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Photography – Electronic still picture imaging – Extended sRGB color encoding – e-sRGB

Foreword

This PIMA standard has been developed in order to meet the industry need for a complete, fully-documented, publicly available definition of an extended gamut color encoding that is an extension of the sRGB color encoding. e-sRGB provides a way to encode output-referred images that does not limit the color gamut to those colors capable of being displayed on a CRT display. For example, colors used for company logos or other graphics may be outside the sRGB gamut and would therefore need to be clipped or compressed to a less saturated color for encoding. Similarly, some colors in pictorial images printed on high-quality printers cannot be represented on a CRT display. By using a standard output-referred extended gamut color encoding, images containing such colors can be stored and interchanged without limiting or distorting the colors. The e-sRGB encoding allows these colors to be reproduced faithfully on the final output medium, within the capabilities of that medium. Additionally, it is desirable for interoperability reasons to standardize an extended-gamut color encoding that is an extension of sRGB. The e-sRGB color encoding specified in this PIMA standard meets these needs.

Currently, an international standard on extended colour encodings for digital still image storage, manipulation, and interchange is under development as ISO 22028. Other work is progressing as IEC 61966-2-2. Future work in this area may progress as part of a new joint working group between ISO/TC42 and IEC/TC100 that will be set up according to JTAB Decision 3/2000. After an international standard specifying e-sRGB is published, it is anticipated that this PIMA standard will be withdrawn.

Annexes D through H of this PIMA standard are for information only.

Introduction

In the computing industry, the importance of compatibility and interoperability is well understood. Standards such as IEEE 1394 provide compatibility for the transmission of data between computing appliances. Similarly, standards such as sRGB provide compatibility for the transmission of color. sRGB was originally designed by HP and Microsoft, and has received wide adoption in the consumer imaging industry. sRGB is based on a typical CRT color gamut, and it is very well suited for the CRT-centric workflow. The strength of sRGB is its simplicity; it is inexpensive to implement, computationally efficient, and transparent to the end user.

sRGB continues to serve the consumer imaging market. However, consumer imaging is rapidly changing. As the quality of consumer imaging increases, the sophistication and expectations of the customer also increase.

In addition, we are seeing change in the way that consumers use imaging peripherals. The word "peripheral" has become dated and inaccurate. Cameras, printers, palm tops, cell phones, Internet terminals, digital picture frames, set-top boxes and video game consoles are imaging enabled and connected. The consumer imaging workflow is changing from CRT-centric to a peer-to-peer model. For example, directly sending digital photos to a printer is becoming more commonplace. In this example, limiting the gamut of the image data to that of a CRT does not make sense.

This standard for digital color interchange will help meet increased image quality expectations, and also help capitalize on new consumer workflows where the CRT becomes less important. Because sRGB has been widely adopted and will remain core to mainstream consumer color management for many years to come, a desirable solution from an interoperability standpoint is a simple extension to the sRGB space.

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1 Scope

This PIMA standard specifies a family of output-referred extended gamut color encodings designated as e-sRGB. These color encodings are extensions of the sRGB color encoding specified in IEC 61966-2-1. Digital images encoded using e-sRGB can be stored, transmitted, displayed, or printed by digital still picture imaging systems, and are easily converted to the conventional sRGB color encoding. Three precision levels are defined: 10-bits per channel for general applications, and 12- and 16-bits per channel for photography and graphic technology applications. Conversions are provided between e-sRGB and: sRGB, e-sYCC, and sRGB YCC.

2 Normative References

The following standards contain provisions, which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid standards.

CIE 15.2:1986, *Colorimetery*

CIE 122:1996, *The relationship between digital and colorimetric data for computer-controlled CRT displays*

ISO 3664:2000, *Viewing conditions for graphic technology and photography*

ISO/CIE 10527:1991, *CIE standard colorimetric observers*

ISO/IEC 15444-1:2001, *Information Technology - JPEG 2000 image coding system*

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

ITU-R BT.601-5:1999, *Studio encoding parameters of digital television for standard 4:3 and wide screen 16:9 aspect ratios*

ITU-R BT.709-3:1998, *Parameter values for the HDTV standards for production and international programme exchange*

ICC.1:2001 (version 4), *File Format for Color Profiles*

3 Definitions

For the purpose of this standard, the following definitions apply:

3.1
ambient illuminance level
illuminance level due to lighting in the viewing environment, excluding that from the display, measured in the plane of the display faceplate

3.2
ambient white point chromaticity

CIE 1931 xy chromaticity co-ordinates defined by ISO/CIE 10527 and CIE 15.2 representing the chromaticity of lighting in the viewing environment, excluding that from the display, measured in the plane of the display faceplate

3.3

color rendering

mapping of image data representing the colorimetric co-ordinates of the elements of a scene or original to image data representing the colorimetric co-ordinates of the elements of a reproduction

3.4

display black point

CIE 1931 Yxy luminance and chromaticity co-ordinates, as defined by ISO/CIE 10527 and CIE 15.2, of an additive RGB display when its red, green, and blue intensities are set at the minimum of their normal operating range, measured using a flareless (or flare corrected) instrument with its optical axis perpendicular to the display faceplate

3.5

display model offset

system offset parameter from the CRT display model described in CIE 122 representing the black offset level excluding veiling glare and internal flare

3.6

display white point

CIE 1931 Yxy luminance and chromaticity co-ordinates, as defined by ISO/CIE 10527 and CIE 15.2, of an additive RGB display when its red, green, and blue intensities are set at the maximum of their normal operating range, measured using a flareless (or flare corrected) instrument with its optical axis perpendicular to the display faceplate

3.7

image background

area adjacent to the border of an image which, upon viewing the image, may affect the local state of adaptation of the eye

NOTE – In ISO 3664, the image background is referred to as the image surround.

3.8

image surround

field outside the background, filling the field of vision

NOTE – In ISO 3664, the image surround is referred to as the image viewing environment.

3.9

instrument flare

optical radiation from a source outside the intended measuring location collected by the measuring instrument which affects the measurement result

3.10

internal flare

optical radiation due to internal scattering and internal reflection

NOTE – This definition is from CIE 122.

3.11

output-referred image data

encoding of rendered image colorimetry appropriate for a specified real or virtual output device and viewing conditions

NOTE – A single scene can be colour rendered to a variety of output-referred representations depending on the anticipated output viewing conditions, media limitations, and/or artistic intents.

3.12
standard output-referred image data
output-referred image data which is referred to a standardized real or virtual output device and viewing conditions

NOTE 1 – Image data intended for open interchange is most commonly standard output-referred. This is because with standard output-referred image data it is generally sufficient to specify the standard output to which the image data is referred to interpret the colour appearance described by the image data.

NOTE 2 – Standard output-referred image data may become the original for a subsequent reproduction process. For example, sRGB output-referred image data is frequently considered to be the original for the colour rendering performed by an sRGB printer.

3.13
veiling glare
light, reflected from an imaging medium, that has not been modulated by the means used to produce the image

NOTE 1 – Veiling glare lightens and reduces the contrast of the darker parts of an image.

NOTE 2 – In CIE 122, the veiling glare of a CRT display is referred to as ambient flare.

3.14
viewing flare
veiling glare that is observed in a viewing environment but not accounted for in radiometric measurements made using a prescribed measurement geometry

NOTE – The viewing flare is expressed as a percentage of the luminance of the adopted or adapted white.

4 Requirements

4.1 General

e-sRGB is an extended color-gamut RGB encoding of the colorimetry of an output-referred image on a reference display. The standard output-referred image has the desired color appearance when viewed in the reference viewing conditions. The image colorimetry is encoded in terms of RGB values for a virtual additive color device having a specified set of primaries, no cross-talk between the color channels, and a luminance dynamic range defined by an associated black point and white point.

Three different precision levels are defined, and shall be identified as e-sRGB10, e-sRGB12 and e-sRGB16, for 10-, 12- and 16-bits/channel (30-, 36- and 48-bits/pixel) representations, respectively.

The measured image colorimetry shall be based on colorimetric measurements as described in CIE Publication No. 15.2 using the CIE 1931 two-degree standard observer defined in ISO/CIE 10527. For all measurements, instrument flare shall be eliminated or corrected for when performing the measurements.

NOTE – Care should be taken to differentiate between measurements made with flareless (or flare corrected) instruments, where instrument flare has been removed, and measurements where viewer observable types of flare such as internal flare and veiling glare have been removed.

4.2 Reference Viewing Conditions

Specifications for the reference viewing conditions are derived from ISO 3664, are as specified in IEC 61966-2-1, and shall be as follows:

The reference ambient illuminance level shall be 64 lux. The reference surround average luminance level shall be 4.1 cd/m^2, and the chromaticity should average to x= 0.3457, y = 0.3585 (that of CIE illuminant D50).

The reference image background luminance shall be 16 cd/m^2 (one-fifth of the display white point luminance). The reference image background chromaticity should be x = 0.3127, y = 0.3290 (that of CIE illuminant D65).

NOTE – If the actual output viewing conditions differ significantly from those specified here, appropriate transformations may be necessary to determine the corresponding colorimetry that would produce the desired color appearance in the reference viewing conditions [1]. However, for actual viewing conditions similar to the reference viewing conditions, it should not be necessary to make such adjustments. The reference viewing conditions were selected to make such adjustments unnecessary for many practical applications.

4.3 Reference Display

Specifications for the reference display are as specified in IEC 61966-2-1, and shall be as follows:

4.3.1 Reference Display White Point

e-sRGB shall be an encoding of the colors of an image on a reference display having a display white point with the chromaticity values of CIE Standard Illuminant D65 (x = 0.3127, y = 0.3290) and a luminance of 80 cd/m^2. Accordingly, the reference display white point tristimulus values are X_W = 76.037, Y_W = 80.000 and Z_W = 87.125.

4.3.2 Reference Display Black Point Luminance

The reference display shall have a display black point with a luminance of 0.2 cd/m^2.

NOTE – IEC 61966-2-1 specifies a display model offset of zero, however the display black point is non-zero because of veiling glare secified to be present when performing the black point measurement.

NOTE – See Annex D for information relating to the reference display black point and the viewer observed display black point.

4.3.3 Reference Display Primaries

The chromaticity values for the e-sRGB primaries are as specified in ITU-R BT.709-3, and shall be as listed in Table 1.

	x	y
Red	0.640	0.330
Green	0.300	0.600
Blue	0.150	0.060

Table 1: CIE chromaticities for ITU-R BT.709-3 reference primaries.

