EVALUATION OF CHROMA SUBSAMPLING FOR HIGH DYNAMIC RANGE VIDEO COMPRESSION

Ronan Boitard[⋆] *Mahsa T. Pourazad*[⋆†] *Panos Nasiopoulos*[⋆]

[⋆] University of British Columbia, Vancouver, Canada
[†]TELUS Communications Inc., Vancouver, Canada

ABSTRACT

Subsampling chroma channels of video content is a processing performed in most video distribution pipelines. In such pipelines, chroma subsampled content also undergoes video coding, using a codec, before being distributed. Presently, it is common practice to optimize compression efficiency and visual quality of content with respect to its subsampled version rather than the original one. Although this may suffice for traditional imagery, it is unclear if emerging technologies such as Wide Color Gamut and High Dynamic Range are more sensitive to quality loss due to chroma subsampling. In this article, we assess the efficiency of chroma subsampling when compressing HDR content. We compare the performance of two different downsampling filters against the full chroma sampling. Objective results show that distributing 4:4:4 is more efficient than its 4:2:0 counterpart at medium to high bit-rates. For low bit-rates, this increase in efficiency is reduced and in some cases even reversed.

Index Terms— High Dynamic Range, Video Compression, Chroma Subsampling, Perceptual Encoding

1. INTRODUCTION

Broadcasters rely on several lossy processing steps, applied prior to distribution, to distribute video content efficiently and deliver the highest possible visual quality while using the lowest bandwidth. Among them, chroma subsampling has been established since the early stages of digital video as a mandatory step of most distribution pipelines. Chroma subsampling is assumed to reduce bandwidth requirements with limited impact on video quality. However, with the deployment of emerging technologies such as High Dynamic Range (HDR) [1] and Wide Color Gamut (WCG) [2], this assumption may not hold anymore. This is mostly due to the fact that color distortion are more noticeable at high luminance values. We propose, in this article, to test this assumption for HDR content.

This paper is structured as follows: Section 2 describes the chroma subsampling process and HDR video distribution pipeline. Section 3 assesses the impact of subsampling, when no compression is applied, while Section 4 compares the compression efficiency of full (4:4:4) and sub (4:2:0) chroma sampling. Finally Section 5 concludes this paper.

(a) (b)

Fig. 1: Example of artifacts generated by chroma subsampling. (a) **4:4:4** full chroma sampling, (b) **4:2:0 MPEG** chroma sampling.

2. RELATED WORK

2.1. Chroma Subsampling

Chroma subsampling consists in several color pixels sharing the same chroma value, thus lowering the spatial resolution of chroma channels vertically, horizontally or both. Chroma subsampling alleviates the memory and throughput requirements for both encoder and decoder.

One drawback of chroma subsampling is the loss of color information, which can be propagated throughout the pipeline (video coding, transcoding, etc.). Furthermore, the distortion optimization performed at the coding stage is based on the chroma subsampled video rather than the full chroma sample one. Thus, choices made inside the encoder may not optimize the distortion with respect to the original source (e.g., the full chroma video), but rather the subsampled content. In addition, visible artifacts can occur near high gradient at the edge of the used gamut as detailed in [3] and illustrated in Fig. 1.

Recently, edge-aware subsampling techniques have been proposed using luma information [4]. However, altering the subsampling as proposed in [4] requires to have a fixed upsampling filter at the decoding stage, which is not a viable scenario for distribution applications. Thus, we will not consider such techniques in our study.

2.2. HDR Video Distribution Pipeline

Fig. 2 illustrates a typical HDR distribution pipeline as investigated in the HDR and WCG activities of MPEG [5]. Before broadcasting, perceptual encoding is first applied on each color channel of the HDR video. Perceptual encoding converts HDR absolute physical values (representing light intensities in cd/m^2) to a more perceptually uniform domain [6]. Then, color channels are converted to a luma/chroma representation. The next step is the chroma downsampling, which filters chroma values so that a smaller number of pixels (lower resolution) represent approximately the original colors. The quantization to integer values is then performed on the targeted bit-depth n. A video codec is then used to compress the chroma downsampled content. Compression removes information based on a rate-distortion criterion, which is a trade-off between the distortion and bit-rate. At the end-user side, a decoder reconstructs the video based on the information embedded in the broadcasted bit-stream. The quantization is inverted before chroma upsampling reconstructs the full resolution chroma channels. Finally, content is converted back to R'G'B' color channel before being perceptually decoded to light values that are displayed by the HDR TV.

