Brighter, more colorful colors and darker, deeper colors based on a theme of brilliance

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Abstract: A methodology for achieving brighter, more colorful colors and deeper, darker colors based on Evans' zero gray (G_0)[1] and his concept of brilliance as a percept in color vision was demonstrated in media produced under current digital video and digital cinema standards – basically the sRGB set of primaries. Objects or surfaces in a scene represented in sRGB as having gray content in the Evans sense are rendered as original. Flesh tones are preserved. Those features not having gray content – a highly colorful arrangement of flowers, a clear blue sky, and the glossy red lipstick of a beautiful lady – are made brighter, more colorful and deeper, darker when rendered in a set of primaries that emulate, for example, the xvYCC encoded standard and whose colors extend beyond those of sRGB.

Introduction

In his 1935 paper, Maximum Visual Efficiency of Colored Materials[2], David MacAdam stated, "One of the most compelling objectives of pigment and dye chemists has been to … produce colors of ever greater purity without the sacrifice of brightness." Yet, to this day, as digital video and digital cinema media technology shows the real promise of going well beyond MacAdam's maximum visual efficiency in the perceptual sense, attempts to implement such technology through brighter, more colorful primaries than those standard in the industry have been met with the hue and cry of unnaturalness.[3]

Have we been so conditioned to these standards - most of us since childhood - that we consider video and cinema as a separate reality from what we see every day? This paper asserts that perhaps not – that perhaps it is instead a matter of rendering. That certain features of a scene – specifically object or surface colors, flesh tones - should be rendered as original while other features such as a blue sky on a crisp winter's day, a sunset, or a colorful arrangement of flowers are clear candidates for brighter, more colorful or deeper, darker renderings.

Background

In Part II of their 1996 paper[4], NCS, *Natural Color System,* Hard, Sivik, and Tonnquist partitioned the NCS space into nuance (Figure 1) by the primary percepts of blackness, whiteness, and chromaticness and the secondary attributes of grayness, clearness, and deepness. The secondary attribute, grayness, is noted as influenced by Evans' earlier studies[1] of what he termed brilliance. To Evans, brilliance is a percept that takes on the appearance of gray that diminishes to zero (G0) as the luminance of a chromatic stimulus approaches that of its surround. Beyond G0, the stimulus appears fluorent as it progresses from the surface mode of appearance below G0 to the luminance mode where its brightness exceeds that of its surround. The appearance of brilliance to Evans is mutually exclusive – either gray or fluorent – and further, that G0 is directly related to the relative chromatic strength of colors.

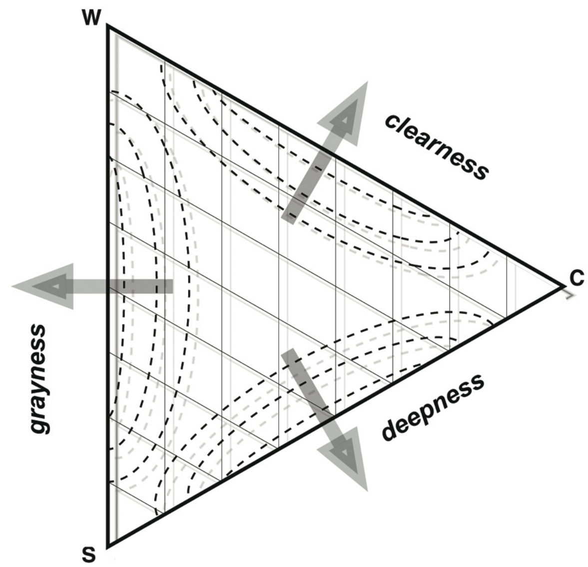


Figure 1: NCS nuance partitioning by whiteness (w), blackness (s), and chromaticness (c) with lines of iso-grayness, deepness, and clearness.

