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| --- | --- | --- | --- |
| *Title:* | **Fidelity adaptive video coding mode** | | |
| *Status:* | Input Document to JCT-VC | | |
| *Purpose:* | Proposal | | |
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# Abstract

The current HEVC range extensions design for 4:4:4 chroma formats, exhibits different rate-distortion behaviour for upconverted 4:2:0 sequences compared to the 4:2:0 design. In order to address this disparity in a content dependent manner, this contribution proposes a mode which permits a per-slice constant chroma QP offset to be applied on a CU basis. Additionally to compensate for overheads relating to small chroma transform units, this mode further restricts the minimum TU size for chroma to 8x8, consequently disabling the Intra-NxN split mode for chroma in 8x8 CUs. A non-RDO based naïve mode estimator that examines source picture activity is provided to demonstrate control of the mode in both native 4:4:4 environments and for upconverted 4:2:0 sources.

The design is shown to be capable of preserving the current 4:4:4 performance on native 4:4:4 sequences, while also being capable of providing the effect of a fixed qpoffset and simulating the 4:2:0 behaviour on upconverted 4:2:0 sequences. Furthermore, it is demonstrated that the in-loop nature of the design provides an intermediate operating point between these two extremes that is dependent upon the nature of the content.

# Background

It has previously been observed in [1] that there is a bitrate increase of approximately 10% when coding a sequence in 4:4:4 that has been upconverted from 4:2:0 and compared against the native coding in 4:2:0. Since there is no new real information in the upconverted pictures, it would be desirable if the video codec could be configured in such a way as to attain a performance similar to 4:2:0 for this content.

Further analysis of this condition shows that there is also an associated chroma PSNR increase as shown in Figures 1–6. Using tools in the HM+RExt software to report per syntax element bit statistics, we find that the bitrate increase can be associated with the following areas (further information is provided in Table 1):

1. Coefficient coding
2. Coded block flags
3. Chroma intra angular mode

The first of these is related to quantisation and the relative sizes between 4:2:0 and 4:4:4. For any given block size in 4:2:0[[1]](#footnote-1), the chroma TU size in 4:4:4 is doubled. This affects the HEVC quantiser, which includes a term to adjust the step size according to the transform size, the effect of which is to halve the step size for a given QP for 4:4:4 chroma TUs relative to their 4:2:0 equivalent[[2]](#footnote-2).

The second is again due to the increase in relative sizes and the persistence of 4x4 chroma TUs, which are equivalent to adding 2x2 TUs in 4:2:0. This extra level of hierarchy incurs additional signalling overhead for the extra TUs.

The third is simple to explain, the current RExt draft for 4:4:4 coding treats chroma in a very similar manner to luma, in particular, the intra NxN mode signals four chroma modes as opposed to the single mode in 4:2:0.

