WIDER COLOR GAMUT TECHNOLOGIES **FOR PRODUCTION PROFESSIONALS**

The film and video production industries have seen enormous advances in image capture, manipulation, and rendering techniques over the past two decades. Improvements in camera sensor resolution to 4K and then 8K pixels, coupled with higher frame rates, expanded sampling bit depths, and high dynamic range technology, along with more powerful editing and gamma/color correction tools, have resulted in a quantum leap in photorealism.

Even so, one goal still remains out of reach–reproducing a gamut of color shades that approaches or equals the visible color spectrum, as defined by the CIE 1931 standard observer diagrams. The CIE color space was established 91 years ago, yet as of today we can only reproduce about 65% of it with the latest display technology. And unless we change our current approach to displaying colors, we're not likely to see further gains.

A Question of Geometry

The CIE 1931 visual color space diagram resembles an inverted horseshoe in shape, with a flat line between blue and red and a long curve arcing from blue through green and back to red. Reproducing all the color shades in the 1931 space would require multiple primary colors to closely match the horseshoe shape. Ideally, we'd use at least six primary colors – for example, red, green, blue, magenta, yellow, and cyan – to define the boundaries of our display's color gamut. While this would not result in 100% coverage, we'd come pretty close.

But that task is impossible with our current system of tristimulus (three color) imaging. Going back to the first color television demonstrations in the 1940s, we've continued to mix three primary colors of red, green, and blue to create color shades. While the resulting triangular-shaped gamuts of color produced by different display types have slowly increased in size over the decades, they still exclude too many shades of color. *(Illustrations 1 & 2)*

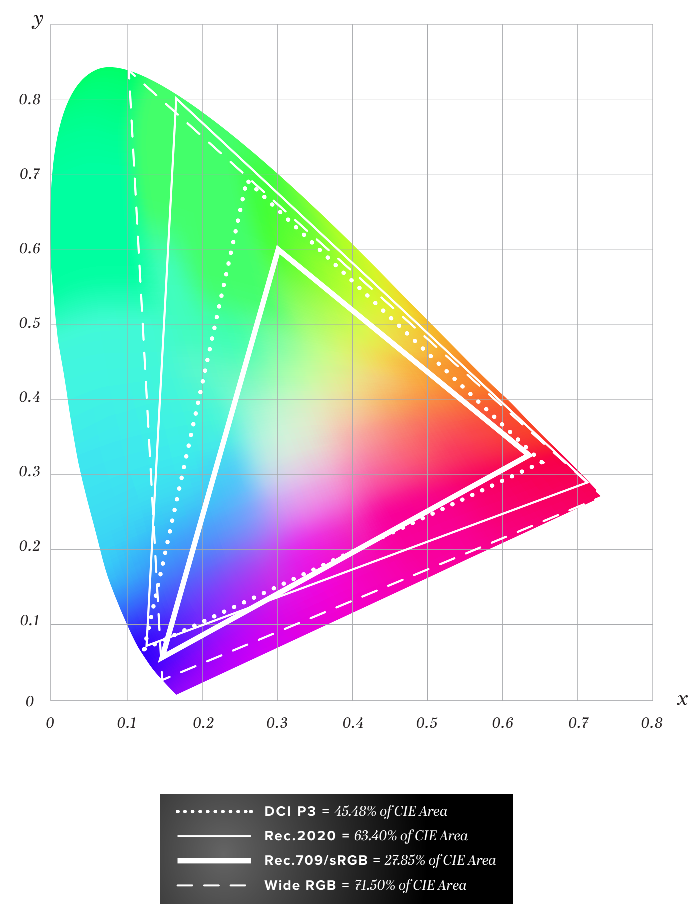

ILLUSTRATION 1: SAMPLE OF EXISTING COLOR GAMUTS

Expanding the Playing Field

The obvious answer to this dilemma is to add more primary colors and expand the shape of a display's color gamut. Even a four-primary system would produce significantly more colors and could work with several existing display architectures. Additional primaries would yield even more colors, although this increases complexity and therefore costs.

