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An Introduction to High Efficiency Video Coding Range Extensions

Bin Li and Jizheng Xu
(Microsoft Research Asia, Beijing 100080, China)

Abstract

High Efficiency Video Coding (HEVC) is the latest international video coding standard, which can provide the similar quality with about half bandwidth compared with its predecessor, H.264/MPEG-4 AVC. To meet the requirement of higher bit depth coding and more chroma sampling formats, range extensions of HEVC were developed. This paper introduces the coding tools in HEVC range extensions and provides experimental results to compare HEVC range extensions with previous video coding standards. Experimental results show that HEVC range extensions improve coding efficiency much over H.264/MPEG-4 AVC High Predictive profile, especially for 4K sequences.

Keywords

H.265; High Efficiency Video Coding (HEVC); MPEG-H; range extensions; video compression

1 Introduction

High Efficiency Video Coding (HEVC) [1] is the latest international video coding standard, standardized as ITU-T Recommendation H.265 and ISO/IEC 23008- (MPEG-H Part 2). Compared with its predecessor, H.264/MPEG-4 Advanced Video Coding (AVC) [2], about 50% bit saving can be achieved [3]. Although HEVC version 1 supports a wide variety of applications, some key features are not included and left for further developments.

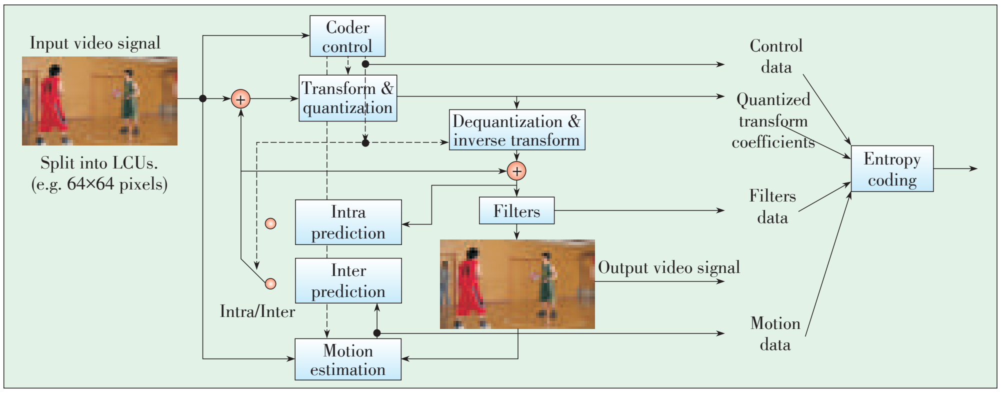
After the finalization of HEVC version 1, several extensions of HEVC are being developed. Of these, Range Extensions (RExt) support various chroma sampling formats and higher bit depth. Screen Content Coding Extensions (SCC) are based on RExt, mainly focusing on improving the coding efficiency for screen content [4]. The development of SCC started in Apr. 2014 and is expected to be finalized in early 2016. Both RExt and SCC are single-layer extensions of HEVC. There are also several extensions of HEVC targeting multiple layers. Scalable HEVC extension (SHVC) focuses on serving a same content with different bandwidth (e.g., different spatial resolution, as known as spatial scalability and different quality, as known as SNR scalability) [5]. Multiview and 3D extensions focus on the encoding of multiple views video content. HEVC Version 2 includes range extensions, scalable extensions and multiview extensions. 3D video coding is enabled in HEVC version 3. SCC will be included in HEVC version 4, which is expected to be finalized in early 2016.

The version 1 of HEVC was finalized in Jan. 2013. Only 4:2:0 chroma sampling format with 8–10 bit per sample was considered in HEVC version 1. To enhance capabilities, HEVC range extensions handle different chroma sampling formats, such as 4:4:4, 4:2:2, and 4:0:0 (monochrome), and higher bit depth encoding. Several new coding tools are added into HEVC range extension, such as cross-component prediction (CCP) [6] and Residual Differential Pulse-Code Modulation (RDPCM) [7], etc. This paper provides an overview of the new added coding tools and comprehensive experimental results comparing with HEVC range extensions with previous video coding standard are also provided.

