CROSS-COLOR CHANNEL PERCEPTUALLY ADAPTIVE QUANTIZATION FOR HEVC

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Uniform Reconstruction Quantization (URQ)

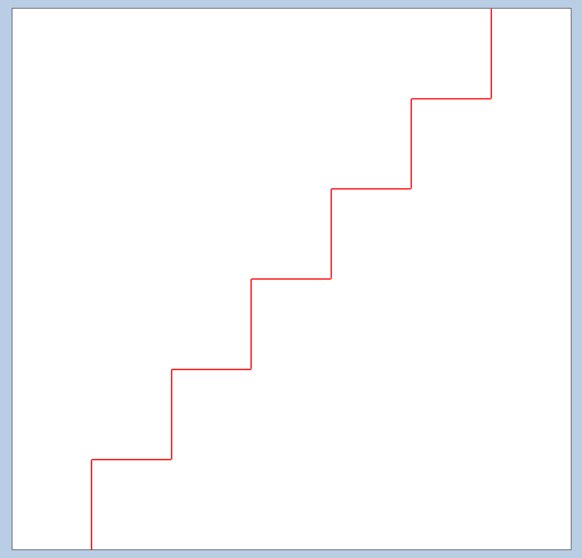

Figure 1: Uniform Quantization Step Size (QStep) of URQ in HEVC. The Quantization Parameter (QP) has a binary logarithmic relationship with the QStep.

- URQ uniformly quantizes transform coefficients based on a QStep/QP (see Figure 1) without taking into account the perceptual characteristics of luma and chroma pixel data in a Coding Unit (CU).
- Bits are, therefore, wasted on perceptually insignificant luma and chroma pixel regions. URQ is not a perceptually optimized quantization technique, which constitutes a significant drawback.

AdaptiveQP in HEVC

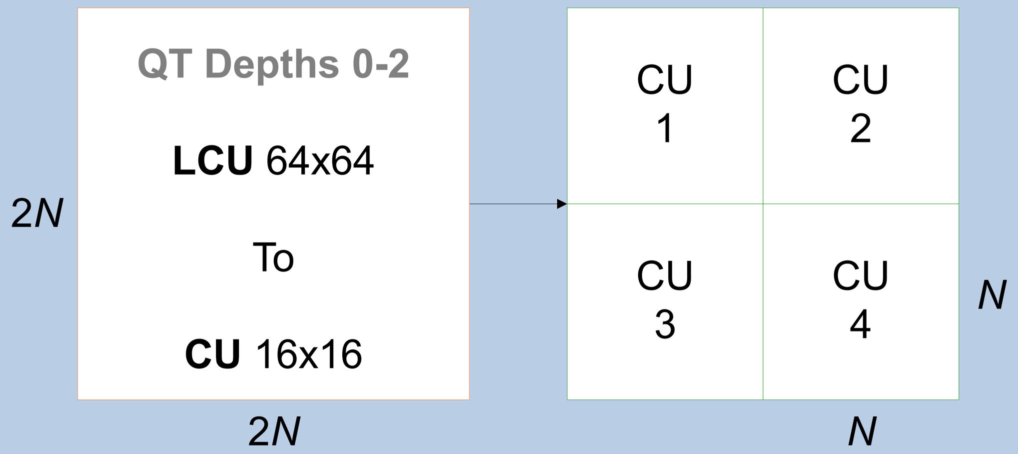

Figure 2: In AdaptiveQP, the $2N \times 2N$ CUs at QuadTree (QT) depth levels 0-2 are partitioned into four $N \times N$ CUs, where N=32 (level 0), N=16 (level 1) or N=8 (level 2). Each CU is then partitioned into four sub-blocks.

$$Q = q + \left[6 \times \log_2 (n) \right] \quad (1)$$

$$n = \frac{f \cdot l + t}{l + f \cdot t} \quad (2)$$

$$f = 2 \quad (3)$$

$$l = 1 + \min\left(\sigma^2_{Y,k}\right), \quad k = 1,....,4 \quad (4)$$

Q — CU-level perceptual QP.
q — Frame-level QP.
n — Normalized spatial activity in a luma CB.
f — Scaling factor (default QP adaptation range in HM).
l — Non-normalized spatial activity in a luma CB.
t — Mean spatial activity for all $2N \times 2N$ CUs.
$\sigma^2_{Y,k}$ — Variance of pixels in sub-block k of a luma CB.

