Enabling HEVC: Intel® Media SDK 2014

A white paper unlocking new video technology opportunities!

HEVC is an exciting, cutting edge, highly efficient, new video compression technology enabling next generation of digital media applications, products and services. Intel is at the forefront of this development, leading the HEVC technology revolution. Intel Media SDK aims to offer industry leading, among the best in the class developer focused HEVC solutions with the best tradeoff of quality versus performance. This paper introduces the capabilities of Intel's first developer HEVC product offering, the Media SDK HEVC Software Encoder and Decoder. The paper also identifies the opportunities that are just around the corner with the expected unleashing of a range of extremely powerful, higher performance HEVC solutions suited for different applications, services, eco-systems, and devices.

March 25, 2014, v1.1

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Introduction

HEVC (aka, H.265) [1-4] is a new, highly efficient, video compression standard from ISO MPEG that promises substantially higher compression over H.264 (aka, AVC) [4,6], its previous generation standard completed around 10 years ago. In particular HEVC promises roughly a factor of 2 in compression H.264, that had delivered a factor of 2 in compression over MPEG-2, its earlier generation standard. H.264 is currently dominant having supplemented or displaced MPEG-2 in nearly all digital video applications, services, products, and eco-systems. Over next few years the time seems ripe for HEVC due to its advantages to supplement or displace H.264 in the same manner. Overall MPEG has an excellent history [4] of delivering state of the art video standards that have a wide industry following.

Intel® Media SDK is a well known developer product that implements state of art standards based highly optimized decoders, corresponding efficient and highly optimized encoders, file/stream formatting, and pre- and postpocessing tools supporting efficient coding. Intel® Media SDK implements many Codec and tools components initially in software, and later as hybrid (of software and hardware) or entirely in hardware. The reason for ths multi-tier approach is faster time to market for software solutions, followed by hybrid solutions that contains partial hardware acceleration, and lastly blazingly fast hardware solutions that scale. Intel® Media SDK 2014 is available for Windows (client/server), and Linux (Server), and in near future for Android. Intel® Media SDK 2014 supports Intel® 2nd/3rd generation Core™ platform, 4th/5th generation Core™ and Xeon™ platforms as well as its Atom™ platform.

Intel® Media SDK 2014 is just being released and includes a number of signficant additions and enhancements including software implementation of HEVC Codec Encoder and Decoder. Since not all HEVC implementations are created equal, this white paper attempts to quantify the quality and performance a developer should expect from Intel® Media SDK HEVC Software implementation. Rest of the white paper is organized as per the following sections.

- HEVC Compression Basics
- Intel® Media SDK Overview
- Intel® Media SDK HEVC Codec Quality
- Intel® Media SDK HEVC Encoder Quality vs Performance Tradeoffs
- Intel® Media SDK HEVC Decoder Performance

Appendix A at the end of the document provides summary of quality and performance results.

HEVC Compression Basics

HEVC video compression although a highly efficient standard it builds on the well known classical interframe coding framework of block motion compensated transform coding. However unlike previous MPEG/ITU-T standards instead of using smaller, fixed size processing units of macroblocks and blocks for prediction and coding it uses much larger processing structures and transforms.

HEVC Data Hierarchy

Figure 1 shows high level data structure hierarchy; top 2 portions of the hierarchy are shown only to explain key concepts while other portions of the hierarchy are employed by HEVC.

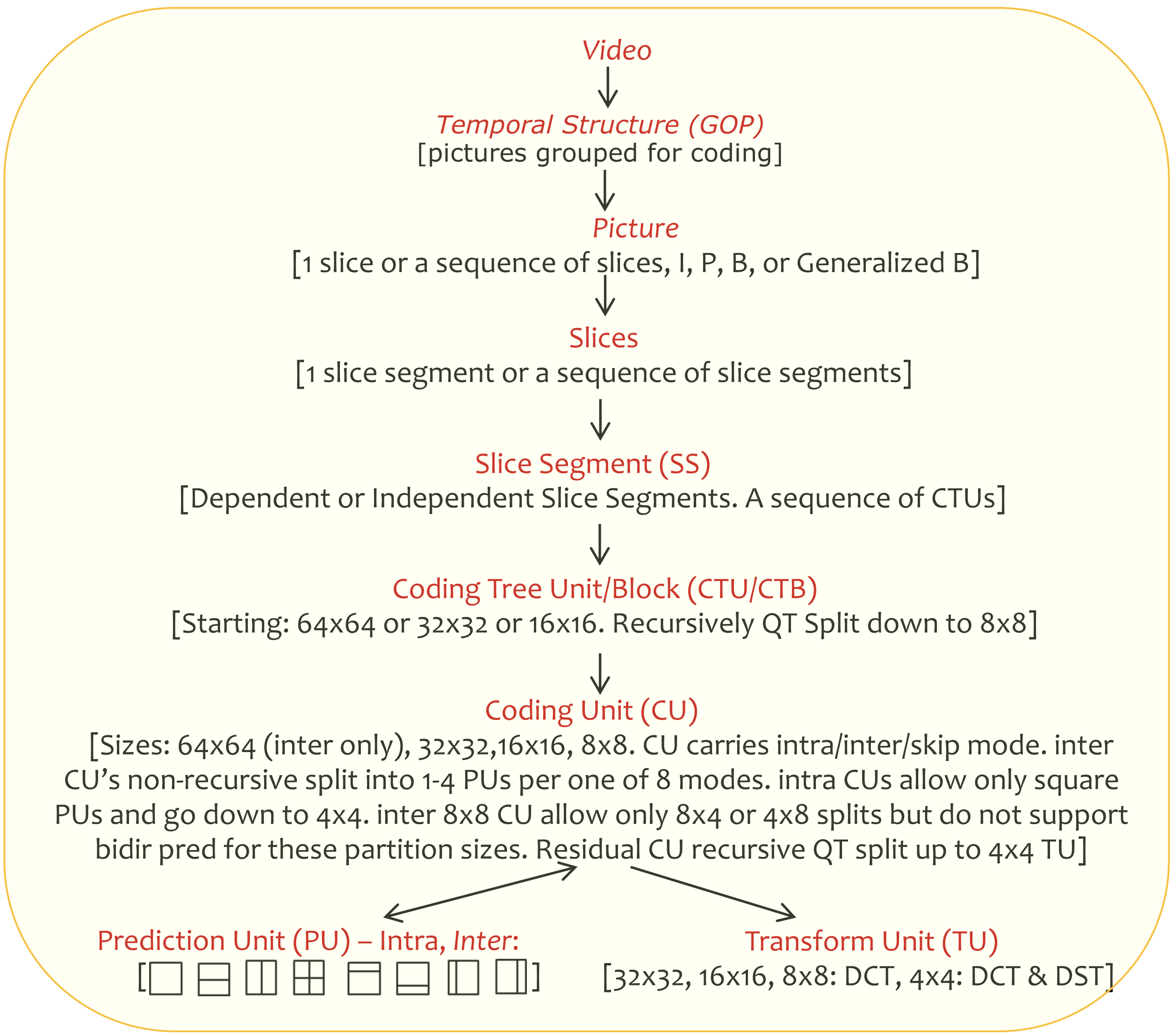

Figure 1 Layers in HEVC data hierarchy. Video, and GOP layer are conceptual only (not explicit) while the others are actual layers.

HEVC Partitioning, Prediction and Coding Technologies

We now introduce relevant components of HEVC processing structures as well as discuss actual video coding algorithms. Due to significant amount of details only the high level concepts are covered. Further, the presentation style used is 2 column with a key concept shown in the first column and the second column showing a related illustration. . Since this is a brief overview, the concepts are simplified and not necessarily covered in extreme detail.

Coding Tree Unit/Block (CTU/CTB)

- Defined at a high level
- A CTU consists of 3 CTBs (1 luma plus 2 chroma)
- Luma CTB starting size one of
    - 64x64
    - 32x32
    - 16x16
- Corresponding Chroma CTB, half in size horizontally and vertically
- Luma CTB split by recursive QuadTree down to 8x8

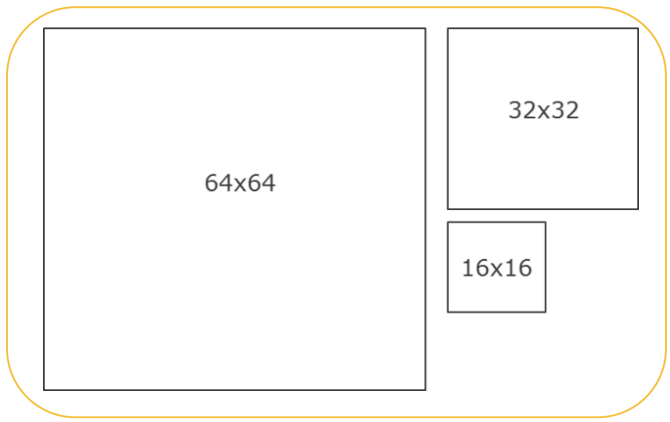

Figure 2A Luma CTB starting size options

Coding Unit (CU)

- Always Square
    - Largest CU (LCU) as big as size of luma CTB
    - As small as 8x8
    - Sizes: 64x64, 32x32, 16x16, 8x8
- Traversed in Zig-zag order
- Types: Intra, Inter, Skip
- Intra CU
    - Largest size 32x32
    - Partitioned in to square Prediction Units (PU) up to 4x4
- Inter CU
    - Largest size 64x64
- 8x8 CU parttioned into 8x4, and 4x8 PUs only; no bidirectional pred

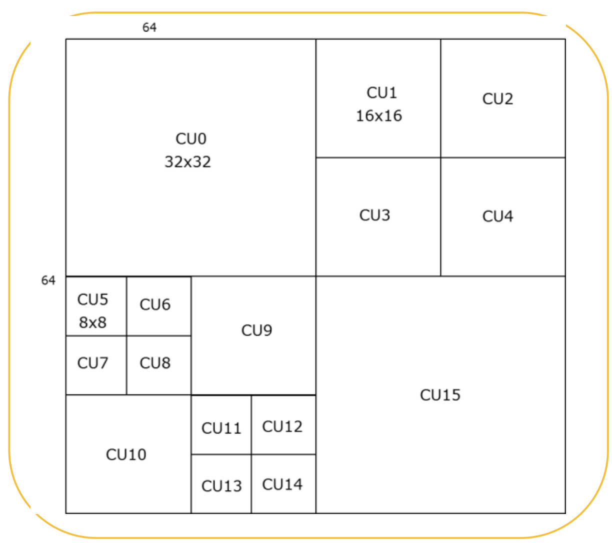

Figure 2B Partitioning of a luma CTU into CUs

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Prediction Unit (PU)

- CU partitioning into Prediction partitions is nonrecursive
- Intra CUs partitioned into square Prediction partitions
  - 32x32
  - 16x16
  - 8x8
  - 4x4
- Inter CU (64x64, 32x32, 16x16, 8x8) partitioned into
  1 of 8 Prediction partition modes
  - Partitioned into 1, 2, or 4 partitions
  - 8x8 PU is partitioned into 8x4, 4x8 only;
    also no bidirectional prediction mode for 8x8 PUs
- Using PU partitions, a residual CU is constructed prior to coding

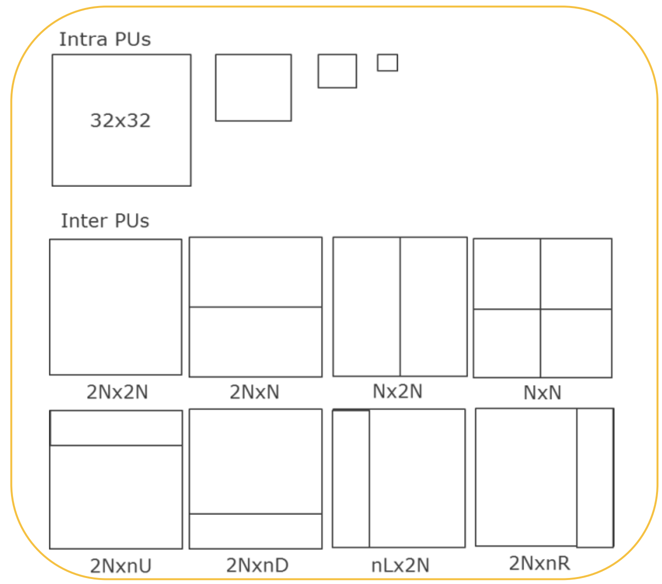

Figure 2C Intra and Inter PU examples

Transform Unit (TU)