The rest of this paper is organized as follows. Section 2 introduces HEVC version 1 briefly. Section 3 focuses on the new coding tools in HEVC range extensions. Section 4 provides several experimental results to show the coding efficiency of HEVC range extensions. Section 5 concludes the paper.

2 Brief Introduction to HEVC Version 1

Similar to H.264/MPEG-4 AVC, a block-based hybrid framework is applied to HEVC (**Fig. 1**). Intra- or inter-prediction is applied for each block. A 2D transform may be applied to the prediction residue (the other option is transform skip [8], [9], which skips the transform process and the residue is signaled in pixel domain rather than transform domain). The quantized coefficients together with mode information are signaled in the bitstream via Context-Adaptive Binary Arithmetic Cod-



▲Figure 1. Framework of High Efficiency Video Coding.

ing (CABAC). After a deblocking filter is applied to the reconstructed signals, the Sample Adaptive Offset (SAO) filter [10], which is a non-linear filter, can also be applied to improve the reconstruction quality. Some key concepts of HEVC are introduced below.

1) Blocking structure

The basic unit in HEVC is the Coding Tree Unit (CTU), which can be up to 64 x 64 in luma samples [11]. A hierarchical quadtree structure is used to split CTU into Coding Unit (CU). The CU size can be from 8 x 8 to 64 x 64, in luma samples. Each CU can be coded with intra-prediction or inter-prediction. The CU can be further split into a Prediction Unit (PU). The PU is the basic unit to carry the prediction information, which means that all the pixels in one PU are predicted using the same rule. Eight kinds of PU are supported in HEVC. Transform Unit (TU) is used to signal the residue information. TU is also organized as a quadtree, with the root of each TU tree is the CU. Within an intra-coded CU, a TU is always part of a PU. However, for an inter-coded CU, a TU can cross different PUs.

2) Intra-prediction

HEVC applies 33 angular directional intra-prediction, DC mode and planar mode to utilize spatial correlations. The intra-prediction of HEVC is performed on TU level to make better use of the surrounding pixels already being reconstructed. For luma component, all the 35 intra-prediction modes can be used. To simplify the design, only the horizontal, vertical, planar, DC and luma prediction direction (when luma direction is one of the previous four directions, mode 18, left-downward diagonal mode) can be used for chroma components. The reusing the luma direction by chroma components is also called Direct Mode (DM). The two chroma components have the same direction. The intra-prediction direction is signaled using three most probable modes (MPMs) deriving from neighboring blocks that have been previously decoded and the 32 remaining modes.

3) Inter prediction

HEVC uses inter prediction to remove temporal correlations. the luma motion compensation process is performed with the precision up to 1/4-pel, using 8-tap (7-tap for several positions) separate interpolation filters [12]. 4-tap separate interpolation filter is used for chroma components with 1/8-pel precision. Advanced Motion Vector Predictor (AMVP) and merge mode are used to signal the motion information. In AMVP mode, up to two motion vector predictors can be used to predict the current motion vectors (MVs) of the current PU. In merge mode, all the motion information (including inter prediction direction, reference picture index(es), and motion vector(s)) are inherited from a specific merge candidate. Up to five merge candidates can be used.

4) Transform

4 x 4 to 32 x 32 DCT-like transform can be used in HEVC. For the 4x4 luma TUs in intra-prediction CU, a 4 x 4 DST-like transform is used [13], [14]. A special transform skip mode is also supported for certain type of content (especially screen content) in 4 x 4 TUs [8], [9].

3 HEVC Range Extensions

This section gives an overview of HEVC range extensions. New features in HEVC range extensions can be divided into three categories: extension of chroma sampling formats, extension of bit depths, and new coding efficiency enhancement tools.