- AdaptiveQP is a luma-based perceptual quantization technique in JCT-VC HEVC HM.
- Compared with URQ, it can decrease bitrates without incurring a discernible loss of reconstruction quality.
- AdaptiveQP increases or decreases the QP of an entire CU based on the variance of pixels in sub-block k of a Y Coding Block (CB) only, which constitutes a shortcoming. See equations (1)-(4) and Figure 2.

Proposed C-BAQ Technique in HEVC

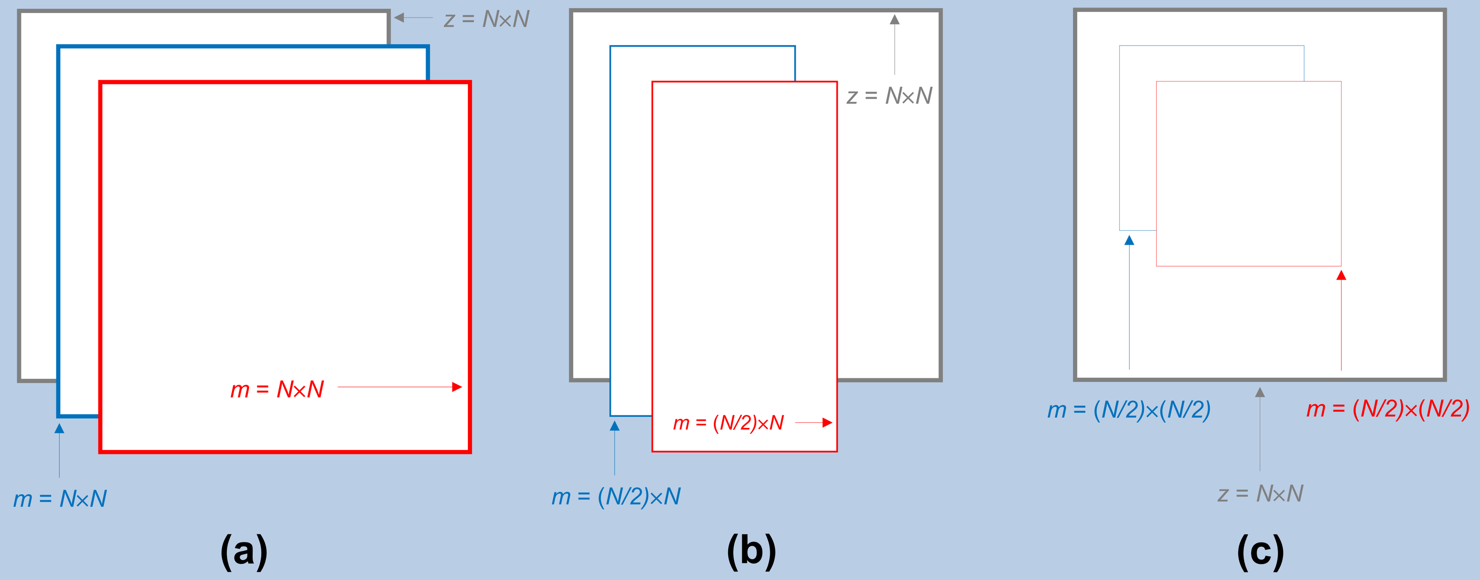

Figure 3: The sizes of sub-blocks k in luma and chroma CBs, in C-BAQ, within a $2N \times 2N$ CU: Y (gray), Cb (blue), Cr (red). There are four constituent sub-blocks in the Y, Cb and Cr CBs. Variables: z (Y sub-block) and m (Cb and Cr sub-blocks).

$$\tilde{Q} = q + \left[6 \times \log_2 (\tilde{n}) \right] \quad (5)$$

$$\tilde{n} = \frac{f \cdot (l + b + d) + t}{(l + b + d) + f \cdot t} \quad (6)$$

$$b = 1 + \min\left(\sigma^2_{Cb,k}\right), \quad k = 1,....,4 \quad (7)$$

$$d = 1 + \min\left(\sigma^2_{Cr,k}\right), \quad k = 1,....,4 \quad (8)$$

$\tilde{Q}$ — CU-level cross color channel perceptual QP.
$\tilde{n}$ — Normalized combined spatial activity in all three CBs.
b — Non-normalized spatial activity in a Cb CB.
d — Non-normalized spatial activity in a Cr CB.
$\sigma^2_{Cb,k}$ — Variance of pixels in sub-block k of a Cb CB.
$\sigma^2_{Cr,k}$ — Variance of pixels in sub-block k of a Cr CB.