- Residual CU, QuadTree recursively split into TUs
- TUs of following sizes (no 64x64 TU)
  - 32x32
  - 16x16
  - 8x8
  - 4x4
- Chroma TU of 1/4 th size of luma TU but smallest
  TU for chroma is 4x4 (no 2x2 TUs for chroma)
- TU of size 4x4 flagged by coded/not coded
- DCT Transform on all TU sizes (32x32, 16x16, 8x8, 4x4)
- DST Transform on size 4x4 TU

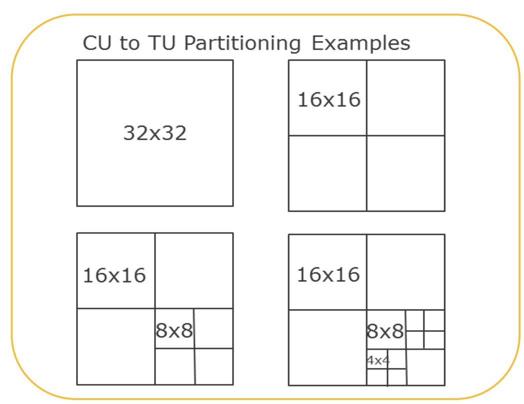

Figure 2D Partitioning of a CU into TUs

Intra Coded PU

- Each Intra Coded PU
    - Pred mode for Luma
    - Pred mode for Chroma
- All TUs in a PU use the same mode
- For Luma candidate choices for prediction mode
    - Planar
    - DC
    - 33 Angular Pred Directions
- For Chroma candidate choices for prediction mode
    - Planar
    - DC
    - Hor
    - Vert
    - Luma pred mode copy

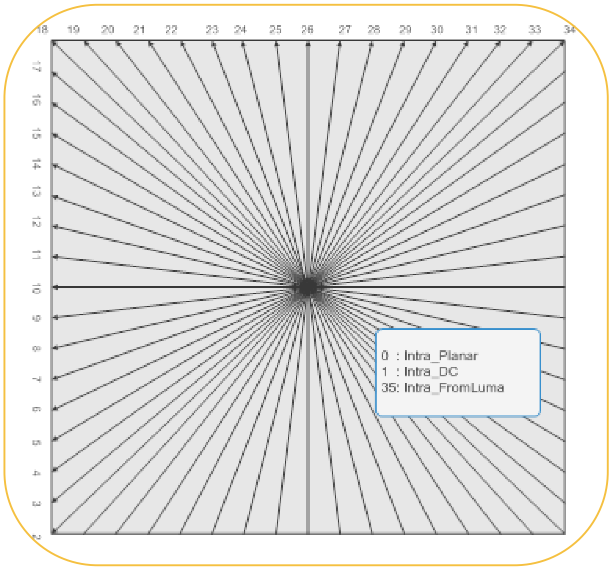

Figure 2E Intra Luma prediction directions

Inter Coded PU

- Motion Pars specified explicitly or implicitly
    - Motion vector
    - Ref Picture Index
    - Picture List Usage Flag

- For inter coded CU with PredMode=Skip, CU coded with no transform coeff, or motion vector, and ref picture flag, and ref picture list usage obtained by motion merge.

- For inter coded CU with PredMode=Inter, either use Motion merge or explicit motion pars

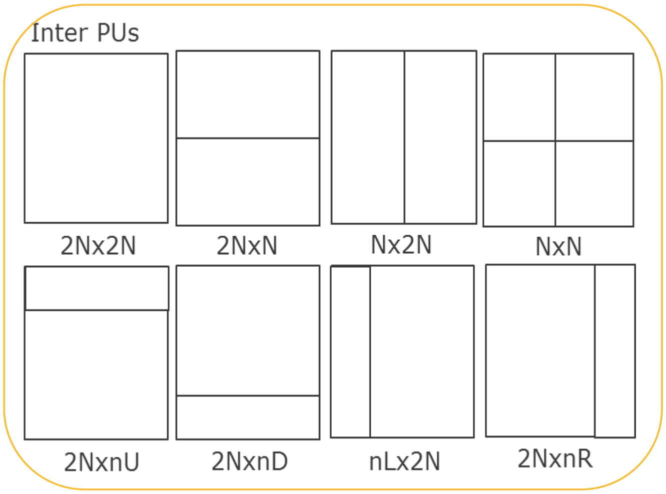

Figure 2F Inter Coded PU Partitionings

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Motion Merge

- Spatial Merge Candidates
  - 5 positions
  - Select 4 Candidates
  - Remove Partition Redundancy
- Temporal Merge Candidates
  - 2 positions
  - Select 1 candidate
- Merge Process
  - Remove duplicates from Spatial and Temporal Candidates
  - Add combined Bi-predicitve candidates
  - Add nonscaled bi-predictive candidates
  - Add zero merge candidates
  - Final merge candidates

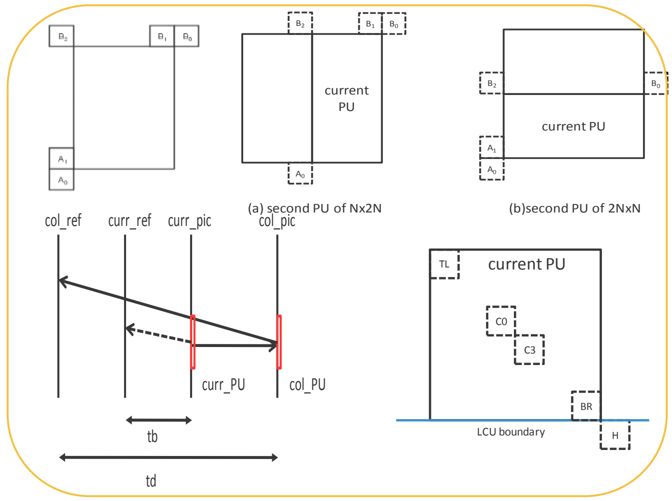

Figure 3A Spatial Merge candidates position, position of second PU of Nx2N, and 2NxN, MV scaling of temporal merge, coding of spatial merge, Temporal Merge candidates C3 and H

Transforms

- 4x4 integer DST approx. Size 4 basis matrix shown on right.
- 4x4 integer DCT approx. Size 4 basis matrix shown on right.
- 8x8 integer DCT approx. Size 8 basis matrix shown on right.
- 16x16 integer DCT approx. Size 16 basis matrix shown on right.
- 32x32 ineger DCT approx. Size 32 basis matrix not shown.

29	55	74	84
74	74	0	-74
84	-29	-74	55
55	-84	74	-29

64	64	64	64
83	36	-36	-83
64	-64	-64	64
36	-83	83	-36

64	64	64	64	64	64	64	64
89	75	50	18	-18	-50	-75	-89
83	36	-36	-83	-83	-36	36	83
75	-18	-89	-50	50	89	18	-75
64	-64	-64	64	64	-64	-64	64
50	-89	18	75	-75	-18	89	-50
36	-83	83	-36	-36	83	-83	36
18	-50	75	-89	89	-75	50	-18

64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64
90	87	80	70	57	43	25	9	-9	-25	-43	-57	-70	-80	-87	-90
89	75	50	18	-18	-50	-75	-89	-89	-75	-50	-18	18	50	75	89
87	57	9	-43	-80	-90	-70	-25	25	70	90	80	43	-9	-57	-87
83	36	-36	-83	-83	-36	36	83	83	36	-36	-83	-83	-36	36	83
80	9	-70	-87	-25	57	90	43	-43	-90	-57	25	87	70	-9	-80
75	-18	-89	-50	50	89	18	-75	-75	18	89	50	-50	-89	-18	75
70	-43	-87	9	90	25	-80	-57	57	80	-25	-90	-9	87	43	-70
64	-64	-64	64	64	-64	-64	64	64	-64	-64	64	64	-64	-64	64
57	-80	-25	90	-9	-87	43	70	-70	-43	87	9	-90	25	80	-57
50	-89	18	75	-75	-18	89	-50	-50	89	-18	-75	75	18	-89	50
43	-90	57	25	-87	70	9	-80	80	-9	-70	87	-25	-57	90	-43
36	-83	83	-36	-36	83	-83	36	36	-83	83	-36	-36	83	-83	36
25	-70	90	-80	43	9	-57	87	-87	57	-9	-43	80	-90	70	-25
18	-50	75	-89	89	-75	50	-18	-18	50	-75	89	-89	75	-50	18
9	-25	43	-57	70	-80	87	-90	90	-87	80-	70	57	-43	25	-9

Figure 3B Transform basis matrices

Interpolation Filter

- Luma
  - ¼ pel interpolation
  - 7/8 tap filter
- Chroma
  - 1/8 pel interpolation
  - 4 tap filter

Position	Filter coefficients
1/4	-1, 4, -10, 58, 17, -5, 1
2/4	-1, 4, -11, 40, 40, -11, 4, -1
3/4	1, -5, 17, 58, -10, 4, -1

Position	Filter coefficients
1/8	-2, 58, 10, -2
2/8	-4, 54, 16, -2
3/8	-6, 46, 28, -4
4/8	-4, 36, 36, -4
5/8	-4, 28, 46, -6
6/8	-2, 16, 54, -4
7/8	-2, 10, 58, -2

Figure 3C 4-tap DCT/IF Luma Filter, and 8 tap

Deblock Filtering

- Overall Process
- Boundary strength calculation
  - Based on if P or Q is intra, P or Q has nonzero coef, Pand Q have different ref, P and Q have different num of MVs..
  - 3 levels of strength 0, 1, 2
- Threshold value β and Tc calculation from input Q
- Filter on/off Decision

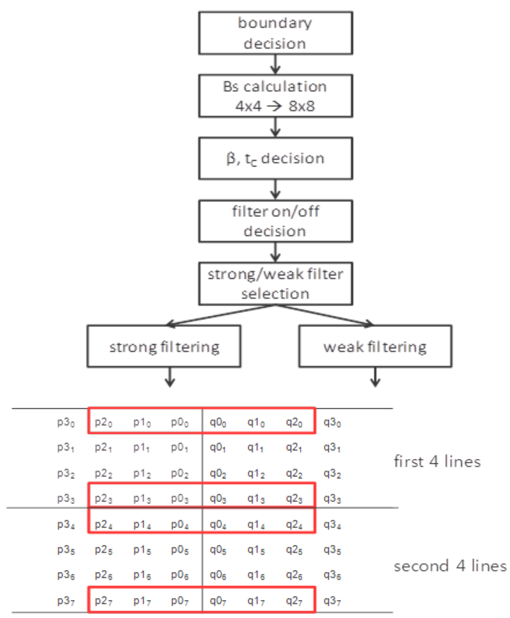

Figure 3D Deblock filterign in HEVC

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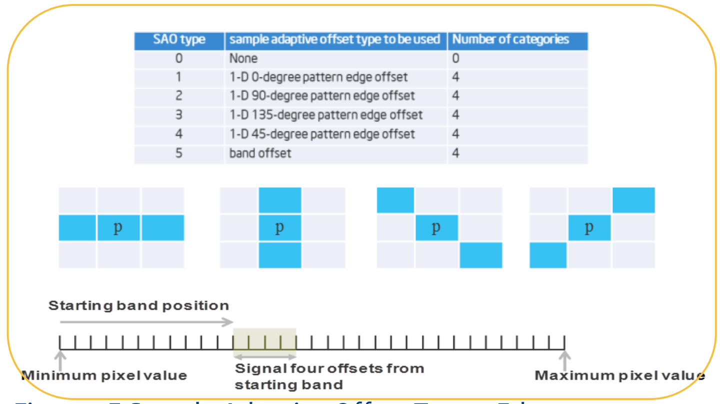
Sample Adaptive Offset (SAO)

- Applied to reconstructed video
- SAO Types
- Details of how SAO Types work
  - 3 pel patterns for pixel classification in Edge Offset
  - Pixel Classification Rules for Edge Offset
  - Grouping 4 bands and Representation



SAO type	sample adaptive offset type to be used	Number of categories
0	None	0
1	1-D 0-degree pattern edge offset	4
2	1-D 90-degree pattern edge offset	4
3	1-D 135-degree pattern edge offset	4
4	1-D 45-degree pattern edge offset	4
5	band offset	4

Figure 3E Sample Adaptive Offset Types, Edge Classification, and Grouping of Bands

HEVC Encoder

Figure 4 shows high level block diagram of HEVC Encoder. Input video frames are partitioned recursively from CTB's to CUs and then nonrecursively into PUs. The prediction partition PUs are then combined to generate Prediction CUs that are differenced from the original resulting in residual CU's that are recursively QT split into TUs and coded with variable Block Size (VBS) transform of 4x4 (DST or DCT approx), or 8x8, 16x16, and 32x32 (DCT approx only). CU/PU Partitioner partitions into CU/PU, and the TU partitioner partitions into TUs. An Encode Controller controls the degree of partitioning performed which depends on quantizer used in transform coding. The CU/PU Assembler and TU Assembler perform the reverse function of partitioner. The decoded (every DPCM encoder incorporates a decoder loop) intra/motion compensated difference partitions are assembled following inverse DST/DCT to which prediction PUs are added and reconstructed signal then Deblock, and SAO Filtered that corespondingly reduce appearance of artifacts and restore edges impacted by coding.

