Appendix O: TIFF Class Y - YC_bC_r Images

This appendix, written after the release of Revision 5.0 of the TIFF specification, is still in draft form and is subject to change. Please send any comments to Eric Hamilton of C-Cube Microsystems.

Introduction

Digitizers of video sources that create RGB data are becoming more capable and less expensive. Class R RGB is adequate for this purpose (see Appendices G and H). However, for both digital video and image compression applications a color difference color space is needed. The television industry depends on YC_bC_r for digital video. For image compression, subsampling the chrominance components allows for greater compression. Class Y supports these images and applications.

Class Y is based on CCIR Recommendation 601-1, "Encoding Parameters of Digital Television for Studios. " Class Y also has parameters that allow the description of related standards such as CCIR Recommendation 709 and technological variations such as component sample positioning.

YC_bC_r is a distinct PhotometricInterpretation type. RGB pixels are converted to and from YC_bC_r for storage and display.

Class Y defines the following tags:

YC_bC_rCoefficients	transformation from RGB to YC_bC_r
YC_bC_rSubSampling	subsampling of the chrominance components
YC_bC_rPositioning	positioning of chrominance component samples relative to the luminance samples

In addition, ReferenceBlackWhite, which specifies coding range expansion, is required by Class Y (see Appendix H).

Class Y YC_bC_r images have three components: Y, the luminance component, and C_b and C_r, two chrominance components. Class Y uses the international standard notation YC_bC_r for color difference component coding. This is often incorrectly called YUV, which properly applies only to composite coding.

The transformations between YC_bC_r and RGB are linear transformations of un-interpreted RGB component data, typically gamma-corrected values. The YC_bC_rCoefficients tag describes the parameters of this transformation.

Another feature of Class Y comes from subsampling the chrominance components. A Class Y image can be compressed by reducing the spatial resolution of chrominance components. This takes advantage of the relative insensitivity of the human visual system to chrominance detail. The YC_bC_rSubSampling tag describes the degree of subsampling which has taken place.

When a Class Y image is subsampled, each C_b and C_r sample is associated with a group of luminance samples. The YC_bC_rPositioning tag describes the position of the chrominance component samples relative to the group of luminance samples: centered or cosited.

Class Y requires use of the ReferenceBlackWhite tag. This tag expands the coding range by describing the reference black and white values for the different components that allow headroom and footroom for digital video images. Since the default for ReferenceBlackWhite is inappropriate for Class Y, it must be used explicitly.

At first sight it may seem that the information conveyed by Class Y and the Appendix H colorimetry information are redundant. However, decoding YC_bC_r to RGB primaries requires the YC_bC_r tags and interpretation of the resulting RGB primaries requires the colorimetry and transfer function information. See Appendix H for details.

Extensions to Existing Tags

Class Y images use a distinct PhotometricInterpretation Tag value:

PhotometricInterpretation
Tag = 262 (106 hex)
Type = SHORT
N = 1

This Tag indicates the color space of the image.

0 = Bilevel, grayscale (0=white)
1 = Bilevel, grayscale (0=black)
2 = RGB
3 = Palette
4 = Transparency mask
5 = CMYK
6 = YC_bC_r

A value of 6 indicates that the image data is in the YC_bC_r color space. TIFF uses the international standard notation YC_bC_r for color difference component coding. Y is the luminance component. C_b and C_r are the two chrominance components. RGB pixels are converted to and from YC_bC_r form for storage and display.

Tags defined in Class Y

YC_bC_rCoefficients
Tag = 529 (211 hex)
Type = RATIONAL
N = 3

The transformation from RGB to YC_bC_r image data. The transformation is specified as three rational values which represent the coefficients used to compute luminance, Y.

The three rational coefficient values, *LumaRed*, *LumaGreen* and *LumaBlue*, are the proportions of red, green, and blue respectively in luminance, Y.