In this article, perceptual encoding consists of applying the SMPTE ST 2084 [7] (also known as Perceptual Quantizer - PQ [8]) on each R, G, B color channel independently. The used luma/chroma decomposition is Y'C_bC_r while the chroma downsampling corresponds to a 4:2:0 sampling (two chroma values, one for each channel, associated with four luma values). The targeted bit-depth is 10 bits and is achieved using the BT.1361 restricted range equations [9], meaning that code value are limited to the range [64-940]. The used codec is the ITU-T H.265 / MPEG-H Part 2 'High Efficiency Video Codec' (HEVC) [10]. This pipeline corresponds to the HDR10 pipeline [11].

3. CHROMA SAMPLING COMPARISON

In our first experiment, two different chroma samplings are considered: **4:2:0 MPEG** and **4:2:0 Lanczos**. **4:2:0 MPEG** uses the 3-tap filter considered in the MPEG Call for Evidence (CfE) for HDR and WCG video coding [5]. **4:2:0 Lanczos** is a 6-tap Lanczos filter. These chroma sampling schemes are applied on three HDR test video sequences from the database provided to the MPEG HDR Ad Hoc group [5]. More specifically, the HDR videos are downsampled to 4:2:0 and then upsampled to 4:4:4 using these two sampling schemes. The results are then compared against **4:4:4**, which is a full chroma sampling (not using downsampling and upsampling) in terms of t-PSNR-Y and PSNR-DE0100. Note that the **4:4:4** sampling involves only the distortion introduced by the combination of perceptual encoding and quantization. We observe from Table 1 that the chroma subsampling significantly affects the color accuracy.

PSNR-DE0100 in dB			
Sequence	**4:4:4**	**4:2:0 Lanczos**	**4:2:0 MPEG**
FireEater2	52.32	48.80	48.42
Market3	42.11	36.88	36.77
BalloonFestival	45.36	40.46	40.63

Table 1: Impact of perceptual encoding and chroma downsampling on the color accuracy in dB (PSNR-DE0100 from HDRtools [12]).

4. CHROMA SUBSAMPLING AND COMPRESSION

In our second experiment, we evaluate the combined distortion of chroma subsampling and video compression, which corresponds to a typical broadcast scenario as illustrated in Fig. 2. To this end, we compressed six HDR sequences using HM 16.7 with Range-Extension (RExt) to enable full chroma sampling video coding. The main-RExt profile was used and the only difference in the configuration was the use of 4:4:4 or 4:2:0 chroma sampling. We used the Quantization Parameters (QP) described in the MPEG CfE [5].

Figs. 3 to 5 report the values obtained by the tPSNR-XYZ (distortion metric computed on the XYZ color channels), and the PSNR-DE0100 metric (which is based on the ΔE_{00} [15]) at different bit-rates for three out of the six sequences tested. Both metrics are available in the HDRtools software package [12]. The tPSNR-XYZ results show that full chroma sampling performs better for high bit-rates. However, as the bit-rate decreases, the gain is reduced and for low bit-rates it becomes negative (see Fig. 5). This is because low bit-rates are achieved by removing low frequency information. Thus, at low bit-rates, medium to high frequency details, which were preserved through the use of full chroma sampling, are still removed during compression. However, such low bit-rates ($\leq$ 2 Mbps) are an unlikely scenario for HDR broadcasting.

The gain in color accuracy (PSNR-DE0100 metrics) seems less dependent on the bit-rate and is close to 1 dB for most sequences. Only the FireEater2 sequence results (Fig. 4) have a limited gain in color accuracy, close to 0.5 dB. FireEater2 is mostly a dark sequence, which explains the lower impact of using full chroma sampling. Note that the more colorful the sequence is, the more impact full chroma sampling has (BalloonFestival results show an average gain of 2 dB, Fig. 3). We also observe that the longer filter used (6-tap **4:2:0 Lanczos** versus 3-tap **4:2:0 MPEG**) does not result in higher compression efficiency.

From this evaluation, we conclude that using full chroma sampling instead of chroma subsampling increases compression efficiency. This work establishes that chroma subsampling does not improve compression efficiency for HDR content and a recent study [16] reported that it can strongly degrade the quality of Experience (QoE) when processes such

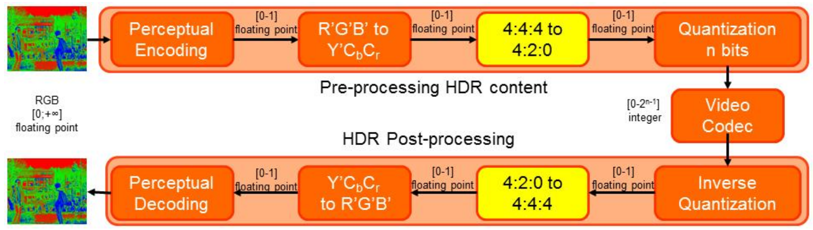

Fig. 2: Typical distribution pipeline of HDR video content.

