ATD, Appearance Equalivalence, and Desktop Publishing

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Abstract

Companion papers show why the CIE L*a*b* system of color coordinates is not optimal for use in desktop publishing (DTP) systems and how ATD remedies most of the problems of CIE L*a*b*.

Since DTP deals primarily with the reproduction of images, DTP applications do not need to model human vision. They need only reproduce accurately in the image the reflective properties of the original. The eye does the rest. Linear arithmetic is adequate for this task.

An intermediate color space decouples scanner calibration from printer control, leading to a system that is nearly device independent. Plots of Munsell and other color grids show the intermediate space to be uniform.

The uniformity of the intermediate space and the linearity of the model lead to accurate gamut compression and negligible transformation errors using integer arithmetic operations on the 8-bit quantities associated with inexpensive DTP equipment. The resulting images are substantially better than those produced by current DTP programs.

Introduction

In a companion paper we highlighted the shortcomings of CIE L*a*b* for DTP. More generally, we can say that color models based on colorimetry fall short as bases for DTP programs for two main reasons:

- Their need to address the general problems of perception of all emitted and reflected light under all viewing conditions make them too complicated. The restricted area of DTP, or even the broader area of graphic arts (GA) allows for many simplifications.
- Their theoretical underpinnings lack the ties to GA that would make them useful in fulfilling one of the major needs of the DTP industry, a GA color exchange space.

Colorimetry-based systems do serve one important need. Their modeling of human vision, to the extent that they are successful in doing so, makes them helpful in predicting and controlling errors in color reproduction. Guth's ATD[1,2] system, as the companion papers to this one make clear, models human vision better than CIE L*a*b* or even CIE L*u*v*.

The above considerations led us to devise the Light Source AeQ™ color management system. This system is grounded in the realities of the GA world and uses an underlying vision model based on Guth's. At its heart is a device independent color space that we believe to be an excellent candidate for a standard GA color exchange space. This paper does not describe the entire AeQ system; it simply defines the device independent space and shows why this space satisfies all of the important criteria for a GA color exchange space.

Criteria for a Color Exchange Space

In establishing criteria for a color exchange space for the GA industry, it is important to begin by realizing that almost all of the images we deal with start out as a mixture of cyan, magenta, yellow and black (CMYK) dyes on film or paper. They normally enter computer systems as sets of pixels from a scanner. Each pixel is characterized by values on red, green, and blue (RGB) scales. GA software provides automatic or manual manipulation of the RGB values, then transforms them to CMYK control values appropriate for the target output device.

The two end points of the above process are the same, namely a combination of CMYK dyes on an output medium. Over a wide range of media, the eye's ability to adapt to the white substrate and just see the surface color allows us to make a very important simplification. If the output CMYK values match those of the original, we can expect the reproduced image to look like the original, regardless of illumination. Without being able to predict how they will look in any particular viewing environment, we can still predict that they will look like each other.

Each of the CMYK dyes has a characteristic spectral curve shape. While there are individual differences, they are within fairly narrow bounds. This means that the metameric anomalies that one can create with arbitrary spectral curves simply do not happen with CMYK combinations. We can therefore say that not only will equal CMYK combinations produce equivalent appearance, but also, nearly equal combinations will produce nearly equal appearance.

This leads us to our first set of criteria for a color exchange space:

1. Device independence. The encoding of the image should ideally contain information to allow reconstructing the mixture of dyes in the original, independently of how the image was acquired or how it will be output.

2. Substrate independence. The encoding should be relative to a standard substrate, such as white paper. Input from or output to a substantially different medium should entail an appropriate transformation.

3 . The space should use RGB coordinates and have a clearly defined one-to-one mapping into the traditional CIE XYZ coordinates. This is essential to allow calibration of input and output devices to the space's coordinates.

4. The space should be linked to a uniform linear chromaticity space by a simple two-way transformation. These properties facilitate the computations associated with gamut compression and assure that coordinate differences are good predictors of color differences.

