

THE PRISMATIC COLOR SPACE FOR RGB COMPUTATIONS

PETER SHIRLEY AND DAVID HART

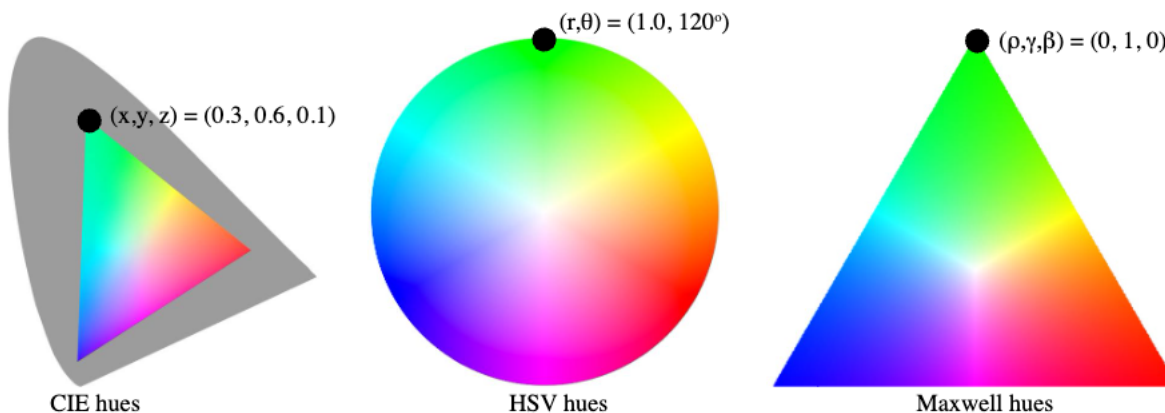


FIGURE 1. Many color spaces have a set of 2D hue cross-sections and a light/dark dimension. This figure shows two popular hue cross sections, and a less often used triangular one. Left: the CIE hue space footprint and an RGB gamut shown in color. Middle: the polar hue space popular in RGB computer graphics. Right: the Maxwell color triangle we examine in this paper.

ABSTRACT. In the spirit of the HSV color space, we introduce a simple transform of the RGB color cube into a light/dark dimension and a 2D hue. The hue is a normalized (barycentric) triangle with pure red, green, and blue at the vertices, often called the *Maxwell Color Triangle*. Each cross section of the space is the same barycentric triangle, and the light/dark dimension runs zero to one for each hue so the whole color volume takes the form of a prism. This prismatic space has advantages computationally and intuitively for some common color operations used in computer graphics and image processing.

1. INTRODUCTION

There is a long history of volumetric color spaces for various applications as detailed in the extensive book by Kuehni and Schwarz [2]. Most of these spaces are designed to specify either any perceivable color, or for any printable color, with some subset of that space displayable on an RGB monitor (left of Figure 1). These are mostly separated into a single brightness/luminance dimension and a 2D hue dimension. With the advent of RGB monitors, the ideas from these historical spaces were used to develop various cylindrical and conical color spaces coving displayable RGB colors with the HSV and HSB color spaces being popular examples [1]. The cross-section of these cylindrical spaces are usually color disks as shown in the middle of Figure 1. The light/dark (usually luminance)

Date: October 28, 2015.

Purity LLC Tech Report #1. shirley@purity.mobi, dahart@limnu.com.

dimension of these spaces is usually normal to those thus forming a cylinder. While cylindrical color volumes such as HSV are very useful, there are two limitations for our purposes:

- the conversion from RGB to HSV and back is cumbersome and thus inefficient;
- the hue that is a linear combination of two other hues in RGB is not a linear combination in HSV.

We note that both color disks and color triangles are the main way hue spaces are discussed throughout history, and we will argue that the color triangles overcome these limitations.

