JND-Based Perceptual Video Coding for 4:4:4 Screen Content Data in HEVC

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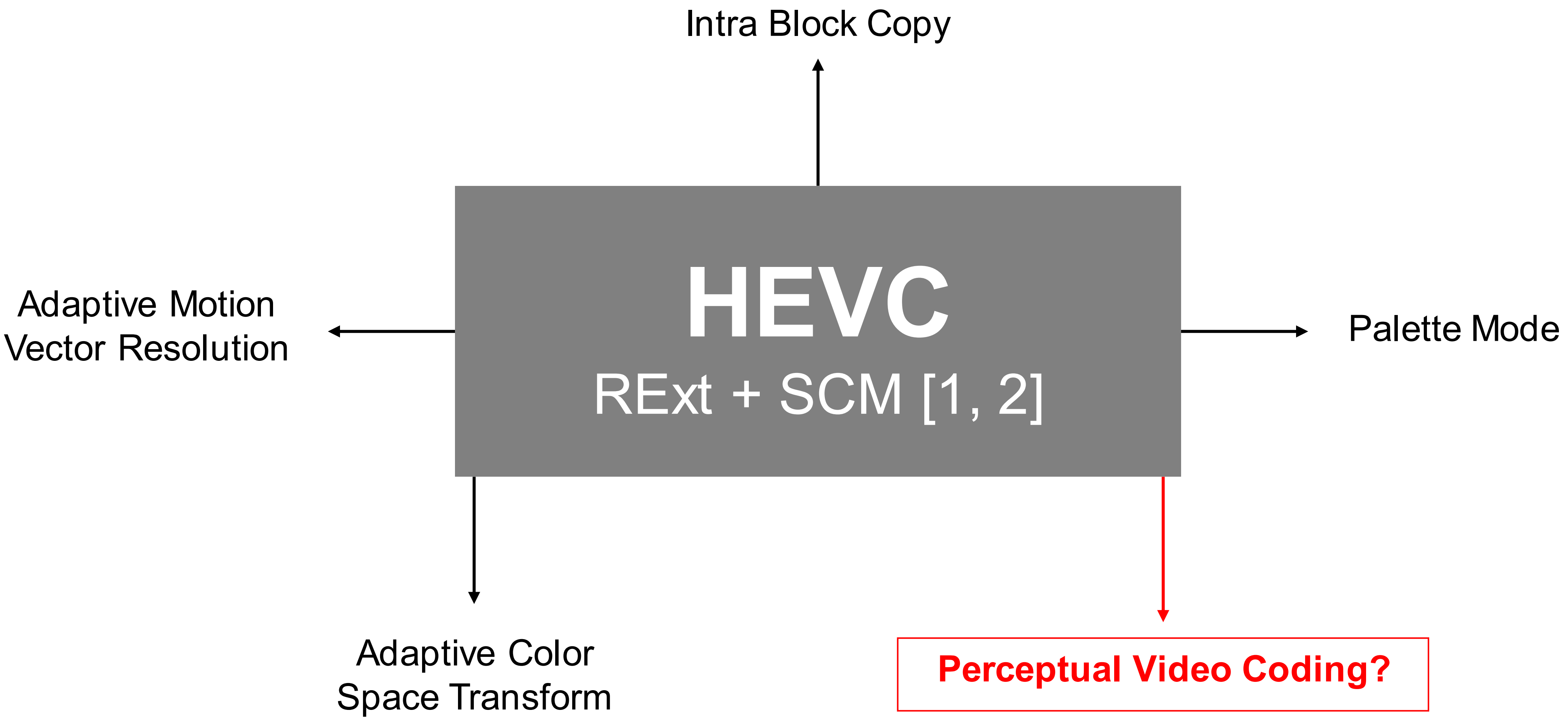
Outline