YC_bC_r Coefficients (cont'd)

Y, C_b, and C_r may be computed from RGB using the luminance coefficients specified by this tag as follows:

$$Y = (\textit{LumaRed} * R + \textit{LumaGreen} * G + \textit{LumaBlue} * B)$$
$$C_b = (B - Y) / (2 - 2 * \textit{LumaBlue})$$
$$C_r = (R - Y) / (2 - 2 * \textit{LumaRed})$$

R, G, and B may be computed from YC_bC_r as follows:

$$R = C_r * (2 - 2 * \textit{LumaRed}) + Y$$
$$G = (Y - \textit{LumaBlue} * B - \textit{LumaRed} * R) / \textit{LumaGreen}$$
$$B = C_b * (2 - 2 * \textit{LumaBlue}) + Y$$

In disciplines such as printing, film and video there are practical reasons to provide footroom codes below the ReferenceBlack code and headroom codes above ReferenceWhite code. In such cases the values of the transformation matrix used to convert from YC_bC_r to RGB must be multiplied by a scale factor in order to produce full range RGB values. These scale factors depend on the reference ranges specified by the ReferenceBlackWhite tag. See the ReferenceBlackWhite and TransferFunction tags for more details.

The values coded by this tag will typically reflect the transformation specified by a standard for YC_bC_r encoding. The following table contains examples of commonly used values.

Standard	*LumaRed*	*LumaGreen*	*LumaBlue*
CCIR Recommendation 601-1	299 / 1000	587 / 1000	114 / 1000
CCIR Recommendation 709	2125 / 10000	7154 / 10000	721 / 10000

The default values for this tag are those defined by CCIR Recommendation 601-1: 299/1000, 587/1000 and 114/1000, for *LumaRed*, *LumaGreen* and *LumaBlue*, respectively.

YC_bC_r SubSampling

Tag = 530 (212 hex)
Type = SHORT
N = 2

Specifies the subsampling factors used for the chrominance components of a YC_bC_r image. The two fields of this tag, *YC_bC_rSubsampleHoriz* and *YC_bC_rSubsampleVert*, specify the horizontal and vertical subsampling factors respectively.

YC_bC_rSubSampling (cont'd)

The two fields of this tag are defined as follows:

Short 0: *YC_bC_rSubsampleHoriz*:

- 1 = ImageWidth of this chroma image is equal to the ImageWidth of the associated luma image.
- 2 = ImageWidth of this chroma image is half the ImageWidth of the associated luma image.
- 4 = ImageWidth of this chroma image is one quarter the ImageWidth of the associated luma image.

Short 1: *YC_bC_rSubsampleVert*:

- 1 = ImageLength (height) of this chroma image is equal to the ImageLength of the associated luma image.
- 2 = ImageLength (height) of this chroma image is half the ImageLength of the associated luma image.
- 4 = ImageLength (height) of this chroma image is one quarter the ImageLength of the associated luma image.

Both C_b and C_r have the same subsampling ratio. Also, *YC_bC_rSubsampleVert* shall always be less than or equal to *YC_bC_rSubsampleHoriz*.

ImageWidth and ImageLength are constrained to be integer multiples of *YC_bC_rSubsampleHoriz* and *YC_bC_rSubsampleVert* respectively. TileWidth and TileLength have the same constraints. RowsPerStrip must be an integer multiple of *YC_bC_rSubsampleVert*.

The default values of this tag are [2, 2].

YC_bC_rPositioning

Tag = 531 (213 hex)
Type = SHORT
N = 1

Specifies the positioning of subsampled chrominance samples relative to luminance samples.

Specification of the spatial positioning of pixel samples within components relative to the samples of other components is necessary for proper image post processing and accurate image presentation. In Class Y files, the position of the samples in subsampled chrominance components are defined with respect to the luminance component. Since components must be sampled orthogonally (along rows and columns), the spatial position of the samples in a given subsampled component may be determined by specifying the horizontal and vertical offsets of the first sample, i.e. the sample in the upper left corner, with respect to the luminance component. The horizontal and vertical offsets of the first chrominance sample are denoted Xoffset[0,0] and Yoffset[0,0] respectively. Xoffset[0,0] and Yoffset[0,0] are defined in terms of the number of samples in the luminance component.