2. BARYCENTRIC HUE SPACE

Since the 1800s combinations of red, green, and blue lights have often been used in psychology experiments to mix colors, and the proportional weights of those primary lights have been used to represent the colors as a triangle, often called a *Maxwell Color Triangle* (right of Figure 1 because of Maxwell's seminal work with developing that area of color science).

That hue space when represented with barycentric coordinates is shown in Figure 2, with the brightest RGB color with those ratios shown in the circles. This 2D Maxwell hue space has often been used in computer vision as an approximation to albedo extraction, and has been called *normalized RGB* [3].

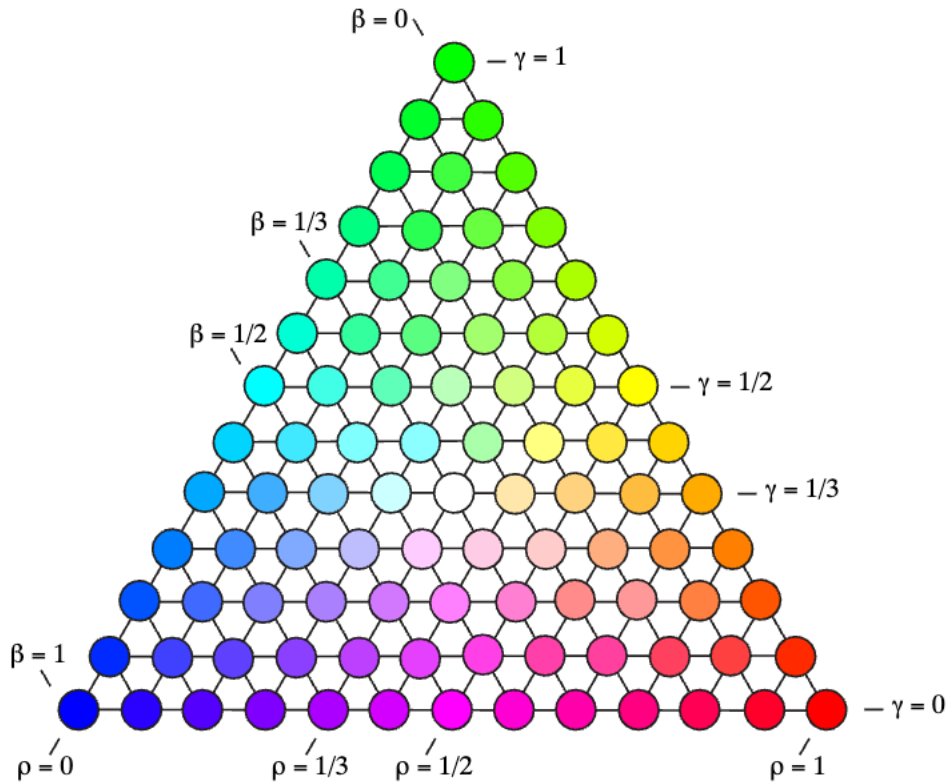


FIGURE 2. The 2D barycentric representation of hue with RGB primaries.

We note that the CIE XYZ space is itself a barycentric space with non-physical primary lights. Like the CIE color space, the Maxwell space has the same nice properties of linearity and triangular color gamuts in its cross sections.

3. MAXWELL COLOR VOLUME

The transforms to the barycentric components are:

$$(\rho, \gamma, \beta) = \frac{1}{R + G + B} (R, G, B)$$

If we add a light/dark dimension to the Maxwell Color Triangle we get a volume transform of RGB. Since our goal is simplicity we use a scale that always goes from zero to one:

$$L = \max(R, G, B)$$

This implies the inverse transform:

$$(R, G, B) = \frac{L}{\max(\rho, \gamma, \beta)} (\rho, \gamma, \beta)$$

3.1. Barycentric Hue and Conventional Luminance. While we have used the prismatic color space in our own work, the barycentric hue cross sections can be combined with the conventional luminance:

$$L = rR + gG + bB,$$

where (r, g, b) are constants that sum to one. Given this, and the barycentric hue (ρ, γ, β) , the inverse transform obtained algebraically is:

$$(R, G, B) = \frac{(\rho, \gamma, \beta)L}{3(\rho + \gamma + \beta)}$$

For unbounded (R, G, B) this color space is an infinite prism with no top (similarly to the xyY CIE space which is an infinite extruded horseshoe).

