Performance Comparison of VVC, AV1 and EVC

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ABSTRACT

This paper presents a study comparing the coding efficiency performance of three video codecs: (a) the Versatile Video Coding (VVC); (b) AV1 codec of the Alliance for Open Media (AOM); and (c) the MPEG-5 Essential Video Coding (EVC). Two approaches to coding were used: (i) constant quality (QP) for VVC, AV1, EVC; and (ii) target bit rate (VBR) for AV1. Constant quality encoding is performed with all the three codecs for an unbiased comparison of the core coding tools. Whereas, target bitrate coding is done with the AV1 codec to study the compression efficiency achieved with rate control, which can and does have a significant impact. Performance is tabulated for on two fronts: (1) objective performance based on PSNR's and (2) informal subjective assessment. Our general conclusion derived from the assessment of objective metrics and subjective evaluation is that VVC appears to be superior to AV1 and EVC under both constant quality and target bitrate coding. However, relative to currently popular codecs such as AVC and HEVC, that difference is modest.

1 INTRODUCTION

Versatile Video Coding (VVC) is a video coding standard for video compression currently under development (due in 2020) by the Joint Video Experts Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11 [4]. The current version of VVC, known as VTM-5.0, uses a subset of the tools in Joint Exploration Model (JEM). VTM-5.0 provides an additional average bitrate savings of up to 35% for equivalent perceptual quality on top of HEVC. The latest version of the reference software (VTM-5.0) is available at https://vcgit.hhi.fraunhofer.de/jvet/VVCSoftware_VTM.

The AV1 video codec is a high quality open source video codec developed by the Alliance for Open Media, a Joint Development Foundation project formed to define and develop media codecs, media formats, and related technologies to address marketplace demand for an open standard for video compression and delivery over the web [5]. A stable initial release of AV1 was deployed in March 2018. Built on baseline VP9 by the addition of new coding tools, coding efficiency gains have been reported for large enough data sets [6]. The latest version of the codec is available at https://aomedia.org/.

The Essential Video Coding (EVC) standard, launched by MPEG and due in mid-2020, targets to provide similar coding efficiency to that of HEVC but with clear licensing conditions (royalty-free in a baseline profile and with managed IPR in a main profile). The latest version of the codec, known as ETM-1.0, is available at https://gitlab.com/MPEG-5/ETM (access requires getting credentials from coordinators of EVC project).

2 STRUCTURE OF AV1, EVC, VVC CODECS

2.1. Basic Structure

All the three codecs follow the general structure of a hybrid motion-compensated video codec that has been in use since at least H.261 (1988). Table 1 summarizes the comparative structure of EVC, AV1 and VVC. The basic block size is 128x128 pixels, which can be subdivided further for purposes of prediction and transform, right down to 4x4 size. The block partitioning for VVC and EVC is the Quad/Ternary/Binary tree (QTBT + TT) structure. In AV1, a ten-way recursive partitioning structure is used (which resembles the QTBT + TT, e.g. a square block can be subdivided into 4 (rect.) or 3 (2 squares, one rect.) blocks in a variety of ways in addition to the block division structure used in VP9). Transforms in AV1 and VVC include DCT, DST types and identity up to size 64x64. Additionally, VVC has mode dependent secondary transforms. In EVC, only the DCT-II with sizes up to 128x128 is used. Blocks can be predicted in either Intra (56, 65 and 30 directional modes in AV1, VVC and EVC respectively), Inter (with 1/8^{h}, 1/16th, 1/16th motion vector accuracy in AV1, VVC and EVC respectively). Though the AV1 codec does not explicitly contain B-frames, a method called compound prediction effectively offers the same functionality (although it appears no direct analog of hierarchical B-frames, such as in HEVC, exists). AV1 supports tiles, though not slices (as in VVC), which are not needed in TCP/IP communication, but useful over RTP.

