STANDARDS

Standards Update

David McDowell, Editor

The Many Faces of RGB

Until recently, RGB was the color space that everyone used but no one defined very well, certainly not formally. True, the television community had defined the chromaticities of the RGB phosphors used in television, first by SMPTE for the analogue NTSC and PAL systems and then later by ITU for digital image systems. They also defined transfer functions, but more about that later. These definitions were all tied to the characteristics of physical devices - television cameras and displays - and the needs of the television industry.

However, in addition to display spaces, digital imaging needs three component color spaces with more robust specifications than the television standards provide, and which are able to handle larger data gamuts and which minimize quantization and other artifacts. For convenience we still call them RGB, but in many cases they only bear a distant relationship to the SMPTE definitions used for NTSC television.

In this issue, with the help of Jack Holm of Hewlett Packard Company and Kevin Spaulding of Eastman Kodak Company, I would like to identify some of work being done in the area of RGB standardization, and some of the thinking that has led to this work. But, as Jack and Kevin would urge you, for more detailed information please study the standards and specifications themselves and the reference documents listed at the end.

Image State

When we say "RGB" what we are really referring to is a way to encode colorimetric data that is more efficient than using the traditional CIELAB or CIEXYZ and that is also easier to convert into the device drive signals needed in practical applications.

Before we even begin talking about RGB, we need to introduce a concept that is new to most of us, and that impacts the whole area of color space definition. That concept is referred to by some as "image state". It has many ramifications, and Kevin in particular has written a number of papers on the topic, but the key one for RGB color spaces is the idea of scene-referred data vs. rendered or output-referred data. ISO TC42 has started to address this topic as part of ISO 22028-1 Photography and graphic technology - Extended colour encodings for digital image storage, manipulation and interchange - Part 1: Architecture and requirements

What that boils down to in terms of an RGB color space is whether the encoded color data represents the color of the scene or whether it represents a reproduction of the scene. This is very significant because it turns out that the colorimetry of a scene generally does not equal the colorimetry of a pleasing reproduction of that scene.

One of the complexities this forces us to deal with is that the conversion of scene-referred data into output-referred data requires the use of proprietary and frequently preference-based color rendering transforms. These transforms are, in part, needed to account for differences in the viewing conditions of the scene-referred image and the output-referred image.

However, the larger and more complex issue is related to the fact that scenes are almost unlimited, and perhaps even more important quite variable, in their range of both lightness and colorfulness. Any rendered image (television, monitor, print, etc.) is bound by the limitations of the real or virtual media characteristics. Adding to all of this is the issue of viewer preferences (humans usually prefer enhanced contrast and colorfulness, but these preferences may be user, market, and image dependent). Because of this complexity, most work being done clearly focuses on the encoding of either scene-referred data or output-referred data, but avoids defining transforms between the two.

These gamut and data encoding issues, coupled with the workflows of the expected applications, play a major role in the struggles to standardize new RGB data spaces.

Television RGB

Lets go back and look at our television definitions of RGB and focus on the values defined in the HDTV video camera standard known as Recommendation ITU-R BT.709. It turns out that this is to some extent a hybrid between a scene-referred space (un-rendered) and an output-referred space (rendered), because it defines a specific relationship between the color of the original scene and the encoded color values, but these encoded color values are supposed to be appropriate for output on a typical television (the characteristics of which are not specified).

This is accomplished by defining phosphor chromaticities, a white point and an "opto-electronic transfer characteristic" for a standard video camera. These characteristics, together with the characteristics of a typical television display, effectively define not only the color encoding, but also the color rendering function as well. So while a reading of the standard gives the appearance that this standard is basically a scene-referred encoding, in practice it has features in common with an output-referred encoding since the resulting signals are assumed to be adapted for an output display with a certain color gamut and dynamic range (but an unspecified output transfer characteristic).

ITU-R BT.709 also defines issues such as picture size, signal format, and luminance/color-difference signals, but no digital encoding is specified. That is covered in ITU-R BT 1361.

More is Needed

Clearly, as we move into digital imaging more robust RGB definitions are needed. Right now that "more" is being addressed by several groups including IEC TC100 (Audio, Video And Multimedia Systems And Equipment), ISO TC42 (Photography), and the newly formed International Imaging Industry Association (I3A). I3A was recently formed through the merger of the Photographic and Imaging Manufacturers Association (PIMA), and the Digital Imaging Group (DIG). (It should be noted that specifications developed under PIMA before the merger still carry the PIMA designation.)

