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Title:	**Improved robustness for calculation of cross-component linear model parameters**
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Author(s) or Contact(s):	Christian Helmrich — Email: christian.helmrich@hhi.fraunhofer.de
Source:	Fraunhofer HHI, Einsteinufer 37, 10587 Berlin, Germany

Abstract

In JVET-L0191, a simplified parameter calculation for the cross-component linear model (CCLM) predictor in the Versatile Video Coding (VVC) standard was presented and, at the 12th JVET meeting in 2018, adopted into the draft specification. According to this simplification, the CCLM parameters α and β can be derived by means of a straight-line fitting between a maximum and a minimum luma-chroma pair of sample values, as opposed to the previously used more complex linear regression from multiple luma and chroma samples. As a result, the algorithmic complexity of the CCLM tool is reduced without losing much coding efficiency.

This contribution presents evidence that the simplified line fitting between two extreme sample values is quite susceptible to statistical outliers and suggests two straightforward modifications to the CCLM method:

1. fitting of the straight line between the average of the largest two luma and the average of the smallest two luma samples (instead of only the largest and only the smallest value), with *accurate* averaging,
2. fitting of the straight line between the average of the largest two luma and the average of the smallest two luma samples, with *inaccurate* averaging (no offset of 1 before division) saving some additions.

Both modifications have negligible impact on the VTM encoder and decoder complexity (encoder runtime 100%, decoder runtime 100–102%) and reportedly provide 0.3–0.4% coding efficiency gain in each of the chromatic channels (Cb and Cr BD-rate gains for both All-Intra and Random Access). Given this consistent objective benefit, it is requested to study one of the proposed modifications – preferably, variant 2 – in a CE test after the upcoming JVET meeting, possibly as an alternative to the current CE 3 test 2.5 of JVET-L0342.

1 Introduction to Simplified CCLM

Cross-component linear model (CCLM) prediction is a coding tool allowing to exploit statistical redundancies in the coding of multiple signal channels (here, luminance/luma and chromatic/chroma picture planes). Traditionally, the CCLM predictor parameters α and β are derived via linear regression methods attempting a least mean squares (LMS) approximation of the data points (here, pairs of luma-chroma sample values) $[x, y]$ by a straight line $y = \alpha \cdot x + \beta$, as illustrated in Fig. 1. In case of image and video coding, such an approach can be used to predict a chroma sample value y from already coded luma sample value(s) x, thus achieving increased coding efficiency on many input sequences [1] [2]. Since the computational complexity of linear-regression based line-fitting algorithms is quite high especially in picture coding, a simplified line fitting was recently proposed in JVET-L0191 [2] and subsequently adopted into the VVC draft specification [3]. Instead of determining the straight line from all available luma-chroma sample pairs, this proposal fits the line only between the data point A with the minimum luma value and the data point B with the maximum luma value. This reduces the number of operations (particularly multiplications) required by the algorithm, leaving the search for the local luma minimum and maximum as the major operations of the CCLM method. Note that the actual CCLM *prediction*, which uses more operations than the model calculation at medium and large CUs (since it is carried out for each chroma sample in the CU) is not affected by the simplification.