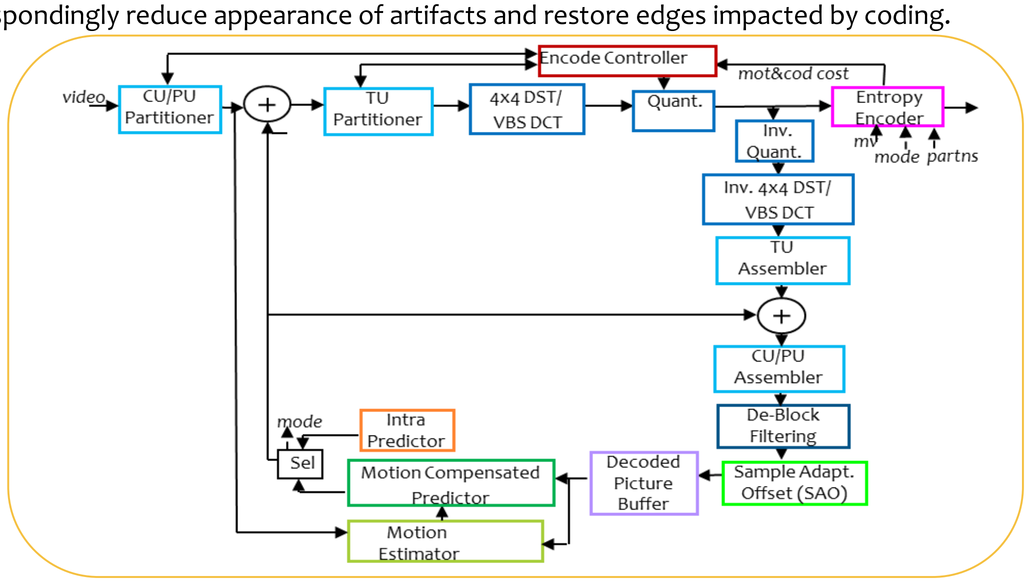


Figure 4 HEVC Encoder

Intel® Media SDK, and Media Tools Overview

The Intel® Media SDK allows developers to enable next generation media applications that empower their end-users with a great experience in creating, editing and consuming media content on Intel® Processors and Graphics.

While Intel Media SDK is designed to be a flexible solution for many media workloads, it focuses only on the media pipeline components which are commonly used and usually the most in need of acceleration, such as follows.

- Decoding from video elementary stream formats (H.264, MPEG-2, VC-1, and JPEG/Motion JPEG) to uncompressed frames
- Selected video frame processing operations
- Encoding uncompressed frames to elementary stream formats (H.264, MPEG-2)

The Intel® Media SDK optimized media libraries are built on top of Microsoft* DirectX*, DirectX Video Acceleration (DVXA) APIs, and platform graphics drivers. Intel Media SDK exposes the hardware acceleration features of Intel® Quick Sync Video built into 2nd and all following generations of Intel® Core™ processors.

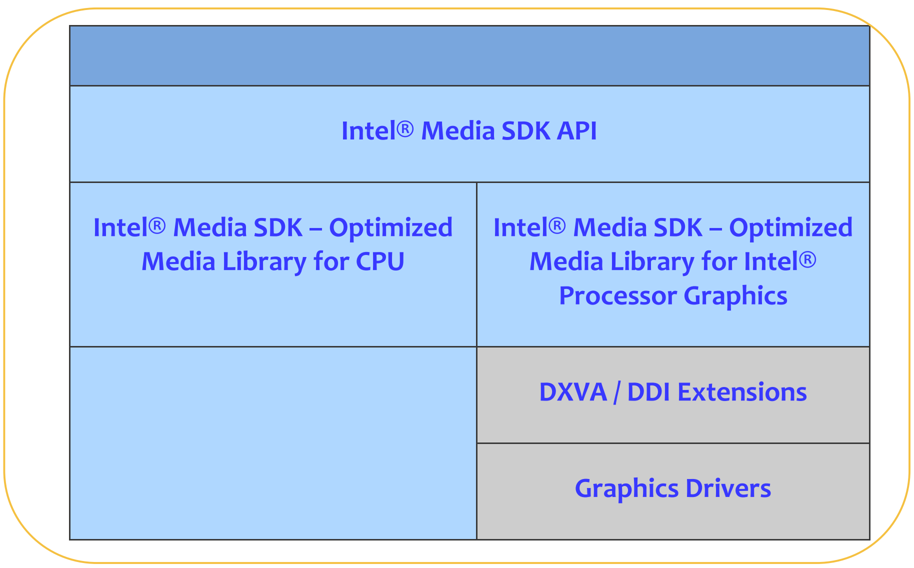


Figure 5A Intel® Media SDK Application stack

Additional Features of Media SDK 2013 consist of:

- MPEG-2: Full Hardware MPEG-2 Encode leveraging 4th Gen Processors
- JPEG: Support for MJPEG /JPEG. Decode Hardware accelerated on 4th Gen Processors
- H.264: (1) 4K Encode, (2) Rolling I-frames, (3) Macroblock Bitrate Control, (4) Lookahead Bit Rate Control, (5) Trellis Quantization
- VPP: (1) Image Stabilization, (2) Advanced Frame Rate Conversion
- System: DTS computation

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Intel® Media SDK 2014

Intel® Media SDK 2014 adds new codecs and other features to the last year's version, Media SDK 2013. It is available in two flavors:

(1) Media SDK for Windows 2014

(2) Media SDK for Linux Servers 2014

Figure 5B shows a high level architecture stack of Media SDK for Windows 2014. In this stack Intel® Media SDK API is shown as a layer above the software libraries, and the Hardware DLLs for fixed function hardware/Execution Unit (EU) based acceleration which is the layer above Graphics Drivers. Media SDK Applications, Production Media Foundation Transforms (MFTs), Audio Library, and plug-ins (Intel® HEVC Software Encoder/Decoder, and 3rd party HEVC and others) represent the layer above Intel® Media SDK API, above which resides the MFT Applications layer.

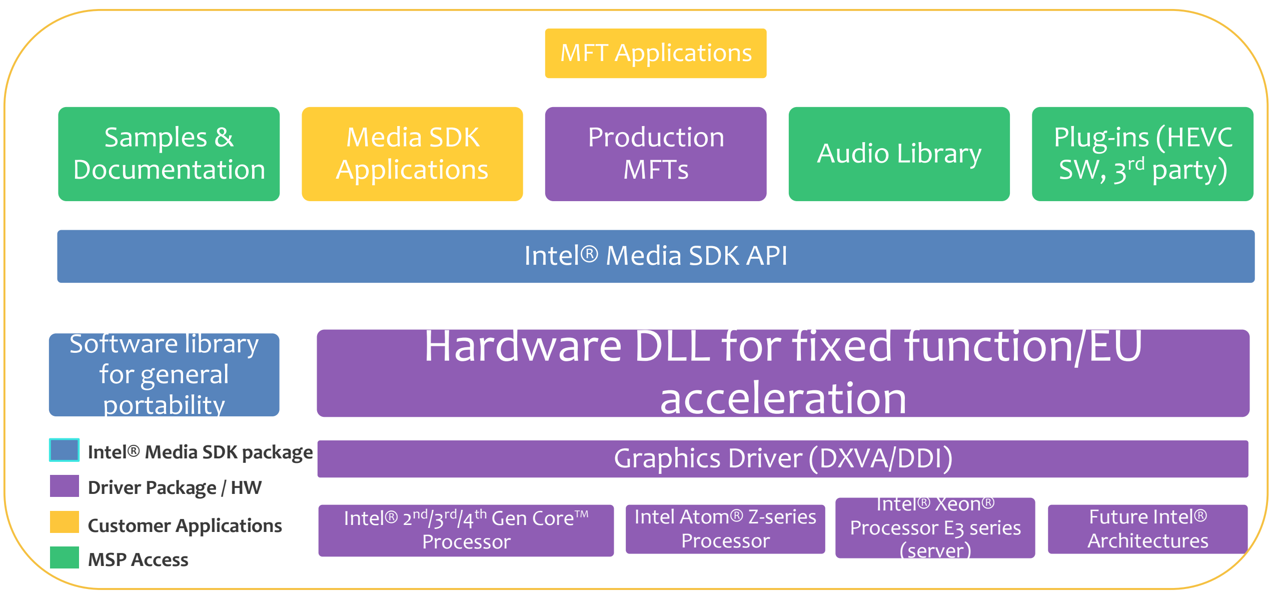


Figure 5B High level Architecture Intel® Media SDK for Windows 2014

New Features of Media SDK for Windows 2014 consist of:

- HEVC: HEVC Software Encode and HEVC Software Decode as separate plugin via Media Solutions Portal (MSP).
- H.264: (1) Improved Encode quality and BRC, (2) Region of Interest Encoding, (3) Adaptive Picture types, Look ahead and others.
- VPP: (1) Frame composite API, (2) Deinterlacer choices: Bob or Advanced.
- System: Splitter/Muxer support for MPEG-2 TS, and MPEG-4.
- Paid plug-ins or Tools available at MSP.

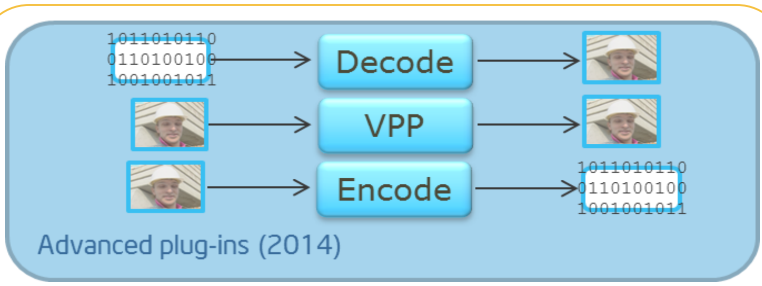
A complete list of all components and features of Media SDK 2014 is summarized in Figure 5C.