Table 1 – Average relative bitrate changes due to coding upconverted 4:2:0 content in 4:4:4 (intra)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | ***Class A,B,C,D,E*** | | | | ***Class F*** | | | |
|  | **Qp 37** | **Qp 32** | **Qp 27** | **Qp 22** | **Qp 37** | **Qp 32** | **Qp 27** | **Qp 22** |
| LAST\_SIG\_X\_Y: | 6.7 | 8.2 | 7.9 | 8.9 | 1.5 | 14.9 | 18.7 | 20.6 |
| SIG\_COEFF\_GROUP\_FLAG: | 0.8 | 0.7 | 0.8 | 0.9 | 0.7 | 0.1 | 0 | 0.2 |
| SIG\_COEFF\_MAP\_FLAG: | 23.9 | 20.2 | 19.7 | 17.9 | −30.3 | −4.7 | 0.2 | −2.3 |
| GT1\_FLAG: | 9.7 | 8.8 | 9.4 | 10.1 | −3.7 | 5.2 | 10 | 13.6 |
| GT2\_FLAG: | 0.9 | 0.7 | 0.8 | 1.3 | 0.3 | 0.7 | 1.7 | 2.4 |
| ESCAPE\_BITS: | 9.7 | 10.4 | 13.9 | 17.7 | −1.9 | 0 | 1.8 | 7.7 |
| QT\_CBF: | 37.6 | 33 | 23.9 | 18.4 | 106.3 | 50.1 | 32.7 | 24.5 |
| SIGN\_BIT: | 19.3 | 19.4 | 19 | 19 | 17.1 | 16.2 | 17.2 | 19 |
| INTRA\_DIR\_ANG: | −5.9 | −0.1 | 4.6 | 6 | 6 | 16.7 | 18 | 16.3 |
| PART\_SIZE: | −2.7 | −1.1 | −0.7 | −0.3 | 0.5 | 0.3 | 0.3 | 0.2 |
| SPLIT\_FLAG: | 0.1 | 0 | 0.1 | 0 | 0.6 | 0.5 | 0.2 | 0 |
| TRANSFORM\_SKIP\_FLAGS: | −0.9 | −0.4 | −0.4 | −0.4 | −4.7 | −2.1 | −2.6 | −3.6 |
| TRANSFORM\_SUBDIV\_FLAG: | −0.3 | 0 | 0 | 0 | 0 | 0.2 | 0 | −0.1 |
|  |  |  |  |  |  |  |  |  |
| Common total: | −2.4 | −1.4 | −0.3 | −0.4 | 8.2 | 2.2 | 1.7 | 0.9 |
| Chroma total: | 98.6 | 98.6 | 97.9 | 98.4 | 90.5 | 96.8 | 97.7 | 97.1 |
| Luma total: | 3.6 | 2.7 | 2.3 | 1.9 | 1.2 | 0.8 | 0.4 | 1.8 |
| Total: | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

# QP offset

A straightforward solution is to change the chroma QP offset by +6 to compensate for the quantiser effect. Results for this case are shown in figures below using an empirically chosen offset of +5.

However, this does raise some pertinent questions:

1. An encoder may not know a priori that the sequence has a low chroma fidelity which may benefit from using the QP offset
2. Content may have mixed characteristics, whereby part contains regions of high chroma fidelity and other parts may be low fidelity. This may be due to a mix of say screen content and natural video content, or even due to the nature of the chroma in a native 4:4:4 sequence which in some areas could have very low fidelity.
3. Can the codec be more flexible in terms of behaviour, ie, not having two discrete operating points 4:4:4 and 4:2:0, but rather to have them as points on a continuum.

# CU adaptivity

The proposed method to address these points is a CU-adaptive scheme that identifies low fidelity areas of the picture, and in each area, changes the implied coding parameters and structure to be better tuned for low fidelity source data. Principally, changes are made such that certain 4:4:4 features are restricted to behave as if 4:2:0 content was being encoded, and that the derived chroma QP is adjusted to compensate for differences due to the larger transform sizes.

More specifically, for each CU, an encoder has the option of signalling (or deriving) a flag that, when asserted, has the following effect:

* Applies an additional offset in the derivation of the chroma QP for the given CU. The offset to be applied is signalled in the PPS.
* Applies a restriction to limit the minimum transform unit size for chroma to 8x8. This is analogous to the minimum TU size for chroma of 4x4 in 4:2:0.
* For an 8x8 CU, to signal a single intra chroma mode as opposed to four modes, effectively disabling the NxN split for chroma (as per 4:2:0).

The depth in the coding tree at which the flag may be signalled is tuneable using a PPS parameter. When the CTB tree reaches this maximum depth, a single flag is signalled that applies to all CUs below the maximum signalling depth.

# Encoder implementation

This section contains a description of the encoder's non-normative behaviour relating to the proposed mode. During the mode decision process, the following steps are performed:

1. For the current CU, estimate the transform domain activity of the source data to determine the mode decision. In the case where the current CU is below the maximum depth at which the mode can be signalled, the estimation is performed once for the area covered by the minimum CU size and applies to all smaller CUs in the sub-tree.
2. For a CU with the mode enabled, adjust the chroma lambda to the appropriate value for the effective QP offset. The lambda is calculated at the start of the slice in the usual manner.