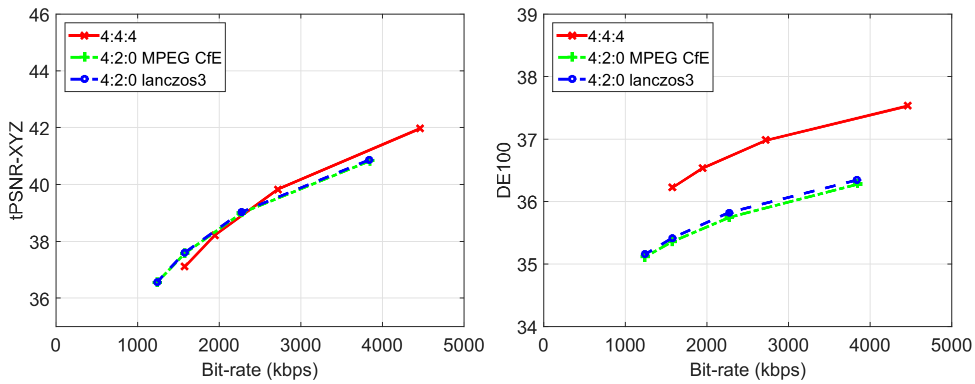

Fig. 3: tPSNR-XYZ and PSNR-DE0100 at different bit-rates for the BalloonFestival sequence [13].

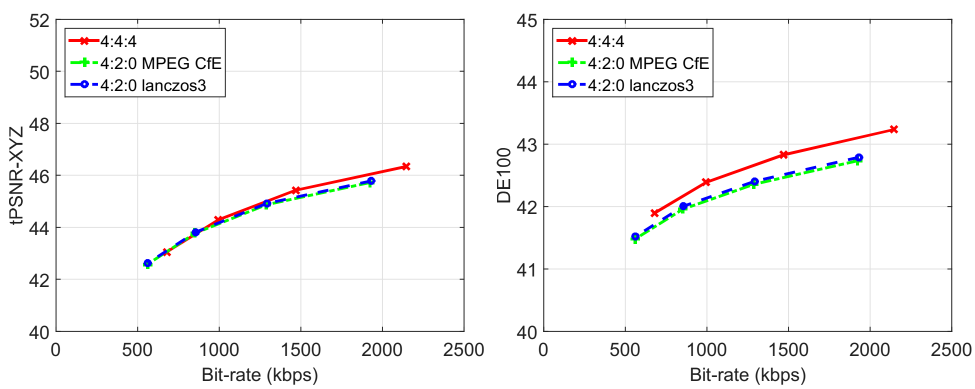

Fig. 4: tPSNR-XYZ and PSNR-DE0100 at different bit-rates for the FireEater2 sequence [14].

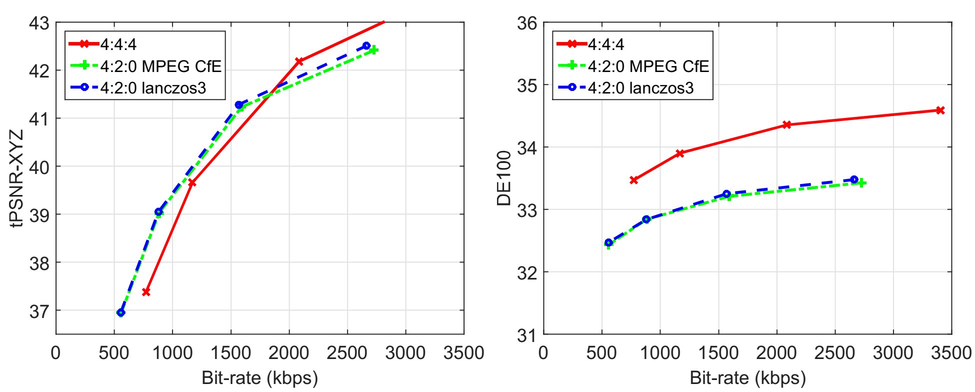

Fig. 5: tPSNR-XYZ and PSNR-DE0100 at different bit-rates for the Starting sequence.

as tone/color mapping are required at the decoder stage. However, the main obstacle to the removal of chroma subsampling is that, currently, the main10 profile of HEVC does not support full chroma sampling. There is ongoing talk in MPEG activities to include this feature in the next generation standards.