4.3.4 Reference Display Rendering Intent

e-sRGB is an encoding of the colorimetry of a standard output-referred image. Color rendering shall be performed as necessary to produce the desired image appearance on the reference display, including the extended gamut, for encoding as e-sRGB. Images encoded in e-sRGB may contain colors that are outside the color gamut for an actual output medium. Therefore, subsequent color rendering may be needed to map the encoded e-sRGB colorimetry to that appropriate for the actual output medium. Such color rendering should attempt to maintain the encoded appearance (as determined from the encoded colorimetry and reference viewing conditions) on the actual output medium when it is viewed using comparable viewing conditions. If the actual viewing conditions are significantly different from the reference viewing conditions, the color rendering from e-sRGB to the actual medium should attempt to maintain the general appearance of the image as represented by its appearance using the reference viewing conditions. In some cases, the color appearance encoded in e-sRGB may not be ideally suited for display on a particular real output medium using particular viewing conditions. For example, the visual appearance of a high-quality transparency, brightly illuminated with a dark surround, will typically be different from that of a high-quality CRT display image of the same scene viewed using the e-sRGB viewing conditions. Therefore, in some applications, it may be desirable to alter the color appearance description provided by e-sRGB encoding accordingly to produce the optimal image for the intended output medium and viewing conditions.

Image colorimetry encoded as e-sRGB shall not contain colors outside the spectral locus, or colors whose luminance is larger than that of the display white point or less than zero after correcting to remove internal flare and veiling glare. Image colorimetry encoded as e-sRGB should not contain colors which are outside the gamut bounds of the ICC PCS as defined in the ICC Profile Format Specification 3.0.

NOTE – One method of determining if an image color is valid is to construct a table of allowed digital code value triplets, and to then check potential colors for encoding against the table. Another method is to construct a convex hull and test for inclusion. The correct table or convex hull can be calculated by transforming e-sRGB triplets to XYZ and LAB, and then determining if they meet the above requirements and recommendations. In some applications, testing for valid colors is unnecessary because the source material may be assumed to contain only valid colors.

NOTE – Consideration should be given to the gamut limitations of real media, particularly those of sRGB, in performing color rendering to produce image colorimetry for encoding as e-sRGB. It is anticipated that images will routinely be transformed from e-sRGB to sRGB using the default transform specified in 4.6 (clipping), so image colorimetry encoded as e-sRGB should produce results that are acceptable for the intended application when this transform is applied. This situation may result in different tradeoffs. For example, a shade of cyan outside the sRGB gamut may be gamut compressed from its true color for encoding in e-sRGB when the accurate specification of the color is less important than the absence of artifacts resulting from applying the transform specified in Annex C. In another use, the same cyan color may be accurately specified because the use requires it, or the image structure is such that the specified transform to sRGB does not produce objectionable artifacts.

4.4 e-sRGB Encoding

4.4.1 Encoding Principles

e-sRGB values shall be determined from CIE X, Y and Z tristimulus values which have been scaled so that the Y values range from 0.0 to 1.0 (divide by 80). The tristimulus values encoded shall be those produced by the phosphor excitation of a theoretical perfect display which does not include any internal flare or veiling glare (R=0, G=0, B=0 is equivalent to $X_N=0$, $Y_N=0$, $Z_N=0$). A matrix transformation shall be applied to the scaled values (see Section 4.4.2) followed by a nonlinear encoding function for one of three different bit-depths (see Section 4.4.3). The viewer observed image tristimulus values, which include internal flare and veiling glare (both the veiling glare present in the display measurements and the viewing flare in the reference viewing conditions) shall be those that produce the desired color appearance on the reference display when viewed using the reference viewing conditions.

NOTE – Recommended methods for relating theoretical perfect display tristimulus values to viewer observed image tristimulus values with internal flare, measurement veiling glare, and viewing flare are discussed in Annexes D and E.

NOTE – Images intended to be viewed using other viewing conditions, or on a medium different from the reference display, can be encoded in e-sRGB by first determining the corresponding tristimulus values that produce the desired color appearance on the reference display when viewed using the reference viewing conditions. The corresponding tristimulus values can be determined by using an appropriate color appearance transformation to account for the differences between the viewing conditions. Additionally, it may be necessary to account for differences in the media characteristics, and the possibility that the desired appearance may be affected by the viewing conditions.

4.4.2 e-sRGB Conversion Matrix

The following matrix from IEC 61966-2-1 shall be used to compute linear e-sRGB values ($R_{e\text{-}sRGB}$, $G_{e\text{-}sRGB}$ and $B_{e\text{-}sRGB}$) from the image tristimulus values (X_N, Y_N and Z_N):

$$\begin{bmatrix} R_{e-sRGB} \\ G_{e-sRGB} \\ B_{e-sRGB} \end{bmatrix} = \begin{bmatrix} 3.2406 & -1.5372 & -0.4986 \\ -0.9689 & 1.8758 & 0.0415 \\ 0.0557 & -0.2040 & 1.0570 \end{bmatrix} \begin{bmatrix} X_N \\ Y_N \\ Z_N \end{bmatrix} \tag{1}$$

The Y_N values used as the input to equation 1 shall be between 0 and 1.

NOTE – This matrix will map image tristimulus values with the chromaticity of D65 to equal linear e-sRGB values. A D65 chromaticity with a Y_N value of 1.0 will map to linear e-sRGB values of 1.0. A D65 chromaticity with a Y_N value of 0.0 will map to linear e-sRGB values of 0.0.

NOTE – The matrix in equation 1 can be derived from the chromaticities shown in Table 1.

4.4.3 Nonlinear Encoding of e-sRGB

The functional form of the e-sRGB nonlinearity shall be:

If $R_{e\text{-}sRGB}$, $G_{e\text{-}sRGB}$, $B_{e\text{-}sRGB} < -0.0031308$

$$\begin{aligned} R'_{e-sRGB} &= -\left(1.055 \times (-R_{e-sRGB})^{(1.0/2.4)} - 0.055\right) \\ G'_{e-sRGB} &= -\left(1.055 \times (-G_{e-sRGB})^{(1.0/2.4)} - 0.055\right) \\ B'_{e-sRGB} &= -\left(1.055 \times (-B_{e-sRGB})^{(1.0/2.4)} - 0.055\right) \end{aligned} \tag{2a}$$

If $-0.0031308 \le R_{e\text{-}sRGB}$, $G_{e\text{-}sRGB}$, $B_{e\text{-}sRGB} \le 0.0031308$

$$\begin{aligned} R'_{e-sRGB} &= 12.92 \times R_{e-sRGB} \\ G'_{e-sRGB} &= 12.92 \times G_{e-sRGB} \\ B'_{e-sRGB} &= 12.92 \times B_{e-sRGB} \end{aligned} \tag{2b}$$

If $R_{e\text{-}sRGB}$, $G_{e\text{-}sRGB}$, $B_{e\text{-}sRGB} > 0.0031308$

$$\begin{aligned} R'_{e-sRGB} &= 1.055 \times R_{e-sRGB}{}^{(1.0/2.4)} - 0.055 \\ G'_{e-sRGB} &= 1.055 \times G_{e-sRGB}{}^{(1.0/2.4)} - 0.055 \\ B'_{e-sRGB} &= 1.055 \times B_{e-sRGB}{}^{(1.0/2.4)} - 0.055 \end{aligned} \tag{2c}$$

Finally,

$$\begin{aligned} R''_{e-sRGB} &= R'_{e-sRGB} \times 255.0 \times 2^{n-9} + offset \\ G''_{e-sRGB} &= G'_{e-sRGB} \times 255.0 \times 2^{n-9} + offset \end{aligned} \tag{3}$$

$$B''_{e-sRGB} = B'_{e-sRGB} \times 255.0 \times 2^{n-9} + offset$$

where: $$offset = 2^{n-2} + 2^{n-3} \qquad (4)$$

and n is the number of bits used for each of the R, G, and B channels of the encoding.

For e-sRGB10, n shall be 10.
For e-sRGB12, n shall be 12.
For e-sRGB16, n shall be 16.

NOTE – The range of linear $R_{e\text{-}sRGB}$, $G_{e\text{-}sRGB}$, and $B_{e\text{-}sRGB}$ values that can be encoded as e-sRGB is from -0.53 to 1.68.

NOTE – The following table shows sample neutral patch encodings for e -sRGB10, e-sRGB12 and e-sRGB16

Y	e-sRGB10	e-sRGB12	e-sRGB16
0.00000	384	1536	24576
0.01010	435	1741	27856
0.03030	481	1925	30803
0.07071	534	2137	34199
0.14141	594	2376	38023
0.29293	679	2714	43426
0.59596	790	3158	50536
0.79798	846	3383	54126
1.00000	894	3576	57216

4.5 Inverse e-sRGB Encoding

4.5.1 General

The conversion of e-sRGB values back to image tristimulus values is accomplished by inverting the nonlinear functions given in equations 2a, 2b, 2c, and 3, and then applying the inverse of the matrix given in equation 1.

4.5.2 Inverse Nonlinear Encoding of e-sRGB

The nonlinear e-sRGB values shall be converted to linear *e-sRGB* values using equations:

$$\begin{aligned} R'_{e-sRGB} &= \frac{R''_{e-sRGB} - offset}{255.0 \times 2^{n-9}} \\ G'_{e-sRGB} &= \frac{G''_{e-sRGB} - offset}{255.0 \times 2^{n-9}} \\ B'_{e-sRGB} &= \frac{B''_{e-sRGB} - offset}{255.0 \times 2^{n-9}} \end{aligned} \tag{5}$$

where n is the number of bits used for each of the R, G, and B channels of the encoding.

and, if $R'_{e\text{-}sRGB}, G'_{e\text{-}sRGB}, B'_{e\text{-}sRGB} < -0.04045$

$$\begin{aligned} R_{e-sRGB} &= -\left[\left(-R'_{e-sRGB} + 0.055 \right) \big/ 1.055 \right]^{2.4} \\ G_{e-sRGB} &= -\left[\left(-G'_{e-sRGB} + 0.055 \right) \big/ 1.055 \right]^{2.4} \\ B_{e-sRGB} &= -\left[\left(-B'_{e-sRGB} + 0.055 \right) \big/ 1.055 \right]^{2.4} \end{aligned} \tag{6a}$$

if $-0.04045 \leq R'_{e\text{-}sRGB}, G'_{e\text{-}sRGB}, B'_{e\text{-}sRGB} \leq 0.04045$

$$\begin{aligned} R_{e-sRGB} &= R'_{e-sRGB} \div 12.92 \\ G_{e-sRGB} &= G'_{e-sRGB} \div 12.92 \\ B_{e-sRGB} &= B'_{e-sRGB} \div 12.92 \end{aligned} \tag{6b}$$

if $R'_{e\text{-}sRGB}$, $G'_{e\text{-}sRGB}$, $B'_{e\text{-}sRGB} > 0.04045$

$$\begin{aligned} R_{e-sRGB} &= \left[\left(R'_{e-sRGB} + 0.055\right) / 1.055 \right]^{2.4} \\ G_{e-sRGB} &= \left[\left(G'_{e-sRGB} + 0.055\right) / 1.055 \right]^{2.4} \\ B_{e-sRGB} &= \left[\left(B'_{e-sRGB} + 0.055\right) / 1.055 \right]^{2.4} \end{aligned} \tag{6c}$$

4.5.3 Inverse e-sRGB Conversion Matrix

The conversion from linear e-sRGB values ($R_{e\text{-}sRGB}$, $G_{e\text{-}sRGB}$ and $B_{e\text{-}sRGB}$) to the corresponding image tristimulus values (X_N, Y_N and Z_N) shall be given by:

$$\begin{bmatrix} X_N \\ Y_N \\ Z_N \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} R_{e-sRGB} \\ G_{e-sRGB} \\ B_{e-sRGB} \end{bmatrix} \tag{7}$$

NOTE – When this matrix is applied to linear e-sRGB values that are equal, image tristimulus values with the chromaticity of D65 are obtained.

