

SMPTE STANDARD**Academy Color Encoding
Specification (ACES)**

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Foreword

SMPTE (the Society of Motion Picture and Television Engineers) is an internationally-recognized standards developing organization. Headquartered and incorporated in the United States of America, SMPTE has members in over 80 countries on six continents. SMPTE's Engineering Documents, including Standards, Standards and Engineering Guidelines, are prepared by SMPTE's Technology Committees. Participation in these Committees is open to all with a bona fide interest in their work. SMPTE cooperates closely with other standards-developing organizations, including ISO, IEC and ITU.

SMPTE Engineering Documents are drafted in accordance with the rules given in Part XIII of its Administrative Practices.

SMPTE ST 2065-1 was prepared by Technology Committee 10E.

Intellectual Property

At the time of publication no notice had been received by SMPTE claiming patent rights essential to the implementation of this standard. However, attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. SMPTE shall not be held responsible for identifying any or all such patent rights.

Introduction

This section is entirely informative and does not form an integral part of this Engineering Document.

The Academy Color Encoding Specification (ACES) defines a digital color image encoding appropriate for both photographed and computer-generated images. It is the common color encoding for the Academy Image Interchange Framework. In the flow of image data from scene capture to theatrical presentation, ACES data encode imagery in a form suitable for creative manipulation. Later points in the workflow provide forms suitable for critical viewing.

Based on the definition of the ACES virtual RGB primaries, and on the color matching functions of the CIE 1931 Standard Colorimetric Observer, ACES derives an ideal recording device against which actual recording devices' behavior can be compared: the Reference Input Capture Device (RICD). As an ideal device, the RICD would be capable of distinguishing and recording all visible colors, and of capturing a luminance range exceeding that of any contemporary or anticipated physical camera. The RICD's purpose is to provide a documented, unambiguous, fixed relationship between scene colors and encoded RGB values. When a real camera records a physical scene, or a virtual camera (i.e. a CGI rendering program) creates an image of a virtual scene, an Input Device Transform (IDT) converts the resulting image data into the ACES RGB relative exposure values the RICD would have recorded of that same subject matter. Figure 1 illustrates the pipeline for creating ACES images from various image capture devices.

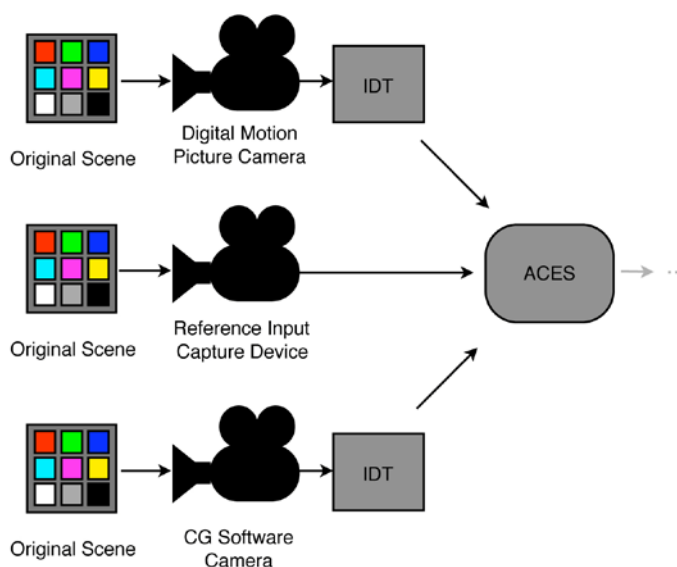


Figure 1 – Creation of ACES images from various image capture devices

ACES images are not directly viewable for final image evaluation, much as film negative or files containing images encoded as printing density are not directly viewable as final images. As an intermediate image representation, ACES images can be examined directly for identification of image orientation, cropping region or sequencing; or examination of the amount of shadow or highlight detail captured; or comparison with other directly viewed ACES images. Such direct viewing cannot be used for final color evaluation. Instead, a Reference Rendering Transform (RRT) and a selected Output Device Transform (ODT) are used to produce a viewable image when that image is presented on the selected output device. Figure 2 illustrates the ACES image capture and reproduction pipeline using the RICD.