3.1 Extension of Chroma Sampling Formats

One of the main purpose of developing HEVC range extensions is to support different chroma sampling formats. Only 4:2:0 is supported in the HEVC version 1 profiles, in which the chroma components have half the resolution of luma in both horizontal and vertical directions. However, a higher chroma fidelity is required in some applications. Besides 4:2:0, the range extensions support 4:4:4 (where the chroma components have the same resolution as luma), 4:2:2 (where the chroma components have the half horizontal resolution as luma, but the same vertical resolution as luma), and 4:0:0 (monochrome, only the video content only has the luma component).

In the 4:4:4 case, the decoding process is quite similar to the 4:2:0 decoding process. The only difference is that the two chroma components have the same spatial resolution as the luma component. One square luma rectangle still corresponds to two square chroma rectangles, the only difference being that all three rectangles are the same size. If 4:4:4 coding is used, the video can be coded in RGB format directly or in YCbCr format. Usually, in the RGB coding, the G component is treated as the luma component and the R and B components are treated as the chroma components.

In the 4:2:2 case, the decoding process needs to be changed accordingly, as one square luma block corresponds to two non-square chroma rectangles. For example, a 16 x 16 luma block corresponds to two 8 x 16 chroma blocks (one 8 x 16 Cb block and one 8 x 16 Cr block). To avoid introducing a new non-square transform, the chroma transform needs to be specially handled. In the HEVC range extensions, the non-square chroma block will further split in vertical direction. Thus, two chroma transforms with half the horizontal luma size and half the vertical luma size will be used. In the above example, the 8x16 chroma blocks will be spilt into 8x8 blocks. So, for each chroma component, two 8 x 8 transforms are applied. The deblocking filter is applied to the newly added transform edge in the 4:2:2 content.

3.2 Extension of Bit Depths

The other main purpose of HEVC range extensions is to support higher bit depth encoding. Only up to 10 bit is supported in the HEVC version 1. But some applications, such as those for medical and military purposes, require higher fidelity. Thus, higher bit depth encoding is supported in HEVC range extensions. The main changes to support higher bit depth includes: when extended precision processing is enabled, the dynamic range of coefficients is enlarged and the de-quantization process is adjusted accordingly. When high precision offsets is enabled, the precision of weighted prediction is increased. The SAO offsets can also be scaled up to better support the higher bit depth content.

3.3 New Coding Efficiency Enhancement Tools

Several new coding tools are included in the HEVC range extensions to improve the coding efficiency or to provide finer control of encoding parameters. This sub section provides a brief introduction of them.

Cross-Component Prediction (CCP): CCP is used to remove the correlation among color components [6]. CCP is primarily designed for RGB content, but it also provides some bit saving for YCbCr content. CCP is only enabled for 4:4:4 content. When CCP is used, the residue of the first component is used to predict the residue of the other two components via a linear prediction model. The CCP is only used when the three components use the same method to generate the prediction (including inter prediction and intra-prediction if the three components use the same intra-prediction direction, i.e., DM mode for chroma).

Residual Differential Pulse—Code Modulation (RDPCM): Two kinds of RDPCMs are supported in HEVC range extensions [7]. RDPCM modifies the residue in pixel domain, so it is enabled when the residue is signaled in pixel domain. When the transform is bypassed, e.g., in the blocks coding in lossless mode or TUs coded with transform skip, the RDPCM may be used. When horizontal RDPCM is used, the decoded residue is modified as r[x][y] += r[x−1][y] and when vertical RDPCM is used, the decoded residue is modified as r[x][y] += r[x][y−1], where r[x][y] is the residue at the (x, y). The residue is modified one by one, and the modification process looks like differential coding. Thus, it is called RDPCM. For intra-coded CUs, implicit RDPCM is used. The horizontal and vertical RDPCM is applied when the horizontal and vertical intra-prediction is used, respectively. For inter-coded CUs, explicit RDPCM is used. The RDPCM direction is signaled in the bitstream when explicit RDPCM is used. Because RDPCM is only enabled for lossless coded blocks and transform skip TUs, it mainly helps to improve the coding efficiency for lossless coding and screen content coding.