RGB Definition Work

These groups are developing a number of standards and industry specifications, which are in various states of approval. These documents, which will be discussed in the following paragraphs and summarized in the table, are:

- IEC 61966-2-1:1999, Multimedia systems and equipment - Colour measurement and management - Part 2-1: Colour management - Default RGB colour space - sRGB.
- IEC 61966-2-2:CDV, Multimedia systems and equipment - Colour measurement and management - Part 2-2:

Comparison of RGB Definitions

	sRGB	*e-sRGB*	*ROMM RGB*	*(E)RIMM RGB*
Reference	IEC 61966-2-1:1999	PIMA 7667:2001	PIMA 7666:2001	PIMA 7466 (WD)
Type of encoding (image state)	output-referred (CRT)	output-referred (print)		scene-referred
RGB primaries	R: x=0.6400, y=0.3300 G: x=0.3000, y=0.6000 B: x=0.1500 y=0.0600 (from ITU-R BT.709-3)		R: x=0.7347, y=0.2653 G: x=0.1596, y=0.8404 B: x=0.0366 y=0.0001	
transfer function	C’=12.92ΔC for C •0.0031308 C’=1.055ΔC$^{1/2.4}$-0.055 for C >0.0031308	C’=-1.055Δ(-C)$^{1/2.4}$+0.055 for C < -0.0031308 C’=12.92ΔC for |C| • 0.0031308 C’=1.055ΔC$^{1/2.4}$-0.055 for C >0.0031308 *(extended from sRGB)*[1]	C’=16ΔC for C <0.001953 C’=C$^{1/1.8}$ for C ∅0.001953	*RIMM RGB* C’=(4.5ΔC) /1.402 for C •0.018 C’=(1.099ΔC$^{0.45}$-0.099)/1.402 for C >0.018 *(from ITU-R BT.709-3)* *ERIMM RGB* C’=29.0487ΔC for C •0. 00271828 C’=(logC+3)/5.5 for C >0. 00271828
adapted white point luminance	unspecified		160 cd/m^2	15,000 cd/m^2
adapted white point chromaticity	unspecified		x= 0.3457, y = 0.3585 (D_{50})	
encoding white point luminance	80 cd/m^2		142 cd/m^2	15,000 cd/m^2
encoding white point chromaticity	x= 0.3127, y = 0.3290 (D_{65})		x= 0.3457, y = 0.3585 (D_{50})	
media white point luminance	80 cd/m^2		142 cd/m^2	N/A
media white point chromaticity	x= 0.3127, y = 0.3290 (D_{65})		x= 0.3457, y = 0.3585 (D_{50})	N/A
viewing surround	*“background”* 20% of display white point luminance level (16 cd/m^2) *“surround”* 20% reflectance of ambient illuminance level (4.1 cd/m^2)		“average” (20% of the adapted white point luminance level)	
viewing flare	1% (0.8 cd/m^2)		included in 0/45 measurements	N/A
veiling glare	0.2 cd/m^2		included in 0/45 measurements	N/A
viewer observed black point (ideal viewing conditions)	1.0 cd/m^2 D_{65} chromaticity		0.5 cd/m^2	N/A
viewing flare (typical)	5%		0.75%	N/A
encoding bit depth	8 provided as an example, others allowed	10, 12, 16	8, 12, 16	*RIMM RGB*: 8, 12, 16 *ERIMM RGB*: 12, 16
color gamut	CRT-based (ITU-R BT.709-3)	extended		
valid relative luminance range[2]	0.0 to 1.0			*RIMM RGB*: 0.0 to 2.0 *ERIMM RGB*: 0.0 to 316.2
encoding range	linear RGB: 0.0 to 1.0	linear RGB: -0.53 to 1.68.	linear RGB: 0.0 to 1.0	linear RGB: *RIMM*: 0.0 to 2.0 *ERIMM*: 0.0 to 316.2

1. The e-sRGB color encoding transfer function also includes an offset to allow the encoded values to be unsigned; see PIMA 7667 for details.
2. Excluding viewing flare and veiling glare.

Colour management - Extended RGB colour space - scRGB.

- I3A 7466:WD, Photography - Electronic still picture imaging - Reference Input Medium Metric RGB Color encoding: RIMM-RGB
- PIMA 7666:2001, Photography - Electronic still picture imaging - Reference Output Medium Metric RGB Color encoding: ROMM-RGB
- PIMA 7667:2001, Photography - Electronic still picture imaging - Extended sRGB color encoding - e-sRGB

sRGB

IEC 61966-2-1, generally referred to as sRGB, is applicable to the encoding and communication of RGB colours used in computer systems and similar applications by defining encoding transformations for use in defined reference conditions. It colorimetrically defines an RGB color space that is based on the average performance of personal computer displays in a defined viewing environment. It builds on the assumption that most computer displays are similar in their key color characteristics-the phosphor chromaticities (primaries) and transfer function. It notes that because RGB spaces are native to displays, scanners and digital cameras, which are the devices with the highest performance constraints, an RGB space matched to the typical performance of such devices offers performance advantages compared to spaces such as CIELAB or CIEXYZ. It is optimized for multimedia applications where it can both describe color in an unambiguous way and be the native space for actual hardware devices.