If we overlay several popular color gamut standards on the CIE 1931 standard observer diagram, we can see that adding a cyan primary to existing red, green, and blue primaries will achieve a large increase in displayable color shades. This changes the triangular gamut shape to a rectangular shape that covers more of the CIE color space. *(Illustration 3)*

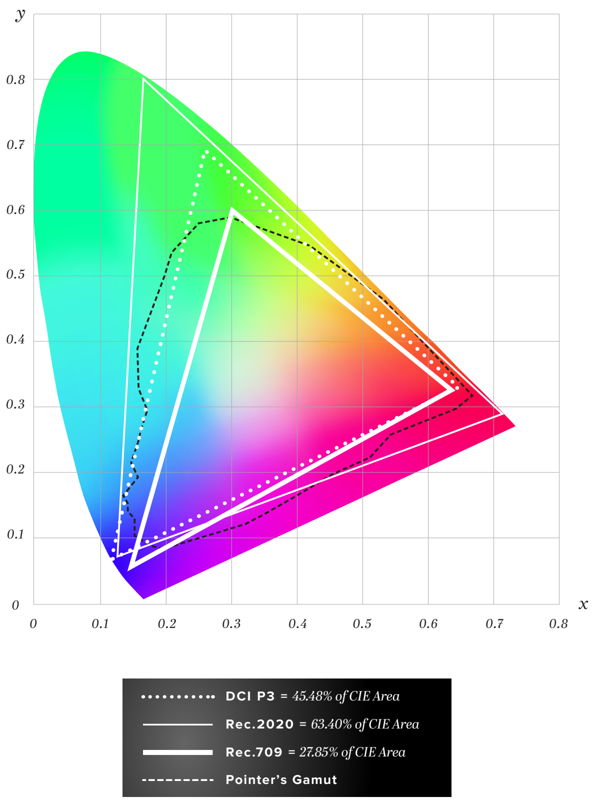

ILLUSTRATION 2: SAMPLE OF EXISTING COLOR GAMUTS INCLUDING POINTER'S GAMUT

This problem is particularly vexing for those who work with surface colors, including graphic designers and artists and anyone who manufactures, blends, or applies inks, pigments, paints, and dispersions. The Pointer Gamut of surface colors (1980) has an irregular, circular shape, and while many of its color shades fall inside contemporary display gamuts, there are still many shades of cyan, magenta, and yellow that lie outside.

The limitations of triangular color gamuts are just as frustrating for post-production professionals, particularly colorists. The sensors in still photo and video cameras can capture an enormous volume of visible colors outside of the established display gamuts, ranging from near infrared to near ultraviolet along with their associated luminance values. But once again, our tristimulus imaging systems can't display many of them. And these missing color shades are essential to real-life depiction of colors.

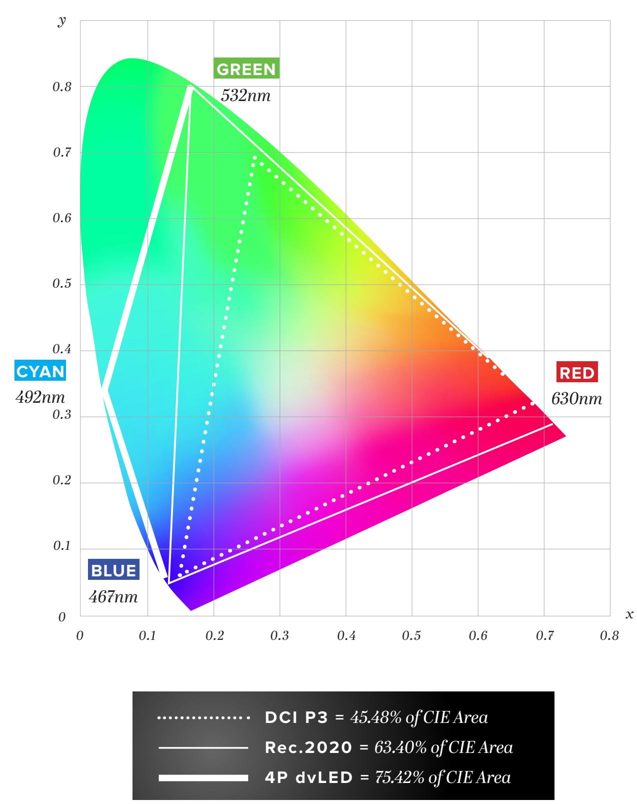

ILLUSTRATION 3: RGB PLUS CYAN

Careful determination of the loci for cyan and green would result in nearly 100% reproduction of Pointer's Gamut for the first time on any display, along with additional missing color shades from emissive light sources. If we then shift the red primary, we'll expand the display gamut even further, capturing shades of magenta along the way. This new display gamut, defined by four primary color coordinates, would now encompass the entire DCI P3 color gamut, the Adobe Wide RGB gamut, and most of the ITU BT.2020 gamut.

