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Conversion and coding practices for HDR/ WCG Y'CbCr 4:2:0 video with PQ transfer characteristics

ITU-T H-series Recommendations – Supplement 15

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Supplement 15 to ITU-T H-series Recommendations

Conversion and coding practices for HDR/WCG Y'CbCr 4:2:0 video with PQ transfer characteristics

Summary

Supplement 15 to the ITU-T H-series of Recommendations provides guidance on the processing of high dynamic range (HDR) and wide colour gamut (WCG) video content. The purpose of this document is to provide a set of publicly referenceable recommended guidelines for the operation of advanced video coding (AVC) or high efficiency video coding (HEVC) video coding systems adapted for compressing HDR/WCG video for consumer distribution applications. This document includes a description of processing steps for converting from 4:4:4 RGB linear light representation video signals into non-constant luminance (NCL) Y'CbCr video signals that use the perceptual quantizer (PQ) transfer function defined in SMPTE ST 2084 and Recommendation ITU-R BT.2100. Although the focus of this document is primarily on 4:2:0 Y'CbCr 10 bit representations, these guidelines may also apply to other representations with higher bit depth or other colour formats, such as 4:4:4 Y'CbCr 12 bit video. In addition, this document provides some high-level recommendations for compressing these signals using either the AVC or HEVC video coding standards. A description of post-decoding processing steps is also included for converting these NCL Y'CbCr signals back to a linear light, 4:4:4 RGB representation.

This Supplement was jointly developed by ITU-T Study Group 16 and ISO/IEC JTC1 SC29/WG11 and the ISO title is ISO/IEC TR 23008-14 "*Information technology – High efficiency coding and media delivery in heterogeneous environments – Part 14: Conversion and coding practices for HDR/WCG Y'CbCr 4:2:0 video with PQ transfer characteristics*".

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Introduction

High dynamic range (HDR) video is a type of video content in which the sample values span a larger luminance range than conventional standard dynamic range (SDR) video. HDR video can provide an enhanced viewer experience and can more accurately reproduce scenes that include, within the same image, dark areas and bright highlights, such as emissive light sources and reflections. Wide colour gamut (WCG) video, on the other hand, is video characterized by a wider spectrum of colours compared to what has been commonly available in conventional video. Recent advances in capture and display technology have enabled consumer distribution of HDR and WCG content. However, given the characteristics of such content, special considerations may need to be made, in terms of both processing and compression, compared to conventional content.

This Supplement provides a set of recommended guidelines on the processing of consumer distribution HDR/WCG video. This includes recommendations for converting a video signal, in a linear light RGB representation with ITU-R BT.2020 colour primaries, to a 10-bit, narrow range, PQ encoded (as defined in SMPTE ST 2084 and Recommendation ITU-R BT.2100), 4:2:0, non-constant luminance Y'CbCr representation. These guidelines may also apply to other representations with a higher bit depth or other colour formats, such as 4:4:4 Y'CbCr 12 bit video. The scope of this document is illustrated in Figure 1.