Just prior to the Hard, Sivik, and Tonnquist 1996 paper, the most resounding acknowledgement of Evans' work on brilliance came in a 1993 paper[5] where Nayatani related "The authors now believe that the function [G0] is a fundamental quantity in the color appearance of object and luminous colors." Influenced by this belief, Nayatani defined his Nayatani Theoretical Color Space (NTCS)[6] unifying many of the concepts and effects of color theory by simply inserting a reference gray (Gr) into the hexagonal NCS, considering black B and white W to be colors in their own right, and introducing an octahedral structure where each of the opponent color axes are orthogonal to each other, city block distance prevails in the NTCS percepts of whiteness (w) or blackness (bk) and chromaticness (c), and that in any color, the sum of c, w or bk, and grayness (gr) is always normalized to 100.

Zero gray ($gr = 0$) as illustrated in Figure 2 corresponds to Evans' G0. For $0 < gr \leq 100$, the color is said to be perceived in surface or object mode, and below $gr = 0$ (negative values), the color is said to be perceived as fluorent. Furthermore, as grayness decreases in the region above the Gr-B line from the point Gr where $gr = 100$, the color becomes brighter and more colorful as illustrated by the upper overlain arrow in Figure 2 and deeper, darker below the Gr-B line.

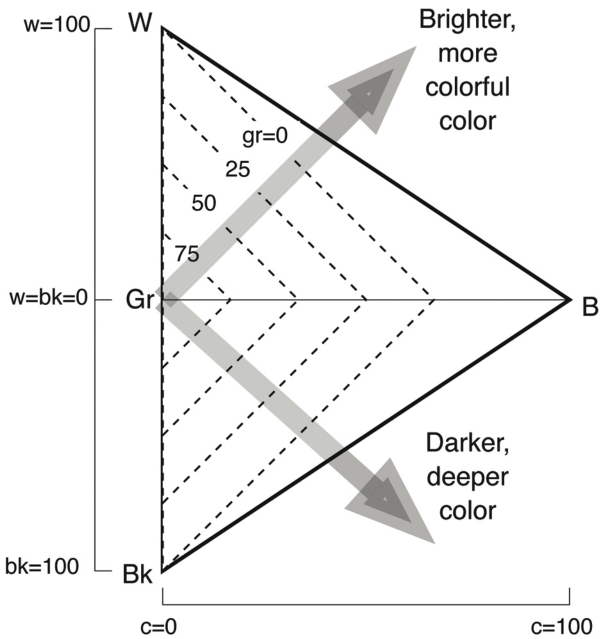


Figure 2: The loci of constant gray[j] in an equi-hue plane for blue in the NTCS overlain with arrows showing the direction of brighter, more colorful colors and of deeper, darker colors originating at Nayatani's Gr

Purpose

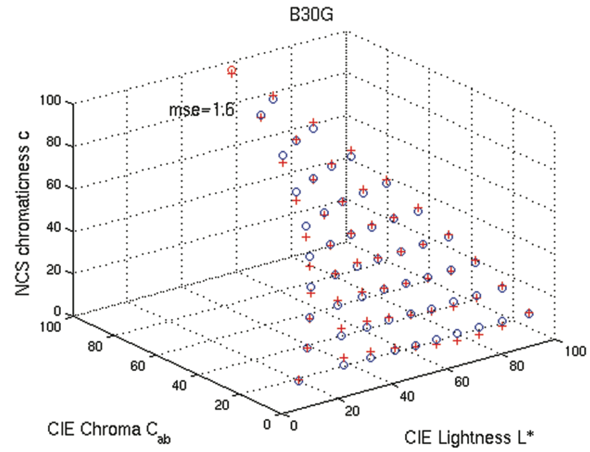
The purpose here then is to demonstrate brighter, more colorful colors and darker, deeper colors in such a way as to preserve those colors said to be in object or surface mode –i.e. having gray content ($0 < gr \leq 100$). Those colors without gray content ($gr < 0$) are then candidates for expansion in chroma and lightness according to a sigmoid function of their gray value that preserves smoothness across the transition from zero gray.