4.6 File Format Requirements

e-sRGB image data shall only be exchanged in open systems using image file formats which identify the image data as e-sRGB and require correct interpretation, or include a restricted ICC profile as specified in ISO/IEC 15444-1 (including amendments), which allows readers and applications that do not recognize e-sRGB image data to interpret it correctly.

Annex A

(normative)

Conversions Between e-sRGB and sRGB Encodings

A.1 General

The relationship between sRGB and e-sRGB is defined so that conversion may take place with simple bit shifting, addition, and subtraction. For the conversion from sRGB to e-sRGB, the computationally simple relationship provides easy integration of sRGB data into e-sRGB workflows and imaging pipelines with negligible latency impact. For the case where data is moving from e-sRGB to sRGB, larger gamut data must be mapped into a smaller gamut. The best gamut mapping approach depends on the computational capabilities of the system, the color rendering performed to produce the e-sRGB image data, the image quality goals of the designer, and the quality expectations of the customer.

This annex specifies transformations between sRGB and e-sRGB. The computationally simple and exact transformation specified is required when converting from sRGB to e-sRGB. A default transformation that utilizes RGB clipping is provided for converting from e-sRGB to sRGB, however it is anticipated that more advanced gamut mapping algorithms may be employed for this conversion. Such algorithms may improve the mapping of colors outside the sRGB gamut.

NOTE – Care should be taken when applying more advanced gamut mapping when converting from e-sRGB to sRGB, to assure some real benefit. The color rendering used in producing the e-sRGB image data in the first place should assume the default gamut mapping transform. Unsatisfactory results could be obtained if an alternative transform is used. For example, an ICC input profile that maps the full e-sRGB gamut directly to the XYZ PCS should not be used with an sRGB output profile, if the CMM performs gamut mapping by clipping the XYZ values. Clipping XYZ values will produce a different, unexpected result from clipping RGB values. In this example, an input profile that clips to sRGB on input should be used with the sRGB output profile. On the other hand, the RGB clipping specified in the default transform can produce substantial hue errors for colors far outside the sRGB gamut. If such colors are utilized in an e-sRGB encoding, it may be beneficial to employ a sophisticated gamut mapping algorithm that maintains constant hue and lightness.

The following transformations also provide numerical accuracy for conversion of 8-bit sRGB values to e-sRGB. 8-bit sRGB values are exactly represented in e-sRGB with no roundoff error. For *n*-bit e-sRGB, an integer number of bits represent the sRGB range. One additional bit is added to provide encoding space for the extended range. The default conversion equations between *n*-bit e-sRGB and 8-bit sRGB are provided below.

A.2 Conversion from sRGB to e-sRGB

The conversion of 8-bit sRGB values to *n*-bit e-sRGB values shall be accomplished as follows:

$$\begin{aligned} R'_{e-sRGB} &= R'_{sRGB} \times 2^{n-9} + offset \\ G'_{e-sRGB} &= G'_{sRGB} \times 2^{n-9} + offset \\ B'_{e-sRGB} &= B'_{sRGB} \times 2^{n-9} + offset \end{aligned} \qquad \text{(A1)}$$

where the offset is calculated using equation 4 and *n* is the number of bits used for each of the R, G, and B channels of the e-sRGB encoding.

A.3 Conversion from e-sRGB to sRGB

The conversion of *n*-bit e-sRGB values to 8-bit sRGB values may be accomplished as follows:

$$\begin{aligned} R'_{sRGB} &= \left(R'_{e-sRGB} - offset\right) \div 2^{n-9} \\ G'_{sRGB} &= \left(G'_{e-sRGB} - offset\right) \div 2^{n-9} \\ B'_{sRGB} &= \left(B'_{e-sRGB} - offset\right) \div 2^{n-9} \end{aligned} \qquad \text{(A2)}$$

where the offset is calculated using equation 4 and *n* is the number of bits used for each of the R, G, and B channels of the e-sRGB encoding.

NOTE – Although the above transform from e-sRGB to sRGB implies gamut clipping if applied to integer values, it is expected that capable devices may employ more sophisticated gamut mapping to convert from e-sRGB to sRGB. Where possible, e-sRGB data should not be arbitrarily clipped down to sRGB in imaging workflows; the conversion to sRGB should only be used for compatibility with sRGB displays and legacy sRGB workflows.

Annex B

(normative)

e-sYCC Color Encoding

B.1 Conversion from e-sRGB to e-sYCC

The transformation from *n*-bit e-sRGB values R''_{e-sRGB}, G''_{e-sRGB}, B''_{e-sRGB} to *m*-bit e-sYCC shall be as follows:

$$\begin{aligned} R'_{e-sRGB} &= \frac{R''_{e-sRGB} - offset}{255.0 \times 2^{n-9}} \\ G'_{e-sRGB} &= \frac{G''_{e-sRGB} - offset}{255.0 \times 2^{n-9}} \\ B'_{e-sRGB} &= \frac{B''_{e-sRGB} - offset}{255.0 \times 2^{n-9}} \end{aligned} \qquad \text{(B1)}$$

where: $$offset = 2^{n-2} + 2^{n-3} \qquad \text{(B2)}$$

Then a modified version of the ITU-R BT.601-5 YCbCr conversion, where the chrominance magnitude is reduced by a factor of two, is applied:

$$\begin{aligned} Y'_{e-sYCC} &= 0.299R'_{e-sRGB} + 0.587G'_{e-sRGB} + 0.114B'_{e-sRGB} \\ Cb'_{e-sYCC} &= \left(B'_{e-sRGB} - Y'_{e-sYCC}\right)/\,3.544 \\ Cr'_{e-sYCC} &= \left(R'_{e-sRGB} - Y'_{e-sYCC}\right)/\,2.804 \end{aligned} \qquad \text{(B3)}$$

or equivalently:

$$\begin{bmatrix} Y'_{e-sYCC} \\ Cb'_{e-sYCC} \\ Cr'_{e-sYCC} \end{bmatrix} = \begin{bmatrix} 0.2990 & 0.5870 & 0.1140 \\ -0.0844 & -0.1656 & 0.2500 \\ 0.2500 & -0.2091 & -0.0407 \end{bmatrix} \begin{bmatrix} R'_{e-sRGB} \\ G'_{e-sRGB} \\ B'_{e-sRGB} \end{bmatrix} \qquad \text{(B4)}$$

resulting in Y'_{e-sYCC} which, except for the Y encoding limitations in 4.4.2 could range from approximately –0.75 to 1.25, and Cb'_{e-sYCC}, Cr'_{e-sYCC} ranging from –0.5 to 0.5. The subset within this space where luma ranges from 0.0 to 1.0, and chroma ranges from -0.25 to 0.25 is equivalent to the YCbCr space derived from applying transform B4 to sRGB, and corresponds to the YcbCr space derived by applying the standard Rec. 601 transform to sRGB, and then dividing the chrominance values by two.

For digital encoding of e-sYCC, the luma channel is clipped to the 0.0 to 1.0 range. This gives improved bit depth utilization with negligible impact on potential gamut encoding size. The chroma channels are left to range from –0.5 to 0.5.

The *m*-bit encoding shall be:

If $Y'_{e-sYCC} < 0.0$ $$Y''_{e-sYCC} = 0 \qquad \text{(B5a)}$$

If $0.0 \leq Y'_{e-sYCC} \leq 1.0$ $$Y''_{e-sYCC} = Y'_{e-sYCC} \times \left(2^{m} - 1\right) \qquad \text{(B5b)}$$

If $Y'_{e-sYCC} > 1.0$ $$Y''_{e-sYCC} = 2^m - 1 \tag{B5c}$$

For the chroma channels,

$$\begin{aligned} Cb''_{e-sYCC} &= \left(2^m - 1\right) \times Cb'_{e-sYCC} + 2^{m-1} \\ Cr''_{e-sYCC} &= \left(2^m - 1\right) \times Cr'_{e-sYCC} + 2^{m-1} \end{aligned} \tag{B6}$$

B.2 Conversion from e-sYCC to e-sRGB

The transformation from *m*-bit e-sYCC values to *n*-bit e-sRGB shall be as follows:

$$Y'_{e-sYCC} = \frac{Y''_{e-sYCC}}{2^m - 1} \tag{B7}$$

$$\begin{aligned} Cb'_{e-sYCC} &= \frac{Cb''_{e-sYCC} - 2^{m-1}}{2^m - 1} \\ Cr'_{e-sYCC} &= \frac{Cr''_{e-sYCC} - 2^{m-1}}{2^m - 1} \end{aligned} \tag{B8}$$

$$\begin{bmatrix} R'_{e-sRGB} \\ G'_{e-sRGB} \\ B'_{e-sRGB} \end{bmatrix} = \begin{bmatrix} 1.0000 & 0.0000 & 2.804 \\ 1.0000 & -0.6882 & -1.4282 \\ 1.0000 & 3.5440 & 0.0003 \end{bmatrix} \begin{bmatrix} Y'_{e-sYCC} \\ Cb'_{e-sYCC} \\ Cr'_{e-sYCC} \end{bmatrix} \tag{B9}$$

$$\begin{aligned} R''_{e-sRGB} &= R'_{e-sRGB} \times 255.0 \times 2^{n-9} + offset \\ G''_{e-sRGB} &= G'_{e-sRGB} \times 255.0 \times 2^{n-9} + offset \\ B''_{e-sRGB} &= B'_{e-sRGB} \times 255.0 \times 2^{n-9} + offset \end{aligned} \tag{B10}$$

where: $$offset = 2^{n-2} + 2^{n-3} \tag{B11}$$

Annex C

(normative)

Conversions between e-sRGB and sRGB YCC encodings

The sRGB based YCbCr color encoding consistent with ITU-R BT.601-5, which is specified in a proposed amendment to ISO/IEC 15444-1 as sRGB YCC, potentially spans a larger gamut than sRGB. Conceptually, this potential exists because the sRGB gamut within the YCbCr encoding range is geometrically shaped like a diamond within a cube. There is significant unused encoding range in chromatic areas that are lighter and darker than the sRGB primaries and secondaries. Much of the gamut mismatch between sRGB and reflectance prints is due to the lack of coverage that sRGB provides for dark chromatic colors. Utilizing the e-sRGB nonlinearity to define the extended gamut region of sRGB YCC allows for the transmission of image data which gives significantly better gamut coverage of consumer imaging devices than sRGB alone, while taking advantage of the current widespread use of sRGB YCC image data exchange.