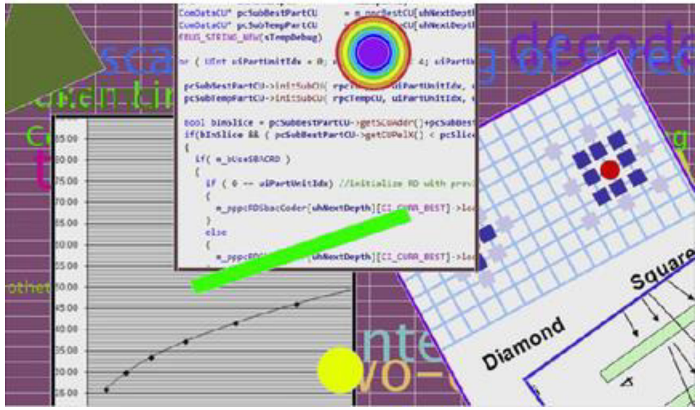
- HEVC Screen Content Coding
- YCbCr 4:4:4 and Coding Blocks
- JND-Based Perceptual Video Compression
- Proposed Technique
- Performance Evaluation
- Conclusions and Future Work
- References

HEVC Screen Content Coding Extension (SCM)

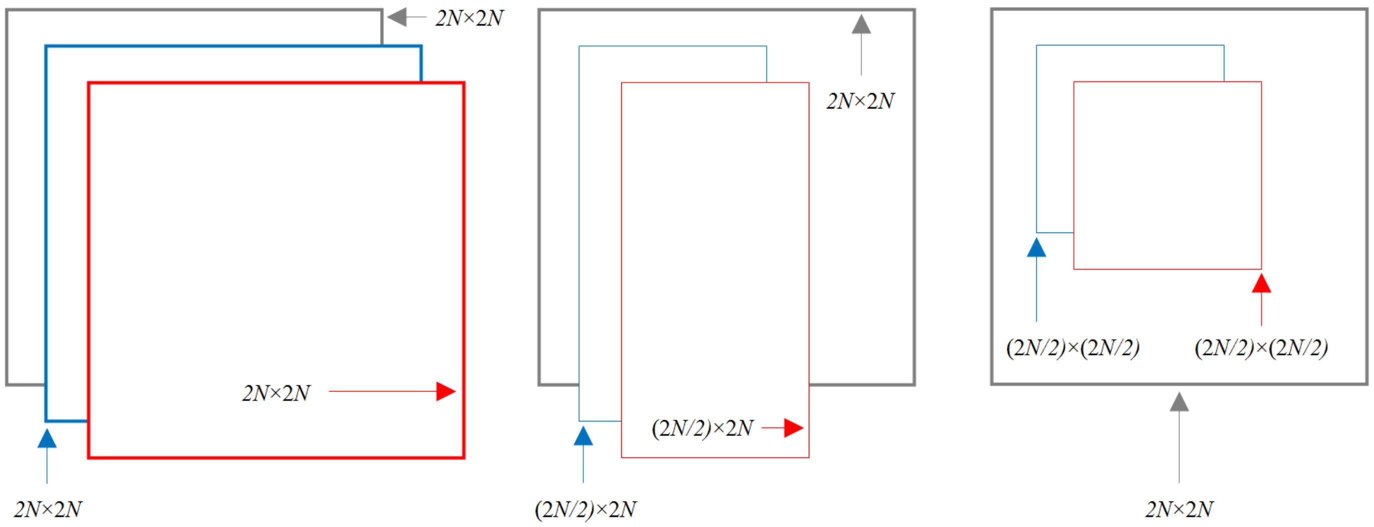


Motivation

- Perceptually optimized video coding is not exploited in HEVC RExt + SCM [1, 2].
- YCbCr 4:4:4 screen content video data contains a high degree of perceptual redundancy in all three color channels [3].
  - In particular, the perceptual compression of high bit depth chrominance data can facilitate considerable overall bitrate reductions.
- JND-Based Perceptual Quantization (PQ)
  - JND-Based Coding Block (CB)-Level PQ
    - PQ performed on Y, Cb and Cr CBs.
    - Exploits JND-based luminance masking and also chrominance masking parabolic piecewise functions.



Coding Block (CB)-Level Quantization



(a) 4:4:4 YCbCr CB Sizes **(b)** 4:2:2 YCbCr CB Sizes **(c)** 4:2:0 YCbCr CB Sizes

- HEVC enables the Quantization Step Size (QStep) to be modified at the CB level [3].
  - The data can be separately quantized in each color channel. This is useful for potential perceptual quantization techniques, particularly for YCbCr 4:4:4 data in which perceptual redundancy is high.
  - The size of chroma CBs is dependent on the chroma sampling ratio of the video data.

