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ICC Technical Note

Applying partial adaptation by the CMM between iccMAX profiles with different PCS observing conditions

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Introduction

As we view the world around us the light reflecting from objects changes as the lighting conditions change. For instance, the light entering the eye of an object under sunlight is significantly different than the light entering the eye indoors under a light bulb. However, the appearance of the objects doesn't generally change to an observer as the lighting conditions change. This is due to a process known as adaptation by the human visual system (HVS) which accounts for changes in the lighting (or viewing conditions) to approach a perception of constant appearance of the objects. When the appearance doesn't change due to a change in the viewing conditions one can say that the adaptation is complete.

Chromatic adaptation is a mathematical approximation that is used to predict the colorimetry of objects under one lighting condition based on the colorimetry of the object under another lighting condition given the colorimetry of the two lighting conditions. The Bradford and CAT02 transforms are examples of chromatic adaptation approaches.

For some variations of lighting conditions (for instance in cases where the light source has a strong hue) this constancy is only approximate, and the appearance of the objects shifts relative to the color of the light source. An example of this is a piece of paper that appears white in daylight but doesn't appear entirely white in a room illuminated using a red light bulb. In this case the adaptation is only partial with some of the redness of the light source becoming part of the appearance of the paper. This is known as partial adaptation.

Partial adaption is modeled as a linear combination of complete adaptation and no adaptation using a degree of adaptation scale factor ranging from 0.0 (representing no adaptation) to 1.0 (representing complete adaptation).

The matrix/vector equation (eq. 1) expresses this as follows:

$$\mathbf{c}_2 = \left(\mathbf{M}^{-1} \begin{bmatrix} d\left(L_2 / L_1 \right) + 1 - d & 0 & 0 \\ 0 & d\left(M_2 / M_1 \right) + 1 - d & 0 \\ 0 & 0 & d\left(S_2 / S_1 \right) + 1 - d \end{bmatrix} \mathbf{M} \right) \mathbf{c}_1 \qquad \text{(eq. 1)}$$

where:

$\mathbf{c}_1$ represents the XYZ colorimetry under the first lighting condition,

$\mathbf{M}$ represents a matrix that converts XYZ colorimetry to LMS cone values,

L_X , M_X , S_X represent the LMS cone values for the X^{th} illuminant,

d represents the degree of adaptation from the first lighting condition to the second lighting condition, and

$\mathbf{c}_2$ represents the resulting adapted colorimetry under the second lighting condition.

Partial adaptation and ICC workflows

ICC v4 workflows are based on an assumption of complete adaptation to an illuminant, either the D50 PCS illuminant or the illuminant of the source or destination colorimetry which has been chromatically adapted to D50. In practice many observing situations give rise to a state of partial or incomplete adaptation, and chromatic adaptation transforms, such as the Bradford and the CAT02 transforms, may include a partial adaptation factor. In iccMAX there can be different observing conditions in source and destination profiles, and it may be desirable to implement some degree of partial adaptation between them to better reflect the actual adaptation condition. In principle this can be done by suitable modification of the custom-to-standard (c2sp) and standard-to-custom (s2cp) transforms in the profile, but in this technical note it is recommended that partial adaptation be implemented as a CMM operation rather than a fixed transform in the profile.

Consider the application of profiles P1 and P2 by a CMM, which currently can be logically expressed as the function:

$$\mathbf{v}_2 = B2Ax_{P2}\left(FromXYZ_{P2}\left(S2CP_{P2}\left(C2SP_{P1}\left(ToXYZ_{P1}\left(A2Bx_{P1}\left(\mathbf{v}_1 \right) \right) \right) \right) \right) \right) \qquad \text{(eq. 2)}$$

where:

$\mathbf{v}_1$ represents device values sent to profile P1,

$A2Bx_{P1}$ represents the application of the AToBx tag of profile P1,

$ToXYZ_{P1}$ represents any conversions needed to get results of applying P1 transform to get XYZ colorimetry,

$C2SP_{P1}$ represents the application of the customToStandardPCC tag of profile P1,

$S2CP_{P2}$ represents the application of the standardToCustomPCC tag of profile P2,

$FromXYZ_{P2}$ represents any conversions needed to convert XYZ to what is needed by P2 transform,

$B2Ax_{P2}$ represents the application of the BToAx tag of profile P2, and

$\mathbf{v}_2$ represents the resulting device values coming out of profile P2.

The problem with applying a degree of adaptation within the customToStandardPCC and standardToCustomPCC tags is that this results in applying a degree of adaption to a degree of adaptation (consider the math).