Video Encoders	All: H.264(AVC), MPEG-2, MVC, H.265(HEVC) Windows Only: MJPEG Rate Control: CBR, VBR, CQP, LA, ICQ, ICQ-LA, VCM, AVBR(Windows only)
Video Decoders	All: H.264(AVC), MPEG-2, VC-1, MVC, H.265(HEVC) Windows Only: MJPEG
Video Processing (VPP) Filters	All: Deinterlace, Resize/Crop, Color Conversion, Denoising, Frame Rate Conversion, Composition Windows Only: ProcAmp(Brightness, Contrast, Hue, Saturation Control), Sharpening, Image Stabilization
Supported OS	Microsoft* Windows* 8/8.1 (Desktop, Modern UI via MFT) Microsoft* Windows* 7 (and Vista* for older Media SDK releases/Drivers) Microsoft* Windows Server 2012 (Windows* 8+ or Windows Server 2012 required for DX11 support) Ubuntu* 12.04 LTS (64 bit) (to be changed to CentOS v7 in 2014) SUSE Linux Enterprise Server* (SLES) 11.3 (64 bit)
IDE/Build	Windows: Visual Studio 2005 – 2012 Linux: Build autogeneration via cmake: Makefile, Eclipse, CodeBlocks
Misc.	MSP: Audio libraries, tools, sample code, plug-ins (HEVC and 3rd party) Windows Client Only: Media Foundation Transforms, DirectShow filters, Custom User-defined Filters, Stereoscopic 3D control library, Protected Content Development Package (PCDP)**

Figure 5C List of Features of Intel® Media SDK & Intel® Media Solutions Portal (MSP)

Choices and Flexibility

The advanced plug-in architecture of Media SDK 2014 offers a choice of plug-ins for key codecs and other functionalities while ensuring that the plugins work robustly and efficiently in a well-designed environment.



The plug-in architecture supports

- Plug-ins for Video Frame Processing: (1) Extends Pipeline, (2) Replaces with Custom Processing
- Intel® Plug-ins: (1) HEVC Software Encode and Decode, (2) VP8 Software Decode
- Third Party Plug-ins

The plug-in architecture adds considerable flexibility, such as with multiple vendors offering plugins for HEVC Codec, a developer will have a choice of acquiring and selecting the best plugin for their needs.

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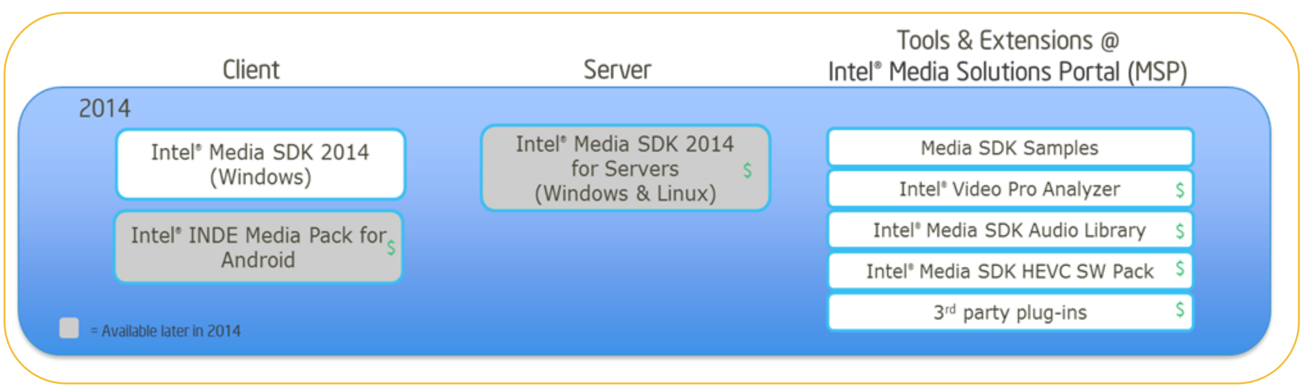
New Media Codecs and Tools Offerings

- Intel® Media SDK HEVC Software Pack *(paid for plug-in available from Intel at MSP)*
  - The Media SDK HEVC Software Pack includes multithreaded HEVC Encoder and HEVC Decoder capable of running on up to 8 threads. The Encoder and Decoder are up to SSE4 and AVX2 optimized for Intel Core™, and Atom™ platforms.
  - The HEVC Software Decoder is capable of real time decode of HEVC 4K encoded streams on an Intel® Core ™ Haswell CPU 2 - 3.5 GHz, 4 Cores.
  - The HEVC Software Encoder supports a range of coding modes with the slowest mode allowing quality visually similar to HEVC HM and the fastest mode allowing up to 4.5 frames/sec encoding of HD1080p on the aforementioned Haswell system.
  - The HEVC Software Decoder supports HEVC Main Profile 8 bits, Level 1.0 to 6.2.
- Intel® Video Pro Analyzer *(paid for Tool available from Intel at MSP)*
  - HEVC and VP9 Codec Bitstream Visual Analysis Tool
- Intel® Media SDK Audio Library *(paid for plug-in available from Intel at MSP)*
  - Architecture very similar to Media SDK video APIs
- Muxer/Splitter *API*
  - MPEG TS and MPEG-4 container formats supporting MPEG-2, H.264, AAC, MP3
- *Intel INDE Media Pack for Android*
  - *Media Classes to enable Video Editing*
  - *Media Classes to enable Game Capture*
- *Media Debugging and Performance Analysis Tools*
  - Media SDK System Analyzer Tool
  - Media SDK Tracer Tool
- *Intel Graphics Performance Analyzer*
  - Tool for Analysis of media workloads

A GPU assisted HEVC Hybrid Decoder, as well as performance optimized HEVC Encoder will follow later in 2014.

Summary of Media SDK 2014



Intel® Media SDK HEVC Software Codec Quality

In this section we first describe a test methodology employed for evaluating quality and then report on relative quality measurements for the Media SDK HEVC Codec with respect to MPEG HEVC HM13 Codec, well known as a high quality reference albeit impractically slow.

Quality Evaluation Tests

For the purpose of quality evaluation, four test sets, one for each of the 4 main resolutions each consisting of 6 publicly available challenging video test sequences, are standardized along with 4 quantizer (Qp) values used for measuring the rate distortion characteristics of a codec. For each sequence, 4 well-spaced Qp quantizer values (but avoiding extreme values of Qp) are determined such that HEVC encoding generates bit-rates in a suitable range.

Wherever possible, test sequences that are available in multiple resolutions are included in the test set such that behavior of codec over multiple resolutions can be tracked.

Specifically, Table 1A shows selected Ultra Definition 4K (UHD4K) test set, Table 1B shows High Definition 1080p (HD1080p) test set, Table 1C shows High Definition 720p (HD720p), and Table 1D shows Standard and Extended Standard Definition (SD/XD) test set.

Table 1A **UHD4K** Test Set and Quantizers used for Codec RD characteristics measurement

No.	Sequence	Resolution	fps	#frm	Qp1	Qp2	Qp3	Qp4
1	Park_joy_3840x2160_50	3840x2160	50	500	26	29	33	37
2	Ducks_take_off_3840x2160_50	3840x2160	50	500	28	31	35	37
3	Crowd_run_3840x2160_50	3840x2160	50	500	26	30	34	38
4	PeopleOnStreet_3840x2160_30	3840x2160	30	150	22	27	32	37
5	Traffic_3840x2048_30	3840x2048	30	300	18	22	26	30
6	NebutaFestival_2560x1600_60	2560x1600	60	300	30	33	36	39

Of the sequences referred to in Table 1A, Park_Joy_3840x2160, Ducks_take_off_3840x2160 and Crowd_run_3840x2160 sequences can be obtained from http://media.xiph.org/video/derf/ while PeopleOnStreet_3840x2160, Traffic_3840x2048, and NebutaFestival_2560x1600 are MPEG HEVC test sequences can be obtained from ftp://hvc:US88Hula@ftp.tnt.uni-hannover.de/testsequences .

Table 1B **HD1080p** Test Set and Quantizers used for Codec RD characteristics measurement

No.	Sequence	Resolution	fps	#frm	Qp1	Qp2	Qp3	Qp4
1	Park_joy_1920x1080_50	1920x1080	50	500	26	29	33	37
2	Ducks_take_off_1920x1080_50	1920x1080	50	500	28	31	35	37
3	Crowd_run_1920x1080_50	1920x1080	50	500	26	30	34	38
4	TouchDownPass_1920x1080_30	1920x1080	30	570	23	26	30	34
5	BQTerrace_1920x1080_60	1920x1080	60	600	25	27	31	34
6	ParkScene_1920x1080_24	1920x1080	24	240	23	26	29	32

*Other names and brands may be claimed as property of others.

Of the sequences referred to in Table 1B, Park_Joy_1920x1080, Ducks_take_off_1920x1080, Crowd_run_1920x1080 and TouchDownPass_1920x1080 sequences can be obtained from http://media.xiph.org/video/derf/ while BQTerrace_1920x1080 and ParkScene_1920x1080 are standard MPEG HEVC test sequences and can be obtained from ftp://hvc:US88Hula@ftp.tnt.uni-hannover.de/testsequences .

Table 1C **HD720p** Test Set and Quantizers used for Codec RD characteristics measurement

No.	Sequence	Resolution	fps	#frm	Qp1	Qp2	Qp3	Qp4
1	Park_joy_1280x720_50	1280x720	50	500	26	29	33	37
2	Ducks_take_off_1280x720_50	1280x720	50	500	28	31	35	37
3	Crowd_run_1280x720_50	1280x720	50	500	26	30	34	38
4	City_1280x720_30	1280x720	30	300	22	24	27	29
5	Crew_1280x720_30	1280x720	30	300	22	26	29	32
6	Sailormen_1280x720_30	1280x720	30	300	24	26	28	30

Of the sequences referred to in Table 1C, Park_Joy_1280x720, Ducks_take_off_1280x720, and Crowd_run_1280x720 sequences can be obtained from http://media.xiph.org/video/derf/ while City_1280x720, Crew_1280x720, and Sailormen_1280x720 are MPEG SVC test sequences with limited public distribution (but can be made available on request).

Table 1D **SD/XD** Test Set and Quantizers used for Codec RD characteristics measurement

No.	Sequence	Resolution	fps	#frm	Qp1	Qp2	Qp3	Qp4
1	BasketBallDrillText_832x480_50	832x480	50	500	21	24	27	30
2	PartyScene_832x480_50	832x480	50	500	24	27	30	33
3	RaceHorses_832x480_30	832x480	30	300	24	27	30	33
4	City_704x576_30	704x576	30	300	22	24	26	28
5	Crew_704x576_30	704x576	30	300	22	25	28	31
6	Soccer_704x576_30	704x576	30	300	22	25	28	31

Of the sequences referred to in Table 1D, BasketBallDrillText_832x480, PartyScene_832x480, and RaceHorses_832x480 are standard MPEG HEVC test sequences that can be obtained from ftp://hvc:US88Hula@ftp.tnt.uni-hannover.de/testsequences while City_704x576, Crew_704x576, and Soccer_704x576 can be obtained from ftp://ftp.tnt.unihannover.de/pub/svc/testsequences/.

To measure quality of an HEVC codec while many techniques such as peak signal-to-noise ratio (PSNR), structural similarity index (SSIM), other objective quality metrics, or even full Subjective quality tests, in our own competitive quality assesment tests we have found results of most such measures to be fairly consistent with each other as long as codecs are compared in a constant quantizer mode, eliminating dependence on different types of bit rate control (BRC) techniques.

We now briefly describe a statstically tractable technique to compare video quality produced by the codec being tested as compared to the reference codec. Rate Distortion (RD) characteristics for both the codecs are computed using each codec's 4-point PSNR/Bitrate measurements followed by application of MPEG's new BDrate ([5]) curve fitting procedure that generates a continuous RD curve that tightly fits the measured points. A single measurement of 'goodness' of the codec being tested against the reference codec in the form of BDrate is then computed that reflects percentage difference between the codecs. The BDrate percentage difference if positive means that the codec being tested is worse in quality, that is it costs 'x' percentage more bits to generate the same PSNR quality as the reference. The BDrate difference measurement procedure allows a straightforward way of computing and independently verifying quality of codec with respect to a reference codec.

Quality Evaluation Results

A video sequence undergoing testing is encoded with both the MPEG HEVC HM13 Software Reference Encoder, as well as Media SDK HEVC Software Encoder (in its 3 main modes TU1, TU4, and TU7). For each codecs (and for each of the modes of Media SDK HEVC) encoding is performed using 4 well spaced suitable constant Qps for each sequence as shown in Tables 1A-1D. For each codec and mode, for each of 4 constant Qps, the bitrates and PSNRs are noted and are used for BDrate curve fitting to generate a continuous curve.