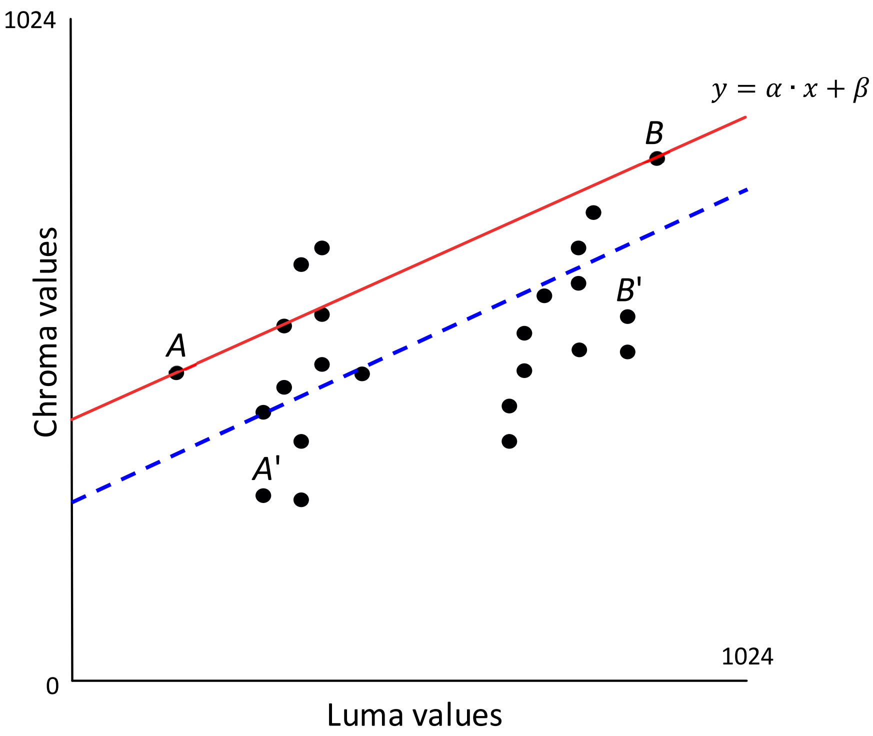

***Fig. 1**. Straight-line fitting in VVC's simplified CCLM predictor. Illustration based on that in JVET-L0191. The red line indicates the adopted approach, while the blue line indicates the proposed improvement.*

According to JVET-L0191, the simplified CCLM calculations save about 80 lines of source code and reduce the decoding runtime in the random-access and low-delay B configurations by a few percent. Unfortunately, losses in chromatic coding efficiency of up to about 1% for UHD content (class A) are reported as well [2], which can be attributed to the increased susceptibility of the simplified CCLM fitting algorithm to statistical outliers: strong variances in the extreme values (minimum A and maximum B) relative to the remaining set of luma-chroma points are much more likely to result in inaccurate line-fittings than in LMS-based CCLM. In fact, such a scenario is depicted in Fig. 1 taken from L0191, wherein the red colored line does not fit the data very well – almost all remaining luma-chroma pairs between A and B end up underneath the fitted line.

2 Proposed Modifications to CCLM

To counteract the CCLM inaccuracy described above, it is proposed to search not only for the smallest luma value A and largest luma value B but also for the second-smallest luma value A' and the second-largest luma value B', as shown in Fig. 1. Then, the trend line can be fitted between the average of the data points at A and A' and the average of the data points at B and B', leading to the blue colored line in Fig. 1 which generally leads to a better data-fit. Two variants of averaging A, A' and B, B' can be specified, differing in complexity:

1. *accurate* integer averaging: $(A + A' + 1) >> 1$, $(B + B' + 1) >> 1$, where “>>” is a bit-wise right-shift,
2. *inaccurate* integer averaging: $(A + A') >> 1$, $(B + B') >> 1$, saving four “+ 1” over the accurate variant.

Table 1 summarizes the algorithmic operations consumed by the proposed modified CCLM calculation in comparison with the previously adopted CCLM versions. It can be seen that, due to the search for two more extreme luma values, the number of comparisons doubles. Note that the number of operations required by either of the proposed two variants is still much lower than that for the initial CCLM adopted in VTM 2 [1].

3 Experimental Results

Bjøntegaard delta (BD) rate gains on the SDR-category Common Test Conditions (CTC) set of sequences [5] [6] were measured to verify the presence of significant coding efficiency increases without increases in codec runtime due to the proposed changes. VTM software version 3 with default configuration is used [4].