	EVC (Main)	**AOM AV1 (1.0)**	**H.266/VVC VTM 5.0 (June 2019)**
Block Structure	Quad Tree + TT CTU size up to 128x128	10-way split, like QTBT. Largest block size 128x128.	(QTBT) + Ternary Tree (TT) CTU size up to 128x128
Intra Prediction	30 intra prediction modes (including angular, DC, bilinear & plane).	56 intra directional modes 4 non-directional modes Recursive filt-based intra pred Chroma prediction from Luma Color palette based intra pred Intra block copy	65 angular intra prediction modes (+ others, 81 total) with improved intra mode coding Cross-component linear model (CCLM) prediction Sub-partitions
Inter prediction	1/16th pel MV accuracy 2 interp. Filters for MC Hierarchical weighted prediction (P, B frames) Adaptive motion vector resolution Affine motion prediction Decoder-side motion vector refinement	1/8th pel MV Pred Single and compound prediction (similar to P and B in VP9) Extended reference frames (3 to 7) Dynamic spatial and temporal motion vector referencing Overlapped block motion compensation (OBMC) Warped motion compensation Advanced compound prediction	1/16th pel MV Pred 2 interp. Filters for MC Hierarchical weighted prediction (P, B fr.) Gen. Bi-prediction Enhanced MV prediction tools Sub-CU based motion vector prediction Adaptive motion vector resolution Affine motion prediction Decoder-side MV Refinement
Transform	DCT-II sizes 4x4 up to 128x128	Transforms 4x4 up to 64x64 DCT, ADST (VP9), Flipped ADST, DST-I, Identity. Hor./Vert. indep.	Transforms 4x4 up to 64x64 Adaptive multiple core transforms Mode dependent non-separable secondary transforms (4x4)
Loop filter + Other	Deblocking filter, Hadamard transform	Constr. directional enh. filter Loop restoration filters Deblocking filter, Frame super resolution Film grain synthesis	Deblocking filter, SAO, Adaptive loop filter
Entropy Coding	Multiplier based context adaptive entropy coding	Multi-symbol arithmetic coding Level map coefficient coding	Modified CABAC (with Context models for transform coef. levels)

Table 1. Tool comparison resume of codecs (AV1, EVC, VVC).

2.2. Other Previously Published Performance Comparisons

We briefly review some recently published comparisons of these codecs, specifically [14] from Technicolor, [6] from AOM team members, [11] from HHI, and [15] from FastVDO. [6], [11], and [15] are from 2018.

Paper [14], by Technicolor, 2019, compares the AV1, VVC, EVC and HEVC codecs. The tests were done on classes A1, A2, B, C, D of the JVET sequences under the constraints specified in the common test conditions (CTC) of JVET [16] for VVC, EVC and HEVC. The AV1 configuration parameters were set to closely resemble the CTC conditions, for a fair comparison. The tests were done only in the constant quality mode (using fixed quantization parameters). Figure 1. tabulates the performance comparison of the codecs in terms of percentage bitrate gain and encoding/decoding speed compared with respect to HEVC (HM-16.18). A negative sign in the percentage bitrate gain indicates a gain, otherwise a loss. The figure indicates that VVC (VTM-4.0) outperforms the other codecs (~30% gain with respect to HM-16.18) but has ~7x encoding complexity. Since 2018, the encoder complexity has recently been reduced, as we report below.

Paper [6], by AOM and led by Google, 2018, provides a valuable review of the key tools in the AV1 codec, in comparison to the previous VP9. Figure 2 captures for example the changes in the block partitioning structure from VP9, which we find reminiscent of the QTBT (quadtree-binary tree) structure of HEVC. The key differences are: that some elements of two levels of decomposition in QTBT are captured in one shot, and that only square blocks can be further decomposed. Their tests concluded that AV1 is 22% more efficient than x265 (representing HEVC), 28% more than VP9.

Paper [11], led by HHI, 2018, provides some overall performance comparisons between VP9, AV1, HEVC (HM-16.18) and VVC (JEM 7.0). The results are described in Figure 3. Their tests indicate that AV1 is ~30% more efficient than VP9 but has encoder runtime 20X longer. In this paper, we derive our own comparisons, to add to this growing body of literature.

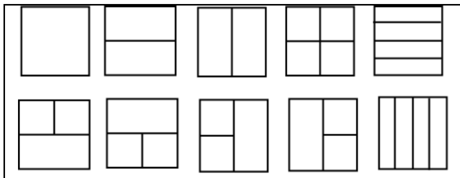
Paper [15], by FastVDO, 2018, compares the coding efficiency performance of VVC Benchmark Set 1 (BMS1), AV1 and HEVC (HM-16.18). Tests were done in both constant quality (QP) and target bit rate (VBR) mode for AV1. Figure 4 gives a snapshot of the bitrate gains. The general conclusion derived from the assessment of objective metrics and subjective evaluation is that VVC (BMS1) appears to be superior to AV1 and HEVC under both constant quality and target bitrate coding constraints. AV1 shows superior coding gains with respect to HEVC under target bitrate coding, but in general has increased computational complexity and henceforth an encode time factor of 20 – 30 over HEVC.

