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                       Improved chroma prediction
                   draft-midtskogen-netvc-chromapred-02

Abstract

   This document describes the technique used to improve the chroma
   prediction in the Thor video codec.

Status of This Memo

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1. Introduction

   Modern video coding standards such as Thor [I-D.fuldseth-netvc-thor]
   form predictions for the luma channel (Y) and chroma channels (U and
   V) which are encoded separately (in that order). The prediction for
   each channel has spatial or temporal dependencies only in its own
   channel. Most of the perceived information of a video is to be found
   in the luma channel, but there still remain correlations between the
   luma and chroma channels. For instance, the same shape of an object
   can often be seen in all three channels, and if this correlation is
   not exploited, some structural information will be transmitted three
   times. Thor will attempt to improve the chroma prediction by finding
   linear relationships between the each of the initial chroma
   predictions and the luma prediction, and if certain criteria are
   satisfied, use that relationship to form a new prediction based on
   the reconstructed luma samples.

2. Definitions

2.1. Requirements Language

   The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
   "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
   document are to be interpreted as described in RFC 2119 [RFC2119].

3. Background

   The improved predictions are derived from the reconstructed luma
   samples using a mapping. The underlying assumption is that the
   colours can be identified by their luminosities. Informally we can
   say that a new chroma prediction is formed from the reconstructed
   luma block painted with the colours of the initial chroma prediction.

There is often a linear correlation between the luma and chroma channel, so that a chroma sample c can be expressed by the linear function

$$c = a*y + b$$

Figure 1: Linear relationship

where y is the corresponding luma sample. This observation has been previously been used in techniques to convert YUV 4:2:0 and YUV 4:2:2 images to YUV 4:4:4, and in a (rejected) proposal for HEVC as a special intra mode. Thor, however, generalises the prediction, so it does not depend on the coding mode (i.e. whether inter or intra, or the kind of inter/intra mode).

Since it would be too costly to transmit the values a and b in the linear mapping, and since both the encoder and decoder must be able to compute identical predictions, a and b are derived from data available to both using linear regression.

4. Computing the improved prediction

Since the assumption that the correlation is the same in the predicted block and in the reconstructed block is not always true, the new prediction from luma might not be better even when there is a very good correlation in the predicted block. Therefore, we can only expected an improvement if the initial prediction is bad, and the luma residual is used as an estimate for this. The initial chroma prediction is kept unless the average squared difference between the reconstructed luma samples yr and the predicted y samples for an N*N prediction block is above 64:

```
_N_ _N_
\    \
/__ /__ (yr(i, j) - y(i, j)) ^ 2
i=1 j=1
------------------------------- > 64
              N*N
```

Figure 2: Requirement for improvement 1

The encoder and decoder must compute a and b using the same least square fit for an N*N prediction block, where y and c denote the luma and chroma samples in the initial prediction:

```
            _N_ _N_                                    _N_ _N_
            \   \                                      \   \
    Ysum = /__ /__ y(i, j)              Csum = /__ /__ c(i, j)
            i=1 j=1                                    i=1 j=1

            _N_ _N_                                    _N_ _N_
            \   \                                      \   \
   YYsum = /__ /__ y(i, j) ^ 2         CCsum = /__ /__ c(i, j) ^ 2
            i=1 j=1                                    i=1 j=1

            _N_ _N_
            \   \
   YCsum = /__ /__ y(i, j) * c(i, j)
            i=1 j=1
```

Figure 3: Equations for linear regression 1

These sums will all be contained within a 32 bit signed integer when
the internal bitdepth is 8. Otherwise 64 bit integers must be used.
Then the following must be computed using 64 bit arithmetic
regardless of bitdepth:

$$SSyy = YYsum - ((Ysum * Ysum) >> 2*log2(N))$$
$$SScc = CCsum - ((Csum * Csum) >> 2*log2(N))$$
$$SSyc = YCsum - ((Ysum * Csum) >> 2*log2(N))$$