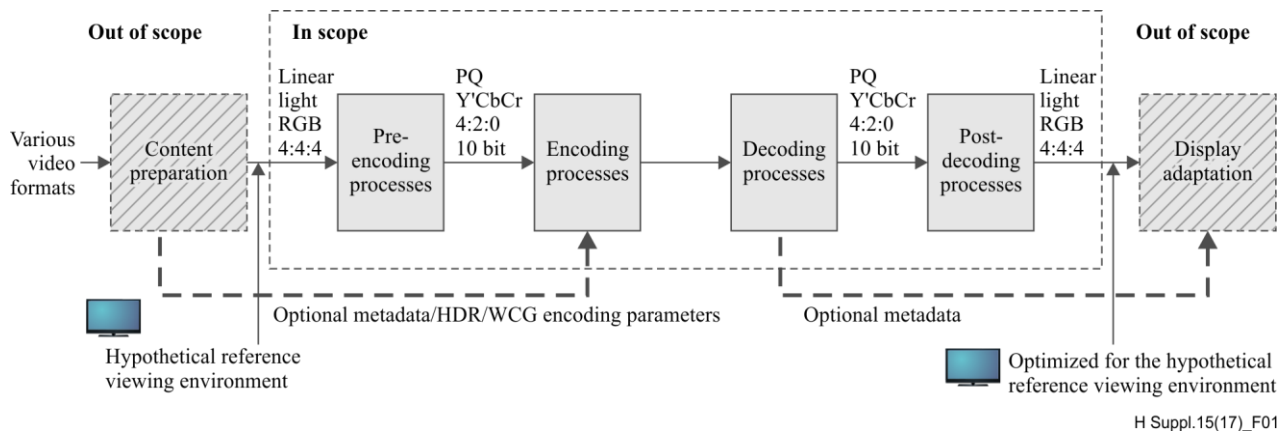


Figure 1 – Illustration of the scope of this document

The content preparation step, as well as the display adaptation step, are considered to be out of the scope of this document. However, metadata generated during the content preparation step may be passed through the encoder-decoder chain and can significantly affect the display adaptation step. The content preparation step may include filtering and image enhancement processing such as de-noising, colour correction and sharpening, as well as other processes. Such methods are deliberately not described in this document. The processing steps described in this document are made available for reference only and the document does not contain any elements of normative nature. It is possible to replace one or more of the processing steps described in this document, for example, in order to reduce computational complexity or to improve fidelity. This document's intention is to provide some guidelines for operating an HDR/WCG video system that is constrained to code a 10-bit, PQ (as defined in [SMPTE ST 2084] and [ITU-R BT.2100-0]), 4:2:0, non-constant luminance Y'CbCr signal representation. This configuration is also aligned with the HDR10 media profile defined in [DECE], the interface defined in [CTA 861-G] and the restrictions in [Blu-ray2015]. The processing steps in this document are optimized with the intention of providing the best possible result when the same hypothetical reference viewing environment (HRVE) is used before and after the HDR/WCG system. This document does not account for when the viewing environment used after the HDR/WCG system is different from the viewing environment used as the HRVE. In particular, display adaptation, such as the techniques described in the SMPTE ST 2094 standards, is not considered in this document. [ITU-R BT.2390-0] contains additional information on viewing environments and examples of parameters that may be appropriate to apply for practical HDR/WCG systems. This document does not provide a description of any preferred HRVE, but acknowledges the fact that in many applications of HDR/WCG video it may be desirable to have a well-defined HRVE description in order to ensure alignment between content preparation and content consumption.

Supplement 15 to the H-Series of Recommendations

Conversion and coding practices for HDR/WCG Y'CbCr 4:2:0 video with PQ transfer characteristics

1 Scope

This Supplement provides guidance on the processing of high dynamic range (HDR) and wide colour gamut (WCG) video content. The purpose of this document is to provide a set of publicly referenceable recommended guidelines for the operation of AVC or HEVC video coding systems adapted for compressing HDR/WCG video for consumer distribution applications. This document includes a description of processing steps for converting from 4:4:4 RGB linear light representation video signals into non-constant luminance (NCL) Y'CbCr video signals that use the perceptual quantizer (PQ) transfer function defined in [SMPTE ST 2084] and [ITU-R BT.2100-0]. Although the focus of this document is primarily on 4:2:0 Y'CbCr 10 bit representations, these guidelines may also apply to other representations with higher bit depth or other colour formats, such as 4:4:4 Y'CbCr 12 bit video. In addition, this document provides some high-level recommendations for compressing these signals using either the AVC or HEVC video coding standards. A description of post-decoding processing steps is also included for converting these NCL Y'CbCr signals back to a linear light, 4:4:4 RGB representation.

2 References

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3 Definitions

This Supplement defines the following terms. The definitions used in the AVC [ITU-T H.264] and HEVC [ITU-T H.265] standards also apply.

3.1 electro-optical transfer function (EOTF): The function used in the post-decoding process to convert from a non-linear representation to a linear representation.

3.2 full range: A range in a fixed-point (integer) representation that spans the full range of values that could be expressed with that bit depth, so that for 10-bit signals, black corresponds to code value 0 and peak white corresponds to code value 1023 for Y', as per the full range definition from [ITU-R BT.2100-0].

3.3 inverse electro-optical transfer function (inverse EOTF): A function used in the pre-encoding process to convert from a linear representation to a non-linear representation, computed as the inverse of the EOTF.

NOTE – In this document the pre-encoding process is assumed to operate on HDR/WCG video content that has been prepared for a hypothetical reference viewing environment as shown in Figure 1. The content preparation step may contain processing such as applying an opto-optical transfer function (OOTF), in which the HDR/WCG video is converted from one linear representation (corresponding to the scene) to another linear representation (corresponding to the display). The OOTF has the role of applying a "rendering intent". In systems where no such OOTF is applied in the content preparation step, the process of converting from a linear representation (corresponding to the scene) to a non-linear representation is typically called the opto-electrical transfer function (OETF).