Methodology

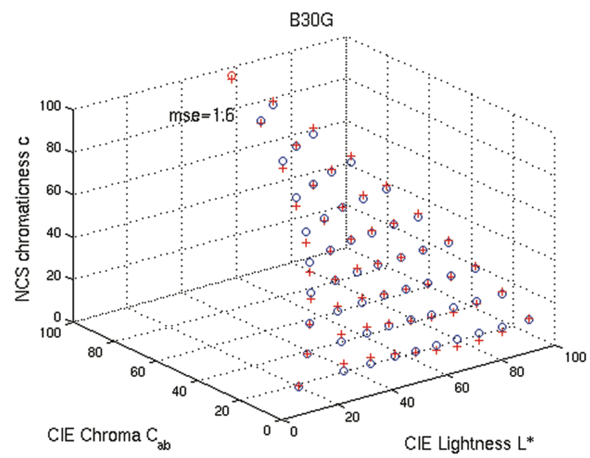
As a demonstration of some practical interest, sRGB was chosen as the source set of primaries and a set of extended primaries that emulate the xvYCC encoded standard[8] as the target. The opportunity for brighter, more colorful colors of deeper, darker colors in a full grid of sRGB scalar values was computed according to Nayatani's relationships[7] between grayness gr and NCS chromaticness C, whiteness W, and blackness S:

$$gr = 2\min(W, S) \qquad (1)$$

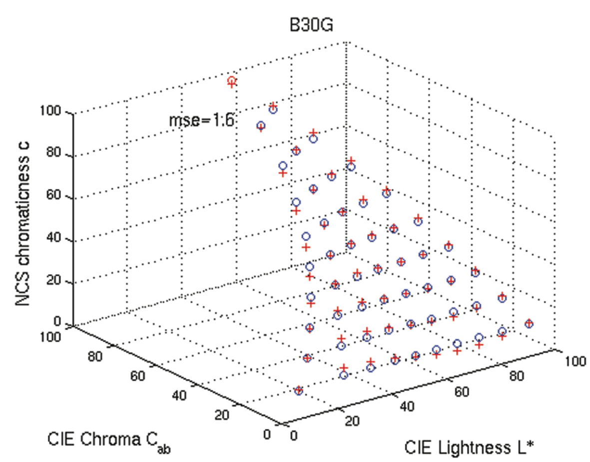
where NCS chromaticness C and blackness S were derived from the set of twenty-four (24) NCS aim color patches and their corresponding CIE XYZ values in illuminant A, the CIE 1931 observer, for the NCS notation[9,10] Whiteness was computed from $W = 100 - C - S$, the normalization relationship for the NCS notation.



(a) NCS Blackness



(b) NCS Chromaticness



(c) CIELAB Hue

Figure 3: Predicted (crosses) and actual (o's) NCS blackness and chromaticness and CIELAB hue as a function of LCh for illuminant D50 for NCS Hue B30G with a mean-square error noted as "mse".

NCS chromaticness and blackness derived from CIE LCh

The given NCS primary attributes and their corresponding CIE XYZ values were first chromatically adapted to the D50 illuminant consistent with the sRGB and target primaries, and their corresponding CIE LCh values computed for each of the twenty-four (24) NCS hues using a similar methodology as Derefeldt and Sahlin[11]. These data for each NCS hue were regressed against their given NCS chromaticness C and blackness S giving the functions in polynomial form $S_n = f_n(C, L,)$ and $C_n = g_n(C, L,)$ for $n = 1, 2, \ldots, 24$ NCS hues (see Figures 3(a) and (b)).

Because the space of constant NCS hue is a warped space in terms of CIELAB hue (h_{ab}), CIELAB hue was regressed within each of the NCS hue sets giving the additional polynomial form $h_{ab,n} = h_n(C, L,)$ for $n = 1, 2, \ldots, 24$ shown in Figure 3(c) for the purpose of interpolating NCS chromaticness and blackness from the computed CIE LCh values in the sRGB grid.