A single BDrate difference for Media SDK HEVC codec in each of 3 modes is then calculated with respect to the HEVC HM13 reference, and provides a measure of departure of the Media SDK Codec and its modes in percentage bits with respect to this reference.

In Table 2A-2D, we show the measured BDrate percentage bitrate difference results for each sequence of Table 1A-1D (together comprising the four aforementioned test sets). The percentage BDrate difference shown in this table is for TU1 Mode (the highest quality mode) of Media SDK. Also, in Fig. 6A-6D we show the corresponding RD characterstics differences between the two Codecs for the cases where the difference in quality is the highest and the lowest for each test set.

Table 2A Quality Evaluation Results on **UHD4K** test set for Intel® Media SDK HEVC Software Codec (**TU1** and **TU4** modes) with respect to MPEG HEVC HM13 Codec

No.	Sequence	MSDK TU1 mode BDrate (percentage)			MSDK TU4 mode BDrate (percentage)		
		Y	U	V	Y	U	V
1	Park_joy_3840x2160_50	5.88	22.34	19.79	29.37	31.53	44.36
2	Ducks_take_off_3840x2160_50	10.30	63.30	108.67	31.97	8.68	74.58
3	Crowd_run_3840x2160_50	6.96	41.05	42.12	27.10	57.73	63.90
4	PeopleOnStreet_3840x2160_30	3.96	22.59	33.52	21.14	69.28	88.40
5	Traffic_3840x2048_30	5.21	20.81	14.11	29.02	49.72	53.44
6	NebutaFestival_2560x1600_60	4.18	104.70	98.30	80.04	28.48	17.65
	Average	**6.08**	**45.80**	**52.75**	**36.44**	**40.90**	**57.05**

As can be observed from Table 2A that on the UHD4K test set, the average BDrate percentage difference of luma of Media SDK HEVC Codec in TU1 mode is around 6% and in TU4 mode is around 36% over MPEG HEVC HM13, an ideal reference that is around 20 times slower (shown in next section). This means that for UHD4K test set, the Media SDK codec in TU1 mode requires 6% higher bits, and in TU4 requires 36% higher bits to achieve the same luma PSNR quality as HM13.

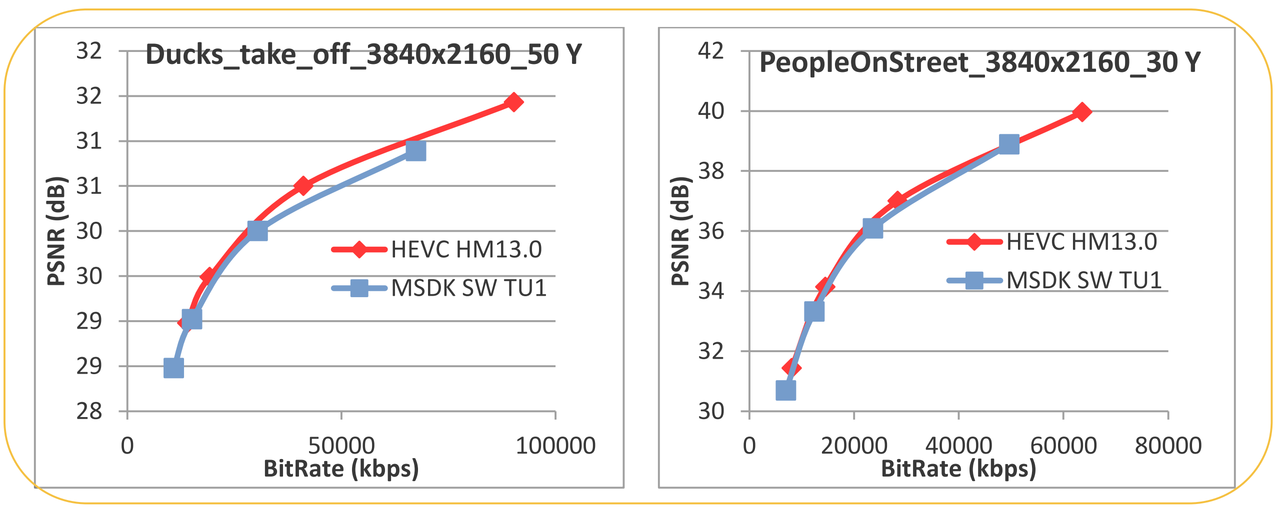


Figure 6A1 RD results of UHD4K scenes with the biggest and the smallest quality difference wrt HM13 for MSDK TU1 mode

Next, Fig 6A1 shows that Media SDK HEVC Codec in TU1 mode results in the highest BDrate percentage difference on *Ducks_take_off_3840x2160_50* sequence and the lowest BDrate percentage difference on *PeopleOnStreet_3840x2160_30* sequence, with respect to HM13 reference.

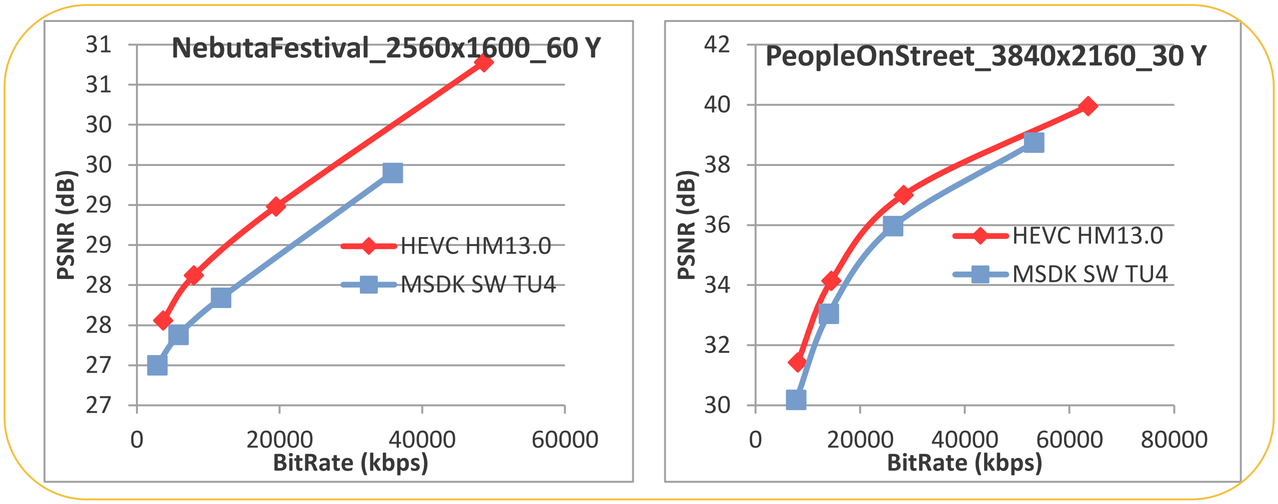


Figure 6A2 RD results of UHD4K scenes with the biggest and the smallest quality difference wrt HM13 for MSDK TU4 mode

Fig 6A2 shows that Media SDK HEVC Codec in TU4 mode results in the highest BDrate percentage difference on *NebutaFestival_2560x1600_60* sequence and the lowest BDrate percentage difference on *PeopleOnstreet_3840x2160_30* sequence, with respect to HM13 reference.

Table 2B Quality Evaluation Results on **HD1080p** test set for Intel® Media SDK HEVC Software Codec (**TU1** and **TU4** modes) with respect to MPEG HEVC HM13 Codec

No.	Sequence	MSDK TU1 mode BDrate (percentage)			MSDK TU4 mode BDrate (percentage)		
		Y	U	V	Y	U	V
1	Park_joy_1920x1080_50	4.75	18.54	27.40	26.63	34.45	52.31
2	Ducks_take_off_1920x1080_50	7.24	35.97	56.38	24.82	18.89	79.29
3	Crowd_run_1920x1080_50	5.56	36.52	39.75	27.93	62.96	67.22
4	TouchDownPass_1920x1080_30	4.83	42.89	57.00	36.71	91.41	105.65
5	BQTerrace_1920x1080_60	9.17	19.96	38.42	52.98	70.56	113.78
6	ParkScene_1920x1080_24	4.71	8.67	9.03	26.50	45.67	46.75
	Average	**6.04**	**27.09**	**37.99**	**32.59**	**53.99**	**77.50**

Table 2B shows similar BDrate percentage differences on the HD1080p test set. The average BDrate percentage difference for luma of Media SDK HEVC Software Codec in TU1 mode is around 6% and in TU4 mode is around 32% over HM13.

*Other names and brands may be claimed as property of others.

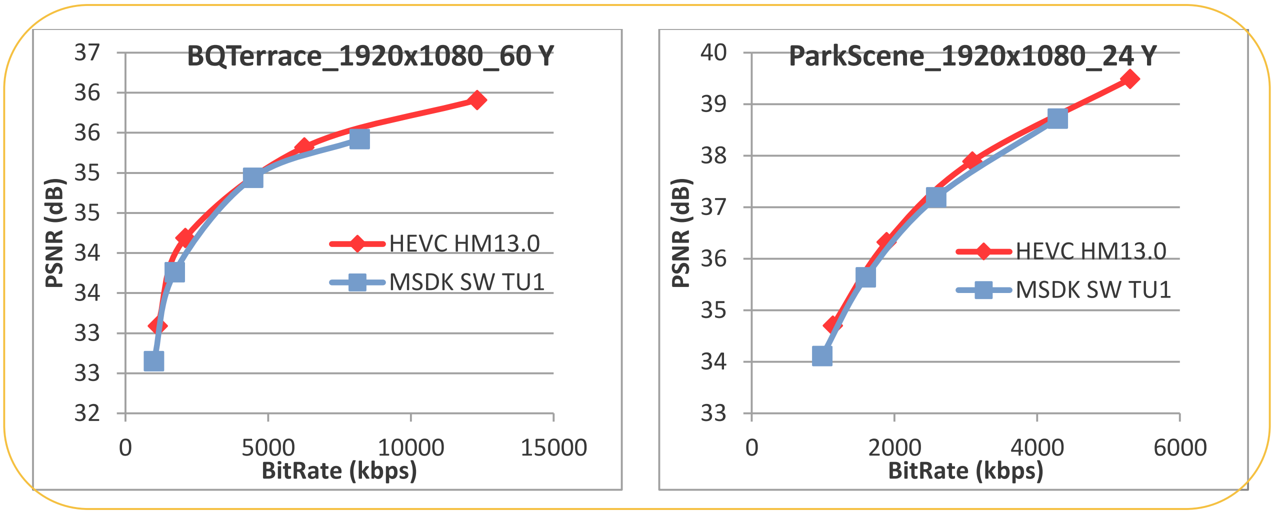


Figure 6B1 RD results of 1080p scenes with the biggest and the smallest quality difference wrt HM13 for MSDK TU1 mode

Further, Fig. 6B1 shows that for HD1080p test set, Media SDK HEVC Software Codec in TU1 mode results in the highest BDrate percentage difference on *BQTerrace_1920x1080_60* sequence and the lowest BDrate percentage difference on *ParkScene_1920x1080_24* sequence, with respect to HM13.

