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| *Title:* | **Additional experiment results for frame packing arrangement SEI message for 4:4:4 content in 4:2:0 bitstreams** | | |
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# Abstract

This contribution proposes a method to extend the use of the frame packing arrangement SEI message to represent 4:4:4 content in nominally 4:2:0 bitstreams. The contribution is an update of the prior contributions JCTVC-K0240 and JCTVC-L0316 that provides additional experiment results. With the proposed method, it is reported that one constituent frame (e.g. in a top-bottom packing or alternating-frame coding scheme) can be decoded compatibly as an ordinary 4:2:0 image, or can be supplemented with the data from another constituent frame to form a complete 4:4:4 image representation. It is proposed to include support for the additional scheme into the frame packing arrangement SEI message in both AVC and HEVC, to facilitate deployment of systems using this method. Since 4:2:0 is the most widely supported format in products, it is asserted that having an effective way of conveying 4:4:4 content through such decoders can provide the substantial benefit of enabling widespread near-term deployment of 4:4:4 capabilities (especially for screen content coding). The proposed method operates by packing the samples of a 4:4:4 frame into two 4:2:0 frames and encoding the two 4:2:0 frames as the constituent frames of a frame packing arrangement. The semantics of 'content\_interpretation\_type' are extended to signal this packing arrangement. The proposed scheme is asserted to be of high practical value for applications involving screen content. Relative to native 4:4:4 encoding, the proposed scheme can provide the advantage of compatibility with the ordinary 4:2:0 decoding process that is expected to be more widely supported in decoding products.

# Introduction

Most video codecs that are commercially available today support only the 4:2:0 format, which sub-samples the chroma resolution, as opposed to using a 4:4:4 format, in which the chroma information is represented at the same resolution used for the luma. The YUV 4:2:0 format is considered sufficient and efficient for "mainstream" content (i.e. most natural and animated video content) since users do not ordinarily see a perceptible difference between the two formats for such content. However, there are a variety of existing and emerging applications (e.g., as discussed in [1] and [2]) that operate with screen content, and for such content, the difference between these two formats can be easily perceived (see Appendix). In such applications, a 4:4:4 format is strongly preferred over the YUV 4:2:0 format. However, the lack of wide-spread support for video codecs supporting 4:4:4 formats is a hindrance for these applications. Moreover, for certain critical uses such as scrolling titles and hard-edged graphics, there may sometimes be a significant benefit for 4:4:4 use in other scenarios.

In this contribution, we propose an approach to use codecs designed for YUV 4:2:0 content to compress and represent 4:4:4 content through the use of frame packing. The contribution is an update of the prior contributions JCTVC-K0240 [2] and JCTVC-L0316 [3] that includes the proposal of an additional content interpretation type (indicating band separation filtering) and provides additional experiment results. This proposal is similar to the frame packing of stereo (3D) content into 2D images, and builds on the framework established for that by extending the semantics of the frame packing arrangement SEI message. Unlike the frame packing of stereo content wherein there is a left and right view, the frame packing of the 4:4:4 content is done using a main view and an auxiliary view. Both the main and auxiliary views are in an equivalent of a 4:2:0 format. The main view may be independently useful, while the auxiliary view is useful when interpreted appropriately together with the main view.

# Proposed modifications

## Packing a YUV 4:4:4 frame into main and auxiliary views

A YUV (YCbCr, YCoCg, GBR, etc.) 4:4:4 frame can be represented as follows, wherein Y444, U444, and V444 are the Y, U, and V planes comprising the YUV 4:4:4 frame. Let the resolution of these planes be represented by width and height .

Y444

U444

V444

The YUV 4:4:4 frame represented above can be packed into two YUV 4:2:0 frames (as main and auxiliary frames) as follows:

Y420 U420 V420

Main view

B1

B2

B3

(YUV 4:2:0 frame)

B6

B7

B8

B9

B4

B5

Auxiliary view

(YUV 4:2:0 frame)

**Figure 1:** Illustration of main and auxiliary frame regions formed by proposed frame packing scheme.

The areas marked as B1 to B9 make up the Y, U and V planes of the two YUV 4:2:0 frames representing the main and auxiliary views. These areas are related to Y444, U444, and V444 as follows:

**Main view**

Area B1, , where the range of is .

Area B2, , where the range of is .

Area B3, , where the range of is .

**Auxiliary view**

Area B4, , where the range of is .

Area B5, , where the range of is .

Area B6, , where the range of is .

Area B7, , where the range of is .