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JND-Based CB-Level Perceptual Quantization

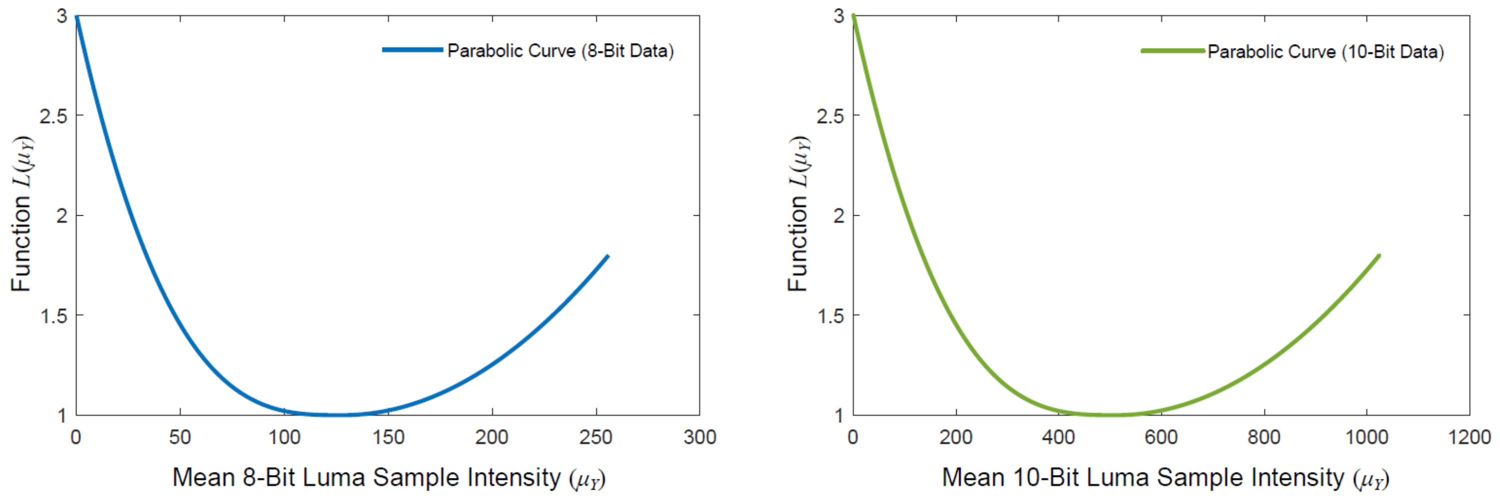
$$L(\mu_Y)=\begin{cases} a\cdot\left(1-\dfrac{2\mu_Y}{2^b}\right)^d+1, & \text{if } \mu_Y\le\dfrac{2^b}{2} \\ c\cdot\left(\dfrac{2\mu_Y}{2^b}-1\right)^f+1, & \text{otherwise}\end{cases}$$

$$C_{Cb}(\mu_{Cb})=\begin{cases} \dfrac{-\mu_{Cb}\cdot(g-1)}{h+g} & \text{if } \mu_{Cb}\le h \\ 1 & \text{if } h<\mu_{Cb}<j \\ \dfrac{(\mu_{Cb}-j)\cdot(k-1)}{(2^b-1-j)+1}, & \text{otherwise}\end{cases}$$

$$C_{Cb}(\mu_{Cb})=\begin{cases} \dfrac{-\mu_{Cb}\cdot(g-1)}{h+g} & \text{if } \mu_{Cb}\le h \\ 1 & \text{if } h<\mu_{Cb}<j \\ \dfrac{(\mu_{Cb}-j)\cdot(k-1)}{(2^b-1-j)+1}, & \text{otherwise}\end{cases}$$

- $L(\mu_Y)$, $C_{Cb}(\mu_{Cb})$ and $C_{Cr}(\mu_{Cr})$ constitute the JND-based visibility thresholds for luminance masking and chrominance masking; they are based on luminance and chrominance adaptation.
- $L(\mu_Y)$, $C_{Cb}(\mu_{Cb})$ and $C_{Cr}(\mu_{Cr})$ also act as weights to modify the URQ QStep at the CB level.
- Assuming that the quantization-induced errors, denoted as q_Y, q_{Cb} and q_{Cr}, do not exceed $L(\mu_Y)$, $C_{Cb}(\mu_{Cb})$ and $C_{Cr}(\mu_{Cr})$, then visually lossless coding is achieved.
- Applying $L(\mu_Y)$, $C_{Cb}(\mu_{Cb})$ and $C_{Cr}(\mu_{Cr})$ to the URQ QStep at the CB level facilitates considerable bitrate reductions, especially so for high bit-depth chrominance data.