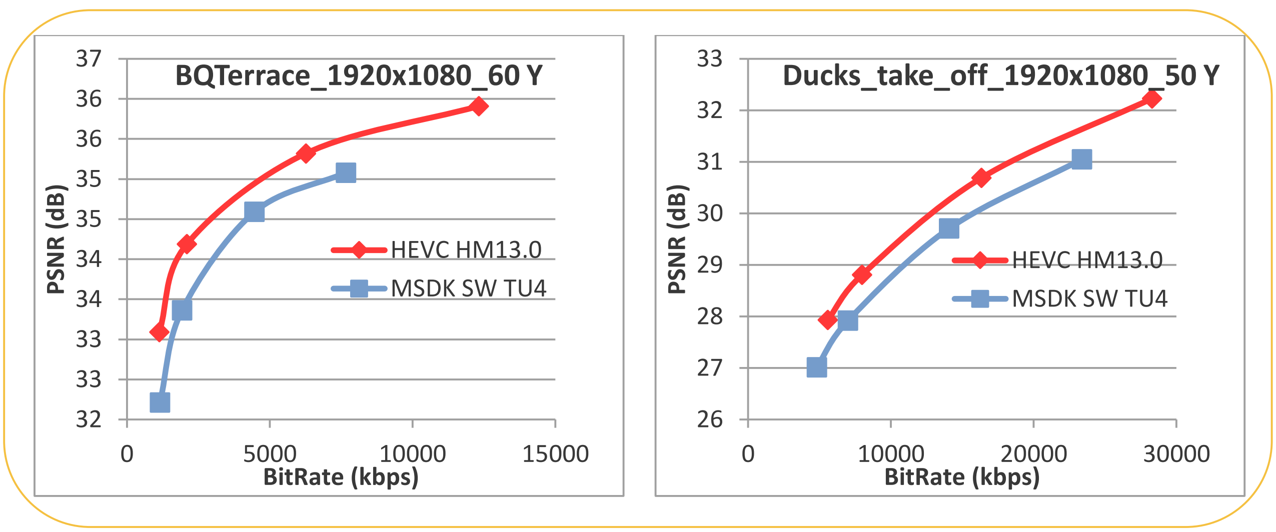


Figure 6B2 RD results of 1080p scenes with the biggest and the smallest quality difference wrt HM13 for MSDK TU4 mode

Fig. 6B2 shows that for HD1080p test set, Media SDK HEVC Software Codec in TU4 mode results in the highest BDrate percentage difference on *BQTerrace_1920x1080_60* sequence and the lowest BDrate percentage difference on *Ducks_take_off_1920x1080_50* sequence, with respect to HM13.

Table 2C Quality Evaluation Results on **HD720p** test set for Intel® Media SDK HEVC Software Codec (**TU1** and **TU4** modes) with respect to MPEG HEVC HM13 Codec

No.	**Sequence**	**MSDK TU1 mode BDrate (percentage)**			**MSDK TU4 mode BDrate (percentage)**		
		Y	**U**	**V**	**Y**	**U**	**V**
1	Park_joy_1280x720_50	4.86	17.44	35.65	25.89	34.79	53.97
2	Ducks_take_off_1280x720_50	6.83	30.76	58.52	24.40	30.61	93.75
3	Crowd_run_1280x720_50	5.16	35.89	39.01	28.66	64.13	68.39
4	City_1280x720_30	6.24	14.14	19.54	31.62	45.82	54.38
5	Crew_1280x720_30	9.96	63.92	44.36	36.08	96.00	76.43
6	Sailormen_1280x720_30	8.38	13.37	11.61	38.31	57.74	77.82
	Average	**6.90**	**29.25**	**34.78**	**30.83**	**54.85**	**70.79**

Next, it can be seen from Table 2C that on the HD720p test set, the average BDrate percentage difference for luma of Media SDK HEVC Software Codec in TU1 mode is around 7% and in TU4 mode is around 31% over HM13.

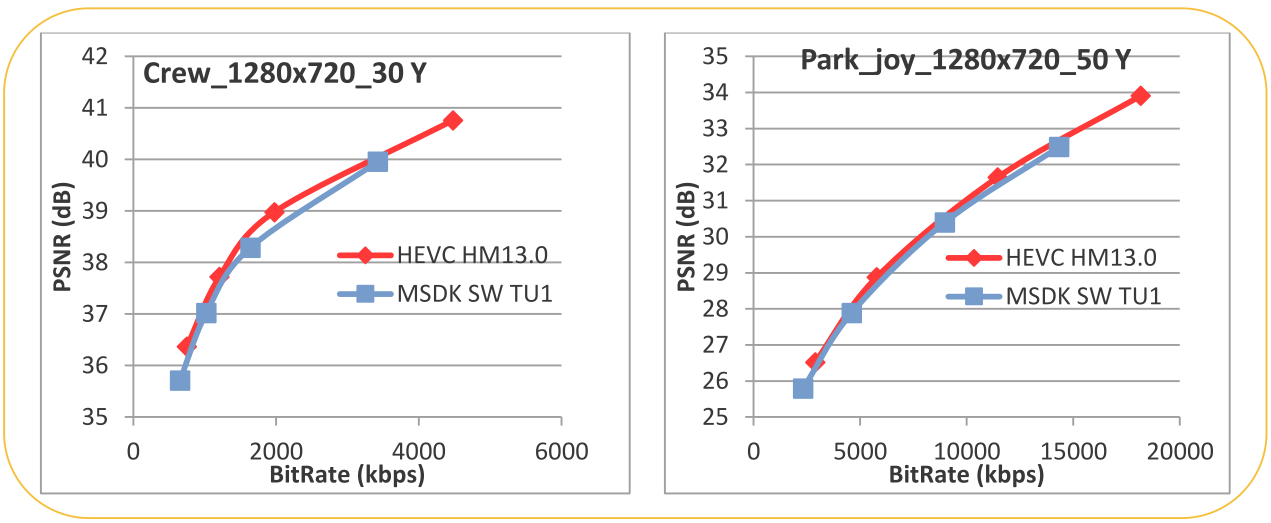


Figure 6C1 RD results of 720p scenes with the biggest and the smallest quality difference wrt HM13 for MSDK TU1 mode

Further, Fig. 6C1 shows that for HD 720p test set, Media SDK HEVC Software Codec in TU1 mode results in the highest BDrate percentage difference on *Crew_1280x720_30* sequence and the lowest BDrate percentage difference on *Park_Joy_1280x720_50* sequence, with respect to HM13.

*Other names and brands may be claimed as property of others.

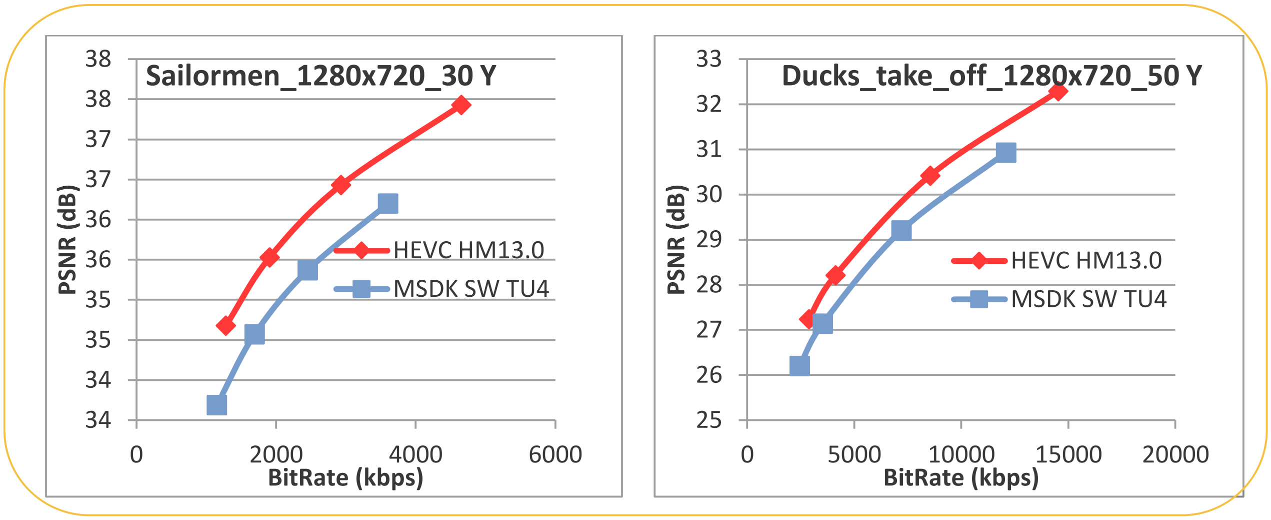


Figure 6C2 RD results of 720p scenes with the biggest and the smallest quality difference wrt HM13 for MSDK TU4 mode

Fig. 6C2 shows that for HD 720p test set, Media SDK HEVC Software Codec in TU4 mode results in the highest BDrate percentage difference on *Sailormen_1280x720_30* sequence and the lowest BDrate percentage difference on *Ducks_take_off_1280x720_50* sequence, with respect to HM13.

Table 2D Quality Evaluation Results on **SD/XD** test set for Intel® Media SDK HEVC Software Codec (**TU1** and **TU4** modes) with respect to MPEG HEVC HM13 Codec

No.	Sequence	MSDK TU1 mode BDrate (percentage)			MSDK TU4 mode BDrate (percentage)		
		Y	U	V	Y	U	V
1	BasketBallDrillText_832x480_50	8.28	36.10	41.13	40.65	107.04	114.71
2	PartyScene_832x480_50	4.16	16.92	18.88	38.16	62.25	65.74
3	RaceHorses_832x480_30	8.15	32.85	49.39	33.38	69.14	88.65
4	City_704x576_30	6.27	5.09	15.92	30.31	39.67	55.87
5	Crew_704x576_30	10.42	54.14	39.63	29.20	82.46	72.34
6	Soccer_704x576_30	3.68	24.44	39.92	28.33	50.28	73.51
	Average	**6.83**	**28.26**	**34.15**	**33.34**	**68.47**	**78.47**

Furthermore, it can be seen from Table 2D that on the SD/XD test set, the average BDrate percentage difference of Media SDK HEVC Codec in TU1 mode is around 7%, and in TU4 mode is 33% over HM13.

Also, Fig. 6D1 shows that the Media SDK HEVC Codec in TU1 mode results in the highest BDrate percentage difference on *Crew_704x576_30* sequence and the lowest BDrate percentage difference on *Soccer_704x576_30* sequence, with respect to HM13.

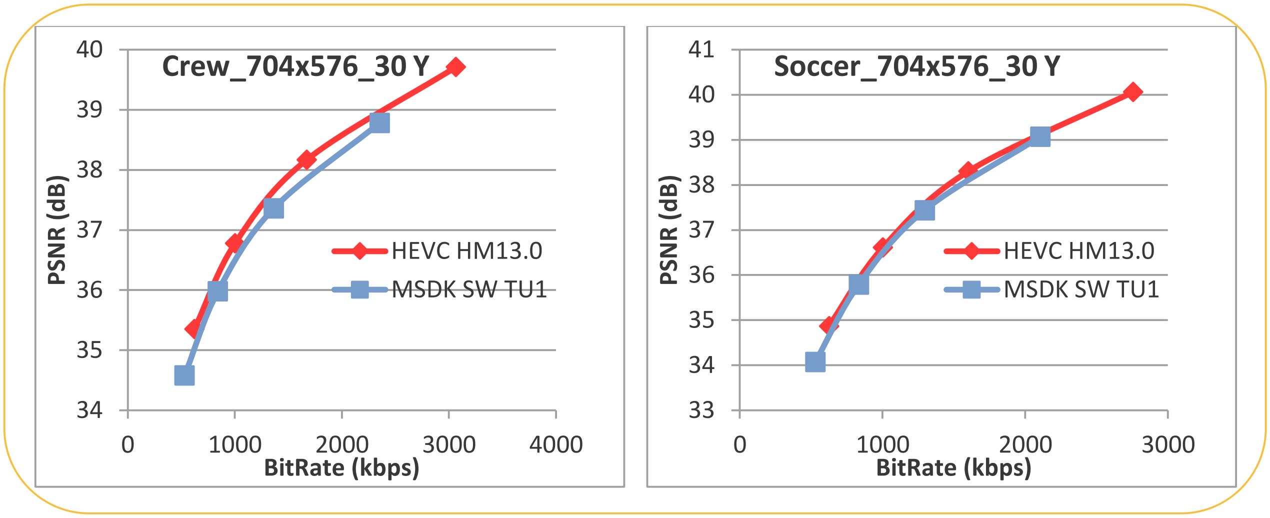


Figure 6D1 RD results of SD/XD scenes with the biggest and the smallest quality difference wrt HM13 for MSDK TU1 mode

Fig. 6D2 shows that the Media SDK HEVC Codec in TU4 mode results in the highest BDrate percentage difference on *BasketBallDrillText_832x480_50* sequence and the lowest BDrate percentage difference on *Crew_704x576_30* sequence, with respect to HM13.