This annex specifies transformations between e-sRGB to sRGB YCC. In cases where the e-sRGB gamut used is fully contained in the sRGB YCC gamut, no gamut mapping is required and there will be an exact correspondence between the sRGB image data and the e-sRGB image data represented using the sRGB YCC encoding. This will be the case when transforming from sRGB YCC to e-sRGB. In cases where the e-sRGB gamut used extends beyond the sRGB YCC gamut, some gamut mapping will be required prior to transforming the e-sRGB image data to sRGB YCC. The conversion from e-sRGB to sRGB YCC specified here utilizes clipping, however it is anticipated that more advanced gamut mapping algorithms may be employed.

C.1 Conversion from e-sRGB to sRGB YCC

The transformation from *n*-bit e-sRGB values R''_{e-sRGB}, G''_{e-sRGB}, B''_{e-sRGB} to *m*-bit sRGB YCC should be as follows:

$$\begin{aligned} R'_{e-sRGB} &= \frac{R''_{e-sRGB} - offset}{255.0 \times 2^{n-9}} \\ G'_{e-sRGB} &= \frac{G''_{e-sRGB} - offset}{255.0 \times 2^{n-9}} \\ B'_{e-sRGB} &= \frac{B''_{e-sRGB} - offset}{255.0 \times 2^{n-9}} \end{aligned} \quad \text{(C1)}$$

where:

$$offset = 2^{n-2} + 2^{n-3} \quad \text{(C2)}$$

Then the ITU-R BT.601-5 YCbCr conversion is applied:

$$\begin{aligned} Y'_{sRGBYCC} &= 0.299R'_{e-sRGB} + 0.587G'_{e-sRGB} + 0.114B'_{e-sRGB} \\ Cb'_{sRGBYCC} &= \left(B'_{e-sRGB} - Y'_{sRGBYCC}\right)/1.772 \\ Cr'_{sRGBYCC} &= \left(R'_{e-sRGB} - Y'_{sRGBYCC}\right)/1.402 \end{aligned} \quad \text{(C3)}$$

or equivalently:

$$\begin{bmatrix} Y'_{sRGBYCC} \\ Cb'_{sRGBYCC} \\ Cr'_{sRGBYCC} \end{bmatrix} = \begin{bmatrix} 0.2990 & 0.5870 & 0.1140 \\ -0.1687 & -0.3313 & 0.5000 \\ 0.5000 & -0.4187 & -0.0813 \end{bmatrix} \begin{bmatrix} R'_{e-sRGB} \\ G'_{e-sRGB} \\ B'_{e-sRGB} \end{bmatrix} \quad \text{(C4)}$$

The resulting $Y'_{sRGBYCC}$ values are clipped into a range of 0 to 1, and the resulting $Cb'_{sRGBYCC}$ and $Cr'_{sRGBYCC}$ are clipped into a range of -0.5 to 0.5.

The *m*-bit sRGB YCC encoding is:

$$Y''_{sRGBYCC} = Y'_{sRGBYCC} \times \left(2^{m} - 1\right) \tag{C5}$$

For the chroma channels,

$$\begin{aligned} Cb''_{sRGBYCC} &= \left(2^{m} - 1\right) \times Cb'_{sRGBYCC} + 2^{m-1} \\ Cr''_{sRGBYCC} &= \left(2^{m} - 1\right) \times Cr'_{sRGBYCC} + 2^{m-1} \end{aligned} \tag{C6}$$

C.2 Conversion from sRGB YCC to e-sRGB

The conversion from *m*-bit sRGB YCC to *n*-bit e-sRGB shall be as follows:

$$Y'_{e-sYCC} = \frac{Y''_{sRGBYCC}}{2^{m} - 1} \tag{C7}$$

$$\begin{aligned} Cb'_{e-sYCC} &= \frac{\dfrac{Cb''_{sRGBYCC}}{2^{m} - 1} - 0.5}{2} \\ Cr'_{e-sYCC} &= \frac{\dfrac{Cr''_{sRGBYCC}}{2^{m} - 1} - 0.5}{2} \end{aligned} \tag{C8}$$

Finally, equations B9 through B11 are applied from Annex B to produce the *n*-bit e-sRGB values.

Annex D

(informative)

Viewer Observed CRT Display Colorimetry and Black Point

In 4.3.4, the following requirement is stated for e-sRGB encoding: "Color rendering shall be performed as necessary to produce the desired image appearance on the reference display for encoding as e-sRGB." The performance of color rendering is a normative requirement, but the nature of the color rendering is left open. Methods for performing color rendering are largely proprietary, and objectives are frequently application specific. The details of how to perform color rendering are beyond the scope of this standard.

The color rendering requirement forces a distinct division of labor. Devices producing e-sRGB must perform all color rendering necessary to produce the desired standard output-referred appearance. Devices consuming e-sRGB image data must assume that the colorimetry represented by the data is the desired colorimetry on the reference display viewed using the reference viewing conditions.

In practice, sRGB data is sent directly (without adjustment) to a real CRT display calibrated according to the specifications in IEC 61966-2-1. This practice is consistent with the intent of sRGB, which was designed to provide simple, computationally efficient color management. e-sRGB was designed and optimized for compatibility with existing sRGB images, processes and workflows. From this design intent, it follows that the 8-bit sRGB portion of e-sRGB is to be sent directly (without adjustment) to a real CRT display calibrated according to the specifications in IEC 61966-2-1.

Accounting for the colorimetry that a viewer observes on a CRT display is necessary both for correctly color rendering data for the display, and further reproducing the displayed data with a non-reference device, such as a color printer. While algorithms for rendering to and from sRGB are generally proprietary, such algorithms often require knowledge of the viewer observed black point of the display and the corresponding viewer observed colorimetry. In Annex D of IEC 61966-2-1, the typical display surface reflectance is listed as 5%, excluding the specular component. This value is consistent with experience in photography and graphic technology, and correlates to a viewer observed black point in the reference viewing conditions of 1.0 cd/m^2.

The chromaticity of the viewer observed black point results from a combination of the chromaticity of the ambient illumination, the spectral reflectance of the CRT display, and the chromaticity of the internal flare. Many color rendering algorithms and color transformations are not capable of efficiently addressing a black point with a chromaticity different from that of the white point. Furthermore, there is variation both in the spectral reflectance and internal flare of CRT displays. Therefore, it is practical to define the chromaticity of the black point to be the same as the whitepoint (D65).

A luminance of 1.0 cd/m^2 in the sRGB viewing conditions, with the chromaticity of CIE Standard Illuminant D65 (x = 0.3127, y = 0.3290) gives viewer observed black point tristimulus values of:

$$X_{K,V} = 0.95,\ Y_{K,V} = 1.00,\ Z_{K,V} = 1.09.$$

These are the recommended viewer observed black point tristimulus values for use in determining viewer observed colorimetry. They include contributions from internal flare and veiling glare, but not from instrument flare.

Note that the *viewer observed black point* luminance value recommended above is different from the *reference display black point* luminance value specified in 4.3.2. Display black point luminance values on the order of those specified in 4.3.2 are consistent with measurement where ambient illumination is blocked from the display faceplate. Commonly, ambient illumination is not blocked from a CRT in typical viewing environments. Therefore, using the *viewer observed black point* defined above generally results in more accurate and pleasing color reproduction. If the reference display black point luminance specified in 4.3.2 are used to determine viewer observed colorimetry, some color rendering algorithms may produce sRGB and e-sRGB digital values which are not optimally suited for direct display in the reference viewing conditions. In producing the image data, these color rendering algorithms will assume the viewer observed colorimetry is somewhat darker and of higher chroma than is actually observed, resulting in potentially washed-out blacks and slightly desaturated colors.

Annex E

(informative)

Recommendations for Transforming Between e-sRGB and ROMM RGB, and for Constructing e-sRGB ICC Profiles

E.1 Conversions Between e-sRGB and ROMM RGB

The following differences must be addressed to convert back and forth between e-sRGB and ROMM RGB:

1. different e-sRGB and ROMM RGB nonlinear encodings
2. e-sRGB D65 white point chromaticity and ROMM RGB D50 white point chromaticity
3. e-sRGB ITU-R BT.709 primaries and ROMM RGB primaries
4. e-sRGB white point luminance of 80 cd/m^2 and ROMM RGB media white point luminance of 142 cd/m^2
5. e-sRGB viewer observed media black point luminance of 1.0 cd/m2 and ROMM RGB media black point luminance of 0.5 cd/m^2, with additional viewing flare luminance of 1.2 cd/m^2

NOTE – Viewing flare is defined to be veiling glare that is observed in specified viewing conditions but not accounted for in radiometric measurements made using a prescribed measurement geometry. In the case of e-sRGB, the prescribed measurement geometry includes all observer viewed veiling glare and internal flare, so there is no viewing flare due to the reference viewing conditions (although there may be some in more typical viewing conditions). In the case of ROMM RGB, the viewing flare is specified to be 0.75% of the observer adaptive white in the reference viewing conditions. The measurement conditions are analogous to 45/0 or 0/45 reflection densitometry as specified in ISO 5-4 and ISO 13655. The result of these specifications is that the media characteristics and viewing conditions are sufficiently similar to preclude the necessity of explicit adjustments to accommodate differences. It is reasonable to consider the viewer observed black point, viewing flare, and image luminance level differences to essentially cancel out, in which case the encoded e-sRGB linear values can be directly transformed to normalized ROMM RGB linear values, and vice-versa.