4. EXAMPLE USES

We came up with the Maxwell color volume in doing color modifications for the the iPhone photo processing app *Subjective*. We found that it performed well in practice for all of our desired operations.

4.1. Modifying Saturation. A common basic color operation is to change saturation (sometimes called *purity* or *colorfulness*, or *chroma*) where we move the color away from or closer to the most saturated version of the color. One of the three barycentrics will be smallest and keep going from $N = (\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$ in the direction of the barycentric of our hue $C = (\rho, \gamma, \beta)$, and that smallest channel will get to zero when fully saturated giving barycentric of the pure color P . The isolines of saturation each form inscribed equilateral triangles. This suggests the expression for saturation:

$$s = 1 - 3\min(C)$$

Thus C expressed in terms of s is:

$$C = N + s(P - N)$$

which implies

$$P = N + (C - N)/s$$

Given P we can modify s as done in Figure 4.1.

For example of a color running through those formulae, if the RGB color is $(0.75, 0.25, 0.25)$, the barycentric hues are $(\rho, \gamma, \beta) = (0.6, 0.2, 0.2)$, and the saturation is $s = 0.4$, and the pure version of the hue is $P = (1/3, 1/3, 1/3) + (0.6 - 1/3, 0.2 - 1/3, 0.2 - 1/3)/0.4 = (1, 0, 0)$. The original hue C is a pink, and the pure color P is red as we would expect.



FIGURE 3. The saturation s of the original image (left) is changed to $s^{0.7}$ (right). Image courtesy Uwe Schwarzbach.

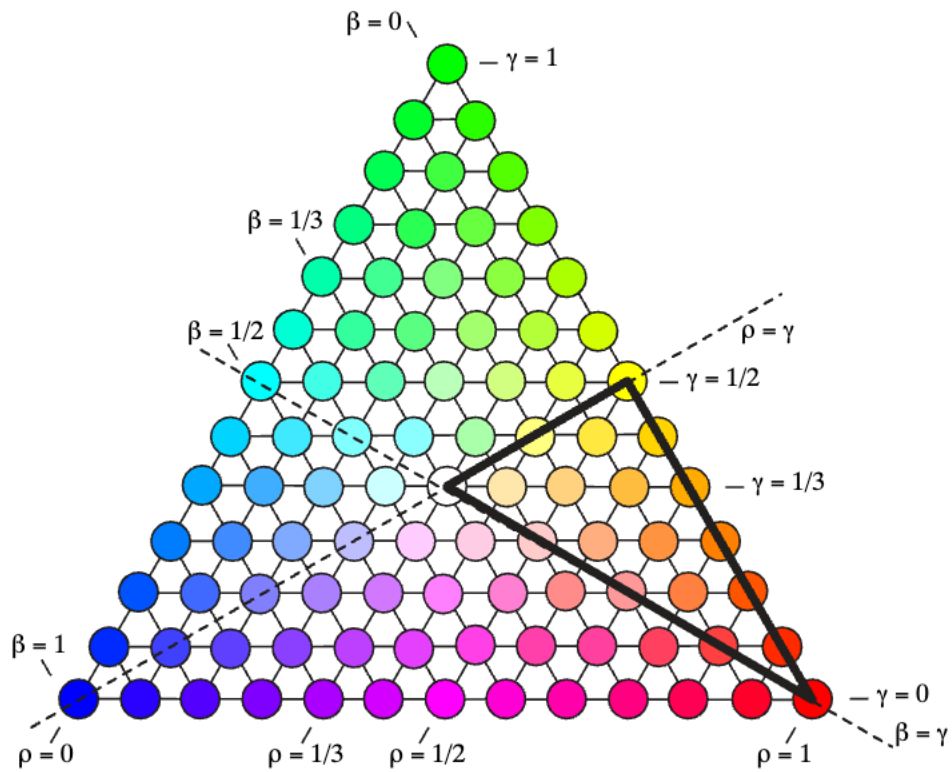


FIGURE 4. The dark triangle encloses the hues achievable with red, yellow, neutral colors.