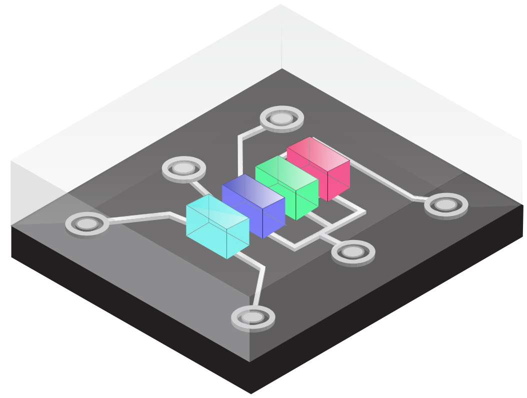

ILLUSTRATION 4B: RGB AND CYAN DVLED

Due to current variations in manufacturing costs and complexity, some display types are more suitable for modification to a four primary (RGBC) system than others. Two displays widely used in the digital cinema industry – direct-view (dv) LED walls and 3-chip DLP™ projectors – are strong candidates.

dvLED walls are fast becoming the preferred choice for virtual background sets, and practical demonstrations have already been conducted by 6P Color of an RGBC pixel array for dvLEDs, using a specially developed cyan LED chip *(Illustrations 4A and 4B)*. For projection, the usual combining prism that combines images from separate red, green, and blue digital micromirror device chips will require either modification to add a fourth DMD imaging surface or a dual-prism system to add in cyan *(Illustration 4C)*.

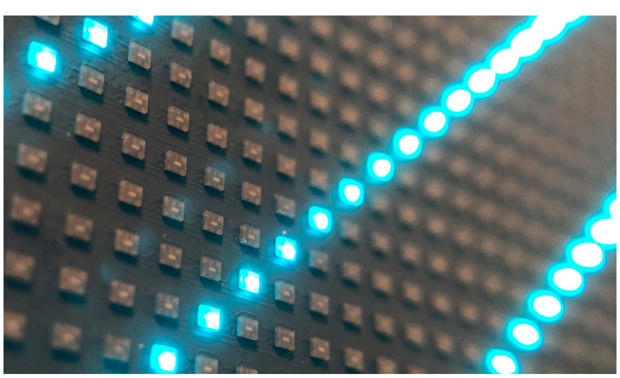

ILLUSTRATION 4A: PHOTOGRAPH OF RGB AND CYAN DVLEDS

ILLUSTRATION 4C: PHOTOGRAPH OF STACKED PROJECTOR SYSTEM DEVELOPED BY 6P AS A TEST RIG FOR EXPANDED PRIMARIES

For post-production houses, two types of direct-view displays could be modified to use an RGBC pixel stripe. LCD grading monitors, which use arrays of white LED backlights and RGB color filters, need only modify the filter array to add the fourth (cyan) color. And large OLED displays, which combine a white OLED emitter with an RGBW color filter array, could undergo a similar conversion, alternating rows of white and cyan pixels to achieve a balance between overall luminance and an expanded color gamut. Looking to the future, a new crop of direct-view microLED displays using RGBC LED chips could be adapted for use in post-production environments.

More Colors, Fewer Color Formats

Breaking out of the triangle by adopting multi-primary displays for production and post is just one way to rethink how we work with color. There's also a new, simplified method for specifying absolute color and luminance values and translating those values across legacy cinema and video color transmission formats. Historically, we've defined color shades as either combinations of separate red, green, and blue primaries, or as weighted color values mathematically derived from corresponding human color sensitivity to those colors.

The first process creates a color shade by combining specific levels of each primary color. The luminance value of that color shade is then increased or decreased by raising or lowering the overall levels of red, green, and blue simultaneously while keeping their ratios constant.

The second process, originally adopted for bandwidth- constricted television broadcasts, defines an overall luminance value Y (usually for green) and a pair of color difference values (R-Y, B-Y). This weighted color system was developed for NTSC television, using values of 59% green, 30% red, and 11% blue.