Improvements on Transform Skip: HEVC range extensions further improve the transform skip mode to provide better coding efficiency. In HEVC version 1, only 4x4 TUs can use transform skip. In HEVC range extensions, all the TUs, from 4x4 to 32x32, can use transform skip [15]. Rotation is applied to intra 4x4 TUs using transform skip [16]. The coefficients at the right bottom are moved to the upper left, using the equation of r[x][y] = coeff[4−x−1][4−y−1], where r[x][y] means the rotated coefficient at (x, y) position and coeff[x][y] means the unmodified coefficient at (x, y). This technique is also applied to the lossless coded blocks (where transform is bypassed). The context to encode the significant map of transform bypass (including transform skip and lossless coded) TUs is also modified to improve the coding efficiency [16].

Others: The intra reference pixel smoothing filter can be disabled in the HEVC range extensions [17]. Disabling intra reference pixel smoothing filter helps the lossless encoding. Localized control of chroma Quantization Parameter (QP) is supported to provide the ability to adjust the chroma QP in a finer granularity [18]. Several new coding tools are added into the HEVC range extensions, such as persistent rice parameter adaptation [19], CABAC bypass alignment [20], etc.

3.4 HEVC Range Extensions Profiles

Several new profiles have been defined for HEVC range extensions. The extended precision processing is enabled in the 16-bit profiles and disabled in the other profiles. CABAC bypass alignment is enabled in High Throughput profile and disabled in all the other profiles.

Monochrome, Monochrome 12 and Monochrome 16 profiles are defined 4:0:0 (monochrome) content with different bit depth range. All the new range extensions coding tools can be enabled in Monochrome 16 profile, but they cannot be used in Monochrome and Monochrome 12 profiles.

Main 12 profile only extends the bit depth range of Main profile to 8−12 bits. 4:2:0 and 4:0:0 contents can be used in Main 12 profile. The new range extensions coding tools in range extensions are not enabled in Main 12 profile.

Main 4:2:2 10 and Main 4:2:2 12 profiles are defined for 4:2:2 content with different bit depth range. 4:2:0 and 4:0:0 content can also be used in these profiles. All the new range extensions coding tools, except localized control of chroma QP, are disabled in these two profiles.

Main 4:4:4, Main 4:4:4 10 and Main 4:4:4 12 profiles are defined to support 4:4:4 content with different bit depth range. All the chroma sampling formats, including 4:2:0, 4:4:4, 4:0:0, and 4:2:2, can be used in these profiles. All the new range extensions coding tools can be used in these profiles.

Main Intra, Main 10 Intra, Main 12 Intra, Main 4:2:2 10 Intra, Main 4:2:2 12 Intra, Main 4:4:4 Intra, Main 4:4:4 10 Intra, Main 4:4:4 12 Intra and Main 4:4:4 16 Intra profiles are defined for all intra coding.

Main 4:4:4 Still Picture and Main 4:4:4 16 Still Picture profiles are defined for the case there is only one intra picture in the whole bitstream.

High Throughput 4:4:4 16 Intra profile is defined for all intra coding, with CABAC bypass alignment enabled.

4 Coding Efficiency of HEVC Range Extensions

To show the coding efficiency of range extensions, this section provides the coding efficiency results of HEVC range extensions with previous video coding standards. The first part of this section compares HEVC range extensions with H.264/MPEG-4 AVC High Predictive profiles. The second part of this section compares HEVC range extensions with HEVC version 1. The latest available reference software is used in the test. HM-16.7 [21] is used to generate HEVC version 1 and range extensions bitstreams and JM-19.0 [22] is used to generate H.264/MPEG-4 AVC bitstreams. Both HM-16.7 and JM-19.0 are configured with similar settings.

Three coding structures are used in the tests. One of these is Random Access (RA) coding structure, in which intra refresh is relatively frequent and the delay is not a critical issue. In the test, random access points are inserted into the bitstreams about once a second. A Hierarchical-B coding structure with group of pictures (GOP) size of 8 is used in the RA coding structure. Temporal scalability with four different layers is supported in the HEVC RA coding structure, while it is not supported in the H.264/MPEG-4 AVC RA coding structure. The supporting of temporal scalability with four different temporal layers in HEVC RA coding structure brings about 0.3% performance drop on average [23]. Besides, the low delay (LD) B coding structure is used for real-time communications, in which the coding delay is critical and the random access support is less important. IBBB (without picture reordering) coding structure with hierarchical quantization parameter (QP) is used in LD coding. The third one is all-intra (AI) coding structure, in which no temporal prediction is applied and all the pictures use intra-picture prediction only.