Figure 4: Equations for linear regression 2

Still using 64 bit arithmetic, if

$$SSyy > 0 /\backslash 2 * SSyy * SSyy > SSyy * SScc$$

Figure 5: Requirement for improvement 2

then it is assumed that the correlation is reasonably good and a new
prediction will be computed and used. Otherwise, the initial
prediction will be kept. First, a and b must be computed. 2^{15} is
added to b to ensure correct rounding later on.

```
   a = (SSyc << 16) / SSyy
   b = (((Csum << 16) - a * Ysum) >> 2*log2(N)) + (1 << 15)
```

Figure 6: Equation for linear regression 3

The final operations are performed with 32 bit arithmetic, so a must
be clipped to [-2^(31-B), 2^(31-B)], where B is the bitdepth, and b
must be clipped to [-2^31, 2^31-1]. The a new chroma prediction c'
is computed using the reconstructed luma samples yr, a and b, and a
clipping function saturating the results to an 8 bit value:

```
       c'(i, j) = clip((a * yr(i, j) + b) >> 16)
```

Figure 7: Improved chroma prediction

The above assumes 4:4:4 format. For the 4:2:0 format the predicted
luma block must be subsampled first:

```
     y'(i,j) = (y(2*i, 2*j)   + y(2*i+i, 2j) +
                y(2*i, 2*j+1) + y(2*i+1, 2*j+1) + 2) >> 2
```

Figure 8: Subsampling of predicted luma block

The resulting new chroma prediction must also be subsampled. The
clipping is performed before the subsampling.

```
    c'(i, j) = (clip((a*yr(2*i, 2*j) + b) >> 16) +
               clip((a*yr(2*i+1, 2*j) + b) >> 16) +
               clip((a*yr(2*i, 2*j+1) + b) >> 16) +
               clip((a*yr(2*i+1, 2*j+1) + b) >> 16) + 2) >> 2
```

Figure 9: Subsampling of improved chroma prediction

In intra mode the chroma prediction improvement must be performed
right after each transform, since the new chroma reconstruction will
be used to predict the next block.

5. Performance

   The improved chroma prediction may significantly improve the
   compression efficiency for images or video containing high
   correlations between the channels. It is particularly useful for
   encoding screen content, 4:4:4 content, high frequency content and
   "difficult" content where traditional prediction techniques perform
   poorly. Little quality change is seen for content not in these
   categories, but there is a general small increase in chroma PSNR.

   An encoded configured for low delay and high complexity was used for
   the following results. The numbers have been computed using the
   Bjontegaard Delta Rate (BDR [BDR]). The rates for Y, U and V have
   been shown separately.

	4:4:4			4:2:0		
Sequence	Y	U	V	Y	U	V
cad_waveform	-21.3%	-27.0%	-24.0%	0.5%	-1.3%	-1.1%
pcb_layout	-9.2%	-13.3%	-10.6%	-1.6%	-3.1%	-3.5%
ppt_doc_xls	-6.3%	-14.1%	-12.7%	-0.1%	-0.8%	-0.8%
vc_doc_sharing	-2.9%	-6.4%	-6.9%	0.3%	-1.2%	-0.6%
web_browsing	-0.5%	-1.1%	-1.5%	0.3%	-0.5%	-1.0%
wordEditing	-1.8%	-5.9%	-4.8%	1.5%	1.2%	1.1%
park_joy	-0.5%	-2.6%	-0.9%	-0.0%	-0.8%	0.4%
old_town_cross	-0.1%	-2.2%	-1.2%	0.0%	-0.6%	-0.2%
Average	-5.3%	-9.1%	-7.8%	0.1%	-0.9%	-0.7%