The following general procedure is recommended for converting from e-sRGB to ROMM RGB:

1. Invert the nonlinear encoding as specified in equations 5, 6a, 6b, and 6c to produce linear e-sRGB values that range from –0.53 and 1.68.
2. Apply a matrix to transform the primaries and perform the chromatic adaptation. The following matrix employs a linear Bradford type chromatic adaptation transform:

$$\begin{bmatrix} R_{ROMM} \\ G_{ROMM} \\ B_{ROMM} \end{bmatrix} = \begin{bmatrix} 0.529 & 0.330 & 0.141 \\ 0.098 & 0.874 & 0.028 \\ 0.017 & 0.118 & 0.865 \end{bmatrix} \begin{bmatrix} R_{e-sRGB} \\ G_{e-sRGB} \\ B_{e-sRGB} \end{bmatrix} \qquad \text{(E1)}$$

3. Clip the resulting linear ROMM RGB values to range between 0 and 1.
4. Apply the ROMM RGB nonlinear encoding as specified in 4.4.4 of PIMA 7666.

NOTE – The above transform will essentially maintain the image appearance encoded in e-sRGB in ROMM RGB, except for clipping (which should be minimal). In some cases, it may be appropriate to perform color rendering to produce a slightly different appearance when transforming to ROMM RGB.

The following general procedure is recommended for converting from ROMM RGB to e-sRGB:

1. Invert the nonlinear encoding as specified in 4.5.2 of PIMA 7666 to produce linear ROMM RGB values that range from 0 and 1.
2. Apply a matrix to transform the primaries and perform the chromatic adaptation. The following matrix employs a

linear Bradford type chromatic adaptation transform:

$$\begin{bmatrix} R_{e-sRGB} \\ G_{e-sRGB} \\ B_{e-sRGB} \end{bmatrix} = \begin{bmatrix} 2.034 & -0.727 & -0.307 \\ -0.229 & 1.232 & -0.003 \\ -0.009 & -0.153 & 1.162 \end{bmatrix} \begin{bmatrix} R_{ROMM} \\ G_{ROMM} \\ B_{ROMM} \end{bmatrix} \qquad \text{(E2)}$$

3. Apply the e-sRGB nonlinear encoding as specified in 4.4.3.

NOTE – The above transform will essentially maintain the image appearance encoded in ROMM RGB in e-sRGB. In some cases, it may be appropriate to perform color rendering to produce a slightly different appearance when transforming to ROMM RGB, particularly considering the e-sRGB reference display rendering intent specified in 4.3.4.

E.2 Constructing ICC.1:1998-09 (version 2) Profiles

The following general recommendation is provided for constructing e-sRGB ICC Profile Format Specification version 2 input profiles:

1. Invert the nonlinear encoding as specified in equations 5, 6a, 6b, and 6c to produce linear e-sRGB values that range from –0.53 and 1.68.

NOTE – The scaling of ICC profiles for different bit-depths by the CMM is different from the scaling of the nonlinearity specified in equation 3 (and inverted in equation 5) for different bit depths of e-sRGB. The e-sRGB scaling is required to maintain exact correspondence between the quantized levels of the different bit depths of e-sRGB, and between sRGB and e-sRGB. Because of this scaling difference, exact e-sRGB ICC profiles will be slightly different for each bit-depth. However, in some applications the e-sRGB(16) profile may provide acceptable results with e-sRGB(10) and e-sRGB(12), because the maximum error caused by the scaling difference in transforming the e-sRGB encoded image colorimetry to the ICC PCS will be equivalent in magnitude to a change of one e-sRGB digital count. Larger errors up to 0.1% are obtained if e-sRGB(10) or e-sRGB(12) profiles are used without matching the profile bit depth to the e-sRGB bit depth. It is therefore recommended that the e-sRGB(16) profile be used where it is desirable to use a single e-sRGB profile for different e-sRGB bit depths, and the error introduced is not considered significant. Because of potential for the introduction of errors, it is also recommended that transformations between e-sRGB and ICC color processing workflows be minimized.

2. Apply a matrix to transform the linear e-sRGB values to CIE *XYZ* tristimulus values and perform the chromatic adaptation. The following matrix employs a linear Bradford type chromatic adaptation transform:

$$\begin{bmatrix} X_N \\ Y_N \\ Z_N \end{bmatrix} = \begin{bmatrix} 0.436 & 0.385 & 0.143 \\ 0.223 & 0.717 & 0.061 \\ 0.014 & 0.097 & 0.714 \end{bmatrix} \begin{bmatrix} R_{e-sRGB} \\ G_{e-sRGB} \\ B_{e-sRGB} \end{bmatrix} \qquad \text{(E3)}$$

3. Clip the resulting linear CIE *XYZ* tristimulus values to range between 0 and 1.
4. Apply the ICC PCS encoding.

The following general recommendation is provided for constructing e- sRGB ICC Profile Format Specification version 2 output profiles:

1. Convert the PCS encoding to produce linear CIE *XYZ* tristimulus values that range from 0 and 1.
2. Apply a matrix to transform the CIE *XYZ* tristimulus values to linear e-sRGB values and perform the chromatic adaptation. The following matrix employs a linear Bradford type chromatic adaptation transform:

$$\begin{bmatrix} R_{e-sRGB} \\ G_{e-sRGB} \\ B_{e-sRGB} \end{bmatrix} = \begin{bmatrix} 3.134 & -1.617 & -0.491 \\ -0.979 & 1.916 & 0.034 \\ 0.072 & -0.229 & 1.405 \end{bmatrix} \begin{bmatrix} X_N \\ Y_N \\ Z_N \end{bmatrix} \qquad \text{(E4)}$$

3. Apply the e-sRGB nonlinear encoding as specified in 4.4.3.

E.3 Constructing ICC.1:2001 (version 4) Perceptual Intent Profiles

The following additional inverse tristimulus value normalization step is recommended for constructing e-sRGB ICC Profile Format Specification version 4 perceptual intent input profiles:

$$\begin{aligned} X_{PCS} &= X_N \times \left(X_{P,W} - X_{P,K}\right) \times \frac{Y_{P,W}}{X_{P,W}} + X_{P,K} \\ Y_{PCS} &= Y_N \times \left(Y_{P,W} - Y_{P,K}\right) + Y_{P,K} \\ Z_{PCS} &= Z_N \times \left(Z_{P,W} - Z_{P,K}\right) \times \frac{Y_{P,W}}{Z_{P,W}} + Z_{P,K} \end{aligned} \tag{E5}$$

where X_N, Y_N and Z_N are the image tristimulus values as determined in E.2 input profile step 3, X_{PCS}, Y_{PCS} and Z_{PCS} are the image tristimulus values to be transformed to ICC PCS values, $X_{P,W}$, $Y_{P,W}$ and $Z_{P,W}$ are the tristimulus values of the ICC PCS perceptual intent white point, and $X_{P,K}$, $Y_{P,K}$ and $Z_{P,K}$ are the tristimulus values of the ICC PCS perceptual intent black point.

The following additional tristimulus value normalization step is recommended for constructing e-sRGB ICC Profile Format Specification version 4 perceptual intent output profiles:

$$\begin{aligned} X_N &= \frac{\left(X_{PCS} - X_{P,K}\right) X_{P,W}}{\left(X_{P,W} - X_{P,K}\right) Y_{P,W}} \\ Y_N &= \frac{\left(Y_{PCS} - Y_{P,K}\right)}{\left(Y_{P,W} - Y_{P,K}\right)} \\ Z_N &= \frac{\left(Z_{PCS} - Z_{P,K}\right) Z_{P,W}}{\left(Z_{P,W} - Z_{P,K}\right) Y_{P,W}} \end{aligned} \tag{E6}$$

where X_N, Y_N and Z_N are the image tristimulus values to be matrixed in E.2 output profile step 2, X_{PCS}, Y_{PCS} and Z_{PCS} are the image tristimulus values determined from the ICC PCS values, $X_{P,W}$, $Y_{P,W}$ and $Z_{P,W}$ are the tristimulus values of the ICC PCS perceptual intent white point, and $X_{P,K}$, $Y_{P,K}$ and $Z_{P,K}$ are the tristimulus values of the ICC PCS perceptual intent black point.

NOTE – Equations E5 and E6 map the e-sRGB viewer observed black point to and from the ICC perceptual intent reference medium black point.

E.4 Constructing ICC.1:2001 (version 4) Colorimetric Intent Profiles

The following additional inverse tristimulus value normalization step is recommended for constructing e-sRGB ICC Profile Format Specification version 4 colorimetric intent input profiles:

$$\begin{aligned} X_{V50} &= X_N \times \left(X_{W50} - X_{K,V50}\right) \times \frac{Y_{W50}}{X_{W50}} + X_{K,V50} \\ Y_{V50} &= Y_N \times \left(Y_{W50} - Y_{K,V50}\right) + Y_{K,V50} \\ Z_{V50} &= Z_N \times \left(Z_{W50} - Z_{K,V50}\right) \times \frac{Y_{W50}}{Z_{W50}} + Z_{K,V50} \end{aligned} \tag{E7}$$

where X_N, Y_N and Z_N are the image tristimulus values as determined in E.2 input profile step 3, X_{V50}, Y_{V50} and Z_{V50} are the e-sRGB viewer observed image tristimulus values converted to a D_{50} adapted white point using matrix E3 (to be converted to PCS values), X_{W50}, Y_{W50} and Z_{W50} are the tristimulus value of the e-sRGB reference display white point given in Section 4.3.1 converted to D_{50} using matrix E3, and $X_{K,V50}$, $Y_{K,V50}$ and $Z_{K,V50}$ are the tristimulus values of the e-sRGB viewer observed black point provided in Annex D converted to D_{50} using matrix E3.

The following additional tristimulus value normalization step is recommended for constructing e-sRGB ICC Profile Format Specification version 4 colorimetric intent output profiles:

$$
\begin{aligned}
X_N &= \frac{\left(X_{V50} - X_{K,V50}\right)X_{W50}}{\left(X_{W50} - X_{K,V50}\right)Y_{W50}} \\
Y_N &= \frac{\left(Y_{V50} - Y_{K,V50}\right)}{\left(Y_{W50} - Y_{K,V50}\right)} \\
Z_N &= \frac{\left(Z_{V50} - Z_{K,V50}\right)Z_{W50}}{\left(Z_{W50} - Z_{K,V50}\right)Y_{W50}}
\end{aligned}
\qquad \text{(E8)}
$$

where X_N, Y_N and Z_N are the image tristimulus values to be matrixed in E.2 output profile step 2, X_{V50}, Y_{V50} and Z_{V50} are the e-sRGB viewer observed image tristimulus values converted to a D_{50} adapted white point using matrix E3, X_{W50}, Y_{W50} and Z_{W50} are the tristimulus value of the e-sRGB reference display white point given in Section 4.3.1 converted to D_{50} using matrix E3, and $X_{K,V50}$, $Y_{K,V50}$ and $Z_{K,V50}$ are the tristimulus values of the e-sRGB viewer observed black point provided in Annex D converted to D_{50} using matrix E3.