Luma CB-Level Perceptual QStep Adjustment



$$PQP_Y = \left[6 \times \log_2 \left(PStep_Y \right) \right] + 4$$

$$PStep_Y = QStep_Y \cdot \left[L(\mu_Y) \right]$$

- The luma CB-level perceptual QP, denoted as PQP_Y, has a binary logarithmic relationship with the corresponding perceptual QStep, denoted as $PStep_Y$.
- Recall that the CB-level luma URQ QStep, denoted as $QStep_Y$, is weighed by $L(\mu_Y)$.

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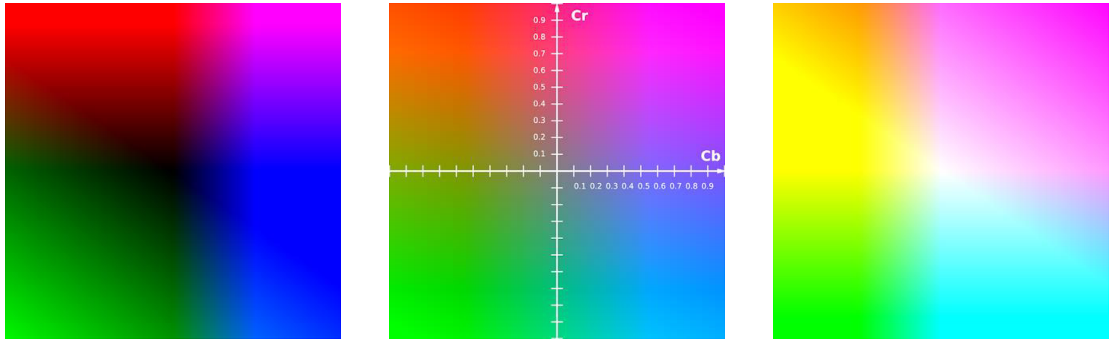
Chroma CB-Level Perceptual QStep Adjustment



(a) Cb, Cr Plane (Y = 0) **(b)** Cb, Cr Plane (Y = 0.5) **(c)** Cb, Cr Plane (Y = 1)

$$OQP_{Cb} = PQP_Y + PQP_{Cb}$$

$$PQP_{Cb} = \left[6 \times \log_2\left(QStep_{Cb} \cdot \left[C_{Cb}\left(\mu_{Cb}\right)\right]\right)\right] + 4$$

$$OQP_{Cr} = PQP_Y + PQP_{Cr}$$

$$PQP_{Cr} = \left[6 \times \log_2\left(QStep_{Cr} \cdot \left[C_{Cr}\left(\mu_{Cr}\right)\right]\right)\right] + 4$$

- The Human Visual System (HVS) is considerably less perceptually sensitive to quantization induced compression artifacts that are present in reconstructed chroma data.
- We exploit the CU-level chroma Cb and Cr CB QP offset signalling mechanism in the Picture Parameter Set (PPS).
  - $C_{Cb}(\mu_{Cb})$ and $C_{Cr}(\mu_{Cr})$ weigh the Cb and Cr URQ QSteps at the CB level.
  - The chroma perceptual QPs, denoted as PQP_{Cb} and PQP_{Cr}, are employed as offsets against PQP_Y.
  - This results in CB-level perceptual chroma offset QPs, denoted as OQP_{Cb} and OQP_{Cr}.