Rather than performing a full RDO test for the mode, a simple estimator has been developed. The estimator uses the HM transform to analyse the co-located chroma blocks in the source video data to determine the amount of high-frequency activity. The mode decision is based upon a simple threshold that counts the number of high-frequency coefficients with a magnitude above a particular value:

The estimation is performed for both chroma components, and if either exceeds the threshold, the mode is asserted. The thresholds for loFiQuant and loFiCountThreshold are 8 and 8 respectively.

Undoubtedly better estimators or mode decision processes can be developed. It would be expected that using an RDO test would be possible to further exploit the relative trade-offs of the mode.

## Current implementation limitation

The current encoder implementation has a limitation with regard to the setting of the correct lambda for SAO decisions, where the lambda is only set once per CTU. When the maximum depth is set to zero, ie the mode operates on a CTU basis, the design behaves as intended.

# Experimental Results

This section reports the results using the common test conditions of [2] for 4:2:0 sequences, and [3] for 4:4:4 sequences. Due to the limitation described above, the current results are presented using lowfidelity\_max\_depth set to 0, i.e. per-CTU determination of the mode.

To illustrate the potential of such a mode, results are presented for a subset of sequences that illustrate the typical behaviours. Full results are provided with the contribution document.

The graphs in figures 1–6 show the rate-distortion performance of several configurations. The dash-dot lines represent the performance of the current RExt software when coding 4:4:4, the dotted lines (when present) show the performance of 4:2:0 coding (ie, without upconversion to 4:4:4), the dashed lines show the performance of encoding 4:4:4 with a fixed chroma QP offset of +5, and the solid lines represent the proposed solution operating at 4:4:4 (with the aforementioned depth constraint).

Figures 1 and 2 demonstrate the effectiveness of the mode estimator for different content types. In the case of content that is upconverted from 4:4:4, the system has a similar effect to using a QP offset of +5 (see Figure 1). When presented with native 4:4:4 content, the system maintains the current behaviour, ie that of no QP offset.

|  |  |
| --- | --- |
| Figure 1 – Upconverted 4:2:0 (Kimono) | Figure 2 – Native 4:4:4 (Kimono) |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **versus 4:2:0**  **(···+···)** |  | **class** |  | **BD-Rate** | | | | **Y'** | **Cb** | **Cr** | | 4:4:4 | ·-·▽·-· | i\_main |  | 17.06 | -57.58 | -53.47 | | 4:4:4 | ·-·▽·-· | ld\_main |  | 13.45 | -67.82 | -66.2 | | 4:4:4 | ·-·▽·-· | ra\_main |  | 14.19 | -68.24 | -64.61 | | qpoffset+5 | - -△- - | i\_main |  | -0.42 | -25.56 | -22.81 | | qpoffset+5 | - -△- - | ld\_main |  | -0.08 | -32.12 | -31.39 | | qpoffset+5 | - -△- - | ra\_main |  | -0.26 | -33.77 | -30.43 | | lofi | —×— | i\_main |  | 3.18 | -31.12 | -30.92 | | lofi | —×— | ld\_main |  | 1.59 | -42.57 | -44.14 | | lofi | —×— | ra\_main |  | 1.83 | -42.74 | -42.02 | | |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **versus 4:4:4 (·-·▽·-·)** |  | **class** | **time (%)** | **BD-Rate** | | | | **Y'** | **Cb** | **Cr** | | qpoffset+5 | - -△- - | i\_main10 | 93.48 | -24.84 | 50.25 | 53.97 | | qpoffset+5 | - -△- - | ld\_main10 | 89.96 | -21.59 | 80.17 | 85.95 | | qpoffset+5 | - -△- - | ra\_main10 | 93.19 | -23.32 | 71.83 | 77.35 | | lofi | —×— | i\_main10 | 101.92 | 0 | 0.01 | 0.02 | | lofi | —×— | ld\_main10 | 100.92 | 0.04 | 0.03 | 0.1 | | lofi | —×— | ra\_main10 | 101.35 | 0.07 | 0.04 | 0.08 | |

Figures 3 and 4 provide two typical examples of the system behaviour for content upconverted from 4:2:0, where, Figure 3 has similar characteristics to those of Figure 1. Figure 4 on the other hand demonstrates that the naïve estimator is not always successful at identifying the nature of the content.