Only objective PSNR-based test results are provided in this section. The coding efficiency is measured in terms of Bjøntegaard-delta bit rate (BD-rate) [24], which measures the bit rate difference at the same quality. A negative number means bit rate reduction (performance gain) and a positive number means bit rate increase (performance loss).

4.1 Comparison of HEVC Range Extensions with H.264/MPEG-4 AVC High 4:4:4 Predictive Profile

To show the coding efficiency of HEVC RExt, we compare it with H.264/MPEG-4 AVC High 4:4:4 Predictive profile. Two sets of coding results are provided in this paper. The first test set uses the sequences specified in HEVC RExt Common Test Condition (CTC) [25]. The sequences in the first test set are 8–12 bit per sample, in YUV 4:2:2, YUV 4:4:4 and RGB 4:4:4 format. The second test set uses the Netflix sequence [26], which is in YUV 4:4:4 10-bit format, with a spatial resolution of 4096 x 2160 and the temporal resolution 60 Hz to reflect the 4K video application. We choose 10 clips (120 pictures in each clip) from the Netflix sequence to conduct the test. The start time in the original sequence of the 10 clips is provided

▼Table 1. Clips of Netflix sequence used in the test

Clip name	Start time (s)	Clip name	Start time(s)
NarrotorWorking	6.84	CityDayView	27.76
Vegetable	39.44	FlowerMarket	46.30
Vegetable2	55.34	FoodMarket	70.53
PeopleWalking	81.89	AztecRitualDance	97.70
CouplesDancing	115.27	Motorcycles	133.00

▼Table 2. Coding performance of HEVC range extensions over H.264/MPEG-4 AVC (RExt CTC sequences)

	All Intra Main-tier			All Intra High-tier			All Intra Super-High-tier		
	Y/G	U/B	V/R	Y/G	U/B	V/R	Y/G	U/B	V/R
RGB 4:4:4	−34.7%	−27.2%	−29.4%	−28.0%	−24.2%	−25.6%	−23.2%	−20.2%	−21.3%
YCbCr 4:4:4	−26.4%	−26.0%	−30.9%	−25.0%	−26.9%	−33.6%	−22.5%	−27.1%	−33.9%
YCbCr 4:2:2	−21.4%	−13.5%	−14.3%	−18.1%	−13.9%	−17.7%	−14.3%	−12.1%	−15.3%
	Random Access Main-tier			Random Access High-tier					
RGB 4:4:4	−40.1%	−35.5%	−36.3%	−32.3%	−30.3%	−31.2%			
YCbCr 4:4:4	−40.0%	−51.2%	−50.1%	−38.8%	−47.9%	−56.8%			
YCbCr 4:2:2	−31.9%	−21.7%	−20.4%	−28.3%	−28.1%	−30.4%			
	Low Delay B Main-tier			Low Delay B High-tier					
RGB 4:4:4	−39.8%	−35.1%	−37.2%	−30.9%	−30.6%	−31.3%			
YCbCr 4:4:4	−45.2%	−56.1%	−62.2%	−42.0%	−49.3%	−60.4%			
YCbCr 4:2:2	−37.7%	−28.4%	−28.4%	−32.8%	−30.7%	−35.3%			

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▼Table 3. Coding performance of HEVC range extensions over H.264/MPEG-4 AVC (Netflix sequence clips)