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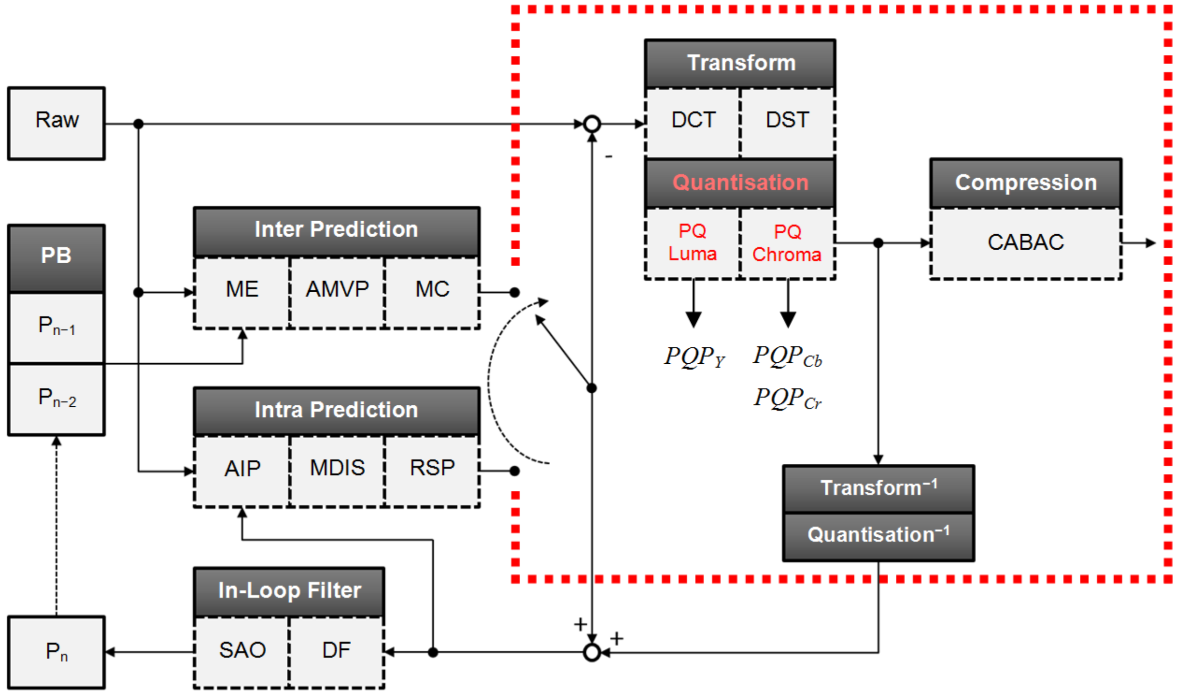
Implementation: HEVC Coding Pipeline



- Straightforward encoder side implementation due to exploiting the CU-level QP offset signalling mechanism in the PPS [4].
- Guaranteed bitstream conformance in accordance with HEVC standard v4 (i.e., ITU-T with Rec. H.265 v4) [5].

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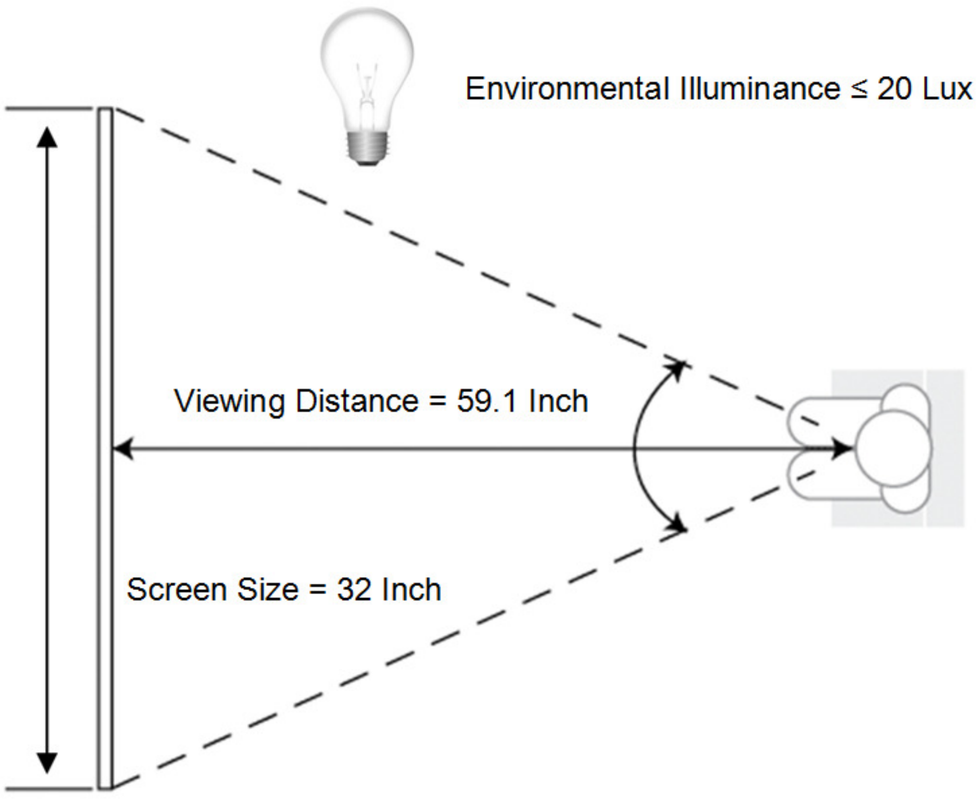
Performance Evaluation: Subjective Evaluations