NB, the decision process is currently being performed once per CTU, for the entire CTU, the behaviour is likely to change if the maximum depth restriction is relaxed.

|  |  |
| --- | --- |
| Figure 3 – Upconverted 4:2:0 (Johnny) | Figure 4 – Upconverted 4:2:0 (BlowingBubbles) |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **versus 4:2:0 (···+···)** |  | **class** |  | **BD-Rate** | | | | **Y'** | **Cb** | **Cr** | | 4:4:4 | ·-·▽·-· | i\_main |  | 9.84 | -49.81 | -48.49 | | 4:4:4 | ·-·▽·-· | ld\_main |  | 5.13 | -69.34 | -68.09 | | 4:4:4 | ·-·▽·-· | ra\_main |  | 7.87 | -63.43 | -61.3 | | qpoffset+5 | - -△- - | i\_main |  | 0.29 | -8.88 | -6.69 | | qpoffset+5 | - -△- - | ld\_main |  | 0.25 | -22.35 | -19.82 | | qpoffset+5 | - -△- - | ra\_main |  | 0.08 | -17.91 | -13.73 | | lofi | —×— | i\_main |  | 1.48 | -16.82 | -13.55 | | lofi | —×— | ld\_main |  | 1.23 | -32.26 | -29.07 | | lofi | —×— | ra\_main |  | 1.5 | -26.8 | -22.57 | | |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **versus 4:2:0 (···+···)** |  | **class** |  | **BD-Rate** | | | | **Y'** | **Cb** | **Cr** | | 4:4:4 | ·-·▽·-· | i\_main |  | 8.93 | -53.05 | -51.99 | | 4:4:4 | ·-·▽·-· | ld\_main |  | 6.78 | -72.75 | -71.8 | | 4:4:4 | ·-·▽·-· | ra\_main |  | 8.03 | -69.11 | -67.85 | | qpoffset+5 | - -△- - | i\_main |  | -1.04 | -17.99 | -16.34 | | qpoffset+5 | - -△- - | ld\_main |  | -0.86 | -34.85 | -34.76 | | qpoffset+5 | - -△- - | ra\_main |  | -0.78 | -31.41 | -29.39 | | lofi | —×— | i\_main |  | 8.66 | -52.07 | -50.86 | | lofi | —×— | ld\_main |  | 6.74 | -72.12 | -71.03 | | lofi | —×— | ra\_main |  | 7.92 | -68.32 | -66.96 | |

Figures 5 and 6 show two cases that handle native 4:4:4 content. Figure 5, shows cases where the system maintains the current behaviour, and Figure 6 shows an interesting case, where, for native 4:4:4 content, the estimator sometimes chooses to exploit the mode for some of the blocks.

|  |  |
| --- | --- |
| Figure 5 – Native 4:4:4 (EBULupoCandleLight) | Figure 6 – Native 4:4:4 (EBURainFruits) |
| |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **versus 4:4:4 (·-·▽·-·)** |  | **class** | **time**  **(%)** | **BD-Rate** | | | | **Y'** | **Cb** | **Cr** | | qpoffset+5 | - -△- - | i\_main10 | 96.51 | -8.95 | 77.43 | 79.87 | | qpoffset+5 | - -△- - | ld\_main10 | 98.88 | -5.74 | 115.31 | 116.94 | | qpoffset+5 | - -△- - | ra\_main10 | 97.9 | -7.22 | 101.63 | 102.62 | | lofi | —×— | i\_main10 | 100.18 | -0.07 | 1 | 1.51 | | lofi | —×— | ld\_main10 | 100.01 | -0.03 | 0.9 | 1.43 | | lofi | —×— | ra\_main10 | 101.05 | 0.15 | 1.39 | 1.64 | | |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **versus 4:4:4 (·-·▽·-·)** |  | **class** | **time (%)** | **BD-Rate** | | | | **Y'** | **Cb** | **Cr** | | qpoffset+5 | - -△- - | i\_main10 | 97.28 | -9.59 | 61.74 | 61.15 | | qpoffset+5 | - -△- - | ld\_main10 | 98.91 | -4.15 | 109.07 | 107.54 | | qpoffset+5 | - -△- - | ra\_main10 | 97.29 | -5.97 | 90.55 | 89.69 | | lofi | —×— | i\_main10 | 99.99 | -2.81 | 18.26 | 20.44 | | lofi | —×— | ld\_main10 | 97.76 | -0.22 | 23.6 | 26.52 | | lofi | —×— | ra\_main10 | 98.18 | -1.04 | 22.9 | 25.66 | |