4.2. **Color Grading.** Reducing the color palette has recently been very popular in film, and has long been popular among painters and printers where a reduced palette has practical advantages in addition to artistic considerations. The painter Anders Zorn popularized a palette of just white, black, red, and yellow. This so called “Zorn palette” captures skin tones accurately and neutralizes greens and blues. White and black are used to make tints and tones of the same hue so just in uence Y . The barycentric hues are just combinations of the red, yellow, and neutral points as shown in Figure 4.2.

The simplest way to color grade is to leave colors in the palette unchanged and project others to the boundary. This method is of course sometimes too simple but often works surprisingly well.



FIGURE 5. The reduction to a Zorn palette. Image courtesy Uwe Schwarzbach.



FIGURE 6. Using barycentric hue for approximate skin detection. Image courtesy Bahai.us at ckr.

For the Zorn case the triangle is bounded by the other $\beta = 0$ and the line $\beta = \gamma$ and $\gamma = \rho$. We do the projection of points outside that boundary in two steps which we have found to generate the most pleasing results in practice. First we check for $\beta > \gamma$ and if so, we keep ρ constant and equalize the other two components:

$$(\rho', \gamma', \beta') = (\rho, (1 - \rho)/2, (1 - \rho)/2)$$

Then if $\gamma' > \rho'$ we maintain the ratio of β' to γ' , $k = \beta'/\gamma'$:

$$(\rho'', \gamma'', \beta'') = \left(1 - \frac{1+k}{2+k}, \frac{1}{2+k}, \frac{k}{2+k}\right)$$

A sample of this transformation is shown in Figure 4.2.

4.3. Skin Detection. Hue spaces in general, and the Maxwell triangle hue space in particular, are often used by computer vision practitioners to try to factor out shading to get a rough measure of diffuse albedo. Skin tends to have the interesting property that the hue is about the same for people of different skin tone. An example of using distance (raised to a power for narrowing) of (ρ, γ, β) from $(0.4, 0.3, 0.3)$ is shown in Figure 4.3. Though crude and prone to false positives, this is a very simple and robust computation.

5. DISCUSSION

We have used the prismatic space described in Section 3 for processing colors in images and have found it to be robust and intuitive, with the common hues having “nice” locations in barycentric space. Like any other space that separates hue and lightness, the space can be stored efficiently with two chromatic channels at lower precision (and one of the three barycentric coordinates can be stored implicitly because they sum to one). For unbounded RGBs the more conventional luminance channel can be used and stored at a higher precision and/or range.

We have not discussed non-linearities such as gamma. The prismatic space can be used without reference to that (i.e., in nonlinear form), or can be used using linear RGB. In our experience using the perceptual (non-linear) values directly is often a good tactic in practice for both image quality and computational reasons, but this will be application dependent.

The prismatic space is very close in spirit and detail to HSV. The main penalty in using it is that the barycentric math on triangles is less familiar to most disciplines than polar masks on disks, but we think the computational advantages of the space more than make up for that.

REFERENCES

- [1] George H. Joblove and Donald Greenberg. Color spaces for computer graphics. In *Proceedings of SIGGRAPH*, 1978.
- [2] Rolf G Kuehni and Andreas Schwarz. *Color ordered: a survey of color systems from antiquity to the present*. Oxford University Press, 2007.
- [3] Vladimir Vezhnevets, Vassili Sazonov, and Alla Andreeva. A survey on pixel-based skin color detection techniques. In *Proc. Graphicon*, volume 3, pages 85–92. Moscow, Russia, 2003.