NOTE – Since the e-sRGB media white point has a luminance factor of 1.0 and the chromaticity of CIE Illuminant D_{50} in the ICC PCS, there is no difference between absolute and relative colorimetric intent profiles.

Annex F

(informative)

e-sRGB Color Encoding Design Considerations

F.1 Big RGB Color Spaces and Encodings

RGB color encodings provide an intuitive and convenient way to communicate color. sRGB is an example of an RGB color encoding that is based on the characteristics of a typical computer CRT display. One limitation of sRGB is that the gamut of a CRT does not encompass the large color gamuts that today's inkjet printers are able to produce on special media. Figure F1 gives a comparison of the sRGB gamut space with the gamut of a CMYK inkjet printer on glossy photo media.

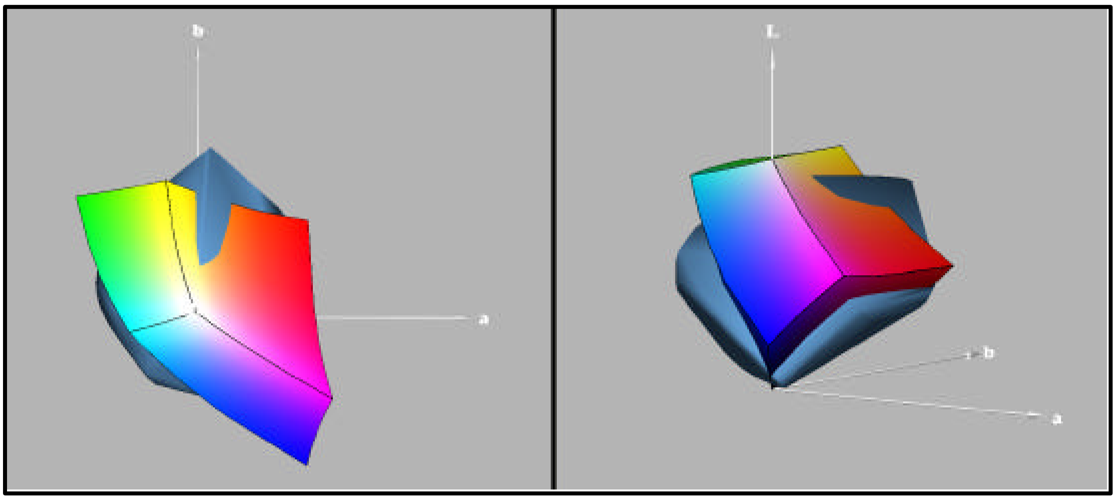

*Figure F1: CIE L*a*b* Space Comparison of sRGB gamut (multicolor surface) and photo inkjet.*

Figure F1 shows that sRGB cannot accurately represent many of the dark chromatic colors that the printer can print on photo media. Virtually all printer colors that are printed at the ink-capacity limit of the media are out of the sRGB gamut. From the perspective of printers, this gamut mismatch is the primary reason for investing in a new color standard for consumer imaging.

A number of large RGB color spaces, such as Adobe RGB, Bruce RGB, SMPTE-240 RGB, and Colormatch RGB, have been proposed for interchange and editing in the imaging industry. The majority of proposed RGB spaces do not have the necessary gamut size to cover photo inkjet printers. A space that does not meet the basic objective of covering the gamut of most color reproduction devices should not be considered for a future imaging standard.

The scRGB proposal does have the gamut size required to cover color reproduction devices. However, it appears from the draft versions of the specification that scRGB is scene-referred. It accommodates over-range values of approximately 8 times the adopted white. Large amounts of headroom are necessary for scene-referred encodings to accommodate highlights which have not undergone color rendering, but are wasteful for output-referred encodings. Furthermore, scene-referred encodings should not be used for general image data interchange. Special image processing workflows that include color rendering are required to correctly interpret scene-referred image data.

Another proposed standard is Kodak's ROMM RGB encoding. ROMM-RGB is output-referred, and for many nonsRGB centric workflows, ROMM RGB is an attractive option. However, given the pervasiveness of sRGB in the consumer marketplace, there are compelling reasons to also define an encoding that is much more compatible with sRGB. As defined, ROMM RGB is print centric, with extended RGB primaries, a D50 whitepoint and an effective gamma of 1.8. sRGB is CRT display centric, with a D65 whitepoint and an effective gamma of 2.2. As a result, translating pixel values between sRGB and ROMM involves applying two 1D LUTs and a 3x3 matrix. This transformation is more complex than a single 1D LUT, and can lead to inconsistent output if different chromatic adaptation methods are used. A similar conversion can be accomplished using a 1D LUT for a color encoding formed by simply extending the encoding range of the original sRGB space. Finally, when moving from sRGB to ROMM RGB, knowledge of the sRGB gamut surface is lost. Careful control of the sRGB gamut surface is desirable when mapping into particular device spaces such as CMYK. For example, this control allows a color printer to translate CRT device yellow to a printer device yellow that is entirely unpolluted with cyan or magenta ink. For many applications, the extended sRGB approach provides an elegant solution to the issue of sRGB compatibility and computational efficiency.

F.2 Extended Range sRGB Color Space

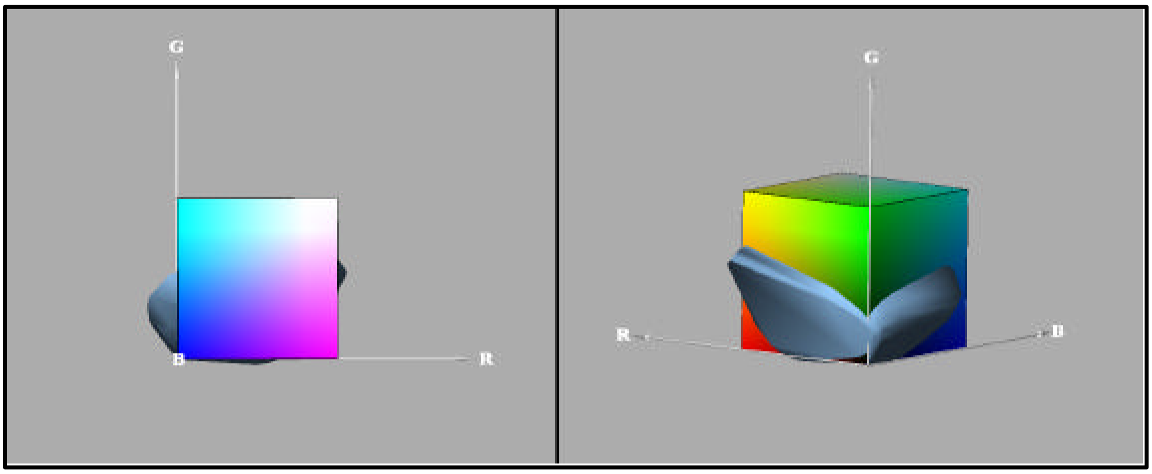

Figure F2: sRGB compared to a photo inkjet in sRGB space.

Figure F2 compares a typical large photo printer gamut with the sRGB gamut in a linear-luminance sRGB space. This RGBspace is a 3x3 transform from CIE *XYZ* where the color gamut of sRGB display space is represented as a unit cube. The color gamut for a typical photo inkjet printer is also shown for comparison, and can be seen to extend beyond the sRGB gamut in many regions. Imagine that we simply scale the sRGB solid a small amount, and then re-center it so that it covers both the printer and monitor gamuts. This is equivalent to allowing sRGB values to range into negative values and overflow values. The concept of negative color values is fairly simple to understand with some knowledge of complementary additive colors. For example, positive red gives increasing red chroma and increasing lightness. Negative red gives increasing cyan chroma, and decreasing lightness. Cyan is the complement of red. Similarly, negative green and blue contributes to higher chroma and darker colors in magenta and yellow, respectively. Extending into this negative range gives the design freedom to define a new large-gamut sRGB space for imaging.

F.3 Extended Range sRGB Encoding Definition

An extended range sRGB encoding must combine color science considerations such as gamut size and gamma functions with computational considerations. For compatibility with sRGB, the same Reference Display Conditions, Reference Viewing Conditions, and Reference Observer Conditions that are defined in the IEC sRGB standard are used. The encoding of e-sRGB is defined to be closely related to sRGB. The definition exactly encodes eight bit sRGB. In addition, the size of the encoding range is increased by 75% in the negative region and 25% in the positive overflow region. A minimum of nine bits is required to represent the original sRGB along with the extended gamut region, and additional bits can be used to encode more tone levels. To simplify implementation, but also provide flexibility, encoding size has been standardized to only a few different bit depths: 10, 12, and 16 bits per channel. The relationship between sRGB and e-sRGB is defined so that conversion can take place with simple bit shifting, addition, and subtraction. In addition, 8-bit sRGB values are exactly represented in e-sRGB with no roundoff error. To meet these objectives, an integer number of bits represent the sRGB range. One additional bit is added to provide encoding space for the extended range.

F.4 Gamut Size

To design the extended range sRGB encoding, it was necessary to determine the range that will give coverage of both the CRT gamut and printer gamuts. Table F1 provides the range in linear luminance sRGB required to cover the gamuts of a number of different printers. These printers utilize different inks, and are tested on their recommended media. Also included in Table F1 are values for the Pantone coated color set, and the sRGB optimal color space gamut given by Hill et al. [2]. The optimal color space gamut is the reflectance color space of block dyes with moving vertical flanks, illuminated with D65.