- C-BAQ is a cross-color channel perceptual quantization method which improves upon AdaptiveQP.
- C-BAQ computes the pixel variances in all three CBs. See equations (5)-(8) and Figure 3.
- This greatly decreases bitrates (See Table 1) without affecting perceptual quality (see Figures 4 and 5).

Figure 4: KristenAndSara 4:2:0 sequence coded with C-BAQ (left) versus AdaptiveQP (right).

Figure 5: DuckAndLegs 4:4:4 sequence compressed with C-BAQ (left) versus AdaptiveQP (right).

Table 1: BD-Rate results attained by the proposed C-BAQ technique compared with AdaptiveQP. The All Intra (AI) results are shown on the left and the Random Access results (RA) are shown on the right.

C-BAQ versus AdaptiveQP (YCbCr 4:2:0) – AI				C-BAQ versus AdaptiveQP (YCbCr 4:2:0) – RA			
Sequence	BD-Rate %			**Sequence**	BD-Rate %		
	Y	**Cb**	**Cr**		**Y**	**Cb**	**Cr**
FourPeople (8-bit)	−9.5	−8.6	−9.9	FourPeople (8-bit)	−8.7	−7.5	−8.0
KristenAndSara (8-bit)	−14.3	−12.3	−12.5	KristenAndSara (8-bit)	−15.5	−12.8	−11.8
ParkScene (8-bit)	−5.4	−8.0	−7.8	ParkScene (8-bit)	−4.0	−6.1	−6.2
Traffic (8-bit)	−8.6	−10.6	−13.5	Traffic (8-bit)	−4.9	−7.0	−9.0
C-BAQ versus AdaptiveQP (YCbCr 4:2:2) – AI				**C-BAQ versus AdaptiveQP (YCbCr 4:2:2) – RA**			
Sequence	BD-Rate %			**Sequence**	BD-Rate %		
	Y	**Cb**	**Cr**		**Y**	**Cb**	**Cr**
PeopleOnStreet (8-bit)	−9.8	−13.4	−9.6	PeopleOnStreet (8-bit)	−5.3	−5.5	−3.9
DuckAndLegs (10-bit)	−6.0	−4.2	−8.3	DuckAndLegs (10-bit)	−8.0	−9.2	−11.0
ParkScene (10-bit)	−9.7	−9.2	−16.1	ParkScene (10-bit)	−7.5	−12.8	−13.5
Traffic (10-bit)	−9.2	−12.2	−15.3	Traffic (10-bit)	−5.0	−9.3	−11.4
C-BAQ versus AdaptiveQP (YCbCr 4:4:4) – AI				**C-BAQ versus AdaptiveQP (YCbCr 4:4:4) – RA**			
Sequence	BD-Rate %			**Sequence**	BD-Rate %		
	Y	**Cb**	**Cr**		**Y**	**Cb**	**Cr**
PeopleOnStreet (8-bit)	−11.8	−14.0	−9.0	PeopleOnStreet (8-bit)	−6.7	−7.1	−6.4
DuckAndLegs (10-bit)	−14.0	−7.0	−11.2	DuckAndLegs (10-bit)	−15.9	−13.1	−16.1
ParkScene (10-bit)	−15.6	−8.7	−19.3	ParkScene (10-bit)	−12.0	−16.4	−17.0
Traffic (10-bit)	−11.1	−13.4	−15.9	Traffic (10-bit)	−5.6	−11.3	−11.9

- **Best Overall Bitrate Reductions**: 15.9% (Y), 13.1% (Cb) and 16.1% (Cr) — See Table 1 and Figure 5.
- **Discussion:** C-BAQ achieves superior results when applied to the 4:4:4 version of a given sequence.
- **Conclusion:** Cross-color channel CU-level QP selection is superior to luma-based CU-level QP selection.
- **Future Work:** CB-level perceptual quantization of 4:4:4 high bit-depth video data.