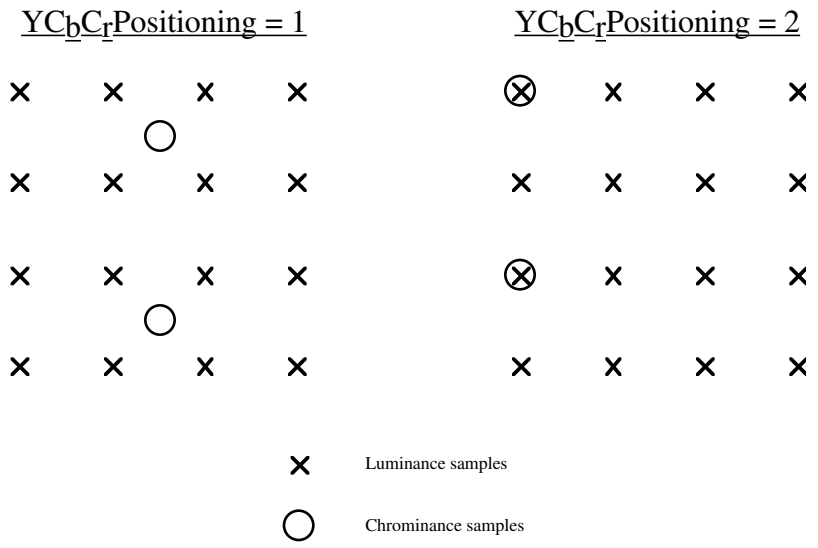
YC_bC_rPositioning (cont'd)

The values for this tag are defined as follows:

Tag value	YC_bC_r Positioning	X and Y offsets of first chrominance sample
1	centered	Xoffset[0,0] = *ChromaSubsampleHoriz* / 2 - 0.5 Yoffset[0,0] = *ChromaSubsampleVert* / 2 - 0.5
2	cosited	Xoffset[0,0] = 0 Yoffset[0,0] = 0

Tag value 1 (centered) must be specified for compatibility with industry standards such as Postcript Level 2 and QuickTime. Tag value 2 (cosited) must be specified for compatibility with most digital video standards, such as CCIR Recommendation 601-1.

As an example, for *ChromaSubsampleHoriz* = 4 and *ChromaSubsampleVert* = 2, the centers of the samples are positioned as illustrated below:



Proper subsampling of the chrominance components incorporates an anti-aliasing filter which reduces the spectral bandwidth of the full resolution components. The type of filter used for subsampling determines the value of the YC_bC_rPositioning tag.

For YC_bC_rPositioning = 1 (centered), subsampling of the chrominance components can easily be accomplished using a symmetrical digital filter with an even number of taps (coefficients). A commonly used filter for 2:1 subsampling utilizes two taps (1/2,1/2).

For YC_bC_rPositioning = 2 (cosited), subsampling of the chrominance components can easily be accomplished using a symmetrical digital filter with an odd number of taps. A commonly used filter for 2:1 subsampling utilizes three taps (1/4,1/2,1/4).

The default value of this tag is 1.

ReferenceBlackWhite

Tag = 532 (214 hex)
Type = LONG
N = 2 x SamplesPerPixel

This tag specifies a pair of image data values (codes) for each component of the image data. The first value conveys the image data value associated with ReferenceBlack and the second value conveys the image data value associated with ReferenceWhite.

Computer graphics commonly places black and white at the extremities of the binary representation of image data, for example black at code 0 and white at code 255. In other

disciplines such as printing, film and video there are practical reasons to provide footroom codes below ReferenceBlack and headroom codes above ReferenceWhite.

In print applications, the reference values typically correspond to 100% and 0% ink coverage. In film applications, the reference values typically correspond to the densities Dmax and Dmin. In video applications, the reference black value corresponds to 7.5 IRE and 0 IRE in systems with and without setup respectively and the ReferenceWhite corresponds to 100 IRE units.