Gamut	R Range	G Range	B Range
sRGB	(0.000, 1.000)	(0.000, 1.000)	(0.000, 1.000)
Inkjet 1, 4-ink, photo media	(-0.188, 1.066)	(-0.036, 0.852)	(-0.071, 0.901)
Inkjet 1, 4-ink, coated media	(-0.173, 0.982)	(-0.013, 0.857)	(-0.044, 0.978)
Inkjet 2, 4-ink, photo media	(-0.184, 1.035)	(-0.029, 0.896)	(-0.051, 0.939)
Inkjet 3, 6-ink, photo media	(-0.206, 1.030)	(-0.021, 0.896)	(-0.045, 0.959)
Inkjet 3, 6-ink, coated media	(-0.152, 1.028)	(0.003, 0.842)	(-0.022, 0.989)
Inkjet 4, 6-ink, photo media	(-0.190, 1.040)	(-0.033, 0.887)	(-0.053, 0.932)
Color EP 1, plain paper	(-0.096, 0.959)	(0.007, 0.919)	(-0.023, 0.959)
Color EP 2, plain paper	(-0.088, 0.982)	(0.028, 0.850)	(-0.020, 0.901)
Pantone Coated Full Set	(-0.178, 1.528)	(-0.036, 0.849)	(-0.080, 0.848)
Pantone w/out fluorescents	(-0.178, 1.103)	(-0.036, 0.849)	(-0.080, 0.848)
Optimal Color Space	(-.460, 1.483)	(-.124, 1.124)	(-.114, 1.114)

Table F1: Linear luminance sRGB gamut boundaries for color gamuts

The definition of e-sRGB gives a range of about (-0.53, 1.68). This range gives a gamut that encompasses the color reproduction devices and other gamuts listed in Table F1. The range of (-0.53, 1.68) arises because of the choice to span the non-linear encoding range of –75% to 125%, along with the choice to use a negative range gamma curve that matches the positive range curve. It is notable that the e-sRGB definition gives computational advantages for algorithms and 3D CLUT interpolation, and also produces a close fit to the range of visible object colors. Figure F3 is plotted in linear-luminance sRGB space. The color point markers in Figure F3 represent a uniform sampling of the e-sRGB (nonlinear) encoding space. The solid color gamut is the optimal color space for D65.

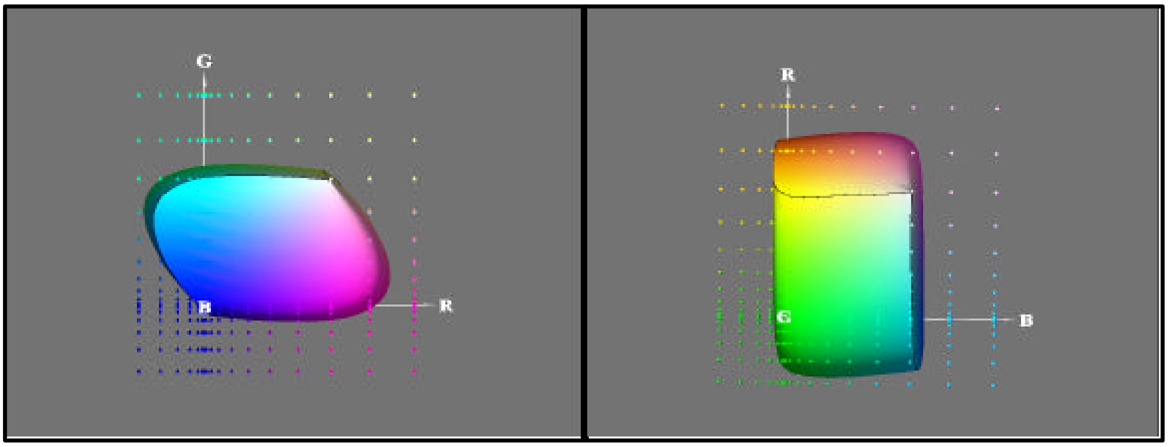

Figure F3: e-sRGB compared to the D65 optimal color space.

F.5 Encoding Nonlinearity (Gamma)

Another consideration to the design of e-sRGB is the gamma function. To maintain compatibility with sRGB, we defined the gamma to be equal to the sRGB gamma for the original valid sRGB range. Figure F4 shows the original sRGB gamma function as a black curve.

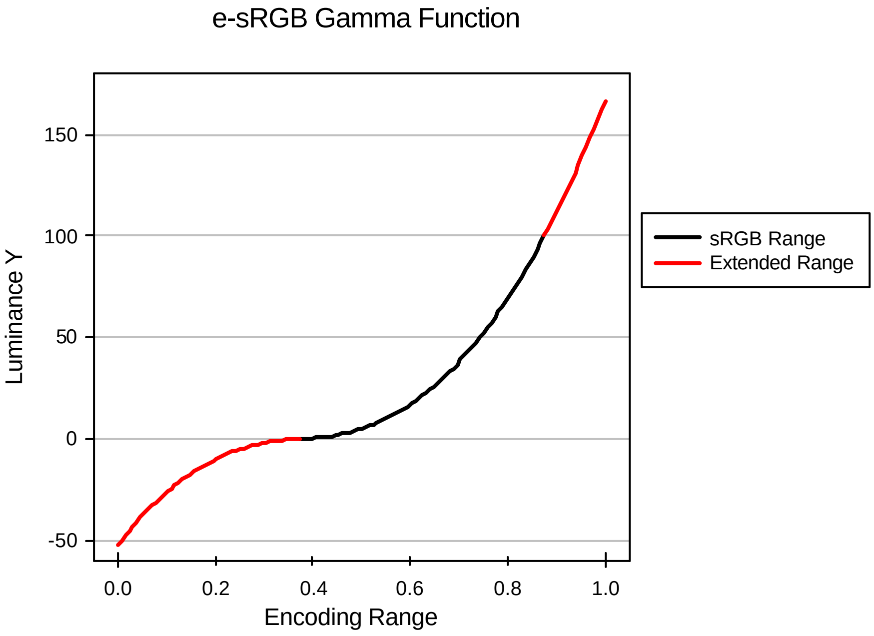

Figure F4: e-sRGB Gamma Function

The extensions to the gamma function should be simple and efficient to compute and encode. The obvious choice for the light end of the range is to apply the existing gamma function. This continuation is shown as a red curve on the right side of Figure F4. The curve for the negative range must be continuous with the positive range curve, and minimize unexpected changes in encoding density of chroma and hue. When extending the range into negative values, the only way to prevent a change in encoding density of chromatic colors would be to continue with the 1/12.92 slope that ends the real sRGB range. Unfortunately, this slope is so shallow that an excessive amount of the encoding range would need to be devoted to the negative range to reach the gamut coverage goals. Re-using the positive range gamma curve for the negative range is an attractive option because it simplifies the definition and implementation of the space. The negative gamma curve is shown as a red curve on the left side.

F.6 Analysis

The perceptual linearity of a color space and encoding efficiency are closely related. To represent continuous images with no gradations or contouring artifacts, we must encode several tone levels for each increment in L* lightness. Because sRGB is close to linear in L*, it accurately encodes continuous images with only 256 gray levels. More gray levels are required if the tone reproduction of the image is modified during editing. For example, transforms that fix over or under exposed images require more than 256 gray levels so that detail can be pulled out of shadow or highlight regions. Figure F5 shows the number of encoding levels available to encode one increment in L*, as a function of L*, for 16-bit sRGB spaces. Because figure F5 is plotted with respect to log base 2 for the encoding levels, it is easy to see how any choice of bit depth relates to encodable levels. For example, to match the encoding accuracy of sRGB in the dark range, The previously proposed sRGB-64 linear color encoding must use 6 or 7 additional bits. By definition, e-sRGB requires one additional bit to match sRGB's accuracy, and this is confirmed in the graph.

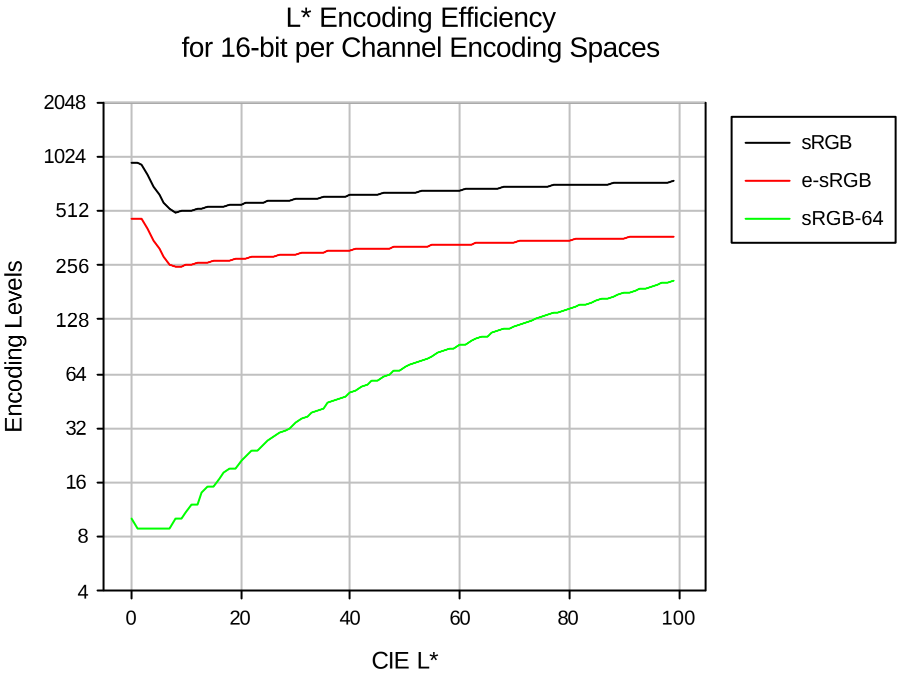

Figure F5: L Encoding Efficiency for sRGB, e-sRGB, and sRGB-64*

Plotting the available encoding levels for chroma produces interesting results. Figure F6 shows the chroma encoding granularity of the three sRGB spaces. The data in figure F6 was produced by computing the number of unique RGB values that exist between JND (1 CIE94 delta E) chroma steps in CIELab. The left three plots show constant L* chroma transitions from the neutral axis to sRGB primary colors. The right three plots show similar transitions from the neutral axis to a photo inkjet C, M, and Y primary colors. In each of the right three plots, the inkjet primary is out of the sRGB gamut. As e-sRGB transitions out of the sRGB gamut in these cases, accelerating negative values are produced which gives a reversal in the chroma encoding density. The result is that the efficiency of encoding and transmitting high chroma data is improved. However, this effect may need to be accounted for if image-editing algorithms are applied in e-sRGB.