# Recommendation

The authors recommend the adoption in time for the DAM ballot of some mechanism that allows an encoder to adapt to chroma fidelity in 4:4:4 content.

# References

1. M. Budagavi, M. Zhou, “Mixed chroma format coding”, JCTVC-L0250, Geneva, CH, January 2013
2. F. Bossen, “Common HM test conditions and software reference configurations”, JCTVC-L1100, Geneva, CH, January 2013.
3. D. Flynn and K. Sharman, “Common test conditions and software reference configurations for HEVC range extensions”, JCTVC-L1006, Geneva, CH, January 2013.

# Patent rights declaration(s)

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# Proposed Text Specification

The following specification text represents the proposed solution, integrated into the draft range extensions amendment text.

* + - * **Picture parameter set RBSP syntax**

|  |  |
| --- | --- |
| pic\_parameter\_set\_rbsp( ) { | **Descriptor** |
| ... |  |
| if( pps\_extension\_flag ) { |  |
| **lowfidelity\_enabled\_flag** | u(1) |
| if( lowfidelity\_enabled\_flag ) { |  |
| **lowfidelity\_max\_depth** | ue(v) |
| **lowfidelity\_qp\_cb\_offset** | ue(v) |
| **lowfidelity\_qp\_cr\_offset** | ue(v) |
| **}** |  |
| ... |  |
| } |  |

* + - * **Picture parameter set RBSP semantics**

**lowfidelity\_enabled\_flag** equal to 1 specifies that cu\_lowfidelity\_flag may be present in the coding unit syntax structure. lowfidelity\_enabled\_flag equal to 0 specifies that cu\_lowfidelity\_flag is not present in the coding unit syntax structure.

**lowfidelity\_max\_depth** specifies the maximum depth at which the cu\_lowfidelity\_flag is present in the bitstream.

**lowfidelity\_qp\_cb\_offset** specifies an additional chroma qp offset that is to be applied during the scaling of chroma Cb transform coefficients.

**lowfidelity\_qp\_cr\_offset** specifies an additional chroma qp offset that is to be applied during the scaling of chroma Cr transform coefficients.

* + - * **Coding unit syntax**

|  |  |
| --- | --- |
| coding\_unit( x0, y0, log2CbSize ) { | **Descriptor** |
| ... |  |
| if( CuPredMode[ x0 ][ y0 ] != MODE\_INTRA | | log2CbSize = = MinCbLog2SizeY ) |  |
| **part\_mode** | ae(v) |
| CuLoFiFlagDone = 0 |  |
| if( CuPredMode[ x0 ][ y0 ] = = MODE\_INTRA ) { |  |
| ... |  |
| if( LoFiFlagPresent && ChromaArrayType = = 3 && IntraSplitFlag ) { |  |
| **cu\_lowfidelity\_flag**[ x0 ][ y0 ] | ae(v) |
| CuLoFiFlagDone = 1 |  |
| } |  |
| if( ChromaArrayType = = 3 && IntraSplitFlag && !cu\_lowfidelity\_flag[ x0 ][ y0 ] ) |  |
| for( j = 0; j < nCbS; j = j + pbOffset ) |  |
| for( i = 0; i < nCbS; i = i + pbOffset ) |  |
| **intra\_chroma\_pred\_mode**[ x0 + i ][ y0 + j ] | ae(v) |
| else if( ChromaArrayType > 0 ) |  |
| **intra\_chroma\_pred\_mode**[ x0 ][ y0 ] | ae(v) |
| } |  |
| } |  |
| ... |  |
| if( rqt\_root\_cbf ) { |  |
| if( LoFiFlagPresent && !CuLoFiFlagDone ) |  |
| **cu\_lowfidelity\_flag**[ x0 ][ y0 ] | ae(v) |
| MaxTrafoDepth = ( CuPredMode[ x0 ][ y0 ] = = MODE\_INTRA ?   ( max\_transform\_hierarchy\_depth\_intra + IntraSplitFlag ) :   max\_transform\_hierarchy\_depth\_inter ) |  |
| transform\_tree( x0, y0, x0, y0, log2CbSize, 0, 0 ) |  |
| ... |  |
| } |  |