e-sRGB

PIMA 7667, or e-sRGB, is generally similar to sRGB except that it allows extended encoding of RGB values that range from -0.53 to 1.68. This allows for the encoding of a larger or extended color gamut compared to sRGB. However this also requires 10 bits per component as a minimum encoding bit depth. While both sRGB and e-sRGB are output-referred, sRGB is designed to be appropriate for CRT-centric imaging systems, while e-sRGB provides additional flexibility for high quality print- based paths. PIMA 7667 also includes the specification of a standard luminance-chrominance encoding for sRGB called sRGB YCC. sRGB YCC offers some significant advantages, because it uses the same YCbCr transform used for decorrelation purposes in JPEG compression.

e-sRGB or sRGB YCC may also proceed as part of an International Standard in IEC 61966-2 or ISO 22028. Discussions are ongoing about how this should proceed. Because of the desire for some level of quick standardization, there is a draft amendment to the sRGB standard that specifies the encoding equations for an "sYCC". These equations are identical to those for sRGB YCC, although other specifications in PIMA 7667 are not included. At present, the draft amendment also includes equations similar to those for 10-bit e-sRGB, but some major technical issues have yet to be resolved.

scRGB

Another extended-range color encoding based on the sRGB primaries, referred to as Extended RGB colour space or scRGB, is under consideration by IEC TC100 in IEC 61966-2-2,. Nominally, this appears to be a scene-referred encoding, however, there is still considerable discussion concerning the particulars, and therefore it is not included in the table. This color encoding uses a linear encoding, and is primarily intended for computer graphics applications.

ROMM RGB

PIMA 7666, known as ROMM RGB, achieves an extended gamut by using primaries that are theoretical rather than physical. Because these primaries are not required to be related to any physical device they can be chosen to represent an optimum balance between a number of parameters. Key issues in choosing the ROMM RGB primaries were the size of the color gamut enclosed, the quantization efficiency of the encoding, and the hue consistency of the color encoding during the application of non-linear transformations such as tonescale manipulations.

RIMM RGB

I3A 7466, known as RIMM RGB, is a scene-referred color encoding that is a companion to ROMM RGB. It uses the same imaginary primaries as ROMM RGB, but incorporates a different nonlinear transfer function due to the larger dynamic range requirements associated with a scene-referred space. The RIMM RGB nonlinearity is based on that defined in ITU-R BT.709. I3A 7466 also defines an extended dynamic range version of this color encoding known as ERIMM RGB. This color encoding has a logarithmic nonlinearity function and a large enough dynamic range to handle the full range of information captured on color negative film, but requires a minimum bit-depth of 12 bits.

Useful References

Some useful references on image state are:

ISO 22028-1:WD, Photography and graphic technology - Extended colour encodings for digital image storage, manipulation and interchange - Part 1: Architecture and requirements, available from isotc42@i3a.org

Spaulding, K. E; Woolfe, G.J.; and Giorgianni, E.J.; "Optimized Extended Gamut Color Encoding for Scene-Referred and Output-Referred Image States"; Journal of Imaging Science and Technology, Vol. 45, No. 5, September/October 2001, pp 418-426

Spaulding, K. E.; Woolfe, G. J.; and Giorgianni, E. J.; "Image States and Standard Color Encodings (RIMM/ROMM RGB)", IS&T Eighth Color Imaging Conference: Color Science and Engineering: Systems, Technologies, Applications (2000), pp 288-294

Süsstrunk, S.; Buckley, R.; and Swen, S.; "Standard RGB Color Spaces", IS&T Seventh Color Imaging Conference: Color Science, Systems, and Applications (1999), pp 127-134

Holm, J.; "Issues Relating to the Transformation of Sensor Data into Standard Color Spaces", Proceedings, IS&T/SID Fifth Color Imaging Conference: Color Science, Systems, and Applications (1997), pp. 290-295

Woolfe, G. J.; and Spaulding, K. E., "Color Image Processing Using an Image State Architecture", 9th Congress of the International Colour Association, Rochester, NY June 24-29,2001

More Standards Information

More information on the standards mentioned may be obtained at www.iec.ch and www.I3A.org. Information about sRGB is available at www.srgb.com.

For suggestions for future updates, or standards questions in general, please contact the author at mcdowell @npes.org or mcdowell@kodak.com