- ITU.T P.910 Subjective Evaluation [6]
  - Four Participants
  - Viewing Distance = 59.1 Inch
  - Environmental Illuminance ≈ 20 Lux
  - TV/VDU Screen Size = 32 Inch
  - Mean Opinion Score (MOS)
  - Spatiotemporal Analysis
- Subjective Tests Conducted
  - 106 Visual inspections (compressed data versus anchors).
  - MOS = 5 (Visually Lossless) chosen by participants in all RA QP = 22 tests.
  - High reductions of the PSNR values in luma and chroma data does not correlate with human visual perception.



Performance Evaluation: Subjective Evaluations

(a) Kimono (10-Bit YCbCr 4:4:4) — Raw Data

(b) Kimono (10-Bit YCbCr 4:4:4) — RA QP = 22 (Inter)

- As proved to be the case with all screen content tested, including Camera-Captured Content (Kimono), the compressed data, as shown above, is indistinguishable from the raw data.
- Considerable bitrate reductions, of up to 48.3% are attained by SC-PAQ on the Kimono 10-Bit YCbCr 4:4:4 sequence without inducing a loss of perceptual visual quality; see (b) above.

Performance Evaluation: Subjective Evaluations

(a) SSIM Index Map (Y Channel)

(b) SSIM Index Map (Cb Channel)

(c) SSIM Index Map (Cr Channel)

- In (a), (b) and (c), the structural reconstruction errors (SSIM Index Map) are shown for the reconstructed data in the Y, Cb and Cr channels, respectively.
- In spite of the considerable reductions of the PSNR values for quantifying the reconstruction errors in the compressed video data, these reconstruction errors are imperceptible to the HVS.
- Focusing on chrominance data in particular (i.e., the data in the Cb and Cr channels), high levels of quantization can be applied thus facilitating considerable bitrate reductions.

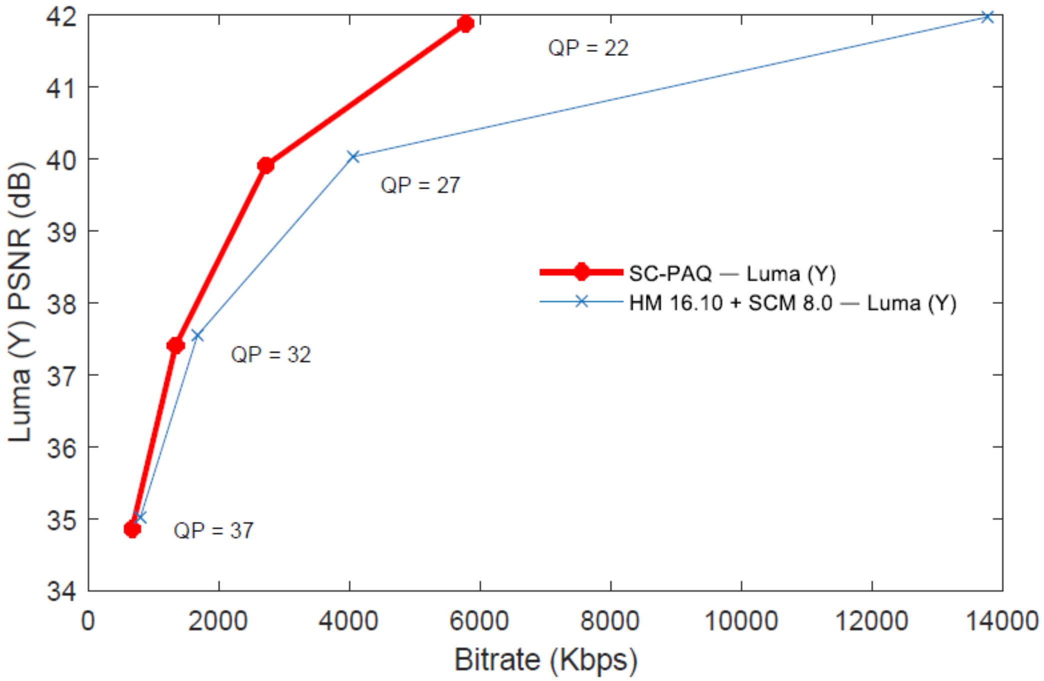
Performance Evaluation: Objective Evaluations