* + - * **Coding unit semantics**

**cu\_lowfidelity\_flag**[ x0 ][ y0 ] equal to 1 specifies that an additional chroma qp offset shall be applied during the scaling process of chroma transform coefficients. cu\_lowfidelity\_flag[ x0 ][ y0 ] equal to 0 specifies that no additional chroma qp offset shall be applied dring the scaling process of chroma transform coefficients. When cu\_lowfidelity\_flag[ x0 ][ y0 ] is not present, its value is inferred to be equal to lowfidelity\_forced\_flag.

* + - * **Transform unit syntax**

|  |  |
| --- | --- |
| transform\_unit( x0, y0, xBase, yBase, log2TrafoSize, trafoDepth, blkIdx ) { | **Descriptor** |
| ... |  |
| if( cbf\_luma[ x0 ][ y0 ][ trafoDepth ] ) |  |
| residual\_coding( x0, y0, log2TrafoSize, 0 ) |  |
| if( log2TrafoSize > 2 | | ChromaArrayType = = 3 && !cu\_lowfidelity\_flag[ xBase ][ yBase ] ) { |  |
| ... |  |
| residual\_coding( x0, y0 + ( tIdx << log2TrafoSizeC ), log2TrafoSizeC, 1 ) |  |
| residual\_coding( x0, y0 + ( tIdx << log2TrafoSizeC ), log2TrafoSizeC, 2 ) |  |
| } else if( blkIdx = = 3 ) { |  |
| ... |  |
| residual\_coding( xBase, yBase + ( tIdx << log2TrafoSize ), log2TrafoSize, 1 ) |  |
| residual\_coding( xBase, yBase + ( tIdx << log2TrafoSize ), log2TrafoSize, 2 ) |  |
| } |  |
| } |  |
| } |  |

**Scaling, transformation and array construction process prior to deblocking filter process**

**Derivation process for quantization parameters**

...

When ChromaArrayType is not equal to 0, the following applies.

The variable loFiCbQpOffset and loFiCrQpOffset are derived as follows:

– If lowfidelity\_cu\_flag[ xCb ][ yCb ] is equal to 1, loFiCbQpOffset is set equal to lowfidelity\_qp\_cb\_offset, and loFiCrQpOffset is set equal to lowfidelity\_qp\_cr\_offset.

– Otherwise, loFiCbQpOffset and loFiCrQpOffset are both set equal to 0.

The variables qPCb and qPCr are set equal to the value of QpC as specified in Table 8‑9 based on the index qPiequal to qPiCb and qPiCr, respectively, and qPiCb and qPiCr are derived as follows:

qPiCb = Clip3( −QpBdOffsetC, 57, QpY + pps\_cb\_qp\_offset + slice\_cb\_qp\_offset + loFiCbQpOffset ) (8‑260)

qPiCr = Clip3( −QpBdOffsetC, 57, QpY + pps\_cr\_qp\_offset + slice\_cr\_qp\_offset + loFiCrQpOffset ) (8‑261)

The chroma quantization parameters for the Cb and Cr components, Qp′Cb and Qp′Cr, are derived as follows:

Qp′Cb = qPCb + QpBdOffsetC (8‑262)

Qp′Cr = qPCr + QpBdOffsetC (8‑263)

1. Ignoring 4x4, where there is special handling in 4:2:0 due to the absence of 2x2 chroma transforms [↑](#footnote-ref-1)
2. This isn't the same for 4:2:2, whereby the transform is implemented as two TUs of the same size as 4:2:0 [↑](#footnote-ref-2)