            Figure 10: Compression Performance, improved prediction for intra
                                 blocks only

```
+--------------+------------------+------------------+
|              |      4:4:4       |      4:2:0       |
+--------------+------+------+------+------+------+------+
|Sequence      |  Y   |  U   |  V   |  Y   |  U   |  V   |
+--------------+------+------+------+------+------+------+
|cad_waveform  |-23.1%|-28.9%|-26.1%| -2.6%| -3.6%| -3.5%|
|pcb_layout    |-21.0%|-29.0%|-21.0%| -5.4%| -7.9%| -5.4%|
|ppt_doc_xls   | -9.0%|-19.0%|-17.5%| -0.2%| -0.2%| -1.2%|
|vc_doc_sharing| -4.7%| -9.6%| -9.6%| -0.1%| -1.0%| -0.4%|
|web_browsing  | -0.6%| -1.5%| -1.5%| -0.5%| -1.2%| -1.2%|
|wordEditing   |-11.3%|-13.7%|-11.7%| -3.0%| -4.2%| -3.2%|
|park_joy      | -5.5%| -7.4%| -7.1%| -0.9%| -1.9%| -1.6%|
|old_town_cross| -1.7%| -3.6%| -2.2%| -0.3%| -4.1%| -1.6%|
+--------------+------+------+------+------+------+------+
|Average       | -9.6%|-14.1%|-12.1%| -1.6%| -3.0%| -2.3%|
+--------------+------+------+------+------+------+------+
```

Figure 11: Compression Performance, improved prediction using intra
only coding

```
+--------------+------------------+------------------+
|              |      4:4:4       |      4:2:0       |
+--------------+------+------+------+------+------+------+
|Sequence      |  Y   |  U   |  V   |  Y   |  U   |  V   |
+--------------+------+------+------+------+------+------+
|cad_waveform  |-11.5%|-14.4%|-12.7%|  0.0%| -1.8%| -1.7%|
|pcb_layout    | -3.2%| -5.5%| -4.8%| -0.9%| -2.4%| -3.4%|
|ppt_doc_xls   | -0.1%| -0.7%| -0.3%|  0.0%| -0.2%| -0.6%|
|vc_doc_sharing| -0.4%| -0.6%| -1.6%| -0.0%| -0.4%| -0.6%|
|web_browsing  |  0.1%|  0.2%|  0.1%|  0.5%| -0.0%| -0.9%|
|wordEditing   | -3.7%| -5.8%| -6.2%|  0.4%| -0.9%| -1.4%|
|park_joy      | -1.6%| -8.6%| -1.5%|  0.0%| -3.5%| -0.2%|
|old_town_cross| -0.0%| -0.4%| -0.1%|  0.0%|  0.1%| -0.2%|
+--------------+------+------+------+------+------+------+
|Average       | -2.5%| -4.5%| -3.4%|  0.0%| -1.1%| -1.1%|
+--------------+------+------+------+------+------+------+
```

Figure 12: Compression Performance, improved prediction for inter
blocks only

```
+--------------+-------------------+-------------------+
|              |       4:4:4       |       4:2:0       |
+--------------+------+------+------+------+------+------+
|Sequence      |  Y   |  U   |  V   |  Y   |  U   |  V   |
+--------------+------+------+------+------+------+------+
|cad_waveform  |-25.8%|-31.7%|-28.2%| -2.4%| -5.5%| -5.4%|
|pcb_layout    |-11.5%|-16.1%|-13.5%| -2.4%| -4.1%| -5.6%|
|ppt_doc_xls   | -6.3%|-14.3%|-13.2%| -0.2%| -0.8%| -0.8%|
|vc_doc_sharing| -3.0%| -6.7%| -8.2%|  0.1%| -0.9%| -1.1%|
|web_browsing  | -0.5%| -1.2%| -1.5%|  0.2%| -0.3%| -2.0%|
|wordEditing   | -3.4%| -6.8%| -6.6%|  0.6%| -0.5%| -1.4%|
|park_joy      | -1.7%| -9.2%| -1.7%| -0.0%| -4.0%|  0.0%|
|old_town_cross| -0.1%| -2.2%| -1.0%|  0.1%| -0.5%| -0.1%|
+--------------+------+------+------+------+------+------+
|Average       | -6.5%|-11.0%| -9.2%| -0.5%| -2.1%| -2.0%|
+--------------+------+------+------+------+------+------+
```

Figure 13: Compression Performance, improved prediction for intra and
inter blocks

6. IANA Considerations

This document has no IANA considerations yet. TBD

7. Security Considerations

This document has no security considerations yet. TBD

8. Acknowledgments

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9. References

9.1. Normative References

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