Expansion in the target set of primaries

Once grayness gr is available for each grid point in the sRGB cube, an expansion factor α is computed for each point where:

$$\alpha = \left(\frac{100 - gr0 - gr}{gr1 - gr0} \right)^{\eta} \qquad (2)$$

for $gr < gr0$, η a parameter greater than 1, and $gr1 = -60$ chosen as a practical or realistic minimum gray value within the extent of the sRGB primaries. Figure 4 plots this expansion factor α as a function of gray value for test values of η and $gr0$.

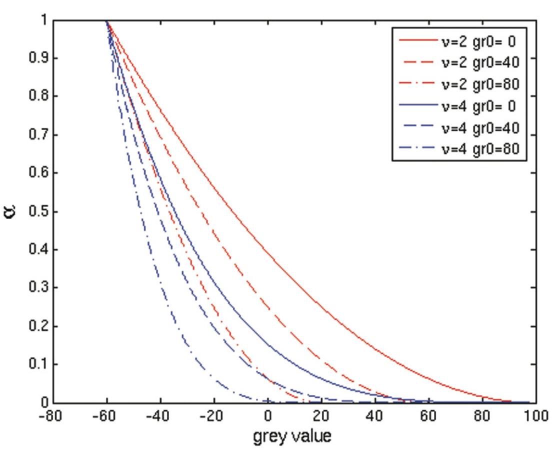


Figure 4: Lightness and chroma expansion factor α as a function of the grayness (gr) of the source sRGB primaries for various parameter values of η and $gr0$

Figure 5 illustrates the expansion method in an equi-hue plane of the target set of primaries showing the result $(L_{out}C_{out})$ of an expansion of an input value $(L_{in}C_{in})$ with appropriate hue along the line passing through the lightness value L_{Gr} of Nayatani's reference gray (Gr) and the coordinates of the input. $C_{\max}$ is the maximum chroma at that hue and L_{CMax} its corresponding lightness computed from the target set of primaries, and α the expansion factor computed from the above. The result, as illustrated, is a brighter, more colorful color. When the input lightness value L_{in} is below L_{Gr}, the result is a deeper, darker color.

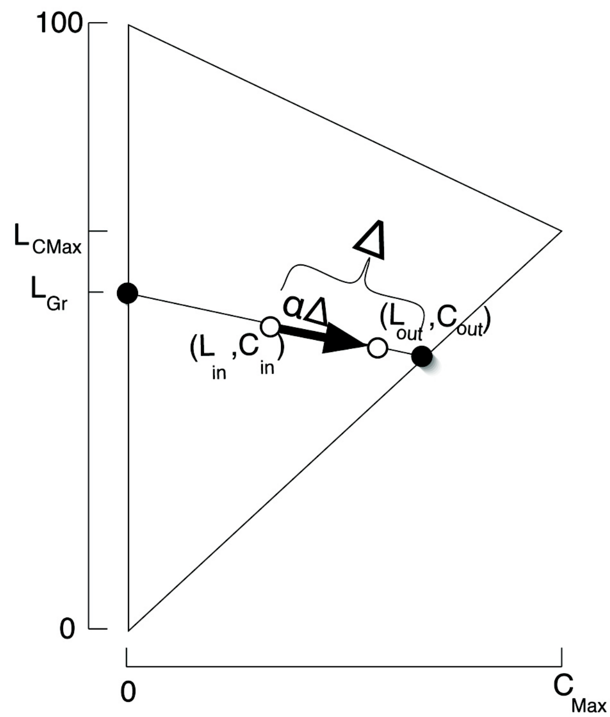


Figure 5: An equi-hue plane in the target set of primaries showing the result $L_{out}C_{out}$ of an expansion of an input value in $L_{in}C_{in}$.

Like Evans' G0, the lightness value $L_{C_{MAX}}$ at maximum chroma is a strong function of the chromatic strength of colors, and both mediate whether a color is made brighter, more colorful or deeper, darker and to what degree depending on their relative position to reference gray (L_{GR}).