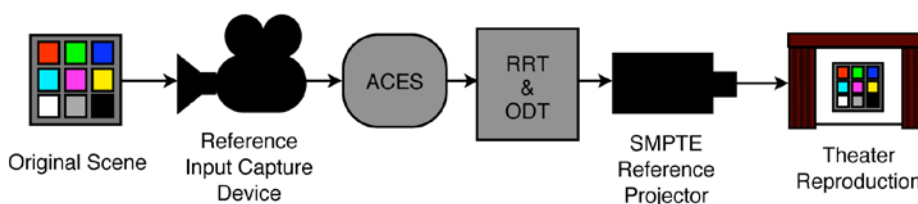


Figure 2 – ACES Capture and Reproduction using the RICD

Practical conversion of photographic or synthetic exposures to ACES RGB relative exposure values requires procedures for characterizing the color response of a real or virtual image capture system. These procedures are outside the scope of this standard.

The Image Interchange Framework of which ACES is a part provides theoretical and practical structure for color correction and artistic adjustment. Encoding in ACES does not obsolete creative judgment; rather, it facilitates it.

1 Scope

The specification defines the Academy Color Encoding Specification (ACES).

2 Conformance Notation

Normative text is text that describes elements of the design that are indispensable or contains the conformance language keywords: "shall", "should", or "may". Informative text is text that is potentially helpful to the user, but not indispensable, and can be removed, changed, or added editorially without affecting interoperability. Informative text does not contain any conformance keywords.

All text in this document is, by default, normative, except: the Introduction, any section explicitly labeled as "Informative" or individual paragraphs that start with "Note:".

The keywords "shall" and "shall not" indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

The keywords, "should" and "should not" indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.

The keywords "may" and "need not" indicate courses of action permissible within the limits of the document.

The keyword "reserved" indicates a provision that is not defined at this time, shall not be used, and may be defined in the future. The keyword "forbidden" indicates "reserved" and in addition indicates that the provision will never be defined in the future.

3 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 indicated 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 edition of the standards indicated below.

ISO 22028-1:2004, Photography and graphic technology — Extended colour encodings for digital image storage, manipulation and interchange — Part 1: Architecture and requirements

SMPTE RP 177:1993, Derivation of Basic Television Color Equations

IEEE Standard for Floating-Point Arithmetic P754-2008

4 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

4.1 Academy Color Encoding Specification (ACES): An RGB color encoding for exchange of image data that have not been color rendered, between and throughout production and postproduction, within the Academy's Image Interchange Framework.

4.2 camera flare: unwanted irradiation in the image plane of an optical system, caused by the scattering and reflection of a proportion of the radiation which enters the system.

4.3 capture system noise: positive or negative signal value fluctuations, unmodulated by scene image content, introduced into an image by the image capture system.

4.4 color component transfer function: single variable, monotonic mathematical function relating to intensity applied individually to one or more color channels of a color space.

4.5 color encoding: generic term for a quantized digital encoding of a color space, encompassing both color space encodings and color image encodings.

4.6 color image encoding: digital encoding of the color values for a digital image, including the specification of a color space encoding, together with any information necessary to properly interpret the color values such as the image state and the intended image viewing environment.

4.7 color space: geometric representation of colors in space, usually of three dimensions.

4.8 color space encoding: digital encoding of a color space, including the specification of a digital encoding method, and a color space data metric.

4.9 image state: attribute of a color image encoding indicating the color rendering state of the image data.

4.10 observer adaptive white: color stimulus that an observer, adapted to a set of viewing conditions, would judge to be perfectly achromatic and to have a luminance factor of unity.

4.11 perfect reflecting diffuser: ideal isotropic, nonfluorescent diffuser with a spectral radiance factor equal to unity at each wavelength of interest.

4.12 Reference Input Capture Device (RICD): RICD hypothetical camera which records an image of a scene directly as ACES RGB relative exposure values.

4.13 relative exposure values: relative responses to light of an image capture system determined by the integrated spectral responsivities of its color channels and the spectral radiances of scene stimuli.

4.14 scaled XYZ color space: color space based upon the CIE 1931 Standard Colorimetric Observer, with X, Y and Z uniformly scaled such that the Y value of a perfect reflecting diffuser is 1.0.

4.15 surround: area adjacent to the border of an image, which, upon viewing the image, can affect the local state of adaptation of the eye. In the context of a scene capture, a 'normal' surround is one where the nature of the scene surrounding the view captured does not significantly alter the state of viewer adaptation from that when viewing exclusively the view captured.