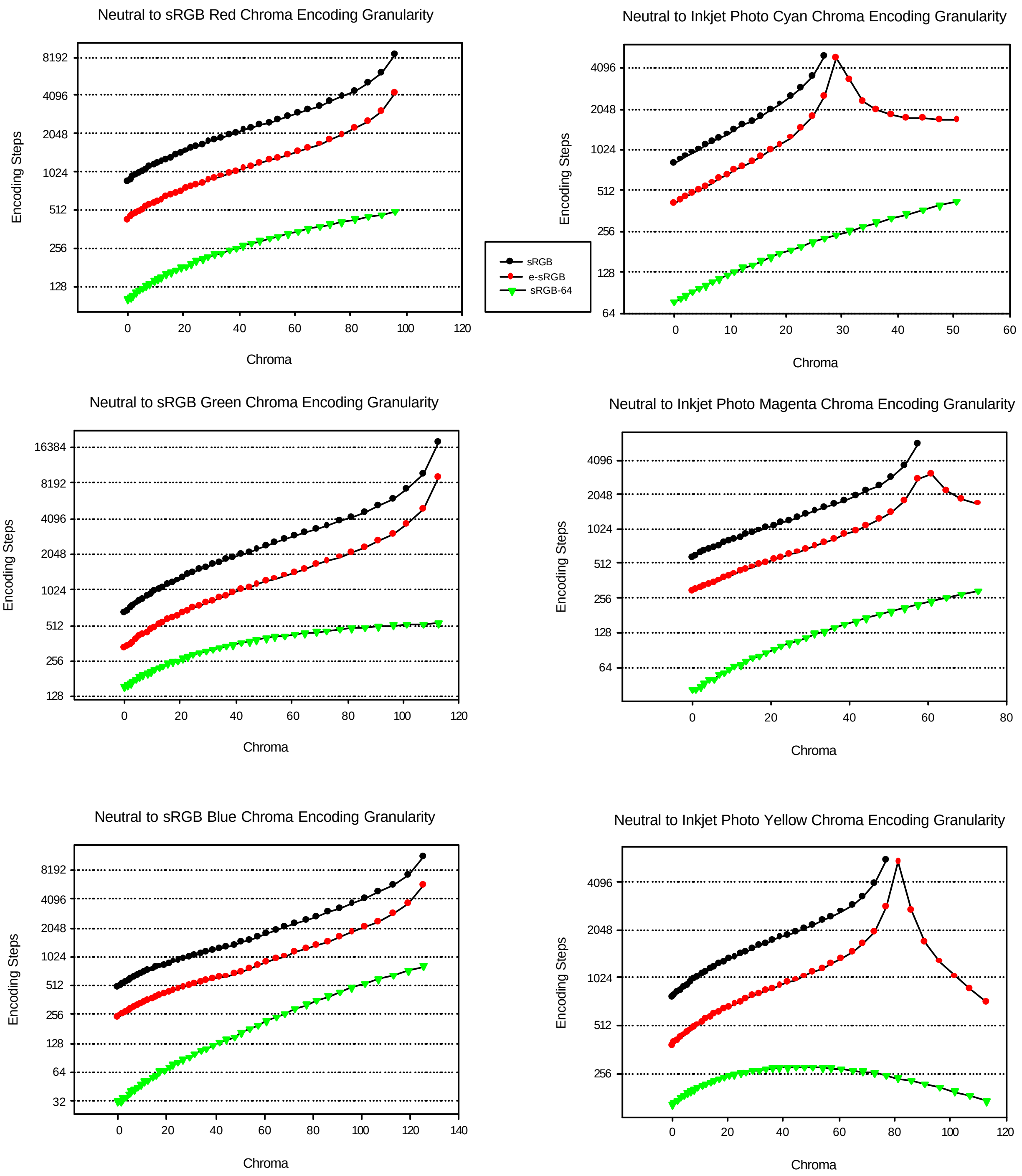

Figure F6: Chroma Encoding Efficiency for sRGB, e-sRGB, and sRGB-64

Figures F7 and F8 show the hue constancy of e-sRGB for transitions from the middle of the neutral axis to primary, secondary, and tertiary colors. This data was plotted in CIECAM97s space, which has reasonable hue constancy.

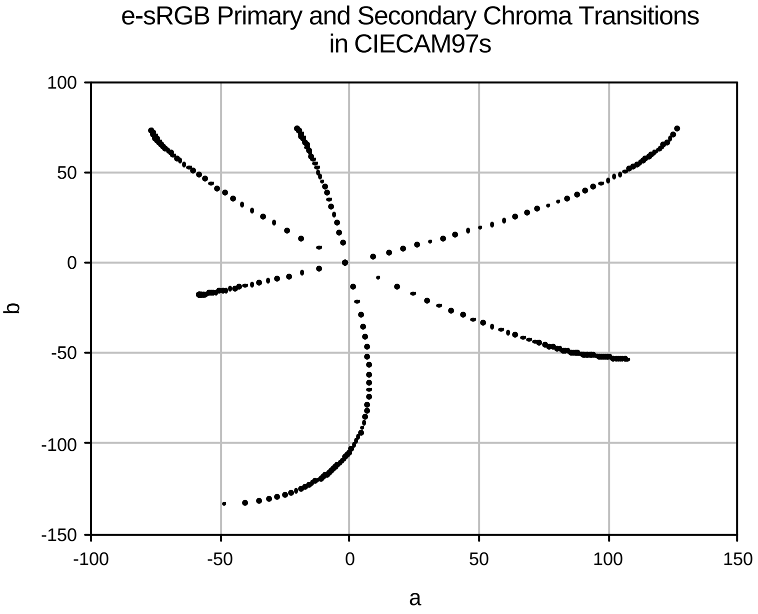

Figure F7: Hue Constancy of e-sRGB Transitions to Primaries and Secondaries

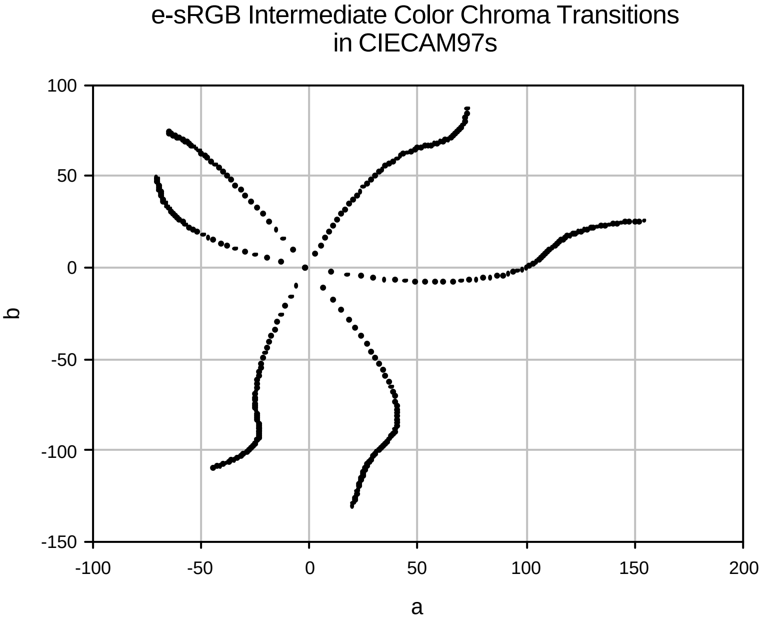

Figure F8: Hue Constancy of e-sRGB Transitions to Tertiary Colors

Figures F7 and F8 show reasonable hue constancy. Figure F8 demonstrates an interesting effect where the shift in acceleration of the gamma curve creates a change in direction of hue shift for some transitions in e-sRGB. This effect is not relevant to the applicability of e-sRGB as an encoding space, but may have some effect if editing algorithms are applied in e-sRGB. Similar to what was seen in figure F6 with chroma encoding density, it is possible that these hue changes work to correct the shifting hue trend in sRGB, giving benefit to image editing applications. However, this effect along with the change in chroma density should be studied further with respect to image editing transformations.

F.7 Conclusions

Color management for the consumer marketplace gives a unique set of challenges. The typical consumer has high expectations of the results, but also expects color management to work transparently. sRGB has worked well to meet these needs because of its simplicity and direct applicability to a CRT-based workflow. Today, consumer imaging is rapidly changing. High quality digital imaging equipment is now available at consumer price-points, and customer expectations are increasing. In addition, emerging peer-to-peer workflows make the central CRT less important in the color reproduction pipeline. For these reasons, a new color standard for the consumer marketplace is needed to enable the encoding and transmission of large gamut and high bit-precision color data. e-sRGB is a roughly perceptually uniform color encoding space that gives a large gamut and higher precision to enable higher quality consumer imaging. Utilizing as few as nine bits per channel, e-sRGB exactly duplicates sRGB and adds extended gamut ranging from about –53% to 168% of sRGB. This range is large enough to cover high-end consumer color reproduction devices. These benefits are gained by making minimal modifications to sRGB, thus retaining the original benefits and cross-compatibility with sRGB.

Annex G

(informative)

Considerations in the Editing of e-sRGB Image Data

It should be noted that specifications for the editing of e-sRGB image data are beyond the scope of this standard. However, it is recognized that in some applications there may be a need to edit images that are encoded as e-sRGB. This annex provides information in this regard.

As described previously, the e-sRGB color encodings use offsets and over-ranging to obtain extended color gamut coverage. These encoding mechanisms have advantages over "wide-primary" extended gamut approaches in terms of sRGB compatibility and gamut coverage. However, they also result in encodings that are fundamentally different from encodings where {0, 0, 0}code values mean black, and {2^n, 2^n, 2^n} code values mean white. For example, with the e-sRGB(10) encoding, black is represented by {384, 384, 384} and white is represented by {894, 894, 894}. The digital code value triplets {0, 0, 0} and {1023, 1023, 1023} are illegal, because the former does not represent physically realizable image colorimetry, and the latter is prohibited by the rendering intent and encoding requirements.

A consequence of this type of encoding is that a number of image processing operations must be performed using algorithms which are different, or have been designed to accommodate offsets and over-ranging. In many cases, image processing packages are not equipped with these algorithms. This is why the scope statement of this standard does not list "manipulation" as a potential use for e-sRGB image data. When manipulation of e-sRGB image data is desired, and users are unsure of whether their algorithms will appropriately deal with offsets and over ranging, it is recommended that the e-sRGB image data first be converted to a color encoding without offsets or over ranging. sRGB (IEC 61966-2-1) and ROMM RGB (PIMA 7666) are examples of such encodings. sRGB would be the most appropriate choice when the extended gamut of e-sRGB is of little importance and lossless transformation within the sRGB gamut is desired. ROMM RGB is a better choice if it is important to maintain as much of the extended gamut as possible. After manipulation, ROMM RGB image data can then be converted back to e-sRGB. Because the transformation to and from ROMM RGB is slightly lossy, the highest precision ROMM16 RGB encoding should be used, and the number of conversions in the workflow should be minimized. It is also possible that some colors encoded as e-sRGB will be outside the ROMM RGB gamut, and will have to be gamut mapped when performing the conversion.

Conversion from e-sRGB to a color encoding without offsets or over-ranging is recommended when users either know their manipulation algorithms are not designed to accommodate offsets and over-ranging, or are unsure. In applications and workflows where algorithms designed to accommodate offsets and over-ranging are available, these algorithms can and should be used to directly manipulate e-sRGB image data.

Annex H
(informative)

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