Applying partial adaptation in the CMM

The double application of partial adaptation can be avoided by having the profiles only perform complete adaptation in their PCC conversion transforms and then having the CMM apply the degree of adaptation. This can be accomplished by replacing (eq. 1) with the following function that would logically be applied by the CMM:

$$\mathbf{v}_2 = B2Ax_{P2}\left(FromXYZ_{P2}\left(Adj1To2\left(ToXYZ_{P1}\left(A2Bx_{P1}\left(\mathbf{v}_1\right)\right)\right), d\right)\right) \qquad \text{(eq. 3)}$$

where:

$\mathbf{v}_1$, $A2Bx_{P1}$, $ToXYZ_{P1}$, $FromXYZ_{P2}$, $B2Ax_{P2}$, and $\mathbf{v}_2$ are the same as in (eq. 1)

$Adj1To2$ represents a function that applies a degree of adaptation as follows:

$$\mathbf{c}_2 = Adj1To2\left(\mathbf{c}_1, d\right) = \left[d\left(S2CP_{P2}\left(C2SP_{P1}\left(\mathbf{c}_1\right)\right)\right) + \left(1-d\right)\mathbf{c}_1\right] \qquad \text{(eq. 4)}$$

and:

$\mathbf{c}_1$ represents the XYZ colorimetry coming out of profile P1,

d represents the degree of adaptation from profile P1 to profile P2 (ranging from 0.0 to 1.0 with 1.0 representing complete adaptation),

$C2SP_{P1}$ and $S2CP_{P2}$ represent the same transforms as in equation (eq. 1), and

$\mathbf{c}_2$ represents the resulting adapted colorimetry to be applied by profile P2.

This works as long as the $C2SP_{P1}$ and $S2CP_{P2}$ transforms use the same adaptation/adjustment approach. A proof of this can be found in the worked example in the Annex.

For a CMM to implement partial adaptation with a combination of profiles it needs to additionally be provided with both a control option to specify that partial adaptation is to be performed as well as control option to specify the degree of adaptation as well. Then equations (eq. 2) and (eq 3) can be applied by the CMM as part of the application of the profiles.

Annex – Worked Example

Consider the case of partial adaptation in LMS coordinates (using a Bradford or CAT02 transform $\mathbf{M}$) then the $C2SP_{P1}$ and $S2CP_{P2}$ transforms are defined as follows:

$$C2SP_{P1}(\mathbf{c}) = \mathbf{M}^{-1}\begin{bmatrix} L_{D50}/L_{P1} & 0 & 0 \\ 0 & M_{D50}/M_{P1} & 0 \\ 0 & 0 & S_{D50}/S_{P1} \end{bmatrix}\mathbf{Mc}$$

$$S2CP_{P2}(\mathbf{c}) = \mathbf{M}^{-1}\begin{bmatrix} L_{P2}/L_{D50} & 0 & 0 \\ 0 & M_{P2}/M_{D50} & 0 \\ 0 & 0 & S_{P2}/S_{D50} \end{bmatrix}\mathbf{Mc} \qquad \text{(eq. 5)}$$

And the adaptation is represented through substitution by:

$$S2CP_{P2}(C2SP_{P1}(\mathbf{c})) = \mathbf{M}^{-1}\begin{bmatrix} L_{P2}/L_{D50} & 0 & 0 \\ 0 & M_{P2}/M_{D50} & 0 \\ 0 & 0 & S_{P2}/S_{D50} \end{bmatrix}\mathbf{MM}^{-1}\begin{bmatrix} L_{D50}/L_{P1} & 0 & 0 \\ 0 & M_{D50}/M_{P1} & 0 \\ 0 & 0 & S_{D50}/S_{P1} \end{bmatrix}\mathbf{Mc}$$

$$S2CP_{P2}(C2SP_{P1}(\mathbf{c})) = \mathbf{M}^{-1}\begin{bmatrix} L_{P2}/L_{D50} & 0 & 0 \\ 0 & M_{P2}/M_{D50} & 0 \\ 0 & 0 & S_{P2}/S_{D50} \end{bmatrix}\begin{bmatrix} L_{D50}/L_{P1} & 0 & 0 \\ 0 & M_{D50}/M_{P1} & 0 \\ 0 & 0 & S_{D50}/S_{P1} \end{bmatrix}\mathbf{Mc}$$

$$S2CP_{P2}(C2SP_{P1}(\mathbf{c})) = \mathbf{M}^{-1}\begin{bmatrix} \left(L_{P2}/L_{D50}\right)\left(L_{D50}/L_{P1}\right) & 0 & 0 \\ 0 & \left(M_{P2}/M_{D50}\right)\left(M_{D50}/M_{P1}\right) & 0 \\ 0 & 0 & \left(S_{P2}/S_{D50}\right)\left(S_{D50}/S_{P1}\right) \end{bmatrix}\mathbf{Mc}$$