5. Linear. The transformations necessary to embed scanned images in the space or to output images from the space should require only linear operations. Since the desired input and output forms are the same, and since small differences in the input should correspond to small differences in the output, there is really no need for the intermediate color space to differ drastically in form from the input or output spaces. Such a gentle relationship can easily be approximated linearly.

6. Includes virtually all printable colors. There is a tradeoff between the size of the space and the effective use of the necessarily limited number of bits available for encoding coordinates. Including all printable colors guarantees that some coordinate combinations will be used only rarely and some will be wasted. However, a space that does not include all printable colors has limited use as an interchange medium.

In addition to the above, it is useful to require explicitly certain criteria that recognize the computational and storage realities of DTP systems.

7. The space should use 8-bit integers, and nearly all of the resulting 256 values of each color coordinate should represent commonly occurring values.

8. All of the transformations required for moving into or out of the space or between the RGB format and the associated chromaticity space should be definable in terms of operations that can be performed rapidly on inexpensive DTP computing equipment.

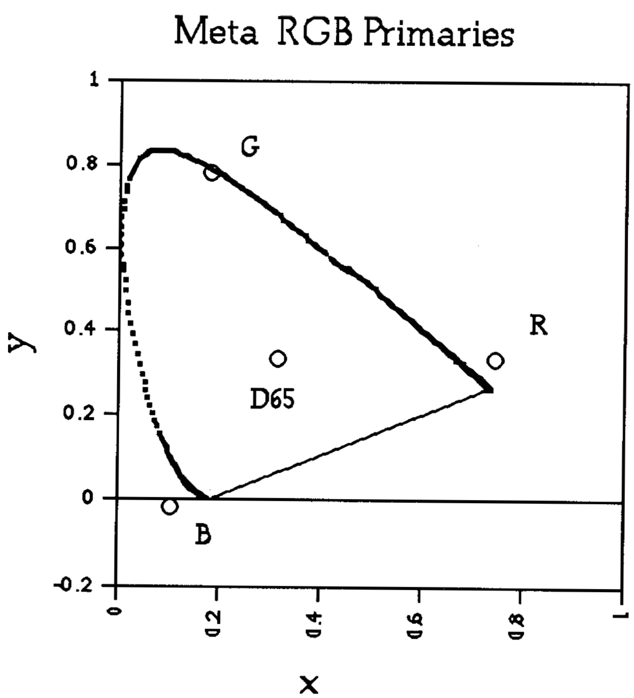

Figure 1. AeQ Meta RGB Primaries

The AeQ Meta RGB Space

The Light Source AeQ color management system contains a space that meets the above criteria. For purposes of exposition, the criteria are stated above, before the space is defined. However, the definition of the space and the development of the criteria happened iteratively during the course of developing a functioning color management system for DTP. While the current paper cannot describe all aspects of the AeQ system, the space described here is part of a functioning system that consistently produces results better than those from any commercially available package.

Figure 1 shows the locations of the primaries of the AeQ Meta RGB space in the standard XYZ space. Note that they lie outside the normal horseshoe boundary. This is slightly wasteful, but it achieves three important results:

1. It helps span the entire space of printable colors.
2. It facilitates compression of the space for display on monitors.
3. It approximates a linear and uniform color metric space.

The choices of the red, green, and blue primaries and the additional choice of D65 to be the white point of the space give rise to a linear transformation, i.e., a 3 by 3 matrix, relating the AeQ Meta RGB coordinates to the standard XYZ coordinates:

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} .257 & .066 & .049 \\ .115 & .286 & -.009 \\ -.026 & .015 & .438 \end{vmatrix} \times \begin{vmatrix} R \\ G \\ B \end{vmatrix}$$

The inverse transformation is:

$$\begin{vmatrix} R \\ G \\ B \end{vmatrix} = \begin{vmatrix} 4.271 & -.963 & -.500 \\ -1.709 & 3.878 & .271 \\ .314 & -.189 & 2.243 \end{vmatrix} \times \begin{vmatrix} X \\ Y \\ Z \end{vmatrix}$$

These matrices assume that the RGB values lie in the range 0 to 255, and the Y value ranges from 0 to 100.