Moreover, [15] also concluded that the results of [6], [11], and [15], while superficially different were actually consistent, and the differences in results could be reasonably accounted for by differences in coding conditions and settings, as well as test data characteristics.

BD-Rate PSNR YUV*	**Reference**				
		HM-16.18	**VTM-4.0**	**AV1**	**ETM-1.0**
Test	**HM-16.18**		42.7%	27.6%	18.5%
	VTM-4.0	-29.5%		-8.8%	-17.1%
	AV1	-21.0%	10.4%		-7.1%
	ETM-1.0	-15.0%	21.0%	9.3%	

Run time Vs HM-16.18	**VTM-4.0**	**AV1**	**ETM-1.0**
Encoding	7.36x	6.71x	3.62x
Decoding	1.23x	2.48x	1.36x

Figure 1. (a) Technicolor performance comparison of AV1, HEVC (HM-16.18), VVC (VTM-4.0) & EVC (ETM-1.0) for JVET sequences in classes A1, A2, B, C, D [14]; (b) encoder speed with respect to HEVC (HM-16.18).



AV1 Average Perf. Gains in BD-Rate (%)

Codec	Y	Cb	Cr
VP9	-28.07	-30.1	-31.8
x265	-22.75	-39.18	-40.17

Figure 2. AOM comparisons of AV1 to VP9, in block partitioning (a), and in performance (b), to VP9 and x265, from [6]. From the point of view of commercial codecs, AV1 has mainly x265 and VP9 to compare with.

	VP9	HM	AV1
HM	-25.00%		
AV1	-22.90%	2.30%	
JEM	-48.70%	-31.60%	-32%

	VP9	HM	AV1
HM	2.66		
AV1	55.82	20.95	
JEM	22.58	8.48	0.40

Figure 3. (a) HHI performance comparison of VP9, AV1, HEVC (HM), and JEM, quoted from [11]. (b) encoder speed comparison [11], where the AV1 encoder performs on par with HEVC, but with 20X more complexity/run time, while JEM is better in performance/speed. Key differences between the AOM [6] and HHI [11] tests are that AOM used x265, while HHI used the HM reference SW. Another important factor is that the test data were different in the two cases. In particular, [6] used screen-content sequences in the test, whereas [11] did not.

	AV1 over HM 16.18		
	Y	U	V
Class A2	23.49%	42.23%	29.31%
Class B	16.88%	26.86%	26.51%
Class C	21.13%	31.50%	37.79%
Class D	16.14%	22.46%	24.25%
Class E	24.33%	35.21%	41.33%
Overall	20.39%	31.65%	31.84%

	BMS 1.0 over HM 16.18			
	Y	U	V	EncT
Class A2	-27.76%	-35.13%	-30.39%	825%
Class B	-21.84%	-36.10%	-36.53%	850%
Class C	-18.52%	-28.61%	-31.15%	1012%
Class D	-17.97%	-26.69%	-28.24%	930%
Class E	-17.95%	-27.00%	-29.02%	803%
Overall	**-20.81%**	**-30.71%**	**-31.07%**	**884%**

	AV1 over HM 16.18		
	Y	U	V
Class A2	-10.43%	-18.14%	-17.05%
Class B	-7.53%	-17.59%	-16.91%
Class C	-6.49%	-14.69%	-15.18%
Class D	-5.19%	-14.11%	-14.03%
Class E	-5.29%	-12.96%	-12.87%
Overall	-6.99%	-15.50%	-15.21%

Figure 4. FastVDO comparison of codecs: a) constant quality mode AV1 vs HM16.18 (for 1s), 22X runtime; b) constant quality mode VVC (BMS1) vs HM16.18 (full 10s); c) target bitrate mode AV1 vs HM16.18 for, 1s test [15]. Moreover, [15] provided an explanation of the slight variance of results between the teams.

3 FASTVDO EXPERIMENTAL SETUP

The new simulations are performed using: a) Rocks cluster distribution (an open source Linux cluster distribution for high performance computing) with 34 cores (5 AMD Phenom II X6 1055T's and 1 AMD Phenom II X4 955) b) two quad core (i7 6700) and one 6 core (i7 8700) windows systems with RAM capacity of 16GB each. We test a variety of test sequences, in both constant quality and target bitrate settings (AV1).

