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| *Title:* | **Clipping during 4:2:0 to 4:4:4 conversions** | | |
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# Abstract

This contribution provides informative recommendations relating to chroma processing, especially pertaining to the Non-Constant Luminance (NCL) and Constant-Luminance (CL) representations [2]. In particular, it is suggested that when processing chroma information, e.g. for the purpose of chroma format conversion or rescaling among others, any necessary clipping should be performed while also taking in account the relationships of and information from all available color planes. This can help in reducing conversion artefacts and in improving subjective quality.

# Introduction

The majority of digital image and video applications employ a Y’CbCr color space encoding for the representation of images, given its ability of better exploiting the correlation between different color planes versus other color spaces such as RGB or XYZ. Y’CbCr, also called as YCbCr, Y’UV, or YUV, comprises of a luma (Y’) component, and two chroma/color components (Cb and Cr). In its most common form, the Y’ component is computed as an approximation of the luminance/brightness information of the image (Y) of the CIE 1931 XYZ color space, as follows:

where the prime ( *'* ) symbol indicates the application of a transfer function [2][3] on the original linear light R, G, and B signals. This is called the non-constant luminance representation, which is the most prevalent representation in the majority of video coding [1][4] and processing systems. In this framework, a transfer function is applied onto the signal since it can enable the use of perceptual quantization, which can allow a preliminary type of compression to be used onto the signal, i.e. from a floating point to a fixed precision representation, commonly required by the majority of interfaces and video coding and processing systems. In the above equation also, the *wYR*, *wYG*, and *wYB* weights correspond to the constant weights used for the conversion of the linear light R, G, and B quantities back to the CIE 1931 Y component and have been specified according to the color gamut limitations of the current RGB color space compared to the overall XYZ color space. Also . In general, conversion from RGB to XYZ is performed using a 3x3 matrix conversion of the form:

with the *a* weights relating to the gamut limitations of the RGB color space in question. Common RGB color spaces currently in use include the ITU-R BT.601, BT.709 (sRGB), and BT.2020 [2] color spaces, Adobe RGB, scRGB, CIE RGB, P3DCI, and P3D65 among others.

Given a particular RGB color space, the Cb and Cr components in the Y’CbCr (NCL) representation are then computed as:

with and

with

The values of alpha and beta have been computed in a way that guarantees that Cb and Cr are always within the range of [-0.5, 0.5]. The -0.5 case can occur for Cb when B’ is equal to 0 and G’=R’=1, while 0.5 can occur when B’ is equal to 1, and G’=R’=0. Similarly, for Cr, -0.5 can occur when R’ is equal to 0 and G’=B’=1, while 0.5 can occur when R’ is equal to 1, and G’=B’=0.

However, it can be observed, that given the relationship of Cb or Cr with Y’ as well as of Y’ with B’ and R’ respectively, these limits are impacted by the value of Y’. If Y’ is known, then Cb and/or Cr are only allowed to be within a particular range of values. More specifically, if then the following applies:

If then the minimum possible value for Cb would be equal to , i.e. when B’=0 and consists of only R’ and G’.

Otherwise, the minimum would occur when G’=R’=1. Then . In this case, the minimum would be equal to . If we combine the two, then:

If, on the other hand, then the maximum possible value for Cb would be equal to , i.e. when B’=1 regardless of what the values for R’ and G’ may be.

Otherwise, the maximum would occur when G’=R’=0, in which case . In this scenario, the maximum would be equal to . Combining the two results in:

Quite similarly we can derive that the minimum and maximum values for Cr, given , would be equal to:

It should be further noted that knowledge of two components, e.g. and . can allow us to further refine the limits of the last color component. More specifically, we now have:

Given the above relationship between R’, the known values for Y’ and Cb, and therefore the known value for B’, the following can be derived:

If then the minimum possible value for Cr would be equal to , i.e. when R’=0 and consists of only B’ and G’.

Otherwise, the minimum would occur when G’=1. In that case, we can compute R’ as . Then, the minimum would be equal to . If we combine the two, we can compute that:

If, on the other hand, then the maximum possible value for Cr would be equal to , i.e. when R’=1 regardless of what the value of G’ is.

Otherwise, the maximum would occur when G’=0, in which case . In this scenario, the maximum would be equal to . Combining the two results we get that:

In an extreme case, we know that if then Cr=0.

Similarly for Cb, the limits, given Y’ and Cr, would be:

and, if we know that , then Cb=0. Similarly, if Y = 0, then both Cb and Cr components will have to be equal to 0.

One can make very similar derivations for the Constant Luminance or other similar representations. These though we will not be presented in this document and are left as an exercise to the reader.

# Recommendation

It should be quite obvious that if a system is aware of the color component relationships, i.e. the transfer function(s), representation dependencies, and color space/primaries used, then the above, or equivalent, equations could be used to improve chroma processing. We have, unfortunately, observed that most systems currently do not do so. Most video systems tend to process color planes independently and ignore these characteristics. Assuming data in an N-bit integer representation, e.g. N=8, values are commonly clipped independently to stay within the valid limits of the N-bit representation, i.e. from a value of 0 up to (2^N)-1. If it is known that the data also correspond to a particular limited representation, such as the standard/limited representation used for TV applications[[1]](#footnote-1) additional clipping within that range may be performed. Additional clipping is commonly performed when the signal is converted back to an RGB representation. This may result in accumulation of out of range sample values, and thus the presence of artifacts in the final image representation.

In a particular example that is of considerable interest to most video engineers, the conversion of 4:2:0 Y’CbCr to 4:4:4 Y’CbCr and/or RGB data may result in invalid Y’CbCr values that could be eliminated early on in the process. Such conversion essentially involves the use of a vertical and a horizontal interpolation step. The values can be clipped within their valid range at every processing step to avoid propagation of the unclipped signal, and thus the possibility of more severe errors, in any subsequent steps. Similar considerations could be made when rescaling or otherwise filtering an image in the Y’CbCr domain. In addition, if conversion from 4:4:4 to 4:2:0 or 4:2:2 is performed while retaining luma siting, the same principles could also be considered in that context as well, potentially avoiding the creation of invalid values in subsequent coding or processing steps.

Additional improvements of such a scheme could be made by intelligently selecting which component to process first. On the other hand, compression concepts could also be devised that account for the relationships of luma and chroma components. However, these are outside the scope of this contribution and will not be discussed in more detail.

# Conclusion

This contribution presented a mathematical analysis of the relationships between the different color components in a Y’CbCr color representation. Theoretical lower and upper limits for the color components are established, which can allow for improved video processing.

# References

1. ISO/IEC 230082:2014 HEVC Second Edition
2. Recommendation ITU-R BT. 2020, “Parameter values for ultra-high definition television systems for production and international programme exchange” (2012).
3. SMPTE ST 2084:2014, “High Dynamic Range Electro-Optical Transfer Function of Mastering Reference Displays”, 2014.
4. Call for Evidence (CfE) for HDR and WCG Video Coding, MPEG document M36131, Switzerland, Feb.2015

# Patent rights declaration(s)

**Apple Inc may have current or pending patent rights relating to the technology described in this contribution and, conditioned on reciprocity, is prepared to grant licenses under reasonable and non-discriminatory terms as necessary for implementation of the resulting ITU-T Recommendation | ISO/IEC International Standard (per box 2 of the ITU-T/ITU-R/ISO/IEC patent statement and licensing declaration form).**

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1. For 8 bit signals, luma is enforced to be in the range of 16 up to 235 and the two chroma components in the range of 16 up to 240. [↑](#footnote-ref-1)