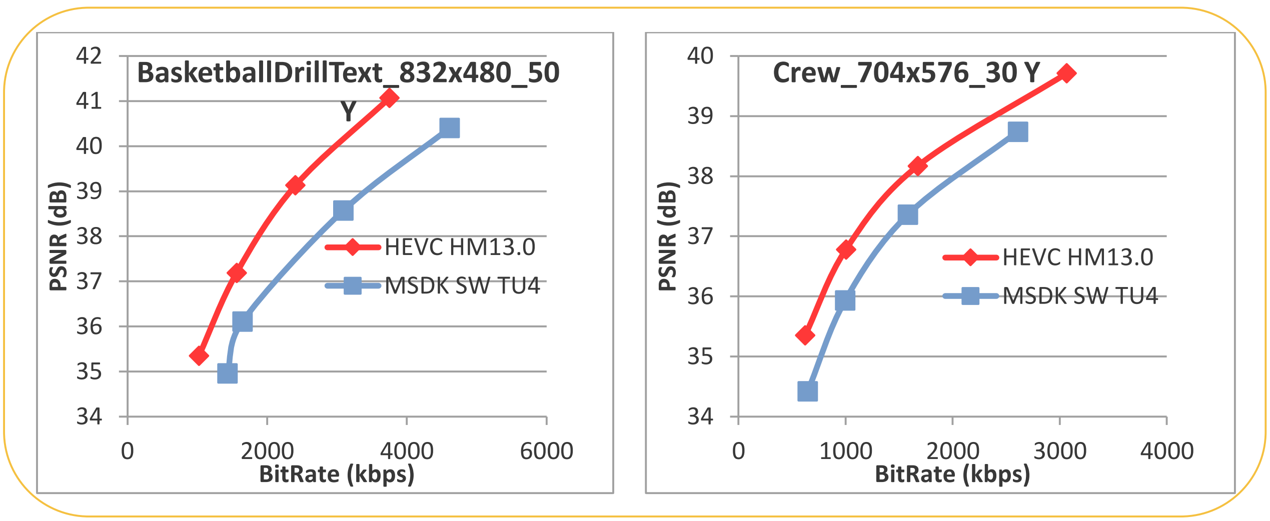


Figure 6D2 RD results of SD/XD scenes with the biggest and the smallest quality difference wrt HM13 for MSDK TU4 mode

To summarize, the BDrate percentage bitrate difference of the MSDK HEVC codec with respect to an ideal (but very slow) HM13 reference shows a difference in TU1 mode of 6-7%, and in TU4 mode of 32-36% on all test sets. This basically means that to achieve the same PSNR quality, the Media SDK HEVC Codec in its highest quality (TU1) mode requires 6-7% higher bitrate, and in TU4 mode it requires 32-36% higher bitrate as compared to HM13 Codec, which relative to TU1 mode is around 18-20 times slower, and with respect to TU4 mode it is 175 to 200 times slower. The speed issue is discussed at length in the next section.

Intel® Media SDK HEVC Encoder Quality vs Performance Tradeoffs

For measurement of encoding speed (fps) and speed vs quality tradeoffs, a recently released reference PC Platform (Intel® Core™ i7-4770K CPU @ 3.5 GHz – 4 Cores/8Threads) is employed.

Intel® Media SDK HEVC Software Encoder Performance

We measure encoding speed (fps) of Media SDK HEVC Software Encoder in TU1 (highest quality) mode and MPEG HEVC HM13 on different resolution test sets. The results of these measurement comparing the two speeds is shown in Fig. 7A.

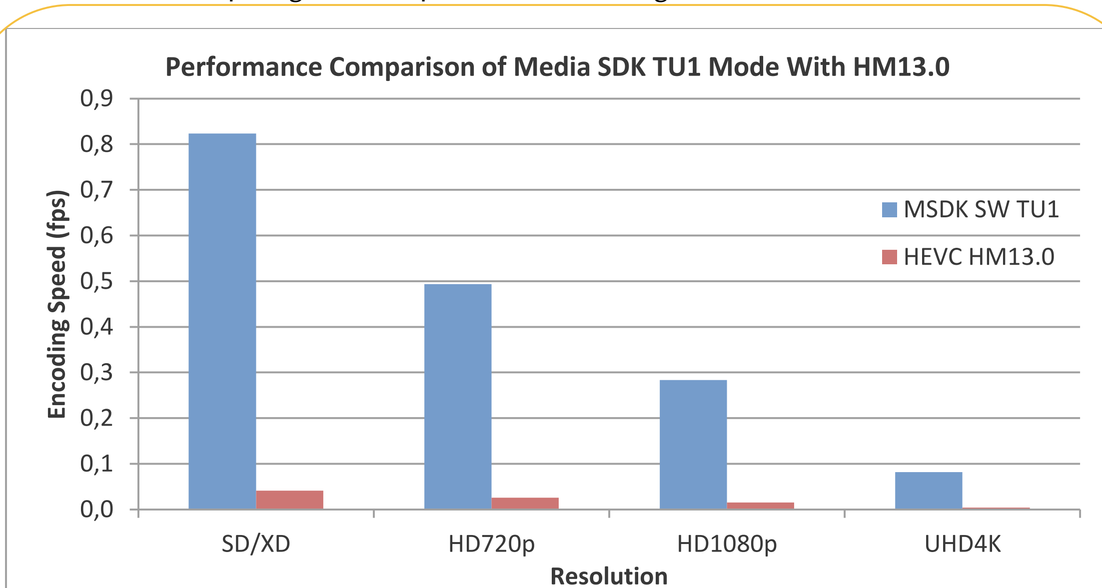


Figure 7A Average encoding speed comparison of Media SDK TU1 mode with HM13

From Figure 7A it can be seen that the encoding speed of the TU1 mode is 18 to 20 times the speed of HM13 for all 4 resolution test sets. Earlier we had shown that for TU1 mode the loss in quality was around 6-7% wrt HM13.

Next in Table 3A-3D we show measurement of encoding speed of Media SDK HEVC Software Encoder in TU1 (highest quality), TU4 (middle quality and speed), and TU7 (fastest speed) modes.

Table 3A Encoding Speed of **UHD4K** test set on Media SDK HEVC Software Codec (TU1, TU4, TU7 modes)

No	Sequence	MSDK TU1 mode	MSDK TU4 mode	MSDK TU7 mode
		Enc, fps	Enc, fps	Enc, fps
1	Park_joy_3840x2160_50	0.08	0.71	1.17
2	Ducks_take_off_3840x2160_50	0.08	0.55	0.87
3	Crowd_run_3840x2160_50	0.08	0.68	1.17

4	PeopleOnStreet_3840x2160_30	0.08	0.59	1.08
5	Traffic_3840x2048_30	0.09	0.89	1.41
6	NebutaFestival_2560x1600_60	0.16 *	1.68 *	2.60 *
	Average	**0.08**	**0.68**	**1.14**

** For average calculation, NebutaFestival is excluded as its size is 2560x1600 while others are 3840x2160.*

Table 3B Encoding Speed of **HD1080p** test set on Media SDK HEVC Software Codec (TU1, TU4, TU7 modes)

No	Sequence	MSDK TU1 mode	MSDK TU4 mode	MSDK TU7 mode
		Enc, fps	Enc, fps	Enc, fps
1	Park_joy_1920x1080_50	0.25	2.23	3.89
2	Ducks_take_off_1920x1080_50	0.27	2.23	3.52
3	Crowd_run_1920x1080_50	0.27	2.08	3.70
4	TouchDownPass_1920x1080_30	0.31	3.52	6.25
5	BQTerrace_1920x1080_60	0.31	3.92	5.70
6	ParkScene_1920x1080_24	0.29	2.97	4.62
	Average	**0.28**	**2.83**	**4.61**

Table 3C Encoding Speed of **HD720p** test set on Media SDK HEVC Software Codec (TU1, TU4, TU7 modes)

No	Sequence	MSDK TU1 mode	MSDK TU4 mode	MSDK TU7 mode
		Enc, fps	Enc, fps	Enc, fps
1	Park_joy_1280x720_50	0.46	4.28	7.53
2	Ducks_take_off_1280x720_50	0.48	4.44	7.19
3	Crowd_run_1280x720_50	0.48	3.98	7.36
4	City_1280x720_30	0.48	4.71	7.62
5	Crew_1280x720_30	0.55	5.01	8.98
6	Sailormen_1280x720_30	0.51	4.36	7.42
	Average	**0.49**	**4.46**	**7.68**

Table 3D Encoding Speed of **SD/XD** test set on Media SDK HEVC software Codec (TU1, TU4, TU7 modes)

No	Sequence	MSDK TU1 mode	MSDK TU4 mode	MSDK TU7 mode
		Enc, fps	Enc, fps	Enc, fps
1	BasketBallDrillText_832x480_50	0.84	6.17	13.33
2	PartyScene_832x480_50	0.81	6.53	13.20
3	RaceHorses_832x480_30	0.82	6.52	13.52
4	City_704x576_30	0.79	7.45	13.22
5	Crew_704x576_30	0.84	6.55	13.49
6	Soccer_704x576_30	0.84	6.49	13.99
	Average	**0.82**	**6.62**	**13.46**

As can be seen From Table 3A-3D the encoding speed of TU4 mode is 8 to 10 times that of TU1 mode, and that the encoding speed of TU7 mode is 1.75 to 2 times that of TU4 mode. In other words TU7 mode reflects an overall speed of 14 to 20 times that of TU1 mode.

A side-side comparison of encoding speed of different modes and for the 4 different resolution test sets is shown by the bar graphs of Fig. 7B. It shows that the TU7, the fastest mode is able to reach average encoding speed of 3.5 to 6 fps for HD1080p content, over 7 to 9 fps for HD720p, and around 13-14 fps for SD/XD content.

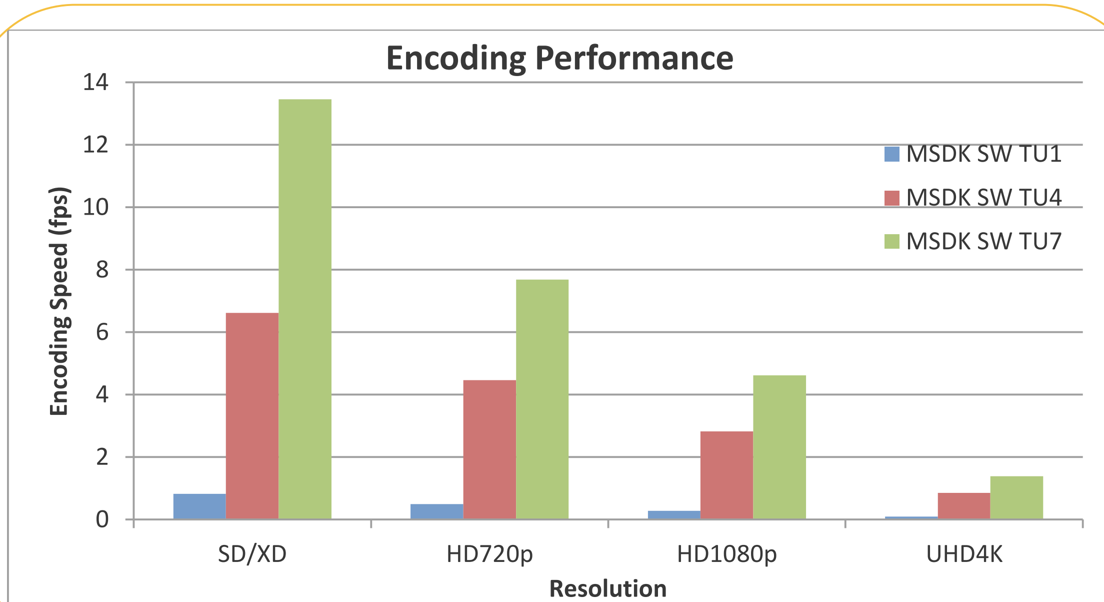


Figure 7B Average encoding speed of different test sets on Media SDK HEVC Software Encoder

Quality vs Performance in Different Modes

We now show results of Codec Quality vs Encoding Performance tradeoffs for Media SDK HEVC Encoder for all 4 resolutions tested.