	All Intra Main-tier			All Intra High-tier			All Intra Super-High-tier		
	Y/G	U/B	V/R	Y/G	U/B	V/R	Y/G	U/B	V/R
AztecRitualDance	-25.5%	-25.5%	-34.1%	-25.1%	-34.1%	-45.5%	-24.6%	-44.4%	-58.4%
CityDayView	-27.1%	-32.5%	-42.4%	-26.5%	-40.9%	-49.9%	-23.4%	-44.5%	-60.1%
CouplesDancing	-46.7%	-60.8%	-59.6%	-47.7%	-68.1%	-71.4%	-36.5%	-76.3%	-81.2%
FlowerMarket	-27.9%	-31.3%	-34.6%	-22.2%	-38.5%	-42.9%	-22.5%	-43.7%	-49.3%
FoodMarket	-31.4%	-27.7%	-42.8%	-29.4%	-32.6%	-52.3%	-25.6%	-31.1%	-58.8%
Motorcycles	-52.8%	-52.4%	-58.5%	-51.8%	-63.5%	-71.5%	-37.1%	-74.7%	-85.2%
NarrotorWorking	-35.8%	-39.6%	-37.8%	-38.2%	-44.9%	-43.5%	-39.6%	-47.6%	-45.2%
PeopleWalking	-52.8%	-60.2%	-62.2%	-55.2%	-70.3%	-76.8%	-38.4%	-79.1%	-88.5%
Vegetable	-24.0%	-22.7%	-30.0%	-20.0%	-26.7%	-34.8%	-18.4%	-23.9%	-28.2%
Vegetable2	-37.2%	-37.4%	-42.8%	-34.8%	-47.2%	-53.6%	-28.0%	-59.0%	-66.0%
Average	-36.1%	-39.0%	-44.5%	-35.1%	-46.7%	-54.2%	-29.4%	-52.4%	-62.1%

	Random Access Main-tier			Random Access High-tier		
AztecRitualDance	-44.6%	-53.8%	-59.3%	-45.3%	-63.9%	-70.9%
CityDayView	-58.8%	-73.8%	-73.2%	-63.3%	-84.6%	-89.9%
CouplesDancing	-75.0%	-87.0%	-83.1%	-76.8%	-94.6%	-92.0%
FlowerMarket	-57.8%	-61.5%	-71.9%	-33.6%	-50.8%	-59.1%
FoodMarket	-59.4%	-58.2%	-76.1%	-52.4%	-54.7%	-85.7%
Motorcycles	-81.2%	-84.8%	-85.6%	-86.4%	-93.5%	-95.0%
NarrotorWorking	-62.4%	-76.9%	-70.8%	-62.7%	-86.8%	-81.8%
PeopleWalking	-74.3%	-83.7%	-81.5%	-77.5%	-92.1%	-91.6%
Vegetable	-52.5%	-59.9%	-70.8%	-30.2%	-46.0%	-60.3%
Vegetable2	-66.5%	-76.5%	-76.6%	-69.1%	-85.9%	-88.4%
Average	-63.2%	-71.6%	-74.9%	-59.7%	-75.3%	-81.5%

	Low Delay B Main-tier			Low Delay B High-tier		
AztecRitualDance	-51.5%	-65.2%	-68.8%	-50.4%	-67.7%	-73.9%
CityDayView	-75.9%	-87.8%	-90.5%	-73.9%	-89.7%	-96.7%
CouplesDancing	-77.6%	-89.0%	-85.0%	-77.6%	-92.4%	-90.6%
FlowerMarket	-56.2%	-62.6%	-69.8%	-35.3%	-54.3%	-60.0%
FoodMarket	-61.9%	-65.0%	-85.2%	-51.5%	-58.3%	-87.7%
Motorcycles	-81.4%	-86.3%	-87.3%	-83.7%	-91.1%	-93.4%
NarrotorWorking	-69.5%	-84.8%	-79.9%	-67.2%	-86.5%	-82.9%
PeopleWalking	-76.4%	-84.7%	-83.1%	-78.7%	-89.4%	-89.9%
Vegetable	-56.1%	-64.6%	-78.6%	-34.7%	-50.1%	-64.3%
Vegetable2	-75.3%	-86.3%	-87.5%	-73.1%	-88.1%	-91.6%
Average	-51.5%	-65.2%	-68.8%	-50.4%	-67.7%	-73.9%

in **Table 1**. The coding results using HEVC CTC sequences are provided in **Table 2** and the coding results using Netflix sequences are provided in **Table 3**. The QP range is 22-37 for Main-tier, 17-32 for High-tier, and 12-27 for Super-High-tier.