3.1 Test Sequences

Nine 10-bit and 8-bit YCbCr 4:2:0 video sequences (from JVET test sequence set) at different resolutions, each 10-second-long, are chosen as the test set. Table 1 lists the sequences, with resolutions, frame rates, frame counts and bitdepth.

Class	Sequence name	Resolution	Frame count	Frame rate	Bit depth
A1	Campfire	4K	300	30	10
A2	CatRobot1	4K	600	60	10
B	Cactus	1080p	500	50	8
B	BasketballDrive	1080p	500	50	8
C	BQMall	832x480	600	60	8
D	BasketballPass	416x240	600	60	8
D	RaceHorses	416x240	300	30	8
E	FourPeople	720p	600	60	8
F	SlideEditing	720p	300	30	8

Table 2: Test Data Set for FastVDO comparison, drawn from the JVET common test conditions (CTC).

3.2 Encoder Configuration

The software versions used are a) ETM 1.0 (EVC) main profile; b) AV1 version 1.0 and c) VTM 5.0 (VVC) next profile. The encoders are all configured for random access coding (where intra predicted keyframes are inserted at regular intervals, usually 1 second intervals, to enable playback from specific points) with internal bitdepth set as 10. The hierarchical group of pictures (GOP) size is set as 16 frames for EVC and VVC. This means that an inter predicted keyframe is inserted every 16 frames. All frames in between the intra keyframe and inter keyframe are bi-predicted using a hierarchical structure. AV1 does not use the concept of GOP, but instead uses alternative reference frames (ARF) and golden frames to achieve bi-prediction. The ARF and golden frame distance is set as 16 to imitate the GOP structure. Constant quality (QP) encoding was performed with the EVC and VVC encoders, whereas both QP and target bitrate (VBR) encoding was done for AV1. For AV1, moreover, the cpu-used parameter was set as 0 and the number of passes set as 2. More details on the command line arguments used can be found in the following sections.

3.2.1 Constant Quality Coding (QP)

ETM- 1.0: Each sequence is encoded at four specific quality parameters (QP’s); 22, 27, 32, 37. Example command line arguments for EVC encoding & decoding in a Windows system:

Encode: evca_encoder.exe -i <input.yuv> -q <QP> -p <intra period> -f <number of frames> -z <frame rate> -o <encoded file> --config “encoder_randomaccess.cfg”
Decode: evca_decoder.exe -i <encoded file> -o <output reconstructed file>

***VTM- 5.0*:** Each sequence is encoded at four specific quality parameters (QP’s); 22, 27, 32, 37. Example command line arguments for BMS1 encoding & decoding in a Windows system:

Encode: EncoderApp.exe -c encoder_randomaccess_main.cfg -i <input.yuv> -q <QP> -ip <intra period> -f <number of frames> -fr <frame rate> -b <encoded file>

Decode: DecoderApp.exe -b <encoded file> -o <output reconstructed file>

AV1 1.0: Each sequence is encoded at four specific quality parameters (QP's); 23, 31, 39, 47. Example command line arguments for AV1 encoding & decoding in a Windows system:

aomenc.exe --cpu-used=0 --tune=psnr -b 10 --input-bit-depth=8 --threads=0 --profile=0 --width=1920 --height=1080 --fps=50/1 --lag-in-frames=19 --min-q=31 --max-q=39 --auto-alt-ref=1 --passes=2 --kf-max-dist=48 --kf-min-dist=48 --min-gf-interval=16 --max-gf-interval=16 --drop-frame=0 --static-thresh=0 --bias-pct=50 --minsection-pct=0 --maxsection-pct=2000 --arnr-maxframes=7 --arnr-strength=5 --sharpness=0 --undershoot-pct=100 --overshoot-pct=100 --frame-parallel=0 --tile-columns=0 --end-usage=q --cq-level=31 input.yuv -o <encoded file>

aomdec.exe --rawvideo -o <output reconstructed file> <encoded file>

3.2.2 Target Bitrate Coding (VBR) for AV1

3.2.2.1. AV1. In VBR mode the AV1 encoder is configured to get bitrates close to those obtained in the QP mode for the other codecs, so that the results can be compared. Example command line arguments for AV1 encoding & decoding in a Windows system is given below. We highlight that we use –cpu-used=0, rather than =1, as used by HHI (a faster mode):