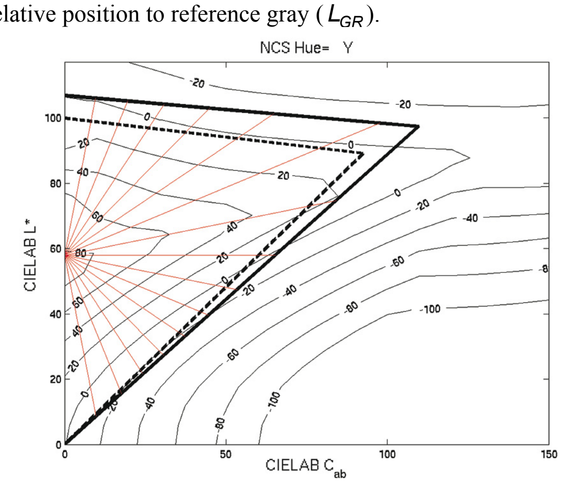


Figure 6: Locus of equi-gray levels in CIELAB for the NCS hue Y overlain by the extent of the sRGB primaries (dashed) and the xvYCC target set (solid).

Figure 6 plots the loci of equi-gray values for the NCS hue Y to illustrate these dependencies. The radial lines originating at reference gray (L_{GR}) indicate the direction of expansion, whether deeper, darker or brighter, more colorful. The magnitude of the expansion varies according to the gray value of the input color and the extent of the target set of primaries relative to sRGB. Y as shown and to a certain extent G are low in chromatic strength and have a relatively high lightness values L_{CMAX} at maximum chroma. Hence, they most likely would be made deeper, darker, but to a smaller extent.

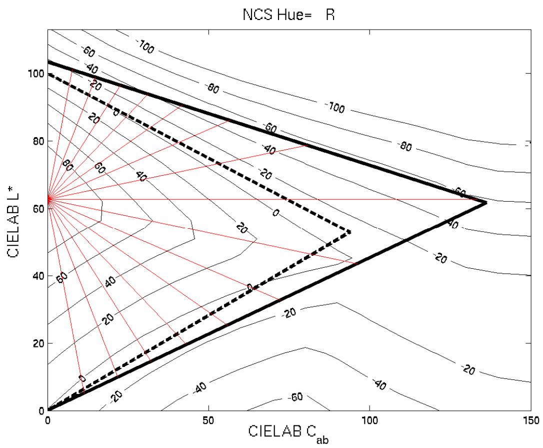


Figure 7: Locus of equi-gray levels in CIELAB for the NCS hue R overlain by the extent of the sRGB primaries (dashed) and the xvYCC target set.

Blue and red (shown in Figure 7), on the other hand, are high in chromatic strength with more moderate lightness values L_{CMAX}, and they would be equally likely made brighter, more colorful to a larger extent or deeper, darker to a lesser extent.

Results and Discussions

The color expansion potential of sRGB by this methodology

Figure 8 plots loci of equi-grayness for $gr <= 0$ (less than zero gray content) in CIELAB as computed from the sRGB grid and, as such, illustrates the potential in sRGB for expanding colors and making them brighter, more colorful or deeper, darker. For example, those regions in white would approach maximum chroma when expanded in the target set of primaries per the above, and those regions enclosed by the inner-most shell ($gr = 0$) would retain their original quality as having gray content. As can be seen, sRGB provides ample opportunity for making brighter, more colorful colors or deeper, darker colors in the targeted primaries in this context.

Imaging examples

This methodology was applied to a number of images to test the hypothesis that outside the region of gray content (e.g., object color and flesh tones), brighter, more colorful colors and deeper, darker colors are possible. The parameters $\eta = 4$ and $gr0 = 0$ were chosen as a more than adequate demonstration of the methodology.