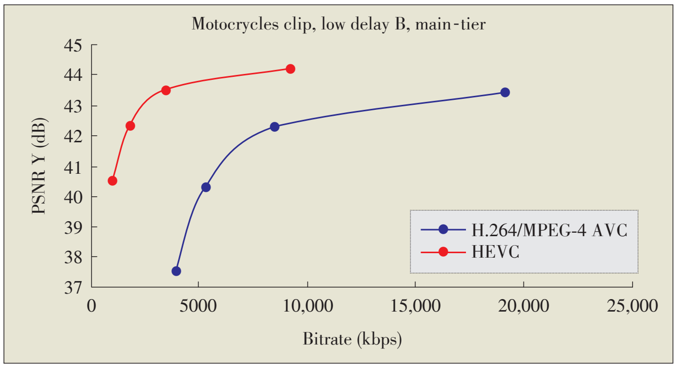
From Table 2, we can know that for RGB 4:4:4 sequences, compared with H.264/MPEG-4 AVC, HEVC saves 23.2%-34.7% bit-rate for All Intra coding. 32.3%-40.1% bits saving is achieved for Random Access coding and 30.9%-39.8% bits saving is achieved for Low Delay B coding, at different bit rate ranges. Table 2 also shows that the bit saving is higher at Main-tier, which indicates that improving the coding efficiency at high quality end is more challenging.

It can be seen from Table 3 that, when compared with H.264/MPEG-4 AVC, HEVC saves about 29.4%-36.1% bits for All Intra coding. 59.7%-63.2% bits saving is achieved for Random Access coding and 50.4%-51.5% bits saving is achieved for Low Delay B coding. Table 3 also shows that the bits saving of HEVC of H.264/MPEG-4 AVC is much larger for 4K sequences. An example R-D curve of Motorcycles clip under Low Delay B coding structure at Main-tier is shown in **Fig. 2**.

4.2 Comparison of HEVC Range Extensions with HEVC Version 1

We also provide the coding efficiency of HEVC RExt over HEVC version 1. We use HEVC version 1 test sequences and HEVC version 1 CTC [27] to perform the test. The overall coding performance of HEVC RExt over HEVC version 1 is provided in **Table 4**. The QP range used in the test is 22-37. Both HEVC version 1 encoding and RExt encoding are configured using 4:2:0 8-/10-bit encoding. The only difference is that new coding tools are enabled in the RExt encoding configurations.

Table 4 shows that for 4:2:0 content, HEVC range extensions do not provide much performance improvements except for Class F sequences. The main reason for this phenomenon is that Class F sequences are screen content and HEVC range ex-



▲**Figure 2. R-D curve of motocrycles clip under low delay B coding structure at main-tier.**

▼**Table 4. Coding performance of HEVC RExt over HEVC version 1**

	All Intra Main			All Intra Main10		
	Y	U	V	Y	U	V
Class A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Class B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Class C	−0.3%	−0.2%	−0.3%	−0.3%	−0.2%	−0.3%
Class D	−0.5%	−0.5%	−0.6%	−0.5%	−0.4%	−0.5%
Class E	−0.2%	−0.1%	−0.1%	−0.2%	0.0%	−0.1%
Class F	−4.9%	−5.2%	−5.4%	−5.0%	−5.2%	−5.7%
Overall	−1.0%	−1.0%	−1.1%	−0.2%	−0.1%	−0.2%

	Random Access Main			Random Access Main10		
Class A	0.0%	−0.1%	0.3%	0.0%	0.3%	−0.4%
Class B	0.0%	0.1%	0.1%	0.0%	−0.1%	−0.1%
Class C	−0.2%	−0.4%	−0.4%	−0.2%	−0.5%	−0.6%
Class D	−0.3%	−0.5%	−0.7%	−0.3%	−0.5%	−0.5%
Class E						
Class F	−3.7%	−4.2%	−4.3%	−3.8%	−3.9%	−4.6%
Overall	−0.1%	−0.2%	−0.2%	−0.1%	−0.2%	−0.4%