4.16 tristimulus value: amounts of the three reference color stimuli, in a given trichromatic system, required to match the color of the stimulus considered.

4.17 viewing environment: context in which a color stimulus is viewed, producing a color appearance. Typical viewing environment components include viewing flare, surround, absolute luminance and observer adaptive white.

5 Academy Color Encoding Specification (ACES)

5.1 General

The Academy Color Encoding Specification shall be defined as specified in this section. ACES is specified in three successive layers: a color space, a color space encoding, and a color image encoding. This structure meets the requirements for extended-gamut color encodings as given in ISO 22028-1.

5.2 ACES Color Space

5.2.1 Color space type

The color space type shall be colorimetric: additive RGB.

Note: The ACES color space type can also be considered to be of the type input-device-dependent and as such has an associated reference image capture device known as the ACES reference image captured device (RICD).

5.2.2 Colorimetric specification

ACES RGB values shall represent scene colors as measured at the focal plane of the ACES Reference Image Capture Device.

The ACES RICD shall have the spectral sensitivities, which are linear combinations of the CIE 1931 color-matching functions, tabulated in Annex A, shall be free of capture system noise, and shall introduce camera flare amounting to 0.5% of the captured values of a perfect reflecting diffuser. The captured values shall thus be augmented by flare and then scaled by a factor S , calculated as follows:

$$S = \frac{0.18000}{0.18000 + 0.00500}$$

Note 1: In practice, ACES RGB values represent scene colors as measured by a real or virtual capture device. As such, captured values from real devices include both capture system noise and camera flare.

Note 2: If an image captured with any real or virtual capture device contains camera flare of an amount different than the amount specified, that difference can be reconciled in the transformation of the camera data to ACES RGB or preserved as an expression of creative intent.

Note 3: For the ACES RICD camera flare ought to be considered equivalent to veiling glare.

5.2.3 RGB primaries chromaticity values

The RGB primaries chromaticity values shall be those found in Table 1.

Table 1 – ACES RGB primaries chromaticity values

	R	G	B	CIE x	CIE y
Red	1.00000	0.00000	0.00000	0.73470	0.26530
Green	0.00000	1.00000	0.00000	0.00000	1.00000
Blue	0.00000	0.00000	1.00000	0.00010	-0.07700

5.2.4 Color space white point

The color space white point shall be that found in Table 2.

Table 2 — ACES RGB white point chromaticity values

	R	G	B	CIE x	CIE y
White	1.00000	1.00000	1.00000	0.32168	0.33767

Note: The total absence of light is represented by CIE $X = 0.00000$, $Y = 0.00000$, $Z = 0.00000$

5.2.5 Converting ACES RGB values to CIE XYZ values

ACES R , G , and B values shall be converted to scaled CIE XYZ tristimulus values using the normalized primary matrix (NPM) calculated and applied using the methods provided in Section 3.3 of SMPTE RP 177.

Note: Equation 1 shows the relationship between ACES R , G , and B values and scaled CIE XYZ tristimulus values. NPM , rounded to 10 significant digits, is derived using the color space chromaticity coordinates specified in sections 5.2.3 and 5.2.4 and the methods provided in Section 3.3 of SMPTE RP 177.

$$NPM = \begin{bmatrix} 0.9525523959 & 0.0000000000 & 0.0000936786 \\ 0.3439664498 & 0.7281660966 & -0.0721325464 \\ 0.0000000000 & 0.0000000000 & 1.0088251844 \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = NPM \bullet \begin{bmatrix} R_{ACES} \\ G_{ACES} \\ B_{ACES} \end{bmatrix}$$

Equation 1 – ACES RGB to CIE XYZ Conversion

5.2.6 Converting CIE XYZ values to ACES RGB values

CIE XYZ tristimulus values shall be converted to ACES R , G , and B values using the matrix inverse of the normalized primary matrix calculated and applied using the methods provided in Section 3.3 of SMPTE RP 177.

Note: Equation 2 shows the relationship between scaled CIE XYZ tristimulus values and ACES R , G , and B values. NPM^{-1} is the matrix inversion of NPM .

$$\begin{bmatrix} R_{ACES} \\ G_{ACES} \\ B_{ACES} \end{bmatrix} = NPM^{-1} \bullet \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Equation 2 – CIE XYZ to ACES RGB Conversion