Area B8, , where the range of is .

Area B9, , where the range of is .

In the above equations, and are either the same as or represent filtered versions of and respectively, where the range of is . This choice is explained in more detail in section 2.4.

### Advantages

The proposed packing method is designed such that:

* The main view is a YUV 4:2:0 equivalent of the original YUV 4:4:4 frame
  + Systems can optionally just display just the main view if YUV 4:2:0 output is needed
* The auxiliary view fits the content model of a YUV 4:2:0 frame and is well suited for compression in this manner, in terms of
  + Geometric consistency across its Y, U and V components
  + Motion is highly correlated across its Y, U and V components

The packing method is illustrated by the following example wherein a YUV 4:4:4 frame contains a circle represented using gray color (checkerboard pattern) for the Y plane, blue color (horizontal lines) for the U plane and red color (vertical lines) for the V plane and how the resultant main and auxiliary views are formed in YUV 4:2:0 format.

Y444 U444 V444

YUV 4:4:4 frame

Y420 U420 V420

Main view

(YUV 4:2:0 frame)

Y420 U420 V420

Auxiliary view

(YUV 4:2:0 frame)

**Figure 2:** Illustration Spatial correspondence relationships in proposed frame packing scheme.

## Extension to frame packing arrangement SEI message

The proposed method to signal the frame packing of YUV 4:4:4 content involves extending the semantics of the syntax element 'content\_interpretation\_type' which is part of the frame packing arrangement SEI message as defined in the AVC [4] and HEVC [5] specifications. The text for the proposed extension is provided in Section 8 (Appendix II) below. In addition to that specification text, it is also recommended for the standard to include a figure similar to one of the above figures and some non-normative explanatory information as provided above and below.

## System operation at the decoding end

The proposed extension to the frame packing arrangement SEI message informs the decoder that the decoded pictures contain main and auxiliary views of a 4:4:4 frame as the constituent frames of the frame packing arrangement. This information can be used to process the main and auxiliary views appropriately for display or other purposes.

When the system at the decoding end desires the video in 4:4:4 format and is capable of reconstructing the 4:4:4 frames from the main and auxiliary views, it should do so and the output format should be 4:4:4. Otherwise, only the main view should be given as output and the output format will then be 4:2:0.

## Pre-processing and post-processing

When content\_interpretation\_type is set to 3, the indication is that none of the chroma samples underwent an anti-alias filtering operation during the process of frame packing i.e. and =. In such a case, the chroma samples comprising the main view are a result of a direct sub-sampling of the chroma planes representing the 4:4:4 frame. As shown in the appendix, direct sub-sampling without filtering can create aliasing artifacts for certain types of screen content when only the main view is used to generate a 4:2:0 output.

In order to reduce the aliasing artifacts and improve the visual quality for the case where only the main view is used, the content\_interpretation\_type can be set to 4 and the main view can be generated using filtered/pre-processed versions of the 4:4:4 chroma planes. In such a case, it is recommended that the filter choice be made based on the chroma sample grid alignment with luma sample grid (inferred from chroma\_sample\_loc\_type\_top\_field and chroma\_sample\_loc\_type\_bottom\_field). For simplicity, in the case when the chroma sample grid aligns with the luma sample grid for each particular direction (horizontal/vertical), it is suggested that that the 3-tap filter [0.25 0.5 0.25] be used in that direction. If the chroma sample grid positions are centered between the luma sample positions for a particular direction (horizontal/vertical), then it is suggested that the 2-tap filter [0.5 0.5] be used in that direction. Another possible filter choice for the latter case is [0.125 0.375 0.375 0.125].

For example, if we consider the case where the chroma sample grid is not aligned with the luma sample grid in both horizontal and vertical directions (i.e. when chroma\_sample\_loc\_type\_top\_field and chroma\_sample\_loc\_type\_bottom\_field are equal to 1), the 2-tap filter [0.5 0.5] would be applied in both directions, such that and are obtained as follows:

When pre-processing is used (content\_interpretation\_type set to 4), the main view does not contain samples and but contains their filtered counterparts and . The auxiliary view contains the other chroma samples.

If the decoding system decides to output a 4:4:4 frame, a post-processing step should be applied to estimate the samples , as , from the encoded packed frame. For example, a simple suggested estimation of and would be as follows:

In the proposed form, with content\_interpretation\_type equal to 4 and chroma\_sample\_loc\_type\_top\_field and chroma\_sample\_loc\_type\_bottom\_field equal to 1, with the suggested anti-alias filter of [0.5 0.5], the value would perfectly reconstruct the input values in the absence of quantization error and rounding error. When considering quantization error, using somewhat different values would be advised (e.g., as determined by quantization step-size-dependent cross-correlation analysis).