We next define a computationally streamlined approximation to Guth's ATD space:

$$A = \frac{R + 3G}{4}$$

This corresponds to the light-dark opponent system.

$$T = R - G$$

This corresponds to the red-green opponent system.

$$D = \frac{R + G - 2B}{2}$$

This is the yellow-blue opponent system.

Notice that these computations can all be done simply by logical shifts and additions. In practice we perform the computations with 32-bit integers and do shift operations last. This maximizes precision.

The above formulas differ from the usual NTSC weightings. They are specifically tuned to the spectral functions associated with CMY dyes. Even though the definition of A has no blue component, it is a very good approximation to Y, the normal tristimulus luminance coordinate.

Finally we define the chromaticity space associated with the AeQ Meta RGB space:

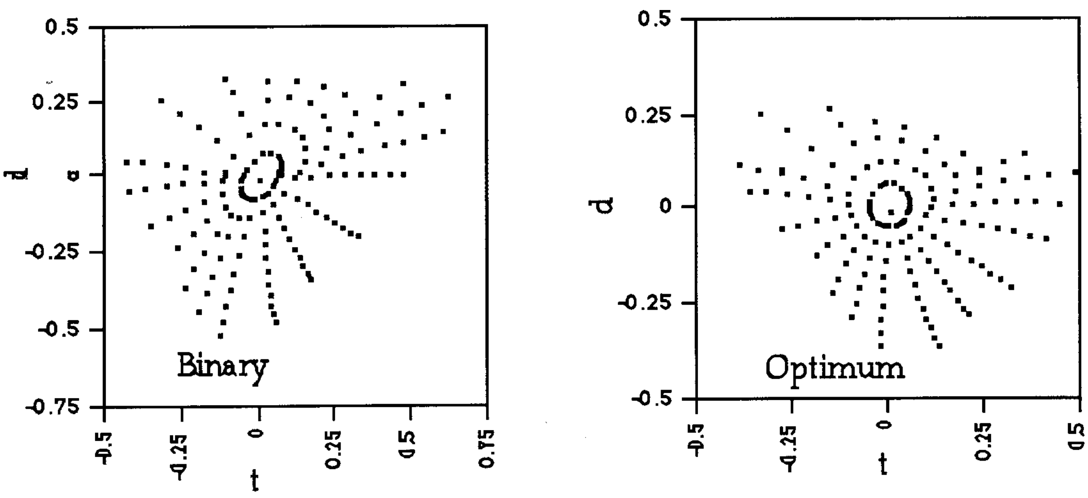

Figure 2. Munsell value 5 colors in the AeQ Meta chromaticity space

$$d = \frac{R + G - 2B}{2R + 3G + 2B}$$

$$t = \frac{R - G}{R + 1.5G + B}$$

Figure 2 shows that the binary coefficients are close to optimal. With optimized transformation coefficients the Munsell patches form equally spaced concentric circles, and the hue lines are straight. This shows that we have a candidate uniform chromaticity space. This makes it useful in defining and managing tolerances, mixing colors, and performing gamut compression computations.

Since t and d are immediately related to RGB, it is easy to predict the sizes of output errors directly from the sizes of RGB input errors. This property is essential for gamut mapping.

Conclusion

The AeQ Meta RGB space is an ideal candidate for a standard graphic arts color exchange space. It is device independents 8-bit friendly, and tuned for computational efficiency. It is linked to the traditional CIE XYZ space by a 3 by 3 matrix. It is linked by an extremely simple transformation to a true chromaticity space in which color judgments can be made in a uniform manner.

The AeQ Meta RGB space meets all of the criteria for a color exchange space set forth earlier in this paper. All of these criteria arise out of real needs and problems of DTP. No other candidate space that we know of meets these criteria.

Finally, while we can't yet reveal all of the details, the AeQ Meta RGB space is at the heart of a functioning DTP color management system that produces uniformly outstanding images on a variety of inexpensive equipment. A great deal of this success can be attributed to the properties of the AeQ Meta RGB space.

References

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