	Low Delay B Main			Low Delay B Main10		
Class A						
Class B	0.0%	0.1%	0.0%	0.0%	0.2%	0.4%
Class C	−0.1%	0.1%	0.1%	−0.1%	0.2%	0.1%
Class D	−0.1%	0.2%	0.1%	0.0%	0.1%	0.6%
Class E	−0.1%	−1.1%	2.1%	−0.1%	−0.3%	1.0%
Class F	−2.4%	−2.1%	−2.3%	−2.5%	−2.4%	−4.2%
Overall	−0.5%	−0.5%	−0.1%	−0.5%	−0.4%	−0.4%

	Low Delay P Main			Low Delay P Main10		
Class A						
Class B	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
Class C	−0.1%	0.1%	0.2%	0.0%	0.3%	0.0%
Class D	0.0%	0.2%	0.6%	0.0%	0.3%	0.8%
Class E	−0.2%	−1.3%	1.3%	−0.1%	−0.4%	0.8%
Class F	−2.5%	−1.8%	−2.2%	−2.4%	−2.4%	−3.5%
Overall	−0.5%	−0.5%	−0.1%	−0.5%	−0.4%	−0.3%

tensions improves quite a lot for screen content. For nature content, HEVC range extensions provide almost the same coding efficiency as HEVC version 1.

5 Conclusion

This paper provides an overview of HEVC range extensions. HEVC range extensions provide the ability to handle higher bit depths and higher fidelity chroma sampling formats for video. Several new coding tools are also added in the HEVC range extensions. The experimental results show that for 4K sequences, compared with H.264/MPEG-4 AVC High Predictive profile, HEVC range extensions save about 36.1% bit-rate for All intra-coding, 63.2% bit-rate for Random Access coding and 51.5% bit-rate for Low Delay B coding, at Main-tier quality range.

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Biographies

Bin Li (libin@microsoft.com) received the B.S. and Ph.D. degrees in electronic engineering from the University of Science and Technology of China (USTC), Hefei, Anhui, China, in 2008 and 2013, respectively. He joined Microsoft Research Asia (MSRA), Beijing, China, as an Associate Researcher in 2013. He has authored or co-authored over 20 papers. He holds over 10 granted or pending U.S. patents in the area of image and video coding. He has more than 30 technical proposals that have been adopted by Joint Collaborative Team on Video Coding. His current research interests include video coding, processing, and communication. Dr. Li received the best paper award for the International Conference on Mobile and Ubiquitous Multimedia from Association for Computing Machinery in 2011. He received the Top 10% Paper Award of 2014 IEEE International Conference on Image Processing. He has been an active contributor to ISO/MPEG and ITU-T video coding standards. (JCT-VC). He is currently the Co-Chair of the Ad Hoc Group of Screen Content Coding extensions software development.

Jizheng Xu (jzxu@microsoft.com) (M'07-SM'10) received the B.S. and M. S. degrees in computer science from the University of Science and Technology of China (USTC), and the Ph.D. degree in electrical engineering from Shanghai Jiaotong University, China. He joined Microsoft Research Asia (MSRA) in 2003 and currently he is a Lead Researcher. He has authored and co-authored over 100 conference and journal refereed papers. He has over 30 U.S. patents granted or pending in image and video coding. His research interests include image and video representation, media compression, and communication. He has been an active contributor to ISO/MPEG and ITU-T video coding standards. He has over 40 technical proposals adopted by H.264/AVC, H.264/AVC scalable extension, High Efficiency Video Coding, HEVC range extension and HEVC screen content coding standards. He chaired and co-chaired the ad-hoc group of exploration on wavelet video coding in MPEG, and various technical ad-hoc groups in JCT-VC, e.g., on screen content coding, on parsing robustness, on lossless coding. He co-organized and co-chaired special sessions on scalable video coding, directional transform, high quality video coding at various conferences. He also served as special session co-chair of IEEE International Conference on Multimedia and Expo 2014.