3.4 narrow range: A range in a fixed-point (integer) representation that does not span the full range of values that could be expressed with that bit depth, so that for 10 bit representations, the range from 64 (black) to 940 (peak white) is used for Y', and the range from 64 to 960 is used for Cb and Cr, as per the narrow range definition from [ITU-R BT.2100-0].

NOTE – Narrow range is, in some applications, called by synonyms such as: "limited range", "video range", "legal range", "SMPTE range" or "standard range".

3.5 opto-electrical transfer function (OETF): The function that converts linear scene light into the video signal, typically within a camera.

3.6 opto-optical transfer function (OOTF): A function that maps relative scene linear light (typically the camera output signal) to display linear light (typically, the signal driving a mastering monitor).

3.7 random access point access unit (RAPAU): An access unit in the bitstream containing an intra-coded picture with the property that all pictures following the intra-coded picture in output order can be correctly decoded without using any information preceding the random access point access unit in the bitstream.

3.8 transfer function: In this document, a transfer function refers to any of the following; EOTF, inverse EOTF, OETF, inverse OETF, OOTF or inverse OOTF.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

AVC	Advanced Video Coding [ITU-T H.264]
CL	Constant Luminance
EOTF	Electro-Optical Transfer Function
FIR	Finite Impulse Response
HD	High Definition

HDR	High Dynamic Range
HEVC	High Efficiency Video Coding [ITU-T H.265]
HRVE	Hypothetical Reference Viewing Environment
HVS	Human Visual System
IQU	Up-scaling and Inverse Quantization
LUT	Look-Up Table
MAD	Mean Absolute Difference
NCL	Non-Constant Luminance
PQ	Perceptual Quantizer (as defined in [SMPTE ST 2084] and [ITU-R BT.2100-0])
QD	Quantization, Down-scaling
QP	Quantization Parameter
RAPAU	Random Access Point Access Unit
RGB	colour system using Red, Green and Blue components
SSE	Sum of Squared Errors
SDR	Standard Dynamic Range
SEI	Supplemental Enhancement Information
SPS	Sequence Parameter Set
OETF	Opto-Electrical Transfer Function
OOTF	Opto-Optical Transfer Function
VUI	Video Usability Information
WCG	Wide Colour Gamut
XYZ	The CIE 1931 colour space. Y corresponds to the luminance signal.
Y'CbCr	Colour space representation commonly used for video/image distribution as a way of encoding RGB information, also commonly expressed as YCbCr, Y'C _B C _R , or Y'C' _B C' _R . The relationship between Y'CbCr and RGB is dictated by certain signal parameters, such as colour primaries, transfer characteristics and matrix coefficients. Unlike the (constant luminance) Y component in the XYZ representation, Y' in this representation might not be representing the same quantity. Y' is commonly referred to as "luma". Cb and Cr are commonly referred to as "chroma".

5 Conventions

5.1 General

The mathematical operators used in this document are similar to those used in the C programming language. However, the results of integer division and arithmetic shift operations are defined more precisely and additional operations are defined, such as exponentiation and real-valued division. Numbering and counting conventions generally begin from 0, e.g., "the first" is equivalent to the 0-th, "the second" is equivalent to the 1-th, etc.

5.2 Arithmetic operators

The following arithmetic operators are defined as follows:

+	Addition
−	Subtraction (as a two-argument operator) or negation (as a unary prefix operator)
*	Multiplication, including matrix multiplication
x^y	Exponentiation. Denotes x to the power of y. In other contexts, such notation is used for superscripting not intended for interpretation as exponentiation.

/	Integer division with truncation of the result towards zero. For example, $7 / 4$ and $(-7) / (-4)$ are truncated to 1 and $(-7) / 4$ and $7 / (-4)$ are truncated to -1.
÷	Used to denote division in mathematical formulae where no truncation or rounding is intended.
$\frac{x}{y}$	Used to denote division in mathematical formulae where no truncation or rounding is intended.
$\sum_{i=x}^y f(i)$	The summation of $f(i)$ with i taking all integer values from x up to and including y .
$x \% y$	Modulus. Remainder of x divided by y , defined only for integers x and y with $x \geq 0$ and $y > 0$.