Figure 9(a) illustrates the range of grayness value for the Flowers image. Gray to white is intended to represent decreasing degrees of gray content ranging from a value of 100 at reference gray to a value of zero (white). The shades of red represent decreasing degrees of less than zero gray content and, hence, prime candidates for expansion. Figure 9(b) illustrates the direction of expansion - brighter, more colorful in red or deeper, darker in blue according to the methodology presented in this paper.

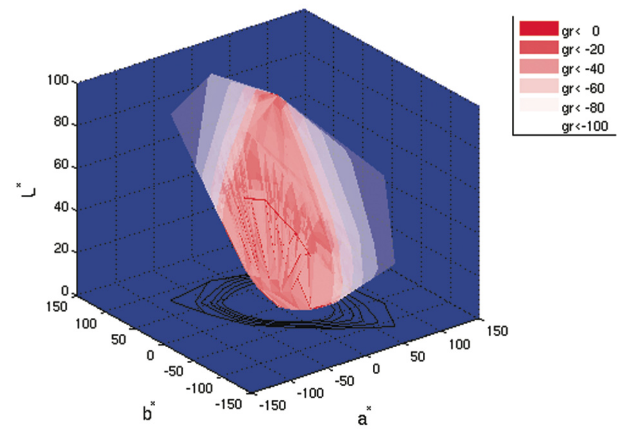


Figure 8: Locus of equi-gray levels, gr<0, for the sRGB primaries in CIE-LAB

Note the flower in the upper center of the arrangement. The outer portions of its petals are brighter, more colorful (red) as noted in Figure 9(b) whereas the inner portions of the petals are deeper, darker (blue). Figure 9(d) illustrates the result in the targeted primaries as compared to the original in Figure 9(c). Under certain viewing conditions, the noted flower actually appears fluorent.

(a) gray value

(b) direction of expansion

(c) original sRGB version

(d) targeted version

Figure 9: The Flowers Image

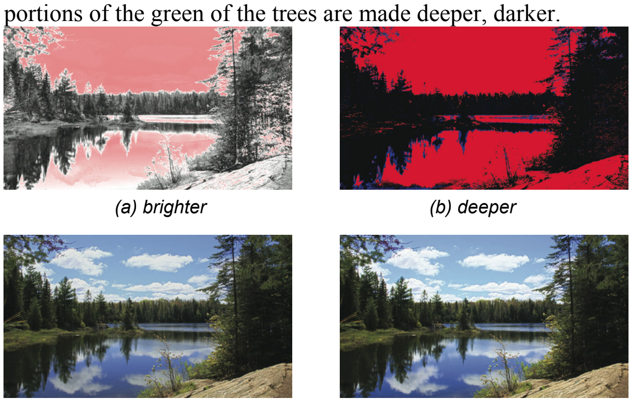
Figure 10, the image of the Lady, is presented as an example of where this methodology distinguishes flesh tone as having gray content (Figure 10(a)) and, hence, kept as original. Figure 10(c), rendered to the targeted primaries and when compared to the original (Figure 10(c)), indicates a modest brightening, more colorful region in the lips but little or no effect on the flesh tones.

(a) gray value (b) direction of expansion

(c) original sRGB version (d) targeted version

Figure 10: The Lady

In Figure 11, the Peck Lake image, the blue of the sky and its reflection in the water is made brighter, more colorful, and portions of the green of the trees are made deeper, darker.



(a) brighter (b) deeper

(c) original sRGB version (d) targeted version

Figure 11: Peck Lake

Conclusions

Overall, a methodology for achieving brighter, more colorful colors and deeper, darker colors based on Evans' G_0 and his concept of brilliance as a percept for color vision was demonstrated in media produced under current digital video and digital cinema standards – i.e. the sRGB set of primaries. Objects in the scene having gray content in the Evans/Nayatani sense are rendered as original. Flesh tones are preserved, and those features of a scene not having gray content are rendered into brighter, more colorful colors or deeper, darker colors in a set of primaries whose colors extend those of sRGB.

Acknowledgements

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Biographies

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