Finally, our results also indicate that the longer sampling filter used does not seem to increase compression efficiency. Furthermore, since in a typical broadcast scenario, there is no foreknowledge about the chroma upsampling filter at the decoding stage, using longer filter may be the source of new artifacts. Thus, if chroma subsampling is still need, due for example to hardware limitations or very low bit-rates requirements, we recommend the use of short filters to minimize error propagation.

5. CONCLUSION

In this paper, we evaluated the impact of chroma subsampling on the compression efficiency of HDR video content. We observed that using chroma subsampling always decreases the accuracy of color reproduction. Results obtained from the tPSNR-XYZ metric indicated that using chroma subsampling reduces the compression efficiency at medium to high bit-rates, while some gain can be achieved at low bit-rates. However, these low bit-rates correspond to unlikely scenarios for HDR distribution. Furthermore, full chroma sampling significantly increases the color accuracy for all tested content and bit-rates. These results suggest the use of full chroma sampling for future HDR video coding/distribution.

6. REFERENCES

[1] R. Boitard, M. T. Pourazad, P. Nasiopoulos, and J. Slevinsky, "Demystifying high-dynamic-range technology: A new evolution in digital media.," *IEEE Consumer Electronics Magazine*, vol. 4, no. 4, pp. 72–86, oct 2015.

[2] C. Poynton, J. Stessen, and R. Nijland, "Deploying wide color gamut and high dynamic range in hd and uhd," *SMPTE Motion Imaging Journal*, vol. 124, no. 3, pp. 37–49, apr 2015.

[3] J. Strom, J. Samuelsson, and K. Dovstam, "Luma adjustment for high dynamic range video," in *IEEE Data Compression Conference (DCC)*, 2016.

[4] J. Korhonen, "Improving image fidelity by luma-assisted chroma subsampling," in *2015 IEEE International Conference on Multimedia and Expo (ICME)*. jun 2015, pp. 1–6, IEEE.

[5] A. Luthra, E. Francois, and W. Husak, "Call for evidence (cfe) for hdr and wcg video coding," in *ISO/IEC JTC1/SC29/WG11 MPEG2014/N15083*, Geneva, Switzerland, 2015.

[6] R. Boitard, R. K. Mantiuk, and T. Pouli, "Evaluation of color encodings for high dynamic range pixels," in *Proc. SPIE 9394, Human Vision and Electronic Imaging XX*, 2015.

[7] Society of Motion Picture & Television Engineers, "High dynamic range electro- optical transfer function of mastering reference displays table," in *SMPTE ST 2084*. 2014, SMPTE.

[8] T. Kunkel, G. Ward, B. Lee, and S. Daly, "Hdr and wide gamut appearance-based color encoding and its quantification," in *2013 Picture Coding Symposium (PCS)*, San Jose, Dec. 2013, pp. 357–360, IEEE.

[9] International Telecommunication Union, "Worldwide unified colorimetry and related characteristics of future television and imaging systems," in *Recommendation ITU-R BT.1361*, 2002.

[10] M. T. Pourazad, C. Doutre, M. Azimi, and P. Nasiopoulos, "Hevc: The new gold standard for video compression: How does hevc compare with h.264/avc?," *IEEE Consumer Electronics Magazine*, vol. 1, no. June, pp. 36–46, 2012.

[11] D. Le Gall et al., "High dynamic range with hevc main10," in *ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11*, Warsaw, PL, 2015.

[12] A. M. Tourapis and D. Singer, "Hdrtools: A software package for video processing and analysis," in *ISO/IEC JTC1/SC29/WG11 MPEG2014/m35156*, Strasbourg, France, 2014.

[13] D. Malas, R. V. der Bleuten, E. Francois, K. Minoo, and E. Alshina, "Cablelabs content input hdr wcg," in *ISO/IEC JTC1/SC29/WG11 MPEG2014/ m35465*, Lausanne, CH, 2014.

[14] S. Lasserre, F. LeLéannec, and E. Francois, "Description of hdr sequences proposed by technicolor," in *ISO/IEC JTC1/SC29/WG11 JCTVC-P0228*, San Jose, USA, 2013, IEEE.

[15] G. Sharma, W. Wu, and E. N. Dalal, "The ciede2000 color-difference formula: Implementation notes, supplementary test data, and mathematical observations," *Color Research and Application*, vol. 30, no. 1, pp. 21–30, 2005.

[16] M. Azimi, R. Boitard, M. T. Pourazad, and P. Nasiopoulos, "Evaluation of backward-compatible hdr transmission pipelines," in *ISO/IEC JTC1/SC29/WG11 JCTVC-W0106*, San Diego, USA, 2016.