5.3 Bit-wise operators

The following bit-wise operators are defined as follows:

&	Bit-wise "and". When operating on integer arguments, operates on a two's complement representation of the integer value. When operating on a binary argument that contains fewer bits than another argument, the shorter argument is extended by adding more significant bits equal to 0.
	Bit-wise "or". When operating on integer arguments, operates on a two's complement representation of the integer value. When operating on a binary argument that contains fewer bits than another argument, the shorter argument is extended by adding more significant bits equal to 0.
^	Bit-wise "exclusive or". When operating on integer arguments, operates on a two's complement representation of the integer value. When operating on a binary argument that contains fewer bits than another argument, the shorter argument is extended by adding more significant bits equal to 0.
$x \gg y$	Arithmetic right shift of a two's complement integer representation of x by y binary digits. This function is defined only for non-negative integer values of y . Bits shifted into the MSBs as a result of the right shift have a value equal to the MSB of x prior to the shift operation.
$x \ll y$	Arithmetic left shift of a two's complement integer representation of x by y binary digits. This function is defined only for non-negative integer values of y . Bits shifted into the LSBs as a result of the left shift have a value equal to 0.

5.4 Assignment operators

The following assignment operators are defined as follows:

=	Assignment operator
++	Increment, i.e., $x++$ is equivalent to $x = x + 1$; when used in an array index, evaluates to the value of the variable prior to the increment operation.
--	Decrement, i.e., $x--$ is equivalent to $x = x - 1$; when used in an array index, evaluates to the value of the variable prior to the decrement operation.
+=	Increment by amount given, i.e., $x += 3$ is equivalent to $x = x + 3$, and $x += (-3)$ is equivalent to $x = x + (-3)$.
-=	Decrement by amount given, i.e., $x -= 3$ is equivalent to $x = x - 3$, and $x -= (-3)$ is equivalent to $x = x - (-3)$.

5.5 Relational, logical and other operators

The following operators are defined as follows:

==	Equality operator
!=	Not equal to operator
!x	Logical negation "not"
>	Larger than operator
<	Smaller than operator
≥	Larger than or equal to operator
≤	Smaller than or equal to operator
&&	Conditional/logical "and" operator. Performs a logical "and" of its Boolean operators, but only evaluates the second operand if necessary.

|| Conditional/logical "or" operator. Performs a logical "or" of its Boolean operators, but only evaluates the second operand if necessary.

a ? b : c Ternary conditional. If condition a is true, then the result is equal to b; otherwise the result is equal to c.

5.6 Mathematical functions

The following mathematical functions are defined as follows:

$$\text{Abs}(x) = \begin{cases} x & ; \quad x \geq 0 \\ -x & ; \quad x < 0 \end{cases}$$

Ceil(x) the smallest integer greater than or equal to x.

$$\text{Clip3}(x, y, z) = \begin{cases} x & ; \quad z < x \\ y & ; \quad z > y \\ z & ; \quad \text{otherwise} \end{cases}$$

Floor(x) the largest integer less than or equal to x.

EOTF⁻¹(x) the inverse EOTF used to convert a linear light representation to a non-linear light representation.

$$\text{Max}(x, y) = \begin{cases} x & ; \quad x > y \\ y & ; \quad \text{otherwise} \end{cases}$$

$$\text{Max}(x, y, z) = \begin{cases} x & ; \quad x > \text{Max}(y, z) \\ y & ; \quad y > \text{Max}(x, z) \\ z & ; \quad \text{otherwise} \end{cases}$$

$$\text{Min}(x, y) = \begin{cases} x & ; \quad x < y \\ y & ; \quad \text{otherwise} \end{cases}$$

$$\text{Min}(x, y, z) = \begin{cases} x & ; \quad x < \text{Min}(y, z) \\ y & ; \quad y < \text{Min}(x, z) \\ z & ; \quad \text{otherwise} \end{cases}$$

$$\text{Round}(x) = \text{Sign}(x) * \text{Floor}(\text{Abs}(x) + 0.5)$$

$$\text{Sign}(x) = \begin{cases} 1 & ; \quad x > 0 \\ 0 & ; \quad x = 0 \\ -1 & ; \quad x < 0 \end{cases}$$

EOTF(x) the EOTF used to convert a non-linear light representation x to a linear light representation.

5.7 Order of operations

When order of precedence in an expression is not indicated explicitly by use of parentheses, the following rules apply:

- Operations of a higher precedence are evaluated before any operation of a lower precedence.
- Operations of the same precedence are evaluated sequentially from left to right.

Table 1 specifies the precedence of operations from highest to lowest; a higher position in the table indicates a higher precedence.

NOTE – For those operators that are also used in the C programming language, the order of precedence used in this document is the same as that used in the C programming language.

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