## Band separation filtering for the auxiliary frame

In the frame packing scheme illustrated in section 2.1, sample values of and frames are placed directly into (and are directly unpacked from) the auxiliary frames. We thus refer to these schemes as “direct” packing approaches. Alternatively, we can consider the auxiliary frame samples as an enhancement layer signal to be combined with the main frame (or base layer frame) data. The main and auxiliary frame data can be formed using low-pass and high-pass band separation filtering, instead of direct sample packing. With this variation, the primary signal energy can be concentrated into the main frame, and arbitrarily low bit rates can be allocated to the supplemental auxiliary frame data that forms the enhancement signal.

Instead of encoding auxiliary frame samples directly, a two-dimensional, three-band wavelet decomposition can first be applied to and before the actual encoding process. Mathematically, for an array , where *=* or , define the following:

, for .

, for .

, for .

, for .

, for

, for

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, for

, for

A typical four-band wavelet decomposition breaks the frame into “LL”, “LH”, “HL” and “HH” subbands (“LL” = low-pass in both vertical and horizontal directions, “LH” = low-pass vertical, high-pass horizontal, and so forth). However, in our wavelet packing scheme as defined by the above equations, the “HL” and “HH” bands are not created; instead, the vertical high-pass signal is kept at full horizontal resolution, i.e., B2 and B3 are the “LL” bands of and respectively, B4 and B5 are vertical high-pass signals, i.e. a vertical “H” band of and , respectively, B6 and B8 consist of even-numbered rows of the “LH” band of , and B7 and B9 consist of odd-numbered rows the “LH” band of . That way, the decoder would apply the corresponding inverse wavelet operations after decoding the main and auxiliary frames to obtain and samples. Moreover, an additional vertical band separation can be performed, such that B6 and B8 are an “LHL” and “LHH” band of , and B7 and B9 are an “LHL” and “LHH” band of .

When the auxiliary frames are transmitted at lower bit rates (lower quality relative to the main frame), the chroma information from the main frame ( and ) sets the minimum level of quality for the and reconstruction, and any information from the auxiliary frame is used to improve beyond that minimum quality level. In the case of the “direct” frame packing method, wherein samples from the auxiliary frame are directly unpacked into and frames, such an approach would cause the chroma samples obtained from the auxiliary frame (3 out of 4) to have a lower quality compared to the chroma samples obtained from the main frame. However, the band-separation frame packing approach incurs a larger rounding error in the pre-processing steps than the direct frame packing approach because of the additional filtering operations involved (in the absence of bit-depth expansion).

We have experimented with the use of lifting-based band-separation filtering to mitigate the rounding error effects, with clipping to eliminate the bit-depth expansion. However, this introduces a different type of distortion. This topic is further discussed in our recent conference publication at the *IEEE Data Compression Conference* (DCC 2013) [6].

# Experiment results

We initially tested an end-to-end system for packing a 4:4:4 frame into two 4:2:0 frames, based on Microsoft’s implementation of an AVC software encoder and decoder with a simple “IPPP” (forward-predictive) coding structure [2]. We have since conducted similar tests using the HEVC HM 9.0 encoder [7] using the Low Delay Main configuration. In January, we presented some test results using our own screen content test sequences [3]. In this contribution, we provide results using the common 4:4:4 screen content test sequences that were used in other committee contributions [9].

Each encoder starts with a 4:4:4 input frame, constructs a 4:2:0 frame with twice the height of the 4:4:4 frame, places the main view in the top half and the auxiliary view in the bottom half of the 4:2:0 frame, and encodes the 4:2:0 frame. This corresponds to the use of the frame packing arrangement SEI message with frame\_packing\_arrangement\_type equal to 4. The decoder decodes the 4:2:0 frame, extracts the main and auxiliary views and reassembles the 4:4:4 frame for output (using to simplify the initial testing).

We tested both the “direct” frame packing approach and the band-separation frame packing approaches on both AVC and HEVC platforms.

In each experiment, the main frame QP (including luma QP and main frame chroma QP) was fixed and the auxiliary frame QP (representing QP for 3/4 of the chroma samples) was varied over a range of values. Auxiliary frame QP changes bring only chroma PSNR changes. With the luma QP fixed in each case, we compare the chroma PSNR performance for different schemes.