aomenc.exe --cpu-used=0 -b 10 --input-bit-depth=8 --threads=0 --profile=0 --width=1920 --height=1080 --fps=50/1 --lag-in-frames=19 --min-q=0 --max-q=63 --auto-alt-ref=1 --passes=2 --kf-max-dist=150 --kf-min-dist=0 --drop-frame=0 --static-thresh=0 --bias-pct=50 --minsection-pct=0 --maxsection-pct=2000 --arnr-maxframes=7 --arnr-strength=5 --sharpness=0 --undershoot-pct=100 --overshoot-pct=100 --frame-parallel=0 --tile-columns=0 --end-usage=vbr --target-bitrate=<in_kbps> input.yuv -o <encoded file>

aomdec.exe --rawvideo -o <output reconstructed file> <encoded file>

4 RESULTS & SUMMARY

The modified Bjøntegaard Delta Rate (BD rate) [10] metric - which is a measure of the integral of the rate difference between two rate-distortion (RD) curves, is used for objective evaluation. Negative values of BD rate indicate a bitrate gain in percentage. The results from VTM 5.0 constant quality (QP) encoding is used as the reference. RD curves are also plotted for selected sequences. Cropped regions of the selected sequences are shown at full resolution as part of the subjective evaluation.

4.1 Constant Quality Coding (QP)

In Table 3 the BD rates obtained with AV1 and ETM-1.0 (EVC) over VVC are tabulated (1s tests). We note that constant quality (QP) testing is important in evaluating the core toolsets, indicating the potential of each codec, and not rate control, which is an encoder only technology that is available to any encoder. Of course, in real applications, rate control is almost always used, so that testing for target rate is more directly indicative of performance in practice. From our point of view, therefore, it is useful to test by each method to obtain an overall picture.

	Random access		
	Over VTM 5.0		
	Y	U	V
Class A1	14.23%	25.81%	24.43%
Class A2	15.47%	37.21%	29.80%
Class B	16.35%	22.23%	23.07%
Class C	12.04%	25.57%	35.55%
Class D	11.22%	17.66%	21.42%
Class E	13.93%	16.54%	19.99%
Class F	9.77%	10.70%	13.01%

	Random access		
	Over VTM 5.0		
	Y	U	V
Class A1	18.63%	43.01%	35.61%
Class A2	16.37%	38.67%	26.42%
Class B	19.36%	39.12%	33.17%
Class C	20.71%	26.09%	31.83%
Class D	15.46%	20.05%	16.59%
Class E	18.45%	24.12%	26.99%
Class F	13.96%	16.71%	18.37%

Table 3: BD rates for constant quality mode; a) AV1 vs VTM 5.0 (for 1s); b) ETM 1.0 vs VTM 5.0 (for 1s).

The rate distortion (RD) curves for two example sequences (10-bit 4K CatRobot & 8-bit 1080p BasketballDrive) are given in Figure 5. Overall PSNR is used for BDRATE calculations and RD plots.

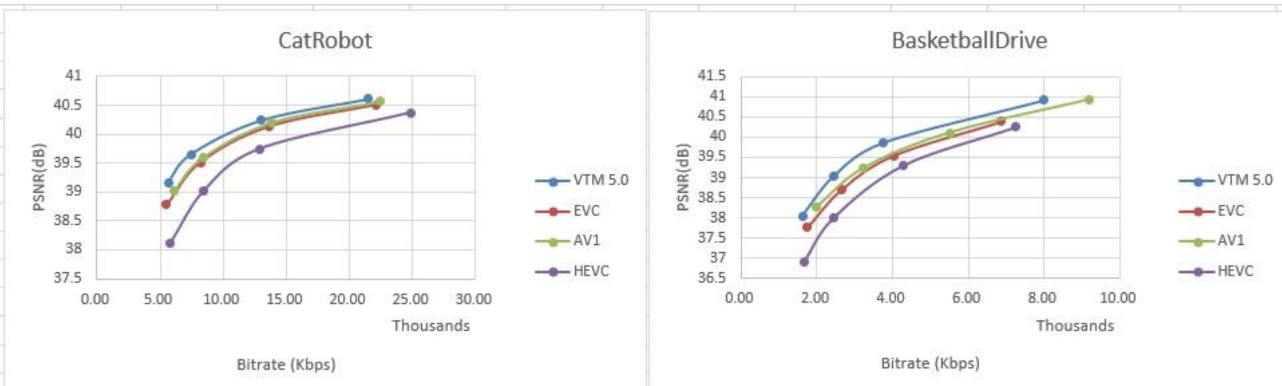


Figure 5: Example RD curves in constant quality mode, for two test sequences; VVC slightly outperforms AV1 and EVC, and varies with the test data. AV1 appears to slightly edge out EVC in PSNR.