$$S2CP_{P2}(C2SP_{P1}(\mathbf{c})) = \mathbf{M}^{-1}\begin{bmatrix} L_{P2}/L_{P1} & 0 & 0 \\ 0 & M_{P2}/M_{P1} & 0 \\ 0 & 0 & S_{P2}/S_{P1} \end{bmatrix}\mathbf{Mc} \qquad \text{(eq. 6)}$$

which represents a complete adaptation from P1 to P2. Applications of (eq.3) and (eq. 4) can be shown to be equivalent to partial adaption of LMS by substituting the results of (eq. 6) into (eq. 4) giving:

$$Adj1To2(\mathbf{c}_1, d) = d\left(S2CP_{P2}\left(C2SP_{P1}(\mathbf{c}_1)\right)\right) + (1-d)\mathbf{c}_1$$

$$Adj1To2(\mathbf{c}_1, d) = d\left(\mathbf{M}^{-1}\begin{bmatrix} L_{P2}/L_{P1} & 0 & 0 \\ 0 & M_{P2}/M_{P1} & 0 \\ 0 & 0 & S_{P2}/S_{P1} \end{bmatrix}\mathbf{M}\mathbf{c}_1\right) + (1-d)\mathbf{c}_1$$

$$Adj1To2(\mathbf{c}_1, d) = \mathbf{M}^{-1}\begin{bmatrix} d\left(L_{P2}/L_{P1}\right) & 0 & 0 \\ 0 & d\left(M_{P2}/M_{P1}\right) & 0 \\ 0 & 0 & d\left(S_{P2}/S_{P1}\right) \end{bmatrix}\mathbf{M}\mathbf{c}_1 + (1-d)\mathbf{I}\mathbf{c}_1$$

$$Adj1To2(\mathbf{c}_1, d) = \mathbf{M}^{-1}\begin{bmatrix} d\left(L_{P2}/L_{P1}\right) & 0 & 0 \\ 0 & d\left(M_{P2}/M_{P1}\right) & 0 \\ 0 & 0 & d\left(S_{P2}/S_{P1}\right) \end{bmatrix}\mathbf{M}\mathbf{c}_1 + (1-d)\mathbf{M}^{-1}\mathbf{I}\mathbf{M}\mathbf{c}_1$$

$$Adj1To2(\mathbf{c}_1, d) = \left(\mathbf{M}^{-1}\begin{bmatrix} d\left(L_{P2}/L_{P1}\right) & 0 & 0 \\ 0 & d\left(M_{P2}/M_{P1}\right) & 0 \\ 0 & 0 & d\left(S_{P2}/S_{P1}\right) \end{bmatrix}\mathbf{M} + \mathbf{M}^{-1}\begin{bmatrix} (1-d) & 0 & 0 \\ 0 & (1-d) & 0 \\ 0 & 0 & (1-d) \end{bmatrix}\mathbf{M}\right)\mathbf{c}_1$$

$$Adj1To2(\mathbf{c}_1, d) = \left(\mathbf{M}^{-1}\left(\begin{bmatrix} d\left(L_{P2}/L_{P1}\right) & 0 & 0 \\ 0 & d\left(M_{P2}/M_{P1}\right) & 0 \\ 0 & 0 & d\left(S_{P2}/S_{P1}\right) \end{bmatrix} + \begin{bmatrix} (1-d) & 0 & 0 \\ 0 & (1-d) & 0 \\ 0 & 0 & (1-d) \end{bmatrix}\right)\mathbf{M}\right)\mathbf{c}_1 \qquad \text{(eq. 7)}$$

$$Adj1To2(\mathbf{c}_1, d) = \left(\mathbf{M}^{-1}\begin{bmatrix} d\left(L_{P2}/L_{P1}\right)+1-d & 0 & 0 \\ 0 & d\left(M_{P2}/M_{P1}\right)+1-d & 0 \\ 0 & 0 & d\left(S_{P2}/S_{P1}\right)+1-d \end{bmatrix}\mathbf{M}\right)\mathbf{c}_1$$

Note: The same holds true if both $C2SP_{P1}$ and $S2CP_{P2}$ represent a Material Adjustment Transform based on Wpt Normalization as follows:

$$C2SP_{P1}(\mathbf{c}) = \mathbf{A}_{D50}^{-1}\mathbf{A}_{P1}\mathbf{c}$$

$$S2CP_{P2}(\mathbf{c}) = \mathbf{A}_{P2}^{-1}\mathbf{A}_{D50}\mathbf{c}$$

Then the combined adjustment is equivalent to

$$S2CP_{P2}\left(C2SP_{P1}(\mathbf{c})\right) = \mathbf{A}_{P2}^{-1}\mathbf{A}_{D50}\mathbf{A}_{D50}^{-1}\mathbf{A}_{P1}\mathbf{c} = \mathbf{A}_{P2}^{-1}\mathbf{A}_{P1}\mathbf{c}$$

which represents a direct adjustment from P1 to P2.