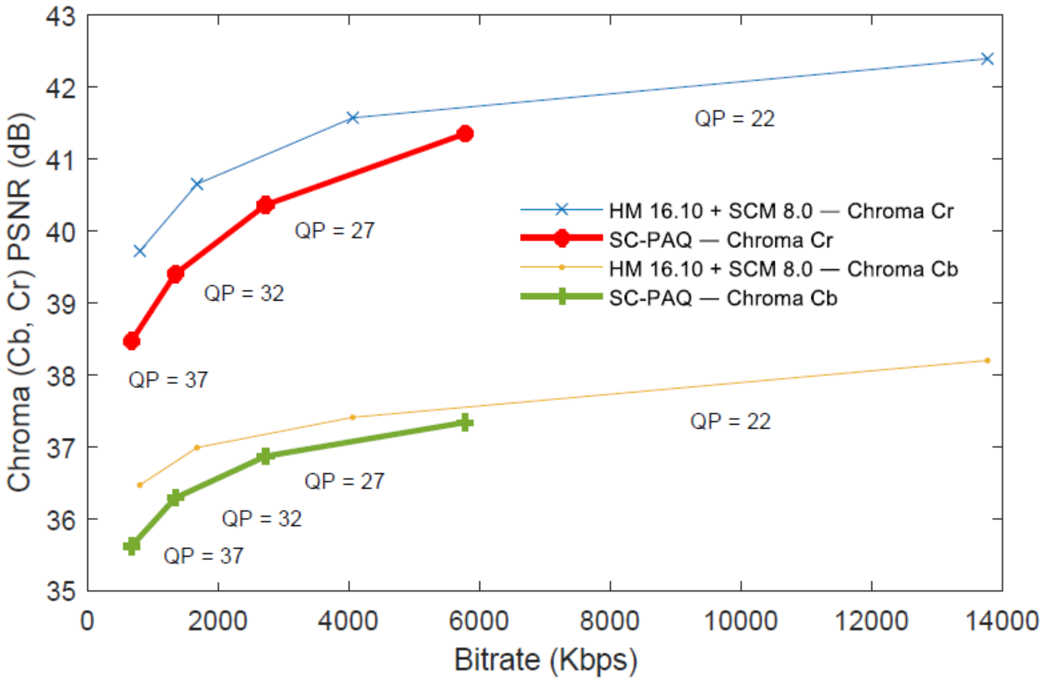
Overall Bitrate Reductions (%) Per Sequence and PSNR Value Reductions (dB) Per Channel — RA: Averaged Over QPs 22, 27, 32, 37