	AV1	ETM-1.0
Encoding	0.95x	0.4x
Decoding	2x	1x

Table 4: Encoding and decoding time relative to VVC VTM5.0 in software for AV1 and EVC. That is, VVC and AV1 have a similar encoding time, while VVC is 2x faster in decoding than AV1 at this time. Meanwhile, VVC and EVC have a similar decoding time, but EVC is over 2X faster in encoding than VVC. All of these software speed figures will migrate as codec technology evolves.

From the BD rate tables and curves it can be seen that VTM 5.0 (VVC) outperforms AV1, which in turn modestly outperforms EVC, in constant quality mode. The average encoding time factors for VVC and AV1 are about similar and almost 2x relative to EVC. That is, VVC and AV1 are more complex (2x) to encode than EVC, while AV1 is 2X more complex to decode than either VVC or EVC. Table 4 shows the relative encoding and decoding speeds of AV1 and EVC with respect to VVC.

Figure 6 gives an indication of the performance of AVC, HEVC, and VVC (c. 2018), by FastVDO [Figure 7 shows a frame from the original BasketballDrive (1920x1080) sequence (scaled to fit the page) and cropped sections (original size) of the reconstructed frame encoded using the VVC, AV1, EVC and HEVC encoders in constant quality mode (the bitrates are approximately around 1500Kbps). Increased levels of blocking, edge artifacts and blurring are visible in the reconstructed frame using HEVC while the VVC, AV1 and EVC crops look similar, though VVC appears to be slightly better in visual quality.

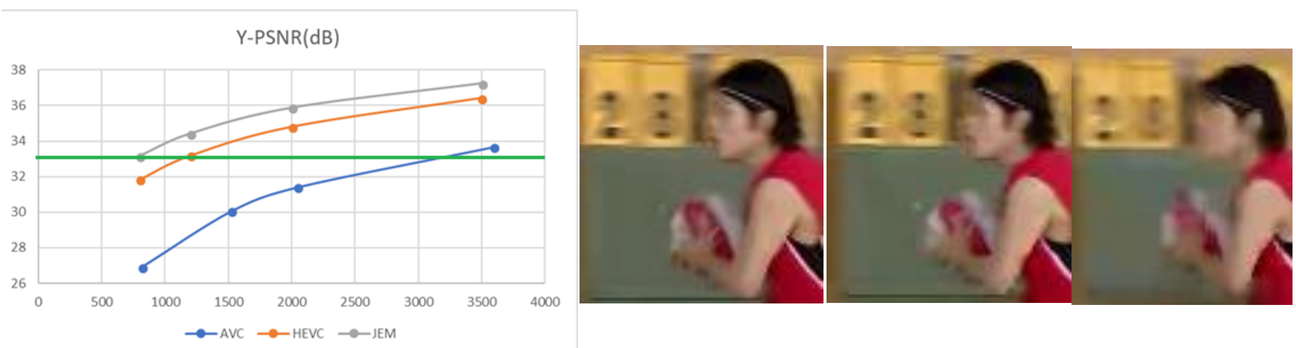


Figure 6. FastVDO example low bitrate coding (from 2018), with 3 codecs (AVC/HEVC/VVC draft), on a 1080p50 sequence (Basketball Drive), with (a) objective metric Y-PSNR; (b) crop visuals at 0.8 Mb/s (that is 3000:1 compression!), using VVC, HEVC, and AVC (H.266/5/4) L to R. (a) Hor. Line suggests that as of now, 0.8 Mb/s VVC ~ 1.2 Mb/s HEVC ~ 3.2 Mb/s AVC (VVC=1.33X HEVC = 4X AVC in coding efficiency). This also shows that in terms of the codec technologies currently widely used in the market (most notably AVC), EVC, AV1, and VVC all have very significant coding efficiency benefits (roughly 3X or more).

Figure 7a): Original frame from BasketballDrive sequence.