We also compared chroma BD bit rate performance using HEVC HM 10.0 with 4:4:4 range extensions (Encoder Version "[10.0\_RExt1.0\_dev][Windows][VS 1700][32 bit]") [8] on common 4:4:4 screen content test sequences [9]. The BD bit rate comparison result is shown in Table 1. The detailed PSNR curves are attached in the spread sheet. We tested both lower-rate (luma QP=26) and higher-rate (luma QP=16) scenarios. From Table 1, we can see that for the low-rate scenario, band separation generally has better performance than direct frame packing, while in the high-rate scenario, direct frame packing is a little better. This is due to the rounding error incurred by the band separation approach, as the bit depth was not extended to avoid introduction of rounding error (although this would actually be possible with 8-bit video encoding using the Main 10 profile).

Using the HM draft 4:4:4 coding extension, we were able to encode the 4:4:4 test sequences with the 4:4:4 HM directly and compare their performance with that of the frame packing schemes. One example of the rate-distortion performance comparison is shown in Figure 3. It can be seen that HM native 4:4:4 coding performs substantially better than frame packing (with or without band separation), since there is no redundant motion and segmentation information that needs to be sent for an auxiliary frame. While this indicates that native 4:4:4 format encoding has superior compression performance, the frame packing scheme is useful when 4:4:4 format is not supported by the decoder (or encoder).

Table 1: Chroma BD rate comparison of band separation scheme relative to direct packing  
on common 4:4:4 screen content test sequences.

|  |  |  |
| --- | --- | --- |
| **Test Sequence** | **Luma QP=26** | **Luma QP=16** |
| *doc\_sharing* | −4.8% | 5.0% |
| *web\_browsing* | −22.2% | 5.1% |
| *twist* | −0.3% | −0.7% |
| *map* | −9.8% | −6.3% |
| *word\_editing* | −20.6% | −2.0% |
| *cad* | 14.3% | 23.3% |
| *cbt* | −13.3% | 2.7% |
| *ppt* | −7.7% | 3.5% |
| *programming* | −26.6% | −7.0% |
| **Average** | **−10.1%** | **2.6%** |

**Figure 3:** Example rate-distortion performance of different packing schemes on common screen content test sequence *ppt*. The resolution of the 4:4:4 test sequence is 1080p with 200 frames, frame rate 20 fps.

# Conclusion

This proposal enables the creation of a system in which the existing 4:2:0 decoding process becomes the core component of a 4:4:4 decoder. Moreover, a subset of the decoded output can provide compatibility with existing 4:2:0 decoding systems. Since 4:2:0 is the most widely supported format in products, having an effective way of conveying 4:4:4 content through such decoders can provide the substantial benefit of enabling widespread near-term deployment of 4:4:4 capabilities.

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# Patent rights declaration(s)

**Microsoft Corporation may have current or pending patent rights relating to the technology described in this contribution and, conditioned on reciprocity, is prepared to grant licenses under reasonable and non-discriminatory terms as necessary for implementation of the resulting ITU-T Recommendation | ISO/IEC International Standard (per box 2 of the ITU-T/ITU-R/ISO/IEC patent statement and licensing declaration form).**

# Appendix I: Description of accompanying example images

We have attached a set of BMP pictures for comparison. Note that in order to view the true differences, the BMP files have to be opened and displayed in original resolution of without any scaling.

OriginalText.bmp is the original screen capture in the RGB color space.

444Text.bmp is the screen capture with the color conversion from RGB to YUV 4:4:4, and from YUV 4:4:4 back to RGB.

420AverageSubsamplingText.bmp is the screen capture with the color conversion from RGB to YUV 4:4:4, applying the [0.5 0.5] filter on chroma while downsampling from YUV 4:4:4 to YUV 4:2:0, using replication to upsample from YUV 4:2:0 to YUV 4:4:4, and from YUV 4:4:4 back to RGB.

420DirectSubsamplingText.bmp is the screen capture with the color conversion from RGB to YUV 4:4:4, no chroma filtering while downsampling from YUV 4:4:4 to YUV 4:2:0, using replication to upsample from YUV 4:2:0 to YUV 4:4:4, and from YUV 4:4:4 back to RGB.

For example, in areas with red text on green background, the difference in quality between the different variants can be easily seen. 444Text.bmp is almost identical to OriginalText.bmp and is expected. 420DirectSubsamplingText.bmp has the worst quality. While 420AveragetSubsamplingText.bmp is better than 420DirectSubsamplingText.bmp, the quality is significantly lower than that of 444Text.bmp.