Using Class Y and the CCIR Recommendation 601-1 video standard as an example, code 16 represents ReferenceBlack and code 235 represents ReferenceWhite for the luminance (Y) component. For the chrominance components (Cb and Cr), code 128 represents ReferenceBlack and code 240 represents ReferenceWhite. With Cb and Cr the ReferenceWhite value is used to code reference blue and reference red respectively.

The full range component value, FullRangeValue, is converted from the code by:

```
FullRangeValue = (code - ReferenceBlack) * CodingRange
  / (ReferenceWhite - ReferenceBlack);
```

The code is converted from the full range component value by:

```
code = (FullRangeValue * (ReferenceWhite - ReferenceBlack) / CodingRange)
  + ReferenceBlack;
```

For RGB images, and for the Y component of YCbCr images, the CodingRange is 2 ** BitsPerSample - 1. For the Cb and Cr components of YCbCr images, the CodingRange is 127.

For RGB images, in the default special case of no headroom or footroom this conversion can be omitted because the scaling multiplier is one and the value equals the code.

For YCbCr images, in the case of no headroom or footroom the conversion for Y can be omitted since the value equals the code. For Cb and Cr, ReferenceBlack must still be subtracted from the code. In the general case, the scaling multiplication for each component code can be factored into the YCbCr transform matrix.

ReferenceBlackWhite (cont'd)

Useful ReferenceBlackWhite values for Class Y images are:

[0, 255, 128, 255, 128, 255] no headroom/footroom
[16, 235, 128, 240, 128, 240] CCIR Rec. 601-1 headroom/footroom

Useful ReferenceBlackWhite values for Class R images are:

[0, 255, 0, 255, 0, 255] no headroom/footroom (default)
[16, 235, 16, 235, 16, 235] CCIR Rec. 601-1 headroom/footroom

Default is [0, (2 ** BitsPerSample) - 1] for each sample in a pixel.

Ordering of Component Samples

This section defines the ordering convention used for Y, C_b, and C_r component samples when the PlanarConfiguration tag value = 1 (interleaving). For PlanarConfiguration = 2, component samples are stored as 3 separate planes and the ordering is the same as for other PhotometricInterpretation tag values.

For PlanarConfiguration = 1, the component sample order is based on the subsampling factors, *ChromaSubsampleHoriz* and *ChromaSubsampleVert,* defined by the YC_bC_rSubSampling tag. The image data within a TIFF file is comprised of one or more "data units", where a data unit is defined to be a sequence of samples:

- one or more Y samples
- a C_b sample
- a C_r sample

The Y samples within a data unit are specified as a two dimensional array having *ChromaSubsampleVert* rows of *ChromaSubsampleHoriz* samples.

Expanding on the example in the previous section, consider a YC_bC_r image having *ChromaSubsampleHoriz* = 4 and *ChromaSubsampleVert* = 2:

Y component Cb component Cr component

Y_{00}	Y_{01}	Y_{02}	Y_{03}	Y_{04}	Y_{05}		
Y_{10}	Y_{11}	Y_{12}	Y_{13}				

Cb_{00}	

Cr_{00}	

For PlanarConfiguration = 1, the sample order is:

$Y_{00}, Y_{01}, Y_{02}, Y_{03}, Y_{10}, Y_{11}, Y_{12}, Y_{13}, Cb_{00}, Cr_{00}, Y_{04}, Y_{05}$ ...

Minimum Requirements for TIFF Class Y

A TIFF Class Y image follows the general TIFF Class X guidelines. See the TIFF 6.0 specification, Appendix G. In addition to the core field requirements, a TIFF Class Y file must have the following characteristics:

SamplesPerPixel = 3. SHORT. Three samples representing Y, Cb and Cr.
BitsPerSample = 8,8,8. SHORT.
Compression = none (1), LZW (5) or JPEG (6). SHORT.
PhotometricInterpretation = YC_bC_r (6). SHORT.
ReferenceBlackWhite = 6 LONGS. Specify the reference values for black and white.

If the conversion from RGB is not according to CCIR Recommendation 601-1, code YC_bC_rCoefficients.