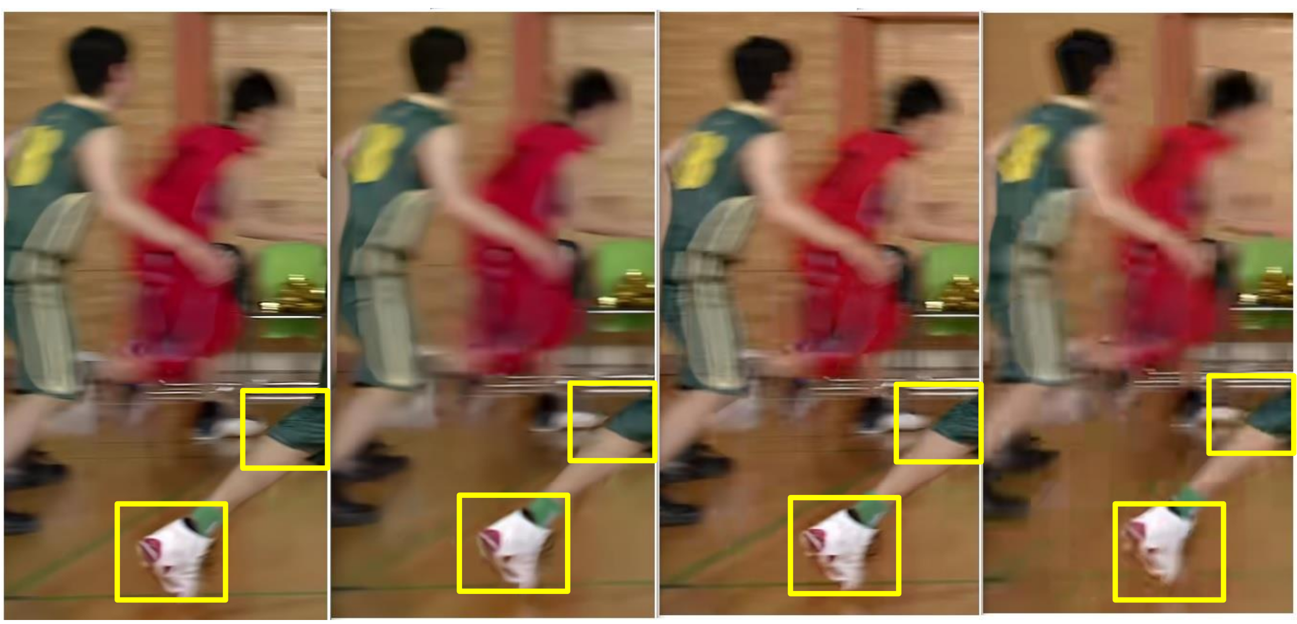


Figure 7b): Cropped section of a frame from BasketballDrive encoding using, from left-to-right, VVC, AV1, EVC and HEVC respectively, in constant QP mode, showing fairly similar quality, with VVC slightly better (look at the shoe laces, and the ripples on the shorts on a player). All tested codecs are better than HEVC (at far right), and all codecs are significantly better than AVC (not shown here; but see fig. 6). AV1 and EVC appear to be of very similar quality on this test sequence.

4.2 Target Bitrate Coding (VBR)

In Table 5 the BDRATES obtained with AV1 (VBR mode) over VVC are presented (with 1s testing). Since VVC & EVC itself does not have an effective rate control, this test was conducted as follows: We took the constant QP results from VVC tested early, and then set rate control on AV1 to match the rates. The updated RD plots with the AV1(VBR mode) curve added is given in Figure 8.

	Random access		
	Over VTM 5.0		
	Y	U	V
Class A1	10.59%	21.58%	20.07%
Class A2	12.50%	34.07%	26.47%
Class B	7.34%	11.66%	14.45%
Class C	8.65%	11.71%	22.78%
Class D	4.02%	10.84%	14.06%
Class E	10.60%	13.54%	16.96%
Class F	6.03%	7.26%	9.51%

Table 5: BDRATES (AV1 vs VTM 5.0) for target bitrate mode, 1s test.