Table 1. *Number of operations in different CCLM calculations. N: number of chroma reference samples, *: incl. right-shifts needed for averaging. Note that the actual CCLM application is not included here.*

CCLM Config.	**Multiplies**	**Additions**	**"Divisions"**	**Comparisons**	**Sum** excl. div.
VTM 2.x [1]	$2N + 2 + 2$	$7N + 3$	2		$9N + 7$
VTM 3.x [2]	1	3	1	$2N$	$2N + 4$
Proposed Variant 1	1	3 + 8	1	$4N$	$4N + 12 + 4$*
Proposed Variant 2	1	3 + 4	1	$4N$	$4N + 8 + 4$*

Table 2 lists the BD-rate results for modification variant 1 (accurate integer averaging), whereas Table 3 contains the BD-rate values for modification variant 2 (inaccurate integer averaging). It can be noticed that

- both variants lead to very similar overall BD-rate performance,
- consistent BD-rate gains are reached for both chroma channels,
- no significant runtime increases are observed for either variant.

This indicates that both proposals successfully increase the chromatic coding efficiency by approximately 0.3–0.4% with, as desired, insignificant effect on the algorithmic complexity of the CCLM predictor. Note that the given decoder runtimes are not very reliable (the inter-run variance is estimated to be around ±2%).

Table 2. *BD-rate [6] results for VTM 3.0.0 with vs. without proposed modification variant **1**, SDR CTC [5].*

All Intra	**Gain Y** (%)	**Gain Cb** (%)	**Gain Cr** (%)	**Time Enc.** (%)	**Time Dec.** (%)
Class A1	–0.12	–0.20	–0.15	101	101
Class A2	–0.10	**–0.43**	–0.33	101	100
Class B	–0.04	**–0.41**	**–0.56**	100	99
Class C	–0.06	**–0.41**	**–0.55**	100	102
Class E	–0.03	–0.22	–0.19	100	100
Overall	–0.07	–0.35	–0.39	100	100
Random Access	**Gain Y** (%)	**Gain Cb** (%)	**Gain Cr** (%)	**Time Enc.** (%)	**Time Dec.** (%)
Class A1	–0.10	–0.08	–0.17	100	104
Class A2	–0.06	–0.19	–0.08	100	103
Class B	–0.03	–0.17	**–0.56**	100	101
Class C	0.00	–0.27	–0.21	100	100
Class E					
Overall	–0.04	–0.18	–0.29	100	102

Table 3. *BD-rate [6] results for VTM 3.0.0 with vs. without proposed modification variant **2**, SDR CTC [5].*

All Intra	**Gain Y** (%)	**Gain Cb** (%)	**Gain Cr** (%)	**Time Enc.** (%)	**Time Dec.** (%)
Class A1	–0.14	–0.32	–0.31	99	100
Class A2	–0.10	**–0.46**	–0.32	100	102
Class B	–0.04	–0.37	**–0.57**	100	99
Class C	–0.06	**–0.43**	**–0.60**	100	100
Class E	–0.03	–0.25	–0.33	100	101
Overall	–0.07	–0.37	**–0.45**	100	100
Random Access	**Gain Y** (%)	**Gain Cb** (%)	**Gain Cr** (%)	**Time Enc.** (%)	**Time Dec.** (%)
Class A1	–0.12	–0.30	**–0.40**	100	102
Class A2	–0.06	–0.27	–0.05	99	101
Class B	–0.02	–0.22	**–0.53**	99	103
Class C	0.03	–0.23	–0.17	100	99
Class E					
Overall	–0.04	–0.25	–0.31	100	101

4 Summary and Conclusion

This contribution proposed two variants of a modification to the simplified cross-component linear model (CCLM) predictor described in L0191 and recently adopted in the VVC standardization. The suggested low-complexity changes stabilize the straight-line fitting algorithm in the CCLM, thus providing BD-rate gains of 0.3–0.4% in the chroma channels. At the same time, the algorithmic complexity of the CCLM calculation remains only one half (or less for large CUs) of that of the CCLM design previously adopted in VTM 2 [1].

In light of the outcome of this study, it is requested to allow the study of one of the presented modification variants in a new round of CE 3 after the 13th JVET meeting. Specifically, it is suggested to test variant 2 since it yields the same BD-rate gains as variant 1 while requiring four additions less per CCLM coded CU.

5 References

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6 Patent Rights Declaration(s)

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