Similar chroma artifacts are observed with AVC-compressed screen content without using the proposed approach and were avoided by using the proposed approach.

# Appendix II: Proposed text for AVC & HEVC specifications

The proposed extension is limited to the semantics of **content\_interpretation\_type** and is shown in green below:

**content\_interpretation\_type** indicates the intended interpretation of the constituent frames as specified in Table D‑9. Values of content\_interpretation\_type that do not appear in Table D‑9 are reserved for future specification by ITU-T | ISO/IEC and shall not be present in bitstreams conforming to this version of this Specification. Decoders shall ignore frame packing arrangement SEI messages that contain reserved values of content\_interpretation\_type.

For each specified frame packing arrangement scheme, there are two constituent frames that are referred to as frame 0 and frame 1.

Table D‑9 – Definition of content\_interpretation\_type

|  |  |
| --- | --- |
| **Value** | **Interpretation** |
| 0 | Unspecified relationship between the frame packed constituent frames |
| 1 | Indicates that the two constituent frames form the left and right views of a stereo view scene, with frame 0 being associated with the left view and frame 1 being associated with the right view |
| 2 | Indicates that the two constituent frames form the right and left views of a stereo view scene, with frame 0 being associated with the right view and frame 1 being associated with the left view |
| 3 | Indicates that the two constituent frames form the main and auxiliary views (4:2:0 frames) representing a 4:4:4 frame, with frame 0 being associated with the main view and frame 1 being associated with the auxiliary view. Indicates that the chroma samples of frame 0 should be interpreted as unfiltered samples of the 4:4:4 frame (without anti-alias filtering). |
| 4 | Indicates that the two constituent frames form the main and auxiliary views (4:2:0 frames) representing a 4:4:4 frame, with frame 0 being associated with the main view and frame 1 being associated with the auxiliary view. Indicates that the chroma samples of frame 0 should be interpreted as having been anti-alias filtered prior to frame packing. |
| 5 | Indicates that the two constituent frames form the main and auxiliary views (4:2:0 frames) representing a 4:4:4 frame, with frame 0 being associated with the main view and frame 1 being associated with the auxiliary view. Indicates that the chroma samples of frame 0 should be interpreted as having been band-separation filtered prior to frame packing. |

NOTE 6 – The value 2 for content\_interpretation\_type is not expected to be prevalent in industry use of this SEI message. However, the value was specified herein for purposes of completeness.

NOTE 7 – When content\_interpretation\_type is equal to 4, the anti-alias filtering performed by the encoder is outside the scope of this Specification. However, it is suggested that the filter selection should be made based on the alignment of chroma sampling grid with luma sampling grid along each direction (horizontal and vertical) as follows:

* If the chroma sampling grid aligns with the luma sampling grid for a given direction, the filter [0.25 0.5 0.25] should be used for that direction (along with a rounding operation).
* Otherwise, the filter [0.5 0.5] or [0.125 0.375 0.375 0.125] should be used for that direction (along with a rounding operation).

NOTE 8 – When content\_interpretation\_type is equal to 5, the band-separation filtering performed by the encoder is outside the scope of this Specification. However, it is suggested that this filtering should be performed using the Haar wavelet (i.e., [0.5 0.5] and [0.5 −0.5] filtering with rounding) for both the horizontal and vertical directions

When content\_interpretation\_type is equal to 3, 4, or 5, it is a requirement of bitstream conformance that:

* quincunx\_sampling\_flag shall be equal to 0
* spatial\_flipping\_flag shall be equal to 0
* frame0\_grid\_position\_x shall be equal to 0
* frame0\_grid\_position\_y shall be equal to 0
* frame1\_grid\_position\_x shall be equal to 0
* frame1\_grid\_position\_y shall be equal to 0

When content\_interpretation\_type is equal to 3, it is a requirement of bitstream conformance that:

* chroma\_loc\_info\_present\_flag shall be equal to 1
* chroma\_sample\_loc\_type\_top\_field shall be equal to 2
* chroma\_sample\_loc\_type\_bottom\_field shall be equal to 2

When content\_interpretation\_type is equal to 5, it is a requirement of bitstream conformance that:

* chroma\_loc\_info\_present\_flag shall be equal to 1
* chroma\_sample\_loc\_type\_top\_field shall be equal to 1
* chroma\_sample\_loc\_type\_bottom\_field shall be equal to 1