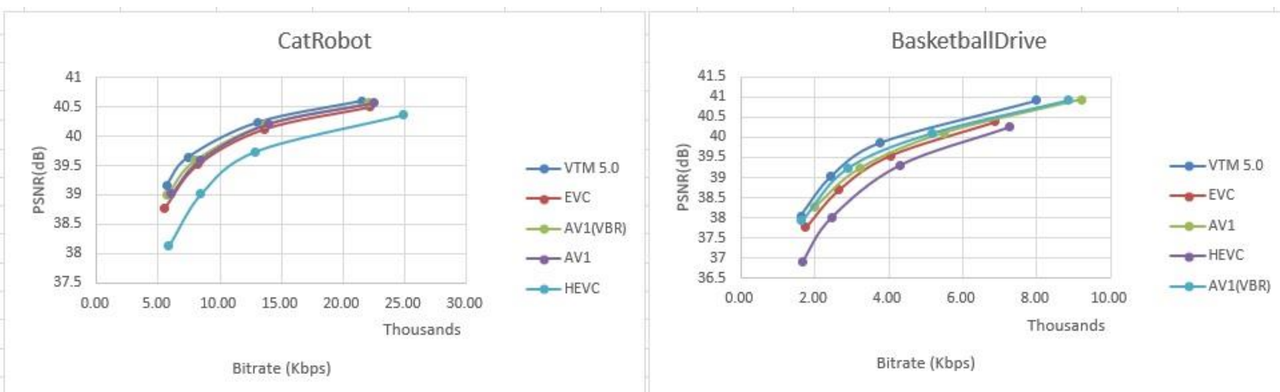


Figure 8. Updated Figure 4 with AV1 (VBR mode) added for two example sequences.

From the BD rate tables and curves it can be inferred that AV1 fares better in coding efficiency with VTM-5.0 (VVC) in target bitrate mode compared to constant quality (QP) mode. The average encoding time factor for AV1 is about 1.5x relative to VVC in this mode.

5 CONCLUSIONS

It can be concluded that the VVC reference software (VTM 5.0) performs better in terms of coding efficiency when compared to EVC reference software (ETM 1.0) and AV1 (under both constant quality and target bitrate mode). AV1 is slightly better in coding efficiency than EVC, but visually the difference is minimal. The encoding time (a measure of complexity) for AV1 is comparable to VVC (0.95x in constant QP mode and 1.5x in target bitrate (VBR) mode) but much slower than EVC (2.5x). Likewise, decoding AV1 currently takes twice as long as VVC or EVC. However, from the point of view of codecs currently in wide use, H.264/AVC still dominates, with as much as 80% of the market share in online use, see figure 9 [17]. And compared to

H.264/AVC, all of these three codecs have a quite similar performance, though currently at somewhat different speeds. Both the coding performance, as well as the software speeds, will evolve as the technologies mature.

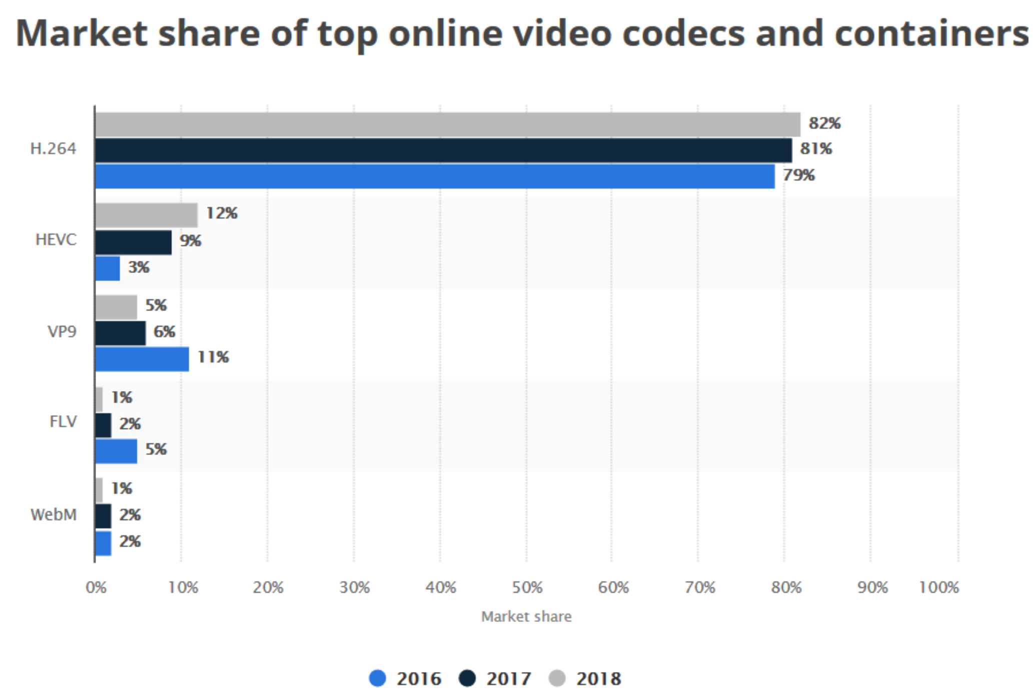


Figure 9. Worldwide market share of leading video codecs (and containers) for online use, from [17].

6 REFERENCES
7

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