Sequence (YCbCr 4:4:4)	SC-PAQ versus HM 16.10 + SCM 8.0				SC-PAQ versus IDSQ [16]			
	Bitrate (%)	Y PSNR (dB)	Cb PSNR (dB)	Cr PSNR (dB)	Bitrate (%)	Y PSNR (dB)	Cb PSNR (dB)	Cr PSNR (dB)
Basketball Screen	**−13.9%**	−0.45 dB	−2.94 dB	−2.91 dB	**−11.8%**	−0.18 dB	−2.82 dB	−2.81 dB
CAD Waveform	**−4.6%**	−1.39 dB	−4.07 dB	−4.58 dB	**−4.4%**	−1.36 dB	−3.82 dB	−4.42 dB
Console	**−9.7%**	−0.79 dB	−3.29 dB	−3.68 dB	**−9.1%**	−0.64 dB	−3.08 dB	−3.48 dB
Desktop	**−5.5%**	−1.14 dB	−3.80 dB	−3.77 dB	**−5.5%**	−0.90 dB	−3.58 dB	−3.50 dB
Flying Graphics	**−12.6%**	−0.44 dB	−3.12 dB	−2.91 dB	**−11.4%**	−0.32 dB	−3.07 dB	−2.89 dB
Kimono (10-Bit)	**−48.3%**	−0.13 dB	−0.74 dB	−1.19 dB	**−40.6%**	0.01 dB	−0.67 dB	−1.08 dB
Mission Control 3	**−11.7%**	−0.55 dB	−2.84 dB	−2.78 dB	**−9.7%**	−0.28 dB	−2.69 dB	−2.62 dB
PCB Layout	**−2.1%**	−1.80 dB	−5.30 dB	−6.39 dB	**−2.1%**	−1.33 dB	−5.19 dB	−5.87 dB
PPT DOC XLS	**−5.0%**	−0.85 dB	−3.28 dB	−3.29 dB	**−4.3%**	−0.50 dB	−3.00 dB	−3.13 dB

- Experimental Setup: SC-PAQ versus Two Anchors (HM 16.10 + SCM 8.0 [7] and IDSQ [8]); Random Access Configuration (RA); QPs 22, 27, 37 and 37 and YCbCr 4:4:4 Test Sequences.
- Quantification: Bitrate reductions (and Y, Cb and Cr PSNR reductions) attained by SC-PAQ.
- Due to the higher levels of perceptual quantization applied to the chroma channels, the SC-PAQ PSNR values in the Cb and Cr channels are, as expected, significantly inferior to anchors.

Performance Evaluation: Objective Evaluations





- Plots showing the bitrate reductions achieved by SC-PAQ on the Kimono 10-Bit YCbCr 4:4:4 sequence: luma channel (left) and chroma channels (right).
- 10-Bit data contains a higher degree of variance in each color channel. Therefore, our evaluations showed that large bitrate reductions (i.e., up to 48.3%) can be achieved on this type of data.

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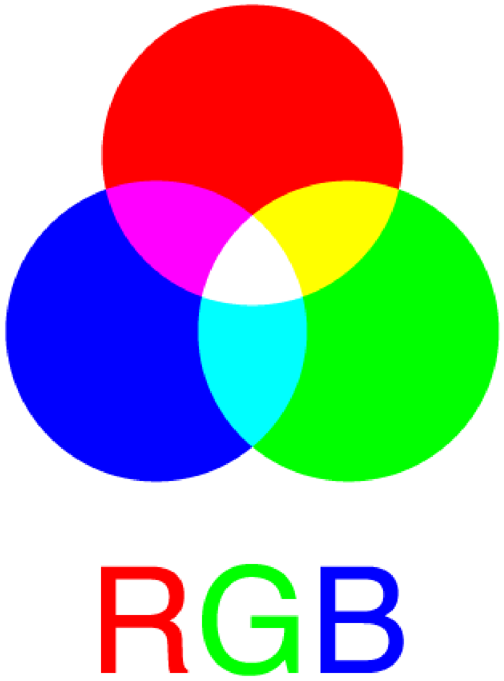
Conclusions and Future Work

- Conclusions
  - JND modelling can be applied to both luma and chroma video data.
  - JND-based perceptual quantisation of chroma data significantly decreases bitrates.
  - Perceptual quantisation is more effective when applied to high bit depth YCbCr 4:4:4 screen content video data.
  - Subjective evaluations are critically important for perceptual coding techniques.
  - Objective visual quality metrics are not useful for measuring perceptual quality.
- Future Work
  - Extend the proposed technique to high bit depth RGB (GBR) video data.
  - Multiple applications for the proposed SC-PAQ technique including medical image and video coding.



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