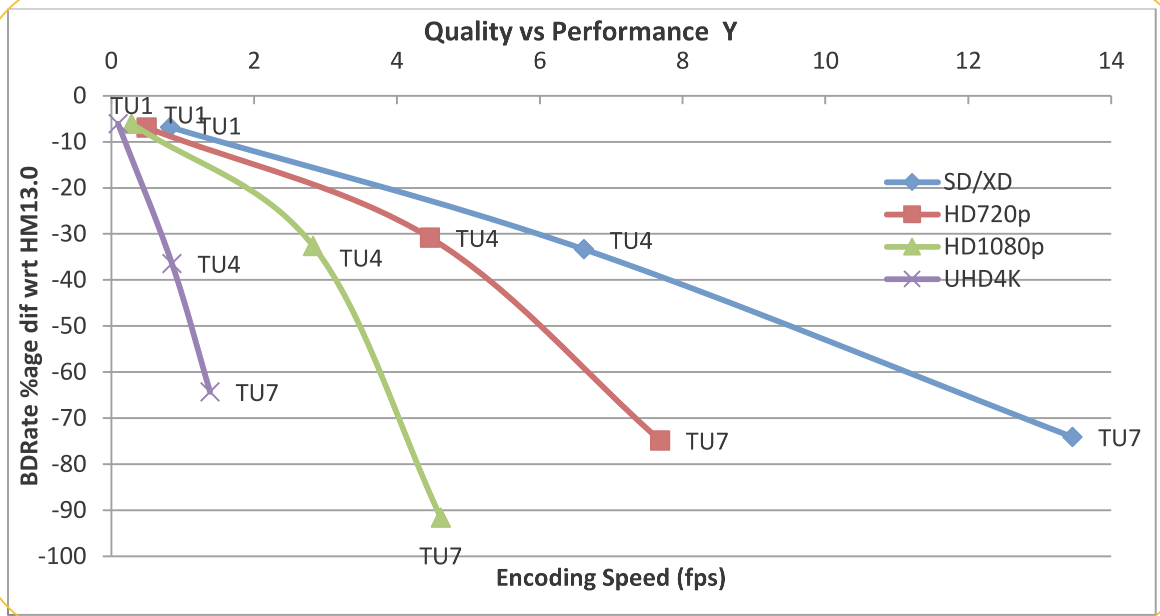


Figure 7C Quality vs Encoding Speed Tradeoffs of Media SDK HEVC Software Encoding modes

Figure 7C shows a comparison of Quality (as negative BDrate percentage dif wrt HEVC HM13) vs Encoding Performance (fps) for each of the four resolution test sets at each of the three different TU1, TU4, TU7 encoding modes. The y-axis basically shows the quality difference in terms of loss of BDrate percentage difference in the process of increasing speed up of the encoder in going from TU1 to TU4 to TU7 operating points.

Intel® Media SDK HEVC Software Decoder Performance

In this section we describe results of decoding speed measurement of Intel® Media SDK HEVC Decoder. For measurement of decoding speed (fps), the same reference PC Platform (Intel® Core™ i7-4770K CPU @ 3.5 GHz – 4 Cores/8Threads) used for encoding speed measurement is employed.

The Media SDK HEVC Software Decoder is able to achieve very high threading throughput consuming over 90% of resources on the noted machine.

For measurement of decoder performance, longer bitstreams of typically around 1000 or more frames are necessary to obtain a stable measurement. Thus, each of the video sequences of Table 1A - 1D since they are relatively short were extended by palindromic repetition (so as not to introduce sudden scene changes that might introduce an unnatural behavior in the measurement) to 900 – 1200 frames long and compressed with HEVC using the same Qp quantizers as in Table 1A-1D. These longer compressed streams were then used for decoder performance measurment.

*Other names and brands may be claimed as property of others.

Tables 4A-4D show average speed of decoding bitstreams of each sequence of each of the 4 test sets as well as an overall average deoding speed for each category.

Table 4A Decoding Speed Results on **UHD4K** test set for Intel® Media SDK HEVC Codec

No	Sequence	MSDK TU1 mode	MSDK TU4 mode	MSDK TU7 mode
		Dec, fps	Dec, fps	Dec, fps
1	Park_joy_3840x2160_50	70.98	62.31	67.98
2	Ducks_take_off_3840x2160_50	72.83	66.19	61.57
3	Crowd_run_3840x2160_50	73.07	67.90	74.39
4	PeopleOnStreet_3840x2160_30	65.06	59.67	65.50
5	Traffic_3840x2048_30	54.70	46.48	49.75
6	NebutaFestival_2560x1600_30	172.78 *	144.69 *	159.11 *
	Average	67.33	60.51	63.84

** For average calculation, NebutaFestival is excluded as its size is 2560x1600 while others are 3840x2160.*

Table 4B Decoding Speed Results on **HD1080p** test set for Intel® Media SDK HEVC Codec

No	Sequence	MSDK TU1 mode	MSDK TU4 mode	MSDK TU7 mode
		Dec, fps	Dec, fps	Dec, fps
1	Park_joy_1920x1080_50	183.16	205.53	232.34
2	Ducks_take_off_1920x1080_50	198.84	242.18	233.12
3	Crowd_run_1920x1080_50	135.32	212.90	244.08
4	TouchDownPass_1920x1080_30	221.87	312.77	346.70
5	BQTerrace_1920x1080_60	255.18	329.90	368.03
6	ParkScene_1920x1080_24	203.97	291.99	326.28
	Average	199.72	265.88	291.76

Table 4C Decoding Speed Results on **HD720p** test set for Intel® Media SDK HEVC Codec

No	Sequence	MSDK TU1 mode	MSDK TU4 mode	MSDK TU7 mode
		Dec, fps	Dec, fps	Dec, fps
1	Park_joy_1280x720_50	273.47	412.55	477.47
2	Ducks_take_off_1280x720_50	300.95	461.09	476.58
3	Crowd_run_1280x720_50	220.06	383.81	463.36
4	City_1280x720_30	300.66	512.35	564.14
5	Crew_1280x720_30	267.24	494.03	538.53
6	Sailormen_1280x720_30	283.76	504.51	561.94
	Average	274.36	461.39	513.67

Table 4D Decoding Speed Results on **SD/XD** test set for Intel® Media SDK HEVC Codec

No	Sequence	MSDK TU1 mode	MSDK TU4 mode	MSDK TU7 mode
		Dec, fps	Dec, fps	Dec, fps
1	BasketBallDrillText_832x480_50	504.41	942.65	1067.21
2	PartyScene_832x480_50	476.69	866.48	1031.10

3	RaceHorses_832x480_30	408.82	687.30	908.16
4	City_704x576_30	509.83	1011.16	1134.78
5	Crew_704x576_30	402.83	804.19	905.82
6	Soccer_704x576_30	475.78	964.00	1099.34
	Average	463.06	879.30	1024.40

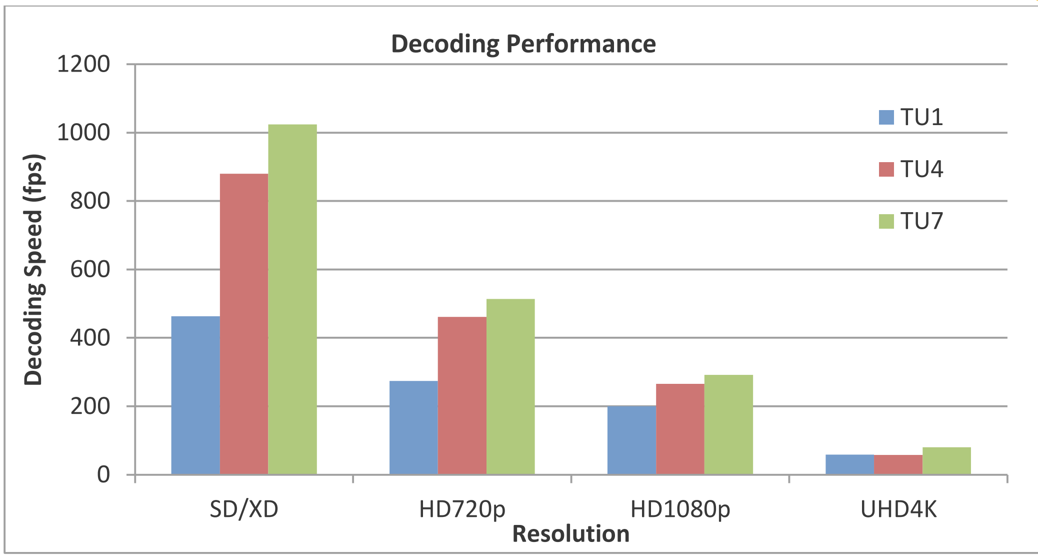


Figure 8 MSDK HEVC Software Decoding speed bar graph for different resolutions

As can be see from Table 4A-4D, as expected, the decoding speed is inversely proportional to the spatial resolution of video sequence being decoded. Average decoding speed for 1080p resoution content is roughly 4 times that of 4K resolution content (Table 4B vs Table 4A), average decoding speed of 720p resolution content is almost a factor of 1.6 of 1080p content (Table 4C vs Table 4B) , and that of SD/XD resolution content is close to a factor of 2 as compared to decoding speed of HD720p content (Table 4D vs Table 4C).

Further, Figure 8 shows a combined graph of variation of Media SDK HEVC Software Decoder performance (fps) across various resolutions test sets. Including the rendering overhead, on this platform one UHD4K stream or four HD1080p streams can be easily decoded in realtime.

Summary

In this white paper we first presented an overview of the new MPEG HEVC compression standard, and then introduced Intel® Media SDK, a developer product. Next we presented a test methodology for quality evaluation of HEVC Codecs and applied the methodology to evaluate quality of Intel® Media SDK HEVC Software Codec. Encoder Quality versus performance tradeoffs of various modes of Intel Media SDK HEVC Software Encoder were discussed next. This was then followed by evaluation of performance of HEVC Software Decoder of Intel® Media SDK.

As can be seen from results of thorough testing, Media SDK HEVC Software Codec delivers impressive encoding and decoding performance while achieving excellent tradeoffs in quality to meet the overall needs of demanding video developers.

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Appendix A: Quality and Performance Summary of Intel® Media SDK HEVC Software Codec

Media SDK Quality Preset	TU1	TU4	TU7
Quality (BDrate percentage) loss with respect to HEVC HM13 Reference Codec	Luma BDrate percentage	Luma BDrate percentage	Luma BDrate percentage
Standard Definition/Extended Definition (SD/XD)	7%	33%	74%
High Definition 720p (HD720p)	7%	31%	75%
High Definition 1080p (HD1080p)	6%	33%	92%
Ultra High Definition 4K (UHD4K)	6%	36%	64%

Multi-threaded Encode Performance on Haswell†	frames per sec. (multi-threaded 4 core)	frames per sec. (multi-threaded 4 core)	frames per sec. (multi-threaded 4 core)
Standard Definition/Extended Definition (SD/XD)	0.82	6.62	13.46
High Definition 720p (HD720p)	0.49	4.46	7.68
High Definition 1080p (HD1080p)	0.28	2.83	4.61
Ultra High Definition 4K (UHD4K)	0.08	0.68	1.14

Multi-threaded Decode Performance on Haswell†	frames per sec. (multi-threaded 4 core)	frames per sec. (multi-threaded 4 core)	frames per sec. (multi-threaded 4 core)
Standard Definition/Extended Definition (SD/XD)	463	879	1024
High Definition 720p (HD720p)	274	461	514
High Definition 1080p (HD1080p)	200	266	292
Ultra High Definition 4K (UHD4K)	67	61	79

† Intel® Core-i7 Processor 4770k: 4 Core, 3.5 GHz.