'_a, and B'_a.

7. Calculate R_cY, G_cY, and B_cY from R’, G’, and B’.

8. Calculate Y from R_cY, G_cY, and B_cY using M_B^{-1}.

9. Calculate R_c, G_c, and B_c from R_cY, G_cY, and B_cY and Y.

10. Calculate R, G, and B from R_c, G_c, and B_c.

11. Calculate X, Y, and Z, from R, G, B, and Y.