This system is described as the YCbCr format for digital television and OTT content distribution. Over time, the process of converting between different image acquisition, mastering, and transport color formats has required tedious and complex mathematical calculations. A typical cinema production chain would involve image acquisition in the RAW (uncompressed) color format, with exposure, gamma, and color correction performed in another intermediate format. This finished master file is converted yet again to the XYZ format for cinematic distribution and subsequently to color sub-sampled formats like 4:2:0 for broadcast, optical disc, and over-the-top (OTT) streaming services.

Time To Simplify

Now, 6P Color has developed a new system, which uses the expression Yxy, for specifying color and luminance values. It's a simple, straightforward expression that translates easily to any other legacy color format. In this notation, Y represents a luminance value for a given color value, and xy represents the data coordinates for that color value on the CIE 1931 standard observer chart *(Illustration 5)*.

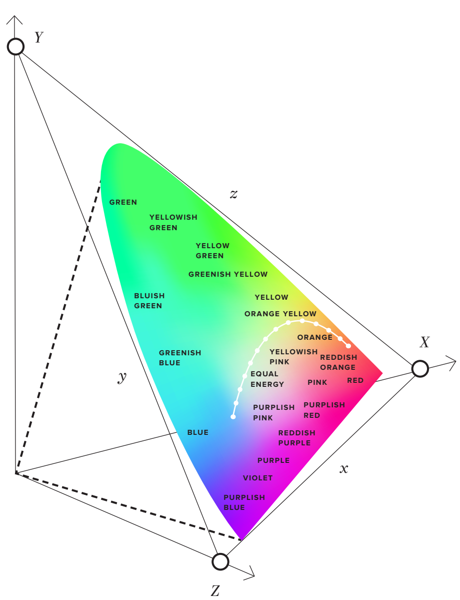

ILLUSTRATION 5: Yxy AS A PROJECTION OF XYZ

Yxy represents all color shades on the full CIE 1931 visual color gamut just as the XYZ format does and can be substituted for RGB or YCbCr image information without an increase in data payload, using existing 4:4:4, 4:2:2, and 4:2:0 sampling formats. In addition, Yxy is a more efficient way to transmit color information and greatly simplifies the mathematical process of translating between different image distribution formats.

TABLE 1. HOW YXY IS SUBSTITUTED INTO DIFFERENT DATA STREAMS

	RGB	$Y\,C_R C_B$	XYZ	$I\,C_P C_T$
x	R	C_B	X	C_T
Y	G	Y	Y	I
y	B	C_R	Z	C_P

In addition, the Yxy process uses a new approach to transmitting color data called Data Range Reduction (DRR). It's based solely on data efficiency and not on any optical properties, such as commonly used optical-optical transfer functions (OOTFs) or optical-electronic transfer functions (OETFs). DRR works with existing distribution systems and facilitates simpler and quicker conversions between source (camera) and display gammas.

Here's an example: Three linear 16-bit words, representing color values and luminance and scaled between 0 and 1, are extracted from a source content RAW image file. The source content white point is then used to calculate an XYZ data set for digital cinema. Finally, this XYZ data set is converted to Yxy, and DRR compresses the data for transport.

TABLE 2. APPLICATION OF DRR (T)

Bits	Y	x	y	f-Stop	PSNR
16	Not applied	Not applied	Not applied	24	
12	0.6	0.6	0.6	20	68.8
10	0.5	0.5	0.5	20	51.5
8	0.4	0.4	0.4	20	43.6

LSB & MSB

Bits	Y		x		y	
	LSB	MSB	LSB	MSB	LSB	MSB
8	1	254	1	254	1	254
10	4	1019	4	1019	4	1019
12	16	4076	16	4076	16	4076

At the display end, the compressed Yxy values have inverse DRR applied. The uncompressed data is then translated back to the XYZ format, with color gamut, gamma, and target white point information simplifying final conversion from XYZ to that display's native primary colors.

Summary

The innovations described here – a multi-primary display system, a new and simplified way to express color values, and a more efficient, user-friendly way to transport color data – are long overdue in today's world of cinema and video production. All three tools will enhance the creative process; greatly expanding the color gamut of direct view and projection displays while reducing and streamlining the acquisition, editing, post-production, and distribution of cinema and video content across a myriad of viewing platforms.

